Stock Annex: Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerrak and Kattegat, eastern English Channel)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Herring
Working Group	Herring Assessment Working Group for the Area south of 62°N (HAWG)
Created	
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A. General

A.1. Stock definition

Autumn spawning herring distributed in ICES subarea 4, divisions 3.a and 7.d. The stock consists of four major spawning components; contributions of these individual components to the total stock differ over time. Mixing with other stocks occurs, especially in Division 3.a (with Western Baltic Spring Spawning herring). Recent studies have shown that the different spawning aggregations of this stock are genetically homogeneous (Mariani *et al*., 2005; Reiss *et al*., 2009).

A.2. Fishery

Countries involved: Norway, Denmark, Sweden, Germany, The Netherlands, Belgium, France, UK, Faroe Islands, and Ireland.

North Sea Autumn Spawning herring (NSAS) are exploited by a variety of fleets, ranging from small purse seiners to large freezer trawlers, of different nations. The majority of the fishery takes place in the Orkney-Shetland area and northern North Sea in the 2nd and 3rd quarters, and in the English Channel (Division 7.d) in the 4th quarter. Juveniles are caught in Division 3.a and as bycatch in the industrial fishery in the central North Sea. For management purposes, four fleets are currently defined: Fleet A is harvesting herring for human consumption in 4 and 7.d, but includes herring bycatches in the Norwegian industrial fishery; Fleet B is the industrial (<32 mm mesh size) fleet of EU nations operating in 4 and 7.d. North Sea Autumn Spawners are also caught in 3.a in Fleets C (human consumption) and D (small mesh).

A.3. Ecosystem aspects

Herring is a key pelagic species in the North Sea and is thus considered to have major impact as prey and predator to most other fish stocks in that area (Dickey-Collas *et al*., 2010).

The North Sea is semi-enclosed and situated on the continental shelf of northwestern Europe and is bounded by England, Scotland, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium and France. It covers an area of ~750 000 km^2 of which the greater part is shallower than 200 m. It is a highly productive (>300 gC m^{-2} yr^{-1}) ecosystem but with primary productivity varying considerably across the sea. The highest values of primary productivity occur in the coastal regions, influenced by terrestrial inputs of nutrients, and in gyre areas such as the Dogger Bank and at tidal fronts. Changes observed in trophic structure or diversity may be indicative changes in resilience of this ecosystem (Thrush *et al.*, 2009). This trend may partially be a response to inter-annual changes in the physical oceanography of the North Atlantic (Reid *et al.*, 2001).

Herring are an integral and important part of the pelagic ecosystem in the North Sea. As plankton feeders they form an important part of the food chain up to the higher trophic levels. Both as juveniles and as adults they are an important source of food for some demersal fish, birds and for sea mammals (see review by Dickey-Collas *et al*., 2010). Over the past century the top predator, man, has exerted the greatest influence on the abundance and distribution of herring in the North Sea. Spawning–stock biomass has fluctuated from estimated highs of around 4.5 million tonnes in the late 1940s to lows of less than 100 000 tonnes in the late 1970s (Mackinson, 2001; Mackinson and Daskalov, 2007; Simmonds, 2007). The species has demonstrated robustness in relation to recovery from such low levels once fishing mortality is curtailed in spite of recruitment levels being adversely affected (Nash *et al*., 2009; Payne *et al*., 2009).

Their spawning and nursery areas, being near the coasts, are particularly sensitive and vulnerable to anthropogenic influences (Röckmann *et al*., 2011). The most serious of these is the ever increasing pressure for marine sand and gravel extraction and the development of wind farms. This has the potential to seriously damage and to destroy the spawning habitat and disturb spawning shoals and destroy spawn if carried out during the spawning season. It also has the potential to destroy traditional spawning grounds which are currently unused but likely to be recolonised (Schmidt *et al*., 2009). Similarly, trawling at or close to the bottom in known spawning areas can have the same detrimental effects. It is possible that the disappearance of spawning on the western edge of the Dogger Bank could well be attributable to such anthropogenic influences.

In more recent years the oil and gas exploration in the North Sea has represented a potential threat to herring spawning although great care has been taken by the industry to restrict their activities in areas and at times of known herring spawning activity.

Changes in the environment and productivity in the early life-history stages of North Sea autumn spawning herring.

This stock has, since 2002, produced a series of below average year classes, a situation which has not been observed previously (Payne *et al*., 2009). This was despite the stock being well above the B_{lim} of 800 000 tonnes.

Stock productivity, as represented by the number of recruits-per-spawner from the assessment, has been low for the last decade. Although there have been changes during this low-productivity regime, at no point has this metric approached the levels seen during the 1990s.

Year-class strength in this stock is determined during the larvae phase (Dickey-Collas and Nash, 2005; Payne *et al*., 2009). The trend of reduced larval survival between the early (as indicated by the SCAI index) and the late- (as indicated by the IBTS0 index) larval stages has continued in the most recent years.

The IBTS0 index is regarded by the working group as not being representative of recruitment to the Downs spawning component, as observations of small larvae in this region are removed from the index calculation. A more appropriate metric is therefore to base the metric of larval survival on the abundance of larvae from the three northern components (i.e. excluding the Downs). However, both metrics shows a very similar trend: larval survival during the most recent decade is an order of magnitude less than during the 1990s.

All indicators therefore suggest that the stock remains in the low-productivity regime observed in previous years.

The general reduction in larval survival is generally thought to be associated with changes in the physical and biological environment (ICES, SGRECVAP 2008; Payne *et al.*, 2009). The change in survival rate co-varies with an increase in the mortality rate of the very young larvae (Fässler *et al.*, 2011). The specific reasons for this are not known but there appears to be correlations between the mortality trends and the residuals of the stock-recruit relationship, the stock biomass and temperature. WKHELP reviewed the current knowledge of density-dependence processes in the biology of NSAS and concluded the evidence is not strong enough to neither confirm nor rule out density-dependent mechanisms at the early larval stages (WKHELP, ICES CM 2012/ACOM:72).

Furthermore, recent work has shown that the reduced survival is also correlated with a reduction in larval growth rate (Payne *et al.*, 2013). Individual larval growth rates were estimated for 200 larvae captured before and after the onset of reduced productivity period using a model-based analysis of the otolith ring-widths. Hydrographic-backtracking models complemented the otolith analysis by reconstructing the environmental history and spawning origin of each larva. A mixed-modelling approach was then employed to analyse the combined dataset. After correcting for the effect of other explanatory variables, a significant reduction in larval growth rate around the time of capture of 8%, concurrent with the reduced larval survival and recruitment, was identified. The authors attributed this result to changes in either the amount or quality of available food. More work, however, is required to understand the mechanisms underpinning these observations in greater detail.

The environment also influences the growth of individual North Sea herring. Temperature significantly explains the variation in growth between cohorts of North Sea herring since the mid-1980s (Brunel and Dickey-Collas, 2010). Cohorts experiencing warmer conditions throughout their lifetime attain higher growth rates, but have shorter life expectancy and smaller asymptotic size, and vice-versa for herring experiencing colder conditions. However, recent work in the 2012 benchmark has also suggested that predictions of growth and mortality are currently not feasible (ICES, WKPELA 2012).

Bycatch, slipping and discard

Bycatch consists of the retained 'incidental' catch of non-target species and discard is a deliberately (or accidentally) abandoned part of the catch returned to the sea as a result of economic, legal, or personal considerations. This section therefore deals with these two elements of the fishery. Cetacean, seabird and other threatened, rare species which may form part of a bycatch are considered separately in the next section. Discarding is illegal for Norwegian vessels, and slippage and high grading are now illegal for EU vessels if quota is still available and the fish are above minimum landing size.

The indications are that large-scale discarding is not widespread in the directed North Sea herring fishery. A number of direct-observer surveys have been conducted on Scottish, Dutch and Norwegian pelagic trawlers, (Napier *et al.*, 1999; 2002; Borges *et al.*, 2008; van Helmond and Overzee, 2010a). The overall discard rate was less than 5% of the landed catch. It is likely that there are different discard rates between the specific fishing types. There is disagreement about the amount of slippage compared to discarding by the differing fleets (**slippage**- fish released from the nets whilst still in the water but still resulting in the mortality of the majority of pelagic fish, **discarding**- fish dumped back into the sea after having been brought on board). In freezer trawlers discarding can occur through sorting the catch and through emptying of tanks via the processing belts without sorting. For both pursers and trawlers 'poor' fish quality was a significant cause of discarding. Another reason is the processing capacity of freezer trawlers when catches are abundant (Helmond and Overzee, 2010b). The strength of year classes influences discarding behaviour, particularly of undersized fish. The influence of strong herring year classes was apparent in the composition of discards with smaller, younger fish accounting for a high proportion of the fish discarded in 2001. Since the mid-2000s the stronger recruitment of mackerel has probably led to an increase in discarding due to mixed hauls of herring and mackerel.

Since 2015, a landing obligation is in place for pelagic fleets operating in the North Sea and the Baltic. All species for which a TAC regime exists have to be landed. This implies also fishes below minimum landing sizes (BMS), which are reported in a specific catch category and their amount is counted against the quota. In the North Sea herring fishery, this BMS category includes fishes lost or damaged during landing operations or fish processing. **Incidental Catch**: The incidental catch of non-target species in the North Sea pelagic herring fishery in general is considered to be low (Borges *et al*., 2008). A study by Pierce *et al.* (2002) investigated incidental catch from commercial pelagic trawlers in Scotland over the period January to August 2001. The target species, herring, accounted for 98% by weight of the overall catch with an overall incidental catch of 2.3% made up of mackerel, haddock, horse mackerel and whiting. However, onboard sampling during 2002, by Scottish and German observers, found substantial discards of herring, taken as bycatch in the mackerel fishery over the 3rd and 4th quarters, after herring quotas had been exhausted (Ref?). This was not found in a study of the Dutch fleet (Borges *et al*., 2008) where the herring fishery was found to be relatively "clean". Updates of the time-series of Dutch discarding due to sorting suggest an approximate discard of <5% of the catch (Helmond and Overzee, 2010a).

Ecosystem considerations. A potential ecosystem impact of the North Sea herring fishery is the removal of fish that could provide other "ecosystem services". The North Sea ecosystem needs a trophic link to graze the plankton and act as prey for other organisms. If herring biomass is very low, other species, such as sandeel, may replace its role (it has been suggested that the shift from herring to sandeel as prey for seals along the English coast in the 1970s, resulted from the collapse of the herring stock), or the system may shift in a more dramatic way. The interaction of herring with cod and Norway pout population dynamics has been alluded to (Cushing, 1980; Huse *et* al., 2008; Fauchald, 2010), and Speirs *et al.* (2010) suggest that the current biomass of herring will prevent the recovery of the cod population even if fishing mortality on cod is reduced. Large populations of predator fish like saithe, cod and whiting, but also to some degree large cetacean or seal populations, will also impact the herring biomass (ICES, WGSAM REPORT, ICES, 2011). However, many of the current ecosystem models are very sensitive to the assumptions about herring, or do not include herring as a predator and prey species, thus it is difficult to test the impact of increasing or reducing the herring biomass on the ecosystem functioning as a whole. It is highly likely that, for Good Environmental Status (GES), the North Sea requires a certain threshold of herring biomass.

Interactions with Protected, Endangered, Threatened Species (PETS): Interactions between the directed North Sea herring fishery with PETS species are, in general, considered to be low. Species which may interact with the fishery are considered below.

Cetacean bycatch: Since 2000, the Sea Mammal Research Unit (SMRU) of St Andrew's University in Scotland, under contract to DEFRA, has carried out a number of surveys to estimate the level of cetacean bycatch in UK pelagic fisheries. SMRU, in collaboration with the Scottish Pelagic Fishermen's Association, placed observers on board of thirteen UK vessels for a total of 190 days at sea, covering 206 trawling operations around the UK. No cetacean bycatch was observed in the herring pelagic fishery in the North Sea. Pierce *et al.* (2002) also reports that no bycatches of marine mammals were observed in over 69 studied hauls, and considers that the underlying rate for marine mammals in the pelagic fisheries studies (pelagic trawls in 4.a and 6.a) is no more than 0.05 (i.e. five events per 100 hauls) and may well be considerably lower than this. Consequently, the cetacean bycatch by the pelagic trawl fishery can be regarded as negligible. This was also confirmed by a UK observer programme that ended in 2003 (Northridge, pers. Comm.) and by Dutch observers (one catch from 2007–2009 over 210 days observed; Couperus, 2009; ICES, 2011b).

***Seal bycatch*:** The bycatch of seals in directed pelagic herring fishery in the North Sea is reported to be "very rare" (Aad Jonker, pers. comm.). Independent verification also confirms this to be so, with perhaps one animal being caught by the whole North Sea fleet a year (Bram Couperus (IMARES, pers. comm.). Northridge (2003) observed 49 seals taken in 312 pelagic trawl tows throughout UK waters and reports that the fishery in northwestern Scotland has the highest observed seal bycatch levels of UK pelagic trawl fisheries, possible amounting to dozens per year. Although not confirmed, it was assumed that the majority were grey seals *Halichoerus grypus*. This species is mainly distributed around the Orkneys and Outer Hebrides; out of a UK population of 129 000, only around 7000 and 5900 are distributed off the Scottish and English North Sea coasts respectively (SCOS, 2002), and so bycatch rates in the North Sea are likely to be substantially less than off the NW Scottish coaSt The eastern Atlantic population of the grey seal is not considered to be threatened.

***Other bycatch*:** Sharks are occasionally caught by pelagic trawlers in the North Sea, although this is rare, with a maximum of two specimens per trip (Aad Jonker, pers. comm.). Survival rates are apparently high; sharks are released during or after the codend has been emptied. The species are unknown, although blue shark *Prionace glauca*, which preys primarily upon schooling fishes such as anchovies, sardines and herring, are known to have been caught by pelagic trawls off the SW English coast (Bram Couperus (IMARES, pers. comm.). Gannets (*Morus bassanus*), which frequently dive at and around nets, were observed by Napier *et al.* (2002) entangled in the nets but were not present in samples. Actual mortality rates of caught gannets have not been assessed in detail, and some have been observed alive after release from the gear. An extrapolation from observed mortalities corresponds to around 560 gannet deaths per year, although this is based on a relatively low sample frame. Seabird bycatch in the North Sea is considered to be comparatively rare. Off NW Scotland, 1–3 birds may be caught, especially in grounds off St Kilda (Aad Jonker (former freezer trawler skipper), pers. comm.). IMARES observers in the North Sea only recorded one incident of seabird bycatch over ten trips (Bram Couperus, pers. comm.).

B. Data

B.1. Commercial catch

Commercial catch data are obtained from national laboratories of nations exploiting herring in the North Sea. Since 1999 (catch data 1998), these laboratoriess have used a spreadsheet to provide all necessary landing and sampling data. This spreadsheet which was developed originally to ease the handling of Mackerel data supplied to its (then parent) Working Group (WGMHSA) and it was then further adapted to the special needs of the Herring Assessment Working Group (HAWG). The current version used for reporting the catch data is v1.6.4. Traditionally, the SALLOCL-programme (Patterson, 1998) is used to allocate samples to catches that do not contain direct biological samples. This programme calculates the required standard outputs on sampling status and biological parameters. It also clearly documents any decisions made by the species coordinators for filling in missing data and raising the catch information of one nation/quarter/area with information from another dataset.

Since 2007, the commercial catch and sampling data have also been stored and processed using the InterCatch database. In the first year, larger discrepancies (up to 5%) between the two applications occurred, but since 2008 the estimates of CANON, CATON and WECA have been highly comparable. However, InterCatch operates on the basis of Subdivisions and lacks the capacity to store catch information by rectangle and catch–length frequency distribution. This level of data division is a prerequisite of the HAWG. Both data collation methods are, therefore, still used in parallel.

The “wonderful table” lists all of the information on area Total Allowance Catches (TACs) and estimated catches of herring in both the North Sea and Division 3.a, to show the derivation of the total catch of North Sea autumn spawning herring (NSAS) each year. The following figure explains where the estimates in the table are derived from.

Year		2007	2008	
Sub-Area IV and Division VIId: TAC (IV and VIId)				
Recommended Divisions IVa, b [1]	22			
Recommended Divisions IVc, VIId	14			
Expected catch of spring spawners				
Agreed Divisions IVa,b [2]	TAC human consumption in IVa and b	303.5	174.6	Total TAC for human consumption in North Sea
Agreed Div. IVc, VIId	TAC human consumption in IVc and VIId	37.5	26.7	
Bycatch ceiling in the small mesh fishery	TAC industrial fishery	31.9	18.8	
CATCH (IV and VIId)				
National landings Divisions IVa,b [3]		326.8		
Unallocated landings Divisions IVa,b		21.9		
Discard/slipping Divisions IVa,b [4]		0.1		
Total catch Divisions IVa,b [5]		348.8		
National landings Divisions IVc, VIId [3]		34.3		
Unallocated landings Divisions IVc,VIId		4.7		
Discard/slipping Divisions IVc, VIId [4]		-		
Total catch Divisions IVc, VIId		39.0		Herring caught in the North Sea
Total catch IV and VIId as used by ACFM [5]		**387.8**		
CATCH BY FLEET/STOCK (IV and VIId) [10]				
North Sea autumn spawners directed fisheries (Fleet A)		379.6		NS catch human consumption
North Sea autumn spawners industrial (Fleet B)		7.1		NS catch industrial fishery
North Sea autumn spawners in IV and VIId total		**386.7**		
Baltic-IIIa-type spring spawners in IV		1.1		Catch of WBSS in IV, estimated by splitting
Coastal-type spring spawners		0.0		e.g. spring spawner in river estuaries (Thames, Wash)
Norw. Spring Spawners caught under a separate quota in IV [20]		0.7		direct information from Norway
Division IIIa: TAC (IIIa)				
Predicted catch of autumn spawners	22			
Recommended spring spawners	22			
Recommended mixed clupeoids				
Agreed herring TAC		69.4	51.7	
Agreed mixed clupeoid TAC				
Bycatch ceiling in the small mesh fishery		15.4	11.5	
CATCH (IIIa)				
National landings		47.3		
Catch as used by ACFM		47.4		
CATCH BY FLEET/STOCK (IIIa) [10]				
Autumn spawners human consumption (Fleet C)		16.4		
Autumn spawners mixed clupeoid (Fleet D) [19]		3.4		
Autumn spawners other industrial landings (Fleet E)				Catch of NSAS in IIIa, estimated by splitting
Autumn spawners in IIIa total		**19.8**		
Spring spawners human consumption (Fleet C)		25.3		
Spring spawners mixed clupeoid (Fleet D) [19]		2.3		
Spring spawners other industrial landings (Fleet E)				
Spring spawners in IIIa total		**27.6**		
North Sea autumn spawners Total as used by ACFM		**406.5**		

Current methods of compiling fisheries assessment data. The stock coordinator is responsible for compiling the national data to produce the input data for the assessments. In addition to checking the data, the major task involved is to allocate samples of catch numbers, mean length and mean weight-at-age to un-sampled catches. There are, at present, no defined criteria on how this should be done, but the following general process is implemented by the stock coordinators. Searches for appropriate samples by gear (fleet), area and quarter are made. If an exact match is not available the search will move to a neighbouring area if the fishery extends to this area in the same quarter. More than one sample may be allocated to an un-sampled catch; in this case a straight mean or weighted mean of the observations may be used. If there are no samples available, the search will move to the closest non-adjacent area by gear (fleet) and quarter.

The Working Group acknowledges the effort some members have made to provide "corrected" data, which in some cases differ significantly from the officially reported catches. Most of this valuable information is gathered on the basis of personal knowledge of the fishery and good relations between the scientist responsible and the fishermen. In addition, the Working Group recognises, and highlights, the inherent conflict of interest between obtaining details of unallocated catches by country and increasing the transparency of data handling by the Working Group.

Uncertainty in the catch data. A thorough examination of the precision of the international market sampling for North Sea herring and its influence on the assessment was carried out in 2001 for the period 1991 to 1998 (ICES, 2001db). The conclusion was that the fishery is well sampled. Estimates of catch-at-age delivered by the combined international sampling programme for North Sea herring were rather precise and the contribution of this variability to the overall precision of the assessment at the time was relatively small and acceptable.

