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Report of the Benchmark Workshop on West of Scotland Herring (WKWEST)

2–6 February

Dublin, Ireland

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive Summary

The WKWEST meeting was held in the Marine Institute, 80 Harcourt Street, Dublin, Republic of Ireland, 2–6 February 2015, to benchmark the assessments of herring in VIaN and VIaS, VIIb,c (or alternatively VIa, VIIb,c combined) and the Celtic Sea, VIIg,j. The data compilation process and intercessional work began in October 2015. Previous assessments of these stocks applied the Integrated Catch Analysis (ICA) model. The 2014 Benchmark Workshop on Pelagic Stocks (WKPELA) changed the assessment model for Celtic Sea VIIg,j herring to the State-space Assessment Model (SAM). However, WKWEST concludes that the Age Structure Assessment Program (ASAP) offers an improved fit to recruitment signals than SAM for Celtic Sea VIIg,j herring. In the case of VIaS, VIIb,c both analytical and non-analytical assessments had suggested this stock was extremely low, but the exact size of the stock is uncertain. For all stocks in the VIa, VIIb,c region, the mixing of the stocks and doubt as to whether the two stocks can be accurately identified in both the catch and survey data persisted as a major source of uncertainty.

Twenty people participated in the Benchmark process which included stakeholders and three independent reviewers from outside the ICES community.

Assessments of VIaN and VIaS, VIIb,c were attempted in an effort to resolve issues related to survey data and to increase assessment quality. The principal problem revolved around there not being a robust method that could be applied to the acoustic survey data that could identify the origin (VIaN or VIaS, VIIb,c) of the herring occurring in the area. As such it was not possible to allocate survey catches to each area and thus have a tuning index for an analytical assessment for the two stocks. The unsplit acoustic survey was used as an index of abundance for a VIa, VIIb,c analytical assessment, along with data from Scottish groundfish surveys which also sampled the combined stocks. This SAM assessment of the VIa, VIIb,c meta-population provides stock dynamics and management reference points for the area as a whole. Because no robust method of determining the relative stock sizes could be found, it is not possible to provide indicators of the sizes of each stock. In regard to management, the meta-population spans two management areas thus this assessment cannot provide specific advice concerning each of the management units. To determine the quantities of herring in each of the stocks, and hence management areas, it is imperative that new and robust methods are developed to adequately identify individuals, mainly in the surveys, to their respective parent population (stock).

In the case of Herring in the Celtic Sea, VIIIg,j, the input data remains the catch and biological data and the HERAS survey. There was a minor change to the assumed natural mortality rate from the previous benchmark WKPELA (ICES, 2014), which remains more in line with other stocks on the European shelf area but also reflects the recent dynamics of the Celtic Seas ecoregion. The age range used from the survey and in the assessment remain as revised last year as was the extension to the plus group (9+ winter rings). The assessment model for Celtic Sea, VIIg,j herring was changed to the ASAP model based on statistical criteria which showed this was the most appropriate model and due to the SAM model tending to 'smooth out' variability of recruitment which was clearly occurring in the catch data. The revised reference points, using the new assessment techniques, especially F_{MSY} were more in line with previous perceptions of the stock than those produced in 2014.

Stock annexes for herring in the area VIa, VIIb,c and the Celtic Sea, VIIg,j were completed according to the work done.

During the Herring Assessment Working Group (HAWG) in March 2015 WGSAM informed the HAWG chairs that there were an errors in the values of natural mortality that had been used at the Benchmark. The corrections for the Celtic Sea were relatively straightforward and were presented in the HAWG report. In the case of VIa, VIIb,c it was decided at the HAWG to implement a WKWEST Extension by correspondence to investigate the consequences of the changed natural mortality on the Benchmark procedures and where necessary finalize new protocols. The report details the original Benchmark deliberations with a separate section detailing the final conclusions for the VIa, VIIb,c assessment.

1 Introduction

This benchmark workshop considered the assessment method (including projections) and appropriate reference points for three ICES advisory units:

- Herring to the west of Scotland (VIa North)
- Herring to the west of Ireland (VIa South and VIIa,b)
- Herring in the Celtic Sea (Celtic Sea, VIIg,j)

The benchmark took place over five months with an initial WebEx on the 1 October, data collection meeting on 18-20 November 2014 and a five day meeting 2-6 February 2015.

In addition to the external co-chair, two independent scientists from outside the ICES community reviewed all stages and provided comments and input during the discussions: Tim J. Miller (USA) and Gary Melvin (Canada).

This report documents and justifies the decisions made by the workshop to establish new assessment and forecast methods along with combining stocks in adjacent management areas in to one meta-population assessment unit. Where it is not possible to determine the size of distinct populations, the Workshop does not provide advice on the management options other than to highlight that smaller stocks should be protected under any exploitation plan. The report should be used as a record of the rational for the new stock annexes. The stock annexes provide the “recipe” for the recommended stock assessment methods and will be used until the next benchmark (approximately every 3–5 years).

Due to the correction in the natural mortalities used for the assessment of the Celtic Sea and VIa, VIIb,c herring stocks the results reported here for the Celtic Sea differ slightly from what is reported by the HAWG (ICES HAWG, 2015). A WKWEST Extension explored the VIa, VIIb,c assessment and those deliberations and conclusions are reported in a separate section 3.11 of the report. In regard to the assessment protocols and the reference points this section has the final deliberations of the Benchmark, other sections provide the background. A minority dissenting position is documented in Annex 7.2.

2 Description of the Benchmark process

2.1 Terms of Reference WKWEST – Benchmark Workshop on West of Scotland herring stocks 2015/2/ ACOM:34

A **Benchmark Workshop on herring stocks in the waters West of Scotland** (WKWEST), chaired by External Chair Steven Cadrin, USA and ICES Chair Richard Nash, Norway, and attended by two invited external experts Gary Melvin, Canada and Timothy Miller, USA will be established and will meet in Dublin 18–20 November 2014 for a data compilation meeting and in Dublin, Ireland for a 5 day Benchmark meeting 2–6 February 2015 to:

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short-term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:
   i. Stock identity and migration issues;
   ii. Life-history data;
   iii. Fishery-dependent and fishery-independent data;
   iv. Further inclusion of environmental drivers, multispecies information, and ecosystem impacts for stock dynamics in the assessments and outlook.

b) Agree and document the preferred method for evaluating stock status and (where applicable) short-term forecast and update the stock annex as appropriate. Knowledge of environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the methodology. If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

c) Evaluate the possible implications for biological reference points, when new standard analyses methods are proposed. Propose new MSY reference points taking into account the WKFRAME2, results and the introduction to the ICES advice (section 1.2), WKMSYREF3.

d) Develop recommendations for future improving of the assessment methodology and data collection;

e) Compile and review available fleet and fisheries data for fisheries in the Celtic Sea (VIIf,g);

f) Produce a mixed fisheries annex for the Celtic Sea region (VIIf,g);

g) As part of the evaluation:
   i. Conduct a 3 day data compilation workshop (DCWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;
   ii. Following the DCWK, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting

Stocks	Stock leader
her-vian	Emma Hatfield
her-irlw	Afra Egan
Her-irls	Afra Egan

The Benchmark Workshop will report by 06 March 2015 for the attention of ACOM.

2.2 The benchmark process

The ICES Advisory Committee (ACOM) acted on the recommendation of the herring assessment working group, (HAWG) that three herring stocks in the waters West of Scotland undergo a benchmark assessment in 2015. The HAWG provided ACOM with a provisional "issue list" that articulated the need for each of the stocks to have their assessment method undergo an ICES benchmark examination. These issue lists formed the basis of the benchmark process.

To accomplish this work, one scientist was asked to coordinate the data and assessments for herring in VIa, VIIb,c, and individual scientists were tasked with leading the data compilation and assessment development for each stock. These stock leaders were responsible for their team, the investigations, and were asked to lead discussions in plenary. They were also responsible for the completion of the report sections and stock annex. The meeting coordinator for herring in VIa, VIIb,c was Maurice Clarke (Ireland), stock leaders were Emma Hatfield (Scotland) for herring in VIa north (her-vian) and Afra Egan (Ireland) for herring in VIa south and VIIb,c (her-irls) and herring in Divisions VIIaS,b,d,e (Celtic Sea; her-irlw). In addition to national experts, stakeholders attended the benchmark meetings.

An initial online (WebEx) meeting was convened on the 1 October 2014 to introduce the stocks, identify data sources and issues that needed to be addressed at both the Data Compilation Workshop and the Benchmark. All stock teams were encouraged to submit working documents at least two weeks prior to the benchmark workshop in February 2015 to assist all workshop members in preparations for the meeting. The data compilation meeting was held at the Marine Institute in Dublin, Ireland 18-20th November 2014. This meeting used the issue lists to initiate a workplan and to encourage sharing of ideas among the participants. The participants emphasized that the ability to split the survey and catch data would play a predominant role in determining the appropriate stock units in the benchmark. Between the data compilation meeting and the benchmark workshop, work was ongoing and two meetings (11 December 2014, 8 January 2014) were held online via conference calls (i.e. WebEx) to garner further input from the external reviewers in an iterative manner.

The Benchmark workshop (WKWEST) was convened in Dublin at 10.00 am on 2 February 2015. The first day of the benchmark workshop was spent in plenary on the following topics: natural mortality assumptions, changing environmental conditions and biological parameters, catch data corrections, stock identification, progress in splitting the survey data, and a preliminary discussion of assessment methods and unit decisions for VIaN and VIaS, VIIb,c.

The second day continued with plenary on natural mortality estimations; assessment methods, and unit decisions for VIaN, VIaS, VIIb,c; and, a summary of plans and progress to date on population genetic studies of herring in these areas. The possibility of having to utilize one assessment for area VIa, VIIb,c was explored along with means to provide information on the relative sizes of the stocks which spawn in VIaN and VIaS, VIIb,c. In addition, the question of revised catch options for the area were discussed. A period of the latter part of the day was spent reviewing the various assessment model options for the Celtic Sea and methods to objectively choose between the various candidate models.

During the third day reference points for the combined areas (VIa, VIIb,c) were explored, along with how to deal with management reference points and management plans that are currently in place for the separate VIaN and VIaS, VIIb,c stocks. Further explorations for inclusion of both acoustic and bottom-trawl surveys were explored and results presented. Time was also set aside for a presentation of updated Celtic Sea assessments where the exclusion of selected acoustic surveys was explored.

On the fourth day a series of updated VIa, VIIb,c assessments using updated catch data and a range of combinations of tuning indices, with the intention of deciding on the final set up for an assessment were presented. With an agreed run, the management reference points for the VIa, VIIb,c meta-population were initiated and initial outputs discussed. The various assessment options for the Celtic Sea, VIIg,j were reviewed and the ASAP option decided as the most robust based on statistical criteria. From these results the relevant management reference points were estimated.

On the final day the reference points and splitting procedures, along with the choice of recruitment time-series for projections were discussed. In the case of the Celtic Sea, VIIg,j agreed recommendations on the assessment procedure, including reference points and catch options could be formulated. The presentation of recent 'exploratory assessments' for VIaS, VIIb,c revealed a large degree of uncertainty which resulted in the Workshop not having a reliable methods to determine the relative sizes of the VIaN and VIIaS, VIIb components of VIa, VIIb,c. In the light of this disappointing finding the Workshop could only go so far as to provide a method of determining the meta-population size in VIa; VIIb,c and recommend that methods of identifying the two components in catches and surveys be vigorously pursued. With an analytical assessment of the meta-population appropriate reference points were estimated based on various forms of a stock and recruitment relationship.

After the benchmark workshop meeting, the report was finalized by correspondence.

As documented earlier, due to a corrected time-series of natural mortality values being made available in the last days of the HAWG, it was necessary to implement a WKWEST Extension after the closure of the HAWG meeting to investigate the VIa, VIIb,c assessment procedure. This was done through correspondence and two WebEx meetings. The original model was reformulated and tested. In addition some preliminary work was undertaken on a new model which wasn't considered at the Benchmark for VIa, VIIb,c but was used for the Celtic Sea herring assessment. WKWEST Extension came to a consenus opinion as to the best assessment, however, Ireland exercised its right to add a minority dissenting opinion in Annex 7.2. Therefore, this report consists of the original plus extra sections which detail the findings and deliberations of the WKWEST Extension.

3 Herring in VIa, VIIb,c

3.1 Stock ID and substock structure

Historical background to stock assessment and management of herring to the west of the British Isles

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 in the North Sea, beginning in 1977.

In 1969, the ICES Working Group recognized 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 VIa (west of Scotland and north-west Ireland) and Divisions VIIg-k with the southern part of VIIa (south of 52°30′N) (Celtic Sea).

Total allowable catches (TACs) for **Division VIa** 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 VIIb, this herring resource was not assessed analytically, and a precautionary TAC was imposed during the closure time of Division VIa.

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 HAWG, 1982) recommended new management units: one for **VIa North** and a second one for **VIa South and VIIb,c**. The rationale was that the fisheries in the two areas were distinct, the fisheries were prosecuted by different countries (Figure 3.1.1) and there were rather different recent (1970s) patterns of fishing activity in the two areas (Figure 3.1.2). These units were adopted by the European Commission in 1982.

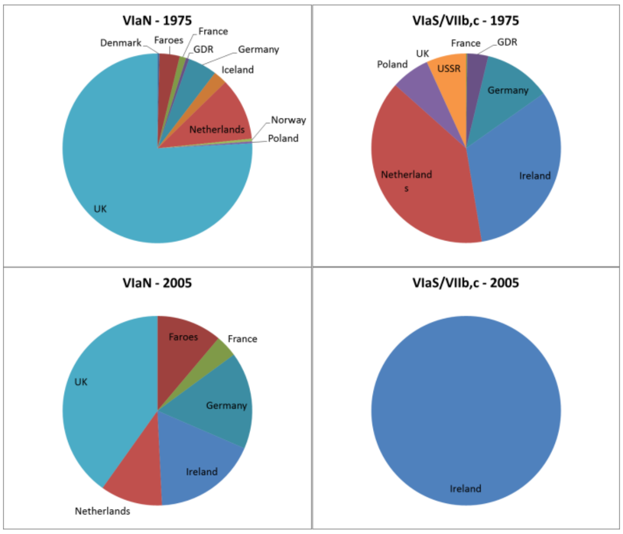


Figure 3.1.1. Catch by country in VIaN (left panels) and VIaS/VIIb,c (right panels) in 1975 (upper panels) and 2002 (lower panels) to show the changes in fishery participants over time in the two areas. Catches are working group catches.

In 1978, at the recommendation to cease fishing in area VIa, the EC requested ICES to examine the **Clyde** populations separately from the rest of VIa. The question revolved around the closure of the fishery on autumn spawning populations and the presence of spring spawners in the Clyde. The HAWG convened in September 1978 to evaluate the position of herring in the Firth of Clyde in relation to neighbouring herring stocks and assess the state of the Clyde stock. The outcome was that the HAWG recommended the Clyde fishery should be treated as a separate management unit to the rest of Division VIa. The first TAC regulation was introduced in 1979 and a number of management regulations were defined in the period following. The first analytical assessment was carried out in 1982. Management of the Clyde has remained separate since 1979.

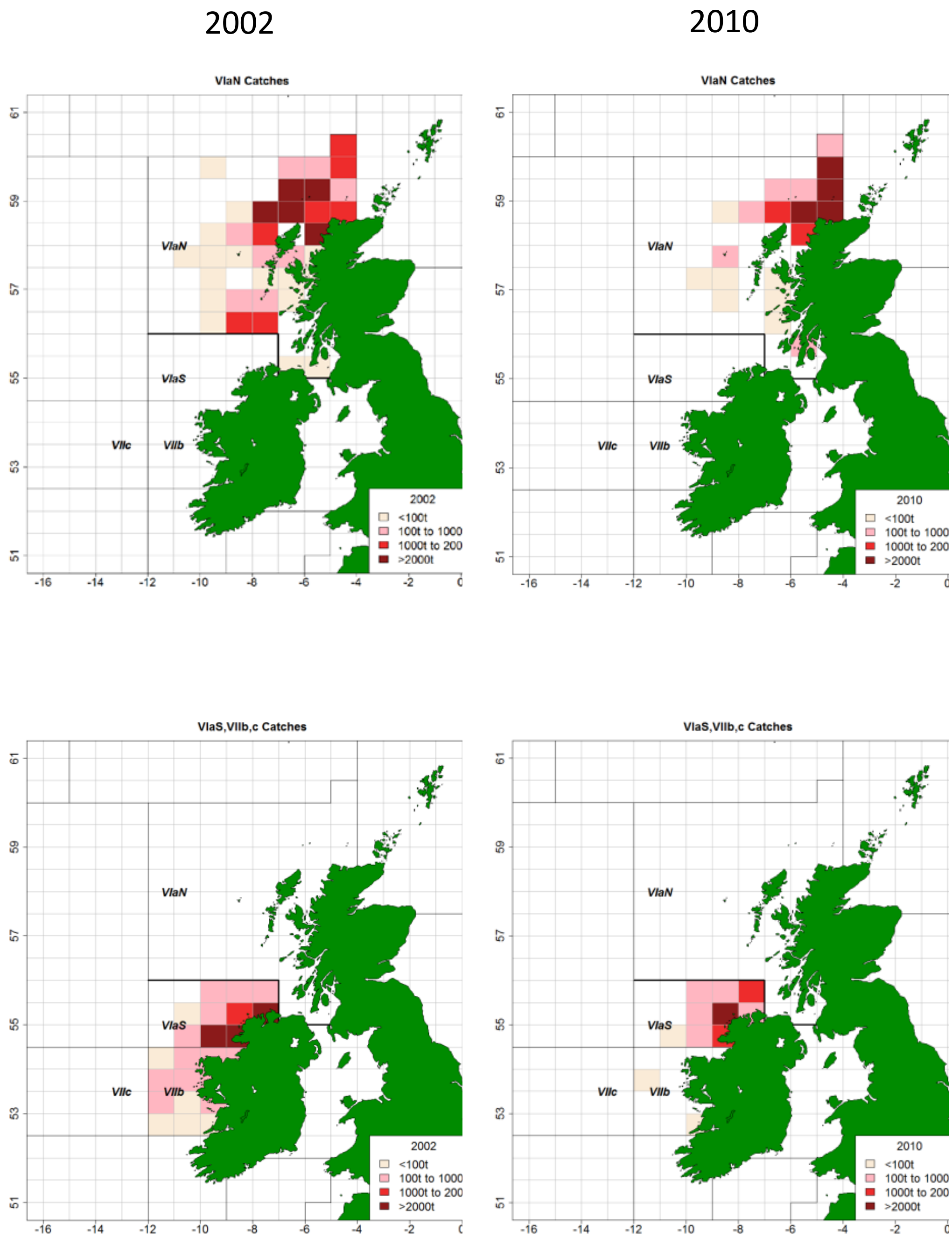


Figure 3.1.2. Catch by ICES statistical rectangle in VIaN (upper plots) and VIaS/VIIb,c (lower plots) on 2002 (left panels) and 2010 (right panels). Catches in VIaN are working group catches; in VIaS/VIIb,c they are the official catches.

Much of the decision-making behind many of these changes, around Ireland in particular, has been reviewed extensively in the publication "The Herring Fisheries of Ireland" (Molloy, 2006).

Current assessments

Currently (ICES HAWG, 2014) the putative herring stocks to the west of the British Isles are assessed separately as 1: VIa North; 2: VIaS and VIIb,c; 3: Irish Sea and 4: Celtic Sea and VIIj (Figure 3.1.3). Herring in the Clyde is recognized as a separate stock but due to the very low catches, no survey information and the perception of a very low stock size, is not currently assessed analytically. In 2011 under the provisions of the TAC and Quota Regulations (57/2011), the European Commission delegated the function of setting the TAC for certain stocks which are only fished by one Member State, to that Member State. This provision currently applies to herring in the Firth of Clyde with TAC setting responsibility delegated to Scotland. The assessments are undertaken using annually obtained landings, catch- and weight-at-age along with a variety of survey tuning indices for analytical assessments, increasingly through the use of the state-space assessment model SAM (ICES HAWG, 2014). In all cases, landings data are assigned to the area (stock) and statistics formulated by area.

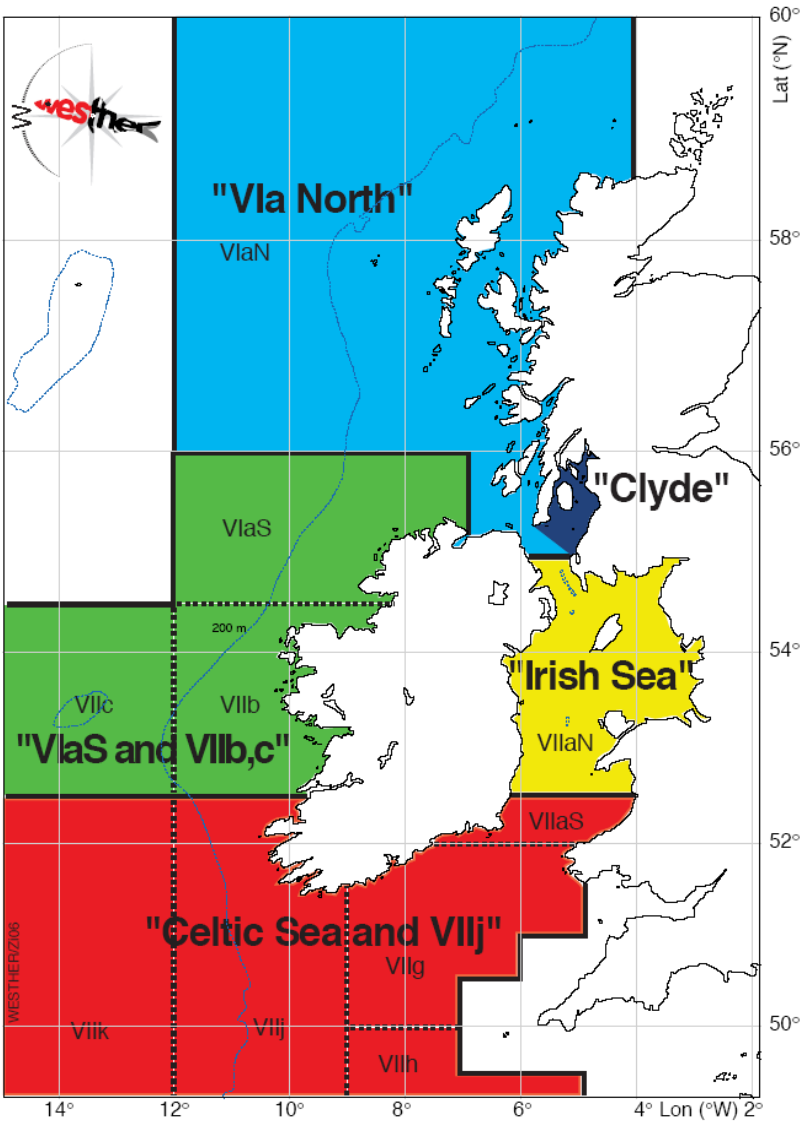


Figure 3.1.3. Current defined assessment and management areas for herring stocks to the west of the British Isles.

Current management and fisheries

At present the management is based on the four main fisheries, i.e. Celtic Sea and VIIj, Irish Sea, VIaS and VIIb,c and VIa 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 B_{pa} wherever possible (if this reference point is defined). A timeline of changes to fisheries and management in Divisions VIa and VIIb,c is shown in Figure 3.1.4.

The VIa North fishery operates throughout the year, and has been primarily a summer fishery, i.e. not targeting spawning aggregations, since the mid-1990s (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 (Figure 3.1.1). In VIaS, VIIb,c the fisheries tend to be on spawning aggregations.

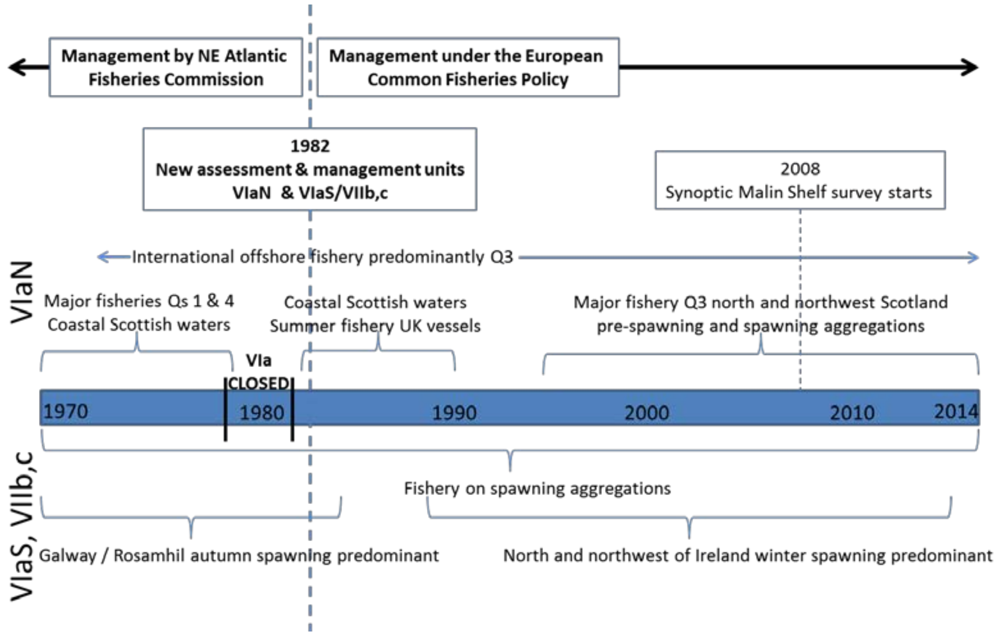


Figure 3.1.4. Diagram to show the timeline of changes to fisheries and management in VIaN and VIaS, VIIb,c.

Council Regulation (EC) 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 VIa North fishery where international fleets are important. In most cases the fleet sizes vary between years, both in 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 VIaS, VIIb,c stock are managed by local committees. These committees each have a set of local management objectives (ICES HAWG, 2014).

In VIaS, VIIb,c the fishing season is considered to run from late autumn into 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 VIaS, VIIb,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 B_{pa} only if transboundary catches are eliminated (Figure 3.1.1).

In VIa 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 VIa North fishery until after the 1 October; nor are those vessels allowed to fish within the 12 nautical mile limit north of Barra Head.

Scientific background

Historical perception of herring stocks spawning to the west of the British Isles

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.

Parrish and Saville (1965) illustrated two major groups of shelf spawners, the Scottish west coast Minch stock and Irish Sea stock. The principal North Sea stock(s) were also illustrated along with interchange between west of Scotland and North Sea distributions. They divided the shelf spawners into northern Irish Sea, southern Irish Sea (Dunmore autumn/winter spawners), Clyde winter-spring spawners and Minch summer-autumn spawners. They also pointed out the high similarity between Irish Sea and Minch herring.

In subsequent years, further spawning locations were recorded so that at present the following are still considered the main spawning components: Irish Sea (combined Manx and Mourne), Celtic Sea (Dunmore East), south-west Ireland (Baltimore, Kerry and Galway), northwest Ireland (Donegal), Firth of Clyde and Scottish west coast (Minch). The HAWG (ICES HAWG, 1979) carried out correlation analyses on age composition data to determine possible associations between fish from several of these spawning components. They concluded that the south Minch and the northwest of Ireland were areas in which a complex stock mixing took place. King (1985) examined a number of morphometric characteristics of fish from nine of the west coast spawning grounds and proposed a number of associations. Using this method, the Irish Sea components (Manx and Mourne) were shown to be closely related with a certain degree of intermingling. The association between the Clyde stock and both the Manx and Minch stocks indicated that autumn spawners present in the Clyde could migrate out of the Clyde to spawn in these regions (also suggested by Morrison and Bruce (1981) on the basis of tagging experiments). There was a clear separation of the Dunmore East stock from the three stocks on the west coast of Ireland. The later stocks (west Cork, Kerry and Galway) were shown to be closely related suggesting they could be considered as one cohesive unit. This is in agreement with the findings of Grainger (1976). The similarities in morphological characteristics of Donegal and Minch stocks could be due to mixing of autumn and spring spawners which are difficult to separate, rather than a close affinity of the two stocks.

In summary, Parrish and Saville (1965), ICES HAWG (1979) and King (1985) suggested an interlinking of herring in areas VIa and VIIaN, 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 3.1.5 taken from the 2010 report of the ICES Study Group on the evaluation of assessment and management strategies of the western herring stocks (SGHERWAY) 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.

Research into stock discreteness / mixing

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 via four research objectives: (i) estimation of genetic and phenotypic differentiation between spawning aggregations; (ii) determination of stock origins and life history of juveniles; (iii) determination of composition of feeding aggregations; (iv) improved guidelines for the conservation and management of biodiversity and stock preservation.

In all, 5966 herring were collected: 1377 spawning adults from eight of the ten main spawning areas; 1716 juveniles; 2349 non-spawning adults; 524 outgroup herring (Figure 3.1.6).

The project's scientific results, summarized in Hatfield *et al*. (2007a), provided little evidence of discrete 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) (Figure 3.1.7). 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.

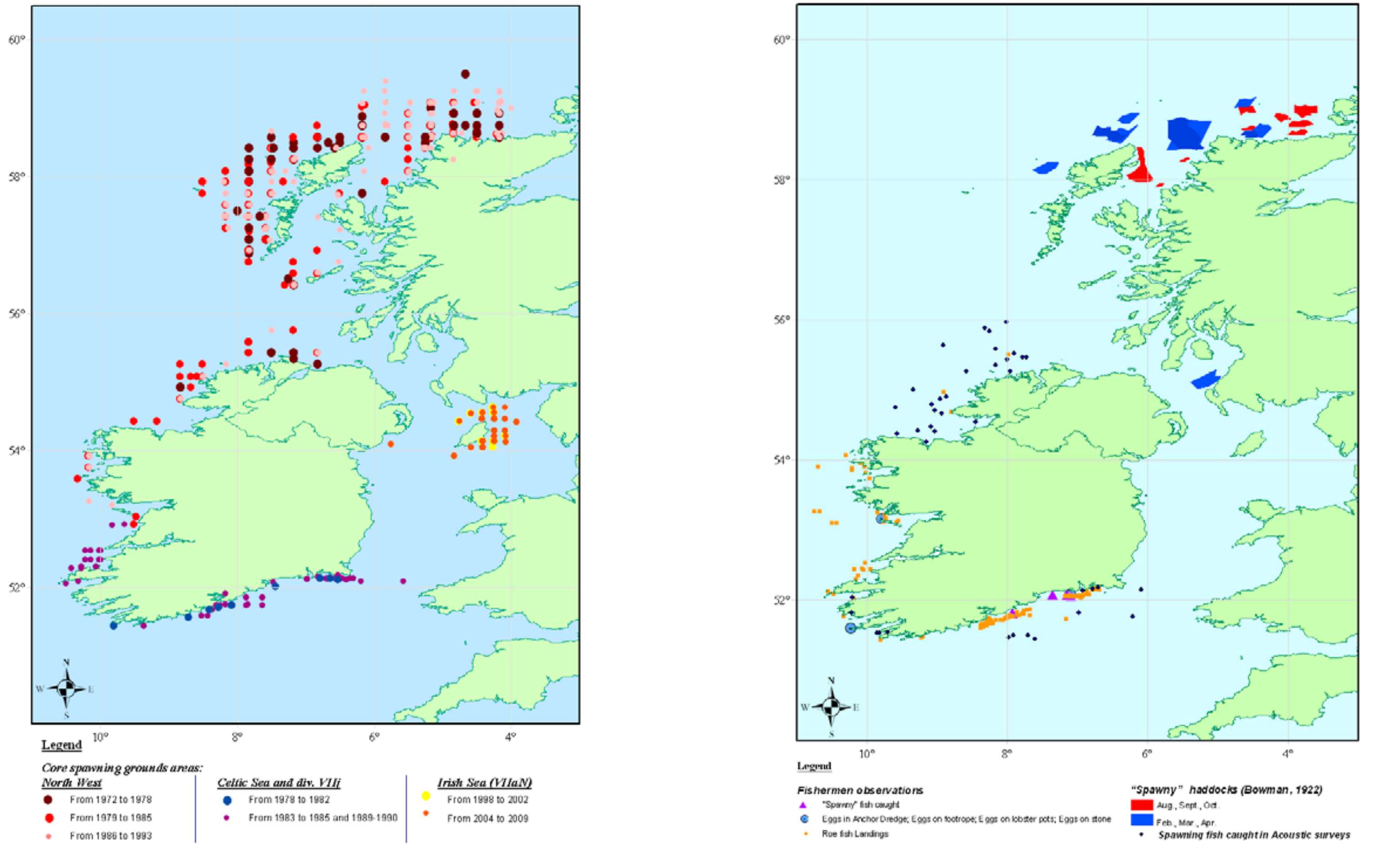


Figure 3.1.5. (Left panel) map representing the core areas of spawning grounds according to the different stock larval densities, keeping the stations that contained ≥ than 85% of the distribution of larval density per year. The different colours highlight the temporal dynamics of the different stocks. (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.

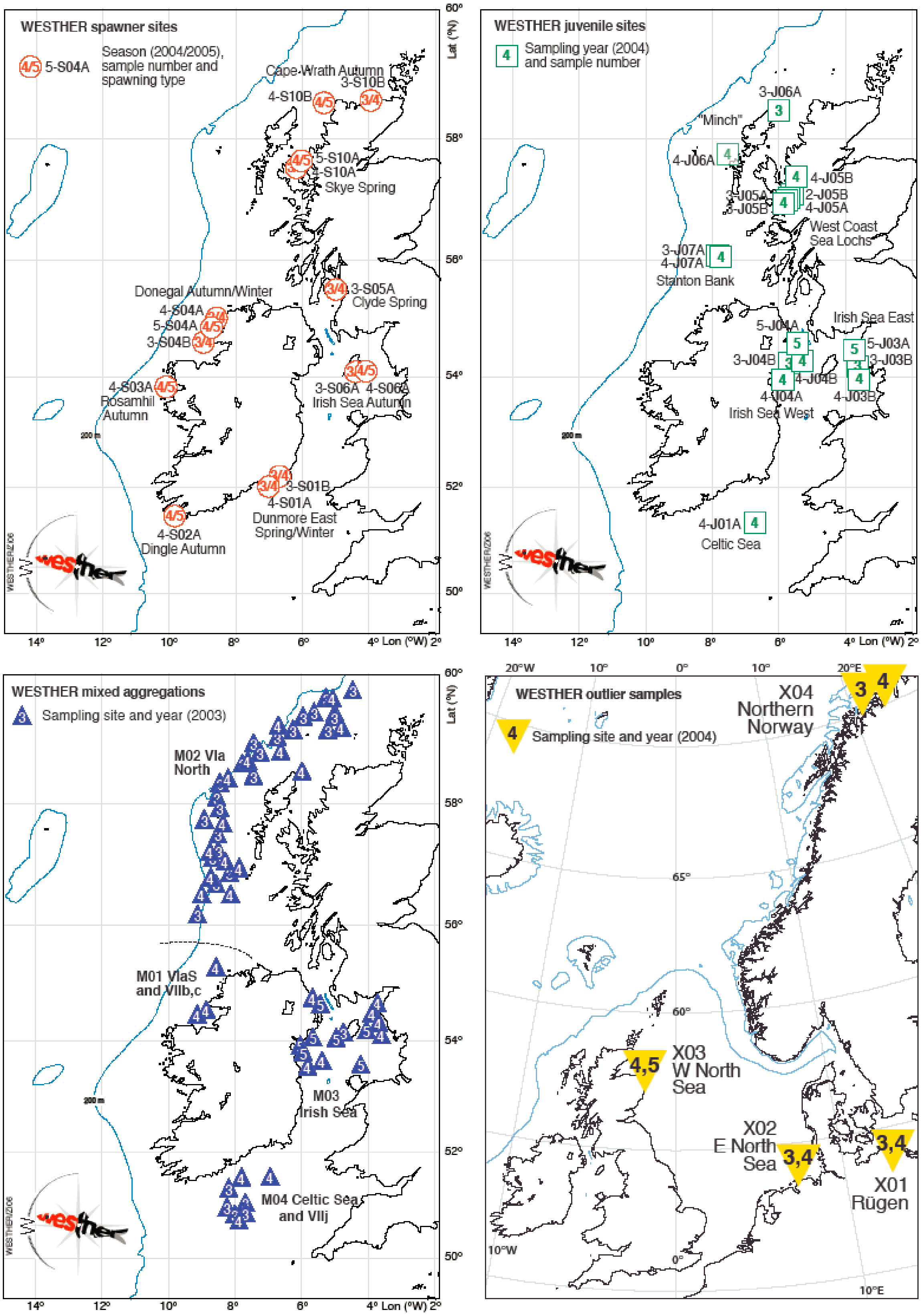


Figure 3.1.6. Realized sampling from the WESTHER project during 2003, 2004 and 2005: Spawners (red circles); Juveniles (green squares); "Mixed" adults (blue triangles); Outgroups (yellow triangles).

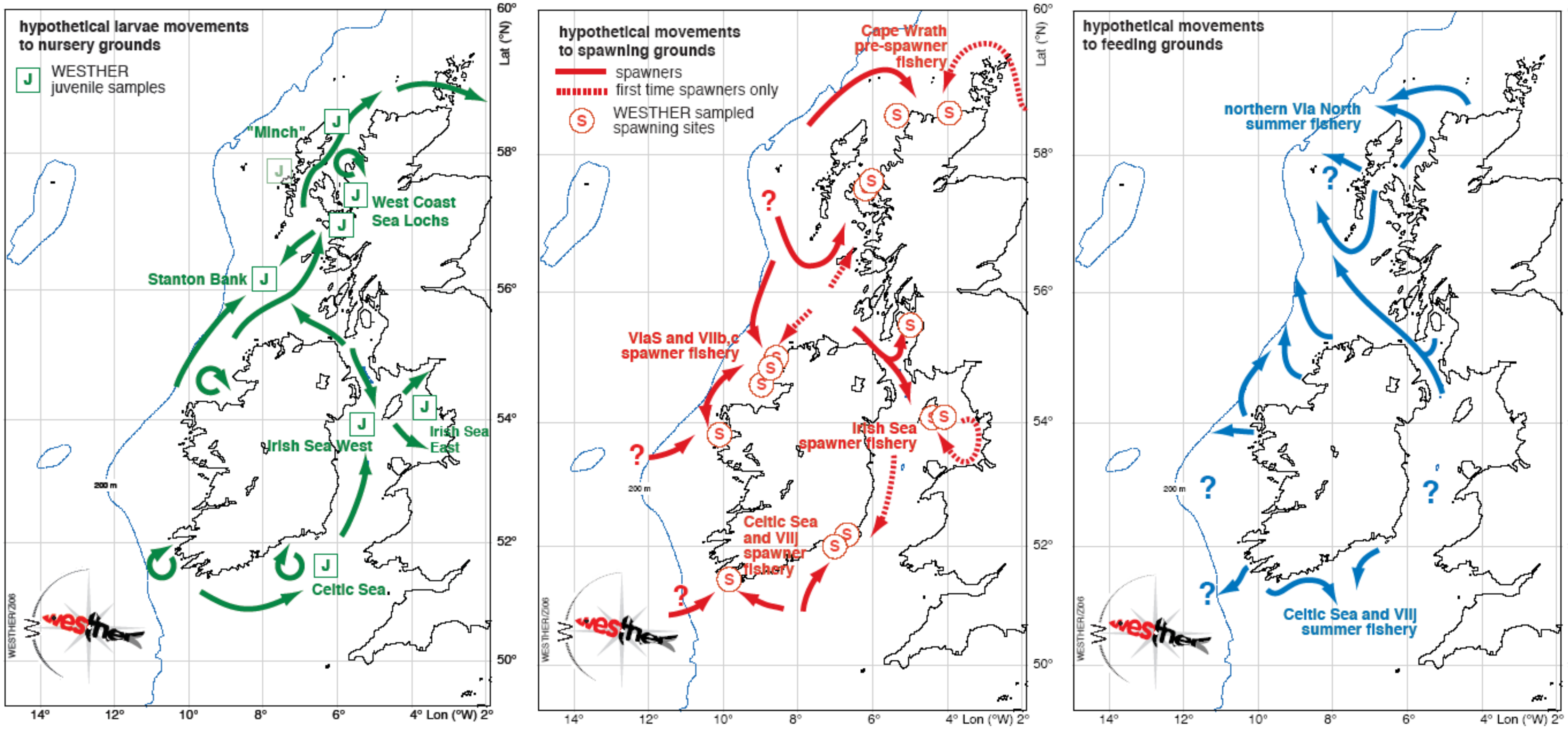


Figure 3.1.7. Hypothetical movements of juveniles and adults to feeding and spawning grounds based on historical evidence and WESTHER results.

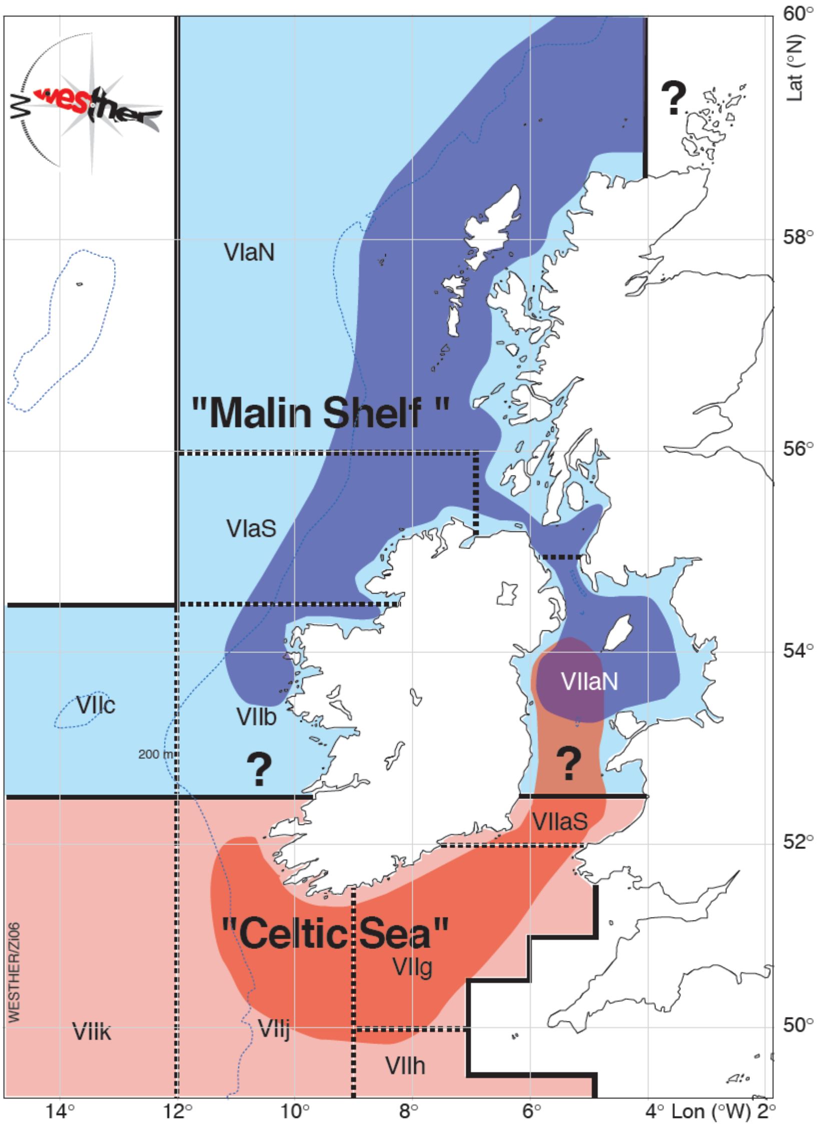


Figure 3.1.8. Proposed assessment units for assessments of Western stocks, based on grouping suggested from WESTHER. Darker colours indicate known distribution of herring in those areas.

WESTHER examined the assessment and management issues that derived from its results and presented the following conclusions to the 2007 HAWG (ICES, 2007):

Assess the herring to the west of the British Isles as two stock units - Malin Shelf (including the current ICES stocks VIa North, VIaS/VIIb,c, Clyde and Irish Sea (VIIaN)) and Celtic Sea (the current Celtic Sea and VIIj stock) (Figure 3.1.8). In the area studied in WESTHER it can be hypothesized that there are two stock units within which data can be pooled for assessment. However, the boundary at the northern edge is unclear and there is no evidence presented in the report which separates autumn spawners in the north of Scotland west of 4°W from autumn spawning fish east of 4°W (the North Sea stock). The boundary is there for convenience;

Survey effort should be increased or diverted to a combined survey on non-spawner distributions mixing on the Malin Shelf;

The current monitoring of the spawning components should be maintained, but not to the detriment of a wider scale Malin Shelf survey. Spawning ground surveys might provide data on the dynamics of individual stock components, which are thought to be useful for the development of a fleet-based advice;

Management plans should be fleet/area based, aiming at preventing the local depletion of any population unit in the area, and should make adaptive changes if current fishing practices change, specifically the introduction of a new 1st or 2nd quarter fishery in the southern part of VIa North and/or northern part of VIaS/VIIb,c;

Management plans should recognize the importance of the populations in the north of area VIa as a potential source of herring to spawning grounds to the south;

Management plans should recognize that there are potentially two separate stock units on the west coast of the British Isles, these constitute a population in the Celtic Sea and VIIj and a metapopulation centred on area VIa.

HAWG supported the results and conclusions of WESTHER. HAWG recognized the need to provide sound management advice for these areas, and in particular the importance of ensuring as far as possible that there is no depletion of local components. However, HAWG noted that WESTHER was not funded to evaluate the extent of mixing in the fisheries or to evaluate alternate management strategies for the area. HAWG considered that it was unclear what management regime would provide the most cost-effective method for successful management and what data would be needed to support this management.

The genesis of SGHERWAY

Two of the basic assumptions of stock assessment are that (1) the stock is a closed unit, and (2) the data used in assessments are representative of the entire stock. The first assumption implies that stock gain is only through birth, not immigration, and loss from the stock is through mortality, not emigration. The second assumption implies that catches are not removed from certain components only, but fishing mortality is distributed homogenously over the entire stock. Data from surveys should also be a relative measure of the entire stock (throughout its geographical distribution).

The current assessment of herring to the west of the British Isles assumes separate stocks in the following ICES areas, i.e. VIa North, VIaS, VIIb,c, Irish Sea, and Celtic Sea and VIIj. The results from WESTHER suggested that under the current stock assessment units (ICES HAWG, 2014), both the basic assumptions above 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. For example, data for the assessment of VIa North herring are from both the commercial fishery and the summer acoustic survey where aggregations are suggested to be a mixture of fish originated from several spawning sites outside VIa North (i.e. adults from VIaS, VIIb,c, Irish Sea and possibly even the Clyde).

HAWG considered that it was necessary to move towards an integrated management plan for the whole of the western herring stock area through a series of iterations involving the following steps:-

i) examination of alternative management strategies based on their ability to deliver protection to local populations and provide cost-effective information applicable for management of the two stock units of herring to the west of the British Isles;

ii) replacement of existing or development of new cost-effective assessment and data collection schemes which will be required to support this management;

iii) movement to coordinated management for the region.

Additionally, HAWG was requested to *"examine the WESTHER report and its recommendations to provide information on necessary changes to ICES long-term management advice concerning the herring stock to the West of Scotland (herring in VIa(N))"*.

HAWG response stated that that in the absence of any evaluated and coordinated management strategy for the herring to the west of the British Isles, the current separation of management units (VIaN, VIaS, VIIb,c Irish Sea and Celtic Sea) afforded the best possible protection for local spawning stocks. However, it did not afford protection to the fish of one stock distributed in another management area at feeding time.

Provided both the spawning fisheries (VIaS, VIIb,c) and the fishery in the mixing area (predominantly VIa(N)) were maintained at a fishing mortality that would be sustainable for each component, this should afford protection for these units, in the short term. HAWG considered that further work was required on examining the issues surrounding surveys, assessment and management of each of the current three management units to the north of the area. This could be initiated partly through a new study group or study contract. It would be a number of years before ICES could provide a fully operational integrated strategy for these units. HAWG therefore proposed a number of terms of reference for a study group, SGHERWAY.

SGHERWAY was convened, in 2008, to address a series of recommendations produced by the EU funded project WESTHER and had three main terms of reference:

- evaluate the utility of a synoptic acoustic survey in summer for the Hebrides, Malin and Irish shelf areas, in conjunction with PGHERS surveys of VIaN and the North Sea;
- explore a combined assessment of the three stocks and investigate its utility for advisory purposes;
- evaluate, through simulation, alternative management strategies for the metapopulation of VIaN, VIaS/VIIb,c and VIIaN.

SGHERWAY modified these terms of reference slightly during its term (2008–2010) but the essential work remained the same.

SGHERWAY was asked to evaluate the utility of a synoptic acoustic survey in summer for the Hebrides, Malin and Irish shelf areas. The evaluation was based on results of a combined survey programme in 2008 and 2009, and an analysis of time-series of existing surveys in the area. The synoptic Malin Shelf survey covers all areas in which mixing of the various western herring stocks is likely to occur at that time. Survey results can be used to establish time-series for the constituent components of the Malin Shelf stock complex. However, such time-series would not be available for a number of years. The amount of mixing between stocks cannot be resolved by the current sampling regime in the Malin Shelf survey. Consequently, a sampling programme was developed to allow proper identification of fish population origins, making use of otolith and body shape techniques. Methods have been developed to accurately determine spawning origin e.g. otolith microstructure (Clausen *et al.*, 2007), otolith shape analyses (Burke *et al.*, 2008) and parasite prevalence methods (Campbell *et al.*, 2007). For any of these methods, however, in the WESTHER project an identification success rate of only 0.8 was achieved. This lack of discriminating power has consequences for management as fisheries independent data now represents incorrect proportions of spawners by spawning area. However, by combining an analysis of both body and otolith morphology measured during the WESTHER project an average success rate of 0.85 was achieved (Hatfield *et al.*, 2007b), with the success rate for some spawning groups achieving 0.95 or greater. Initial analyses have compared the 2010 and onwards survey samples to the fish of known spawning origin collected during the EU project WESTHER. This sampling programme was initiated in the 2010 synoptic acoustic survey.

A combined assessment of the three stocks VIaN, and VIaS, VIIb,c and VIIaN (called the Malin Shelf metapopulation within SGHERWAY) was explored and its utility for advisory purposes investigated. It was found that the combined assessment gives important information on the Malin Shelf metapopulation, though it is unlikely to be useful for management advice purposes. In an ideal situation for stock assessment catches should be split by population and the survey index should provide an unbiased estimate of the abundance of the spawning populations (Kell *et al.*, 2009). Simulations conducted by Kell *et al.* (2009) have shown that if the fisheries take place on the mixed populations and the combined catches comprise different populations the assessment does not accurately detect high exploitation rates and the depletion of individual populations. Additional data would be required to separate catches or estimate mixing rates. In recent years the fisheries in the three areas (VIaN; VIaS, VIIb,c; Irish Sea) have been conducted on specific components at different times of the year. The mixing between stocks in these areas occurs during the feeding season. The current Malin Shelf survey is carried out during the feeding season and sampling to split the stocks using morphological techniques was initiated in 2010 to address the problem. It is hoped that this will improve the assessments of these stocks with more detailed information becoming available.

Where single species/stock approaches give a distorted view on individual populations and catch characteristics do not reflect population dynamics there is a need for metapopulation management. Alternative management strategies for the metapopulation of VIaN and VIaS, VIIb,c and Irish Sea were investigated. The study aimed to show how meta-populations can be sustainably managed, approaching MSY levels, either by taking a very precautionary approach or investing in more reliable survey information. The tools evaluated did not, under all conditions, suffice to manage the metapopulation sustainably. In none of the scenarios where the Irish Sea population was included in the modelled Malin Shelf survey (assumed to comprise herring from the VIaN and VIaS, VIIb,c and Irish Sea populations) could the Irish Sea stock be sustainably managed. Even under low fishing pressure, the dynamics would not be clear enough to sustainably manage the Irish Sea stock and prevent it from extinction. However, managing the VIaN and VIaS, VIIb,c stocks sustainably under different mixing scenarios and misidentification levels was possible. SGHERWAY showed that managing meta-populations was only possible with detailed information on fisheries independent data. However, whenever subcomponents of the meta-population differ considerably in abundance, sustainable management is impossible for the smallest subcomponent. Where there is uncertainty of stock identification fishing mortality should be kept at low levels. Whenever identification rates increase, fishing mortality may also be increased.

Malin Shelf survey (MSHAS) split caveats

At the 2014 HAWG meeting, preliminary analyses were performed to provide a split of the Malin Shelf survey time-series (2008–2013) to derive an age-based abundance index for the VIaS, VIIb,c stock (ICES, 2014). Data were derived from analyses of otolith and body morphometry from the 2010 to 2013 surveys, from hauls across the entire surveyed area, as the basis for a quadratic discriminant analysis (QDA). The WESTHER baseline dataset of spawning herring from 2003 to 2005 (Figure 3.1.6) was used as the training set for the 30 variable QDA and the resultant model was applied to the 2008–2013 MSHAS numbers-at-age data to derive an age-based abundance index for the VIaS/VIIB,c stock. However, the validity of the WESTHER baseline was unproven at the time of the analyses. It was agreed that attempts would be made to sample spawning herring from both VIaN and VIaS in 2014, to derive data to compare to the WESTHER baseline data. Two samples were collected from each area and Marine Institute scientists will present these results at WKWEST.

The analysis presented at the 2014 HAWG allowed an exploratory analytical assessment to be performed for the VIaS, VIIb,c stock. It resulted in the lowest SSB for that stock of the various runs carried out. A rough assessment of the VIaN stock was performed using the remainder of the Malin Shelf index as the VIaN tuning index. It was problematic, giving survey catchabilities of 8–10. However, it showed that the VIaN stock is still somewhat bigger than the VIaS, VIIb,c stock.

The unequal size of the two stocks presents problems for the split of the MSHAS time-series if the stocks are indeed of unequal size. Analyses carried out during the SGHERWAY project showed that the levels of sampling carried out on the MSHAS would be appropriate to stocks of a similar size. If the VIaS, VIIb,c stock is considerably smaller than the VIaN stock then considerably more fish per survey would need to be sampled to ensure the smaller stock is represented in those samples. Additionally a bias-correction of the baseline would be needed in order to correct for an over-assignment to the smaller stock. At the time of WKWEST it was not possible to split the survey indices, though more work is planned for the future. The future work includes industry sponsored investigations in to the feasibility of using modern genetic techniques to identify individuals to their parent stock.

3.2 Issues list

There are essentially three parts to the issue list A. Issues relating to VIaN B. Issues relating to VIaS, VIIb,c and C. Issues relating to a combination of the two stocks as a metapopulation in VIa, VIIb,c.

A. During the HAWG in 2014 the following matters were identified as needing attention for subdivision VIaN during the Benchmark in 2015 (WKWEST):

1) (New) data to be considered and/or quantified
    a) Additional M - predator relations
    b) Prey relations
    c) Catch data currently assumes biological stock only caught in stock area
2) Tuning series
    a) Obtain a disaggregated series from MSHAS for VIaN and VIaS, VIIb,c separately
    b) Investigate the MIK survey as a possible recruit index
    c) Investigate groundfish survey data as a tuning index

   d) MSHAS uncertainty (abundance and biological parameters)
   e) Relative stock sizes of VIaN vs.VIaS, VIIb,c and implications on splitting stocks in survey
3) Discards
   a) Rarely available (sensitivity analysis for various scenarios?)
4) Biological Parameters
   a) Natural mortality
   b) Maturity ogive
   c) Explore F_{prop} and M_{prop} given changes in fishery
5) Assessment method
   a) Replace ICA
6) Biological Reference Points
   a) Current data seem appropriate but would be revised after new assessment developed

B. During the HAWG in 2014 the following matters were identified as needing attention for subdivisions VIaS, VIIb,c during the Benchmark in 2015 (WKWEST):

1) (New) data to be considered and/or quantified
   a) Additional M - predator relations
   b) Prey relations
   c) Ecosystem drivers
      i) Understand bottom up forcing which appears to be a strong feature of this stock
2) Utility of historic time-series for assessing current stock status (low productivity).
3) Lack of coherence in catch-at-age
4) Tuning series
   a) Obtain a disaggregated series from MSHAS for VIaN and VIaS, VIIb,c separately
   b) Investigate the MIK survey as a possible recruit index
   c) Investigate groundfish survey data as a tuning index
   d) MSHAS uncertainty (abundance and biological parameters)
   e) Relative stock sizes of VIaNvs.VIaS, VIIb,c and implications on splitting stocks in survey
5) Discards
   a) Not available (sensitivity analysis for various scenarios?)
6) Biological Parameters
   a) Natural mortality
   b) Maturity ogive
7) Assessment method
   a) No method at present, though it is expected that tuned assessment will be available by 2015
8) Biological Reference Points

a) Current data seem appropriate but would be revised after new assessment developed

C. During the HAWG in 2014 the following additional matters were identified as needing attention for Divisions VIa, VIIb,c during the Benchmark in 2015 (WKWEST):

1) Stock identity
2) Noisiness of the current acoustic index for VIaN
3) Use of VMS approaches to prepare more spatially appropriate CNAA
4) Appropriate assessment methodology for a meta-population
    a) Appropriate management reference points in such a scenario

3.3 Scorecard on data quality

The accuracy (potential bias) of input data for the assessment is evaluated according to the scorecard developed by the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (ICES WKACCU, 2008). The workshop developed a practical framework for detecting potential sources of bias in fisheries data collection programs. A scorecard was applied to indicators of bias for a suite of parameters that are important for stock assessments. The scorecard can be used to evaluate the quality of data sources used for stock assessments, and to reduce bias in future data collections by identifying steps in the data collection process that must be improved.

No major biases are considered to occur in the data for the VIaN herring stock (see text tale below):

WKACCU scorecard: VIaN	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				
Final indicator				
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part				
2. Area misreporting				Area misreporting suspected between adjacent areas up to 1997
3. Quantity misreporting				
4. Population of vessels				

WKACCU scorecard: VIaN	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				Mixing with other herring stocks known but not quantified
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme				Observer programme ceased end of 2010
2. Raising variable				As above
3. Size of the catch effect				As above
4. Damaged fish discarded				As above
5. Non response rate				As above
6. Temporal coverage				As above
7. Spatial coverage				As above
8. Highgrading				As above
9. Slipping behaviour				Slipping suspected
10. Management measures leading to discarding behaviour				
11. Working conditions				Unknown
12. Species replacement				
Final indicator				
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				Not relevant
2. Area misreporting				Not relevant
3. Effort misreporting				Not relevant
4. Source of information				Not relevant
Final indicator				Not relevant
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				
5. Availability of all the landings/discards				

WKACCU scorecard: VIaN	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
6. Non sampled strata				
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				Last exchange and workshop in 2005
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				

WKACCU scorecard: VIaN	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				
Final indicator				
Final indicator				

No major biases are considered to occur in the data for the VIaS, VIIb,c herring stock (see text Table below):

WKACCU scorecard: VIaS, VIIb,c	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff				
2. Species misreporting				
3. Taxonomic change				
4. Grouping statistics				
5. Identification Key				
Final indicator				
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part				
2. Area misreporting				Misreporting suspected with adjacent areas
3. Quantity misreporting				
4. Population of vessels				
5. Source of information				

6. Conversion factor				
7. Percentage of mixed in the landings				Unknown level of mixing, varies over the historical record
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme				
2. Raising variable				
3. Size of the catch effect				
4. Damaged fish discarded				
5. Non response rate				
6. Temporal coverage				
7. Spatial coverage				
8. Highgrading				
9. Slipping behaviour				
10. Management measures leading to discarding behaviour				
11. Working conditions				Unknown
12. Species replacement				
Final indicator				
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				No relevant
2. Area misreporting				No relevant
3. Effort misreporting				No relevant
4. Source of information				No relevant
Final indicator				
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				Potentially not
5. Availability of all the landings/discards				Some not fully available
6. Non sampled strata				Potentially some strata
7. Raising to the trip				
8. Change in selectivity				

9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				Last otolith exchange and workshop in 2015
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				
5.Size/maturity effect				
6. Catchability effect				
Final indicator				

I. MATURITY STAGE		
Recall of bias indicator on length/age structure		
1. Sampling protocol		
2. Appropriate time period		
3. Spatial coverage		
4. Staff trained		
5. International reference set		
6. Size/maturity effect		
7. Histological reference		
8. Skipped spawning		
Final indicator		
Final indicator		

3.4 Multispecies and mixed fisheries issues

The targeted fishery for herring in the VIa, VIIb,c, is considered to be clean in by-catch, disturbance of the seabed and discarding (ICES HAWG, 2010). Scottish discard observer programs since 1999, and more recently Dutch observers, indicate that discarding of herring in these directed fisheries is at a low level. The Scottish discard observer program has recorded occasional catches of seals and zero catches of cetaceans in the past. Unfortunately the Scottish discard observer program is no longer active. There is disagreement about the amount of slippage compared to discarding by the differing fleets.

VIaN

Historically, catches have been taken from this area by three fisheries; (i) a Scottish domestic pair-trawl fleet and the Northern Irish fleet; (ii) the Scottish single boat trawl and purse-seine fleets and (iii) an international freezer-trawler fishery. In recent years the fisheries prosecuted by these latter two fleets have become more similar both temporally and spatially. In 2013, the Scottish trawl fleet fished predominantly in areas similar to the freezer trawler fishery, and rarely in the coastal areas in the southern part of VIaN (ICES HAWG, 2014). Recently (since 2006) the majority of the fishery has been prosecuted in quarter 3 (Annex 7.1). This pattern has continued in 2013, with 86% of catches taken in quarter 3. Since 2006, the quarter 3 fishery has concentrated in the northern part of the area. This trend has continued in 2013, with around 99% of the quarter 3 catches taken north of the Hebrides and to the north of Scotland. Prior to 2006 there was a much more even distribution of effort, both temporally and spatially. The contraction is believed to be related to the economics of fishing rather than a contraction of the stock.

There has been considerable uncertainty in the amount of landings from this stock in the past (ICES HAWG, 2014). Area misreporting is less of a problem than in the past, but almost all countries still take catches of herring in other areas and report it into VIaN.

VIaS, VIIb,c

The pattern of this fishery has changed over time. In the early part of the 20th century the main spawning components were winter spawners off the north coast of Ireland, and this was where the main fishery took place. In the 1970s and 1980s the west of Ireland autumn-spawning components were dominant and the fishery was mainly distributed along the coasts of VIIb,c and VIaS (ICES HAWG, 2014). More recently the northern grounds have become important again, and in 2013 a large part of the catch came from this area in autumn, targeting prespawners. In 2013, the majority (64%) of WG catches were reported from the first quarter. Subdivision VIaS accounted for the vast majority of catch, with only 10t reported from VIIb. Fishing opened in the fourth quarter in late October and closed in late December. Discarding is not considered to be a major feature of the Irish fishery at present.

3.5 Ecosystem drivers

Herring constitute some of the highest biomass of forage fish to the west of Scotland and Ireland and are thus are an integral part of the ecosystem. Herring link zooplankton production with higher trophic levels (fish, sea mammals and birds) but also can act as predators on other fish species by their predation on fish eggs. Spawning-stock biomass has fluctuated from approximately 450 kt in the late 1960s to fewer than 80 kt in recent years. This large range is due to an interaction of naturally induced changes in productivity of the stock and exploitation. Grainger (1978, 1980) found significant negative correlations between sea surface temperature and catches from the west of Ireland component of this stock at a time-lag of 3–4 years later. This indicates that recruitment responds favourably to cooler temperatures. The influence of the environment on herring productivity means that the biomass will always fluctuate (Dickey-Collas *et al.*, 2010a). Temperature trends are similar for the sea area to the west of Scotland and the North Sea (Figure 3.5.1). The broad trend in oceanic temperatures over the period 1900–2006 is warming (Figure 3.5.1a). Oceanic temperatures around the Scottish coast for the period (1970–2006) have increased by ~0.5°C (Figure 3.5.1b). Salinity and surface temperature of coastal waters around the Scottish coast also shows a slight increasing trend over the same period (Figure 3.5.1c and d).

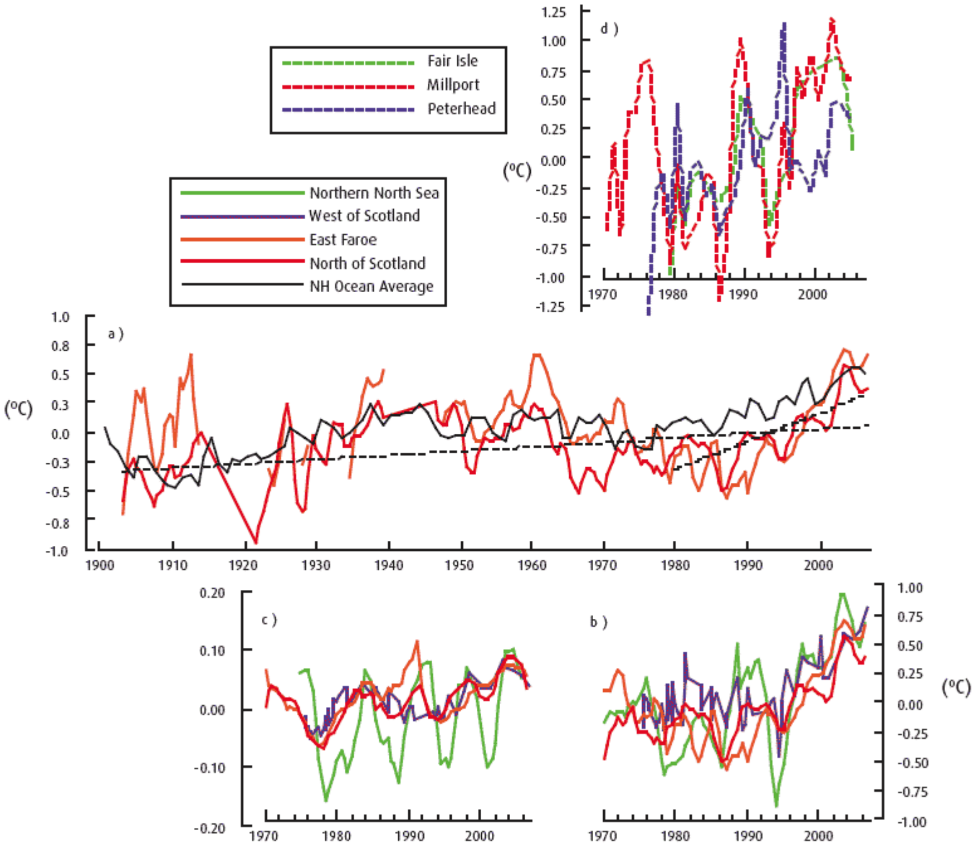


Figure 3.5.1: From Baxter *et al.*, (2008); a) Long-term (1900–2006) variability of oceanic temperatures to the north of Scotland and east of Faroe (including the northern hemisphere (NH) Ocean Average temperature time-series, as collated by the National Ocean and Atmospheric Administration). Dashed lines show the linear trend from 1980–2006 (0.24°C per decade) and from 1900–2006 (0.04°C per decade). b) Variability of oceanic temperatures (1970-2006) to the north of Scotland, east of Faroe, west of Scotland and the northern North Sea. c) Variability of salinity (1970-2006) to the north of Scotland, east of Faroe, west of Scotland and the northern North Sea. d) Variability of surface temperature of coastal waters around Scotland.

The environmental conditions in the North Sea and west of Scotland are similarly affected by climate change, with trends in oceanic temperature, sea surface temperature and salinity all increasing over recent decades around the coast of Scotland Figure 3.5a – d). Climate models predict a future increase in air and water temperature and a change in wind, cloud cover and precipitation in Europe (Drinkwater, 2010). Analysis of habitats and trends over time in the North Sea of herring early life stages' suggests that the projected changes in temperature may not affect the potential habitats but may influence the productivity of the stock (Röckmann *et al.*, 2011). It is unclear whether this is the case on the west of Scotland. West of Scotland herring have complex migration routes with spawning on gravel beds off the west and northwest of Ireland and Scotland. The larvae are transported to the north and east, some into the sea lochs of Scotland and with a substantial amount ending up in the North Sea. The juveniles stay in shallower areas until the onset of sexual maturation; thereafter they join the existing mature population on the spawning grounds (Dickey-Collas *et al.*, 2010b). After spawning, the adult mature herring migrate to a range of overwintering areas, and then return offshore to the north and west of Scotland and Ireland to feed in spring and summer. Feeding herring can generally be found in the areas with highest zooplankton abundance (Maravelias, 2001). Through complex interactions, herring has a major impact on most other fish stocks as predator and is itself as prey for fish, seabirds and marine mammals (ICES WGSAM, 2012). Recent work, using length-based ecosystem modelling, suggests a link between herring biomass and North Sea cod (Speirs *et al*., 2010). This suggests that through herring predation on cod eggs and larvae, strong cod recruitment is unlikely with the current state of the North Sea ecosystem. There is no similar model for west of Scotland herring, therefore it is difficult to predict the impact of increasing or reducing the herring biomass on the west of Scotland ecosystem functioning as a whole. However, as herring constitute a large part of the overall biomass of plankton feeding and forage fish in the west of Scotland and Ireland ecosystem, impacts from changes in productivity from environmental drivers are likely to be widely felt.

Drivers for changes in time of spawning in VIaS, VIIb,c

Since the mid-1990s both scientists and fishers have noted that herring spawn increasingly in winter/spring off NW Ireland. This is in marked contrast to the situation that pertained from the 1960s to the early 1990s, when the herring stock was large, and the fishery very successful, and most spawning took place in autumn. In order to investigate this, the long time-series of maturity sampling conducted by Ireland, since 1961, was analysed.

This analysis considers only the main herring population that spawns on known grounds on along the Irish coast (O'Sullivan *et al*., 2013), and supports the large-scale fishery. It ignores a small stock, colloquially called "harvest herring", spawning in bays, and historically exploited by artisanal craft in late summer. Harvest herring have largely disappeared in recent decades, but were shown by Farran (1944) to differ in their recruitment and population dynamics, and was always a small stock size.

Detailed biological and fisheries data have been collected from commercial landings since 1957. Sampling effort focused on obtaining spatially and temporally representative samples. Information about the sample, such as the vessel, area, date, location and biological characteristics (i.e. length to the nearest half centimetre interval, weight in grammes (only after 1975), sex, maturity stage of the gonads, and age) were recorded. The maturity status of herring is assessed using an eight-stage classification system based on Landry and McQuinn (1988). Fish were assigned to seasonal spawning components (i.e. AS, WS, SS or "unknown" (U)) based on the stage of their gonads at the time of sampling. Fish were assigned to a given spawning component according to the scheme below, adapted from Harma *et al.* (2012).

	Maturity stage		
Spawning type	Aug-Nov	Dec-Feb	Mar-May
Autumn spawner (AS)	6,7		
Winter spawner (WS)		5,6	
Spring spawner (SS)			5,6
Unknown (U)	1-5; 8	1-4;7-8	1-4; 7,8

An investigation into these data showed a trend over time from AS to WS. This agrees with statements from the industry of the spawning season becoming progressively later over time (Figure 3.5.2). We can distinguish three distinct periods as follows:

- 1920s: large stock dominated by spring-spawning (Clarke *et al*., 2011 and references therein);

- 1957–1994: large stock dominated by autumn spawning;
- 1995–present: small stock dominated by winter spawning.

It was not possible to determine if winter and autumn spawning fish constitute different stocks, components or simply expressions of herring's plasticity to changing environmental conditions over time. Given that there is no means to separate them in the assessment they must currently be considered as part of the same population. What is clear is that if we take temperature as a parameter indicative of the environment and its variability (as in Melvin *et al.*, 2009), there is a clear relationship between increased water temperatures (Figures 3.5.3 and 3.5.4) and a progression from autumn dominated to winter/spring dominated spawning. There appears to have been a marked switch since the mid-1990s.

Given the decline of the AS component, concomitant with environmental changes since the early 1990s, it would seem likely that spawning in late spring would be similarly attenuated. Spring-spawning became a feature of the fishery for a while in the mid-1990s. However, since then quota restrictions have prevented fishing after late February and there is no evidence as to whether spring-spawning is still important. For a while, in the mid-1990s, it appeared that the stock was returning to the conditions that pertained in the 1920s (Molloy, 1995). The 1920s fishery was dominated by spring-spawning (Molloy, 1995), but that was because the British boats who mainly participated in it were otherwise engaged in autumn North Sea fishery. Autumn fishery was very important for small-scale artisanal craft on the Irish coast (Feeney, 2001).

Farran (1938), working on Irish herring stocks, was the first to show that autumn spawning herring had smaller and more numerous oocytes than spring spawners. Van Damme *et al.* (2009) demonstrated that both spawning types start oocyte development at the same time in spring. During the maturation cycle, fecundity is down-regulated through atresia in relation to body condition. The development of the oocytes is the same for both spawning strategies until autumn when autumn spawners shed a relatively large number of small eggs. In winter spawners, oocyte development and down-regulation of fecundity continues, resulting in larger eggs and lower fecundity. Thus, in theory, autumn and winter spawners could switch spawning strategies, indicating a high level of reproductive plasticity.

In conclusion, there is no evidence of the various components being separate stocks. However, as shown by van Damme *et al.* (2010) there is a mechanism allowing plasticity between autumn and winter/spring-spawning, which means it cannot be ruled out. Autumn spawning used to be dominant, but a switch to winter spawning took place in the mid-1990s, concomitant with warmer temperatures. There is not enough information to judge the importance of spring-spawning, but there is no evidence to suggest it is important at the present time. Judgment is reserved on differentiation of these sympatric temporal spawning variants. However assessing them together as a stock complex within VIaS, VIIb,c is the only practical solution because no basis exists to separate them at this time, and there is no evidence that they are indeed separate populations.

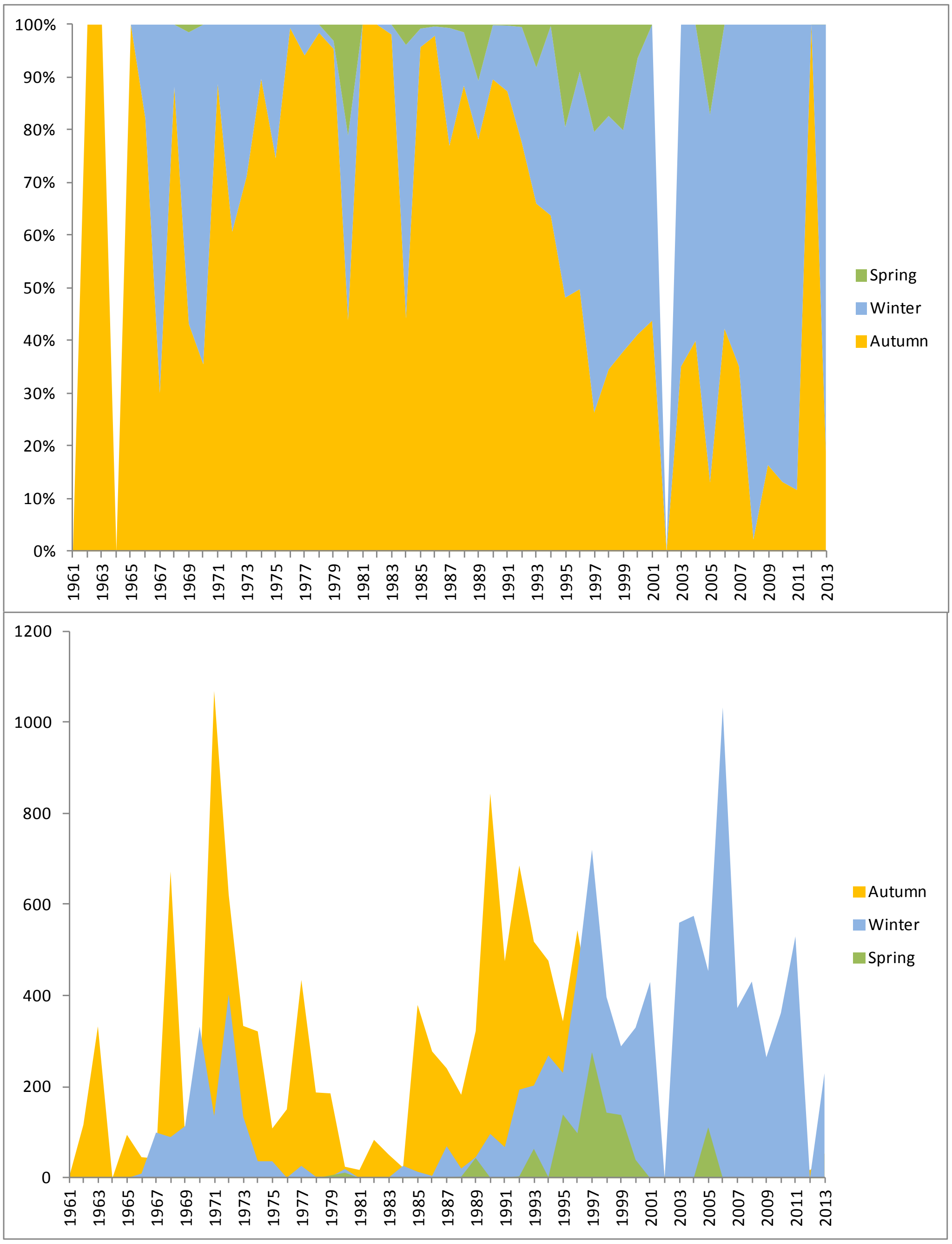


Figure 3.5.2. Percentage occurrence of known autumn, winter and spring-spawning herring from VIaS and VIIb,c (upper panel) and total numbers of each spawning type observed (lower panel).

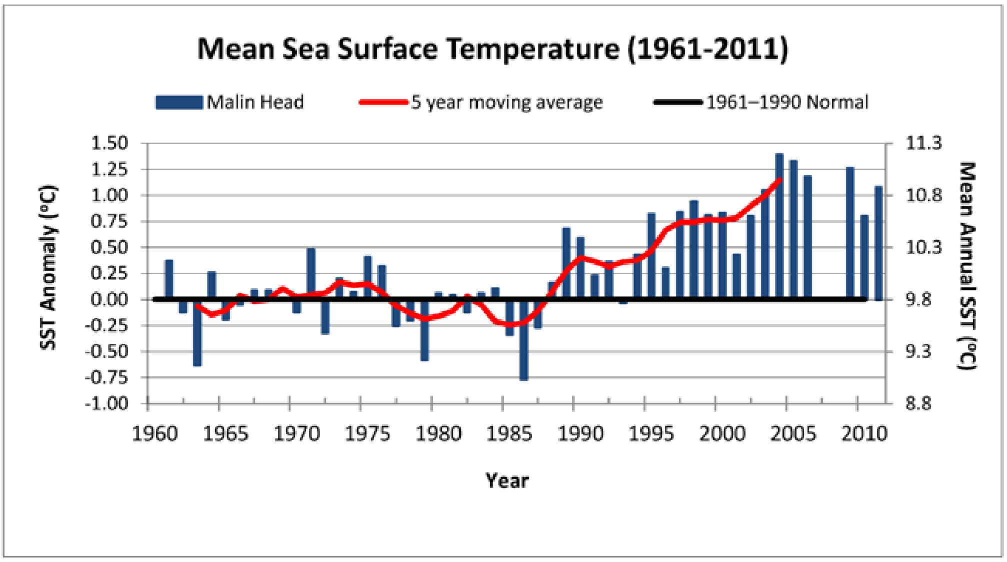


Figure 3.5.3. Temperature anomaly (January) for the Malin Head SST series.

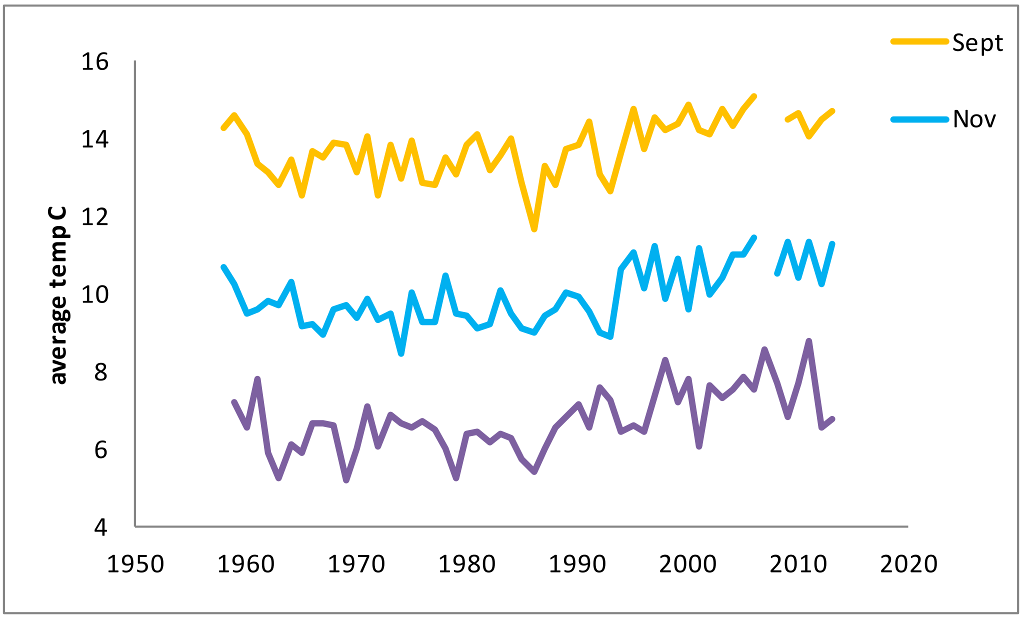


Figure 3.5.4. Temperature (mean by month of March, September and November) for the Malin Head SST series 1961–present.

3.6 Stock Assessment of Herring in Divisions VIa, VIIb,c

WKWEST recognized the conclusions and recommendations of WESTHER and SGHERWAY and considered the meta-population structure of the herring resource in the combined Divisions VIa and VIIb,c. Despite the efforts to apply a splitting procedure using updated baseline information on morphometric patterns, estimates of stock composition are not sufficient for splitting the mixed-stock survey data. The management strategy evaluation by Hintzen *et al.* (2014) for herring in Divisions VIa and VIIb,c showed that failure to account for mixing produced biased estimates of component stock sizes and reference points, and the information in a survey is limited.

Therefore, on the basis of data quality and performance of alternative models and model configurations, WKWEST determined that the assessment of the meta-population of herring in combined Divisions VIa and VIIb,c is the best available scientific information for determining stock status and offering catch advice for the fisheries in the areas. This possible outcome was considered in the 2014 ICES advice:

"The stock identity of herring west of the British Isles was reviewed by the EU-funded project WESTHER. This identified Division VIa (North) as an area where acoustic survey catches contain a mixture of fish from Divisions VIa (North), VIa (South), VIIb,c, and VIIa (North). The extent of stock mixing in Division VIa (North) catches is unknown. In 2008 ICES began to evaluate the management for Divisions VIa (South), VIIb,c, and Division VIIa (North). ICES is working to produce assessments that take mixing into account. Efforts to split the Malin Shelf acoustic survey according to stock component increased in 2013. Considerable progress has been made to disaggregate the Malin Shelf Acoustic Survey and provide information on the Divisions VIa (South) and VIIb,c stock component and this work has provided a stock-specific, fisheries-independent index for this stock for the first time. If a split index is not possible at the next benchmark in 2015, it will be necessary to assess this stock along with the Division VIaN as a metapopulation, and the Malin Shelf Acoustic Survey could be used as tuning. Such an approach to assessing metapopulations together whilst managing separately is used in the Subarea IV and Division VIId (North Sea) herring."

In conjunction with this decision on the benchmark procedure for stock assessment and catch advice, WKWEST also recommends that the meta-population structure of the herring resource in Divisions VIa and VIIb,c be considered in advice for each management area (Divisions VIa North, VIa South and VIIb,c) to conserve the distinct spawning components. The management strategy evaluation by Kell *et al.* (2009) that was based on herring in Divisions VIa and VIIb,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 VIa and VIIb,c showed that smaller population units (e.g. herring in VIIa North) are extremely vulnerable to overexploitation.

The definition of management units and allocation to management units are policy decisions that are beyond the scope of WKWEST. However, WKWEST explored methods for providing guidance on the splitting of catch to management areas. WKWEST does not recommend the use of the exploratory assessments of the separate areas (Division VIa North and Divisions VIa South and VIIb,c) as scientific information available for splitting the mixed-stock catch advice to management areas due to conflicting results on relative stock sizes dependent on the combination of survey indices used. The recommendation from WKWEST on spatial splitting procedure is that alternative splitting procedures should also be considered by HAWG, advice drafting groups, ACOM and managers.

Based on data properties and model performance, WKWEST considers the stock assessment of combined areas VIa, VIIb,c to be a Category 1 Quantitative Assessment with a full analytical assessment capable of catch forecasts. By comparison, WKWEST considers the exploratory assessments of separate areas (Division VIa North and Divisions VIa South and VIIb,c) to be Category 2 Data-Limited Assessments, because of considerable data and model problems caused by stock mixing and temporal variability of stock composition.

3.6.1 Catch – quality, misreporting, discards

3.6.1.1 VIaN

Commercial catch is obtained from national laboratories of nations exploiting herring in VIaN. Since 1999 (catch data 1998), these laboratories have used a spreadsheet to provide all necessary landing and sampling data, which was developed originally for mackerel in the Working Group on mackerel, horse mackerel, sardine and anchovy (WGMHSA) and further adapted to the special needs of the Herring Assessment Working Group. The majority of commercial catch data of multinational fleets is 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 co-ordinators for filling in missing sampling data and raising the catch information of one nation/quarter/area with information from another dataset.

The transparency of data handling by the Working Group is high and all data handling prior to the actual input to assessment is available in an archive system held by ICES. 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. Since 2007, the corresponding datasets are also stored in InterCatch, where they are accessible to the stock coordinators only.

The catch-at-age matrix, an integral part of the assessment of VIaN herring, is constructed by combining this information from all national laboratories with VIaN herring sampling programmes. The national sampling programmes have all been shaped under different restraints and therefore differ in their approach to sampling catches. The data are aggregated only after national sampling information has been used to raise the numbers of herring caught at age to national catch levels, ensuring the constraints inherent in national sampling procedures are respected as far as possible. Although the Working Group investigates the sampling coverage routinely to ensure the quality of the catch data in this respect, there is at the moment no requirement for national data submitters to provide a measure of the uncertainty associated with the estimated numbers-at-age provided to the Working Group, neither has it been possible to easily incorporate such information into the present assessment.

Until 2003 the VIaN catch data extended back to the early 1970s; in 2004 the dataset was extended back to 1957.

This fishery had a strong tradition of misreporting before 2000, though this has generally reduced over the last decade or so. It is believed that the shortfall between the TAC and the catch was used to misreport catches from other areas (from Divisions IVa and VIaS). 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 HAWG, 2002). Improved information from the fishery in 1998–2002 allowed for reallocation of many catches due to area misreporting (principally from VIaN to IVaW). This information was obtained from only some of the fleets.

As a result of perceived problems of area misreporting of catch from IVa into VIaN, 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 (VIaN). 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 IVa into area VIaN 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 IVa into VIaN. New sources of information on catch misreporting from the UK became available in 2006 and these were incorporated into the catch time-series in 2007 (ICES HAWG, 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 northwest of the continental shelf in area VIaN) 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; however, biases and sampling designs are not documented. Data from some fleets suggest discards are minor; they are included but not raised. Slippage and highgrading are not recorded. Detailed information on the number of samples, number of fish measured and aged by country and quarter are presented and described annually in the HAWG report. The sampling coverage of this stock is variable (see text table below) but in most cases exceeds the EU sampling requirements for fisheries in Division VIa of 25 fish aged per 1000 t sampled. However, the sampling is frequently unbalanced, being available from only one or two métiers in the fishery.

Data year	Official Catch	Sampled Catch	Age Readings	Age Readings per 1000t
2013	25446	17386	1014	40
2012	21296	9081	300	14
2011	21358	13808	974	46
2010	22510	14294	1909	85
2009	21306	11470	993	47
2008	25216	9837	757	30
2007	33735	18366	1196	35
2006	34230	22135	1590	46
2005	31392	14129	778	25
2004	33344	23092	384	12
2003	31662	28835	1650	52
2002	41649	31787	2384	57
2001	35688	24974	2335	65
2000	37789	20749	1441	38

Discrepancies in the catch data from 2000 to 2005 were discovered during the data checking for the 2015 benchmark. Differences were mostly minor, except for the catch in 2000 where there was a 26% discrepancy due to incorrect area allocations. The input files for catch in tonnes (*caton*), catch numbers-at-age (*canum*) and weights-at-age in the catch (*west*) were all revised and provided for use in the benchmark. The detailed discussion is given in a Working Document (Hatfield. WD to WKWEST 2015).

HAWG 2014			WKWEST 2015				
caton			caton			%difference	
2000	18322		2000	23162		2000	26.42
2001	24556		2001	25251		2001	2.83
2002	32914		2002	32914		2002	0.00
2003	28081		2003	28081		2003	0.00
2004	25021		2004	26459		2004	5.75
2005	14129		2005	14129		2005	0.00

3.6.1.2 VIa, VIIb,c herring

Commercial catch in recent years has come exclusively from Ireland. The Netherlands holds 8% of the quota and Ireland 92%. The Dutch proportion is usually swapped with Ireland. Sampling of the catch is conducted by the Irish Marine Institute. Sampling intensity is good. However the opportunistic nature of the fishery in recent years and the low TACs may mean that the full demographic diversity of the population is not captured in the catch sampling.

The quality of the catch data has improved markedly in recent years, owing to improvements in control and enforcement, especially since 2004. In the late 1980s and early 1990s, there was a market for roe and many catches were slipped if they did not contain the appropriate maturity stage. This slippage is not reflected in the historic catch data. Discarding is known to take place on the part of freezer trawlers targeting other species in this area (ICES HAWG, 2012). Overall discarding is considered to be negligible.

The northern boundary of the management area is not meaningful in a biological context. Fish are known to traverse the boundary in the feeding season and one of the spawning grounds straddles it. Irish catches that are reported north of the boundary but are associated with the VIaS, VIIb,c stock are reallocated from VIaN to VIaS, VIIb,c each year.

3.6.1.3 VIa, VIIb,c

The commercial catch data for the combined stock has the same underlying quality as that of the separate stocks, because it is an addition of the data in each area. Biological samples are allocated to the appropriate stock in the individual areas, and this is then combined.

3.6.2 Surveys

Several surveys cover this combined stock either in full or in part. An internationally coordinated herring acoustic survey covers the stock annually in July (Malin Shelf Summer Herring Acoustic Survey (MSHAS)). In addition, two Scottish bottom-trawl surveys (SWC-IBTS) cover area VIa in Q1 and Q4 respectively.

3.6.2.1 Acoustic surveys

Background

An acoustic survey has been carried out in Division VIaN in June-July since 1991 by Marine Scotland Science. It originally covered an area bounded by the 200 m depth contour and 4°W in the north and west and extended south to 56°N (Figure 3.6.2.1); it has provided an age-disaggregated index of abundance as the sole tuning index for the analytical assessment of VIaN herring since 2002.

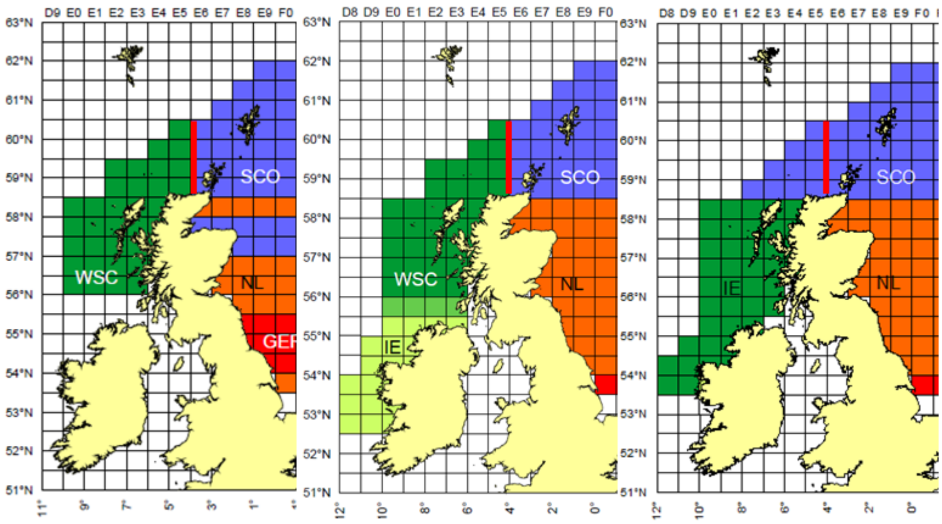


Figure 3.6.2.1. Survey area layout development for the Malin Shelf Herring Acoustic Survey. Left; coverage 1991 to 2007. Middle; 2008 to 2010. Right; 2011–present. N.B. The vertical red line at 4° west longitude denotes the eastern limit of the VIaN survey area

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.*, 2007, ICES HAWG, 2007, ICES SGHERWAY, 2010). The survey was augmented with the participation of the Irish Marine Institute and the area was expanded to cover all of ICES Divisions VIa, VIIb. 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 VIaN.

