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Survey report

MS *Ligrunn*, MS *Inger Hildur* and MS *Nybo* 2.-14.02.2015

Distribution and abundance of Norwegian spring spawning herring during the spawning season in 2015

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Contents

Summary

The objective of the survey was to estimate the year class abundance and spawning stock biomass (SSB) of Norwegian spring spawning (NSS) herring during the period of spawning migration from wintering areas at/off the northern Norwegian coast towards the coastal spawning ground further south.

The three vessels, *Nybo*, *Ligrunn* and *Inger Hildur*, covered the potential distribution of migrating herring from 62º-70.5ºN during the period 2.-14. February 2015, following a survey strategy with predefined strata and west-east transects with a distance of 10 nm or less based on expected distribution. Hull mounted Simrad EK60 echo sounders (38 kHz) were used to estimate the distribution and density, whereas Simrad sonars were used accordingly to look for potential aggregations closer to surface, as well as avoidance and migration behaviour.

Herring were observed acoustically more or less continuously from 62.5º to 70ºN. Herring was in more dense concentrations closer to the coast, clearly following the shelf edge during its southward migration.

Observations from echo sounder and sonars overlapped very well, suggesting insignificant problems with vessel avoidance. The sonar investigations also demonstrated southward migration speeds of 0.56 knots and 0.48 knots in areas south and north of 67ºN, respectively.

The official estimate of SSB index, to be treated as a relative one, comparable to previous indices of NSS herring during the spawning season, was 6.2 million t, with a sampling variance (CV) of 19.6%. This estimate is 86% of the last estimate of 7.2 million t in 2008. In comparison the official advice is based on a predicted SSB in 2015 of 3.5 million t, which is only 51% of the 2008 official SSB of 6.9 mill t.

The year class 2004 was clearly dominating, with 2006 and 2009 coming next, and with the first time spawners of the 2011 year class at about the same levels. This year class composition was similar to that observed in the Norwegian Fishery during autumn 2014, clearly confirming the problem with no large year classes in recent years. In comparison, the main survey used in the tuning of the assessment in recent years, the ecosystem survey in May in the Norwegian Sea 2014, indicated equal abundance of 2009 and 2004 year classes. This discrepancy signifies the importance of having more than one survey estimation year class abundance.

The observers on board representing the fishermen had deep concerns regarding the potential underestimation of the spawning stock due to immigration directly from the west in the Norwegian Sea, which was not covered by the survey. This is something that clearly is a possibility but cannot be treated analytically. The observers were also concerned about underestimation in the northern part of the distribution area with bad weather, preventing the survey from progressing while herring were migrating southwards. This has also occasionally happened at earlier surveys, but it cannot be excluded that the underestimation was larger in 2015 than in earlier years due to longer periods with bad weather. Another concern was herring observed at the surface above the hull mounted transducers very close to the surface in the northern areas. However, given that observations with sonar data and echo sounder data did show very good consistency, this concern potentially only is a minor problem in the survey.

To conclude, the results of the present survey, which demonstrates discrepancies compared with official stock assessment as well as the May survey in the Norwegian Sea, signifies the importance of the coming full evaluation of the NSS herring stock assessment and advice process though the benchmark work that is to be carried out on the stock over the next year. This process including detailed analyses of all input data and the assessment models themselves is clearly needed before any firm conclusions may be drawn on the actual trends and SSB level of this stock. However, the survey of NSS herring during the spawning season has been considered a successful one, with a very good co-operation between scientists and fishermen, and it will hopefully be carried out also in future years.

Survey participants:

<u>MS *Nybo*</u>		
Aril Slotte	Survey coordinator	2 -16.02.2015
Egil Ona	Head of acoustics	2 -16.02.2015
Gunnar Lien	Acoustics	2 -16.02.2015
Valantine Anthonypillai	Biology	2 -16.02.2015
Jostein Røttingen	Biology	2 -16.02.2015
Øyvind Tangen	Biology	2 -16.02.2015
Torfinn Gangstad	Observer	2 -16.02.2015
<u>MS *Ligrunn*</u>		
Hector Pena	Survey leader	2 -12.02.2015
Espen Johnsen	Acoustics	2 -12.02.2015
Are Salthaug	Acoustics	2 -16.02.2015
Jens Christian Holst	Observer	2 -16.02.2015
<u>MS *Inger Hildur*</u>		
Kjell Rong Utne	Survey leader	2 -16.02.2015
Endre Grimsbø	Acoustics	2 -16.02.2015
Lage Drivenes	Acoustics	2 -16.02.2015
Eilert Hermansen	Biology	2 -16.02.2015

Introduction

Acoustic surveys on NSS herring has been carried out regularly since the 1980s, with some breaks in 2001-2004 and 2009-2014. The survey in 2015 was initiated based on the pressure from fishermen and fishermen's organizations that IMR should conduct more surveys on this commercially important stock. The Norwegian Sales Organization for Pelagic fish also decided to support the survey financially, covering the full costs of three commercial vessels over two weeks.

Given the special interest in the survey and financial support from the fishermen, a reference group consisting of a mixture of scientists and fishermen and representatives from fishermen's organizations were set up to take care of the survey planning. This was to make sure that there was a good dialog on how to ensure a good survey coverage in time and space, as well as on how the analyses etc were conducted. Therefore representatives were also invited onboard as observers on the survey, and have also taken part in the discussions related to analyses and reporting. This was to ensure that the investigations also have a stamped acceptance among fishermen in general.

The main objective of the survey was to estimate the year class abundance and spawning stock biomass index during the period of spawning migration from wintering areas at/off the northern Norwegian coast towards the coastal spawning ground further south.

A sub-objective was to compare two different software solutions for abundance estimation, the BEAM used up to date for most of NSS herring estimates, and the newly developed StoX. StoX is expected to be the future software used in abundance estimation of most stocks surveyed by IMR.

Finally, it was also a purpose that the results of the survey should be compared with previous surveys on NSS herring during the spawning season, as well as the main survey in the stock assessment carried out in the Norwegian Sea in May, and the official stock assessment SSB provided by ICES WGWIDE.

Material and methods

Survey design and sampling

During the period 2-14th of February the spawning grounds from Møre (62ºN) to Troms (70º) were covered acoustically by the commercial vessels MS *Nybo*, *Ligrunn* and *Inger Hildur*, following a survey strategy with predefined strata and west-east transects with a distance of 10 nm or less based on expected distribution (Figure 1) (See also Annex 1). In order to verify acoustic observations and to analyse year class structure over the surveyed area, trawling was carried out all over the area at a total of 20 stations, and in addition a small purse seine was used for sampling at 5 stations on near surface registrations (Figure 2). The purse seine catches were treated carefully and the fish released quickly after a sample was taken with a large dip net.

Biological sampling

The following variables of individual herring were analysed: Total weight (W) in g and total length (L_T) in cm (measured to nearest 0.5 cm below) on up to 100 individuals per sample, and in addition the sex, maturity stage, stomach fullness and gonad weight (W_G) in g (given maturity stage<7) were measured in 30 individuals. The maturity stages were determined by visual inspection of gonads as recommended by ICES (Anon. 1962): immature = 1 and 2, maturing = 3 to 4, ripe = 5, spawning = 6, spent = 7 and recovering = 8. Extra attention was paid to potential infection of ichtyophonus, given recent occurrence in North Sea herring.

Echo sounder data

Acoustical data were recorded with 38 kHz SIMRAD EK 60 echo sounder and echo integrator onboard all three vessels. All three vessels were calibrated at the tip of the fishing pier in Ålesund prior to the survey according to standard methods (Foote et al., 1987), adjusted for split beam methods as described in Ona (1999). The CU 60 mm calibration sphere was used on the primary frequency 38 kHz, and the WC 38.1 mm were used on the 200 kHz onboard NYBO. All vessels were satisfactorily calibrated, and the calibration reports with new gain estimates and raw data are stored on the survey disc at NMD.

A comparative check for measuring echo sounder performance outside Bodø and outside Tromsø revealed that one of the vessels had lower performance than the two other vessels, measuring a weaker bottom echo than the two other vessels. The problem showed to be some weak pings, probably caused by the transmitter or receiver of the echosounder, causing a weaker area backscattering in 5- 15% of the data. The rest of the transmissions were ok and usable. Matlab analysis was used to identify the weak pings of the transmission pulse, and further used to remove these in the survey data. Computations and corrections were manually checked, and found to work very well, and a new database output was generated for this vessel. A special report on this problem will be worked out later. The herring data for this vessel was corrected by 16% positive, which was very close to the discrepancy seen in the Bodø bottom comparison.

LSSS, Large Scale Survey System (Korneliussen et al. 2006) was applied in the interpretation of the data. The recorded area echo abundance, i.e. the nautical area backscattering coefficient (NASC), s_A (MacLennan et al., 2002), was interpreted and distributed to herring and ‘other’ items. The data were stored with a resolution of 1 nmi on the horizontal scale and 10 m intervals.

Abundance estimation methods

In order to update the official ICES WGWIDE index on abundance of NSS herring during the spawning season, the conversion of the area echo abundance to numerical fish quantities and biomass was achieved using the adopted mean target strength to length relationship for herring (Foote, 1987) as used in the standard assessment surveys on NSS herring in ICES WGWIDE up to date, and standard methods by MacLennan et al (2002) (See Annex 1).

Abundance estimation software

Two different software solution developed by IMR were used and compared in the abundance estimation, the StoX (See Annex 2) the BEAM (See Annex 3). BEAM is used up to date for most of NSS herring estimates, and the newly developed StoX is expected to be the future software used in abundance estimation of most stocks surveyed by IMR.

Sonar data and analyses

Data from Simrad SIMAD SH80 (Nybo) Simrad SX90 (Inger Hildur) and Simrad SX93(Ligrunn) sonars were logged continually during the survey during the survey to study the potential underestimation of herring in the surface, vessel avoidance and migration direction ad speed (See Annex 4)

Results

Distribution and density

As observed in previous years with surveys during the spawning season the herring was mostly distributed in layers during (Slotte, 1998*a*; Slotte & Tangen 2005, 2006); close to the surface at night time and closer to bottom at daytime. In the deeper off shore areas, the daytime layer was often observed as deep as 300-400 m.

The geographical distribution extended all over the study area from Ålesund (62.5ºN) to Malangsgrunnen off Troms (70ºN), with highest densities close to shore demonstrating an along shelf migration to the spawning grounds (Figure 3).

Abundance estimates

The official estimate of SSB index using StoX, to be treated as a relative one, comparable to previous SSB indices of NSS herring during the spawning season, was 6.2 million t, with an uncertainty (CV) of 19.6% (Table 1). This estimate is 86% of the last estimate of 7.2 million t in 2008 (Figure 4). In comparison the official advice is based on a predicted SSB in 2015 of 3.5 million t, which is only 51% of the 2008 official SSB of 6.9 mill t.

The year class 2004 was clearly dominating, with 2006 and 2009 coming next, with the first time spawners of the 2011 year class (62% were maturing) at about the same levels (Table 1). This year class composition was similar to that observed in the Norwegian Fishery during autumn 2014, clearly confirming the problem with no large year classes in recent years (Figure 5). In comparison, the main survey used in the tuning of the assessment in recent years, the ecosystem survey in May in the Norwegian Sea, indicated equal abundance of 2009 and 2004 year classes. This discrepancy signifies the importance of having more than one survey estimation year class abundance.

BEAM estimation both using only values from the same transects as in StoX, as well as estimation including all transects, all resulted in estimates of 6.4 million t (See Annex 3), so strictly speaking the same estimate as in StoX, which signifies that different methods reach similar results for the point estimate. Still the StoX software, transect and strata based, makes it easy to estimate the uncertainty and it is a part of the StoX software, and not in BEAM.

Sonar observations

No major differences in the occurrence of herring aggregations were found between sonar registrations and echo sounder acoustic densities (aggregated from 0 to 100 m depth) (See annex 4). These results indicate that echo sounder biomass estimations are not seriously biased by unaccounted fraction of herring in the upper layers, and that no significant fraction of herring was distributed in the echo sounder blind zone. The sonar investigations also demonstrated that the fish were moving. In the areas south and north of Vesterålen the schools were migrating at average southward migration speeds of 0.56 knots and 0.48 knots, respectively.

Geographical variations in age, length, weight

North of 67ºN the 2011 year class appeared in the samples, and dominated the abundance together with 2004 year class, south of this limit the 2011 year class was hardly present in samples (Figure 6). This presence of young first time spawning fish in the north was also evident in the mean weight (Figure 7) and length (Figure 8) in the samples. This size dependent distribution pattern is in accordance with the observations in earlier years, which has been thoroughly discussed in Slotte and Dommasnes, 1997, 1998, 1999, 2000; Slotte, 1998*b*; Slotte, 1999*a*, Slotte 2000, 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, 1999*b*). 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.

Discussion and conclusions

Quality of the commercial vessels for abundance estimation

The survey must be considered to be a success, as the overall the acoustic data recorded were of acceptable quality and the coverage with three vessels is the best ever during the spawning season of NSS herring. Still it must be emphasised that there were a few things that should be improved in future surveys. Firstly, the problem with a lack of a drop keel was evident on the survey, when weather conditions became worse. This led to the only opportunity of surveying transects with the wind, in the west-east direction. Future surveys should preferably have vessels with a drop keel to avoid this. Secondly, we only had one frequency, the 38 kHz, which did result in more unsure interpretation of acoustic data. In the future, it is clear that the quality will increase with more acoustic frequencies for correct interpretation. Thirdly, only one of the vessels were equipped for trawling, and the survey clearly demonstrated the need for more trawl sampling both on herring for age estimation, and on registrations where one is unsure which species are recorded acoustically.

