Stock Annex: Herring (*Clupea harengus*) in divisions 6.a and 7.b–c (West of Scotland, West of Ireland)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Herring
Working Group:	Herring Assessment Working Group for the Area South of 62ºN (HAWG)
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A. General

The EU funded project WESTHER (A multidisciplinary approach to the identification of herring (*Clupea harengus* L.) stock components west of the British Isles using biological tags and genetic markers - Q5RS-2002-01056) was a multidisciplinary study that ran from 2003 to 2006. The project examined stock identity using a number of techniques (morphometric (body and otolith) and meristic characteristics; internal parasites; otolith microstructure and microchemistry; genetics), each carried out on the same individual fish. The project's overall goal was to describe the population structure of herring stocks in western European waters, distributed from the southwest of Ireland and the Celtic Sea to the northwest of Scotland. The project's scientific results, summarised in Hatfield et al. (2007a), provided little evidence of discreet structuring of juvenile and adult herring west of the British Isles, outside the spawning seasons. However, high classification success of spawning aggregations for several of the methods used (e.g. Campbell et al., 2007) provided evidence of population structuring by spawning time and spawning sites, indicating a high degree of natal fidelity. Evidence suggested significant migration and mixing of herring that originate in different spawning areas, especially to and from feeding grounds and by repeat spawners to spawning grounds (Campbell et al. 2007; Geffen et al 2011). The degree of mixing of juvenile and first time spawners was more area specific, but still significant in some areas, e.g. mixing of Celtic and Irish Sea juveniles in the Irish Sea. Overall there was considerable mixing of spawning components in both the juvenile and adult phases, however the population structures are maintained despite this mixing of populations.

The preservation of intraspecific population integrity is a prerequisite for maintaining population and life history diversity which in turn affect the performance of individual species in providing important ecosystem services (Schindler et al., 2010). A fish population complex composed of several populations appear more stable in terms of production (recruitment as a whole) because of the complementary or independent dynamics among the populations within the population complex – the so-called portfolio effect (Schindler et al., 2010). The resilience of a population complex (or stock, see box 1) is weakened if the population diversity within the population complex is decreased and the dynamics of the populations become more synchronous (Hilborn et al.

2003; Schindler et al., 2010). Stability occurs when the populations within the population complex can respond asynchronously to the same environmental conditions. Differences in life histories are important for stability, because they lead to differential responses to inter annual variations in environmental conditions (Hilborn et al., 2003, Secor et al., 2009).

When managing a mixture of populations, one must consider the dynamics of the entire stock when estimating recruitment, mortality and other assessment relevant issues, as it is an impossible task of targeting a single population in a mixed fishery (McQuinn 1997). Combined assessments must be performed with caution, though, as an assessment of the metapopulation could fail to detect overexploitation of stocks and fail to detect and distinguish between the effects of exploitation and regime shifts., Kell et al., 2009).

The management strategy evaluation by Kell et al. (2009) that was based on herring in Divisions 6.a and 7.b-c concluded that assessment of the meta-population could fail to detect overexploitation of component stocks. Furthermore, the management strategy evaluation by Hintzen et al. (2014) for herring in Divisions 6.a and 7.b-c showed that smaller population units are extremely vulnerable to overexploitation. The results from WESTHER suggested that under the current stock assessment units (see ICES 2014), basic assumptions for performing stock assessment are violated. Violating the assumption of a closed stock unit for stock assessment will be less problematic if the catch and survey input data are only from spawning aggregations and the fisheries only exploit spawning aggregations. With the level of mixing indicated by WESTHER this, however, is not the case. WKWEST attempted to offer guidance on potential methods for splitting catch advice to each stock, but the problems in assessing each area separately (e.g., mixed-stock surveys) precluded the development of any practical splitting procedure. Conclusively, in order to provide sound management advice for herring in 6.a, 7.b-c, and in particular the importance of ensuring as far as possible that there is no depletion of local components, alternate management strategies for the area was evaluated by WKWEST and a combined assessment was concluded being the most robust approach to assess the status of the herring populations in the area.

A.1. Stock definition

The definition of herring stocks to the west of the British Isles has changed considerably over the last five decades. Parrish and Saville (1965) considered the herring stocks to the west of the British Isles to consist of two main components, the 'oceanic' and 'shelf' populations. The oceanic populations consisted of a Scottish west coast winter/spring spawning stock and a southern Irish winter/spring spawning stock. The boundary between these two stocks was considered to be the central to southern west coast of Ireland. The other boundary was in the Irish Sea. In summary, Parrish and Saville (1965), ICES (1979) and King (1985) suggested an interlinking of herring in areas 6.a and 7.aN, and the Celtic Sea appearing as a separate group. The status of the west coast of Ireland populations appeared unclear. However, it did appear that boundaries between putative stocks probably occurred on the west coast of Ireland and toward the southern Irish Sea. Figure 1 shows the locations of the major spawning grounds to the west of the British Isles, based on the results of larvae surveys carried out in various areas between 1972 and 2009 and from other anecdotal information.

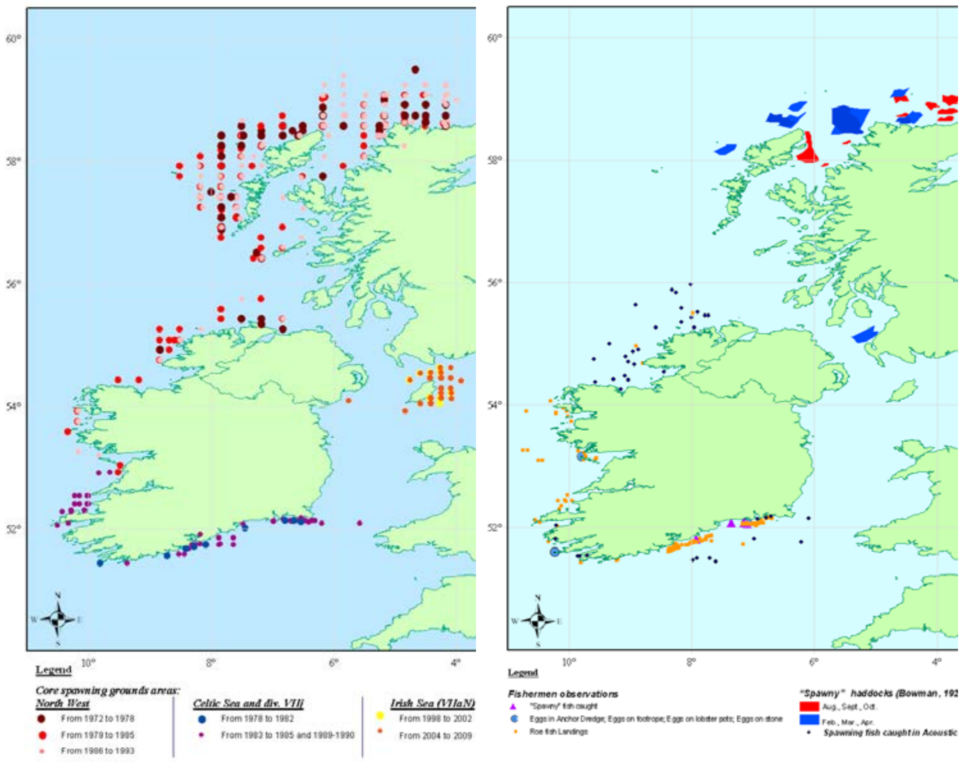

Figure 1. (Left panel) map representing the core areas of spawning grounds according to the different stock larval densities, keeping the stations that contained ≥ than 85% of the distribution of larval density per year. The different colours highlight the temporal dynamics of the different stocks. (Right panel) map to show the presence of spawning grounds to the west of the British Isles showing the spread of other, mostly, anecdotal information gathered at different times.

A.2. Fishery

Seasonal fisheries for herring take place in many different areas around the coast of the west of the British Isles (Scotland, Ireland, northwest England, the Isle of Man and Wales). These western herring stocks were considered by ICES for the first time in 1969 (ICES, 1970). The assessment and management of the western stocks was considered necessary due to the possible diversion of effort to these waters because of the decline of the North Sea herring fishery, which ended in a 4-year-closure there from 1977 onwards.

A.2.1. General description

The major part of the fishery in the area is carried out by vessels from Ireland and the UK; vessels from the Netherlands, Germany and the Faroes participate in the fishery to a lesser extent.

Seasonal fisheries for herring take place in many different areas around the coast of the west of the British Isles (Scotland, Ireland, northwest England, the Isle of Man and Wales). These western herring stocks were considered by ICES for the first time in 1969 (ICES, 1970). The assessment and management of the western stocks was considered necessary due to the possible diversion of effort to these waters because of the decline of the North Sea herring fishery, which ended in a 4-year-closure there from 1977 onwards.

The ICES Working Group recognised two stocks – one inhabiting the area north and north-west of Ireland and west of Scotland and the other inhabiting the area south of Ireland (Celtic Sea). The Working Group did not consider the population in the Irish Sea as a separate stock. The appropriate management units were considered as coincident with ICES Division 6.a (west of Scotland and north-west Ireland) and Divisions 7.g-k with the southern part of 7.a (south of 52o 30'N) (Celtic Sea).

