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: Norwegian Spring-spawning herring

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 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 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.
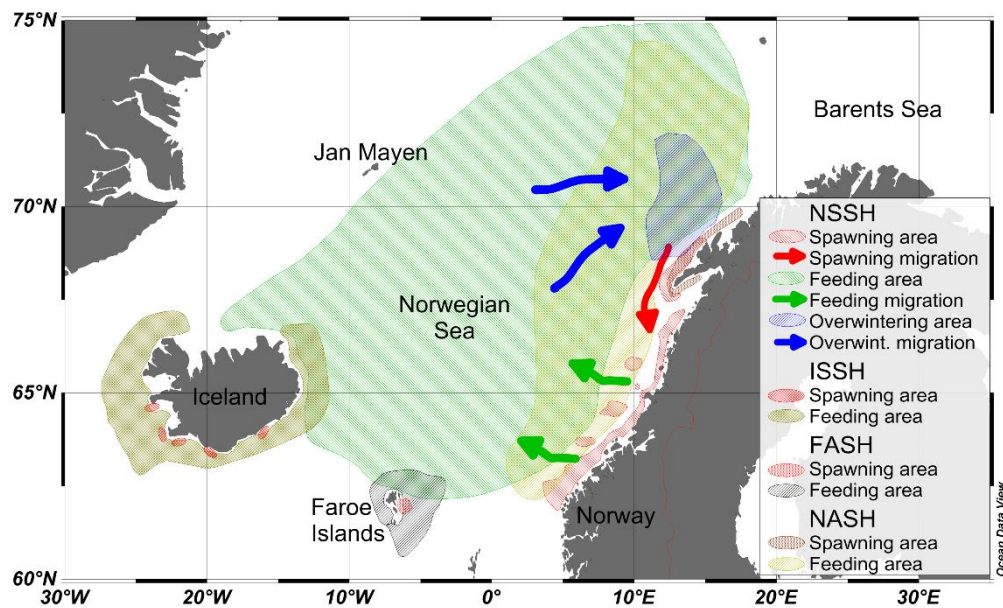
Figure 1. Current migration pattern of the adult part of the Norwegian spring-spawning herring (NSSH) and interactions with other surrounding stocks, i.e. Icelandic summer-spawning herring (ISSH), Faroese autumn-spawning herring (FASH), and Norwegian autumn-spawning herring (NASH) (from Pampoulie *et al.* 2015).

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 plan. The Coastal States also agree on the allocation of the TAC into national quota. The Coastal States involved are the European Union, Faroe Islands, Iceland, Norway and the Russian Federation. The fishery is carried out all year-round by purse-seines and pelagic trawlers. The catches are used as well for reduction purposes and human consumption. 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 (Homrum *et al.* 2014), which covers the period 1995–2013 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 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.

Due to limitations by some countries to enter the EEZs of other countries the fisheries do not necessarily depict the distribution of herring in the Norwegian Sea and the preferred fishing pattern of the fleets given free access to any zone.

Most of the catches consist of herring only and discarding is absent or very low. In recent years increasing amounts of bycatch of mackerel are reported on the traditional fishing grounds, pointing to a change in de distribution of mackerel.

A.3. Ecosystem aspects

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 late May until early July (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 off-

shore 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. 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 (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 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

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B. Data

B.1. Commercial catch

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, the so called 'disfad' file. None sampled catches 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 area. Norwegian spring-spawning herring is sometimes caught in the same areas as other herring stocks, e.g. in IVa.

B.1.3. Weight at age of the catch

Annual weight at age of the catch originate in 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 taken from the Norwegian survey in the wintering area. The survey was stopped in 2008. From 2009 onwards weight at age of the stock is taken from commercial catches taken in the overwintering area in January. In 2010 sampling of data on weight at age in the stock in this period and area has increased to improve the precision of the estimates.

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, while the historical overview of development in M applied, and exceptions to it, can be found in a previous stock annex.

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 in 1995 (unpublished PhD. Thesis) 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 WKHERMAT evaluated the information on maturity for this stock. This work was planned to be carried out in the benchmark assessment in 2008 but at that time this information was not available. WKHERMAT proposed to use maturity o-gives based on back calculation of rings on the scale. This information provided a long time-series which is reproducible. WGWIDE introduced this time-series in the 2010 assessment.

B.2.4.1. Maturity data used in the assessments from 2010 onwards (inserted in 2011)

In 2010 a Workshop (WKHERMAT)[1] was held to evaluate existing maturity-at-age data. The Workshop was held because data on maturation were not available and considered in the benchmark assessment in 2008. The work of the Workshop therefore concluded the benchmark process. Three sources of maturity information were considered. The three different data sources were: a) maturity ogive used in assessment, b) survey data on maturity staging collected during surveys 4 and 5 and c) back-calculated maturity ogive using Gulland's method (Engelhard *et al.*, 2003; Engelhard and Heino (2004). In addition, data on maturity cycle in Norwegian spring-spawning herring were presented and guidelines for sampling of maturity data were discussed in accordance with PGCCDBS.

The May surveys may potentially provide data to construct updated maturity ogives for the most recent years. The surveys indicate that most (but not all) herring in the Norwegian Sea are mature and most (but not all) herring in the Barents Sea are immature. However, the time-series is short and there are some problems. For the age groups which occur both in the Norwegian Sea and Barents Sea, quantitative information on annual abundance is required for the calculated weighted average maturity representative for the stock in both areas combined. The available information on

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[1]   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

the distribution of these age groups is not very reliable because there appear to be differences in the catchability in the survey between the Norwegian Sea and the Barents Sea. This needs to be addressed further before data from the survey can be used for maturity ogive estimations.

The back calculation dataset indicates that maturation of ages 3, 4 and 5 has varied considerable over time and that maturation of large year classes is slower than for others. This applies to a lesser extend to the 2002 year class. However, the estimates for this year class are suggesting that at least a correction needs to be considered in the maturation assumed for this year class in previous assessments by ICES. WKHERMAT considered the dataset derived by back calculation as a suitable potential 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 recent years. Since the surveys do not provide suitable data at the moment, assumptions have to be made for recent year classes.

WGWIDE considered the results of WKHERMAT in 2010 and adopted the maturity o-gives derived from back calculation of scales for the historical period (years 1950–2007) in the assessment. WGWIDE recommends that this dataset remains updated in future years. For the most recent years for which no data are available from this method (including the years considered in the forecast) the following default maturity o-gives will be assumed. For 'normal' year classes (average, median and weak year classes), an average maturity-at-age will be assumed from the periods 1983–present from the back calculation dataset excluding the strong year classes 1983, 1991, 1992, 1998, 1999, 2002, etc. For year classes which are considered strong, preliminary estimates will be assumed to be the average of the recent strong year classes 1983, 1991, 1992, 1998, 1999, 2002, etc. in the dataset.

The default maturity o-gives 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

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

In 2015 and 2016 some of the survey series have been re-estimated with a new software StoX (ICES 2016a), which provide estimates of precision that can be implemented in new stock assessment models. Only the point values are provided in the tables in the annex.

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.