Observers' main concern with the survey

Torfinn Gangstad and Jens Christian Holst participated in the survey as observers for the Norwegian pelagic fishermen. They represented a cooperative group composed of representatives from Norges Fiskarlag, Fiskebåt and Pelagisk Forening set together to cooperate with the IMR in the planning, running and reporting of the survey. The observers thus participated on behalf of the cooperative group in the planning meetings preceding the survey, during the survey on Nybo (Gangstad) and Ligrunn (Holst) and after the survey in report meetings and the writing of this report through this Annex 5. The cooperation with the IMR personal has been very good throughout.

In Annex 5 they present a discussion on their observations and thoughts about various sources of bias in the relative herring estimate. The discussion includes various experiences made by Norwegian herring skippers throughout the years. They acknowledge that these observations are not quantitative but claim they are valid qualitative observations valuable in evaluating various sources of bias in the relative estimate. New, and prior to the survey, unknown bias to science, like the high concentration herring migration front, is presented in the annex.

They are concerned regarding the potential underestimation of the spawning stock due to immigration directly from the west in the Norwegian Sea, which was not covered by the survey. This is something that clearly is a possibility but cannot be treated analytically. They were also concerned about underestimation in the northern part of the distribution area with bad weather, preventing the survey from progressing while herring were migrating southwards. This has also occasionally happened at earlier surveys, but it cannot be excluded that the underestimation was larger in 2015 than in earlier years due to longer periods with bad weather. Another concern was herring observed at the surface above the hull mounted transducers very close to the surface in the northern areas. However, the comparison between sonar data and echo sounder data did show very good consistency, indicating that this concern potentially only is a minor problem in the survey.

It the view of the observers the summed bias in the relative estimate is significant and large. Some of its sources could be corrected for, like bubble noise and migration, while others, like diffuse herring in the surface acoustic blind zone and herring outside the survey area, cannot be corrected for today. They strongly encourage work which can further enlighten these and other sources of bias in future acoustic herring stock estimates. At present none of the estimates in the spawning survey index (See Figure 4) has been corrected for any suspected biases. However, the basis of the index is that the bias in the surveys is comparable from year to year, suggesting that the actual trend in the survey is correct. This may not necessarily be true, and hence the suggestion to further work to correct for potential biases is something also the scientists agree to.

Comparison with previous spawning surveys and official assessment

To conclude, the results of the present survey indicates discrepancies between the spawning survey, May survey and official stock assessment, that signifies the importance of the coming benchmark work on NSS herring that is to be carried out on the stock over the next year. This process including a full evaluation of all input data and the assessment models themselves is clearly needed before any firm conclusions may be drawn. However, the 2015 survey of NSS herring during the spawning season has been considered as being successful, with a very good co-operation between scientists and fishermen, and it will hopefully be carried out also in future years.

Acknowledgement

The Norwegian Sales Organisation for Pelagic Fish is thanked for the valuable financial contribution to the survey. The whole reference group with members from fishermen and fishermens organisations are also thanked for valuable contribution to the planning of the survey. Observers Jens Christian Holst and Torfinn Gangstad are thanked for valuable input to analyses and reporting. Instrument personell Gunnar Lien, Lage Drivenes and Endre Grimsbø are thanked for valuable help with acoustics during the survey. Jostein Røttingen and Eilert Hermansen are thanked for their help with biological analyses and consistent age reading. Gavin Macaulay is thanked for the valuable work correcting acoustic data. All the participants and the rest of the crew on board *Nybo*, *Ligrunn* and *Inger Hildur* are thanked for their valuable work during the cruise. It must be emphasised that everybody from the vessels did what they possibly could to support the scientific crew; the service was splendid from the beginning to the end. Thanks to all for a very nice survey both scientifically and socially.

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Tables

Table 1. The overall areas estimate of abundance (TSN), total biomass (TSB) and spawning stock biomass (SSB) of Norwegian spring spawning herring during the spawning season 2-14.February 2015.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TSN (1000)	TSB (t)	Mean weight (g)
Length																		
18	293653	-	-	-	-	-	-	-	-	-	-	-	-	-	-	293653	10060.4	34.26
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
20	32472	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32472	1574.9	48.5
21	32472	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32472	1883.4	58
22	26223	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26223	1730.7	66
23	-	116824	-	-	-	-	-	-	-	-	-	-	-	-	-	116824	8786.6	75.21
24	-	16236	31404	-	-	-	-	-	-	-	-	-	-	-	-	47640	4249.8	89.21
25	-	142285	615727	-	-	-	-	-	-	-	-	-	-	-	-	758011	75047.3	99.01
26	-	75417	1019846	29903	-	-	-	-	-	-	-	-	-	-	-	1125166	124161.3	110.35
27	-	15169	437637	-	-	-	-	-	-	-	-	-	-	-	-	452806	57656.8	127.33
28	-	17660	200271	15169	-	-	-	-	-	-	-	-	-	-	-	233100	35342.6	151.62
29	-	-	149949	90547	-	-	-	-	-	-	-	-	-	-	-	240496	43447.2	180.66
30	-	-	98865	43119	49442	-	-	-	-	-	-	-	-	-	-	191427	38598.5	201.64
31	-	-	31467	95527	118702	-	-	-	-	-	-	-	-	-	-	245697	59754.3	243.2
32	-	-	-	274418	694511	-	-	-	-	-	-	-	-	-	-	968929	251130.4	259.18
33	-	-	-	177749	1013907	120884	-	159256	19124	105009	-	-	-	-	-	1595930	457106.5	286.42
34	-	-	-	-	985149	224665	332874	433230	165212	1200933	72495	158924	-	-	-	3573481	1135934.8	317.88
35	-	-	-	20104	185121	51100	309137	1297642	521374	3096111	291775	667692	-	-	-	6440056	2173564.5	337.51
36	-	-	-	-	-	51077	-	617284	74100	2282343	58168	495228	51974	62308	-	3692483	1307512.8	354.1
37	-	-	-	-	51205	-	51205	64165	32748	573656	-	254567	-	154785	19453	1201786	448179.4	372.93
38	-	-	-	-	-	-	-	-	-	79985	-	116951	32758	-	-	229694	96225.5	418.93
TSN(1000)	384819	383590	2585168	746535	3098039	447726	693216	2571576	812558	7338038	422438	1693363	84731	217094	19453	**21498345**		
TSB(t)	15249	38093	314653	172847	892330	142560	226689	858178	274326	140298	2541334	600414	33946	73987	7042		**6331947**	
Mean length (CM)	19.0	25.0	26.7	31.6	33.4	34.3	34.9	35.2	35.2	35.5	35.2	35.9	37.3	36.9	37.0			
% mature	0	28.6	62.1	100	100	100	100	100	100	100	100	100	100	100	100			100
SSB (t)	0	10895	195400	172847	892330	142560	226689	858178	274326	140298	2541334	600414	33946	73987	7042		**6170246**	
Mean weight (g)	39.6	99.3	121.7	231.5	288.0	318.4	327.0	333.7	337.6	346.3	332.1	354.6	400.6	340.8	362.0			**294.5**

Figures

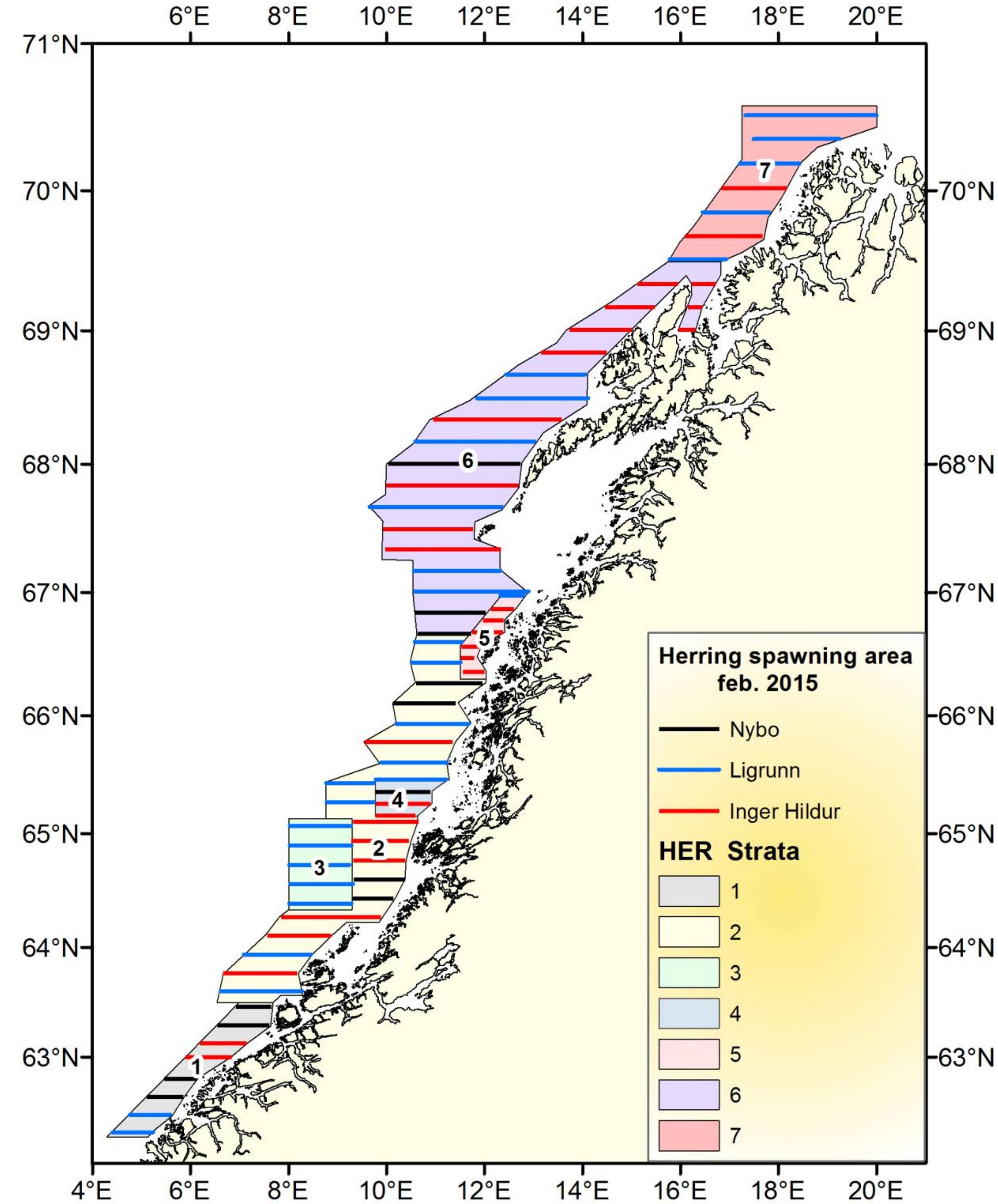

Figure. 1. Strata and transects covered 2-14.February 2015 with *Nybo, Inger Hildur* and *Ligrunn*

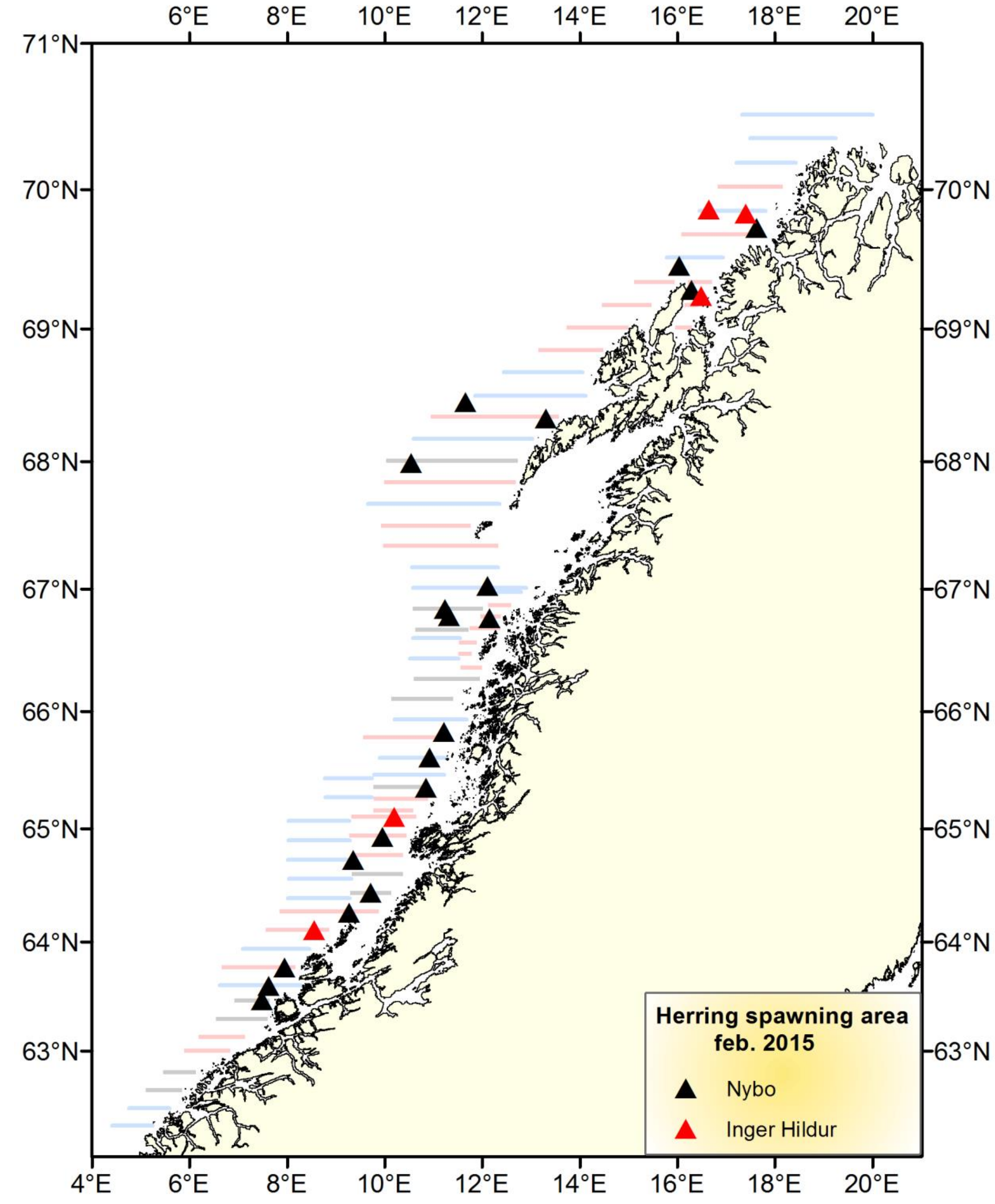

Figure. 2. Trawl stations with Nybo and purse seine stations with Inger Hildur taken at acoustic registrations2-14.February 2015.