TACs for Division 6.a were set by the North-East Atlantic Fisheries Commission (NEAFC) from 1972 until the closure of the herring fishery in 1978. The fishery was not reopened until July 1981. Despite a considerable fishery being carried out in the adjacent Division 7.b, this herring resource was not assessed analytically, and a precautionary TAC was imposed during the closure time of Division 6.a.

In 1981 the ICES Herring Assessment Working Group (HAWG) reviewed the fisheries in both areas, based on work carried out by working groups in the late 1970s and early 1980s which found that the stocks exploited off the west coast of Scotland were biologically different from those off the north coast of Ireland. The result was that in 1982, HAWG (ICES, 1982) recommended new management units: one for 6.a North and a second one for 6.a South & 7.b-c. The rationale was that the fisheries in the two areas were distinct, the fisheries were prosecuted by different countries and there were rather different recent (1970s) patterns of fishing activity in the two areas. These units were adopted by the European Commission in 1982.

A.2.2. Fishery management regulations

At present the management is based on the four main fisheries, i.e., Celtic Sea and 7.j, Irish Sea, 6.aS and 7.b-c and 6.a North. In all cases annual TACs are agreed for each of the fisheries. These are ideally based on scientific advice which is given in accordance with the Precautionary Approach and aim at maintaining the stocks above Bpa wherever possible (if this reference point is defined). A timeline of changes to fisheries and management in Divisions 6.a and 7.b-c is shown in Figure 3.1.4.

The 6.a North fishery operates throughout the year, and has been primarily a summer fishery, i.e., not targeting spawning aggregations, since the mid-1990s (see Figure 3.1.4). This fishery has been linked to the local mackerel fishery in the area and the North Sea herring fishery in the adjacent management area to the east (see Figure 2). In 6.aS and 7.b-c the fisheries tend to be on spawning aggregations.

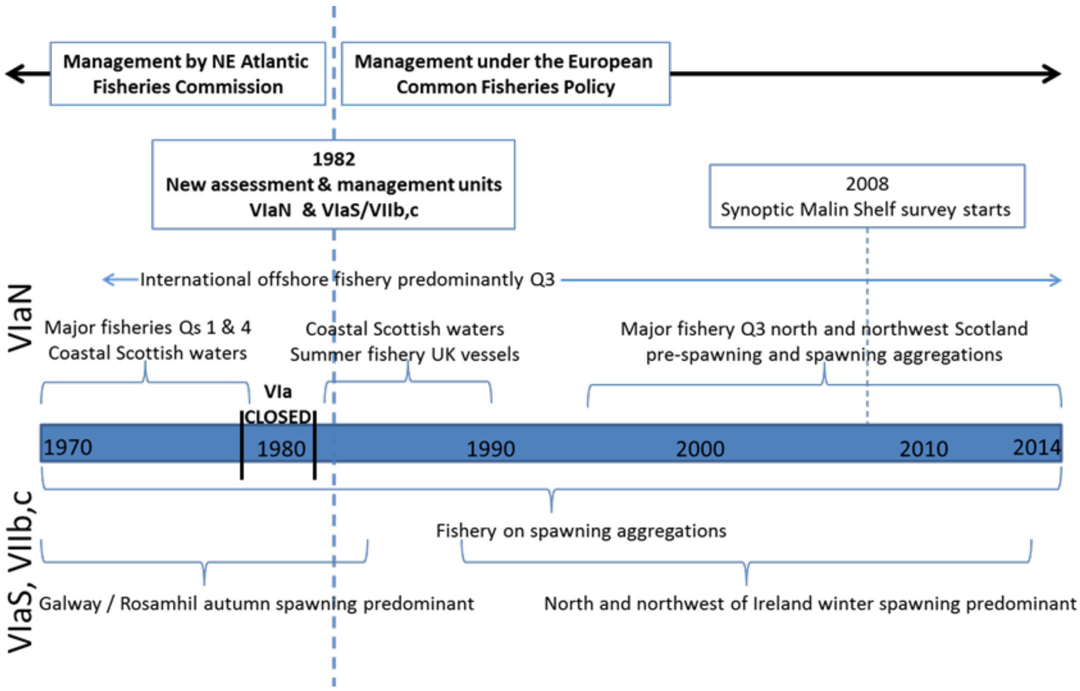

Figure 2. Diagram to show the timeline of changes to fisheries and management in 6.aN and 6.aS/7.b-c.

Council Regulation (EC, 2008) No 1300/2008, of 18 December 2008, established a multi-annual management agreement for the stock of herring distributed to the west of Scotland and the fisheries exploiting that stock. TAC constraints are set for each of the other 'stocks' or areas (the management units) to the west of the British Isles and in general these fisheries are managed at the regional level and prosecuted by discrete 'local fleets'. The exception is the 6.a North fishery where international fleets are important. In most cases the fleet sizes vary between years, both in terms of the numbers of vessels taking part in the various fisheries and the size and capacity of those vessels.

In addition to TAC constraints there are a number of other management measures currently enforced. The Republic of Ireland's fisheries for the 6.aS and 7.b-c stock are managed by local committees. These committees each have a set of local management objectives (ICES, 2014).

In 6.aS and 7.b-c the fishing season is considered to run from late autumn into the spring. It opens on the 1 October and closes around the end of March the following year. Here individual vessels have individual quotas. In 2000 the Irish Northwest Pelagic Management Committee was established to deal with the management of the 6.aS and 7.b-c stock. In recent years the ICES advice has remained unchanged. ICES have recommended that a rebuilding plan be put in place that will reduce catches. If no rebuilding plan is established, there should be no fishing. The rebuilding plan should be evaluated with respect to the precautionary approach. A rebuilding plan was proposed by the Pelagic RAC in 2013. This was evaluated by STECF in 2013 (STECF, 2013), and it was found to be capable of rebuilding the stock to above Bpa only if transboundary catches are eliminated (see Figure 3.1.1).

In 6.a North, there was an area closure (adopted in the 1970s), commonly called "The Butt of Lewis Box" from 31 August to 15 September, designed as a measure to protect spawning fish. This was reopened to fishing in 2008 following a STECF review in 2007. It was not possible to show either beneficial or deleterious effects from this closure. Republic of Ireland vessels do not participate in the 6.a North fishery until after the 1

October; nor are those vessels allowed to fish within the 12 nautical mile limit north of Barra Head.

A.3. Ecosystem aspects

Herring are an important prey species in the ecosystem and also one of the dominant planktivorous fish.

Herring fisheries tend to be clean with little bycatch of other fish. Scottish discard observer programs since 1999 indicate that discarding of herring in these directed fisheries are at a low level. These discard observer programs have recorded occasional catches of seals and zero catches of cetaceans.

In addition to being a valuable protein resource for humans, herring represent an important prey item for many predators including cod and other large gadoids, dogfish and sharks, marine mammals and sea birds. Because the trophic importance of herring puts its stocks under immense pressure from constant exploitation, it is important that management takes into account all anthropogenic, environmental and biological variables.

The Atlantic herring, *Clupea harengus*, is numerically one of the most important pelagic species in North Atlantic ecosystems with widespread distribution. Within the Northeast Atlantic they are encountered from the north of Biscay to Greenland, and east into the Barents Sea. It is thought that herring stocks comprise many reproductively isolated subpopulations through specific spawning grounds and seasons (e.g. autumn and spring spawners), but the taxonomic status of these subpopulations remains unclear.

Herring are demersal spawners and produce dense beds of benthic eggs deposited on gravelly substrates. This behaviour is considered to be an evolutionary remnant of herrings' river spawning past. Each female produces a single batch of eggs per year, releasing a ribbon of eggs that adheres to the benthos; the male sheds milt while swimming a few centimetres above the female. This particular behaviour renders herring vulnerable to anthropogenic activity such as offshore oil and gas industries and gravel extraction.

The eggs take about three weeks to hatch, dependant on the temperature. The larvae on hatching are 6-9mm long and are immediately planktonic. Their yolk sac lasts for about a week during which time they will begin to feed on phytoplankton and crustacean larvae. Their planktonic development lasts around three to four months during which time they are passively subjected to the residual drift which takes them to coastal nurseries. The habitats of juveniles are primarily pelagic, and hydrographical features such as temperature and the depth of thermocline, as well as abundance of zooplankton affect their distribution. Adult fish are pelagic and found mostly in continental shelf seas to depths up to 200m. They form large shoals with diurnal migration patterns through the water column which can be associated with the availability of prey and stage of maturity. In the winter the feeding activity and growth are very slow. Herring can reach 40cm in length and have a maximum lifespan of 10 years although most herring range between 20-30cm and are less than 7 years.

Assessing age and year class for herring can be problematic due to the extended spawning season of autumn spawners from September to January. Using the convention of January 1st as the birthday, 0-group refer to fish born between 3 and 18 months ago but 0-group autumn spawners belong to a different class from 0-group spring spawners. Time series of a stock's age structure helps its management and it is vital that they are extended for all the 'West of Scotland' herring components in the 6.aN (North), 6.aS (South) and 6.b areas.