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 allow 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 SGHERWAY, 2010; see Section 3.1).

The stock is highly contagious in its spatial distribution, which explains some of the high variability of the time-series. The survey covers the area at the time of year when aggregations of herring from both the VIaN and VIaS, VIIb,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 WGIPS, 2014).

3.6.2.2 Scottish bottom-trawl survey indices SWC-IBTS Q1 and Q4

Background

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 HAWG, 2012). Marine Scotland Science carries out two similar bottom-trawl surveys in western waters (Q1 and Q4) covering the herring stocks in ICES Division VIa which potentially could be used in a similar way to inform the assessment of herring stocks in this area also (herring in VIaN and herring in VIaS, VIIb,c).

The Scottish West Coast Groundfish 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 VIa, but has since 1996 additionally covered the northern part of the Irish Sea and between 1996 and 2006 it extended into VIIb. The target species for this survey are cod, haddock, whiting, saithe and herring.

The Scottish West Coast Groundfish 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 groundgear 'C' and a 20 mm internal liner. Standard haul duration was initially 60 min, but in 1998 this was changed to 30 min, in line with the protocols for the North Sea IBTS. 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 parts. 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 3.6.2.2).

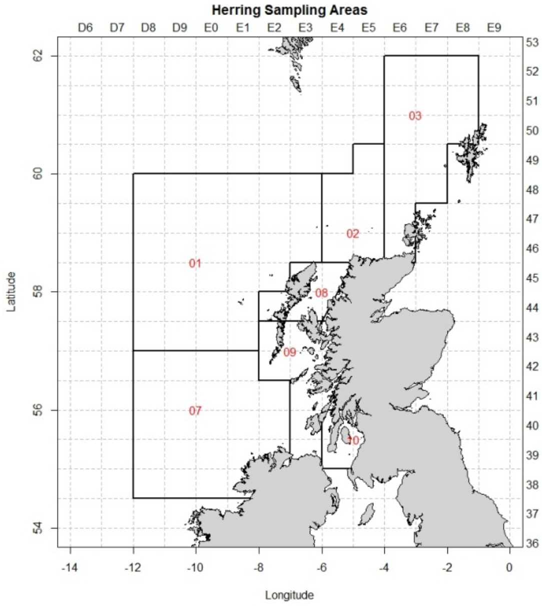


Figure 3.6.2.2. Scottish herring sampling areas.

From 2011 onwards both the Q1 and Q4 SWC-IBTS changed to a random stratified survey design with station positions being randomly distributed within a series of '*a priori*' sampling strata (Figure 3.6.2.3). 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.

As the surveys cover all of VIa it is plausible to calculate a numbers-at-age index for each of the two stocks (VIaN and VIaS, VIIb,c) as well as a combined index for all of VIa for use in a combined VIa, VIIb,c assessment.

Data availability

Data were available from approximately 50 hauls per year per quarter (Figure 3.6.2.4). Within the periods 1986–2010 for SWC-IBTS Q1 and 1996–2009 for SWC-IBTS Q4, the two surveys are considered consistent in 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 VIa. 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.

Area and stock coverage

It was decided to restrict the calculations to hauls within ICES Division VIa as it was surveyed consistently over the time-series, and also consistently by both surveys (Figure 3.6.2.5). Indices were calculated for Q1 and Q4 separately for three different assessment scenarios; VIaN assessment, VIaS, VIIb,c assessment and a combined assessment of the two stocks (VIa, VIIb,c).

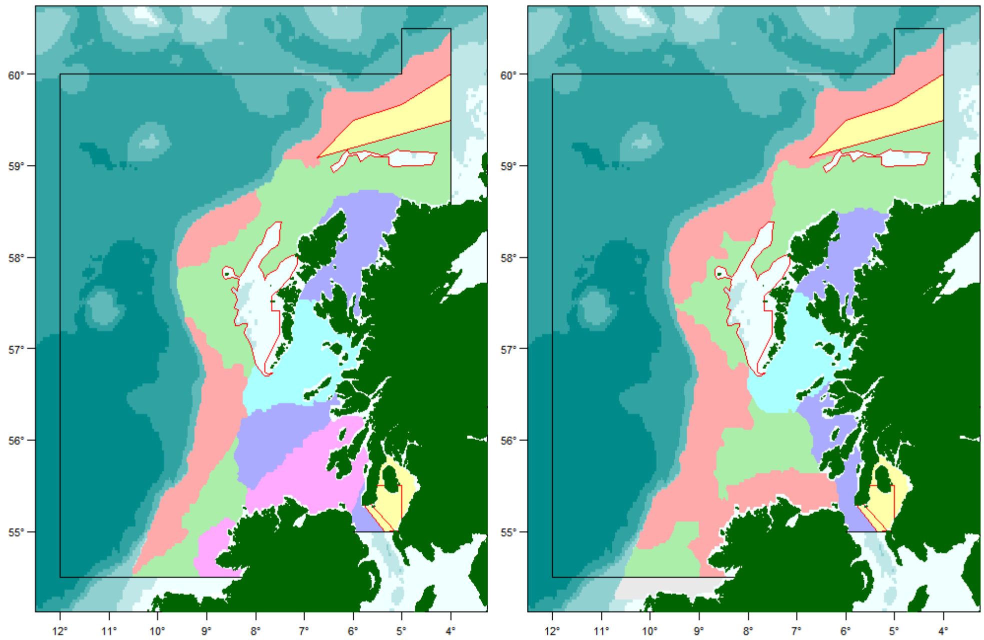


Figure 3.6.2.3. Area stratification in the Scottish West coast trawl surveys since 2011. Q1 (left) and Q4 (right). Protected areas closed to trawling are marked with a red line.

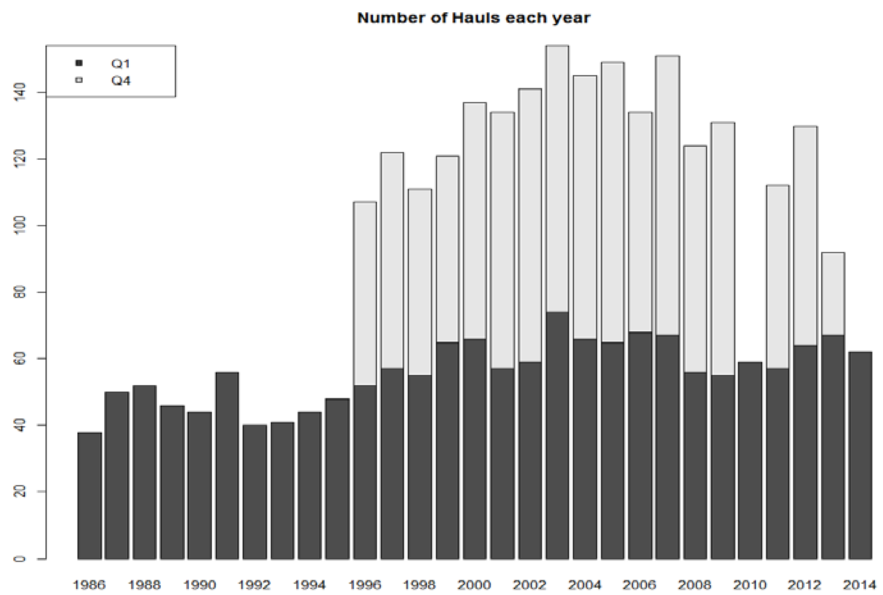


Figure 3.6.2.4. Number of hauls in each year and quarter in the Scottish bottom-trawl surveys.

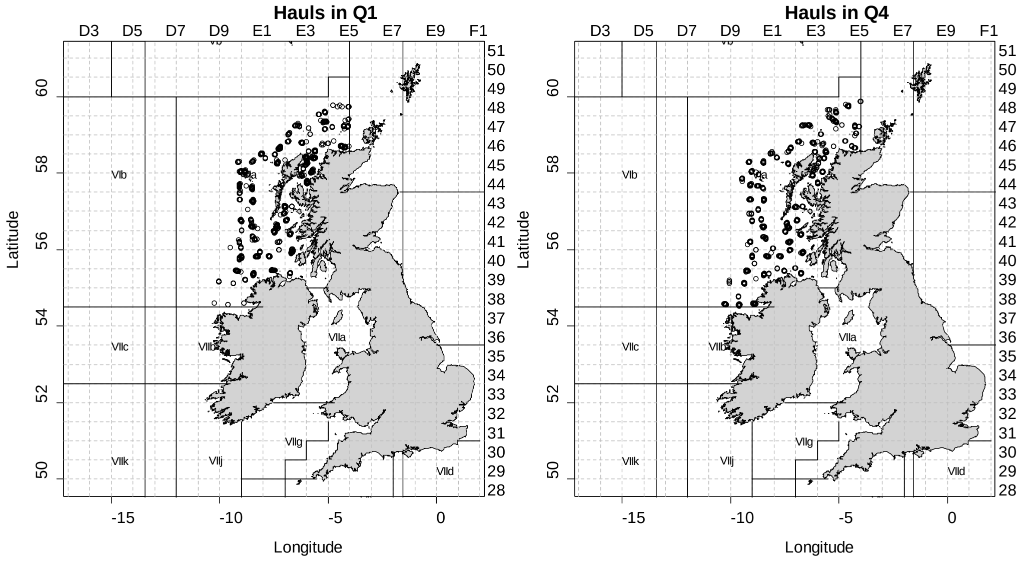


Figure 3.6.2.5. Haul positions in VIa in Q1 and Q4 Scottish west coast bottom-trawl survey (1986–2010 and 1996–2009 respectively).

As discussed at the data collation work shop in November 2014, juvenile fish encountered in VIa during these surveys are not likely to be from VIaN, but rather from VIaS, VIIb,c, or even other herring stocks present in the Celtic Seas area. To capture this in the index 0-2 wr fish were not included in the index for VIaN, and the index for that area only contains 3wr and older fish from hauls within the VIaN stock area (Figure 3.6.2.2.5). The younger herring (1 and 2wr) from all of VIa were included however in the VIaS index along with ages 3 and up from hauls within the VIaS stock area (Figure 3.6.2.6).

Finally an index was calculated using all ages from all hauls in VIa for use in an assessment of the combined VIa, VIIb,c meta-population.

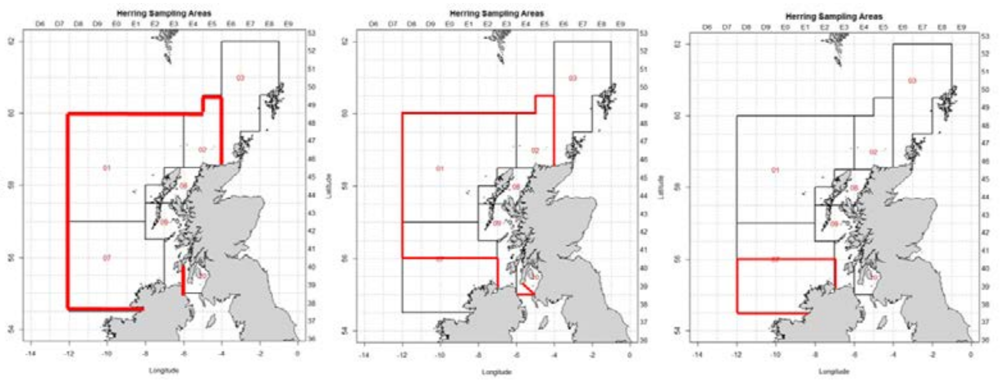


Figure 3.6.2.6. Areas the index was calculated for and the component herring sampling areas. Left; VIa. Middle; VIaN. Right; VIaS.

Index calculation using the Scottish herring sampling areas stratification

A cpue index for each of the Scottish herring sampling areas was calculated first:

Numbers-at-length per haul are standardized 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 standardized number-at-length from each haul within that area to produce standardized numbers-at-age for each haul. Within each area the catch per unit of effort of fish at each age is calculated by summing the age frequencies, dividing the value by the number of valid hauls and multiplying 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 of 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 VIa, 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 of 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 vs. age 2, year 2 and so forth).

Results

The indices calculated for the three area combinations seem able to capture some of the dynamics in the stocks with some stronger cohorts visible but also some year effects (Figure 3.6.2.7). The internal consistency indicates that the indices for VIa and VIaN are able to follow cohorts to some extent especially for the older ages and could bring some benefits to the assessment (Figure 3.6.2.8). The Quarter 1 survey generally has the highest internal consistency, but there also seems to be some signal in the Quarter 4 survey. Relative to the herring acoustic survey used to tune the present VIaN assessment, the internal consistencies for the trawl surveys in the larger area

(VIa and VIaN) are quite similar. For the VIaS geographical area, however, the index has no internal consistency for either survey and would only be contributing noise rather than a useful signal if used in an assessment.

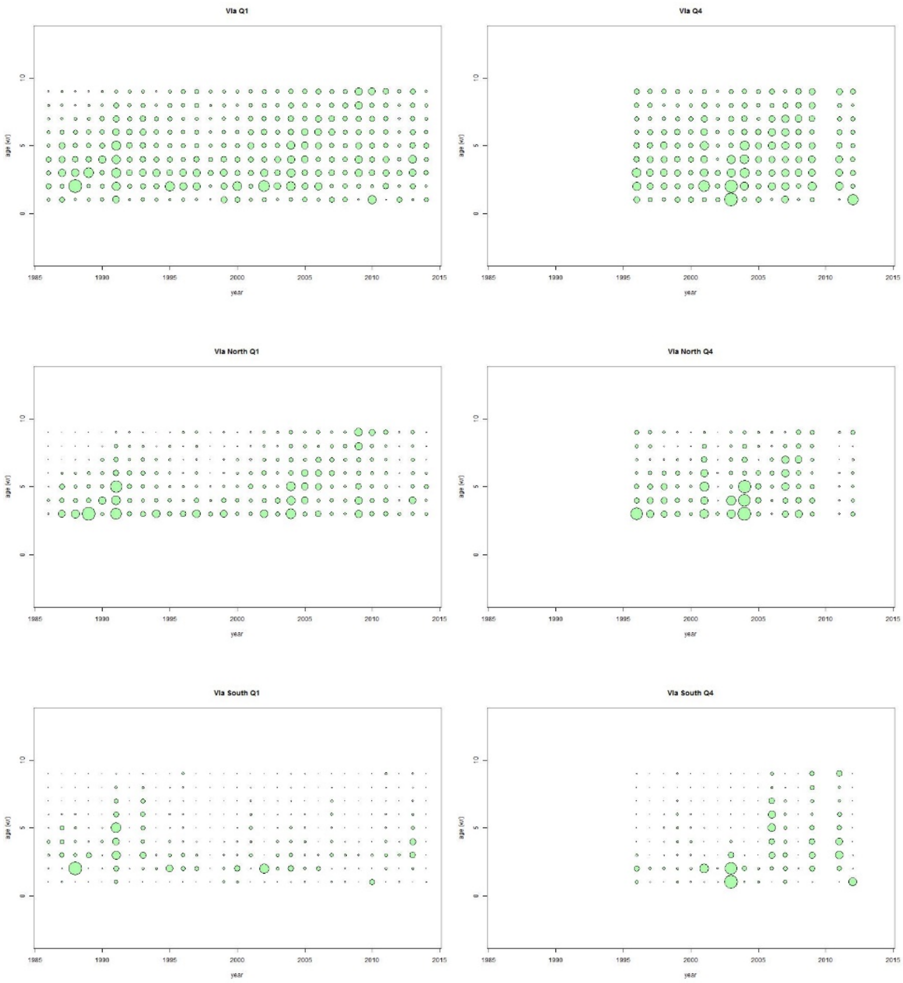


Figure 3.6.2.7. Indices for the three stocks by survey. Left column Q1, right column Q4. Top; VIa. Middle; VIa North. Bottom; VIa South.

Effect of new stratification on index calculations

A cursory examination of the haul positions under the new stratification regime from 2011 did not look like it redistributed the effort considerably for covering the old strata appropriately for index calculation (Figures 3.6.2.9 and 3.6.2.10) and the index was calculated for all years using the Scottish herring sampling areas stratification throughout for consistency.

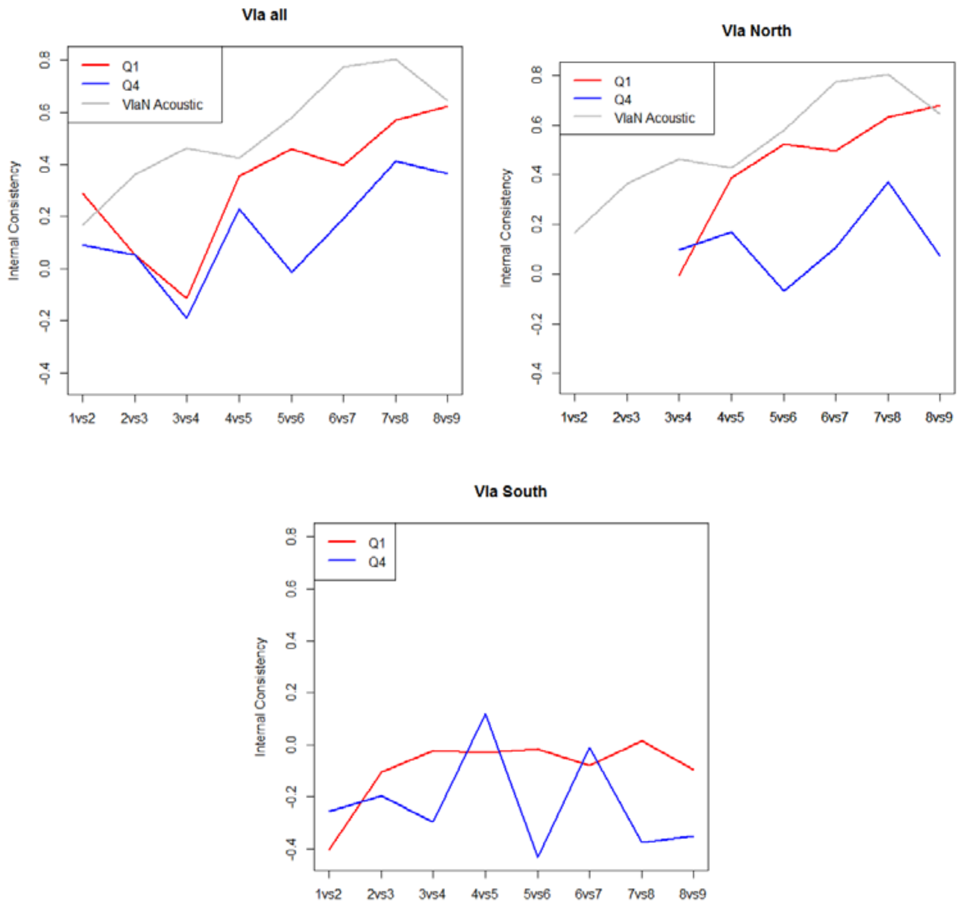


Figure 3.6.2.8. Internal consistencies for each of the three scenarios for Q1 and Q4. Internal consistency for the VIaN Acoustic survey index included for reference in VIa and VIaN.

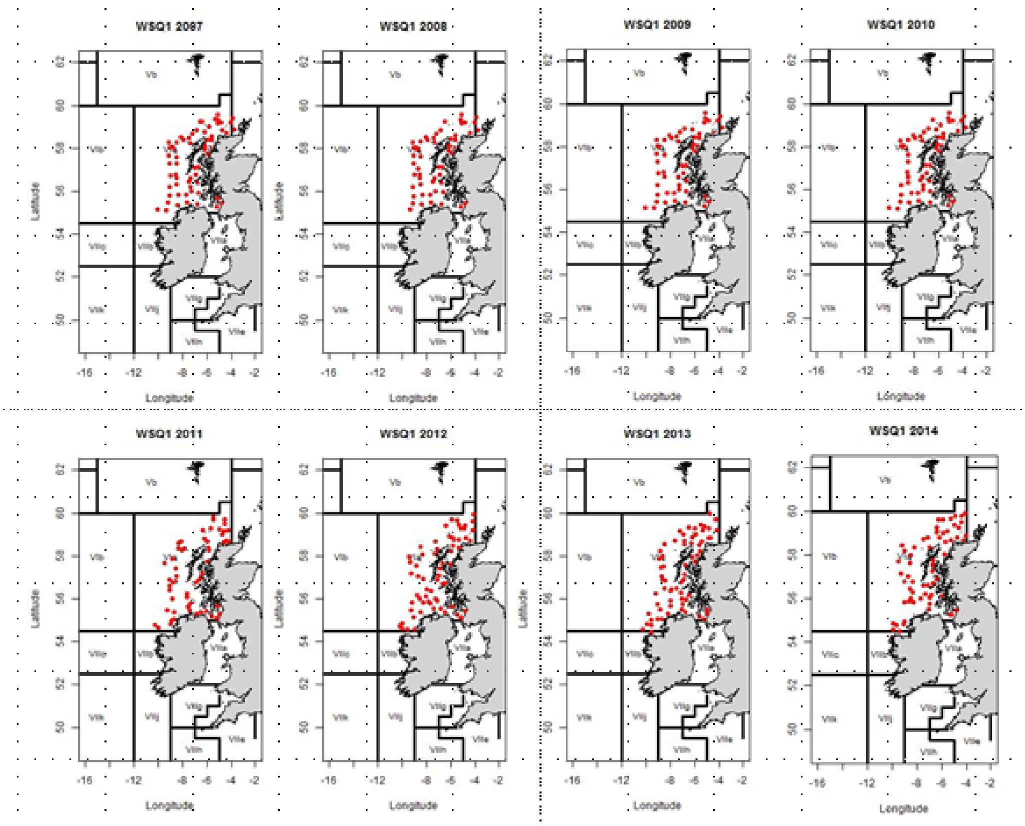


Figure 3.6.2.9. Haul positions for the SWC-IBTS Q1 in the years before and after the change in stratification in 2011.

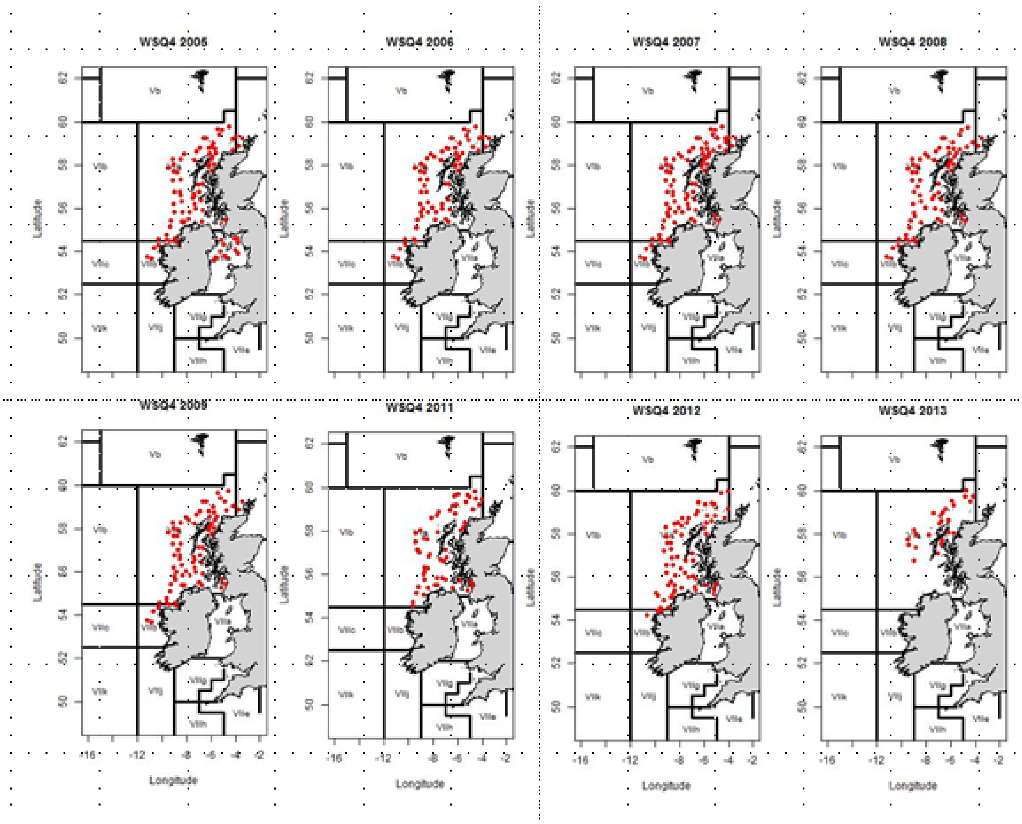


Figure 3.6.2.10. Haul positions for the SWC-IBTS Q4 in the years before and after the change in stratification in 2011 (2013 Q4 is not included in the index due to the lack in coverage).

A comparison was made between the index-at-age calculated using the old stratification and a new index calculated using the new strata. This new index calculation is used to calculate the index-at-age for the demersal species which the new survey strata are optimized for. The calculation procedure is almost identical with the old one, but is weighted with the area of each strata rather than the number of hauls within each and is calculated as follows:

With the new design, all otoliths taken within each of the six strata are combined to form an ALK. This ALK is applied to all LFs in the stratum individually to produce age frequencies for each haul. Finally, for each stratum the age frequencies are summed, the values divided by the number of valid hauls and the results multiplied by ten. This procedure can be summarized as

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

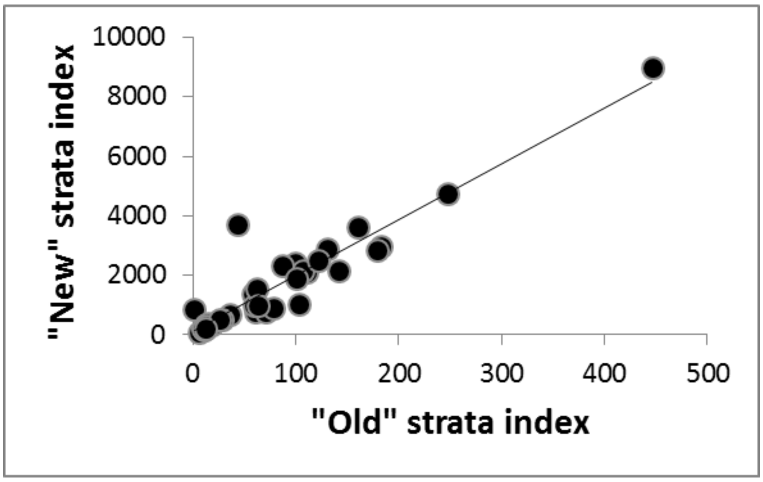
where Na,l,h is the number of fish at age a and length l caught during haul h, Hi is the number of valid hauls in stratum i and cpuei,a is the catch per unit of effort of fish at age a in stratum i.

For each age, the age frequency for each stratum 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. The final index value for each age is given by:

$$I_a = \frac{\sum_{i=1}^{S} (CPUE_{i,a} \times A_i)}{\sum_{i=1}^{S} A_i}$$

where Ai = area ($m^{2)}$ of stratum i and S = number of strata.

As is evident in Figure 3.6.2.11, the choice of strata has very little effect on the final calculated index for herring. The values calculated by using the old strata are highly correlated with the values calculated using the strata of the present survey design. The one clear outlier to this pattern is from 1wr fish in 2014 and this age is not considered well sampled in the survey. The relative index values are highly correlated and only differ in scale due to the difference in calculation method where the new method scales the index to the area of the strata. The old index is smaller by a factor of 21 on average (min 10, max 27).



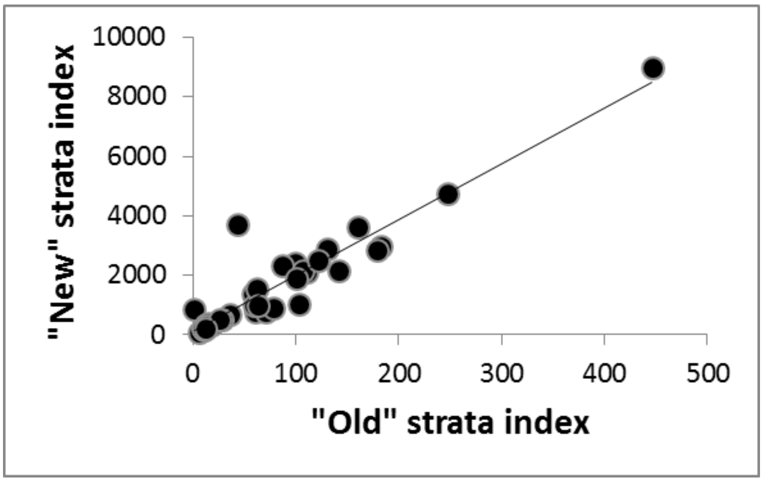


Figure 3.6.2.11. Old strata calculated index at year and age plotted against the new strata calculated index at year and age. Linear regression R^2=0.88.

Some analyses of the IBTS input data

A basic examination of the properties of the IBTS Scottish indices was performed. Catch curves show that fish are fully selected by 3-winter ring in the quarter 4 index (Figure 3.6.2.12). The mortality signal from the quarter 4 index is very noisy with considerable negative mortality (Table 3.6.2.1 and Figure 3.6.2.12). Cohorts from the beginning of the time-series appear to have a completely different selectivity (Figure 3.6.2.12, right). The series does demonstrate an ability to track strong cohorts (Figure 3.6.2.13), with the 1996, the 1993, the 1998 and 2000 year classes appearing strong. However these are not always the cohorts that are picked up in either the catch or acoustic series, which may suggest an ageing error. Log catch ratios show considerable noise and negative mortality but when smoothed with a moving average a picture emerges of constant though very noisy mortality on cohorts hatched before 1996 and a lower level of mortality signal thereafter (Figure 3.6.2.14), assuming that there are no changes in selectivity of the survey over time.

The quarter 1 survey also displays a noisy mortality signal (Figure 3.6.2.15), Table 3.6.2.2). Some of the cohorts in the middle of the series (for instance 2000) display a shallow pattern suggesting almost no mortality at all. Though the time-series is shorter, the early part of the series also displays what appears as a differing (lower) selectivity. The series also tracks the 1998 and 2000 cohorts well (Figure 3.6.2.16). The raw mortality signal (Figure 3.6.2.17) displays high frequency noise, with a tendency towards lower overall mortality for cohorts hatched since the mid-1990s.

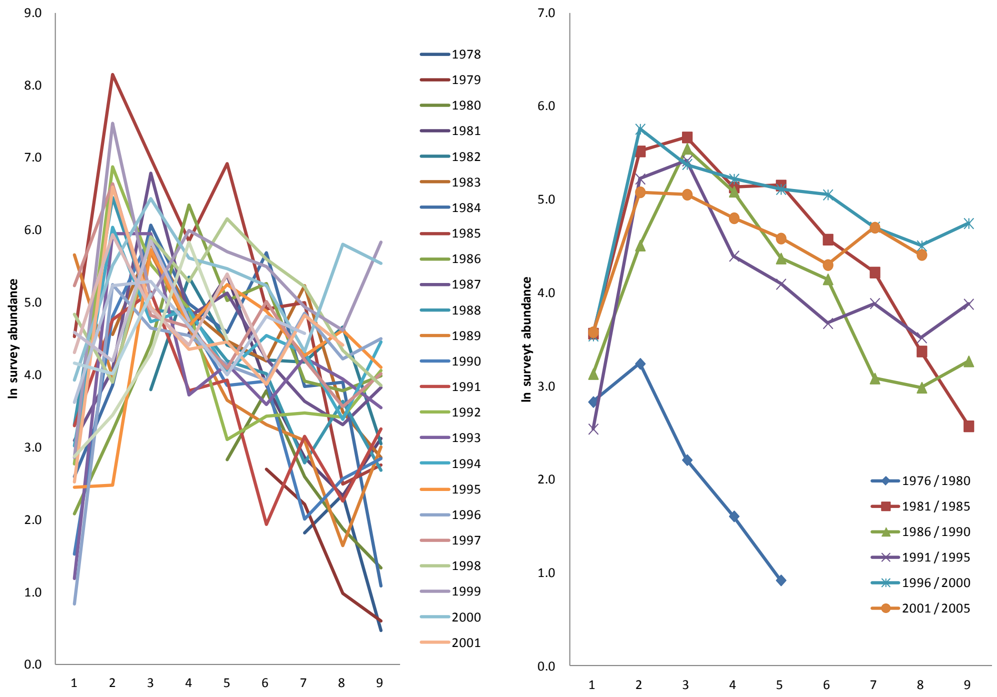


Figure 3.6.2.12. Catch curves based on the Scottish IBTS quarter 4 index, by age. Left panel shows catch curves by cohort and right panel shows these data smoothed by a 5-year moving average.

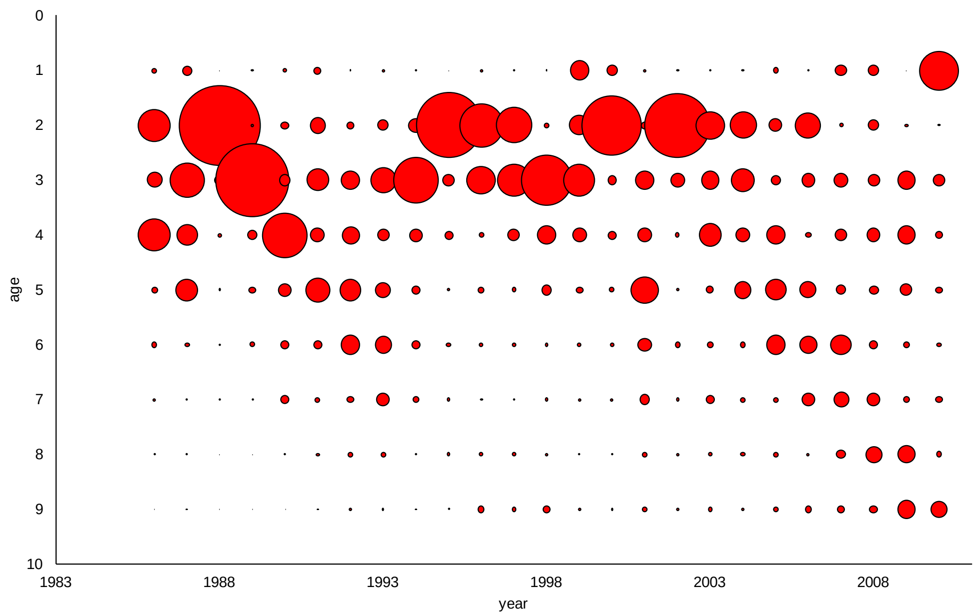


Figure 3.6.2.13. Survey abundance at age from the Scottish IBTS quarter 4 index, standardized by the yearly mean.

Figure 3.6.2.14. Ln catch ratios for the main fully selected age groups, smoothed by a 4-year moving average, for the quarter 4 Scottish IBTS survey.

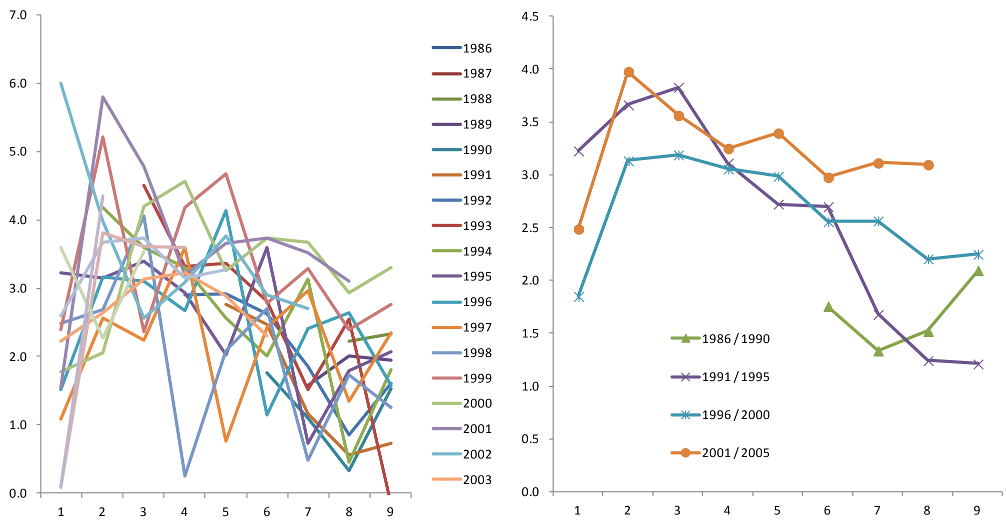


Figure 3.6.2.15. Catch curves based on the Scottish IBTS quarter 1index. Left panel shows catch curves by cohort and right panel shows these data smoothed by a 5-year moving average.

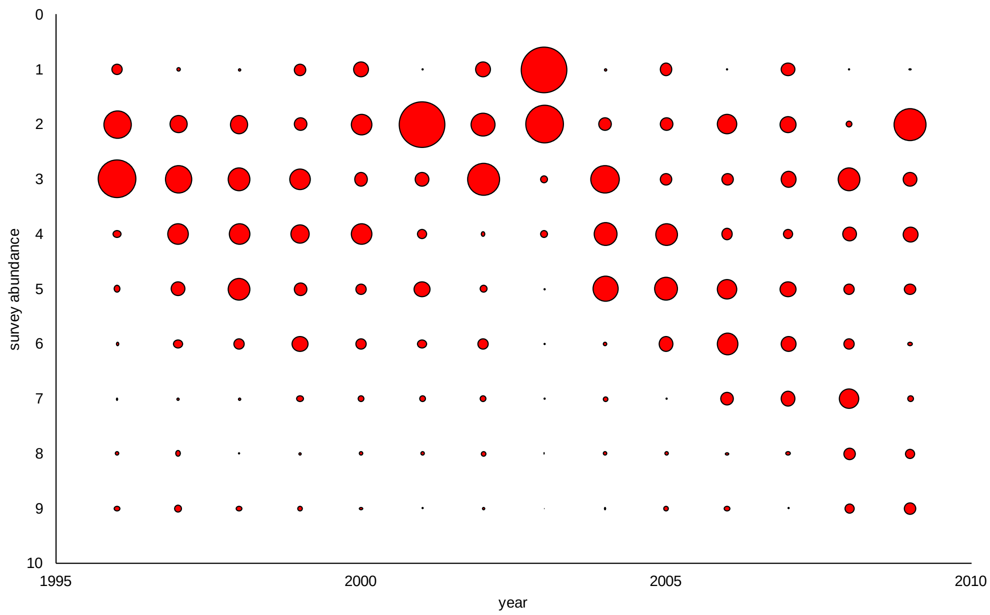


Figure 3.6.2.16. Survey abundance at age from the Scottish IBTS quarter 1 index, standardized by the yearly mean.

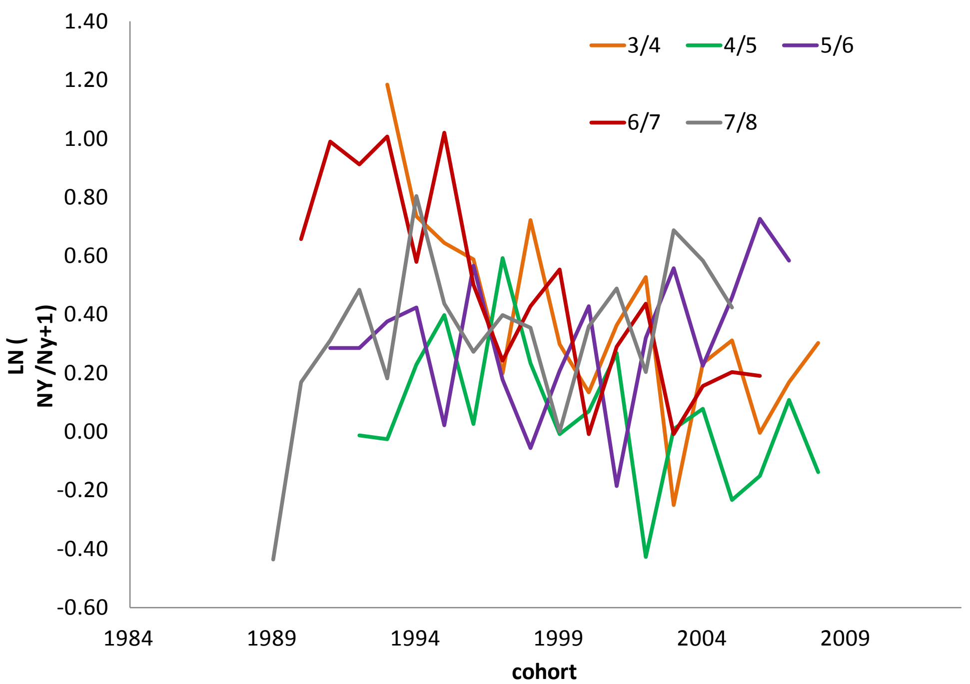


Figure 3.6.2.17. Ln catch ratios for the main fully selected age groups, smoothed by a 4-year moving average, for the quarter 1 Scottish IBTS survey.

Discussion

From the simple analysis presented here it appears that the Scottish Groundfish surveys in Q1 and Q4 contain information on the abundance-at-age of herring in area VIa. The best ability to track herring cohorts in this survey was found in the Quarter 1 survey and by considering all of area VIa as one unit. This is not surprising given that we know herring in these areas are likely present in a mix of unknown proportion between the different stock components at the time of the surveys. This is also the combination that has the highest amounts of samples increasing the likelihood of detecting patterns if present.

The change in survey design to a different stratification in 2011 does not appear to affect the calculation of the index following the "old" strata. This is perhaps not surprising given the apparently very small difference in the distribution of hauls. It is possible though that the precision of the index values will have changed between the two regimes, and a more thorough investigation should be carried out to ascertain whether the survey should be considered as one across this time of change in design or if it is more prudent to treat the survey after 2011 as a new survey altogether.

An Irish groundfish survey (IGFS Q4) covers the southern part of the area in quarter 4 and an index based on the combined dataset would possibly capture the stock dynamics even better. It should be recommended that an investigation is carried out into this possibility for augmenting the Scottish survey index in the southern areas not covered by the Scottish survey.

Another point to consider is whether a bottom trawl can be considered an appropriate sampling device for pelagic fish such as herring. From acoustic surveys in the area we do know that the majority of herring is found schooling above the bottom rather than in the surface, and it is assumed that this is the case during the trawl survey also. An investigation of the catchability of herring in the bottom-trawl survey is advisable and could be achieved by combining the trawl survey with concurrent acoustic monitoring.

Conclusions

- The Scottish bottom-trawl survey provides some information on the dynamics of herring in VIa;
- The best index of abundance-at-age comes from the Q1 survey which is also the longest running and by combining the entire area of VIa;
- It appears that the new stratified design used after 2011 has little effect on the calculated index, but further investigations should be carried out to verify this.

Table 3.6.2.1. Ln catch ratios (ln $c_{a,y}$ / $c_{a+1,y+1}$) for the Scottish IBTS quarter 4 index, by cohort. Red cells indicate negative mortality.

cohort	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9
1976								
1977								-0.61
1978							-0.53	1.88
1979						0.48	1.23	0.39
1980					-0.95	1.18	0.73	0.54
1981				-0.80	1.52	1.00	0.52	-0.79
1982			-1.55	0.93	0.21	0.02	-0.48	1.61
1983		-1.26	0.91	0.43	0.28	-1.04	1.75	0.63
1984	-1.25	-2.22	1.08	0.40	-1.10	1.85	-0.07	2.82
1985	-3.61	1.16	1.14	-1.06	2.00	-0.08	2.50	-0.26
1986	-1.14	-1.20	-1.92	1.32	-0.23	1.36	0.13	-0.21
1987	-0.99	-2.71	1.98	-0.33	0.91	0.59	0.33	-0.52
1988	-3.14	1.56	0.03	0.67	0.17	1.23	-0.85	0.96
1989	1.68	-1.71	1.04	1.00	0.34	0.22	1.45	-1.37
1990	-3.28	-1.12	1.17	0.92	-0.07	1.92	-0.56	-0.27
1991	-1.47	-0.38	1.36	-0.16	2.00	-1.21	0.89	-0.99
1992	-4.11	1.36	0.62	1.80	-0.33	-0.04	0.07	-0.65
1993	-4.76	0.00	2.23	-0.43	0.56	-0.65	0.30	0.39
1994	-3.03	1.30	-0.17	0.87	-0.50	0.23	0.92	-1.06
1995	-0.03	-3.25	1.06	-0.58	0.37	0.61	-0.34	0.51
1996	-4.41	0.60	0.10	0.41	0.21	-0.93	0.64	-0.28
1997	-1.41	1.83	0.16	0.56	-0.91	0.80	0.65	-0.45
1998	0.94	-2.01	0.62	-0.86	0.56	0.39	0.87	0.49
1999	-4.61	2.40	-0.92	0.29	0.20	0.56	0.32	-1.22
2000	-1.58	-0.93	0.82	0.15	0.23	0.91	-1.48	0.26
2001	-4.08	1.66	0.59	-0.11	0.59	-0.95	0.41	
2002	-1.61	-0.07	0.62	0.68	-0.82	0.23		
2003	-1.64	1.03	0.50	-0.98	1.18			
2004	-0.58	-0.84	-1.54	1.34				
2005	0.40	-1.65	1.09					
2006	0.14	-1.09						
2007	-2.79							
2008								

Table 3.6.2.2. Ln catch ratios (ln $c_{a,y}$ / $c_{a+1,y+1}$) for the Scottish IBTS quarter 1 index, by cohort. Red cells indicate negative mortality.

	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9
1986								
1987								
1988								-0.10
1989							-0.44	0.06
1990						0.66	0.77	-1.21
1991					0.29	1.32	0.60	-0.18
1992				-0.01	0.29	0.76	1.00	-0.75
1993			1.18	-0.04	0.55	1.29	-1.04	2.71
1994		0.59	0.29	0.74	0.56	-1.13	2.67	-1.35
1995	0.08	-0.25	0.46	0.91	-1.57	2.85	-1.05	-0.27
1996	-1.64	0.06	0.42	-1.46	2.99	-1.27	-0.22	1.05
1997	-1.48	0.32	-1.35	2.83	-1.65	-0.55	1.63	-1.00
1998	-0.19	-1.37	3.79	-1.84	-0.61	2.23	-1.26	0.48
1999	-2.82	2.85	-1.82	-0.48	1.89	-0.51	0.90	-0.37
2000	-0.27	-2.14	-0.38	1.31	-0.48	0.06	0.75	-0.37
2001	-4.25	1.03	1.58	-0.47	-0.08	0.22	0.42	
2002	2.02	1.41	-0.53	-0.67	0.87	0.19		
2003	-0.41	-0.50	-0.09	0.35	0.59			
2004	-1.08	-0.06	0.59	-0.14				
2005	-3.73	0.21	0.02					
2006	1.32	-1.26						
2007	-4.24							
2008								

3.6.3 Fishery-dependent information

The current annual acoustic survey for herring in VIaN and VIaS,VIIb,c is conducted during summer and surveys a mixture of fish from the two stocks in these areas. At the time of the survey the vast majority of adult fish are observed in VIaN, thereby providing little information on the abundance of the stock in VIaS, VIIb,c without a quantitative splitting method. Although limited fishing has occurred in VIaS and VIIbc in recent years (focused on Glen Head and Tory Island grounds), fishers report seeing increasing large amounts of herring in the inlets and bays on the Donegal coast. The fish appear inshore from early October until late December when they move more offshore to the traditional spawning grounds. This has led the Irish industry to the view that the stock is larger than it has been for many years, contrary to the current scientific views. Unfortunately, there are no scientific data to support industry's perception or to specifically evaluate this stock given the timing of the survey. The results of stock discrimination studies and splitting approaches are not considered reliable, although future improvements to morphological stock discrimination and new genetic studies may resolve the issues.

Irish fleets fishing in this fishery have reported large and increasing quantities of herring on the grounds, particularly in the northern part of the area in the last five years. This was especially the case during 2011, 2012, 2013, and 2014 and again at the start of January 2015. This seems to be totally at odds to the scientific advice. In 2014 the fishing industry encountered and documented a large aggregation of herring (dimensions 2.7 by 1 km). Using density estimates from other surveys of aggregations, an *ad hoc* and very subjective estimate of 27 000 t was generated. This represents a significant portion of the current biomass (ICES HAWG, 2014) attributed to the VIaS stock if it is anywhere near valid. Again in 2015 large aggregations of herring were observed and recorded in the area. Herein lies the dilemma. The information as collected and reported **cannot** be used in a quantitative matter to evaluate the stock status, however, it does confirm that relatively large aggregations of fish are being observed during the spawning season in the region, their abundance may be increasing and that these biomass observations should be investigated. This is particularly true given that this southern stock cannot reliably be evaluated from the existing summer acoustic survey.

The fishing industry can, and should, make a valuable contribution to the understanding of the distribution and abundance of this stock at a time when government agencies are not available to survey the stock, but they must move away from the anecdotal/qualitative approach that is difficult to incorporate into a scientific analysis/evaluation. Regardless of how well an aggregation of fish is documented it is virtually impossible to quantify the biomass unless the echosounder is of a high enough quality and calibrated. In addition, the ad hoc approach to documenting distribution of individual aggregations makes it difficult to provide an unbiased estimate of biomass or to compare inter annual trends in abundance unless there is some consistency in surveying between years. Minimum biomass estimates of aggregations are, however, possible from a calibrated acoustic system. It is recommended that the Irish fishing industry work with the appropriate government agencies and scientific staff to establish an acoustic survey design and sampling scheme that will document the distribution and abundance of herring that both occur and spawn in VIaS, VIIb,c in such a manner that the data can be incorporated into an analytical assessment and review.

3.6.4 Weights, maturities, growth, natural mortality

3.6.4.1 VIaN - Weights, maturities, growth

Maturity-at-age

The data used to derive the maturity ogive are from herring caught and sampled within the geographical area illustrated in Figure 3.6.4.1.1, bounded in the east by 4°W longitude and to the south by 56°N latitude. The maturities-at-age for VIaN herring are derived from the summer acoustic survey in VIaN, presented for the years 1992-2013 in Figure 3.6.4.1.2.

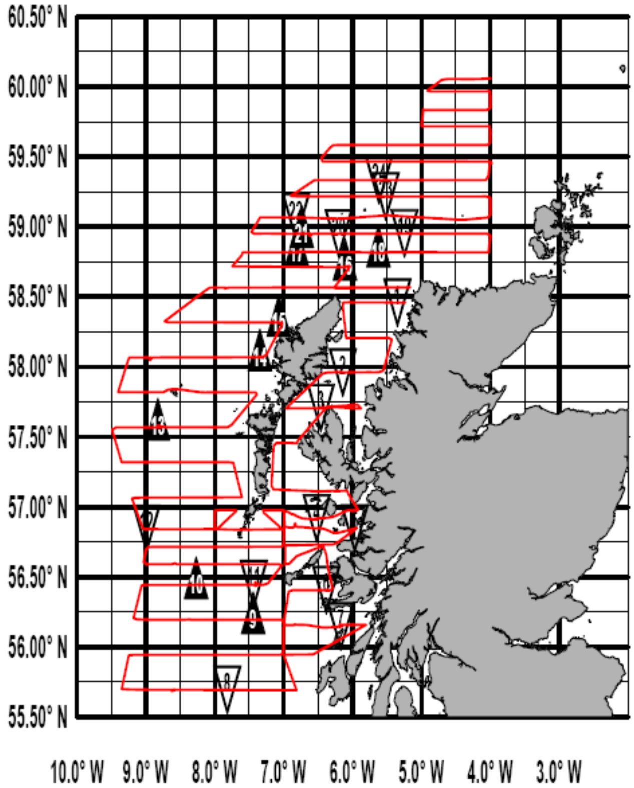


Figure 3.6.4.1.1. Map of the west of Scotland showing the cruise track and position of fishing trawls undertaken during the July 2009 west coast herring acoustic survey. Filled triangles indicate trawls in which significant numbers of herring were caught, whereas open triangles indicate trawls with few or no herring. The area bounded by 4°W longitude in the northeast and to the south by 56°N latitude is the area for which the VIaN survey indices and maturity ogives are derived each year, from 1992 to 2014.

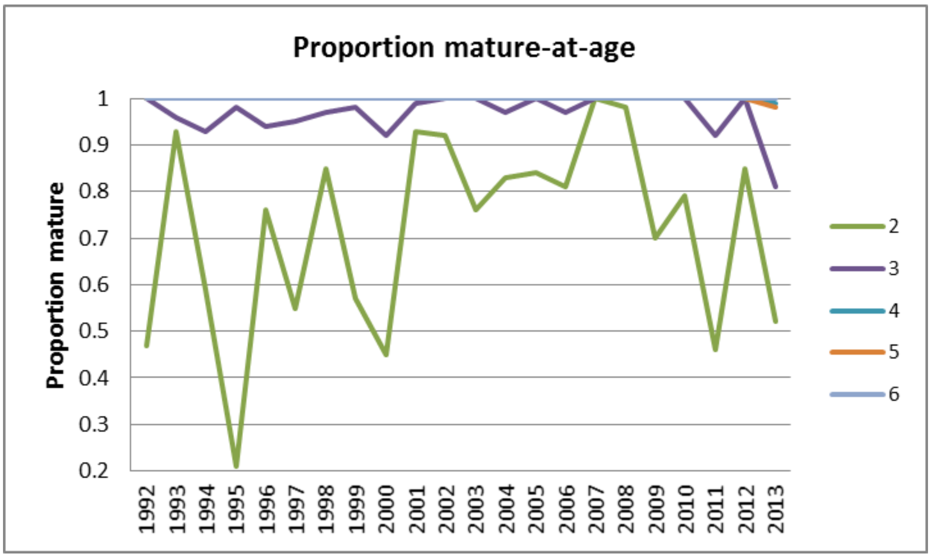


Figure 3.6.4.1.2. Proportion mature-at-age (2 to 6 winter rings) from the summer herring acoustic survey in VIaN, for the survey time-series 1992 to 2013.

The proportion mature at 2-wr is highly variable but without any apparent trend. The majority of herring in the summer VIaN survey are mature by 4-wr. It is not certain exactly what drives the high variability for the 2-wr herring. It is likely a combination of limited sampling of that age group within the surveyed area, varying proportions of herring returning to VIaN from the North Sea after their sojourn there as juveniles, varying proportions of herring from other populations within the VIaN survey (Clyde, VIaS and Irish Sea (VIIaN)) and natural variability.

Stock characteristics (lengths–at–age etc)

Size-at-age for different spawning components

The WESTHER project produced data on size-at-age for the various samples collected. These included spawning herring collected across the project area and allowd a comparison of size-at-age for all the spawning components. The plots in Figure 3.6.4.1.3 show (eviscerated) weights-at-age for the various spawning components. Spawning times for herring in VIaN (samples off Skye and Cape Wrath (S10A and S10B respectively)) and in VIaS (Rosamhil and Donegal A, B (S03A, SO4A and S04B respectively)) are highlighted.

In the years in which the samples were taken (2003 to 2005), and where there were sufficient numbers of herring per age group to allow comparison, winter and spring spawners tended to have a smaller mean size at spawning than autumn spawners in the same area up until 6-wr (comparing Donegal (S04A, winter) with Donegal (S04B, autumn) samples and Skye (S10A, spring) with Cape Wrath (S10B, autumn) samples). However, the size ranges encountered in both VIaN and VIaS were overlapping and likely not significantly different. The relationships for lengths-at-age showed the same patterns as eviscerated weights-at-age.

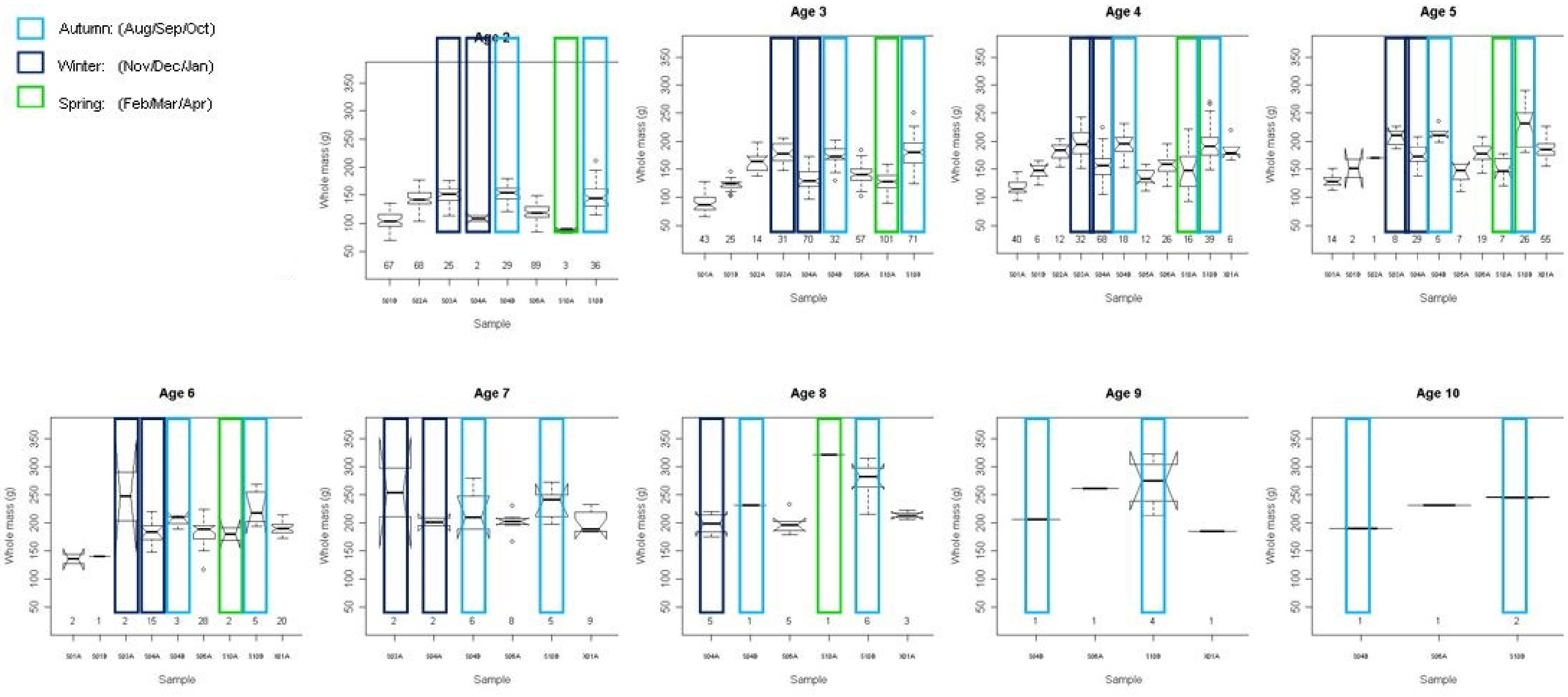


Figure 3.6.4.1.3. Eviscerated weights-at-age for samples of spawning herring sampled for the WESTHER project. Numbers above the x-axis are the numbers per sample per age group. Age refers to numbers of winter rings. The letter number codes on the X-axis refer to the following spawning groups: S01 – Celtic Sea, S02 – Dingle Bay, S03 – Rosamhil, S04 – Donegal, S05 – Clyde, S06 – Irish Sea, S10A – Skye, S10B – Cape Wrath.

Lengths- and weights-at age for VIaN herring

Lengths- and weights-at-age in the catches were derived from the calculation of total international catch-at-age and mean weights- and lengths-at-age in the catches using the 'sallocl' programme (Patterson, 1998a). Data were readily available for 2000 to 2013 and are illustrated in Figure 3.6.4.1.4. Weights-at-age in the stock were derived from the summer acoustic survey in VIaN from herring caught and sampled within the geographical area illustrated in Figure 3.6.4.1.1, bounded in the east by 4°W longitude and to the south by 56°N latitude. The same year range is shown for easy comparison.

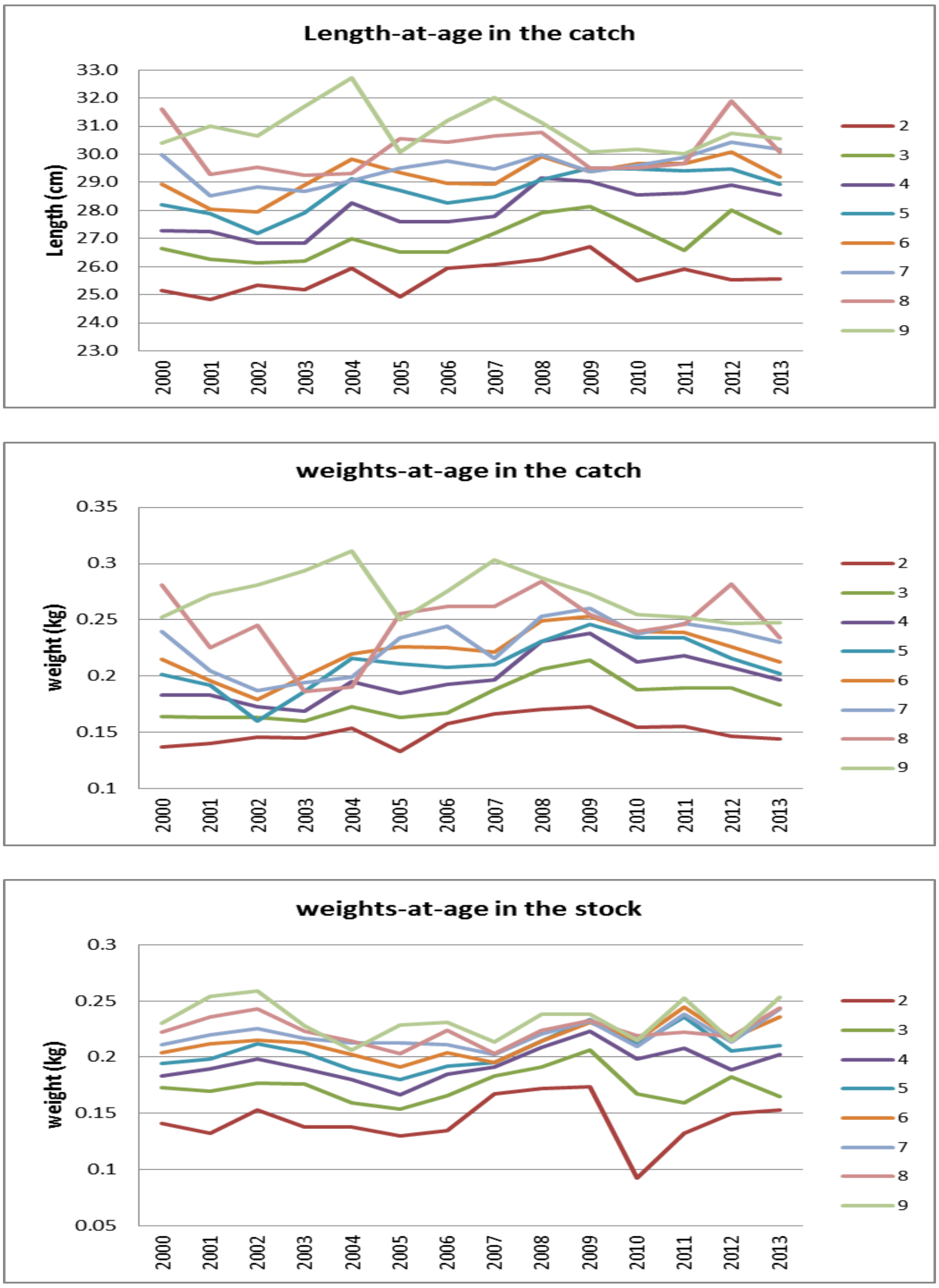
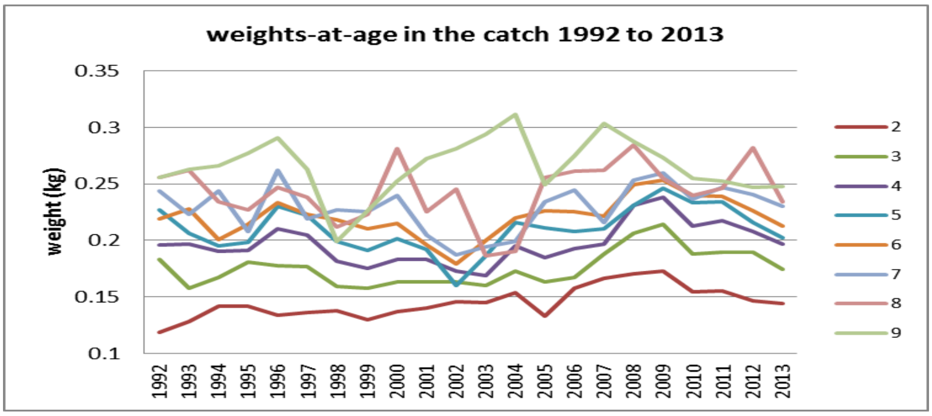


Figure 3.6.4.1.4. Lengths- and weights-at-age (2 to 9+ winter rings) in the catch in VIaN and weights-at-age (2 to 9+ winter rings) in the stock from 2000 to 2013.

There is a slight trend in increasing length-at-age but not in weight-at-age in either the catch or the stock for the given time-series. Weights-at-age are variable but about the same in 2013 as in 2000. There was a general increase in weights-at-age from 2000 to the late 2000s followed by a decline for most age classes after that.



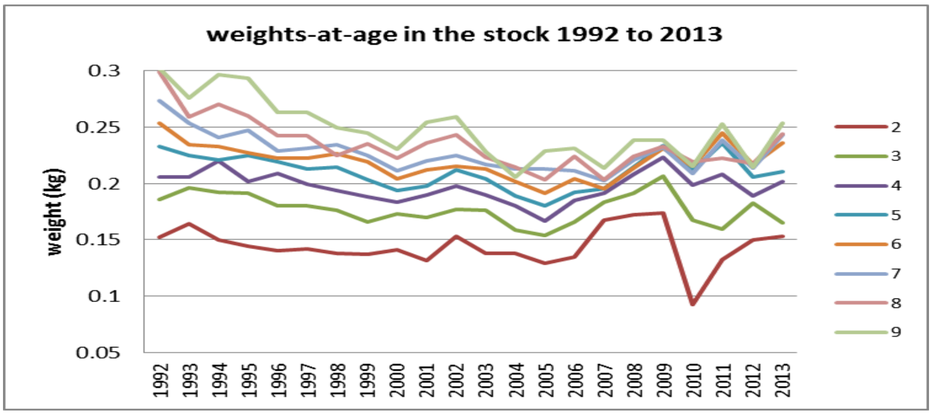


Figure 3.6.4.1.5. Weights-at-age (2 to 9+ winter rings) in the catch and in the stock in VIaN from 1992 to 2013.

The longer time-series in Figure 3.6.4.1.5, from 1992 to 2013, shows more variability. For most age classes, weights-at-age in both the catch and the stock declined from 1992 to around 2000, then increased from 2000 to the late 2000s and then declined subsequently. Overall, weights-at-age in the catch are the same in 2013 as in 1992. However, weights-at-age in the stock, sampled over the same geographical area, are lower in 2013 than in 1992.

3.6.4.2 VIaS, VIIb,c

Mean Weights

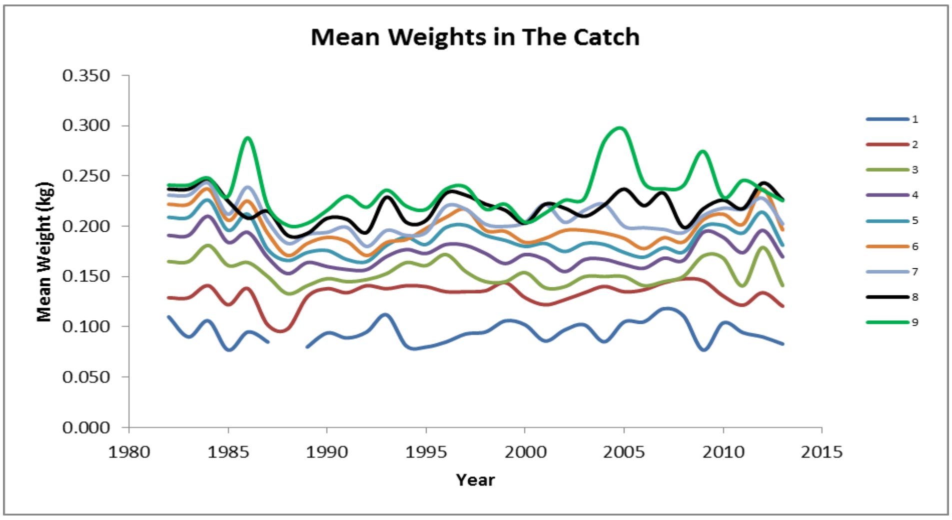
Mean weights in the stock (WEST) are calculated using samples taken from Q1 and Q4 each year. A mean weight-at-age is then calculated. Mean weights in the catch (WECA) are calculated using samples from all quarters of the fishery and a mean weight-at-age derived.

Trends in mean weights over time

The mean weights in the catch have a quite stable pattern over the time-series, although variable weights are only available from the early 1980s (Figure 3.6.4.2.1). Younger ages (1-6 winter ring) show an overall downward trend with more fluctuations evident in older ages (7-9 wr). 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.

In 2013 there were slight decreases in the mean weights of all age groups in the catch. The mean weights are now similar to 2011 after slight increases in 2012. The largest decrease (0.041 kg) was in 6-wr. Generally the oldest and youngest ages are poorly represented in the catch data. Overall there is little trend over time in weights at age.

The mean weights in the stock at spawning time have been calculated from Irish samples taken during the main spawning period that extends from October to February (Figure 3.6.4.2.1). The mean weights in the stock for all age groups, except 8-wr, have decreased since 2012. The largest decrease was in 3-wr. Overall there is little trend over time in stock weights at age.



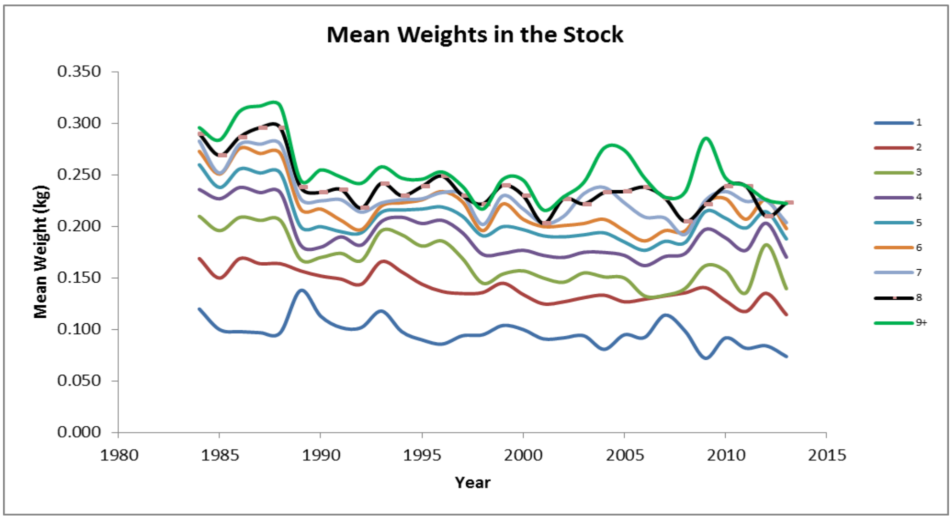


Figure 3.6.4.2.1 Herring in Divisions VIaS, VIIb,c. Mean weights in the catch (kg) and mean weights in the stock (kg) by age (1-9+) in winter rings. For years before 1981 the values fixed at 1981 were used.

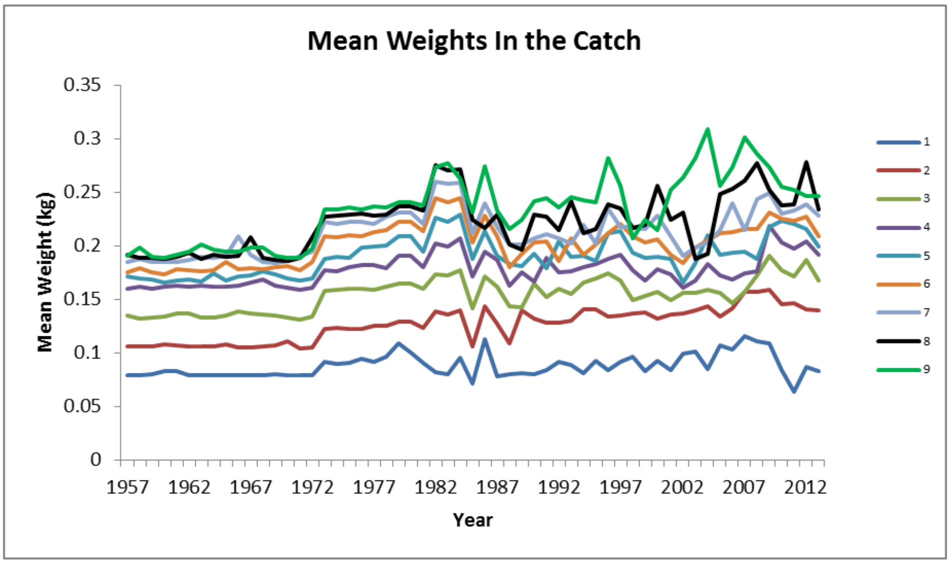
Maturity-at-age

The maturity ogive used in the assessment considers 1-wr to be all immature and all subsequent age groups as fully mature. Maturity ogives have been produced from the data collected in the summer acoustic surveys from 2008–2014. The maturity data are given in the stock annex and show variations in the percentage of fish mature and immature at each age class between years.

3.6.4.3 Combined data for VIa, VIIb,c

Mean Weights

Mean weights in the catch were compiled from the separate assessments and weighted by the combined catch in numbers. Weights-at-age in the stock at spawning time were taken from the recent VIaN assessment (Section 3.6.4.1). The mean weights in the catch for the entire time-series (1957–2012) are shown in Figure 3.6.4.3.1. From 1957–1980 very small variations in mean weight can be seen. From 1981 the annual variations are more pronounced. There is no clear trend in mean weight over time with increases and decreases apparent during different times. The mean weights in the stock are also presented in Figure 3.6.4.3.1. The time-series presented runs from 1991–2013. From 1957–1990 constant values were used. In 2010 a decrease can be seen for the younger ages. There was no data for 1 winter ring fish in 2013. Most age classes (2–9+ wr) have increased in the terminal year with the exception of 3 winter ring fish.



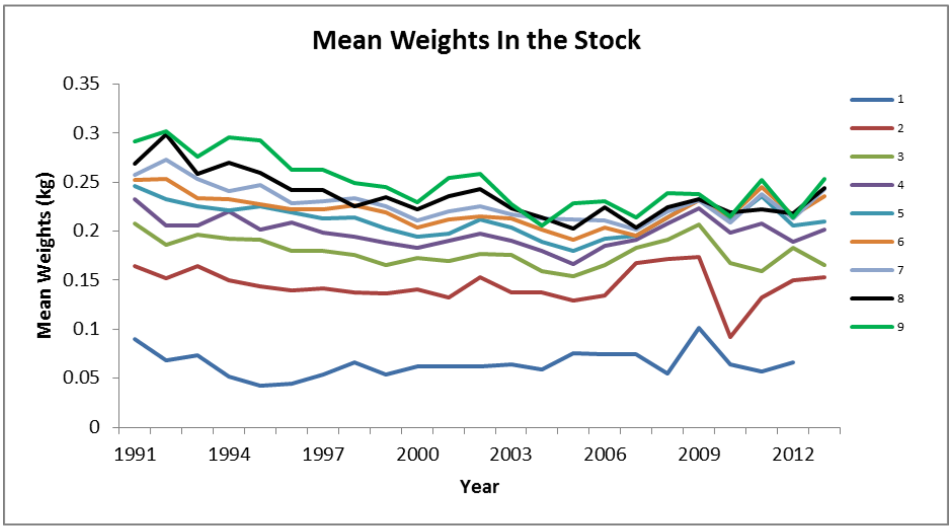


Figure 3.6.4.3.1 Herring in Divisions VIa, VIIb,c. Mean weights in the catch (kg) 1957-2013 and mean weights in the stock (kg) 1991-2013 by age (1-9+) in winter rings. For years before 1991 the values fixed at 1991 were used.

Maturity Ogive

The maturity ogive for the combined assessment is taken from observed maturity-at-age in the Malin Shelf survey 2008–2014, following the procedure for the current VIaN assessment. The maturity ogive from 1991–2013 is presented in Figure 3.6.4.3.2 below. Prior to 1991 a constant maturity ogive is used which assumes 0%, 57% and 96% maturity at 1, 2 and 3 wr respectively. In the variable ogive 1-wr are considered to be immature. The greatest annual variability can be seen in 2 and 3-wr. Age classes from 4-wr up are 100% mature.

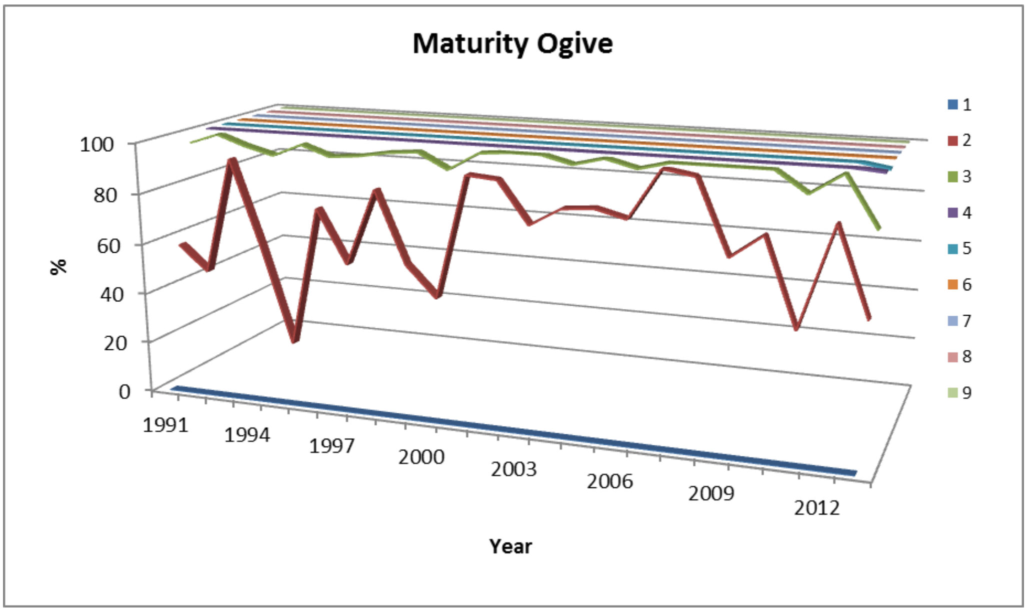


Figure 3.6.4.3.2 Herring in Divisions VIa, VIIb,c maturity ogive at age by year from 1991-2013.

3.6.4.4 Natural Mortality

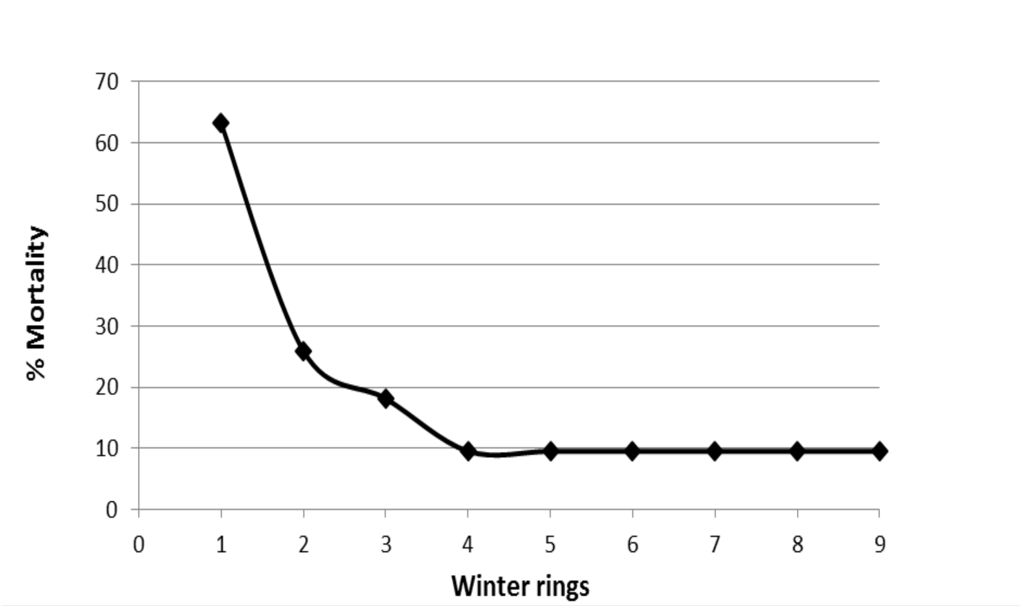
This section was updated and is reported in section 3.11.

3.6.4.4.1 Background on natural mortality (M) for the west coast of the British Isles

The natural mortality (M) currently used (1957–2013) for the VIaN herring stock is based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 (ICES, 1987). Values for M were also applied to herring stocks in adjacent areas. M values used in the current stock assessment are fixed by age and over time and are highest at 1-ringer (1.0) and decrease rapidly to 0.1 from 4-ringers onwards (Table 3.6.4.4.1). Figure 3.6.4.4.1 shows M represented as an overall percent mortality per winter ring age group.

Table 3.6.4.1: M currently used (1957 – 2013) for the VIaN herring stock

Age (winter rings)	1	2	3	4	5	6	7	8	9
M value	1.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1



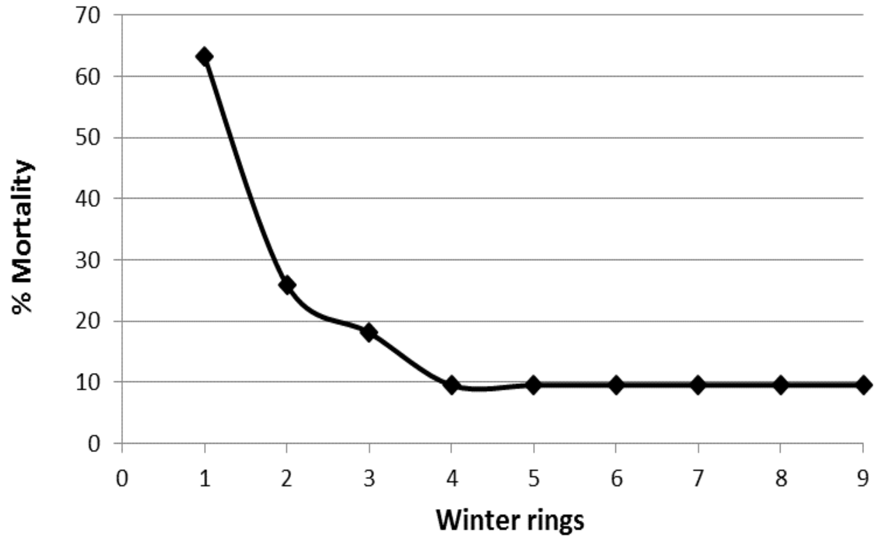
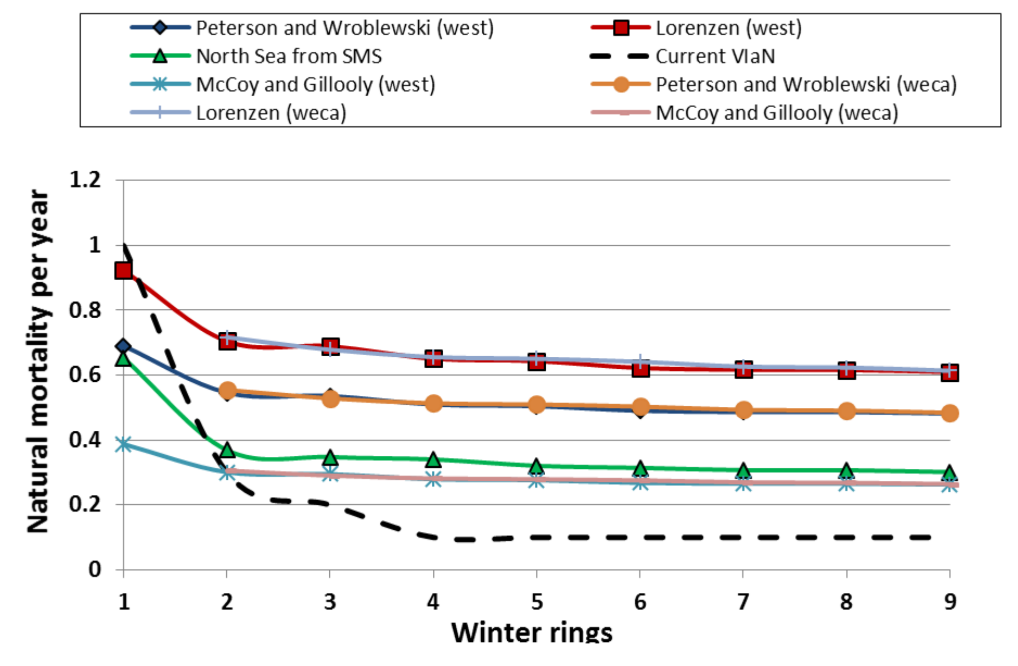


Figure 3.6.4.4.1: Natural mortality (represented as % annual mortality) currently used in the VIaN herring assessment.

It is generally accepted that true M is high during larval stages and decreases to a steady rate followed by an exponential increase when the fish nears maximum age (Chen and Watanabe, 1989; Jennings *et al.*, 2001; Siegfried and Sanso, 2013). Choices of M are often more ideological rather than evidence driven and uncertainty always surrounds values for M in assessment models. M may vary with size, sex, parasite load, density, food availability and predator numbers (Siegfried and Sanso, 2013), but this is difficult to measure empirically. Age invariable M is sometimes used as a default in assessments (Hewitt and Hoenig, 2005), but may not be appropriate to a stock if, for example, predation is high and size selective. Also, the choice of M may be more important if fishing mortality (F) is low and sometimes less than M, as is the case currently in the North Sea (ICES WKPELA, 2012).

There is empirical evidence that M is closely related to body size in pelagic fish populations (Petersen and Wroblewski, 1984; Lorenzen, 2000; Powers, 2014). Here, M is derived from relationships described by Peterson and Wroblewski (1984), Lorenzen (1996), and McCoy and Gillooly (2008) using *west* and *weca* data from 2013 to compare with the current M values used in the VIaN herring stock. These Ms are compared to values from the North Sea stochastic multispecies model (NS-SMS) as a reference. The values of M-at-age for the various functions used are shown in Figure 3.6.4.4.2. All M values are highest at 1- winter ring followed by a fairly rapid decrease to a stable low rate from 2-wr onwards.



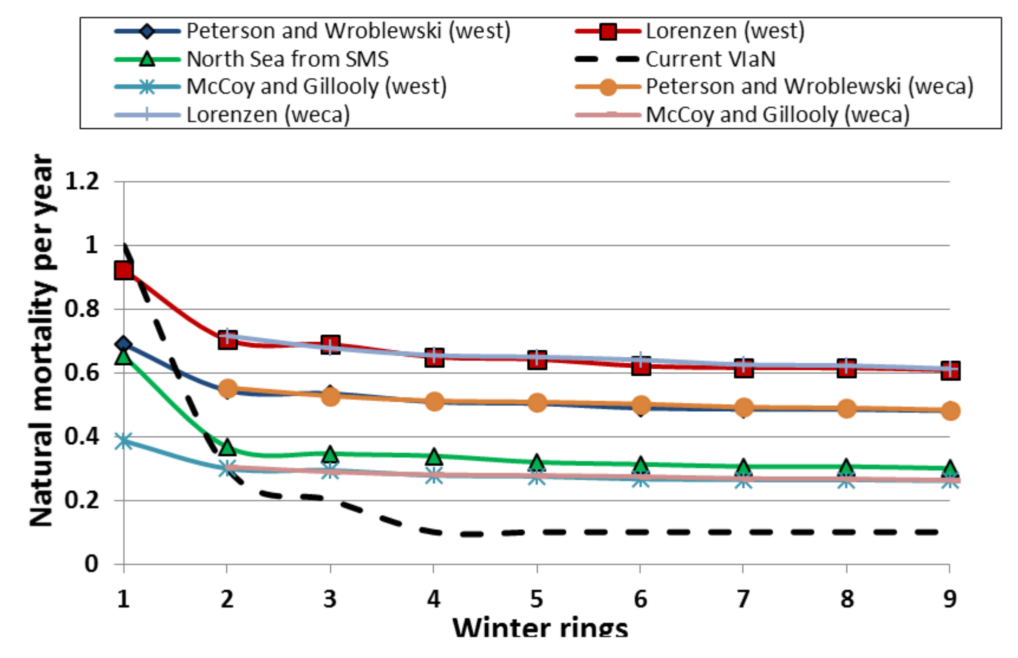


Figure 3.6.4.4.2: Natural mortality (M) estimates vs. age (winter rings) for various functions using 2013 data. Lorenzen (2000), Petersen and Wroblewski (1996) and McCoy and Gillooly (2008) functions were applied using weight data from *west* and *weca*. For comparison, Ms from the North Sea (from a multispecies model) and current VIaN herring stock assessment are also shown.

3.6.4.4.2 The North Sea multispecies model (NS-SMS)

There was an error in the North Sea model which was communicated by WGSAM in March 2015. Updated values for the North Sea are given in Section 3.11.

The 2012 benchmark assessment for North Sea herring (ICES WKPELA, 2012) recommended replacing time invariable estimates of M with time variable estimates of M from the NS-SMS. From 2012 onwards the assessment of North Sea autumn spawning (NSAS) herring includes variable estimates of M-at-age derived directly from the NS-SMS model, used in WGSAM (Lewy and Vinther, 2004; ICES 2011). The input data to the assessment are the smoothed values of the raw NS-SMS model annual M values, which are variable both at-age and over the period 1963–2010. M in years outside this period are filled and estimated for each age as a five year running mean in the forward direction for 2011+ and in the reverse direction for years prior. The M estimates are variable along the period covered by the assessment (Figure 3.6.4.4.4). Inspection of the trends in the stock size of the main herring predators suggests that the increase in natural mortality of all age groups >1 in the early period, approximately 1963-1975, is likely linked to the gadoid outburst in the late 1960s, in particular predation by cod and saithe (ICES WGSAM, 2013). From approximately 1976 onwards, natural mortality decreased again while the gadoid population reduced in size as well. From approximately 1991 onwards, close to the period where a regime shift in the North Sea is thought to have occurred, an increase in natural mortality can be observed again. In the more recent years (2008–2010) natural mortality appears to decrease again. M from the NS-SMS has decreased steadily for 1- group herring in recent years from a high of ~0.9 in the early period (up to the late 1970s) to ~0.65 in recent years. M for 2-wr and older in the NS-SMS is also variable and is generally higher than the M currently used in VIaN (Figure 3.6.4.4.2). It is possible that M estimates for the VIaN herring stock are influenced by similar drivers to North Sea herring. Many predator species inhabit both the North Sea and the area to the west of Scotland, including some of the main predators of herring; e.g. saithe and mackerel (Marine Scotland Science, 2014). If M on the VIaN herring stock in the west of Scotland is similar to M in the North Sea, then the trends in the main predator species' abundance would be comparable between areas. However, predators and prey would also have to overlap in space and time, and M may also be variable depending on the age-specific relationships between herring and predators; both parameters are difficult to measure. The Celtic Sea herring assessment began using M from the NS-SMS in 2014; it might also be an appropriate index of M for the VIaN herring stock.

To explore the relevance of the North Sea herring M for VIaN herring, the species preying on herring in the North Sea and their rates of consumption of herring were examined. In addition, the SSB of potential predators to the west of Scotland was compared with those in the North Sea. The M-at-age from the NS-SMS was explored, as the influence of predators on herring M will vary with age; it was, therefore, important to look at all species that may prey on herring throughout their life history. Predator influence on M for herring will vary depending on species' spatial overlap, feeding behaviour and predator biomass. Rates of predation on herring used in the NS-SMS model are shown in Table 3.6.4.4.2.

Table 3.6.4.4.2: Predators showing the percentage of herring in their diet included in the NS –SMS (sources; ICES (2012), Engelhard *et al.* (2014)).

Species	Percentage of herring in diet
Saithe *Pollachius virens*	17
Whiting *Merlangius merlangus*	6
Cod *Gadus morhua*	8
Horse mackerel *Trachurus trachurus*	3
Mackerel *Scomber scombrus*	2
Haddock *Melanogrammus aeglefinus*	0
Grey gurnard *Eutrigla gurnardus*	0
Starry ray *Amblyraja radiata*	0
Harbour seal *Phoca vitulina*	6
Harbour Porpoise *Phocoena phocoena*	3
Grey seal *Halichoerus grypus*	0
Minke whale *Balaenoptera acutorostrata*	6
Gannet *Morus bassanus*	11
Guillemot *Uria aalge*	14
Puffin *Fratercula arctica*	8
Razorbill *Alca torda*	9

NS-SMS model predictions

The number of species in the NS-SMS model that prey highly on forage species is relatively small (Engelhard *et al.*, 2014). Seabirds and seals appear to have a more modest effect on forage fish in general (including herring) in the North Sea. The main fish species that impact forage species in the North Sea are saithe, whiting, cod, mackerel and horse mackerel (Figure 3.6.4.4.3). The impact of predators on herring in the North Sea varies depending on age group (Table 3.6.4.4.3).