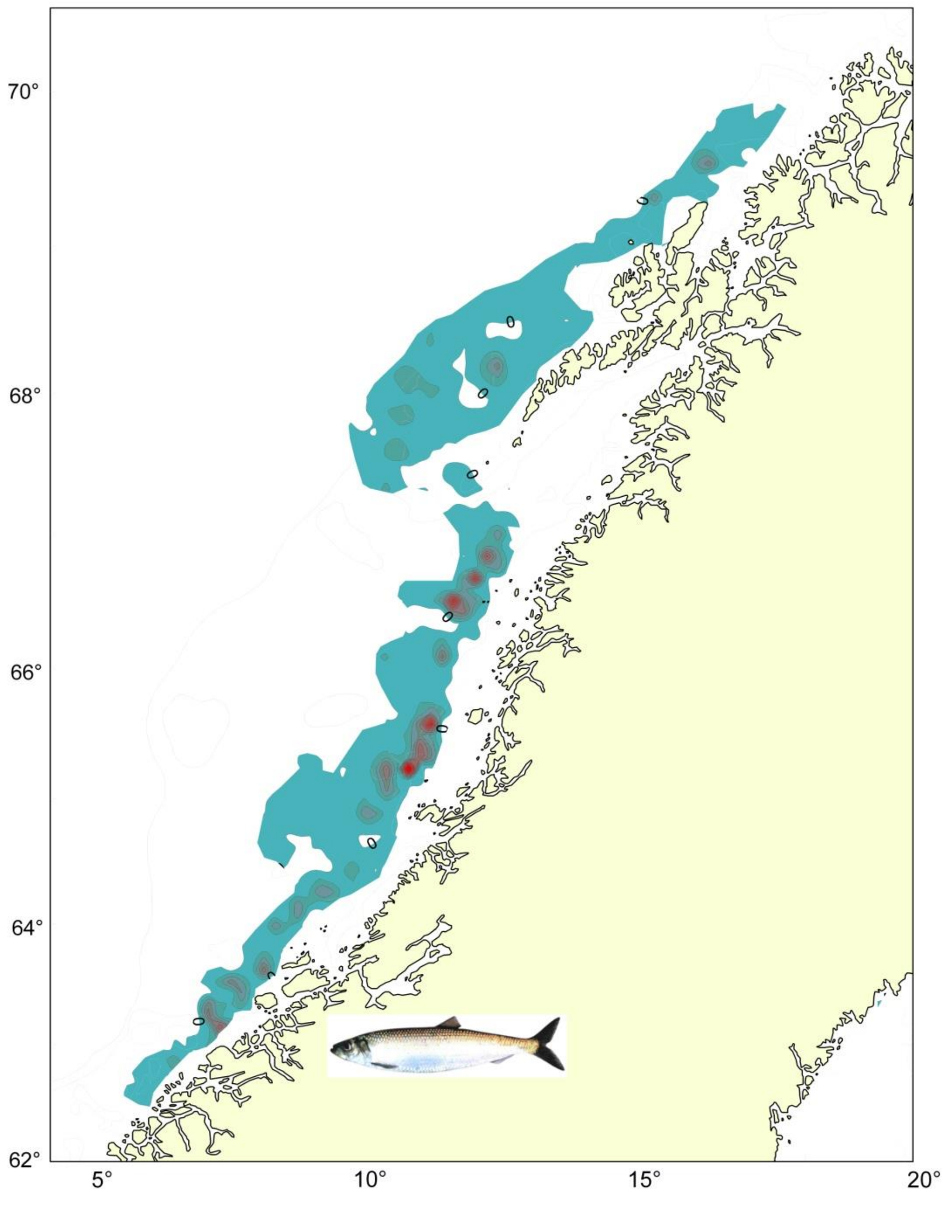

Figure 3. Distribution and density of herring recoreded during 2-14.februar 2015.

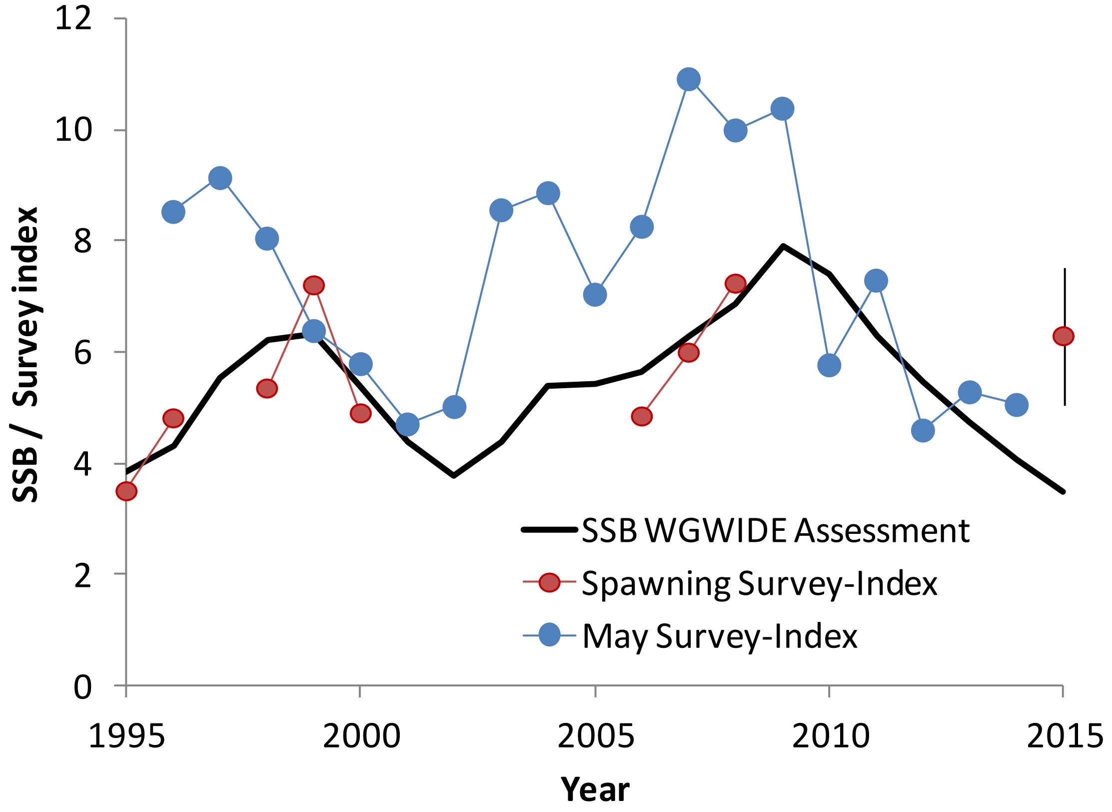

Figure 4. Spawning stock biomass (SSB) from ICES assessment (ICES WGWIDE 2014), compared with spawning survey index (uncertainty [CV] is given for the latest 2015 estimate) og from the May survey index.

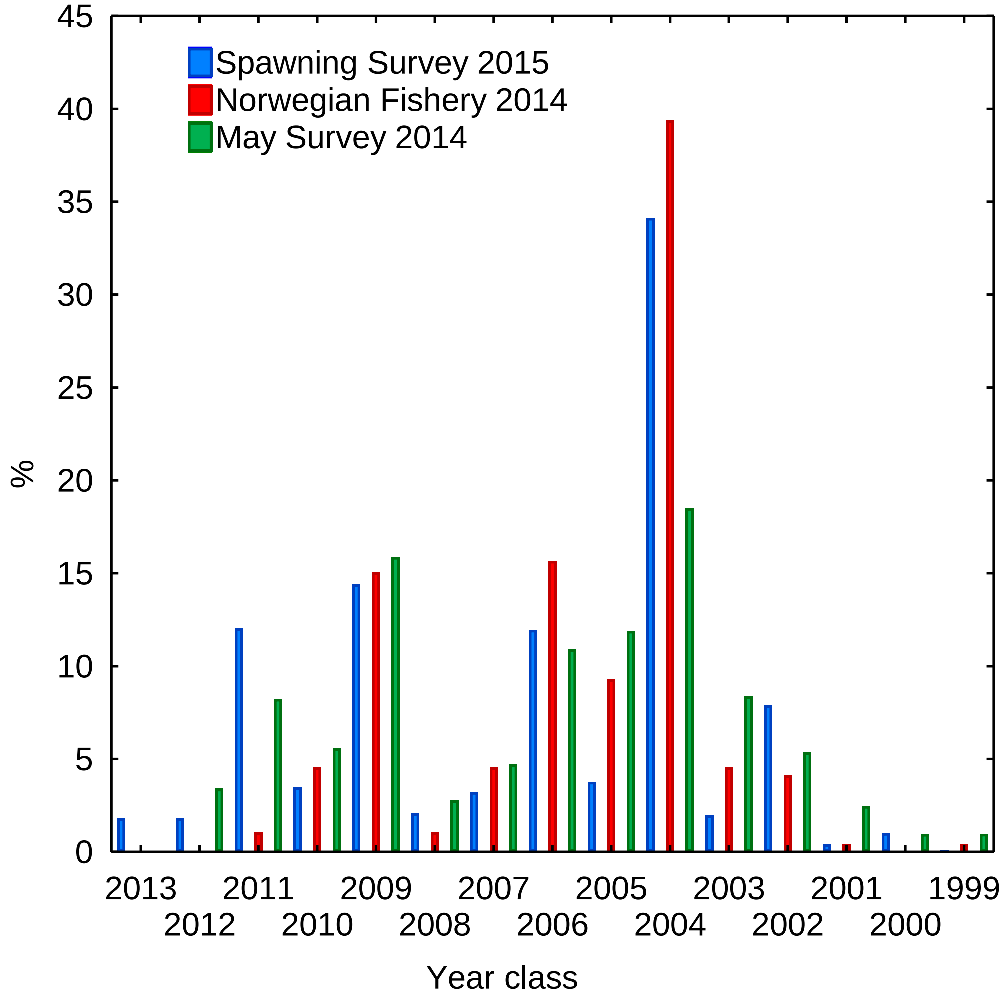

Figure 5. Comparison of relative year class composition between May Survey 2014, Norwegian Fishery during Autumn 2014 and the current survey during the spawning season 2015.