Sampling of commercial catch: Sampling of commercial catch is conducted by the national institutes of the member states. HAWG has recommended for years that sampling of commercial catches should be improved for most of the stocks. In January 2008, a new directive for the collection of fisheries data was implemented for all EU member states (Commission Regulations 2008/949/EC, 2008/199 and 2008/665). The provisions in the "data directive" define specific sampling levels. Most of the nations, who participate in the herring fisheries assessed here have to obey this data directive. The definitions applicable for herring and the area covered by HAWG are given below:

Area	sampling level per 1000 t catch		
Baltic area (3.a (S) and 3.b-c)	1 sample of which	100 fish measured and	50 aged
Skagerrak (3.a (N))	1 sample	100 fish measured	100 aged
North Sea (IV and 7.d):	1 sample	50 fish measured	25 aged
NE Atlantic and Western Channel ICES areas 2, 5, 6, 7. (excluding d) 8,9, 10, 12, 14	1 sample	50 fish measured	25 aged

Exemptions to the above mentioned sampling rules are:

Concerning lengths:

1) the national programme of a Member State can exclude the estimation of the length distribution of the landings for stocks for which TACs and quotas have been defined under the following conditions:

1.1) the relevant quotas must correspond to less than 5% of the Community share of the TAC or to less than 100 tonnes on average during the previous three years;

1.2) the sum of all quotas of Member States whose allocation is less than 5% must account for less than 15% of the Community share of the TAC.

If the condition set out in point (1.1) is fulfilled, but not the condition set out in point (1.2), the relevant Member States may set up a coordinated programme to achieve the implementation of the sampling scheme described above for their overall landings, or another sampling scheme, leading to the same precision.

Concerning ages:

1) the national programme of a Member State can exclude the estimation of the age distribution of the landings for stocks for which TACs and quotas have been defined under the following conditions:

   1.1) the relevant quotas correspond to less than 10% of the Community share of the TAC or to less than 200 tonnes on average during the previous three years;

   1.2) the sum of all quotas of Member States whose allocation is less than 10%, accounts for less than 25% of the Community share of the TAC.

If the condition set out in point (1.1) is fulfilled, but not the condition set out in point (1.2), the relevant Member States may set up a coordinated programme as mentioned for length sampling.

If appropriate, the national programme may be adjusted until 31 January of every year to take into account the exchange of quotas between Member States.

B.2. Biological sampling

Weight-at-age

Catch-at-age data (including catch number-at-age, mean weight-at-age in the catch, mean length-at-age) are derived from the raised national figures received from the national laboratories. The data are obtained either by market sampling, by on-board observers or self-sampling by the industry, and processed as described above. Information on recent sampling levels and nations providing samples should be provided as part of the working group report (typically Section 2.2.).

Mean weights-at-age in the stock and proportions mature (maturity ogive) are derived from the June/July international acoustic survey (see next paragraph). All 1 winter-ring fish are assumed to be immature, and all fish over five winter-rings are assumed to be mature.

For North Sea herring, increasing fish size has been observed from 1940 to 1980, possibly resulting from a decreasing competition for food while the stock collapsed (Burd, 1984; Saville *et al.*, 1984; Bailey *et al.*, 1984). Particularly large year-classes may also suffer from intra-cohort competition and have a slower growth than average ones (ICES, 2008). Superimposed to these density-dependent effects, environmental factors such as plankton production (Shin and Rochet, 1998) and temperature (Brunel and Dickey-Collas, 2010) also influence growth. There is no study dealing specifically with variations in North Sea herring maturation, but it has been shown for other stocks having also collapsed and recovered in the recent history, that maturation was closely related to growth (i.e. faster growth resulting in earlier maturation) (Engelhard and Heino, 2004; Melvin and Stephenson, 2007).

Maturity

Growth and maturation variations are the expression of phenotypic plasticity in response to variability in environmental factors such as food level (Berrigan and Charnov, 1994), temperature (Atkinson, 1994), and density-dependent processes (Engelhard and Heino, 2004).

Maturation seems to be closely related to growth. Poor growth between age 1 and 2 often leads to a low proportion of mature individuals at age 2. If growth is also poor between age 2 and 3, maturation is further delayed. As the assessment of North Sea herring and the projections are based on smoothed stock weight data, most of the inter-annual variability in growth is filtered out. Therefore the weights-at-age used for the prediction (assumed same as last year of data) are not too different from the weight observed in the data in the assessment of the following year. Brunel, 2012 showed, however, that the assumption made for the maturity ogive used in the projections (an average of the last three years of data) generates large errors, particularly for slow maturing cohorts. However, given the absence of a predictive model for growth, and hence maturation, it seems difficult to propose an alternative to improve this situation.

The precision of the maturity-, sex-, and age estimates are analysed every 3–4th year according to a pre-set schedule defined by ICES, ICES Working Group on Commercial Catches (WGCATCH) and ICES Working Group on Biological Parameters (WGBIOP). Through exchanges and workshops, the individual estimates of maturity stage, sex, and age are subject to a quality check by calibrating the laboratories involved in supplying data on those biological parameters. From these workshops, estimates of the uncertainty around the estimates of maturity, sex and age are available for consideration by the HAWG.

Natural mortality

History of natural mortality in the NSAS assessment.

Natural mortality-at-age was up to 2011fixed by age for the entire time-series of the assessment, as calculated by the equivalent of the current ICES multispecies working group in 1987 (ICES, 1987; Table B2.1).

Table B2.1. Metrics for natural mortality (M) used for the assessment of North Sea autumn spawning herring up to 2011. Taken from ICES 1987.

Age	Herring Assessment WG meetings in years				Multispecies WG meetings		
	1964-1970	1970-1983	1984-1986	1987	1984[1]	1985[2]	1986[3]
0	0.20	0.10	1.00	1.00[4]	1.07	0.82	1.067[4]
1	0.20	0.10	0.80	1.00	0.46	0.84	1.023
2	0.20	0.10	0.10	0.30	0.13	0.16	0.253
3	0.20	0.10	0.10	0.20	0.44	0.30	0.274
4	0.20	0.10	0.10	0.10	0.13	0.12	0.131
5	0.20	0.10	0.10	0.10	0.19	0.13	0.131
6	0.20	0.10	0.10	0.10	0.10	0.12	0.117
7	0.20	0.10	0.10	0.10	0.10	0.10	0.100
8+	0.20	0.10	0.10	0.10	0.10	0.10	0.100

[1] Anon. (1984b) key-run, mean 1974-1983.
[2] Anon. (1986b) key-run, mean 1974-1984.
[3] Anon. (1987a) key-run, mean 1978-1982.
[4] Mortality rate per half year.

The Multispecies VPA carried out in 1986 was, according to Anon. (1987a), an improvement on the 1985 MSVPA mainly because:

In 2012, at the benchmark of the North Sea herring stock (ICES, WKPELA 2012), it was decided to replace these with time variable estimates of natural mortality (M) at age. These are derived directly from the multispecies stock assessment model, the SMS model, used in WGSAM (Lewy and Vinther, 2004; ICES, 2011) thus incorporating a direct link between the North Sea ecosystem and the NSAS stock dynamics. The M estimates are variable along the time period covered by the assessment and are the result of predator–prey overlap and diet composition. The trends in total M of NSAS are a result of the contribution of each of the predators to the predation mortality of the NSAS stock. The time-series of M adopted at the benchmark in 2012 was from the 2011 key run of the SMS model covering the period 1963–2010 (WGSAM 2011) (Figure B2.1, left panel). Annual total predation and background mortality estimates from the SMS model, spanning 1963 to 2010, were obtained and scrutinized for patterns during the 2012 benchmark (ICES, WKPELA 2012).

Many different predators have herring in their diet. Young herring are primarily eaten by cod, saithe and whiting, where whiting mainly predates on age 2–4-herring. The contribution of saithe and cod alone was found to be responsible for nearly 90% of the predation mortality from age 4 onwards. Predation mortality by cod went down in the period 1995–2010 while predation mortality went up for saithe. In the years 2008–2010 however total predation mortality was seen to have gone down rapidly.

Cod showed a nearly continuous decline in biomass while saithe increased considerably over the years up to 2005 but crashed in the most recent years. These trends in cod and saithe biomass were in agreement with the trends observed in the single species assessments. Herring mortality (ages 2 and older) had, according to the SMS 2011 key run, increased over the period 1991–2007 but seems to have reduced again in more recent years. This trend is in close agreement with the development of the saithe stock, while the decline in the cod stock seemed to have been compensated by the saithe increase over the years.

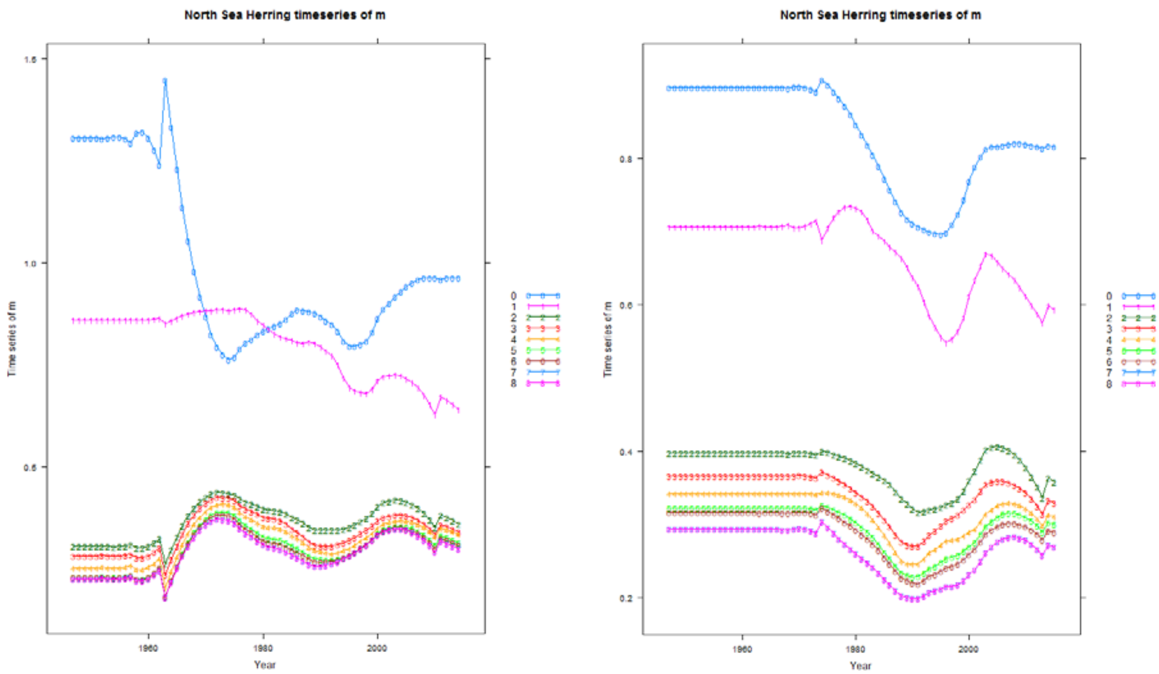


Figure B2.1. Time-series of smoothed time varying absolute natural mortality values at age 0–8+ as used in the North Sea herring assessment. Left panel: Smoothed time varying natural mortality estimates at age for North Sea herring derived from the SMS model 2011 North Sea key run (WGSAM 2011) for the time period 1963–2010 as used in the assessment up to 2015. Right panel: Natural mortality values based on the 2015 North Sea key run (WGSAM 2015) for the time period 1974–2014 as used in the assessment in 2016 (ICES, HAWG 2016). Note differing scale between the two panels.

An updated and revised time-series from WGSAM was available to HAWG for use in the assessment in 2016 (WGSAM 2014; 2015). The time-series of M contained substantial revisions over the time-series resulting in a lower overall natural mortality for herring in the order of 13% (over all ages, Figure B2.1, right panel).

The changes introduced from 2011 to 2015 in the WGSAM reviewed North Sea SMS key run include lower historical cod catches, higher biomass of medium–large grey gurnards and large starry rays, inclusion of hake, revision of mackerel assessment, revision of the haddock stock definition and the division of sandeel into two stocks and a truncation of the time-series to 1974–2014. Together, these changes resulted in lower cod biomass and hence predation by cod, higher predation by grey gurnards and starry ray and increasing predation by hake.

Lower cod biomass occurred as a result of the revision of historical catches to a lower level of unallocated mortality and as a result, the main prey of cod were predicted to have a lower natural mortality. In some species, this effect was counteracted by the increased estimated biomass of grey gurnards, starry ray and, in the later years, hake. However, these predators did not have a substantial effect on the natural mortality of large (3+) herring, and hence the estimated natural mortality of these were reduced as a result of the lower cod biomass following the lower historic cod catches. With the decrease in biomass of large cod M of 2+herring has decreased over time, but the effect is counteracted in later years as the biomass of large hake and grey gurnard have increased.

WGSAM (WGSAM, 2014; 2015) advised that:

- The 2015 key run time-series is seen as more accurate than the previous time-series as the change in historic catches by WGNSSK is based on the best available knowledge;
- The increased cod biomass in the last two years is uncertain and hence smoothing the values at least in the last years of the period is recommended;
- WGSAM does not recommend updating existing dataseries of natural mortality by simply adding the latest three new years. The time-series as a whole shows patterns which are not retained by this procedure. For example, herring shows an increased natural mortality over the past decade, but adding only the latest three years will give the impression that natural mortality has decreased over the last five years.

Based on these recommendations and the view that the assessment of the state of the North Sea herring stock should be based on the best available scientific information available, the 2015 key run was adopted by HAWG 2016 for the assessment of North Sea herring in 2016.

Procedures for the use of the SMS generated M in NSAS assessment

Natural mortality estimates are derived from the most up to date key run from the SMS model used in WGSAM ((Lewy and Vinther, 2004). This is at present the 2015 key run (WGSAM 2015). The input data to the assessment are the smoothed values (loess smoother, span=0.5, order=2) of the raw SMS model annual M values for ages 0–7 winter rings. Natural mortality in years outside the time period covered by the key run (presently 1974 to 2014) are filled and estimated for each age as a five year running mean in the forward direction (2015+ at present, i.e. mi = (Mi-1+Mi-2+Mi-3+Mi-4+Mi-5)/5 where mi is the smoothed natural mortality and Mi is the raw natural mortality in year i) and in the reverse direction for years prior to 1974 (i.e. mi = (Mi+1+Mi+2+Mi+3+Mi+4+Mi+5)/5).

M on age 8+ winter rings is assumed to be the same as that at age 7 winter rings.

B.3. Surveys

B.3.1 Acoustic: ICES Coordinated Acoustic Surveys for herring in North Sea, Skagerrak and Kattegat (HERAS)

The ICES coordinated acoustic surveys started in 1979 around Orkney and Shetland with the first major coverage in 1984. An index derived from that survey has been used in assessments since 1994 with the time-series data extending back to 1989. The survey was extended to 3.a to include the overlapping Western Baltic spring spawning stock (WBSS) in 1989, and the index has been used with a number of other tuning indices since 1991. The early survey had occasionally covered 6.a (North) during the 1980s and was extended westwards in 1991 to cover the whole of 6.a (North). Since 1991, this survey provides the only tuning index for 6.a (North) herring and from 2008 for the whole Malin Shelf. By carrying out the coordinated survey at the same time from the Kattegat to Donegal (Ireland), all herring in these areas are covered simultaneously, reducing uncertainly due to area boundaries as well as providing input indices to three distinct stocks. The surveys are coordinated under ICES Working Group for International Pelagic Surveys (WGIPS).

The acoustic recordings are carried out using Simrad EK60 38 kHz sounder echo-integrator with transducers mounted on the hull, drop keel or towed bodies. Prior to 2006, Simrad EK500 and EY500 were also used. Further data analysis is carried out using either BI500, Echoview or Echoann software. The survey track is selected to cover the area giving a basic sampling intensity over the whole area based on the limits of herring densities found in previous years. A transect spacing of 15 nautical miles is used in most parts of the area with the exception of some relatively high density sections, east and west of Shetland, north of Ireland and in the Skagerrak where short additional transects are carried out at 7.5 nautical miles spacing, and in the southern area, where a 30 nautical miles transect spacing is used.

The following target strength to fish length relationships have been used to analyse the data:

Herring	TS = 20 log L - 71.2 dB
Sprat	TS = 20 log L -71.2 dB
Gadoids	TS = 20 log L - 67.5 dB
mackerel	TS = 21.7 log L - 84.9 dB

Data are reported through a standardised data exchange format and uploaded into the FishFrame Acoustic database, hosted at DTU Aqua, Charlottenlund, Denmark. National estimates are aggregated through FishFrame during WGIPS to calculate global estimates for the North Sea, 6.a (North) the Malin Shelf and the western Baltic Sea. The exchange format currently holds information on the ICES statistical rectangle level, with at least one entry for each rectangle covered, but more flexible strata are accommodated by allowing multiple entries for abundance belonging to different strata. Data submitted consist of the ICES rectangle definition, biological stratum, herring abundance by proportion of autumn spawners (North Sea and 6.a North) and spring spawners (Western Baltic), age and maturity, and survey weight (survey track length). Data are presented according to the following age/maturity classes: 1 immature (maturity stage 1 or 2), 1 mature (maturity stage 3+), 2 immature, 2 mature, 3 immature, 3 mature, 4, 5, 6, 7, 8, 9+ mature. In addition to proportions-at-age, data on mean weight and mean length are reported at age/maturity by biological strata. Data are combined using an effort weighted mean based on survey effort reported as number of nautical miles of cruise track per statistical rectangle. A combined survey report is produced annually. Apart from the Biomass index for 1-9+-ringers, mean weight-at-age in the catch and proportions mature are derived from the survey to be used in the NSAS assessment.

Precision estimates on the biological samples obtained during the acoustic surveys are available since 2012 (WGIPS 2012). Average weight and length values with corresponding standard deviations have been computed for North Sea herring (based on the combined biological information collected during the Dutch, German, Danish and Scottish acoustic surveys (HERAS) and the Malin Shelf area (MSHAS; based on Irish survey data in 2012). Bootstrapping is used to characterise uncertainty in maturity-at-age. Details on the results are given in the Working Group report of WGIPS (ICES, 2012).

Precision estimates of the spawning–stock biomass estimates obtained from the acoustic surveys are available for the period 2004–2011. In the precision estimation exercise done during WGIPS 2012, uncertainty in global mean acoustic density estimates is characterised. Because mean size of adult herring does not vary a lot (most adult age classes have mean lengths of 25–30 cm), uncertainty in mean acoustic density should give a good, albeit conservative, estimate of uncertainty in total stock biomass. Areas containing the vast majority of adult herring (90–95%) in the North Sea have traditionally been covered by the Netherlands and Scotland. In the areas covered by the other nations participating in the international survey, a great proportion of immature herring is encountered. Schools and aggregations of immature herring will exhibit different morphological and acoustic characteristics that are not representative of the adult portion of the stock. Therefore, only data from the Netherlands and Scotland were used to estimate uncertainty in the mean acoustic density and stock size of the North Sea herring spawning–stock biomass (SSB).

Bootstrapping was used to estimate uncertainty in the mean acoustic density. Bootstrapping was done by stratum, treating observations from vessels equally and using lengths of survey track as weights when calculating mean density. Estimates of mean acoustic density were calculated for 1000 bootstrap replicates per stratum. The overall mean acoustic density is the mean of these 1000 bootstrap estimates, and confidence limits were obtained as quantiles of the distribution.

The results of this exercise for the period 2004–2011 are shown below. The level of acoustic uncertainty is the same order of magnitude, with the exception of the survey in 2006, when the distribution of the acoustic density values was much wider than usual.

Table B.3.1. Confidence intervals (C. I.) obtained from 1000 bootstrap replicates of acoustic survey data based on the Dutch and Scottish North Sea herring surveys.