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

The survey has been carried out by Norway since 1992 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. This survey has not been conducted since 2007/2008. The indices from this survey have not been re-estimated. The results of this survey are shown in Table B.3.2.1.

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.

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 CM 2015/SSGIEOM:05) 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 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 and 2004. The indices in the years 2009–2015 are the re-evaluated values 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 in the years 2008–2015 are the re-evaluated values 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.

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 access 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).

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.

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 (2010) is given in Figure B.3.7.1.

B.4. Commercial CPUE

No commercial CPUE data are used in the assessment.

B.5. Other relevant data

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

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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 Share-Point site for WGWIDE.

2) Model options:
   - i.   Time span: 1988-2016
   - 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 2016
   - 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 18, 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 and Fleet 1 as estimated by StoX

      c)   The model uses catch advice according to ICES for the year after the last year of catch data with relative standard error of 10% 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 assumed equal to the last catch data year.

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+	Yes
Fprop	Proportion of fishing mortality before spawning	1988-last data year	2-12+	Yes
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+	Yes
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 2016 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 2016 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

$$\log(F_{a,t}) = \mu_{a,t}^F + \delta_{a,t}^{(1)} = U_{a,t} + V_t + \delta_{a,t}^{(1)}$$

where

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

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

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

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

where $\mathbf{F}_t^*$ 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

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

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 re-cruits 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 $\log(\boldsymbol{C}_t) = \left\{\log\left(C_{a,t}\right)\right\}_{a=a_{min},\dots,A}$ 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

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

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

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

$$I_{a,t} = q_a^f N_{a,t}\exp\left(-\delta_t^f Z_{a,t}\right)$$

For each fleet, the fixed parameters are $\left\{q_a^f\right\}_{a=a_{min},\dots,a_m^f}$, 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	$\{\log F_{a,t}\}_{\substack{a=a_{min},\dots,A_m, \\ t=1,\dots,T}}$	Random	σ_1^2	l_F
F: Selectivity	$\{U_{a,t}\}_{\substack{a=a_{min},\dots,a_m-1, \\ t=1,\dots,T}}$	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	$\{C_{a,t}\}_{\substack{a=a_{min},\dots,A, \\ t=1,\dots,T}}$	Observation	Optionally elements in $\boldsymbol{\Sigma}_t^c$	l_C
Abundance indices	$\{I_{a,t}^f\}_{\substack{a=a_{min}^f,\dots,A^f, \\ t=1,\dots,T}}$	Observation	$\{q_a^f\}_{a=a_{min},\dots,a_m^f}$ Optionally elements in $\boldsymbol{\Sigma}_t^f$	$\{l_I^f\}_{f=1\dots,n_f}$

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 $\boldsymbol{\Sigma}'^O$ and is decomposed as follows

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

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 spe-

cific year. In all cases considered here, only one scaling factor for each dataset is considered, i.e. $h_i = h \; \forall i$, such that

$$\Sigma'^O = h\Sigma^O$$

such the error structure is completely determined by Σ^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 Σ^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. The alternative (fall-back) 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 has been made to the software, but data have been revised on several occasions, also for the present benchmark. WKPELA decided to maintain TASACS as used by WGWIDE 2015 as a fall-back, with no alterations except for revisions of the data. This section is an overview of how the model is set up and used.

- 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

$U = q*N + \mathcal{m}$ ✎ 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. Table C.2.3 is a copy of the FleetWgt file that is input to TASACS. It specifies the weighting set for each survey observation.

At the 2008 benchmark, the following criteria for exclusion of data were adopted.

- Data outside the range of years and age windows selected by WGs prior to the 2008 benchmark are still excluded. These were mostly surveys with incomplete coverage.
- Survey data of poor year classes with mostly noise are excluded. This applies to year classes where survivor numbers are not estimated, as discussed below.

- Reject ages where the analysis of consistency between and within surveys indicate severe problems. For instance for survey 1, the conclusion from the correlation analyses is not to use information at ages older than age 11.
- If there is a conflict between data from different surveys, discard the data where known problems with the survey indicates that these are the least reliable. This applied in particular to conflicts between survey 2 and survey 5, where survey 2 indicated a rapid decline in the stock and survey 5 a more gentle decline. Since representative sampling of old fish in survey 2 is a known problem, caused by vertical segregation in the wintering areas in the Lofoten fjord, the survey 2 data are ignored and the survey 5 data used at ages above 10 years.
- If there are internal inconsistencies in the old ages in a survey (mismatch between abundance at young and old age), the old ages are ignored.
- No zero values are used.

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

Table C.2.3. Weighting of survey data. This table is a copy of the FleetWgt file used by TASACS.

Age structured tuning indices

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1. Spawning grounds along the Norwegian coast only strong ycl for all

 1988 2015

 -1 -1 -1 -1

 2 15

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 1. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0. 0.