A.3.1. Hydrographical features of the distribution area

The shelf circulation is influenced by the poleward flowing 'slope current', which persists throughout the year north of the Porcupine Bank, but is stronger in the summer. A schematic representation of the oceanographic conditions in this area is presented in Figure 2. Over the Rockall plateau, domes of cold water are associated with retentive circulation. Thermal stratification and tidal mixing generate a northwards running coastal current known as the Irish coastal current which runs northwards along the west coast (ICES, 2007a). The main oceanographic features in these areas are the Islay and the Irish Shelf fronts. The waters to the west of Ireland are separated by the Irish shelf front. This front causes turbulence and this may bring nutrients from deep waters to the surface. This promotes the growth of phytoplankton and dinoflagellates where there is increased stratification. Associated with this is increased growth of zooplankton and aggregations of fish. The Islay front persists throughout the winter due to the stratification of water masses of different salinities (ICES, 2006). The ability to quantify any variability in frontal location and strength is an important element in understanding fisheries recruitment (Nolan and Lyons, 2006). These fronts play an important role in the transport of larvae and juveniles.

In the North, most of the continental shelf is exposed to prevailing southwesterly winds and saline oceanic waters cross the shelf edge between Malin head off the north coast of Ireland and Barra head in the Outer Hebrides. The Irish shelf current flows northwards and then eastwards along the north coast of Ireland (Reid et al, 2003). Freshwater dis-charges from rivers such as the Shannon and Corrib interact with the Eastern North Atlantic water on the Irish shelf front to produce the observed circulation pattern (ICES, 2006).

Sea surface temperature data have been collected from Malin head on the North coast of Ireland since 1958. During periods of low winter temperatures, there is less pronounced heating during the summer. This can be seen in 1963, 1978 and 1985-1986. During these years there were also stormy conditions. This is concurrent with the lower winter temperatures (ICES, 2007b). There is considerable variability over the complete time series. A definite trend can be identified from the early 1990s. Since 1990 sea surface temperatures measured at stations along the northwest coast of Ireland have displayed a sustained increasing trend, with winter temperatures >6○ and higher summer temperatures during the same period (Nolan and Lyons, 2006).

Environmental conditions can cause significant fluctuations in abundance in a variety of marine species including fish. A study conducted in 1980 found that west coast herring catches showed strong correlations with temperature and salinity at a constant lag of three or four years. Oceanographic variation associated with temperature and salinity fluctuations appears to affect herring in the first year of life, probably during the winter larval drift (Grainger, 1980).

Productivity in this region is reasonably high on the shelf but drops rapidly west of the shelf break. This area is important for many pelagic fish species. The shelf edge is a spawning area for mackerel *Scomber scombrus* and blue whiting *Micromesistius potassou*. Historically, there were important commercial fisheries for many demersal species also. On the shelf, the main resident pelagic species is herring (ICES, 2007b). Preliminary examination of productivity shows that overall productivity in this area is currently lower than it was in the 1980s. Further information on this can be found in the HAWG report 2007 (ICES, 2007b).

B. Data

B.1. Commercial catch

In the following sections the input data for the combined assessment are described by area (6.aN and 6.aS, 7.b-c).

B.1.1. Landings data

Landings data for both constituent stocks were added to provide a combined official landings series. These were then adjusted using the nett unallocated and areas misreported catches to achieve a combined working group estimate of catch. This includes discard data (see B.1.2 below).

B.1.1.1. 6.aN landings

Commercial catch is obtained from national laboratories of nations exploiting herring in 6.a (N). Since 1999 (catch data 1998), these labs have used a spreadsheet to provide all necessary landing and sampling data, which was developed originally for the Mackerel Working Group (WGMHSA) and further adapted to the special needs of the Herring Assessment Working Group. The current version used for reporting the 2002 catch data was v1.6.4. The majority of commercial catch data of multinational fleets was provided on these spreadsheets and further processed with the SALLOCL-application (Patterson, 1998a). This program gives the needed standard outputs on sampling status and biological parameters. It also clearly documents any decisions made by the species coordinators for filling in missing sampling data and raising the catch information of one nation/quarter/area with information from another data set.

Transparency of data handling by the Working Group. The current practice of data handling by the Working Group is that the data received by the coordinators is available in a folder called "archive". These high-resolution data are not reproduced in the report. The archived data contains the disaggregated dataset (disfad), the allocations of samples to unsampled catches (alloc), the aggregated dataset (sam.out) and (in some cases) a document describing any problems with the data in that year.

Current methods of compiling fisheries assessment data. The species coordinator is responsible for compiling the national data to produce the input data for the assessments. In addition to checking the major task involved is to allocate samples of catch numbers, mean length and mean weight-at-age to unsampled catches. There are at present no defined criteria on how this should be done, but the following general process is implemented by the species coordinators. Searches are made for appropriate samples by gear (fleet) area quarter, 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 unsampled 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, but not in all cases.

Until 2003 the 6.a(N) catch data extended back to the early 1970s; since 1986 the series has run from 1976 to present. In 2004 the data set was extended back to 1957. Details are given below.

Historic Catches from 1957 to 1975

The working group has obtained preliminary estimates of catch and catch-at-age for the period 1957 to 1975. These have been estimated from records of catch presented in HAWG reports from 1973, 1974, 1981 and 1982. Intervening reports were also consulted to check for changes or updates during the period. Catch-at-age data were available from 1970 to 1975 from the 1982 Working Group report, and catches-at-age for the period 1957 to 1972 were estimated from paper records of catch-at-age by national fleets for 1957 to 1972, held at FRS Marine Laboratory Aberdeen. The fishing practices of national fleets were established for the period 1970 to 1980 from catches in 6.a and 6.a (N) recorded in the 1981 and 1982 Working Group reports respectively. This procedure suggested that, on average, more than 90% of catch by national fleet could be fully assigned to either 6.a (N) or 6.a (S). The remaining catch was assigned assuming historic proportions. During this period catches were split into autumn and spring spawning components; anecdotal information on trials to verify this separation suggests it was not a robust procedure. Currently about 5% of herring in 6.a (N) is found to be spent at the time of the acoustic surveys in July, and thought to be spring spawning herring. However, at present the Working Group assesses 6.a (N) herring as one stock, regardless of spawning stock affiliation. In the earlier period higher proportions were allocated as spring spawners. Currently the designated 'spring spawning' component is not included in the catch at age matrix, but the catch tones express the full amount giving rise to SoP differences in the early years. Similarly, a small Moray Firth juvenile fishery was also included in 6.a (N) catch in earlier years because it was thought that these juveniles were part of the 6.a (N) stock. Separating this component in the historic data was difficult, and as the fishery ceased in the very early 70s this has no implications for current allocation of these fish. The Moray Firth is, geographically, part of 4.a (ICES stat. rectangles 44E6, 44E7, 45E6) and is now managed as part of that area. Currently there are no juvenile herring catches from the Moray Firth. A full detail of the analysis carried out is provided as an appendix (Appendix 11) to the 2004 Working Group report. Further investigations are required before determining the correct actions concerning the 'spring spawners' in early period. The consequence of this is to slightly reduce the apparent stock size in the early years, when is already at an all time high. It has no implications for fitting of any survey data, or influence on the B_{lim} reference point, however, it might further increase the high R seen at high SSB in a S/R relationship.

Allocation of catch and misreporting

This fishery has had a strong tradition of misreporting before 2000, though this has reduced in recent years. It is believed that the shortfall between the TAC and the catch was used to misreport catches from other areas (from 4.a to the east and from 6.a (S) to the south). In the past, fishery-independent information confirmed that large catches were being reported from areas with low abundances of fish, and informal information from the fishery and from other sources confirmed that most catches of fish recorded between 4°W and 5°W were most probably misreported North Sea catches. The problem was detailed in the Working Group report in 2002 (ICES, 2002). Improved information from the fishery in 1998 - 2002 allowed for re-allocation of many catches due to area misreporting (principally from 6.a (N) to 4.a (W)). This information was obtained from only some of the fleets

As a result of perceived problems of area misreporting of catch from 4.a into 6.a (N), Scotland introduced a fishery regulation in 1997 with the aim to improve reporting accuracy. Under this regulation, Scottish vessels fishing for herring were required to hold a license either to fish in the North Sea or in the west of Scotland area (6.a (N)). Only one licensed option could be held at any one time. However in 2004, the requirement to carry only a single license was rescinded. Area misreporting of catch taken in area 4.a into area 6.a (N) then increased in 2004 and continued in 2005. It is possible, therefore, that the relaxation of this single area license contributed to a resurgence in area misreporting. In 2007, as in 2006, there was no misreporting from 4.a into 6.a (N). New sources of information on catch misreporting from the UK became available in 2006 (see ICES, 2007). This information was associated with a stricter enforcement regime that may be responsible for the lack of that area misreporting since 2006.

The Butt of Lewis box, (a seasonal closure to pelagic fishing of the spawning ground in the north west of the continental shelf in area 6.a(North) since the late 1970s was opened to fishing in 2008 following a STECF review in 2007. It has not been possible to show either beneficial or deleterious effects from this closure.

Catches are included in the assessment. Biases and sampling designs are not documented. Discards are not included, though data from some fleets suggest these are very minor. Slippage and high grading are not recorded.

B.1.1.2. 6.aS 7.b-c landings

The commercial catch data are provided by national laboratories belonging to the nations that have quota for this stock. In recent years, only Ireland has been catching herring in this area, and the data are derived entirely from Irish sampling. Sampling is performed as part of commitments under the EU Council Regulation 1639/2001.