Year	95% C.I. lower [%]	95% C.I. upper [%]	50% C.I. lower [%]	50% C.I. lower [%]
2004	-20.4	+21.0	-7.5	+7.2
2005	-23.0	+24.6	-8.8	+8.5
2006	-34.8	+43.9	-15.3	+13.3
2007	-17.2	+17.4	-5.6	+5.8
2008	-25.2	+28.3	-9.7	+8.8
2009	-22.7	+26.1	-8.9	+8.3
2010	-19.7	+23.7	-7.4	+7.0
2011	-17.2	+20.3	-6.6	+6.3

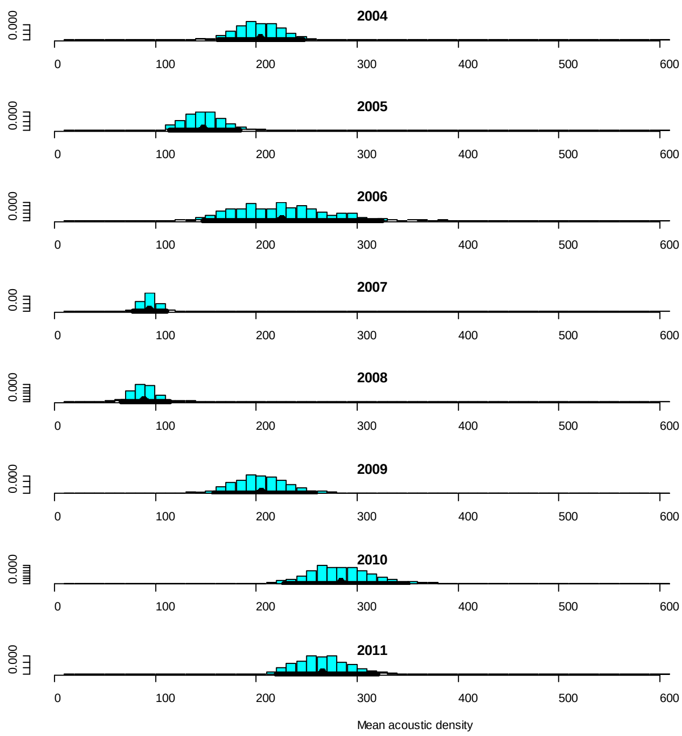


Figure B.3.1.1. Distribution of mean acoustic density (in m²/nmi²), by year, based on 1000 bootstrap replicates of acoustic data from the Dutch and Scottish North Sea herring surveys. Mean acoustic density is indicated with a black dot on the x-axis, while the horizontal bar shows 95% confidence limits.

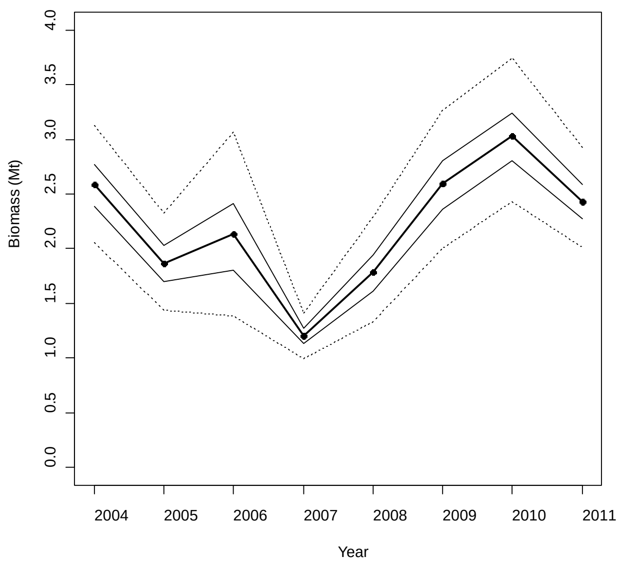


Figure B.3.1.2. Approximate 50% and 95% confidence limits for North Sea herring SSB (x1000 t) estimates from the acoustic survey. The confidence limits are based on the assumption that confidence limits for annual estimates of mean acoustic density can be translated to confidence limits of biomass estimates by expressing them as relative deviations from the mean values. These confidence limits only account for spatio-temporal variability of acoustic observations.

B.3.2 International Bottom Trawl Survey in 1st Quarter (IBTS-1Q)

The International Bottom Trawl Survey (IBTS) started out as the International Young Herring Survey (IYHS) in 1966 with the objective of obtaining annual recruitment indices for the combined North Sea herring populations (Heessen *et al*., 1997). It has been carried out every year since, and it was realized that the survey could provide recruitment indices not only for herring, but for other roundfish species as well. The survey was standardised gradually from 1977, and is considered fully standardised from 1983 onwards, where it became known as the International Bottom Trawl Survey (IBTS). Examination of the catch data from the 1st quarter IBTS showed that these surveys also gave indications of the abundances of the adult stages of herring, and subsequently the catches have been used for estimating 2–5+ ringer abundances. The surveys use standardized procedures among all participants. The standard gear is a GOV trawl, and at least two hauls are made in each statistical rectangle. In 2007 the IBTS was extended into English Channel. In 1977 sampling for late stage herring larvae was introduced at the IBTS 1st quarter, using Isaacs-Kidd Midwater trawl (IKMT). These catches appeared as a good indicator of herring recruitment. However, examination of IKMT performance showed deficiencies in its catchability of herring larvae, and a more applicable gear, a midwater ring net (MIK) was suggested as an alternative gear. Hence, gear type was changed in the mid-1990s, and the MIK has been the standard gear of the programme since. This MIK is of 2 meter in diameter, has a long two-legged bridle, and is equipped with a black netting of 1.5 mm mesh size. Two oblique hauls (to a maximum depth of either 100 m or 5 m from the bottom) per ICES statistical rectangle are made at night.

Indices of 2–5+ ringer herring abundances in the North Sea (from/in 1st quarter). Fishing gear and survey practices were standardised from 1983 onwards and herring abundance estimates of 2–5+ ringers are available since. Catches in Division 3.a are not included in this index. These estimates are determined by the standard IBTS methodology developed by the ICES IBTS working group. The time-series was used in North Sea herring assessment until 2011. During the Benchmark in 2012, it was decided not to include the 2–5+ index in the assessment due to a general inability of the index to track cohorts and poor precision.

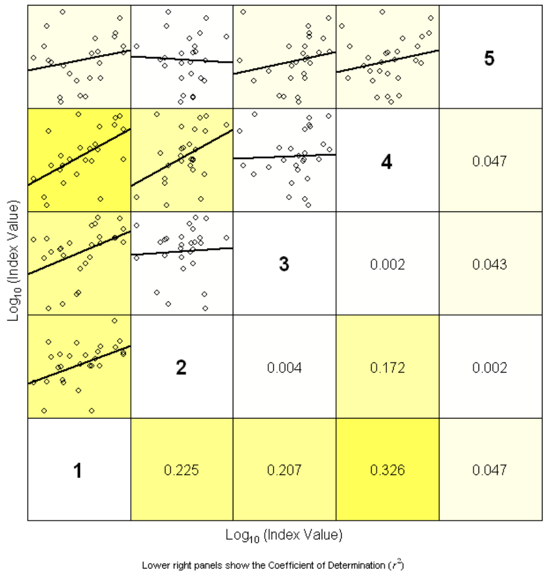


Figure B.3.2.1. Fitted linear relationships of cohort trends within the IBTS surveys. Internal consistency of cohorts in the IBTS-1Q survey.

Index of 1-ringer recruitment in the North Sea (1st quarter). The 1-ringer index of recruitment is based on trawl catches in the entire survey area, hence, all 1-ringer herring caught in Division 3.a is included in this index. Indices are calculated as an area weighted mean over means by ICES statistical rectangle, and are available for year classes 1977 to recent. The Downs herring hatch later than the other autumn spawned herring and generally appears as a smaller sized group during the 1st quarter IBTS. A recruitment index of smaller sized 1-ringers is calculated using the standard procedure, but solely based on abundance estimates of herring <13 cm (ICES CM 2000/ ACFM:10, and ICES CM 2001/ ACFM:12).

IBTS0 index of 0-ringer recruitment in the North Sea (1st quarter). The catches of late stage herring larvae (using the MIK gear) are used to calculate a 0-ringer index of autumn spawned herring in the North Sea and used as a proxy for recruitment strength (Nash and Dickey-Collas, 2005). A flowmeter at the gear opening is used for estimation of volume filtered by the gear, and using this information together with information on bottom depth, the density of herring larvae per square meter is estimated for each haul.

Data storage: The data are initially tabulated in an excel sheet where the data are scrutinised for consistency and quality and the different correction factors that standardise the data among nations are applied. The data are then uploaded to the ICES "eggs-and-larvae" database where the historic data are also held. This database is used for a range of larval species and different sets of data can be selected and downloaded and can be accessed by contacting the ICES secretariat.

Index calculation: The mean herring density (in no. per m^2) in statistical rectangles is raised to mean within subareas, and based on areas of these subareas an index of total abundance is estimated. The series provides estimates for sub-areas as well as the total index.

In order to consider "skewness" in sampling intensity due to less intense or no sampling in some areas, the averaging of densities is first done for statistical rectangles and subsequently for defined, larger sections. Finally, abundances are found for the sections and these are summed for the total area.

In order to exclude the Downs herring larvae (spawns in November–February in the southern Bight of the North Sea and in the eastern English Channel), which are too patchily distributed and too young (might reach extreme abundances), the abundances of larvae south of 54°N for which the mean size at station is below 20 mm are excluded before calculating the standard IBTS0 index.

The procedure is the following:

1) Averages of no-per-m^2 is calculated for each rectangle

2) Averages of no-per-m^2 for rectangles are averaged for sections defined by:

If stat1 is the first two digits of "statistical rectangle" and stat4 is the two last then:

if stat4<F2 and stat1>39 and stat1<46 then section='cw';

if stat4>F1 and stat1>39 and stat1<46 then section='ce';

if stat4<F2 and stat1<40 and stat1>34 then section='sw';

if stat4>F1 and stat1<40 and stat1>34 then section='se';

if stat4<F2 and stat1>45 then section='nw';

if stat4>F1 and stat1>45 then section='ne';

if stat4>F8 then section='ka';

if stat1<35 then section='ch';

3) Averages of no-per-m^2 for subareas are multiplied by section-area factors defined by:

if section='cw' then af=28;

if section='ce' then af=33;

if section='sw' then af=12;

if section='se' then af=30;

if section='nw' then af=27;

if section='ne' then af=11;

if section='ka' then af=10;

if section='ch' then af=10;

miksec=section average in no-per-m^2 *af*3086913600;

4) The index is then the sum of all abundances in sections (which amount to an estimate of the total number of larvae)

IBTS0 = sum of miksec.

Summary of data missing and data excluded due to data inconsistencies: The following section contains information about the completeness of the survey data used to calculate the IBTS0 index over the years. The information has been gathered from the annual Herring Assessment Working Group reports where such issues are normally reported and are listed by year. Further details are available in the respective Working Group reports.

1977 Scottish data have no larvae length measurements and therefore no mean length.
1978 Swedish data have no larvae length measurements and therefore no mean length.

1983 Northwestern part not surveyed

2002 No French data available. Dutch data excluded from data base and index calculation

2010 Dutch data excluded from database and index calculation

2011 Swedish part of survey in 3.a not carried out

B.3.3. Surveys of larval herring

Surveys of larval herring have a long tradition in the North Sea. Sporadic surveys started around 1880, and available scientific data goes back to the middle of the 20th century. The coordination of the International Herring Larvae Surveys in the North Sea and adjacent waters (IHLS) by ICES started in 1967, and from 1972 onwards all relevant data are achieved in a database (ICES, WGIPS). The surveys are carried out annually to map larval distribution and abundance. Larval abundance estimates derived from these surveys are used as relative indicators of the herring spawning biomass in the assessment.

Nearly all countries surrounding the North Sea have participated in the history of the IHLS. Most effort was undertaken by the Netherlands, Germany, Scotland, England, Denmark and Norway. A number of other nations have contributed occasionally. A sharp reduction in ship time and number of participating nations occurred at the end of the 1980s. Since 1994 only the Netherlands and Germany contribute to the larvae surveys, with one exception in 2000 when also Norway participated.

Larvae Abundance Index (LAI): The total area covered by the surveys is divided into four subareas corresponding to the main spawning grounds. These subareas have to be sampled in different given time intervals. The sampling grid is standardized and stations are approximately 10 nautical miles apart. The standard gear is a GULF III or GULF VII sampler (Nash *et al.*, 1998). The abundance of newly hatched larvae (less than 10 mm total length; 11 mm for the southern North Sea) are used as the basis for the index calculation. To estimate larval abundance, the mean number of larvae per square meter obtained from the ichthyoplankton hauls is raised to rectangles of 30x30 nautical miles and the corresponding surface area. These values are summed up within the given unit and provide the larval abundance per unit for a given time interval.

Multiplicative Larval Abundance Index (MLAI): The use of both LAI and LPE (Larval Production Estimates) estimates as indices of spawning–stock biomass rely on a complete coverage of the survey area. Due to the substantial decline in ship time and sampling effort since the end of the 1980s, these indices could not be calculated in their traditional form since 1994. Instead, a multiplicative model was developed for calculating a Multiplicative Larvae Abundance Index (MLAI, Patterson and Beveridge, 1995). In this approach the larvae abundances are calculated for a series of sampling units. The total time-series of data is used to estimate the year and sampling unit effects on the abundance values. The unit effects are used to fill un-sampled units so that an abundance index can be estimated for each year.

Calculation of the linearised multiplicative model is done using the equation:

$$\ln(LAI_{year,LAI\ unit}) = MLAI_{year} + MLAI_{LAI}\ unit + u_{year,\ LAI\ unit}$$

where $MLAI_{year}$ is the relative spawning stock size in each year, $MLAI_{LAI}$ unit are the relative abundances of larvae in each sampling unit and $u_{year,\ LAI\ unit}$ are the corresponding residuals (Gröger *et al.*, 1999; 2000). The unit effects are setup so that the first sampling unit is used as a reference (Orkney/Shetland 01–15.09.72) and the parameters for the other sampling units are redefined as differences from this reference unit. The model is fitted the Larval Abundance Indices derived above ($LAI_{year, LAI\ unit}$). The MLAI is updated annually and represents all larval data since 1972. The time-series has previously been used as a spawning stock index of the spawning–stock biomass in the herring assessment.

The MLAI, however, assumes that the sampling unit effects ($MLAI_{LAI\ unit}$) are constant throughout the time-series: in response to this limitation, another larval abundance index (**SCAI- Spawning Component Abundance Index**) was developed (Payne, 2010). The SCAI index, like MLAI, also models the LAIs as the basic data unit. However, rather than considering the sampling units as providing information about the entire stock, as in the MLAI, the SCAI considers them to be representative of the individual spawning components. Furthermore, the SCAI can be considered as analogous to a simple biomass model applied at the component level, and therefore auto-correlation is explicitly incorporated i.e. the abundance estimated in one year also provides information about the expected level in neighbouring years. Breaks in the time-series are therefore not a problem for the SCAI, as it can effectively "bridge" these the gaps in a sensible manner based upon the modelled auto-correlation structure. SCAI can therefore provide information about the dynamics of the individual components: summing these component-wise indices together therefore also provides an estimate of the abundance of the combined stock. Furthermore, the sum of the fitted abundance indices across all components is a proxy for the biomass of the total stock, even though they only model processes at the component level.

When comparing the model fit of the SCAI and the MLAI, no significant differences occur. Both indices provide comparable survey trends on the SSB estimation. However, preference is given to the SCAI, as it give insight into the dynamics of the individual spawning components, in addition to the total spawning stock.

Details regarding the development and calculation of the SCAI index can be found in (Payne, 2010). The code for generating the SCAI index is available on the herring stock assessment code repository, https://github.com/ICES-dk/wg_HAWG in the directory /tree/master/NSAS/data/SCAI.

B 3.4 North Sea herring spawning components

This section has been lifted from ICES, HAWG (2015) and only the figures relating to the SCAI are updated and reported in the current HAWG reports.

The North Sea autumn-spawning herring stock is generally understood as representing a complex of multiple spawning components (Cushing, 1955; Harden Jones, 1968; Iles and Sinclair, 1982; Heath *et al.*, 1997). Most authors distinguish four major components, each defined by distinct spawning times and sites (Iles and Sinclair, 1982; Corten, 1986; Heath *et al.*, 1997). Three of the components spawn in the North Sea in August/September (the Orkney-Shetland, the Buchan and the Banks components). In the English Channel, the Downs component spawns during December and January. Although the different components mix outside the spawning season and are exploited together, each component is thought to have a high degree of population integrity (Iles and Sinclair, 1982) and, therefore, could be expected to have relatively unique population dynamics.

Monitoring and maintaining the diversity of local populations is widely viewed as critical to the successful management of marine fish stocks. Changes in the relative composition of the combined stock can give rise to differences in exploitation rates between the components (Bierman *et al.*, 2010) and the associated risk of local depletions (Kell *et al*., 2009). Maintaining such spatial diversity within a stock should provide increased resilience to both anthropogenic and natural stressors (Harden Jones, 1968; McPherson *et al*., 2001; Secor *et al*., 2009).

Here we collate the available information, from a variety of different sources, about the individual components.

International Herring Larval Survey

The spawning component abundance index (SCAI: Payne, 2010) was developed to characterize the relative dynamics of the individual North Sea spawning components. The SCAI is a statistical model designed to analyse the larval abundance indices (LAIs) generated by the IHLS (see Section 2.3.2 of the HAWG Report). Interpretation of these time-series is made difficult by missing observations (especially since the 1990s), high sampling noise and differences in the spawning intensity between surveys. The SCAI model, however, is robust to these problems, gives a good fit to the data and proves capable of both handling and predicting missing observations well (Payne, 2010).

SCAI provides an index of the abundance of early larvae (less than 10–11 mm) on the spawning grounds. The abundance of herring early-larvae have been shown to be an appropriate and reliable proxy for the corresponding biomass of spawning adults (Postuma and Zijlstra, 1974; Heath, 1993). The SCAI is also shown to be significantly correlated with the SSB estimated in the stock assessment here. The use of the SCAI as an index of the component spawning biomasses therefore appears justified.

The SCAI model analysis shows that the Downs component appears to have a different set of dynamics from the other three components (Figure 2.11.1). Recovery from the 1970s stock collapse was much slower in this component, and the late 1980s peak displayed by the other three components is relatively weak. In recent times, however, the Downs component has increased consistently to a point where it is the largest component in the stock.

The SCAI indices can also be used to examine the relative composition of the stock (Figure 2.11.2). The composition of the stock has changed appreciably over time. The largest fraction of the total SSB in the past 35 years has generally been represented by the Orkney-Shetland component (on average 50%), but the ratio has ranged between 25 and 80%. The relative contribution of the Downs component to the total stock has increased systematically since the start of the IHLS survey in the early 1970s. During the post-2001 reduced-productivity period, the Downs fraction has increased its proportion further, suggesting that it has been impacted less than the other components.

Recent estimate of the SCAI in the Downs component has been impacted by missing LAI observations in two sampling unit of the IHLS in the English Channel. The rapid reduction in the Downs component seen in Figure 2.11.2 is not thought to be credible.

Recent years also suggest rapid increases in the Orkney/Shetland and Buchan components. While the precision of the terminal year estimate in the SCAI index is reduced there are now several years of data to support this overall trend.

IBTS0 Larval Index

The historical time-series of the IBTS0 larval index (1976–2010) is given here in Table B.3.4.1. The updated series from 1995 is given in the Working Group report. The ring-net hauls for 0-ringers during the IBTS in the eastern English Channel also include Downs herring larvae and additional sampling in this region has been per-formed since 2007 (Section 2.3.3.1). In surveys since, concentrations of smaller larvae which are thought to be of the Downs component occurred. Nevertheless, these small larvae (separated as <20 mm) have until now been excluded from the standard estimation of 0-ringer recruitment (IBTS0 index). Furthermore, recent studies showed that the daily mortality rates of newly hatched larvae of North Sea herring have increased over the time-series and there are uncertainties on the mortality level for these small larvae (Fässler *et al*., 2011).

Table B.3.4.1. North Sea herring. Density and abundance estimates of 0-ringers caught in February during the IBTS. Values given for year classes by areas are density estimates in numbers per square metre. Total abundance is found by multiplying density by area and summing up.

