Stock Annex: Herring (*Clupea harengus*) in subareas 1, 2, and 5, and in divisions 4.a and 14.a (Norwegian Spring Spawning)

Stock specific documentation of standard assessment procedures used by ICES.

Stock: Herring (*Clupea harengus*) in subareas 1, 2, and 5, and in divisions 4.a and 14.a (Norwegian Spring Spawning)

Working Group: Working Group on Widely Distributed Stocks

Created:

Authors:

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A. General

A.1. Stock definition

The Norwegian spring-spawning herring (*Clupea harengus*) is the largest herring stock in the world. It is widely distributed and highly migratory throughout large parts of the NE Atlantic during its lifespan (Dragesund *et al*., 1997; Figure A.1.1). Formally, the description of the Norwegian spring-spawning herring stock is not linked to specific areas and the ICES advice applies to all areas where it occurs. By far the majority of the adult stock occurs in Divisions 2.a,b 5.a,b and 14.a. Juveniles of the stock have their nurseries in Division 1.a. In some years, small amounts of Norwegian spring-spawning herring can be found in adjacent areas mixing with other herring stocks during the feeding season.

It is a herring type with large number of vertebrae (Runnstrøm 1941), large size at age, large maximum size, different scale- (Lea 1929; Runnstrøm 1936) and otoliths shape (Einarsson 1951; Libungan *et al*. 2015) characteristics from other herring stocks and large variation in year-class strength.

A.1.1 Mixing/separation of NSSH with/from other adjacent herring stocks (Lisa)

Suggest to have such a section. Write status based on workshop in Ireland November 2018 – and perhaps also other information??

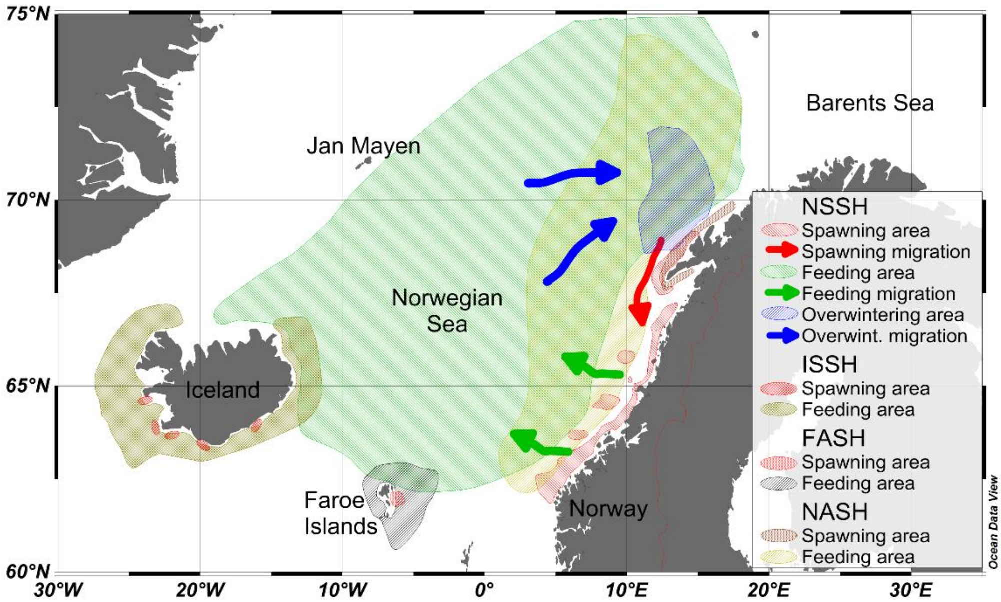

Figure A.1.1. Current migration pattern of the adult part of the Norwegian spring-spawning herring (NSSH) and interactions with other surrounding stocks, i.e. Icelandic summer-spawning herring (ISSH), Faroese autumn-spawning herring (FASH), and Norwegian autumn-spawning herring (NASH) (from Pampoulie *et al.* 2015). NB!! Herring south of 62 are not visualised/described – suggest to use map that also includes e.g. North Sea herring!! – or rewrite!! Eydna checks ....

A.2. Fishery and management

The fishery is regulated and carried out by the Coastal States. The TAC is set by the Coastal States and derived from an agreed long-term management strategy (Anon 2018). The Coastal States also agree on the allocation of the TAC into national quota. The fishery is carried out all year-round by purse-seines and pelagic trawlers. The catches are used for reduction purposes as well as human consumption with an increasing fraction used for human consumption during 2010-2020. The traditional fishing pattern follows the clockwise migration pattern of the herring. Changes in the migration pattern have occurred in the past and consequently also leading to changes in the fishery, following the fish. The most recent description of distribution and migration pattern of the stock derives from a Working Group established by the Coastal States (Anon, 2020), which covers the period 2013-2020 and is based on information from the fishery and research surveys.

The Norwegian spring-spawning herring is sometime caught mixed with other herring stocks (Figure 1). In the southern part along the Norwegian coast it can be mixed with North Sea herring. In Icelandic waters it can be mixed with Icelandic summer-spawning herring and they are separated in the catches on basis of maturity stage and are assessed separately. In Faroese waters where NSS-herring can be mixed with a small local autumn-spawning stock and in Norwegian waters where it can be mixed with number of small local stocks, particularly autumn-spawners near Lofoten (Husebø *et al*. 2005), and the stocks are not separated in the catches and thereby assessed together.

Most of the catches consist of herring only and discarding is absent or very low. By-catch of mackerel has been reported on the traditional fishing grounds, in years when there is considerable spatiotemporal overlap between herring and mackerel in the feeding areas.

A.3. Ecosystem aspects (Eydna, Maxim)

A.3.1. Spawning and recruitment

The herring spawns along the Norwegian west coast in February-March. Large variations in the north–south distribution of the spawning areas have been observed through the centuries (Devold 1963; Dragesund *et al*. 1997). The larvae drift north and northeast and distribute as 0–group in fjords along the Norwegian coast and in the Barents Sea. The Barents Sea is by far the most important juvenile area for the large year classes (Dragesund 1970; Holst and Slotte 1998), which form the basis for the large production-potential of the stock. Some year classes are in addition distributed into the Norwegian Sea basin as 0–group. Examples of this are the 1950 and 2002 year classes. Most of the young herring leave the Barents Sea as 3 years old and feed in the northeastern Norwegian Sea for 1–2 years before recruiting to the spawning stock (Holst and Slotte, 1998). Large year classes typically mature at a higher mean age due to density-dependent growth (Toresen 1990; Holst 1996). However, exceptions occur and for example the 2002 year class was a large year class, with a fast growth rate and a relatively early maturation compared to other large year classes (ICES, 2010). Juveniles growing up in the Norwegian Sea grow faster than those in the Barents Sea and mature one year earlier (Runnstrøm 1936). When mature, the young herring starts joining the adult feeding migration in the Norwegian Sea.

Norwegian spring-spawning herring is one of the few stocks for which data have been collected over a very long period. Figure A.1.1.1 shows the dynamics of the stock in the past century indicated by assessments which go back to 1907.

The stock's size dynamic is governed by huge fluctuations in recruitment. A number of hypotheses have been suggested to explain the variability of recruitment. For example, larval survival and subsequent year-class strength in NSSH can be enhanced by early hatching time (Husebø *et al.*, 2009), reduced cannibalism (Dalpadado *et al.*, 2000), rapid displacement of larvae to the Barents Sea nursery area (Vikebø *et al.*, 2010), and higher temperature in the Barents Sea (Toresen and Østvedt, 2000). Moreover, a recent study by Skagseth *et al*. (2015) shows that years with high recruitment coincide with predominantly southwesterly winds and weak upwelling in spring and summer, which lead to an enhanced northward coastal current during the larval drift period. Also in most peak recruitment years, low-salinity anomalies were observed to propagate northward during the spring and summer.

A.3.2. Feeding and overwintering

The feeding migration starts just after spawning with the maximum feeding intensity and condition increase occurring from May until July-September (Homrum *et al*., 2016). The feeding migration is in general length dependent, meaning that the largest and oldest fish perform longer and typically more western migrations than the younger ones.

After the dispersed feeding migration the herring concentrate in one or more wintering areas in September-October. These areas shift periodically and since 1950 the stock has used at least 6 different wintering areas in different periods (Dragesund *et al*. 1997; Huse *et al.* 2010). During the 1950s and 1960s they were situated east of Iceland and since around 1970 in Norwegian fjords. From 2002 when the large year classes of 1998/98 started recruiting to the spawning stock a new wintering area was established off the Norwegian coast between 69º30′N and 72ºN and in 2007\2009 no herring was observed in the fjords in winter. The stock has recently utilized this offshore wintering area but the survey covering the oceanic wintering area until 2007 (*Survey 3* below) showed a strong decrease in the biomass in the wintering stock in the area and the fishery indicate that the wintering is now scattered with herring wintering both in fjords in northern Norway and in oceanic areas.

After wintering, the spawning migration starts around mid-January.

A.3.3. Migration and trophic interaction

A characteristic feature of this herring stock is a very flexible and varying migration pattern. The migration is characterized as relatively stable periods and periods characterized by large changes occurring at varying time intervals (Dragesund *et al.* 1997; Huse *et al*. 2010). The changes may or may not be correlated between the major distribution areas: Spawning, feeding and wintering. Changes in migration pattern are frequently observed in association with large year classes entering the adult stock. At present we see a period of large changes in both the wintering and feeding area.

In May the herring is migrating westwards into the Norwegian Sea for summer feeding and the main concentrations are found in the central part of this area as shown by the International Ecosystem Survey in Nordic Seas (IESNS). In July the herring are spread out over a wide area feeding around the fringes of the Norwegian Sea, particularly in the northern and western region, while almost no herring are observed in the central region. This is shown by the Ecosystem Summer Survey in Nordic Seas (IESSNS), which in the latest years has indicated for example the most westerly distribution of the herring north of Iceland observed since the collapse of the stock in the late 1960s (ICES 2015). The herring is occupying the feeding grounds at least throughout August according to the fishery and moves then progressively eastwards to the overwintering areas. At the beginning of the feeding season the herring on the western feeding grounds are in better condition (Homrum *et al*. 2016), probably because these have started their feeding migration earlier. As the feeding season proceeds the condition in east and west is more similar, but in October in the latest years the condition is again better in west than in east, indicating that fish in the west may not yet have started their migration for the winter areas. Since around 2012, there is an indication from the fishery for a prolonged duration of the stock on the feeding grounds and possibly oceanic overwintering of part of the stock in the mid and eastern part of the Norwegian Sea. This remains to be explored in a more quantitative manner.

A.4. References

Anon, 2020. Updated Report of the Coastal States Working Group on the distribution of Norwegian spring spawning herring in the North-East Atlantic and the Barents Sea. 5-6 October 2020. 59 pp.

Anon. 2018. Agreed record of conclusions of fisheries consultations between Iceland, the European Union, the Faroe Islands, Norway and the Russian Federation on the management of the Norwegian spring-spawning (Atlanto-Scandian) herring stock in the North-East Atlantic in 2019. London, 6 November 2018. 6 pp. Dalpadado, P., Ellertsen, B., Melle, W., Dommasnes, A., 2000. Food and feeding conditions of Norwegian spring-spawning herring (Clupea harengus) through its feeding migrations. ICES Journal of Marine Science 57, 843–857.

Devold, F. 1963. The life history of the Atlanto-Scabndian herring. Rapports et Procẽs-Verbaux des Réunions Conseil international pour L'Exploration de la Mer 154: 98–108.

Dragesund, O. 1970. Factors influencing year-class strength of Norwegian spring-spawning herring (Clupea harengus L.). Fisk Skrift Ser Havunders. 15: 381–450.

Dragesund, O., Johannessen, A. & Ulltang, Ø. 1997. Variation in migration and abundance of Norwegian spring-spawning herring (Clupea harengus L.). Sarsia 82, 97–105.

Einarsson, H. 1951. Racial analyses of Icelandic herrings by means of the otoliths. Rapport et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer 128: 55–74.

Holst, J.C. 1996. Long term trends in the growth and recruitment pattern of the Norwegian spring-spawning herring (Clupea harengus Linnaeus 1758). PhD. thesis, University of Bergen, Bergen, Norway ISBN 82-77444-032-4.

Holst, J.C. and Slotte, A. 1998. Effects of juvenile nursery on geographic spawning distribution in Norwegian spring-spawning herring (Clupea harengus L.). ICES J Mar Sci. 55: 987–996.

Homrum, E. í, Óskarsson, G.J., Slotte, A. 2016. Working Document to WKPELA 2016. Spatial, seasonal and interannual variations in growth and condition of Norwegian spring-spawning herring during 1994–2015. 41 pp.

Huse, G., Holst, J.C., Fernö, A., 2010. Establishment of new wintering areas in herring co-occurs with peaks in the 'first time/repeat spawner' ratio. Marine Ecology Progress Series 409, 189–198.

Husebø, Å., Stenevik, E.K., Slotte, A., Fossum, P., Salthaug, A., Vikebø, F., Aanes, S.,Folkvord, A., 2009. Effects of hatching time on year-class strength in Norwegian spring-spawning herring (Clupea harengus). ICES Journal of Marine Science 66: 1710–1717.

ICES. 2010. Report of the Workshop on estimation of maturity ogive in Norwegian spring-spawning herring (WKHERMAT), 1–3 March 2010, Bergen, Norway. ICES CM 2010/ACOM:51. 47 pp.

ICES. 2015. Cruise report from the International Ecosystem Summer Survey in the Nordic Seas (IESSNS) with M/V "Brennholm", M/V "Eros", M/V "Christian í Grótinum" and R/V "Árni Friðriksson", 1 July - 10 August 2015. Working Document to ICES Working Group on Widely Distributed Stocks (WGWIDE), AZTI-Tecnalia, Pasaia, Spain, 25–31 August 2015. 47 pp.

Lea, E. 1929. The herring scale as a certificate of origin. Rapports et Procěs-Verbaux des Réunions de Conseil Permanent International pour L'Exploration de la Mer 53: 21–34.

Libungan, L.A ., Óskarsson, G.J., Slotte, A., Jacobsen, J.A. and Pálsson, S. 2015. Otolith shape: a population marker for Atlantic herring Clupea harengus. Journal of Fish Biology 86: 1377–1395.

Pampoulie, C., Slotte, A., Óskarsson, G.J., Helyar, S.J., Jónsson, Á., Ólafsdóttir, G., Skírnisdóttir, S., Libungan, L.A., Jacobsen, J.A. Joensen, H., Nielsen, H.H. Sigurðsson, S.K., Daníelsdóttir, A.K. 2015. Stock structure of Atlantic herring Clupea harengus in the Norwegian Sea and adjacent waters. Marine Ecology Progress Series. 522: 219–230

Skagseth, Ø., Slotte, A., Stenevik, E.K., Nash, R.D.M, 2015. Characteristics of the Norwegian Coastal current during years with high recruitment of Norwegian spring-spawning herring (Clupea harengus L.). PLOSone. DOI: 10.1371/journal.pone.0144117.