Commercial catch at age data are submitted in Exchange sheet v 1.6.4. These data are usually processed using SALLOCL (Patterson, 1998b). However, since only one country participates in this fishery this system is not required. Ireland acts as stock coordinator for this stock.

Since 2007, InterCatch, which is a web-based system for handling fish stock assessment data, has been used. National fish stock catches are imported into InterCatch. Stock coordinators then allocate sampled catches to unsampled catches, aggregate them to stock level and download the output. The InterCatch stock output can then be used as input for the assessment models. It is envisaged that this system will replace SALLOCL and other previously used systems.

Since 2007, landings data were revised with respect to reallocation of catches between area 6.aS and 6.aN, for the years 2000-2005. Before 2000, a comprehensive reallocation was used. For 2000-2005, various procedures were used. These attempted to deal with the increasing Irish catches along the 56° line and opportunistic Irish catches of herring in 6.aN during the 4th and 1st quarter mackerel fishery. In some years some catches were reallocated, while in others no reallocations were made. In 2007, it was considered that the most correct procedure was that used before 2000. Therefore a retrospective reallocation has been conducted. It does not adequately consider the Irish herring catches in 6.aN, nor does the reallocation consider fishing along the 56° line. However, in the absence of better information on Irish directed herring fishing in 6.aN, this procedure provides the best possible method.

B.1.2. Discards estimates

The combined dataset includes discards (from 6.aS and 7.b-c only) in the historic period, when they were available.

In 6.aN discards are not included in the catch or catch at age. It has been considered that discarding is very minor. Slippage and high grading are not recorded. However there is evidence from Dutch observer schemes that discarding does occur, though it is not currently possible to raise these estimates to the total catch.

In 6.aS and 7.b-c discards were included in the 1980s and 1990s when estimates were available. At that time, an important market was the Japanese roe market. The development of this market coincided with a decline in a number of other herring markets. The roe market is no longer the main market for Irish herring. Since that time, discards have not been included in the assessment and are thought to be negligible.

B.2. Biological sampling

B.2.1. Maturity

The combined stock uses the same maturity ogive as the 6.aN assessments 1957-2007. For 2008 onwards, the observed proportions mature at age are from the Malin Shelf Acoustic Survey (MSHAS). For 6.aN, maturity were based on observed proportions at age from the 6.a N geographically split survey (MSHAS_N). For 6.aS and 7.b-c, fish of 2+ wr were considered to be 100% mature and 1ringers 0% mature.

B.2.2. Natural mortality

The natural mortality used in the 6.aN assessment until 2013 was based on the results of a multi-species VPA for North Sea herring which was calculated by the ICES multi-species working group in 1987 (Table B.2.1; ICES, 1987). These values for M were also applied to herring stocks in other adjacent areas as they were generally accepted as the best informed proxy for natural mortality available.

Table B.2.1. Previous metrics for natural mortality (M) used for the assessment of 6.aN herring. 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:

From 2012 onwards the assessment of North Sea herring adopted variable estimates of M-at-age derived directly from a new multispecies stock assessment model for the North Sea, the SMS model, used in WGSAM (Lewy and Vinther, 2004; ICES, 2011).

The recent benchmark for herring in 6.a and 7.b-c (ICES, 2015) agreed that there was substantial overlap of predator species between the North Sea and 6.a, 7.b-c areas and that an updating of M from the 1987 multi-species model with current available data in line with the North Sea herring assessment might be appropriate.

The predation of herring to the west of Scotland as elsewhere is likely to be large, particularly for 0- and 1- ring herring (ICES, 2012; Engelhard et al., 2013). Stocks are currently relatively high for mackerel and horse mackerel, two of the main predators of herring at younger ages. Stocks are generally lower for the other fish species currently considered to be main predators of herring in the North Sea, particularly on 1-ring and older fish, although some stocks are increasing (e.g. hake). If mackerel and horse mackerel are in higher abundance in the area to the west of Scotland, M is potentially higher for 0- and 1-ring herring than in the North Sea SMS. It is difficult to ascertain whether M for 6.a herring will be influenced greatly by the biomass of some of the most prolific predators of herring in the North Sea (e.g. saithe, whiting, etc.). The influence of these species on M is likely to be greater on 1-ring herring and older.

Grey seal numbers have increased dramatically over recent decades and their impact on M is likely to be significant to the west of Scotland (Thomas, 2014). However, 0% of grey seal diet is herring in North Sea, and for harbour seal herring contributes 6%. If M values from the North Sea SMS were used in 6.a, this may not adequately incorporate the influence of grey seals on M for 6.a herring stock. This is a consideration when choosing M as predation is likely to be different to the west of Scotland where grey seal numbers in particular are much higher than in the North Sea.

It would appear overall that there are enough similarities in trends in predator fields between the North Sea and West of Scotland that the outputs from the North Sea multispecies model would indeed be a valuable basis for natural mortality of herring in 6.a and 7.b-c. However, given there were also important disparities it was decided not to use the time variant natural mortalities used in the North Sea herring assessment as the temporal dynamics were not likely to be matched entirely to the West of Scotland, but rather take an average for each age and apply this over the entire time series as a proxy for natural mortality.

In conclusion, the most recent benchmark of herring in Division 6.a and 7.b-c (ICES, 2015) agreed the natural mortalities for North Sea herring from the current North Sea multi-species model is the best available proxy for natural mortality of herring in 6.a and 7.b-c. The input data to the assessment of herring in Division 6.a and 7.b-c are averaged annual *M* values from the 2011 SMS keyrun (period 1974 – 2010) for each age (Table B.2.2). This is similar to the previous M for 6.aN in that it is time invariant and age variant. This time series was chosen as it reflects the most recent period of stability in terms of M from the North Sea SMS as it excludes the gadoid outburst of the 1960 which is of little relevance to present conditions.

Table B.2.2: Average M (1974 – 2010) at age for herring from the North Sea multispecies model (SMS) key run 2011 used in the assessment of 6.a and 7.b-c herring

Age (winter rings)	1	2	3	4	5	6	7	8	9
M value	0.767	0.385	0.356	0.339	0.319	0.314	0.307	0.307	0.307

B.2.3. Length and age composition of landed and discarded fish in commercial fisheries

B.2.3.1. Length and age composition of landed and discarded fish in commercial fisheries in 6.aS/7.b-c

Landings data are available for this area from 1970. Data on catch numbers at age, mean weights at age and mean lengths at age are derived from Irish data. Sampling is conducted by area and by quarter. Landings from this fishery, at present, are mainly into the port of Killybegs with lesser amounts landed into Rossaveal. Irish samples are collected from these commercial landings. Length frequency and age data is collected by ICES division by quarter. The length frequency data is added together for each division and quarter and raised to the landings for that area and quarter. The sample weight is divided into the catch weight to get the raising factor. The sum of the length frequencies per quarter is multiplied by the raising factor. An age length key is applied to this data and catch numbers at age calculated.

6.aS\7.b-c herring are currently aged using otoliths and are read using a stereoscopic microscope with reflected light. The minimum level of magnification (15x) is used initially. It is then increased to resolve the features of the otolith. Herring otoliths are generally read in the magnification range of 20x – 25x. The patterns of opaque (summer) and translucent (winter) zones are viewed. The winter (translucent) ring at the otolith edge is counted only in otoliths from fish caught after the 1st January. The first winter ring that is counted is that which corresponds to the second "birth date" of the fish. Therefore a fish of 2 winter rings is a 3 year old. This convention applies to all ICES herring stocks with autumn spawning (Lynch, 2009).

Scales were used in the past for ageing and on average 4 and 5 ringers counted for 46% of the total catch. In 1929 however strong year classes were evident with 4 and 5 ringers making up 85% of the total (Farran, 1928). For the past few years the catch has been mainly composed of 2, 3, 4 and 5 ringers with decreasing proportions of older fish in the catch. This stock is different from the Celtic Sea in that there is no recruitment failure and the Northwest stock is less reliant on incoming recruitment. The catch numbers at age have been mean standardised and are presented in Figure 4.

The precision estimates on 2006 ageing data were worked up using a bootstrap technique. The results of the method found that the relative error is below 20% over the age range 2-6wr. At older ages, estimates of NW herring show higher CVs, which is likely to be due to the relative paucity in the catch.

Mean weights in the stock (WEST) are calculated using samples taken from Q1 and Q4. A mean weight at age is then calculated. Mean weights in the catch (WECA) are calculated using samples from all quarters of the fishery and a mean weight per age derived.

The mean weights in the catch display quite a stable pattern over the time series, although variable weights are only available from the early 1980s. Younger ages (1-6 ring) show an overall downward trend with more fluctuations evident in older ages (7-9 ring). The mean weights in the stock at spawning time have been calculated from Irish samples taken during the main spawning period and show similar patterns to the mean weight in the catch.

B.2.3.2. Length and age composition of landed and discarded fish in commercial fisheries in 6.aN

Catch-at-age data (catch numbers-at-age, mean weights-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 or by onboard observers, and processed as described in Section B.1 above. For information on recent sampling levels and nations providing samples, see Section 2.2. in the most recent HAWG report.

Proportions mature (maturity ogive) and mean weights-at-age in the stock derived from the acoustic survey (see next section) have been used since 1992 and 1993, respectively. Prior to these years, time-invariant values were used.