Area	Northwest	Northeast	Central west	Central east	Southwest	Southeast	Div. 3.a	South' Bight	IBTS-0 index
AREA M2 X 109	**83**	**34**	**86**	**102**	**37**	**93**	**31**	**31**	
YEAR CLASS									**NO. IN 109**
1976	0.054	0.014	0.122	0.005	0.008	0.002	0.002	0.016	17.1
1977	0.024	0.024	0.05	0.015	0.056	0.013	0.006	0.034	13.1
1978	0.176	0.031	0.061	0.02	0.01	0.005	0.074	0	52.1
1979	0.061	0.195	0.262	0.408	0.226	0.143	0.099	0.053	101.1
1980	0.052	0.001	0.145	0.115	0.089	0.339	0.248	0.187	76.7
1981	0.197	0	0.289	0.199	0.215	0.645	0.109	0.036	133.9
1982	0.025	0.011	0.068	0.248	0.29	0.309	0.47	0.14	91.8
1983	0.019	0.007	0.114	0.268	0.271	0.473	0.339	0.377	115
1984	0.083	0.019	0.303	0.259	0.996	0.718	0.277	0.298	181.3
1985	0.116	0.057	0.421	0.344	0.464	0.777	0.085	0.084	177.4
1986	0.317	0.029	0.73	0.557	0.83	0.933	0.048	0.244	270.9
1987	0.078	0.031	0.417	0.314	0.159	0.618	0.483	0.495	168.9
1988	0.036	0.02	0.095	0.096	0.151	0.411	0.181	0.016	71.4
1989	0.083	0.03	0.04	0.094	0.013	0.035	0.041	0	25.9
1990	0.075	0.053	0.202	0.158	0.121	0.198	0.086	0.196	69.9
1991	0.255	0.39	0.431	0.539	0.5	0.369	0.298	0.395	200.7
1992	0.168	0.039	0.672	0.444	0.734	0.268	0.345	0.285	190.1
1993	0.358	0.212	0.26	0.187	0.12	0.119	0.223	0.028	101.7

Area	Northwest	Northeast	Central west	Central east	Southwest	Southeast	Div. 3.a	South' Bight	IBTS-0 index
AREA M2 X 109	**83**	**34**	**86**	**102**	**37**	**93**	**31**	**31**	
YEAR CLASS									**NO. IN 109**
1994	0.148	0.024	0.417	0.381	0.332	0.148	0.252	0.169	126.9
1995	0.26	0.086	0.699	0.092	0.266	0.018	0.001	0.02	106.2
1996	0.003	0.004	0.935	0.135	0.436	0.379	0.039	0.032	148.1
1997	0.042	0.021	0.338	0.064	0.178	0.035	0.023	0.083	53.1
1998	0.1	0.056	1.15	0.592	0.998	0.265	0.28	0.127	244.0
1999	0.045	0.011	0.799	0.2	0.514	0.22	0.107	0.026	137.1
2000	0.284	0.011	1.052	0.197	1.156	0.376	0.063	0.006	214.8
2001	0.08	0.019	0.566	0.473	0.567	0.247	0.209	0.226	161.8
2002	0.141	0.04	0.287	0.028	0.121	0.045	0.003	0.157	54.4
2003	0.045	0.005	0.284	0.074	0.106	0.021	0.022	0.154	47.3
2004	0.017	0.010	0.189	0.089	0.268	0.187	0.027	0.198	61.3
2005	0.013	0.018	0.327	0.081	0.633	0.184	0.007	0.131	83.1
2006	0.004	0.001	0.240	0.025	0.098	0.018	0.040	0.228	37.2
2007	0.013	0.009	0.184	0.029	0.067	0.047	0.018	0.007	27.8
2008	0.145	0.139	0.277	0.241	0.101	0.093	0.160	0.433	95.8
2009	0.077	0.085	0.228	0.073	0.350	0.253	0.000	0.139	77.1
2010	0.024	0.004	0.586	0.063	0.187	0.090	0	0.080	77.0

IBTS 1 ringer

The proportion of the autumn and winter spawning components in recruiting year classes of North Sea herring can also be inferred through the abundance of different sized fish in the IBTS. The 1-ring fish from Downs spawning sites (winter) are believed to be smaller than those from the more northern autumn-spawning sites, because this component hatches later than the autumn spawned herring and generally appear as a smaller sized group during the 1st quarter IBTS. A recruitment index of small 1-ring fish is calculated based on abundance estimates of herring <13 cm (ICES CM 2000/ ACFM:12 and ICES CM 2001/ ACFM:12). Table 2.3.3.2 includes abundance estimates of 1-ringer herring <13 cm, calculated as the standard index but is in this case for herring <13 cm only. In the time-series, the proportion of 1-ringers <13 cm (of total catches) is in the order of 22%, and the contribution from Division 3.a to the overall abundance of <13 cm herring varies markedly. Both the total abundance and the relative proportion of this smaller size component has, on average, been relatively high for a number of year classes although there is considerable variation between year classes (Figure B.3.4.1) and fluctuates between 7 and 70% (Figure B.3.4.2).

Table 2.3.3.2. North Sea herring. Indices of 1-ringers from the IBTS 1st Quarter for the 1977 to 2010 year classes, the recent years can be found in the Working Group report. . Estimation of the small sized component (possibly Downs herring) in different areas. " North Sea" = total area of sampling minus 3.a.

Year class	Year of sampling	All 1-ringers in total area (IBTS-1 index) (no/hour)	Small<13 cm 1-ringers in total area (no/hour)	Proportion of small in total area vs. all sizes	Small<13cm 1-ringers in North Sea (no/hour)	Proportion of small in North Sea vs. all sizes	Proportion of small in 3.a vs small in total area
1977	1979	168	11	0.07	12	0.07	0.00
1978	1980	316	108	0.34	106	0.34	0.09
1979	1981	495	51	0.1	41	0.08	0.25
1980	1982	798	177	0.22	185	0.23	0.03
1981	1983	1270	192	0.15	185	0.15	0.10
1982	1984	1516	346	0.23	297	0.20	0.20
1983	1985	2097	315	0.15	298	0.14	0.12
1984	1986	2663	596	0.22	390	0.15	0.39
1985	1987	3693	628	0.17	529	0.14	0.22
1986	1988	4394	2371	0.54	720	0.16	0.72
1987	1989	2332	596	0.26	531	0.23	0.17
1988	1990	1062	70	0.07	62	0.06	0.18
1989	1991	1287	330	0.26	337	0.26	0.05
1990	1992	1268	125	0.1	130	0.10	0.03
1991	1993	2794	676	0.24	176	0.06	0.76
1992	1994	1752	283	0.16	240	0.14	0.21
1993	1995	1346	449	0.33	445	0.33	0.08
1994	1996	1891	604	0.32	467	0.25	0.28
1995	1997	4403	1356	0.31	1089	0.25	0.25
1996	1998	2276	1322	0.58	1399	0.61	0.02
1997	1999	753	152	0.2	149	0.20	0.09
1998	2000	3304	1068	0.32	939	0.28	0.18
1999	2001	2499	328	0.13	307	0.12	0.13
2000	2002	3881	1520	0.39	1436	0.37	0.12
2001	2003	2837	664	0.23	180	0.06	0.75
2002	2004	979	665	0.68	710	0.73	0.01
2003	2005	1015	341	0.34	357	0.35	0.02
2004	2006	900	115	0.13	121	0.13	0.02
2005	2007	1322	303	0.23	304	0.23	0.07
2006	2008	1792	417	0.23	444	0.25	0.01
2007	2009	2339	734	0.31	623	0.27	0.21
2008	2010	1206	279	0.23	286	0.24	0.05
2009	2011	2939	1331	0.45	1407	0.48	0.02
2010	2012	1353	279	0.21	288	0.21	0.04

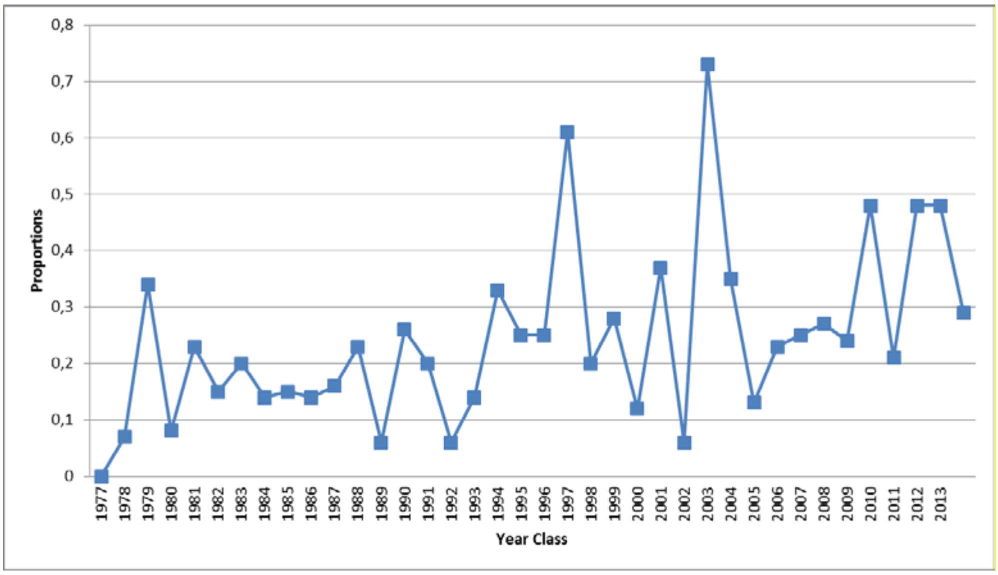


Figure B.3.4.1. North Sea herring. Proportion of small 1-ringers versus all sizes in the North Sea.

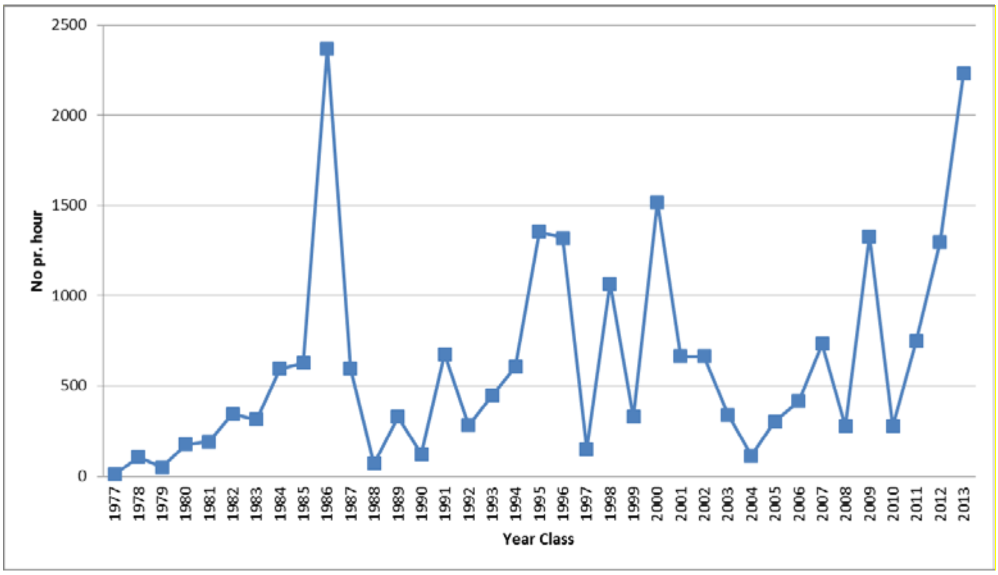


Figure B.3.4.2. North Sea herring. Index (Numbers per hr) of small (<13cm) 1-ringers in the North Sea.

IBTS acoustic information

Since 2007, the IBTS 1st quarter survey area has been extended to the eastern English Channel, and both additional GOV hauls and ring-net sampling are carried out in this area to provide more information on Downs herring (ICES CM 2007/ACFM:11). Acoustic data are also recorded and show large herring schools along the French coaSt The mean density of these shoals of herring, which were found during the survey in a localized area, can however not be raised to represent the whole area. This is due the nature of the IBTS survey design, which does not adopt systematic area coverage with transects. Furthermore, large schools close to the coast in shallow and inaccessible waters were regularly detected with a horizontal echo sounder during the period 2007–

2014. Figure B.3.4.3 shows the catch composition (percentage by age) of the pelagic/bottom hauls carried out on these schools since 2008. In 2014, the 4 winter ring fish represented 61% of the total catch.

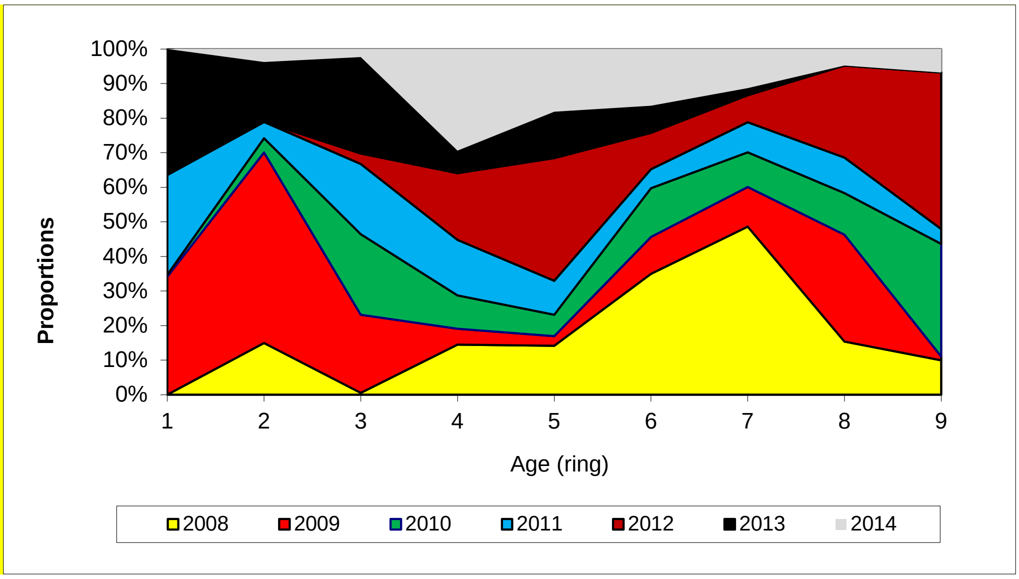


Figure B.3.4.3. North Sea herring. Catch composition (percentage by age) from hauls (pelagic and bottom trawls) in the Eastern English Channel during IBTS 2008 to 2014.

Fisheries and TAC in the 4.c/7.d

Historically, the TAC for herring in 4.c and 7.d has been set as a proportion of the total North Sea TAC and this has varied between 6 and 16% since 1986. The proportion has been relatively high, particularly between 2002 and 2005. However, ICES expressed concerns regarding Downs herring in 2005 and recommended that the proportion used to determine the TAC should be set to the long-term average of the proportions used since 1986 (around 11%). Since 2005, this proportion fluctuated between 9 to 14%. (Figure B.3.4.4). The catches in 2014 in 4.c and 7.d were 38 244 t (TAC 51 704 t). The TAC in 2015 was set to be 48 986 t.

Except in 2010, the tendency to overfish the Downs TAC has markedly reduced since 2005 (Figure B.3.4.5).

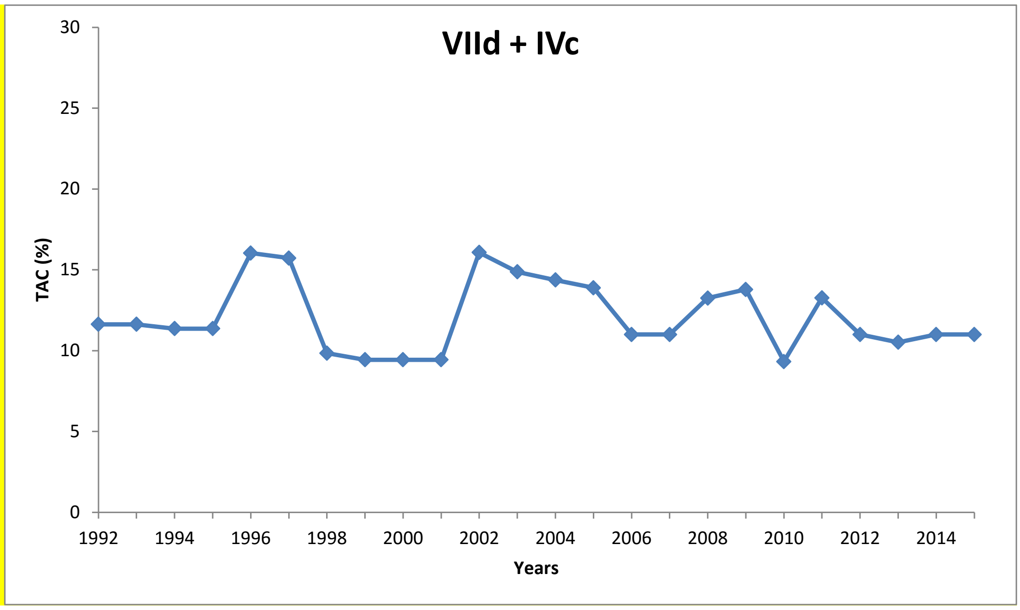


Figure B.3.4.4. North Sea herring. TAC (%) for Divisions 4.c and 7.d.

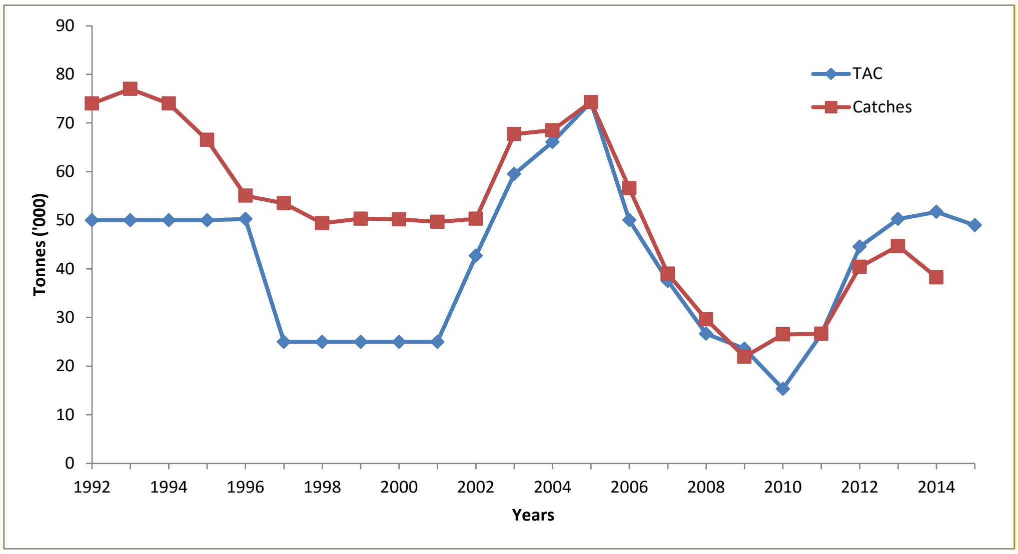


Figure B.3.4.5. North Sea herring. Downs herring in 4.c and 7.d. Comparison of historical catches and TACs.

The Downs herring has been considered highly sensitive to overexploitation (Burd, 1985; Cushing, 1968; 1992). Furthermore, the directed fishery in Q4 and Q1 targets aggregations of spawning herring. Preliminary studies undertaken by HAWG (ICES CM 2006/ACFM:20) based on population profiles suggested that total mortality (Z) was significantly higher for the 1998 and 1999 year classes of Downs herring compared to herring caught in the northern part of the North Sea.

Downs herring is also taken in other herring fisheries in the North Sea and mixes with other components of North Sea herring in the summer whilst feeding. There is also a summer industrial fishery in the eastern North Sea exploiting juvenile Downs and North Sea autumn spawning herring. Otolith microstructure studies of catches from the northern North Sea suggested that the proportion of Downs herring may vary considerably from year to year (26 to 60 %) and may also vary between fleets (Bierman *et al.*, 2010).