0-winter ring herring:

M is shown to be strongly age-dependent; between 75% and 99% of the total juvenile mortality occurs during the first year of life (De Barros and Toresen (1998) for Norwegian Spring-spawning herring). The primary predators of 0-ring herring are mackerel and horse mackerel in the NS-SMS (Table 3.6.4.4.3), and the model is sensitive to assumptions about their abundance (Dickey-Collas *et al.*, 2010b). The relatively high abundance of these species to the west of Scotland should be considered when choosing M for 0- and 1-ring fish. Also, larval and juvenile herring from the west of Scotland can inhabit the North Sea for a significant period, therefore it is important to consider predators that span this broader area and overlap with the juvenile herring that exhibit this behaviour.

1-wr herring:

The main predators of 1-wr herring in the NS-SMS are whiting, saithe and seabirds, accounting for approximately 90% of the predation on herring (Table 3.6.4.4.3).

2-wr and older:

Herring of 2-wr and older are primarily eaten by saithe, whiting and cod in the North Sea (Table 3.6.4.3). Whiting mainly preys on 2-wr herring and to a lesser degree on 4-

wr herring (ICES, 2011). The contribution of saithe and cod alone makes up for nearly 90% of predation mortality from 4-wr onwards (ICES, 2011).

Table 3.6.4.4.3: Approximate % contribution of predators to herring mortality rate, ranked in order of importance for 0-, 1- and 2-wr herring in the North Sea SMS, example from 2008 data (ICES, 2011).

wr	%	wr	%	wr	%
Mackerel	30	Whiting	50	Saithe	40
Horse mackerel	30	Saithe	20	Whiting	30
Whiting	20	Seabirds	20	Cod	20
Seabirds	10	Cod	6	Seabirds	4
Cod	5	Mackerel	2	Harbour porpoise	4
Saithe	4	Horse Mackerel	1	Mackerel	1
Harbour porpoise	1	Harbour porpoise	1	Horse mackerel	1

The predators accounting for approximately 90% of all predation of herring in the North Sea are: mackerel, horse mackerel, whiting and seabirds for the 0-wr herring; saithe, whiting and seabirds for the 1-wr herring; saithe, whiting and cod for the 2-wr herring; saithe and cod for 4-wr and older (ICES, 2011). The overall biomass of herring consumed in the North Sea per predator species from the NS-SMS is shown in Figure 3.6.4.4.3.

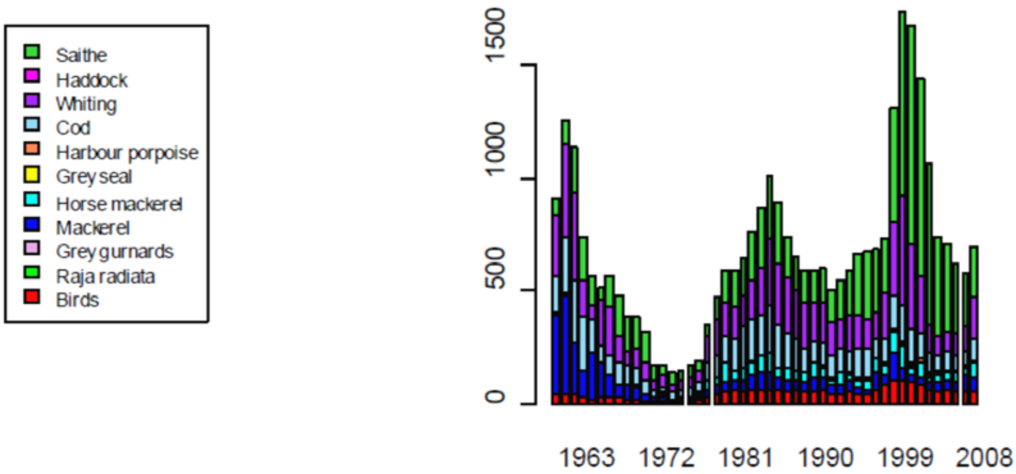
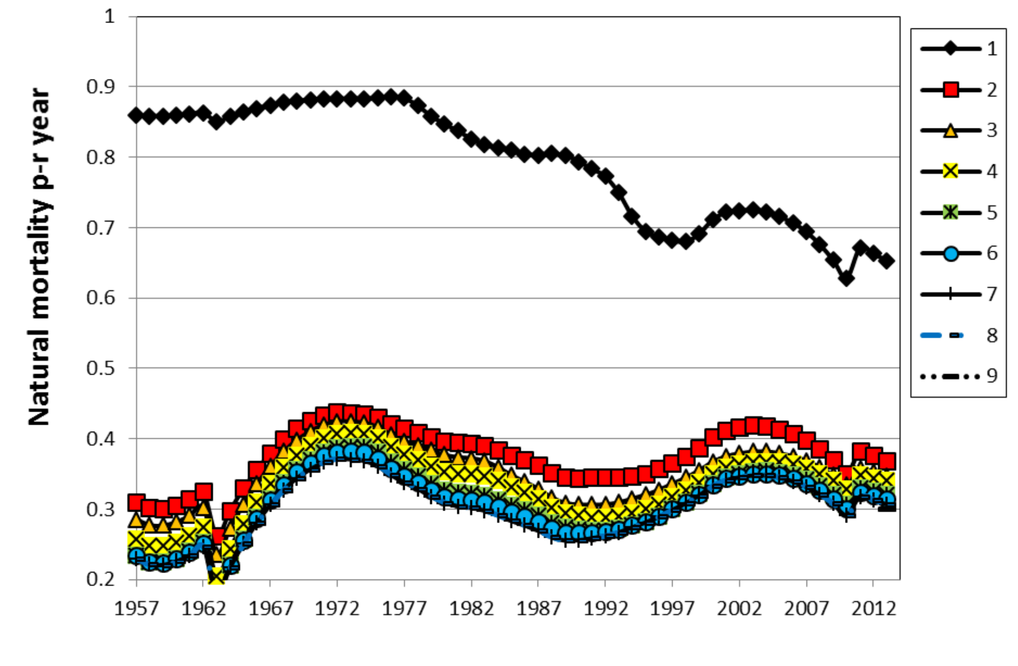


Figure 3.6.4.4.3: Overall biomass of herring eaten (1000 t) by individual predator species in the North Sea (from ICES, 2011)



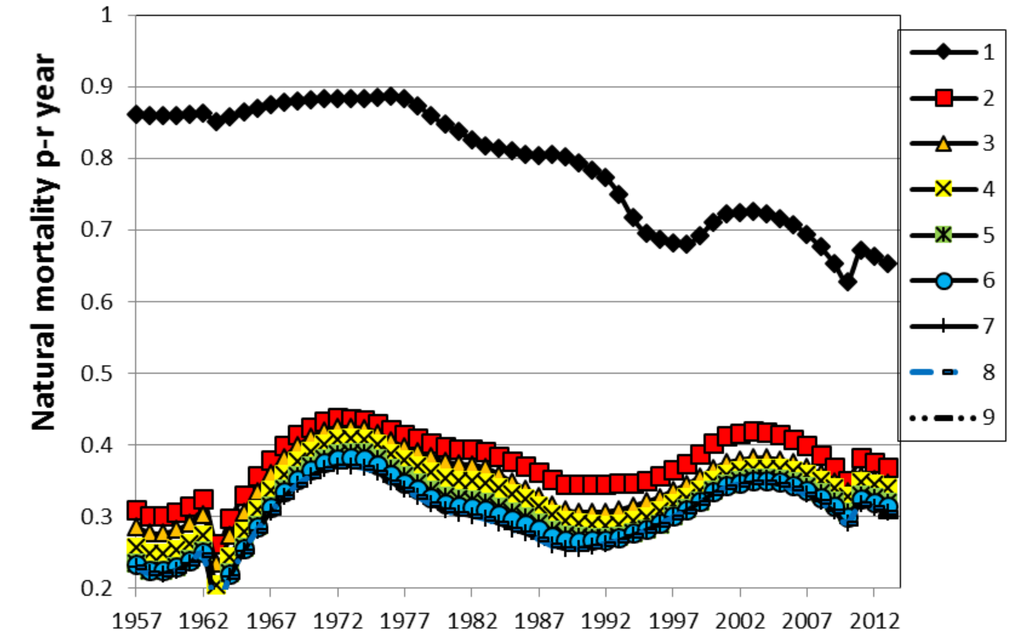
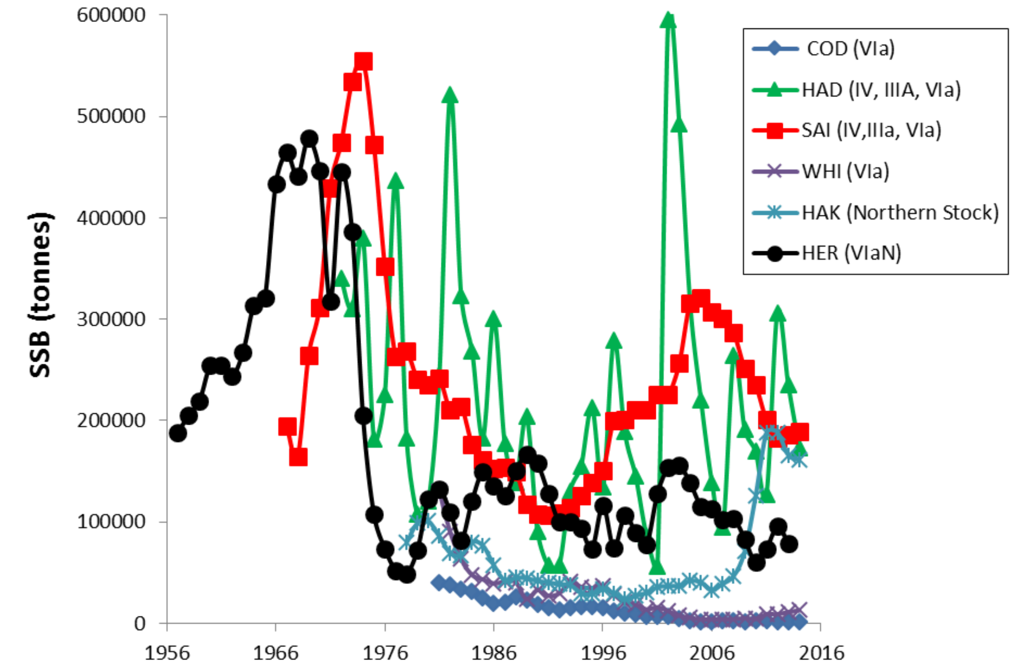


Figure 3.6.4.4.4: Natural mortality-at-age per year for North Sea herring. The input data to the assessment are the smoothed values of the raw SMS model annual M values, which are both age and time variable.



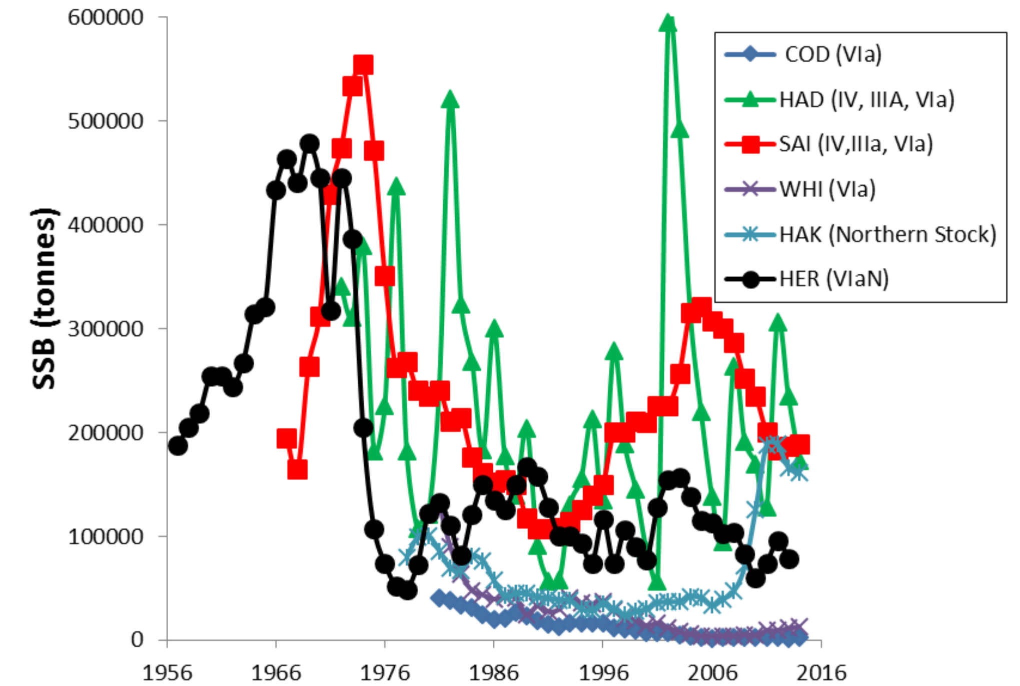
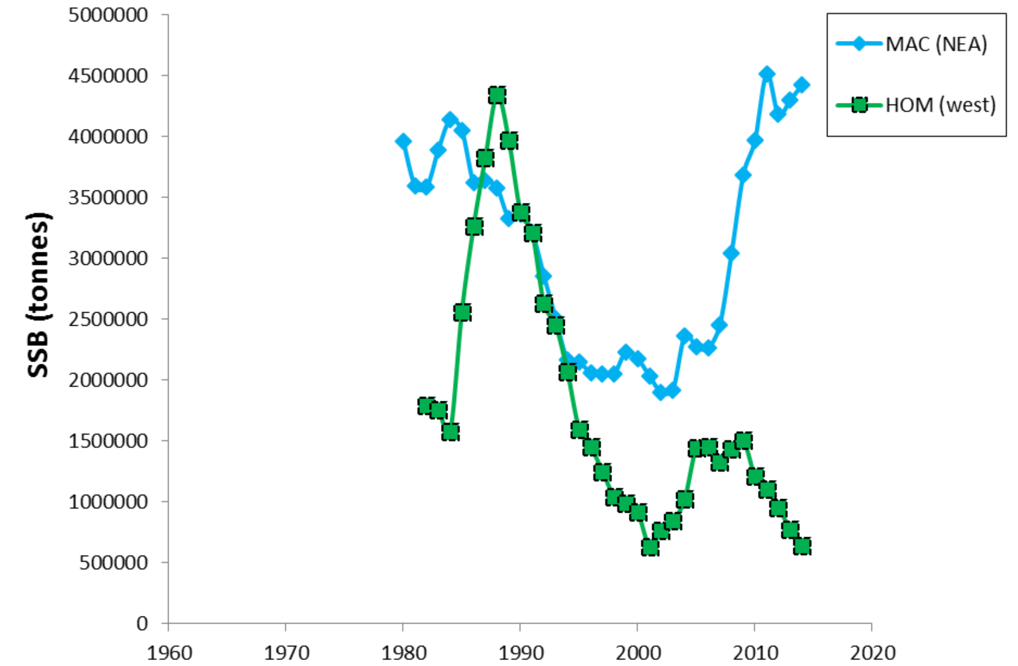


Figure 3.6.4.4.5: Time-series of SSB of VIaN herring and potential main piscivorous predators of herring to the west of Scotland (ICES, 2014).



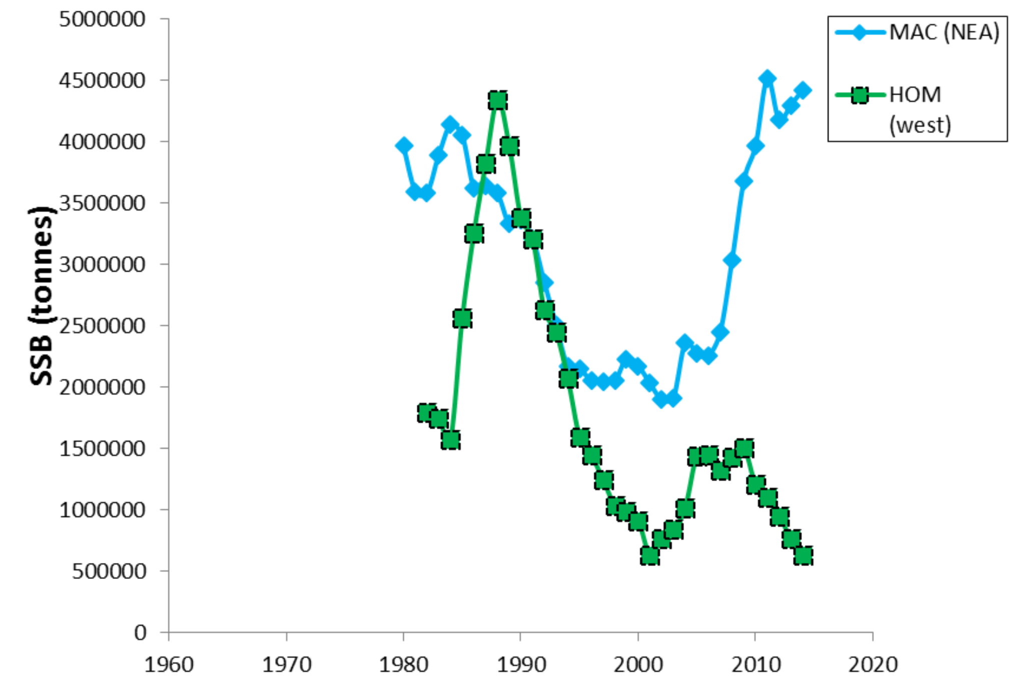
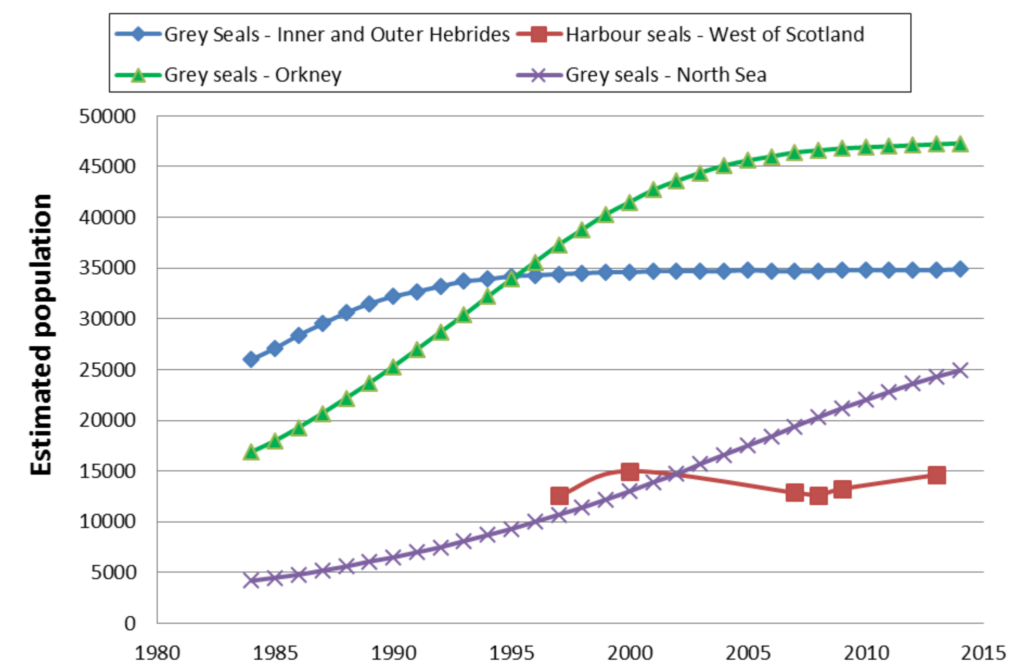


Figure 3.6.4.4.6: Time-series of SSB for the Northeast Atlantic mackerel (MAC - NEA) and western horse mackerel (HOM - west) stocks (ICES, 2014).



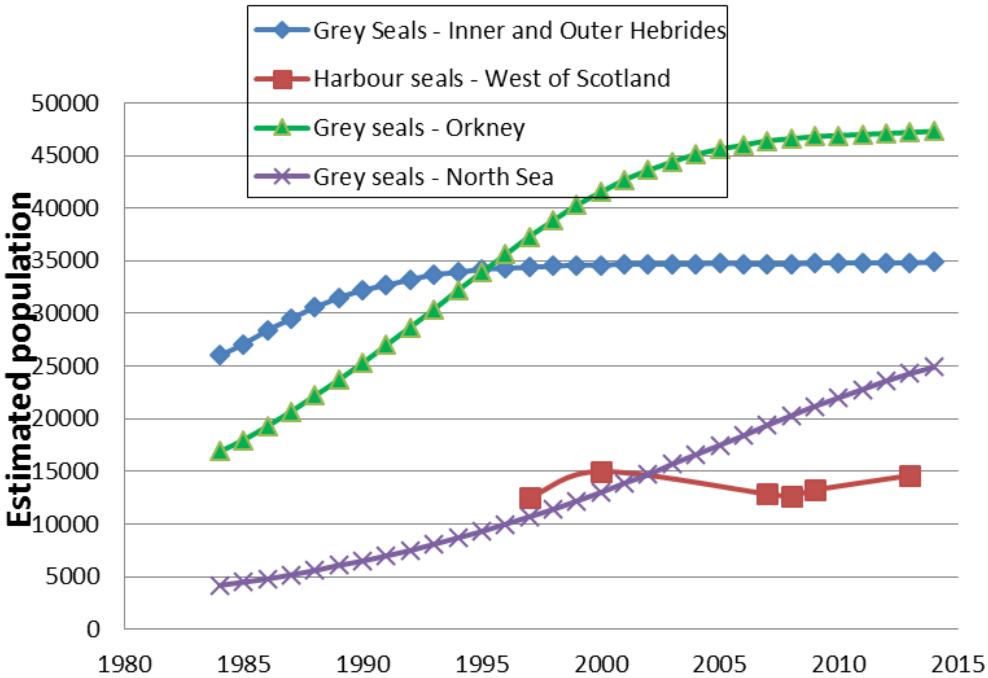


Figure 3.6.4.4.7: Estimates of grey seal total population size, in thousands, at the beginning of each breeding season from 1984-2014, made using the model of British grey seal population dynamics fitted to pup production estimates and a total population estimate from 2008, and using the old priors. The harbour seal data are the best time-series of complete haul-out counts available for the whole area to the west of Scotland (Thomas, 2014).

3.6.4.4.3 Abundance of herring predators in the North Sea and to the west of Scotland

The abundance trends over time of the main predators of herring to the west of Scotland provide an indication of the appropriateness of using M from NS-SMS for the VIaN herring stock. Some commercial fish stocks are assessed in VIa (e.g. cod, whiting); other species are assessed over a larger area (e.g. saithe, mackerel). It is difficult to make assumptions about the spatial overlap of main predators with herring, and the age-specific effects, but describing the broad trends of abundance of the main predators is a useful first step. Figure 3.6.4.4 shows the trends in M from the NS-SMS over time. Figures 3.6.4.4 5, 3.6.4.4 6 and 3.6.4.4 7 show the trends of some of the fish and marine mammal species that are likely to be the main predators of herring in this area.

Fish predators of VIaN herring

Mackerel and horse mackerel are major predators of 0-wr herring in the North Sea; it is possible that their effect on M in the VIaN herring stock is even greater for 0-wr fish as the stock is also in the North Sea for a significant period (Marine Scotland Science, 2014). Stocks are currently high and increasing for mackerel and although decreasing for horse mackerel, are still at relatively high levels compared to herring (Figure 3.6.4.4 6). Cod has declined in biomass in the North Sea and VIa overall, while saithe increased considerably over the years 1990 to 2005 (Figure 3.6.4.4 5). Saithe SSB trends have been decreasing since 2005, but are also likely to be an important predator of herring to the west of Scotland due to its distribution and abundance compared to other gadoids (Marine Scotland Science, 2014). Whiting is an important predator of 1-wr herring, but has less of an impact for older herring in the NS-SMS (ICES, 2011). However, whiting SSB is relatively low and decreasing in recent years to the west of Scotland. Herring mortality for ages 2-wr and older increased over the period 1991–2007 (Figure 3.6.4.4 4) but seems to have decreased in more recent years (ICES, 2011). This trend appears to be in broad agreement with the development of the saithe stock (Figure 3.6.4.4 5), the most prolific predator of 2+ wr herring.

Other predators to the west of Scotland – grey seals to the west of Scotland

The grey seal population estimates to the west of Scotland (Thomas, 2014) appear to have increased from the 1980s to a present estimation of about 35 000 in the area including the Inner and Outer Hebrides (Figure 3.6.4.4 7). Grey seals around the Orkney Islands have increased dramatically in recent years to around 47 000 individuals from around 20 000 in the 1980s. The total estimated abundance of grey seals in the West of Scotland in 2013 including Orkney is approximately 82 000 individuals. Grey seals from Orkney and North Sea will also affect herring from both the North Sea and to the west of Scotland. Numbers of grey seals are higher to the west of Scotland than the North Sea (approximately 25 000 individuals currently); therefore their contribution to M is likely to be higher to the west of Scotland than in the North Sea. Grey seals are also known to travel much further offshore than harbour seals. Predation on the VIaN herring stock could be as much as 3.6% of the total-stock biomass (Hammond, *pers. comm.*). This needs to be considered in the final decision on M for the VIaN stock. However, there is a caveat because are still issues relating to the calculation of this biomass, given the size frequency distributions produced that are inconsistent with the known size frequency distribution for VIaN herring.

Other predators to the west of Scotland – harbour seals to the west of Scotland

Harbour seal populations appear to be relatively stable at approximately 14 500 individuals to the west of Scotland (SW Scotland, W Scotland and Outer Hebrides). Harbour seals are likely to consume a greater proportion of herring in their diet than grey seals; however, numbers are lower than grey seals to the west of Scotland (Hammond, *pers. comm.*).

Other predators to the west of Scotland – seals off NW Ireland

Current abundance estimates of harbour seals (Duck and Morris, 2013) and grey seals (Ó Cadhla *et al.*, 2013) off the northwest of Ireland are shown in Table 3.6.4.4 4.

Table 3.6.4.4.4: Abundance estimates of harbour seals and grey seals off the northwest of Ireland (Duck and Morris, 2013; Ó Cadhla *et al.*, 2013)

Harbour Seals	2003	2011/12	diff. (%)
DONEGAL	555	654	17.80%
LEITRIM	0	0	
SLIGO	376	309	-17.80%
MAYO	316	470	48.70%
GALWAY	467	860	84.20%

Grey seals	2009–2012
DONEGAL	844–1085
MAYO	1841–2367
GALWAY NW	1456–1872
GALWAY (Slyne Head)	364–468

Other predators to the west of Scotland – cetaceans to the west of Scotland

The two species of cetacean that contribute to M of herring in the NS-SMS are harbour porpoise and minke whale (3% and 6% herring in diet, respectively (Table 3.6.4.4 2)). Both are also likely to contribute substantially to herring M in the VIaN herring stock. Current abundance estimates (2013) for some of the main cetaceans that may prey on herring are shown in Table 3.6.4.4 5. Other species that we have abundance estimates for and may prey on herring to the west of Scotland are: white-beaked dolphin, common dolphin and bottlenose dolphin.

Table 3.6.4.4.5: Current abundance estimates of harbour porpoise, minke whale, white-beaked dolphin, common dolphin and bottlenose dolphin (Hammond *et al.*, 2013).

Species	Inner Hebrides and Minches	West of Hebrides/West of Ireland/Shelf	Ireland (inshore coastal)
Harbour porpoise	12 076	11 011	10 716
Minke whale	0	1938	2216
White-beaked dolphin *Lagenorhynchus albirostris*	3219	2071	273
Common dolphin *Delphinus delphis*	2199	1720	11 661
Bottlenose dolphin *Tursiops truncatus*	246	1481	313

Other predators to the west of Scotland – Seabirds to the west of Scotland

The four seabird species that are included in the NS-SMS model as predators of herring are gannet, guillemot, puffin and razorbill (Engelhard *et al.*, 2014). These species also have a substantial populations to the west of Scotland, and therefore may also contribute more to M, particularly to younger age groups of herring. Current abundance estimates (British Trust for Ornithologists, 2013) for the area to the west of Scotland of the four seabird species included in the NS-SMS are shown in Table 3.6.4.4 6.

Table 3.6.4.4.6: Estimated population of selected west of Scotland seabirds (British Trust for Ornithologists 2013)

Species	Population size approx.
Gannet	150 000
Guillemot	80 000
Puffin	100 000
Razorbill	100 000
TOTAL	430 000

3.6.4.4.4 Discussion

It is very difficult to quantify predator/prey impacts due to lack of specific knowledge of the spatial overlap of stocks and unknown age variable effects. The predation of herring to the west of Scotland as elsewhere is likely to be large, particularly for 0- and 1-wr herring. Stocks are currently relatively high for mackerel and horse mackerel, two of the main predators of herring at younger ages in the North Sea. Stocks are generally lower for the other fish species currently considered to be main predators of herring in the North Sea, particularly on 1-wr and older fish, although some stocks not included as predators of herring in the NS-SMS 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-wr herring than in the NS-SMS. It is difficult to ascertain whether M for VIaN herring will be influenced greatly by the SSB 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-wr 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. However, in the NS-SMS, 0% of grey seal diet is herring, and for harbour seal herring contributes 6%. If raw M values directly from the NS-SMS were used in VIaN, this may not adequately incorporate the influence of grey seals on M for the VIaN herring stock. This should be a consideration when choosing M as predation is likely to be different from the west of Scotland where grey seal numbers in particular are much higher than in the North Sea.

The trends of M-at-age from the NS-SMS are useful as a starting point for M for the VIaN herring stock. However, there are some caveats; some species are potentially in greater abundance to the west of Scotland; hake, mackerel, horse mackerel, grey seals, some cetaceans, some seabird species, etc. Populations of these species need to be considered when applying M from NS-SMS, as well as species' propensity to prey on herring. This is also age specific; therefore tracking M from SMS for VIaN herring may be more valid for certain age groups over others particularly as is the case to the west of Scotland, when different species influence M for each of the age groups.

The spatial overlap of herring with predator stocks in the area to the west of Scotland is complex; however, broad trends of predator abundance should inform the choice of M. Using NS-SMS predation data as a guide is reasonable because there is a lot of overlap and mixing of many species between the areas. Age-specific effects of predators on herring are unknown for the VIaN herring stock, but likely to be similar to the North Sea; there is mixing of species and stocks, including the mixing of juvenile herring. Stocks are currently high and increasing for mackerel and although decreasing for horse mackerel, are still at relatively high levels compared to herring. Mackerel and horse mackerel are two of the main predators of herring at younger ages. Overall, there is potentially greater influence on M for VIaN herring from: mackerel, horse mackerel, hake, grey seals, some cetaceans, some seabird species, etc. Some seabirds known to prey on herring in the North Sea are in higher abundance to the west of Scotland. Impact is likely to be slightly greater than for the same species in the North Sea.

3.6.4.4.5 Using M from NS-SMS

The natural mortality which has been used in the VIaN assessment (Table 3.6.4.4 1) is based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 (ICES, 1987). These values for M were also applied to herring stocks in adjacent areas. From 2012 onwards the assessment of NSAS herring includes variable estimates of M-at-age derived directly from the NS-SMS model, used in WGSAM (Lewy and Vinther, 2004; ICES, 2011). Members of WKWEST decided that the best approach going forward with the available data would be to update the current vector to incorporate the average M per age over the time-series 1974–2013. This time-series reflects the most recent period of stability for M from the NS-SMS (excludes the gadoid outburst of the 1960s). This is similar to the previous M in that it is time invariant and age variant. The average M from the most recent multispecies model run (2014) is shown in Table 3.6.4.4 7.

Table 3.6.4.4.7: Average M (1974 – 2013) from the most recent NS-SMS (2014).

Age (winter rings)	1	2	3	4	5	6	7	8	9
M value	0.7063	0.3525	0.2800	0.2551	0.2399	0.2258	0.2169	0.2169	0.2169

WKWEST members agreed that there was substantial overlap of species between areas and that an updating of M from the 1987 multispecies model with current available data were warranted. As a result, the values of M in Table 3.6.4.7 were used in the final inputs to model runs.

3.6.5 Assessment Model

This is the first time a combined assessment has been carried out on herring in this area. Three assessment models were used to explore the combined assessment of herring in VIa, VIIb,c. These were a separable VPA without tuning, ICA and SAM which both include tuning indices. The separable VPA and ICA have been previously used to assess herring in VIaS, VIIb,c while ICA has been used to assess herring in VIaN.

Separable VPA

Separable VPAs (Darby and Flatman, 1994) were conducted using the data above, but excluding the tuning series. These assessments were done to investigate the catch-at-age data under a range of terminal F scenarios, ranging from optimistic to pessimistic. This follows the procedure used in recent years for the VIaS, VIIb,c stock, for which a tuning series was not available. Separable VPAs were conducted for terminal F_s of 0.2, 0.45 and 0.7. F=0.2 is a low target F, approximating to recent estimates of F_{MSY} for the constituent stocks. F=0.7 approximates a pessimistic scenario. The results of these runs are presented in Figure 3.6.5.1. Residual patterns are presented in Figure 3.6.5.2, and demonstrate age effects at youngest and oldest ages. Only the most optimistic scenario predicts SSB not to be at the lowest in the series. The most pessimistic scenario estimates F to be the highest in the series. Recruitment in the last year is not adjusted and is not considered to be well estimated (Figure 3.6.5.1.)

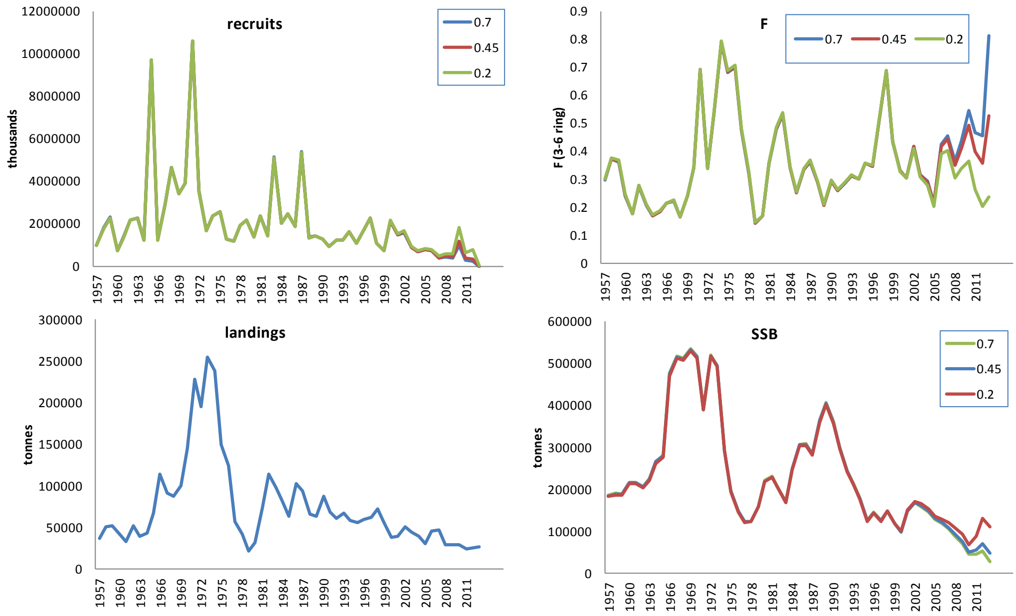
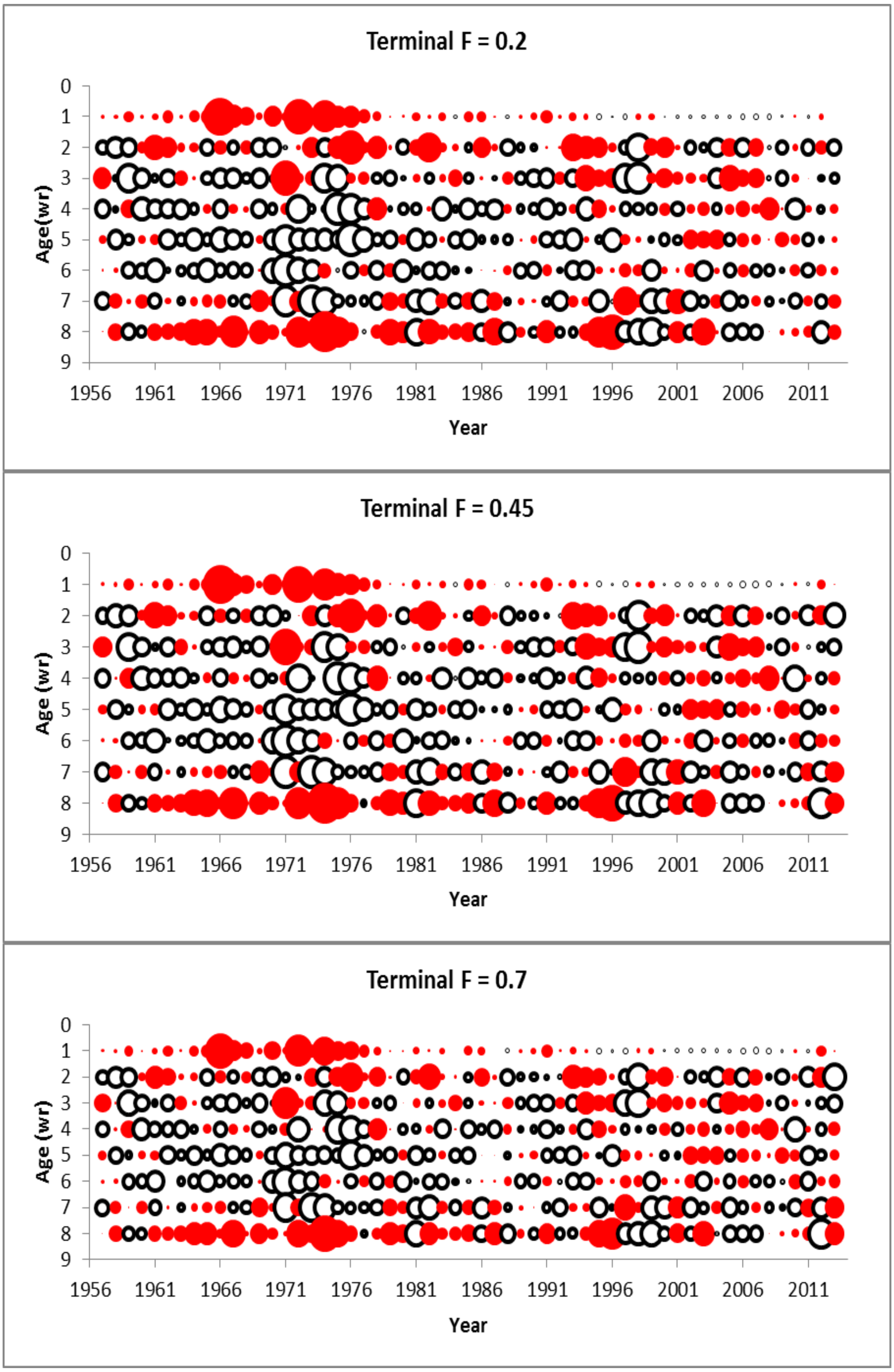


Figure 3.6.5.1. Herring in Divisions VIa, VIIb,c. Trajectories over time in SSB, F, recruitment and landings as outputs from the separable VPA runs.


Terminal F = 0.2
Age(wr)
Year
Terminal F = 0.45
Age (wr)
Year
Terminal F = 0.7
Age (wr)
Year
0
1
2
3
4
5
6
7
8
9
1956
1961
1966
1971
1976
1981
1986
1991
1996
2001
2006
2011

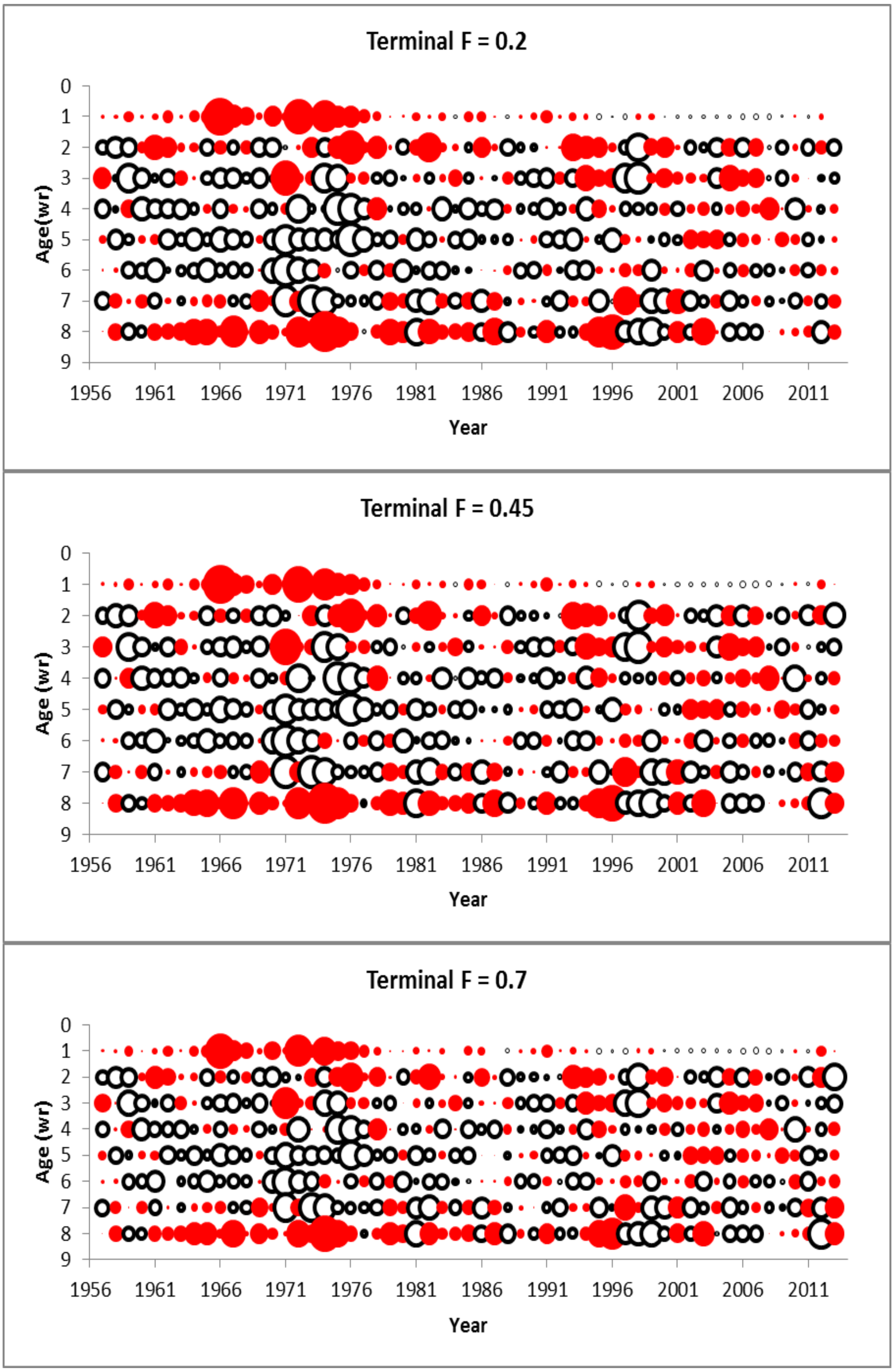


Figure 3.6.5.2. Herring in Divisions VIa, VIIb,c. Fishing mortality residuals in the separable model for the three scenarios (terminal F= 0.2, top, 0.45, middle and 0.7, bottom). Red indicates positive values, and white cell indicate negative values.

ICA

An ICA (Patterson, 1998b) base run was conducted using settings as per the SGHERWAY Malin assessment, tuned with the Malin Shelf acoustic survey 2008-2013. Model fit was good except for youngest ages in the acoustic survey. There is some degree of year effect in 2011 in the acoustic survey, but otherwise the residual pattern was quite balanced. However there were some large residuals at the 1-wr in the survey (Figure 3.6.5.3). The catch residuals are relatively free from bias also (Figure 3.6.5.4). The assessment offers a reasonably precise estimation of SSB but its estimation of F is weak (Figure 3.6.5). Retrospective bias is minimal in stock trajectories (Figure 3.6.5.6) or selection pattern (Figure 3.6.5.7).

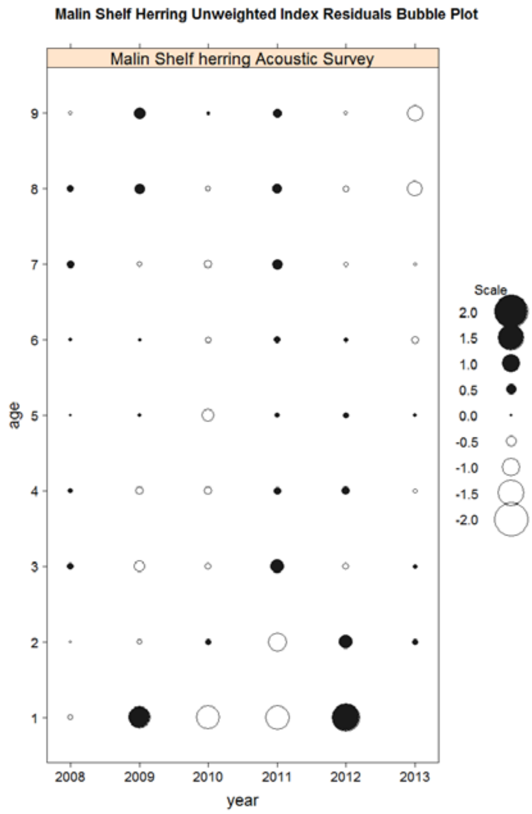


Figure 3.6.5.3. Herring in Divisions VIa, VIIb,c. Residuals about the fit to the Malin Shelf acoustic survey in the ICA base run.

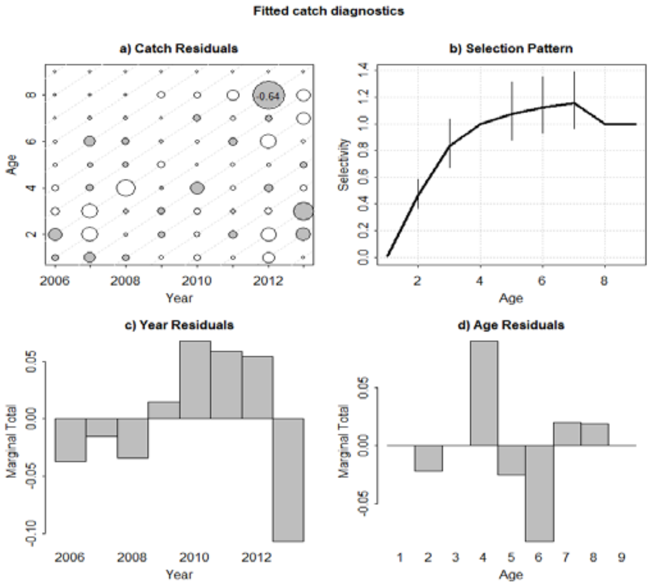


Figure 3.6.5.4. Herring in Divisions VIa, VIIb,c. Catch residuals by age and year and fitted selection pattern from the ICA base run.

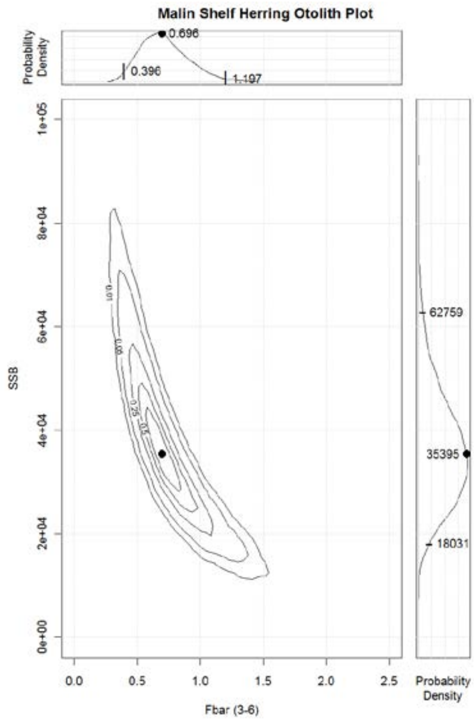


Figure 3.6.5.5. Herring in Divisions VIa, VIIb,c. Precision in estimation of SSB and F from the ICA base run.

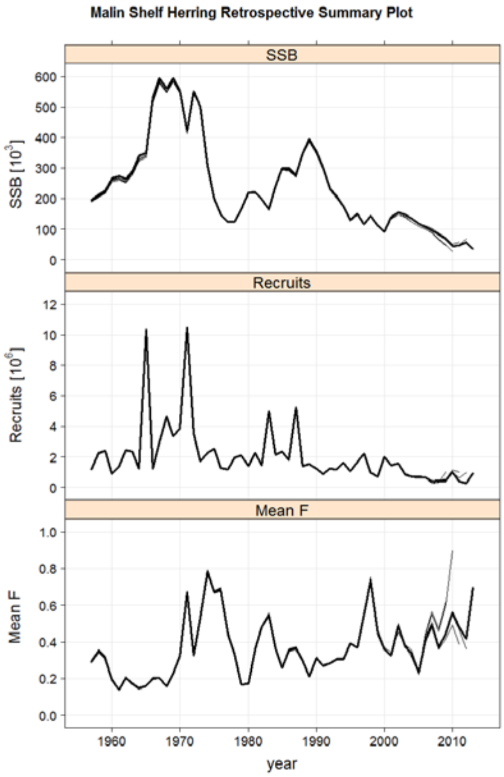


Figure 3.6.5.6. Herring in Divisions VIa, VIIb,c. Retrospective pattern in stock trajectories from the ICA base run.

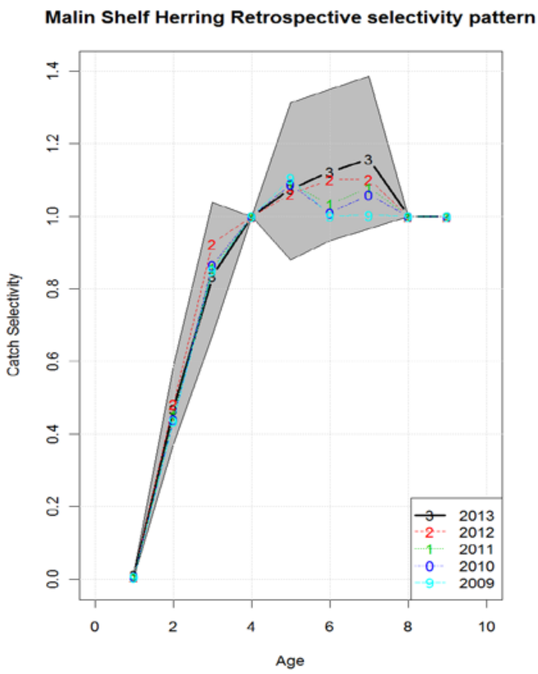


Figure 3.6.5.7. Herring in Divisions VIa, VIIb,c. Retrospective pattern in selection from the ICA base run.

SAM

SAM is a state–space stock assessment model (Nielsen, 2009; Nielsen and Berg, 2013) that is currently used to assess several fish stocks including many herring stocks such as North Sea, Irish Sea (VIIaN) and Western Baltic Spring-spawning herring. The SAM model uses the standard exponential decay equations to carry forward the N's (with appropriate treatment of the plus-group), and the Baranov catch equation to calculate catch-at-age based on the F's (ICES WKPELA, 2013). The exploration of the SAM model for the assessment of herring in VIa, VIIbc was appropriate given many of the issues with the ICA model highlighted in previous pelagic benchmark meetings (ICES WKPELA, 2012; 2013; 2014).

A multistep approach has been taken to obtain an appropriate model configuration that both encapsulates existing scientific knowledge and describes the available data were as follows:

1) Data Selection; a basic approach taken to set up SAM using the same data as the ICA assessment as a starting point;
2) Model refinement; Finding the optimum settings with the data available;
3) Data refinement; exploring the use of new natural mortality values and different tuning indices;
4) Final sensitivity analysis; to find the final settings and agree a final model configuration.

Optimum fitting was considered, where appropriate, taking into account AIC, negative log likelihood and variance/covariance matrices. When optimum fitting was obtained, changes to input data such as M, survey age range, and plus groups were examined. The objective of refining the model was to reduce the effective number of free parameters in the model by binding selected parameters together. This refinement uses one fitted parameter to represent more than one variable in the model i.e. binding ages together. The reduction in the number of parameters can lead to a poorer quality fit but it has the benefit of producing a simpler model that is quicker to run and easier to interpret (ICES WKPELA, 2012). The Akaike Information Criteria or AIC value is used to assess the model performance with a lower value indicating an improved fit. In the following text, binding is represented in the following notation:

1,2,2,2,2,3

which means that the first age is free, the next set of ages (2,3,4,5) are bound and the last age (6) is also free. Screening over a range of options was performed, in order to obtain an optimum range of settings. This screening was performed in FLSAM.

Base Run settings

The base run using SAM was configured using combined data (1957–2013) from VIaN and VIaS, VIIb,c tuned with the Malin Shelf herring acoustic survey (2008–2013). The natural mortality used was from the 1987 North Sea MSVPA. Similar to other SAM-based herring stock assessments all fishing mortality states are free except the oldest ages to ensure stability. It was assumed that the random walks for fishing mortality were correlated. In the base run the survey catchability parameters were bound in three blocks ages 1:2 3:7 and 8:9 bound. Variance in fishing mortality random walk by age from FLICA is calculated over the whole time-series using the *var* function and in R. The results showed differing variance for age 1-wr compared to the other ages. The variance for age 1-wr was left unbounded and the variances for all other ages were bound to improve stability. As a starting point the observation variance on the catch data at age 1-wr was left free, 2:4, 5:7 and 8:9 were bound. The observation variances on the survey ages 1:9 were all bound. The settings are presented in Table 3.6.5.1.

Table 3.6.5.1. Herring in Divisions VIa, VIIb,c. Settings for SAM base case run.

SAM Settings	Combination
Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
Correlated random walks for F	correlated (TRUE)
Coupling of catchability parameters	1,1,2,2,2,2,2,3,3
Variances in F random walk	1,2,2,2,2,2,2,2,2
Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
Coupling of observation variances - Catch	1,2,2,2,3,3,3,4,4
Coupling of observation variances - Survey	5,5,5,5,5,5,5,5,5

The base run (run 1) was not substantially improved upon by additional work. The AIC was reduced by binding survey observation variances for ages greater than 2 (run 8) or 6 (run 9). However the retrospective pattern worsened considerably. Binding the catchability parameters did not improve the AIC (runs 3-5). Changing the catch observation variance bindings into 4 blocks (run 6) did not improve the model fit, whereas using a single block (run 7) did not improve diagnostics.

Some diagnostics from the base run are presented in Figures 3.6.5.8-3.6.5.11. In general the residual pattern of the survey fitting was well balanced with little evidence of year effects (Figure 3.6.5.8). This indicates that the SAM model can fit to the available tuning. The base run was characterized by poor survey fit at 7-winter ring only. All of the runs gave a very similar stock perception with high F and low SSB at the end of the series. Additional runs were carried out to test the settings and find the optimum configuration (Table 3.6.5.2).

Table 3.6.5.2 Herring in Divisions VIa, VIIb,c. Details of the SAM runs conducted.

Run	Parameter	Details	AIC	SSB	F	nLL
1	See Table 3.6.5.1		824.57	37 235	0.59	399.783
2	Catch observation variance Catchability	1,2,2,2,2,2,3,3,3 1,1,2,2,2,2,2,2,2	851.21	40 336	0.55	414.607
3	Catchability	1,1,2,2,2,3,3,3,3	826.06	38 600	0.58	400.03
4	Catchability	1,1,1,2,2,2,2,2,2	845.46	41 689	0.54	410.732
5	Catchability	1,1,2,2,2,3,3,3,3	826.06	38 600	0.59	400.03
6	Catch observation variance	1,2,2,3,3,3,4,4,4	827.25	39 300	0.61	400.627
7	Catch observation variance	1,1,1,1,1,1,1,1,1	931.91	39 300	0.61	455.957
8	Survey Observation variance	1,2,2,2,3,3,3,3,3	808.62	29 378	0.73	389.311
9	Survey Observation variance	1,2,2,2,2,3,3,3,3	808.97	31 008	0.69	389.484
10	6aN tuning index	Base run settings	1249.33	93 995	0.25	610.665
11	Survey ages 3-6	Obs var catch 1,1,1,1,1,1,1,1,1 Obs var survey 2,2,2,2,2,2,2,2,2	851.92	48 679	0.42	415.958
12	Time invariant M, as per Celtic Sea	Run using stock assessment.org		75 735	0.30	401.52
13	Time variant North Sea figures		822.53	46 212	0.48	398.267
14	Survey ages	2-9 only	787.21	30 638	0.70	380.606

The initial exploratory work conducted suggests that SAM is a stable and appropriate platform for assessing the combined stocks. The base case formulation was not improved upon by subsequent runs where settings were adjusted. In all of the initial runs where a single tuning series was used the catchability of the Malin Shelf acoustic survey estimated by SAM was high (Figure 3.6.5.11). Further runs were conducted by changing the input data.

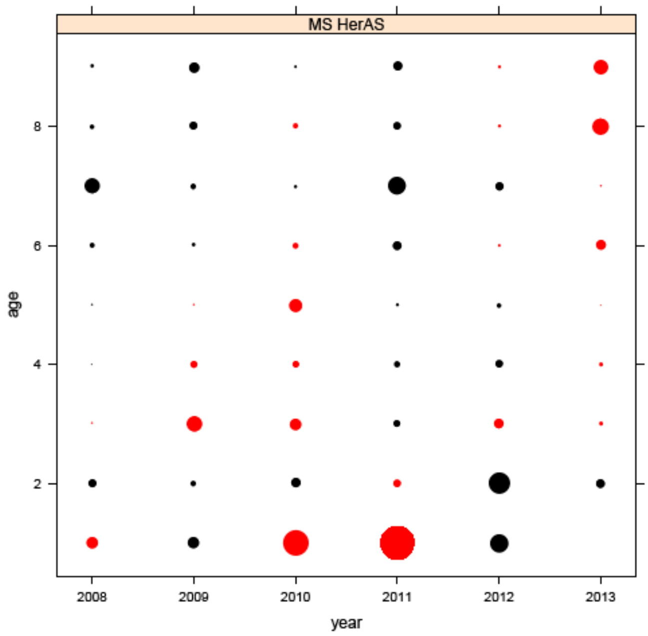


Figure 3.6.5.8. Herring in Divisions VIa, VIIb,c. Residuals about the model fit to the Malin Shelf Acoustic Survey, from SAM base case run

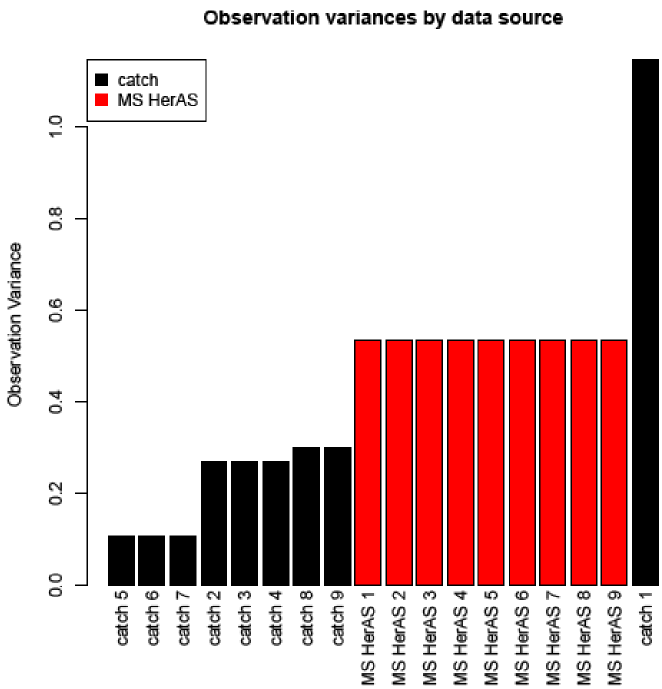


Figure 3.6.5.9. Herring in Divisions VIa, VIIb,c. Observation variances by source, from SAM base case run.

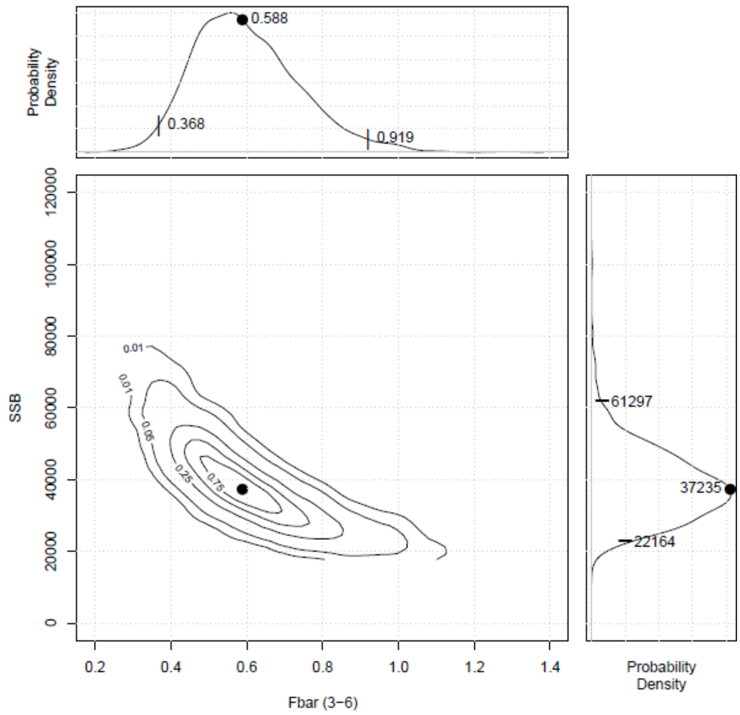


Figure 3.6.5.10. Herring in Divisions VIa, VIIb,c. Uncertainty in estimation of SSB and F, from SAM base case run.

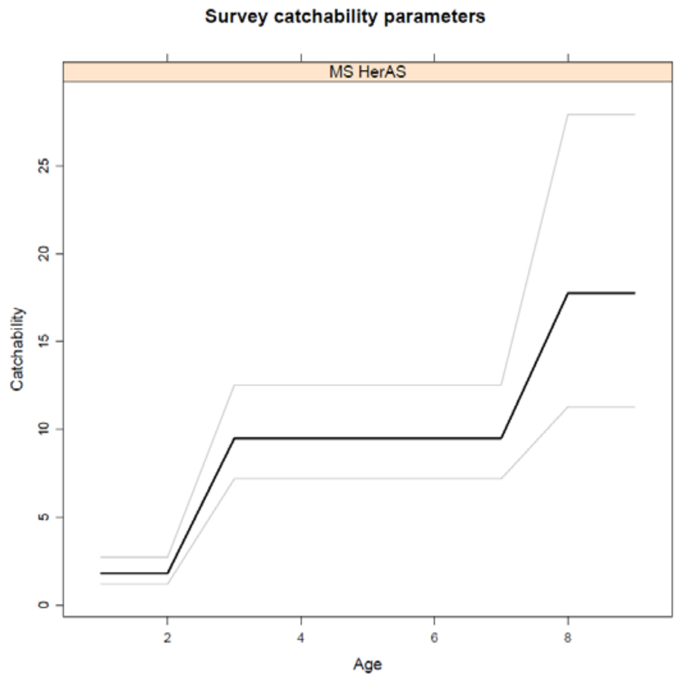


Figure3.5.11. Herring in Divisions VIa, VIIb,c. Malin Shelf acoustic survey catchability, from SAM base case run.

Changing natural mortality

The natural mortality which has been used in the separate VIaN and VIaS, VIIb,c assessments is based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 and were applied to herring stocks in adjacent areas (Anon., 1987). Natural mortality was fixed by age, were used in the assessment in subsequent years, and assumed to be as follows:

Winter rings	My-1 %
1	1
2	0.3
3	0.2
4	0.1
5	0.1
6	0.1
7	0.1
8	0.1
9	0.1

Based on O'Malley *et al.*, (2015), it was decided that there was a basis to change the natural mortality using the most recent North Sea Multispecies assessment which uses data from 1974-2013. An average was calculated over this time-series and applied to the combined assessment. The new natural mortalities are given in the text table below.

Winter rings	My-1 %
1	0.71
2	0.35
3	0.28
4	0.26
5	0.24
6	0.23
7	0.22
8	0.22
9	0.22

Survey Data Included

The Malin shelf acoustic survey is not the only survey that was available for tuning this combined assessment of herring in VIa, VIIb,c. The use of the Scottish IBTS data as an additional tuning index was examined. The Q1 IBTS runs from 1986–2010 and the Q4 survey time-series runs 1996–2009. See section 3.6.2.2 for more detail. The West of Scotland acoustic survey which was conducted from 1991–2007 was also used as it covers this geographic area and has a longer time-series than the Malin shelf survey. Different survey combinations were tested and a sensitivity analysis was carries out.

Final Model Run

The optimal model formulation was achieved when all four tuning indices were used (Table 3.6.5.3). The updated natural mortality values were used. The final settings are detailed in Table 3.6.5.4 below.

Table 3.6.5.3 Herring in Divisions VIa, VIIb,c. Survey Indices used in the final run.

Final Run tuning series	Age (wr) range
Malin Shelf acoustic survey	1-9
West Of Scotland Acoustic Survey	1-9
IBTS Q1	2-9
IBTS Q4	2-9

Table 3.6.5.4 Herring in Divisions VIa, VIIb,c. Final Model Settings

Final Run SAM Settings	Combination
Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
Correlated random walks for F	correlated (TRUE)
Coupling of catchability parameters MS HERAS	1,2,3,3,3,3,3,3,3
Coupling of catchability parameters WoS HERAS	4,5,6,6,6,6,6,6,6
Coupling of catchability parameters IBTS Q1	7,7,7,7,7,7,7,7,7
Coupling of catchability parameters IBTS Q4	8,8,8,8,8,8,8,8,8
Variances in F random walk	1,2,2,2,2,2,2,2,2
Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
Coupling of observation variances - Catch	1,2,2,2,2,2,2,3,3
Coupling of observation variances - MS HERAS	4,5,5,5,5,5,5,5,5
Coupling of observation variances - WoS HERAS	6,7,7,7,7,7,7,7,7
Coupling of observation variances - IBTS Q1	8,9,9,9,9,9,9,9,9
Coupling of observation variances - IBTS Q4	10,11,11,11,11,11,11,11,11

Final Model Diagnostics

The survey residuals from each of the tuning series used are presented in Figure 3.6.5.12. There is no clear pattern in the Malin Shelf acoustic survey or the west of Scotland acoustic survey residuals. The IBTS survey in Q1 shows year effects in 1986, 1998 and 2004. The Q4 IBTS survey has clear year effects in 2000, 2001, 2002, 2004 and 2005.

Catch residuals are shown in Figure 3.6.5.13 and are well balanced and do not show any clear pattern. There are no age effects or year effects present.

The catchability at age for both acoustic surveys is presented in Figure 3.6.5.14. The trend in both surveys is the same with constant catchability estimated from age 3–9. The catchability values are less than 1.7 which is a significant improvement on previous runs where very high catchability values were estimated.

The observation variance by data source is presented in Figure 3.6.5.15. The final assessment model is dominated by information from the catch, the Malin Shelf acoustic survey and the West of Scotland acoustic survey which the SAM model perceives as being more precise than the IBTS surveys. Age 1-wr from both acoustic survey are seen as less precise that the remaining survey ages from 2+ wr. The catch-at-age 1-wr and the IBTS data from Q1 and Q4 are also considered less precise than the older ages in both the catch and surveys.

Figure 3.6.5.16 shows the fishery selectivity by period with a clear shift in the mid-1990s evident. Selection changes from being flat topped at the oldest 2 ages to becoming dome shaped in the late 2000's. This represents a change in exploitation towards younger fish. This is also evident in the separate VIaS, VIIb,c exploratory assessment.

The correlation matrix from the final run is presented in 3.5.17. There are some strong correlations between the fitted parameters in particular the catchability parameters between ages 1-8-wr ("LogFpar") in the survey. A strong positive correlation can also be seen between the fishing mortality random walks ("logSdLogFsta").

Figure 3.6.5.18 shows the trajectories for SSB, recruitment and mean F over the complete time-series from 1953–2013. SSB peaked in the late 1960's and has fluctuated at a lower level since then. The estimate for SSB in the terminal year is around 250 000 t. Recruitment also peaked in the early portion of the time-series with no strong year classes evident in recent years. Fishing mortality was at its highest in the early 1970's. Since the late 1990's F has been below 0.2.

The analytical retrospective for this stock (Figure 3.6.5.19) shows some deviations in SSB and recruitment between years with no clear retrospective pattern emerging. The estimates of F are more consistent between years.

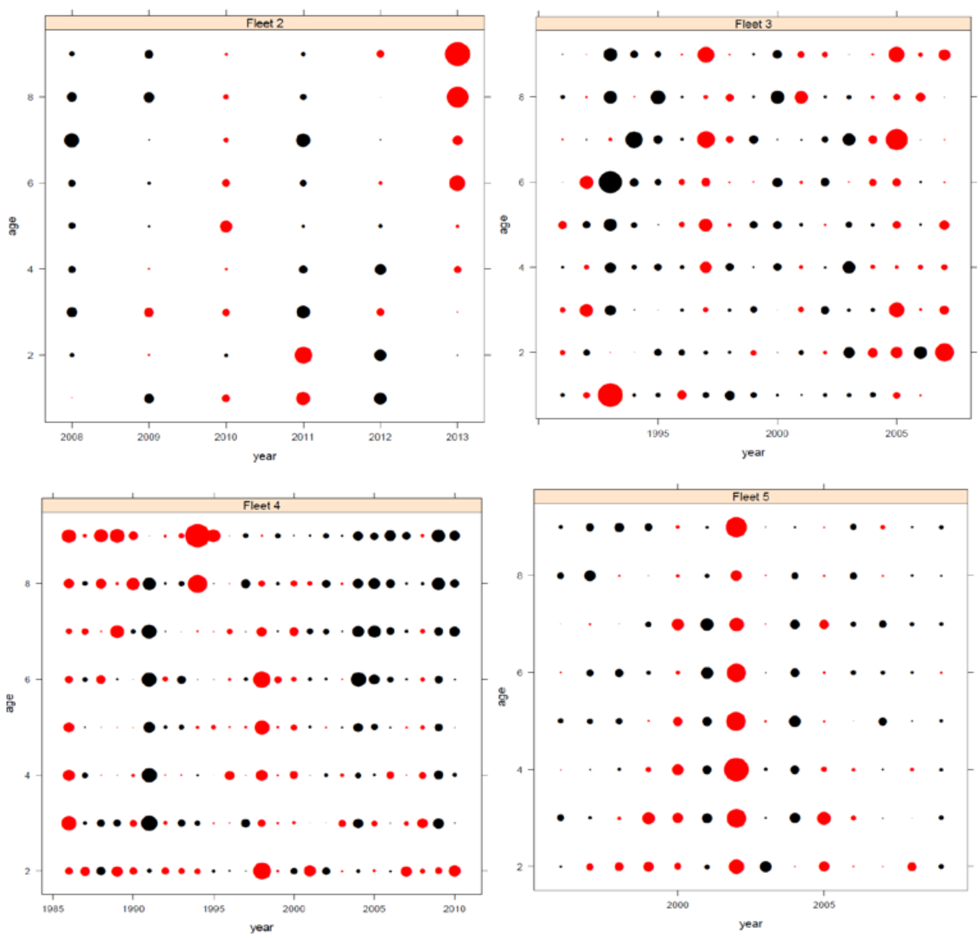


Figure 3.6.5.12: Herring in Divisions VIa, VIIb,c. Survey residuals by fleet. Fleet 2 (top left) Malin Shelf acoustic survey, Fleet 3 (top right) West of Scotland acoustic survey, Fleet 4 (bottom left) IBTS Q1 and Fleet 5(bottom right) IBTS Q4.

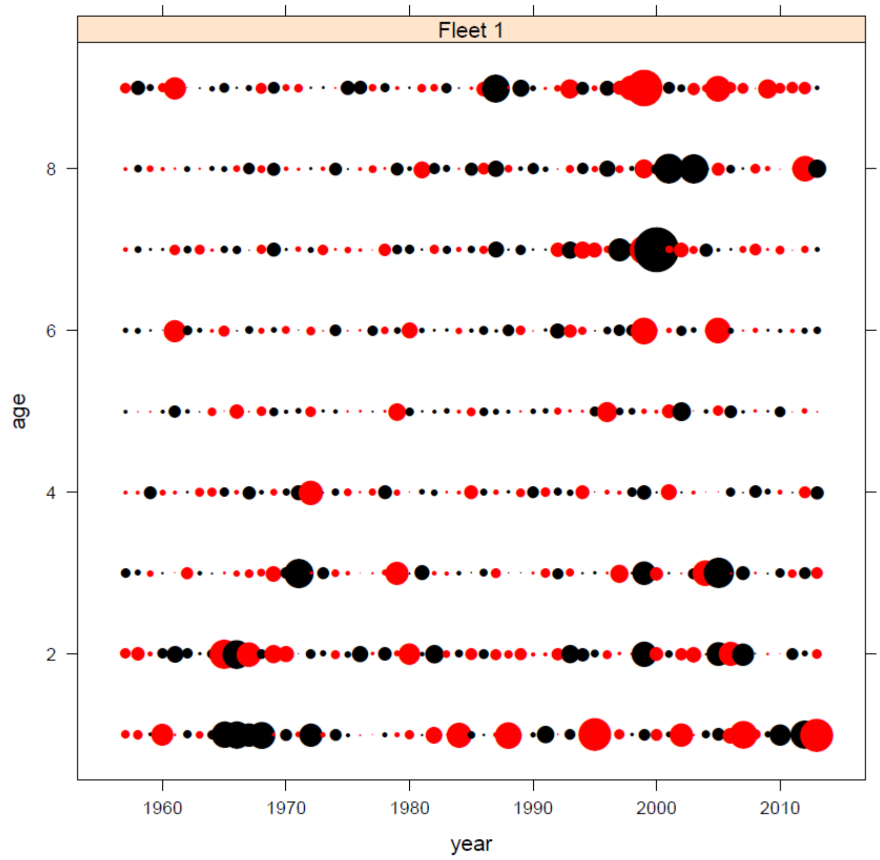
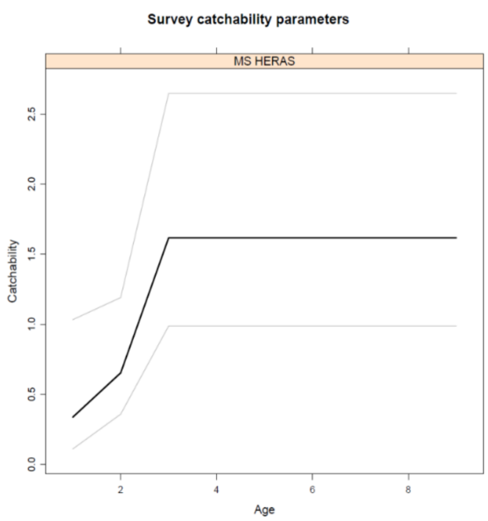


Figure 3.6.5.13: Herring in Divisions VIa, VIIb,c. Catch residuals by year.



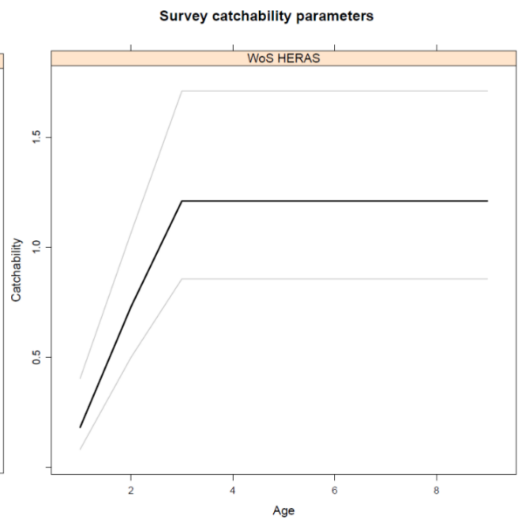


Figure 3.6.5.14: Herring in Divisions VIa, VIIb,c. Survey catchability parameters. Malin Shelf acoustic survey (left), West of Scotland acoustic survey.

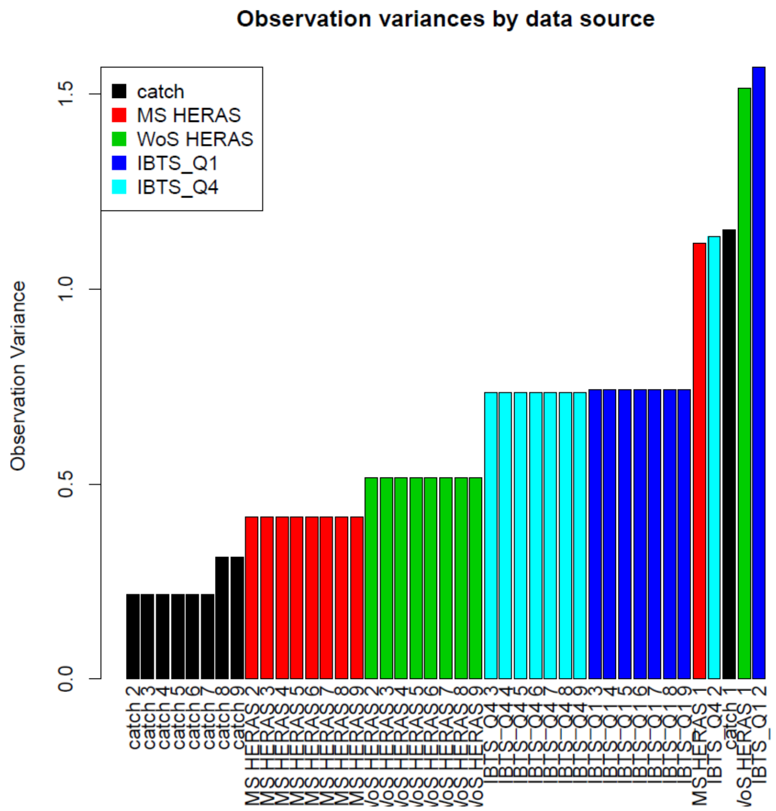


Figure 3.6.5.15: Herring in Divisions VIa, VIIb,c. Observation variance by data source.

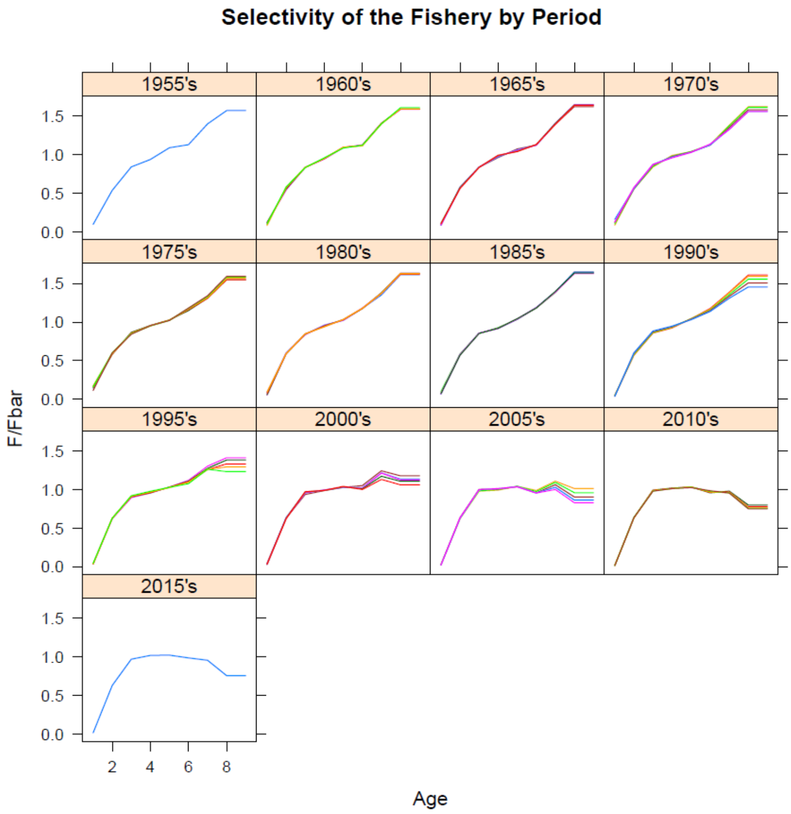


Figure 3.6.5.16: Herring in Divisions VIa, VIIb,c. Selectivity of the fishery by period.

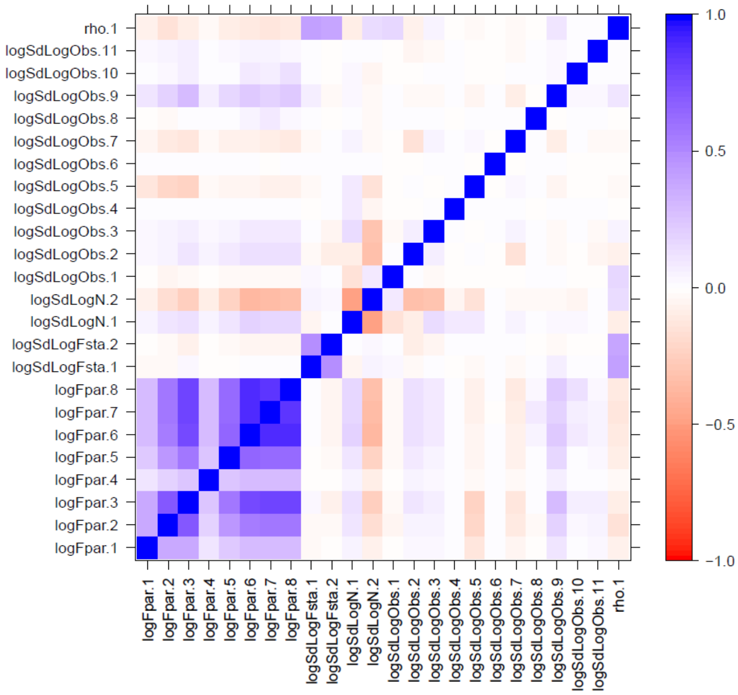


Figure 3.6.5.17: Herring in Divisions VIa, VIIb,c. Correlation matrix for the final FLSAM run. The horizontal and vertical axes show the parameters fitted by the model (labelled with names stored and fitted by FLSAM). The colouring of each pixel indicates the Pearson correlation between the two parameters.

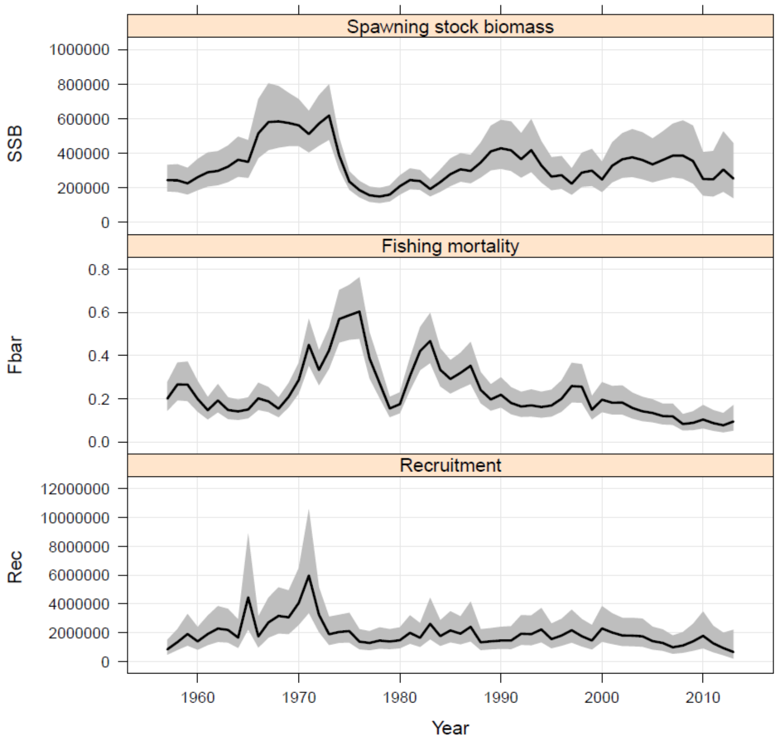


Figure 3.6.5.18: Herring in Divisions VIa, VIIb,c. Stock summary plot from the final FLSAM run

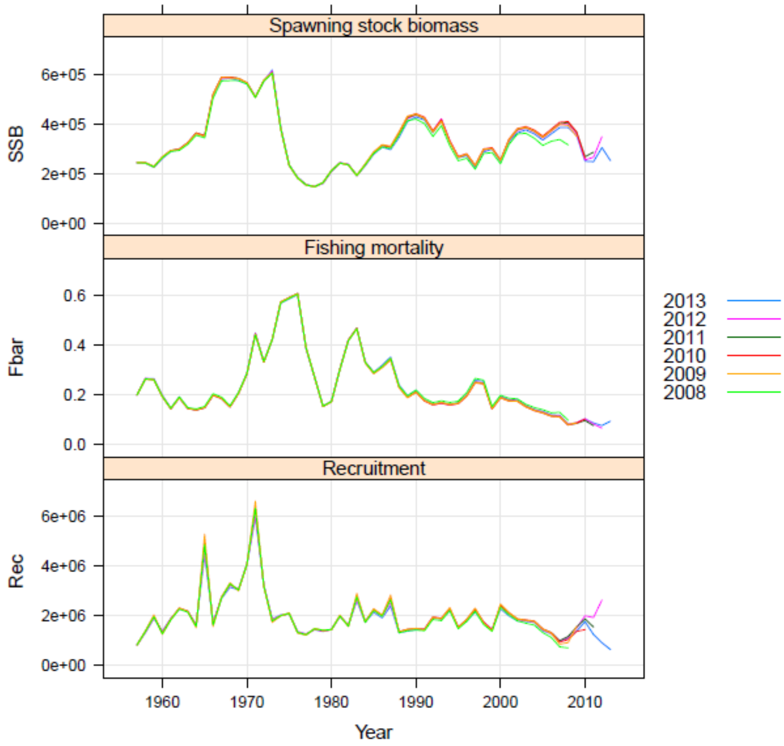


Figure 3.6.5.19: Herring in Divisions VIa, VIIb,c. Retrospective plot from the final FLSAM run

3.7 Short-term projections

Explorations of separate VIaN and VIaS, VIIb,c assessments were developed in an attempt to provide a possible splitting procedure for each management unit from the combined VIa,VIIb,c assessment. However, WKWEST concludes that exploratory analyses of separate divisions are too uncertain to offer management advice, because they are potentially misleading. The recommendation from WKWEST on spatial splitting procedure is that alternative splitting procedures should also be considered by HAWG, advice drafting groups, ACOM and managers. The exploratory assessments are documented here to justify the recommendation.

3.7.1 Short-term forecast for VIa, VIIb,c

A deterministic short-term forecast is required to provide catch options for the year ahead. No attempt is made by WKWEST to allocate these options to the individual management areas. Operating procedures for such forecasts may change over time, to respond to changing management or fisheries related matters. However, WKWEST provides some guidance on how a forecast should be conducted.

If a catch constraint is used in the intermediate year, the catches need to be predicted accurately. This is complicated by the fact that there has been full uptake of the TAC in the management area, VIaS, VIIb,c while that in VIaN management area has not. For this reason, the VIaN forecast has used an F constraint since 2010. The most precautionary approach would be to assume full uptake of TACs in both management areas. Using an F constraint in the forecast could mask important disparities in F on the constituent stocks.

The ICES generic harvest control rule will be the most important catch option. If SSB in the year for which the TAC is to be set is below MSY $B_{trigger}$, then the target F shall be decreased by the stock size in that year relative to the trigger. Because this stock complex is treated as an autumn spawner, SSB is calculated at spawning time (1 October). For such autumn spawning stocks, the SSB for TAC decision is the SSB in the intermediate year, because this is the SSB analogous to SSB at 1 January in the TAC year for spring-spawning stocks. This is based on a decision made at ADGCeltic in 2014.

WKWEST considered means to split the catch advice for the constituent stocks. However, no basis could be found on which to do so, especially given that individual assessments were unobtainable. Consequently WKWEST does not propose providing catch advice for either VIaN or VIaS, VIIb,c based on the combined assessment and forecast.

3.7.2 Exploratory Assessment of the VIaN herring (*Clupea harengus* L.) stock using FLSAM

Introduction

The herring stock in VIaN (Figure 3.7.2.1) has been assessed using ICA (Integrated Catch-at-age Analysis) for many years. There are well documented problems associated with the continued use of ICA into the future (ICES WKPELA, 2012), therefore it is appropriate to explore other model options during this benchmark. We consider the State-space Assessment Model (SAM), implemented through the FLR library (Kell *et al.*, 2007). The SAM model is configured to permit a maximum degree of flexibility and it can also estimate a larger number of parameters. This extra flexibility allows a comparison of parameters with *a-priori* information based on independent analyses of the individual data sources that contribute to the assessment.

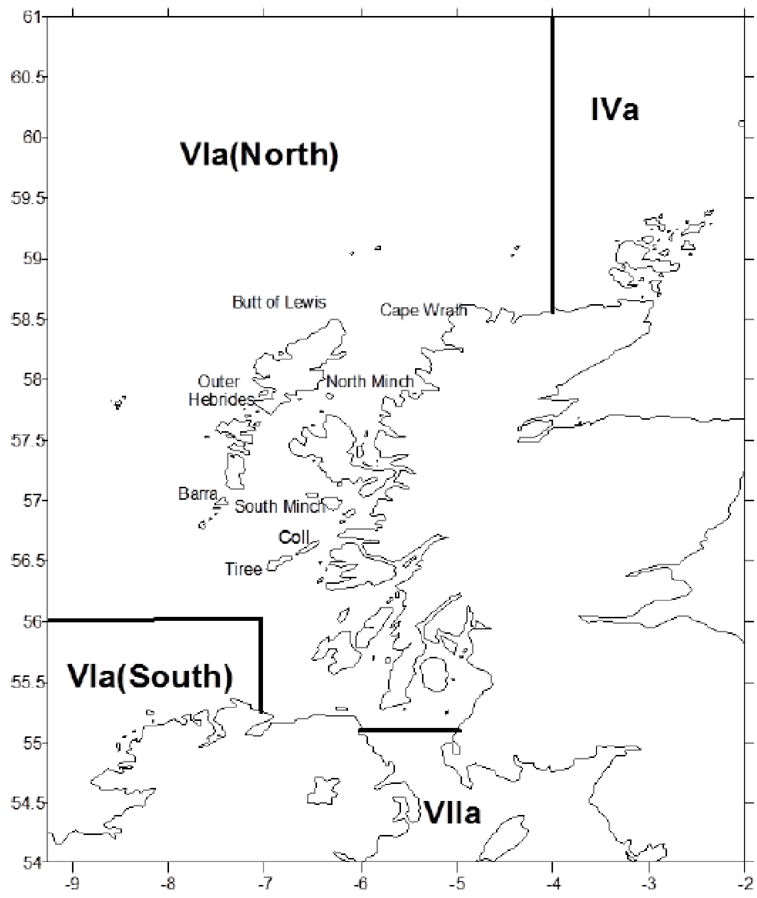


Figure 3.7.2.1: ICES Division VIaN and adjacent areas.

Herring in VIaN – FLSAM final run parameter settings

The final run parameter settings for FLSAM were decided on from the best runs from the combined VIa, VIIb, c assessment (Section 3.6.5). For comparison, an exploratory assessment of VIaN was run with the same settings (FLSAM final VIaN). The Stock Object Configuration for FLSAM final VIaN is shown in Table 3.7.2.1. Configuration settings for the FLSAM final VIaN are shown in Table 3.7.2.2. All fishing mortality states are free except 8- and 9-wr. It was assumed that all random walks for fishing mortality were correlated. The survey catchabilities were bound for 3+ wr with 1- and 2-wr independent. The F random walk variance for 1-wr was left unbound and the variances for all other ages were bound. The variances were separated for recruitment and plus group. The observation variance on the catch data was unbounded for 1-wr, with 2-7 and 8-9+wr bound. The observation variances in the surveys were left unbounded for 1-wr and bound for all other ages. The natural mortality (M) used is an average M from the North Sea multispecies model (NS-SMS) per age over the time-series 1974–2013 (see section 3.6.4.4). This time-series reflects the most recent period of stability for M from the NS-SMS (excludes the gadoid outburst of the 1960s). The decision on updating M was deliberated at the benchmark meeting after considering data outlined in the VIaN natural mortality WD. The updated M vector is an updated time invariant and age variant M from the previous M that was based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 (Anon., 1987). The average M from the most recent multispecies model run (2014) is shown in Table 3.7.2.3.