Biological sampling of the catches was extremely poor in recent history (particularly in 1999). This was particularly the case for the freezer trawler fishery that takes the larger component of the stock based around the shelf break. The lack of samples was due in part to the fact that national vessels tend to land in foreign ports, avoiding national sampling programs. The same fleet is thought to high grade. The long length of fishing trips makes observer programs difficult. Even when samples are taken, age determination is limited for most nations.

Sampling has improved over the last few years. The number of age readings per 1,000 t of catch increased from the low in 1999 of 52 to a high in 2001 of 93. Numbers have decreased again since then to 57 per 1,000 t in 2003. From 1999 to 2003 the sampling has been dominated by Scotland (ranging between 70 and 98% of the age readings), except in 2001, when only 43% of the age determination was on Scottish landings in 6.a (N).

B.3. Surveys

B.3.1. Survey design and analysis

B.3.1.1. Acoustic surveys

An acoustic survey has been carried out in Division 6.aN in June-July since 1991 by Marine Scotland Science. It originally covered an area bounded by the 200m depth contour and 4°W in the north and west and extended south to 56°N (Figure B.3.1.1.1); it has provided an age-disaggregated index of abundance as the sole tuning index for the analytical assessment of 6.aN herring since 2002.

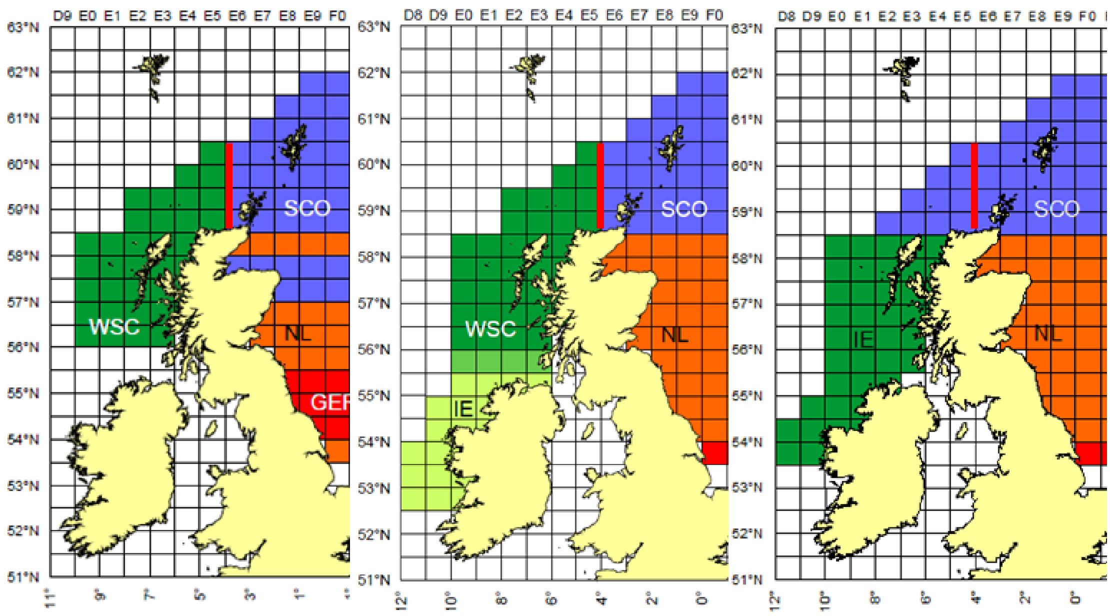

Figure B.3.1.1.1. Survey area layout development for the Malin Shelf Herring Acoustic Survey. Left; coverage 1991 to 2007. Middle; 2008 to 2010. Right; 2011 – present. N.B. The vertical red line at 4° west longitude denotes the eastern limit of the 6.aN survey area

In 2008, it was decided that this survey should be expanded into a larger coordinated summer survey on recommendation from WESTHER, HAWG and SGHERWAY (Hatfield et al. 2007b, ICES 2007b; ICES 2010). The survey was augmented with the participation of the Irish Marine Institute and the area was expanded to cover all of ICES Divisions 6.a and 7.b. The survey has now covered this increased geographical area in the period 2008 to 2014 as well as maintaining coverage of the original survey area in 6.aN. This expanded survey, since 2008 is called the Malin Shelf Herring Acoustic Survey.

In 2011 the survey design was modified to retain capacity to cover the entire survey area in the eventuality that funding was not secured to charter a vessel for the Scottish component of the survey. The Irish vessel took over coverage between 56° and 58.5°, including the coastal areas to the west of Scotland and through the Minches, and Scotland provided coverage in the remainder of the area by extending the area covered by its vessel carrying out the concurrent herring acoustic survey in the northern North Sea. To achieve this, the transect spacing in the Scottish part of the survey was doubled to allow coverage of the increased area. Effective transect spacing is maintained by interlacing transects by a vessel chartered by Marine Scotland Science. Until now, funding has been secured to carry out this design in all years. Should funding not be available in a year to enable chartering an additional vessel, the area coverage can still be maintained with a slight loss in precision due to the increase in transect spacing.

In 2010 The Scottish and Irish vessel both began collecting biological information on herring caught during the survey for use in the morphometric analysis for stock separation recommended in SGHERWAY (ICES 2010).

The stock is highly contagious in its spatial distribution, which explains some of the high variability in the time series. The survey covers the area at the time of year when aggregations of herring from both the 6.aN and 6.aS, 7.b-c stocks are offshore feeding (i.e not at spawning time). These distributions of offshore herring aggregations are considered to be more available to the survey compared to surveying spawning aggregations which aggregate close to the seabed and are generally found inshore of the areas able to be surveyed by the large vessels carrying out the summer acoustic surveys. The survey uses the same target strength as for the North Sea surveys and there is no reason to suppose why this should be any different. Species identification is generally not a major problem (ICES, 2014).

B.3.1.2. Scottish bottom trawl survey index SWC–IBTS Q1 and Q4

Indices of abundance at age derived from the International Bottom Trawl Survey in Quarter 1 in the North Sea (IBTS-Q1) have been used to tune the North Sea herring assessment for ages 2-5+ (ICES, 2012). Marine Scotland Science carries out two similar bottom trawl surveys in western waters (Q1 and Q4) covering the herring stocks in ICES Division 6.a which potentially could be used in a similar way to inform the assessment of herring stocks in this area also (herring in 6.aN and herring in 6.aS).

The Scottish West Coast Ground fish survey in quarter 1 (SWC-IBTS Q1) began in 1981. It has been carried out in a consistent manner since 1986 until 2010 when the survey was redesigned. The survey initially covered ICES Division 6.a, but has since 1996 additionally covered the Northern part of the Irish Sea and between 1996-2006 it extended into 7.b. The target species for this survey are cod, haddock, whiting, saithe and herring.

The Scottish West Coast Ground fish survey in quarter 4 (SWC-IBTS Q4) started out in 1990 as a mackerel recruit survey and is still used for this purpose. Since 1996 this survey has targeted cod, haddock, whiting, saithe and herring in addition to mackerel and the surveyed area mimics that of the Q1 survey.

Both surveys uses a standard 36/47 GOV research trawl fitted with heavy ground gear 'C' and a 20 mm internal liner. Standard haul duration was initially 60 min, but in 1998 this was changed to 30 min. Full technical details are available in the IBTS survey manual (ICES, 2010).

Until 2010 the survey design was a typical “fixed station” ICES statistical rectangle based sampling strategy with minimum one trawl per rectangle and two in rectangles with very variable depth to cover deep and shallow part. Age sampling of herring was stratified within 10 “Scottish herring sampling areas” aiming to collate area specific age length keys for each of these areas (Figure B.1.3.2.1).

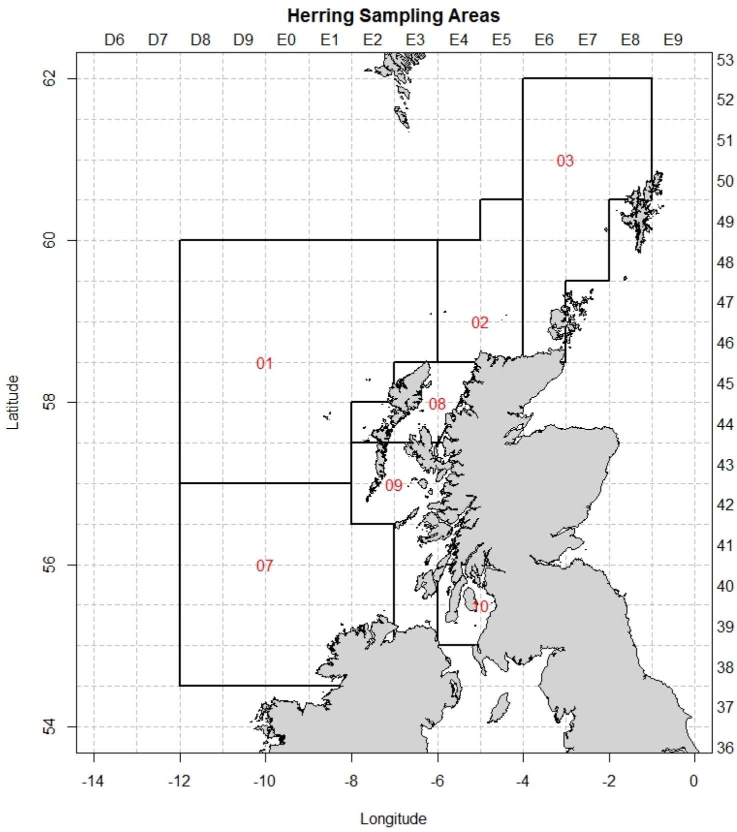

Figure B.1.3.2.1. Scottish herring sampling areas.