Conclusions

The Downs TAC is set up to conserve the spawning aggregation of Downs herring. Uncertainties concerning the status of, and recruitment to, this component of the North Sea herring stock are high, and HAWG is not aware of any evidence to suggest that this measure is inappropriate. HAWG therefore recommends that the 4.c–7.d TAC be maintained at 11% of the total North Sea TAC (as recommended by ICES). This recommendation should be seen as an interim measure prior to the development of a more robust harvest control rule for setting the TAC for Downs herring. A future harvest control rule will have to be supported by increased research effort into dynamics of the components, with a view to increasing the amount of component-resolved information (e.g. catch data and survey data split by component, and incorporation of this information into the assessment model). Any new management approach should provide an appropriate balance of F across stock components and be similarly conservative until the uncertainty about contribution of the Downs and other components to the catch in all fisheries in the North Sea is reduced. Possible methods to approach this problem are discussed by Kell *et al.* (2009).

B.4. Commercial cpue

B.5. Other relevant data

B.5.1 Separation of North Sea Autumn Spawners and III.a-type Spring Spawners

North Sea autumn spawners (NSAS) and 3.a-type spring spawners occur in mixtures in fisheries operating in Divisions 3.a and 4.a East (ICES, 1991/Assess:15; Clausen *et al.*, 2007): mainly 2+ ringers of the Western Baltic Spring Spawners (WBSS) and 0–2-ringers from the NSAS, including winter spawning Downs herring. In addition, several local spawning stocks have been identified with a minor importance for the herring fisheries (ICES, 2001a).

Prior to 1996, the method for separation of these components was based on the use of vertebral counts as described in former reports of this Working Group (ICES, 1990). The method assumes that for autumn spawners, the mean vertebral count is 56.5 and for spring spawners 55.80. The fractions of spring spawners (fsp) are estimated from the formula (56.50-v)/(56.5–55.8), where v is the mean vertebral count of the (mixed) sample with the restriction that the proportion should be one if fsp>=1 and zero if fsp<=0. The method is quite sensitive to within-stock variation (e.g. between year classes) in mean vertebral counts.

The method for separation of the herring stock components has developed the past decade. Prior to 1996, the splitting key used by ICES was calculated from a sample-based mean vertebral count using a cut-off algorithm for calculating the proportion of WBSS in a sample as MIN(1,MAX(0,(VSsample-55.8)/(56.5–55.8))), where VSsample is the sample mean vertebrae count and assuming a population mean VS of 55.8 for WBSS and 56.5 for NSAS. This method is still being used to split samples of Norwegian catches from the transfer area in 4.a EaSt In the period from 1996 to 2001 splitting keys were constructed using information from a combination of vertebrae count and otolith microstructure (OM) methods (ICES, 2001a). From 2001 and onwards, the splitting keys have been constructed solely using the otolith microstructure method which uses visual inspection of season-specific daily increment pattern from the larval origin of the otolith, with the exception of the splitting key made for the mixture area in Subdivision 4.aEast, where vertebrae counts currently is the only method used to split the mixed stock (Mosegaard and Madsen, 1996; ICES, 2004; Clausen *et al*., 2007).

Otolith shape analysis has been used to discriminate between populations for a variety of species and for herring this approach has had increasing success with development of imaging techniques and statistical methods. Both temporal and geographical separation of populations give rise to variation in the shape of otoliths (Messieh, 1972; Lombarte, 1992; Arellano *et al*., 1995). These variations may suggest differences in the environmental conditions of the dominant habitats of populations within a species. However, both genetic and environmental influences have been reported as relevant in determining otolith shape (Cardinale *et al*., 2004). Using Fourier Series Shape Analysis on otoliths from Alaskan and Northwest Atlantic herring, Bird *et al*. (1986) showed that otolith shape reflects population differences as well as differences between year classes of the same population. Sagittal otoliths have certain morphological features that are laid down early in the ontogeny of the fish (Gago, 1993), and measurements of internal otolith shape in adult herring has proven a powerful tool for stock discrimination (Burke *et al*., 2008).

Image analysis software (MATLAB) has been developed to automatically extract otolith contour curves and calculate 60x4 Elliptic Fourier Coefficients from one or two herring sagittal otoliths per image in batches with more than 1000 images.

From 2009 otolith shape analysis has been used as a supplementary method to increase sample size for estimating stock proportions of NSAS and WBSS in mixing areas of Division 3.a. For each assessment year individual population identity has been established by OM visual inspection and used as a baseline for assignment of shape characteristics to the involved stock components. A baseline of about 800–1200 otoliths with known hatch type has then been used as calibration in an age-structured discriminant analysis where additionally 3000–4000 otolith shapes have been assigned to one of the two hatch types using a combination of shape Elliptic Fourier Coefficients, otolith metrics, fish metrics, length, weight and maturity as well as longitude, latitude, and seasonal parameters.

B.5.1.1. Validation

The purpose of classifying individual spawning type is to estimate proportions of the two major stock components, by age, in both catches and surveys from the different areas and seasons. Combining OM with otolith shape and fish meristic characters in a discriminant analysis approach is expected to increase precision of the estimated stock proportions. Validation of the shape and meristic based methodology was performed using samples of known spawning type from OM analysis.

OM and otolith shape data from the 2010 HAWG were used as a typical example of the procedure for estimating proportions of hatch type representing North Sea autumn and winter spawners and Western Baltic spring spawners in the samples. The data were disaggregated into age groups 0, 1, 2 and 3+ and individuals of known autumn/winter or spring hatched types were used to assign the corresponding shape parameters and fish metrics from the same individuals by cross validated nonparametric nearest neighbour discriminant analysis.

The individual assignment of 1279 otoliths into known hatch type varied somewhat among hatch types and ages (2%–100%) but exhibited an overall error rate of 15.7%

(see text table), however, more importantly, the average absolute error of the proportions of WBSS was only 2%, indicating the robustness of the method for up-scaling the baseline to the larger production sample.

Stock assignment data from 2009 commercial samples of herring in Division 3.a.

		assigned to type		known type	estimated	deviasion		% error in	
Age group	known type	WBSS	NSAS	number	number	Individ. assignm.	prop.	Individ. assignm.	prop.
0	WBSS	34	13	47	44	13	3	27.7%	-6.4%
	NSAS	10	145	155	158	10	3	8.2%	1.9%
1	WBSS	188	72	260	254	72	6	27.7%	-2.3%
	NSAS	66	204	270	276	66	6	26.1%	2.2%
2	WBSS	288	14	302	305	14	3	4.6%	1.0%
	NSAS	17	3	20	17	17	3	82.4%	-15.0%
3+	WBSS	216	4	220	221	4	1	1.8%	0.5%
	NSAS	5	0	5	4	5	1	100.0%	-20.0%
		824	**455**	**1279**	**1279**	**201**	**26**	**15.7%**	**2.0%**

B.5.1.2. Conclusions

The two management stocks mixing in Division 3.a represent a complex underlying subpopulation structuring, where local adaptation, especially in the WBSS component (Bekkevold *et al*., 2005) may drive an evolutionary divergence of otolith shape and create within-stock variation patterns. Nearest neighbour discriminant analysis has been chosen to avoid biased proportions in this situation; however the results still exhibit a small trend in the proportion error with changing proportions. The overall proportion error of 2% is in the order of, or less than, reported assignment errors using OM visual inspection (Clausen *et al*., 2007) and would probably increase precision of the total production sample in relation to the baseline. However the subject needs a more thorough analysis including all years in the emerging time-series.

In the present case where distinction between two stocks may be based on genotypic as well as phenotypic expressions of contrasting life-history characteristics, the chances of successful discrimination are substantial and appear to mainly depend on sampling effort.

The current vertebral count based estimation of WBSS in catches of herring in the transfer area of 4.a East should be combined with an OM calibrated method exploiting differences in meristic characters among stocks such as maturity index, length- weight-age relationships, etc. This appears to be a way forward to a more reliable estimate of the catches of WBSS in the North Sea.

The separation of Downs and other components of the NSAS are yet to be implemented and prior to such an increase in variables (and sources of uncertainty) comparative analysis of assessments with and without such splitting is needed. Such analyses are not yet a possibility and assessment models capable of running assessments on several stocks simultaneously are highly warranted. Analysis of the stock proportions and their sources of variation at different sampling levels is an important tool when planning the optimal sampling strategy for precise estimates of stock proportions-at-age.

B.5.2 Mixing of North Sea spawning components

The biomass of herring in the North Sea is dominated by autumn spawning fish. The known spawning grounds, located along the east coast of Great Britain, show fine spatial structure (Dickey-Collas *et al*., 2010; Figure B.5.2.1) and significant events have occurred at the individual bank level (e.g. recolonisation of the Aberdeen bank ground (Corten, 1999), loss of the Dogger Bank population). However, the individual local spawning groups are typically grouped into four "spawning components" that spawn at four main locations: Orkney/Shetland; Buchan; Banks; and Downs. These spawning components exhibit different growth rates, meristic characteristics and recruitment patterns (Bjerkan, 1917; Cushing and Bridger, 1966). The different components mix during part of the year and most likely experience different fishing pressures but are assessed and managed as one unit (Simmonds, 2007). Genetic studies have not shown a clear distinction between the components of herring in the North Sea (Ruzzante *et al*., 2006; Gaggiotti *et al*., 2009). Despite a decline in abundance of several orders of magnitude during the stock collapse in the late 1970s (Cushing, 1992; Dickey-Collas *et al*., 2010), there has been no loss of genetic diversity (Mariani *et al*., 2005). The current definition of the North Sea herring stock of autumn and winter spawners as a single management unit appears to have operated well in the past (Reiss *et al*., 2009; Simmonds, 2009), despite changes in the relative strengths of the different spawning components and in their relative importance during collapse and recovery.

This complex substock structure of North Sea herring, with its different spawning components, results in the production of offspring with different morphometric and physiological characteristics, different growth patterns and differing migration routes (see Figure B.5.2.1). A healthy North Sea herring stock is not just one where the fishing mortality on the stock is sustainable and the biomass of herring high enough to maintain successful recruitment and other ecosystem services (such as prey for top predators), but also where the phenotypic complexity and sub-stock structure is maintained, thus increasing the resilience of the population (see Schmidt *et al*., 2009).

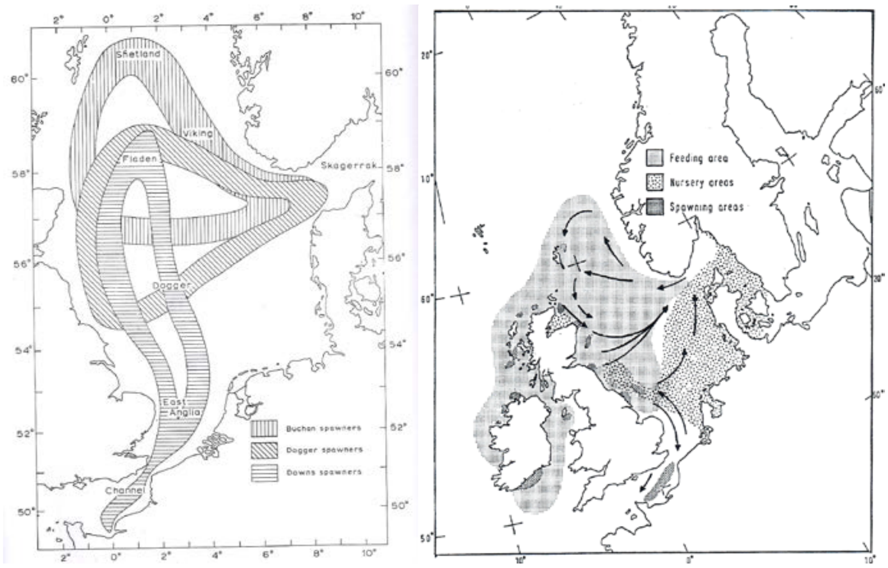
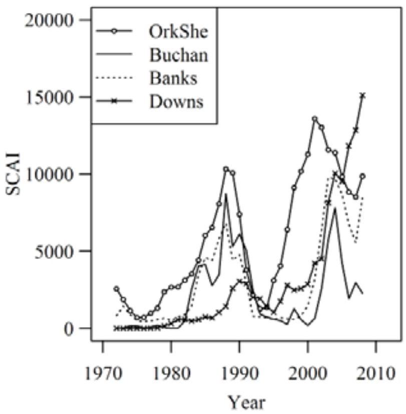


Figure B.5.2.1. Schematic of assumed generalised migration patterns of North Sea herring, taken from Cushing and Bridger (1966) and Burd (1978).

The productivity of the spawning components also varies. The three northern components show similar population trends and differ from the Downs component (Payne, 2010); this appears to be influenced by different environmental drivers (Fässler *et al.*, 2011). Although the different components mix outside their spawning season and are exploited together, each component is thought to have a high degree of population integrity (Iles and Sinclair, 1982) and, therefore, could be expected to have relatively unique population dynamics.

The individual spawning components have been surveyed on a regular basis by the annual international herring larval survey (IHLS) since the early 1970s (Heath, 1993). These surveys enable investigation of the dynamics of each component (Payne, 2010; Figure B5.2.2).



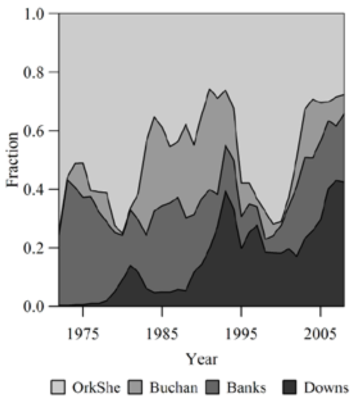


Figure B.5.2.2. a) Time-series of spawning component abundance index (SCAI) for each individual component in the North Sea autumn spawning herring stock b) Time-series of the fraction contribution of each spawning component to the total North-Sea autumn spawning herring stock, as estimated from the spawning component abundance indices (SCAIs). Shaded areas are arranged from top to bottom according to the north-to-south arrangement of the components.

The individual components each follow a broad trend reflecting that of the total stock (i.e. collapse in the late 1970s, peaks in around 1990 and 2000. Appreciable differences also exist, especially between the winter spawning Downs and the other autumn spawning components, leading to the contribution to the stock by each component varying over time (Figure B.5.2.2). The Orkney/Shetland component is generally the largest but its contribution has varied between 25% and 80%, whereas, the Downs component has varied from almost negligible in the 1970s to 40% of the stock in recent times (Payne, 2010). In some years there may be a gradient in the spatial distribution by component but this is not true for all years (Bierman *et al.*, 2010).

The variation in the component abundances has important implications for the input of NSAS juveniles into Subdivision 3.a. Each component represents a spatially and temporally different starting point for the larvae that are ultimately observed in the Skagerrak as juveniles. In making the transition from spawning ground to nursery ground, the different components will experience different conditions (food availability, temperature, and predation) along the way. Accounting for these differences in both starting points and the number of larvae seeded is therefore critical to predicting the number of individuals that make it to the nursery grounds.

In addition there are still historic spawning grounds that have not been recolonised since the collapse of the herring stock in the 1970s (Figure B.5.2.3; taken from Corten, 2002).

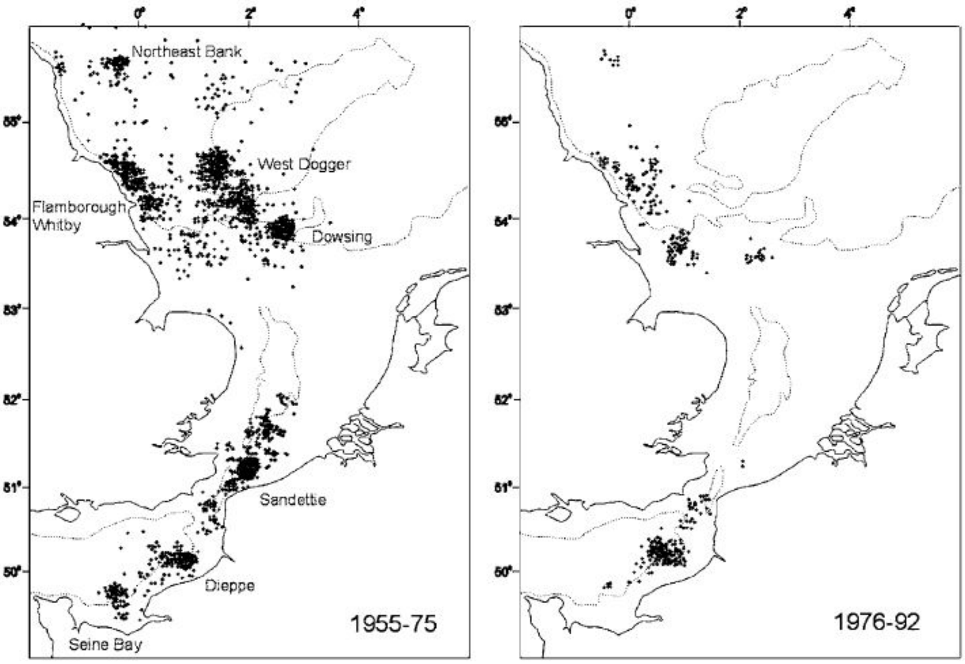


Figure B.5.2.3. The number of spawning grounds in the central and southern North Sea. Each dot represents a catch of spawning herring. Data combined from Dutch fisheries from before the stock collapse (1955–1975) and for the period of the recovery (1976–1992). From Corten, 2002.

C. Assessment methods and settings

C.1. Choice of Stock assessment model

The North Sea autumn spawning (NSAS) herring stock was assessed using the assessment model ICA (Integrated Catch-at-Age) with a separable period and Virtual Population Analysis (VPA) part, from the mid-1990s until 2011. Despite the computational limitations when the model was first created, it was generally regarded as performing well and was considered 'ahead of its time'. However, in later years, a number of technical problems with this assessment became apparent, including non-convergence of the model, its ability to only take a maximum of fifty-nine years of data, the inability to fix technical issues (the core minimisation library is no longer maintained resulting in the inability to compile the ICA Fortran code). Advances in computational power and the development of new assessment methods ultimately led to this model being superseded.

The WKPELA benchmark meeting in February 2012 developed and evaluated the "state–space" assessment model (SAM) approach for NSAS herring. This modelling framework has a number of highly desirable characteristics, such as the stochastic treatment of all observations, a full statistical framework for evaluating model results, open source and cross platform source code, and an extremely high degree of flexibility allowing ready customisation to the peculiarities of the stock. The state–state approach was first pioneered by Gudmundsson (1987; 1994) and Fryer (2002), however, the computationally intensive nature of the method has meant that state–space models have hereto not yet become widespread. Recent advances in both software and hardware in recent years have, however, opened the door to these approaches.

C.2. Model used as basis for advice

The NSAS herring assessment model is based on the state–space assessment model (SAM) (Nielsen *et al*., 2012). Version details and model configuration are listed below. Technical details of the SAM framework can be found in the peer-reviewed literature (Nielsen *et al.*, 2012)

SAM Model details:

The SAM source code is available from the “Stock assessment” version control repository, http://code.google.com/p/stockassessment/: the code used corresponds to revision 7.

Scripts, packages and running environment

The SAM environment detailed above is encapsulated into the Fisheries Library in R (FLR) (Kell *et al.*, 2007) in the form of the package “FLSAM”. All assessments are performed with version 0.99(2013-03-17) of FLSAM, together with version 2.4 of the FLR library (FLCore). The FLCore and FLSAM packages are hosted under version control at the “R-forge” repository, https://r-forge.r-project.org/projects/flr/. Built packages of FLSAM are available from the HAWG stock assessment repository, https://github.com/ICES-dk/wg_HAWG . All scripts to perform the assessment are available from the same location in the folder “tree/master/NSAS”.