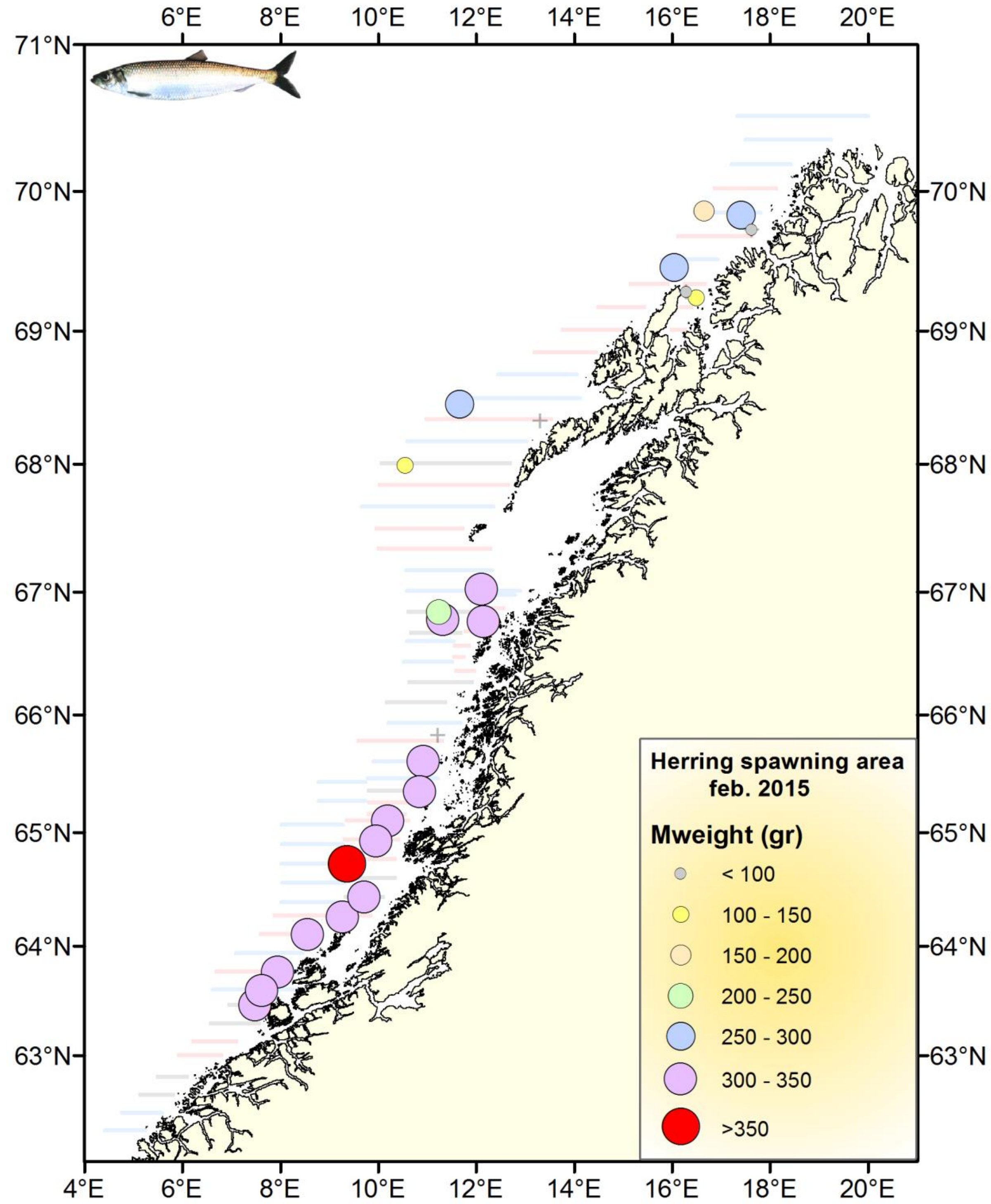

Figure 7. Latitudinal differences in mean herring weight (g) in the survey during the spawning season 2015.

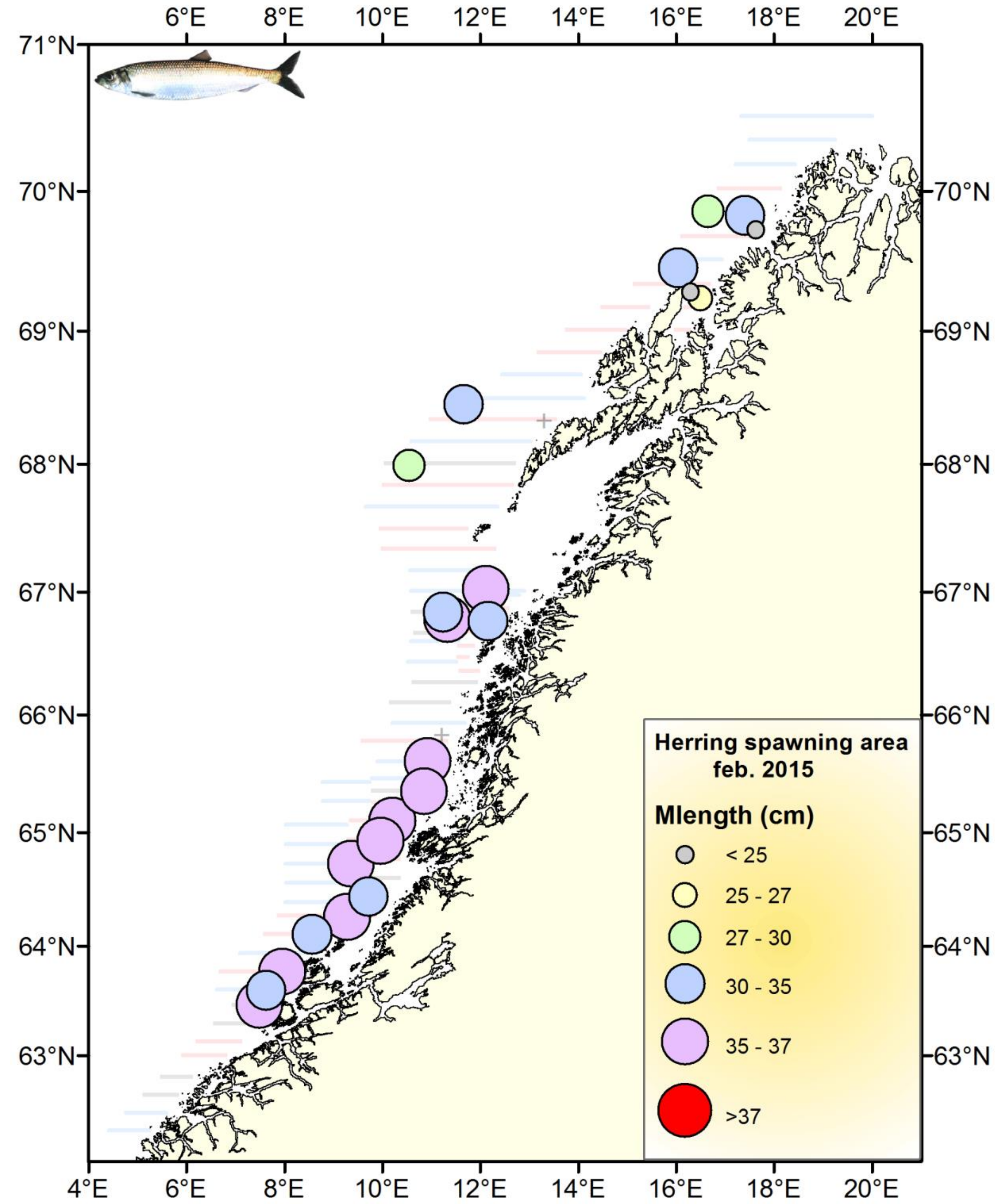

Figure 8. Latitudinal differences in mean herring body length (cm) in the survey during the spawning season 2015.

Annex 1. Survey design and estimation procedures

By Espen Johnsen

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 expected density and age structures of herring. It was decided that all vessels should sail as close as possible to the coast, and that the western limits of the offshore transects should end when no herring was observed for about 10 n.mi. These rules made small changes to the predefined stratum polygon, however, as the migrating herring had not received to strata 1 and 2 by the time of the survey start, the predefined strata 1 and 2 were not covered. Within each stratum, parallel east-west transects with a constant distance and a random starting position was used as the primary sampling unit (Simmonds and MacLennan 2008). More effort was allocated to areas with expected high densities, and the distance between transects was 10 n.mi. in strata 3, 4, 5, 8, and 9, and 6 n.mi. in strata 6 and 7. Figure XX1 shows sailed transects and final stratum borders.

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 1 n mile and a vertical resolution of 10 m, referenced to the 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. 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:

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

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

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

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

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

Variance by stratum is estimated as:

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

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

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

The global relative standard error of NASC

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

where N is number of strata.

Only FF "Nybo" was equipped with a trawl, which was used for ground truthing of acoustic recordings and for biological sampling. FF "Inger Hildur" was equipped with a small purse seine, which was used for biological sampling.

Assignment of trawl stations to transect was done in two different manners; all trawl stations in strata 4, 8 and 9 were used to derive a common length distribution for all transect within the respective strata. Due to a few number of trawl stations within the other strata, stations were assigned manually to transect within strata 3, 5, 6 and 7. All stations had equal weight. Relative standard error by number of individuals by age group was estimated by carrying out a by combining Monto Carlo selection from estimated NASC distributions by stratum with a bootstrapping techniques of the assigned trawl stations. Details are found in Korsbrekke et. al (in prep.).

The acoustic estimates presented in this report use the 38 kHz NASC, and the mean was calculated for data scrutinized as heering and collected along the transects (acoustic recordings taken during trawling, etc 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. <s_A>is the mean backscattering coefficient [m2/nmi.2] (NASC). A is the area of the stratum [nmi.2] and σ is the mean backscattering cross section of the sandeel at length L_l.

The target strength (TS) is used for the conversion where $\sigma = 4\pi\ 10^{(TS/10)}$ is used for estimating the backscattering cross section. Traditionally, TS = 20logL – 71.9 (Foote 1987) has been used for herring during the spawning surveys, however, several papers question this target strength. Ona (2003) describes how the target strength of herring changes with depth, and measured the target strength of herring to be TS = 20logL – 2.3 log(1 + z/10) – 65.4 where z is depth in meters. Still, 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 ICES WGWIDE 2015 as another year in the index.

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. Details can be found in Korsbrekke et. al (in prep).

References

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

Jolly, G. M., and I. Hampton. "A stratified random transect design for acoustic surveys of fish stocks." *Canadian Journal of Fisheries and Aquatic Sciences*47.7 (1990): 1282-1291.

Korsbrekke, K. Dingsøyr, G. and Johnsen, E. In prep. Estimating variance in population characteristics with variance in transect based trawl acoustic surveys. In Prep.

Ona, Egil. "An expanded target-strength relationship for herring." *ICES Journal of Marine Science: Journal du Conseil* 60.3 (2003): 493-499.

Simmonds, J, and David N. MacLennan. *Fisheries acoustics: theory and practice*. John Wiley & Sons, 2008.

Annex 2. Abundance estimation with StoX

By Espen Johnsen

StoX is open source software developed at IMR, Norway to calculate survey estimates from acoustic and swept area surveys. The program is a stand-alone application build with Java for easy sharing and further development in cooperation with other institutes. The underlying high resolution data matrix structure ensures future implementations of e.g. depth dependent target strength and high resolution length and species information collected with camera systems. Despite this complexity, the execution of an index calculation can easily be governed from user interface and an interactive GIS module, or by accessing the Java function library and parameter set using external software like R. Accessing StoX from external software may be an efficient way to process time series or to perform boot-strapping on one dataset, where for each run, the content of the parameter dataset is altered.

Various statistical survey design models can be implemented in the R-library, however, in the current version of StoX the stratified transect design model developed by Jolly and Hampton (1990)[i] is implemented.

StoX has been tested on the 2014 IESNS survey and Norwegian acoustic sandeel and cod surveys. When new statistical methods are implemented it is regarded essential that expert specification demands, documentation and statistical rigorousness is available. According to the plan, a test version of the software will be available for people outside IMR by the end of March 2014.

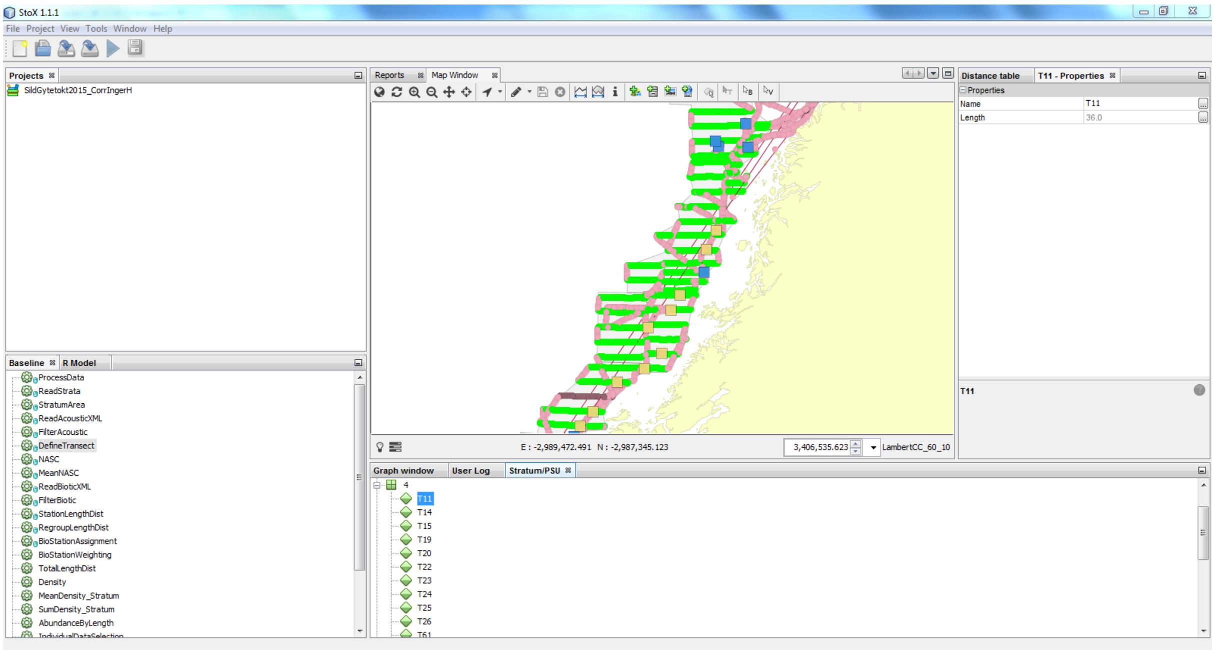

Figure 1. The graphical user interface of StoX with baseline functions (left), GIS-window (center), parameter setting window (right) and transekts by stratum (bottom). The herring spawning survey 2015 is depecited.

[1] Jolly, G. M., and I. Hampton. "A stratified random transect design for acoustic surveys of fish stocks." *Canadian Journal of Fisheries and Aquatic Sciences*47.7 (1990): 1282-1291.

Annex 3. Abundance estimation with BEAM

By Øyvind Tangen and Valantine Anthonypillai

The following target strength (TS) function has been used:

Herring: TS = 20.0 log(L) – 71.9 dB.