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-1 0. 0. 0. 0. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 1. 0. 0. 1. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0.
```

2. Wintering area in Vestfjorden in November-December
 1992 2006
 -1 -1 -1 -1
 1 14
```
-1 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.
-1 0. 0. 0. 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0.
-1 0. 0. 0. 1. 1. 0. 0. 0. 0. 0. 1. 0. 0. 0.
-1 0. 0. 0. 1. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 1. 1. 1. 1. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 1. 1. 1. 1. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 1. 0. 1. 1. 1. 1. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 1. 0. 1. 1. 1. 1. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 1. 0. 1. 1. 1. 1. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 1. 0. 1. 1. 1. 1. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
```

3. Wintering area in Vestfjorden in January
 1991 1999
 -1 -1 -1 -1
 2 15
```
-1 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0.
-1 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0.
-1 0. 0. 0. 1. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0.
-1 0. 0. 0. 1. 1. 0. 0. 0. 0. 0. 1. 0. 0. 0.
```

-1 0. 0. 0. 1. 1. 1. 0. 0. 0. 0. 0. 1. 0. 0.

-1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0. 1.

-1 0. 0. 0. 0. 1. 1. 1. 1. 0. 0. 0. 0. 0. 0.

4. Young herring in the Barents Sea in May

 1991 2015

 -1 -1 -1 -1

 1 2

-1 1. 1.

-1 1. 1.

-1 1. 1.

-1 1. 1.

-1 0. 1.

-1 0. 0.

-1 1. 0.

-1 1. 1.

-1 1. 1.

-1 0. 1.

-1 0. 1.

-1 0. 0.

-1 0. 0.

-1 0. 0.

-1 1. 1.

-1 1. 1.

-1 1. 1.

-1 0. 0.

-1 0. 1.

-1 1. 1.

-1 1. 1.

-1 1. 0.

-1 0. 1.

-1 1. 1.

-1 1. 1.

5. Feeding areas in the Norwegian Sea in May

 1996 2015

 -1 -1 -1 -1

 1 15

-1 0. 0. 0. 1. 1. 1. 1. 0. 0. 0. 0. 0. 1. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0. 1. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0. 1.

-1 0. 0. 0. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0. 0. 0.

-1 0. 0. 0. 1. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0. 0.

-1 0. 0. 0. 1. 1. 0. 1. 1. 1. 1. 1. 1. 0. 0. 0.

-1 0. 0. 0. 1. 1. 1. 0. 1. 1. 1. 1. 1. 1. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 0. 1. 1. 1. 1. 0. 1. 0.