Table 3.7.2.1: Herring in VIaN. FLSAM final stock object configuration

min	max	plus group	min year	max year	min fbar	max fbar
1	9	9	1957	2013	3	6

Table 3.7.2.2: Herring in VIaN. FLSAM final settings

FLSAM parameters	FLSAM base settings
Coupling of fishing mortality states - catch	1,2,3,4,5,6,7,8,8
Correlated random walks for F	Correlated (TRUE)
Coupling of catchability parameters – WoS HERAS	1,2,3,3,3,3,3,3,3
Coupling of catchability parameters – Malin Shelf HERAS	4,5,6,6,6,6,6,6,6
Coupling of catchability parameters – Q1	NA,7,7,7,7,7,7,7,7
Coupling of catchability parameters – Q4	NA,8,8,8,8,8,8,8,8
Variances in F random walk - catch	1,2,2,2,2,2,2,2,2
Coupling of logN RW variances	1,2,2,2,2,2,2,2,2
Coupling of observation variances - catch	1,2,2,2,2,2,2,3,3
Coupling of observation variances - WoS HERAS	4,5,5,5,5,5,5,5,5
Coupling of observation variances – Malin Shelf	6,7,7,7,7,7,7,7,7
Coupling of observation variances – Q1	NA,8,9,9,9,9,9,9,9
Coupling of observation variances – Q4	NA,10,11,11,11,11,11,11,11

Table 3.7.2.3: Herring in VIaN. Average M (1974 – 2013) from the most recent NS-SMS (2014).

Age (rings)	1	2	3	4	5	6	7	8	9
M value	0.7063	0.3525	0.2800	0.2551	0.2399	0.2258	0.2169	0.2169	0.2169

Herring in VIaN – FLSAM 'exploratory' assessment

For an exploratory assessment of the VIaN herring stock using the final settings from the combined VIa, VIIb, c assessment and the updated M (Tables 3.7.2.1, 3.7.2.2 and 3.7.2.3), 4 runs were undertaken. The input data are updated from HAWG 2014, as outlined in the VIaN catch revision WD (see section 3.6.4.1). Two iterations of the herring acoustic surveys (HERAS) were used; the geographical VIaN survey (1991–2013) and a split-area survey (geographical VIaN HERAS 1991–2007 and the Malin Shelf HERAS from 2008–2013). In addition 2 iterations of the Scottish West Coast International Bottom Trawl Survey (SWC-IBTS) were used; quarter 1, 1986–2010 (Q1) and quarter 4, 1996–2009 (Q4). The FLSAM final VIaN runs were as follows:

1) FLSAM final with VIaN and Malin Shelf acoustic assessment;
2) FLSAM final with geographical VIaN acoustic assessment;
3) FLSAM final with VIaN and Malin Shelf acoustic assessment and Q1 SWC- IBTS;
4) FLSAM final with VIaN and Malin Shelf acoustic assessment and Q1 plus Q4 SWC- IBTS.

Herring in VIaN – catch and survey observation variances

Figure 3.7.2.2 shows the observation variances per data source (catches and surveys) for FLSAM final with VIaN and Malin Shelf acoustic assessment, and Q1 plus Q4 SWC- IBTS. It is clear that both the acoustic surveys and the catches are well fitted inside the FLSAM final model, apart from 1-wr fish. The observation variances in the catch for 2–7-wr are relatively low (0.25). For 8–9-wr in the catch the observation variance is higher, but still relatively low (0.5 approximately). The observation variance for 1-wr fish in the catch is high, as expected (1.4). The observation variance in the HERAS for 1-wr fish is very high at 1.5 approximately, but relatively low for 2–9-wr at 0.5. The SWC-IBTS Q1 and Q4 observation variances for 3- to 9-wr are slightly higher than the acoustic surveys at 0.7, but compare well with each other. The 2-wr for the SWC-IBTS Q1 and Q4 are high as expected at 1.6 and 1.1 respectively. The 1-wr from the SWC-IBTS are excluded from the FLSAM final assessment run. These results indicate that the couplings are broadly fitting well for the purposes of the final run, FLSAM final VIaN.

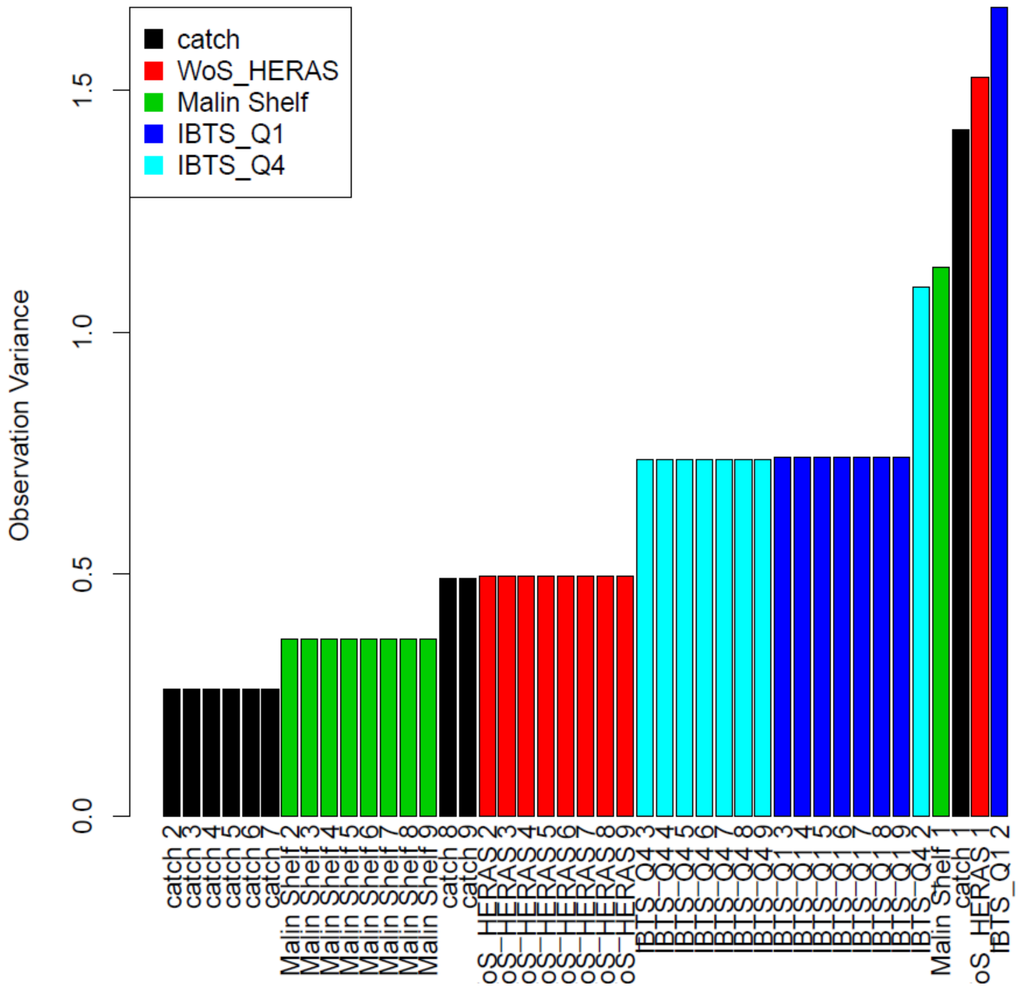


Figure 3.7.2.2: Herring in VIaN. Observation variances by data source from FLSAM final with VIaN and Malin Shelf acoustic assessment, and Q1 plus Q4 SWC- IBTS.

Herring in VIaN – survey residuals

The residuals by age for all the surveys from the FLSAM final VIaN run are shown in Figures 3.7.2.3 to 3.7.2.7. The residuals for the acoustic surveys show no distinct pattern in 2–9-wr (Figures 3.7.2.3, 3.7.2.4 and 3.7.2.5. For the acoustic surveys, age 1-wr residuals are the noisiest, as expected. The SWC-IBTS-Q1 survey has some yearly residual patterns that are of concern, particularly in 1986 and 1998 (Figure 3.7.2.6). There also appears to be some positive residual age effects in older ages in recent years in SWC IBTS-Q1. The SWC IBTS-Q4 survey has some negative year patterns in the residuals, particularly 2002 and 2005 (Figure 3.7.2.7).

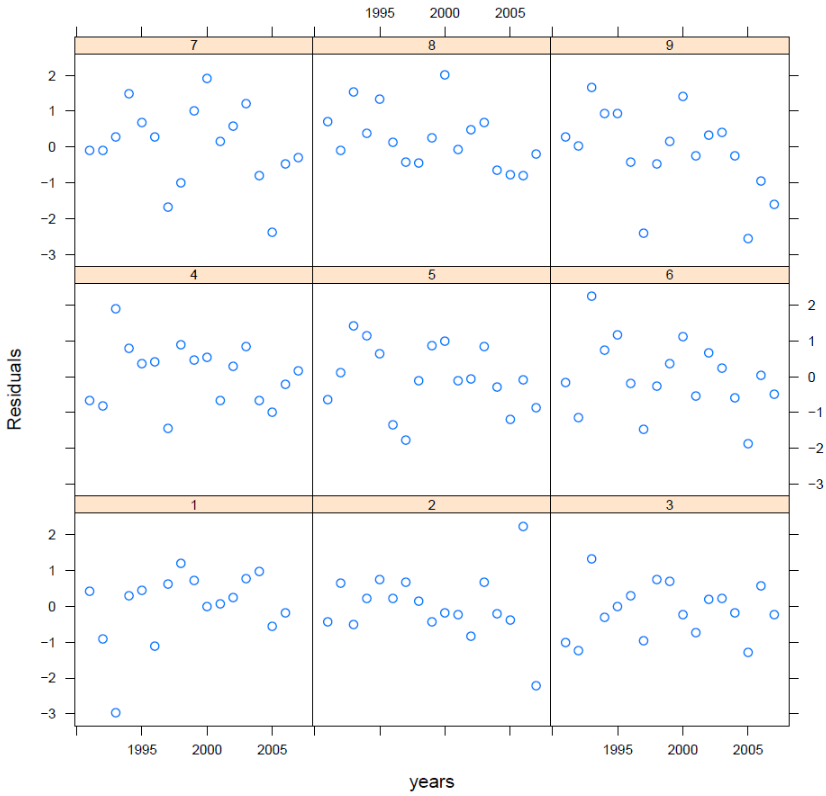


Figure 3.7.2.3: Herring in VIaN. Residuals by age of HERAS 1991–2007

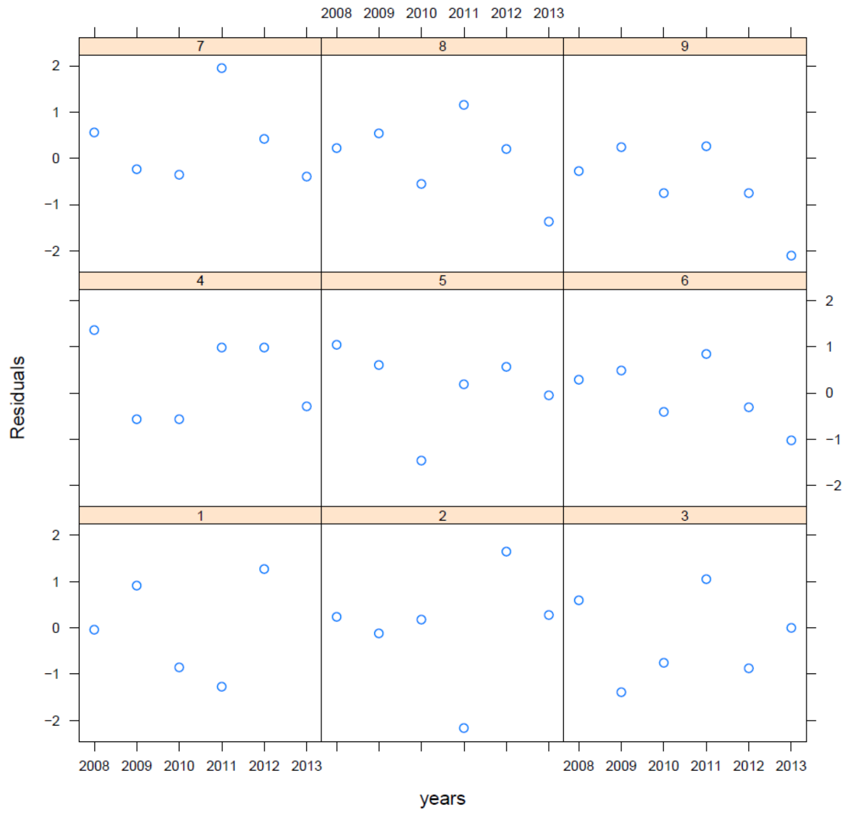


Figure 3.7.2.4: Herring in VIaN. Residuals by age of the Malin Shelf acoustic survey 2008–2013

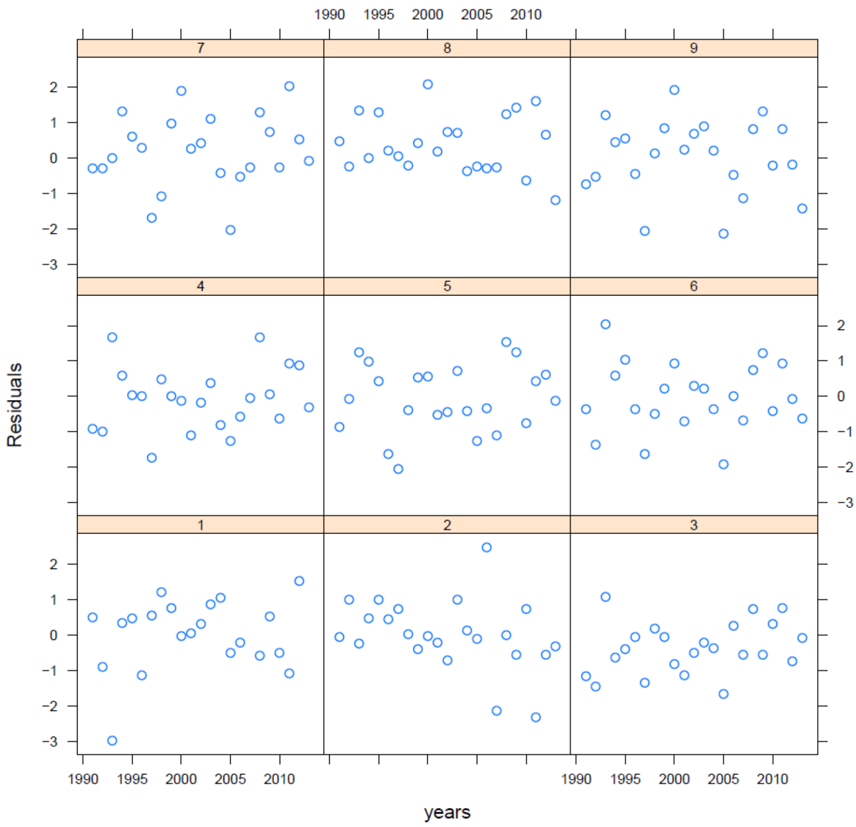


Figure 3.7.2.5: Herring in VIaN. Residuals by age of HERAS 1991–2013

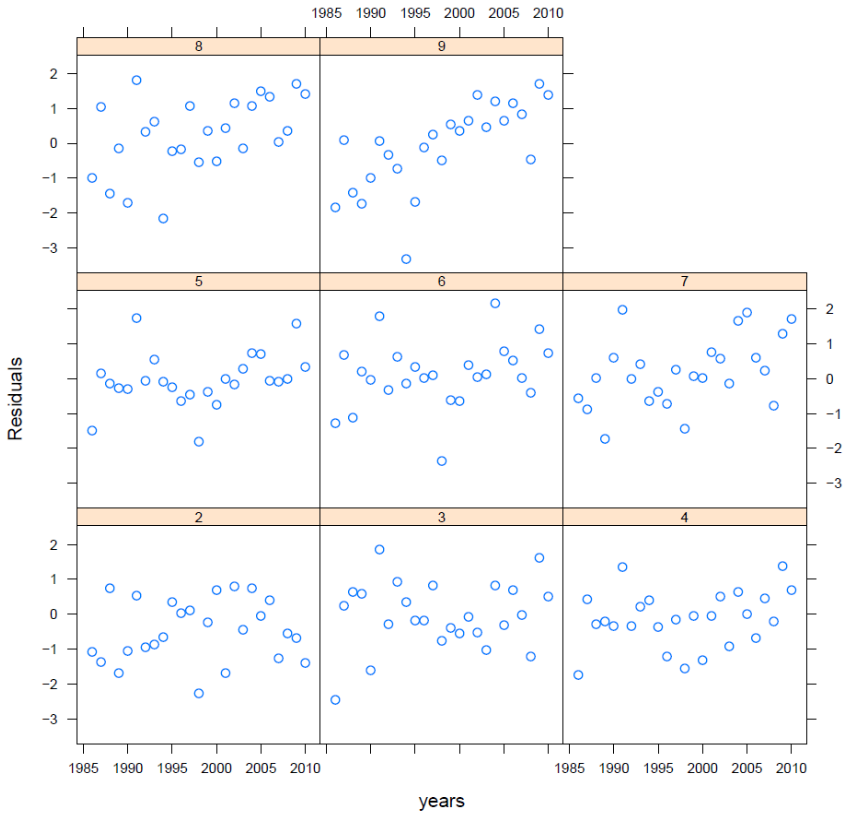


Figure 3.7.2.6: Herring in VIaN. Residuals by age of the Q1 SWC-IBTS survey 1986 – 2010

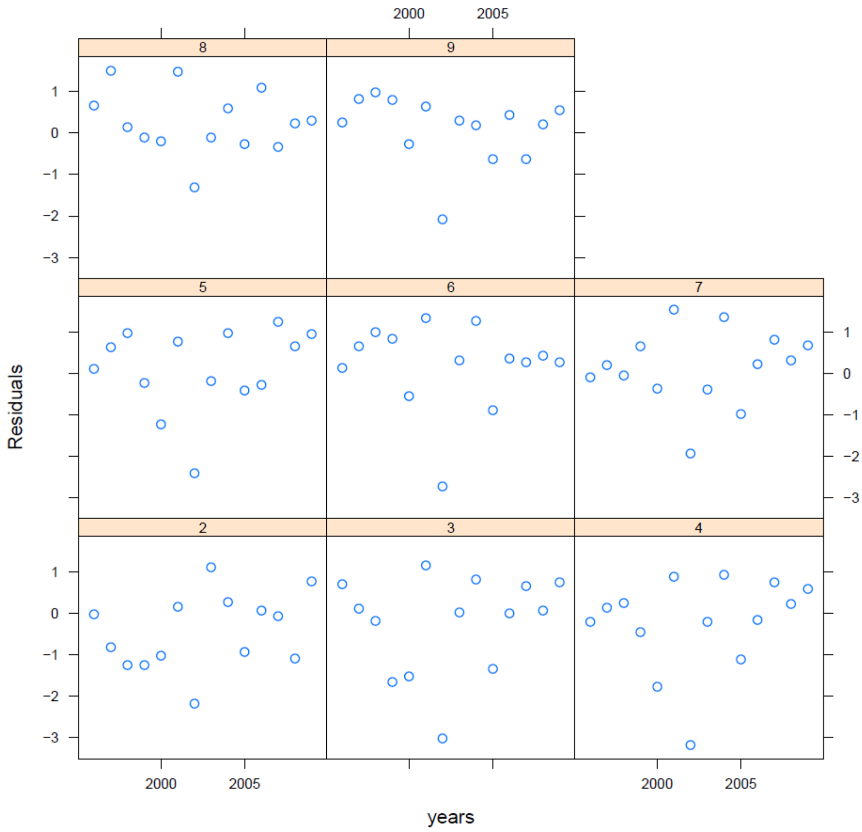


Figure 3.7.2.7: Herring in VIaN. Residuals by age of the Q4 SWC-IBTS survey 1996 – 2009

Herring in VIaN – correlation of parameters

The correlation matrix of fitted parameters for the FLSAM final VIaN runs is shown in Figure 3.7.2.8. The results indicate that the FLSAM final VIaN parameter settings are reasonable, with best results in the FLSAM VIaN and Malin Shelf acoustic assessment with Q1 SWC- IBTS (Figure 3.7.2.8 - bottom left).

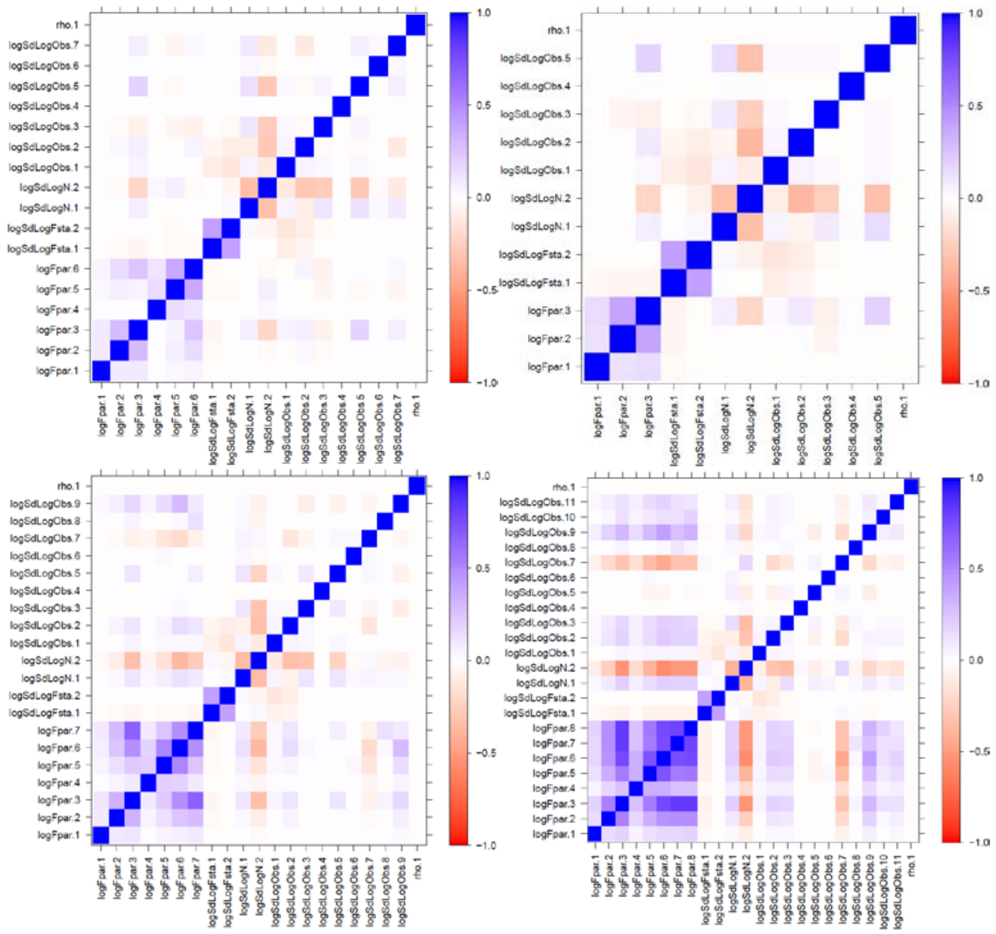


Figure 3.7.2.8: Herring in VIaN. Correlation matrices for FLSAM final VIaN with: VIaN and Malin Shelf acoustic assessment (top left); geographical VIaN acoustic assessment (top right); VIaN and Malin Shelf acoustic assessment with Q1 SWC- IBTS (bottom left), and; VIaN and Malin Shelf acoustic assessment with Q1 plus Q4 SWC- IBTS (bottom right). The horizontal and vertical axes show the parameters fitted by the model (labelled with names stored and fitted by FLSAM). The colouring of each pixel indicates the Pearson correlation between the two parameters.

Herring in VIaN – Internal consistencies of the surveys

For the acoustic surveys, 1-wr are down-weighted in FLSAM final (Figure 3.7.2.2) as VIaN 1-wr are generally not present in the geographical area (Heath *et al.*, 1987). The internal consistency plot for the HERAS (1991–2007) survey is shown in Figure 3.7.2.9. The internal consistency is generally good, but there may be issues with some of the younger age groups. The internal consistency of the Malin Shelf survey (2008–2013) is poor for some age groups also; this is expected for such a short time-series. The internal consistency of the longer time-series (1991–2013) geographical VIaN HERAS survey (Figure 3.7.2.11) fits slightly less well than the shorter time-series (1991–2007) HERAS (Figure 3.7.2.9).

The SWC-IBTS Q1 plot (Figure 3.7.2.12) shows that there are some internal consistency relationships between 5–6-, 6–7-, 7–8- and 8–9-wr. However, the relationship appears to be relatively weak apart from the older ages. There is no relationship between 3–4-wr and between 4–5-wr it is also very weak. The slopes in the SWC-IBTS Q1 survey indicate better fits, associated with higher R² values, than the SWC-IBTS Q4. For SWC-IBTS Q4 (Figure 3.7.2.13), the slope of the relationship between most age groups is close to zero.

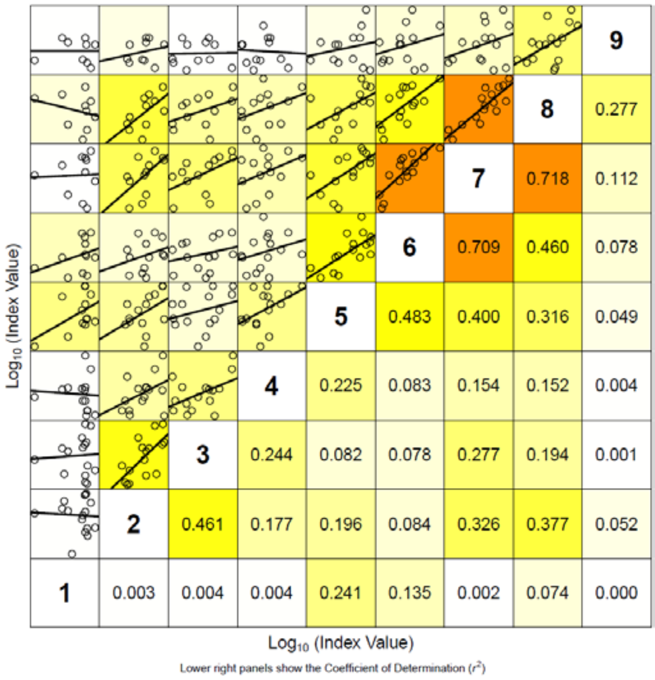


Figure 3.7.2.9: Herring in VIaN. Fitted linear relationships of cohort trends within the HERAS (1991–2007) surveys, described using an internal consistency plot.

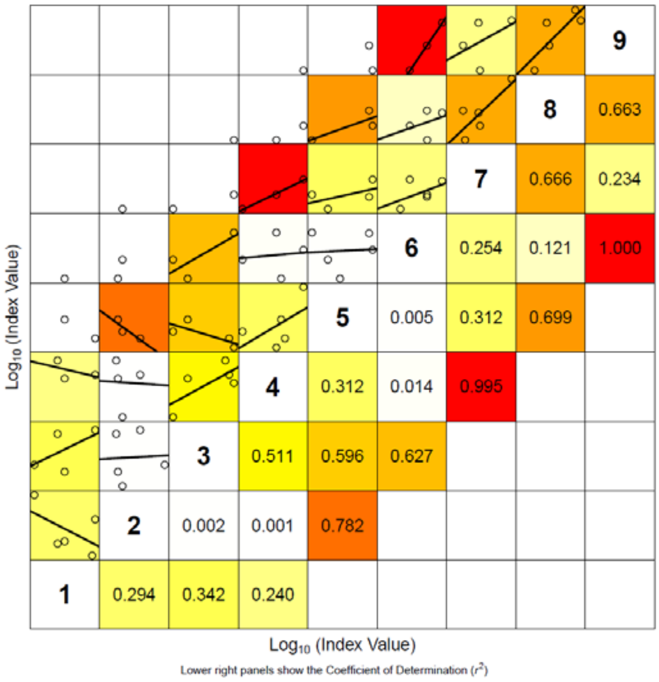


Figure 3.7.2.10: Herring in VIaN. Fitted linear relationships of cohort trends within the Malin Shelf (2008–2013) acoustic surveys, described using an internal consistency plot.

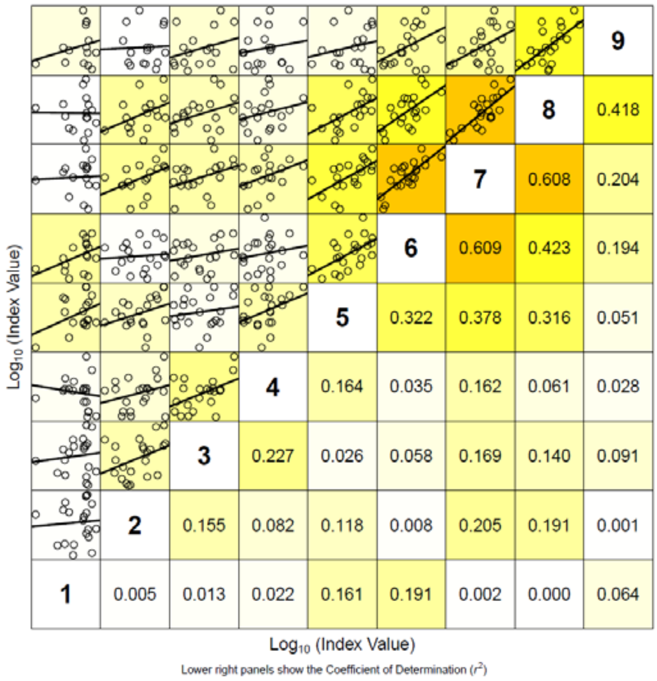


Figure 3.7.2.11: Herring in VIaN. Fitted linear relationships of cohort trends within the HERAS (1991–2013) surveys, described using an internal consistency plot.

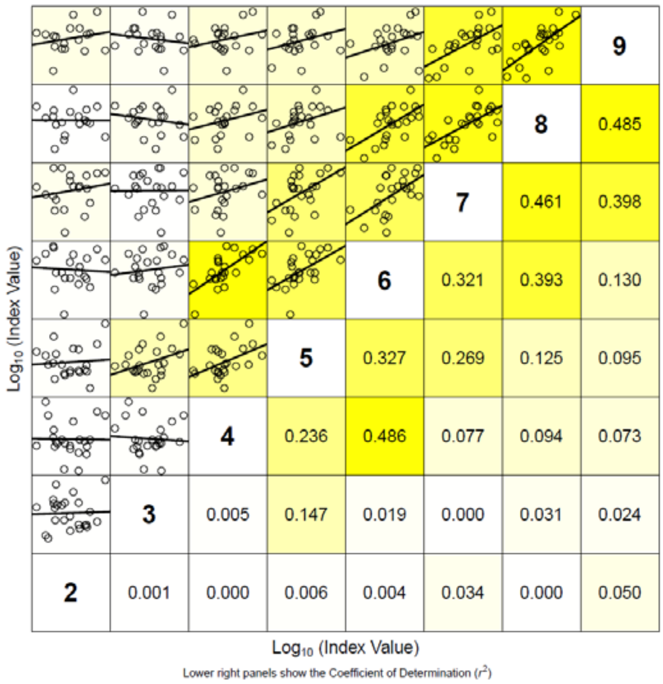


Figure 3.7.2.12: Herring in VIaN. Fitted linear relationships of cohort trends within the SWC-IBTS Q1 survey (1986–2010), described using an internal consistency plot.

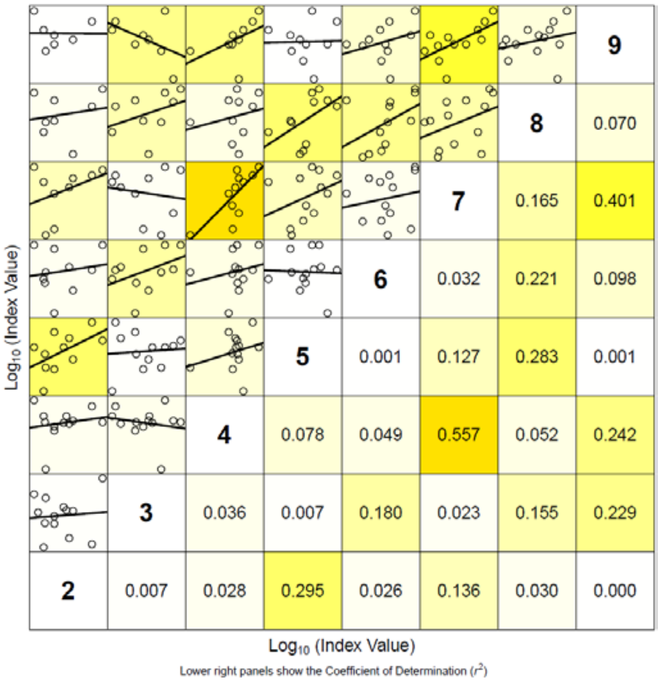


Figure 3.7.2.13: Herring in VIaN. Fitted linear relationships of cohort trends within the SWC-IBTS Q4 survey (1996–2009), described using an internal consistency plot.

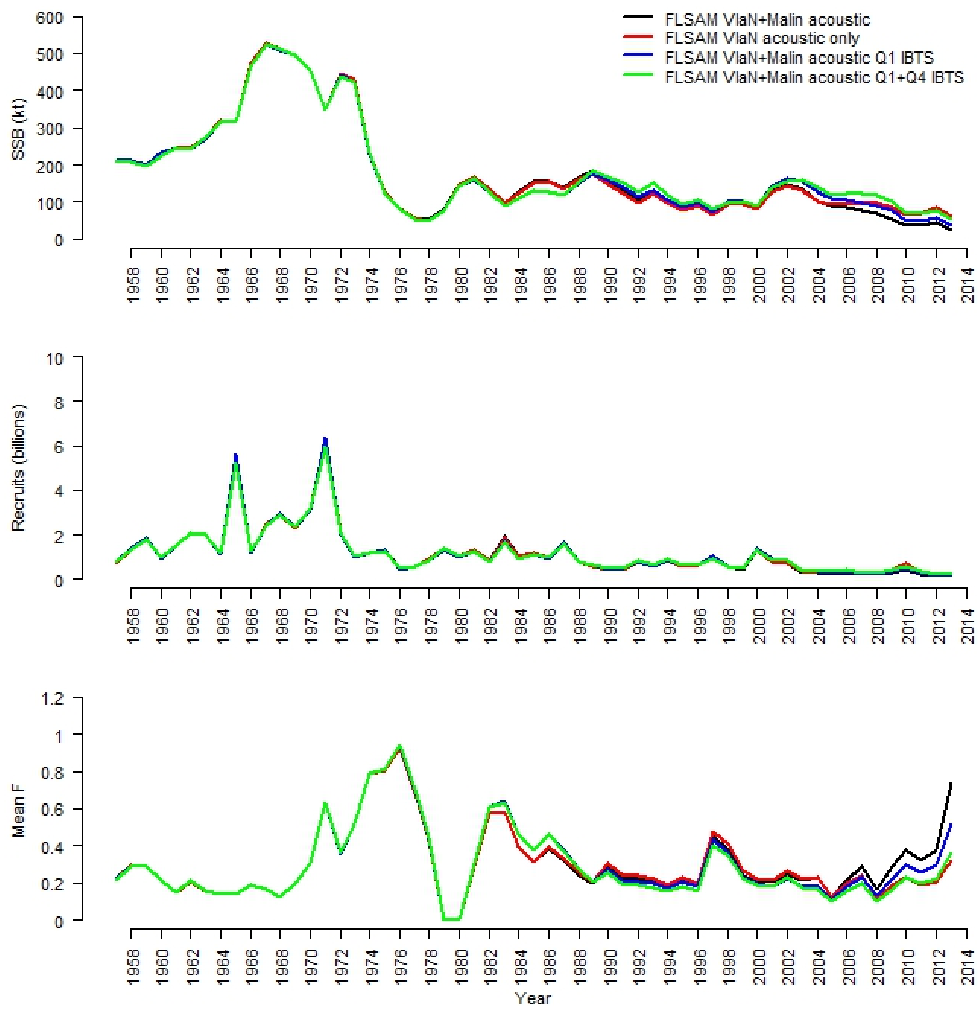


Figure 3.7.2.14: Herring in VIaN. Stock trajectories of SSB (top), Recruits (middle) and Mean F (bottom) for FLSAM final VIaN. The runs are as follows: VIaN and Malin Shelf acoustic assessment (black); geographical VIaN acoustic assessment (red); VIaN and Malin Shelf acoustic assessment with Q1 SWC- IBTS (blue), and; VIaN and Malin Shelf acoustic assessment with Q1 plus Q4 SWC- IBTS (green).

Herring in VIaN – stock trajectories

The stock SSB trajectories for all FLSAM runs are broadly similar (Figure 3.7.2.14), with some spreading in later years. FLSAM with the geographic VIaN HERAS survey has the highest terminal SSB, while FLSAM with both acoustic surveys (VIaN and Malin Shelf) has the lowest. The FLSAM runs with the SWC-IBTS surveys are in between these estimates. The recruitment trajectories are all in agreement, with current recruitment among the lowest in the time-series. Mean F values are spreading in later years with very high values for both surveys that do not include the SWC-IBTS data. Mean F for FLSAM with split-area HERAS is very high at 0.7 approximately. All projections show mean F rising in recent years.

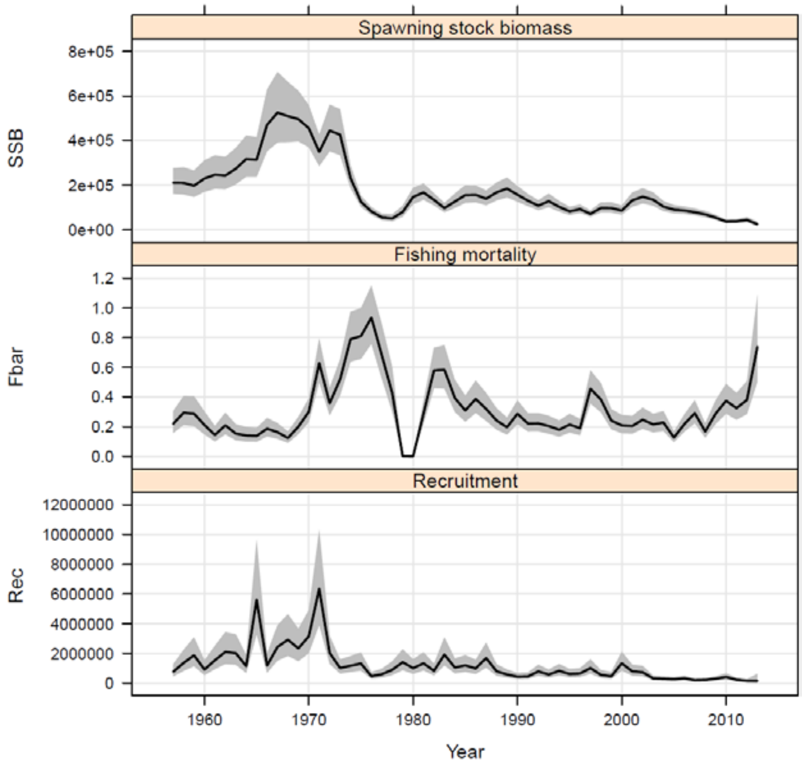


Figure 3.7.2.15: Herring in VIaN. Stock trajectories of SSB (top), Recruits (middle) and Mean F (bottom) for FLSAM final VIaN and Malin Shelf acoustic assessment

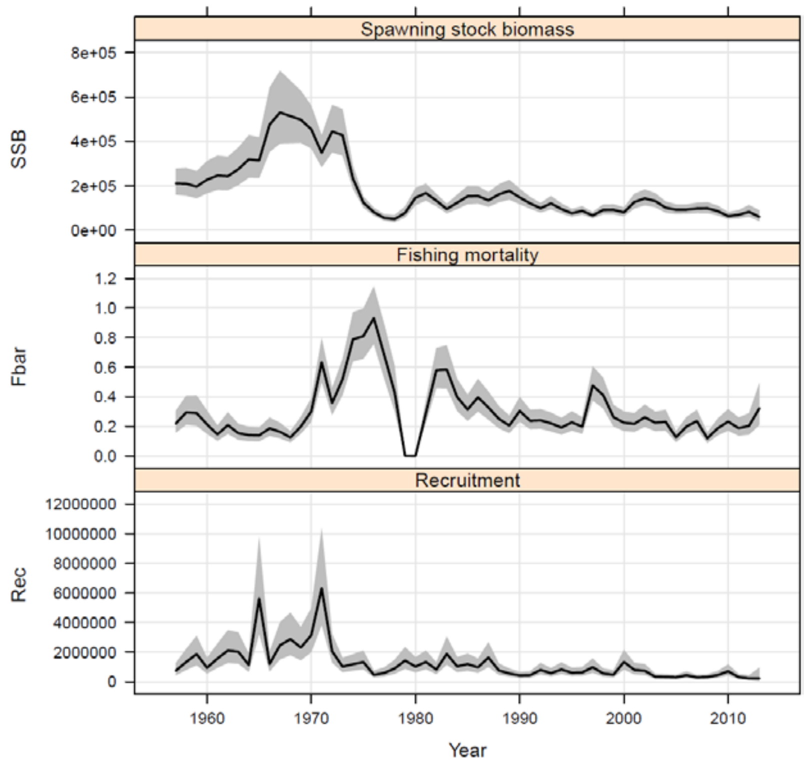


Figure 3.7.2.16: Herring in VIaN. Stock trajectories of SSB (top), Recruits (middle) and Mean F (bottom) for FLSAM final geographical VIaN acoustic assessment

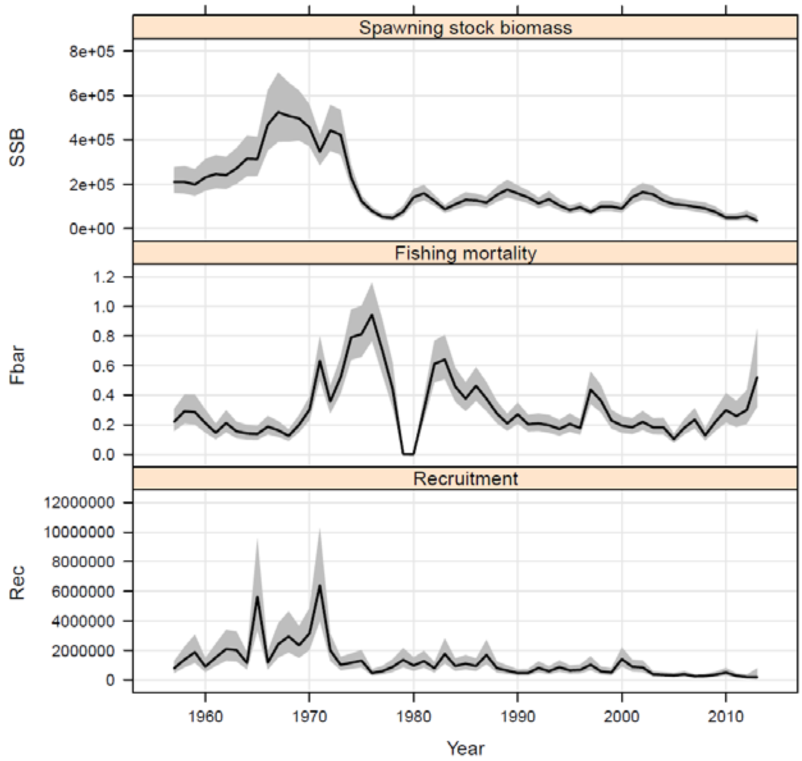


Figure 3.7.2.17: Herring in VIaN. Stock trajectories of SSB (top), Recruits (middle) and Mean F (bottom) for FLSAM final VIaN and Malin Shelf acoustic assessment with Q1 SWC- IBTS

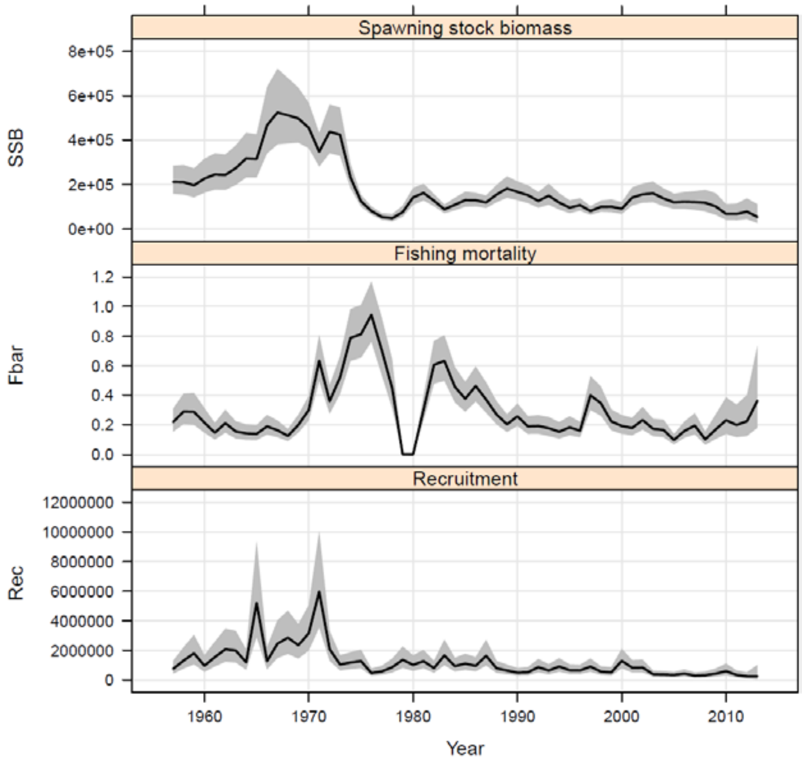


Figure 3.7.2.18: Herring in VIaN. Stock trajectories of SSB (top), Recruits (middle) and Mean F (bottom) for FLSAM final VIaN and Malin Shelf acoustic assessment with Q1 plus Q4 SWC-IBTS

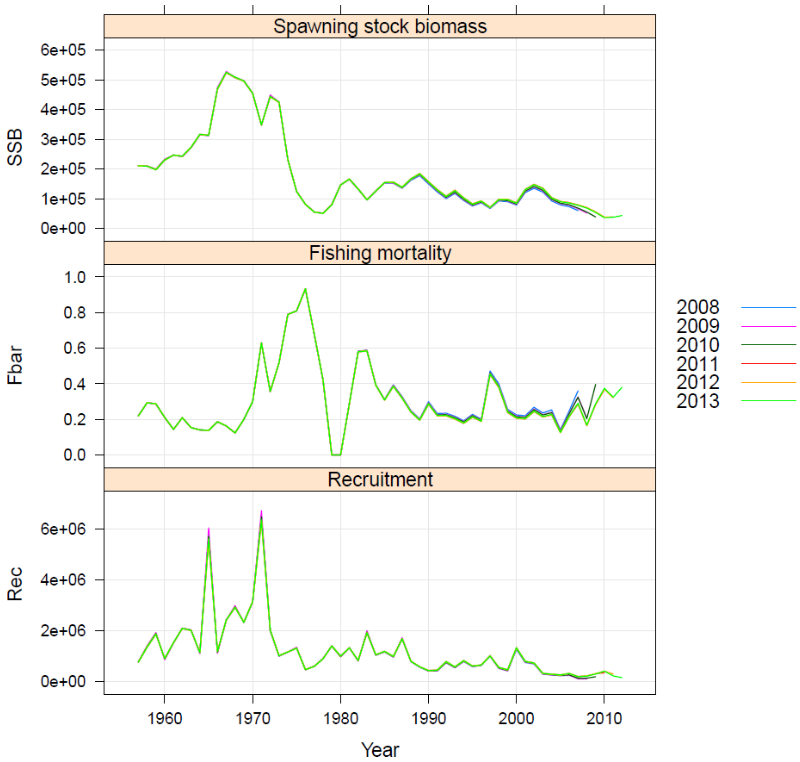


Figure 3.7.2.19: Herring in VIaN. Analytical retrospective patterns for herring in VIaN (2013 to 2008) of SSB, recruitment and mean F3-6 from FLSAM final with VIaN and Malin Shelf acoustic assessment.

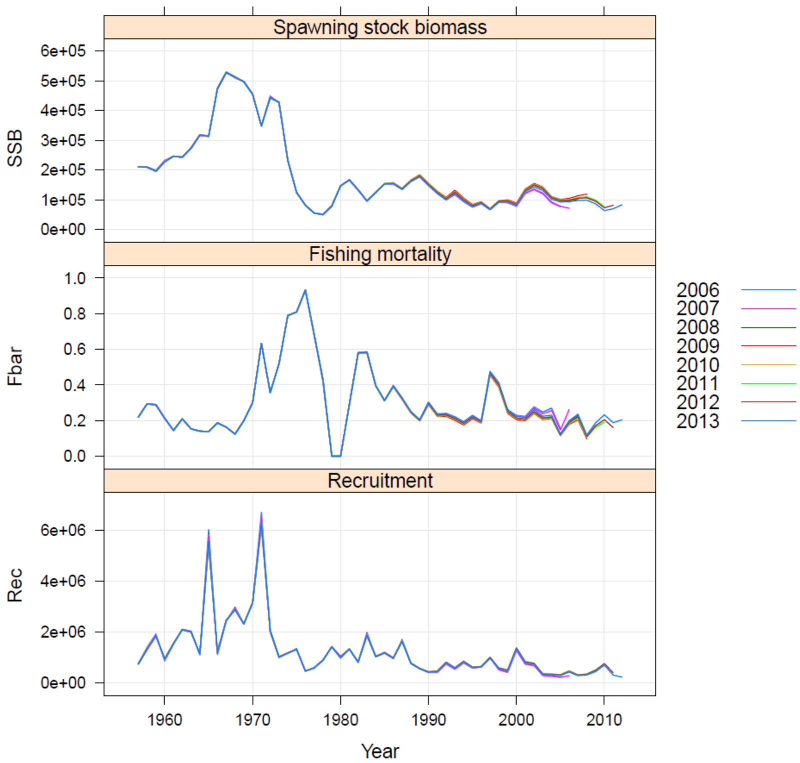


Figure 3.7.2.20: Herring in VIaN. Analytical retrospective patterns for herring in VIaN (2013 to 2006) of SSB, recruitment and mean F3-6 from FLSAM final with geographical VIaN acoustic assessment.

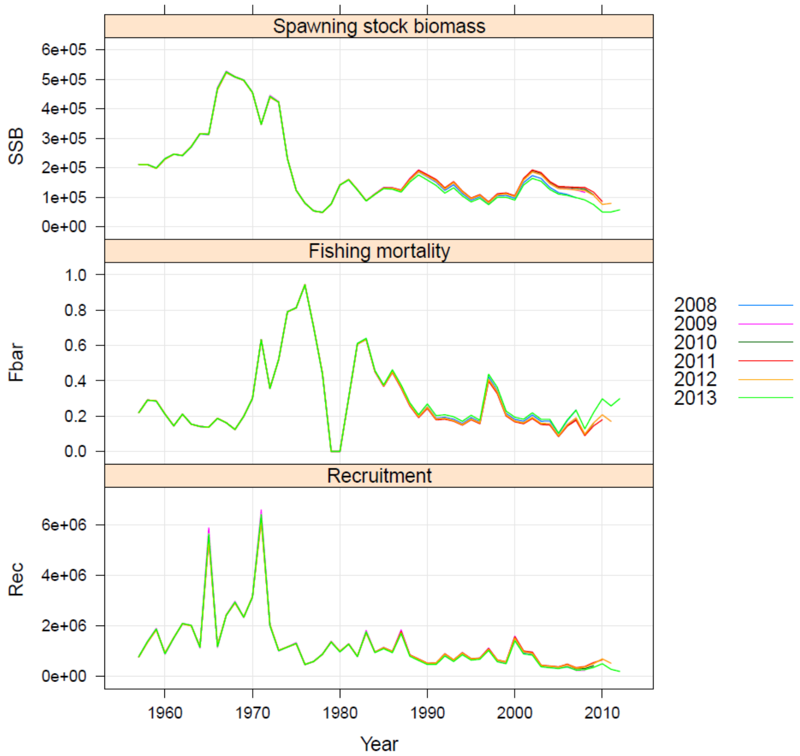


Figure 3.7.2.21: Herring in VIaN. Analytical retrospective patterns for herring in VIaN (2013 to 2008) of SSB, recruitment and mean $F_{3\text{-}6}$ from FLSAM final with VIaN and Malin Shelf acoustic assessment and Q1 SWC- IBTS.

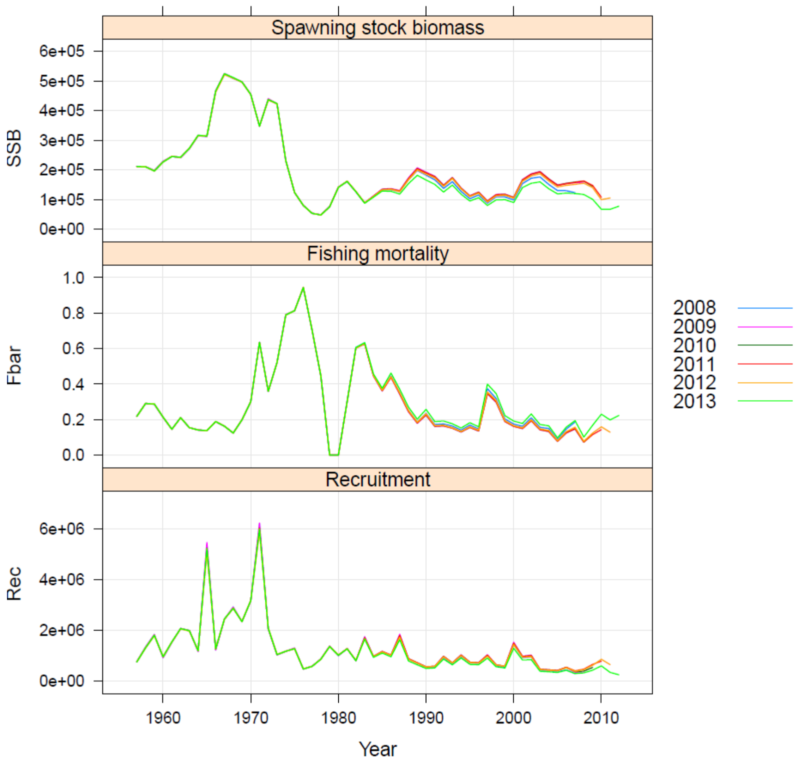


Figure 3.7.2.22: Herring in VIaN. Analytical retrospective patterns for herring in VIaN (2013 to 2008) of SSB, recruitment and mean $F_{3\text{-}6}$ from FLSAM final with VIaN and Malin Shelf acoustic assessment and Q1 plus Q4 SWC- IBTS.

Herring in VIaN – exploratory assessments using sVPA.

By way of comparison with the above, exploratory assessments were performed using a separable VPA (Darby and Flatman, 1994). This approach does not require tuning series, and allows for an analysis of the stock perception as estimated by signals in the catch-at-age only. Figure 3.7.2.23 shows the stock trajectories from 3 sVPA runs, with differing priming terminal Fs. The most pessimistic scenario (F=0.56) predicts SSB to be below Blim, while the most optimistic (F=0.17) predicts SSB to be above the management trigger.

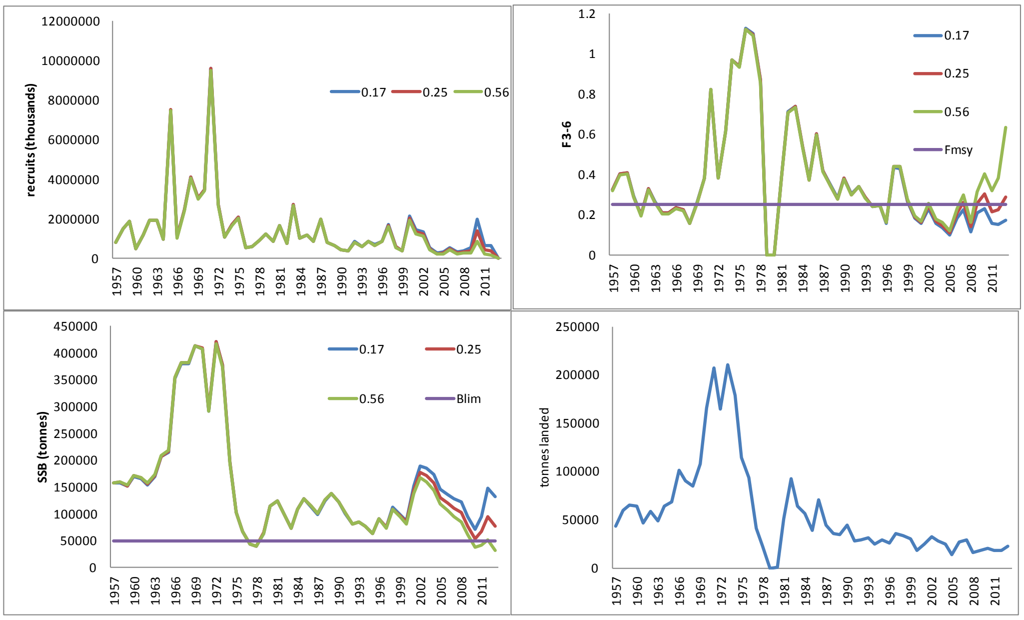


Figure 3.7.2.23: Herring in VIaN. Results of sVPA analyses for VIaN herring under three scenarios of terminal F. Top left, recruits (thousands), top right, F (3-6 wr), bottom left, SSB (tonnes) and bottom right catch (tonnes).

Herring in VIaN – perception of the VIaN stock (SSB, recruitment and mean F)

The overall perception of the stock has changed relatively little as a consequence of using FLSAM for the VIaN stock: the general trends of peaks and troughs still remains consistent with the FLICA assessment model (ICES HAWG, 2014). However, there are some differences. The SSB estimates with FLSAM in the most recent years have decreased. SSB estimates with FLSAM are closer to the original FLICA (ICES, 2014) with the addition of the SWC IBTS Q1 and Q4 data, but are still lower. As a consequence, F is higher with the FLSAM final runs than FLICA (ICES HAWG, 2014). The precision of SSB is best with the VIaN and Malin acoustic survey only (no SWC-IBTS data), although this is also the lowest terminal estimate of SSB (Figure 3.7.2.15).

One of the key advantages of the FLSAM framework is that it provides confidence intervals for all parameters estimated, included SSB, F_{bar} and recruitment. The confidence intervals for these parameters vary over time; generally, the confidence intervals are smallest when there is more data available (time-series), and larger towards either end of the time-series. Increasing the number of indices used in VIaN increases variation in the estimate of SSB, F_{bar} and recruitment (Figure 3.7.2.24).

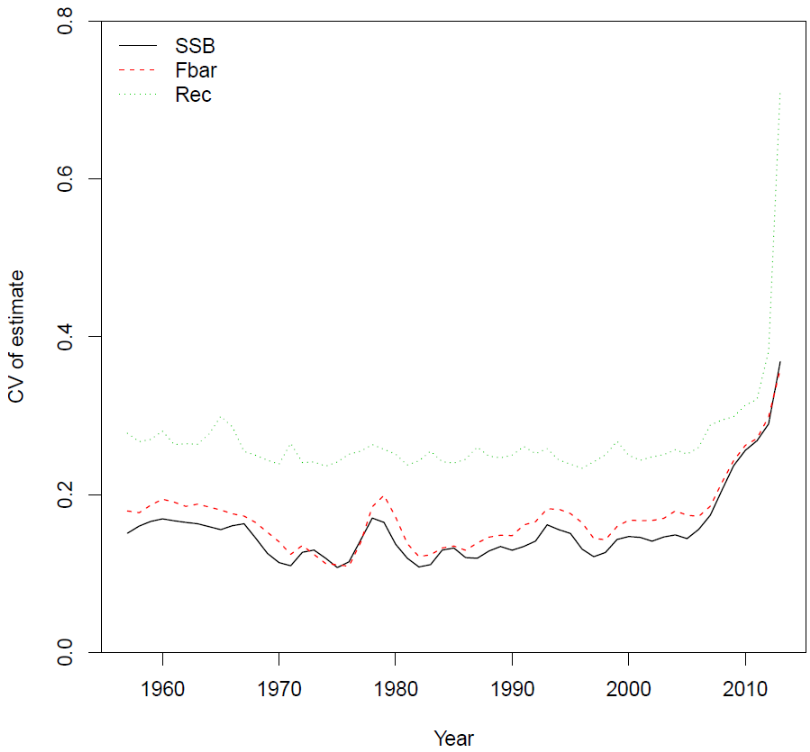


Figure 3.7.2.24: Herring in VIaN. Confidence intervals for all key parameters estimated (SSB, F_{bar} and recruitment) for FLSAM final with VIaN and Malin Shelf acoustic assessment and Q1 plus Q4 SWC- IBTS.

3.7.3 VIaS, VIIb,c Exploratory Assessment

The assessment of herring in VIaS, VIIb,c has been carried out using a separable VPA (Darby and Flatman, 1994). This procedure was followed in the absence of a tuning index. The Malin Shelf acoustic survey has been carried out in this area since 2008 and this tuning index has been used in recent years in exploratory assessment using ICA (Patterson, 1998b). In addition to the previously used models the use of the state space model SAM (Nielsen, 2009; Nielsen and Berg, 2013) was explored. The data used in the assessment are detailed in Table 3.7.3.1 below.

Table 3.7.3.1: Herring in VIaS, VIIb,c. Assessment input data

TYPE	NAME	YEAR RANGE	AGE (wr) RANGE
Caton	Catch in tonnes	1957–2013	1-9 +
Canum	Catch-at-age in numbers	1957–2013	1-9 +
Weca	Weight at age in the commercial catch	1957–2013	1-9 +
West	Weight at age of the spawning stock at spawning time.	1957–2013	1-9 +
Mprop	Proportion of natural mortality before spawning	1957–2013	1-9 +
Fprop	Proportion of fishing mortality before spawning	1957–2013	1-9 +
Matprop	Proportion mature at age	1957–2013	1-9 +
Natmor	Natural mortality	1957–2013	1-9 +

Separable VPA

Following the procedure carried out by the herring assessment working group for many years, a separable VPA was used to screen over four terminal fishing mortalities, 0.2, 0.4, 0.5 and 0.6. This was achieved using the Lowestoft VPA software (Darby and Flatman, 1994). The reference ages for calculation of fishing mortality was 3–6-wr and terminal selection was fixed at 1, relative to 3 winter rings (full selection). This method does not require a tuning series, but does not provide a unique perception of stock status.

Outputs from separable VPAs with terminal Fs of 0.2, 0.4, 0.5 and 0.6 are presented in Figure 3.7.3.5. All scenarios agree that the stock is at the lowest in the series, and is very close to a crash. The text table below shows that all runs show the stock to be considerably lower than B_{pa} (11 000 t) and B_{lim} (81 000 t).

Terminal F	Terminal SSB (t)
0.2	27 404
0.4	13 064
0.5	10 245
0.6	8390

FLICA Assessment

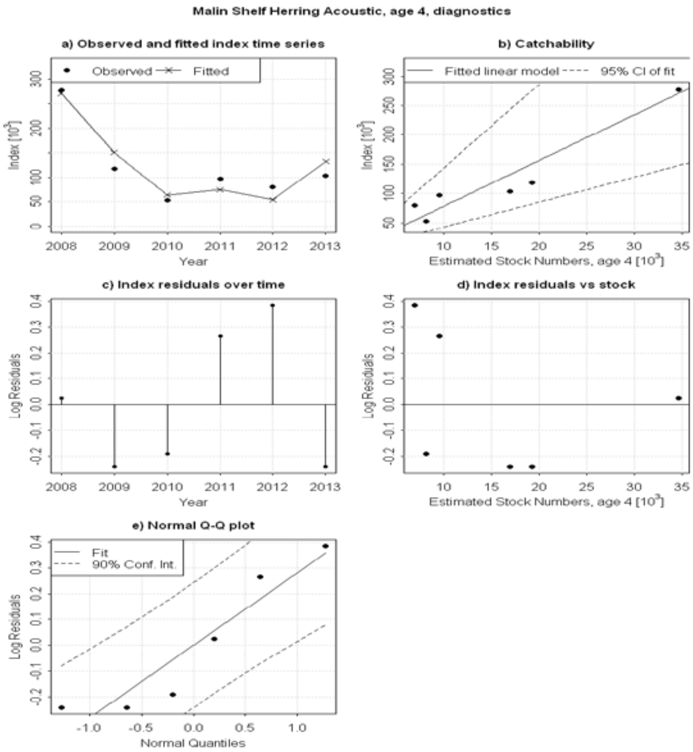
A number of exploratory runs using FLICA (Patterson 1998b) were performed at HAWG 2014 to examine various age ranges in tuning, reference age for separability and terminal value of selection. No changes of settings had any change on the stock trajectories over time. The tuning series used was a split index as available to HAWG 2014. This split was preliminary in nature and was not considered reliable (ICES HAWG 2014).

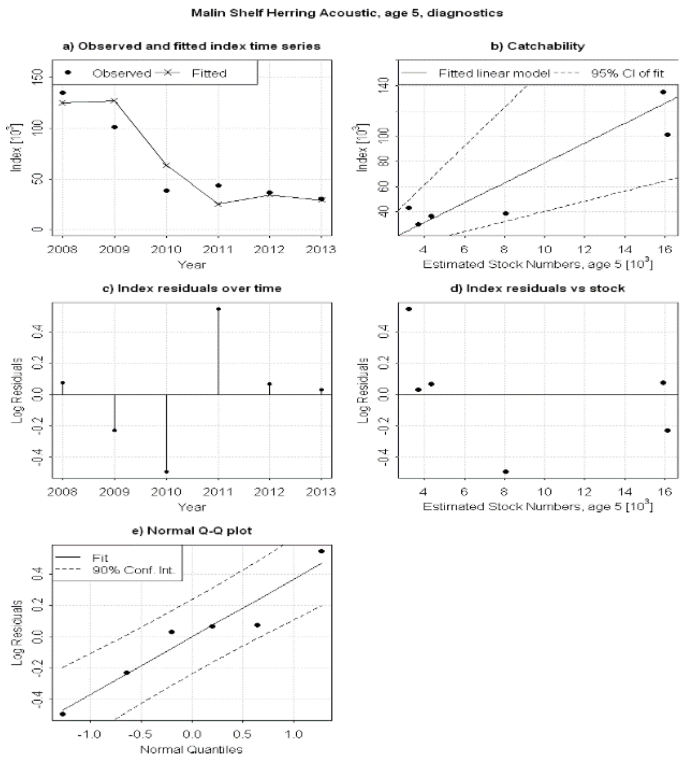
The best case run was chosen as having a reference age at 4-wr because it is the first fully selected age group. The separable period was set at 6 years, the same year range as the tuning series. The tuning series diagnostics for ages 4–6-wr provided the best diagnostics, and are presented in Figure 3.7.3.1. The residual patterns for the fitted survey ages show a reasonably good fit to the data across these ages and relatively trend free residual patterns. There are year effects present in the tuning index in all years (Figure 3.7.3.2 and 3.7.3.3).

The uncertainty plot (Figure 3.7.3.4) shows uncertainty in estimation of SSB to be well below B_{lim}. F is poorly estimated, but even the lower 5th percentile F is high.

A comparison between the FLICA and VPA outputs (terminal F=0.5) is shown in Figure 3.7.3.5. There was good agreement between the approaches. Even including the entire (un-split) Malin Shelf index used as tuning index in ICA provides the same perception of stock status. The results of the best case and exploratory assessments carried out at HAWG show with good certainty that the stock is below B_{lim} and that F is too high. Recruitment has been well below average in recent years.

At WKWEST it was decided to proceed using the unsplit acoustic survey time-series due to difficulties encountered in correctly classifying spawning samples to spawning group (Nolan *et al.*, 2015). Further assessment runs were carried out using different combinations of survey data and updated natural mortality values.


Malin Shelf Herring Acoustic, age 4, diagnostics
a) Observed and fitted index time series
Observed
Fitted
Index [10^3]
Year
b) Catchability
Fitted linear model
95% CI of fit
Estimated Stock Numbers, age 4 [10^3]
c) Index residuals over time
Log Residuals
d) Index residuals vs stock
e) Normal Q-Q plot
Fit
90% Conf. Int.
Normal Quantiles


Malin Shelf Herring Acoustic, age 5, diagnostics
a) Observed and fitted index time series
Observed
Fitted
Index [10^3]
Year
b) Catchability
Fitted linear model
95% CI of fit
Estimated Stock Numbers, age 5 [10^3]
c) Index residuals over time
Log Residuals
d) Index residuals vs stock
e) Normal Q-Q plot
Fit
90% Conf. Int.
Normal Quantiles

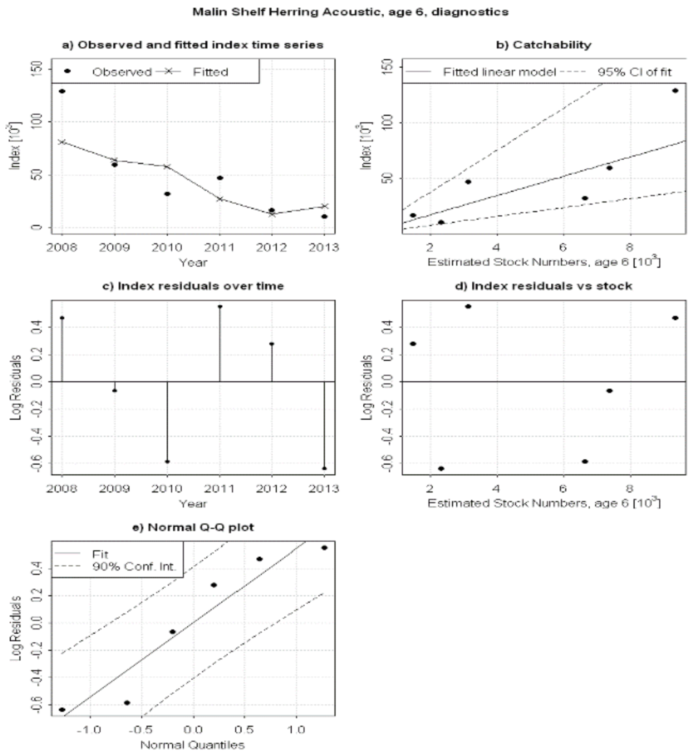


Figure 3.7.3.1. Herring in VIaS, VIIb,c. Diagnostics from the Malin Shelf Acoustic survey age 4 (top), age 5 (middle) and age 6 (bottom) from the HAWG FLICA assessment.

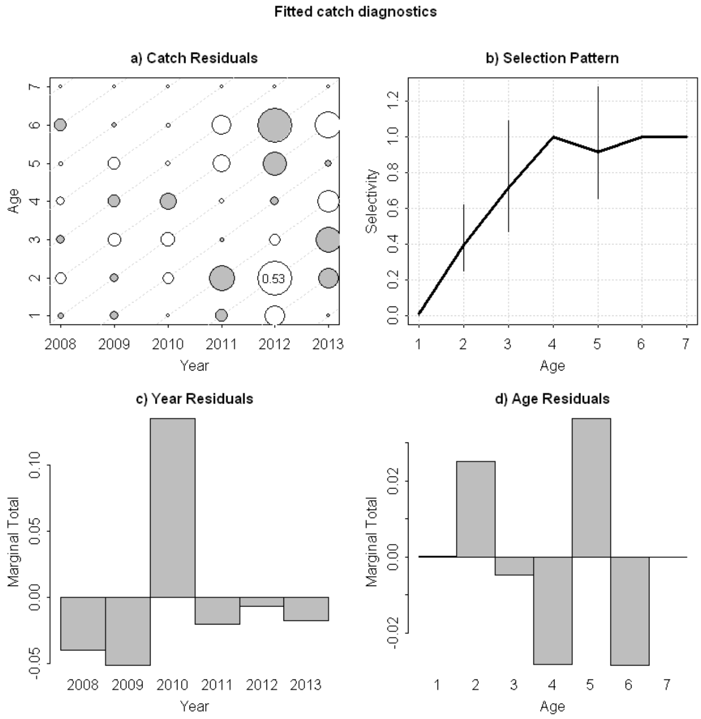


Figure3.7.3.2. Herring in VIaS, VIIb,c. Catch diagnostics plot from HAWG FLICA assessment.

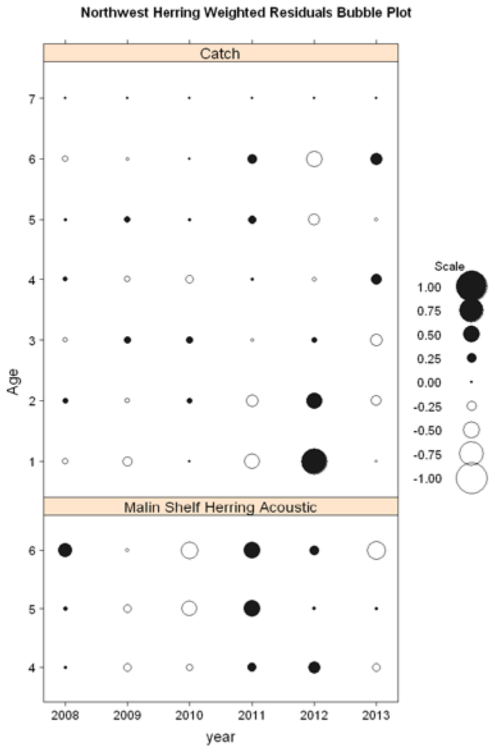


Figure 3.7.3.3. Herring in VIaS, VIIb,c. Catch and survey residuals for base case FLICA assessment.

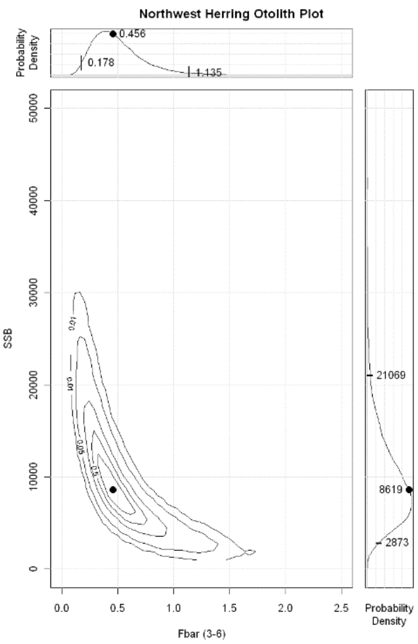


Figure3.7.3.4. Herring in VIaS, VIIb,c. Uncertainty plot showing the results of parametric bootstrapping from the HAWG FLICA assessment.

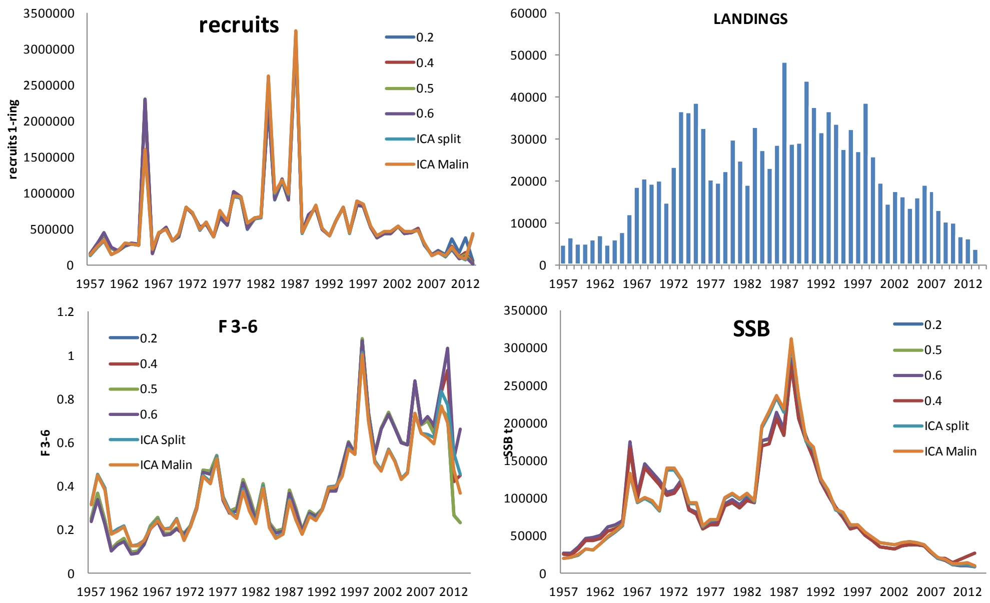


Figure 3.7.3.5. Herring in VIaS, VIIb,c. Results of the separable VPA assessment showing four separable VPAs, based on differing initial values of terminal F, over the period 1957–2013. Recruitment (top), SSB (middle) and mean F (bottom).

Changing natural mortality

The natural mortality which has been used in the separate VIaN and VIaS, VIIb,c assessments is based on the results of a multispecies VPA for North Sea herring which was calculated by the ICES multispecies working group in 1987 and were applied to herring stocks in adjacent areas (Anon., 1987). Natural mortality was fixed by age, were used in the assessment in subsequent years and assumed to be as follows:

WINTER RINGS	MY-1%
1	1
2	0.3
3	0.2
4	0.1
5	0.1
6	0.1
7	0.1
8	0.1
9	0.1

Based on O'Malley *et al.* (2015), it was decided that there was a basis to change the natural mortality using the most recent North Sea Multispecies assessment which uses data from 1974–2013 (see section 3.6.4.4). An average was calculated over this time-series and applied to the combined assessment. The new natural mortality are given in the text table below.

Winter rings	My-1%
1	0.71
2	0.35
3	0.28
4	0.26
5	0.24
6	0.23
7	0.22
8	0.22
9	0.22

Additional FLICA runs

Four additional runs were carried out using FLICA with the same settings as agreed at HAWG 2014. The details of the settings are presented in Table 3.7.3.2 below.

Table 3.7.3.2: Herring in VIaS, VIIb,c. ICA settings used at 2015 benchmark assessment.

ICA Settings	2015
Separable period	6 years (weighting = 1.0 for each year)
Reference ages for separable constraint	4
Selectivity on oldest age	1
First age for calculation of mean F	3
Last age for calculation of mean F	6
Weighting on 1 ringers	0.1
Weighting on other age classes	1

The ages used in tuning are 1–9-wr for the acoustic surveys and 2–9-wr for the IBTS surveys. The new natural mortality values are also used in all subsequent runs.

The addition of different combinations of tuning indices was examined.

1) Malin shelf acoustic survey 2008–2013.
2) Malin shelf acoustic survey 2008–2013 and West of Scotland Acoustic Survey 1991–2007.

Two additional runs were set up using

1) Malin shelf acoustic survey 2008–2013, West of Scotland Acoustic Survey 1991–2007 and Scottish IBTS Q1 1986–2010.
2) Malin shelf acoustic survey 2008–2013, West of Scotland Acoustic Survey 1991–2007, Scottish IBTS Q1 1986–2010 and the Scottish IBTS Q4 1996–2009.

Runs 3 and 4 would not converge and there were no setting options available to rectify this problem.

The stock trajectories from the runs using the acoustic surveys (runs 1 and 2 above) are presented in Figures 3.7.3.6 and 3.7.3.7. Both runs show very similar trajectories for SSB, recruitment and Mean F.

The survey residuals from each of the runs are shown in Figures 3.7.3.8 and 3.7.3.9. When only the Malin shelf acoustic survey is used in tuning (3.7.3.8) no year effects can be seen in the residuals. When the Malin and the West of Scotland surveys (3.7.3.9) are used a year effect can be seen early in the West of Scotland time-series at 1992 with no other year effects after that. The west of Scotland survey has more negative residuals in the early part of the time-series and more positive residuals in the latter part.

From the examples above we can see that the FLICA assessment is very sensitive to the choice of tuning data that is used. Issues with non-convergence of this model have been a feature of other assessments in the past.

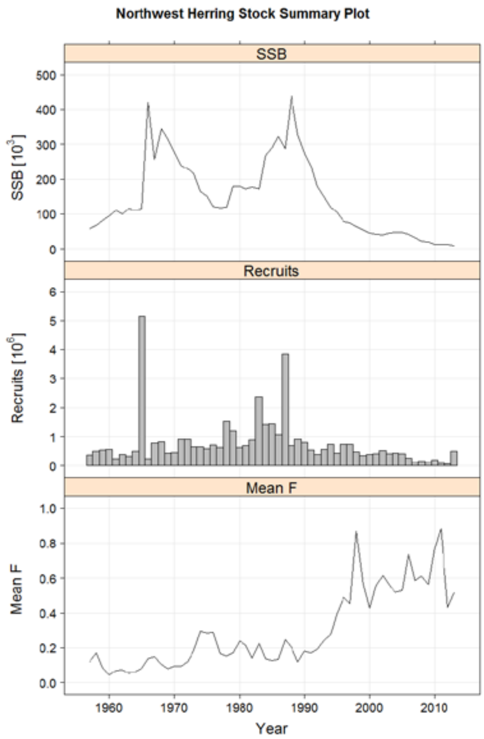


Figure 3.7.3.6: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment tuned with the Malin shelf acoustic survey 2008–2013

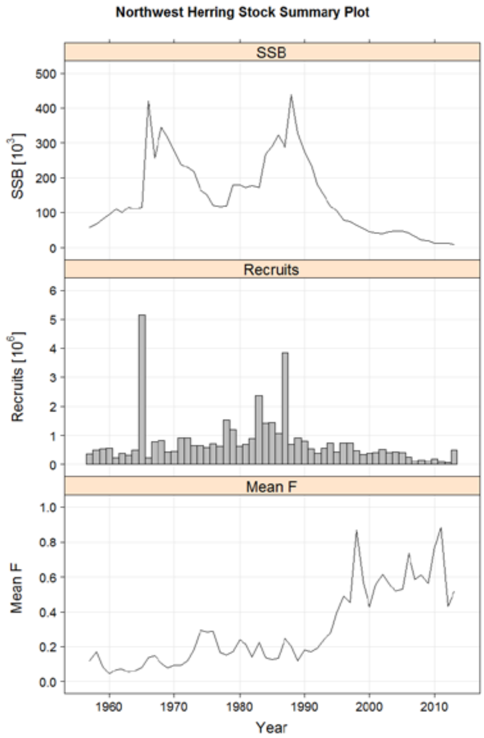


Figure 3.7.3.7: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment tuned with the Malin shelf acoustic survey 2008–2013 and the West of Scotland Acoustic survey 1991–2007.

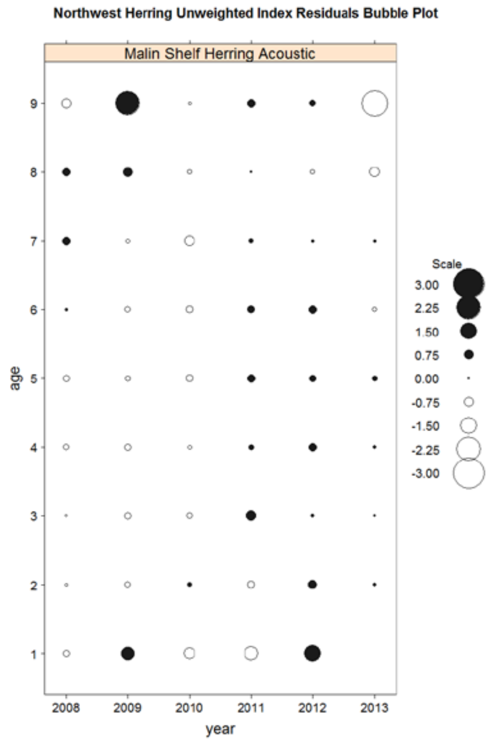


Figure 3.7.3.8: Herring in VIaS, VIIb,c. Survey Residuals when 1 acoustic survey is used in tuning

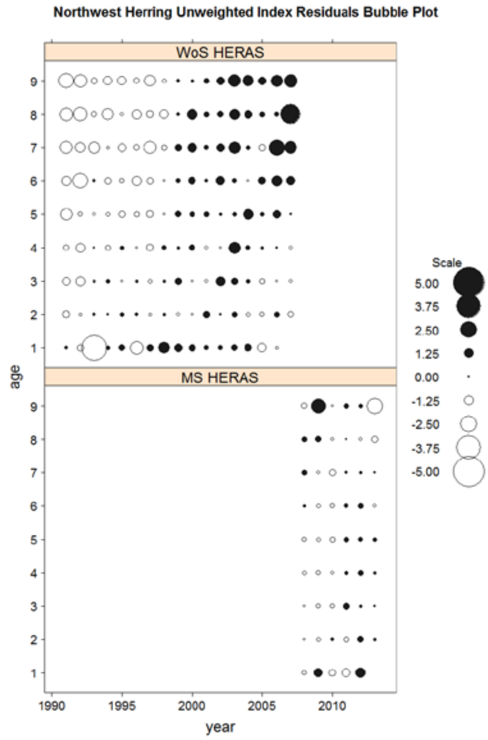


Figure 3.7.1.9: Herring in VIaS, VIIb,c. Survey Residuals when 2 acoustic surveys are used in tuning

FLSAM Runs

For the exploratory assessment of VIaS, VIIb,c herring the final setting for the combined assessment were also applied here. The details of which are given in Table 3.7.3.3 below. The new natural mortality values were used and the different survey combinations (runs 1-4 outlined in the FLICA section above).

Table 3.7.3.3: Herring in VIaS, VIIb,c. FLSAM settings for the VIaS VIIb,c exploratory assessment

Final Run SAM Settings	Combination
Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
Correlated random walks for F	correlated (TRUE)
Coupling of catchability parameters MS HERAS	1,2,3,3,3,3,3,3,3
Coupling of catchability parameters WoS HERAS	4,5,6,6,6,6,6,6,6
Coupling of catchability parameters IBTS Q1	7,7,7,7,7,7,7,7,7
Coupling of catchability parameters IBTS Q4	8,8,8,8,8,8,8,8,8
Variances in F random walk	1,2,2,2,2,2,2,2,2
Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
Coupling of observation variances - Catch	1,2,2,2,2,2,2,3,3
Coupling of observation variances - MS HERAS	4,5,5,5,5,5,5,5,5
Coupling of observation variances - WoS HERAS	6,7,7,7,7,7,7,7,7
Coupling of observation variances - IBTS Q1	8,9,9,9,9,9,9,9,9
Coupling of observation variances - IBTS Q4	10,11,11,11,11,11,11,11,11

The stock summary plots from each of the FLSAM runs are presented in Figures 3.7.3.10 – 3.7.3.13 below. Significant differences in the terminal year estimates of SSB, recruitment and mean F can be seen depending on which tuning indices are applied. When the IBTS data are added the recruitment trajectory levels off and the recruitment peaks that are evident in the late 1960's and 1980's that can be seen in the ICA assessment are no longer visible. The addition of the IBTS data also leads to very high SSB and very low F estimates in the terminal year. When the four runs are plotted together (Figure 3.7.3.14) the two runs with the IBTS data show different trends to the two runs with the acoustic surveys only.

The uncertainty of these key parameters, recruitment, SSB and mean F from each of the runs are presented in Figure 3.7.3.15. Here we can see when the acoustic survey is used in tuning, the uncertainty is low in the early period before increasing in more recent years for each of the three parameters. When the IBTS data are added the pattern changes with high values early on followed by lower values and then uncertainty increases again in the most recent period.

The correlation matrices Figure 3.7.3.16 show strong correlations between fitted parameters. The correlations are stronger correlations as additional tuning series are added. The strongest correlations are between the survey catchability parameters.

The SAM assessment is extremely sensitive to the choice of tuning data. It has a significant impact on the stock trajectories and the model diagnostics.

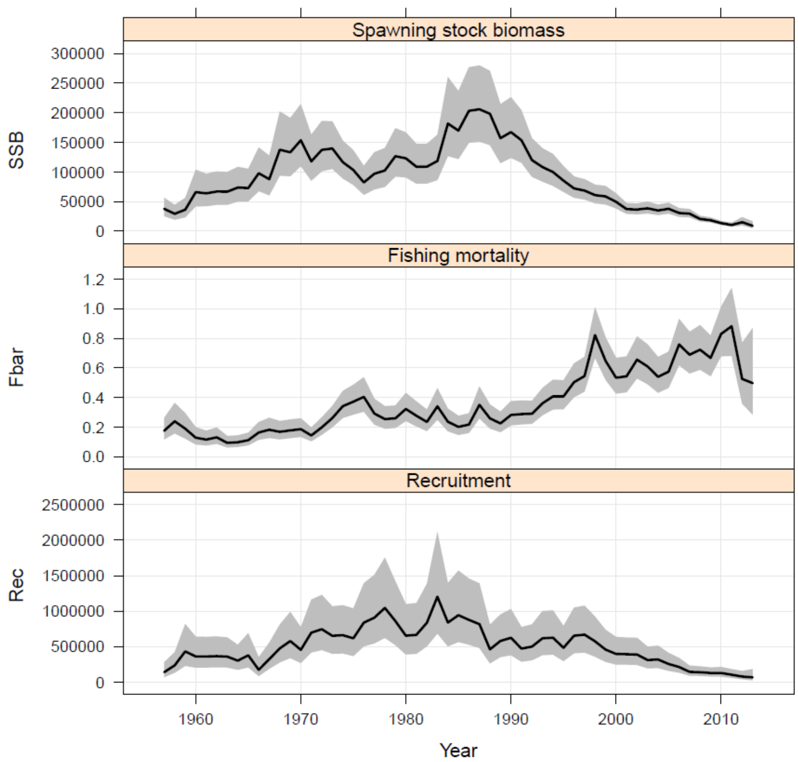


Figure 3.7.3.10: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS FLSAM assessment tuned with the Malin shelf acoustic survey 2008–2013

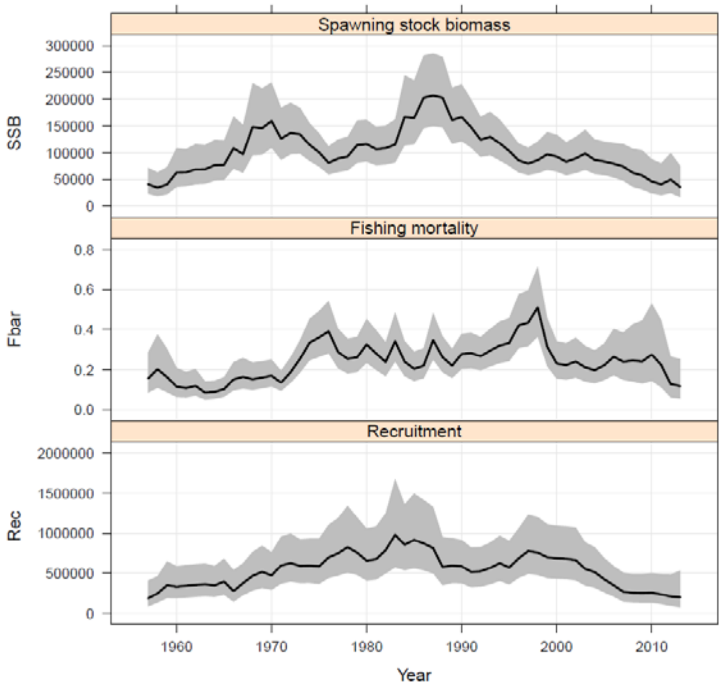


Figure 3.7.3.11: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment tuned with the Malin shelf acoustic survey 2008–2013 and the West of Scotland Acoustic survey 1991–2007.

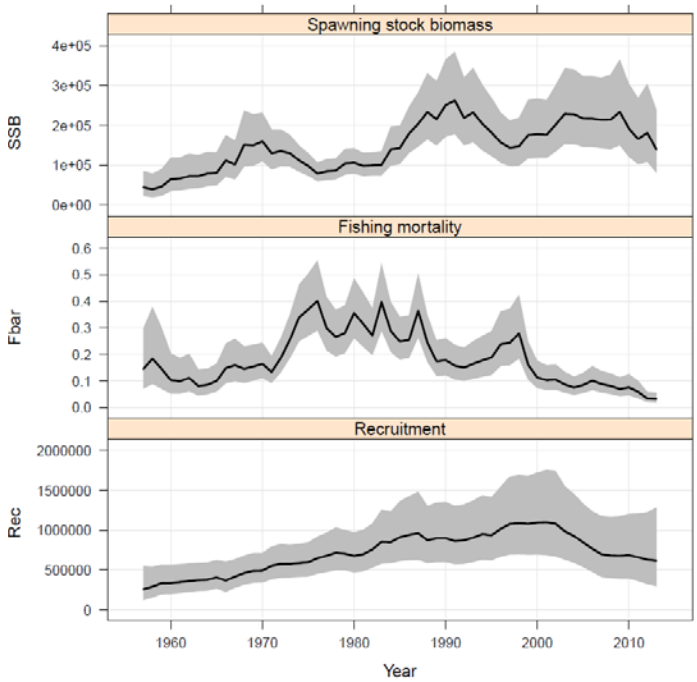


Figure 3.7.3.12: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment tuned with the Malin shelf acoustic survey 2008–2013, the West of Scotland Acoustic survey 1991–2007 and the Scottish IBTS Q1 1986–2010.