Runnstrøm, S. 1936. A study on the life history and migrations of the Norwegian spring herring based on analysis of the winter rings and summer zones of the scale. Fiskeridir. Skr. Ser. Havunders. 5(2):1–110.

Runnstrøm, S. 1941. Racial analysis of the herring in Norwegian waters. Reports on Norwegian Fishery and Marine Investigations 6, 5–10.

Toresen, R., 1990. Long-term changes in growth of Norwegian spring-spawning herring. Journal du Conseil: ICES Journal of Marine Science 47, 48–56.

Vikebø, F.B., Husebø, Å., Slotte, A., Stenevik, E.K., Lien, V.S., 2010. Effect of hatching date, vertical distribution, and interannual variation in physical forcing on northward displacement and temperature conditions of Norwegian spring-spawning herring larvae. ICES Journal of Marine Science 67, 1948–1956.

B. Data

B.1. Commercial catch (Are)

B.1.1. Nominal catch

The catches used in the assessment are the catches provided by the Working Group members.

B.1.2. Catch-at-age

From each country participating in the herring fishery exists a data delivery sheet containing at minimum information about total catch in tons by quarter of the year and ICES area. If the fleet has taken samples then catch in numbers by age, mean weight at age and mean length-at-age for each quarter of the year and ICES area are provided. Catch in tonnes by ICES rectangles and quarters are also reported. These sheets are combined into one file. Catches from quarters and areas with no associated biological samples have then to be allocated to sampled ones. To do so positions of the catches by fleet are plotted, to see where the fleet was operating. Mean weights and mean lengths behind the sampled catches are also plotted. On the basis on these inspections allocations are done. Then the program SALLOC (ICES 1998/ACFM:18) is used to calculate the total international catch in numbers. Output from SALLOC is total catches in numbers by age as well as by quarters and areas. Intercatch is not used since it is not possible to record catch data from two different stocks of the same species in the same ICES area. Norwegian spring-spawning herring is sometimes caught in the same areas as other herring stocks, e.g. in 4.a and 5.a.

B.1.3. Weight at age of the catch

Annual weight at age of the catch originate from national sampling programmes of the commercial catches. They are provided by most fishing nations each year on a quarterly basis. The weight at age of the catch used in the assessment is the average of the different nations weighted over the associated catch numbers. Mean weights by age in the catch by age is also output from SALLOC.

B.1.4. Length-at-age of the catch

Mean length by age in the catch is calculated the same way as mean weight at age of the catch. It is not used in the assessment. Mean length by age in the catch is also output from SALLOC.

B.2. Biological parameters

B.2.2. Weight at age of the stock

Up to 2008, weight of age of the stock was derived from the Norwegian survey in the wintering area. The survey was stopped in 2008. From 2009 onwards annual updates of weight at age in the stock is estimated from Norwegian commercial catches taken in the overwintering area in January.

B.2.3. Natural mortality

In the 2016 benchmark assessment it was decided to continue to use natural mortality M=0.15 for ages 3 and older and M=0.9 for ages 0-2 in all years from 1988 onwards. The basis for using these values is provided below.

In a working group report from 1996 (ICES 1996/ASSESS:14), it says that values of M assumed by the Working Group were 0.16 for ages 3 and older during the years 1950 to 1970 while 0.13 for the years 1971 and subsequently. Attempts to estimate natural mortality from tagging information (Hamre, WD 1997; Patterson, WD 1997a; Tjelmeland, WD 1997) were highly consistent with these values in the range 0.13 to 0.16, but the Working Group did not consider that this parameter could be estimated with sufficient precision to justify a discrimination between levels of 0.13 and 0.16. Consequently, it was decided to predicate the assessment model estimates on an arbitrarily chosen M=0.15 for ages 3 and older.

In the Working Group report from 1992 (ICES 1992) a comparison of acoustic estimates for year classes 1983-1985 and 1988 as 0-group, and the same year classes as 3 year old (VPA) gave an average annual M=0.88, so M=0.9 was used for ages 0-2. Mean value of M for these age groups estimated by de Barros (1995) was consistent with this value. Hence M=0.9 has by used since the 1992 assessment for ages 0–2.

B.2.4. Maturity-at-age

In 2010 the method for estimating maturity-at-age in the stock assessment of NSSH was changed based on work done by the "workshop on estimation of maturity ogive in Norwegian spring-spawning herring" (WKHERMAT; ICES, 2010a). The method which was adopted by WGWIDE in 2010 (ICES, 2010b) is based on work by Engelhard *et al*. (2003) and Engelhard and Heino (2004). They developed a method to back-calculate age at maturity for individual herring based on scale measurements and used this to construct maturity ogives for the year classes 1930–1992.

The NSSH has irregular recruitment pattern with a few large year classes dominating in the stock when it is on a high level. Most of the year classes are, however, relatively small and referred to as "normal" year classes. The back-calculation dataset indicates that maturation of the large year classes is slower than for "normal" year classes.

WKHERMAT and WGWIDE considered the dataset derived by back calculation as a suitable candidate for use in the assessment because it is conceived in a consistent way over the whole period and can meet standards required in a quality-controlled process. However, the back-calculation estimates cannot be used for the most recent years since all year classes have to be fully matured before the calculation can be made. Therefore, assumptions have to be made for the recent year classes. For recent year classes, WGWIDE (ICES, 2010) decided to use average back-calculated maturity for "normal" and "big" year classes, respectively and thereby reducing maturity-at-age for ages 4, 5 and 6 when strong year classes enter the spawning stock. The default maturity ogives used for "normal" and "big" year-classes are given in the text table below.

The default maturity ogives used for 'normal' and strong year classes are given in the text table below.

AGE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
normal yc	0	0	0	0	0.4	0.8	1	1	1	1	1	1	1	1	1	1
strong yc	0	0	0	0	0.1	0.6	0.9	1	1	1	1	1	1	1	1	1

Assumed values should be replaced by back-calculated values in the annual assessments for each year where updated values are available.

The maturity ogives used in the present assessment are presented in the WGWIDE report.

B.3. Surveys (Are, Maxim, Sigurvin, Eydna)

A number of surveys on this stock have been carried out in the Norwegian Sea and Barents Sea to estimate the size of the stock, its age composition or the recruitment to the stock. Some of the surveys have stopped but data are still used in the assessment

The acoustic abundance estimates are calculated with the software StoX (ICES 2016a), which provide estimates of precision that can be implemented in new stock assessment models. In 2015 and 2016 some of the survey series were re-estimated back to 2008?? with StoX. At WGWIDE 2020 it was decided to use the mean value of abundance of bootstrap with 1000 replicates. Only these mean values are provided in the tables in the annex, but the CV from the bootstrap is also used in the assessment.

B.3.1. Survey 1. Norwegian acoustic survey on spawning grounds in February/March

Acoustic surveys on the spawning grounds of Norwegian spring-spawning herring (NSS) have been carried out from 1988 onwards, with some breaks e.g. in 2001–2004 and 2009–2014 (WD10). The majority of NSS herring spawns on banks along the Norwegian coast from Møre (≈62° N) to Vesterålen (≈69° N) in mid-February to mid-March (Figure B.3.1.1). However, the timing and location of spawning within this area and period have varied between years, e.g. there seems to be a trend towards earlier spawning in more recent years. This time-series has been re-estimated (see 2.2.2 in WKPELA 2016). The new abundance estimates are presented in Table B.3.1.1. Data were not available for the years 1990 and 1991 on the needed format so they could not be re-estimated.

This survey is used in the main assessment.

B.3.2. Survey 2. Norwegian acoustic survey in November/December

The survey was carried out by Norway from 1992 to 2007 in the Norwegian fjords where the adult herring overwinter (Figure B.3.2.1). After 2003 also the oceanic areas north of Lofoten/Vesterålen were included in the survey to take account of changes in the wintering area. The fjordic coverage was ceased during the winter 2007/2008 because the herring had totally left the fjords. The indices from this survey have not been re-estimated. The results of this survey are shown in Table B.3.2.1.

This survey is not used in the main assessment.

B.3.3. Survey 3. Norwegian acoustic survey in January

This survey was carried out by Norway in the fjords in the period 1991–1999. The indices from this survey have not been re-evaluated.

The results of the survey in the wintering area in January can be found in Table B.3.3.1.

This survey is not used in the main assessment.

B.3.4. Survey 4 and 5. International ecosystem survey in the Nordic Seas

The international ecosystem survey in the Nordic Seas (IESNS) is aimed at observing the pelagic ecosystem, focusing on herring, blue whiting, zooplankton and hydrography. The survey, carried out annually since 1995, is coordinated by the ICES WGIPS (ICES 2020) and is a cooperative effort by Faroes, Iceland, Norway, Russia, and the EU (Denmark, Germany, Ireland, The Netherlands, Sweden and UK). This trawl-acoustic survey supplies the most important fishery independent time-series for the assessment of NSSH and also a time-series for young blue whiting in the juvenile areas.

The age-disaggregated time-series of abundance of Norwegian spring-spawning herring for the Barents Sea are presented in Table B.3.4.1. No data exist for 2003, 2004 and 2020. The indices since 2009 have been derived by StoX.

The age-disaggregated time-series of abundance of NSSH in the Norwegian Sea are presented in Table B.3.4.2. The indices since 2009 have been derived by StoX.

The survey covers the entire stock during its migration on the feeding grounds, the adults in the Norwegian Sea and juveniles in the Barents Sea. An example of the coverage of the survey (2015) is given in Figure B.3.4.1.

These surveys are used in the main assessment.

B.3.5. Survey 6 and 7. Joined Russian–Norwegian ecosystem autumn survey in the Barents Sea

The survey consists of a trawl survey catching 0–group herring among other species and an acoustic survey estimating one and two year old herring. In 2001, the Working Group decided to include data on immature herring obtained during the Russian-Norwegian survey in August-October in estimating the younger year classes in the Barents Sea.

The youngest age groups (0–3+) of the Norwegian spring-spawning herring stock are found in the Barents Sea at irregular intervals. It is difficult to assess the stock size during autumn, due to various reasons. The age groups 1–3 are found mixed with 0–group herring and are difficult to catch in the sampling trawl used in this survey. The stock size estimates of herring are therefore considered less reliable than those for capelin and polar cod. An example of the distribution of young herring is shown in Figure B.3.5.1. An example of the distribution of 0–group herring is presented in Figure B.3.5.2.

The results from these surveys on 0–group herring are given in Table B.3.5.1 (survey 7). The results for the 1 to 3 age groups are given in Table B.3.5.2 (survey 6).

These surveys are not used in the main assessment.

B.3.6 Survey 8 Norwegian herring larvae survey on the Norwegian shelf

A Norwegian herring larvae survey has been carried out on the Norwegian shelf since 1981 during March-April. The objectives of the survey are to map the distribution of herring larvae and other fish larvae on the spawning grounds on the Norwegian shelf and to collect data on hydrography, nutrients, chlorophyll and zooplankton. The larval indices can be used as indicator of the size of the spawning stock. Two indices are available from this survey.

The re-evaluated indices with associated CVs for the herring larvae are presented in Table B.3.6.1. Examples of the distribution of the herring larvae are given in Figure B.3.6.1.

This survey is not used in the main assessment.

B.3.7 Survey 9 International ecosystem summer survey in Nordic Sea (IESSNS)

This ecosystem survey initiated in 2004 by Norway and have since then been gradually expanded in geographical coverage and scientific complexity (e.g. Nøttestad and Jacobsen 2009). Since 2010 the survey coverage was expanded further with participations of vessels from Iceland and the Faroese in addition to two vessels from Norway. The main objective of the survey is to study abundance, spatio-temporal distribution, aggregation and feeding ecology of Northeast Atlantic mackerel, Norwegian spring-spawning herring, blue whiting and other pelagic species in relation to oceanographic conditions, prey communities and marine mammals. Two different types and independent abundance estimates for herring can be derived from the survey, an acoustic estimate, and swept-area estimate from predefined surface trawl stations.

The acoustic estimates for herring since 2009 are shown in Table B.3.7.1. In 2011 and 2014 the coverage was not complete with regard to herring (Nøttestad *et al*. 2014). An example of the coverage of the survey (2020) is given in Figure B.3.7.1.

This survey is not used in the main assessment.

B.4. Commercial CPUE

No commercial CPUE data are used in the assessment.

B.5. Other relevant data (Aril?)

With the exception of 1999, 2001 and 2005, tagging has been carried out annually between 1975 and 2007. Since 2008 no tagging has been carried out.

The use of the tagging data in the assessment was discontinued since 2006 due to a small number of recaptures. This comes as a result of too low tag density in the stock given the high stock size and amount of fish screened for tags.

B.6. Reference list

Barros, P. C. (1995). Quantitative studies on recruitment variations in Norwegian spring spawning herring (*Clupea harengus* Linnaeus 1758), with special emphasis on the juvenile stage (pp. 143). Doctoral Thesis. Bergen, Norway: University of Bergen

ICES. 2010. Report of the Workshop on estimation of maturity ogive in Norwegian spring spawning herring (WKHERMAT). 1-3 March 2010 Bergen, Norway. ICES CM 2010/ACOM:51 REF. PGCCDBS

ICES. 2016a. referred to regarding StoX – find correct reference???

ICES. 2020. Working Group of International Pelagic Surveys (WGIPS). ICES Scientific Reports. 2:56. 473 pp. http://doi.org/10.17895/ices.pub.6088 .

Nøttestad, L. Salthaug, A., Odd Johansen, G., Anthonypillai, V., Tangen, Ø, Utne, K., Sveinbjörnsson, S.et al.2014. Cruise report from the coordinated ecosystem survey (IESSNS) with M/V "Brennholm", M/V "Vendla", M/V "Finnur Fríði" and R/V "Árni Friðriksson" in the Norwegian Sea and surrounding waters, 2 July - 12 August 2014.

Working Document presented to ICES WGWIDE, Copenhagen, Denmark, 26 August–1 September 2014, 49 pp

Nøttestad and Jacobsen. 2009. referred to in section B.3.7??

C. Historical Stock Development

C1. The main assessment tool XSAM

A model template based on a state space model and structural time-series models for fish stock assessment have been developed and is described in Aanes 2016a and 2016b. The framework builds on well-known statistical models, but offers the possibility to utilize prior knowledge of sampling errors entering the observation models. The framework has been given the name XSAM and WKPELA 2016 decided to use this as the main assessment tool. The setup and usage of XSAM follows:

1) Software used: R and TMB. Documented source code is available at the SharePoint site for WGWIDE.