-1 0. 0. 0. 0. 1. 1. 1. 0. 1. 1. 1. 1. 1. 0.

-1 0. 0. 0. 0. 0. 1. 1. 1. 1. 0. 1. 1. 1. 1. 1.

-1 0. 0. 0. 1. 0. 0. 1. 1. 1. 0. 0. 1. 1. 1. 1.

-1 0. 0. 0. 1. 1. 0. 0. 1. 1. 1. 0. 0. 1. 1. 1.

-1 0. 0. 0. 1. 1. 1. 0. 0. 1. 1. 1. 0. 0. 1. 1.

-1 0. 0. 0. 1. 1. 1. 1. 0. 0. 1. 1. 1. 0. 0. 1.

-1 0. 0. 0. 1. 1. 1. 1. 1. 0. 0. 1. 0. 1. 0. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 0. 0. 1. 0. 1. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 1. 0. 0. 1. 0. 1.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 1. 1. 0. 0. 1. 0.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 1. 1. 1. 0. 0. 1.

-1 0. 0. 0. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 0. 0.

6. As part of the joint IMR-PINRO ecosystem survey in August-September

 2000 2014

 -1 -1 -1 -1

 1 2

-1 1. 0.

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7. Indices for 0 group

 1980 2014

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-1 1.

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. 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. Provided predicted exploitation pattern and recruitment from XSAM the deterministic short term projection using the excel spread sheet developed for TASACS (see D2) yields the same results. This was tested during WGWIDE 2016.

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 (see B.2.4).

AGE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0	0	0	0	0.4	0.8	1	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.

D2. The alternative (fall-back) assessment tool TASACS.

Model used: Deterministic short-term projection, with management option table presenting average F-values for age 5–14 weighted over population numbers at the start of the year.

Software used: A prediction module has been included in TASACS. However, when tested during the benchmark process it gave strange results with extremely low predicted catches at a given F. There was not enough time to solve the problem during the benchmark process, but the aim is to have the prediction module in TASACS updated before WGWIDE in 2016. If not ready then the excel spread sheet which has been applied since the last benchmark will be used. A spreadsheet was developed because available software programmes cannot provide management option tables with annual F-factors which take account for weighted F