As the surveys cover all of 6.a it is plausible to calculate a numbers at age index for each of the two stocks (6.aN and 6.aS) as well as a combined index for all of 6.a for use in a combined 6.a & 7.b-c assessment.

From 2011 onwards both the Q1 and Q4 Scottish West Coast Ground Fish Surveys changed to a random stratified survey design with station positions being randomly distributed within a series of 'a priori' sampling strata (Figure B.1.3.2.2). Tentative K – means clustering of density data for hauls from the previous 'fixed station' surveys time series (1996 – 2010) was carried out separately for each survey in order to create a series of meaningful faunal strata. The species of primary interest for these surveys were juvenile gadoids and therefore the focus of the analysis was on the demersal species: cod, haddock, whiting, saithe and hake. Herring was not considered in the re-stratification.

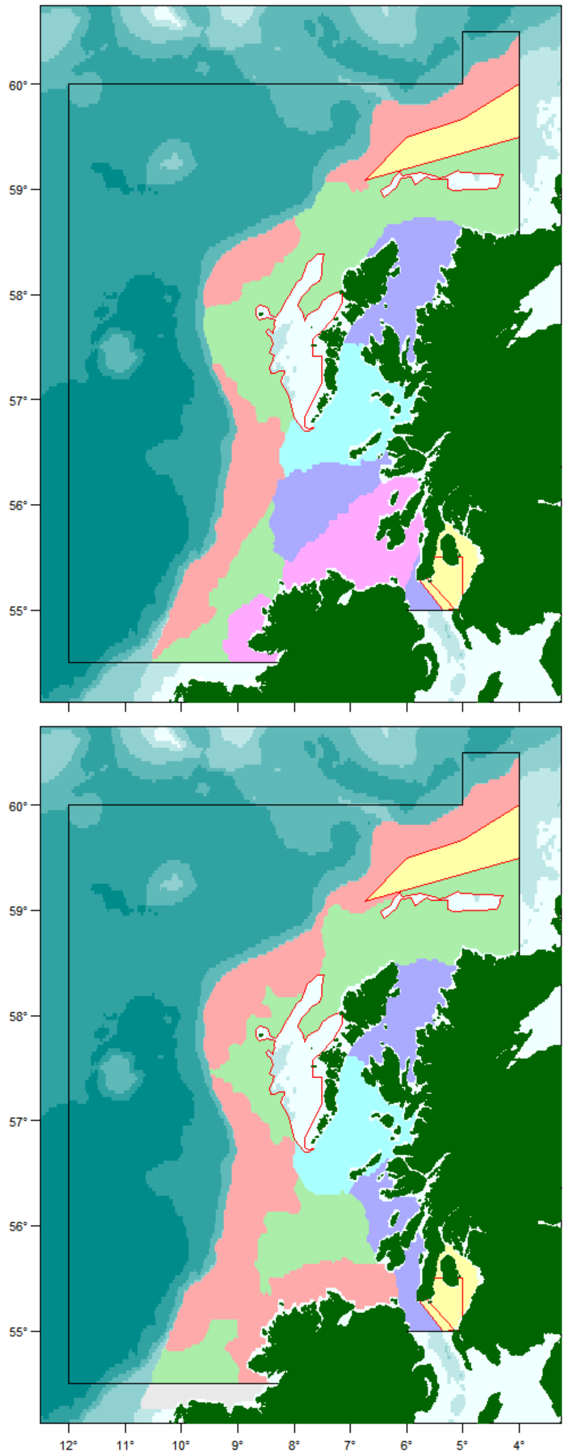

Figure B.1.3.2.2. Area stratification in the Scottish West coast trawl surveys since 2011. Q1 (left) and Q4 (right). Protected areas closed to trawling are marked with a red line.

B.3.2. Survey data used

B.3.2.1. Acoustic surveys

Data from the West of Scotland acoustic survey is used from 1991 – 2007 and from 2008 onwards the combined Malin Shelf survey is used.

B.3.2.2. Scottish bottom trawl survey index SWC–IBTS Q1 and Q4

Data was available from approximately 50 hauls per year per quarter (Figure B.3.2.1.1). Within the periods 1986 -2010 for SWC-IBTS Q1 and 1996 – 2009 for SWC-IBTS Q4, the two surveys are considered consistent in terms of gear use, areas covered and stratification of effort. All years after 2011 can also be considered comparable with the time series after 2011 in all aspects.

There was no survey in Q4 in 2010 due to vessel break down and in Q4 2013 only 50% of the survey was completed, all hauls were in the northern part of 6.a. These two years are therefore excluded from the Q4 index calculations. The years available for index calculation are therefore: For Quarter 1 1986 -2014 and for Quarter 4 1996 -2009 plus 2011-2012.

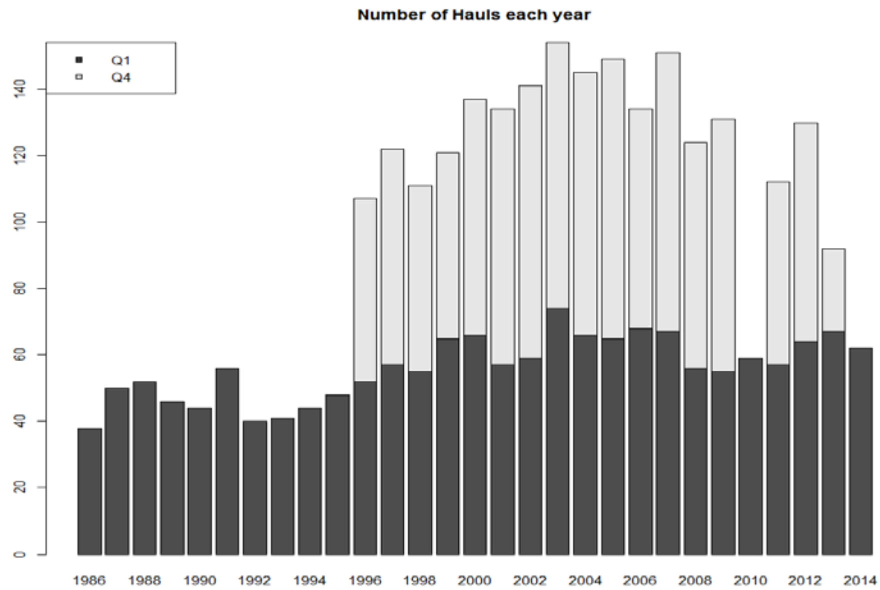

Figure B.3.2.1.1 Number of hauls in each year and quarter in the Scottish bottom trawl surveys.

Area and stock coverage

It was decided to restrict the calculations to hauls within ICES Division 6.a as it was surveyed consistently over the time series, and also consistently by both surveys (Figure B.3.2.1.2). Indices were calculated for Q1 and Q4 independently for three different assessment scenarios; 6.aN assessment, 6.aS assessment and a combined assessment of the two stocks.

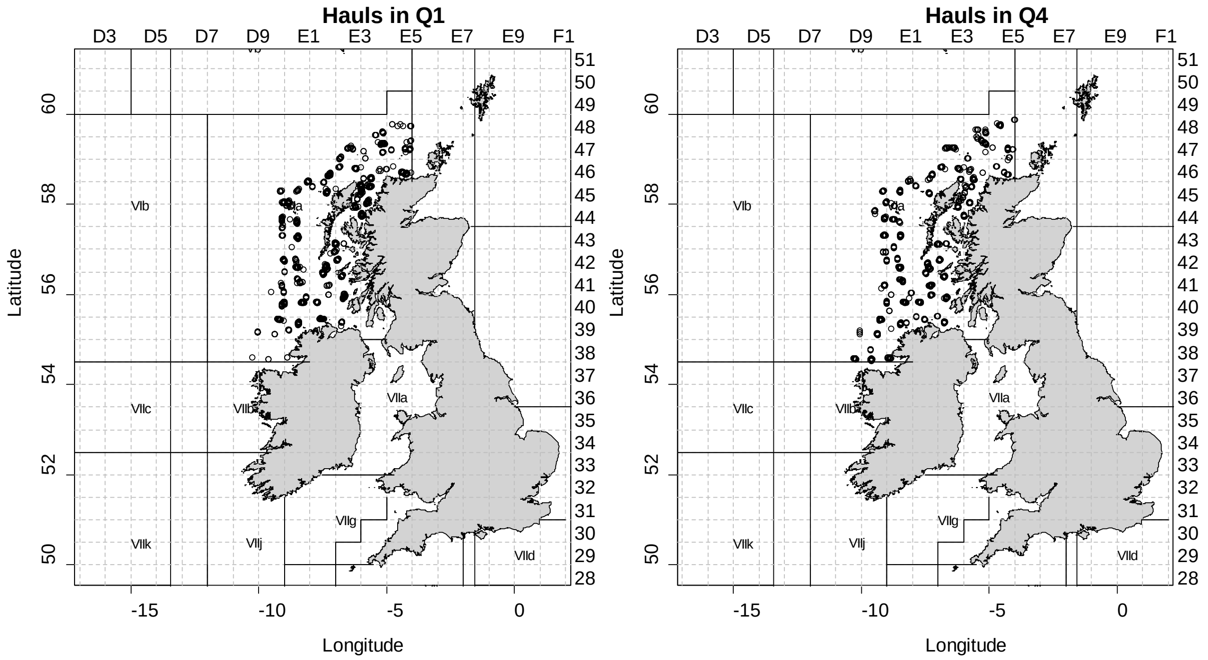

Figure B.3.2.1.2. Haul positions in 6.a in Q1 and Q4 Scottish west coast bottom trawl survey (1986 – 2010 and 1996 – 2009 respectively).