C.3. Assessment model configuration

Input data types and characteristics (Y=data year):

Name	Type	Year range	Age range	Data Modifications	Variable from year to year?
Caton	Catch in tonnes	1947 to Y	-	-	Yes
Canum	Catch-at-age in numbers	1947 to Y	0–8+	See note 1	Yes
Weca	Weight-at-age in the commercial catch	1947 to Y	0–8+	-	Yes
West	Weight-at-age of the spawning stock at spawning time.	1947 to Y	0–8+	See note 2	Yes
Mprop	Proportion of natural mortality before spawning	1947 to Y	0–8+	-	No
Fprop	Proportion of fishing mortality before spawning	1947 to Y	0–8+	-	No
Matprop	Proportion mature-at-age	1947 to Y	0–8+	-	Yes (from 1983 onwards: constant prior to this)
Smoothed_span50_M_NotExtrapolated_NSAS	Natural mortality	1963 to 2010	0–8+	See note 3	Yes

[1] **Catch-at-age data for the years 1978–1979 are exclude from the assessment model fit. All other data, including the fishery-independent surveys, are included for these years.**

[2] **The procedure to calculate the weight-at-age in the stock (*west*), given a set of weight-at-age values as calculated from the acoustic survey, has been standardised and applied uniformly to the raw data. *West* values used in the assessment are calculated as the running mean of data in the assessment year together with the preceding two years (*i.e.*, $s_i=(w_{i-2}+w_{i-1}+w)/3$, where s_i is the smoothed weight and w_i is the raw weight in year *i*)**

[3] **Natural mortality estimates are derived from the most recent SMS model used in WGSAM, presently the key run from 2015 (ICES, 2015). The input data to the assessment are the smoothed values (loess smoother, span=0.5, order=2) of the raw SMS model annual *M* values, which are variable both at-age and over the time period 1974–2014. Natural mortality in years outside this time-period are filled and estimated for each age as a five year running mean in the forward direction for 2014+ (*i.e.* $m_i = (M_{i-1}+M_{i-2}+M_{i-3}+M_{i-4}+M_{i-5})/5$ where m_i is the smoothed natural mortality and M_i is the raw natural mortality in year *i*) and in the reverse direction for years prior to 1974 i.e. $m_i = (M_{i+1}+M_{i+2}+M_{i+3}+M_{i+4}+M_{i+5})/5$.**

Type	Name	Year range	Age range (wr)
Tuning fleet	IBTS-Q1	1984 to Y+1	1
Tuning fleet	IBTS0	1992 to Y+1	0
Tuning fleet	HERAS	1989 to Y (1997 to Y for age 1)	1–8+
Tuning fleet	SCAI	1972 to Y	SSB

Many of the data time-series are made available with a 9+ age group. In such situations, an age 8+ plus group value is produced by arithmetic sum of age 8 and 9 for numbers-at-age variables and an arithmetic mean for other variables.

Model configuration

An example of the SAM model configurations used in the FLSAM package, for the 2011 assessment, is given below. Note that the "maxyear" argument in the range slot should be set to value of the intermediate year in other situations.

```
An object of class "FLSAM.control"

Slot "name":

[1] "NSAS Herring"

Slot "desc":

[1] "North Sea Autumn Spawning Herring Assessment"

Slot "range":

      min       max plusgroup   minyear   maxyear   minfbar   maxfbar
        0         8         8      1947      2011         2         6

Slot "fleets":

  catch    SCAI   HERAS IBTS-Q1   IBTS0
      0       3       2       2       2

Slot "plus.group":

plusgroup
     TRUE

Slot "states":

         age
  fleet    0  1  2  3  4  5  6  7  8
  catch    1  2  3  4  5  6  7  8  8
  SCAI    NA NA NA NA NA NA NA NA NA
  HERAS   NA NA NA NA NA NA NA NA NA
  IBTS-Q1 NA NA NA NA NA NA NA NA NA
  IBTS0   NA NA NA NA NA NA NA NA NA

Slot "logN.vars":

0 1 2 3 4 5 6 7 8
1 2 2 2 2 2 2 2 2

Slot "catchabilities":

         age
  fleet    0  1  2  3  4  5  6  7  8
  catch   NA NA NA NA NA NA NA NA NA
  SCAI    NA NA NA NA NA NA NA NA NA
  HERAS   NA  3  3  4  4  5  5  5  5
  IBTS-Q1 NA  1 NA NA NA NA NA NA NA
```

```
 IBTS0    2 NA NA NA NA NA NA NA NA
Slot "power.law.exps":
       age
 fleet    0  1  2  3  4  5  6  7  8
 catch   NA NA NA NA NA NA NA NA NA
 SCAI    NA NA NA NA NA NA NA NA NA
 HERAS   NA NA NA NA NA NA NA NA NA
 IBTS-Q1 NA NA NA NA NA NA NA NA NA
 IBTS0   NA NA NA NA NA NA NA NA NA
Slot "f.vars":
       age
 fleet    0  1  2  3  4  5  6  7  8
 catch    1  1  2  2  3  3  4  4  4
 SCAI    NA NA NA NA NA NA NA NA NA
 HERAS   NA NA NA NA NA NA NA NA NA
 IBTS-Q1 NA NA NA NA NA NA NA NA NA
 IBTS0   NA NA NA NA NA NA NA NA NA
Slot "obs.vars":
       age
 fleet    0  1  2  3  4  5  6  7  8
 catch    3  4  4  4  4  4  5  5  5
 SCAI    NA NA NA NA NA NA NA NA NA
 HERAS   NA  6  7  7  7  7  8  8  8
 IBTS-Q1 NA  1 NA NA NA NA NA NA NA
 IBTS0    2 NA NA NA NA NA NA NA NA
Slot "srr":
[1] 0
Slot "timeout":
[1] 3600
```

This example configuration encapsulates the following configuration options and bindings:

Minimum age 0, maximum age 8

The model is configured to cover the full time-series of catch data plus the intermediate year i.e. from 1947 to the intermediate year. In the above example, the intermediate year is 2011.

Mean fishing mortality is defined as ages 2–6

The four data sources are included in the following manner

"Catch-at-age" observations are treated as a fishing fleet (fleet =0)

The SCAI index is treated as an SSB index (fleet=3)

The HERAS, IBTS-Q1 and IBTS0 indices are treated as numbers-at-age indices (fleet=2)

The oldest age (8) is treated as a plus group. This is specified in the range slot, and again in the "plus.group" slot

The fishing mortalities at each age are estimated by independent random walks (one for each age), with the exception of ages 7 and 8+, which are represented by a single common random walk. This is expressed in the model configuration above by binding the "state" parameters for ages 7 and 8.

The variances in the estimated numbers at age (logN.vars) are represented by two parameters; one variance for the age 0 numbers and a second for the other ages.

Catchabilities of the individual surveys are bound as follows:

The IBTS-1Q and IBTS0 surveys, each of which contain only a single age group, are represented each with a single catchability parameter (catchabilities slot)

The HERAS survey is represented by three catchability parameters: one for ages 1–2, one for ages 3–4 and one for ages 5–8 (catchabilities slot)

All observations are represented with a linear relationship (i.e. no parameters activated in the "power-law" slot)

The variances of the fishing mortality random walks (f.vars) are bound together in sequential age pairs i.e. four parameters are used, one for age 0–1, one for age 2–3, one for age 4–5, and one for age 6–8

The observation variances of the surveys (obs.vars slot) are bound as follows:

Both the IBTS-1Q and IBTS0 indices are fitted with their own observation variances

The HERAS observation variances are bound into three groups: one covering age 1 on its own, one for ages 2–5 and one for ages 6–8+.

The catch observation variances are also bound into three groups: one covering age 0 on its own, one for ages 1–5, and one for ages 6–8+.

No stock–recruitment relationship is imposed upon the model i.e. the "srr" slot is set equal to 0.

The model is not allowed to use more than one hour to converge i.e. the "timeout" slot is set of 3600

Other notes

Survey data in the intermediate year should be included wherever possible. In particular, the IBTS-1Q and IBTS0 surveys performed in January and February should be ready in time for the assessment meeting (typically in March).

There is no method in the current version of SAM to explicitly bind or alter the representation of the SCAI SSB index in the model, i.e. the catchabilities, observation variances and use of a power-law model.

It is not possible with the current configuration of the SAM framework to reliably estimate the fishing mortality around the time of the closure of the fishery (late 1970s) as the associated rapid changes in F are a clear violation of the model assumptions. Catch data from 1978–1979 are excluded from the assessment for this reason. Furthermore, the fishing mortalities estimated by the model during this time are not considered reliable and therefore F values from 1977–1980 should not be reported. SSB and recruitment, however, can still be estimated during this period (albeit with increased uncertainties). Stock summary plots and tables should be adjusted manually to reflect these limitations.

D. Short-term prediction

A multifleet, multioption, deterministic short-term prediction tool (MFSP) has been used for many years and a FLR implementation of the tool has replaced the MFSP from 2009 onwards. The good agreement between predicted biomass for the intermediate year and SSB taken from the assessment one year after demonstrates that the current prediction procedure for stock numbers works well. The FLR implementation has been extended to allow Monte-Carlo simulations, enabling a stochastic approach by varying population parameters. The stochastic approach is used for illustration purposes only while the deterministic approach is used to provide advice.

Method

Both the Short-Term Forecast Module North Sea (STFMNS, Hintzen) and the MFSP program were extensively tested in 2009 to ensure that they both gave identical results. For the North Sea herring stock, managers have agreed to constrain the total out-take at levels of fishing mortalities for ages 0–1 and 2–6, and need options to show the trade-off between fleets within those limits. In total four fleets are considered; a dedicated human consumption fishery in the North Sea, an industrial fishery in the North Sea, a dedicated human consumption fishery in 3.a, and an industrial fishery in 3.a. In the short term predictions, recruitment in the TAC year (intermediate year) is taken directly as predicted from the assessment model, and recruitment in the advice year is assumed similar to the recruitment regime of lower productivity since 2002.

Input data

Fleet definitions

The current fleet definitions are:

In North Sea:

Fleet A: Directed herring fisheries with purse seiners and trawlers. Bycatches in industrial fisheries by Norway are included.

Fleet B: Herring taken as bycatch under EU regulations.

In Division 3.a:

Fleet C: Directed herring fisheries with purse seiners and trawlers

Fleet D: Bycatches of herring caught in the small-mesh fisheries

The fleet definitions are those defined in Section A.2 above.

In some years, it has been agreed that Norway can transfer parts of its 3.a quota into the North Sea. When estimating the expected catch in the intermediate year, it is assumed that this transfer takes place, hence the assumed catch by the C-fleet of both stocks combined is reduced and the catch by the A-fleet increased with the agreed amount.

Input Data for short-term projections: All the input data for the short-term projections are shown in the table below:

Type	Name	Basis
Weca	Weight-at-age in the commercial catch	The three years average mean weight-at-age for each fleet are used for all prediction years, unless there are indications that some year class has abnormal growth
West	Weight-at-age of the spawning stock at spawning time.	The weights-at-age applied in the last assessment year are used for all prediction years. These are running averages of the raw data calculated as the running mean of data in the assessment year (Y) together with the preceding two years (i.e., Y-2,Y-1,Y)
F	Fishing mortality-at-age in the stock	Selection by fleet-at-age is calculated by splitting the total fishing mortality in the assessment year at each age proportionally to the catch numbers by fleets at that age. These selections-at-age are used for all years in the prediction. For illustration purposes only: variability in the total fishing mortality is generated from a multi-variate random distribution informed by the variance-co-variance matrix as obtained from the assessment output
N	Stock numbers	For the start of the intermediate year the stock numbers at age by 1. Jan that year are taken from the calculations made by SAM. For illustration purposes only: variability in the numbers-at-age is generated from a multi-variate random distribution informed by the variance-co-variance matrix as obtained from the assessment output
Mprop	Proportion of natural mortality before spawning	Standard value of 0.67
Fprop	Proportion of fishing mortality before spawning	Standard value of 0.67
Matprop	Proportion mature-at-age	Average of maturity-at-age of the most recent three years. For illustration purposes only:Varies over time by sampling from historic observations on maturity-at-age values
Natmor	Natural mortality	Average of mortality-at-age of the most recent five years from the smoothed SMS output
R	Recruitment in intermediate (Y+1), advice(Y+2) and continuation (Y+3) years	Recruitment in the intermediate year is estimated inside the SAM assessment model. Recruitment in the advice and continuation year1 is calculated as the weighted geometric mean of the yearsY-10 to year Y. The inverse variance estimate, obtained from SAM, is used as weighting criteria. For illustration purposes only:Variability in the stock numbers propagates through in the recruitment estimates.

[1] For the prediction years, the recruitment has, in recent years, been set to the geometric mean of the recruitments of the year classes from 2002 onwards, as estimated in the assessment of the data year. The low recruitment was assumed because all the year classes from 2002 onwards have been poor except for 2008 year class. Analysis of the time-series of SSB and recruitment data by the SGRECVAP (ICES, 2006) clearly indicates a shift in the recruitment success after 2001. The underlying cause for the change in 2001 is not clear, but there is no evidence to justify an assumption of long term average recruitment in the near future. Consequently, the advice is adapted to the current low recruitment regime.

Prediction

Assumptions for the intermediate year

A-fleet: The TAC for the A fleet has been over-fished every year since 2003 until 2008. Since 2009 however, there is no indication of over-fishing anymore. Hence, catches equal the TAC in the intermediate year.

The catches by the B-fleet have been well below the bycatch quota for the B-fleet. The quota has been reduced recently, and the fraction used has increased. Therefore, the fraction of the TAC in the intermediate year is assumed to be equal to the fraction used in the assessment year. Also the C and D fleets have NSAS catches well below the total Division 3.a quota, partly because the quota also includes WBSS herring. For 2010, the same fraction as in 2009 was assumed; previously a 3 years average has been used in some cases.

Management option tables for the TAC year

The EU-Norway agreement on management of North Sea herring was updated in 2008, to adapt to the present reduced recruitment, accounting for the results by WKHMP (ICES, 2008). The revised rule specifies fishing mortalities for juveniles (F0–1) and for adults (F2–6) not to be exceeded, at 0.05 and 0.25 respectively, for the situation where the SSB is above 1.5 million tonnes. When the SSB is below 1.5 million tonnes F is reduced to give:

F2–6 = 0.25-(0.15*(1500-SSB)/700),

with allowance for a stronger reduction in TAC if necessary. Below 0.8 million tonnes F2–6 = 0.1 and F0–1 = 0.04.

Furthermore, there is a constraint at 15% change in the TAC from one year to the next. The F0–1 and F2–6 stated in the rule are assumed to apply to the total F summed over all fleets. The SSB referred to is taken to be the SSB in the prediction year. For example, the fishing mortalities for 2010 should reflect its consequence for SSB in 2010.

Catches by the C and D fleet influence the fishing opportunities for the B-fleet in particular, since the NSAS herring caught by these fleets mostly are at age 0–2. The assumed catch of NSAS herring by the C and D fleets is derived according to a likely TAC for WBSS herring in a three step procedure:

1) The fraction of the total TAC for WBSS that is taken in Division 3.a is assumed to be the same as the average of the last three years, giving an expected catch of WBSS in Division 3.a.
2) The WBSS caught in Division 3.a is allocated to the C and D fleets assuming the same share as the average of the last three years. The total expected catch of WBSS in 3.a is split accordingly, which gives expected catch of WBSS by fleet.
3) Using the ratio between NSAS and WBSS in the catches by each fleet, the total catch by fleet and the catch of NSAS by fleet are derived from the catch of WBSS by fleet.

These expected catches of NSAS by the C and D fleets are used as catch constraints in the prediction.

The basis for deriving these catches is weak. The main purpose is to provide realistic assumptions on the impact of these fleets when predicting the catches for the North

Sea fleets. The effect of other assumptions for the C and D fleet should be calculated if needed, but are not presented in the advice.

The catches for the A and B fleets are derived according to the harvest rule (see details below in Concepts of management plan).

When the harvest rule leads to SSB below the trigger biomass (1.5 million tonnes), an iterative procedure is needed to find a fishing mortality and a corresponding SSB in accordance with the rule. At present, this is done by a numerical minimisation.

E. Medium-term predictions

F. Long-term predictions

G. Biological reference points

In 2016, ICES requested precautionary and limit reference points for all stocks. The expert group proposed values, which were reviewed by RGPA and finalized in the ADG_NorthSea_2016. These are the reference points used in the 2016 advice. More information is available in the expert group report (2016).

The updated reference points and their technical bases are as follows.

Reference point	Value	Technical basis	Source
MSY $B_{trigger}$	1 500 000 t	Biomass trigger value that results in <5% probability of being below Blim when the ICES MSY AR is applied.	ICES (2016)
F_{MSY}	0.33	Stochastic simulations with Beverton and Ricker stock–recruitment curve from short time-series (2002–2015).	ICES (2016)
B_{lim}	800 000 t	Breakpoint in the segmented regression of the stock–recruitment time-series (1985–2015).	ICES (2016)
B_{pa}	1 000 000 t	Bpa = Blim × exp(1.645 × σ) with σ ≈ 0.10, based on the average CV from the terminal assessment year.	ICES (2012b)
F_{lim}	0.39	FP50% from stochastic simulations with Beverton and Ricker stock–recruitment curve (2002–2015).	ICES (2016)
F_{pa}	0.34	Fpa = Flim × exp(−1.645 × σ) with σ ≈ 0.08, based on the average CV from the terminal assessment year.	ICES (2016)
SSBMGT	800 000 t 1 500 000 t	Informed by simulations and chosen by managers.	EU–Norway (2014)
F_{MGT}	Fages (wr)0–1 = 0.05 F ages (wr)2–6 = 0.26	SSB is greater than the SSBMGT upper trigger of 1.5 million t (based on simulations).	EU–Norway (2014)
	Fages (wr)0–1 = 0.05 F ages (wr)2–6 = 0.26 − (0.16 × (1 500 000−SSB) / 700 000)	SSB is between the SSBMP triggers of 0.8 and 1.5 million t (based on simulations).	EU–Norway (2014)
	F ages (wr)0–1 = 0.04 F ages (wr)2–6 = 0.10	SSB is less than the SSBMP lower trigger of 0.8 million t (based on simulations).	

Prior to 2016, reference points were as follows.

The North Sea herring is nominally being managed by a precautionary management plan. It has been considered that the critical issue is identifying the risk of SSB falling below B_{lim}. The following sections on limit reference points is adapted from ICES, WKHMP (ICES CM 2008 (ACOM:27)) and explores and discusses the issues about precautionary status of the management of North Sea herring.

	Type	Value	Technical basis
Management plan	F_{MP}	$F_{0-1} = 0.05$ $F_{2-6} = 0.25$	If SSB greater than SSB_{MP} upper trigger of 1.5 million t (based on simulations).
		$F_{0-1} = 0.05$ $F_{2-6} = 0.25 - (0.15*(1500000-SSB)/700000)$	If SSB between SSB_{MP} triggers 0.8 and 1.5 million t (based on simulations).
		$F_{0-1} = 0.04$ $F_{2-6} = 0.10$	If SSB less than SSB_{MP} lower trigger of 0.8 million t (based on simulations).
MSY Approach	MSY $B_{trigger}$	not defined	
	F_{MSY}	0.25	Simulations under different productivity regimes, research between 1996 and 2010.
Precautionary approach	B_{lim}	800 000 t	< 0.8 million t; poor recruitment has been experienced. Defined in 1997/2008.
	B_{pa}	1.3 million t	B trigger in the previous harvest control rule.
	F_{lim}	not defined	
	F_{pa}	$F_{2-6} = 0.25$	Target Fs in the harvest control rule.

The benchmark assessment performed in WKPELA 2012 revised the perception of the stock and the current management plan is preconditioned on the former perception of the stock from the then applied assessment methodology. HAWG question the validity of the current management plan. The analysis carried out by WKPELA 2012 implies that the reference points for NSAS may have shifted under the perception of the stock assessment and thus a full revision of the existing management plan for NSAS is highly warranted.

Currently the reference points listed in the above table are considered appropriate for the NSAS stock until revised in the upcoming Management Strategy Evaluation (MSE).