2) Model options:
   i. Time span: 1988-present date
   ii. Age span: 2-12+
   iii. There is no empirical evidence for $\sigma_3^2 > 0$, therefore σ_3^2 is set to 0 and effectively one level in the hierarchy for the latent state of effort is omitted.
   iv. Effort is modelled as an AR(1) process
   v. Selectivity is modelled as a multivariate AR(1) process
   vi. $a_m = 11$, i.e. the selectivity in fishing mortality is assumed constant for ages 11 and above
   vii. Catch-at-age as reported by WGWIDE
   viii. IESNS in the Norwegian Sea (Fleet 5): StoX estimates, age specific q up to age 11, q-plateau at ages above 11
   ix. Spawning survey (Fleet 1): StoX estimates, age specific q up to age 8, q-plateau at ages above 8
   x. Observation model 5 which implies estimating a common scaling factor h across datasets
      a) Use sampling variances for catch-at-age as estimated by ECA (Salthaug and Aanes 2015, Hirst et al. 2012)
      b) Use sampling variances for Fleet 5, Fleet 4 and Fleet 1 as estimated by StoX
      c) The model uses the sum of declared unilateral quotas as input for total catch.
      d) The plusgroup is modelled as a dynamic pool.

3) Analyses are restricted to the years 1988-present. The last year is the year after the last year with catch data. The fishing mortality in the last year is based on the sum of declared catches.
4) Age range for the analyses is 2-12+, but can in principle be extended to any age range
5) Natural mortality is assumed at 0.9 for ages 0, 1 and 2 and 0.15 for all older ages.
6) Input data: Listed in Table C.1.1

Table C.1.1

Type	Name	Year range	Age range	Variable from year-to-year Yes/No
Caton	Catch in tonnes	1988-last data year	--	Yes
Canum	Catch-at-age in numbers	1988-last data year	2-12+	Yes
Weca	Weight at age in the commercial catch	1988-last data year	2-12+	Yes
West	Weight at age of the spawning stock at spawning time.	1988-last data year	2-12+	Yes
Mprop	Proportion of natural mortality before spawning	1988-last data year	2-12+	No
Fprop	Proportion of fishing mortality before spawning	1988-last data year	2-12+	No
Matprop	Proportion mature at age	1988-last data year	2-12+	According to WKHERMAT see B.2.4
Natmor	Natural mortality	1988-last data year	2-12+	No
CatchPred	Prediction of total catch in tonnes	Last data year + 1	--	Yes

Tuning data:

TYPE	NAME	YEAR RANGE	AGE RANGE
Tuning fleet 1	Norwegian acoustic survey on spawning grounds in February/Match	1988-1989, 1994-1996, 1998-2000,2005-2008, 2015-last data year +1	3-12+
Tuning fleet 4	IESNS in the Barents Sea	1991- last data year +1	2
Tuning fleet 5	IESNS in the Norwegian Sea	1996-last data year +1	3-12+

The likelihood function

The model is described in in detail in Aanes 2016a and 2016b implicitly including the likelihood function with all its components. Each component in the likelihood function and the parameters involved it is described in this section. The model includes the components fishing mortality, recruitment and observations. The fishing mortality is modelled as a structural time-series model and the values are latent variables with underlying processes. The recruitment is modelled as a random variable. The parameters to be estimated are the parameters characterizing the latent processes (described below) and the initial values (the numbers-at-age the first year, except for the recruiting age which is modelled as random variables). See Aanes 2016a and 2016b for further details. The likelihood components are summarized in table 1 after the detailed description.

C1.1 Fishing mortality

The fishing mortality is a random variable following a structural time-series model with the following components:

First the fishing mortality is modelled as a separable model with noise

$$\log(F_{a,t}) = \mu^F_{a,t} + \delta^{(1)}_{a,t} = U_{a,t} + V_t + \delta^{(1)}_{a,t}$$

where

$$\left\{\delta^{(1)}_{a,t}\right\}_{a=a_{min},\dots,A} \sim \text{MVN}\left(\mathbf{0}, \mathbf{\Sigma}^{(1)}\right)$$

and here $\mathbf{\Sigma}^{(1)} = \sigma_1^2\mathbf{I}$

Writing $\log(\boldsymbol{F}_t) = \{\log(F_{a,t})\}_{a=a_{min},\dots,A_m}$, the likelihood component for fishing mortality is

$$l_F = 0.5T\log(2\pi)\left|\mathbf{\Sigma}^{(1)}\right| + \sum_{t=1}^{T}\left(\log(\boldsymbol{F}_t) - \log(\boldsymbol{F}^*_t)\right)'\left(\mathbf{\Sigma}^{(1)}_t\right)^{-1}\left(\log(\boldsymbol{F}_t) - \log(\boldsymbol{F}^*_t)\right)$$

where $\boldsymbol{F}^*_t$ are the model predictions of the fishing mortality at time t. This component includes the fixed parameter σ_1^2

The underlying components are selectivity, realized effort and effort is described in the following.

C1.1.1 Selectivity

The selectivity is modelled as a multivariate 1. order autoregressive process

$$U_{a,t} = \alpha_{aU} + \beta_U U_{a,t-1} + \delta^{(2)}_{a,t}, \qquad a_{min} \le a \le a_m$$

and is set constant for ages older than a_m. Note that α_{aU} is age specific but β_U is constant across ages. Above age a_m the selectivity is set constant

$$U_{a,t} = U_{a_m,t}, \qquad a \geq a_m$$

with the constraint:

$$\sum_{a=1}^{a_m} U_{a,t} = 0$$

Since $\left\{\delta_{a,t}^{(2)}\right\}_{a=a_{min},\dots,a_m-1} \sim \text{MVN}\left(\mathbf{0}, \mathbf{\Sigma}^{(2)}\right)$ and writing $\boldsymbol{U}_t = \left\{U_{a,t}\right\}_{a=a_{min},\dots,a_m-1}$, the likelihood component is

$$l_s = 0.5(T-1)\log(2\pi)\left|\mathbf{\Sigma}^{(2)}\right| + \sum_{t=2}^{T}(\boldsymbol{U}_t - \boldsymbol{U}_t^*)'\left(\mathbf{\Sigma}_t^{(2)}\right)^{-1}(\boldsymbol{U}_t - \boldsymbol{U}_t^*)$$

where $\boldsymbol{U}_t^*$ are the model predictions of the selectivity at time t. Here $\mathbf{\Sigma}^{(2)} = \sigma_2^2\mathbf{I}$ (time invariant with one parameter), such that this component includes the fixed parameters $\{\alpha_{aU}\}_{a=a_{min},\dots,a_m-1}$, β_U, and σ_2^2.

C1.1.2 Realized effort

The "realized" effort V_t is a latent variable depending on the underlying effort Y_t according to

$$V_t = Y_t + \delta_t^{(3)}$$

where $\delta_t^{(3)} \sim N(0, \sigma_3^2)$.

$$l_v = 0.5T\log(2\sigma_3^2\pi) + \sum_{t=1}^{T}\frac{(V_t - V_t^*)^2}{2\sigma_3^2}$$

where V_t^* is the model prediction of the effort. This component includes the fixed parameter σ_3^2.

As noted in Aanes (2016a), the herring data does not give any support to estimate this process, since $\log(\sigma_3^2)$ tends to –infinity, or σ_3^2 tends to 0, and convergence is not obtained. This means that this component excluded in the analysis presented here.

C1.1.3 Effort

Effort Y_t is a latent variable following an AR(1) model

$$Y_t = \alpha_Y + \beta_Y Y_{t-1} + \delta_t^{(4)}$$

where $\delta_t^{(4)} \sim N(0, \sigma_4^2)$ and has likelihood component

$$l_y = 0.5(T-1)\log(2\sigma_4^2\pi) + \sum_{t=2}^{T}\frac{(Y_t - Y_t^*)^2}{2\sigma_4^2}$$

where Y_t^* is the prediction given by the model for effort. The fixed parameters are α_Y, β_Y and σ_4^2.

C1.2 Recruitment

Although the framework allows for a flexible definition of the recruits, the log recruits at age a_{min} are here modelled as a random process $R_t \sim N(\mu_R, \sigma_R^2)$ such that the likelihood component becomes

$$l_R = 0.5T\log(2\sigma_R^2\pi) + \sum_{t=1}^{T} \frac{(R_t - R_t^*)^2}{2\sigma_R^2}$$

where R_t^* are the model predictions of log recruitment at time t. The fixed parameters are mean log recruitment μ_R and the variance σ_R^2.

C1.3 Observations

C1.3.1 Catch-at-age

The catch vector at time t is $\log(\boldsymbol{C}_t) = \{\log(C_{a,t})\}_{a=a_{min},\dots,A}$ and the likelihood component is

$$l_C = 0.5\log(2\pi)\sum_{t=1}^{T}|\boldsymbol{\Sigma}_t^c| + \sum_{t=1}^{T}\left(\log(\boldsymbol{C}_t) - \log(\widehat{\boldsymbol{C}}_t)\right)'(\boldsymbol{\Sigma}_t^c)^{-1}\left(\log(\boldsymbol{C}_t) - \log(\widehat{\boldsymbol{C}}_t)\right)$$

Where $\widehat{\boldsymbol{C}}_t$ are the observed catch-at-age and

$$C_{a,t} = \frac{F_{a,t}}{Z_{a,t}}(1 - e^{-Z_{a,t}})N_{a,t}$$

C1.3.2 Abundance indices

For each fleet f

$$\log(\boldsymbol{I}_t^f) = \{\log(I_{a,t}^f)\}_{a=a_{min},\dots,A}$$

$$l_I^f = 0.5\log(2\pi)\sum_{t=1}^{T}|\boldsymbol{\Sigma}_t^f| + \sum_{t=1}^{T}\left(\log(\boldsymbol{I}_t^f) - \log(\widehat{\boldsymbol{I}}_t^f)\right)'(\boldsymbol{\Sigma}_t^f)^{-1}\left(\log(\boldsymbol{I}_t^f) - \log(\widehat{\boldsymbol{I}}_t^f)\right)$$

Where $\widehat{\boldsymbol{I}}_t^f$ are the observed abundance indices at age for fleet f

$$I_{a,t} = q_a^f \mathrm{N}_{a,t}\exp(-\delta_t^f \mathrm{Z}_{a,t})$$

For each fleet, the fixed parameters are $\{q_a^f\}_{a=a_{min},\dots,a_m^f}$, where $q_a^f = q_{a_m^f}^f$, for $a \geq a_m^f$ (i.e. the age at which the catchability is constant sometimes called "q-plateau").

For both catch-at-age and abundance indices at age there are optionally parameters in the observation errors that can be estimated. See *Observation error* below for details.

Table 1. Summary of likelihood components. In addition to the parameters in the table, the model depend on the initial values of abundance which enters through the model for catch-at-age and possibly abundance indices at age (provided that abundance indices are available in the first year of analysis)

Component	Variable	Description	Fixed parameters	Likelihood component
Fishing mortality F	$\{\log F_{a,t}\}_{a=a_{min},\dots,A_m,\ t=1,\dots,T}$	Random	σ_1^2	l_F
F: Selectivity	$\{U_{a,t}\}_{a=a_{min},\dots,a_m-1,\ t=1,\dots,T}$	Random	$\{\alpha_{aU}\}_{a=a_{min},\dots,a_m-1}$, β_U, and σ_2^2	l_s
F: Realized effort	$\{V_t\}_{t=1,\dots,T}$	Random	σ_3^2	l_v
F: effort	$\{Y_t\}_{t=1,\dots,T}$	Random	α_Y, β_Y, σ_4^2	l_y
Recruitment	$\{R_t\}_{t=1,\dots,T}$	Random	μ_R and σ_R^2	l_R
Catch-at-age	$\{C_{a,t}\}_{a=a_{min},\dots,A,\ t=1,\dots,T}$	Observation	Optionally elements in $\mathbf{\Sigma}_t^c$	l_C
Abundance indices	$\{I_{a,t}^f\}_{a=a_{min}^f,\dots,A^f,\ t=1,\dots,T}$	Observation	$\{q_a^f\}_{a=a_{min},\dots,a_m^f}$ Optionally elements in $\mathbf{\Sigma}_t^f$	$\{l_I^f\}_{f=1,\dots,n_f}$

C1.4 Joint and marginal likelihood

Writing θ, y and x for the fixed parameters, random variables (latent states) and observations, respectively, the joint negative log likelihood for the model is

$$l = -\log(f(\theta, y, x)) = l_y + l_v + l_s + l_F + l_R + l_C + \sum_{f=1}^{n_f} l_I^f$$

where n_f is the number of fleets (i.e. number of sets of abundance indices at age) applied in the analysis.

The inference is based on the marginal likelihood, and the negative marginal log likelihood for the observations is

$$l_M = -log[f(\theta, x)] = -log\left[\int f(\theta, y, x)dy\right]$$

which is minimized. Note that in general the likelihood components for the observations $l_C + \sum_{f=1}^{n_f} l_I^f$ is NOT the same as the marginal likelihood for the observations l_M. Therefore, interpretation of the single likelihood components should be made by some care. Remaining details are given in Aanes 2016a and Aanes 2016b.

C1.5 Observation error

For observations from catch and survey on the same form, i.e. abundance/numbers-at-age and time, the structure of the observation error for such data can be generically specified. For observation dataset O the observation error for a specific year is $\mathbf{\Sigma}'^{\mathbf{O}}$ and is decomposed as follows

$$\mathbf{\Sigma}'^{\mathbf{O}} = (\sqrt{\mathbf{h}} \cdot \boldsymbol{\sigma})(\sqrt{\mathbf{h}} \cdot \boldsymbol{\sigma})^{\boldsymbol{t}}\mathbf{R}$$

Where $\mathbf{h} = (h_1, \dots, h_{A^O})^t$ is a scaling-factor of the covariance, $\boldsymbol{\sigma} = (\sigma_1, \dots, \sigma_{A^O})^t$ the standard deviations (i.e. standard errors), and $\mathbf{R}$ is the $A^O \times A^O$ dimensional correlation matrix and A^O the dimension (i.e. number of ages) for the observations for a specific year. In all cases considered here, only one scaling factor for each dataset is considered, i.e. $h_i = h \, \forall i$, such that

$$\boldsymbol{\Sigma'^{O}} = \mathrm{h}\boldsymbol{\Sigma^{O}}$$

such the error structure is completely determined by $\boldsymbol{\Sigma^{O}}$ up to the scaling constant h. A summary of different formulations of observation models is given in Aanes 2016a and 2016b and WGWIDE decided that the data available at WKPELA gave most support for observation model 5, i.e. use sampling errors to parameterize $\boldsymbol{\Sigma^{O}}$, and estimate a common scaling factor h across datasets.

References

Aanes, S. 2016a. A statistical model for estimating fish stock parameters accounting for errors in data: Applications to data for Norwegian Spring-spawning herring. WD4 in ICES. 2016. Report of the Benchmark Workshop on Pelagic stocks (WKPELA), 29 February–4 March 2016, ICES Headquarters, Copenhagen, Denmark. ICES CM 2016/ACOM:34. 106pp.

Aanes, S. 2016b. Diagnostics of models fits by XSAM to herring data. WD12 in ICES. 2016. Report of the Benchmark Workshop on Pelagic stocks (WKPELA), 29 February–4 March 2016, ICES Headquarters, Copenhagen, Denmark. ICES CM 2016/ACOM:34. 106pp.

C2. Exploratory assessment tool TASACS

This is the assessment method introduced by the benchmark in 2008 (ICES 2008), as used by WGWIDE in 2015. Since 2008, only minor amendments have been made to the software, but data have been revised on several occasions, also for the present benchmark. After the change of assessment model in the 2016 benchmark TASACS is annually run as an exploratory assessment by WGWIDE.