To estimate the abundance of herring the unit area abundance for each statistical square was multiplied by the number of square nautical miles in each statistical square and then summed for all the statistical squares over the total area. ICES-squares (0.5° latitude by 1° longitude) were used.

Biomass estimation was calculated by multiplying abundance in numbers by the average weight of the fish in each statistical square and then summing all squares over the total area. The Norwegian BEAM software (Totland and Godø 2001) was used to make the estimation of total biomass and numbers of individuals by age and length in the whole survey area. The trawl stations were allocated in the squares where they were taken and in the squares near by if needed.

Table 1 Total biomass from all the Sa-values recorded.
Table 2 Area, Sa-values, density and the biomass in each square covered
Table 3 Total biomass from the Sa-values representing the transects.
Table 4 Area, Sa-values, density and the biomass in each square covered by transects.

The estimated shows that the herring stock is still dominated by the 2004 year class representing 41 % in weight of the spawning stock. The estimate based on data from only transects were similar to the estimate including data also from surveying in between transects.

Figure 1. Length and age distribution

Figure 2. The distribution and the cruisetracks.

Figure 3. The Sa-values in squares

Table 1: Length and age abundance estimates of Norwegian spring-spawning herring in spawning area 2015

Length	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Tot	Weight	Mean w.
15																0		
16																0		
17																0		
18		34	0	0	0	0	0	0	0	0	0	0	0	0	0	34	1.1	32
19		18	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0.7	37
20		42	0	0	0	0	0	0	0	0	0	0	0	0	0	42	2	48
21		52	0	0	0	0	0	0	0	0	0	0	0	0	0	52	2.9	56
22		71	0	0	0	0	0	0	0	0	0	0	0	0	0	71	4.3	61
23		0	277	0	0	0	0	0	0	0	0	0	0	0	0	277	21.3	77
24		0	60	119	0	0	0	0	0	0	0	0	0	0	0	179	16	90
25		0	113	480	0	0	0	0	0	0	0	0	0	0	0	593	58.9	99
26		0	58	899	29	0	0	0	0	0	0	0	0	0	0	986	109.8	111
27		0	30	596	0	0	0	0	0	0	0	0	0	0	0	626	80.1	128
28		0	20	184	20	0	0	0	0	0	0	0	0	0	0	224	34.7	154
29		0	0	169	68	0	0	0	0	0	0	0	0	0	0	237	41.5	176
30		0	0	86	29	86	0	0	0	0	0	0	0	0	0	201	40.1	201
31		0	0	46	91	114	0	0	0	0	0	0	0	0	0	251	59.8	238
32		0	0	0	216	512	0	0	0	0	0	0	0	0	0	728	189.7	261
33		0	0	0	153	858	92	0	123	31	123	0	0	0	0	1380	394.8	286
34		0	0	0	0	1093	273	312	547	195	1328	117	117	0	0	3982	1266.1	318
35		0	0	0	38	263	38	301	1280	527	3387	263	715	0	0	6812	2307	339
36		0	0	0	0	0	38	0	615	115	2308	115	462	38	115	3806	1355.4	356
37		0	0	0	0	31	0	31	62	31	526	0	248	0	124	1053	398.5	379
38		0	0	0	0	0	0	0	0	0	35	0	53	18	0	106	43.1	408
39		0	0	0	0	0	0	0	0	0	0	0	12	0	0	12	5.3	425
40																0		
N	0	217	558	2579	644	2957	441	644	2627	899	7707	495	1607	56	239	21670	6433.1	
1000 t		11	51.3	320.8	158.5	872	139.6	213	884.7	302.1	2639	167.5	564.3	20.9	88		6433.2	
Mean L		21	24.7	27	32	33.8	34.6	35.1	35.5	35.4	35.7	35.5	36.2	37.1	37		33.8	
Mean w		50.7	91.9	124.4	246.4	294.8	316.4	330.5	336.9	336	342.5	337.8	351.3	372.4	367		297	

Table 2 Area, Sa-values and biomass in each squares

art	stratum	area	sigma	sa	midlat	midlon	density	tons	1000 tons
SILDG03	6200050005100	251	8.13E-07	2	62.25	5.5	671	168812.6	0
SILDG03	6230050005100	453	8.13E-07	180	62.75	5.5	58995	26742064	27
SILDG03	6230060005100	181	8.13E-07	875	62.75	6.5	287300	52092478	52
SILDG03	6300060005100	462	8.13E-07	13	63.25	6.5	4189	1934583	2
SILDG03	6300070005100	251	8.13E-07	6450	63.25	7.5	2115310	5.31E+08	531
SILDG03	6330060005100	199	8.13E-07	16	63.75	6.5	5297	1054296	1
SILDG03	6330070005100	796	8.13E-07	1936	63.75	7.5	635012	5.06E+08	506
SILDG03	6330080005100	167	8.13E-07	1886	63.75	8.5	618235	1.03E+08	103
SILDG03	6400080005100	704	8.13E-07	765	64.25	8.5	251542	1.77E+08	177
SILDG03	6400090005100	383	8.13E-07	1739	64.25	9.5	565671	2.17E+08	217
SILDG03	6400100005100	55	8.13E-07	36	64.25	10.5	11576	633668.6	1
SILDG03	6430080005100	768	8.13E-07	90	64.75	8.5	29897	22955607	23
SILDG03	6430090005100	768	8.13E-07	1062	64.75	9.5	350237	2.69E+08	269
SILDG03	6430100005100	346	8.13E-07	550	64.75	10.5	179450	62003385	62
SILDG03	6500080005100	301	8.13E-07	178	65.25	8.5	58617	17668985	18
SILDG03	6500090005100	754	8.13E-07	1055	65.25	9.5	346990	2.61E+08	261
SILDG03	6500100005100	641	8.13E-07	3391	65.25	10.5	1113009	7.13E+08	713
SILDG03	6500110005100	30	8.13E-07	15	65.25	11.5	4797	144605.4	0
SILDG03	6530090005100	140	8.13E-07	266	65.75	9.5	87381	12273963	12
SILDG03	6530100005100	739	8.13E-07	2719	65.75	10.5	891994	6.59E+08	659
SILDG03	6530110005100	259	8.13E-07	610	65.75	11.5	200194	51800560	52
SILDG03	6600100005100	471	8.13E-07	689	66.25	10.5	217330	1.02E+08	102
SILDG03	6600110005100	580	8.13E-07	3225	66.25	11.5	1022846	5.93E+08	593
SILDG03	6600120005100	14	8.13E-07	29	66.25	12.5	9549	138442.7	0
SILDG03	6630100005100	391	8.13E-07	484	66.75	10.5	149542	58439547	58
SILDG03	6630110005100	711	8.13E-07	3260	66.75	11.5	1007049	7.16E+08	716
SILDG03	6630120005100	249	8.13E-07	3295	66.75	12.5	1076018	2.68E+08	268
SILDG03	6700090005100	35	8.13E-07	736	67.25	9.5	193855	6746832	7
SILDG03	6700100005100	557	8.13E-07	318	67.25	10.5	92525	51523218	52
SILDG03	6700110005100	661	8.13E-07	191	67.25	11.5	58540	38710415	39
SILDG03	6700120005100	522	8.13E-07	753	67.25	12.5	239492	1.25E+08	125
SILDG03	6700130005100	174	8.13E-07	0	67.25	13.5	9	1585.299	0
SILDG03	6730090005100	20	8.13E-07	215	67.75	9.5	51702	1057148	1
SILDG03	6730100005100	682	8.13E-07	1115	67.75	10.5	267570	1.82E+08	182
SILDG03	6730110005100	668	8.13E-07	235	67.75	11.5	66289	44276406	44
SILDG03	6730120005100	320	8.13E-07	118	67.75	12.5	35006	11213606	11
SILDG03	6800100005100	233	8.13E-07	1334	68.25	10.5	376341	87856895	88
SILDG03	6800110005100	634	8.13E-07	656	68.25	11.5	185061	1.17E+08	117
SILDG03	6800120005100	634	8.13E-07	555	68.25	12.5	156415	99112618	99
SILDG03	6800130005100	167	8.13E-07	166	68.25	13.5	51601	8604530	9
SILDG03	6830110005100	20	8.13E-07	856	68.75	11.5	266291	5211681	5
SILDG03	6830120005100	287	8.13E-07	65	68.75	12.5	20103	5770424	6
SILDG03	6830130005100	587	8.13E-07	26	68.75	13.5	8160	4790856	5
SILDG03	6830140005100	359	8.13E-07	91	68.75	14.5	28293	10151937	10
SILDG03	6900140005100	255	8.13E-07	56	69.25	14.5	17505	4465420	4
SILDG03	6900150005100	306	8.13E-07	390	69.25	15.5	121876	37307024	37
SILDG03	6900160005100	287	8.13E-07	248	69.25	16.5	62467	17926322	18
SILDG03	6930150005100	12	8.13E-07	5	69.75	15.5	1549	19296.11	0
SILDG03	6930160005100	449	8.13E-07	1091	69.75	16.5	314384	1.41E+08	141
SILDG03	6930170005100	498	8.13E-07	71	69.75	17.5	18454	9197462	9
SILDG03	7000170005100	578	8.13E-07	0	70.25	17.5	90	51947.59	0
									6433

Figure 1. Length and age frequency

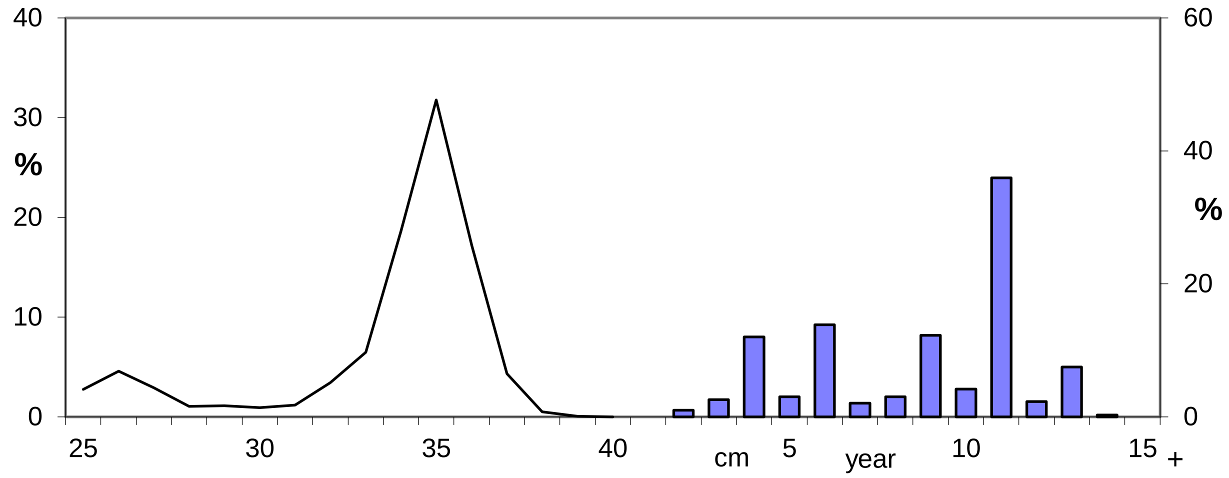

Figure 2. The distribution and the cruisetracks.