Initial stock size: Input to the short-term projection are the stock number-at-age 1 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. Stock number-at-age 0 is geometric mean over a year range. For example in the assessment 2015 the year range was 1988-2011.

Maturity: For the forecast it is recommended to use the maturity associated to 'normal' year classes (see B.2.4).

AGE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0	0	0	0	0.4	0.8	1	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: Weighted average fishing mortalities for each age over 5 years and flat above age 8.
Sel(a) = $\Sigma_y F(a,y)*N(a,y)/\Sigma_y(N(a,y)$

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

Intermediate year assumptions: catch constraint

Stock recruitment model used: not applicable

Procedures used for splitting projected catches: not applicable

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:

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 $B_{TRIGGER}$	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

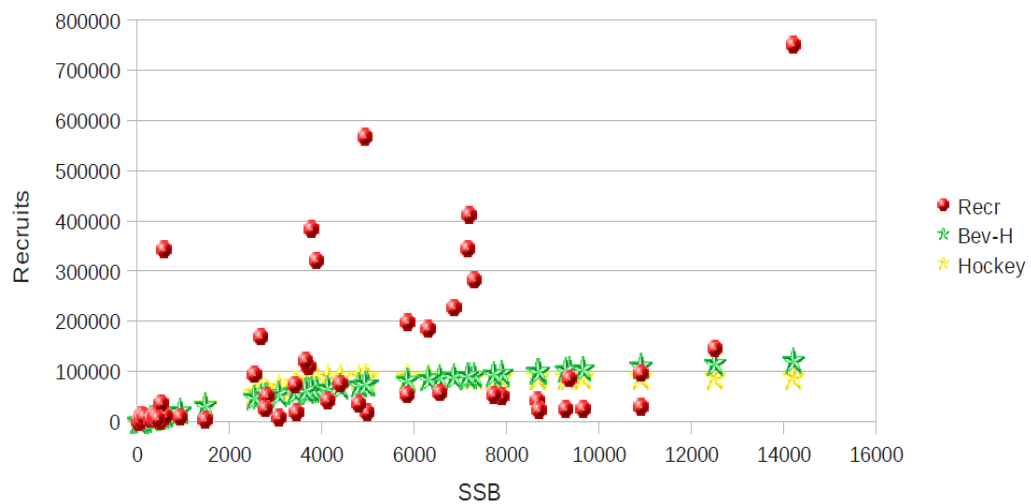|	F01	Fmax
Deterministic	0.23	*
50%ile	0.19	0.77
CV	0.39	0.58

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).
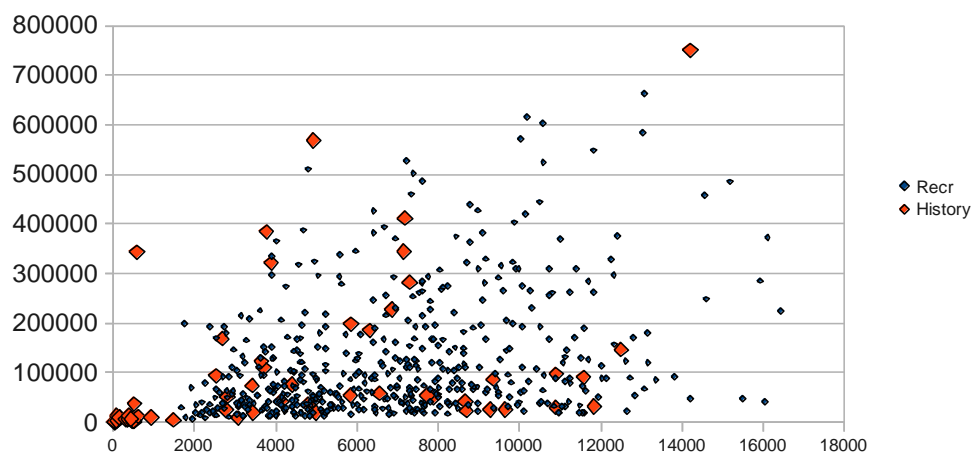

Figure 7.8.2.srmodeldata. Norwegian spring-spawning herring. Stock–recruitment of NSSH from data (big red diamonds) and produced by the model (blue small diamonds) using Beverton–Holt recruitment function.
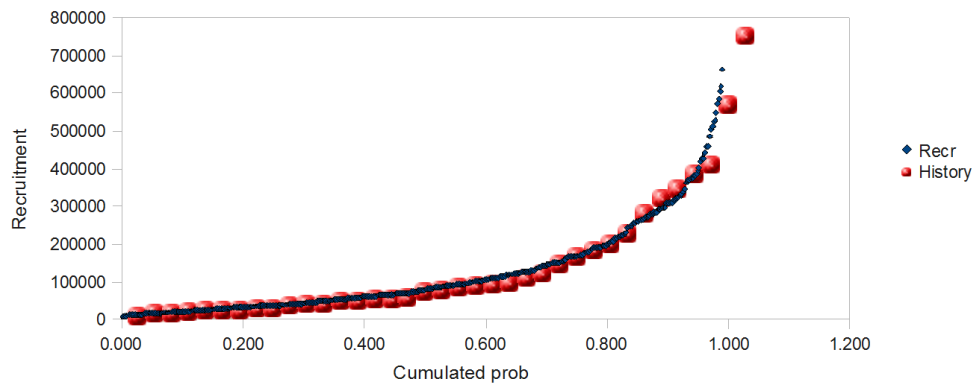
Figure 7.8.2.cumdist. Norwegian spring-spawning herring. Cumulative probability of recruitment values of NSSH from the data (red dots) and produced by the model (small blue diamonds) using Beverton–Holt recruitment function.
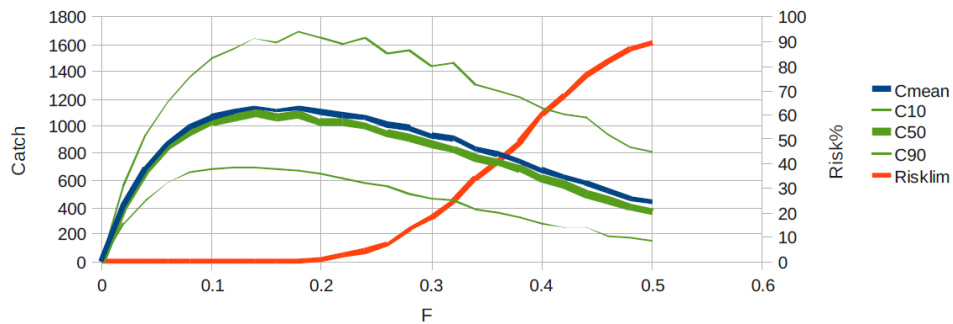

Figure 7.8.2.catch. Norwegian spring-spawning herring. Yield (catch) and the probability of the stock being below Blim (2.5. million tonnes) after 50 years at target F for NSSH using Beverton–Holt recruitment function. C10, C50 and C90 show the 10, 50 and 90 percentiles of catch. Risk$_{lim}$ shows the 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.
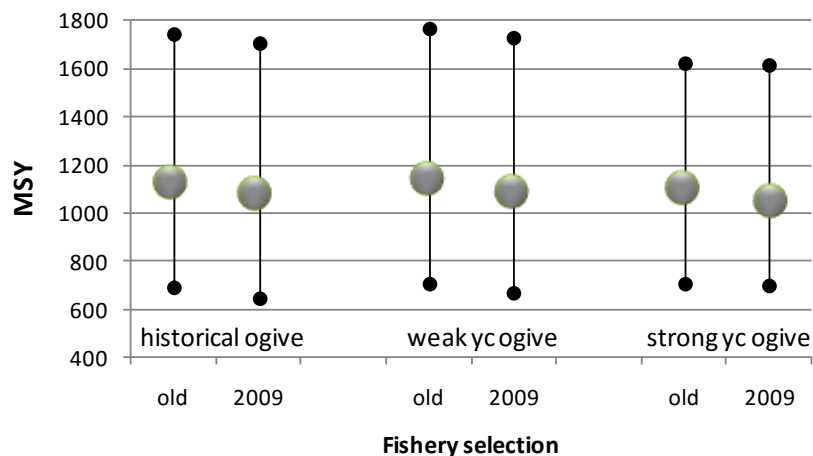

Figure 7.8.2.msyBH. Norwegian spring-spawning herring. The MSY for three different maturity ogives and two different fishery selection patterns with 10 and 90 percentiles using Beverton–Holt recruitment function. See text for further details.