The B_{lim}

The 1998 Study Group on Precautionary Approach to Fisheries Management determined reference points for North Sea herring that were adopted by ICES (ICES CM 1998/ACFM:10). The B_{lim} (800 000 tonnes) was set at a level below which the recruitment may become impaired and was also the formally used MBAL. In 2007, WKREF (ICES CM 2007/ACFM:05) explored limit reference points for North Sea herring and concluded that there is no basis for changing B_{lim}. In 2011, WKHERMP agreed that there was still no basis for changing B_{lim}. A low risk of SSB falling below B_{lim} was therefore the basis of ICES precautionary advice. The evaluation of the lower breakpoint in the benchmark meeting (ICES, WKPELA 2012) showed that the currently used 800 000 tonnes does not seem to have changed under the new perception of the stock. At the WKHELP (ICES CM 2012/ACOM:72) meeting, B_{lim} was re-evaluated following the approach from the benchmark meeting (ICES, WKPELA 2012). A segmented regression stock–recruitment relationship fit to the 1985–2011 pairs as estimated from the 2012 stock assessment gave an estimated breakpoint at about 0.8 million tonnes. When only pairs from 2003 were considered (start of low recruitment survival period), the lowest recruitment observed corresponded to an SSB of 0.8 million tonnes. On this basis B_{lim} was suggested to be at 0.8 million tonnes.

F_{pa} and B_{pa}

Under the current management plan F_{pa} = 0.25 is the F target value in the harvest control rule. The current B_{pa} = 1.3 million tonnes was the trigger point in the LTMP established in 1998. These targets, used in the management plan (which began in 1997), were recommended by the Study Group on Precautionary Approach to Fisheries Management and adopted by ICES as the precautionary reference points (ICES CM 1998/ACFM:10). This means that the precautionary reference points were taken from the previous management plan. In the management plan, the target fishing mortalities were intended as targets and not as limits. They were based on an investigation of risk to falling below 800 000 t SSB, F_{MSY} and consideration of fisheries on both juvenile and adult herring (ICES CM 1997/ACFM:08).

Since WKHELP (ICES CM 2012/ACOM:72) F_{pa} is no longer considered a relevant reference point and B_{pa} has been re-evaluated based on the suggested B_{lim} of 0.8 million tonnes and the uncertainty in the SAM assessment from 2001 to 2011. The assessment indicates that on average, the uncertainty associated with the terminal SSB estimate is in the order of a 10% CV. The assumed risk to fall below B_{lim} while the stock assessment indicates SSB to be at B_{pa} was set at 5%. The following equation has therefore been used to calculate the value of B_{pa}: $\log(B_{lim}) = \log(B_{pa})$ - upper confidence limit * CV. This results in an estimate of B_{pa}, rounded upwards to the nearest 100 000 t of 1 000 000 t.

Note that in this exercise, retrospective bias in the assessment has not been taken into account. The mechanisms behind, and the dynamics of change in, bias are not sufficiently understood. Although the time-series does not indicate any drastic changes in bias pattern from one year to the next, attention should be paid to indications of shifting selection pattern that could be a sign of overestimating SSB.

$B_{trigger}$

No updated $B_{trigger}$ value has been agreed based on the findings from WKHELP (ICES CM 2012/ACOM:72).

The $B_{trigger}$ of the management plan ($B_{MGTtrigger}$) was changed in November 2008 from 1.3.million to 1.5 million tonnes after evaluation and consultation with the stakeholders. Thus currently the $B_{MGTtrigger}$ and B_{pa} are different at 1.5 million tonnes and 1.0 million tonnes respectively. **$B_{MGTtrigger}$ is a harvest rule parameter and is not a reference point by which to judge stock status.** At WKHerTAC that took place in January 2015, a range of $B_{MGTrigger}$ values were evaluated from 1.0 to 1.5 million tonnes. All were considered to be precautionary.

MSY framework for North Sea herring

In 2010 ACOM agreed with HAWG that F_{MSY} for NSAS was 0.25. This was supported by WKFRAME2. The analyses carried out by the 2012 benchmark suggested that MSY reference points may vary over time. Further, WKPELA 2012 suggested that a minor increase in F_{MSY} might be appropriate given the increase in SSB resulting from the FLSAM benchmark assessment. An F_{MSY} around 0.3 was considered.

At WKHELP, the proposed F_{MSY} analyses, taking uncertainty associated with the assessment results and biological characteristics into account, has been executed. The 'plotMSY' software (ICES, WKFRAME 2010) has been used to perform the stochastic yield per recruit and MSY reference point analyses. Both the Ricker as well as the Beverton & Holt stock–recruitment relationship have been used in the analyses. The difference between the point estimates for F_{MSY} based on Beverton and Holt and on

Ricker functions is small. In addition, the understanding about the nature of the stock and recruitment relationship is still insufficient to support either model's underlying assumptions. Therefore a range of values were proposed for F_{MSY}. Those correspond to the median of the estimates resulting from the Ricker and the Beverton and Holt fits which are 0.24 and 0.30.

Concept of a management plan (harvest control rule)

In a harvest control rule, parameters (trigger and targets) serve as guidance to actions according to the state of the stock (ICES Study Group on the Precautionary Approach, ICES, 2002). These should be chosen according to management objectives, one of which should be to have a low risk of bringing the SSB to unacceptably low levels. In an evaluation of a harvest rule, one will use simulations with a 'virtual stock' which as far as possible resembles the stock in question to evaluate the risk as the probability of the virtual SSB being below the B_{lim} value. Within the constraints needed to keep the risk to B_{lim} low, parameters of the rule will be chosen to serve other management objectives, e.g. to ensure a high long-term yield and stable catches over time. Such a management plan would be classed by ICES as precautionary provided the risk of SSB being below B_{lim} is sufficiently low.

The current management plan for NSAS was due revision in 2012.

MSY framework for North Sea herring

There is no ICES MSY framework biomass trigger point for this stock as the MP is thought to have primacy over the ICES MSY framework when providing advice.

In 2010 ACOM agreed with HAWG that F_{MSY} for NSAS was 0.25. This was supported by WKFRAME2. The analyses carried out by WKPELA 2012 suggested that MSY reference points may vary over time. Further, WKPELA suggested that a minor increase in F_{MSY} might be appropriate given the increase in SSB resulting from the FLSAM benchmark assessment. An F_{MSY} around 0.3 was considered. However, associated uncertainty with the WKPELA F_{MSY} has not yet been estimated. Such estimate is required to determine whether the WKPELA proposed estimate is significantly different from the ACOM agreed F_{MSY}. Therefore, and until a full evaluation of F_{MSY} under the current perception of the stock is carried out, F_{MSY} for NSAS remains = 0.25.

Concept of precautionary reference points

Conceptually, precautionary reference points are different from parameters in a harvest control rule. In the precautionary approach, as interpreted by ICES, the function of the reference points is to ensure that the SSB is above the range where recruitment may be impaired or the stock dynamics is unknown. The real limit is represented by B_{lim}, while the B_{pa} takes assessment uncertainty into account, so that if SSB is estimated at B_{pa}, the probability that it is below B_{lim} shall be small. The F_{lim} is the fishing mortality that corresponds to B_{lim} in a deterministic equilibrium. The F_{pa} is related to F_{lim} the same way as B_{pa} is related to B_{lim} (ICES, 2002). In the advisory practice, F_{pa} has been the basis for the advice unless the SSB has been below B_{pa}, where a reduction in F has been advised. Furthermore, F_{pa} and B_{pa} are currently used to classify the state of stock and rate of exploitation relative to precautionary limits. Precautionary reference points have been used by ICES to provide advice and classify the state of the stock in the absence of other information, such as extensive evaluations of management plans.

ICES will accept that a harvest control rule is in accordance with the precautionary approach as long as it implies a low risk to being below B_{lim}, even if other reference points may be exceeded occasionally. When a rule is regarded as precautionary, ICES gives its advice according to the rule. If the rule is followed, then ICES classifies exploitation as precautionary. Within this framework, other precautionary reference points generally will be redundant. However, the precautionary reference points may also be used to classify the stock with respect to precautionary limits, which may lead to a conflicting classification. This discrepancy is still unresolved. The management plan will reduce fishing mortality accordingly. Following the acceptance by ACFM that the management plan is precautionary (and the findings of WKHMP), HAWG has considered that the parameters of the management plan should take primacy over the management against precautionary reference points F_{pa} or B_{pa}.

The precautionary reference points for this stock were adopted in 1998. The analysis carried out by WKPELA 2012 implies that the reference points have shifted under the perception of the stock assessment, thus a thorough scientific process is necessary to revise the existing reference points.

H. Other issues

H.1 Biology of the species in the North Sea

The herring (*Clupea harengus*) is a pelagic species which is widespread in its distribution throughout the North Sea. Herring originated in the Pacific and colonised the Atlantic approximately 3 million years ago (Geffen, 2009). Herring evolved from fish that spawned in rivers and at some later date re-adapted to the marine environment (Geffen, 2009). The herring's unique habit is that it produces benthic eggs which are attached to a gravely substrate on the seabed (Geffen, 2009). The spawning grounds in the southern North Sea are located in the beds of rivers which existed in geological times and some groups of spring spawning herring still spawn in very shallow inshore waters and estuaries. Spawning typically occurs on coarse gravel (0.5–5 cm) to stone (8–15 cm) substrates and often on the crest of a ridge rather than hollows. For example, in a spawning area in the English Channel, eggs were found attached to flints 2.5–25 cm in length, where these occurred in gravel, over a 3.5 km by 400 m wide strip.

As a consequence of the requirement for a very specific substrate, spawning occurs in small discrete areas in the near coastal waters of the western North Sea (Schmidt *et al.*, 2009). They extend from the Shetland Islands in the north through into the English Channel in the south. Within these specific areas actual patches of spawn can be extremely difficult to find.

The fecundity of herring is length related and varies between approximately 10 000 and 60 000 eggs per female (Damme *et al.*, 2009). This is a relatively low fecundity for a teleoSt The age of first maturity is three years old (2-ringers) but the proportion mature-at-age may vary from year to year dependent on growth. Over the past 15 years the proportion mature at age three years (2-ringers) has ranged from 47% to 86% and for four year old fish (3-winter ringers) from 63% to 100%. Above that age, all are considered to be mature.

The benthic eggs take about three weeks to hatch dependant on the temperature. In other regions there is evidence of large interannual variability of egg mortality (Richardson *et al.*, 2011). The larvae on hatching are 6 mm to 9 mm long and rise, due to buoyancy changes, in the water column to become planktonic (Dickey-Collas *et al.*, 2009). Their yolk sac lasts for a few days during which time they will begin to feed on phytoplankton and small zooplankton. Their planktonic development lasts around three to four months during which time they are passively subjected to the residual drift which takes them to various coastal nursery areas on both sides of the North Sea and into the Skagerrak and Kattegat (Heath *et al*., 1997). The environmental impact during this phase is crucial to life cycle closure and probably controls the spawning season of the components (Hufnagl and Peck, 2011).

Herring continue to be mainly planktonic feeders throughout their life although there are numerous records of them taking small fish, such as sprat and sandeels, on an opportunistic basis. Calanoid copepods, such as *Calanus*, *Pseudocalanus* and *Temora,* and the euphausiids *Meganyctiphanes* and *Thysanoessa* still form the major part of their diet during the spring and summer (Hardy, 1924; Savage, 1937; Bainbridge and Forsyth, 1972; Last, 1989) and are responsible for the very high fat content of the fish at this time. Herring also consumes fish eggs (Segers *et al*., 2007).

In the past, herring age has been determined by using the annual rings on the scales. In more recent years the growth rings on the otolith have proved more reliable for age determination. Herring age is expressed as number of winter rings on the otolith rather than age in years as for most other teleost species where a nominal 1 January birth date is applied. Autumn spawning herring do not lay down a winter ring during their first winter and therefore remain as '0' winter ringers until the following winter. When looking at year classes, or year of hatching, it must be remembered that they were spawned in the year prior to their classification as '0' winter ringers.

North Sea herring comprise both spring and autumn spawning groups, but the major fisheries are carried out on the offshore autumn/winter spawning fish. The spring spawners are found mainly as small discrete coastal groups in areas such as The Wash, the Thames estuary, Danish Fjords and the now extinct Zuiderzee herring. Juveniles of the spring spawning stocks are found in the Baltic, Skagerrak and Kattegat, and may also be found in the North Sea as well as Norwegian coastal spring spawners. There is thought to be an input of larvae from the west of Scotland (Heath, 1989).

The main autumn spawning begins in the northern North Sea in August and progresses steadily southwards through September and October in the central North Sea to November and as late as January in the southern North Sea and eastern English Channel. The widespread but discrete location of the herring spawning grounds throughout the western North Sea has been well known and described since the 19th century (Heincke, 1898; Bjerkan, 1917). This led to considerable scientific debate and eventually to investigation and research on stock identity. The controversy centred on whether or not the separate spawning grounds represented discrete stocks or 'races' within the North Sea autumn spawning herring complex (McQuinn, 1997). Resolution of this issue became more urgent as the need for the introduction of management measures increased during the 1950s. ICES encouraged tagging and other studies for separating the spawning components and a review of all the historic evidence to resolve this problem and innovative approaches to assessing mixed and connective stocks (Kell *et al*., 2009; Secor *et al*., 2009). The conclusions were the basis for establishing the working hypothesis that the North Sea autumn spawning herring comprise a complex of at least four spawning components each with separate spawning grounds, migration routes and nursery areas. There is mixing between these components during the summer.

The main four spawning components are:

> The Orkney/Shetland component which spawns from July to early September in the Orkney/Shetland area. Nursery areas for fish up to two years old are found along the east coast of Scotland and also across the North Sea and into the Skagerrak and Kattegat.

The Buchan component which spawns from August to early September off the Scottish east coaSt Nursery areas for fish up to two years old are found along the east coast of Scotland and also across the North Sea and into the Skagerrak and Kattegat.

The Banks or central North Sea component, which derives its name from its former spawning grounds around the western edge of the Dogger Bank. These spawning grounds have now all but disappeared and spawning is confined to small areas along the English east coast, from the Farne Islands to the Dowsing area, from August to October. The juveniles are found along the east coast of England, down to the Wash, and also off the west coast of Denmark.

The Downs component spawns in very late autumn through to February in the southern Bight of the North Sea and in the eastern English Channel. The drift of their larvae takes them north–eastwards to nursery areas along the Dutch coast and into the German Bight (Burd, 1985).

At certain times of the year, individuals from the four stock units may mix and are caught together as juveniles and adults but they cannot be readily separated in the commercial catches other than using otolith methods (Clausen *et al*., 2007; Bierman *et al*., 2009). However North Sea autumn spawning herring are managed as a single unit with the understanding that they comprise many spawning components.

A further complication is that juveniles of the North Sea stocks are found outside the North Sea in the Skagerrak and Kattegat areas and are caught in various fisheries there. The proportions of juveniles of North Sea origin found in these areas varies with the strength of the year class, with higher proportions in the Skagerrak and Kattegat when the year class is good.

In recent decades, recruitment strength is determined during the larval phase (Nash and Dickey-Collas, 2005; Oeberst *et al*., 2009), and larval mortality in the first few weeks of life, although differing between components, co-varies with recruitment strength (Fassler *et al*., 2011).

H.2 Stock dynamics, regulation and catches through 20th century

Over many centuries the North Sea herring fishery has been a cause of international conflict sometimes resulting in war, but in more recent times in bitter political argument. The North Sea herring fishery has a long history and catches between 1600 and 1850 were usually between 40 000 and 100 000 tonnes per year (Poulsen, 2006). Catching opportunities for the fishery were known to be variable. Since the 1900s the annual average catch was 450 000 tonnes. Changes in fleet catching potential have been driven both by changes in catching power and accessibility and responses to markets, particularly the demand from urban populations in the nineteenth century and for fishmeal and oil in the twentieth century. Most of these changes have resulted in greater exploitation pressures that increasingly led to the urgent need to ensure a more sustainable exploitation of North Sea herring. Such pressures really began to exert themselves for the first time during the 1950s when the spawning–stock biomass of North Sea autumn spawning herring fell from above 4 million tonnes in 1947 to 1.4 million tonnes by 1957 (Simmonds, 2007; 2009). That period also witnessed the decline and eventual disappearance of a traditional autumn driftnet fishery in the southern North Sea (Burd, 1978).

At the time, and with the exception of the 12-mile coastal zone, the North Sea was still a free fishing area and the stock was exploited by fleets from at least 14 different nations

(ICES, 1977). Despite the conclusions of the ICES Herring Assessment Working Group becoming more alarming each year (ICES, 1977), the North East Atlantic Fisheries Convention (NEAFC) had no mandate to impose measures unless they were agreed by all member states (Ackefors, 1977). As a consequence, NEAFC could only agree on measures that constituted no real obstacle to any of the national fleets involved (Simmonds, 2007).

The annual landings from 1947 through to the early 1960s were high, but stable, averaging around 650 000 t (Cushing and Bridger, 1966). Over the period 1952–1962, the high fishing mortality (F 0.4 ages 2–6) resulted in a rapid decline in the SSB from around 5 million tonnes to 1.5 million tonnes.

Figure H.2.1 illustrates the dynamics in modelled selectivity (F/F_{bar}) over the past 60 years, shown by age and year in pentads (five year groupings). It is evident that the fishing mortality imposed on the NSAS is quite variable even on a yearly scale, though general patterns can be discerned for the specific age groups.

Fishing mortality on the herring in the central and northern North Sea began to increase rapidly in the late 1960s and had increased to F1.3 ages 2–6, or over 70% per year of those age classes, by 1968. Landings peaked at over 1 million tonnes in 1965, around 80% of which were juvenile fish. This was followed by a very rapid decline in the SSB and the total landings. By 1975 the SSB had fallen to 83 500 tonnes, although the total landings were still over 300 000 tonnes (Simmonds, 2007). At the same time, spawning in the central North Sea had contracted to the grounds off the east coast of England whilst spawning grounds around the edge of the Dogger Bank were no longer used. Recruitment collapsed. This heralded the serious decline and collapse of the North Sea autumn spawning herring stock which led to the moratorium on directed herring fishing in the North Sea from 1977 to 1981 (Cushing, 1992; Dickey-Collas *et al*., 2010).

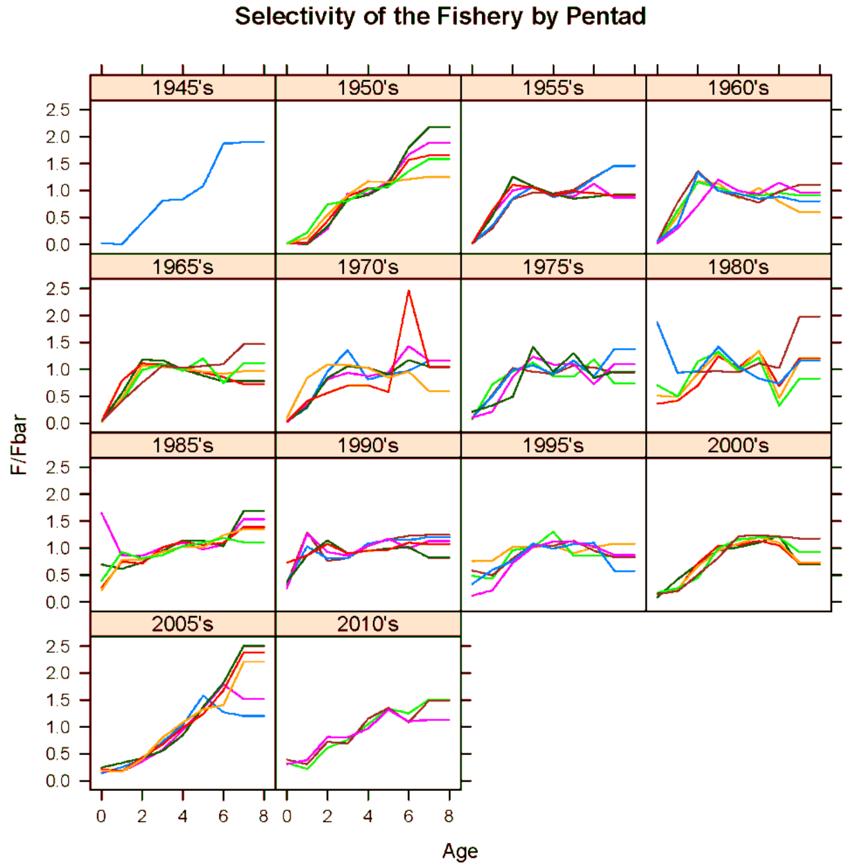


Figure H.2. Selectivity (F/F_{bar}) over the past 60 years, shown by age and year (each year in individual colours) in pentads.