Software used: TASACS (Skagen and Skålevik, 2012). Last update 21.01.2016.

Model options used: VPA, dynamic pool plus group, fitted to 7 age structured surveys and one biomass survey, with manual weighting of data.

Analyses are restricted to the years 1988–present. The last year is the year after the last year with catch data. The fishing mortality in the last year is assumed equal to the last catch data year.

Age range for the analyses is 0–15+

Natural mortality is assumed at 0.9 for ages 0, 1 and 2 and 0.15 for all older ages.

Input data: Listed in Table C.2.1

The surveys (some of them revised with the StoX software in 2016) are described and tabulated in Section B3 and summarized in Table C.2.2. The text table below shows assumed fraction of fishing mortality and natural mortality for each of the age-structured surveys (fleets), and the age from which catchability is independent of age.

	FLEET 1	FLEET 2	FLEET 3	FLEET 4	FLEET 5	FLEET 6	FLEET 7
Prop F & M before survey	0.17	0.91	0.17	0.41	0.41	0.70	0.70

First age with flat catchability	11	10	10	2	11	2	0

The smallest measurable amount is set at 0.001 for all surveys and catch numbers-at-age. The oldest age is handled as a plus group in surveys 1,2,3 and 5, and in the catch numbers-at-age.

Objective function:

The stock numbers are back-calculated from survivor numbers. Estimated survivor numbers are those at the end of the last catch data year, or the end of the year where the year class is at oldest true age. The survivor numbers are model parameters that are estimated by fitting modelled survey data to observations. The modelled survey indices U are derived from the corresponding stock numbers N as

U = q*N. Each catchability q is age and fleet specific but assumed constant over years. The objective function is a sum of weighted squared log survey residuals, including residuals from the larval survey as index of SSB:

$$O = \sum_{a,y,fl} w(a,y,fl)*\log\{U(a,y,fl)/(q(a,fl)*N(a,y))\}+$$

$$\sum_{y} w_{SSB}(y)*\log\{U_{SSB}(y)/(q_{SSB}*SSB(y))\}$$

Optimization (minimization of the objective function as functional of the parameters) is done by a searching routine.

The weighting w(a,y,fl) is either 1 or 0, as described below; weighting according to error variance is not used.

Except for the plus group, catch data are not modelled, and are not included in the objective function. Catches from the plus group could have been included in the objective function, but that is not done in the standard conditioning.

Some survey observations are excluded by giving them zero weight. The principle is that if the survey contributes mostly noise to the assessment it is not included. In addition, when conflicting information appears between different surveys, it is attempted, as far as possible, to use expert knowledge of the performance and known problems of the different surveys, to resolve conflicts by excluding the data that were considered the least reliable.

The survivor numbers for some small year classes are not estimated but set at a small number to indicate that the year class is small, without attempting to quantify exactly how small. This is the case with the year classes 1995, 1996, 2000 and 2001. The oldest year classes (1988 and older, except 1983) were estimated by assuming a terminal fishing mortality taken from younger ages (option 4), with a scaling factor of 1.3, which appears as selection at age 14 in the parameter input (see the TASACS manual (Skagen and Skålevik 2012) Section 2.1.1. for detailed explanation). The survey information for these year classes is not used and is given zero weight.

References

Skagen, Dankert W. ans Skålevik, Å, 2012. Users manual. TASACS. A Toolbox for Age-structured Stock Assessment using Catch and Survey data . Version 1.1, Last update: 20/8-2012 Distributed with the TASACS software.

ICES 2008: Report of the Working Group on Widely Distributed Stocks (WGWIDE) Section 9, Norwegian spring-spawning herring. ICES CM 2008/ACOM:13

Table C2.1. Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year-to-year Yes/No
Caton	Catch in tonnes	1988–last catch data year	==	Yes
Canum	Catch-at-age in numbers	1988–last catch data year	0–15+	Yes
Weca	Weight at age in the commercial catch	1988–last catch data year	0–15+	Yes
West	Weight at age of the spawning stock at spawning time.	1988–last data year	0–15+	Yes
Mprop	Proportion of natural mortality before spawning	1988–last data year	0–15+	No
Fprop	Proportion of fishing mortality before spawning	1988–last data year	0–15+	No
Matprop	Proportion mature at age	1988–last data year	0–15++	According to WKHERMAT see B.2.4
Natmor	Natural mortality	1988–last data year	0–15+	No

Table C.2.2. Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	Norwegian acoustic survey on spawning grounds in February/Match	1995–2005, 2015–last data year+1	5–15+

Tuning fleet 2	Norwegian acoustic survey in Nov/Dec	1992–2001	4–14+
Tuning fleet 3	Norwegian acoustic survey in January	1991–1999	5–15+
Tuning fleet 4	International Ecosystem survey in the Nordic Seas and	1991–last data year+1	1–2
Tuning fleet 5	International Ecosystem survey in the Nordic Seas	1996–last data year+1	4–15+
Tuning fleet 6	Joined Russian-Norwegian ecosystem autumn survey in the Barents Sea	2000–last data year	1–2
Tuning fleet 7	Joined Russian-Norwegian ecosystem autumn survey in the Barents Sea	2000–last data year	0
Tuning fleet 8	Norwegian herring larvae survey	1981–last data year+1	SSB index

D. Short-Term Projection

D1. The main assessment tool XSAM.

Model used: Stochastic forward projection using XSAM with management option table presenting average F-values for age 5-11 weighted over population numbers at the start of the year. The method is documented in Aanes 2016c. In 2018 at WKNSSHMSE (or was it WKNSSHREF?) this was changed to 5-12^{+}. For short term forecast, the mean of the stochastic forecast is very similar to the corresponding deterministic forecast using mean values and is therefore used as basis for management options to be consistent with the implemented management plan. Prediction uncertainty is derived directly from 1000 realisations of stochastic projections defined by XSAM.

Software used: A prediction module has been developed for XSAM and is available on sharepoint.

Initial stock size: Input to the short-term projection is the stock number-at-age 3 and older (survivors) at the 1st of January taken from the final assessment. For instance, if the last data year is 2008, the assessment provides the surviving stock numbers at the

1st of January 2009. Log recruits at age 2 are modelled as a random process $R_t \sim N(\mu_R, \sigma_R^2)$. Consequently, predictions of mean recruitment equal $\exp(\mu_R + 0.5\sigma_R^2)$ where μ_R is the mean recruitment at the log-scale, whereas the recruitment variability corresponds to the estimated variability in recruitment over the years included in the model fit.

Maturity: For the forecast it is recommended to use the maturity associated to 'normal' year classes unless the assessment indicate a strong year class (see B.2.4).

AGE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
normal yc	0	0	0	0	0.4	0.8	1	1	1	1	1	1	1	1	1	1
strong yc	0	0	0	0	0.1	0.6	0.9	1	1	1	1	1	1	1	1	1

F and M before spawning: The SSB is calculated at the 1st of January. Consequently the proportion of F and M before spawning is 0.

Weight at age in the stock: for the intermediate year are the observed weights obtained from the winter survey (reference). For the other years the average of the last 3 years are used. Since 2008 the winter survey has stopped and weight at age data from commercial sampling in the same period and are used

Weight at age in the catch: is the average of the observed catch weights over the last three years.

Exploitation pattern: Predicted by XSAM. Estimates of F in the assessment year is available directly from the fitted model in the assessment year, while projected values follows exploitation pattern predicted the time series model for fishing mortality (see Annex C1 and Aanes 2016c for details). The selectivity component is modelled as a multivariate AR(1) process. Since this is a stationary process the mean predictions will be adjusted accordingly and gradually move towards to the estimated long term mean of selectivity.

Natural mortality: fixed values, the same as used in the assessment.

Intermediate year assumptions: catch constraint.

Stock recruitment model used: See *Initial stock size* above and Annex C1.2.

Procedures used for splitting projected catches: not applicable.

References

Aanes, S. 2016c. Forecasting stock parameters of Norwegian spring spawning herring using XSAM. WD at WGWIDE in 2016.

E. Medium-Term Projections not defined

Model used:

Software used:

Initial stock size:

Natural mortality:

Maturity:

F and M before spawning:

Weight at age in the stock:

Weight at age in the catch:

Exploitation pattern:

Intermediate year assumptions:

Stock recruitment model used:

Uncertainty models used:

1. Initial stock size:
2. Natural mortality:
3. Maturity:
4. F and M before spawning:
5. Weight at age in the stock:
6. Weight at age in the catch:
7. Exploitation pattern:
8. Intermediate year assumptions:
9. Stock recruitment model used:

F. Long-Term Projections not defined

Model used:

Software used:

Maturity:

F and M before spawning:

Weight at age in the stock:

Weight at age in the catch:

Exploitation pattern:

Procedures used for splitting projected catches:

G. Biological Reference Points

G.1. Precautionary and limit reference points: (Eydna, Erling)

The reference points were to be evaluated at WKPELA 2016. Due to time constraint only B_{lim} was evaluated. The conclusion was that it should remain unchanged at 2.5 million tonnes. The reference points will be reviewed next time the management plan will be evaluated, which is expected to take place late autumn 2016.

The reference points for herring were considered by the Workshop on Limit and Target Reference Points (WKREF) held in Gdynia in 2007. Although it was the intention to review and update the biological basis of limit reference point taking into account the possible effects of species interactions and regime shifts, this has not been done because of lack of data. Instead, the breakpoint of a segmented regression applied to the stock recruitment plot was investigated. This breakpoint gives an indication at which SSB recruitment starts to decline and is a candidate for B_{lim}. The breakpoint in the stock recruit data varied between 2–4 million tonnes and seemed to be very sensitive to small changes in the estimates of the poor year classes (points near the origin of the S/R plot) in assessments carried out in different years. WKREF could not explain the sensitivity and considered this behaviour of the model highly undesirable. WKREF decided to ask the Methods Working Group to investigate this observation further. Given this, the use of segmented regression technique to establish a limit biomass reference point for Norwegian spring-spawning herring was not considered appropriate until the observed methodological issue has been resolved.

The currently used values originate in an analysis carried out in 1998.

	ICES CONSIDERS THAT:	ICES PROPOSED THAT:
Precautionary Approach reference points	B_{lim} is 2.5 million t	B_{pa} be set at 5.0 million t
	Flim is not considered relevant to this stock	F_{pa} be set at F = 0.15
Technical basis:		
B_{lim}: MBAL	B_{pa}=B_{lim}*exp(0.4*1.645) (ICES Study Group 1998)	
F_{lim}: not relevant to this stock	F_{pa}: based on medium term simulations (ICES Study Group 1998)	

The new assessment did not give different perceptions of the dynamics and levels of SSB and Fishing Mortality compared to the assessment which was the basis for establishing the reference points. Therefore there was no need to reconsider the reference points because of the new assessment method.

MSY reference points (included in 2010)

HCS Simulation model analysis

HCS is a stochastic simulation model for studying different management scenarios. The parameterization of HCS for NSSH is described in a working document sent for WGWIDE in 2010 (WD, Skagen; the values for weights, natural mortality and initial N-values can be found in ICES 2009, WGWIDE Table 7.10.1.3, input to short-term prediction; see also Skagen 2010, WD WKFRAME). Two stock–recruitment relationships, Beverton–Holt and hockey stick, are explored:

Beverton–Holt: $R = a*SSB/(SSB+b)$

Hockey stick: $S>b: R = a$

$S<b: R = a*SSB/b$

The stock–recruitment parameters are shown in Table 7.8.2. Parameters, and a plot of these together with the data are shown in Figure 7.8.2.srstoch. A plot of the data together with model output for Beverton–Holt function is show in Figure 7.8.2 srmodeldata, and the cumulative distribution of recruitment in data and model output is shown in Figure 7.8.2.cumdist. The long-term sustained yields with Beverton–Holt recruitment function are shown in Figure 7.8.2.catch. A similar figure for hockey stick recruitment function can be found in Skagen 2010 (WD, Skagen).

In WKHERMAT in 2010 a new maturity ogive matrix for NSSH based on a back calculation methods was estimated (ICES 2010, WKHERMAT). This is used in the assessment in 2010. There appears to be a difference in the maturation ogive between strong and weak year classes such that strong year classes tend to mature at later age compared to weak year classes (Engelhart & Heino 2004, ICES 2010, WKFRAME). However, the model used here currently allows only static maturity ogive, and in order to take into account the effect of variation in maturation of strong and weak year classes for MSY and F_{MSY} we have run the analysis using the standard maturity ogive used in assessment the latest years, an ogive estimated for weak year classes and an ogive estimated for strong year classes (Table 7.8.2.modelparams). Furthermore, in year 2009 the selection pattern is different from the historical period, appearing more dome-shaped than the historical sigmoidal selection pattern (Table 7.8.2.modelparams). We have not been able to identify any reason why the selection pattern would have changed, as there have been no changes in gear or fishery in general. Nevertheless, we also studied the effect of possible change in selection pattern by using alternatively the historical (old) or the selection curve from 2009 (Table 7.8.2.modelparams).

The results of the simulation analysis suggest that the MSY, for all the scenarios and with both stock–recruitment functions, is within the same range: between 1 and 1.2 million tonnes (Figure 7.8.2.msyBH, 7.8.2.msyHS, and Table 7.8.2.results). Although the different scenarios result in MSY within the same range, the F_{MSY} has more variation (Figure 7.8.2.fmsy and Table 7.8.2.results). When Beverton–Holt recruitment function is used, the risk of stock going below B_{lim} (2.5 million t.) and $B_{trigger}$ (4 million t.) at F_{MSY} are both very low, whereas with the Hockey stick recruitment function the risk of the stock falling below $B_{trigger}$ at F_{MSY} is relatively high (Table 7.8.2.results). Hockey stick recruitment function appears not to be very useful in modelling population dynamics, as the spawning stock size where MSY is reached is the same point where stock reproductive capacity starts decreasing (see also the discussion in the equilibrium analysis below). When Beverton–Holt recruitment function is used, unweighted F_{MSY} using the historical fishery selection pattern is 0.16 (for all maturity ogive scenarios), and adopting the 2009 selection pattern suggests of F_{MSY} 0.12 (for all maturity ogive scenarios). In NSSH management weighted F values are used, and the weighted values tend to be somewhat lower than unweighted values (Figure 7.8.2.fvalues). As we have no reason to believe that the selection pattern has really changed, we consider unweighted F_{MSY} to be 0.16. This unweighted F value is in close agreement with the reference values originating in an analysis carried out in 1998 (ICES 2008/ACOM 13), where a weighted F_{pa} is defined as 0.150.

Equilibrium and YPR analyses

Deterministic and stochastic equilibrium analyses were carried out using the 'plotMSY' software (ICES 2010, WKFRAME) to determine candidate F_{MSY} values for the Norwegian spring-spawning herring stock. Stock–recruitment pairs from the period 1988-2009, as outputted from the most recent assessment of the stock, were used together with 5-year averages of selectivity, weight and maturity-at-age (back-calculated ogive). Two stock recruit relationships were examined, Beverton and Holt and the ('smooth hockey stick' (segmented regression), and yield-per-recruit (YPR) analyses were also done. For the stochastic analyses, uncertainty (CVs) in the biological and fishery parameters at age were used to create alternative fits to two stock–recruit relationships (*N*=1000).