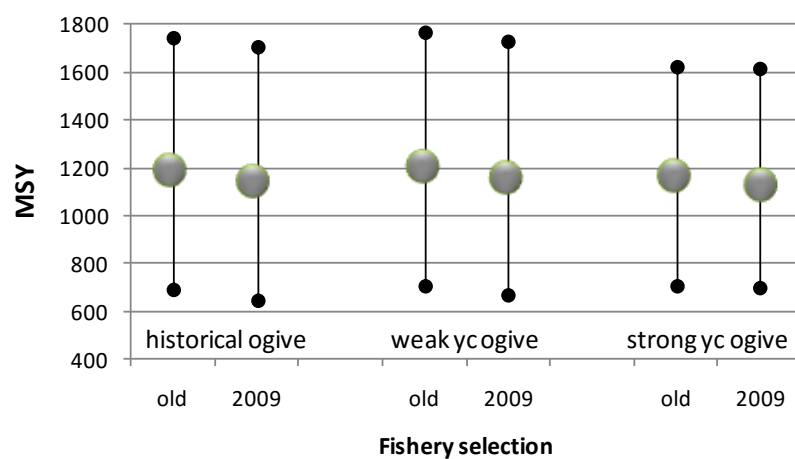
Figure 7.8.2.msyHS. Norwegian spring-spawning herring. The MSY for three different maturity ogives and two different fishery selection patterns with 10 and 90 percentiles using hockey stick recruitment function. See text for further details.
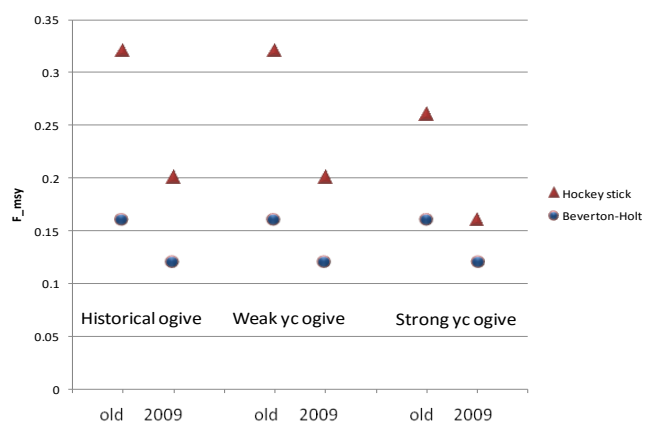

Figure 7.8.2.fmsy. Norwegian spring-spawning herring. F$_{MSY}$ for three different maturity ogives and two different fishery selection patterns with Beverton–Holt and hockey stick recruitment function. See text for further details.
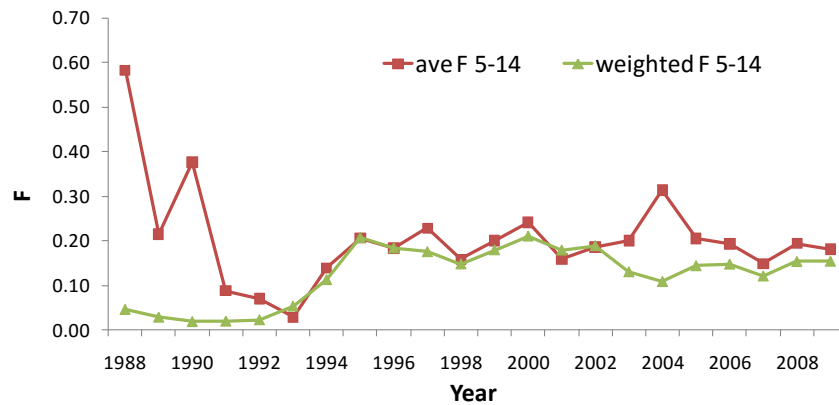
Figure 7.8.2.fvalues. Norwegian spring-spawning herring. Unweighted (red squares) and weighted (green triangles) average F values from the current assessment.
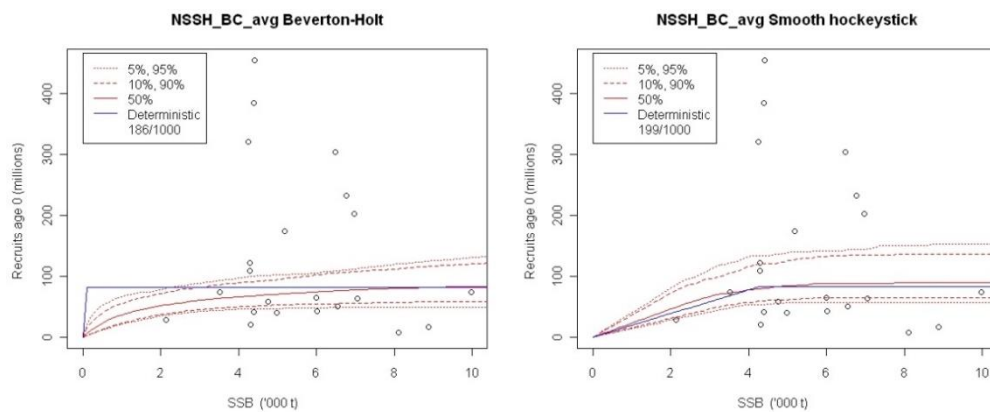
Figure 7.8.2.sr. Deterministic and stochastic (taking into account uncertainty in weights, selectivity and maturity-at-age) stock recruit relationship fits for the Norwegian spring-spawning herring stock. Stock–recruit pairs are from the period 1988–2009.

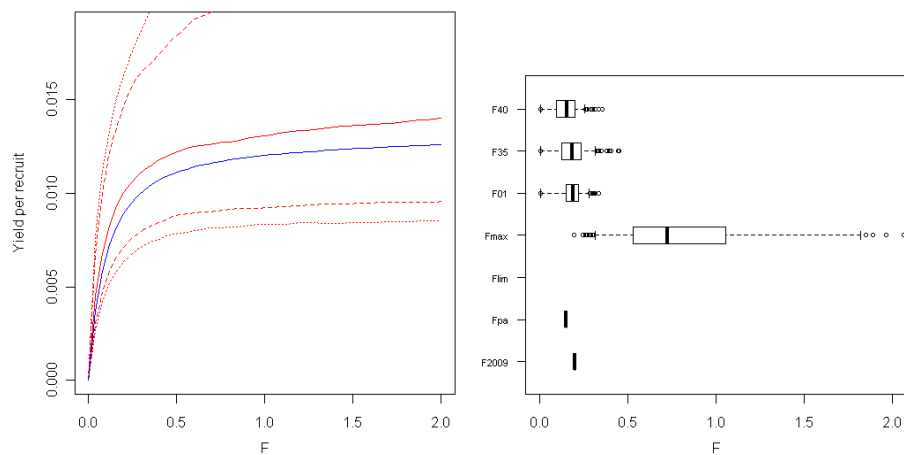**Figure 7.8.2 ypr. The yield-per-recruit (YPR) curve for the Norwegian spring-spawning herring stock (left) and resulting stochastic estimates of *F* reference points (right).**

G.3. Target reference points

The Coastal States have agreed a target reference point defined at F=0.125. (Note that the average fishing mortality is calculated as a weighted mean over the age groups 5–14 (weighted over abundance).

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H. Other Issues   not defined

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+	16	TOTAL	BIOMASS
1988	0	368	290	7773	83	32	11	36	21	40	0	0	0	0		8654	1572
1989	181	18	357	93	4323	114	13	9	64	0	4	43	0	9		5232	1273
1990	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
1991	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
1992*	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
1993*	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
1994	43	99	48	851	480	73	15	152	43	1838	3	3	0	0		3669	1215
1995	3	333	3850	2890	1861	281	17	0	136	72	2216	0	0	0		12166	2633
1996	74	96	1306	4994	1525	582	188	0	0	84	0	1187	0	0		10036	2166