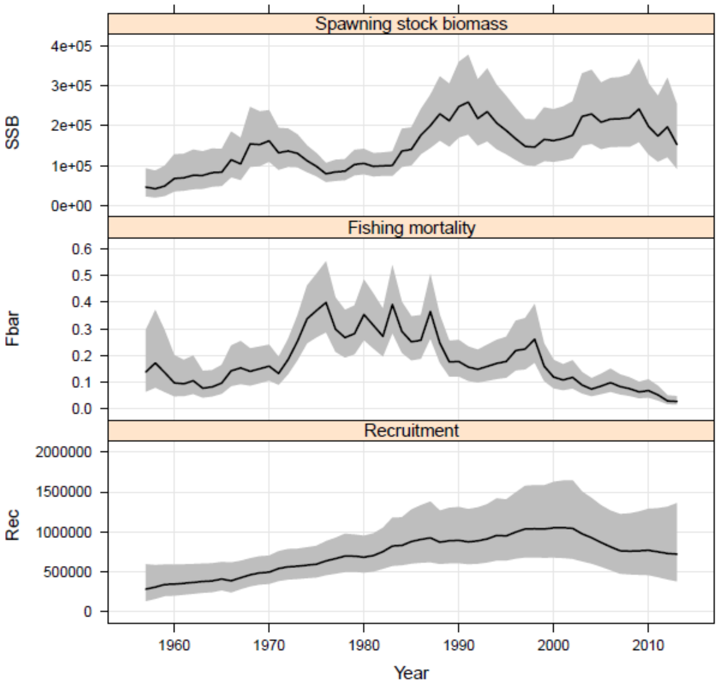


Figure 3.7.3.13: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment tuned with the Malin shelf acoustic survey 2008–2013, the West of Scotland Acoustic survey 1991–2007, the Scottish IBTS Q1 1986–2010 and the Scottish Q4 1996–2009.

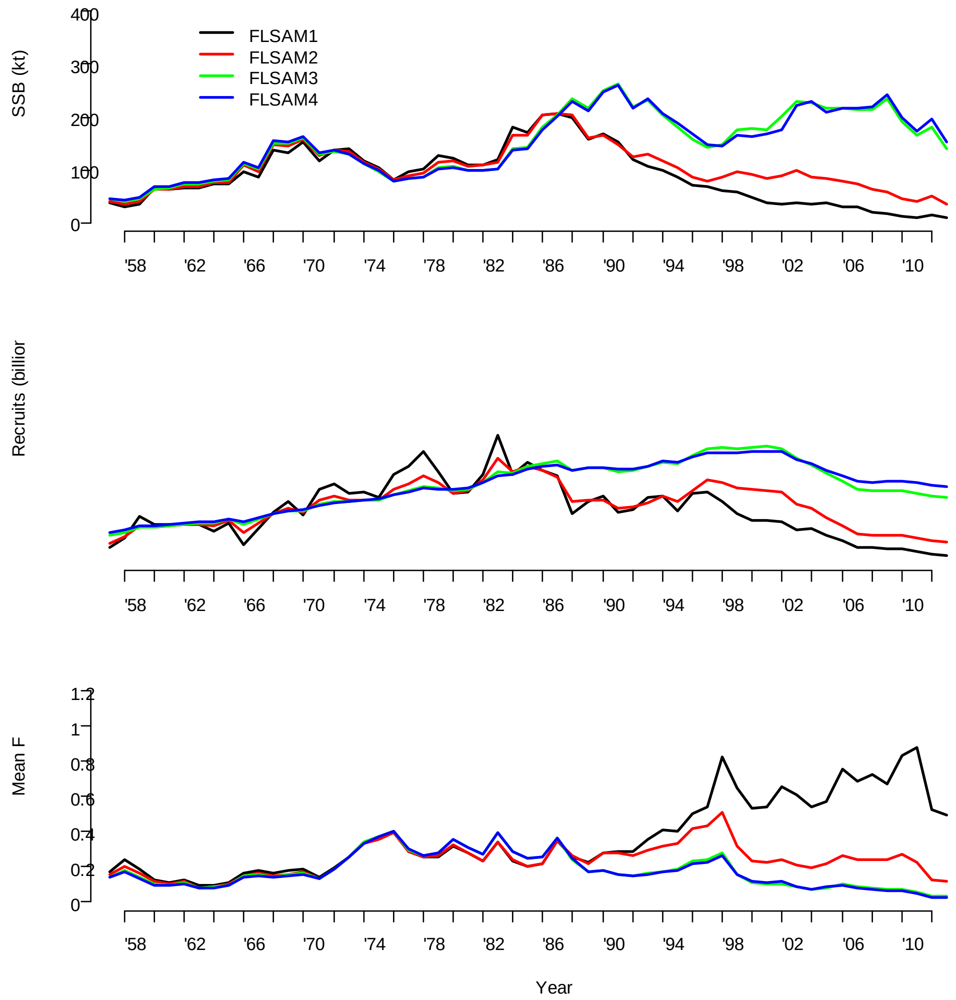


Figure 3.7.3.14: Herring in VIaS, VIIb,c. Stock Summary plots from the VIaS assessment with different tuning indices FLSAM1 (Malin shelf acoustic survey), FLSAM2 (Malin shelf and West of Scotland Acoustic survey), FLSAM3 (Malin shelf acoustic survey, West of Scotland Acoustic survey and the Scottish IBTS Q1) and FLSAM4 (Malin shelf and West of Scotland Acoustic survey, the Scottish IBTS Q1 and Q4).

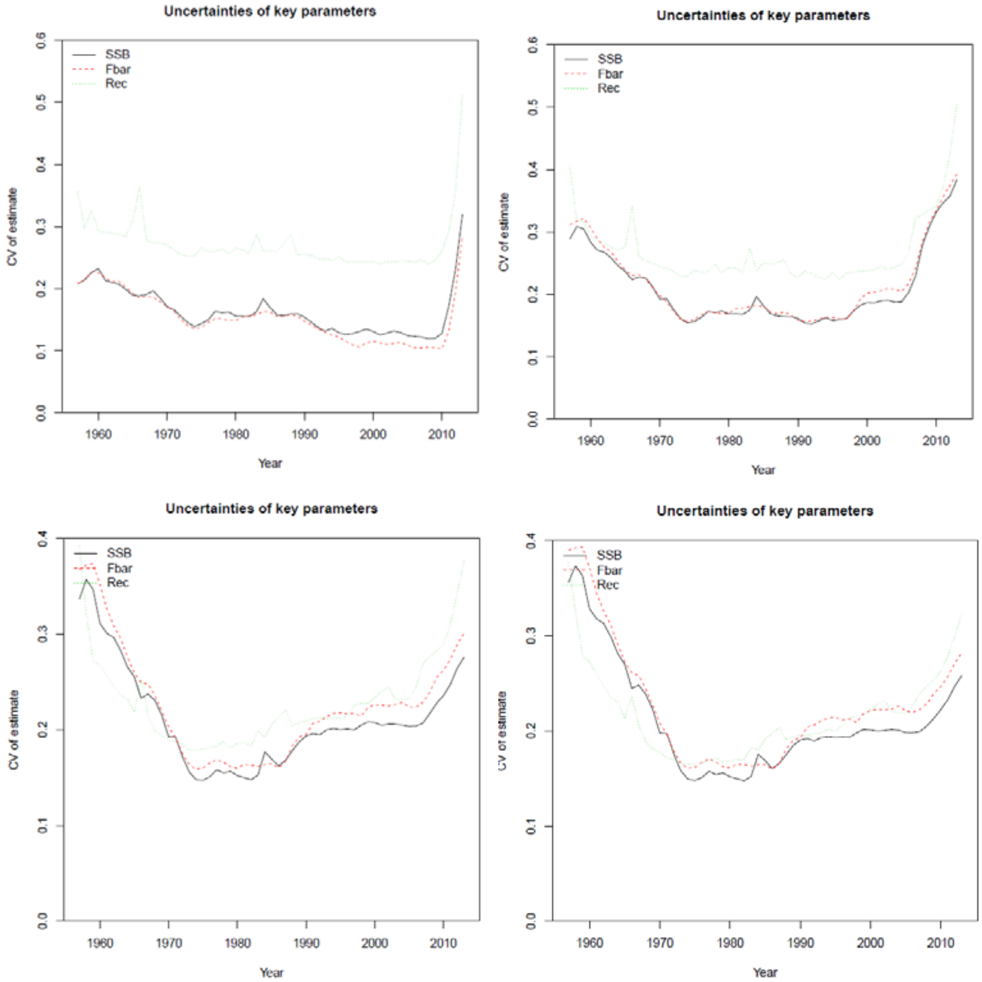


Figure 3.7.3.15: Herring in VIaS, VIIb,c. Uncertainty of key parameters from the FLSAM assessments using the Mailin shelf tuning series (top left), Malin shelf and West of Scotland (top right), Malin shelf, West of Scotland and IBTS Q1 (bottom left) and Malin shelf, West of Scotland and IBTS Q1 and Q4 (bottom right).

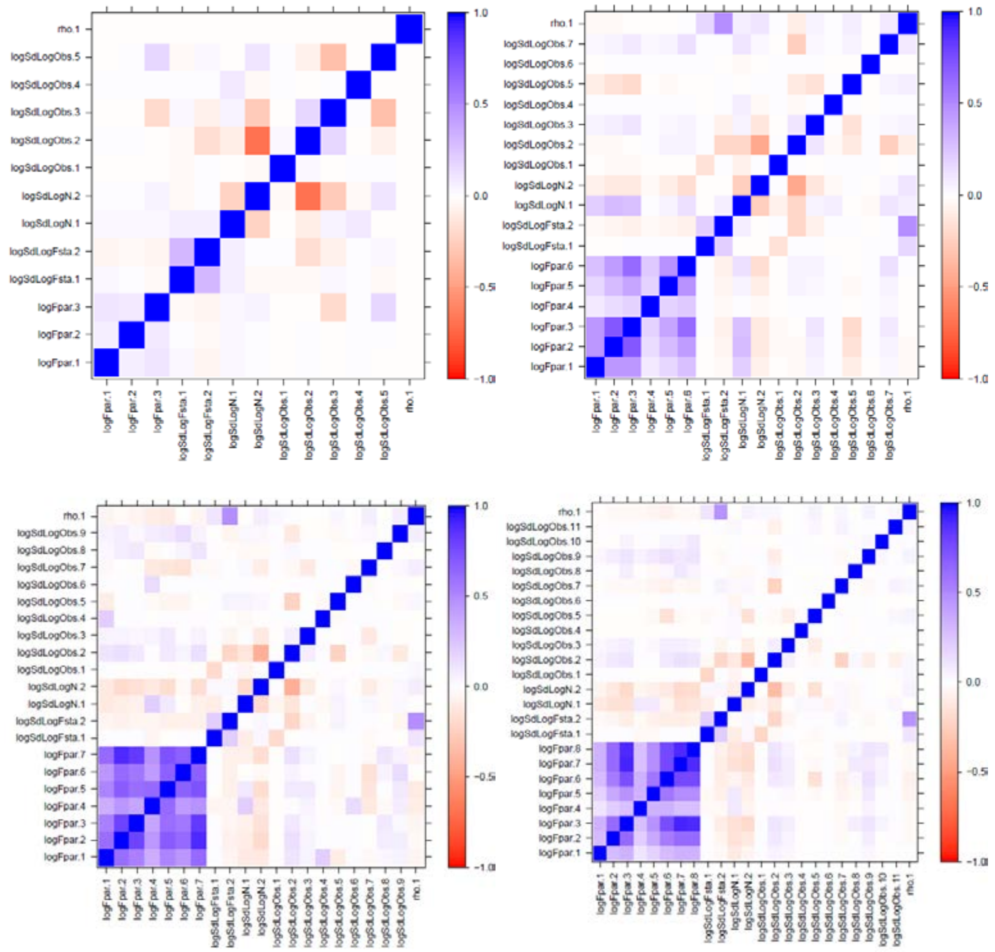


Figure 3.7.3.16: Herring in VIaS, VIIb,c. Correlation matrix plots from the FLSAM runs using the Mailin shelf tuning series (top left), Malin shelf and West of Scotland (top right), Malin shelf, West of Scotland and IBTS Q1 (bottom left) and Malin shelf, West of Scotland and IBTS Q1 and Q4 (bottom right)

Comparisons between FLICA and FLSAM

A comparison plot between FLICA and FLSAM runs using the Malin shelf acoustic survey is presented in Figure 3.7.3.17. These assessments show a similar pattern for SSB, recruitment and mean F in recent times but deviate in the earlier part of the time-series. FLSAM is not showing the peaks in recruitment which occurred in the 1960's and 1980's. Also the SSB peaks are not as pronounced in the FLSAM assessment. The trajectories for mean F are more in agreement.

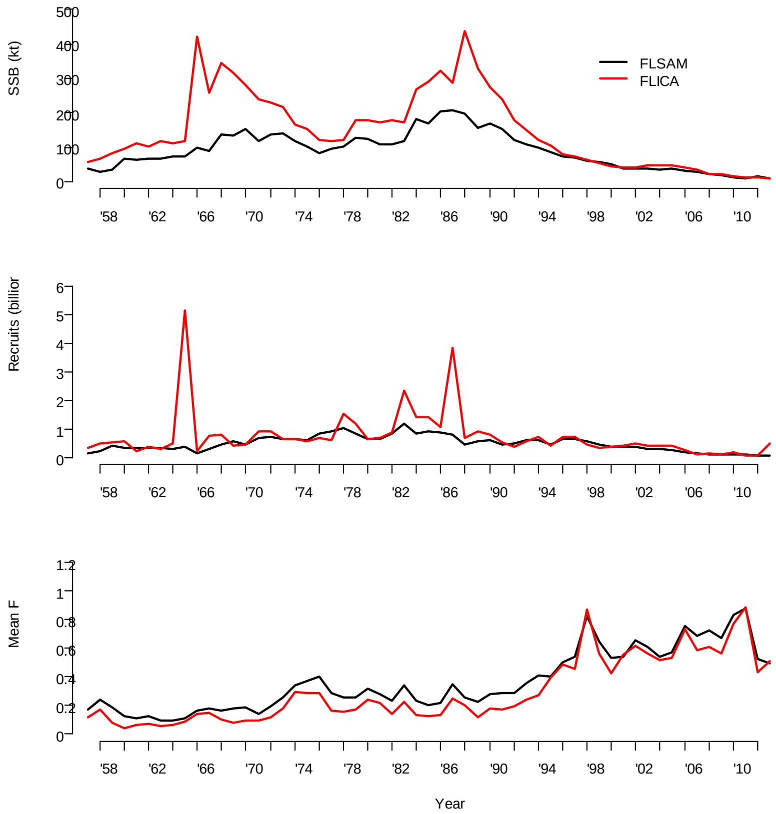


Figure 3.7.3.17: Herring in VIaS, VIIb,c. Comparison of FLICA and FLSAM assessments using Malin shelf survey tuning

FLICA and FLSAM stock summaries using the Malin shelf and West of Scotland acoustic surveys are compared in Figure 3.7.3.18. Similar to the previous run the peaks in SSB and recruitment are not evident in the FLSAM assessment. More divergence can be seen from the late 1990's in mean F than in the previous run.

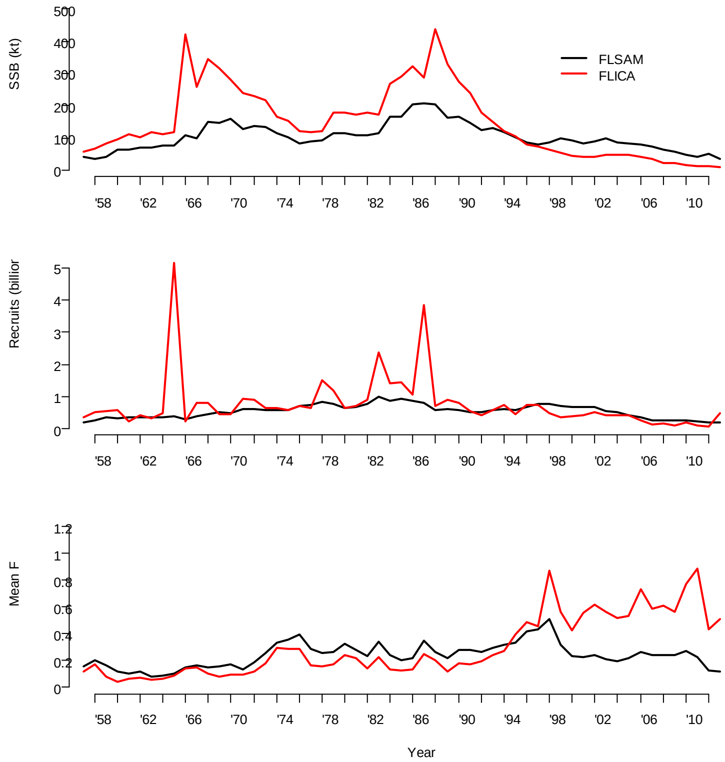


Figure 3.7.3.18: Herring in VIaS, VIIb,c. Comparison of FLICA and FLSAM assessments using the Malin shelf survey and West of Scotland acoustic survey tuning.

3.8 Appropriate reference points (MSY)

3.8.1 Productivity change

The Surplus Production (increase in biomass of the stock during a year, accounting for natural mortality but prior to the removal of the catch) for three of the herring stocks in the vicinity of the British Isles (North Sea, VIaN and the Celtic Sea) were calculated using the methods detailed in Dutil *et al.* (1999) and Dutil and Brander (2003) with the variations laid out in Kjesbu *et al.* (2014). To correct for the variable biomass the surplus production is expressed as Surplus Production per unit stock biomass and is thus an indication of the productivity of the stock. These calculations are based on the assessment outputs and are thus subject to the same caveats with regard to development of the stock over time and the current perception of the stock condition and structure.

In the period up to 1980 all three stocks indicate a similar level of stock productivity which varied over time (Figure 3.8.1.1). After that period, the Celtic Sea remained at about the same mean level until the end of the time-series. The stock productivity in the North Sea increased until around 1997 and thereafter showed a dramatic decrease to 2006. In contrast, VIaN showed a general systematic decrease in productivity from 1980 to 2004. In recent years (2004–2009), the VIaN stock indicated an increase in stock productivity.

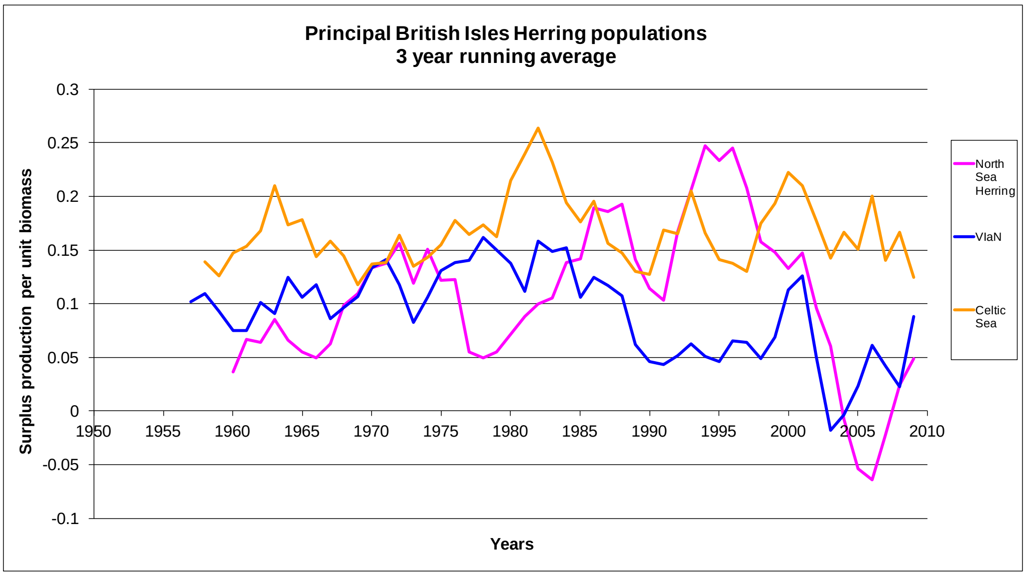


Figure 3.8.1.1 Herring stocks around the British Isles: Changes in annual surplus production per unit stock biomass (productivity) for the North Sea, west of Scotland (VIaN) and Celtic Sea, VIIg,j herring stocks.

These changes in stock productivity reflect interannual variability of recruitment patterns and growth in weight and should be taken in to account when considering the stock dynamics. The variability is also a reflection of the environmental conditions and their effect on each of the stocks. A similar analysis can be done in future for the combined area (VIa, VIIb,c) once an agreed analytical assessment has been undertaken.

3.8.2 Stock and recruitment relationships

3.8.2.1 Introduction

Stock recruitment relationships and potential reference points were explored using plotMSY and EqSim.

PlotMSY is intended to provide robust estimation of deterministic MSY estimates (i.e. without future process error) that could be applied easily and widely. It fits three stock–recruit functions, namely the Ricker, Beverton–Holt, and a smooth Hockey-stick (Mesnil and Rochet, 2010), to estimate MSY quantities. Uncertainty in MSY estimates are characterized by MCMC sampling of the joint pdf of the stock–recruit parameters and sampling from the distributions of other productivity parameters (i.e. natural mortality, weights-at-age, maturities, and selectivity). Stock–recruit model uncertainty can be taken into account by model averaging of the three functions (ICES, 2013b). However, in this case for VIa, VIIb,c herring we have not made use of the model averaging capabilities.

Eqsim (ICES, 2013b) provides MSY reference points based on the equilibrium distribution of stochastic projections. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age, maturities, and selectivity) are resampled at random from the last few years of the assessment. Recruitments are resampled from their predictive distribution which is based on parametric models fitted to the full time-series provided. Random deviations from S-R are the same for each target F. Uncertainty in the stock–recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland *et al.*, 1997).

Guidance on methods to be applied was sought in the WKMSYREF3 report (ICES, 2014). Although the WKMSYREF3 report gave an extensive description of the different methods (i.e. implementations) that could be used, a critical discussion of strength-weaknesses was lacking. When applying eqSim and plotMSY on the same data, WKWEST found substantial differences in the relative weight attributed to the different stock recruitment models.

Because of time constraints within the benchmark workshop, WKWEST decided to use plotMSY as the main tool for estimating reference points.

3.8.2.2 Data

Input data for stock recruitment modelling were taken from the final assessment of VIa, VIIb,c herring in the form of an .RData object. Because of the two year time-lag for winter-ring herring, between SSB and recruitment, a manual manipulation was carried out to shift the stock numbers-at-age, prior to the SRR modelling:

```
x@stock.n[,ac((range(x)["minyear"]): (range(x)["maxyear"]-1))] <- x@stock.n[,ac((range(x)["minyear"]+1): (range(x)["maxyear"]))]
```

The last three years of the assessment were not used for SRR modelling. SRR was modelled for the full time-series and for a shorter time-series 1989–2011 that is thought to reflect the current regime of relatively low productivity. The latter was eventually not used for the estimation of reference points.

3.8.2.3 Results

The results of the SRR modelling are shown in Figure 3.8.2.3.1 and subsequent reference points for the VIa, VIIb,c meta-population are presented below.

B_{lim} was estimated as the median estimate of the breakpoint in the segmented regression analysis (Figure 3.8.2.3.1) using the full time-series. This resulted in an estimate B_{lim} ~ 200 000 tonnes.

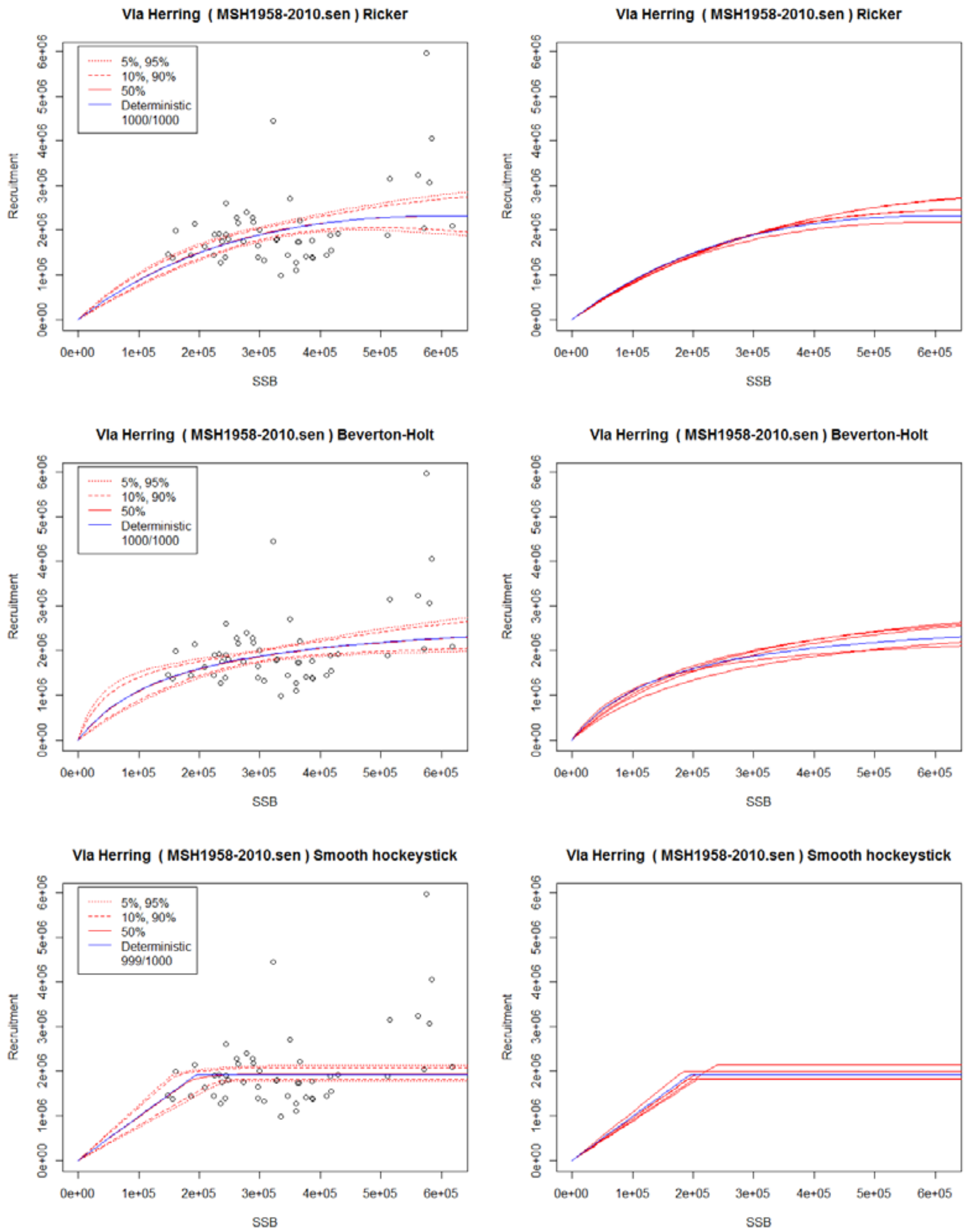


Figure 3.8.2.3.1: Herring in VIa, VIIb,c. Ricker, Beverton–Holt and smooth hockeystick SRR for the herring meta-population in VIa, VIIb,c.

Derivation of B_{pa} is not a straightforward exercise. Different methods have been proposed and applied by different ICES Study Group and Working Group (ICES, 1998; ICES, 2001; ICES, 2002; ICES, 2003b; ICES, 2003c; ICES, 2003a; ICES, 2007; ICES, 2008; ICES, 2011). A formal guidance document on the estimation of B_{pa} has never been released. However, the practice has shown that expert groups either resort to the standard of using a default multiplication factor of 1.4 (ICES, 2013a) or by using the formula $B_{pa} = B_{lim} * \exp(1.645 * \sigma)$, whereby σ is either the assumed or measured uncertainty in the assessment or forecast procedure. WKWEST has opted for the second approach. The assessment uncertainty in the estimated SSB was derived from the SAM assessment (σ=0.3, Section 3.6.5). This resulted in a B_{pa} of 325 000 tonnes. Figure 3.8.2.3.2 shows how the historical reconstruction of the VIa, VIIb,c herring meta-population compares to the reference points.

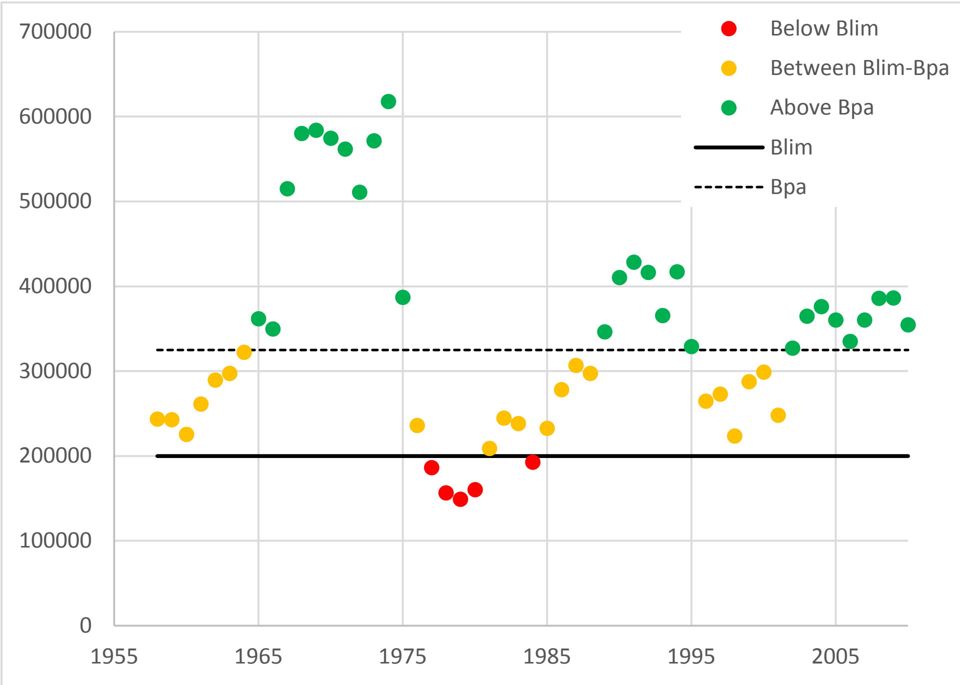


Figure 3.8.2.3.2: Herring in VIa, VIIb,c. Comparison between the historical reconstruction of the VIa, VIIb,c herring meta-population with the reference points.

F_{MSY} was estimated as the median estimate of F_{MSY} using the Ricker stock and recruitment relationship, because the Ricker SRR showed a lower steepness compared to the Beverton–Holt SRR. In the current situation with low productivity of the stock, a lower steepness seems the more plausible asssumption. This results in an F_{MSY} of 0.18.

F_{MSY} ranges were estimated as the 25% and 75% percentiles around the median F_{MSY}, corresponding to 0.16–0.21.

3.8.2.4 Conclusions

The results provide a basis for WKWEST to propose yield and precautionary based reference points for the meta-population contained in VIa, VIIb,c.

Precautionary biomass reference points required are B_{lim}, the limit reference point and B_{pa} the buffer reference point. The latter is usually a candidate for MSY $B_{trigger}$ in the ICES harvest control rule, though it will have another function as a target in rebuilding situations. B_{lim} is estimated as 200 000 t, consistent with the breakpoint in the segmented regression stock recruit relationship. B_{pa}, is based on B_{lim}, raised by assessment CV σ, where σ = 0.3. This produces an estimate of 325 000 t.

F_{MSY} reference points are required for the generic ICES harvest control rule. This includes a proposed range of F_{MSY} estimates. The estimate of F_{MSY} is derived from the Ricker SRR with a point estimate of 0.18, with the lower and upper bounds on estimation being respectively, 0.16 and 0.21. A single candidate for MSY $B_{trigger}$, consistent with the proposed B_{pa}, is SSB = 325 000 t.

3.8.2.5 References

Buckland, S. T., Burnham, K. P., and Augustin, N. H. 1997. Model selection: an integral part of inference. Biometrics, 53: 603-618.

ICES 1997. Report on the Study Group on the Precautionary Approach to Fisheries Management. ICES CM Assess: 07. 45 pp.

ICES 2003. Report on Precautionary Reference Points for Advice on Fisheries Management. ICES CM 2003/ACFM:15. 85 pp.

ICES 2013. Report of the Working Group on Methods of Fish Stock Assessment. 30 September - 4 October 2013, Reykjavik, Iceland. ICES CM. 2013/SSGSUE:09.

ICES 2014. Report of the Joint ICES-MYFISH Workshop to consider the basis for FMSY ranges for all stocks (WKMSYREF3), 17–21 November 2014, Charlottenlund, Denmark. ICES CM. 2014/ACOM:64.

Mesnil, B., and Rochet, M.-J. 2010. A continuous hockey stick stock–recruit model for estimating MSY reference points. ICES Journal of Marine Science, 67: 1780-1784.

3.9 Future Research and data requirements

The current approach to acoustic surveying covers the geographical range of both stocks at a time when they are mixed, but does not allow the separation or splitting of the acoustic index into its components. Catches in VIaN, especially in the historical period, cannot be split into the two stocks either. Consequently, trends in abundance and catches of VIaN and VIaS, VIIb,c cannot be evaluated separately, even when there is evidence to suggest that the stocks are fluctuating independently. Major efforts for stock identification have been underway using morphometrics, otolith shape, and genetics with positive results, but recent validation studies have introduced uncertainty into the approach. The conclusion of WKWEST is that the survey data cannot reliability be split into separate stocks with the currently available information. As such a combined assessment was considered the best approach to evaluating the stock units. This does not diminish the need to split the combined results into the two stocks. The perception of the two stocks at the beginning of January 2015 were, VIaN is stable but at a low biomass level, while VIaS, VIIb,c is very low with a recovery plan. Future research and data requirements should be directed at methods to separate the two stocks and/or methods to evaluate each stock independently.

- Research effort should continue to explore methods to identify the origin of fish within the catch and the survey within the ICES divisions of VIaN and VIaS, VIIb,c. Morphometric and otolith shape analysis need further refinement and genetic advancement are showing promise.
- Further information on the distribution of herring in Divisions VIaN, VIaS and VIIb,c during the year is required to discern the extent of mixing at the time of surveying.
- Explore options to survey spawning aggregations in VIaS, VIIb,c, especially given the observations by the fishing industry.

3.10 External Reviewers report

3.10.1 Issues addressed at the benchmark

All issues identified by the working group related to the terms of reference for VIaN and VIaS, VIIb,c, and Celtic Sea, VIIg,j were addressed at the benchmark. Information was provided on stock identification, migration, life-history indices of abundance and environmental drives of the system. By far the greatest, and most restrictive, issue associated with the mixing of fish from VIaN, VIaS and VIIb,c was an inability to determine to which stock individuals belonged. Although there are most probably fish from other management areas e.g. VIIaN, this was not considered a major matter of concern due to the relatively small proportions of these fish in the Malin Shelf survey and most probable absence in the commercial catches. Both the survey and the catch data contained an unknown portion from each stock. Furthermore, efforts to develop a splitting method using morphometrics and otolith shape were considered uncertain and unsuccessful to date due to the recent results of a validation study (results presented to WKWEST. It should be noted, however, that new population genetic studies offer some promise of providing a tool to identify the origin of individual fish. The inability to split the catch and indices into their components has restricted WKWEST from confidently conducting independent assessments based on a geographical partitioning of the stock units and the primary reason why WKWEST conducted a combined assessment. Based on the data available and the numerous sensitivity runs, the best advice for VIa, VIIb,c will be based on a combined assessment.

Overall the reviewers would like to commend the co-chairs of the WKWEST for their organization of the meeting and coordination of the data presented and reviewed. The meeting was well conducted with all interventions being considered during the deliberations. The presenters for the various components of the stock assessment were thorough and informative. The workshop participants also appreciated the extensive effort made by the assessment teams for completing, in a reasonable time, the numerous re-runs for investigation of model sensitivities and data updates. The host of the WKWEST should also be acknowledged for providing all the meeting requirements.

3.10.2 Use of final stock annex as basis for providing advice

Based on data properties and model performance, WKWEST considers the mixed-stock assessment of combined areas VIa, VIIb,c to be a Category 1 Quantitative Assessment with a full analytical assessment capable of catch forecasts. The definition of management units and catch allocations are policy decisions that are far beyond the scope of WKWEST. However, WKWEST recommends that the meta-population structure of the herring resource in Divisions VIa and VIIb,c be considered in advice for each management area (Divisions VIaN and VIaS, VIIb,c) to conserve the distinct spawning components.

The management strategy evaluation by Kell *et al.* (2009) that was based on herring in Divisions VIa and VIIb,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 VIa and VIIb,c showed that smaller population units are extremely vulnerable to overexploitation. 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.

Explorations of separate VIaN and VIaS,VIIb,c assessments were extremely sensitive to the choice of tuning indices. Although one setup for the separate assessments approximately equaled the estimated biomass and catch projections for VIa, VIIb,c when added together (presumably because the catch used in the assessments were additive), the relative biomass in each area was highly sensitive to the inclusion of bottom-trawl surveys. Exclusion of trawl surveys produced approximately a 85:15

split for VIaN, VIaS, VIIb,c, but including trawl surveys shifted the biomass, producing a ~10:90 split. Therefore, WKWEST concludes exploratory analyses of separate divisions are too uncertain to offer management advice, because they are potentially misleading. Such sensitivities affirm the WKWEST conclusion that the combined area VIa, VIIb,c assessment is the most appropriate approach for advice.

3.10.3 Recommendations for future work

3.10.3.1 The acoustics surveys

The combined VIaN and VIaS, VIIb,c assessment (WKWEST) utilizes two acoustic time-series to calibrate the SAM assessment model. The first index is based on the traditional survey that extends from 1991–2008 when the expanded (into VIaS) Malin survey began and continues to date. The approach adopted by the benchmark workshop for the assessment was to use the two time-series as independent indices with the first index stopping in 2007 and the second commencing in 2008. However, the newer time-series is basically the old geographical coverage expanded to the south. For the sake of consistency, it is **recommended** that between now and the next benchmark an analysis is undertaken whereby the first time-series is extended from 2008 to present using the overlapping coverage and the expanded coverage initiated in 2009 be considered as a new index for the assessment. This would provide a consistent index from 1991 to 2014 or the present.

3.10.3.2 The IBTS

The Scottish IBTS survey in area VIa is conducted in both the 1st and 3rd quarters of the year and changed in 2010 from sampling on an ICES statistical rectangle basis (as used in the North Sea IBTS) to a stratified random design. Although it was suggested that the implications of this on the index were likely minimal the WKWEST felt it more appropriate to break the time-series into two time periods and use only the earlier time-series in the assessment models. The more recent IBTS survey series could be considered for use by HAWG after more years of data are available and/or a determination is made on combining of the two into a single continuous time-series. The Scottish survey does not extend southward far enough to encompass all fish in the area. However, there is a Republic of Ireland survey that does extend further south and these data will be investigated to see if they can be used in conjunction with the Scottish data to provide a more complete coverage, especially of fish spawning in VIaS, VIIb,c.

3.10.3.3 Development of a multistock model for VIa, VIIb,c

It would be beneficial to build an estimation model that simultaneously models as many of the stocks in these management regions as possible. This type of model would allow incorporating information from analyses on stock composition of survey abundance indices and catch if and when it becomes available, but could also allow other approaches to specifying stock composition such as random effects approaches possible in a state-space framework similar to the SAM model currently used for the assessment. When information on stock composition is available, there could be a separate observation model for these data with the partition of survey indices and catches conducted internal to the model. This approach would also allow better accounting for observation uncertainty in estimates of abundance since both stocks exist in the same survey indices and most certainly in the historical landings. Because there is knowledge of the timing of mixing in many cases, flexible time period size and movement specification would be important to incorporate.

3.10.3.4 Issues with estimation of stock–recruit relationship

There are some well-known issues with estimating stock–recruit relationships from estimates derived from assessment models (e.g. Brooks and Deroba, 2015). Most, if not all, methods for estimating stock–recruit relationships external to assessment models make some assumptions about the independence and variance of both recruitment and spawning biomass that are not appropriate to the estimates from assessment models. Specifically, recruitment and SSB estimates from assessment models have variance that vary over time and there is correlation of the estimates with each other whereas fitting methods typically assume no error in SSB and recruitment observations are independent. More advanced methods for fitting these relationships that allow error in SSB, still assume independence of SSB and recruitment and constant variance (e.g. de Valpine and Hastings, 2002).

Some assessment models have the option to estimate stock–recruit relationships internally. This is the best method for estimating stock–recruit relationships because the variation in uncertainty and correlation of recruitment and SSB estimates is taken into account. If a stock–recruit relationship will be the basis of management reference points, then it is also best that the assessment, status determination, and projections are consistent in their usage of stock–recruit relationships.

The combined assessment of VIa, VIIb,c herring based on FLSAM allows internal estimation of some types of stock–recruit relationships, but less-reliable external estimation of stock–recruit relationships was used to derive MSY-based reference points. In future assessments, it might be beneficial to use the stock–recruit relationship consistently in the assessment, reference point, and projections.

3.11 Revised stock assessment due to changes in natural mortality post WKWEST (WKWEST Extension)

At HAWG, 2015, it was discovered that the update assessment based on WKWEST was based on erroneous natural mortality data, provided from the 2014 North Sea multispecies model key run. Work on providing a revised Benchmark assessment was conducted in March-May 2015 by correspondence. Corrections were made to the natural mortality rates and the assessment was rerun using the protocols, data inclusions and rationale as agreed by all participants, in the WKWEST Benchmark report. The updated results are given in section 3.11.1. New reference points were estimated and these are detailed in section 3.11.2. During the update in WKWEST Extension some cursory re-examination of tuning combinations were undertaken along with some preliminary explorations using a different model, not considered at WKWEST. To explore these in detail was beyond the scope of the Extension as this would involve a workload equivalent to the original Benchmark process and was beyond the scope of the update. Some of these explorations etc are mentioned in annex 7.2. The final agreed Benchmark assessment for VIa, VIIb,c had full consensus agreement however, Ireland exercised its rights to place a minority dissenting opinion in annex 7.2.

3.11.1 Revised stock assessment using natural mortality values agreed in May 2015

Due to the errors in the M values used at the Benchmark the assessment was re-run using the M values from the 2011 SMS key run. These data were previously used for the North Sea and Irish Sea herring stocks. It was decided to revert to the previous NS-SMS key run from 2011 and use the average natural mortality-at-age from 1974 –

2010 from this source in the FLSAM assessment (Table 3.11.1.1). This decision was supported by the WKWEST chairs and external reviewers in March 2015.

Table 3.11.1.1: Herring in Division VIa, VIIb,c. Average natural mortality used at WKWEST 2015 and the revised natural mortalities adopted at HAWG 2015.

AGE (RINGS)	1	2	3	4	5	6	7	8	9
WKWEST M	0.706	0.353	0.280	0.255	0.240	0.226	0.217	0.217	0.217
Revised M	0.767	0.385	0.356	0.339	0.319	0.314	0.307	0.307	0.307

The increase in natural mortality-at-age (Figure 3.11.1.1) affected the FLSAM assessment in several ways. First, as expected when natural mortality increases, the perception of the stock changed (Figures 3.11.1.2 and 3.11.1.3). Terminal SSB increased, Fbar decreased and recruitment also increased. The trajectories were also affected, with changes of uneven magnitude over the time-series (Figure 3.11.1.3).

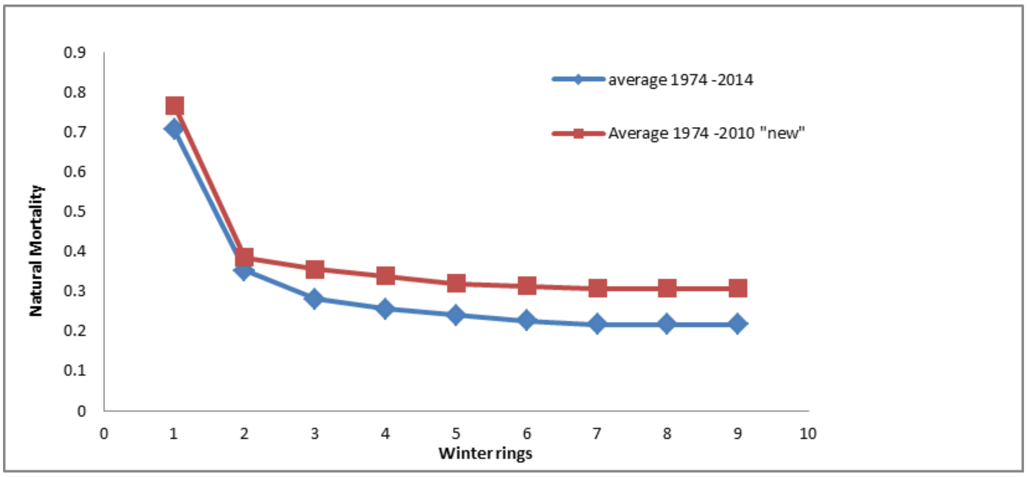


Figure 3.11.1.1. Herring in Division VIa, VIIb,c. Natural mortality-at-age from WKWEST 2015 (blue) and the revised natural mortality-at-age adopted at HAWG 2015 (red).

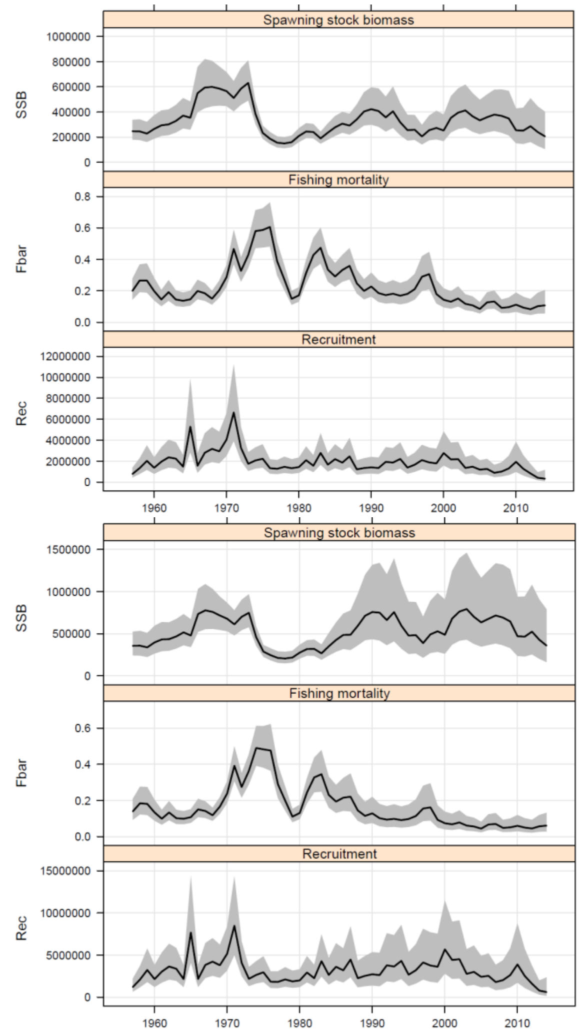


Figure 3.11.1.2: Herring in Division VIa, VIIb,c. The trajectories of SSB, Fbar and recruitment, with associated uncertainty for the original M run (left), and using the revised M at HAWG 2015 (right).

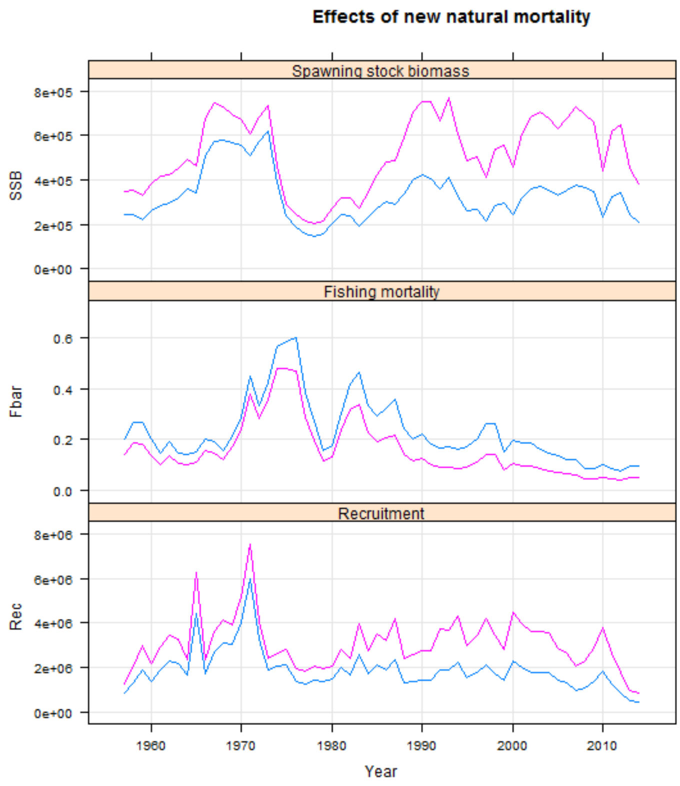


Figure 3.11.1.3: Herring in Division VIa, VIIb,c. The trajectories of SSB, Fbar and recruitment, the original M run (blue), and using the revised M at HAWG 2015 (pink).

Finally, the uncertainties surrounding those estimates were significantly inflated, particularly in the most recent period (Figure 3.11.1.2).

These changes in the FLSAM assessment, particularly the inflation in the uncertainties, caused the assessment to be rejected at HAWG 2015 (ICES, 2015). It was decided to carry out investigations to try to develop a plausible assessment for herring in VIa, VIIb,c under a WKWEST-Extension process and in time for consideration prior to the Celtic Seas ADG.

During this process, several errors were identified in the input data that was used in the VIa, VIIb,c assessment during WKWEST 2015. These were corrected and the revisions were demonstrated to have only a minor effect on the perception of the stock trajectories. It was also demonstrated that these errors were not the cause for the large increase in uncertainty surrounding the stock estimates when the natural mortality was changed at HAWG 2015. It was decided that the revised dataset be used in the revised assessment conducted by WKWEST (Lusseau *et al.*, 2015 WD to WKWEST Extension).

Further investigations led to the conclusion that only a very small change to the assessment accepted at WKWEST was necessary to counter the problems leading to the rejection of the assessment by HAWG (Lusseau *et al.*, 2015 WD to WKWEST Extension). The exclusion of the 1986 data point in the IBTS Q1 index reduced the skewed effect introducing the new M had on the estimates and their CVs. There is good evidence that the survey year in question is not comparable with the other years in the dataseries and therefore it is justified to remove it. WKWEST Extension came to a majority conclusion, that the final model, with this truncated IBTS Q1 time-series, is a suitable candidate model for assessing herring in VIa and VIIbc. The model differs in only three aspects from the model accepted by WKWEST initially: Revised input data and change in natural mortality as described above and truncating the IBTS-Q1 by one year. Full model settings and changed input data are listed in Table 3.11.1.2 and Table 3.11.1.3, diagnostics and full results from the revised final assessment are shown in Figures 3.11.1.4 to 3.11.1.18).

Table 3.11.1.2. Herring in Division VIa, VIIb,c. Model configuration settings for the FLSAM assessment accepted at WKWEST extension May 2015.

FINAL RUN SAM SETTINGS	COMBINATION
Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
Correlated random walks for F	correlated (TRUE)
Coupling of catchability parameters MS HERAS	1,2,3,3,3,3,3,3,3
Coupling of catchability parameters WoS HERAS	4,5,6,6,6,6,6,6,6
Coupling of catchability parameters IBTS Q1	NA,7,7,7,7,7,7,7,7
Coupling of catchability parameters IBTS Q4	NA,8,8,8,8,8,8,8,8
Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
Coupling of observation variances - Catch	1,2,2,2,2,2,2,3,3
Coupling of observation variances - MS HERAS	4,5,5,5,5,5,5,5,5
Coupling of observation variances - WoS HERAS	6,7,7,7,7,7,7,7,7
Coupling of observation variances - IBTS Q1	NA,8,9,9,9,9,9,9,9,
Coupling of observation variances - IBTS Q4	NA,10,11,11,11,11,11,11,11

Table 3.11.1.3. Herring in Division VIa, VIIb,c. Tuning fleets used for the final FLSAM assessment accepted at WKWEST extension May 2015.

TYPE	NAME	YEAR RANGE	AGE RANGE (WR)
Tuning fleet	**IBTS Q1**	**1987 to 2010**	**2–9+**
Tuning fleet	**IBTS-Q4**	**1996 to 2009**	**2–9+**
Tuning fleet	**Malin Shelf acoustic**	**2008 to 2014**	**1–9+**
Tuning fleet	**West of Scotland acoustic**	**1991–2007**	**1–9+**

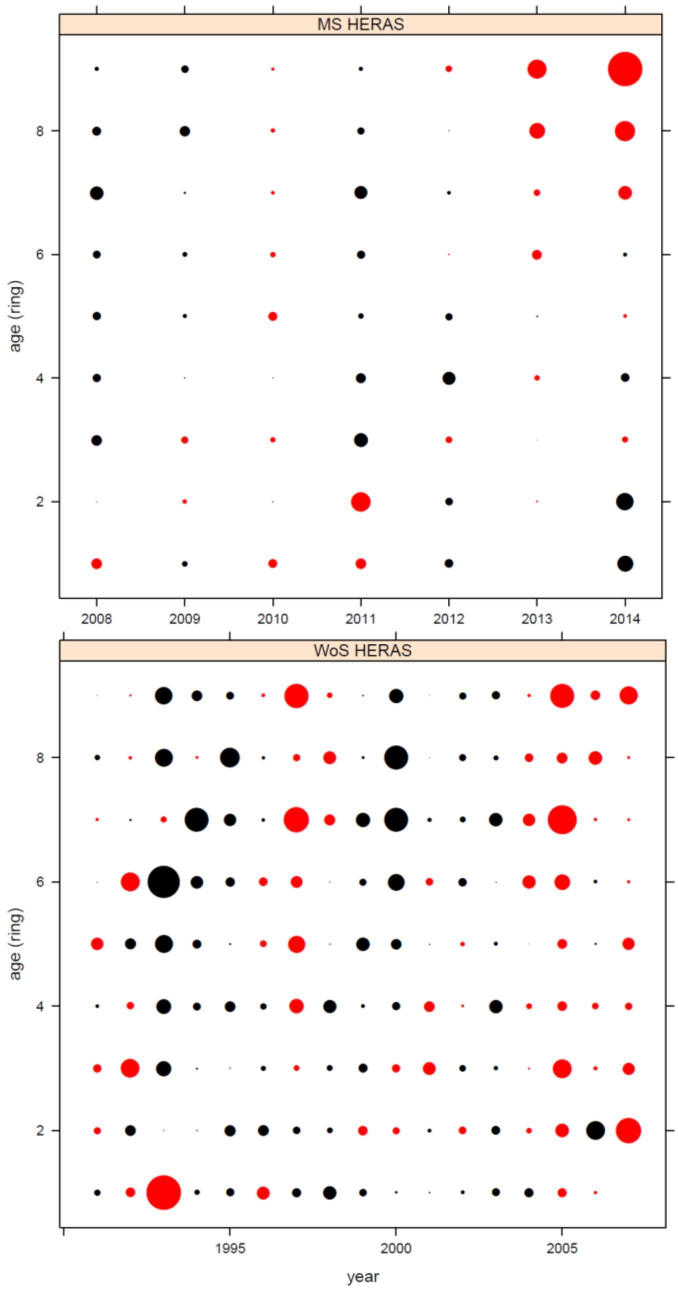


Figure 3.11.1.4. Herring in Division VIa, VIIb,c. Bubble plot of standardized survey residuals from the Malin Shelf acoustic survey (2008–2014) (left) and the West of Scotland geographical area (VIaN) acoustic survey (1991–2007) (right).

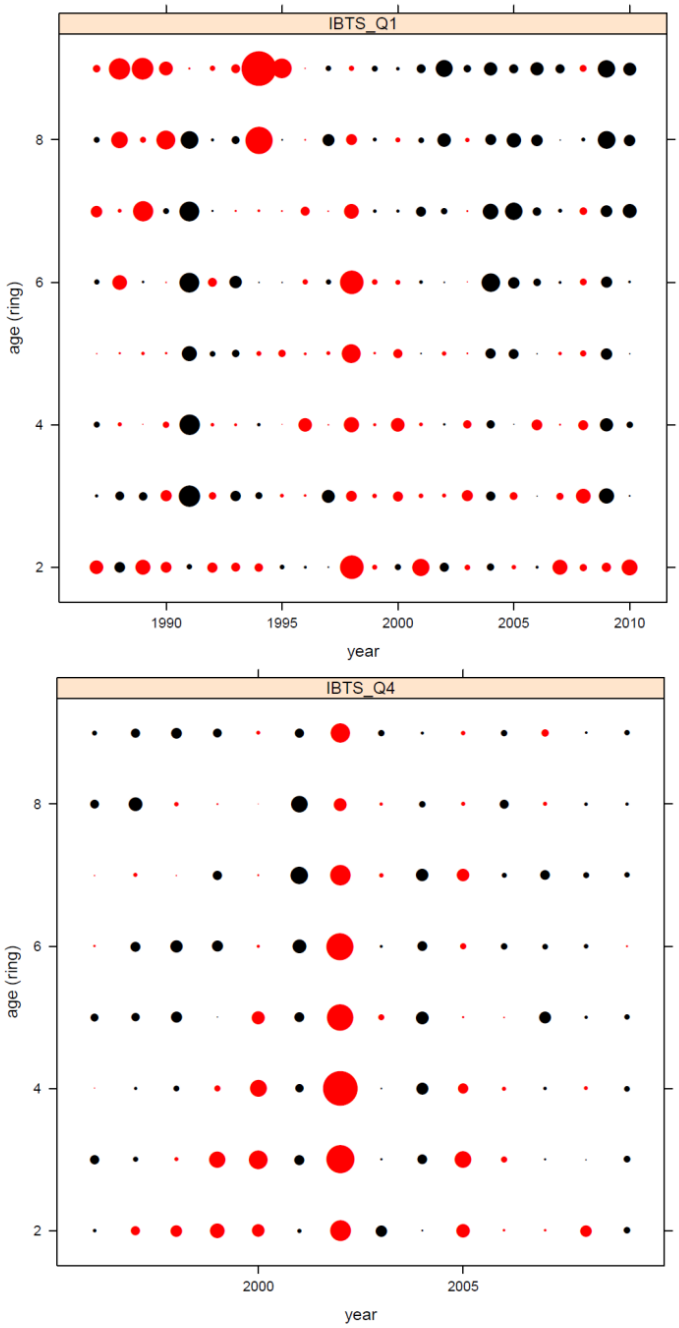


Figure 3.11.1.5. Herring in Division VIa, VIIb,c. Bubble plot of standardized survey residuals from the Scottish bottom-trawl survey in quarter 1 (1987–2010) (left) and quarter 4 (1996–2009) (right).

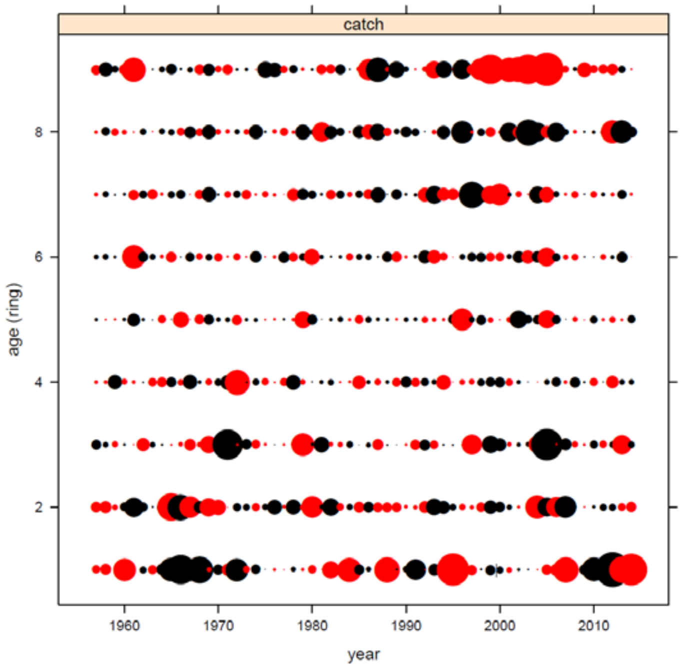


Figure 3.11.1.6. Herring in Division VIa, VIIb,c. Bubble plot of standardized catch residuals (1957–2014).

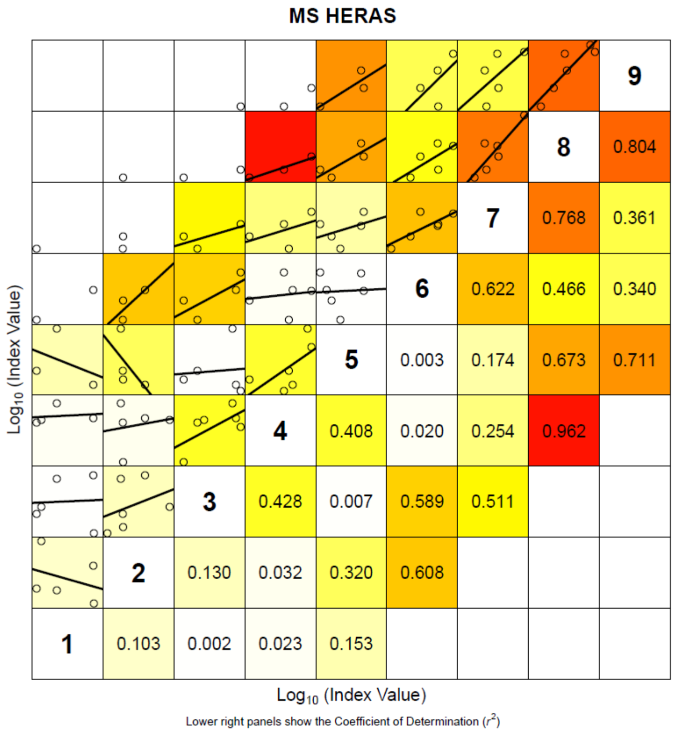


Figure 3.11.1.7. Herring in Division VIa, VIIb,c. Internal consistency between ages (rings) in the Malin Shelf herring acoustic survey time-series (2008–2014).

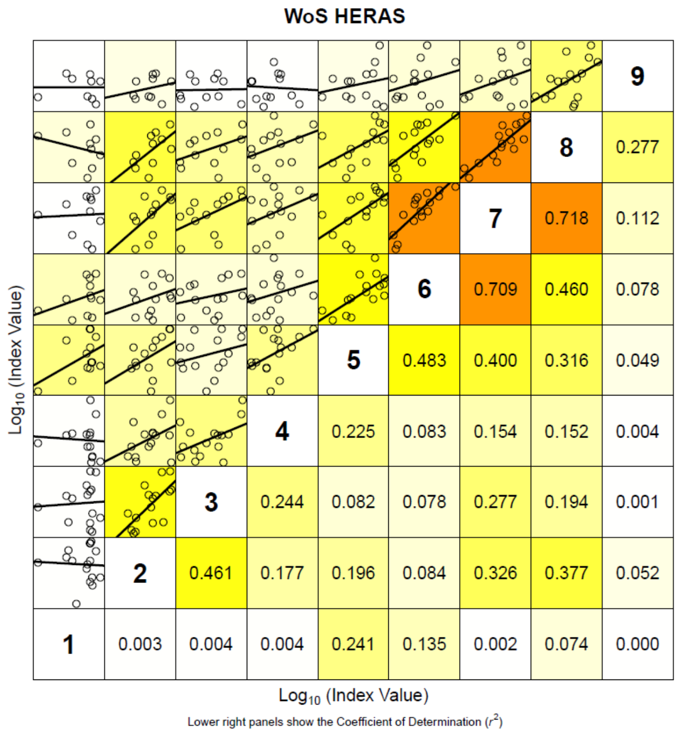


Figure 3.11.1.8. Herring in Division VIa, VIIb,c. Internal consistency between ages (rings) in the West of Scotland acoustic survey time-series (MSHAS_N; 1991 to 2007).

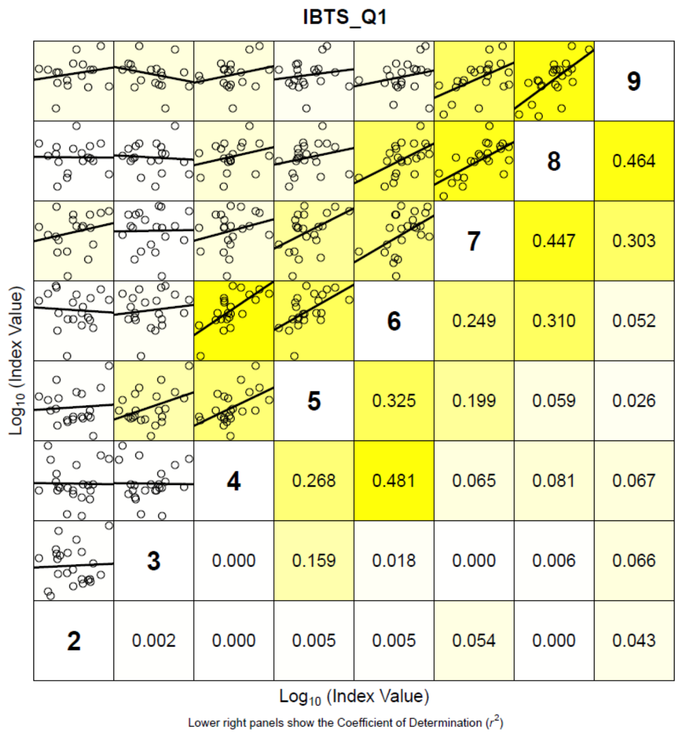


Figure 3.11.1.9. Herring in Division VIa, VIIb,c. Internal consistency plot of the quarter 1 Scottish bottom-trawl survey (1986–2010). Above the numbered diagonal the linear regression is shown including the observations (in points) while under the numbered diagonal the r^2 value that is associated with the linear regression is given.

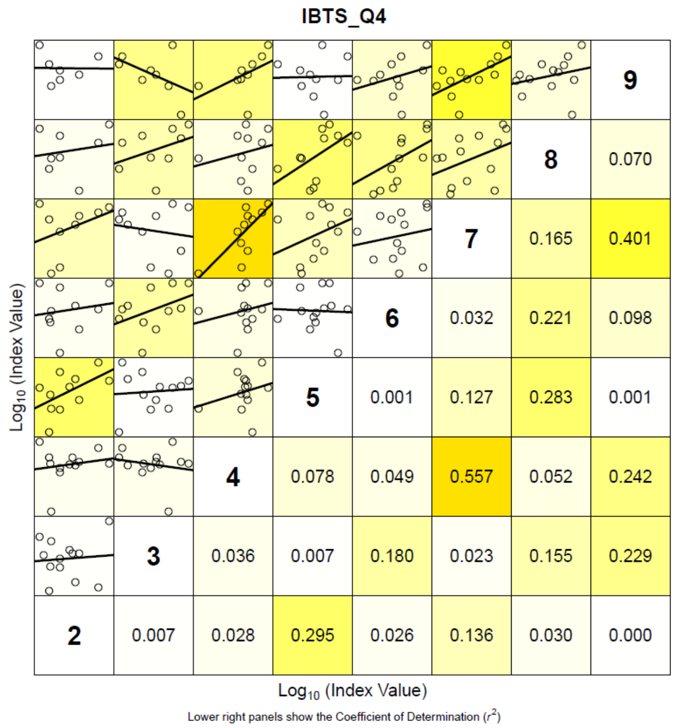


Figure 3.11.1.10. Herring in Division VIa, VIIb,c. Internal consistency plot of the quarter 4 Scottish bottom-trawl survey in (1996–2009). Above the numbered diagonal the linear regression is shown including the observations (in points) while under the numbered diagonal the r² value that is associated with the linear regression is given.

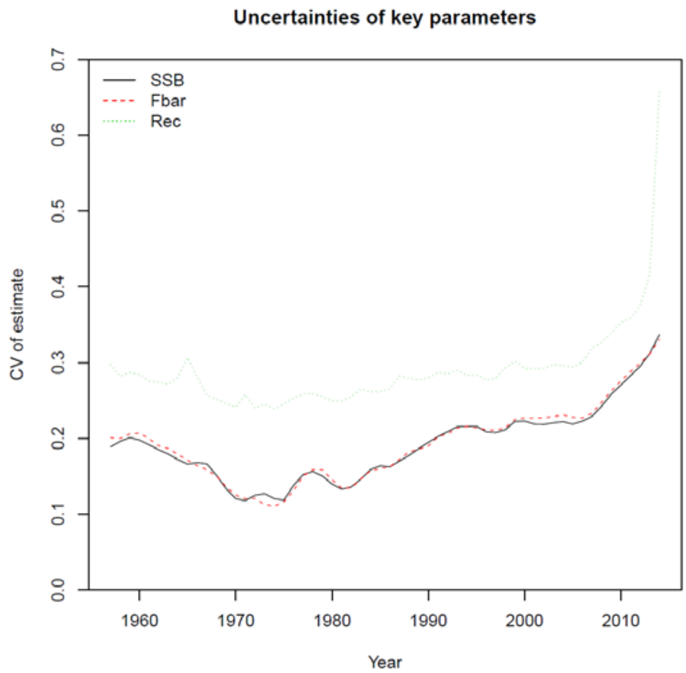


Figure 3.11.1.11. Herring in Division VIa, VIIb,c. Uncertainty estimates in SSB, Fbar and recruitment parameters (1957–2014).

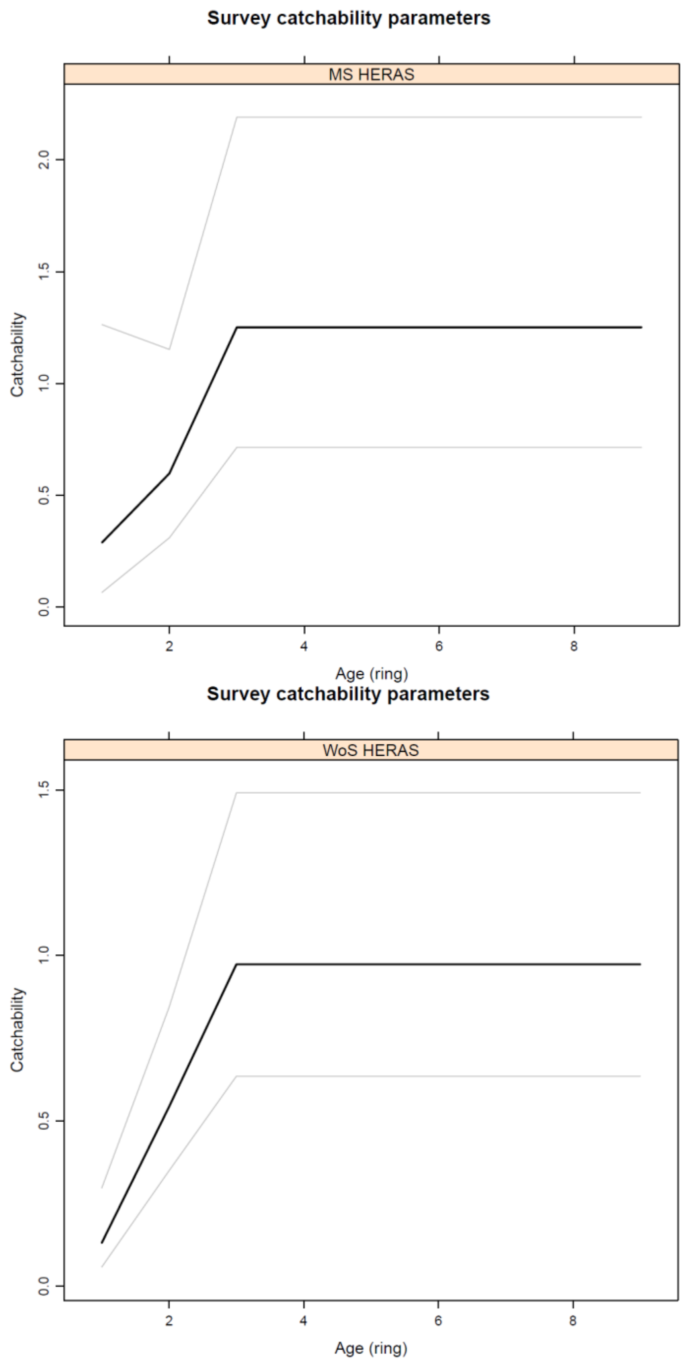


Figure 3.11.1.12. Herring in Division VIa, VIIb,c. Survey catchability parameters from the Malin Shelf acoustic survey (left) and the West of Scotland geographical area (VIaN) acoustic survey (right).

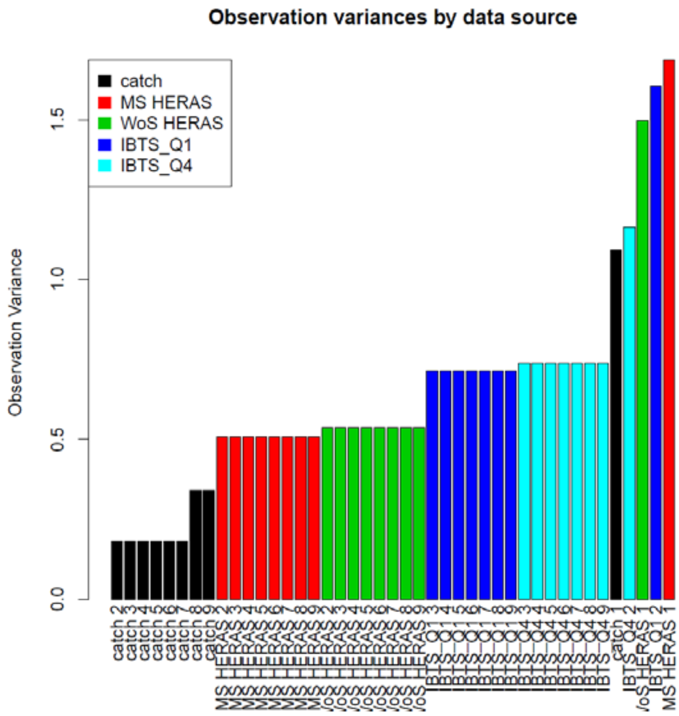


Figure 3.11.1.13. Herring in Division VIa, VIIb,c. Observation variance by data source - ordered from least (left) to most (right). Colours indicate the different data sources. In cases where parameters are bound, observation variances have equal values.

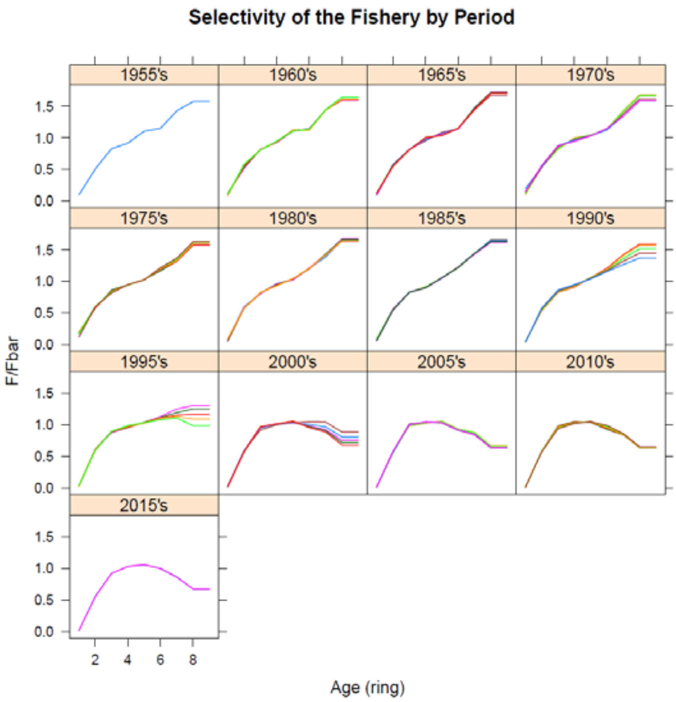


Figure 3.11.1.14. Herring in Division VIa, VIIb,c. Selectivity of the fishery at age (winter rings) by 5-year period.

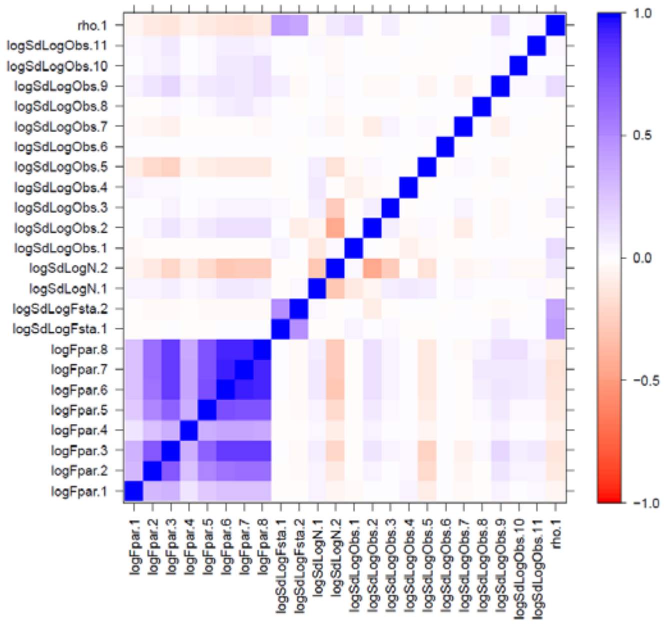


Figure 3.11.1.15. Herring in Division VIa, VIIb,c. Correlation plot of the parameters estimated in the model. The horizontal and vertical axes show the parameters fitted by the model (labelled with names stored and fitted by FLSAM). The colouring of each pixel indicates the Pearson correlation between the two parameters. The diagonal represents the correlation with the data source itself.

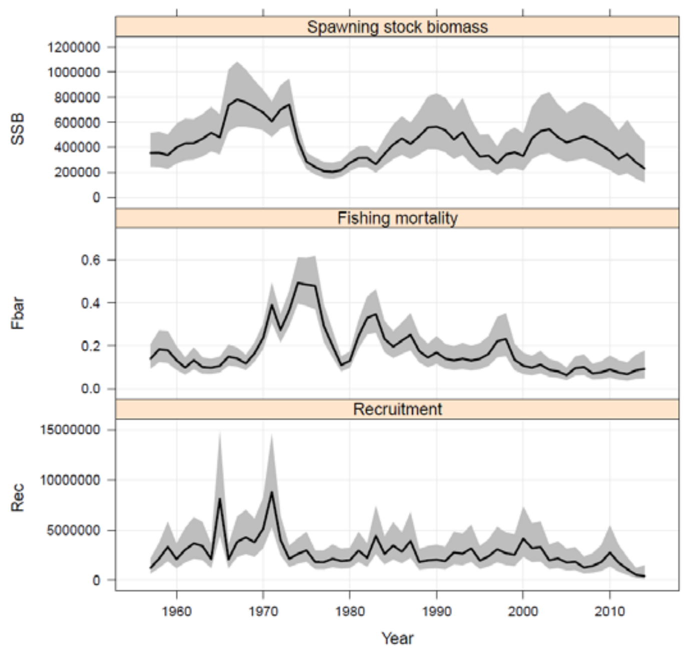


Figure 3.11.1.16. Herring in Division VIa, VIIb,c. Stock summary plot with associated uncertainty for SSB (top panel), F ages 2–6 (middle panel) and recruitment (bottom panel).

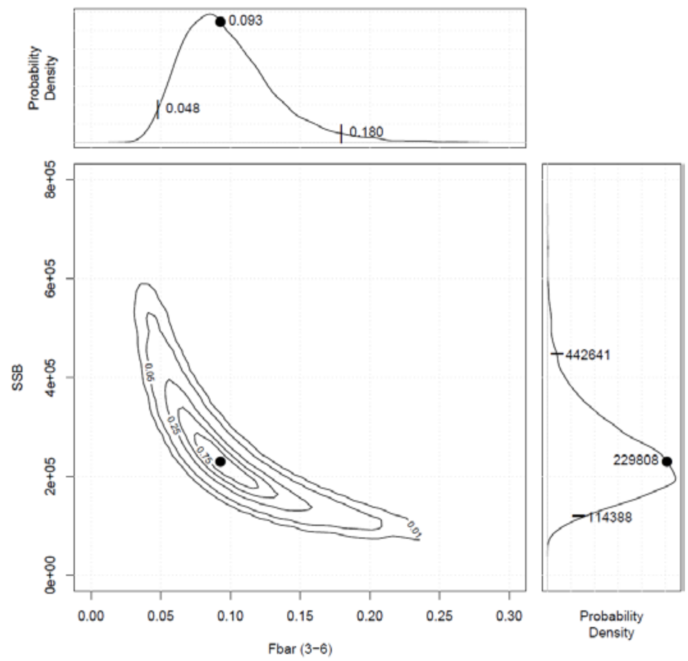


Figure 3.11.1.17. Herring in Division VIa, VIIb,c. Model uncertainty; distribution and quantiles of estimated SSB and F3-6 in the terminal year of the assessment. Estimates of precision are based on a parametric bootstrap from the model estimated variance/covariance estimates.

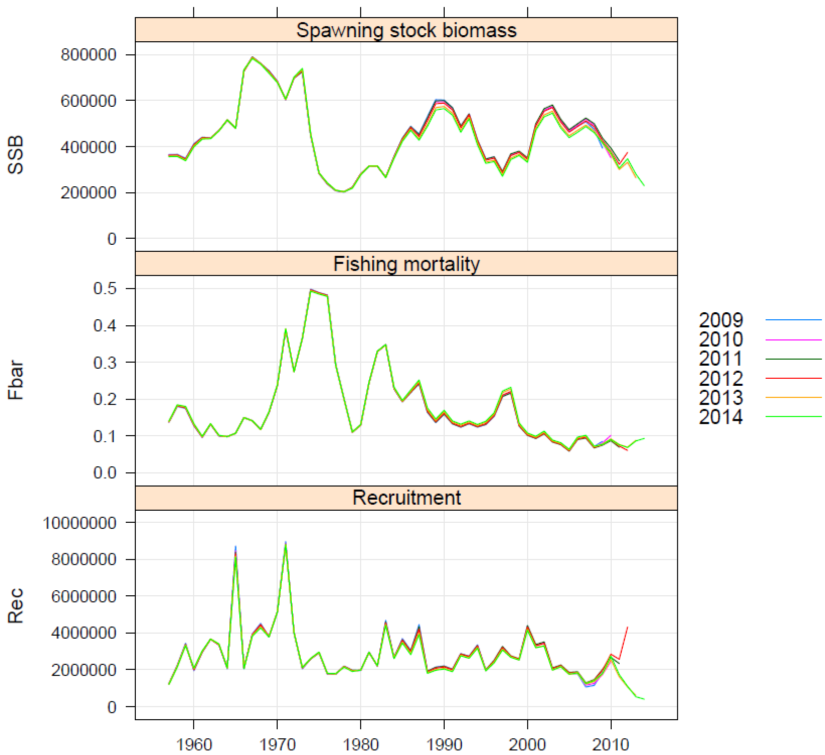


Figure 3.11.1.18: Herring in Division VIa, VIIb,c. Analytical retrospective of the estimated spawning-stock biomass (top panel), fishing mortality (middle panel) and recruitment (bottom panel) as estimated over the years 2009–2014.

3.11.2 Revised stock and recruitment relationships agreed in May 2015

3.11.2.1 Introduction

Stock recruitment relationships and potential reference points were explored using plotMSY and EqSim.

PlotMSY is intended to provide robust estimation of deterministic MSY estimates (i.e. without future process error) that could be applied easily and widely. It fits three stock–recruit functions, namely the Ricker, Beverton–Holt, and a smooth Hockey-stick (Mesnil and Rochet, 2010), to estimate MSY quantities. Uncertainty in MSY estimates are characterized by MCMC sampling of the joint pdf of the stock–recruit parameters and sampling from the distributions of other productivity parameters (i.e. natural mortality, weights-at-age, maturities, and selectivity). Stock–recruit model uncertainty can be taken into account by model averaging of the three functions (ICES, 2013b). However, in this case for VIa, VIIb,c herring we have not made use of the model averaging capabilities.

Eqsim (ICES, 2013b) provides MSY reference points based on the equilibrium distribution of stochastic projections. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age, maturities, and selectivity) are resampled at random from the last few years of the assessment. Recruitments are resampled from their predictive distribution which is based on parametric models fitted to the full time-series provided. Random deviations from S-R are the same for each target F. Uncertainty in the stock–recruitment model is taken into account by applying model averaging using smooth AIC weights (Buckland *et al.*, 1997).

Guidance on methods to be applied was sought in the WKMSYREF3 report (ICES, 2014). Although the WKMSYREF3 report gave an extensive description of the different methods (i.e. implementations) that could be used, a critical discussion of strength-weaknesses was lacking. When applying eqSim and plotMSY on the same data, WKWEST found substantial differences in the relative weight attributed to the different stock recruitment models.

Because of time constraints within the benchmark workshop, WKWEST decided to use plotMSY as the main tool for estimating reference points.

3.11.2.2 Data

Input data for stock recruitment modelling were taken from the final assessment of VIa, VIIb,c herring in the form of the SAM.RData object. Because of the two year time-lag for winter-ring herring, between SSB and recruitment, a manual manipulation was carried out to shift the stock numbers-at-age, prior to the SRR modelling:

```
x@stock.n[,ac((range(x)["minyear"]): (range(x)["maxyear"]-1))] <-
x@stock.n[,ac((range(x)["minyear"]+1): (range(x)["maxyear"]))]
```

This resulted in a time-sries being used from 1957 to 2012.

3.11.2.3 Results

The results of the SRR modelling are shown in Figure 3.11.2.1 and subsequent reference points for the VIa, VIIb,c meta-population are presented below.

B_{lim} was estimated as the median estimate of the breakpoint in the segmented regression analysis (Figure 3.11.2.1). This resulted in an estimate B_{lim} ~ 250 000 tonnes.

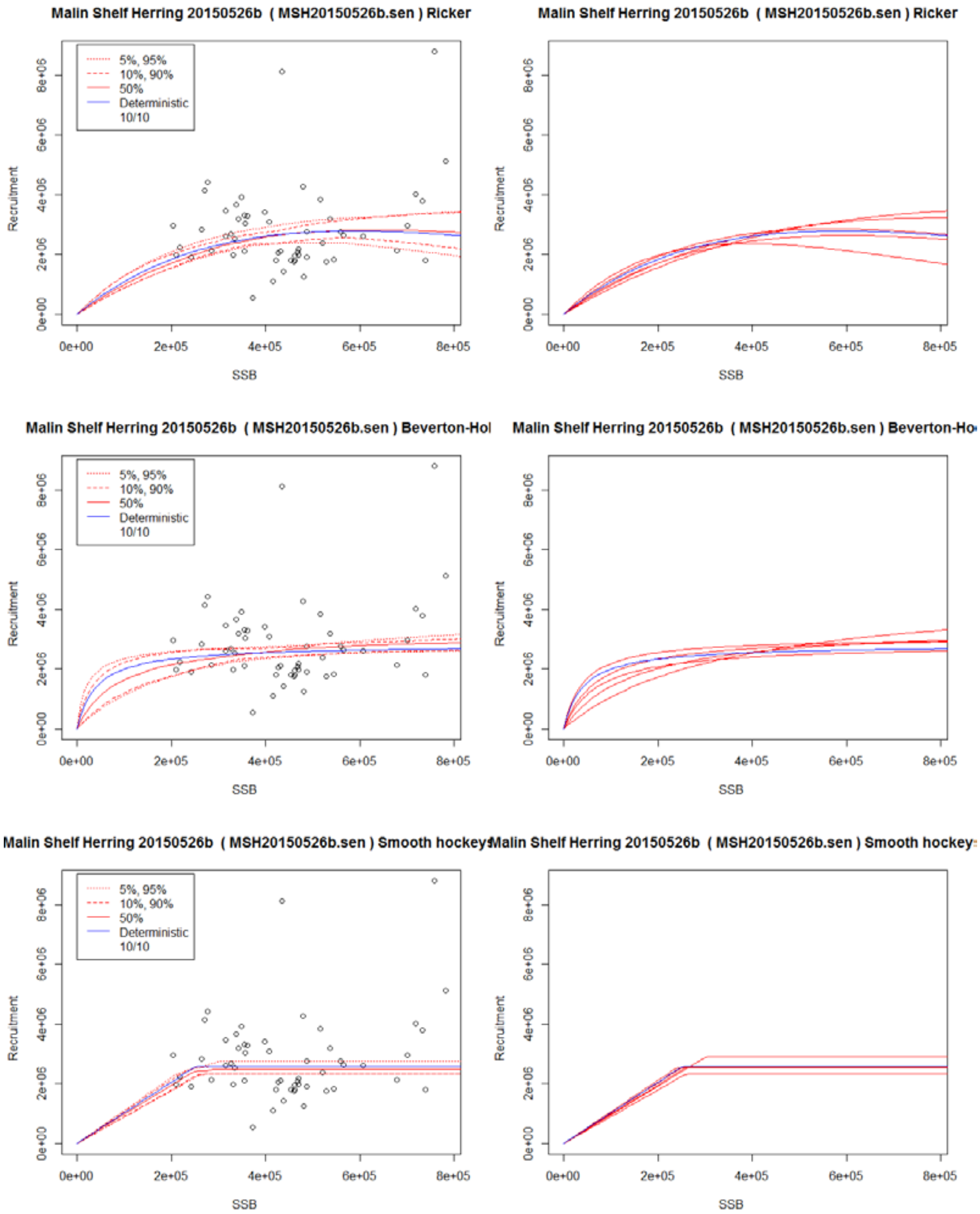


Figure 3.11.2.1: Herring in Division VIa, VIIb,c. Ricker, Beverton–Holt and smooth hockeystick SRR for the herring meta-population in VIa, VIIb,c.

Derivation of B_{pa} is not a straightforward exercise. Different methods have been proposed and applied by different ICES Study Group and Working Group (ICES, 1998; ICES, 2001; ICES, 2002; ICES, 2003b; ICES, 2003c; ICES, 2003a; ICES, 2007; ICES, 2008; ICES, 2011). A formal guidance document on the estimation of B_{pa} has never been released. However, the practice has shown that expert groups either resort to the standard of using a default multiplication factor of 1.4 (ICES, 2013a) or by using the formula $B_{pa} = B_{lim} * \exp(1.645 * \sigma)$, whereby σ is either the assumed or measured uncertainty in the assessment or forecast procedure. WKWEST has opted for the second approach. The assessment uncertainty in the estimated SSB was roughly derived from the SAM assessment (σ=0.3, Section 3.11.1). This resulted in a B_{pa} of 410 000 tonnes.

F_{MSY} was estimated as the median estimate of F_{MSY} using the Ricker stock and recruitment relationship, because the Ricker SRR showed a lower steepness compared to the Beverton–Holt SRR. In the current situation with low productivity of the stock, a lower steepness seems the more plausible asssumption. This results in an F_{MSY} of 0.16.

F_{MSY} ranges were estimated as the 25% and 75% percentiles around the median F_{MSY}, corresponding to 0.13–0.20.

Figure 3.11.2.2 shows how the historical reconstruction of the VIa, VIIb,c herring meta-population SSB and F compares to the reference points.

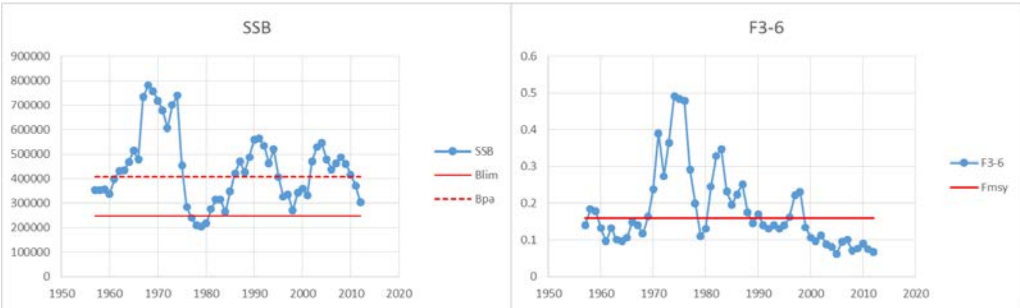


Figure 3.11.2.2: Herring in VIa, VIIb,c. Comparison between the historical reconstruction of the VIa, VIIb,c herring meta-population with the reference points.