As discussed at the data collation work shop in November, juvenile fish encountered in 6.a during these surveys are not likely to be from 6.aN, but rather from 6.aS, or even other herring stock present in the Celtic Seas area. To capture this in the index we did not include any 0-2 wr fish in the index for 6.aN, and the index for that area only contains 3wr and older fish from hauls within the 6.aN stock area (Figure Figure B.3.2.1.3). The younger herring (1 and 2wr) from all of 6.a were included however in the 6.aS index along with ages 3 and up from hauls within the 6.aS stock area (Figure B.3.2.1.3).

Finally an index was calculated using all ages from all hauls in 6.a for use in an assessment of the combined 6.a & 7.b-c stock.

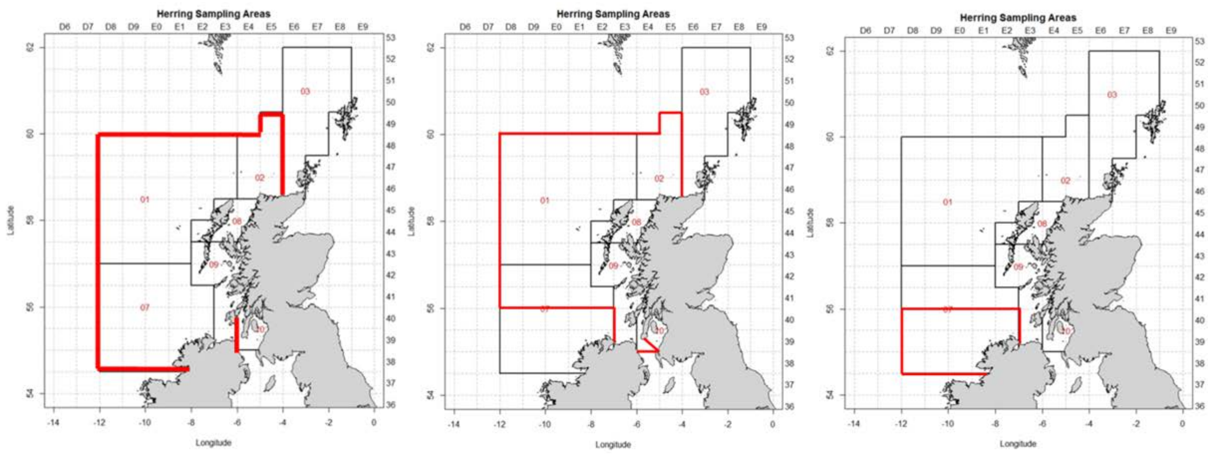

Figure B.3.2.1.3. Areas the index was calculated for and the component herring sampling areas. Left; 6.a. Middle; 6.aN. Right; 6.aS.

Index calculation using the Scottish herring sampling areas stratification

A CPUE index for each of the Scottish herring sampling areas are calculated first:

Numbers at length per haul are standardised to number at length per half hour towing. Aged fish from all hauls within each of the ten Scottish sampling areas are combined to create an area specific Age Length Key (ALK). Area specific ALK is applied to the standardised number at length from each haul within that area to produce standardised numbers at age for each haul. Within each area the catch per unit effort of fish at each age is calculated by summing the age frequencies, divide the value by the number of valid hauls and multiply the result by 10.

$$CPUE_{SA,a} = \frac{\sum_{h=1}^{H_{SA}} \sum_{l=l_{\min}}^{l=l_{\max}} N_{a,l,h} \times 10}{H_{SA}}$$

Where:

$CPUE_{SA,a}$: Catch per unit effort of fish at age a in herring sampling area SA.

$N_{a,l,h}$: Number of fish at age a, length l caught in haul h

H_{SA} : Number valid hauls in sampling area SA

An index at age can then be calculated for combinations of these areas. For example to calculate an index at age for all of Division 6.a, the indices at age for areas 1, 2, 7,8 and 9 are combined as follows. For each age, the age frequency for each sampling area is raised by the number of valid hauls in the area. These raised frequencies are then summed and the result divided by the total number of valid hauls in the assessment region:

$$I_a = \frac{\sum_{SA=1}^{SA=nareas} (CPUE_{SA,a} \times H_{SA})}{\sum_{SA=1}^{SA=nareas} H_{SA}}$$

I_a Index of abundance at age a in region I

$CPUE_{SA,a}$ Catch per unit effort of fish age a in herring sampling area SA

H_{SA} Number valid hauls in sampling area SA.

The internal consistencies of the indices were calculated for each of the indices in line with Payne et al., 2009 where internal consistency refers to correlations between log transformed index values within the same survey (age 1, year 1 versus age 2, year 2 and so forth).

B.4. Commercial CPUE

B.5. Other relevant data

C. Assessment methods and settings

C.1. Choice of stock assess model

The 6.a herring stock was assessed as 6.aN and 6.aS/7.b-c using the assessment model ICA (Statistical Catch at Age with a separable period and VPA part) from the mid-

1990s until 2014 and exploratory assessment methods for 6.aS/7.b-c. 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 WKWEST benchmark meeting in February 2015 developed and evaluated the “state-space” modelling approach for 6.a 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 of basis for advice

The 6.a 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://www.stockassessment.org/.

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 0.99-999 (2014-03-14) 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, http://hawg.googlecode.com. All scripts to perform the assessment are available from the same location in the folder “/trunk/6.a/”.

C.3. Assessment model configuration

Input data are as per the text table below, compiled from the input data for the two component stocks as explained.

Type	Name	How derived	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	Summation	1957 to Y	-	Yes
Canum	Catch at age in numbers	Summation	1957 to Y	1 – 9+	Yes

Weca	Weight at age in the commercial catch	Summation of weca weighted by individual stocks' canum	1957 to Y	1 – 9+	Yes
West	Weight at age of the spawning stock at spawning time.	As per 6.aN; derived from Malin Shelf Acoustic Survey Northern part from 1991. (MSHAS_N)	1957 to Y	1 – 9+	Yes
Mprop	Proportion of natural mortality before spawning	As per 6.aN, 1957-2007; from Malin Shelf Acoustic Survey (MSHAS) 2008-2014	1957 to Y	1 – 9+	No
Fprop	Proportion of fishing mortality before spawning	As per each constituent stock	1957 to Y	1 – 9+	No
Matprop	Proportion mature at age	As per each constituent stock	1957 to Y	1 – 9+	Yes (from 1987 onwards: constant prior to this)
Natmor	Natural mortality	Mean over period 1974 - 2010 for each age from 2011 North Sea multipspecies model key run *	1957 to Y	1 – 9+	No

TYPE	NAME	YEAR RANGE	AGE RANGE (WR)
Tuning fleet	SWC-IBTS Q1	1987 to 2010	2-9+
Tuning fleet	SWC-IBTS-Q4	1996 to 2009	2-9+
Tuning fleet	Malin Shelf acoustic (MSHAS)	2008 to Y	1-9+
Tuning fleet	West of Scotland acoustic (MSHAS_N)	1991 - 2007	1-9+

* Natural mortality estimates are derived from the SMS model used in WGSAM (ICES, 2011). The input data to the assessment are the average values of the raw SMS model annual *M* values for each age over the time period 1974 – 2010.