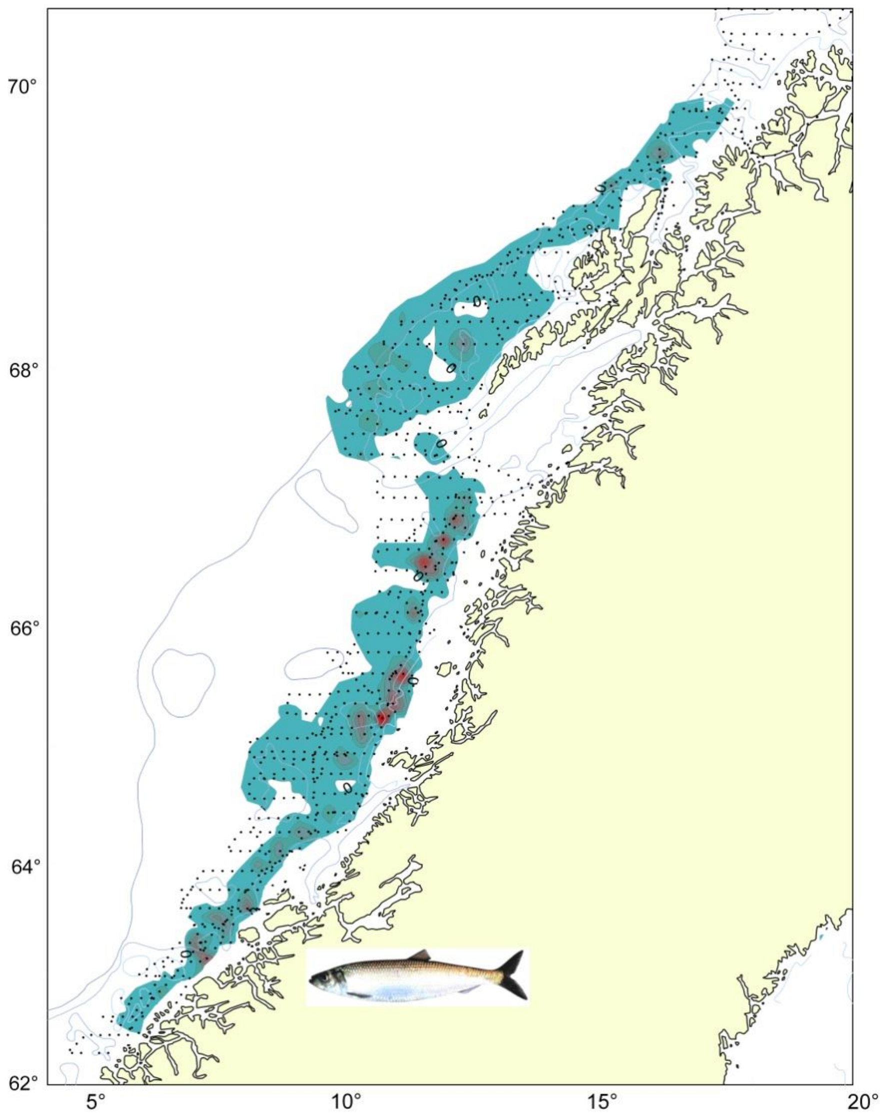

Figure 3. The Sa-values in squares

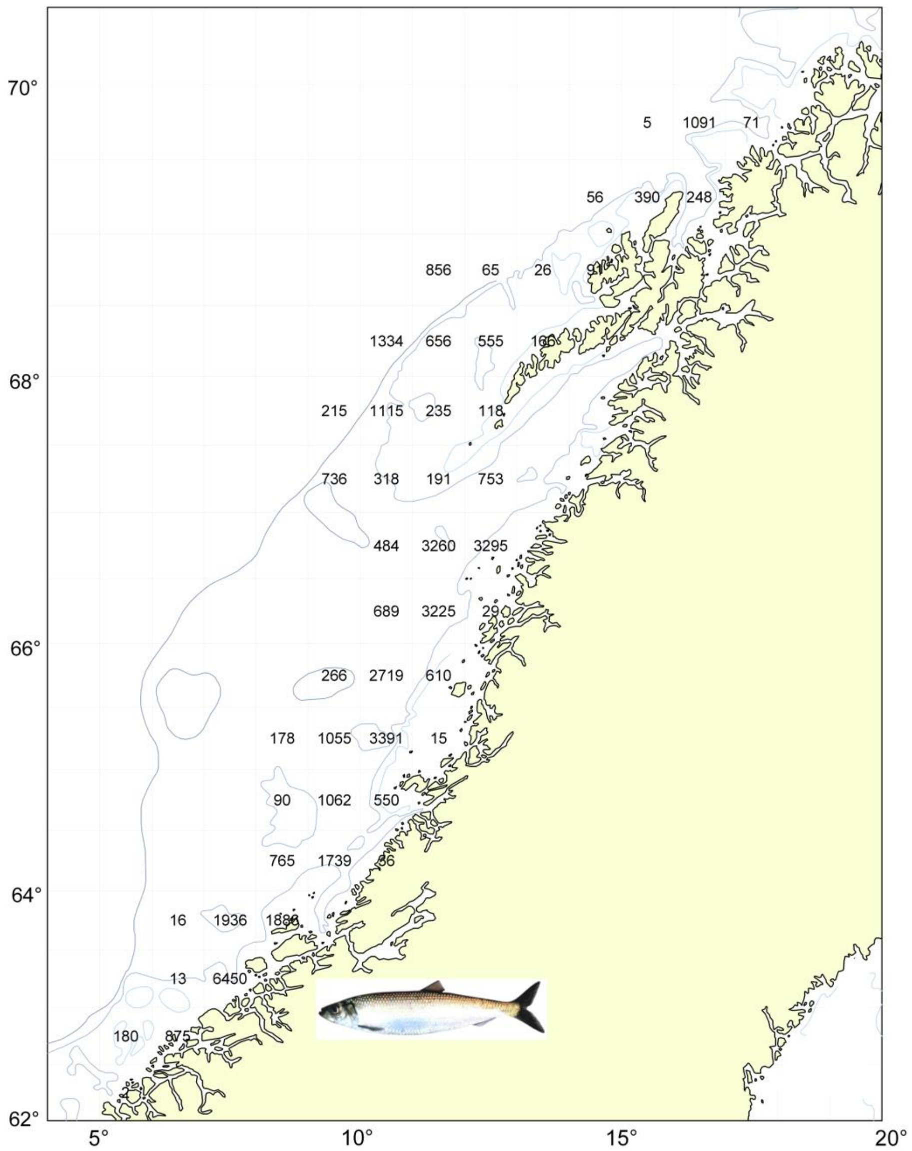

Table 3: Length and age abundance estimates of Norwegian spring-spawning herring in spawning area 2015 from transects.

Length	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Tot	Weight	Mean w.
15																0		
16																0		
17																0		
18		26	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0.8	32
19		15	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0.6	37
20		47	0	0	0	0	0	0	0	0	0	0	0	0	0	47	2.3	48
21		54	0	0	0	0	0	0	0	0	0	0	0	0	0	54	3	56
22		74	0	0	0	0	0	0	0	0	0	0	0	0	0	74	4.5	61
23		0	299	0	0	0	0	0	0	0	0	0	0	0	0	299	23	77
24		0	63	126	0	0	0	0	0	0	0	0	0	0	0	189	16.9	90
25		0	116	495	0	0	0	0	0	0	0	0	0	0	0	611	60.7	99
26		0	60	931	30	0	0	0	0	0	0	0	0	0	0	1021	113.7	111
27		0	32	638	0	0	0	0	0	0	0	0	0	0	0	670	85.7	128
28		0	23	203	23	0	0	0	0	0	0	0	0	0	0	249	38.2	154
29		0	0	188	75	0	0	0	0	0	0	0	0	0	0	263	46.3	176
30		0	0	93	31	93	0	0	0	0	0	0	0	0	0	217	43.5	201
31		0	0	46	92	114	0	0	0	0	0	0	0	0	0	252	59.9	238
32		0	0	0	212	504	0	0	0	0	0	0	0	0	0	716	186.6	261
33		0	0	0	147	825	88	0	118	29	118	0	0	0	0	1325	379.6	286
34		0	0	0	0	1081	270	309	540	193	1312	116	116	0	0	3937	1251.5	318
35		0	0	0	38	263	38	301	1279	527	3386	263	715	0	0	6810	2306	339
36		0	0	0	0	0	39	0	622	117	2331	117	466	39	117	3848	1369	356
37		0	0	0	0	30	0	30	61	30	516	0	243	0	121	1031	391.2	379
38		0	0	0	0	0	0	0	0	0	34	0	51	17	0	102	41.3	408
39		0	0	0	0	0	0	0	0	0	0	0	10	0	0	10	4.2	425
40																0		
N	0	216	593	2720	648	2910	435	640	2620	896	7697	496	1601	56	238	21766	6428.5	
1000 t		11.2	54.4	339.4	158.2	857.6	137.8	211.6	882.9	301.1	2637	167.5	561.7	20.7	87.5		6428.2	
Mean L		21.1	24.7	27	31.9	33.7	34.6	35.1	35.5	35.4	35.7	35.5	36.1	37.1	37		33.8	
Mean w		51.8	91.8	124.9	244.4	294.6	316.7	330.6	337.1	336.1	342.6	337.9	351	371.8	267		295.4	

Table 4 Area, Sa-values and biomass in each squares representing the transects

art	stratum	area	sigma	sa	midlat	midlon	density	tons	1000 tons
SILDG03	62000500(	210	8.13E-07	0	62.25	5.5	0	0	0
SILDG03	62300500(	453	8.13E-07	196	62.75	5.5	64232	29116138	29
SILDG03	62300600(	181	8.13E-07	787	62.75	6.5	258346	46842659	47
SILDG03	63000600(	462	8.13E-07	4	63.25	6.5	1302	601181.1	1
SILDG03	63000700(	251	8.13E-07	5901	63.25	7.5	1935401	4.86E+08	486
SILDG03	63300600(	199	8.13E-07	106	63.75	6.5	34828	6931726	7
SILDG03	63300700(	796	8.13E-07	916	63.75	7.5	300354	2.39E+08	239
SILDG03	63300800(	167	8.13E-07	2790	63.75	8.5	914407	1.53E+08	153
SILDG03	64000800(	704	8.13E-07	886	64.25	8.5	291318	2.05E+08	205
SILDG03	64000900(	391	8.13E-07	2220	64.25	9.5	722035	2.82E+08	282
SILDG03	64001000(	55	8.13E-07	107	64.25	10.5	34482	1887556	2
SILDG03	64300800(	768	8.13E-07	32	64.75	8.5	10561	8109293	8
SILDG03	64300900(	768	8.13E-07	1310	64.75	9.5	432101	3.32E+08	332
SILDG03	64301000(	346	8.13E-07	769	64.75	10.5	251086	86754963	87
SILDG03	65000800(	301	8.13E-07	117	65.25	8.5	38472	11596704	12
SILDG03	65000900(	754	8.13E-07	1436	65.25	9.5	472247	3.56E+08	356
SILDG03	65001000(	641	8.13E-07	2701	65.25	10.5	886603	5.68E+08	568
SILDG03	65001100(	30	8.13E-07	21	65.25	11.5	6853	206579.2	0
SILDG03	65300900(	140	8.13E-07	6	65.75	9.5	1981	278262.8	0
SILDG03	65301000(	739	8.13E-07	2471	65.75	10.5	810825	5.99E+08	599
SILDG03	65301100(	259	8.13E-07	561	65.75	11.5	184033	47618737	48
SILDG03	66001000(	471	8.13E-07	502	66.25	10.5	158359	74620644	75
SILDG03	66001100(	580	8.13E-07	3384	66.25	11.5	1073221	6.22E+08	622
SILDG03	66301000(	355	8.13E-07	558	66.75	10.5	172344	61227688	61
SILDG03	66301100(	711	8.13E-07	4004	66.75	11.5	1237025	8.79E+08	879
SILDG03	66301200(	249	8.13E-07	3949	66.75	12.5	1289465	3.21E+08	321
SILDG03	67000900(	35	8.13E-07	839	67.25	9.5	221125	7695935	8
SILDG03	67001000(	557	8.13E-07	373	67.25	10.5	108583	60465346	60
SILDG03	67001100(	661	8.13E-07	218	67.25	11.5	66968	44283378	44
SILDG03	67001200(	174	8.13E-07	734	67.25	12.5	233556	40642890	41
SILDG03	67300900(	20	8.13E-07	418	67.75	9.5	100204	2048858	2
SILDG03	67301000(	682	8.13E-07	1060	67.75	10.5	254306	1.73E+08	173
SILDG03	67301100(	668	8.13E-07	83	67.75	11.5	23538	15721441	16
SILDG03	67301200(	320	8.13E-07	83	67.75	12.5	24584	7874969	8
SILDG03	68001000(	233	8.13E-07	1141	68.25	10.5	321774	75118199	75
SILDG03	68001100(	634	8.13E-07	509	68.25	11.5	143667	91034398	91
SILDG03	68001200(	634	8.13E-07	1023	68.25	12.5	288581	1.83E+08	183
SILDG03	68001300(	167	8.13E-07	278	68.25	13.5	86441	14414102	14
SILDG03	68301100(	20	8.13E-07	1168	68.75	11.5	363481	7113827	7
SILDG03	68301200(	287	8.13E-07	8	68.75	12.5	2487	713961	1
SILDG03	68301300(	555	8.13E-07	1	68.75	13.5	397	220400.7	0
SILDG03	68301400(	261	8.13E-07	67	68.75	14.5	20945	5465593	5
SILDG03	69001400(	255	8.13E-07	66	69.25	14.5	20661	5270307	5
SILDG03	69001500(	306	8.13E-07	781	69.25	15.5	244392	74809797	75
SILDG03	69001600(	223	8.13E-07	17	69.25	16.5	4377	976915	1
SILDG03	69301500(	12	8.13E-07	117	69.75	15.5	33826	421483.1	0
SILDG03	69301600(	449	8.13E-07	1490	69.75	16.5	429195	1.93E+08	193
SILDG03	69301700(	498	8.13E-07	53	69.75	17.5	13871	6913218	7
SILDG03	70001700(	578	8.13E-07	1	70.25	17.5	154	89050.54	0
									6428

Annex 4. Sonar investigations

By Héctor Peña

Héctor Peña

Introduction

Omnidirectional fisheries sonar are multibeam systems designed for commercial fishing on pelagic species, both for long range searching and short range inspection before capture. The combined sampling with horizontal and vertical beams, allow the observation of fish schools in the entire water column, in regions not accessible for down looking echo sounding. The long range design of these sonars allows a significant increase in the sampling volume of the water column, close to 200 times larger than a down looking single beam echo sounder. Also, fisheries sonars are available in most pelagic fishing vessels, and also in modern research vessels. Recent developments in sonar technology and software tools have made possible the calibration, collection and processing of sonar raw data and effort is now focused on developing methodologies for abundance estimation of schooling fish. Although this goal is still not accomplished, valuable information can be derived using the present tools like: school mapping and spatial distribution, school avoidance to approaching vessel, evaluation of schools in the echo sounder blind zone, etc.

The primary objective for the fisheries sonars in the present survey was to measure the schools in the upper 100 m and evaluate the fraction of schools not measured by the hull mounted echo sounders, which was the standard instrument used for abundance estimation.

Methodology

Sonar data from three fisheries sonars was collected during the entire survey. F/V “Ligrunn” and F/V “Inger Hildur” were equipped with Simrad SX90 low frequency sonar, and F/V “Nybo” had a high frequency sonar Simrad SH80. SX90 sonars were calibrated in Ålesund before departure with standard reference target methodology using especially designed spheres for the operational frequency of 20 kHz.