While the Beverton and Holt fit is reasonable under using the old maturity ogive to estimate SSB (results not shown), the majority of stochastic stock–recruit model fits fell out of the range of the deterministic fit to the data, and thus it can be concluded that the stock–recruit form is unclear and not suitable for the data and the level of uncertainty associated with the parameters. Using the new back-calculated maturity ogive, as has been decided by the working group for the assessment of this stock, results in an very poor Beverton and Holt fit (Figure 7.8.2.XXXsr), with an extremely steep slope at the origin and an asymptote at the geometric mean recruitment level. Given the lack of any clear patterns in the stock–recruit data, a hockey stick model fit, while uncertain around the origin, probably provides the most cautious fit to the data. For the hockey stick, the slope at the origin is the descending limb of the stock–recruit curve, which for this stock is relatively shallow, hence F_{crash} is low. The value for B_{msy} is at the breakpoint in the hockey stick, hence F_{msy} is estimated to be the same as F_{crash} (Table 7.8.2.XXXmsy). The uncertainty with regards to the slope at the origin makes this stock–recruitment function unsuitable as a basis for advice on F_{msy}. In such cases the slope is more useful as an indication of F_{pa} or F_{lim}.

Given the poor fits to stock recruitment functions, a yield-per-recruit analysis was conducted (Figure 7.8.2.XXXypr). The stochastic analysis shows a high degree of uncertainty and a very poorly defined F_{max}. That both the hockey stick and per-recruit analysis suggests a high degree of uncertainty with regards to F_{max} could be down to the assumptions made about the uncertainties input into the analyses, though these assumptions are believed to be realistic given the information on the stock. This would preclude the use of F_{max} as an F_{msy} proxy, although $F_{0.1}$ may remain a viable, safer alternative. The YPR curve shows that F values in the range 0.125-0.15 are likely to result in high long-term yields.

Conclusions

In the equilibrium analysis, the structure of the stock and recruitment pairs as estimated from the most recent assessment does not lead to any clear definition of an optimum yield equilibrium fishing mortality level. Given this uncertainty it is more appropriate to select an F_{msy} proxy tested by a stochastic simulation model that takes into account the long-term trends in the stock biomass. The simulation model results presented in this report and in the stock annex provide a more appropriate method for the determining a viable long-term target, and the values from this analysis could be put forward as potential F_{msy} targets. However, it should be noted that it is clear that the estimation of MSY reference points is very sensitive to the choice of stock–recruitment function and the approach chosen to estimate the reference points. This is in accordance with previous analyses by Skagen (WD 2010) and by WKFRAME (ICES 2010, WKFRAME).

The stochastic model uses unweighted F values, which have historically been found to be slightly lower than the unweighted values (Figure 7.8.2.fvalues). Therefore, a weighted F_{msy} of 0.15 corresponding to the unweighted 0.16 F_{msy} proxy from the simulation analyses is proposed for this stock. This is in agreement with the current simulation-tested management plan F_{pa} level and should ensure high long-term yield with a low risk to the stock.

Table 7.8.2.params. Norwegian spring-spawning herring. Stock recruitment parameters used in the simulation model and their fit to the data (Skagen 2010).

	A-PARAMETER	B-PARAMETER	SSQ
Beverton–Holt	180805	6986	81.85
Hockey stick	88803	3957	81.47

Table 7.8.2.modelparams. Norwegian spring-spawning herring. Age-specific maturation probabilities, exploitation patterns and weight at age in stock and in catches used in the different stochastic simulation scenarios.

	MATURITY OGIVE			EXPLOITATION PATTERN		WEIGHT AT AGE	
AGE	HISTORIC	WEAK YEAR CLASS	STRONG YEAR CLASS	OLD	2009	STOCK	CATCH
0	0	0	0	0.00	0.00	0.001	0
1	0	0	0	0.05	0.00	0.01	0.052
2	0	0	0	0.04	0.87	0.033	0.115
3	0	0	0	0.05	0.26	0.077	0.159
4	0.3	0.4	0.1	0.18	0.29	0.141	0.225
5	0.9	0.8	0.6	0.41	0.47	0.215	0.264
6	1	1	0.9	0.67	0.84	0.27	0.301
7	1	1	1	1.03	0.93	0.306	0.32
8	1	1	1	1.10	1.01	0.336	0.338
9	1	1	1	0.81	1.65	0.346	0.359
10	1	1	1	1.03	1.10	0.364	0.366
11	1	1	1	0.77	0.73	0.369	0.375
12	1	1	1	1.42	1.14	0.411	0.391
13	1	1	1	1.36	0.59	0.353	0.397
14	1	1	1	1.39	0.56	0.389	0.396
15	1	1	1	1.39	0.56	0.393	0.406

Table 7.8.2.results. Norwegian spring-spawning herring. MSY and FMSY values provided by HCS model for different scenario combinations. Risk B_{lim} refers to the probability that SSB < B_{lim} in the last year (2.5 million tonnes), and Risk $B_{trigger}$ refers to the probability that SSB < $B_{trigger}$ ($B_{trigger}$ = 5 million tonnes, risk calculated as risk B_{lim}).

		BEVERTON-HOLT				HOCKEY STICK			
OGIVE	SELECTION PATTERN	FMSY	MSY	RISK B_{LIM}	RISK BTRIGGER	F_{MSY}	MSY	RISK B_{LIM}	RISK $B_{TRIGGER}$
HISTORICAL	old	0.16	1120.1	0	0.026	0.32	1180.1	0.067	0.354
	2009	0.12	1071.5	0.006	0.064	0.2	1135.7	0.088	0.431
WEAK YEAR CLASS	old	0.16	1132.8	0	0.022	0.32	1193.4	0.058	0.321
	2009	0.12	1083.4	0.006	0.051	0.2	1149.4	0.075	0.401
STRONG YEAR CLASS	old	0.16	1093.3	0.002	0.045	0.26	1157.9	0.04	0.232
	2009	0.12	1046.4	0.007	0.086	0.16	1117.9	0.017	0.203

Table 7.8.2.msy. Deterministic and stochastic estimates of *F* and biomass reference points form two stock recruit relationships and yield-per-recruit analysis for the Norwegian spring-spawning herring stock (*=poorly defined).

Beverton-Holt

	Fcrash	Fmsy	Bmsy	MSY
Deterministic	*	*	0.25	1.06
50%ile	0.52	0.15	3.11	0.61
CV	1.09	0.60	0.72	0.61

Hockey Stick

	Fcrash	Fmsy	Bmsy	MSY
Deterministic	0.18	0.18	4.25	0.70
50%ile	0.20	0.20	3.88	0.90
CV	0.71	0.69	0.39	0.49

Per recruit

	F01	Fmax
Deterministic	0.23	*
50%ile	0.19	0.77
CV	0.39	0.58

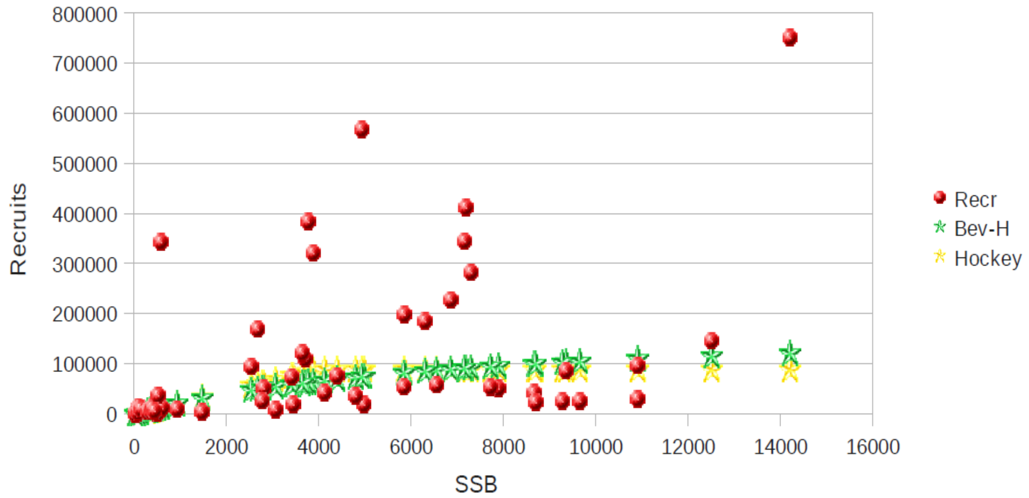

Figure 7.8.2. srstoch. Stock recruitment relationship used in the simulation model. Red dots show the recruitment from data, green stars the fitted Beverton–Holt function and yellow stars the fitted hockey stick function. Figure show also in Skagen 2010 (WD, Skagen).

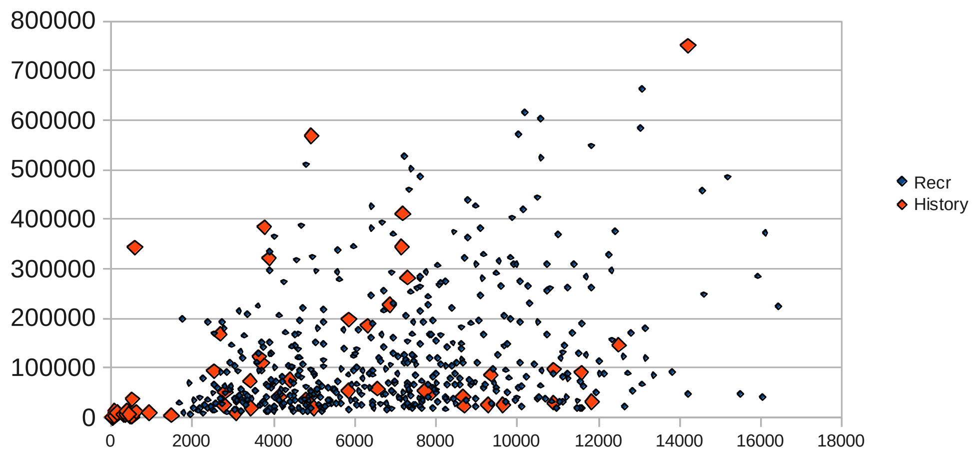

Figure 7.8.2.srmodeldata. Norwegian spring-spawning herring. Stock–recruitment of NSSH from data (big red diamonds) and produced by the model (blue small diamonds) using Beverton–Holt recruitment function.

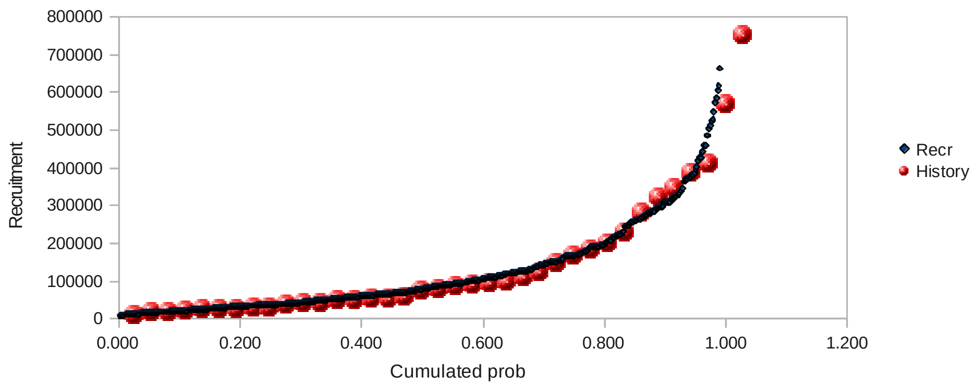

Figure 7.8.2.cumdist. Norwegian spring-spawning herring. Cumulative probability of recruitment values of NSSH from the data (red dots) and produced by the model (small blue diamonds) using Beverton–Holt recruitment function.

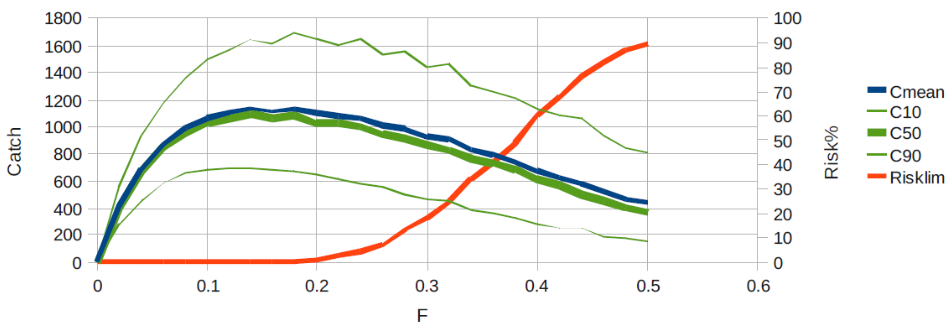

Figure 7.8.2.catch. Norwegian spring-spawning herring. Yield (catch) and the probability of the stock being below Blim (2.5. million tonnes) after 50 years at target F for NSSH using Beverton–Holt recruitment function. C10, C50 and C90 show the 10, 50 and 90 percentiles of catch. $Risk_{lim}$ shows the probability of stock falling below B_{lim} as a percentage of the model runs. For similar figure for hockey stick recruitment function see WD Skagen 2010.

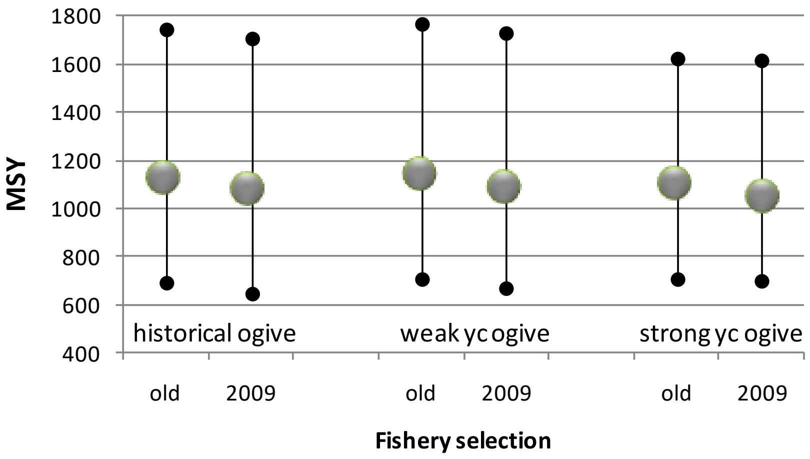

Figure 7.8.2.msyBH. Norwegian spring-spawning herring. The MSY for three different maturity ogives and two different fishery selection patterns with 10 and 90 percentiles using Beverton–Holt recruitment function. See text for further details.