3.11.2.4 Conclusions

The results provide a basis for WKWEST to propose yield and precautionary based reference points for the meta-population contained in VIa, VIIb,c.

Precautionary biomass reference points required are B_{lim}, the limit reference point and B_{pa} the buffer reference point. The latter is usually a candidate for MSY $B_{trigger}$ in the ICES harvest control rule, though it will have another function as a target in rebuilding situations. B_{lim} is estimated as 250 000 t, consistent with the breakpoint in the segmented regression stock recruit relationship. B_{pa}, is based on B_{lim}, raised by assessment CV σ, where σ = 0.3. This produces an estimate of 410 000 t.

F_{MSY} reference points are required for the generic ICES harvest control rule. This includes a proposed range of F_{MSY} estimates. The estimate of F_{MSY} is derived from the Ricker SRR with a point estimate of 0.16, with the lower and upper bounds on estimation being respectively, 0.13 and 0.20. A single candidate for MSY $B_{trigger}$, consistent with the proposed B_{pa}, is SSB = 410 000 t.

4 Celtic Sea, VIIg,j

4.1 Stock Identity

The herring (*Clupea harengus*) to the south of Ireland in the Celtic Sea and in Division VIIj comprise both autumn and winter spawning components. For the purpose of stock assessment and management, these areas have been combined since 1982. The inclusion of VIIj was to deal with misreporting of catches from VIIg. The same fleet exploited these stocks and it was considered more realistic to assess and manage the two areas together. This decision was backed up by the work of the ICES Herring Assessment Working Group (HAWG) in 1982 that showed similarities in age profiles between the two areas. In addition, larvae from the spawning grounds in the western part of the Celtic Sea were considered to be transported into VIIj (ICES HAWG, 1982). Also it was concluded that Bantry Bay which is in VIIj, was a nursery ground for fish of south coast (VIIg) origin (Molloy, 1968).

A study group examined stock boundaries in 1994 and recommended that the boundary line separating this stock from the herring stock of VIaS, VIIb,c be moved southwards from latitude 52°30'N to 52°00'N (ICES, 1994). However, a recent study (Hatfield *et al.*, 2007c) examined the stock identity of this and other stocks around Ireland. It concluded that the Celtic Sea stock area should remain unchanged. Some juveniles of this stock are present in the Irish Sea for the first year or two of their life. Juveniles, which are believed to have originated in the Celtic Sea move to nursery areas in the Irish Sea before returning to spawn in the Celtic Sea. This has been verified through herring tagging studies, conducted in the early 1990s, (Molloy *et al.*, 1993) and studies examining otolith microstructure (Brophy and Danilowicz, 2002). Recent work carried out also used microstructure techniques and found that mixing of 1 winter ring is extensive but also suggests mixing at older ages such as 2 and 3-wr. The majority of winter spawning fish found in adult aggregations in the Irish Sea are considered to be fish that were spawned in the Celtic Sea (Beggs *et al.*, 2008).

4.2 Issue list

During the HAWG in 2014 the following matters arose from the new benchmarked assessment of the Celtic Sea, VIIg,j, and are the main issues requiring attention for the 2015 Benchmark (WKWEST):

1) Tuning series
    a. Celtic Sea Herring Acoustic survey
        i. are there issues with double counting?
        ii. Need to look at survey design, possible revision of dataseries, possible smoothing/standardization of time-series
2) Biological parameters
    a. Decline in mean weights to lowest observed levels is reducing potential yield
        i. Evaluate potential drivers of these trends
3) Assessment method and large retrospectives
    a. Investigate models other than SAM, as only SAM was trialled in 2014

i. Comparison of available stock assessment models and assumptions
ii. Examine the impact of changing the plus group on the assessment diagnostics
iii. Model bias in the survey
iv. Perform sensitivity runs with different model input data configurations
v. Assess performance of different ages in the assessment model
vi. There are large retrospective revisions in the assessment, especially since SAM was introduced
vii. Check other assessment models as potentially more stable platforms
viii. Investigate Mohn's rho
ix. If the retro cannot be eliminated, are there methods available to deal with it?

4) Reference points
   a. re-evaluate the estimation of F_{MSY}, currently revised up to 0.37, this seems very high for a herring stock.
   b. Evaluate stock recruit relationship. The new SAM assessment changed our perception of S/R to a great extent.

4.3 Scorecard on data quality

The accuracy (potential bias) of input data for the assessment is evaluated according to the scorecard developed by the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (ICES WKACCU, 2008). The workshop developed a practical framework for detecting potential sources of bias in fisheries data collection programmes. A scorecard was applied to indicators of bias for a suite of parameters that are important for stock assessments. The scorecard can be used to evaluate the quality of data sources used for stock assessments, and to reduce bias in future data collections by identifying steps in the data collection process that must be improved.

WKACCU scorecard: Celtic Sea	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
A. SPECIES IDENTIFICATION				
1. Species subject to confusion and trained staff	green			
2. Species misreporting	green			
3. Taxonomic change	green			
4. Grouping statistics	green			
5. Identification Key	green			
Final indicator	green			
B. LANDINGS WEIGHT				
Recall of bias indicator on species identification				
1. Missing part	green			

WKACCU scorecard: Celtic Sea	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
2. Area misreporting				
3. Quantity misreporting				During period of roe fishery catches probably underreported
4. Population of vessels				
5. Source of information				
6. Conversion factor				
7. Percentage of mixed in the landings				
8. Damaged fish landed				
Final indicator				
C. DISCARDS WEIGHT				
Recall of bias indicator on species identification				
1. Sampling allocation scheme				
2. Raising variable				
3. Size of the catch effect				
4. Damaged fish discarded				Occurred during roe fishery
5. Non response rate				
6. Temporal coverage				
7. Spatial coverage				
8. Highgrading				During the roe fishery
9. Slipping behaviour				During the roe fishery
10. Management measures leading to discarding behaviour				
11. Working conditions				Unknown
12. Species replacement				
Final indicator				
D. EFFORT				
Recall of bias indicator on species identification				
1. Unit definition				Not relevant
2. Area misreporting				Not relevant
3. Effort misreporting				Not relevant
4. Source of information				Not relevant
Final indicator				
E. LENGTH STRUCTURE				
Recall of bias indicator on discards/landing weight				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Random sampling of boxes/trips				Potentially not

WKACCU scorecard: Celtic Sea	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
5. Availability of all the landings/discards				Some not fully available
6. Non sampled strata				Potentially some strata
7. Raising to the trip				
8. Change in selectivity				
9. Sampled weight				
Final indicator				
F. AGE STRUCTURE				
Recall of bias indicator on length structure				
1. Quality insurance protocol				
2. Conventional/actual age validity				
3. Calibration workshop				Last otolith exchange and workshop in 2005
4. International exchange				
5. International reference set				
6. Species/stock reading easiness and trained staff				
7. Age reading method				
8. Statistical processing				
9. Temporal coverage				
10. Spatial coverage				
11. Plus group				
12. Incomplete ALK				
Final indicator				
G. MEAN WEIGHT				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Statistical processing				
5. Calibration equipment				
6. Working conditions				
7. Conversion factor				
8. Final indicator				
H. SEX RATIO				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Temporal coverage				
3. Spatial coverage				
4. Staff trained				

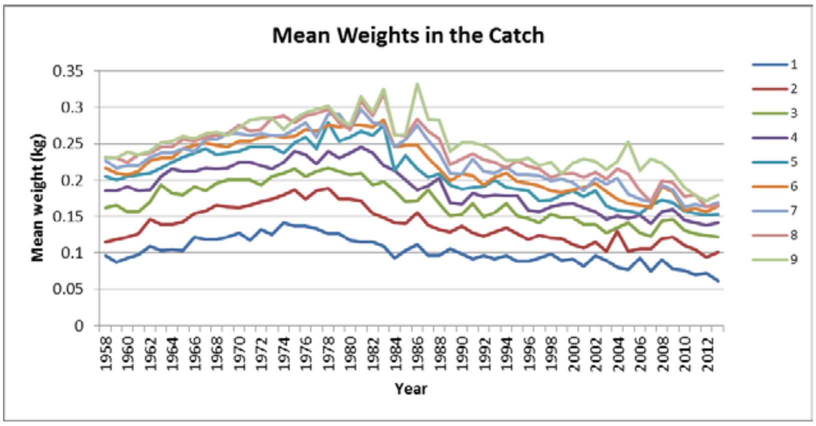
WKACCU scorecard: Celtic Sea	No bias (green)	Potential bias (orange)	Confirmed bias (red)	Comment
5.Size/maturity effect				
6. Catchability effect				
Final indicator				
I. MATURITY STAGE				
Recall of bias indicator on length/age structure				
1. Sampling protocol				
2. Appropriate time period				
3. Spatial coverage				
4. Staff trained				
5. International reference set				
6. Size/maturity effect				
7. Histological reference				
8. Skipped spawning				
Final indicator				
Final indicator				

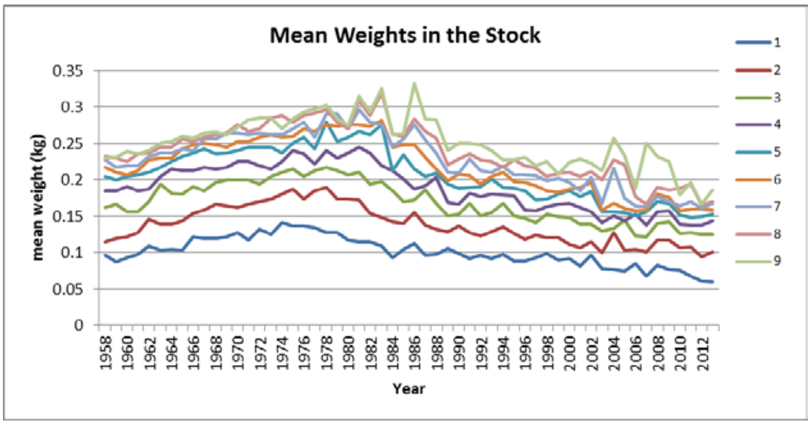
4.4 Multispecies and mixed fisheries issues

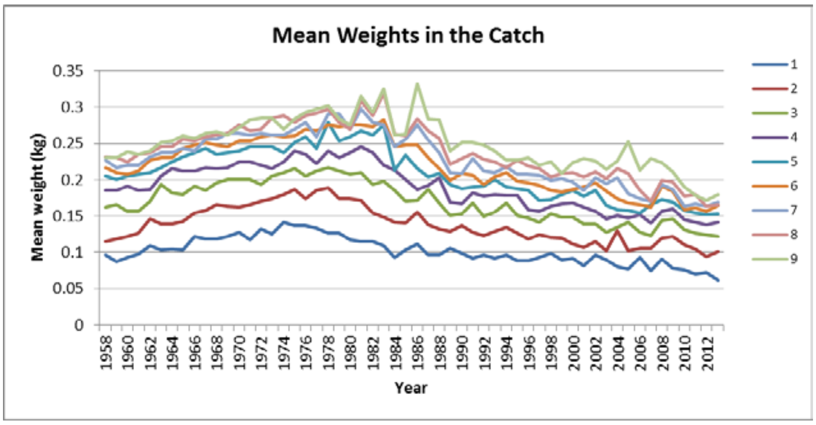
The targeted herring fishery in the Celtic Sea, VIIg,j is considered not to have any significant 'mixed fishery' aspects. Small quantities of fish are landed and discarded, however, the proportion of the total catches is very small.

4.5 Ecosystem drivers

Weights in the catch and in the stock at spawning time have shown considerable fluctuations over time (Figure 4.5.1) but with a decline to lowest observations in the series at the end. The declines in mean weights are a cause for concern, because of their impact on yield and yield-per-recruit. Harma (unpublished) found that global environmental factors, reflecting recent temperature increases (AMO and ice extent) were linked to changes in the size characteristics during the 1970's-1980's. Outside this time period, size-at-age patterns were correlated with more local factors (SST, salinity, trophic and fishery-related indicators). Generally, length-at-age was mostly correlated with global temperature-related indices (AMO and Ice), while weight was linked more to local temperature variables (SST). There was no evidence of density-dependent growth in the Celtic Sea herring population, which is in accordance with previous studies (Molloy, 1984; Brunel and Dickey-Collas, 2010; Lynch, 2011). Rather, stock size exhibited a positive relationship with long-term size-at-age of Celtic Sea herring (Harma, unpublished).







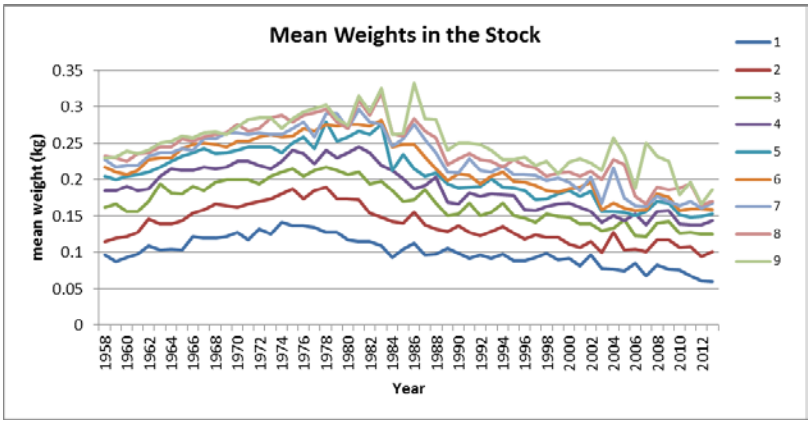


Figure 4.5.1: Herring in Celtic Sea, VIIg,j. Catch weights (top) and Stock weights (bottom) from 1958-2013.

Irish fishers have reported a change towards spawning taking place later in the season, in winter rather than autumn in the neighbouring VIaS, VIIb,c stock (Section 3.5). In the Celtic Sea, a similar situation has been documented by Harma *et al.* (2013). The causes of this are likely to be environmental, though to date they have not been elucidated (Harma *et al.*, 2013). It should be noted that declines in mean weights, examined by Harma *et al.* (2013) are not explained by the relative contribution of heavier-at-age autumn spawners. Rather, both autumn and winter spawners experienced declines in mean weights in recent years.

A shift towards later spawning has also been reported by local fishers in this area. WKWEST received a submission from the Celtic Sea Herring Management Advisory Committee of substantial spawning aggregations in Division VIIj in January 2015. This area was considered mainly as an autumn spawning area (O'Sullivan *et al.*, 2012).

Analyses of productivity changes over time in European herring stocks was examined by ICES HAWG (2006). It was found that this stock was the only one not to experience a change in productivity or so-called regime shift. This is also seen in the Surplus Production per unit stock biomass (see section 3.8.1) using information from the 2013 assessment. Evidence from the new ASAP assessment, for recruits per spawner, does not alter this perception (Figure 4.5.2).

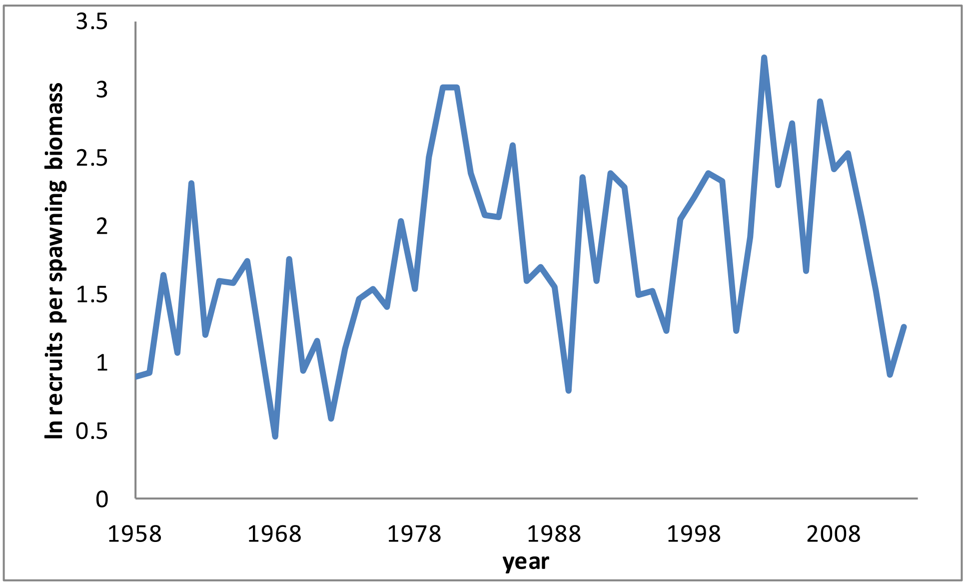


Figure 4.5.2. Herring in Celtic Sea, VIIg,j. Ln (recruits per spawner) over time by cohort in Celtic Sea herring.

4.6 Stock Assessment

4.6.1 Catch – quality, misreporting and discards

The Celtic Sea Herring assessment was run with catch data using ages 1-6+wr from 2010-2013. The plus group was 9-wr until 2007 and 7-wr until 2009. At that point it was reduced to 6-wr, which led to much improved model fitting. This reduced plus group accorded with the attenuation of older ages in the catch-at-age matrix, owing to high mortality at that time. Attempts to increase the plus group at the 2012 and 2103 herring assessment working group never yielded better diagnostics, and it has remained at 6+wr. Mean standardized catch numbers-at-age from 1958–2013 for ages

1-9+wr are presented in Figure 4.6.1, and shows the age structure has now extended beyond age 6-wr and is comparable to the earlier part of the time-series. At WKPELA 2014 the use of 9+wr in the assessment led to improved diagnostics and was therefore used in the final assessment. On this basis it was decided to proceed in 2015 with ages 1-9+wr in the assessment. The catch data used in the assessment includes data from Ireland only.

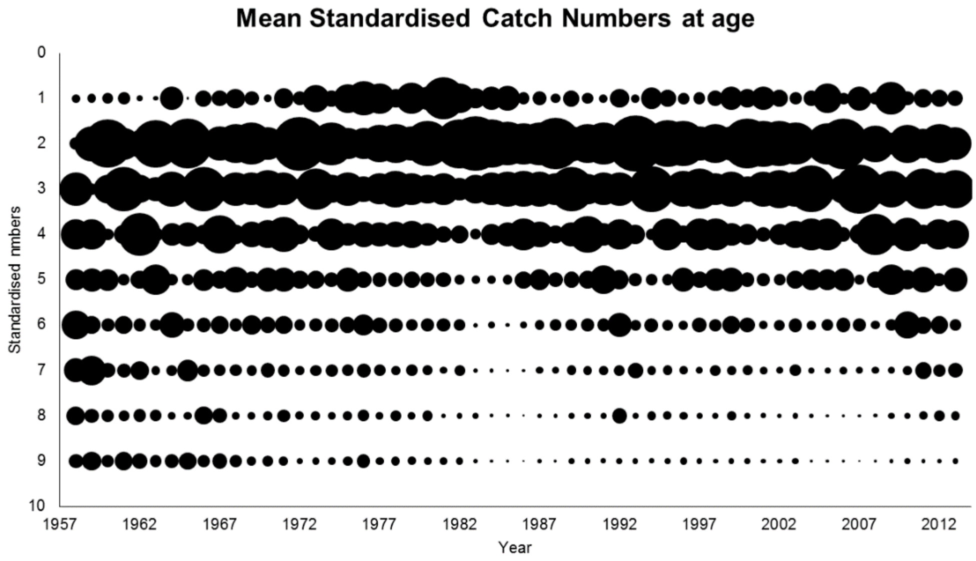


Figure 4.6.1: Herring in Celtic Sea, VIIg,j. Mean Standardized Catch Numbers-at-age 1-9+

Table 4.6.1 shows the trends over time in catch data quality. Landings data are currently expected to be very well estimated, with the best quality landings data coming from the early years when commercial transactions were available, and there was no incentive to misreport (no quotas). Discarding was high during 1980s until late 1990s, though available estimates may be too low. Since then the main reason to discard has been unwanted catch. Like all pelagic fisheries, discarding is known to occur but estimates are unavailable at present. Measures taken in 2012 have reduced the risk of discarding through more flexible individual boat quota regulations.

Table 4.6.1. Herring in Celtic Sea, VIIg,j. Catch data quality over time.

Time period	1958–1977	1977–1983	1983–1997	1998–2004	2004–present
Type of fishery	Cured fish	Closure	Herring roe	Fillet/whole fish	Fillet/whole fish
Quality of catch data	High	Medium	Low	High/medium	High/medium
Source of landings data	Auction data	Auction data	Skipper EC logbook estimate	Skipper logbook EC estimate	Weighbridge verifications
Discard Risk Levels	Low	Low	High	Medium	Medium*
Incentive to discard	None	None	Maturity stage		Size grade, market vs. quota, insufficient storage
Allowance for water (RSW tanks)	na	na	na	20%	2%

Some information on discards is available from independent work conducted by the Irish Whale and Dolphin Group (IWDG), and from the Irish national pelagic observer programme. The latter programme did not record any instances of discarding though coverage is very low. The IWDG programme achieved 5% coverage of the Irish fishery in 2013 and recorded a rate of discarding of 0.8% of observed catch indicates that discarding was very small and was not a significant issue in this fishery (McKeogh and Berrow, 2014). The vast majority of herring discarding observed were due to faulty equipment or blue sharks blocking the pump causing overflow. A similar study in the previous year (Lyne and Berrow, 2012) also found that discarding was less than 1% of catch. Boyd *et al.* (2012) recorded some slippage been in the fishery where errors in targeting and fishing on inconclusive marks lead to discarding of mixed catches of mackerel, sprat and herring. A discard rate of <1% was also reported by Lyne and Berrow (2012) during ten trips surveyed in 2012/2013 season. It is not clear how representative these estimates are of total discarding, as they are taken from low observer coverage.

4.6.2 Surveys

Acoustic surveys have been carried out on this stock from 1990–1996, and again from 1998–2014. During the first period, two surveys were carried out each year designed to estimate the size of autumn and winter spawning components. The series was interrupted in 1997 due to the non-availability of a survey vessel. Since 2005, a uniform design, randomized survey track, uniform timing and the same research vessel have been employed. The time-series currently used in the assessment runs from 2002–2014 and uses ages 2-9-wr. The acoustic time-series is presented in Table 4.6.2. Considerable fluctuations in the biomass estimate can be seen particularly in the last 3 years. There is a scarcity of data for ages 8 and 9-wr. Age 1-wr and to a lesser extent age 2-wr are variable due to the migration out of the Irish Sea nursery area.

Table 4.6.2. Herring in Celtic Sea, VIIg,j. Abundance (thousands) and biomass (thousands of tonnes) with C.V. (%) for acoustic time-series 2002–2013.

RINGS	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
0	0	24	-	2	-	1	99	239	5	0	31	4
1	42	13	-	65	21	106	64	381	346	342	270	698
2	185	62	-	137	211	70	295	112	549	479	856	291
3	151	60	-	28	48	220	111	210	156	299	615	197
4	30	17	-	54	14	31	162	57	193	47	330	44
5	7	5	-	22	11	9	27	125	65	71	49	38
6	7	1	-	5	1	13	6	12	91	24	121	10
7	3	0	-	1	-	4	5	4	7	33	25	5
8	0	0	-	0	-	1		6	3	4	23	0
9	0	0	-	0	-	0		1		2	3	2
							-					
Abundance	423	183	-	312	305	454	769	1147	1414	1300	2322	1286
SSB	41	20	-	33	36	46	90	91	122	122	246	71
CV	49	34	-	48	35	25	20	24	20	28	25	28
Design	AR	AR		R	R	R	R	R	R	AR	AR	AR

Figure 4.6.2 shows the internal consistency of the survey. Agreement between years is generally good, though it is noted that agreement is better at a time-lag of 1 year. The best agreement is between 4 and 7-wr, though in recent years there are few fish greater than 6-wr in the dataseries.

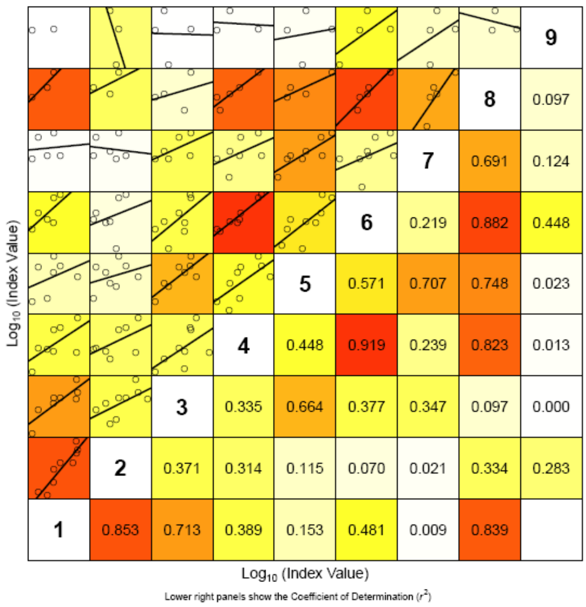


Figure 4.6.2. Herring in Celtic Sea, VIIg,j. Internal consistency in acoustic survey showing coefficient of determination between ages over time.

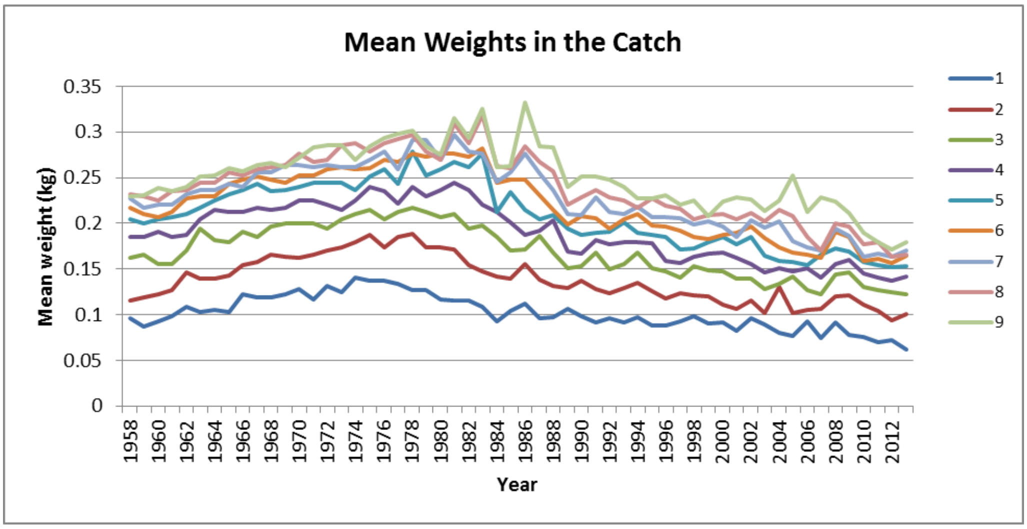
Over the last few years, the distribution of offshore Celtic Sea herring migrating to the spawning grounds south of Ireland has shifted to the east. As a result, it has been necessary to add new survey strata outside the original eastern survey boundary, in an area known as the 'Smalls', in order to ensure the survey continued to cover the migrating and spawning fish. The mileage required for the new strata was obtained by reducing the acoustic survey effort in the western offshore stratum, where little to no herring had been acoustically registered for many years. In 2013 a slight change was made to the transect designs in the inshore strata (where spawning occurs) in order to prevent possible double counting between strata.

Details of other surveys which have been investigated as possible tuning series for this stock are presented in the stock annex (ICES HAWG, 2014). However none offered sufficient year range, data quality or ability to track cohorts.

4.6.3 Weights, maturities and growth

Weights in the catch and in the stock at spawning time have shown considerable fluctuations over time (Figure 4.6.3) but with a decline to lowest observations in the series at the end. The declines in mean weights are a cause for concern, because of their impact on yield and yield-per-recruit. Harma (2014) found that global environmental factors, reflecting recent temperature increases (AMO and ice extent) were linked to changes in the size characteristics during the 1970's-1980's. Outside this time period, size-at-age patterns were correlated with more local factors (SST, salinity, trophic and fishery-related indicators). Generally, length-at-age was mostly correlated with global temperature-related indices (AMO and Ice), while weight was linked more to local temperature variables (SST). There was no evidence of density-dependent growth in the CS herring population, which is in accordance with previous studies (Molloy, 1984; Brunel and Dickey-Collas, 2010; Harma, 2014; Lynch, 2011). Rather, stock size exhibited a positive relationship with long-term size-at-age of Celtic Sea herring (Harma, 2014).

Maturity at 1-wr is considered to be 50% with 100% at subsequent ages. Lynch (2011) investigated trends over time in maturity-at-age, in commercial sampling. Earlier maturity at 1-wr began to increase in the early 1970s and has remained high ever since.



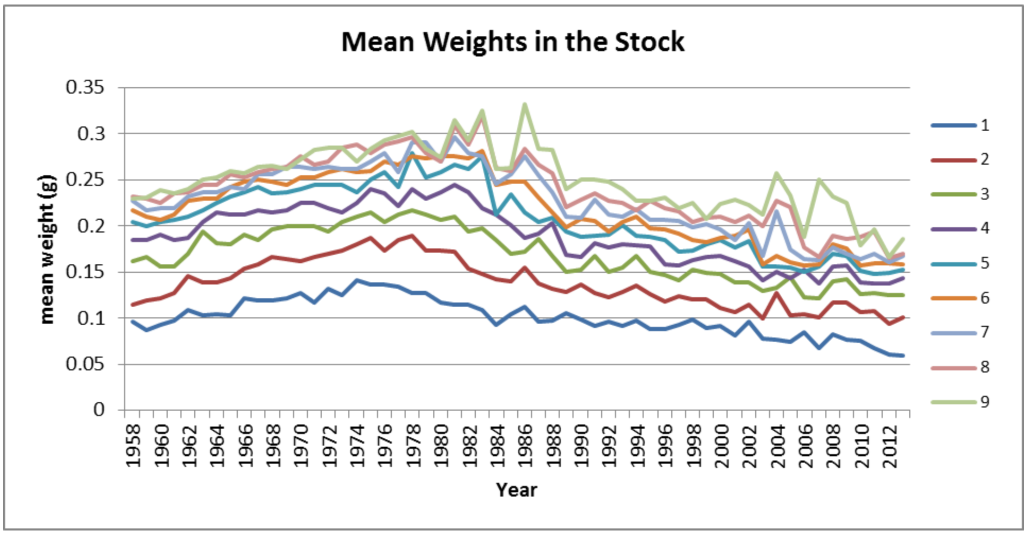


Figure 4.5.3. Herring in Celtic Sea, VIIg,j. Trends over time in mean weights in the catch (above) and in the stock at spawning time (below).

4.6.4 Assessment Model

The Celtic Sea Herring stock was assessed using ICA (Integrated Catch-at-age Analysis) (Patterson, 1998b) for a number of years. This was based on a benchmark conducted in 2007, and an inter-benchmark procedure in 2009 (ICES HAWG, 2007; 2009). The main disadvantages of ICA for the assessment of Celtic Sea Herring are as follows

- Maximum length of a time-series is 59 years;
- The core minimization library is no longer maintained which leads to an inability to fix any technical issues that may arise;
- Reliance on the assumption of separability (8 years in this case) allowed model fitting at the expense of realism. Changes in selection during this period are not considered;
- Unexplained retrospective patterns appeared in the assessment since 2010, leading to difficulties in forecasting and framing management advice.

The benchmark of this stock follows on from work done in WKPELA 2014 (ICES HAWG , 2014). Most data related issues were dealt with at that time, and a new assessment, based on SAM was implemented. However, this assessment presented some additional problems for advice provision in 2014 and consequently a further evaluation was scheduled for WKWEST in 2015.

Due to the issues with the ICA model the exploration of an alternative assessment model was carried out at the 2014 benchmark meeting. SAM was the only model tested at this benchmark. The retrospective patterns from the final SAM assessment showed significant upward and downward revisions in SSB and the pattern is more pronounced than in the previous ICA assessment. The main aim of the benchmark process was not achieved, namely to achieve a model with less retrospective year-on-year revision than the previous model. The SAM model is sensitive to the final year survey data, particularly the abnormally high 2012 survey estimates (ICES WKPELA, 2014). Also the new assessment led to a revision of the estimate of F_{MSY} from 0.25 to 0.37. WKPELA recommended that further work is required to find a more suitable model that is robust to noisy survey data and delivers improved retrospective patterns.

A new benchmark was proposed for 2015 based on deliberations at ACOM

- Consider retrospectives;
- Check robustness of F_{MSY} estimation;
- Check underlying robustness of input data especially survey data;
- Considering other possible models;
- Investigate drivers for reduced mean weights, which are affecting on yields.

The approach taken for WKWEST 2015 was as follows:

1) Model selection – identification and initial testing of a various modelling frameworks namely ICA, SAM, XSA and ASAP.
2) Data refinement – Following on from WKPELA 2014, examining options in relation to survey and catch data used in the assessment.
3) Model refinement– deciding on the optimum model settings.
4) Final evaluation– decision on a final model and final settings.

Details of the assessment input data are presented in Table 4.6.3 below.

Table 4.6.3: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring assessment input data

Data (1-9-wr)	Year range	Notes
Catch tonnes	1958-2013	Catch in tonnes incl. discards
Catch numbers	1958-2013	Catch in numbers
Mean weight catch	1958-2013	Weighted by catch numbers
Mean weight stock	1958-2013	Unweighted, from commercial sampling Oct-Feb
Natural mortality	1958-2013	From North Sea herring multi species, time invariant means
Maturity ogive	1958-2013	50% at 1-ring, 100% subsequently
Proportion of F before spawning	1958-2013	0.5
Proportion of M before spawning	1958-2013	Changed in recent years as fishery began earlier 0.5
Survey	2002-2013	2004 excluded on account of different design

SAM

The use of state space models for stock assessment has become increasingly common in recent years. In the past the reason state-space models have not been more frequently used in stock assessment is that software to handle these models has not been available (Nielsen and Berg, 2013). This is no longer the case. In a state space model the underlying process is considered a random variable that is not observed. A derived variable is observed and is subject to measurement noise (Nielsen, 2009). SAM is a state space stock assessment model that is currently used to assess several fish stocks including many herring stocks such as North Sea, Irish Sea (VIIaN) and Western Baltic Spring-spawning herring. The model allows selectivity to evolve gradually over time. It has fewer model parameters than full parametric statistical assessment models, with quantities such as recruitment and fishing mortality modelled as random effects. The SAM model uses the standard exponential decay equations to carry forward the N's (with appropriate treatment of the plus-group), and the Baranov catch equation to calculate catch-at-age based on the F's (ICES WKPELA, 2013).

Extensive work was carried out at WKPELA 2014 on the Celtic Sea herring stock. The optimum model settings for this stock were established. Additional settings were explored by the herring assessment working group 2014 (ICES HAWG, 2014). The final agreed settings are presented in the table below (plus group being 9+wr). Subsequent runs carried out for the 2015 benchmark concentrate on the choice of input data rather than the settings. The assessment of Celtic Sea herring was carried out using FLSAM which is an R-platform to run SAM.

	SAM SETTINGS BEST COMBINATION	
1	Coupling of fishing mortality states	1,2,3,4,5,6,7,8,8
2	Correlated random walks for F	correlated (TRUE)
3	Coupling of catchability parameters	1,2,3,3,3,3,3,3,3
4	Variances in F random walk	1,2,2,2,2,2,2,2,2
5	Coupling of logN RW Variances	1,2,2,2,2,2,2,2,2
6	Coupling of observation variances - Catch	1,2,3,3,3,4,4,5,5
7	Coupling of observation variances - Survey	6,6,6,6,6,6,6,6,6

Subsequent work by WKWEST, 2015, considered the following as possible improvements to the retrospective pattern:

- ages to be used in tuning
- plus group
- M at 1-winter ring
- Splitting the survey to account for the change in design

Results of SAM

The work conducted by WKPELA (ICES WKPELA, 2014) attempted to achieve an optimal formulation of the SAM approach. It is not entirely clear if the optimum formulation was achieved, owing to some errors that were subsequently spotted in the initial screening. However the formulation that was achieved offers good diagnostics (except for youngest and oldest ages in the survey) and reasonable precision. However the retrospective pattern in the new assessment is worse than in the old one. Therefore the main aim of the benchmark process has not been achieved, namely to achieve a model with less retrospective year-on-year revision than the previous model. The SAM model is rather sensitive to the final year survey data, particularly the abnormally high 2012 survey estimates. Further work, either through another benchmark in future, or through the inter-benchmark process may be required to find the most suitable model that is robust to survey outliers and delivers better retrospective patterns.

Parameterization of the model reduced the effective number of free parameters in the model by binding selected parameters together. This refinement uses one fitted parameter to represent more than one variable in the model i.e. binding ages together. The reduction in the number of parameters can lead to a poorer quality fit but it has the benefit of producing a simpler model that is quicker to run and easier to interpret (ICES WKPELA, 2012). The Akaike Information Criteria (AIC) and the negative log likelihood were used to judge the model performance.

Additional investigations, based on the final SAM model configuration, as used in 2014, focused on investigating the natural mortality (M) at 1-wr, reducing the plus group and the number of ages used in tuning, with a view to improving the retrospective pattern. None of the additional investigations improved the retrospective pattern to any degree, nor did they lead to great changes in diagnostics (variance covariance matrix, negative LL, AIC). However changes did lead to big differences in stock perceptions. This tends to support the view of SAM not being an appropriate platform for management and forecasting of this stock.

Table 4.6.4 shows the results of the various SAM additional runs conducted in 2015. These runs are not presented in detail in this document. Improvements in the retrospective pattern were not achieved. Splitting the tuning index into stanzas relating to the change in survey design, did not improve the retrospective. Likewise, changes to the plus group and the tuning series age range did not improve matters.

Table 4.6.4. Herring in Celtic Sea, VIIg,j. Results of SAM runs conducted in 2015. AIC and negative log likelihoods presented along with terminal SSB and F, and whether there was a retrospective pattern.

plus group (wr)	survey ages (wr)	missing survey	AIC	nLL	retro	Split index
6	1-6	na	676.53	325.27	y	n
6	2-5	na	601.56	287.78	y	n
6	3-5	na	586.47	280.23	y	n
7	2-5	na	699.91	336.95	y	n
7	3-5	na	691	327.53	y	n
9	2-5	na	934	453.01	y	n
9	2-6	na	962	467	y	n
9	1-9	na	1067.7	519.9	y	y
9	1-9	na	1067	519.86	y	n
9	2-5	na	1011	493.74	y	n
9	1-7	na	1016	494	y	n
9	1-7	2012	995	483	y	n
9	1-9	na	1037	504.8	y	n
9	1-9	na	1037	504.878	y	n
9	1-9	2012	1012	492	y	n
9	2-5	na	934	453	y	n
9	2-5	2012	915	443	y	n
9	2-6	na	962	467	y	n
9	2-6	na	940	754	y	n
9	2-7	na	991	481	y	n
9	2-8	na	1005	488	y	n

The best case SAM run is presented in detail in the HAWG report (ICES HAWG, 2014) and diagnostics are not presented here. By way of contrast, a modification of this run, using the previously-used (2-5 wr) tuning age range is represented by the results below (Figure 4.6.4 and 4.6.6). The retrospective pattern is equally bad without any improvement in model diagnostics. The additional runs detailed in Table 4.6.4 above do not offer any improvements on the final HAWG 2014 run.

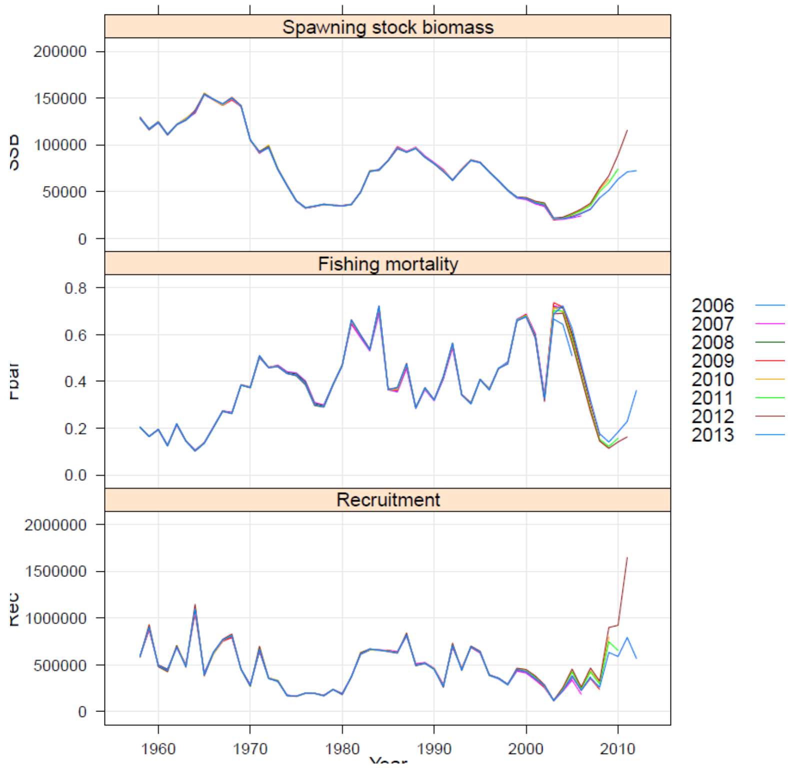


Figure 4.6.4. Herring in Celtic Sea, VIIg,j. Upper panel, retrospective pattern for an adaptation of the base case SAM run with a reduced schedule of tuning ages (2-5-wr).

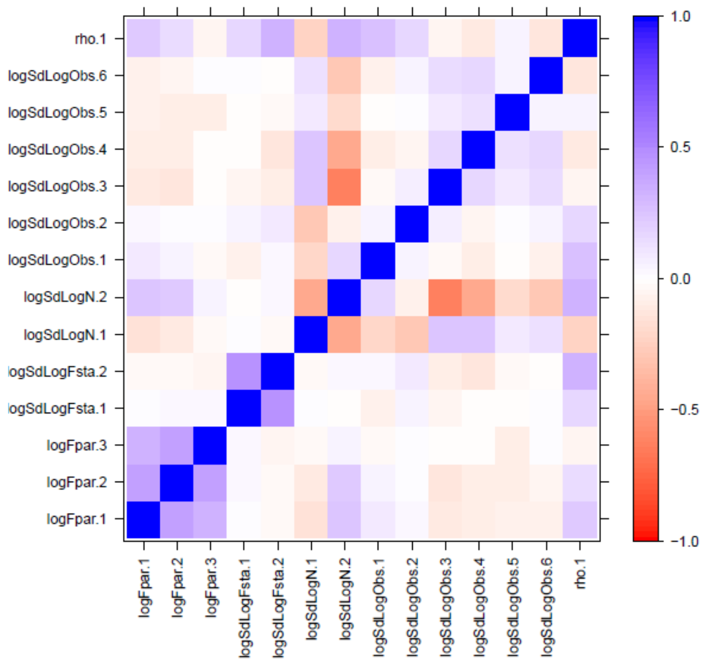


Figure 4.6.5. Herring in Celtic Sea, VIIg,j. Lower panel, correlation matrix for the same run (base case SAM run with a reduced schedule of tuning ages (2-5-wr).

XSA

Extended survivors analysis (Shepherd, 1999; Darby, 2000) is a widely used tool in fisheries stock assessment in Europe. It is not a statistical model, rather it is a deterministic algorithm based accountancy tool that can account for survivorship in a stock given information on catch-at-age, and survey indices. It has been shown to perform better than the older tuning methods in simulation tests. It incorporates some of the important features of full integrated statistical methods, but is computationally less demanding. It would be expected to perform well unless the precision of the catch-at-age data are substantially worse than that of the best abundance index available, and should therefore be useful in many practical situations. It does not, however, allow for the full statistical complexity of the problem, and may be regarded as a useful practical method of intermediate complexity.

The best case XSA run diagnostics are presented below, and are typical of all runs (Figures 4.6.6-4.6.8). Strong year effects are obvious in the survey. In addition, there was no metric that suggested itself as being indicative of a better model formulation. In all cases, the retrospective pattern was quite bad, influenced especially by the high 2012 survey estimate. On the basis of these runs, it was decided not to pursue XSA as a platform for assessing this stock.

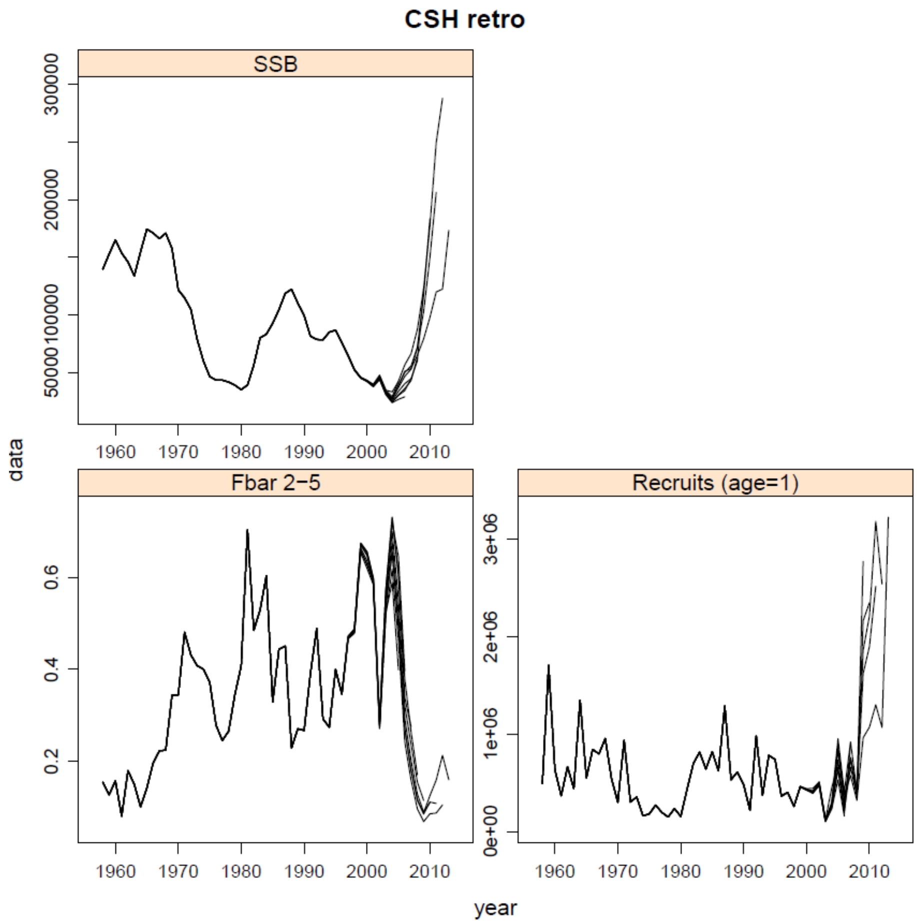


Figure 4.6.6. Herring in Celtic Sea, VIIg,j. Retrospective pattern for base case run using XSA

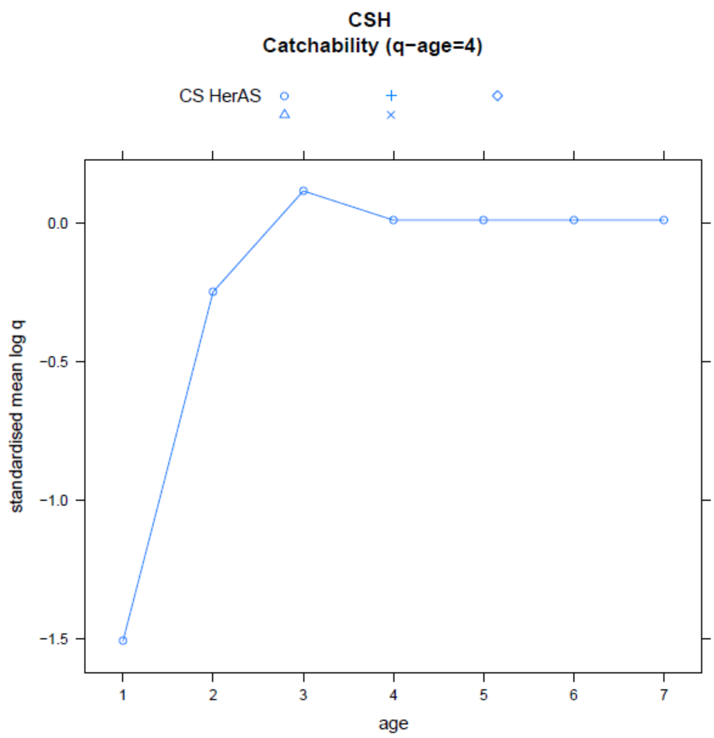


Figure 4.6.7. Herring in Celtic Sea, VIIg,j. Fitted selection pattern for base case XSA assessment run, where q plateau is set at 4-wr.

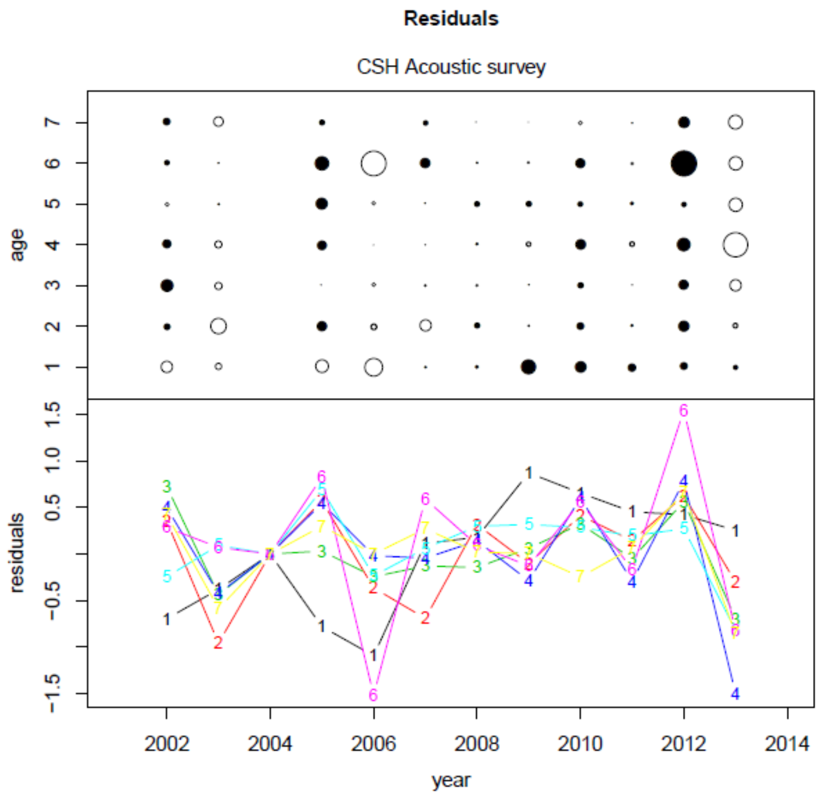


Figure 4.6.8. Herring in Celtic Sea, VIIg,j. Residual pattern for the modelled tuning series from the base case XSA assessment.

ASAP

The Celtic Sea Herring stock was assessed using ASAP 3 (http://nft.nefsc.noaa.gov). ASAP (A Stock Assessment Program) is an age-structured stock assessment modelling program originally develop by Chris Legault and Victor Restrepo while they were at the Southeast Fisheries Science Center (Legault and Restrepo, 1998). ASAP is a variant of a statistical catch-at-age model that can integrate annual catches and associated age compositions (by fleet), abundance indices and associated age compositions, annual maturity, fecundity, weight, and natural mortality-at-age. It is a forward projecting model that assumes separability of fishing mortality into year and age components, but allows specification of various selectivity time blocks. It is also possible to include a Beverton–Holt stock–recruit relationship and flexible enough to handle data poor stocks without age data (dynamic pool models) or with only new and post-recruit age or size groups. Further details on model equations and objective function components and instructions are described in the ASAP 3 Technical Documentation and User's Guide which are provided with the installation.

An initial base run was carried out with the settings in Table 4.6.5 below as a starting point for this assessment.

Table 4.6.5: Herring in Celtic Sea, VIIg,j. Summary of ASAP setting used in the base run (run 1).

Discards Included	No
Use likelihood constant	No
Mean F (Fbar) age (wr)range	2-5
Number of selectivity blocks	1
Fleet selectivity	By Age: 1-9-wr: 0.3,0.5,1,1,1,1,1,1,1 Fixed at age 9-wr
Index units	2 (numbers)
Index month	October (10)
Index selectivity linked to fleet	-1 (not linked)
Index Years	2002-2013 (no survey in 2004)
Index age (wr)range	1-9
Index Selectivity	0.5,0.5,0.5,0.5,1,1,1,1,1 Fixed from ages 5-9-wr
Index CV	0.1 all years
Sample size	No of samples collected per survey
Phase for F-Mult in 1st year	1
Phase for F-Mult deviations	2
Phase for recruitment deviations	3
Phase for N in 1st Year	1
Phase for catchability in 1st Year	1
Phase for catchability deviations	-5
Phase for Stock recruit relationship	1
Phase for steepness -	-5 (Do not fit stock–recruitment curve)
Recruitment CV by year	1
Lambdas by index	1
Lambda for total catch in weight by fleet	1
Catch total CV	0.2 for all years
Catch effective sample size	No of samples from Irish sampling programme
Lambda for F-Mult in 1st year	0 (freely estimated)

Discards Included	No
CV for F mult in the first year	0.5
Lambda for F-Mult deviations	0 (freely estimated)
CV for f mult deviations by fleet	0.5
Lambda for N in 1st year deviations	0 (freely estimated)
CV for N in the 1st year deviations	1
Lambda for recruitment deviations	1
Lambda for catchability in 1st year index	0
CV for catchability in 1st year by index	1
Lambda for catchability deviations	0
CV for catchability deviations	1
Lambda for deviation from initial steepness	0
CV for deviation from initial steepness	1
Lambda for deviation from unexplained stock size	0
CV for deviation from unexplained stock size	1

A number of runs were carried out to explore different data combinations and model settings. Settings are as per Table 4.6.5 above, with the adjustments as summarized in Table 4.6.6 below. The main data options explored involved adjustments to the survey index data. Years where the surveys were problematic were removed and different age combinations were explored. A split time-series was also examined. This is to represent the slight change in the survey design when additional track was covered. Setting such as the CV on the catch data and a number of selectivity options were also examined.

Changes to the age range in tuning were tested in runs 1,2,10 and 11. The retrospective pattern was similar when ages 1-9-wr (run 1 – Figure 4.6.14) and 1-8-wr (run 11) are used. A greater divergence in SSB values in the terminal year can be seen when the age range is reduced to 2-5-wr (run 2) or 3-6-wr (run 10) (Figure 4.6.9). However given the good internal consistency between ages in the acoustic survey, there did not seem any a priori basis to reduce the age range.

Changes to catch CV were investigated in runs 1, 3 and 4. Run 1 and 2 used a CV of 0.2 across all ages. Run 3 reduced this CV to 0.1. Run 4 used higher CVs for periods when the catch data were considered to be less accurate (see stock annex). This approach led to a poorer retrospective pattern. There is no underlying analysis available to estimate the CV on the catch data, and a CV of 0.2 across all years is considered to be a base case scenario.

Runs 5 and 6 investigated differing selection patterns using two blocks of years. Run 5 considered a separate selection pattern from 1997 onwards. This was based on an a priori consideration that the exploitation pattern of the fishery changed at this time. There is empirical evidence of this in catch curves and log catch ratios which showed a shift in the shape of selection after 1996. This also aligns with the end of the targeted roe fishery. This run yielded a much similar retrospective pattern to the base run. Run 6 incorporated two separate separable periods, the second beginning in 2007, when the closed box was instituted as part of the rebuilding plan. It was thought that the closed box may have led to a change in selection and caused the retrospective pattern to worsen. This run again showed a similar retrospective pattern to the base run.

Runs 7 and 9 attempted to deal with the year effect in the 2012 survey, either by splitting the survey to account for the change in design (run 9) or removal of the 2012 survey point (run 7). Neither run improved the diagnostics. Only the removal of the 2013 survey (run 8) improved the retrospective pattern.

Stock trajectories were very similar for all runs, apart from those reducing the age ranges used in tuning the assessment. Run 1 is considered to be the base case run. Further work at WKWEST was required to expertly review the run diagnostics and decide on the best ASAP model formulation.

Table 4.6.6: Herring in Celtic Sea, VIIg,j. Summary of the ASAP runs. The base run is run 1. Base case run indicated in bold.

Run No	Catch Data	Survey data	Comments
1	ages 1-9 wr	ages 1-9 wr	Settings as per summary table (Table 3)
2	ages 1-9 wr	ages 2-5 wr	Settings as per summary table (Table 3)
3	ages 1-9 wr	ages 1-9 wr	Catch CV 0.1 all years
4	ages 1-9 wr	ages 1-9 wr	Catch CV set according to data quality
5	ages 1-9 wr	ages 1-9 wr	2 selection blocks 58-96 and 97-13
6	ages 1-9 wr	ages 1-9 wr	2 selection blocks based on closed area 58-06, 07-13
7	ages 1-9 wr	ages 1-9 wr	No 2012 survey
8	ages 1-9 wr	ages 1-9 wr	No 2013 survey
9	ages 1-9 wr	ages 1-9 wr	split survey series 02-10, 11-13
10	ages 1-9 wr	ages 3-6 wr	Settings as per summary table
11	ages 1-9 wr	ages 1-8 wr	Settings as per summary table

ASAP Base Run Results

Figure 4.6.10 shows the catch proportions-at-age residuals. The residuals are large for the young ages, which is to be expected because these are estimated with low precision. There are no clear patterns in the residuals. Figure 4.6.11 shows the observed and predicted catches. In general, the model followed the observed catches quite closely. Figure 4.6.12 shows the residuals of the index proportions-at-age. There are no clear patterns in the residuals.

Figure 4.6.13 shows the selectivity which is assumed constant over time. The model estimates selectivity-at-ages 1-8-wr with selection fixed at 1 for age 9-wr. The fishery selectivity shows selection to be increasing at age before being fully selected at age 9-wr.

ASAP shows a much improved retrospective pattern than any of the previous models that were applied to these data. This shows a more stable assessment for SSB and mean F. The retrospective from the base run with survey ages 1-9-wr is presented in Figure 4.6.14. The significant revisions in SSB that can be seen in other models are not as pronounced here.

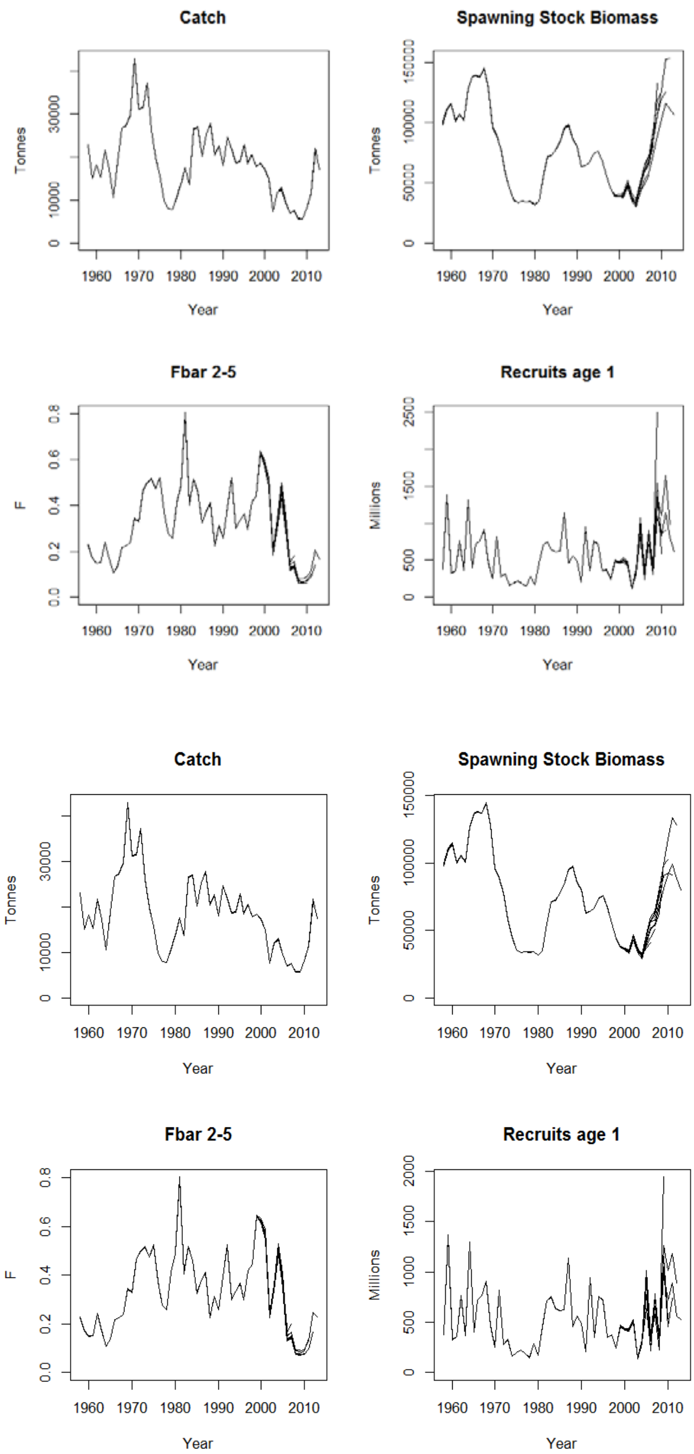


Figure 4.6.9: Herring in Celtic Sea, VIIg,j. Retrospective survey ages 2-5 wr (top) and 3-6 wr (bottom)

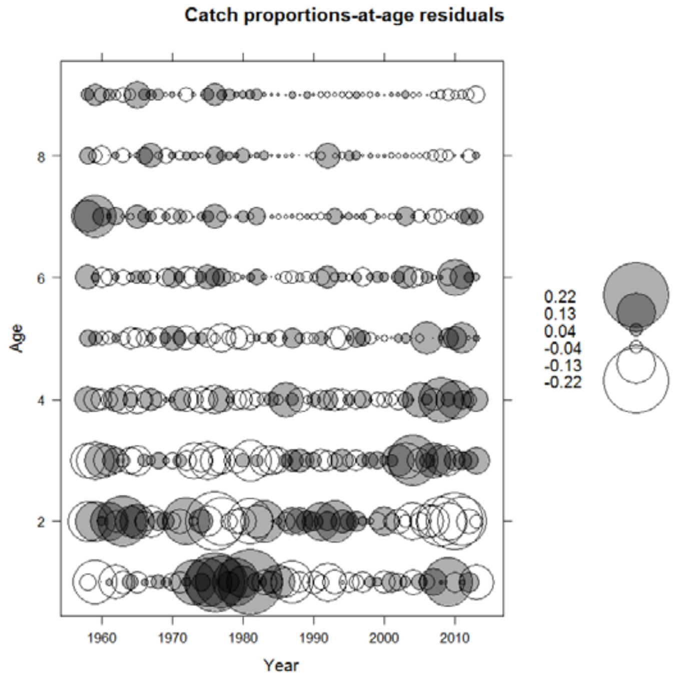


Figure 4.6.10. Herring in Celtic Sea, VIIg,j. Catch proportions at age residuals for the base case ASAP run.

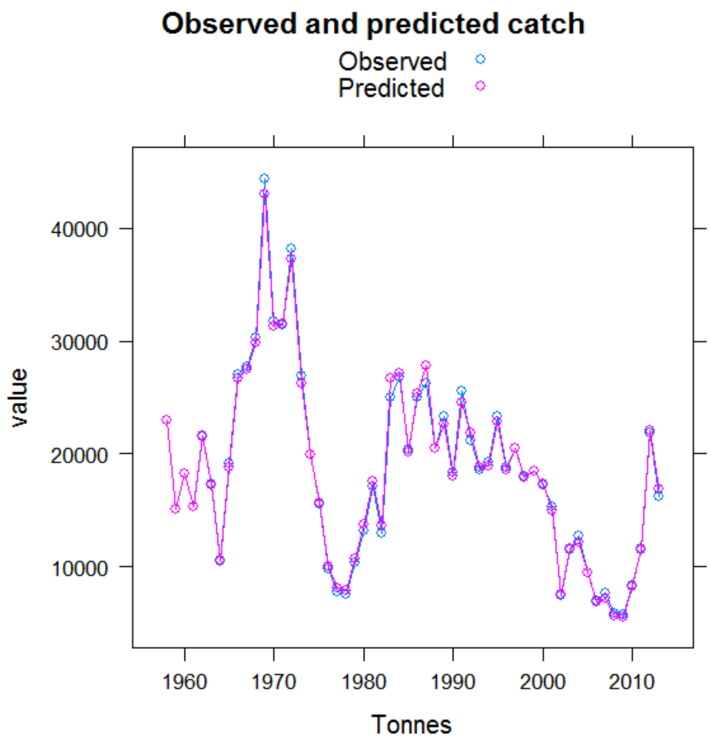


Figure 4.6.11. Herring in Celtic Sea, VIIg,j. Observed catch and predicted catch for the base case ASAP run.

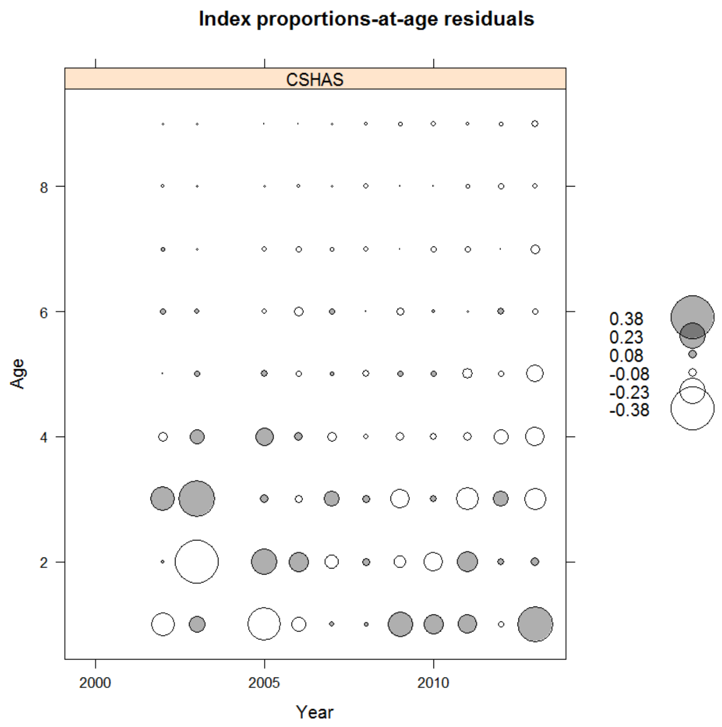


Figure 4.6.12: Herring in Celtic Sea, VIIg,j. Index proportions-at-age residuals (observed–predicted) for the base case ASAP run.

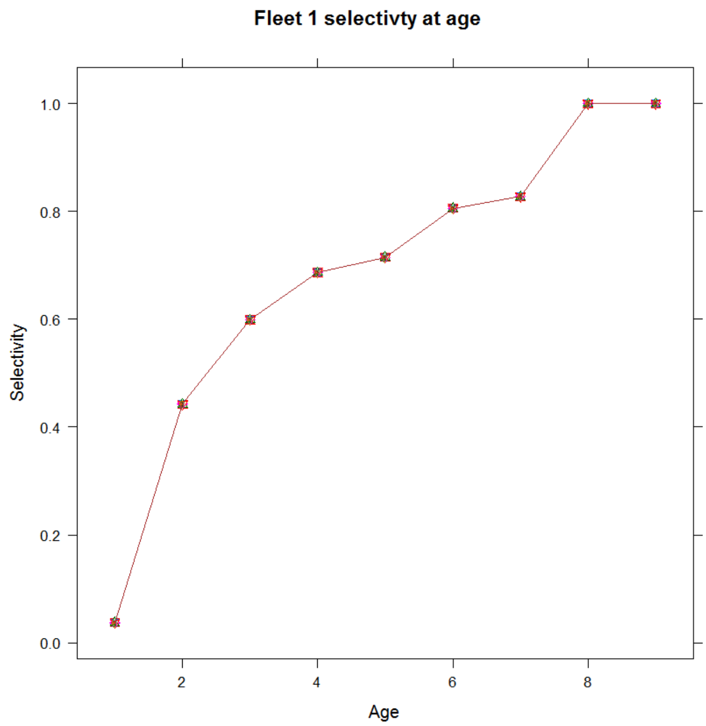


Figure 4.6.13: Herring in Celtic Sea, VIIg,j. Selectivity pattern for the base case ASAP run. Ages are given in winter rings.

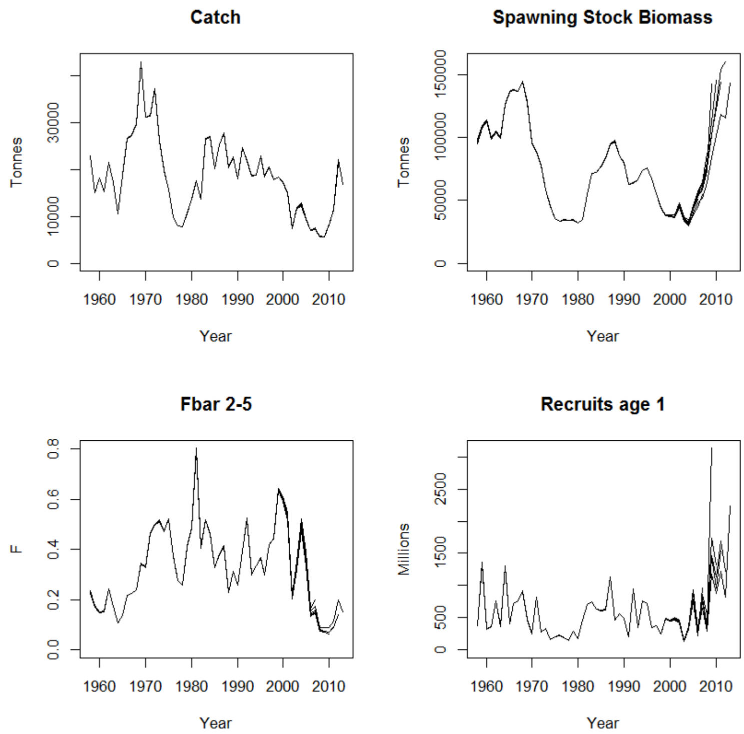


Figure 4.6.14: Herring in Celtic Sea, VIIg,j. Retrospective Analysis from the ASAP base run.

Final Assessment using ASAP

Survey age range

A decision was made to remove age 1 wr from the survey data and tune the final assessment with ages 2-9 wr. The rationale for this decision is based on the fact that 1 wr are often present in the Irish Sea and would not be fully available to the survey. The migration between these two areas was examined and presented as part of the Irish Sea herring benchmark in 2012 (ICES WKPELA 2012). Otolith microstructure techniques were used to quantify the interannual variation in the proportions at age of winter spawners (Celtic Sea fish) in the acoustic survey and catch-at-age estimates. Samples from 2005–2010 were processed (excluding 2009). The results confirmed extensive mixing of winter spawners occurs in the Irish Sea. This leads to bias in the 1+ biomass estimate derived from the acoustic survey with the majority of mixing at ages 1-2 wr. Interannual variation in mixing rates varies between 15% and 60%. This work has not been updated since 2010.

Natural mortality

A considerable amount of work was carried out in 2014 to look at the natural mortality estimates used in this assessment. Full details of this work are presented in the WKPELA report (ICES WKPELA, 2014). The values previously used were based on a North Sea multi species VPA assessment carried out by the ICES multi species group in 1987 and applied to stocks in adjacent areas (ICES, 1987). At WKPELA it was decided to update the natural mortality values based on an updated multi species assessment using data from 1963–2010 which was carried out for the North Sea using the SMS model. The North Sea herring underwent similar stock trajectories over time to this stock, and this may provide a basis for choosing these values. Another reason for preferring the North Sea estimates is that they are high at 1-winter ring, which is biologically more reasonable than the other options examined. The overall choice was based on the following preferences:

- Age variant rather than age invariant;
- Time invariant rather than time variant;
- North Sea derived averages rather than literature derived age-variant methods (ICES HAWG, 2014).

The natural mortality values, at age (wr), presented in the text table below were used in the 2014 benchmark assessment.

1	2	3	4	5	6	7	8	9
0.793	0.377	0.351	0.322	0.312	0.307	0.301	0.301	0.301

At WKWEST an updated run of the North Sea SMS was available using data from 1974-2013. It was decided to calculate an average of these values and use this most recent data to create the natural mortality vector for use in the assessment. The 2015 values are generally lower than the previous estimates and are given in the text table below.

1	2	3	4	5	6	7	8	9
0.706	0.353	0.280	0.255	0.240	0.226	0.217	0.217	0.217

Selection

The fishery selection in the final run has been changed from the base run setting where selection was fixed at 1 for 9-wr. This resulted in selection increasing at all ages before reaching a maximum at age 9-wr. In the final run the selection is fixed at 1 for 3-wr which is the age that Celtic Sea herring are considered to be fully selected. Selection at all other ages is estimated by the model. This gives a dome shaped selection pattern which is considered appropriate to this fishery. The model predicts a drop in selection at age 9-wr (Figure 4.6.15). This may be the case given the lesser abundance of 9-wr in the catch data.

Mohns Rho

The 2014 SAM assessment had a significant retrospective pattern with a downward revision in SSB and an upward revision in F in the terminal year. Retrospective problems have been defined as a systematic inconsistency among a series of estimates of population size, or related assessment variables, based on increasing periods of data (Mohn, 1999). The average rho for recent years is calculated in ASAP to quantify retrospective inconsistency. This calculation was carried out for the 2014 SAM assessment also. When the rho values on SSB are compared between the two models using the same data (catch and survey data 1-9 wr), the ASAP assessment has a lower value (0.22) than the SAM run (0.32). However when the 1 winter ringers are removed from the survey data the final ASAP assessment the Mohns Rho for SSB is increased to 0.35 which is now similar to the previous SAM assessment.

Final Run

Examination of the catch residuals (Figure 4.6.16) from the final run shows bigger residuals at the youngest ages, as would be expected. There is no clear pattern in these residuals with no age or year effects present. The survey residuals also do not show a clear pattern with the largest residuals at younger ages (Figure 4.6.17).

The stock summary is presented in Figure 4.6.18 and shows high SSB in the terminal year, decreasing recruitment and F at a relatively low level.

The retrospective from the final run is presented in Figure 4.6.19. The most divergence in the terminal year estimates can be seen for SSB. Retrospective plots by age classes and plots for F, SSB and recruitment including the Mohns Rho values are presented in Figures 4.6.20-4.6.23.

The trajectories from the final SAM run and the final ASAP run are presented in Figure 4.6.24. Both models show SSB to be at a high level with ASAP showing SSB to be slightly higher in the terminal year. The recruitment is predicted to be increasing with SAM and decreasing with ASAP. Recruitment is poorly estimated for this stock as there is no specific recruitment index available in this assessment. Both models show F to be at a sustainable level.

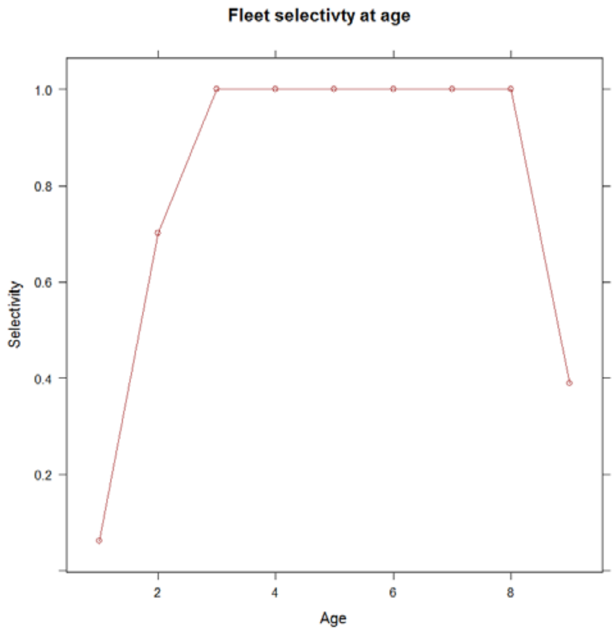


Figure 4.6.15: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring Selectivity in the fishery. Age is given in winter rings.

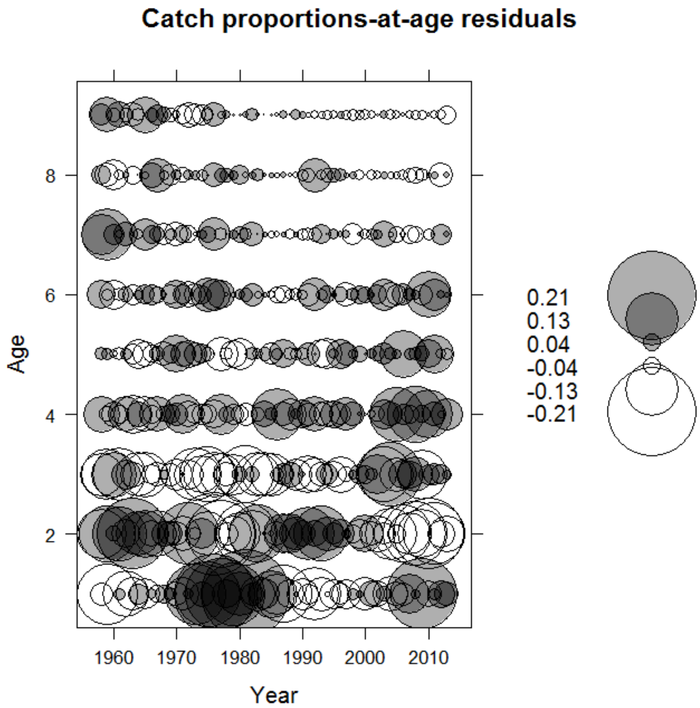


Figure 4.6.16: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring Catch residuals at age (winter rings).

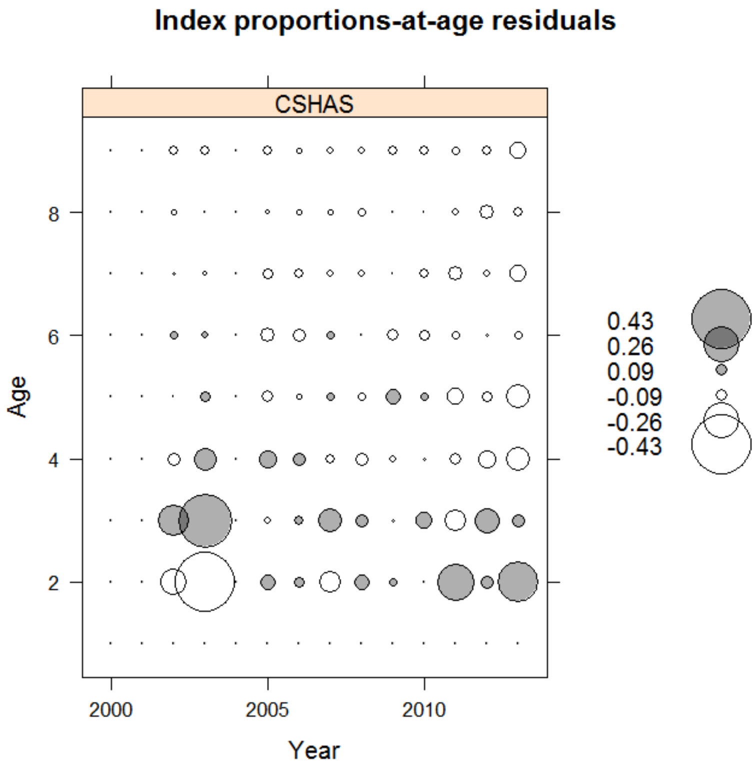


Figure 4.6.17: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring Survey residuals at age (winter rings).

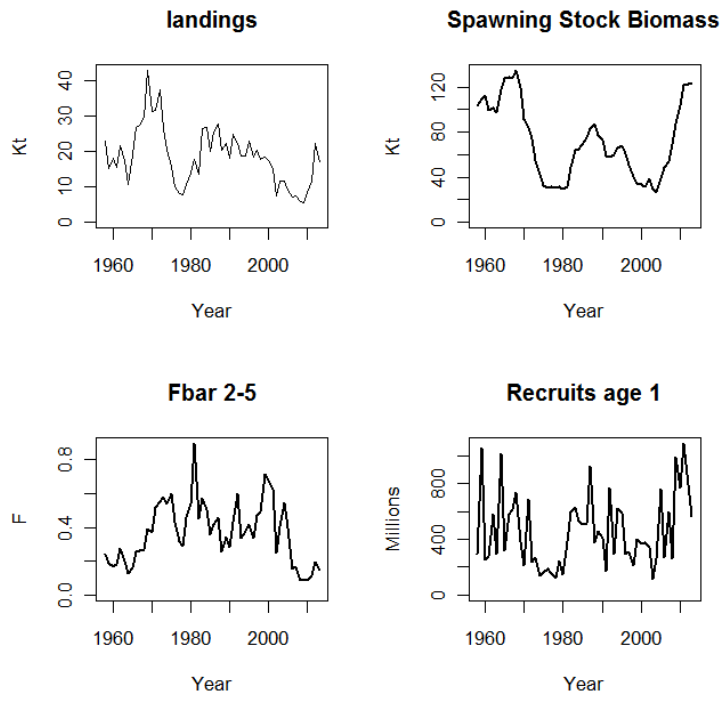


Figure 4.6.18: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring stock summary plot

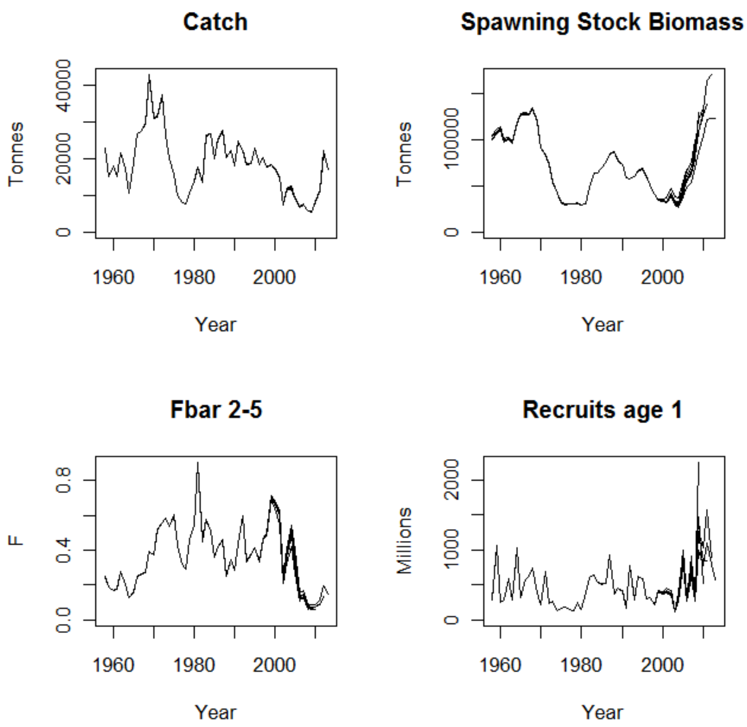


Figure 4.6.19: Herring in Celtic Sea, VIIg,j. Celtic Sea Herring Retrospective plot

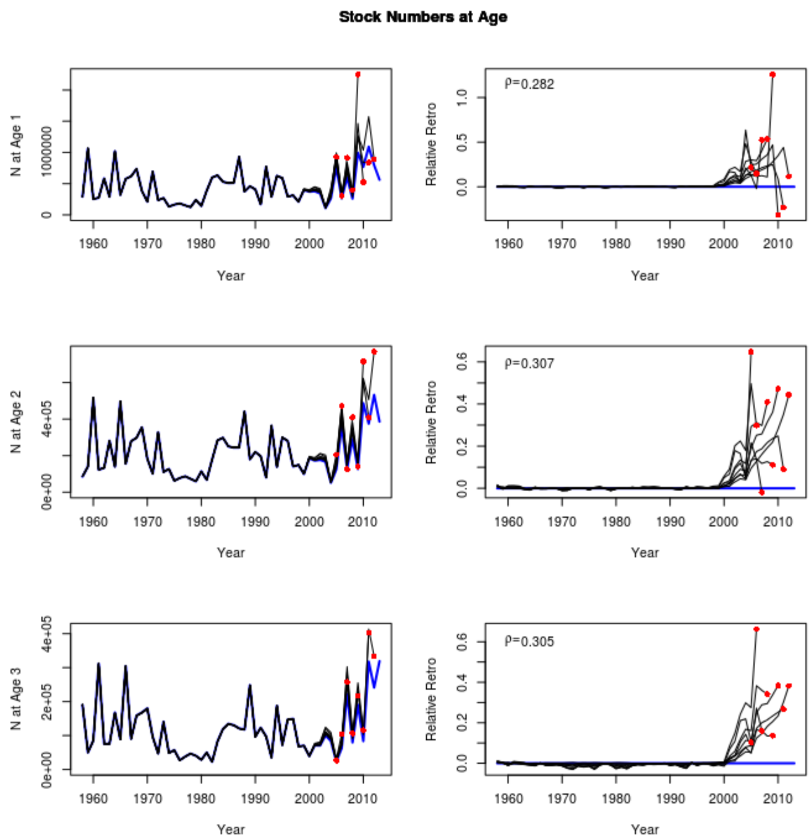


Figure 4.6.20: Herring in Celtic Sea, VIIg,j. Retrospective plots for stock numbers-at-age 1-3-wr

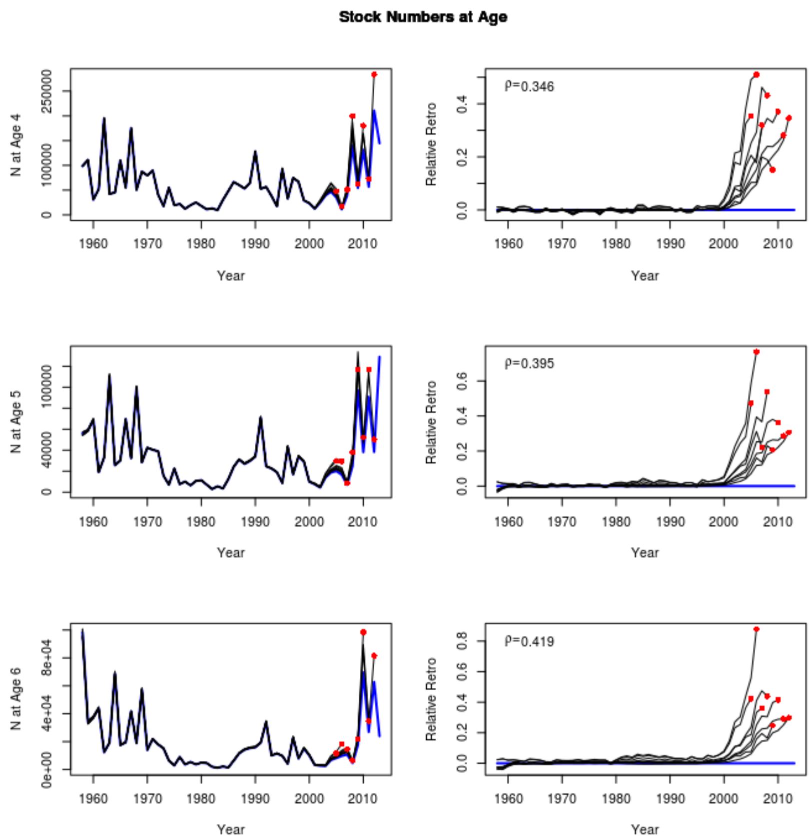


Figure 4.6.21: Herring in Celtic Sea, VIIg,j. Retrospective plots for stock numbers-at-age 4-6-wr.

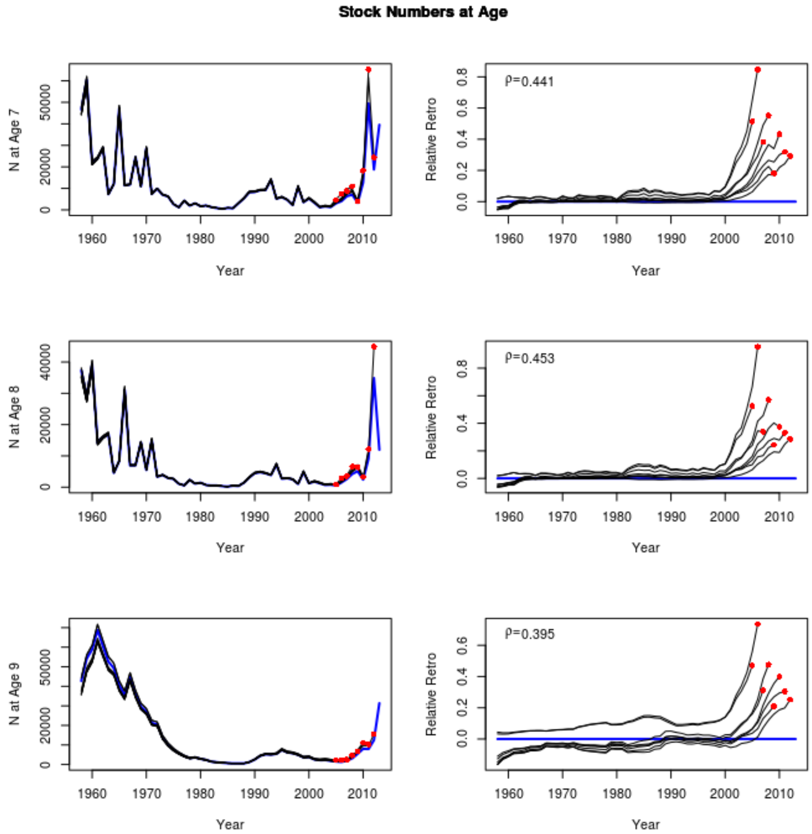


Figure 4.6.22: Herring in Celtic Sea, VIIg,j. Retrospective plots for stock numbers-at-age 7-9-wr.

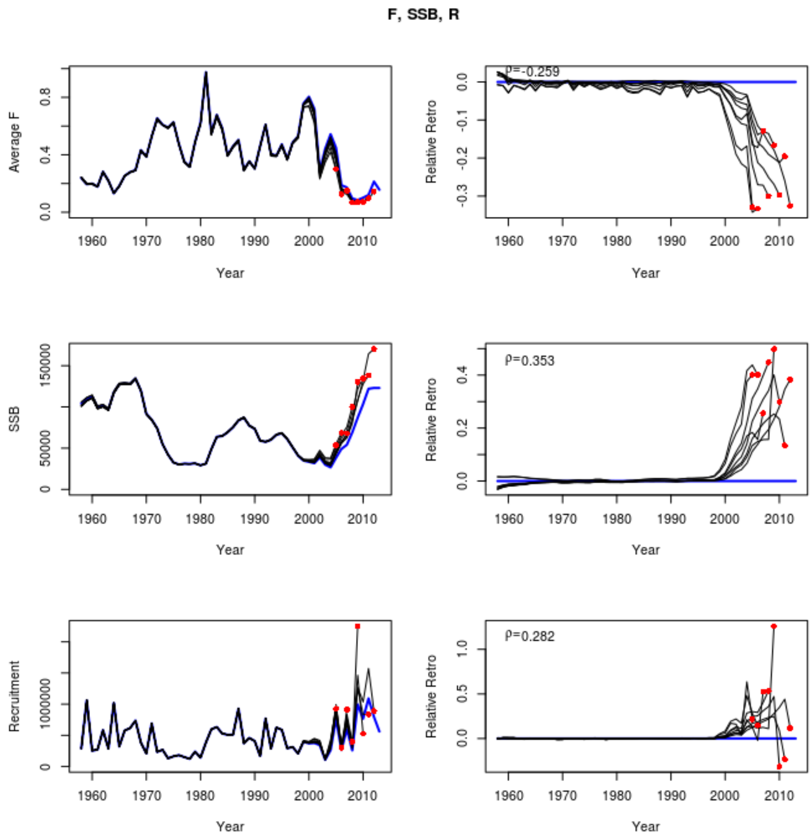


Figure 4.6.23: Herring in Celtic Sea, VIIg,j. Retrospective plots for F (top), SSB (middle) and Recruitment (bottom)

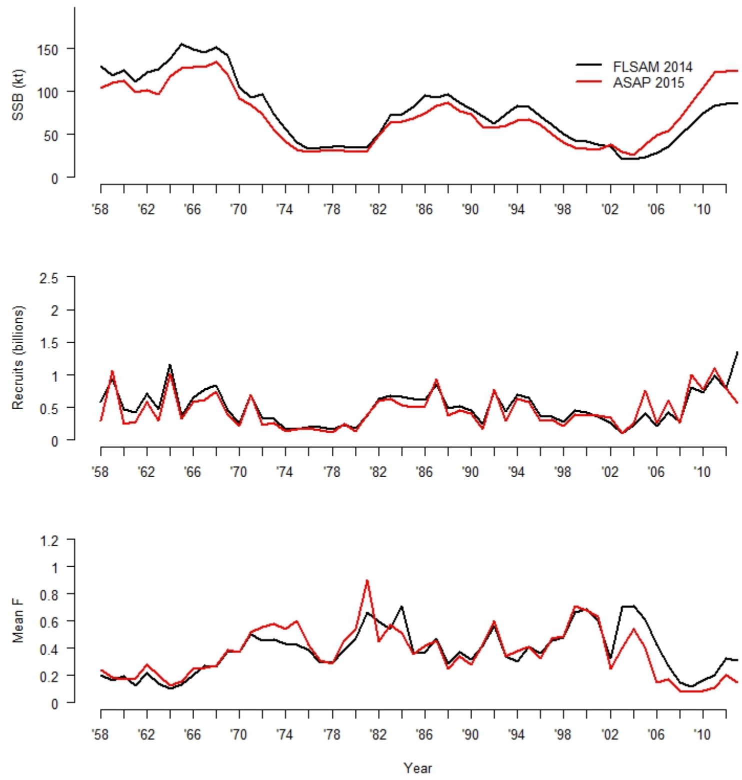


Figure 4.6.24: Herring in Celtic Sea, VIIg,j. Plot comparing final ASAP 2015 and the final SAM 2014

Conclusions

It was not possible to find a formulation of XSA that did not have a very bad retrospective pattern. For this reason and difficulties in deciding on the best formulation of that package, it is not put forward for further work. The work conducted for WKWEST in 2015 does not offer an improvement on the formulation of the SAM model and therefore this assessment model is no longer considered the most appropriate to this stock. ASAP was chosen as the preferred assessment model for Celtic herring, because the historically dominant year classes in the catch are smoothed by the random-walk estimation in SAM, resulting in the appearance of more stable recruitment than suggested by the catch-at-age. Furthermore, the smoothing has important implications for estimates of SSB and reference points. In an investigation of other herring stocks, Dickey-Collas *et al.* (2015) found that recruitment estimates from a parametric "free" estimation model (e.g. ASAP) fluctuate more than those from a random-walk time-series model (e.g. SAM), the random-walk recruitment estimates are more autocorrelated, and these differences produce substantial differences in MSY reference points. They also observed that large year classes were often "smoothed over" in random-walk models. Considerable progress has been made on developing the ASAP model, and in conjunction with the reviewers, an optimum formulation appears to have been achieved. On the basis of this work, ASAP appears to be an improvement on the 2014 final SAM assessment. This model allows a more flexible approach and is considered the most appropriate to the assessment of Celtic Sea Herring.