All sonars were set up for storing raw data in external hard drives, logging continuously during the survey. Sonars and echo sounder were triggered to avoid interference, setting the echo sounder as primary acoustic equipment.

For the present report, sonar data from F/V “Ligrunn” was processed and results discussed. Data from the other two vessels is planned to be processed at a later stage.

Calibration parameters for SX90 sonar from F/V “Ligrunn” were calculated, and used to correct the raw data in the post-processing software Profos (Processing system for omnidirectional fisheries sonar). Raw sonar data was replayed together with echo sounder data, for a better scrutiny process of the fish aggregations, especially relevant when no trawl data was available for species identification.

Sonar settings were defined before departure and remained fixed for the whole survey, using a range of 600 m and sonar tilt of 7 degrees. This configuration is based in theoretical sonar beam pattern, aiming to sample fish schools from the surface up to 80 m. Only the noise filter was disabled during data collection, all other sonar filters were used because they did not affect the raw data.

From a preliminary analysis of the sonar data, which included manually segmentation (identification from background noise) of single schools, it was established criteria for an automatic segmentation process. Among the more relevant parameters are: school size, school acoustic strength (Sv), school shape, minimum of number of detections (pings) required and threshold level above the background noise. These parameters were revised and evaluated during the survey, using the best values for the processing of all the data.

Reports were generated either by ping or aggregated by school which included school characteristics (geographical position, morphology, acoustic strength, speed and direction) and vessel operation (geographical position, speed, etc.).

Mean speed and direction of the observed schools was calculated for two areas, south (from 02.02.15 to 06.02.15) and north of Vesterålen (from 08.02.15 to 14.02.15). Only schools with a numbers of detections between 8 and 40 were used, to avoid wrong estimates from school with too few number of detections and ones with a large number which corresponds to layers.

A preliminary analysis of sonar and echo sounder data for each of transects covered by FV “Ligrunn” was done in special codes using R.

Results

The sonar data storing process was stable and no major problems occurred during the survey. About 600 GB of sonar data was collected during the survey. Data was daily scrutinized using Profos software, taking about 1 hour to process 24 hours of sonar data. The performance of the automatic segmentation of schools was considered good (a detailed quality control of the segmentation was done for each school).

From sonar observations, a total of 228 herring schools were identified during the survey. Herring was found in different types of aggregations; small compact schools close to surface, medium to large compact schools in mid-water column, and large and loose layers also mid-water. North of Vesterålen, younger herring was observed as disperse aggregations from the surface up to 60 m (Figure 1). A total of 228 herring aggregations were observed, with sizes ranging from 10 to 400 m in diameter, the larger ones more related to layers, than compact schools. The mean speed of the schools was 1.3 knots with a general southeast direction.

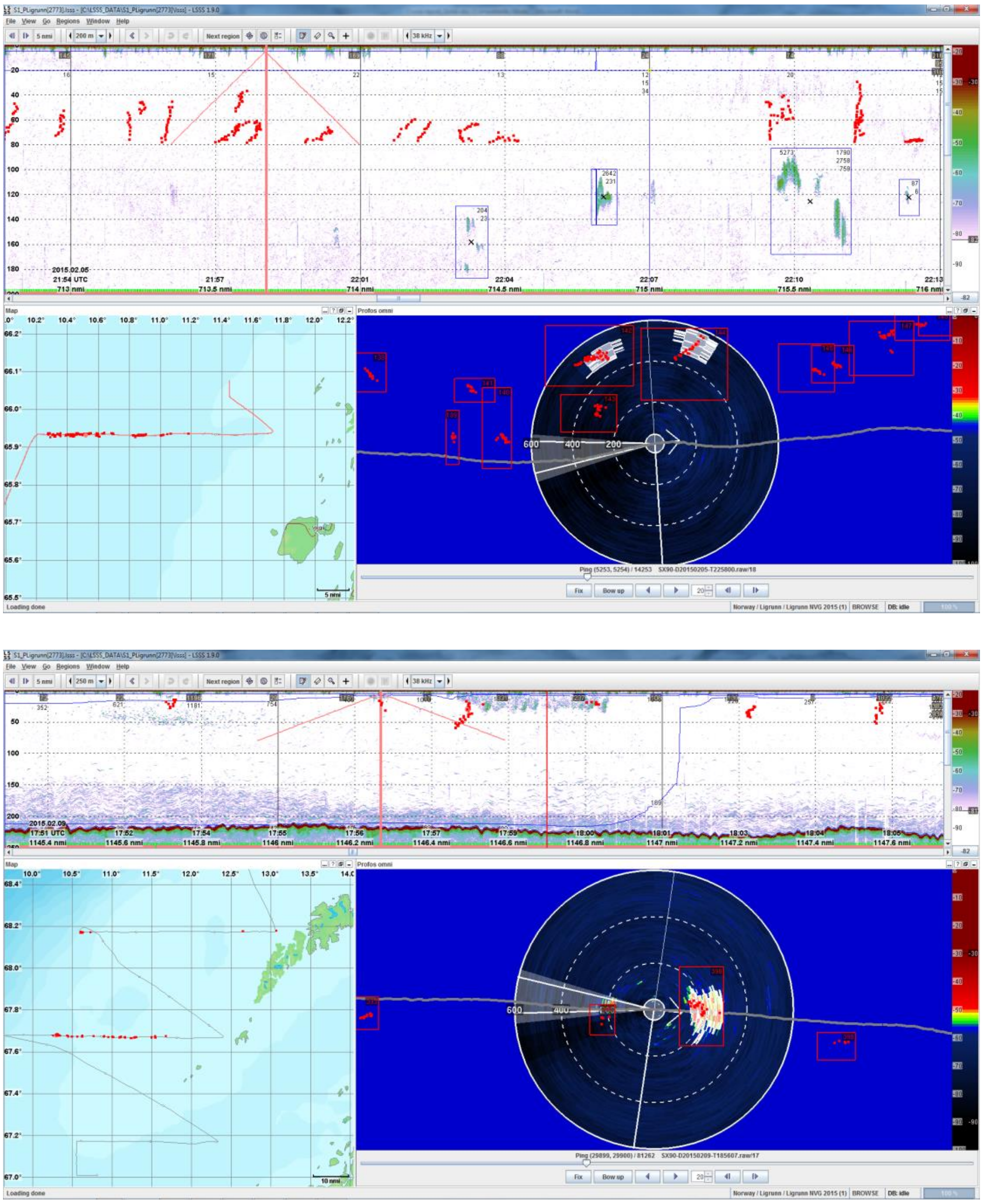

Figure 1. Examples of herring aggregations, observed with sonar and echo sounder. Medium size compact schools between 100 to 150 m (top panel). Disperse small layer from the surface to 50 m (bottom panel).

Results of single schools detected by both sonar and echo sounder indicated that the real detection depth of the sonar was larger than the theoretical depth, reaching up to 150 m. The explanation for this discrepancy is most likely a down bending of the sonar beam, due to the predominant sound speed in the water column in the surveyed area. Therefore, for a combined analysis, fish abundance from echo sounder data was aggregated from 0 to 150 m.

A combined analysis of the aggregations observed with sonar and echo sounder show in general a good agreement between both (Figure 2). Areas with a large number of schools observed in the sonar coincide with areas with high acoustic registrations from the echo sounder.

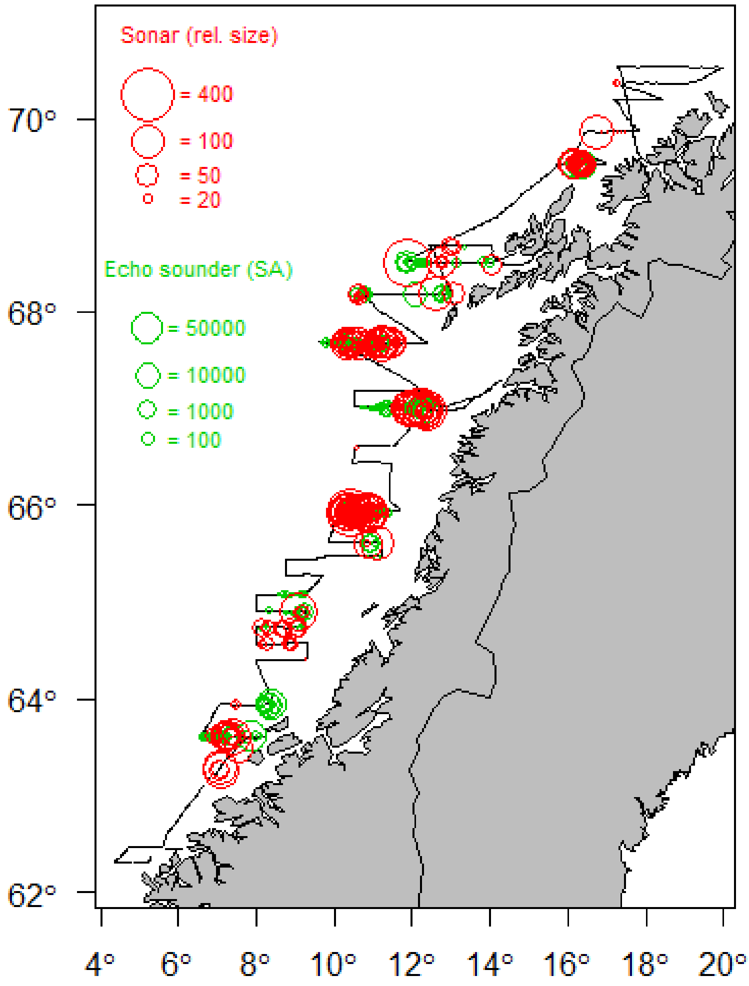

Figure 2. Herring aggregations on transects by FV "Ligrunn", observed with sonar (red) and echo sounder (green). Sonar registrations correspond to the relative size of aggregations in meters, and echo sounder corresponds to nautical area scattering coefficient (S_A, m^2 nmi^{-2}).

A detailed analysis of each transect by areas, confirmed an agreement between the sonar observations and the echo sounder data aggregated from 0 to 150 m (Figure 3); in transects in the Sklinnabanken area (top panel), transects west of Vesterålen (middle panel), and on Haltenbanken (bottom panel). In this last figure, small schools (about 20 m diameter) were observed only with sonar.

It should also be noted from the figures that some registrations are only recorded in the echo sounder. These registrations correspond to disperse herring rather than schools (S_A values below 100 m^2 nmi^{-2}), which in most cases were too weak to be observed by the sonar. Occasional problems occurred when isolating small schools (about 15 m diameter) close to the surface in rough weather, since it was difficult to separate schools from surface reverberation.

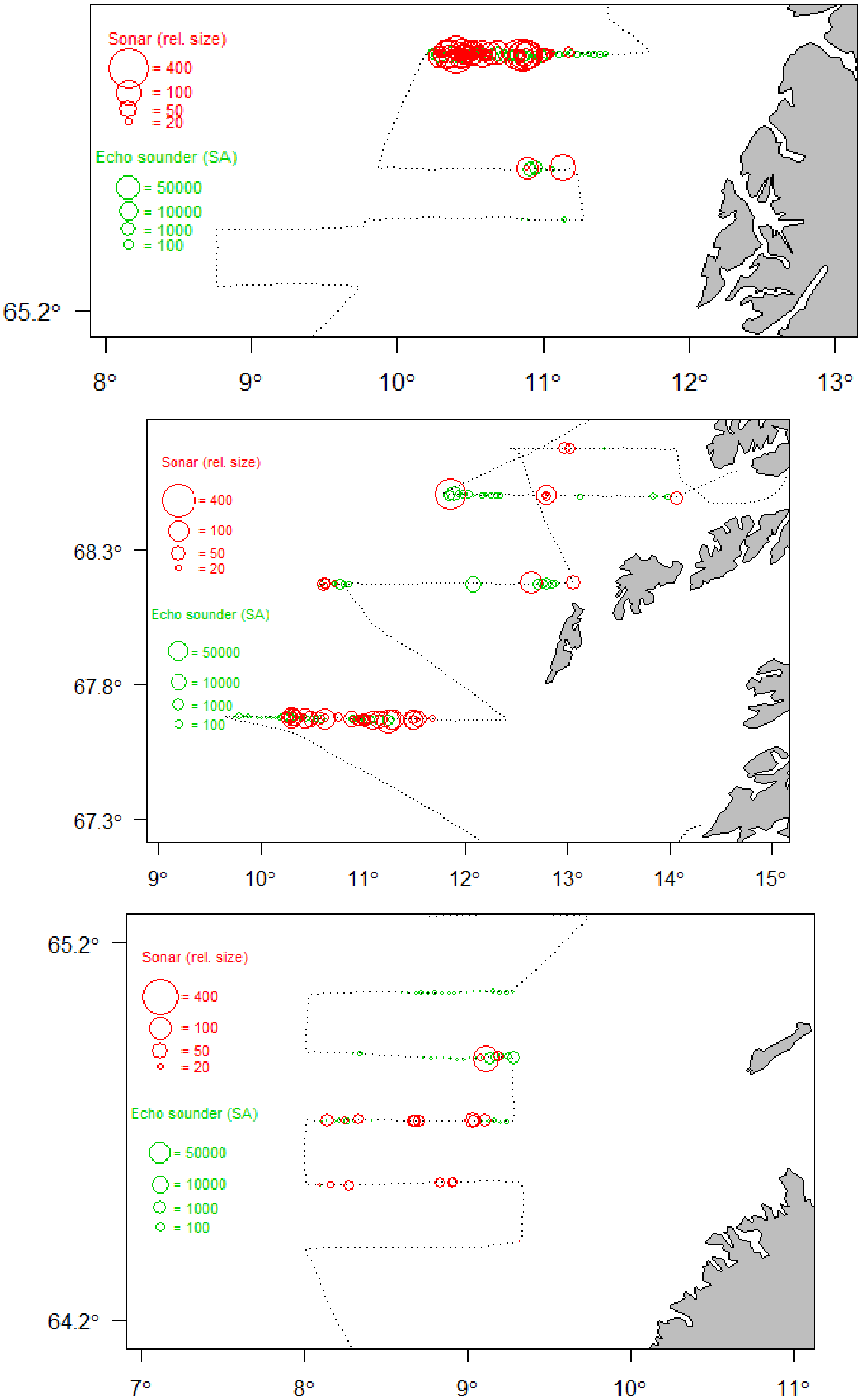

Figure 3. Detailed spatial distribution of herring aggregations on transects by FV "Ligrunn", observed with sonar (red) and echo sounder (green). Sonar registrations correspond to the relative size of aggregations in meters, and echo sounder corresponds to nautical area scattering coefficient (S_A, m^2 nmi^{-2}).