1997*	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
1998	29	154	618	1701	6375	4597	1095	392	139	16	0	189	0	669		15976	3700
1999	76	1089	245	789	1450	4778	3824	891	283	68	0	0	169	200		13875	3349
2000	1030	494	1983	76	363	881	3185	2250	425	40	2	0	14	173		10915	2522
2001**	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2002**	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2003**	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2004**	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2005	30	194	492	1507	3919	5515	450	319	127	75	355	715	371	5		14074	3495
2006	25	93	5375	407	721	2687	2599	110	62	13	65	50	176	57		12438	2789
2007	31	360	1482	10767	542	611	2597	2901	134	218	33	175	256	493		20603	4678
2008	14	59	2150	2486	8396	479	434	1466	1463	145	88	44	129	132		17484	4214
2009	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	16	Total	Biomass
2010	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2011	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2012	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2013	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2014	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			
2015	230	516	2748	768	3223	377	650	2868	720	7251	336	1733	50	229		21712	6390
2016	17	218	253	539	404	2288	242	569	2792	681	4144	197	982	107		13433	4338

* No estimate due to poor weather conditions.

** No surveys.

Table B.3.2.1 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	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 Norwegian 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. 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]	0.043	0.38	0.2	0.28	0
2009	0.286	0.286	0.215	0.072	0
2010	5.121	1.366	0	0	0
2011	1.079	3.802	0.039	0	0
2012	0.884	0.015	0	0	0
2013	0.132	1.982	0.264	0.088	0
2014	3.727	3.055	1.797	0.131	0.044
2015	0.33	11.471	1.218	0.198	0
2016	1.677	5.463	1.668	0.103	0.042

[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. 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	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	1240	631	10809	8271	14827	1513	2257	4848	2734	449	149	151	270	491	48665	10558
2009	0	144	1669	2159	12300	8994	9527	2147	1435	2466	1411	188	193	123	231	43082	9728
2010	234	125	542	2334	1781	8351	5988	5601	869	882	983	578	90	72	57	28622	6633