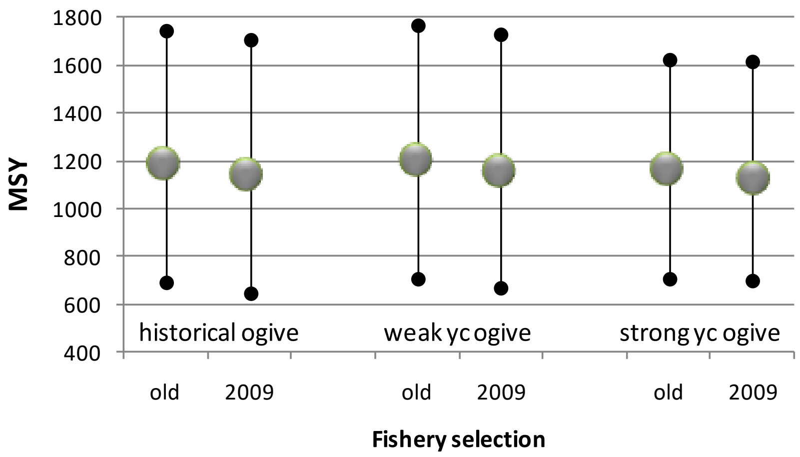

Figure 7.8.2.msyHS. Norwegian spring-spawning herring. The MSY for three different maturity ogives and two different fishery selection patterns with 10 and 90 percentiles using hockey stick recruitment function. See text for further details.

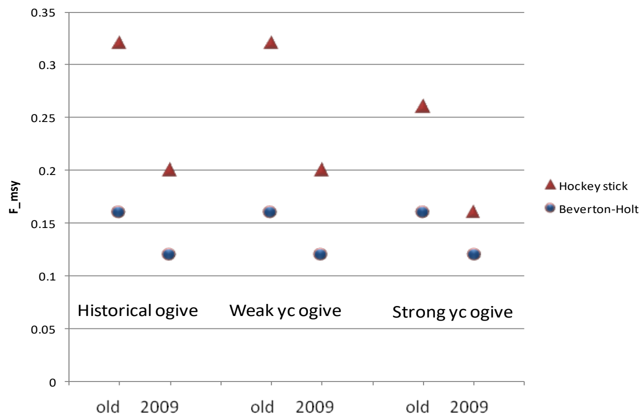

Figure 7.8.2.fmsy. Norwegian spring-spawning herring. F_{MSY} for three different maturity ogives and two different fishery selection patterns with Beverton–Holt and hockey stick recruitment function. See text for further details.

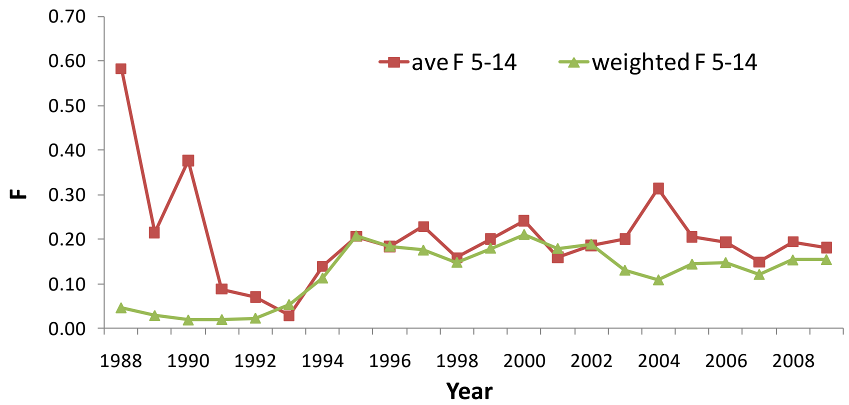

Figure 7.8.2.fvalues. Norwegian spring-spawning herring. Unweighted (red squares) and weighted (green triangles) average F values from the current assessment.

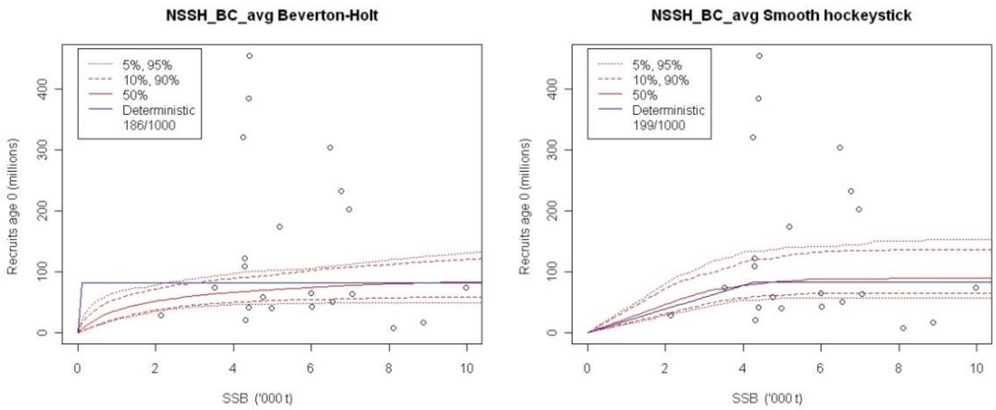

Figure 7.8.2.sr. Deterministic and stochastic (taking into account uncertainty in weights, selectivity and maturity-at-age) stock recruit relationship fits for the Norwegian spring-spawning herring stock. Stock–recruit pairs are from the period 1988–2009.

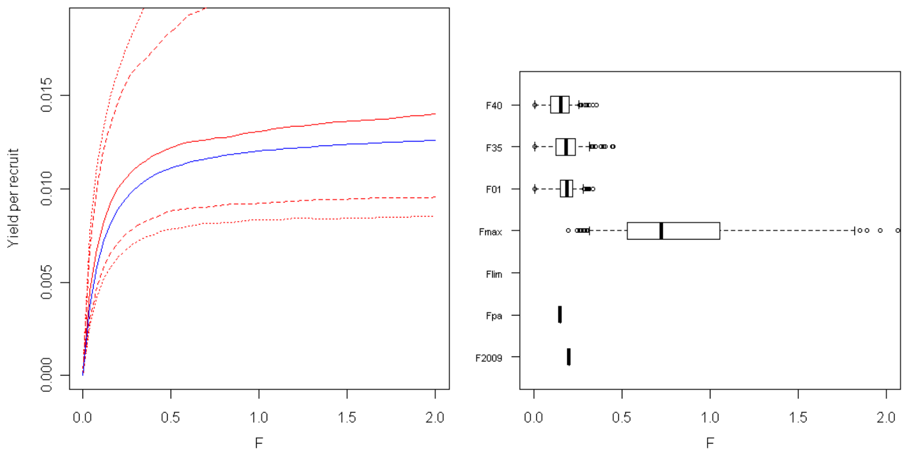

Figure 7.8.2 ypr. The yield-per-recruit (YPR) curve for the Norwegian spring-spawning herring stock (left) and resulting stochastic estimates of *F* reference points (right).

G.3. Target reference points

The Coastal States have agreed a target reference point defined at F=0.14. (Note that the average fishing mortality is calculated as a weighted mean over the age groups 5–12+ (weighted over abundance).

H. Other Issues not defined

Tables in WGWIDE omitted from SA – only other tables here ...

Table B.3.1.1. Norwegian Spring-spawning herring. Re-estimated indices (with StoX) from the acoustic surveys on the spawning stock in February-March (NASF). Numbers in millions. Biomass in thousand tonnes. Survey 1.

YEAR	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	TOTAL	BIOMASS
1988	0	392	307	8015	81	33	12	36	22	45	0	0	0	0	8943	1621
1989	161	16	338	91	3973	101	12	4	55	0	4	42	0	9	4813	1169
1990																
1991																
1992																
1993																
1994	37	100	48	848	483	62	13	144	49	1836	4	4	0	0	3665	1207
1995	4	450	4679	3211	1957	299	20	0	106	55	2327	0	0	0	13745	2860
1996	119	186	1976	7960	2326	875	301	0	0	136	0	1760	0	0	15645	3366
1997																
1998	51	308	978	2982	12859	8133	1851	592	163	43	0	329	0	1400	29705	6886
1999	114	1530	369	1351	2669	9334	7004	1666	511	130	0	0	353	373	25438	6262
2000	1394	691	2600	109	477	1144	4282	2838	493	50	2	0	7	228	14315	3285
2001																
2002																
2003																
2004																
2005	38	238	661	2128	5947	8328	613	503	156	92	576	1152	587	9	21026	5260
2006	26	90	6054	548	882	3362	3311	110	86	20	89	58	246	63	14951	3431

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total	Biomass
2007	33	367	1618	12397	815	655	2956	3205	141	228	40	204	284	470	23427	5350
2008	15	48	2564	2824	8882	522	471	1566	1567	161	102	46	128	136	19090	4553
2009																
2010																
2011																
2012																
2013																
2014																
2015	204	533	2754	744	3267	388	692	2715	784	7222	367	1658	51	237	21662	6365
2016	18	197	237	594	365	2119	240	514	2930	652	3995	199	824	97	12982	4182
2017	19	110	1076	641	880	428	1326	181	206	2026	303	2542	80	729	10550	3314
2018	104	146	1720	2771	459	845	639	1095	444	370	1159	368	1538	354	12013	3262
2019	2	372	310	940	3778	754	879	660	1054	736	412	1807	182	2161	14166	4250
2020	6	44	3502	571	1212	3337	530	609	364	650	131	279	677	825	12750	3274

*** No estimate due to poor weather conditions.**

**** No surveys.**

Table B.3.2.1 OK Norwegian Spring-spawning herring. Estimates obtained on the acoustic surveys in the wintering areas in November-December. Numbers in millions. Survey 2.

	SURVEY 2							AGE								TOTAL
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	TOTAL	BIOMASS
1992		36	1247	1317	173	16	208	139	3742	69					6947	
1993	72	1518	2389	3287	1267	13	13	158	26	4435					13178	
1994		16	3708	4124	2593	1096	34	25	196	29	3239				15209	
1995	380	183	5133	5274	1839	1040	308	19	13	111	39	907			15246	
1996		1465	3008	13180	5637	994	552	92	0	7	41	15	393		25384	
1997	9	73	661	1480	6110	4458	1843	743	66	0	0	64	0	904	16411	
1998	65	1207	441	1833	3869	12052	8242	2068	629	111	14	0	40	573	31144	
1999	74	159	2425	296	837	2066	6601	4168	755	212	0	15	0	146	17754	
2000	56	322	1522	5260	165	497	1869	4785	3635	668	205	0	0	11	18995	
2001	362	522	3916	1528	2615	82	338	864	3160	2216	384	127	0	1	16115	
2002*	7	50	276	1659	624	1029	32	188	516	1831	911	184	0	0	7307	
2003**	586	406	2167	10670	13237	1047	678	41	134	301	1214	502	10	37	31030	
2004**	257	6814	1123	1596	5334	6731	363	280	37	42	187	761	392	83	24000	
2005	61	352	7173	465	685	2030	3101	177	190	57	46	184	476	327	15325	
2006	940	7785	3712	21320	1153	340	2879	4851	4	23	713	4	150	58	43778	
2007	1233	343	4161	2407	6213	226	288	695	694	0	43	0	126	188	16617	3660

*** Much of the youngest yearclasses (-98,-99) wintered outside the fjords this winter and are not included in the estimate**

**** In 2003-2004 a combined estimate from the Tysfjord, Ofotfjord and oceanic areas off Vesterålen/Troms.**

Table B.3.3.1 OKNorwegian spring-spawning herring. Estimates obtained on the acoustic surveys in the wintering areas in January. Numbers in millions. Survey 3.

	SURVEY 3								AGE					
YEAR	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	TOTAL
1991	90	220	70	20	180	150	5500	440							6670
1992		410	820	260	60	510	120	4690	30						6900
1993		61	1905	2048	256	27	269	182	5691	128					10567
1994	73	642	3431	4847	1503	102	29	161	131	3679					14598
1995		47	3781	4013	2445	1215	42	24	267	29	4326				16189
1996		315	10442	13557	4312	1271	290	22	25	200	58	1146			31638
1997*															-
1998	214	267	1938	4162	9647	6974	1518	743	16	4	0	33	7	462	25985
1999**	0	1358	199	1455	4452	12971	7226	1876	499	16	16	0	156	220	30444

*** No estimate due to poor weather conditions.**

**** No surveys since 1999.**

Table B.3.4.1. Delete Norwegian spring-spawning herring. Acoustic estimates (billion individuals) of immature herring in the Barents Sea in May/June. No survey in 2003, 1990-2002. See footnotes. Values in the years 2009-2015 are re-estimated indices with StoX. Survey 4.

	SURVEY 4 AGE				
YEAR	1	2	3	4	5
1991	24.3	5.2			
1992	32.6	14	5.7		
1993	102.7	25.8	1.5		
1994	6.6	59.2	18	1.7	
1995	0.5	7.7	8	1.1	
1996[1]	0.1	0.25	1.8	0.6	0.03
1997[2]	2.6	0.04	0.4	0.35	0.05
1998	9.5	4.7	0.01	0.01	0
1999	49.5	4.9	0	0	0
2000	105.4	27.9	0	0	0
2001	0.3	7.6	8.8	0	0
2002	0.5	3.9	0	0	0
2003[3]					
2004[3]					
2005	23.3	4.5	2.5	0.4	0.3
2006	3.7	35.0	5.3	0.87	0
2007	2.1	3.7	12.5	1.9	0
2008[4]					
2009	0.289	0.300	0.233	0.060	
2010	5.196	1.380	0.000	0.000	
2011	1.166	3.920	0.041	0.000	
2012	0.787	0.030	0.000	0.000	
2013	0.107	2.190	0.211	0.070	
2014	4.239	3.110	1.728	0.127	0.043
2015	0.345	11.760	1.183	0.206	0.000
2016	1.826	5.620	1.568	0.101	0.038
2017	14.522	3.080	0.000	0.000	
2018	7.329	17.420	0.827	0.009	
2019	0.113	2.370	17.481	0.044	
2020[3]					
2021					

[1] **Average of Norwegian and Russian estimates**

[2] **Combination of Norwegian and Russian estimates as described in 1998 WG report, since then only Russian estimates**

[3] **No surveys**

[4] **Not a full survey**

Table B.3.4.2. Selete Norwegian spring-spawning herring. Estimates from the international acoustic surveys on the feeding areas in the Norwegian Sea in May. Numbers in millions. Biomass in thousands. Values in the years 2008-2015 are er-estimated indices by StoX. Survey 5.