Model configuration

An example of the SAM model configurations used in the FLSAM package, for the 2015 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.

```
# Min age represented internally in model
 1
# Max age represented internally in model
 9
# Max age considered a plus group? (0 = No, 1= Yes)
 1
# Coupling of fishing mortality STATES (ctrl@states)
 # 1 2 3 4 5 6 7 8 9 #
 1 2 3 4 5 6 7 8 8 # catch
 0 0 0 0 0 0 0 0 0 # MS HERAS
 0 0 0 0 0 0 0 0 0 # WoS HERAS
 0 0 0 0 0 0 0 0 0 # IBTS_Q1
 0 0 0 0 0 0 0 0 0 # IBTS_Q4
# Use correlated random walks for the fishing mortalities
# ( 0 = independent, 1 = correlation estimated)
 1
# Coupling of catchability PARAMETERS (ctrl@catchabilities)
 # 1 2 3 4 5 6 7 8 9 #
 0 0 0 0 0 0 0 0 0 # catch
 1 2 3 3 3 3 3 3 3 # MS HERAS
 4 5 6 6 6 6 6 6 6 # WoS HERAS
 0 7 7 7 7 7 7 7 7 # IBTS_Q1
 0 8 8 8 8 8 8 8 8 # IBTS_Q4
# Coupling of power law model EXPONENTS (ctrl@power.law.exps)
 # 1 2 3 4 5 6 7 8 9 #
 0 0 0 0 0 0 0 0 0 # catch
 0 0 0 0 0 0 0 0 0 # MS HERAS
 0 0 0 0 0 0 0 0 0 # WoS HERAS
 0 0 0 0 0 0 0 0 0 # IBTS_Q1
 0 0 0 0 0 0 0 0 0 # IBTS_Q4
# Coupling of fishing mortality RW VARIANCES (ctrl@f.vars)
 # 1 2 3 4 5 6 7 8 9 #
```

```
 1 2 2 2 2 2 2 2 2 # catch
 0 0 0 0 0 0 0 0 0 # MS HERAS
 0 0 0 0 0 0 0 0 0 # WoS HERAS
 0 0 0 0 0 0 0 0 0 # IBTS_Q1
 0 0 0 0 0 0 0 0 0 # IBTS_Q4
# Coupling of log N RW VARIANCES (ctrl@logN.vars)
 1 2 2 2 2 2 2 2 2
# Coupling of OBSERVATION VARIANCES (ctrl@obs.vars)
 # 1 2 3 4 5 6 7 8 9 #
 1 2 2 2 2 2 2 3 3 # catch
 4 5 5 5 5 5 5 5 5 # MS HERAS
 6 7 7 7 7 7 7 7 7 # WoS HERAS
 0 8 9 9 9 9 9 9 9 # IBTS_Q1
 0 10 11 11 11 11 11 11 11 # IBTS_Q4
# Stock recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time
 0
# Years in which catch data are to be scaled by an estimated parameter
 0
# Fbar range
 3 6
# Model timeout
 3600
```

This example configuration encapsulates the following configuration options and bindings:

Minimum age 1, maximum age 9. The model is configured to cover the full time series of catch data. Mean fishing mortality is defined as ages 3-6. The five data sources are included in the following manner: “Catch at age” observations are treated as a fishing fleet (fleet =0), the WoS acoustic and Malin Shelf acoustic, SWC-IBTS-Q1 and SWC-IBTS-Q4 indices are treated as numbers-at-age indices (fleet=2).

The oldest age (9) 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 8 and 9+, which are represented by a single common random walk. This is expressed in the model configuration above by binding the “state” parameters for ages 8 and 9.

The variances in the estimated numbers at age (logN.vars) are represented by two parameters – one variance for the age 1 numbers and a second for the other ages.

Catchabilities of the individual surveys are bound as follows: The SWC-IBTS-Q1 and ISWC-IBTS-Q4 surveys are represented each with a single catchability parameter (catchabilities slot).

The WoS acoustic survey is represented by three catchability parameters: one for ages 1, 2 and one for ages 3-9 (catchabilities slot). The same applies for the Malin Shelf acoustic survey. 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) is independently estimated for age 1 and similar for all other ages.

The observation variances of the surveys (obs.vars slot) are bound as follows: Both the SWC-IBTS-Q1 and SWC-IBTS-Q4 indices are fitted with their own observation variances, being variable for age 2 and similar for all other ages. The WoS acoustic observation variances are bound into two groups: one covering age 1 on its own, and one for ages 2-9+. A similar setting is used for the Malin Shelf acoustic survey. The catch observation variances are bound into three groups: one covering age 1 on its own, one for ages 2-7, and one for ages 8-9+.

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 ie the "timeout" slot is set of 3600.

It is assumed that the random walks are correlated.

D. Short-term prediction

Deterministic short-term projections are performed using MFDP (Smith 2000).

Input data are stock numbers on 1st January in the assessment year from the FLSAM assessment. Recruitment in the final year, interim year and advice year are set to the same value estimated by multiplying the SSB 2 years prior to the final year by the recruits per SSB over the last three years in the assessment.

Data for maturity, natural mortality, mean weights-at-age in the catch and in the stock are means of the three last year in the assessment years. A catch constraint in the final year equal to the combined TAC in the two management units is used.

E. Medium-term prediction

F. Long-term prediction

G. Biological reference points

Reference points were estimated using the plotMSY software and the EQsim software. Blim was estimating by fitting a segmented regression stock-recruit model to the SSB-Rec pairs from the entire time-series. To estimate the other reference points, a mixture of the Beverton & Holt, Ricker and Segmented regression models were used. All default settings were used, except that recruitment-SSB pairs had to be shifted an additional 1 year to account for the autumn-spawning behaviour of these herring. Both EQsim as plotMSY indicated that Fmsy was best estimated at 0.16, assuming a mixture of SRR models and the Ricker model for EQsim and plotMSY respectively. Blim was set equal to the breakpoint of the segmented regression model, which in both software tools was estimated at 250 000 tonnes. Bpa was calculated from Blim assuming a CV of

0.3 (as obtained from final year uncertainties in SSB in a 10-year retrospective of the assessment). This resulted in a Bpa value of 410 000 tonnes.

	Type	Value	Technical basis
MSY Approach	MSY $B_{trigger}$	410 000	B_{pa}
	F_{MSY}	0.16	Stochastic simulations from segmented regression stock–recruitment relationship.
Precautionary Approach	B_{lim}	250 000	Breakpoint in segmented regression stock-recruitment relationship
	B_{pa}	410 000	B_{lim} raised by assessment uncertainty
	F_{lim}	Not defined	
	F_{pa}	Not defined	

H. Other issues

H.1. Biology of species

The Atlantic herring, *Clupea harengus*, is numerically one of the most important pelagic species in North Atlantic ecosystems with widespread distribution around the Scottish coast. Within the Northeast Atlantic they are encountered from the north of Biscay to Greenland, and east into the Barents Sea. It is thought that herring stocks comprise many reproductively isolated subpopulations through specific spawning grounds and seasons (e.g. autumn and spring spawners), but the taxonomic status of these subpopulations remains unclear.

Herring are demersal spawners and produce dense beds of benthic eggs deposited on gravelly substrates. This behaviour is considered to be an evolutionary remnant of herrings' river spawning past. Each female produces a single batch of eggs per year, releasing a ribbon of eggs that adheres to the benthos; the male sheds milt while swimming a few centimeters above the female. This particular behaviour renders herring vulnerable to anthropogenic activity such as offshore oil and gas industries and gravel extraction.

The eggs take about three weeks to hatch, dependent on the temperature. The larvae on hatching are 6-9mm long and are immediately planktonic. Their yolk sac lasts for about a week during which time they will begin to feed on phytoplankton and crustacean larvae. Their planktonic development lasts around three to four months during which time they are passively subjected to the residual drift which takes them to coastal nurseries. The habitats of juveniles are primarily pelagic, and hydrographical features such as temperature and the depth of thermocline, as well as abundance of zooplankton affect their distribution. Adult fish are pelagic and found mostly in continental shelf seas to depths up to 200m. They form large shoals with diurnal migration patterns through the water column which can be associated with the availability of prey and stage of maturity. In the winter the feeding activity and growth are very slow. Herring can reach 40cm in length and have a maximum lifespan of 10 years although most herring range between 20-30cm and are less than 7 years.

Assessing age and year class for herring can be problematic due to the extended spawning season of autumn spawners from September to January. Using the convention of January 1st as the birthday, 0-group refer to fish born between 3 and 18 months ago but 0-group autumn spawners belong to a different class from 0-group spring spawners. Time series of a stock's age structure helps its management and it is vital that they are extended for all the '*West of Scotland*' herring components in the 6.aN (North), 6.aS (South) and 7.b-c areas.

There are many hypotheses as to the cause of the irregular cycles shown in the productivity of herring stocks (weights-at-age and recruitment), but in most cases it is thought that the environment plays a key role (through prey, predation and transport). The 6.aN herring stock has shown a marked decline in productivity during the late 1970s and has remained at a low level since then. ICES identifies that the 6.aN stock is currently fluctuating at low levels and is being exploited above F_{msy}.

H.2. Stock dynamics, regulations in 20th century – historic overview

H.3. Current fisheries

See Section A.2.

H.4. Management and advice

Each of the constituent stocks in this meta-population has an agreed long term management plan.

Until 2015, advice for the 6.aN stock was based on an agreed management plan, which included a target fishing mortality, interannual TAC fluctuation constraints and F=0 if SSB< B_{lim}. This plan formed the basis of ICES advice since 2008. The plan was enshrined in EC legislation. There is no information available to advise on the current status of the 6.aN constituent stock.

The ICES advice for the 6.aS/7.b-c stock has been, since 2007, that the stock was below B_{lim}, and that a rebuilding plan was required. A rebuilding plan was proposed by the Pelagic Advisory Council and adopted in 2013 and followed in 2014 and 2015. Based on this plan the TAC was set at 0 t for 2015. This plan is not enshrined in legislation.

There are separate TACs for each of the constituent stocks. The boundary between them is formed by the 56th parallel, the 7th meridian, and the coast of Co. Donegal, Republic of Ireland. These separate management units have existed since 1982.

H.5. Others

Age 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, 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

(The historic perspective, as well as all the other section on the stock annex, should only update in a benchmark workshop. If there is any reason to deviate from the stocks annex, this should be explain in the Working Group report and only update this deviation in the historic perspective after consultation with ICES Secretariat and WG Chair).

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