For a total of 71 schools in the area south of Vesterålen, during the first part of the survey, it was estimated a mean speed of 0.95 knots with a median direction of 122 degrees to the Easts-outheast (Figure 4, left panel). These vectors were then decomposed to directly south using the following formula: $speed_{south} = speed \cdot cos(heading + 180^{o})$ resulting in a median southward speed of the herring was 0.562 knots. Similary, the speed and heading of 57 schools were also recorded from Vesterålen and northwards. Here the mean school speed was 0.54 knots with a median direction of 154 degrees to the South-southeast (Figure 4, right panel). After decomposing the median southward speed of the herring in this area was 0.479 knots.

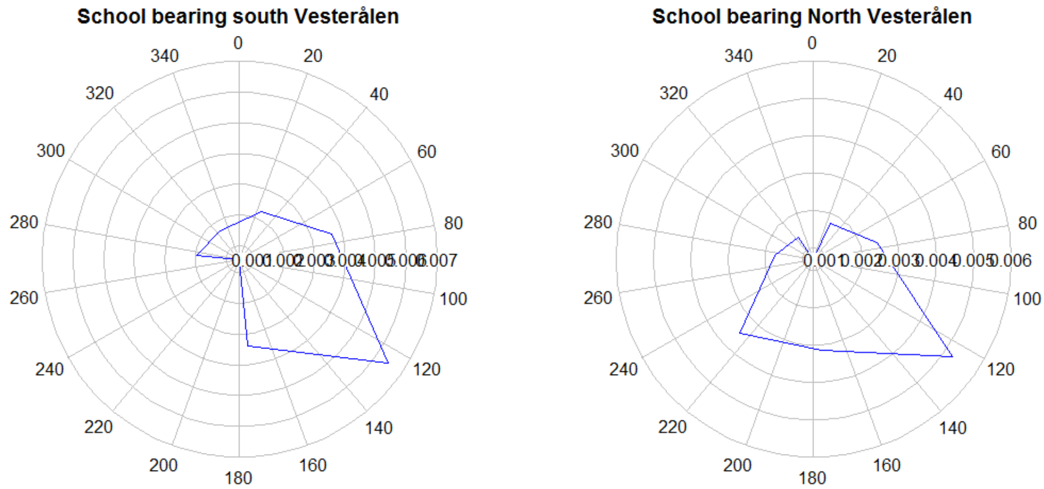

Figure 4. School direction in areas south (from 02.02.15 to 06.02.15) and north of Vesterålen (from 08.02.15 to 14.02.15).

Summary

Herring observations from calibrated Simrad SX90 fisheries sonar onboard FV “Ligrunn” was used to evaluate the fraction of herring not measured by the hull mounted echo sounder. No major differences in the occurrence of herring aggregations were found between sonar registrations and echo sounder acoustic densities (aggregated from 0 to 100 m depth). These results indicate that echo sounder biomass estimations are not seriously biased by unaccounted fraction of herring in the upper layers, and that no significant fraction of herring was distributed in the echo sounder blind zone.

The sonar investigations also demonstrated southward migration speeds of 0.56 knots and 0.48 knots in areas south and north of 67ºN, respectively.

Secondary, results from this survey indicate the feasibility for the collection of sonar data onboard fishing vessels suitable for scientific purposes. Available software is suitable for processing the large volume of data generated in a standard acoustic survey, and automatic segmentation procedures performed in a suitable form.

Future work should include the processing of the sonar data from the other two vessels (FV “Inger Hildur” and FV “Nybo”), more quantitative analysis of the sonar data, including preliminary biomass estimates of herring schools.

Annex 5. Comments from observers

By Jens Christian Holst and Torfinn Gangstad

Sources of bias in the relative estimate

These comments were compiled in cooperation between the observers Torfinn Gangstad and Jens Christian Holst. We have looked into some sources of bias which we are of the opinion ads up to a large and significant positive number. We have tried to include experiences made by herring skippers that could further enlighten these various sources of bias.
Our comments focus on the following sources of bias:

- Migration front
- Herring outside the survey area
- Near field acoustic losses
- Migration/survey progression
- Bubble correction

Migration front

From herring skippers experience, the southern herring spawning migration front is characterised by a higher density than further up the migration path. The north-south stretch of the high density migration front is normally around 5-10 nautical miles and may have densities many times that of the more northern concentrations. This means the southern front of the herring distribution should be treated as a separate stratum with denser survey transects. The front phenomena was unfortunately not communicated to the survey planners by the fishermen beforehand and the survey design was set up without this in mind.

The herring skippers try to fish in the migration front because the largest herring are found there and because the higher densities in this area makes the fishery more efficient. Only under bad weather conditions in the migration front area they will move up along the migration path to find better fishing conditions. During this survey, unfortunately, it seems the front fell in between two transects with 10 nautical miles distance just north of Ålesund and was consequently not measured. This can be suggested as the herring fishery the particular day the survey passed the migration front took place between two transects.

We have not sufficient data to estimate the tonnage lost in the estimate due to the migration front not being covered. Based on the experience of Torfinn Gangstad and other experienced herring skippers it could be a large and significant number. For future surveys we strongly recommend that the southern position of the front to be found, then very fine transects are laid out to cover the front in a separate stratum, for instance with 1 nautical mile distance.

Herring outside the survey area

We divide herring outside the survey area in three main categories: a) those near the survey area and having wintered in northern Norway, b) those having wintered in oceanic waters in the northern Faroese zone and c) those having wintered in the eastern Tampen and Viking Bank area.

a) *Near survey area*

In general the western extent of the transects can be anticipated to have covered the main herring spawning migration from northern Norway. There are however confirmed observations of herring outside the survey area from fishing vessels. On the 9th February the purse seiners ‘Selvåg Senior’ and ‘Ketlin’ sailed courses from Iceland and headed just south of Røst towards Vestfjorden. The vessels had parallel courses with approximately 15 nautical miles distance. Both vessels saw schools of herring along their courses outside the surveyed area on the south-western outer part of the Røstbank but no measurements were made on the extent of the registrations.

We have no basis for estimating the amount of herring lost due to the transects being too short westward.

b) *Oceanic wintering concentrations in the Faroe zone*

In later years the NSS herring summer feeding areas has stretched in particular further and further to the west according to survey and fisheries observations. In the western areas herring have been observed and fished west of Jan Mayen Island and into the Greenland zone at latitudes between Iceland and Jan Mayen. This has resulted in a very long back-migration for the large herring from these areas to the present main wintering areas in northern Norwegian fjords in Vesterålen. During late November 2014 the Faroese Pelagic vessel ‘Nordborg’ fished herring in the northern part of the Faroese zone between the Icelandic and Norwegian zones. The Faroese vessel ‘Finnur Fridi’ fished herring in the northern part of the Faroese zone before Christmas 2014 and ended fishing 23rd December 2014. At this time of year the herring wintering migrations must be assumed to have ceased. If not it seems in any case improbable that the herring in the northern Faroese zone in late December would have migrated northeast to join the herring wintering off the Lofoten Isles or in the Vesterålen area to join the spawning migration route of the herring covered by the survey.

There are no data to estimate the amount of herring wintering in the oceanic waters and tonnages will be speculation. However, the area north of the Faroes is known from historic sources to be an important wintering area for NSSH during the 1950ies and 60ies. We are of the opinion that significant amounts of herring may have wintered in this area during the last winter. For future surveys it is strongly recommended that these western wintering concentrations are covered, for instance in cooperation with the Faroes.

c) *Tampen and eastern Viking bank area*

Commercial catches of North Sea herring in late autumn from the Tampen and eastern Viking Bank area have for many years shown mixing of NSSH in IMR samples. It seems reasonable that this herring have fed in the southern parts of the Norwegian Sea and wintered in the northern North Sea. The area was not covered by the survey and this wintering component is consequently not included in the survey estimate. Again, the amount of NSSH wintering in the area is not known.

Near field losses, above transducer and avoidance

We choose to divide acoustic losses close to the vessel in two categories, a) herring situated above the echo transducer and b) avoidance of fish below the transducer.

a) *Above transducer*

It is well known by the Norwegian herring fishermen that herring may be located very close to the surface during the pre-spawning and spawning period both in schools and diffuse concentrations called 'slør' in Norwegian. 'Slør' are often not distinguishable as herring neither on the echososunder nor on the sonar.

A technique use by herring skippers in areas with no herring visible on the sonar or echosounder but with anticipated thin and diffuse 'slør' concentrations of herring is to floodlight the area in front of the vessel while sailing. Doing this in areas with 'invisible' diffuse herring above the transducer they observe concentrations of herring starting to accumulate as a 'band' on the echosounder screen at about 20-25 metes depth. During this survey this technique was used twice, once on 'Nybo' by Torfinn Gangstad for demonstration to Aril Slotte and Egil Ona present (Torfinn Gangstad, pers comm) and once on 'Inger Hildur' (Bernt Gjendemsjø, pers comm). In both cases the vessel sailed at speeds of 10 knots and no schools had been observed on the echosounder or the sonar. After the light was lit, a band of herring was observed shaping on the echososunder below the vessel. In the case of Inger Hildur the vessel sailed with lights on for about 1000 meters, then the vessel turned and the purse seine was set around the herring with a catch of 80-100 tonnes as estimated by skipper Bernt Gjendemsjø (pers.comm). The purse seine was opened and the herring released alive. In both cases these herring were not part of visible schools available for the acoustic estimate but rather of a diffuse near surface 'slør' concentration. The catch of 80 tonnes of herring was taken with a capelin purse seine at 640 meters length including a 100 meters warp, thus encircling an area of approx. 32 000 square meters. The net was set as a circle and the setting operation was done continuously without stop. With a catch of 80 tonnes this corresponds to 2500 tonnes per square kilometre or 2,5 kilo per square meter.

We have no basis to estimate the amount of acoustically 'invisible' herring above the transducer in the survey. However, based on observations done during the survey the amount could be significant as indicated by the purse seine catch made by 'Inger Hildur' encircling a very limited area. Further focused and dedicated studies of this bias is strongly recommended based on the herring skippers experience with diffuse near-surface densities during the spawning migration. One way to study and estimate the extent of such concentrations would be to make purse seine sets randomly throughout the survey not using light on the vessel. Another way would be to deploy fixed and recording echosounders on the bottom transducing upwards at selected positions along the spawning migration route before the spawning migration starts and retrieving them after the migration for analysis of near surface herring concentrations and their dynamics.

b) *Avoidance*

We define avoidance as herring present in front of the vessel and below the transducer before passing but not being picked up by the instrument due to the fish being scared and fleeing away from the acoustic cone. Avoidance could also reduce the acoustic back scattering contribution from herring due to altered angle to the transducer away from perpendicular because of the fleeing reaction. We have no basis to evaluate the size of this bias but near transducer losses due to avoidance could also be assumed to be significant. Again we encourage further work to quantify this bias.

Migration/survey progression

The southern herring migration speed and the northern survey speed has not been corrected for in the relative estimate. From earlier studies these factors have been described to be significant to the size of acoustic estimates. This survey can be said to be extreme in this regard due to the high southern migration speed of the herring and also the high northern speed of the survey. We are not in a position to estimate this number but it seems reasonable to claim that this may be a very significant bias.

On two occasions the vessels stayed in port due to storm and hurricane loosing approximately three days surveying. During the first 2 days break we had some of the highest herring concentrations passing just outside while in port. We are of the opinion that also these breaks would add a very significant bias to the relative estimate.

Bubble correction

The survey was carried out under partly challenging weather conditions for acoustic work with strong western winds over periods. The bubble noise problem was reduced by only measuring herring on eastern courses thus avoiding to do acoustic measurements on courses heading towards the wind. In general bubble noise therefore seemed to be a relatively small bias during the survey.

Before the survey it was said to be very important to use vessels with drop keels for this survey. Given our observations the survey had not the problems suggested beforehand and a cost-benefit analysis is suggested for future surveys in order to decide if drop keels vessels are required or not. Adding one extra survey vessel may be a good strategy rather than asking for drop keels if these have a much higher price than those not having drop keels.

Summary

Based on experiences made during the survey and also experiences made by herring skippers during practical fishing operations we have compiled an overview of factors we believe cause significant bias in the present relative herring estimate. To produce an absolute estimate at some future stage it is important to take these factors into account. Some are easy to correct for like bubble noise while others will require dedicated and focused work to get a better grip on than what’s available today. We strongly encourage such work to be carried out.