	SURVEY 5							AGE								TOTAL
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	TOTAL	BIOMASS
1996	0	0	4114	22461	13244	4916	2045	424	14	7	155	0	3134			50514	8532
1997	0	0	1169	3599	18867	13546	2473	1771	178	77	288	190	60	2697		44915	9435
1998	24	1404	367	1099	4410	16378	10160	2059	804	183	0	0	35	0	492	37415	8004
1999	0	215	2191	322	965	3067	11763	6077	853	258	5	14	0	158	128	26016	6299
2000	0	157	1353	2783	92	384	1302	7194	5344	1689	271	0	114	0	75	20758	6001
2001	0	1540	8312	1430	1463	179	204	3215	5433	1220	94	178	0	0	6	23274	3937
2002	0	677	6343	9619	1418	779	375	847	1941	2500	1423	61	78	28	0	26089	4628
2003	32073	8115	6561	9985	9961	1499	732	146	228	1865	2359	1769		287	0	75580	6653
2004	0	13735	1543	5227	12571	10710	1075	580	76	313	362	1294	1120	10	88	48704	7687
2005	0	1293	19679	1353	1765	6205	5371	651	388	139	262	526	1003	364	115	39114	5109
2006	0	19	306	14560	1396	2011	6521	6978	679	713	173	407	921	618	243	35545	9100
2007	0	411	2889	5877	20292	1260	1992	6780	5582	647	488	372	403	1048	1010	49051	12161
2008	0	1213	655	10997	8406	14798	1543	2232	4890	2790	511	148	172	244	529	49187	10655
2009	0	137	1817	2280	12118	8599	9735	2054	1433	2608	1375	237	198	112	248	43057	9692
2010	231	119	572	2296	1828	8395	5918	5676	923	888	1002	550	89	42	62	28772	6649
2011	0	1110	921	1663	3592	2605	9303	4390	4257	771	956	732	269	29	33	30731	7336
2012	0	396	2942	410	668	1736	2633	4328	1884	2148	297	604	303	139	41	18540	4476
2013	0	201	718	3555	425	1161	1859	2905	4449	2772	1865	678	790	222	102	21722	5653
2014	13	515	1258	784	2788	715	1118	2634	2268	2806	1118	703	337	72	212	17350	4504
2015	0	391	432	1316	1132	3535	1309	1191	3156	2526	4457	687	816	290	211	21450	5851

						SURVEY 5				AGE							TOTAL
2016	0	75	3550	1538	2229	1749	2631	938	1092	1806	1882	2853	934	436	130	21851	5408
2017	10	131	948	4295	1198	1543	826	1414	317	738	1008	1741	2230	507	237	17159	4152
2018	0	496	1004	1968	5664	970	1409	569	1279	354	675	1564	1464	1498	500	19412	4987
2019	4	157	2625	680	2187	4656	1158	1223	952	1232	823	655	1406	917	803	19487	4805
2020	0	43	472	13065	513	1009	2492	786	629	434	694	324	505	726	902	22616	4210

Table B.3.5.1. Norwegian spring-spawning herring. Abundance indices for 0-group herring 1980-2015 in the Barents Sea, August-October. ***This index has been recalculated since 2006, these are the new values. Survey 7.***

SURVEY 7	
YEAR	ABUNDANCE INDEX
1980	4
1981	3
1982	202
1983	40557
1984	6313
1985	7237
1986	7
1987	2
1988	8686
1989	4196
1990	9508
1991	81175
1992	37183
1993	61508
1994	14884
1995	1308
1996	57169
1997	45808
1998	79492
1999	15931
2000	49614
2001	844
2002	23354
2003	28579
2004	136053
2005	26531
2006	68531
2007	22319
2008	15915
2009	18916
2010	20367
2011	13674
2012	26480
2013	70972
2014	16674
2015	11207

Table B.3.5.2. Norwegian spring-spawning herring. Acoustic estimates (million individuals) of immature herring in the Barents Sea in August-October. Data in black boxes used in the assessment. Survey 6.

SURVEY 6			
	AGE		
YEAR	1	2	3
1999	48759	986	51
2000	14731	11499	0
2001	525	10544	1714
2002			
2003	99786	4336	2476
2004	14265	36495	901
2005	46380	16167	6973
2006	1618	5535	1620
2007	3941	2595	6378
2008	30	1626	3987
2009	1538	433	1807
2010	1047	215	234
2011	95	1504	6
2012	2031	1078	1285
2013	7657	5029	92
2014	4188	1822	6825
2015	1183	9023	3214

Table B.3.6.1. OKNorwegian Spring-spawning herring. The re-evaluated indices for herring larvae on the Norwegian shelf for the period since 1981 ($N*10^{-12}$). Survey 8.

Survey 8	
Year	Index
1981	0.122626
1982	0.575116
1983	2.007957
1984	0.726094
1985	0.544136
1986	0.48801
1987	0.590926
1988	6.145609
1989	7.943702
1990	13.35647
1991	5.902405
1992	2.886389
1993	15.76233
1994	21.93361
1995	16.11461
1996	19.09891
1997	43.17302
1998	32.57131
1999	18.08759
2000	17.81545
2001	33.13493
2002	18.57813
2003*	2.625633
2004	25.28158
2005	41.70205
2006	57.36081
2007 **	57.34159
2008	54.83168
2009***	6.336059
2010	29.63399
2011	42.80365
2012	36.29313
2013	33.05541
2014	40.01117
2015	-1
2016	40.38936

Index 1. The total number of herring larvae found during the cruise.

*** Poor weather conditions and survey was late in April**

**** Only representative for the area 62-66°N**

*****Likely that spawning was particularly early in 2009**

Table B.3.7.1. Norwegian spring-spawning herring. Acoustic estimates from the coordinated ecosystem survey in Norwegian Sea and adjoining waters in July-August (IESSNS). Numbers in millions, biomass in million tonnes. StoX is used for 2016 while Beam is used for 2010-2015. Survey 9.

	SURVEY 9								AGE							TOTAL
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	TOTAL	BIOMASS
2010	544	326	1307	2630	2501	10139	6620	6470	1165	2308	805	422	166	87	143		
2011	0	1042	1122	368	969	1008	3441	2710	2052	395	523	313	87	22	14		
2012	108	794	3197	1256	1203	2674	2255	3999	3495	2923	907	554	301	87	57		
2013	0	95	469	3261	1878	1251	2221	2949	4580	4989	2518	1087	606	151	73		
2014	0	60	1081	606	1526	880	916	1594	2246	3110	995	546	247	64	14		
2015	0	222	675	1783	1733	3349	1186	1596	3214	3431	4428	1106	779	127	15		
2016	40	138	759	647	1630	1639	1989	1526	1264	1954	2187	4196	1460	488	279	20285	6,751

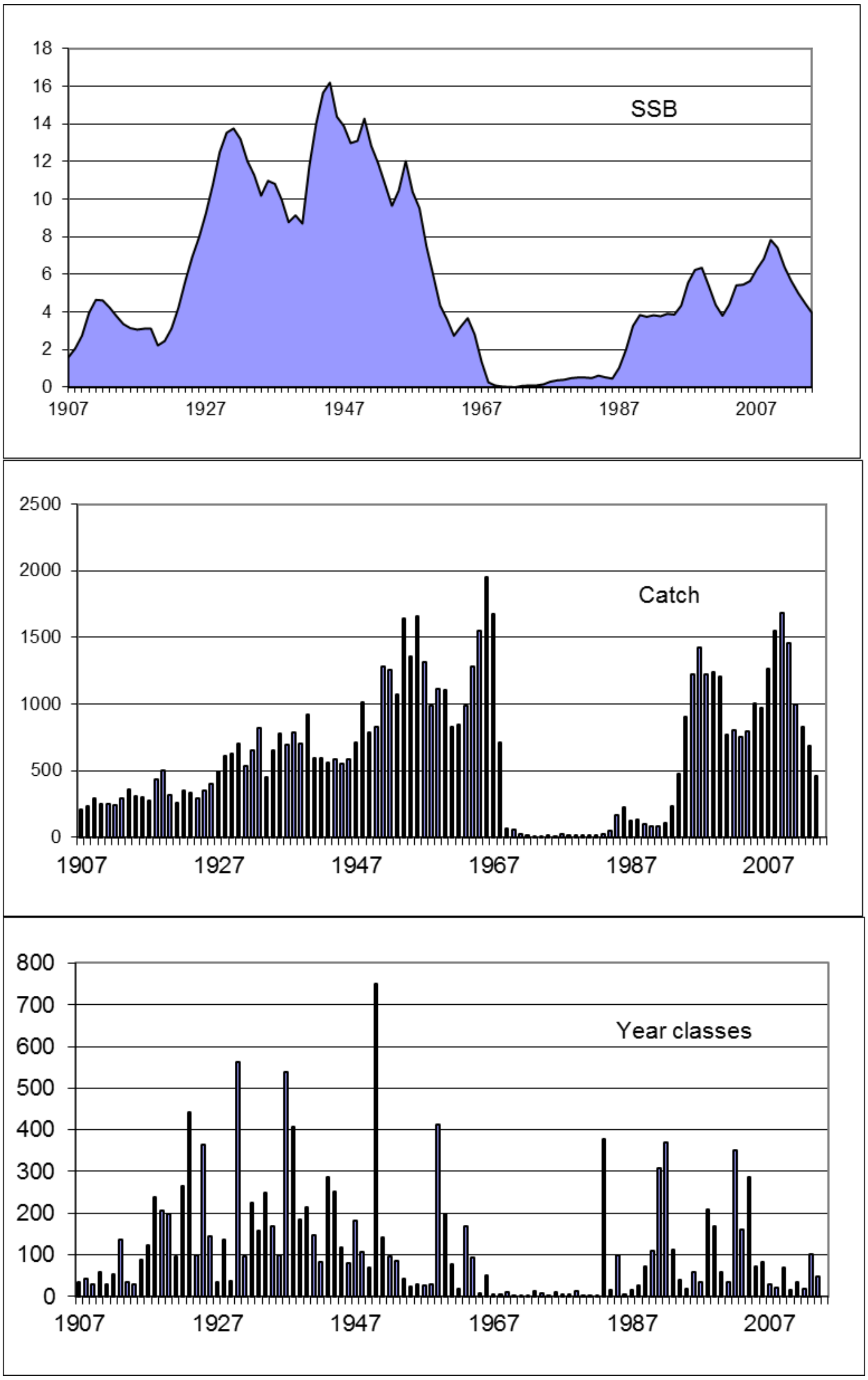

Figure A.1.1.1. Norwegian spring-spawning herring. Long-term trends in spawning stock, catches and recruits (1907-1987 from Toresen and Østvedt; 1988-2015 from WGWIDE 2015). – replace with XSAM time series back in time Erling updates

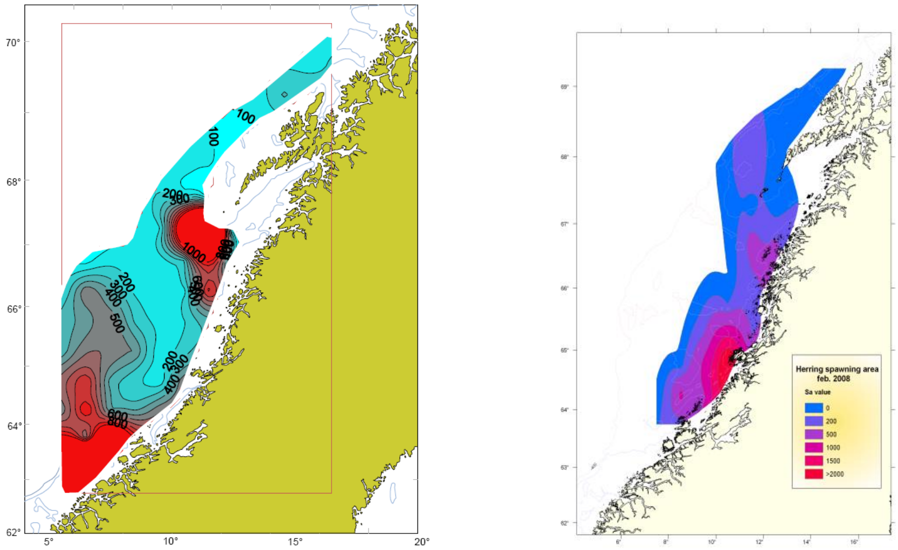

Figure B.3.1.1. NSSH Acoustic survey on spawning grounds in February March, 2007 (left) and 2008 (right). update

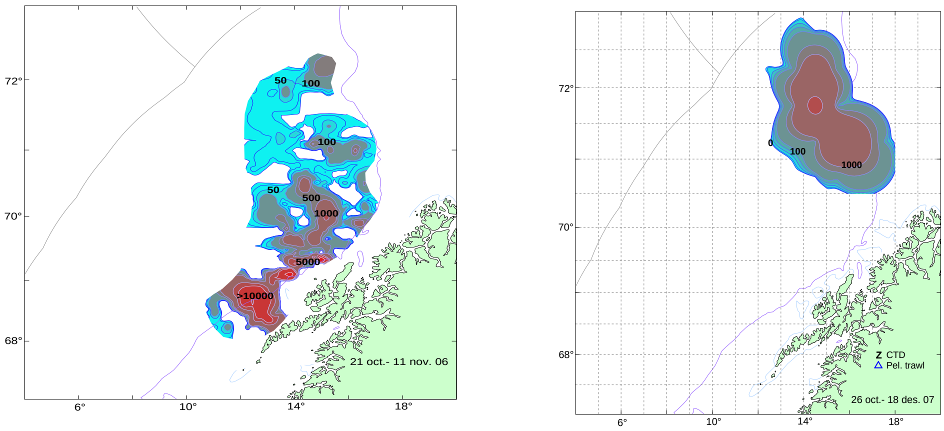

Figure B.3.2.1. NSSH Acoustic survey in November/December 2006 (left panel here) and 2007 (right panel).