2011	0	1205	977	1528	3607	2564	9420	4542	4298	825	892	712	261	37	39	30917	7395
2012	0	378	2895	412	670	1646	2560	4226	2026	2097	298	607	315	155	47	18331	4435
2013	0	205	776	3955	434	1211	2036	3070	4652	2767	1873	692	805	186	83	22747	5888
2014	17	517	1231	798	2790	749	1065	2681	2285	2842	1119	778	350	76	198	17505	4555
2015	0	385	468	1299	1176	3548	1399	1160	3178	2523	4350	712	788	262	194	21443	5846
2016	0	75	3549	1508	2215	1779	2683	929	1143	1770	1851	2877	928	439	136	21889	5419

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. Norwegian 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
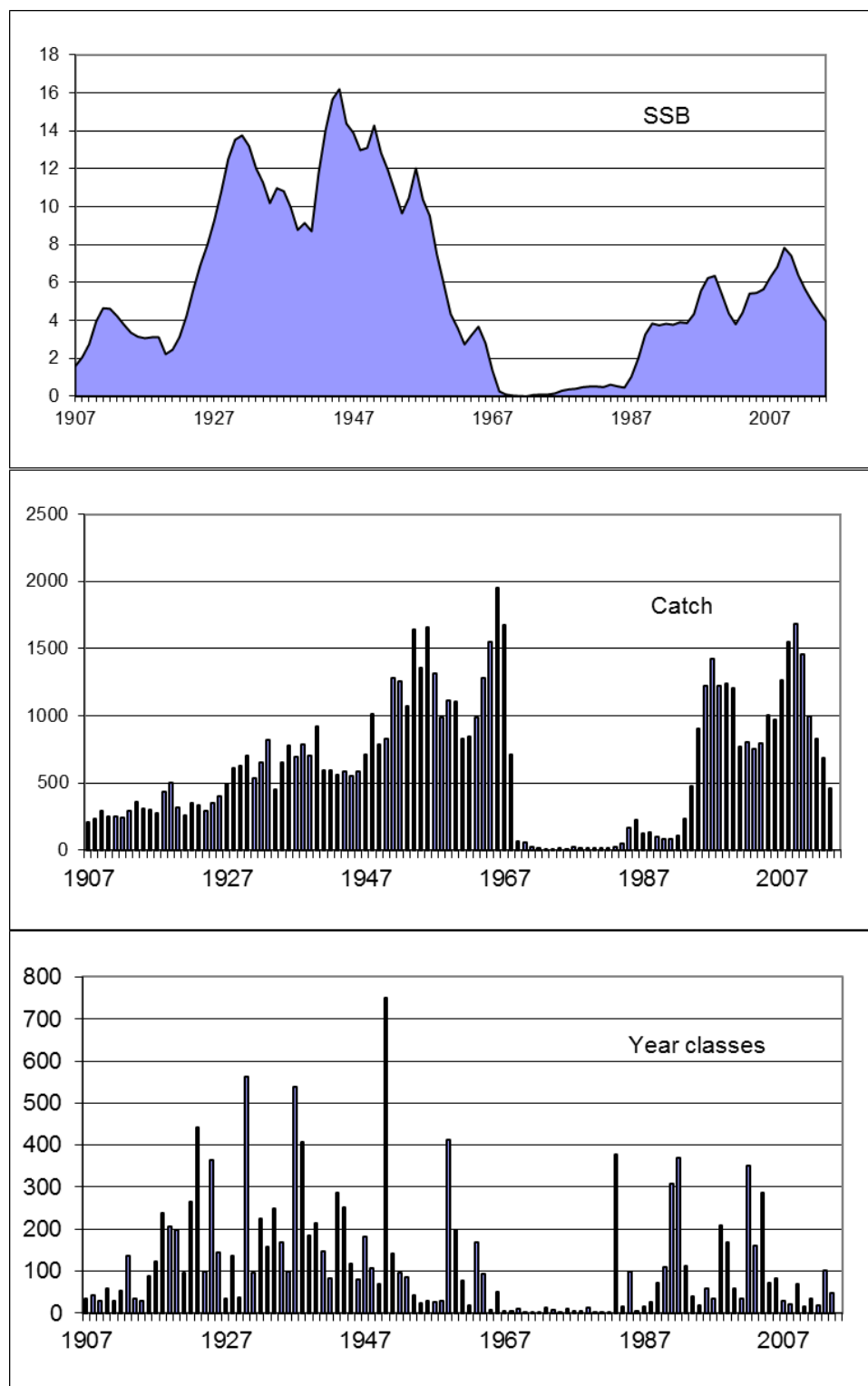
Figure A.1.1.1. Norwegian spring-spawning herring. Long-term trends in spawning stock, catches and recruits (1907-1987 from Toresen and Østvedt; 1988-2015 from WGWIDE 2015).
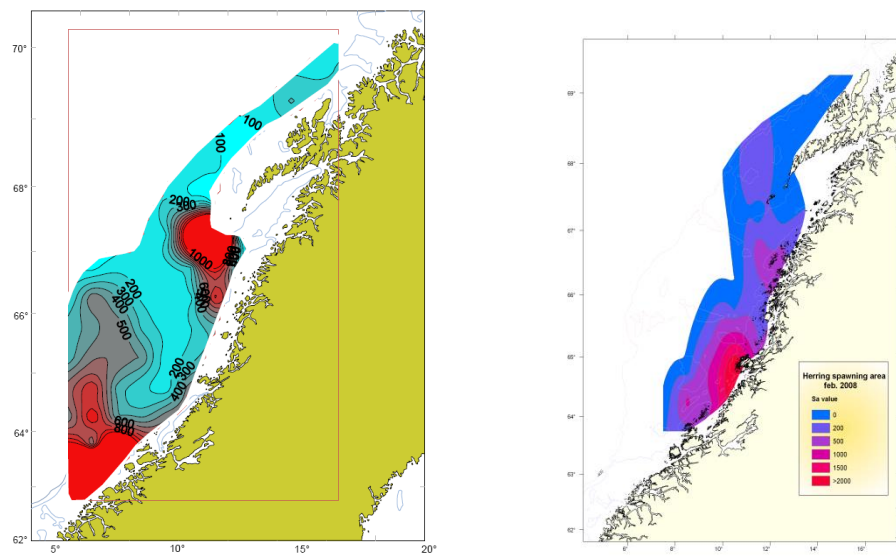
Figure B.3.1.1. NSSH Acoustic survey on spawning grounds in February March, 2007 (left) and 2008 (right).
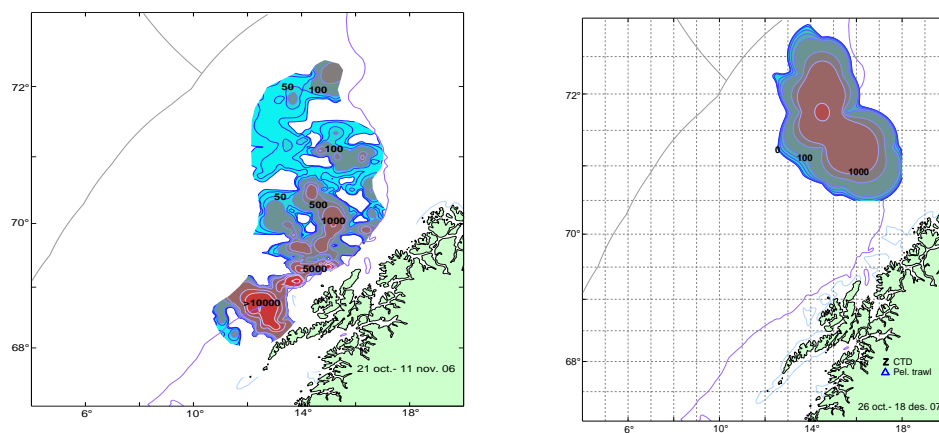

Figure B.3.2.1. NSSH Acoustic survey in November/December 2006 (left panel here) and 2007 (right panel).
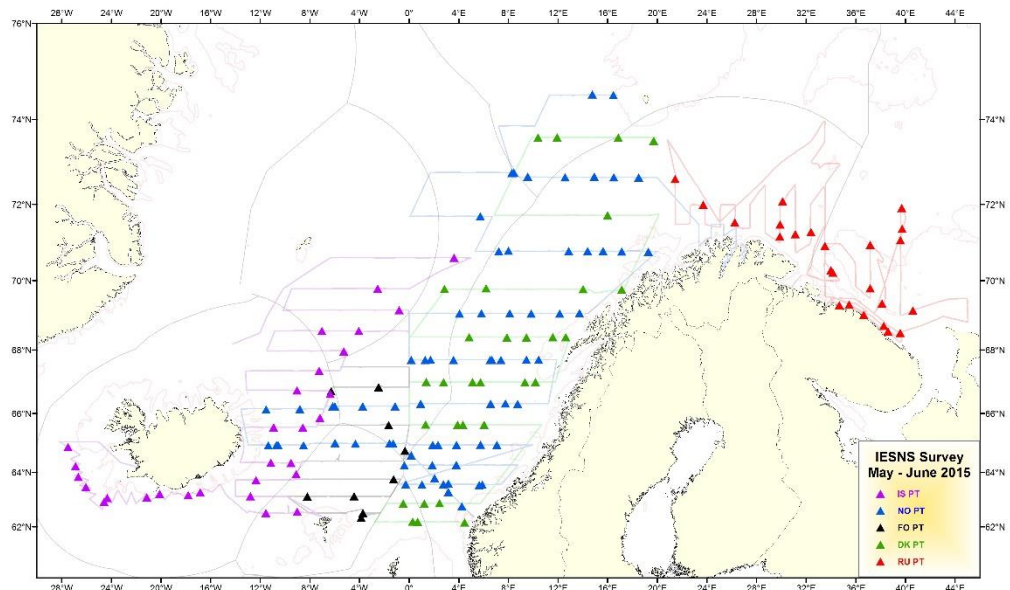
Figure B.3.4.1. Cruise tracks during the International Northeast Atlantic Ecosystem Survey in April-June 2015 and location of trawl stations.
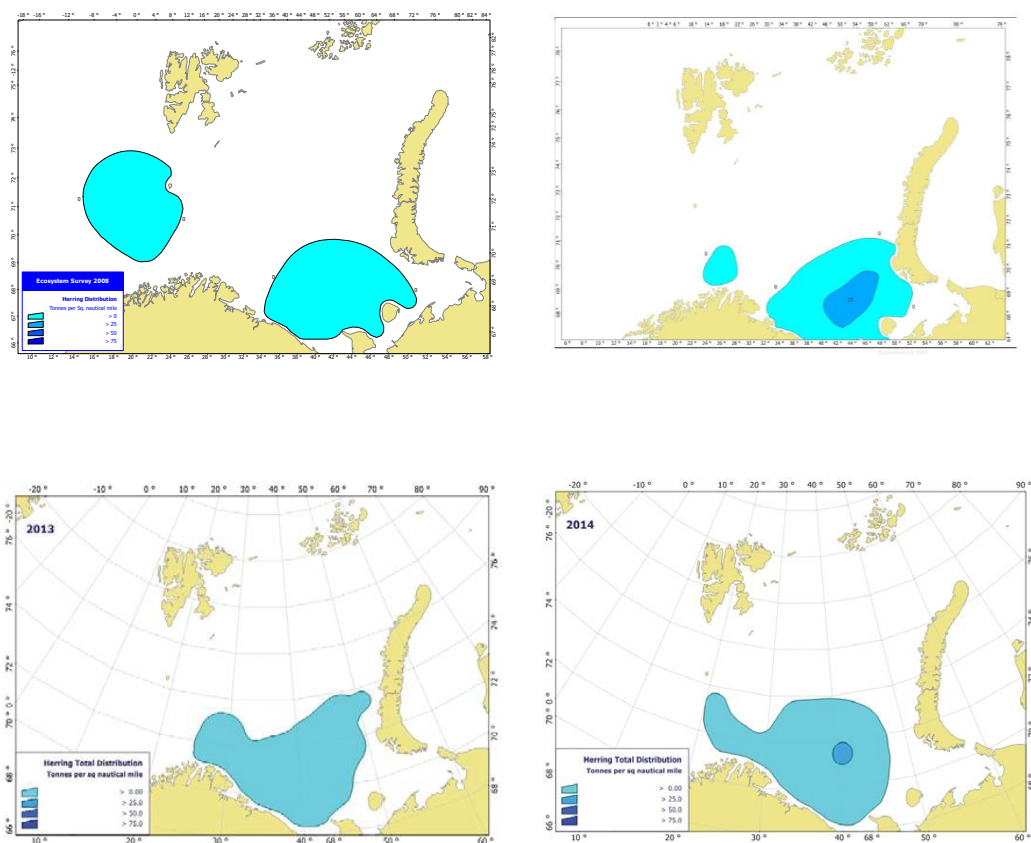
Figure B.3.5.1. Estimated total density of herring (tonnes/nautical mile²) in August-September 2008 (upper left panel), 2007 (upper right panel) and 2013 (lower left panel), 2014 (lower right panel) in Barents Sea. *Survey 6.*
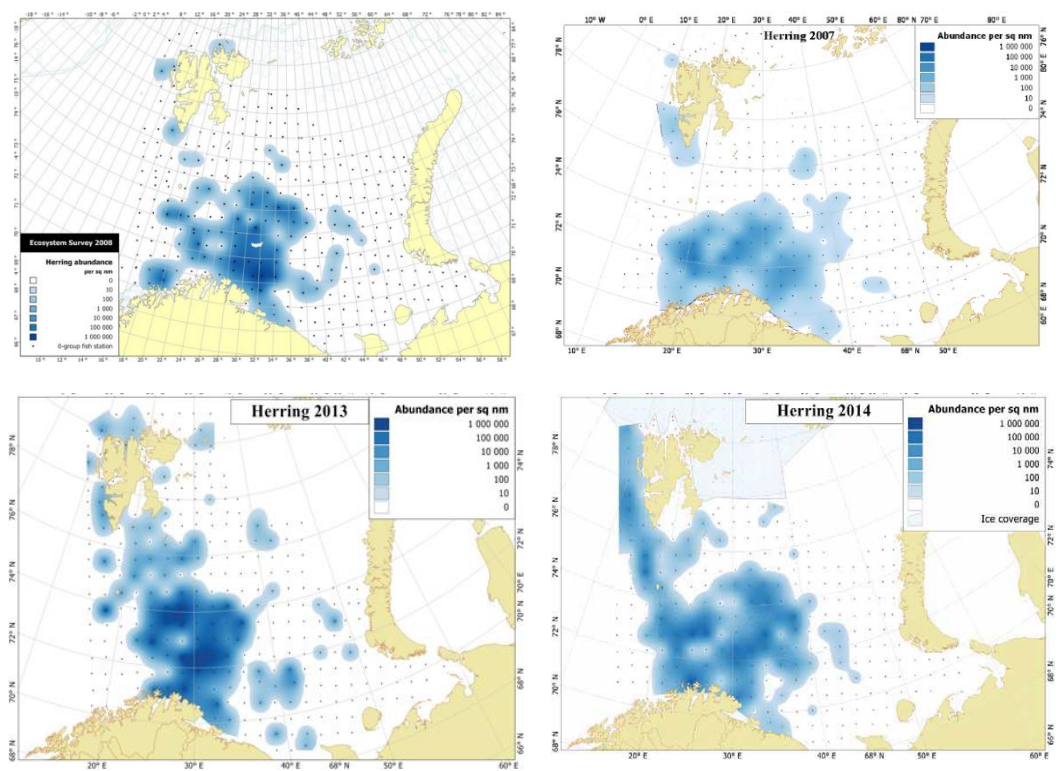
Figure B.3.5.2. NSSH O–group surveys in August/September in the Barents Sea in 2008 (upper left panel) and 2007 (upper right panel) and 2013 (lower left) and 2014 (lower right). *Survey 7.*
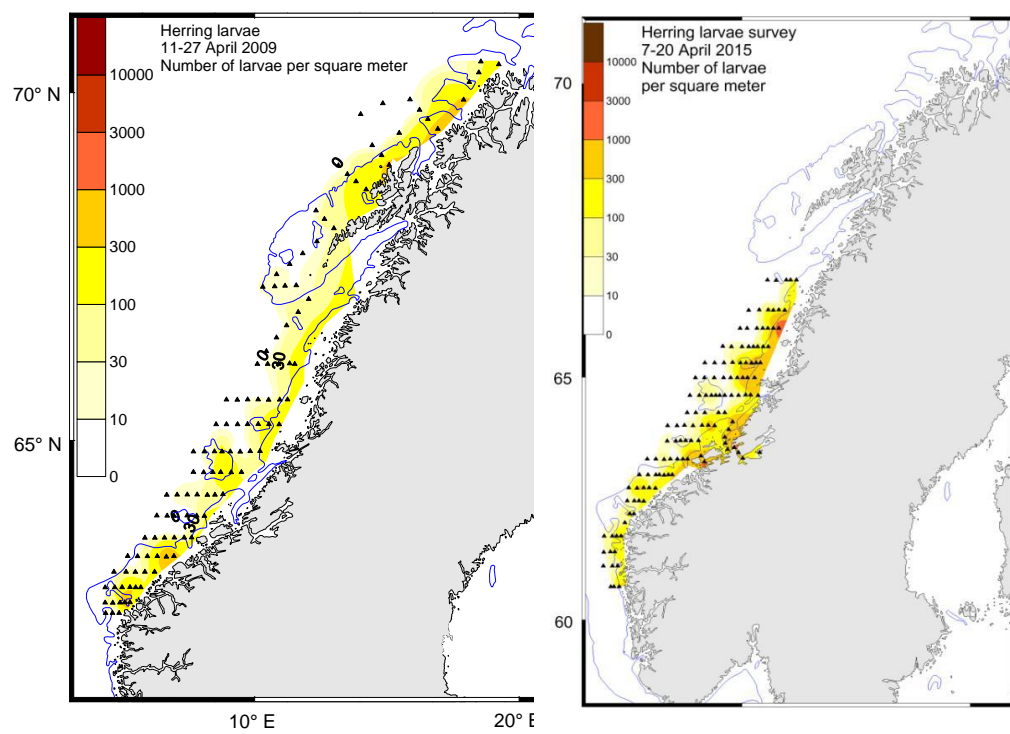
Figure B.3.6.1. NSSH. Distribution of herring larvae on the Norwegian shelf in 2009 (left panel) and 2015 (right panel). The 200 m depth line is also shown.
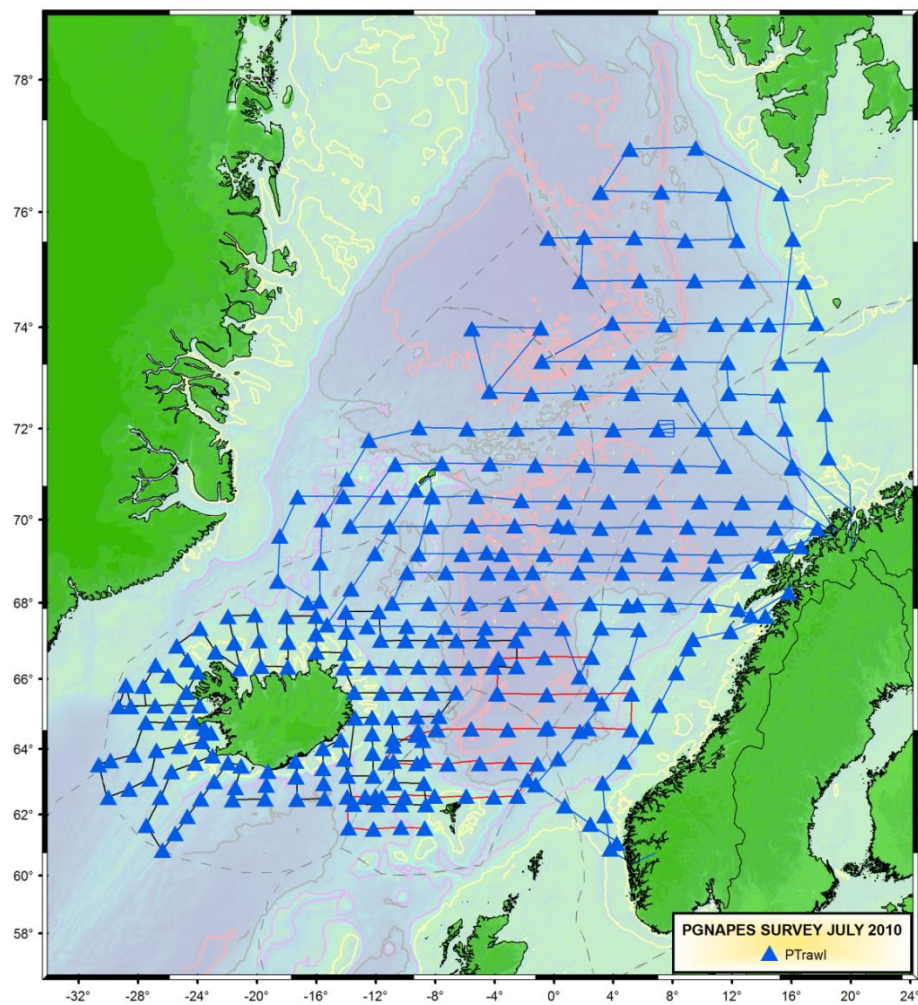
Figure B.3.7.1. Cruise tracks during the coordinated ecosystem survey in Norwegian Sea and adjoining waters in July-August 2010 and location of trawl stations.

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).

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