4.7 Short-term forecast

An updated procedure for the short-term forecast was performed, using the procedure agreed at WKPELA, and HAWG 2014. Recruitment (final year, interim year and advice year) in the short-term forecast is to be set to the same value based on the segmented stock recruit relationship (Figure 4.7.1), based on the SSB in the final year–2 years.

Interim year catch is calculated by summing the Irish quota in the assessment year (minus quarter 1 catch in the assessment year), the estimated Irish and non-Irish catch in quarters 2-4 and an estimate of Irish and non-Irish catch in quarter 1 of the advice year (which may require iteration).

Population numbers at 2-winter ring (N_2) in the interim year should be adjusted as follows:

$$N_{2,\text{ int. year}} = N_{1,\text{final year}} * (\exp(-F_{1,\text{ final year}} = M_{1,\text{ final year}}))$$

Where $N_{1,\text{final year}}$= Numbers-at-age 1-wrin the final year, $F_{1,\text{final year}}$= fishing mortality-at-age 1-wr in the final year and $M_{1,\text{final year}}$= natural mortality-at-age 1-wr in the final year. Mean weights in the catch and in the stock were calculated as means over the last three years.

4.8 Appropriate reference points

The approach to precautionary and yield based reference points was analogous to that followed by WKPELA, in 2014 and HAWG 2014. Examination of the stock recruit relationship from the final ASAP run showed wide range of recruitments, from very low to very high at low stock size, and a rather clear plateau, excepting four abnormally high values. This follows the recommendations of ICES RG/ADGCSHER (2012) and ICES SGBRP (2003), and is using the same basis to the procedure used for western Baltic spring-spawning herring reference point proposals of 2013. Based on these considerations, B_{lim} is proposed as 26 000 t (B_{loss}).B_{pa} is based on B_{lim} raised by assessment uncertainty in estimation of terminal SSB (ICES SGPA, 1997), as follows:

$$\sigma \mid 0.2 < \sigma < 0.3$$

This results in a proposed B_{pa} of 43 000 t. This value is also a candidate for ICES MSY $B_{trigger}$.

A range of F based reference points is also required. The same procedure was used as in ICES HAWG (2010; 2013) using HCS 10-3 (Skagen, 2010; 2013). This approach performs stochastic simulations from a segmented regression stock recruitment relationship (Figure 4.8.1) where the plateau level of recruitment was 424 678 individuals and the breakpoint was estimated as 48 060 t. No errors or biases were incorporated into these simulations, following the procedure of HAWG 2013. Results showed that the highest F consistent with low (<5%) risk of SSB < breakpoint in any year (ICES Risk 2) is F=0.29 (Table 4.8.1). This value is proposed as the upper bound on F_{MSY}. The lower bound estimate of F_{MSY} was taken as the highest F consistent with low risk to proposed B_{lim}, rather than $B_{breakpoint}$ and was found to be F = 0.24.

A feature of the assessment is retrospective bias, with Mohn's ρ in the range 0.3-0.38. Should managers wish to consider this level of retrospective re-estimation of SSB, then lower candidates for the F_{MSY} range would be appropriate (in the range 0.17 to 0.19 analogous to above). Such retrospective bias could also be considered in Management Strategy Evaluation (MSE) work, as was done by ICES RG/ADGCSHER (2012).

Table 4.8.1. Herring in Celtic Sea, VIIg,j. Candidate SSB and F based reference points for Celtic Sea herring along with historic values, for comparison.

	2013	2014	WKWEST	Notes
Blim	26 000	23 000	26 000	Bloss
Bpa	42 000	41 000	43 000	Bloss raised by uncertainty in assessment
MSY Btrigger	-	61 000	43 000	by analogy with other stocks e.g. NS and 3a = Bpa
Management trigger	61 000	61 000	61 000	Management plan 2011; RG/ADGCSHER (2012).
Flim	-	-	-	not required
Fpa	-	-	-	not required
Fmanagement	0.23	0.23	0.23	LTMP evaluated 2012
Fmsy	0.23	0.37		from simulations using different S/Rs in HCS (Skagen 2014)
lower bound			0.24	no retro bias , changepoint = 52 000 t
upper bound			0.29	no retro bias, changepoint = 26 000 t
			0.19	with retro bias, changepoint = 26 000 t
			0.17	with retro bias, changepoint = 52 000 t

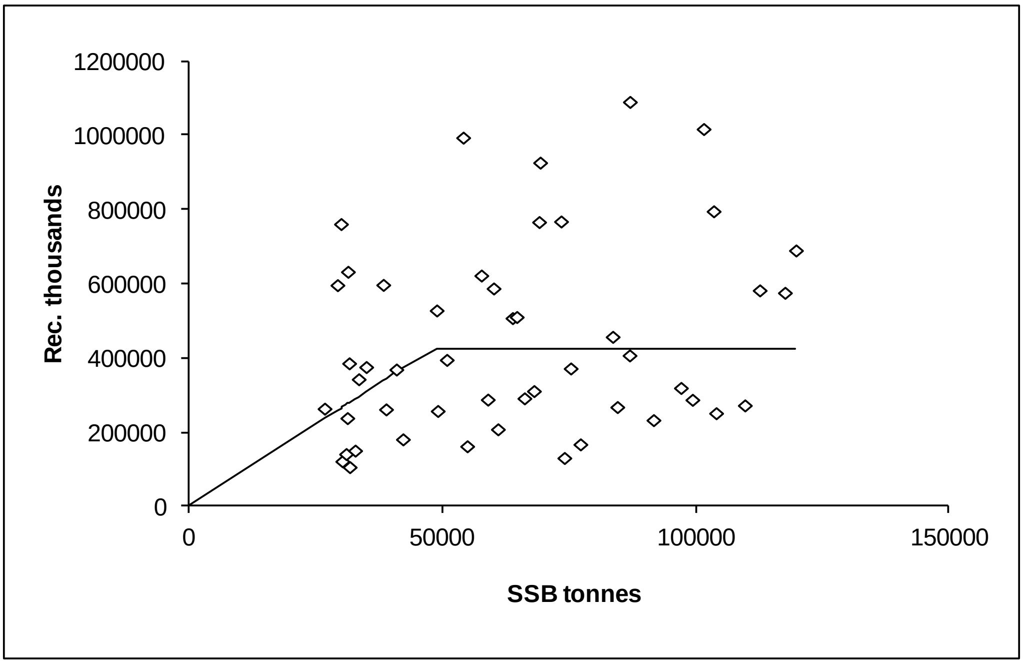


Figure 4.8.1. Herring in Celtic Sea, VIIg,j. Segmented regression, fitted by the algorithm of Julios to the final ASAP run data for Celtic Sea herring.

4.9 Future research and data requirements

There are a number of sources of uncertainty in the past and current assessments and these could be addressed with the following research areas:

1) Investigations into a routine methodology for determining the proportion of 1 and 2 winter ring herring from the Celtic Sea in the Irish Sea nursery areas.
2) Investigations in to the methodologies for determining maturity ogives for the Celtic Sea stock.
3) Investigations in to the effects of environmental conditions and change on the spawning dynamics of the Celtic Sea stock.
4) Exploration of recruitment indices for the Celtic Sea stock.
5) In depth studies on the design of the Celtic Sea acoustic survey to ensure appropriate coverage and the avoidance of 'double counting'.

4.10 External reviewers report

4.10.1 Issues addressed at the benchmark

The major issue addressed at the benchmark was developing a new assessment model for Celtic Sea herring (ASAP) that fits information on recruitment better than the previous assessment method.

4.10.2 Issues with estimation of stock–recruit relationship

There are some well known issues with estimating stock–recruit relationships from estimates derived from assessment models (e.g. Brooks and Deroba, 2015). Most, if not all, methods for estimating stock–recruit relationships external to assessment models make some assumptions about the independence and variance of both recruitment and spawning biomass that are not appropriate to the estimates from assessment models. Specifically, recruitment and SSB estimates from assessment models have variance that vary over time and there is correlation of the estimates with each other whereas fitting methods typically assume no error in SSB and recruitment observations are independent. More advanced methods for fitting these relationships that allow error in SSB, still assume independence of SSB and recruitment and constant variance (e.g. de Valpine and Hastings, 2002).

Some assessment models have the option to estimate stock–recruit relationships internally. This is the best method for estimating stock–recruit relationships because the variation in uncertainty and correlation of recruitment and SSB estimates is taken into account. If a stock–recruit relationship will be the basis of management reference points, then it is also best that the assessment, status determination, and projections are consistent in their usage of stock–recruit relationships.

The assessment of the Celtic Sea, VIIg,j herring based on ASAP allows internal estimation of some types of stock–recruit relationships, but less-reliable external estimation of stock–recruit relationships was used to derive MSY-based reference points. In future assessments, it might be beneficial to use the stock–recruit relationship consistently in the assessment, reference point, and projections.

5 Conclusions

5.1 West of Scotland (VIaN), west of Ireland (VIaS,VIIb,c) and northwest of the British Isles (VIa, VIIb,c)

High levels of uncertainties in the ability of current methods to identify individual fish in either catches or surveys to their spawning population mean that currently it is not possible to analytically assess the VIaN and VIaS, VIIb,c stocks separately. WKWEST has confidence that the combined analytical assessment of the meta-population reflects the dynamics and total herring population size within the area. The assessment is capable of providing management reference points for the meta-population.

However, in the absence of validated methods of identifying the two stocks in the area, WKWEST could not devise a robust method which would discern the relative sizes of the two stocks. Therefore, it will not be possible, in the immediate future, for ICES to provide robust data on the sizes of the stocks which spawn in the management areas VIaN and VIaS, VIIb,c. However, there is anecdotal evidence that the stocks are not the same size and management are advised to ensure that any exploitation pattern imposed in this area ensures that the smaller, more vulnerable, stock is not overexploited.

Based on published literature for stocks in the area there is clear need to determine the relative stock sizes and to ensure that a smaller stock is adequately assessed and protected from over exploitation. There is a clear need to rapidly develop robust methods of being able to identify individuals to their spawning population, both in the catches and surveys. The development of the methods is a matter of priority and this recommendation should be addressed to the EU, national governments, ICES, National laboratories and the prosecutors of the fisheries (fishers and processors etc). It is clear that a combined effort is needed to provide management advice for the herring stocks in this area.

5.2 Celtic Sea, VIIg,j

After applying a number of different assessment models to the Celtic Sea, VIIg,j herring data the ASAP model was chosen as the best, based on the ϱ value of the retrospective patterns in the assessments. In addition, ASAP was the preferred assessment model for Celtic Sea, VIIg,j herring, because the historically dominant year classes in the catch were smoothed by the random-walk estimation in SAM, resulting in the appearance of more stable recruitment than suggested by the catch-at-age. Also, the smoothing had important implications for estimates of SSB and reference points. Dickey-Collas *et al.*, (2014) showed that with other herring stock, recruitment estimates from a parametric “free” estimation model (e.g. ASAP) fluctuate more than those from a random-walk time-series model (e.g. SAM), the random-walk recruitment estimates are more autocorrelated, and these differences produce substantial differences in MSY reference points. Considerable progress has been made on developing the ASAP model, and an optimum formulation appears to have been achieved. Therefore, ASAP appears to be an improvement on the 2014 final SAM assessment and the ASAP model allows a more flexible approach and is considered the most appropriate to the assessment of Celtic Sea, VIIg,j herring.

6 References

Anon 1987. Report of the ad hoc Multispecies Assessment WG. ICES, Doc. C.M. 1987/Assess:9.

Baxter, J.M., Boyd, I.L., Cox, M., Cunningham, L., Holmes, P., Moffat, C.F., (Editors), 2008. Scotland's Seas: Towards Understanding their State. Fisheries Research Services, Aberdeen. pp. 174.

Beggs, S., Schön, P.J., McCurdy, W, Peel, J., McCorriston, P. and McCausland, I 2008. Seasonal origin of 1 ring+ herring in the Irish Sea (VIIaN) Management Area during the annual acoustic survey. Working Document to the herring assessment working group 2008.

Boyd, J., O'Connor, I. and Berrow, S.D. 2012. Report on the Pilot Observer Programme in Irish Pelagic Trawl Fisheries: Implementing Council Regulation (EC) No 812/2004. Galway-Mayo Institute of Technology, Galway, Ireland.

British Trust for Ornithology http://www.bto.org/about-birds/birdtrends/2013/species

Brooks, E. N. and Deroba, J.D. 2015. When "data" are not data: the pitfalls of post-hoc analyses that use stock assessment model output. Canadian Journal of Fisheries and Aquatic Sciences. doi: 10.1139/cjfas-2014-0231.

Brophy, D. and Danilowicz, B.S. 2002. Tracing populations of Atlantic herring (*Clupea harengus* L.) in the Irish and Celtic Seas using otolith microstructure. ICES Journal of Marine Science, 59(6): 1305-1313.

Brunel, T. and Dickey-Collas, M., 2010. Effect of temperature and population density on von Bertalanffy growth parameters in Atlantic herring: a macro-ecological analysis. Marine Ecology Progress Series 405: 15-28.

Buckland, S. T., Burnham, K. P., and Augustin, N. H. 1997. Model selection: an integral part of inference. Biometrics 53: 603-618.

Burke, N., Brophy, D., and King, P.A. 2008. Otolith shape analysis: its application for discriminating between stocks of Irish Sea and Celtic Sea herring (*Clupea harengus*) in the Irish Sea. ICES Journal of Marine Science 65: 1670–1675.

Campbell, N., Cross, M.A., Chubb, J.C., Cunningham, C.O., Hatfield E.M.C., and MacKenzie K. 2007. Spatial and temporal variations in parasite prevalence and infracommunity of spawning herring caught west of the British Isles and in the Baltic Sea. Journal of Helminthology 81: 137–146.

Chen, S. and Watanabe, S. 1989. Age dependence of natural mortality coefficient in fish population dynamics. Nippon Suisan Gakkaishi 55: 205–208.

Clarke, M.W., Egan, A., Mariani, S and Miller, D. 2011. Long term trends in the population dynamics of northwestern Ireland herring revealed by data archaeology. ICES CM 2011/D:04.

Clausen, L.A.W., Bekkevold, D., Hatfield, E.M.C., and Mosegaard, H. 2007. Application and validation of otolith microstructure as a stock identification method in mixed Atlantic herring (*Clupea harengus*) stocks in the North Sea and western Baltic. ICES Journal of Marine Science 64: 377–385.

Darby, C. 2000. Extended survivors analysis (XSA) NAFO SCR Doc. 00/64. 24 pp.

Darby, C.D. and Flatman, S. 1994. Virtual Population Analysis: Version 3.1 (Windows/DOS), User Guide. Inf. Techn. Ser., MAFF Directorate of Fisheries Research, Lowestoft (1): 85 p.

De Barros, P. and Toresen, R. 1998. Variable natural mortality rate of juvenile Norwegian spring-spawning herring (*Clupea harengus* L.) in the Barents Sea. ICES Journal of Marine Science 55 (3): 430-442.

de Valpine, P. and Hastings, A. 2002. Fitting population models incorporating process noise and observation error. Ecological Monographs 72(1): 57-76.

Dickey-Collas M., Engelhard G.H. and Möllmann C. 2010a. Herring. In: Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Möllmann, C., Pinnegar J. (Eds). Resolving climate impacts on fish stocks. ICES Cooperative Research Report 301. pp 121–134.

Dickey-Collas, M., Nash, R. D. M., Brunel, T., van Damme, C. J. G., Marshall, C. T., Payne, M. R., Corten, A., Geffen, A. J., Peck, M. A., Hatfield, E. M. C., Hintzen, N. T., Enberg, K., Kell, L. T., and Simmonds, E. J. 2010b. Lessons learned from stock collapse and recovery of North Sea herring: a review. ICES Journal of Marine Science 67: 1875–1886.

Dickey-Collas, M., Hintzen N. T., Nash, R.D.M., Schon, P-J. and Payne, M. R. 2015. Quirky patterns in time-series of estimates of recruitment could be artefacts. ICES Journal of Marine Science 72: 111–116.

Drinkwater, K. F. 2010. Marine European climate: past, present, and future. In Resolving Climate Impacts on Fish Stocks. pp. 49–75. A.D. Rijnsdorp, M.A. Peck, G.H. Engelhard, C. Möllmann, and J.K. Pinnegar (Eds.). ICES Cooperative Research Report, 301. 370 pp.

Duck, C. and Morris, C. 2013. An aerial survey of harbour seals in Ireland: Part 2: Galway Bay to Carlingford Lough. August-September 2012. Unpublished report to the National Parks & Wildlife Service, Department of Arts, Heritage & the Gaeltacht, Dublin.

Dutil, J.D. and Brander, K. 2003. Comparing productivity of North Atlantic cod (Gadus morhua) stocks and limits to growth production. Fisheries Oceanography 12(4-5): 502-512.

Dutil, J.D., Castonguay, M., Gilbert, D. and Gascon, D. 1999- Growth, condition, and environmental relationships in Atlantic cod (Gadus morhua) in the northern Gulf of St. Lawrence and implications for management strategies in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 56(10):1818-1831.

Engelhard, G.H., M.A. Peck, A. Rindorf, , S.C. Smout, M. van Deurs, K. Raab, K.H. Andersen, S. Garthe, R.A.M. Lauerburg, F. Scott, T. Brunel, G. Aarts, T. van Kooten, and M. Dickey-Collas 2014. Forage fish, their fisheries, and their predators: who drives whom? ICES Journal of Marine Science 71(1): 90-104.

Farran, G. P. 1944. "The herring fishery in Eire 1921 - 1941." Department of Agriculture Journal 51(2): 34 pp.

Farran, G.P. 1938. On the size and number of the ova of Irish herrings. Journal du Conseil Permanent International pour l'Exploration del al Mer 13(1): 91-100.

Feeney, M. 2001. The Cleggan Bay disaster: an account of the savage storm in October 1927 that devastated the Connemara communities of Rossadilisk and Inishbofin. Glencolumbkille: Penumbra Press. 111 pp.

Geffen, A.J., Nash, R.D.M., and Dickey-Collas, M. 2011. Identification of spawning components in mixed aggregations of Atlantic herring (*Clupea harengus*) along the west coast of the British Isle based on chemical composition of otolith cores. ICES Journal of Marine Science 68(7): 1447–1458.

Grainger, R. 1976. The inter-relationships of populations of autumn-spawning herring off the west coast of Ireland. Irish Sea Research Board, Res. Rec. Paper, 32, 21 pp.

Grainger, R. J. 1978 A study of herring stocks west of Ireland and their oceanographic conditions. Unpublished PhD. Thesis. Galway: National University of Ireland. 262 pp.

Grainger, R. J. 1980. Irish west coast herring fluctuations and their relation to oceanographic conditions. ICES Marine Science Symposium on the Biological Basis of Pelagic Stock Management No 29., pp. 19.

Hammond, P.S., Macleod, K., Berggren, P. Borchers, D.L. plus 27 authors 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164: 107-122.

Harma, C. 2014. Long-term dynamics of herring (*Clupea harengus* L.) populations around Ireland. Galway Mayo Institute of Technology. Unpublished PhD. Thesis. 222 pp.

Harma, C., Brophy, D., Minto, C., and Clarke, M. 2012. The rise and fall of autumn-spawning herring (*Clupea harengus* L.) in the Celtic Sea between 1959 and 2009: Temporal trends in spawning component diversity. Fisheries Research 121– 122: 31– 42.

Hatfield, E.M.C., Nash R.D.M., Zimmermann C., Schön P-J., Kelly C., Dickey-Collas M., MacKenzie K., et al., 2007a. The scientific implications of the EU Project WESTHER (Q5RS - 2002 – 01056) to the assessment and management of the herring stocks to the west of the British Isles. ICES CM 2007\L:11, 23 pp.

Hatfield, E.M.C., Mosegaard, H., Jansen, S. Schlickeisen, J. and C. Zimmermann. 2007b. Using otolith and body shape analysis to distinguish herring stocks to the west of the British Isles. ICES CM 2007\L:12. Powerpoint presentation.

Hatfield, E.M.C. et al., 2007c. (WESTHER, Q5RS-2002-01056): A multidisciplinary approach to the identification of herring (*Clupea harengus* L.) stock components west of the British Isles using biological tags and genetic markers.

Heath M.R., McLachlan, P.M. and Martin, J.H.A. 1987. Inshore circulation and transport of herring larvae off the north coast of Scotland. Marine Ecology Progress Series 40: 11-23.

Hewitt, D.A. and Hoenig, J.M. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103: 433-437.

Hintzen, N.T., Roel, B., Benden, D., Clarke, M., Egan, A., Nash, R.D.M., Rohlf, N. and Hatfield, E.M.C. 2014. Managing a complex population structure: exploring the importance of information from fisheries-independent sources. ICES Journal of Marine Science 72(2): 528–542. doi: 10.1093/icesjms/fsu102.

ICES 1970. Report on the state of the herring stocks around Ireland and north-west of Scotland (December 1969). ICES Cooperative Research Report, Series A, No 21. 34 pp.

ICES 1987. Report of the ad hoc Multispecies Assessment WG. ICES, Doc. C.M. 1987/Assess:9.

ICES 1994. Report of the Study group on Herring Assessment and Biology in the Irish Sea and Adjacent Waters. Belfast, Northern Ireland, ICES CM 1994/H:5

ICES 1998. Report of the Study Group on the precautionary approach to fisheries management. ICES C.M. 1998/Assess:10. Ref. D.

ICES 2001. Study Group on the Further Development of the Precautionary Approach to Fisheries Management. ICES C.M. 2001/ACFM: 11.

ICES 2002. Study Group on the Further Development of the Precautionary Approach to Fisheries Management. ICES C.M. 2002/ACFM: 10.

ICES 2003a. Report of the Study Group on Biological Reference Points for Northeast Arctic Cod. ICES CM 2003/ACFM:11.

ICES 2003b. Report of the study group on the precautionary approach to fisheries management. ICES CM 2003/ACFM: 09.

ICES 2003c. Study Group on Precautionary Reference Points for Advice on Fishery Management. ICES CM 2003/ACFM:15.

ICES 2010. Manual for the international bottom trawl surveys in the western and southern areas. Revision III. Addendum to ICES CM 2010/SSGESST:06. Lisbon, Portugal

ICES 2014. ICES Standard Graphs. http://standardgraphs.ices.dk/

ICES HAWG 1979. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG). ICES CM 1979/H:6, 82 pp.

ICES HAWG 1982. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG). ICES CM 1982/Assess:7, 132 pp.

ICES HAWG 2002. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG). ICES CM 2002/ACFM:12.

ICES HAWG 2006. Report of the Herring Assessment Working Group for the Area South of 62oN. ICES CM 2006/ACFM:20.

ICES HAWG 2007. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG). ICES CM 2007/ACFM:11, 340 pp.

ICES HAWG 2009. Report of the Herring Assessment Working Group South of 60° N (HAWG) ICES CM 2009/ACOM:03.

ICES HAWG 2010. Report of the Herring Assessment Working Group for the Area South of 62 ºN (HAWG). ICES CM 2010/ACOM:06. 688 pp.

ICES HAWG 2012. Report of the Herring Assessment Working Group for the Area South of 62 ºN (HAWG). ICES CM 2012/ACOM:06. ??? pp.

ICES HAWG 2014. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG). ICES CM 2014/ACOM:06, 1310 pp.

ICES. 2015. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG), 10-19 March 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/ACOM:06. 763 pp.

ICES RG/ADGCSHER 2012. Report of the Review Group and Advice Drafting Group on the Celtic Sea Herring HCR.

ICES SGBRP 2003. Study Group on Precautionary Reference Points For Advice on Fishery Management. ICES CM 2003/ACFM:15

ICES SGHERWAY 2010. Report of the Study Group on the evaluation of assessment and management strategies of the western herring stocks (SGHERWAY). ICES CM 2010\SSGSUE:08, 194 pp.

ICES SGPA 1997. Report of the Study Group on the Precautionary Approach to Fisheries Management. ICES CM 1997/Assess:07. 45 pp.

ICES WGIPS 2014. Report of the Working Group of International Pelagic Surveys (WGIPS), 20-24 January 2014. ICES CM 2014/SSGESST:01. 360 pp.

ICES WGSAM 2011. Report of the working group on multispecies assessment methods (WGSAM).

ICES WGSAM 2012. Report of the Working Group on multispecies assessment methods (WGSAM). ICES CM 2012/SSGSUE:10.

ICES. 2013. Interim Report of the Working Group on Multispecies Assessment Methods (WGSAM), 21-25 October 2013, Stockholm, Sweden. ICES CM 2013/SSGSUE:10. 99 pp.

ICES WKACCU 2008. Report of the Workshop on methods to evaluate and estimate the accuracy of fisheries data used for assessment (WKACCU). ICES CM 2008\ACOM:32.

ICES WKBALT 2013. Report of the Benchmark Workshop on Baltic Multispecies Assessments (WKBALT). ICES CM 2013/ACOM:43.

ICES WKFRAME-2 2011. Report of the Workshop on Implementing the ICES FMSY framework (WKFRAME-2). ICES CM 2011/ACOM:33.

ICES WKMSYREF3 2014. Report of the Joint ICES-MYFISH Workshop to consider the basis for FMSY ranges for all stocks (WKMSYREF3). ICES C.M. 2014/ACOM:64.

ICES WKPELA 2012. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA). ICES CM 2012/ACOM:47.

ICES WKPELA 2013. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA) ICES CM 2013/ACOM:46.

ICES WKPELA 2014. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA) ICES CM 2014/ ACOM:43.

ICES WKREF 2007. Report of the Workshop on Limit and Target Reference Points (WKREF). ICES CM 2007/ACFM:05.

ICES WKREFBAS 2008. Report of the Workshop on Reference Points in the Baltic Sea (WKREFBAS). ICES CM 2008/ACOM:28.

Jennings, S., Kaiser, M.J. and Reynolds, J.D. 2001. Marine Fisheries Ecology. Blackwell Science., London.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., Scott, F. and Scott, R.D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science 64: 640-646.

Kell, L.T., Dickey-Collas, M., Hintzen, N.T., Nash, R.D.M., Pilling G.M. and Roel B.A. 2009. Lumpers or splitters? Evaluating recovery and management plans for metapopulations of herring. ICES Journal of Marine Science 66: 1776–1783.

King, D.P.F. 1985. Morphological and meristic differences among spawning aggregations of north-east Atlantic herring. *Clupea harengus* L. Journal of Fish Biology 26: 591-607.

Kjesbu, O.S., Bogstad, B., Devine, J.A., Gjøsæter, H., Howell, D., Ingvaldsen, R., Nash, R.D.M. and Skjæraasen, J.E. 2014. Synergies between climate and management for Atlantic cod fisheries at high latitudes. Proceedings of the National Academy of Sciences of the United States of America 111(9): 3478–3483.

Landry, J. and McQuinn, I.H., 1988. Histological and macroscopic identification guide of the sexual maturity stages of Atlantic herring (*Clupea harengus* harengus L.). Canadian Technical Report of Fisheries and Aquatic Sciences 1655, 77 pp.

Legault, C.M., Restrepo, V.R., 1999. A flexible forward age-structured assessment program. ICCAT Coll. Vol. Sci. Pap. 49, 246-253.

Lewy, P. and Vinther. M. 2004. A stochastic age–length-structured multispecies model applied to North Sea stocks. ICES CM 2004/FF:20.

Lorenzen K. 2000. Allometry of natural mortality as a basis for assessing optimal release size in fish-stocking programmes. Canadian Journal of Fisheries and Aquatic Sciences 57: 2374-2381.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49: 627-647.

Lynch, D. 2011. Biological changes in Celtic Sea and southwest of Ireland herring, based on a long-term data archival project. M.Sc. Thesis, D.C.U. Trinity College Dublin, Ireland.

Lyne, P. and Berrow, S.D. 2012. Report on Independent Observer Programme in Celtic Sea herring fishery 2012.

Maravelias, C. D. 2001. Habitat associations of Atlantic herring in the Shetland area: influence of spatial scales and geographic segmentation. Fisheries Oceanography, 10: 259–267.

Marine Scotland Science. 2014. Fish and Shellfish Stocks, 2014 Edition. http://www.scotland.gov.uk/Publications/2014

McCoy, M.W. and Gillooly, J.F. 2008. Predicting natural mortality rates of plants and animals. Ecology Letters 11: 710-716.

McKeogh, E. and Berrow, S. 2014. Results of an Independent Observer Study of the Celtic Sea Herring Fishery, 2013. Unpublished report. Kilrush: Irish Whale and Dolphin Group. 11 pp.

Melvin, G.D., Stephenson, R.L., and Power, M.J. 2009. Oscillating reproductive strategies of herring in the western Atlantic in response to changing environmental conditions. ICES Journal of Marine Science 66(8): 1784–1792. doi:10.1093/icesjms/fsp173.

Mesnil, B., and Rochet, M.-J. 2010. A continuous hockey stick stock–recruit model for estimating MSY reference points. ICES Journal of Marine Science 67: 1780-1784.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES Journal of Marine Science, 56: 473–488.

Molloy, J. 1968. Herring Investigations on the Southwest Coast of Ireland, 1967. ICES CM:68/H:14

Molloy, J. 1984. Density-dependent growth in Celtic Sea herring. ICES CM 1984/H, 30.

Molloy, J. 1995. The Herring Fisheries of Ireland, in the Twentieth Century: Their Assessment and Management. Occasional Papers in Irish Science and Technology. Dublin: Royal Dublin Society. 16 pp.

Molloy, J. 2006. The Herring Fisheries of Ireland (1900-2005). Biology, research, development and assessment. The Marine Institute. 235 pp.

Molloy, J., Barnwall, E. and Morrison, J. 1993. Herring tagging experiments around Ireland, 1991. Fishery Leaflet 7 pp.

Morrison, J.A. and Bruce, T. 1981. Scottish herring tagging experiments in the Firth of Clyde 1975-1979, and evidence of affinity between Clyde herring and those in adjacent areas. ICES CM 1981/H:53.

Nielsen, A. 2009 State-space fish stock assessment model as alternative to (semi) deterministic approaches and stochastic models with a high number of parameters Unpublished report.

Nielsen, A. and Berg, C. 2013. Introduction to stockassessment.org and SAM training course. October 2013, Copenhagen, Denmark. Unpublished report.

Nolan, C, et al., 2015. Splitting Fish of VIaN and VIaS\VIIb,c Origin from the Malin Shelf Herring Acoustic Survey. Working document to WKWEST 2015.

Ó Cadhla, O., Keena, T., Strong, D., Duck, C. and Hiby, L. 2013. Monitoring of the breeding population of grey seals in Ireland, 2009 - 2012. Irish Wildlife Manuals, No. 74. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Dublin, Ireland.

O'Malley, M., Lusseau, S. and Hatfield, E.M.C. 2015. Factors effecting natural mortality of herring west of Scotland. Working Document to WKWEST 2015.

O'Sullivan, D., O'Keefe, E., Berry, A., Tully, O., and Clarke, M. 2013. An Inventory of Irish Herring Spawning Grounds. Irish Fisheries Bulletin 42: 2013. 38 pp.

Parrish, B. B. and Saville A. 1965. The biology of the north-east Atlantic herring populations. Oceanography and Marine Biology Annual Review 3: 323-373.

Patterson, K.R. 1998a. A programme for calculating total international catch-at-age and weight-at-age. WD to HAWG 1998.

Patterson, K.R. 1998b. Integrated Catch at Age Analysis Version 1.4. Scottish Fisheries Research Report. No. 38.

Payne, M.R., Clausen, L.W., Mosegaard, H. 2009. Finding the signal in the noise: objective data-selection criteria improve the assessment of western Baltic spring-spawning herring. ICES Journal of Marine Science 66: 1673 – 1680.

Peterson, I., and Wroblewski, J. S. 1984. Mortality Rates of Fishes in the Pelagic Ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 41: 1117-1120.

Powers, J.E. 2014. Age-specific natural mortality rates in stock assessments: size-based vs. density-dependent. ICES Journal of Marine Science 71(7): 1629-1637.

Röckmann C., Dickey-Collas M., Payne M.R., van Hal R. 2011. Realized habitats of early stage North Sea herring – looking for signals of environmental change. ICES Journal of Marine Science 68: 537–546.

Shepherd, J. G. 1999. Extended survivors analysis: An improved method for the analysis of catch-at-age data and abundance indices. ICES Journal of Marine Science, 56: 584–591.

Siegfried K.I. and B. Sanso. 2013. A Review for Estimating Natural Mortality in Fish Populations http://www.sefsc.noaa.gov/sedar/download/S19_RD29_Andrews_natural%20mortality%20chapter_5_22.pdf?id=DOCUMENT

Skagen, D.W. 2010. HCS 10_3 programs for simulating harvest rules: Outline of program and instructions for users.29 pp.

Skagen, D.W. 2013. HCS 13_4 programs for simulating harvest rules: Outline of program and instructions for users.35 pp. downloaded from http://www.dwsk.net/Downloads.htm on 9th March 2014.

Speirs, D. C., Guirey E. J., Gurney W. S. C., and Heath, M. R. 2010. A length-structured partial ecosystem model for cod in the North Sea. Fisheries Research, 106: 474–494.

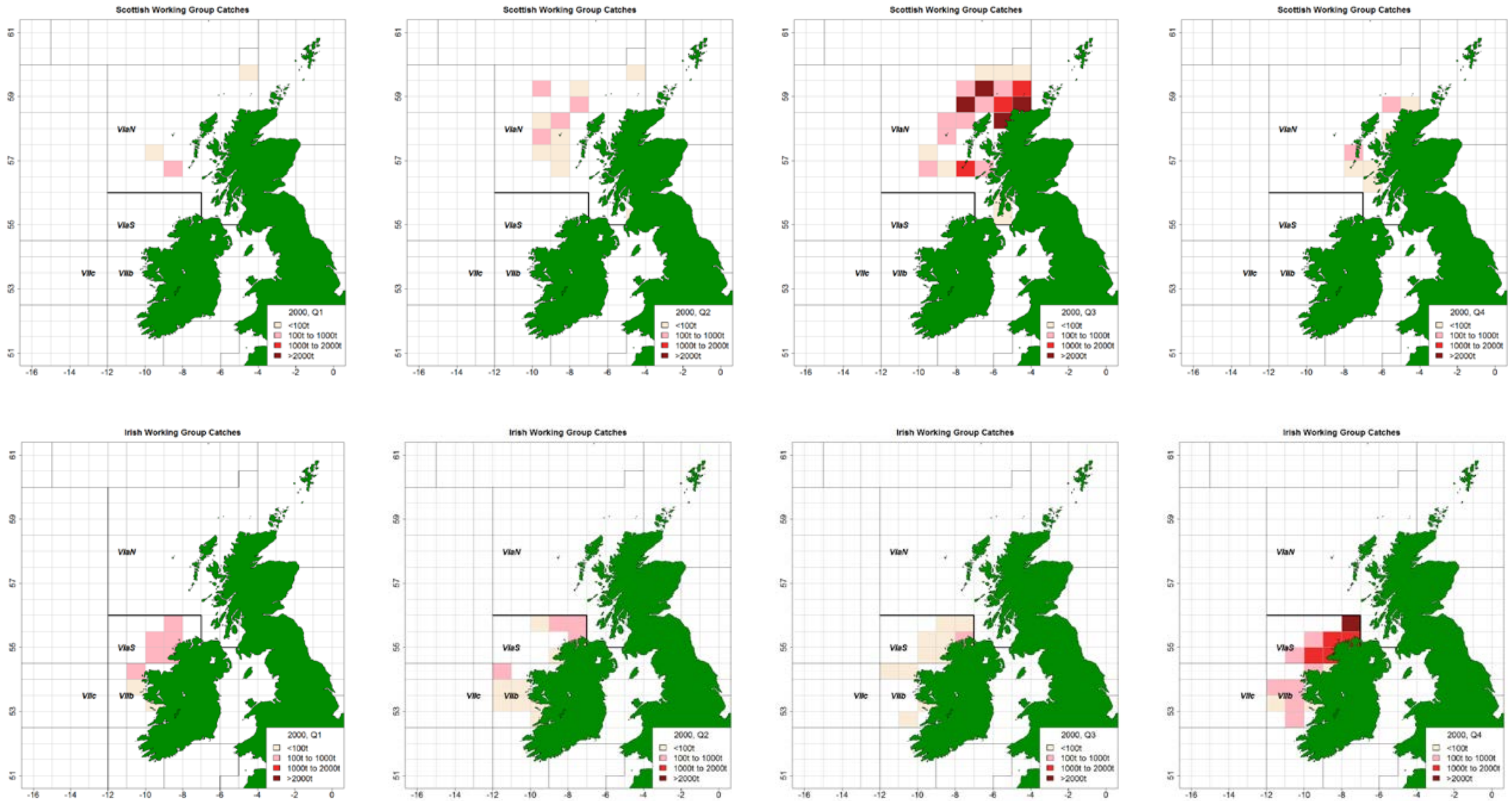
STECF 2013. Evaluation of the proposed management plan of herring in VIaS VIIbc. STECF Plenary Meeting (PLEN-13-01). Edited by F. Scott and E. Jardim. JRC, Fishreg – Maritime Affairs Unit. European Commission. April 3, 2013. doi:10.2788/8920.

Thomas, L. 2014. Estimating the size of the UK grey seal population between 1984 and 2014, using established and draft revised priors. SCOS briefing paper: SCOS-BP 14/02.

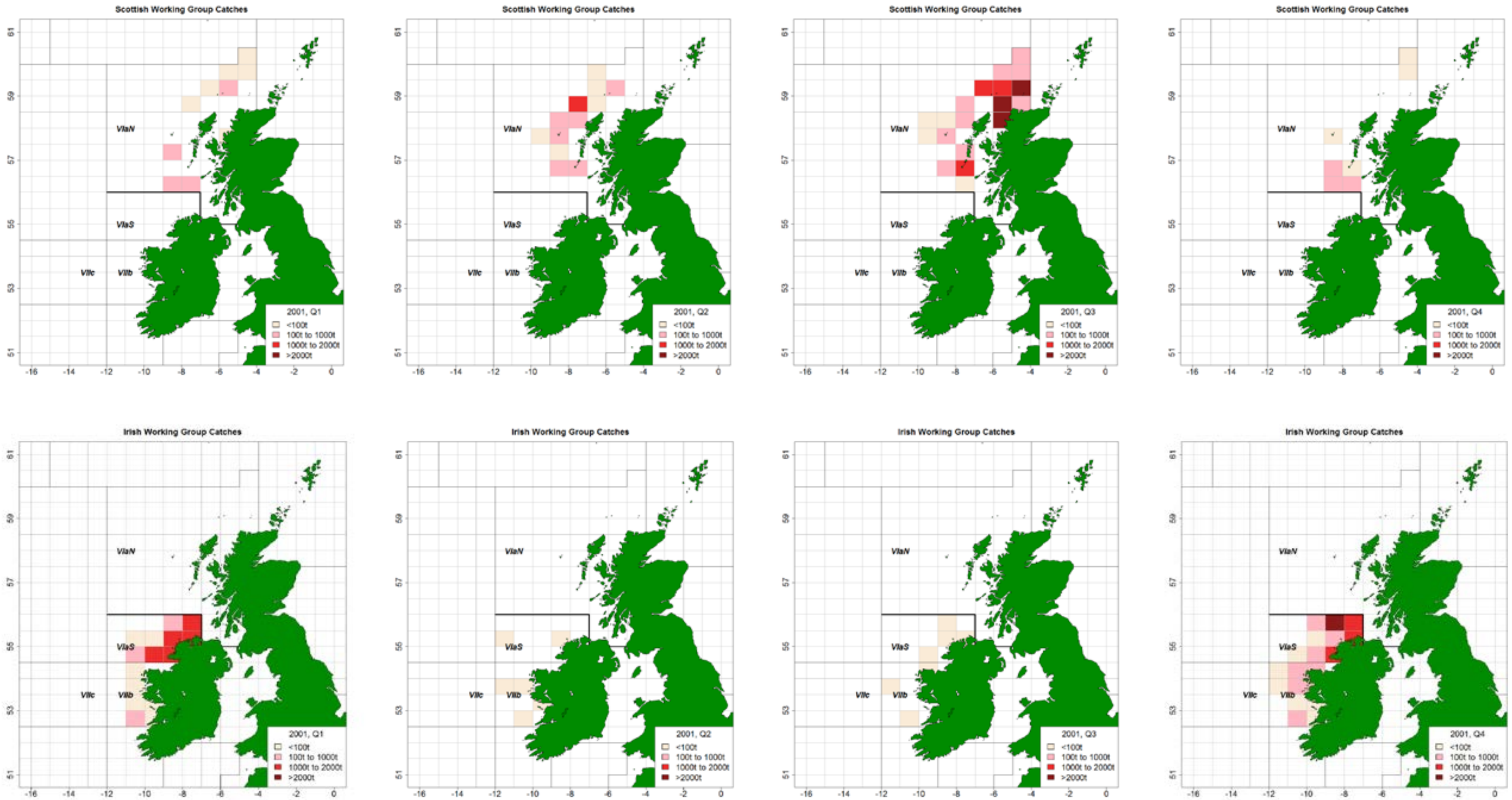
van Damme, C. J. V., Dickey-Collas, M., Rijnsdorp, A. D., & Kjesbu, O. S. (2009). Fecundity, atresia, and spawning strategies of Atlantic herring (*Clupea harengus*). Canadian Journal of Fisheries and Aquatic Sciences 66(12): 2130-2141.

7 Annexes

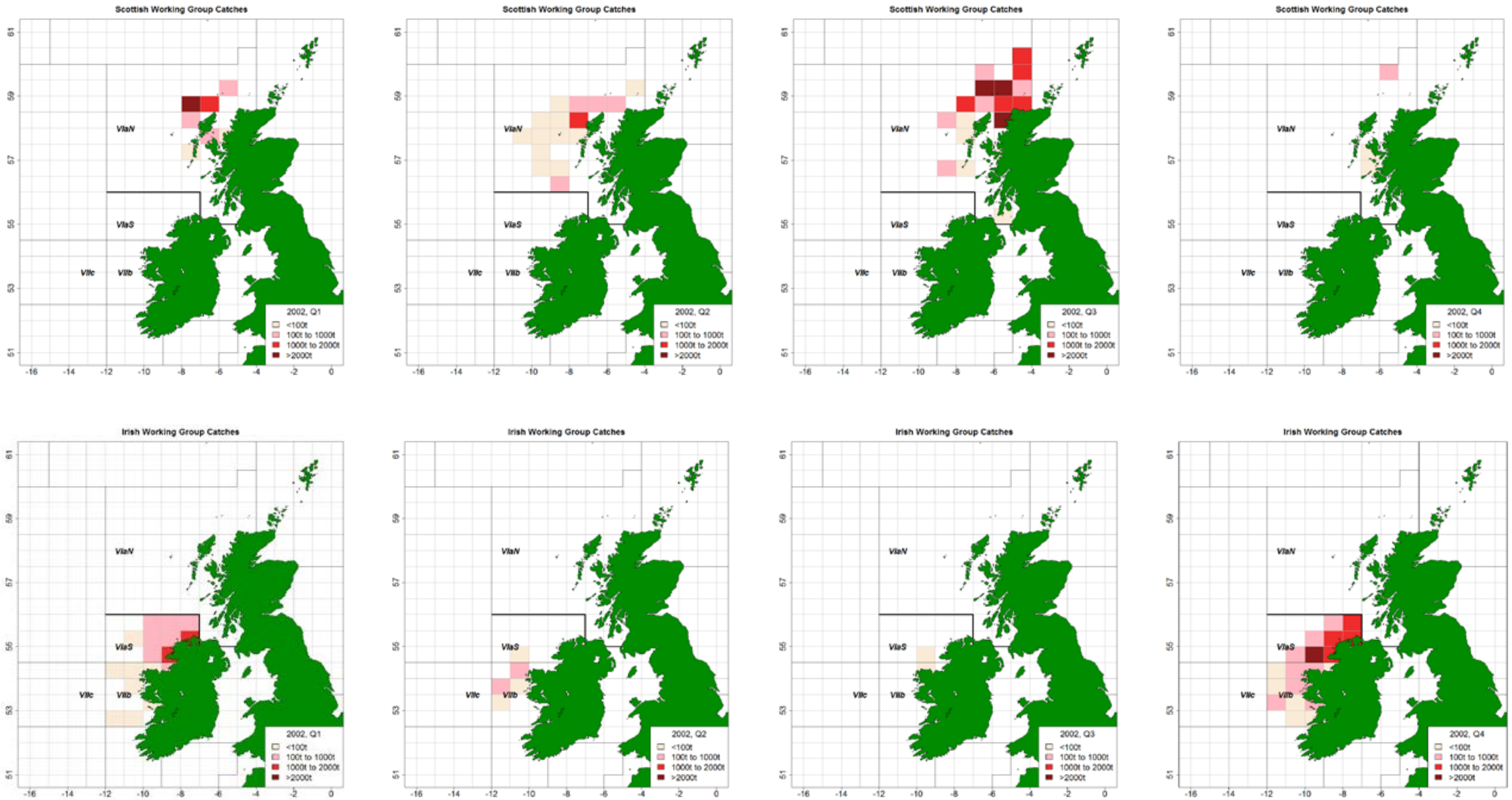
7.1 WG catches for VIa, VIIb,c



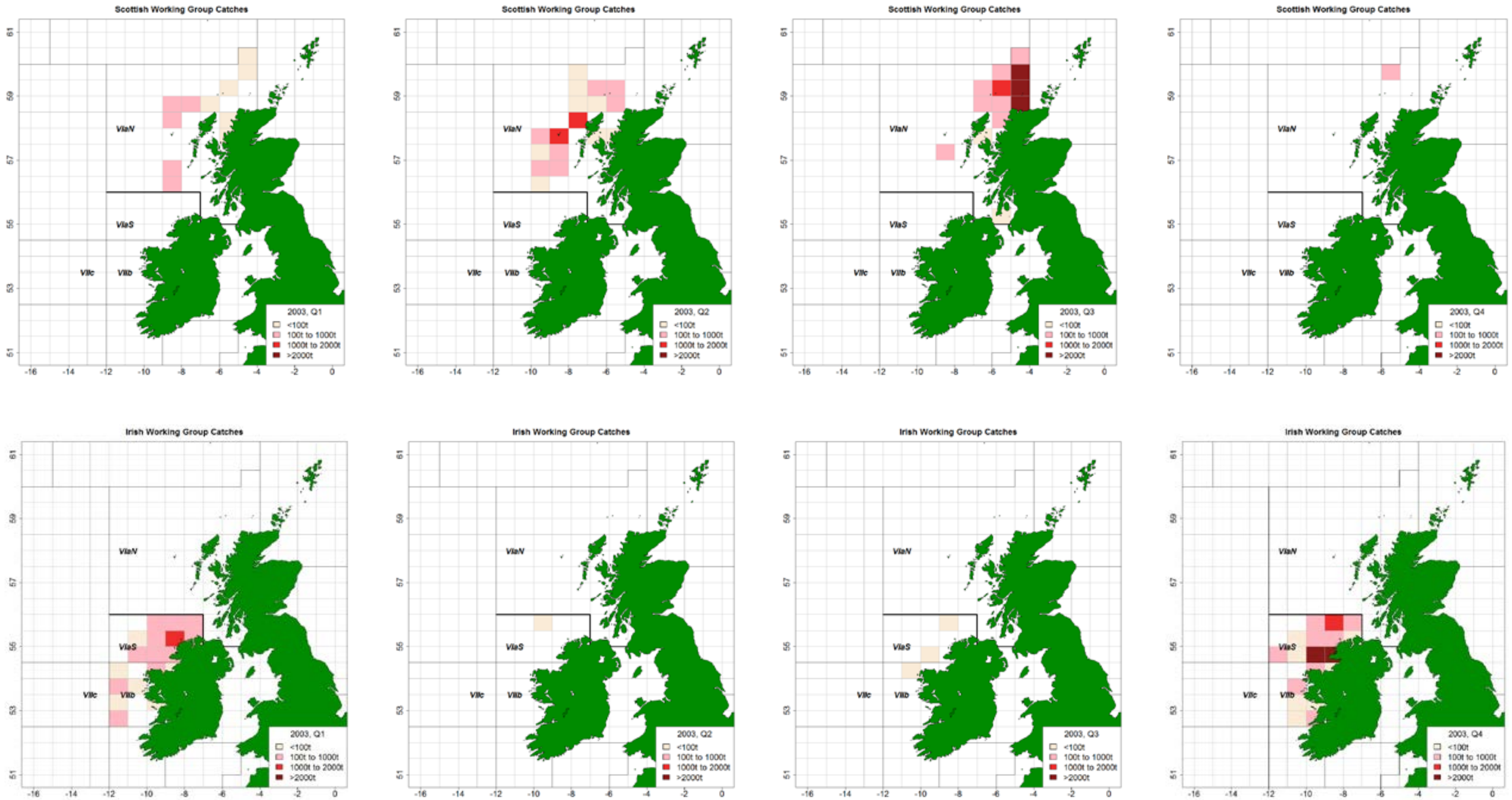
Appendix 7.1a: Herring in VIa, VIIb,c. Working Group catches in 2000 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



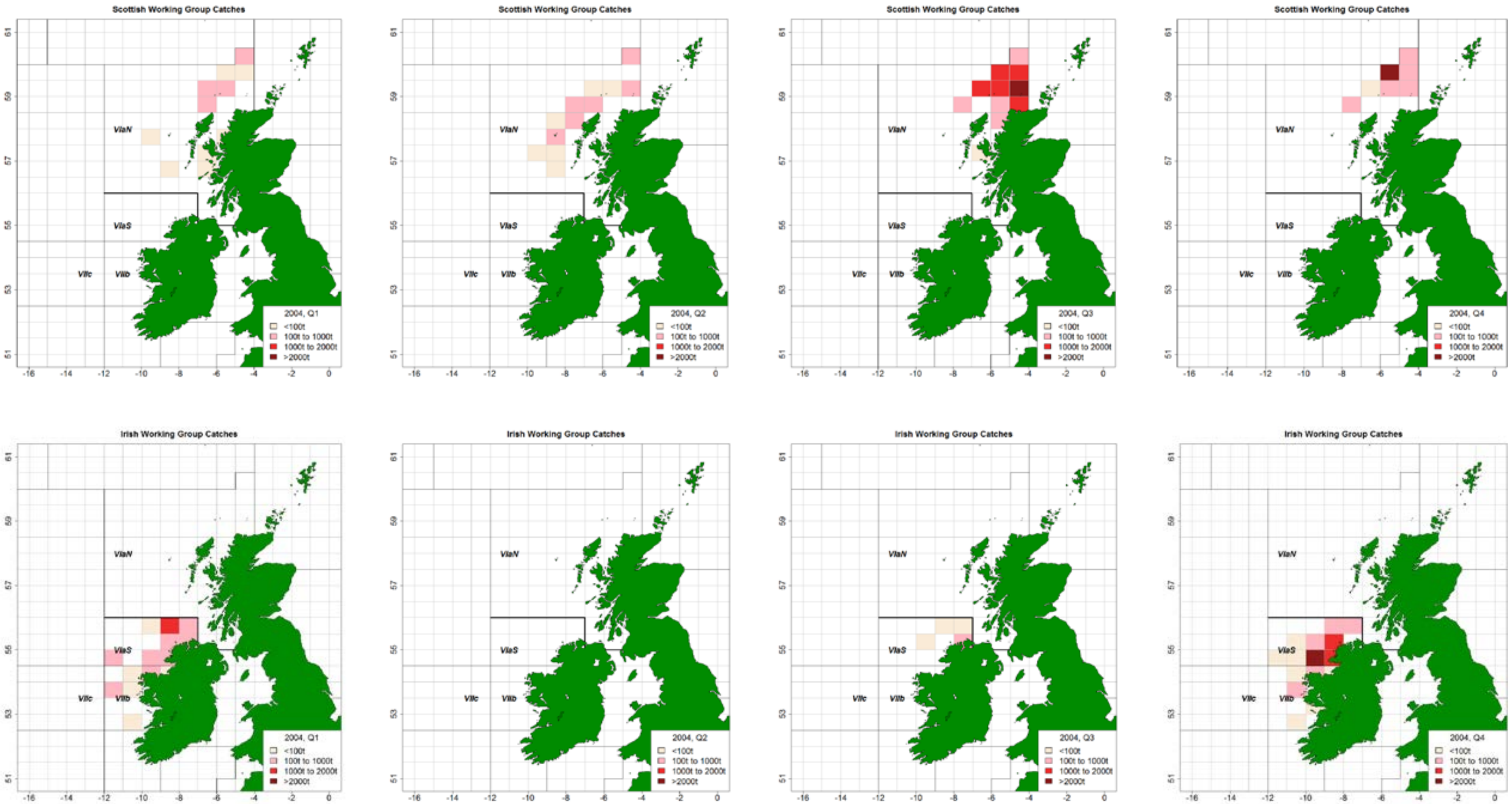
Appendix 7.1b: Herring in VIa, VIIb,c. Working Group catches in 2001 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



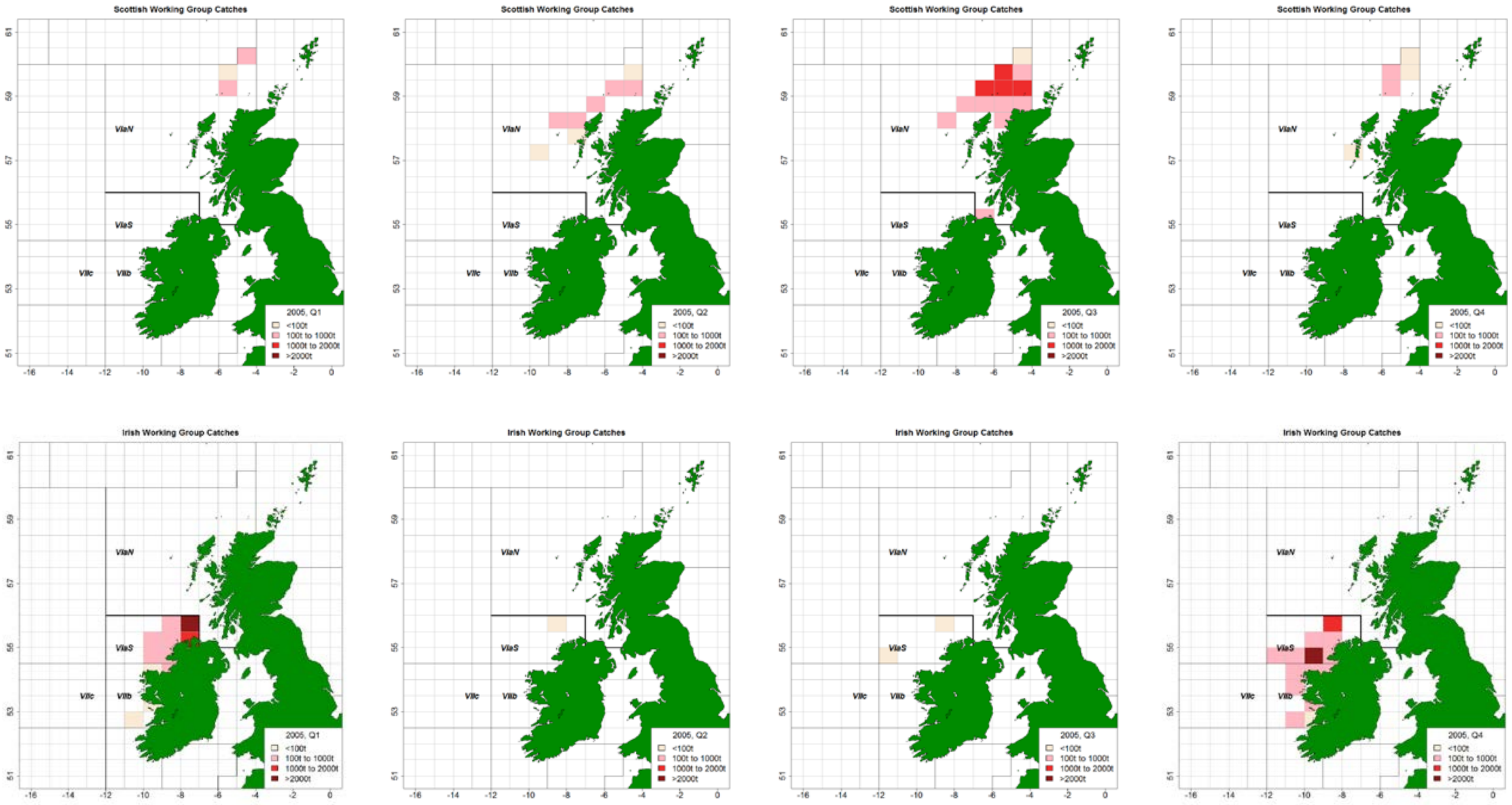
Appendix 7.1c: Herring in VIa, VIIb,c. Working Group catches in 2002 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



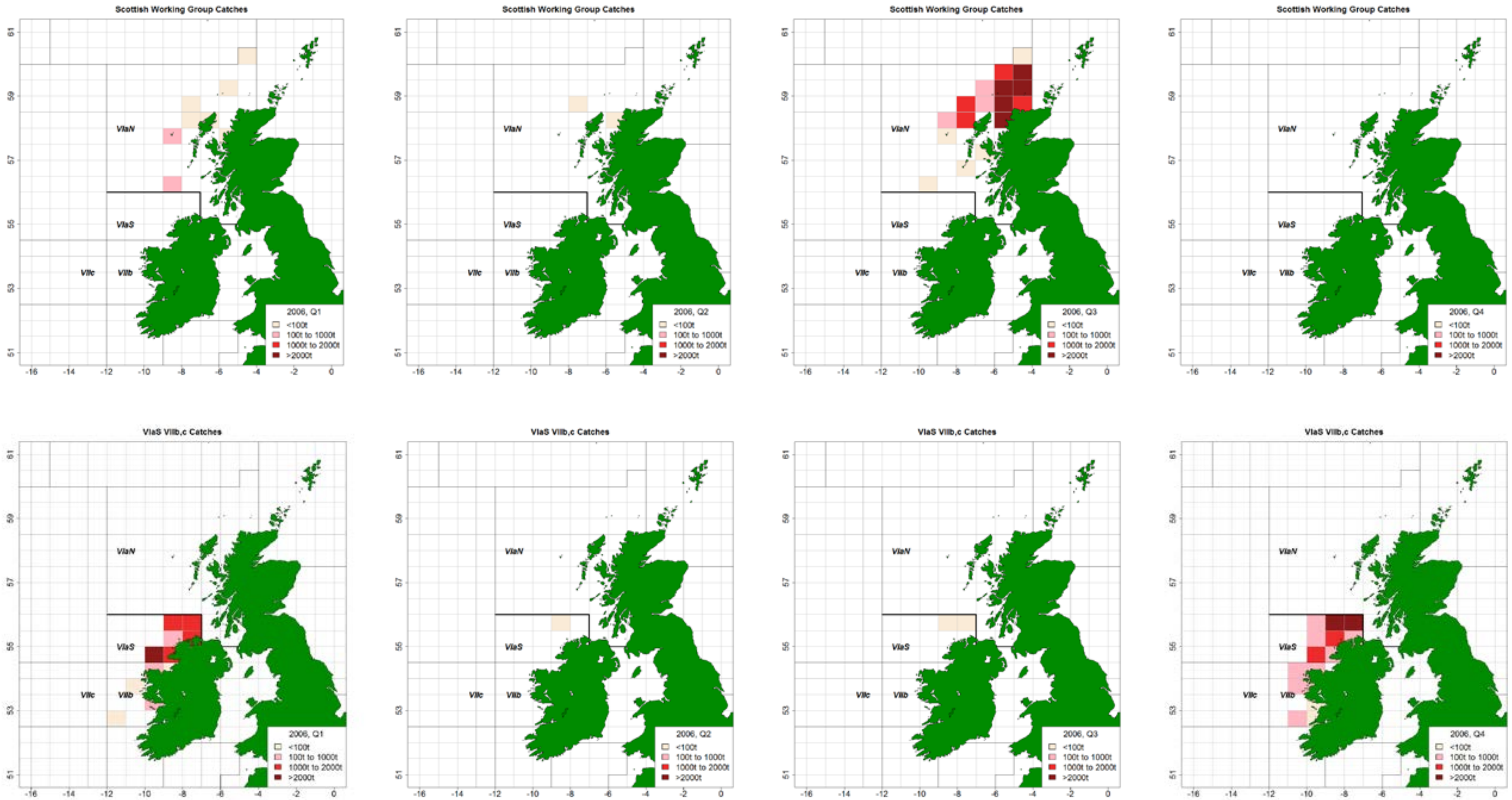
Appendix 7.1d: Herring in VIa, VIIb,c. Working Group catches in 2003 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



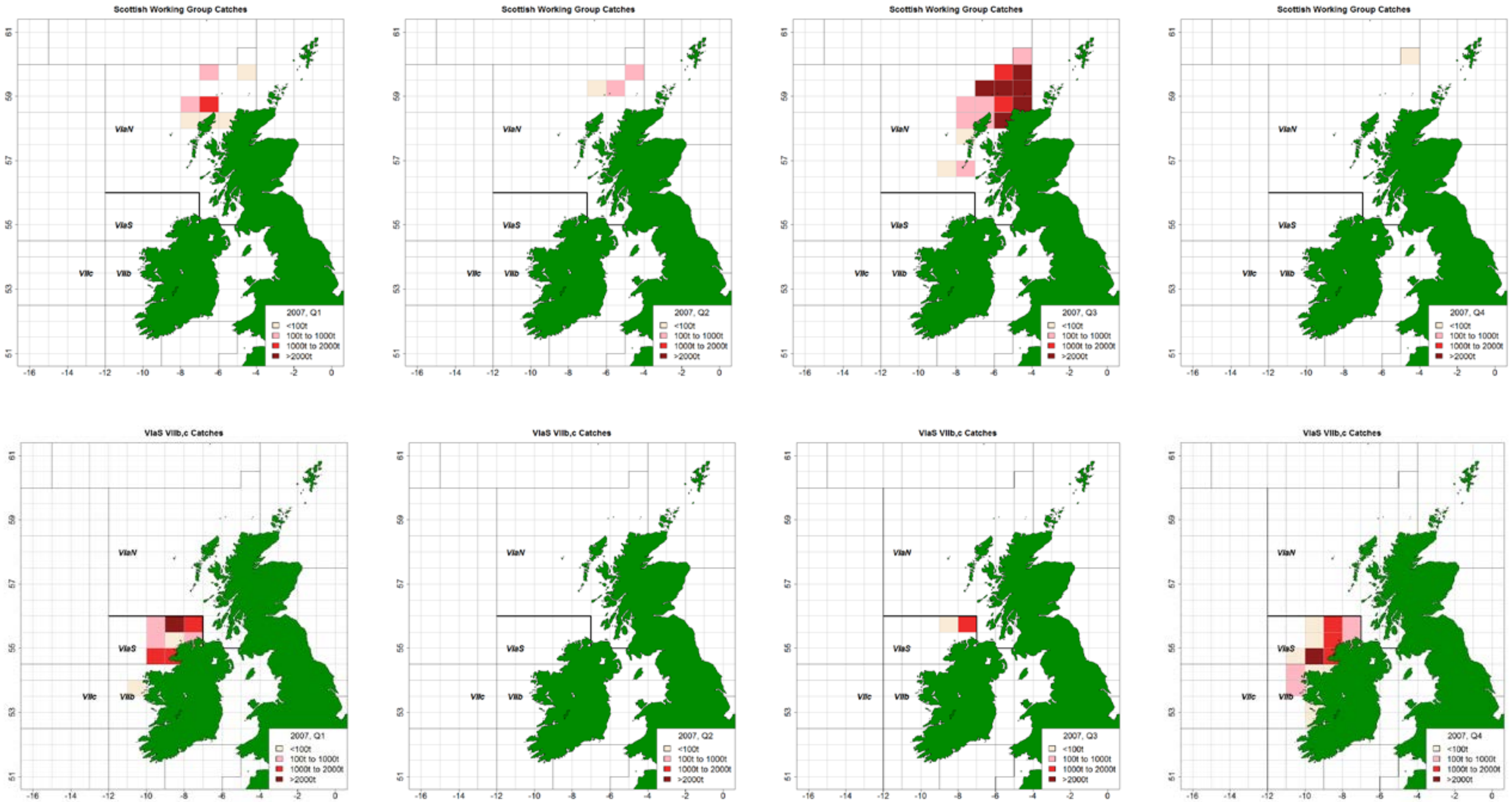
Appendix 7.1e: Herring in VIa, VIIb,c. Working Group catches in 2004 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



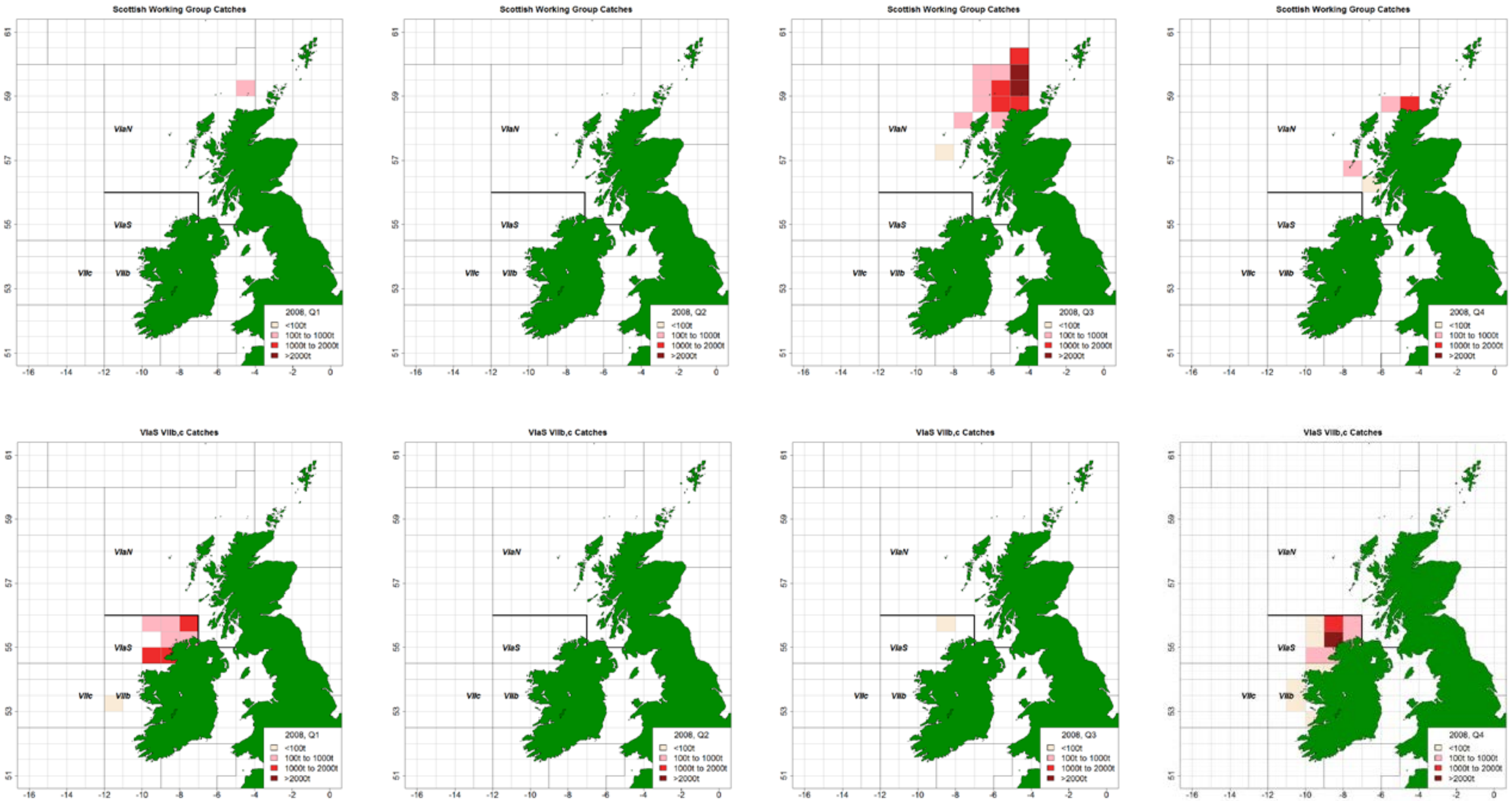
Appendix 7.1f: Herring in VIa, VIIb,c. Working Group catches in 2005 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



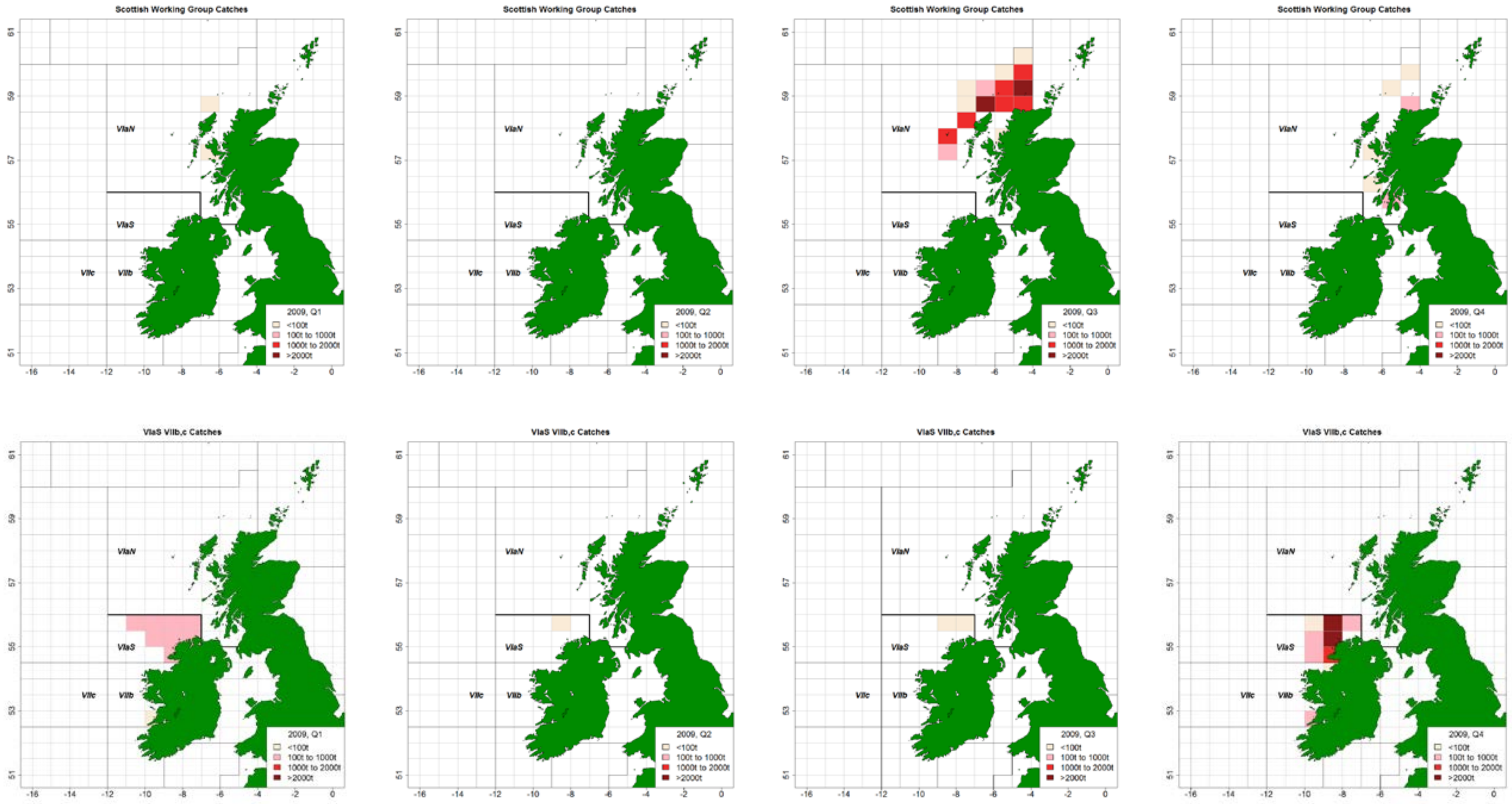
Appendix 7.1g: Herring in VIa, VIIb,c. Working Group catches in 2006 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



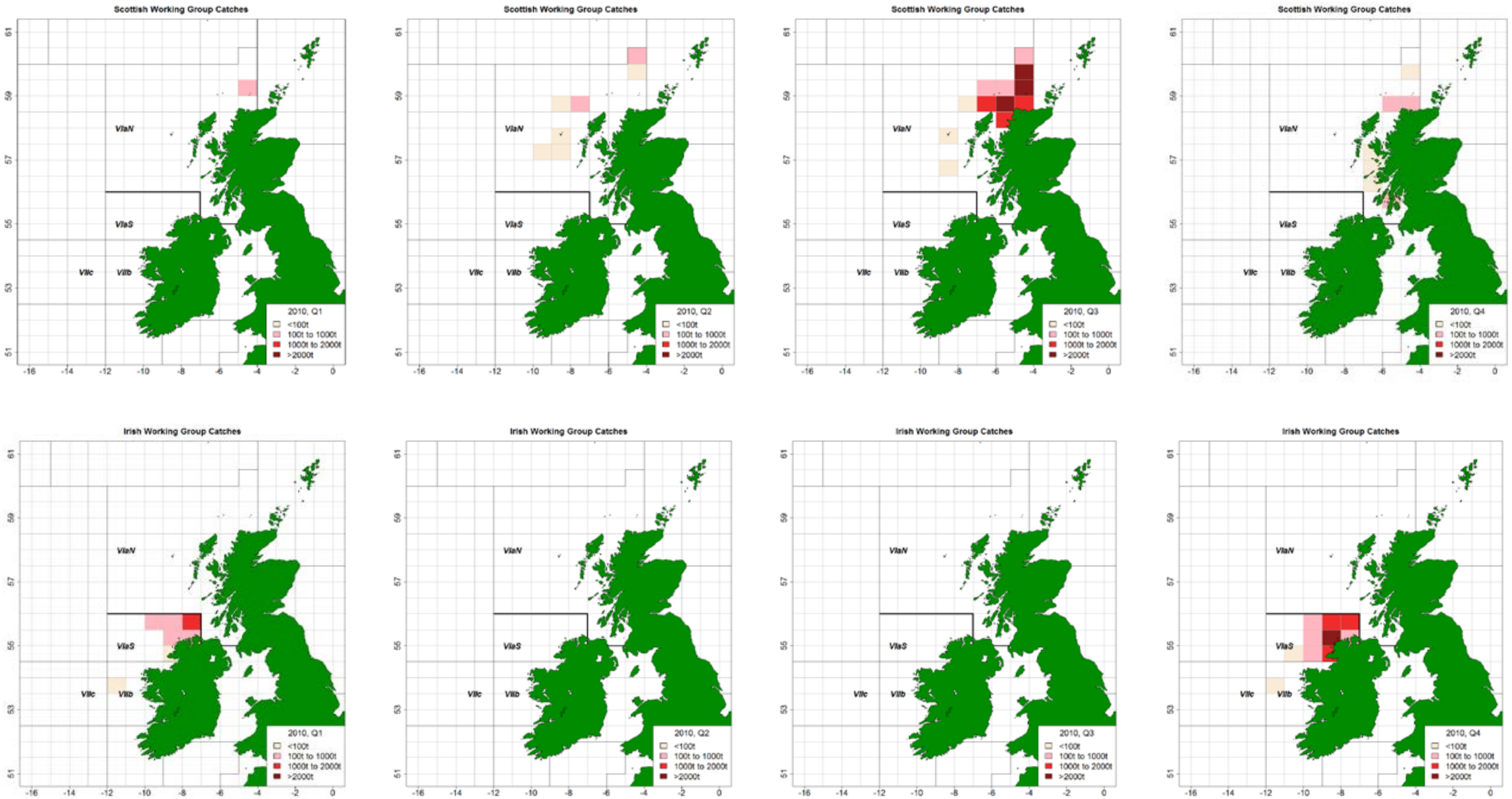
Appendix 7.1h: Herring in VIa, VIIb,c. Working Group catches in 2007 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



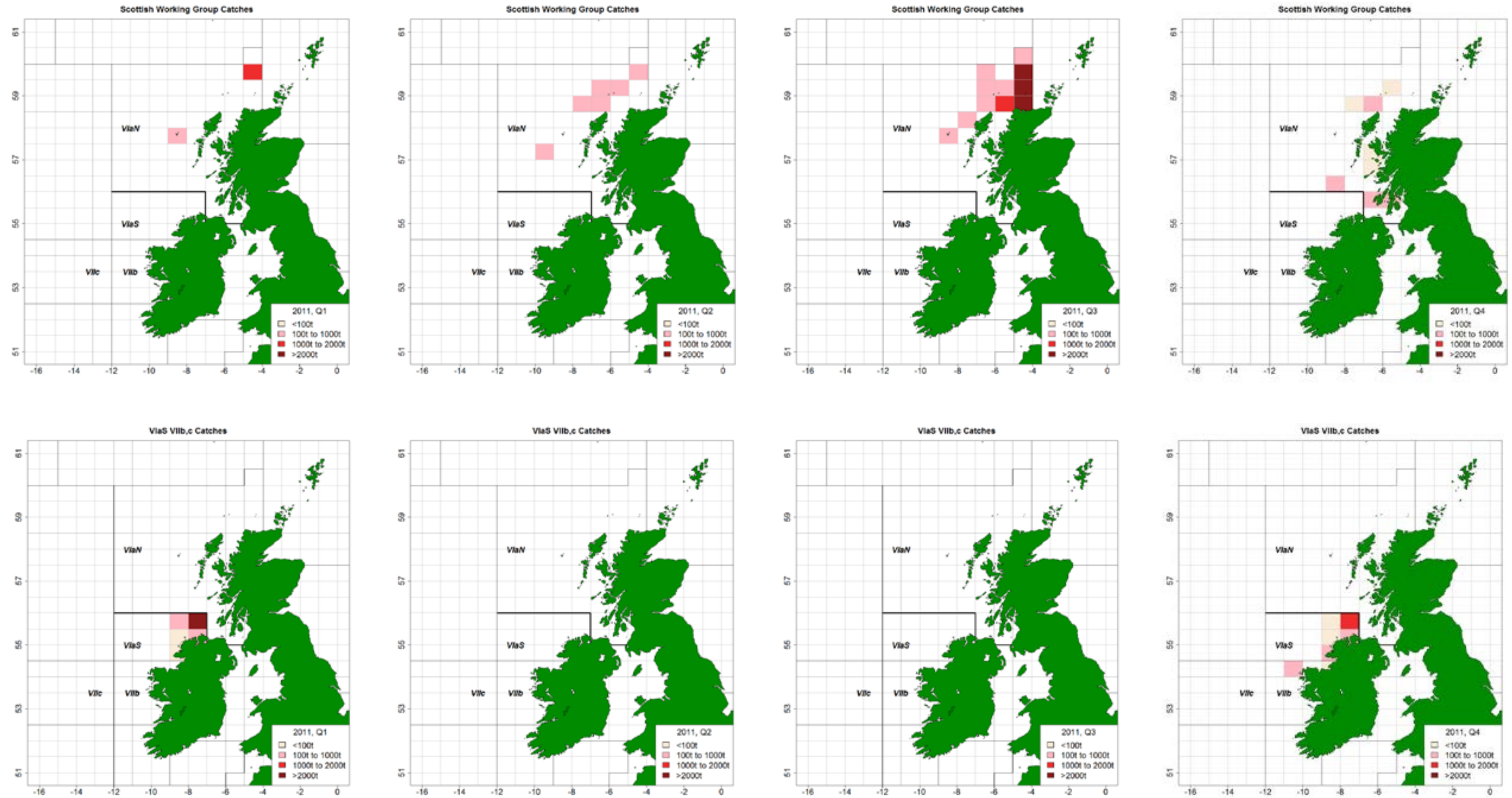
Appendix 7.1i: Herring in VIa, VIIb,c. Working Group catches in 2008 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



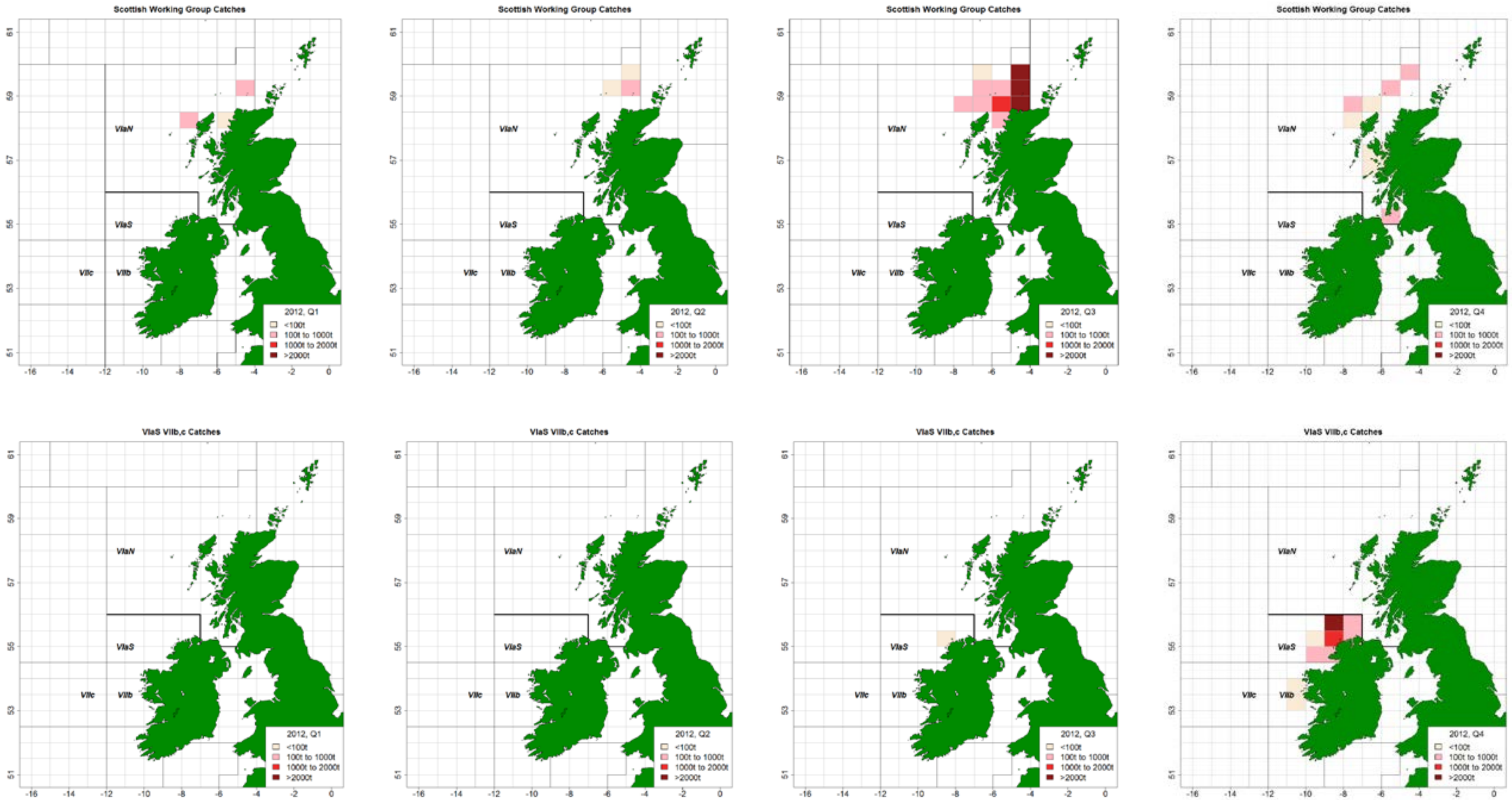
Appendix 7.1j: Herring in VIa, VIIb,c. Working Group catches in 2009 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



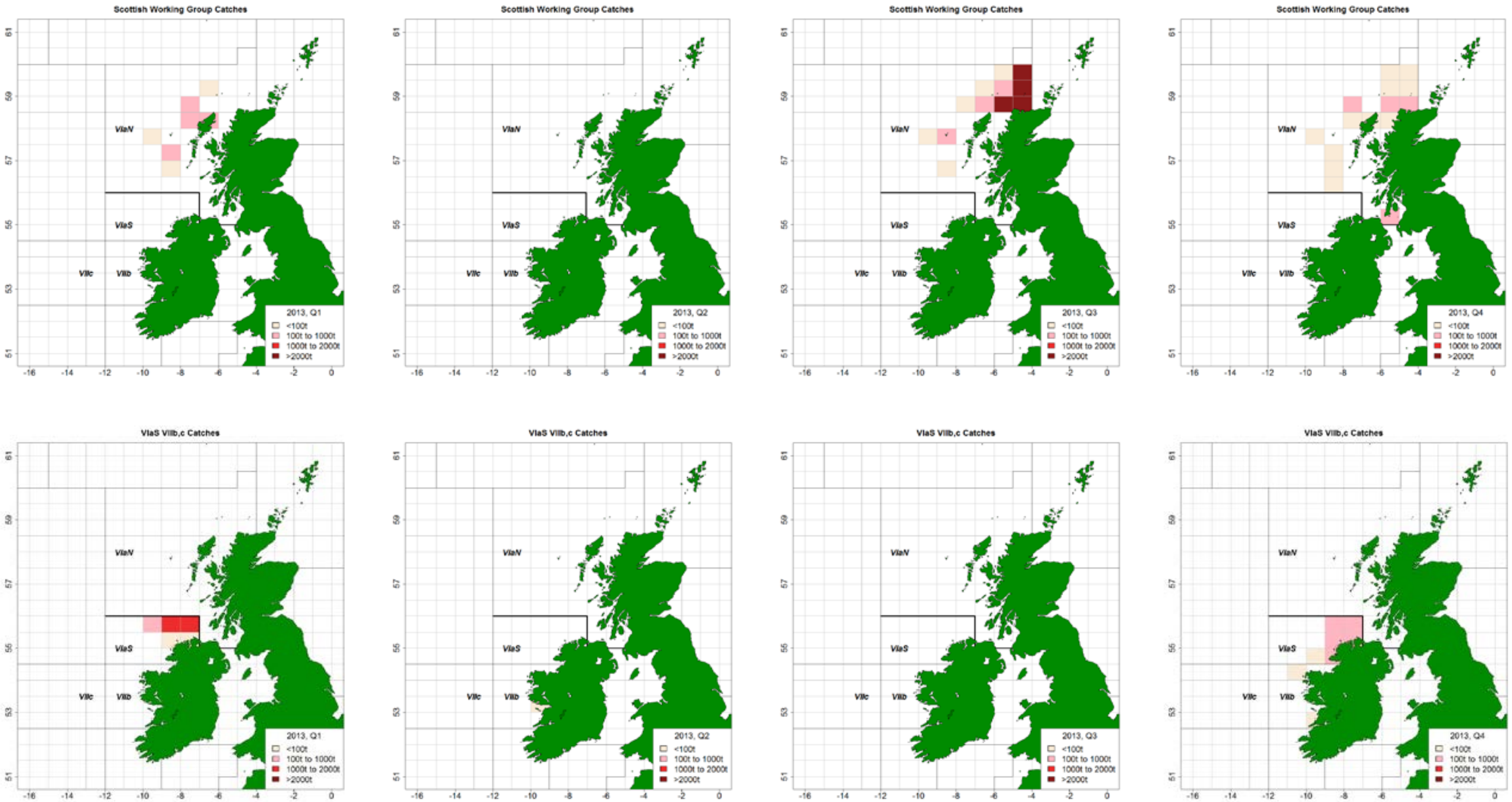
Appendix 7.1k: Herring in VIa, VIIb,c. Working Group catches in 2010 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



Appendix 7.1l: Herring in VIa, VIIb,c. Working Group catches in 2011 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



Appendix 7.1m: Herring in VIa, VIIb,c. Working Group catches in 2012 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).



Appendix 7.1n: Herring in VIa, VIIb,c. Working Group catches in 2013 by quarter reported for VIaN (top row) and VIaS, VIIb,c (bottom row).

7.2 Minority Statement, by Ireland, on the assessment of VIa, VIIb,c herring stocks

7.2.1 Introduction

The proposed benchmark assessment of this stock complex is not the best possible model outcome. This is not a criticism of the SAM model. Benchmark groups in general, and WKWEST in particular, suffer from insufficient time to evaluate assessments. The reason for this dissenting statement is the inclusion of IBTS trawl survey data in the final SAM model, and secondarily the truncation of these data. They were included to achieve a better model fit, within the time constraints of the meeting. There are a number of *a priori* reasons why trawl survey data are inappropriate to tuning herring assessments. Because of an error in natural mortality data, the benchmark had to be extended, by correspondence. This process allowed for a fuller evaluation of the model and better evaluation of including the IBTS data. This section outlines the problems identified with the final assessment, considering process issues, data issues and model issues.

7.2.2 Process

The data preparatory meeting (DCWKWEST), where input data were to be agreed, did not have access to the IBTS data, but they were included, in the final run at WKWEST meeting in February 2015, to improve the model diagnostics. The evaluation of surveys in Section 3.6.2 offers no basis for the inclusion of these data, nor does Section 3.6.5 address *a priori* concerns. The reason for including the IBTS in this final SAM assessment, was that catchability (q) for the acoustic surveys was unreasonably high (in the range 5–17 for 3+ winter ring), see Figure 3.5.11. Including the IBTS data brought the estimated q for acoustics downward to lower levels (Figure 3.5.14).

Upon discovering the error in natural mortality estimates (Section 3.11.1) subsequent modelling work in SAM was conducted through the WKWEST Extension, and also exploration using a different framework, ASAP. The ASAP run analogous to the base case SAM run, which suffered from high acoustic q, had no such problem. Insufficient time was available in WKWEST Extension to fully review the ASAP run, and it remains unclear if it is a best case assessment. However WKWEST-Extension concluded that it was not possible to conclude that the final SAM run is superior to the ASAP run.

7.2.3 Input data

For IBTS data to be included, strong *a priori* reasons are required. IBTS surveys are not routinely used for herring assessment, except in certain circumstances. Herring is an aggregating species, and a catch per unit of effort relationship is difficult to establish. The IBTS is based on the concept that the cpue is proportional to the stock abundance. The western IBTS surveys were not designed as an abundance index for herring, and have been used mainly for demersal fish in recent years. IBTS data in the western area has been used in tuning the mackerel assessment, but only for age zero juveniles. Juvenile mackerel are known to have a less pelagic habit than the adults.