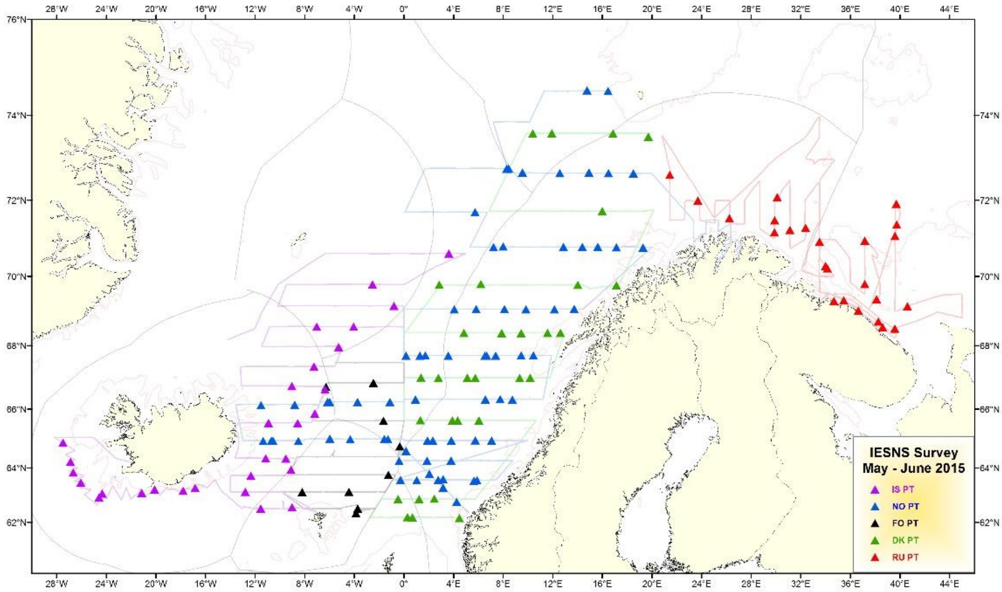

Figure B.3.4.1. Cruise tracks during the International Northeast Atlantic Ecosystem Survey in April-June 2015 and location of trawl stations. latest year Erling

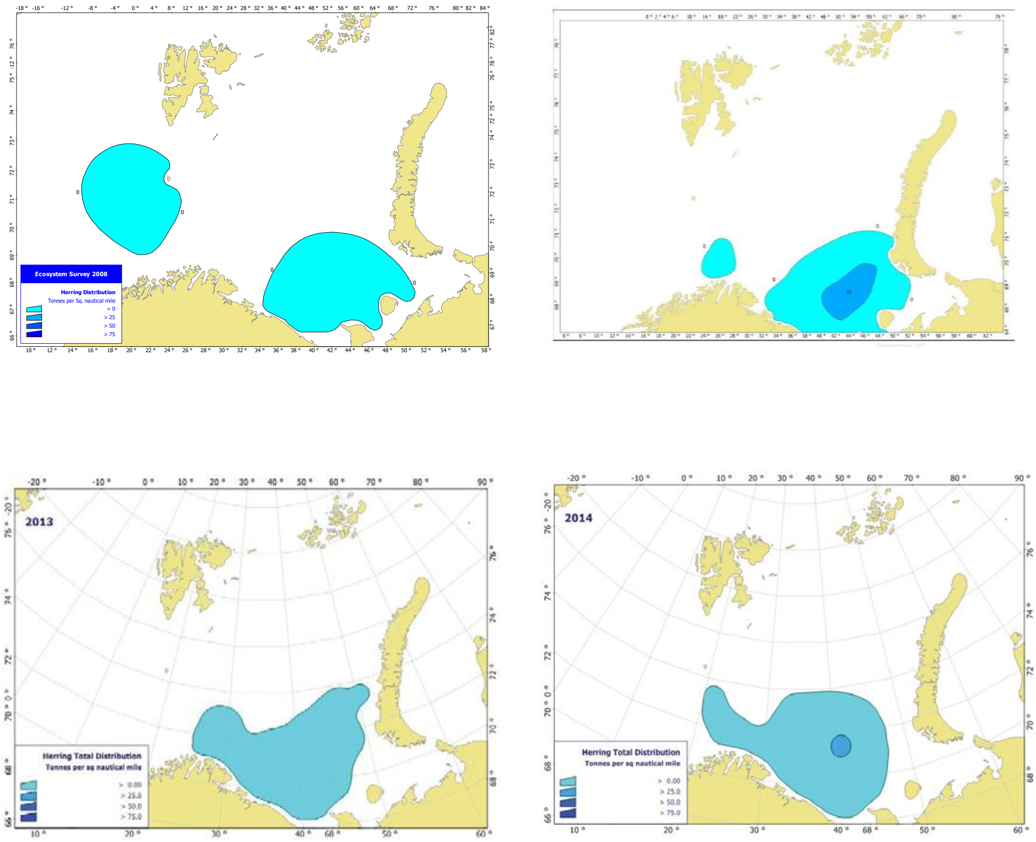

Figure B.3.5.1. Estimated total density of herring (tonnes/nautical mile²) in August-September 2008 (upper left panel), 2007 (upper right panel) and 2013 (lower left panel), 2014 (lower right panel) in Barents Sea. ***Survey 6. Erling update***

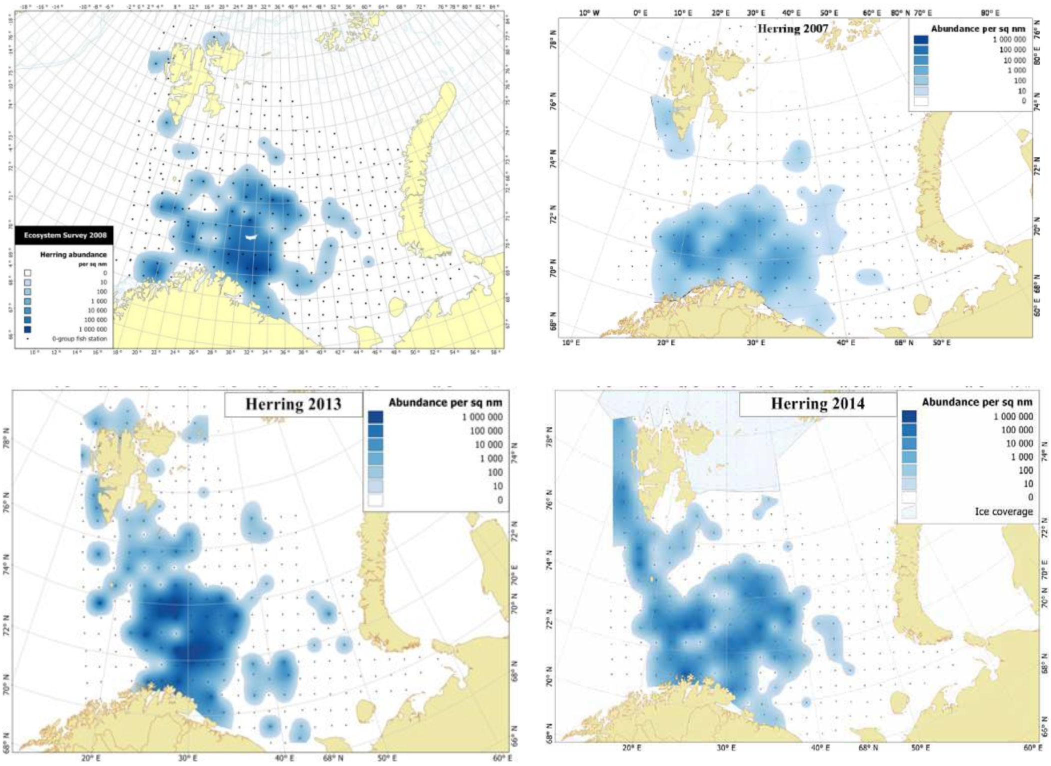

Figure B.3.5.2. NSSH O–group surveys in August/September in the Barents Sea in 2008 (upper left panel) and 2007 (upper right panel) and 2013 (lower left) and 2014 (lower right). ***Survey 7.Erling update***

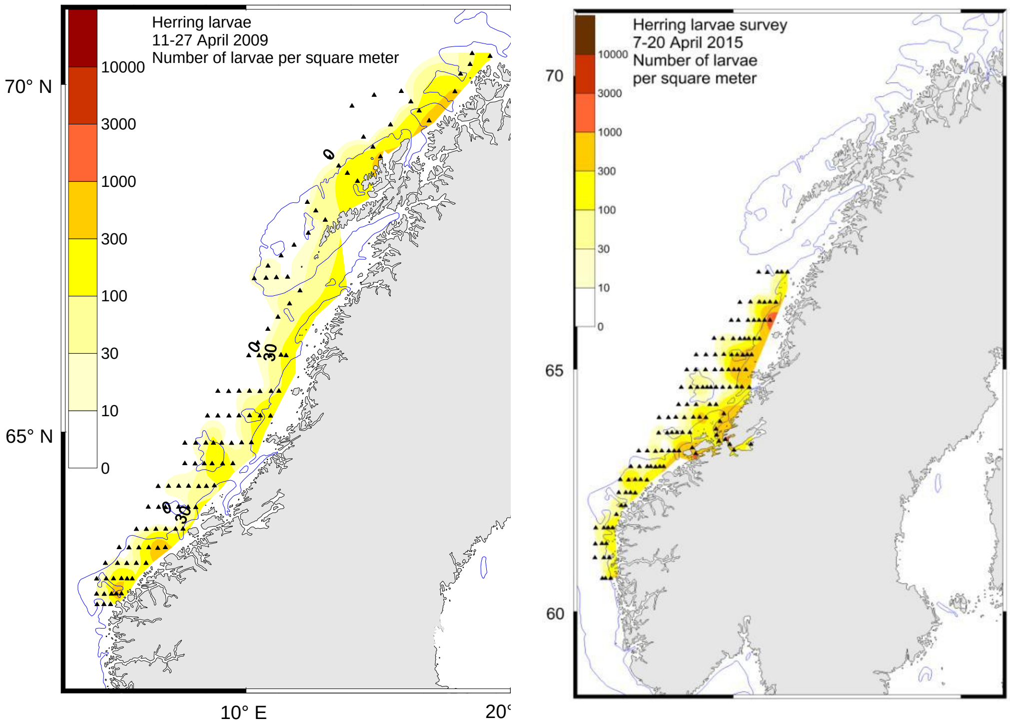

Figure B.3.6.1. NSSH. Distribution of herring larvae on the Norwegian shelf in 2009 (left panel) and 2015 (right panel). The 200 m depth line is also shown.update??

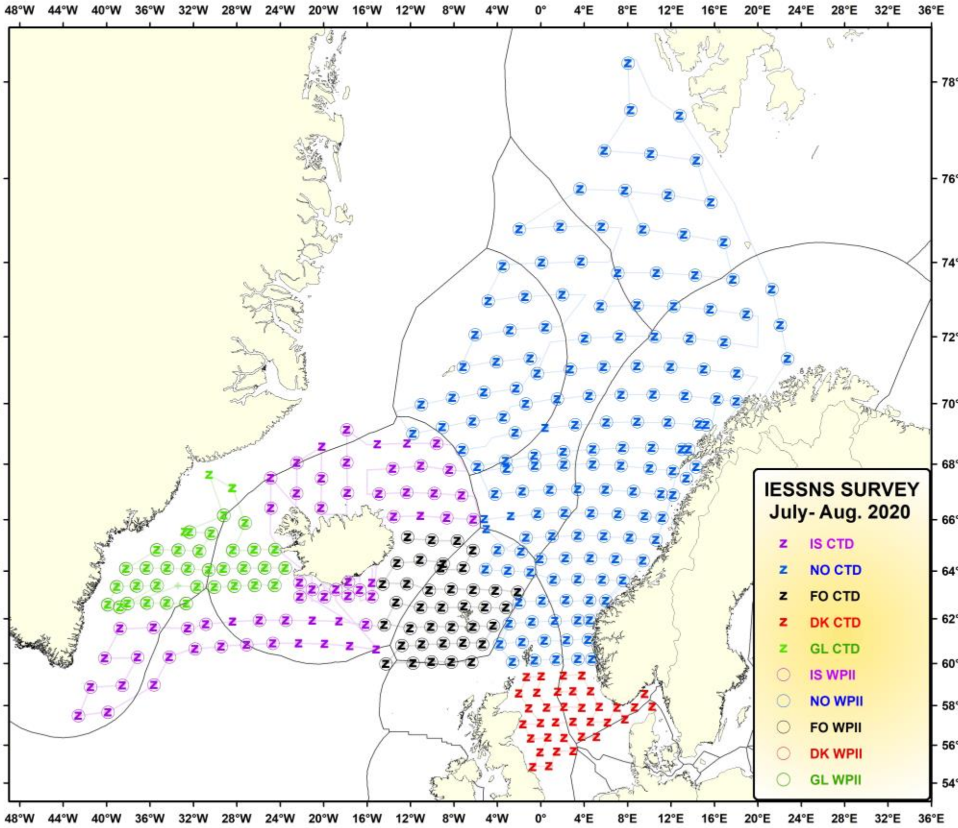

Figure B.3.7.1. Planned cruise tracks during the coordinated ecosystem summer survey in Norwegian Sea and adjoining waters in July-August 2020 and location of fixed surface trawl stations. Eydna – replace with distribution map

Table 9.4.5.3 Herring in the Northeast Atlantic (Norwegian spring-spawning herring). Combined summary of two stock assessments. Data prior to 1988 are from the 2006 assessment year. The assessment from WGWIDE 2015 represents the years 1988-2015 (this assessment does not use re-estimated survey data by StoX). – consistent time series from XSAM - Erling

Year	Recruitment	SSB	Landings	F weighted
	Age 0			Ages 5–14
	thousands	tonnes	tonnes	
1950	751000000	14200000	826000	0.0584
1951	146000000	12500000	1280000	0.0697
1952	96600000	10900000	1250000	0.0728
1953	86100000	9350000	1070000	0.0663
1954	42100000	8660000	1640000	0.1130
1955	25000000	9270000	1360000	0.0783
1956	29900000	10900000	1660000	0.1100
1957	25400000	9650000	1320000	0.1030
1958	23100000	8690000	986000	0.0787
1959	412000000	7180000	1110000	0.1130
1960	198000000	5850000	1100000	0.1360
1961	76100000	4390000	830000	0.1040
1962	19000000	3440000	849000	0.1460
1963	169000000	2670000	985000	0.2530
1964	93900000	2530000	1280000	0.2260
1965	8490000	3060000	1550000	0.2780
1966	51400000	2800000	1960000	0.6960
1967	3950000	1470000	1680000	1.5200
1968	5190000	344000	712000	3.4900
1969	9780000	145000	67800	0.5900
1970	661000	71000	62300	1.3200
1971	236000	32000	21100	1.5300
1972	957000	16000	13200	1.5000
1973	12900000	85000	7020	1.1700
1974	8630000	91000	7620	0.1140
1975	2970000	79000	13700	0.1900
1976	10100000	138000	10400	0.1060
1977	5100000	286000	22700	0.1110
1978	6200000	358000	19800	0.0434
1979	12500000	388000	12900	0.0238
1980	1470000	471000	18600	0.0341
1981	1100000	504000	13700	0.0215
1982	2340000	503000	16700	0.0200
1983	343000000	575000	23100	0.0291
1984	11500000	602000	53500	0.0903
1985	36600000	515000	170000	0.3790
1986	6040000	437000	225000	1.0700
1987	9090000	926000	127000	0.4040
1988	26073900	2002000	135301	0.049

Year	Recruitment	SSB	Landings	F weighted
	Age 0			Ages 5–14
	thousands	tonnes	tonnes	
1989	71555300	3253000	103830	0.031
1990	109336800	3833000	86411	0.022
1991	308890700	3741000	84683	0.024
1992	368283300	3823000	104448	0.028
1993	113172700	3769000	232457	0.065
1994	38661700	3898000	479228	0.133
1995	19594700	3857000	905501	0.235
1996	58595400	4333000	1220283	0.202
1997	33552200	5547000	1426507	0.190
1998	208990500	6229000	1223131	0.161
1999	167923200	6347000	1235433	0.198
2000	57648300	5390000	1207201	0.231
2001	34915000	4381000	766136	0.196
2002	350093900	3796000	807795	0.216
2003	159927700	4408000	789510	0.150
2004	286574800	5413000	794066	0.130
2005	72271900	5445000	1003243	0.176
2006	83338500	5641000	968958	0.184
2007	30173000	6276000	1266993	0.158
2008	20350400	6820000	1545656	0.199
2009	69104000	7829000	1687373	0.191
2010	15306800	7408000	1457014	0.198
2011	34827200	6392000	992998	0.147
2012	18199600	5634000	825999	0.146
2013	100480500	5000000	684743	0.138
2014	47406000	4455000	461306	0.110
2015		3946000		
Average	86902338	4135485	720775	0.313