On the 1st of January 1977, all countries around the North Sea extended their exclusive economic zones (EEZ) to 200 miles (Coull, 1991). The North Sea was no longer a free fishing area and suddenly national governments could introduce conservation measures within their own areas. Using this opportunity, the British government was the first (March 1st, 1977) to declare a total ban on all directed herring fisheries in the British EEZ (Coull, 1991). The scientific argument that a closure of the fishery was required finally persuaded all other countries to join in, so that, all directed herring fisheries in the North Sea ceased by the end of June 1977.

In general, the fishing ban was well respected, except in the Channel area where local trawlers continued to fish small quantities of spawning herring (ICES, 1982). Also, herring could still be landed as a bycatch taken in other fisheries, and limited directed fishing did occur on this basis. It was during this time that the EU agreed on a Common Fisheries Policy and took responsibility for the management in all community waters. Some fleets moved to exploit herring stocks in adjacent areas. Following reports of a recovery of the Downs component, a small TAC for the southern North Sea and Channel area was set in 1981 and 1982. The ban on directed fishing in other areas of the North Sea was lifted in June 1983.

International larvae surveys and acoustic surveys were used to monitor the state of the stocks during the moratorium. By 1980 these surveys were indicating a modest recovery in the SSB from its 1977 low point of 52 000 tonnes. By 1981 the SSB had increased to over 200 000 tonnes. This was associated with an increase in the productivity of the stock, i.e. apparent compensatory recruitment (Nash *et al.*, 2009). Once the fishery reopened in 1981 the North Sea autumn spawning herring stock was managed by a TAC constraint through the EU Common Fisheries Policy and agreement with Norway. The TAC was only applied to the directed herring fishery in the North Sea which exploited mainly adult fish for human consumption. Targeted fishing for herring for industrial purposes was banned in the North Sea in 1976 but there was a 10% bycatch allowance in the fisheries for other species, including the small meshed fisheries for industrial purposes, mainly for sprat. Following the re-opening of the now controlled fishery the SSB steadily increased, peaking at 1.3 million tonnes in 1989. Annual recruitment was well above the long-term average over this period. The 1985 year class was the biggest recorded since 1960 and the third highest in the records dating back to 1946 (Nash *et al.*, 2009). Landings also steadily increased over this period reaching a peak of 876 000 tonnes in 1988. This resulted from a steady increase in fishing mortality to Fages 2–6 = 0.6 (ca. 45%) in 1985 and a high bycatch of juveniles in the industrial fisheries for sprat. Following a period of four years of below average recruitment (year classes 1987–1991), SSB fell rapidly to below 500 000 tonnes in 1993. Fishing mortality further increased, averaging Fages 2–6=0.75 (ca. 52%) over the period 1992–1995, and recorded landings regularly exceeded the TAC. The North Sea industrial fishery for sprat developed rapidly over this period with the annual catch increasing from 33 000 tonnes in 1987 to 357 000 tonnes by 1995. With the 10% bycatch limit as the only control on the catch of immature herring, there was a consequent high mortality on juvenile herring averaging 76% of the total catch in numbers of North Sea autumn spawners over this period.

During the summer of 1991 the presence of the parasitic fungus *Ichthyophonus* spp. was noted in the North Sea herring stock. All the evidence suggested that the parasite was lethal to herring, and that its occurrence could have a significant effect on natural mortality in the stock and ultimately on spawning–stock biomass. High levels of infection were recorded in the northern North Sea north of latitude 60°N whilst infection rates in the southern North Sea and English Channel were very low. Efforts were made to estimate the prevalence of the disease in the stock through a programme of research vessel and commercial catch sampling. This led to estimates of annual mortality up to 16% (Anon., 1993) which was of the same order as the estimate of fishing mortality at the time. It was recognised that the behavioural changes and catchability of infected fish affected the reliability of the estimate of prevalence of the disease in the population. The uncertainty about the effect on stock size varied between estimates of 5% to 10% and 20%. Continued monitoring of the progress of the disease showed that by 1994 the prevalence in the northern North Sea had fallen from 5% in 1992 to below 1% and confirmed that the infection did not appear to be spreading to younger fish. Ultimately it was concluded that the disease had caused high mortality in the northern North Sea during 1991 and subsequently declined to the point where, by 1995, the increase in natural mortality induced by the disease was insignificant.

The increased fishing pressure during the first half of the 1990s and the disease-induced increase in natural mortality led to serious concerns about the possibilities of a stock collapse similar to that in the late 1970s. Reported landings continued at around 650 000 tonnes per year whilst the spawning stock began to decline again from over 1 million tonnes in 1990. The assessments at that time were providing an overly optimistic perception of the size of the spawning stock. It was, for example, not until 1995 that it was realised that the SSB in 1993 had already fallen below 500 000 tonnes. This was well below the minimum biologically accepted level of 800 000 tonnes (MBAL) which had been set for this stock at that time.

The herring stock apparently recovered during the late 2000s and in 2011 some regulatory measures were amended: A licence scheme introduced in 1997 by UK/Scotland, to reduce misreporting between the North Sea and 6.a (North), was relaxed, and the minimal amount of target species in the EU industrial fisheries in 3.a was reduced to 50% (for sprat, blue whiting and Norway pout).

H.3 Current fisheries

There are at least four techniques used to fish for herring in the North Sea:

i) Human consumption fishery using mid-water trawl by single or pair refrigerated seawater (RSW) () trawlers (mesh size 40–44 mm). These are not allowed to carry sorting equipment on board and thus cannot process the catch whilst at sea (other than emptying tanks or slipping catch from the net). They either land their catch as caught or pass it on to a processing vessel. Their catching potential is limited by the size of their tanks. This fishery is operated by vessels from the UK(Scotland), Denmark and Norway.

ii) Human consumption fishery using mid-water trawl by single or paired pelagic freezer trawlers (mesh size 40 mm). These catch and then process on board, offloading frozen blocks of sorted and categorised fish. Their catching potential is limited by their processing capacity, usually 200–250 tonnes per day. This fishery is operated by vessels from Germany, The Netherlands, France and UK(England).

iii) Human consumption fishery using purse seine by RSW trawlers. Purse seine nets are used to encircle the shoals of herring rather than chase them with trawls. These vessels do not carry sorting equipment. Their catching potential is limited by the size of their tanks. This fishery is operated by vessels from Norway, Sweden and Denmark.

iv) Industrial fishery as bycatch. The herring is caught when targeting sprat or Norway pout using mid-water trawls with fine mesh nets (<32 mm). Their catching potential is limited by the size of their tanks and a maximum bycatch percentage of herring. This fishery is operated by Denmark.

All of these fishing methods use fishers experience and acoustic techniques to find the shoals of fish. The mid-water trawls (single and paired) and purse seines are damaged if contact is made with the seabed. The fleets are characterised by a few vessels (all >40 m), with even fewer owners. For example the German, Dutch, English and biggest French vessels are all owned by three companies operating out of the Netherlands.

H.4 Management and ICES advice

Management plan

In 1996, the TACs for herring caught in the North Sea (ICES areas 4 and Division 7.d) were changed mid-year with the intention of reducing the fishing mortality by 50% for the adult part of the stock and by 75% for the juveniles. For 1997, the regulations were altered again to reduce the fishing mortality on the adult stock to 0.25 and for juveniles to less than 0.1 with the aim of rebuilding the SSB up to 1.1 million tonnes in 1998 (Simmonds, 2007).

According to the EU and Norway agreement adopted in December 1997, efforts should be made to maintain the SSB above the Minimum Biologically Acceptable Level

(MBAL) of 800 000 tonnes. An SSB reference point of 1.3 million tonnes was set above which the TACs would be based on an F= 0.25 for adult herring and F= 0.12 for juveniles. If the SSB fell below 1.3 million tonnes, other measures would be agreed and implemented taking account of scientific advice. A management plan was agreed by EU and Norway in 2008. ICES evaluated this management plan and concluded that the plan was consistent with the precautionary approach and the MSY approach. The stock is managed according to this EU-Norway Management agreement; the relevant parts of the text are included here for reference:

Annex 1: Every effort shall be made to maintain a minimum level of SSB greater than 800 000 tonnes (B_{lim}).

Annex 2: Where the SSB is estimated to be above 1.5 million tonnes the parties agree to set quotas for the directed fishery and for bycatches in other fisheries, reflecting a fishing mortality rate of no more than 0.25 for 2 ringers and older and no more than 0.05 for 0–1 ringers.

Annex 3: Where the SSB is estimated to be below 1.5 million tonnes but above 800 000 tonnes, the parties agree to set quotas for the direct fishery and for bycatches in other fisheries, reflecting a fishing mortality rate on 2 ringers and older equal to:

> 0.25-(0.15*(1 500 000-SSB)/700 000) for 2 ringers and older, and no more than 0.05 for 0–1 ringers

Annex 4: Where the SSB is estimated to be below 800 000 tonnes the parties agree to set quotas for the directed fishery and for bycatches in other fisheries, reflecting a fishing mortality rate of less than 0.1 for 2 ringers and older and of less than 0.04 for 0–1 ringers.

Annex 5: Where the rules in paragraphs 2 and 3 would lead to a TAC which deviates by more than 15% from the TAC of the preceding year the parties shall fix a TAC that is no more than 15% greater or 15% less than the TAC of the preceding year.

Annex 6: Notwithstanding paragraph 5 the parties may, where considered appropriate, reduce the TAC by more than 15% compared to the TAC of the preceding year.

Annex 7: Bycatches of herring may only be landed in ports where adequate sampling schemes to effectively monitor the landings have been set up. All catches landed shall be deducted from the respective quotas set, and the fisheries shall be stopped immediately in the event that the quotas are exhausted.

Annex 8: The allocation of the TAC for the directed fishery for herring shall be 29% to Norway and 71% to the Community. The bycatch quota for herring shall be allocated to the Community.

Annex 9: A review of this arrangement shall take place no later than 31 December 2011.

Annex 10: This arrangement enters into force on 1 January 2009.

The EU–Norway agreement calls for a review of the current plan no later than December 2011. This has however not been performed and the demand for a full scale Management Strategy Evaluation and thus a revision of the North Sea Herring Management Plan has now increased considerably in the light of the changes made in the benchmark assessment performed in WKPELA 2012. The benchmark assessment has led to considerable revisions the perception of the stock and suggests that F_{MSY} as well as a target-F should be reconsidered, and thus the harvest control rules for the stock need evaluation against exceptional variations in biology, testing for robustness under varying starting conditions in population size and changes in the North Sea Ecosystem. This should be done as a collaborative iterative process between scientists, managers and stakeholders. To facilitate the process, it would be useful if the trade-off between the objectives of stability and long term yield could be expressed clearly.

The updated plan was assessed by ICES as precautionary in 2015. The revised rule specifies fishing mortalities for juveniles ($F_{0\text{-}1}$) and for adults ($F_{2\text{–}6}$) not to be exceeded, at 0.05 and 0.26 respectively, when the SSB is above 1.5 million tonnes. The current agreement has a constraint on year-to-year change of 15% in TAC, when the SSB is above 800 000 t with the addition that F should not vary by more than 10% greater or lower than that specified in the rules.

The bilateral EU/Norway consultations resulted in a suggested management plan, which was reviewed in January 2015 by WKHerTAC (ICES, 2015). Six HCR options were performed evaluating the long-term management strategy (LTMS) for herring in the North Sea. The six scenarios evaluated a range of $B_{trigger}$ values (1.0–1.5 million tonnes). All scenarios tested assumed a 15% constraint on TAC IAV, a 10% constraint on F (limiting departure from target F) and an interannual quota flexibility of ±10%. For the 3.a TAC setting procedure, the basis of the scenarios tested mainly differed in the fraction of 3.a TAC transferred to the North Sea (0–50%). All scenarios tested were considered to be precautionary for NSAS and WKHerTAC concluded that if the $B_{trigger}$ for NSAS is to be revised, values at or above 1.0 million tonnes would be considered precautionary.

Spawning component diversity

As noted above, the North Sea herring stock can effectively be viewed as a meta-population consisting of at least four unique subpopulations (and potentially more). Maintaining the diversity of spawning components is widely recognized as being crucial to the successful and sustainable exploitation of herring stocks. Large differences in exploitation pressures between the components in the past has led to wide changes in the composition of the total stock e.g. prior to 1980, the Downs component comprised less than a few percent of the total stock, whereas in 2010 it was nearly 50% (Cushing, 1992; Payne, 2010).

Traditionally the EU sets a separate sub-TAC, from within its own North Sea herring TAC, for the southern North Sea and eastern English Channel. This is designed to protect the Downs spawning component as it aggregates to spawn. Downs herring is assumed to be more susceptible to the impacts of exploitation (Cushing, 1992). This sub-TAC is re-negotiated every year and is generally fixed at approximately 11–14% of the total TAC (EU and Norway; see Council regulation (EU) No 57/2011).

The working group responsible therefore needs to provide advice regarding the current component diversity of the stock. The SCAI indices are currently the main source of information in this regard, and therefore should be presented as part of the advice for this stock. Other indicators, where available, should also be presented alongside the SCAI.

Other management measures

There are other management tools currently used for the North Sea herring fishery:

i) Minimum landing size for herring for human consumption fisheries of 20 cm in the North Sea (Council regulation (EC) No 850/98).

ii) Closed areas for both herring and/or sprat fisheries to protect either spawning or juveniles (Council regulation (EC) No 850/98). These closed areas are relatively small and localised, and usually seasonal (Figure H.3.1).

iii) The industrial fishery is not only limited by the bycatch ceiling which is set every year based on the EU/Norway management plan (Council regulation (EU) No 57/2011) but also by a bycatch percentage for each haul. This was initially set such that 10% of the catch of the sprat can be herring (Council regulation (EC) No 850/98) but in recent years this bycatch proportion has been increased to 20% of the catch as the total mixed catch has declined.

iv) In 2009, the EU and Norway agreed a ban on high-grading in the North Sea and eastern English Channel (Council Regulation (EC) No 43/2009). This prevented the discarding of fish of a size that could be landed for which there was still quota available.

v) Since 2015, a landing obligation is in place for pelagic fleets operating in the North Sea and the Baltic.

Within and between the countries in the fishery, the TAC is greatly swapped, with Individual Transferable Quotas (ITQs) (or *de facto* ITQs) in most countries, and some countries selling much of their annual quota (e.g. Belgium). As the fishery catches against an area TAC and the advice is for a stock TAC, the landings against the TAC do not completely reflect the exploitation on the stock, or the true catches from the stock. Fisheries scientists reallocate catch from areas 4 and 3.a, based on sampling, to determine the catches from the stock. In addition, there are two boundary areas where misreporting has been a problem: ICES areas 4/3.a and 4.a/6.a. There are different regulatory solutions to each. Area-misreporting from catches taken in ICES area 4 to 3.a is allowed through EU/Norway agreements, i.e. herring caught in 4 can be written off against 3.a quota. In contrast, in the northern North Sea there are specific licensing regulations to prevent area misreporting, that control the landing of herring catches from and at the border of ICES areas 4.a and 6.a.

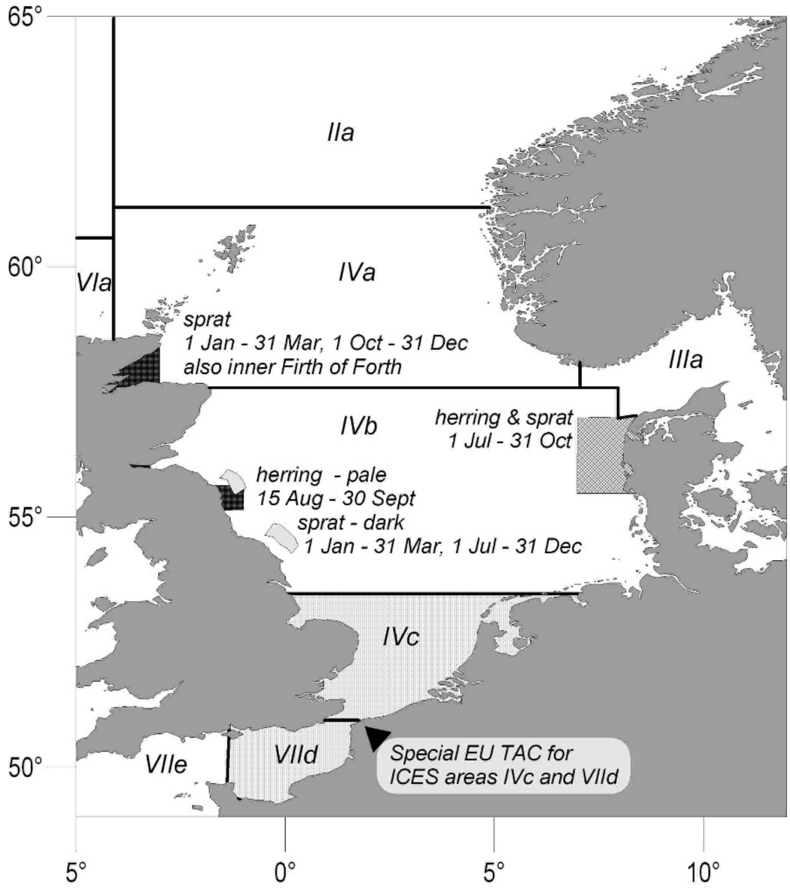


Figure H.3.1. ICES areas and areas closed to fishing on herring and sprat under EU legislation. Black areas denote three small sprat closures to protect juvenile herring. Pale areas denote two closures on the herring fisheries to protect spawning herring around the Banks spawning ground. The shaded area to the west of Denmark is closed to the juvenile herring and the sprat fishery (although there is no targeted juvenile herring fishery).

H.5 Terminology

The WG uses "rings", "ringers", "winter ringers" or "wr" rather than "age" throughout the report to denominate the age of herring, with the intention to avoid confusion. It should be observed that, for autumn spawning stocks, there is a difference of one year between "age" and "rings". HAWG in 1992 (ICES, HAWG 1992) stated that:

"The convention of defining herring age rings instead of years was introduced in various ICES working groups around 1970. The main argument to do so was the uncertainty about the racial identity of the herring in some areas. A herring with one winter ring is classified as 2-years-old if it is an autumn spawner, and one-year-old if it is a spring spawner. Recording the age of the herring in rings instead of in years allowed scientists to postpone the decision on year of birth until a later date when they might have obtained more information on the racial identity of the herring.

The use of winter rings in ICES working groups has introduced a certain amount of confusion and errors. In specifying the age of the herring, people always have to state explicitly whether they are talking about rings or years, and whether the herring are autumn- or spring spawners. These details tend to get lost in working group reports, which can make these reports confusing for outsiders, and even for herring experts themselves. As the age of all other fish species (and of herring in other parts of the world) is expressed in years, one could question the justification of treating West-European herring in a special way. Especially with the present trend towards multispecies assessment and integration of ICES working groups, there might be a case for a uniform system of age definition throughout all ICES working groups.

However, the change from rings to years would create a number of practical problems. Data files in national laboratories and at ICES would have to be adapted, which would involve extra costs and manpower. People that had not been aware of the change might be confused when comparing new data with data from old working group reports. Finally, in some areas (notably Division 3.a), the distinction between spring- and autumn spawners is still hard to make, and scientists preferred to continue using rings instead of years.

The Working Group discussed at length the various consequences of a change from rings to years. The majority of the Group felt that the advantages of such a change did not outweigh the disadvantages, and it was decided to stick to the present system for the time being."

The text table below gives an example for the correlation between age, rings and year class for the different spawning types in late 2002:

Year class (autumn spawners)	2001/2002	2000/2001	1999/2000	1998/1999
Rings	0	1	2	3
Age (autumn spawners)	1	2	3	4
Year class (spring spawners)	2002	2001	2000	1999
Rings	0	1	2	3
Age (spring spawners)	0	1	2	3

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