For herring, in general, IBTS cpue data are only used as an abundance index for juvenile (age 1 ringer only) in the North Sea assessment, again based on proof that juvenile herring are mainly demersal in habit. The western IBTS cannot be used for young herring because, the juveniles are not found in the survey area. Older herring are also strong swimmers and could possibly avoid the trawlnet, especially over the short towing durations used (half hour). Evidence from the North Sea and Irish Sea herring benchmarks shows the poor performance of trawl surveys for adult herring.

Given the absence of *a priori* reasoning to include either IBTS survey, *post hoc* rationales were searched for, though not found (Clarke, M. and Reid, D.G., WD to WKWEST Extension, 2015). The main problems with the IBTS surveys are:

- pervasive negative mortality throughout the abundance matrices (Table 3.6.2.1 and 3.6.2.2)
- r^2 values showing little signal and much noise in the IBTS indices (Figure 7.2.1)
- Stock perception, being inconsistent with that from the acoustics, (Figure 7.2.1).
- No rationale in Section 3.6.2 for truncating the indices at 2009/2010. When the series are extended to their endpoint, they agree with the abundance trend in the acoustic surveys (Figure 7.2.2).

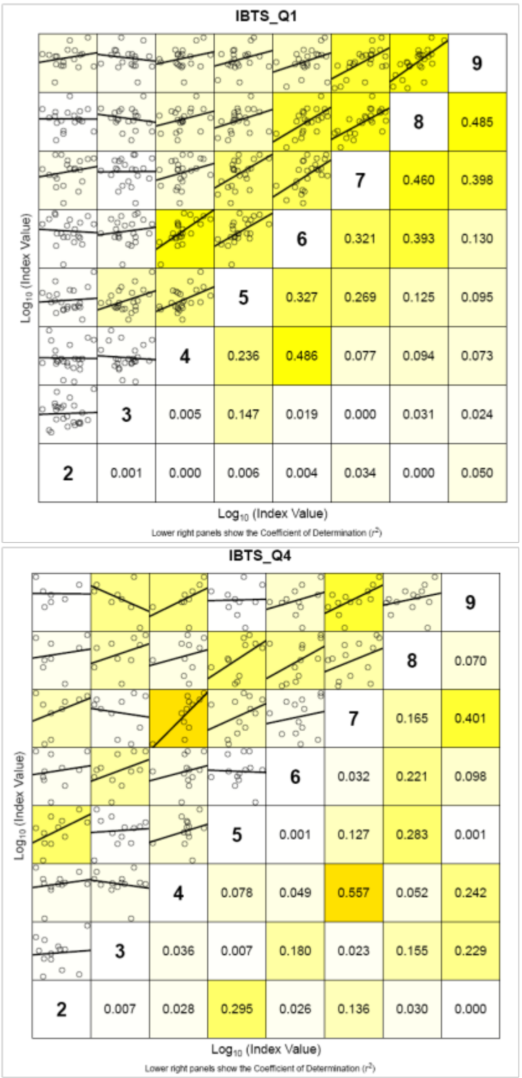


Figure 7.2.1. Herring in VIa, VIIb,c. Internal consistency diagrams for the IBTS data as used in SAM, showing pairwise regressions by age and coefficient of variation values, along with the very low coefficients of determination (r^2).

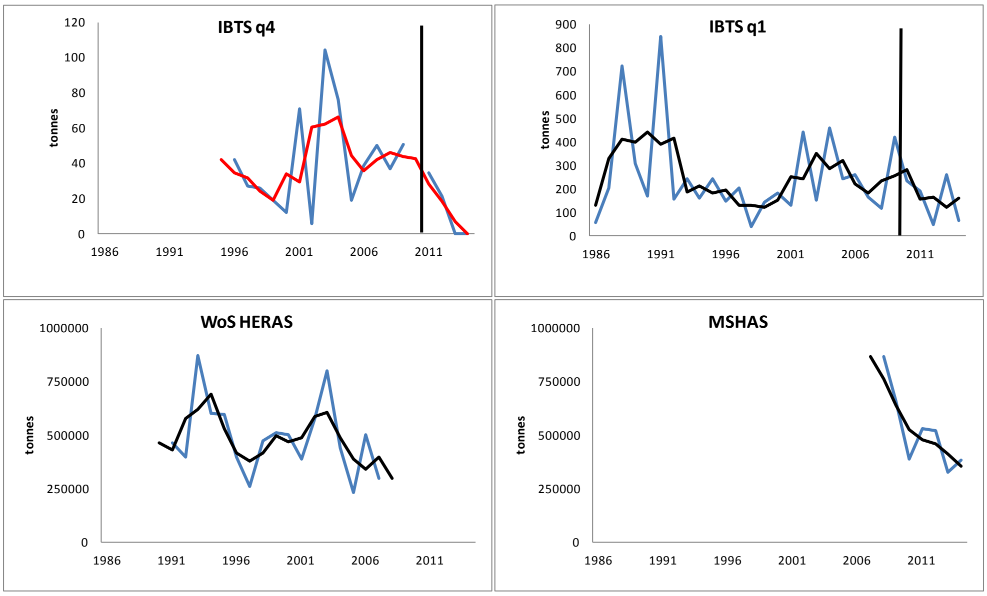


Figure 7.2.2. Herring in VIa, VIIb,c. Stock abundance trajectories as estimated by the acoustic and IBTS indices. Black vertical lines indicate where the IBTS data have been truncated for inclusion in the final SAM.

7.2.4 Model formulations

The final SAM model cannot be shown to be the best model outcome. IBTS data were 'originally' included to improve model diagnostics, despite *a prori* concerns that these data were inappropriate. At the WKWEST meeting insufficient time was available to explore other models. But the opportunity did arise in the context of WKWEST-Extension to examine both SAM and ASAP, it was found that unreasonable q values were not necessarily a feature of the acoustic surveys. Had this information been known to WKWEST it is unlikely that the proposed SAM run would have been settled upon.

The final SAM run has a lower precision (CV on SSB = 0.34, when IBTS is included) while the CV drops to 0.28 when the IBTS data are eliminated. Also, there is a very high correlation between the log F parameters in the final SAM run that lessen considerably when the IBTS is eliminated. Another concern is the high correlation between the log f parameters in the final SAM.

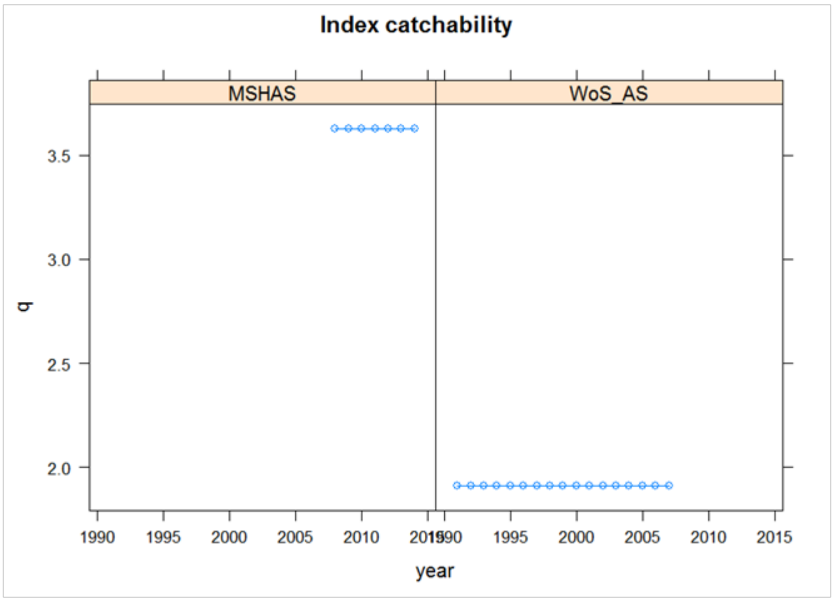
It is also worth noting that the high q (5-14) that caused the initial concern about using a SAM run only tuned with the acoustics was found to be an artefact. The WKWEST Extension SAM run, excluding the IBTS has a maximum q of 5 for any age in the acoustics. This value is rather high and suggests that SAM may not be the best model for these data.

Taken together these considerations show that the final SAM run cannot be shown to be better than the final ASAP run presented to WKWEST Extension, or some other SAM formulation.

The ASAP run is tuned only with the acoustic data, because initial modelling showed that high q was not a feature of ASAP if IBTS was eliminated. Two selection periods were considered based on initial modelling runs. The catch residual pattern is well balanced and without trend. Similarly, an excellent residual pattern was demonstrated in the survey fits (Egan. A. and Clarke, M., Working Document to WKWEST-Extension, 2015). The survey catchabilities from ASAP were 3.7 and 1.9 for the

MSHAS and WoSAS respectively (Figure 7.2.3). The uncertainty of the key parameters of SSB, recruitment and mean F are presented in Figure 7.2.3. Precision is much greater than on the SAM run. Retrospective pattern is almost non-existent with very low rhos of 0.010 for SSB, 0.017 for mean F and 0.0588 for recruitment.

A key concern must be the stock trajectories produced by the various runs. These are presented n Figure 7.2.4.1 It will be apparent that stock perception is very sensitive to the inclusion/exclusion/truncation of IBTS.



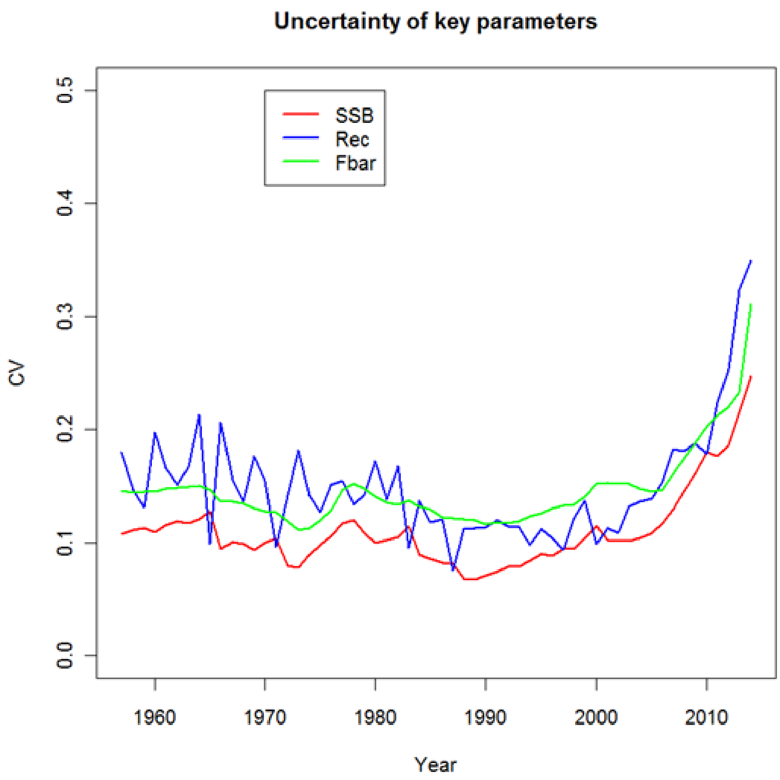


Figure 7.2.3. Herring in VIa, VIIb,c. Modelled catchability on acoustic surveys from ASAP (left) and precision of SSB, F and recruitment from ASAP.

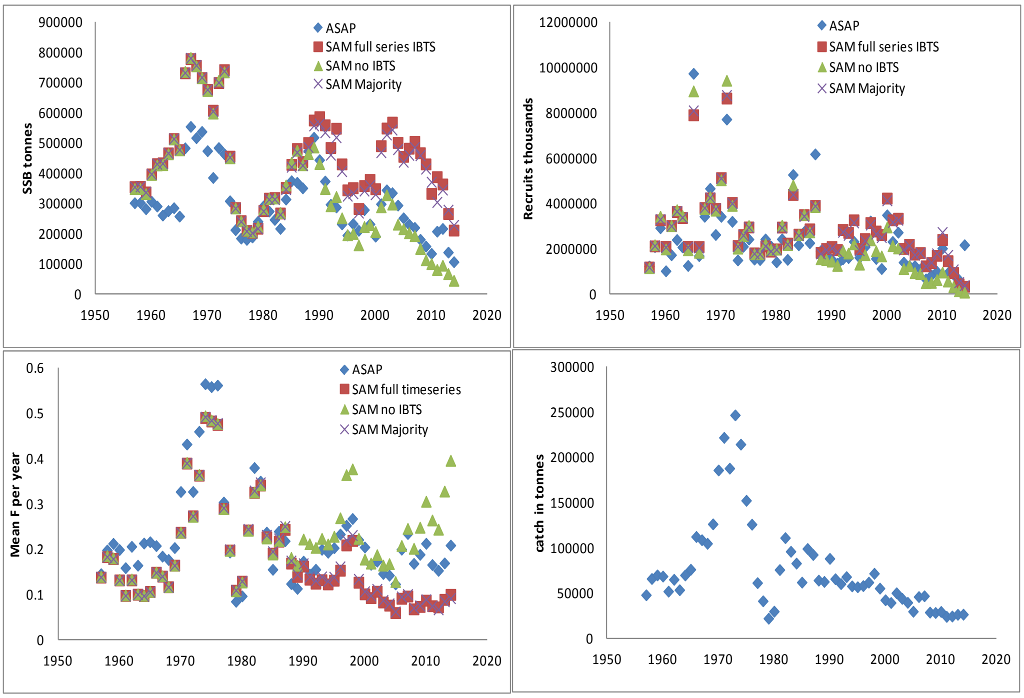


Figure 7.2.4.1 Herring in VIa, VIIb,c. Stock summary trajectories from SAM runs, with and without the truncated IBTS series, and with the extended IBTS series, along with the WKWEST Extension ASAP run tuned only with the acoustic surveys.

7.2.5 References

Clarke, M. and Reid, D.G. 2015. An evaluation of tuning indices for the vombined VIaN/VIaS and VIIbc herring assessment. Working Document to WKWEST Extension.

Egan, A. and Clarke, M. 2015. Updated assessment using ASAP for the combined VIaN and VIaS/VIIbc herring stocks. Working Document to WKWEST Extension.

7.3 New stock annexes

The table below provides an overview of the stock annexes updated at IBPWSRound. Stock Annexes for other stocks are available on the ICES website Library under the Publication Type "Stock Annexes". Use the search facility to find a particular Stock Annex, refining your search in the left-hand column to include the *year*, *ecoregion*, *species*, and *acronym* of the relevant ICES expert group.

Stock ID	Stock name	Last updated	Link
her-67bc_SA	Herring (Clupea harengus) in Divisions VIa and VIIb,c (West of Scotland, West of Ireland)	February 2015	Herring VIa and VIIb,c
her-irls_SA	Herring (Clupea harengus) in Division VIIa South of 52° 30′ N and VIIg,h,j,k (Irish Sea, Celtic Sea and Southwest of Ireland)	February 2015	Herring VIIa and VIIg,h,j,k

7.4 Working Document 1. Revision to catch data for herring in Division VIaN, 2000 to 2005

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Exchange spreadsheets provided to stock coordinators in HAWG each year and containing data on official and working group catch were interrogated to produce catch by statistical rectangle for the fishery for herring in VIaN as part of the preparation for the 2015 benchmark (WKWEST). Data were available from the various countries prosecuting the fishery from 2000 to 2013.

Data were compiled and totals of Official and Working Group catch were checked against the various other sources of catch data, namely the table of "Catch in tonnes by country" presented in HAWG each year, the "caton" file of Working Group catch used as input to the stock assessment and the "disfad" file containing Official and Working Group catches (assembled each year from the data submitted by each country prosecuting the VIaN herring fishery to provide the wherewithal to raise unsampled catches).

It was apparent that there were discrepancies between these various timeseries of catch once the catch by statistical rectangle data were compiled. These discrepancies (Table 1) were investigated.

Table 1. Discrepancies between catch data time series reported from various sources: 2000 to 2005.

Year	HAWG 2014 Report Official	HAWG 2014 Report WG	Caton	Disfad WG	Stat Square Aggregation
2000	37 789	18 322	18 322	20 229	23 154
2001	35 411	24 556	24 556	24 974	24 974
2002	36 283	32 914	32 914	31 787	31 786
2003	28 835	28 081	28 081	28 836	28 836
2004	29 854	25 021	25 021	22 969	22 841
2005	31 392	14 129	14 129	17 009	17 010

Additionally, the table of catch by year and country (Table 5.1.1) listed annually in the Herring Assessment Working Group report was checked and found to be incorrect for a number of the years reported (Table 2), giving incorrect sums of either Official or Working Group catch.

The genesis of the discrepancies was tracked to the 2007 HAWG (ICES, 2007) when various changes were made to catch data from various countries. There were three revisions to the catch data time series. An incorrect allocation of fish to the plus group in the Dutch catches in 2004 and 2005 affected the 2004 Division VIaN catch and the allocations for that year had to be recalculated. Landings data were also revised with respect to reallocation of catches from Division VIaN to Division VIaS, for the years 2000–2005. Thirdly, a readjustment of catch figures was necessary from 2001 to 2004 in light of new information on misreporting from the UK.

Catch data were checked prior to the WKWEST and showed that reallocation of catches from Division VIaN to Division VIaS had been incorrectly performed, to varying extents, for the years 2000, 2001, and 2004 in the 2007 HAWG. For example, in the

2001 HAWG, the 2000 catch was correctly reallocated. In the 2007 HAWG report, however, the same quantity of catch was removed again from the WG catch.

Table 2. Inconsistencies (shaded in grey) in HAWG report Table 5.1.1.

Country	2001	2002	2003	2004
Faroes		800	400	228
France	760	1340	1370	625
Germany	3944	3810	2935	1046
Ireland	4311	4239	3581	1894
Netherlands	4534	4612	3609	8232
Norway				
UK	21 862	20 604	16 947	17 706
Unallocated		878	-7	
Discards*				123
Total	35 411	36 283	28 835	29 854
Area-Misreported	-11 132	-8735	-3581	-7218
WG Estimate	24 556	32 914	28 081	25 021
Source (WG)	2002	2003	2004	2005
Total Official Catch	35 411	35 405	28 842	29 731
Total Catch (incl discards)	35 411	35 405	28 842	29 854
Total Catch (incl disc+unalloc)	35 411	36 283	28 835	29 854
Total Catch (incl disc+unalloc+area misrep)	24 279	27 548	25 254	22 636
HAWG WG estimate vs. Calculated estimate	0.99	0.84	0.90	0.90

Additionally, it was discovered that the readjusted UK catch figures which had been correctly incorporated into the catch data (*caton*) and numbers-at-age in the catch (*canum*) files at that time (ICES, 2007) had been omitted from the appropriate table of catch by country by year (Table 5.1.1) in the WG report.

Official and Working Group catch were calculated correctly and are given in Table 3.

Table 3. Corrected Official and Working Group catches in Division VIaN, from 2000 to 2005 and comparison with the previous incorrect estimates.

Country	2000	2001	2002	2003	2004	2005
Faroes	0	0	800	400	228	1810
France	870	760	1340	1370	625	613
Germany	4615	3944	3810	2935	1046	2691
Ireland	4841	4311	4239	3581	1894	2880
Netherlands	4647	4534	4612	3609	8232	5132
UK	22 816	21 862	20 604	16 947	17 706	17 494
Discards	0	0	0	0	123	772
Unallocated		277	6244	2820	3490	
Corrected Total catch	37 789	35 688	41 649	31 662	33 344	31 392
Corrected Area misreported	14 627	10 437	8735	3581	6885	17 263
Corrected WG catch	23 162	25 251	32 914	28 081	26 459	14 129
Previous WG estimate	18 322	24 556	32 914	28 081	25 021	14 129
% difference	26.42	2.83	0.00	0.00	5.75	0.00

To correct the catch in numbers-at-age (*canum*) data, the data from 2006 with the Dutch recalculation applied (Table 4.1) were retrieved from the spreadsheets created prior to HAWG 2007 (when the various changes to the catches were originally incorporated). Corrections were applied to the data in several steps, duplicating the steps taken prior to the HAWG 2007 and documented extensively in a notebook used at that time to record WG preparation (Hatfield, personal notebook).

To derive the corrected *canum* matrix:

i. a correction factor was derived from the difference between the *caton* data in 2006 and the *caton* corrected in the current exercise, correcting for the Division VIaN to Division VIaS reallocation only
ii. the 2006 *canum* matrix (4.1) was multiplied by the relevant correction factor in each year
iii. the resulting data matrix (4.2) was updated with the additional catches in number-at-age derived from the readjusted misreporting data to give the corrected *canum* matrix (4.3)

Table 4. Numbers-at-age in the catch: (4.1) post 2006 HAWG with Dutch 2004 revision; (4.2) multiplied with the relevant correction factors and (4.3) with the additional numbers added in step (iii) above.

4.1 Post 2006 HAWG numbers plus Dutch 2004 revision									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2000	4511.46	22 960.61	21 825.16	51 420.22	15 504.75	9002.21	3897.69	1835.56	576.39
2001	147.07	82 213.66	15 295.29	9490	24 896.15	9493.19	6784.81	4720.76	1015.07
2002	1144.88	35 410.37	90 203.5	9505.61	19 915.86	29 287.57	9627.55	1289.91	1203.08
2003	53.01	32 708.93	48 448.73	56 629.08	7986.71	4666.69	13 527.25	10 376.27	1330.04
2004	0	6259.4	20 127.8	25 661.33	41 718.7	3767.54	7325.16	8668.17	4119.65
2005	219.7	11 596.2	27 973.19	24 801.9	12 324.79	11 777.34	1221.89	1438.53	1722.4

4.2 WKPELA 2015 corrected canums Dutch plus correct VIaN to VIaS reallocation									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2000	4511.46	22 960.61	21 825.16	51 420.22	15 504.75	9002.21	3897.69	1835.56	576.39
2001	147.07	82 213.66	15 295.29	9490.00	24 896.15	9493.19	6784.81	4720.76	1015.07
2002	992.20	30 688.17	78 174.29	8237.98	17 259.95	25 381.88	8343.65	1117.89	1042.64
2003	46.43	28 646.83	42 431.91	49 596.35	6994.85	4087.14	11 847.31	9087.65	1164.86
2004	0.00	6259.40	20 127.80	25 661.33	41 718.70	3767.54	7325.16	8668.17	4119.65
2005	182.50	9632.71	23 236.71	20 602.39	10 237.93	9783.18	1015.00	1194.96	1430.76

4.3 WKPELA 2015 corrected canums Dutch plus correct VIaN to VIaS reallocation									
plus extra numbers-at-age from corrected UK misreporting									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2000	4511.46	22 960.61	21 825.16	51 420.22	15 504.75	9002.21	3897.69	1835.56	576.39
2001	147.07	82 213.81	15 295.47	9490.20	24 896.38	9493.43	6785.06	4721.03	1015.33
2002	992.20	30 688.17	78 174.29	8237.98	17 259.95	25 381.88	8343.65	1117.89	1042.64
2003	46.43	28 646.83	42 431.91	49 596.35	6994.85	4087.14	11 847.31	9087.65	1164.86
2004	276.60	6259.40	20 127.80	25 661.33	41 718.70	3767.54	7325.16	8668.17	4119.65
2005	182.50	9632.71	23 236.71	20 602.39	10 237.93	9783.18	1015.00	1194.96	1430.76

To derive the corrected *weca* matrix the *weca* data for 2000 to 2005 were extracted from the HAWG 2006 input file (ICES, 2006). The updated data were derived according to the following equation:

$$\frac{(\text{2006 HAWG } canum * \text{2006 HAWG } weca) + (\text{UK corrected } canum * \text{UK corrected weights-at-age})}{(\text{2006 HAWG } canum + \text{UK corrected } canum)}$$

The differences between the *canum* and *weca* data from the 2014 HAWG (and used in that year’s assessment) and from the current exercise for WKWEST 2015 are shown in Table 5.

Table 5. The differences between the *canum* and *weca* data from the 2014 HAWG and from the current exercise for WKWEST 2015.

HAWG 2014									
canum									
	1	2	3	4	5	6	7	8	9
2000	3568.58	18161.91	17263.76	40673.54	12264.3	7120.78	3083.08	1451.93	455.93
2001	142.98	81030.48	14942.91	9305.89	24482.25	9280.71	6624.96	4610.61	1000.53
2002	992.2	38481.61	93975.06	9014.41	18113.71	28016.08	9040.1	1547.86	1422.68
2003	56.12	33331.97	46865.58	53766.66	7462.99	4344.55	12818.38	9187.62	1407.96
2004	0	6843.91	22223.2	27815.23	45782.43	3916.1	7641.76	8481.01	4008.01
2005	182.5	9632.71	23236.71	20602.39	10237.93	9783.18	1014.997	1194.96	1430.76

WKWEST 2015									
canum									
	1	2	3	4	5	6	7	8	9
2000	4511.46	22960.61	21825.16	51420.22	15504.75	9002.21	3897.69	1835.56	576.39
2001	147.07	83318.4	15368.56	9569.987	25175.08	9544.889	6813.777	4741.976	1028.783
2002	992.2029	38481.61	93975.05	9014.404	18113.71	28016.08	9040.097	1547.866	1422.68
2003	56.1154	33331.96	46865.58	53766.67	7462.985	4344.547	12818.38	9187.617	1407.961
2004	0	7235.792	23483.32	29421.79	48394.28	4151.944	8100.364	9023.675	4265.929
2005	182.4999	9632.707	23236.71	20602.39	10237.93	9783.176	1014.997	1194.955	1430.76

%difference									
canum									
	1	2	3	4	5	6	7	8	9
2000	26.42	26.42	26.42	26.42	26.42	26.42	26.42	26.42	26.42
2001	2.86	2.82	2.85	2.84	2.83	2.85	2.85	2.85	2.82
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	5.73	5.67	5.78	5.70	6.02	6.00	6.40	6.44
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

HAWG 2014									
weca									
	1	2	3	4	5	6	7	8	9
2000	0.0834	0.1373	0.1637	0.1829	0.2014	0.2147	0.2394	0.2812	0.2526
2001	0.0490	0.1400	0.1630	0.1830	0.1920	0.1960	0.2050	0.2250	0.2720
2002	0.1070	0.1460	0.1630	0.1730	0.1600	0.1790	0.1870	0.2450	0.2810
2003	0.0600	0.1450	0.1600	0.1690	0.1860	0.2000	0.1940	0.1860	0.2940
2004	0.0000	0.1540	0.1730	0.1950	0.2160	0.2200	0.1990	0.1900	0.3110
2005	0.1084	0.1327	0.1632	0.1845	0.2108	0.2258	0.2341	0.2556	0.2496

WKWEST 2015									
weca									
	1	2	3	4	5	6	7	8	9
2000	0.0834	0.1373	0.1637	0.1829	0.2014	0.2147	0.2394	0.2812	0.2526
2001	0.0490	0.1398	0.1628	0.1828	0.1922	0.1959	0.2047	0.2245	0.2716
2002	0.1066	0.1464	0.1625	0.1728	0.1595	0.1780	0.1863	0.2449	0.2802
2003	0.0609	0.1448	0.1593	0.1690	0.1852	0.1997	0.1942	0.1854	0.2938
2004	0.0000	0.1541	0.1732	0.1948	0.2160	0.2197	0.1986	0.1885	0.3030
2005	0.1084	0.1327	0.1632	0.1845	0.2108	0.2258	0.2341	0.2556	0.2496

%difference									
weca									
	1	2	3	4	5	6	7	8	9
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
2002	0.00	0.01	-0.01	0.00	-0.01	-0.02	-0.01	0.00	-0.02
2003	0.01	0.00	-0.01	0.00	-0.01	-0.01	0.00	-0.01	-0.01
2004	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.03	-0.25
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The *canum* and *weca* input data files for the WKWEST 2015 benchmark assessments for herring in Division VIaN were updated by incorporating the data in the WKWEST 2015 cells above into the input files used for the HAWG 2014 assessment.

The corrected Table 5.1.1. of catch by country and year for the HAWG report is given below.

Table 5.1.1. Herring in VIa (North). Catch in tonnes by country, 1990-2013. These figures do not in all cases correspond to the official statistics and cannot be used for management purposes.

COUNTRY	1990	1991	1992	1993	1994	1995	1996	1997
Faroes	326	482			274		2297	
France	1287	1168	119	818	5087	3672	7836	3093
Germany	7096	6450	5640	4693	7938	3733	9721	8873
Ireland	10 000	8000	7985	8236	6093	3548	9396	1875
Netherlands	7693	7979	8000	6132	8183	7808	6223	9873
Norway	1607	3318	2389	7447	30 676	4840	46 639	4962
UK	38 253	32 628	32 730	32 602	-4287	42 661	-17 753	44 273
Unallocated	2397	-10 597	-5485	-3753	700	-4541		-8015
Discards*	1300	1180	200					62
Total	69 959	50 608	51 578	56 175	54 664	61 271	64 359	64 995
Area-	-25 266	-22 079	-22 593	-24 397	-30 234	-32 146	-38 254	-29 766
WG	44 693	28 529	28 985	31 778	24 430	29 575	26 105	35 233
Source	1993	1993	1994	1995	1996	1997	1997	1998

Country	1998	1999	2000	2001	2002	2003	2004	2005
Faroes					800	400	228	1810
France	1903	463	870	760	1340	1370	625	613
Germany	8253	6752	4615	3944	3810	2935	1046	2691
Ireland	11 199	7915	4841	4311	4239	3581	1894	2880
Netherlands	8483	7244	4647	4534	4612	3609	8232	5132
Norway	5317	2695						
UK	42 302	36 446	22 816	21 862	20 604	16 947	17 706	17 494
Unallocated	-11 748	-8155		277[$]	6244[$]	2820[$]	3490[$]	
Discards*	90						123	772
Total	65 799	61 514	37 789	35 688[$]	41 649[$]	31 662[$]	33 344[$]	31 392
Area-	-32 446	-23 623	-14 627[$]	-10 437[$]	-8735	-3581	-6885[$]	-17 263
WG	33 353	29 736	23 162[$]	25 251[$]	32 914	28 081[$]	26 459[$]	14 129
Source	1999	2000	2001	2002	2003	2004	2005	2006

Country	2006	2007	2008	2009	2010	2011	2012	2013
Faroes	570	484	927	1544	70			
France	701	703	564	1049	511	504	244	586
Germany	3152	1749	2526	27	3583	3518	1829	4025
Ireland	4352	5129	3103	1935	2728	3956	3451	3124
Netherlands	7008	8052	4133	5675	3600	1684	3523	1775
Norway								
UK	18 284	17 618	13 963	11 076	12 018	11 696	12 249	15 906
Unallocated								
Discards*	163				95			30
Total	34 230	33 735	25 216	21 306	22 510	21 358	21 296	25 446
Area-	-6884	-4119	-9162	-2798	-2728	-3599	-2780	-2468
WG	27 346	29 616	16 054	18 508	19 877	17 759	18 516	22 978
Source	2007	2008	2009	2010	2011	2012	2013	2014

$Revised at WKWEST 2015

References

ICES. 2006. Report of the Herring Assessment Working Group South of 62º N (HAWG). ICES CM 2006/ACFM:20. 618 pp.

ICES. 2007. Report of the Herring Assessment Working Group South of 62º N (HAWG). ICES CM 2007/ACFM:11. 546 pp.

7.5 Working Document 2. Natural mortality of the VIaN herring (*Clupea harengus* L.) stock

By Michael O'Malley, Susan Lusseau, Emma Hatfield

Introduction

The natural mortality (M) currently used (1957–2013) for the VIaN herring stock is fixed by age and over time. M values used in the current stock assessment are highest at 1-ringer (1.0) and decrease rapidly to 0.1 from 4-ringers onwards (Table 1). Figure 1 shows M represented as an overall percent mortality per winter ring age group.

Table 1: M currently used (1957 – 2013) for the VIaN herring stock

Age (rings)	1	2	3	4	5	6	7	8	9
M value	1.0	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1

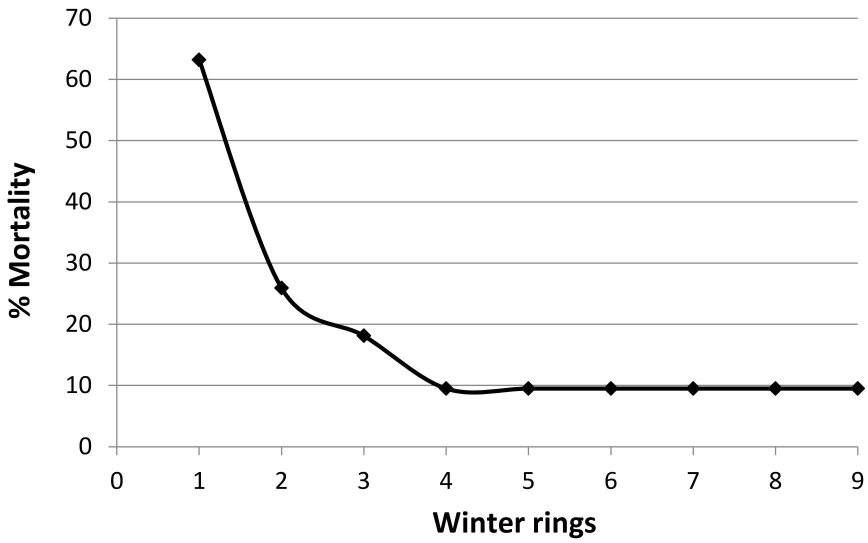

Figure 1: Natural mortality (represented as % mortality) currently used in the VIaN herring assessment.

It is generally accepted that true M is high during larval stages and decreases to a steady rate followed by an exponential increase when the fish nears maximum age (Chen and Watanabe, 1989; Jennings *et al.*, 2001; Siegfried and Sanso, 2013). Choices of M are often more ideological rather than evidence driven and uncertainty always surrounds values for M in assessment models. M may vary with size, sex, parasite load, density, food availability and predator numbers (Siegfried and Sanso, 2013), but this is difficult to measure empirically. Age invariable M is sometimes used as a default in assessments (Hewitt and Hoenig, 2005), but may not be appropriate for a stock if, for example, predation is high. Also, the choice of M may be more important if fishing mortality (F) is low and sometimes less than M, as is the case currently in the North Sea (ICES, 2012).

Comparison between methods for values of M

There is empirical evidence that M is closely related to body size in pelagic fish populations (Petersen and Wroblewski, 1984; Lorenzen, 2000; Powers, 2014). We derived M from relationships described by Peterson and Wroblewski (1984), Lorenzen (1996) and McCoy and Gillooly (2008) using *west* and *weca* data from 2013 to compare with the current M values used in the VIaN herring stock. We also compared M from the North Sea stochastic multi-species model (NS-SMS) as a reference. The values of M-at-age for the various functions used are shown in Figure 2. All M values are highest at 1-ring followed by a fairly rapid decrease to a stable low rate from 2-ringer onwards.

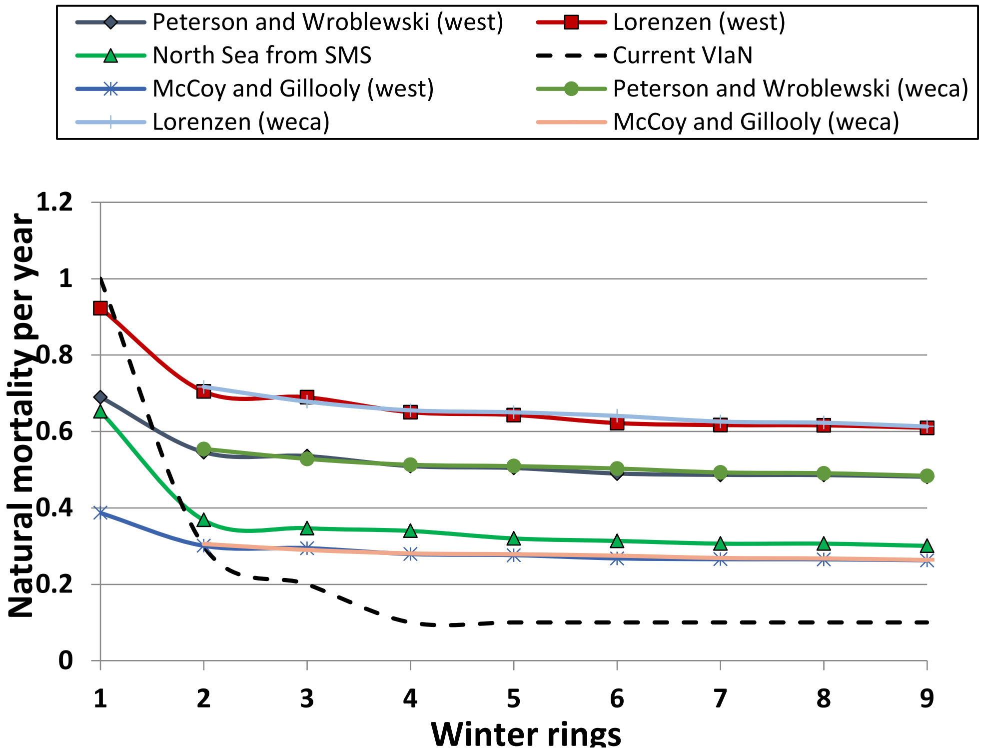

Figure 2: Natural mortality (M) estimates versus age (winter rings) for various functions using 2013 data. Lorenzen (2000), Petersen and Wroblewski (1996) and McCoy and Gillooly (2008) functions were applied using weight data from *west* and *weca*. For comparison, M from the North Sea (from a multispecies model) and current VIaN herring stock assessment is also shown.

The North Sea multi-species model (NS-SMS)

The 2012 benchmark assessment for North Sea herring (ICES, 2012) recommended replacing time invariable estimates of M with time variable estimates of M from the NS-SMS. M from the NS-SMS varies over time, and has decreased steadily for 1-group herring in recent years from a high of ~ 0.9 in the early period (up to the late 1970s) to ~ 0.65 in recent years (Figure 4). M for 2-ringers and older in the NS-SMS is also variable (Figure 4) and is generally higher than the M currently used in VIaN (Figure 2). It is possible that M estimates for the VIaN herring stock are influenced by similar drivers to North Sea herring. Many predator species inhabit both the North Sea and the area to the west of Scotland, including some of the main predators of herring; e.g. saithe and mackerel (Marine Scotland Science, 2014). If M on the VIaN herring stock in the west of Scotland is similar to M in the North Sea, then the trends in the main predator species' abundance would be comparable between areas. However, predators and prey would also have to overlap in space and time, and M may also be variable depending on the age-specific relationships between herring and predators; both parameters are difficult to measure. The Celtic Sea herring assessment began using M from the NS-SMS in 2014; it might also be an appropriate index of M for the VIaN herring stock.

To explore the relevance of the North Sea herring M for VIaN herring, we looked at species preying on herring in the North Sea and their rates of consumption of herring. We also compared the SSB of potential predators to the west of Scotland. We explore M-at-age from the NS-SMS, as the influence of predators on herring M will vary with age; it is, therefore, important to look at all species that may prey on herring throughout their life history. Predator influence on M for herring will vary depending on species' spatial overlap, feeding behaviour and predator biomass. Rates of predation on herring used in the NS-SMS model are shown in Table 2.

Table 2: Predators showing the percentage of herring in their diet included in the NS–SMS (sources; ICES (2012), Engelhard *et al.*, (2013)).

SPECIES	PERCENTAGE OF HERRING IN DIET
Saithe *Pollachius virens*	17
Whiting *Merlangius merlangus*	6
Cod *Gadus morhua*	8
Horse mackerel *Trachurus trachurus*	3
Mackerel *Scomber scombrus*	2
Haddock *Melanogrammus aeglefinus*	0
Grey gurnard *Eutrigla gurnardus*	0
Starry ray *Amblyraja radiata*	0
Harbour seal *Phoca vitulina*	6
Harbour Porpoise *Phocoena phocoena*	3
Grey seal *Halichoerus grypus*	0
Minke whale *Balaenoptera acutorostrata*	6
Gannet *Morus bassanus*	11
Guillemot *Uria aalge*	14
Puffin *Fratercula arctica*	8
Razorbill *Alca torda*	9

NS-SMS model predictions

The number of species in the NS-SMS model that prey highly on forage species is relatively small (Engelhard, 2013). Seabirds and seals appear to have a more modest effect on forage fish in general (including herring) in the North Sea. The main fish species that impact forage species in the North Sea are saithe, whiting, cod, mackerel and horse mackerel (Figure 3). The impact of predators on herring in the North Sea varies depending on age group (Table 3).

0-ringer herring:

M is shown to be strongly age-dependent; between 75% and 99% of the total juvenile mortality occurs during the first year of life (De Barros and Toresen, 1998). The primary predators of 0-ring herring are mackerel and horse mackerel in the NS-SMS

(Table 3), and the model is sensitive to assumptions about their abundance (Dickey-Collas *et al.*, 2010). The relatively high abundance of these species to the west of Scotland should be considered when choosing M for 0- and 1-ring fish. Also, larval and juvenile herring from the west of Scotland can inhabit the North Sea for a significant period, therefore it is important to consider predators that span this broader area and overlap with the juvenile herring that exhibit this behaviour.

1-ringer herring:

The main predators of 1ring herring in the NS-SMS are whiting, saithe and seabirds, accounting for approximately 90% of the predation on herring (Table 3).

2-ringer and older:

Herring of 2-rings and older are primarily eaten by saithe, whiting and cod in the North Sea (Table 3). Whiting mainly preys on 2-ring herring and to a lesser degree on 4-ring herring (ICES, 2011). The contribution of saithe and cod alone makes up for nearly 90% of predation mortality from 4-rings onwards (ICES, 2011).

Table 3: Approximate % contribution of predators to herring mortality rate, ranked in order of importance for 0-, 1- and 2- ring herring in the North Sea SMS, example from 2008 data (ICES, 2011).

0-RING	%	1-RING	%	2-RING	%
Mackerel	**30**	Whiting	**50**	Saithe	**40**
Horse mackerel	**30**	Saithe	**20**	Whiting	**30**
Whiting	**20**	Seabirds	**20**	Cod	**20**
Seabirds	**10**	Cod	**6**	Seabirds	**4**
Cod	**5**	Mackerel	**2**	Harbour porpoise	**4**
Saithe	**4**	Horse Mackerel	**1**	Mackerel	**1**
Harbour porpoise	**1**	Harbour porpoise	**1**	Horse mackerel	**1**

The predators accounting for approximately 90% of all predation of herring in the North Sea are: mackerel, horse mackerel, whiting and seabirds for the 0-ring herring; saithe, whiting and seabirds for the 1-ring herring; saithe, whiting and cod for the 2-ring herring; saithe and cod for 4-rings onwards (ICES, 2011). The overall biomass of herring consumed in the North Sea per predator species from the NS-SMS is shown in Figure 3.

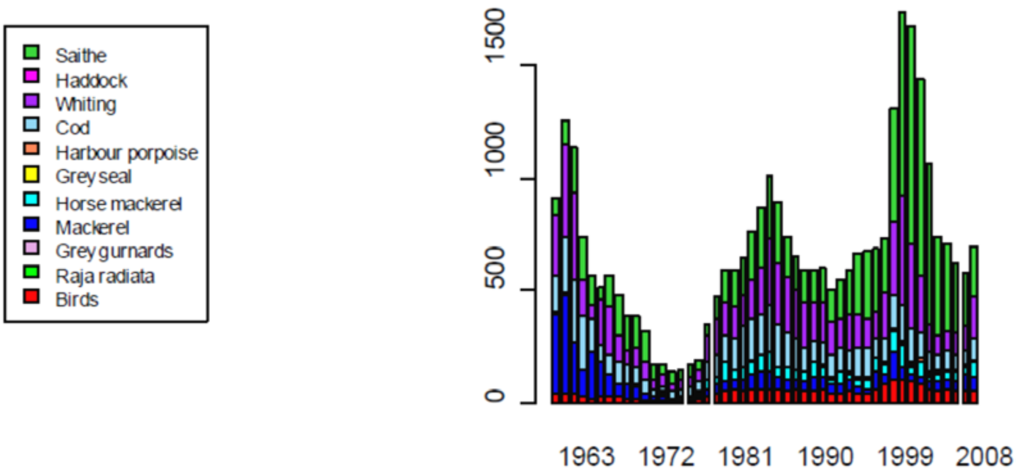

Figure 3: Overall biomass of herring eaten (1000 t) by individual predator species in the North Sea (from ICES, 2011)

Abundance of herring predators in the North Sea and to the west of Scotland

The abundance trends over time of the main predators of herring to the west of Scotland provide an indication of the appropriateness of using M from NS-SMS for the VIaN herring stock. Some commercial fish stocks are assessed in VIa (e.g. cod, whiting); other species are assessed over a larger area (e.g. saithe, mackerel). It is difficult to make assumptions about the spatial overlap of main predators with herring, and the age-specific effects, but describing the broad trends of abundance of the main predators is a useful first step. Figure 4 shows the trends in M from the NS-SMS over time. Figures 5, 6, and 7 show the trends of some of the fish and marine mammal species that are likely to be the main predators of herring in this area.

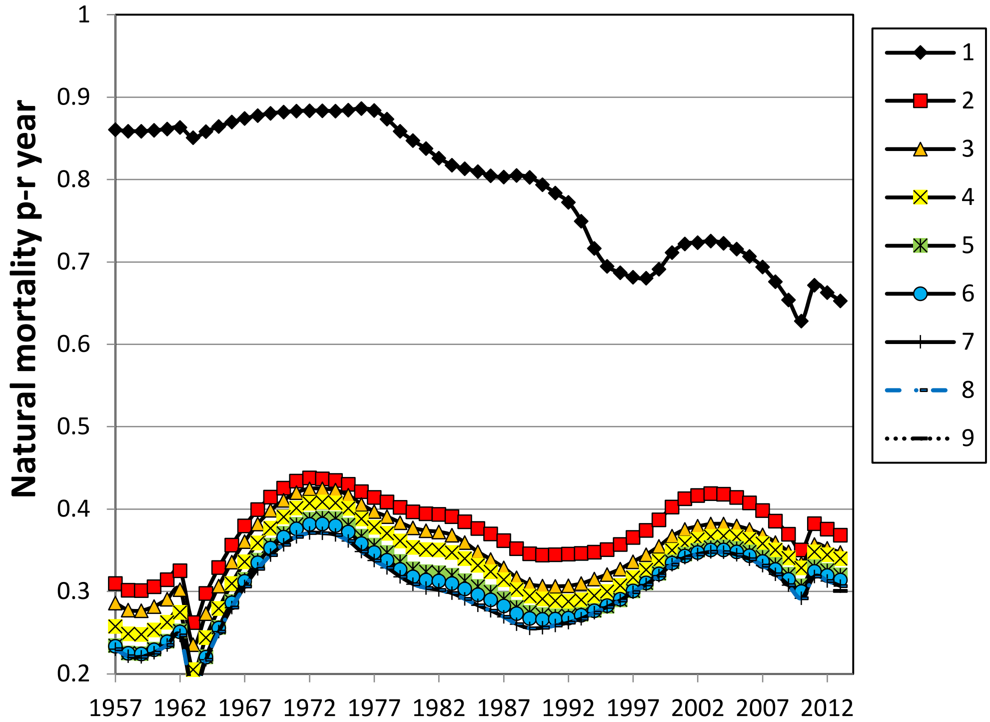

Figure 4: Natural mortality-at-age per year for North Sea herring. The input data to the assessment are the smoothed values of the raw SMS model annual M values, which are both age and time variable.

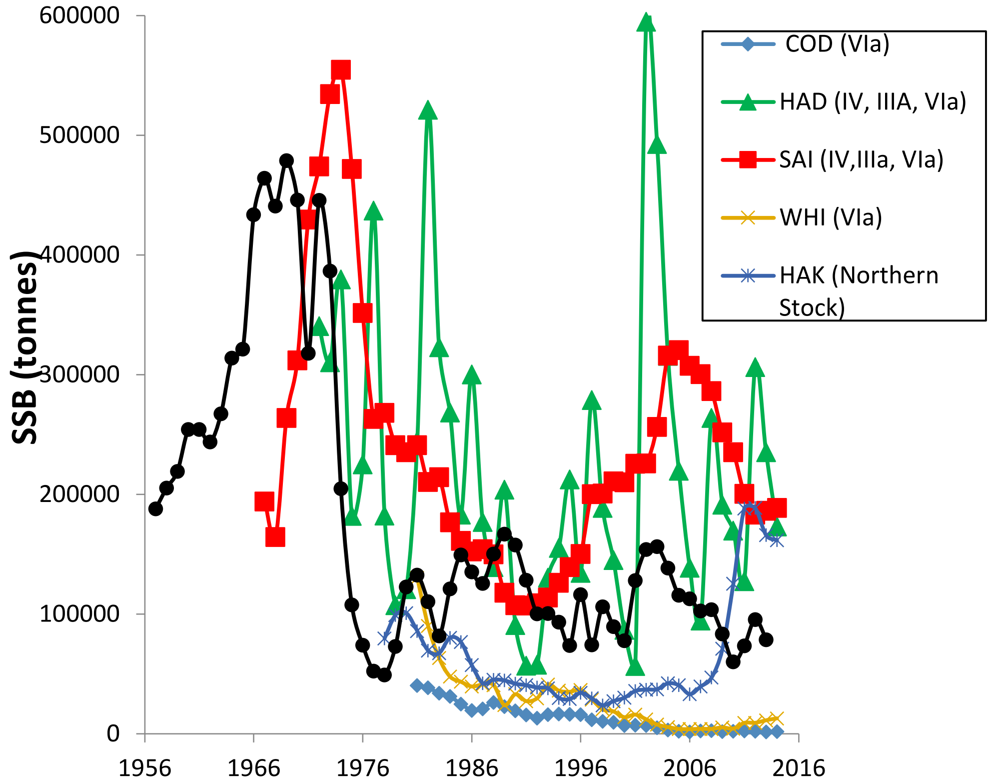

Figure 5: Time series of SSB of VIaN herring and potential main piscivorous predators of herring to the west of Scotland (ICES, 2014).

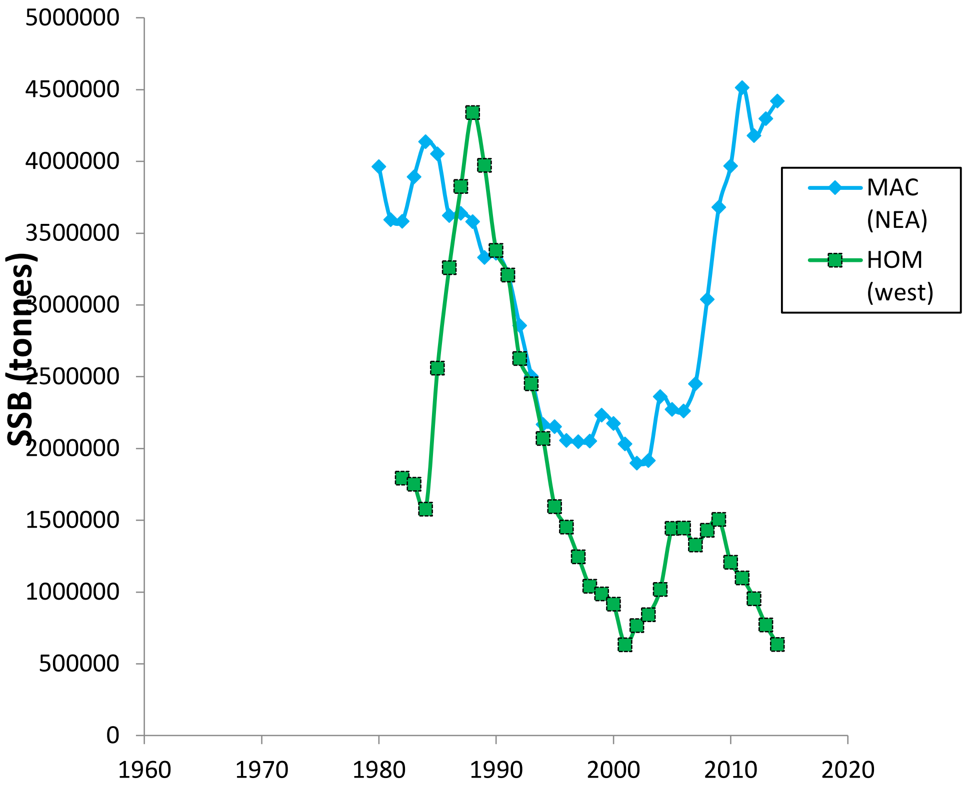

Figure 6: Time series of SSB for the northeast Atlantic mackerel (mac-nea) and western horse mackerel (hom-west) stocks (ICES, 2014).

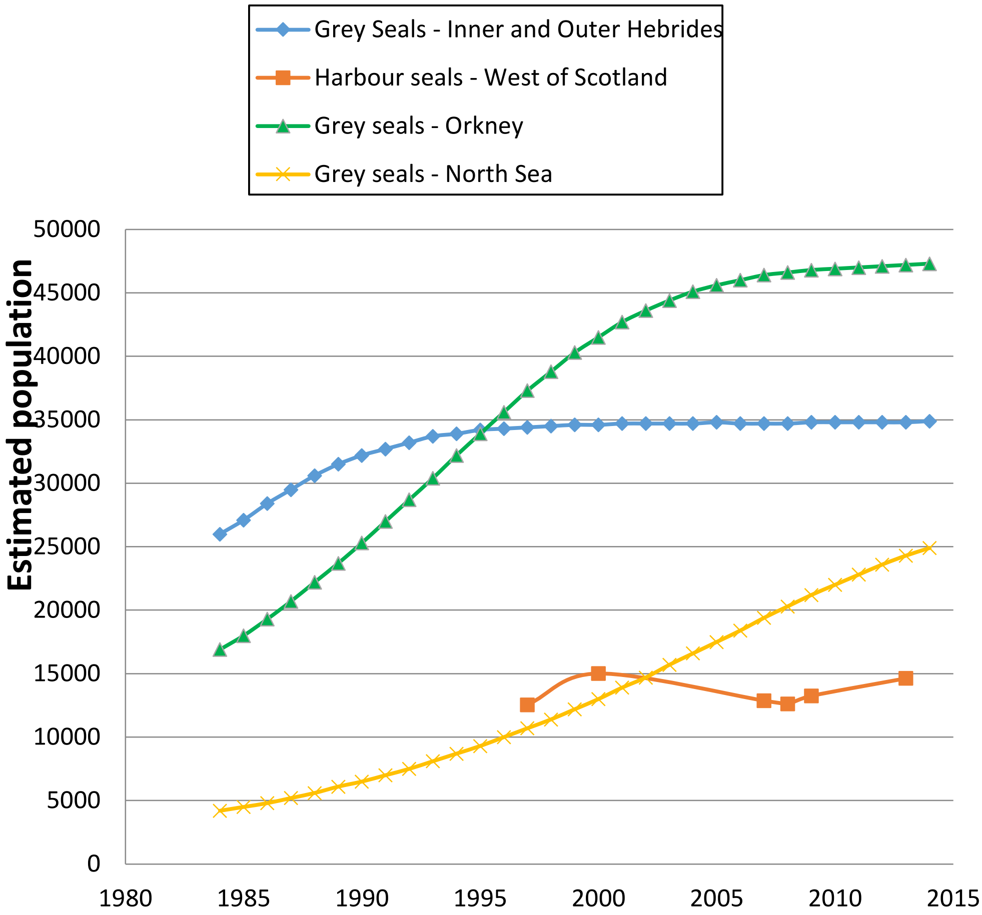

Figure 7: Estimates of grey seal total population size, in thousands, at the beginning of each breeding season from 1984–2014, made using the model of British grey seal population dynamics fitted to pup production estimates and a total population estimate from 2008, and using the old priors. The harbour seal data are the best timeseries of complete haul-out counts available for the whole area to the west of Scotland (Thomas, 2014).

Fish predators of VIaN herring

Mackerel and horse mackerel are considerable predators of 0-ring herring in the North Sea; it is possible that their effect on M in the VIaN herring stock is even greater for 0-ring fish as the stock is also in the North Sea for a significant period (Marine Scotland Science 2014). Stocks are currently high and increasing for mackerel and although decreasing for horse mackerel, are still at relatively high levels compared to herring (Figure 6). Cod has declined in biomass in the North Sea and VIa overall, while saithe increased considerably over the years 1990 to 2005 (Figure 5). Saithe SSB trends have been decreasing since 2005, but are also likely to be an important predator of herring to the west of Scotland due to its distribution and abundance compared to other gadoids (Marine Scotland Science, 2014). Whiting is an important predator of 1-ring herring, but has less of an impact for older herring in the NS-SMS (ICES, 2011). However, whiting SSB is relatively low and decreasing in recent years to the west of Scotland. Herring mortality for ages 2 and older increased over the period 1991–2007 (Figure 4) but seems to have decreased in more recent years (ICES, 2011). This trend appears to be in broad agreement with the development of the saithe stock (Figure 5), the most prolific predator of 2+ ring herring.

Other predators to the west of Scotland

Grey seals to the west of Scotland

The grey seal population estimates to the west of Scotland (Thomas, 2014) appear to have increased from the 1980s to a present estimation of about 35 000 in the area including the Inner and Outer Hebrides (Figure 7). Grey seals around the Orkney Islands have increased dramatically in recent years to around 47 000 individuals from around 20 000 in the 1980s. The total estimated abundance of grey seals in the West of Scotland in 2013 including Orkney is approximately 82 000 individuals. Grey seals from Orkney and North Sea will also impact on herring from both the North Sea and to the west of Scotland. Numbers of grey seals are higher to the west of Scotland than the North Sea (approximately 25 000 individuals currently); therefore their contribution to M is likely to be higher to the west of Scotland than in the North Sea. Grey seals are also known to travel much further offshore than harbour seals. Predation on the VIaN herring stock could be as much as 3.6% of the total stock biomass (Hammond, pers. comm.). This needs to be considered in the final decision on M for the VIaN stock. However, there is a caveat because are still issues relating to the calculation of this biomass, given the size-frequency distributions produced that are inconsistent with the known size-frequency distribution for VIaN herring.

Harbour seals to the west of Scotland

Harbour seal populations appear to be relatively stable at ~14 500 individuals to the west of Scotland (SW Scotland, W Scotland, and Outer Hebrides). Harbour seals are likely to consume a greater proportion of herring in their diet than grey seals; however, numbers are smaller than grey seals to the west of Scotland (Hammond, pers. comm.).

Seals off NW Ireland

Current abundance estimates of harbour seals (Duck and Morris, 2013) and grey seals (Ó Cadhla *et al.*, 2013) off the northwest of Ireland are shown in Table 4.

Table 4: Abundance estimates of harbour seals and grey seals off the northwest of Ireland (Duck and Morris, 2013; Ó Cadhla *et al.*, 2013)

HARBOUR SEALS	2003	2011/12	DIFF. (%)
DONEGAL	555	654	17.80%
LEITRIM	0	0	
SLIGO	376	309	-17.80%
MAYO	316	470	48.70%
GALWAY	467	860	84.20%

GREY SEALS	2009–2012
DONEGAL	844–1085
MAYO	1 841–2367
GALWAY NW	1456–1872
GALWAY (Slyne Head)	364–468

Cetaceans to the west of Scotland

The two species of cetacean that contribute to M of herring in the NS-SMS are harbour porpoise and minke whale (3% and 6% herring in diet, respectively (Table 2)). Both are also likely to contribute substantially to herring M in the VIaN herring stock. Current abundance estimates (2013) for some of the main cetaceans that may prey on herring are shown in Table 5. Other species that we have abundance estimates for and may prey on herring to the west of Scotland are: white- beaked dolphin, common dolphin and bottlenose dolphin.

Table 5: Current abundance estimates of harbour porpoise, minke whale, white-beaked dolphin, common dolphin and bottlenose dolphin (Hammond *et al.*, 2013).

SPECIES	INNER HEBRIDES AND MINCHES	WEST OF HEBRIDES/WEST OF IRELAND/SHELF	IRELAND (INSHORE COASTAL)
Harbour porpoise	12 076	11 011	10 716
Minke whale	0	1938	2216
White-beaked dolphin *Lagenorhynchus albirostris*	3219	2071	273
Common dolphin *Delphinus delphis*	2199	1720	11 661
Bottlenose dolphin *Tursiops truncatus*	246	1481	313

Seabirds to the west of Scotland

The four seabird species that are included in the NS-SMS model as predators of herring are gannet, guillemot, puffin and razorbill (Engelhard *et al.*, 2013). These species also have a substantial presence to the west of Scotland, and therefore may also contribute more to M, particularly to younger age groups of herring. Current abundance estimates (British Trust for Ornithologists, 2013) for the area to the west of Scotland of the four seabird species included in the NS-SMS are shown in Table 6.

Table 6: Estimated population of selected west of Scotland seabirds (British Trust for Ornithologists, 2013)

SPECIES	POPULATION SIZE APPROX.
Gannet	150 000
Guillemot	80 000
Puffin	100 000
Razorbill	100 000
TOTAL	**430 000**

Environment

Temperature trends are similar for the sea area to the west of Scotland and the North Sea. The broad trend in oceanic temperatures over the period 1900–2006 is warming (Figure 8a). Oceanic temperatures around the Scottish coast for the period (1970–2006) have increased by ~0.5°C (Figure 8b). Salinity and surface temperature of coastal waters around the Scottish coast also shows a slight increasing trend over the same period (Figure 8c and d).

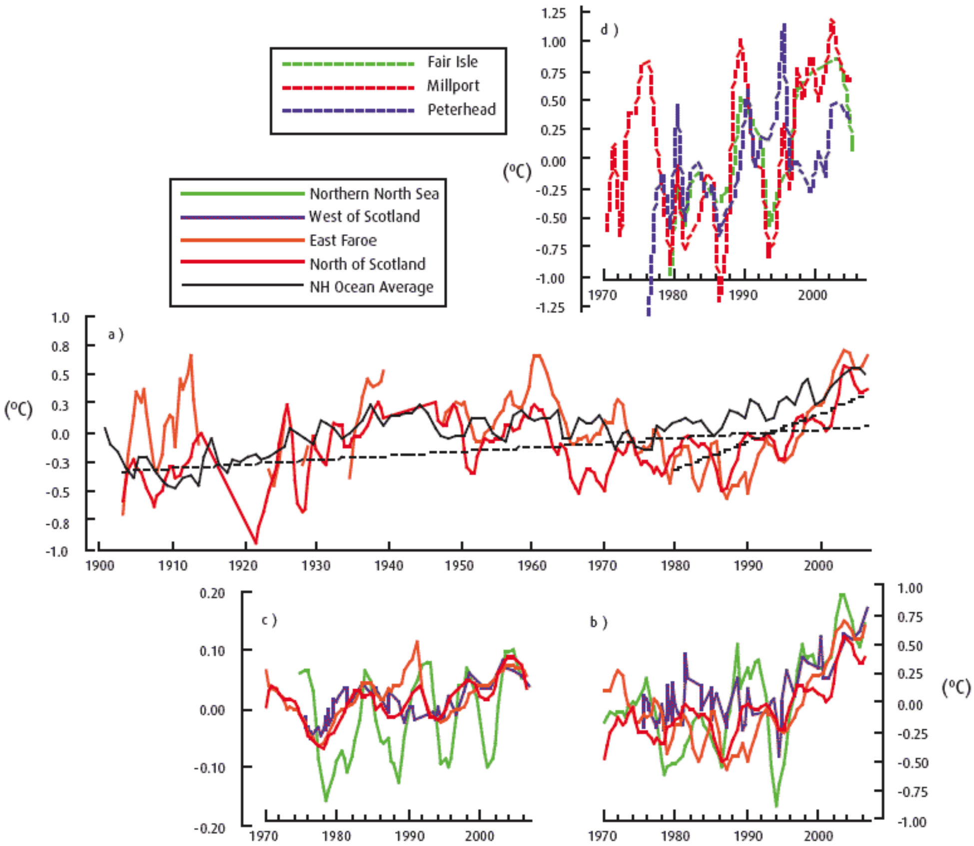

Figure 8: From Baxter *et al.*, (2008); a) Long-term (1900–2006) variability in oceanic temperatures to the north of Scotland and east of Faroe (including the Northern Hemisphere (NH) Ocean Average temperature time series, as collated by the National Ocean and Atmospheric Administration). Dashed lines show the linear trend from 1980–2006 (0.24°C per decade) and from 1900–2006 (0.04°C per decade). b) Variability in oceanic temperatures (1970–2006) to the north of Scotland, east of Faroe, west of Scotland and the northern North Sea. c) Variability in salinity (1970–2006) to the north of Scotland, east of Faroe, west of Scotland and the northern North Sea. d) Variability in surface temperature of coastal waters around Scotland.

Discussion

It is very difficult to quantify predator/prey impacts due to lack of specific knowledge about the spatial overlap of stocks and unknown age variable effects. The predation of herring to the west of Scotland as elsewhere is likely to be large, particularly for 0- and 1-ring herring. 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 NS-SMS. It is difficult to ascertain whether M for VIaN herring will be influenced greatly by the SSB 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. However, 0% of grey seal diet is herring in North Sea, and for harbour seal herring it contributes 6%. If M values from the NS-SMS were used in VIaN, this may not adequately incorporate the influence of grey seals on M for the VIaN herring stock. This should be 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.

The impact of high predation on younger herring will produce an M that is high during larval stages and decreases to a steady rate. The M from the NS-SMS shows this trend, however, studies have shown that this is usually followed by an exponential increase in M when the fish nears maximum age. It is generally accepted that true M is high during larval stages and decreases to a steady rate followed by an exponential increase when the fish nears maximum age. M from SMS does not appear to show such a relationship for older herring.

The trends of M at age from NS-SMS are useful as a starting point for discussion on M for the VIaN herring stock. However, there are some caveats; some species are potentially in greater abundance to the west of Scotland; hake, mackerel, horse mackerel, grey seals, some cetaceans, some seabird species, etc. Populations of these species need to be considered when applying M from SMS, as well as species' propensity to prey on herring. This is also age specific; therefore tracking M from SMS for VIaN herring may be more valid for certain age groups over others. It may be necessary to follow M from NS-SMS for some age groups but not for others, particularly as is the case to the west of Scotland, when different species influence M for each of the age groups.

Conclusions

- The spatial overlap of herring with predator stocks in the area to the west of Scotland is complex; however, broad trends of predator abundance should inform the choice of M. Using NS-SMS predation data as a guide is reasonable because there is a lot of overlap and mixing of many species between the areas;
- Age-specific effects of predators on herring is unknown for the VIaN herring stock, but likely to be similar to the North Sea; there is mixing of species and stocks, including the mixing of juvenile herring;
- Stocks are currently high and increasing for mackerel and although decreasing for horse mackerel, are still at relatively high levels compared to herring. Mackerel and horse mackerel are two of the main predators of herring at younger ages;
- If mackerel and horse mackerel are in higher abundance to the west of Scotland than in the North Sea, M is potentially higher for 0-ring herring than M for NS-SMS. If SSB for the other species (saithe, whiting, etc.) is lower, then their influence on M is potentially lower than NS-SMS for older herring;
- Overall, there is potentially greater influence on M for VIaN herring from: mackerel, horse mackerel, hake, grey seals, some cetaceans, some seabird species, etc.
- Studies have shown that after a rapid decrease of M from the early ages, M usually decreases exponentially when the fish nears maximum age. This trend for older ages is not followed in the M from NS-SMS;

- For grey seals in the NS-SMS, 0% diet is herring, harbour seal is 6%; this is likely to be different to the west of Scotland where grey seal numbers in particular are much higher; grey seals predation on the VIaN herring stock could be as much as 3.6% of the total stock biomass;
- Some seabirds known to prey on herring in the North Sea are in higher abundance to the west of Scotland. Impact is likely to be slightly greater than for the same species in the North Sea;
- The environmental conditions are similarly impacted by climate change, with trends in oceanic temperature, sea surface temperature and salinity all increasing over the last number of decades around the coast of Scotland;
- If using M from NS-SMS as a guide for VIaN herring, it may only be relevant to follow M from NS-SMS for some age groups but not for other.

References

Baxter, J.M., Boyd, I.L., Cox, M., Cunningham, L., Holmes, P., Moffat, C.F., (Editors), 2008. Scotland's Seas: Towards Understanding their State. Fisheries Research Services, Aberdeen. pp. 174.

British Trust for Ornithology http://www.bto.org/about-birds/birdtrends/2013/species

Chen, S. and S. Watanabe. 1989. Age dependence of natural mortality coefficient in fish population dynamics. Nippon Suisan Gakkaishi, 55: 205–208.

De Barros, P. and R. Toresen 1998. Variable natural mortality rate of juvenile Norwegian spring-spawning herring (*Clupea harengus* L.) in the Barents Sea. ICES J. Mar. Sci. (1998) 55 (3): 430-442.

Dickey-Collas, M., Nash, R. D. M., Brunel, T., van Damme, C. J. G., Marshall, C. T., Payne, M. R., Corten, A., Geffen, A. J., Peck, M. A., Hatfield, E. M. C., Hintzen, N. T., Enberg, K., Kell, L. T., and Simmonds, E. J. 2010. Lessons learned from stock collapse and recovery of North Sea herring: a review. – ICES Journal of Marine Science, 67: 1875–1886.

Duck, C. and C. Morris, 2013. An aerial survey of harbour seals in Ireland: Part 2: Galway Bay-to Carlingford Lough. August-September 2012. Unpublished report to the National Parks & Wildlife Service, Department of Arts, Heritage & the Gaeltacht, Dublin.

Engelhard, G.H., M.A. Peck, A. Rindorf, , S.C. Smout, M. van Deurs, K. Raab, K.H. Andersen, S. Garthe, R.A.M. Lauerburg, F. Scott, T. Brunel, G. Aarts, T. van Kooten, and M. Dickey-Collas 2013. Forage fish, their fisheries, and their predators: who drives whom? ICES Journal of Marine Science (10)1093.

Gislason, H. and T. Helgason, 1985. Species interaction in assessment of fish stocks with special application to the North Sea. Dana (5)1-44.

Gislason, H., N. Daan, J.C. Rice and J.G. Pope. 2010. Size, growth and natural mortality of marine fish. Fish and Fisheries 11: 149-158.

Hammond, P.S. *et al.* (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164: 107-122.

Hewitt, D.A. and J.M. Hoenig 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fish. Bull. 103:433-437.

ICES.2011. Report of the Working Group on Multispecies Assessment Methods (WGSAM), 10–14 October 2011, Woods Hole, USA. ICES CM 2011/SSGSUE:10. 229 pp.

ICES. 2012. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA 2012), 13–17 February 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:47. 572 pp

ICES. 2013. Interim Report of the Working Group on Multispecies Assessment Methods (WGSAM), 21-25 October 2013, Stockholm, Sweden. ICES CM 2013/SSGSUE:10. 99 pp.

ICES. 2014. ICES Standard Graphs. http://standardgraphs.ices.dk/

Jennings, S., M. J. Kaiser, and J. D. Reynolds. 2001. Marine Fisheries Ecology. Blackwell Science Ltd., London.

Jensen, A.L. 1995. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53:820-822.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49:627-647.

Lorenzen K. 2000. Allometry of natural mortality as a basis for assessing optimal release size in fish-stocking programmes. Can. J. Fish. Aquat. Sci. 57: 2374-2381.

Marine Scotland Science. 2014. Fish and Shellfish Stocks, 2014 Edition. http://www.scotland.gov.uk/Publications/2014

McCoy, M.W. and J.F. Gillooly. 2008. Predicting natural mortality rates of plants and animals. Ecology Letters 11:710-716.

Ó Cadhla, O., T. Keena, D. Strong, C. Duck, and L. Hiby 2013. Monitoring of the breeding population of grey seals in Ireland, 2009 - 2012. Irish Wildlife Manuals, No. 74. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Peterson, I., and J. S. Wroblewski. 1984. Mortality Rates of Fishes in the Pelagic Ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 41:1117-1120.

Powers, J.E. 2014. Age-specific natural mortality rates in stock assessments: size-based vs. density-dependent. ICES Journal of Marine Science 71:(7) 1629-1637.

Siegfried K.I. and B. Sanso. 2013. A Review for Estimating Natural Mortality in Fish Populations http://www.sefsc.noaa.gov/sedar/download/S19_RD29_Andrews_natural%20mortality%20chapter_5_22.pdf?id=DOCUMENT

Thomas, L. 2014. Estimating the size of the UK grey seal population between 1984 and 2014, using established and draft revised priors. SCOS briefing paper: SCOS-BP 14/02.

ICES. 2014. Report of the Benchmark Workshop on Sprat Stocks (WKSPRAT), 11–15 February 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:48. 220 pp.

7.6 Working Document 3. Revisions to VIa, VIIbc combined FLSAM assessment input data

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Introduction

This document lists the errors encountered during the data scrutiny after HAWG 2015 rejection of the FLSAM assessment, their magnitude and their consequence for the FLSAM assessment for herring in VIa and VIIb,c under both the WKWEST 2015 and the new natural mortalities values adopted at HAWG 2015.

Revisions

CATON

Incorrect catch figures were copied across from the working group report table for the new combined stock CATON. This will not have any effect on the assessment as CATON merely provides a check on CANUM and WECA. The revised CATON is presented in Table 1.

WECA and CANUM

At WKWEST revised catch figures were calculated for VIaN. Catch figures for 2000–2005 were corrected which would have implications for both the WECA and the CANUM files but these files were not adjusted accordingly. Errors were found in the CANUM for 2013 and 2014 but these errors were to a lesser extent. The revised WECA and CANUM values for affected years are in tables 2 and 4 and the percentage change from the input data used during WKWEST in tables 3 and 5 respectively.

FLEET file – MS HERAS acoustic index

When the Malin Shelf survey was first designed it included coverage of 6 ICES statistical rectangles by Northern Ireland in the Clyde and North Channel ((39E3-5 and 40E3-5; Figure 1). When Northern Ireland was no longer able to participate in the survey, the coverage of these rectangles was dropped and it was decided to exclude the data from those rectangles in the index for consistency across years. The rectangles were only fully covered in 2008–2010.

However, through some misunderstandings and miscommunication the updates were not consistently communicated from WGIPS (the survey coordination group) through to HAWG and into the input files, and it seems that the input file contained a mix of updated and not updated information.

Furthermore, in 2013 and 2014, Marine Institute included one of the excluded rectangles in the survey coverage. When data was extracted from the survey database no effort was made to exclude this rectangle as it was assumed to not have any data in it in the database.

The data was corrected by re-extracting data from all years from the acoustic survey database, FishFrame, that stores the aggregated outputs from this survey and are used to combine national data into global survey estimates. The extraction was set to consistently exclude the 6 rectangles for all years (2008–2014) of the survey.

The correctly aggregated timeseries for the Malin Shelf acoustic time series and the percent differences from the index used at WKWEST are displayed in Tables 6 and 7 respectively.

The effect was mainly on abundance of 1wr fish in 2008–2010, with slight discrepancy in 2008 for 2wr and in 2013 and 2014 for 1wr.

MATPROP

While checking the acoustic index data, errors were also identified in the proportion mature input file. These estimates are derived from the acoustic data. However the errors were not all related, merely discovered during checking the newly extracted data against existing tables.

The revised input data and the percentage change from the WKWEST 2015 file for the revised years are shown in Tables 7 and 8 respectively.

For 2010, the revised values for numbers mature and immature resulted in a significant increase in percentage mature from 41% to 88% for 2wr fish.

For 2011 and 2012 it seemed an error had been made in the input file shifting all maturities left one space resulting in 50 and 66% mature 1wr in these two years. They should have been 0% mature and the percentages should instead have referred to 2wr.

WEST

The acoustic data for the VIaN acoustic index was also checked through from the data base source as the mean weight at age in the VIa stock (WEST input file) is derived from the VIaN geographically restrained index (which was used in VIaN assessment, Figure 1). Errors in the compilation of the tables where the input data is taken from were discovered affecting particularly the data in 2010. It looks like three rectangles south of 56°N (40E0, 40E1, and 40E2) had erroneously been assigned to her-vian (VIaN) instead of her-irlw (VIaS) in the FishFrame acoustics database in 2010. This resulted in differences in the WEST for VIaN in 2010 and therefore for the WEST input data for the VIa, VIIbc combined assessment. Smaller discrepancies were also noted in 2013/2014, likely due to the inclusion of data from rectangle 40E3, which is not traditionally included in the index but had been covered in those two years (see above).

The revised WEST input file (restricted to the years 2008–2014) and the percentage change from the file used in WKWEST 2015 are shown in Tables 9 and 10 respectively.

Effect on FLSAM assessment

To investigate the effect of these revised input data on the VIa, VIIbc assessment we compared the final accepted assessment from WKWEST 2015 with an assessment using the revised input data as the only difference. Both datasets were updated to include 2014 values where appropriate and both used the natural mortality from WKWEST 2015.

From both the summary plots for the two assessment runs (Figure 2) and the overlaid stock trajectories (Figure 3) it is clear that the revisions had some effect on the trajectories. The biggest effect was in 2010–2012 where the influence of the errors in the maturity ogive (MATPROP file) and the Weight in the stock (WEST file) had a noticeable impact. The overall effect though was small and the perception of the stock remains roughly the same with the revised data, but with a smoother decline in SSB in recent years compared to the WKWEST assessment.

We then considered whether the errors in the input data could have been a contributing factor to the large increase in uncertainty around the estimates when switching to the corrected natural mortality at HAWG 2015. For this purpose a second set of assessment runs were carried out with the new natural mortality for both sets of input data. Figure 3 compares the summary plots from these two assessment runs and shows little difference in the effect of changing to a higher natural mortality between the original and the revised input data. In figure 4 the trajectories for all four scenarios are overlaid, showing little real difference between the revised and original data sets.

In terms of the uncertainties surrounding the estimates, which was the biggest concern we had under the new natural mortality scenario, the CV's were slightly higher for the two runs using the revised input data compared to the WKWEST data (Figures 6, 7 and 8). Both increased by a similar magnitude when the assessment was run with the new natural mortalities.

Conclusion

Several errors were identified in the input data that was used in the VIa, VIIbc assessment during WKWEST 2015. These were corrected and the revisions were demonstrated to have a minor effect on the perception of the stock estimate trajectories. It was also demonstrated that these errors were not the cause for the large increase in uncertainty surrounding the stock estimates when the natural mortality was changed at HAWG 2015.

We decided that the revised data set should form the basis for the ongoing investigation to find a stable assessment for VIa, VIIbc herring.

Associated documents with diagnostics for models discussed:

"Revised data and WKWEST M.pdf"

"Revised data and New M.pdf"

"WKWEST data and WKWEST M.pdf"

"WKWEST data and New M.pdf"

Table 1. Revised CATON used in VIa combined inter-benchmark assessment.

Year	Landings (tonnes) Revised	Year	Landings (tonnes) Revised
1957	48 508	1986	99 549
1958	66 494	1987	92 960
1959	70 447	1988	64 691
1960	69 160	1989	63 236
1961	52 535	1990	88 662
1962	65 594	1991	66 229
1963	54 089	1992	60 841
1964	70 403	1993	68 541
1965	76 685	1994	58 338
1966	112 834	1995	57 367
1967	109 281	1996	58 639
1968	105 345	1997	62 458
1969	126 777	1998	72 248
1970	186 236	1999	55 845
1971	222 211	2000	43 008
1972	188 230	2001	40 007
1973	246 989	2002	50 740
1974	214 749	2003	44 583
1975	152 765	2004	40 186
1976	126 409	2005	30 360
1977	61 908	2006	46 539
1978	41 871	2007	47 407
1979	22 668	2008	29 394
1980	30 430	2009	28 976
1981	76342	2010	30 118
1982	111 569	2011	24 678
1983	96 511	2012	25 087
1984	83 462	2013	26 947
1985	62 485	2014	27 123

Table 2. Revised WECA (mean weight-at-age in catch in Kg) in affected years used in VIa, VIIbc combined inter-benchmark assessment.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2000	0.092	0.132	0.157	0.179	0.192	0.208	0.23	0.26	0.217
2001	0.084	0.136	0.149	0.173	0.188	0.192	0.208	0.224	0.252
2002	0.099	0.137	0.156	0.161	0.166	0.183	0.19	0.231	0.263
2003	0.101	0.139	0.156	0.168	0.184	0.198	0.198	0.188	0.282
2004	0.085	0.145	0.16	0.184	0.211	0.205	0.202	0.192	0.302
2005	0.107	0.134	0.156	0.172	0.192	0.212	0.215	0.248	0.256

Table 3.Percentage change in WECA (mean weight at age in catch in Kg) in affected years used in VIa, VIIbc combined inter-benchmark assessment compared to WECA used at WKWEST and HAWG 2015.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2000	10%	-1%	-1%	1%	2%	6%	12%	19%	4%
2001	-2%	2%	1%	0%	0%	1%	-3%	1%	16%
2002	-5%	0%	0%	0%	-1%	-1%	-2%	4%	14%
2003	-1%	-1%	1%	0%	0%	1%	-2%	-6%	18%
2004	0%	2%	-1%	3%	1%	0%	-4%	-3%	3%
2005	2%	-1%	2%	1%	5%	2%	5%	2%	-9%

Table 4. Revised CANUM (Catch in Numbers (thousands)) used in VIa, , VIIbc combined inter-benchmark assessment. Only years affected shown.

YEAR	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7	AGE 8	AGE 9+
2000	8612	57525	60750	82126	28850	11737	5362	2526	2178
2001	2463	105035	37149	27103	43625	19498	8555	5769	1537
2002	5050	71122	131724	27896	29737	38231	11787	3153	2067
2003	1787	66151	75580	77956	16895	9521	15343	10111	1711
2004	1401	22358	56475	49142	57400	9076	9647	9999	4589
2005	392	37756	54133	47489	21012	15235	2363	2053	1674
2006	730	28727	45886	44226	63024	36862	23391	3874	5458
2007	207	58903	61713	29954	28003	36040	23342	13816	4374
2008	483	20163	32700	33911	14330	11678	17570	8887	9236
2009	2126	24083	22553	28683	20906	10928	9555	12647	9461
2010	11345	33847	36458	16499	22196	13102	6885	6050	13388
2011	1788	54795	25098	19448	10576	8851	6035	3591	7321
2012	6122	27797	63034	13746	9873	6865	4415	1233	4035
2013	61	16799	22714	65355	13347	8885	5524	4707	5234
2014	34	9171	23970	27799	54375	9537	3989	3291	3715

Table 5.Percentage change in CANUM (Catch in Numbers (thousands)) used in VIa combined inter-benchmark assessment compared to CANUM used at WKWEST and HAWG 2015. Only years affected shown.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2000	83%	32%	37%	-12%	-26%	-48%	-92%	-73%	-67%
2001	-79%	-25%	-20%	2%	-7%	-16%	-44%	-84%	-86%
2002	296%	-3%	2%	1%	-20%	-13%	-20%	-69%	-87%
2003	-63%	15%	-35%	-8%	-2%	-52%	-27%	-53%	-78%
2004	-81%	-65%	14%	-28%	-9%	-10%	-41%	-20%	-46%
2005	-95%	-54%	-48%	-19%	-48%	-19%	-62%	-56%	-62%
2006	0%	0%	0%	0%	0%	0%	0%	0%	0%
2007	0%	0%	0%	0%	0%	0%	0%	0%	0%
2008	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	0%	0%	0%	0%	0%	0%	0%	0%	0%
2010	0%	0%	0%	0%	0%	0%	0%	0%	0%
2011	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	0%	0%	0%	0%	0%	0%	0%	2%	0%
2014	0%	0%	0%	0%	0%	0%	0%	0%	17%

Table 6. Revised MS Heras index used in VIa, VIIbc combined inter-benchmark assessment.

YEAR	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7	AGE 8	AGE 9+
2008	50389	267367	995596	719782	363484	331462	743706	386202	273892
2009	772520	265151	273910	443603	380436	225046	192866	500074	456113
2010	132551	375304	373804	242388	173333	145891	101960	100421	297021
2011	62834	257258	899637	484732	212913	227515	205093	113298	263837
2012	796012	548481	832257	517267	249024	114507	111385	56526	104571
2013	0	209403	434425	671507	194706	70507	61392	28597	37398
2014	1012160	277504	241674	502471	534431	148259	32565	18677	13003

Table 6. Percentage change from MS Heras index used in WKWEST and HAWG 2015 to revised version used in VIa, VIIbc combined inter-benchmark assessment.

YEAR	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7	AGE 8	AGE 9+
2008	-79%	-6%	0%	0%	0%	0%	0%	0%	0%
2009	-17%	0%	0%	0%	0%	0%	0%	0%	0%
2010	-24%	0%	0%	0%	0%	0%	0%	0%	0%
2011	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	-2%	0%	0%	0%	0%	0%	0%	0%	0%
2013	0%	-1%	0%	0%	0%	0%	0%	0%	0%
2014	-2%	-1%	0%	0%	0%	0%	0%	0%	0%

Table 7. Revised maturity ogive (MATPROP input file) for VIa combined assessment. Only year range revised shown

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2008	0	0.91	0.99	1	1	1	1	1	1
2009	0	0.67	0.99	1	1	1	1	1	1
2010	0	0.88	0.99	1	1	1	1	1	1
2011	0	0.50	0.93	1	1	1	1	1	1
2012	0	0.62	0.99	1	1	1	1	1	1
2013	-	0.35	0.72	0.98	0.98	1	1	1	1
2014	0	0.18	0.73	0.99	1	1	1	1	1

Table 8. Percentage change from maturity ogive (MATPROP input file) used in WKWEST 2015 to revised maturity ogive used in Interbenchmark.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2008	-98%	20%	-1%	0%	0%	0%	0%	0%	0%
2009		0%	0%	0%	0%	0%	0%	0%	0%
2010		116%	3%	2%	0%	0%	0%	0%	0%
2011	-100%	-46%	-7%	0%	0%	0%	0%	0%	0%
2012	-100%	-37%	-1%	0%	0%	0%	0%	0%	0%
2013		1%	0%	0%	0%	0%	0%	0%	0%
2014		1%	0%	0%	0%	0%	0%	0%	0%

Table 9. Revised WEST input data (weight in stock in kg) for VIa combined assessment. Only year range revised shown

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2008	0.055	0.172	0.191	0.208	0.214	0.214	0.221	0.224	0.238
2009	0.059	0.151	0.206	0.223	0.233	0.231	0.232	0.232	0.238
2010	0.068	0.162	0.194	0.227	0.239	0.248	0.258	0.226	0.212
2011	0.057	0.132	0.160	0.208	0.236	0.245	0.238	0.222	0.253
2012	0.066	0.150	0.183	0.189	0.206	0.217	0.214	0.218	0.215
2013	0.000	0.155	0.165	0.202	0.210	0.236	0.243	0.245	0.254
2014	0.064	0.108	0.158	0.180	0.206	0.214	0.231	0.244	0.264

Table 10. Percentage change from WEST input file used in WKWEST 2015 to revised WEST input file used in Interbenchmark assessment.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
2008	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	-42%	-13%	0%	0%	0%	0%	0%	0%	0%
2010	7%	75%	16%	15%	13%	15%	23%	3%	-2%
2011	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013		1%	0%	0%	0%	0%	0%	0%	0%
2014	0%	0%	0%	0%	0%	0%	0%	0%	0%

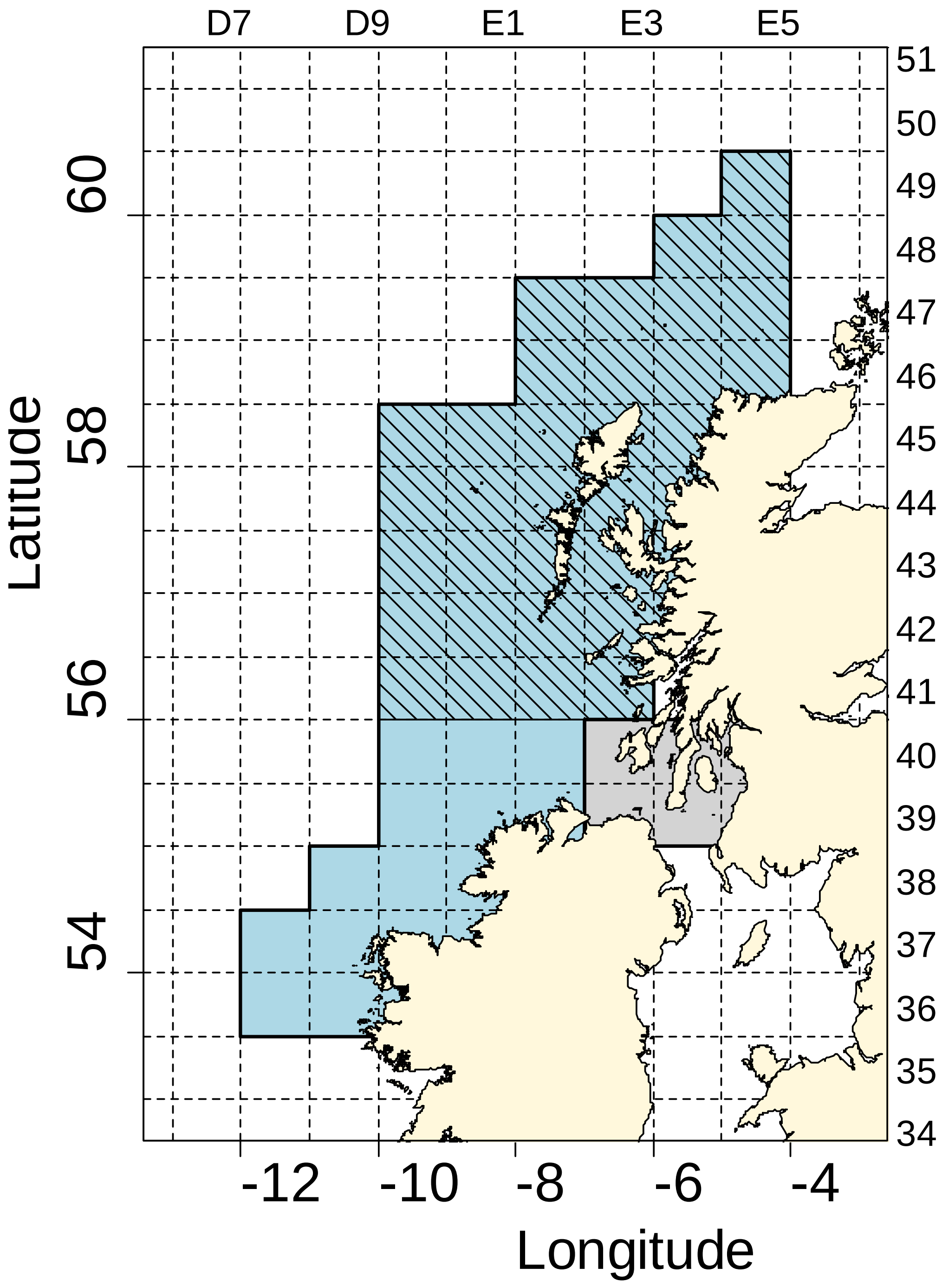
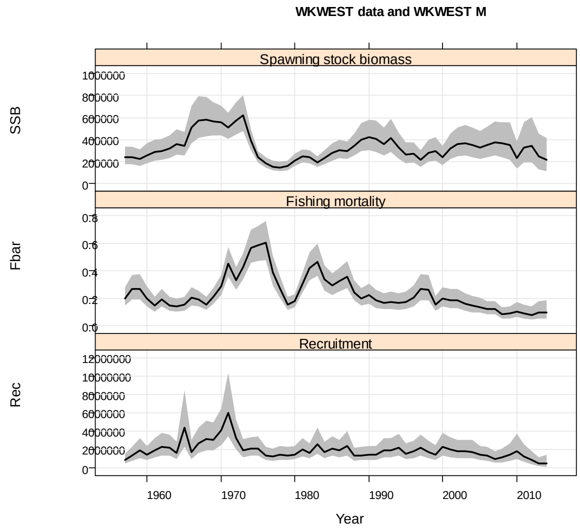


Figure 1. Herring acoustic surveys coverage in VIa. Area covered by the Malin Shelf acoustic survey (MSHAS, 2008–2014) in blue, area covered in the West of Scotland acoustic survey (MSHAS_N, 1991–2007) in blue with hashed lines and rectangles covered in 2008–2010 but not included in either index highlighted in grey.



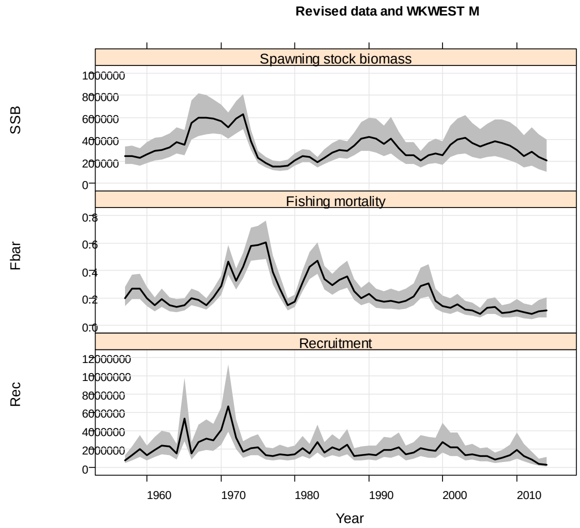


Figure 2. Summary plots for assessments performed with natural mortality used at WKWEST 2015. Input data used at WKWEST 2015 in the left plot and results using the revised input data in the right plot.

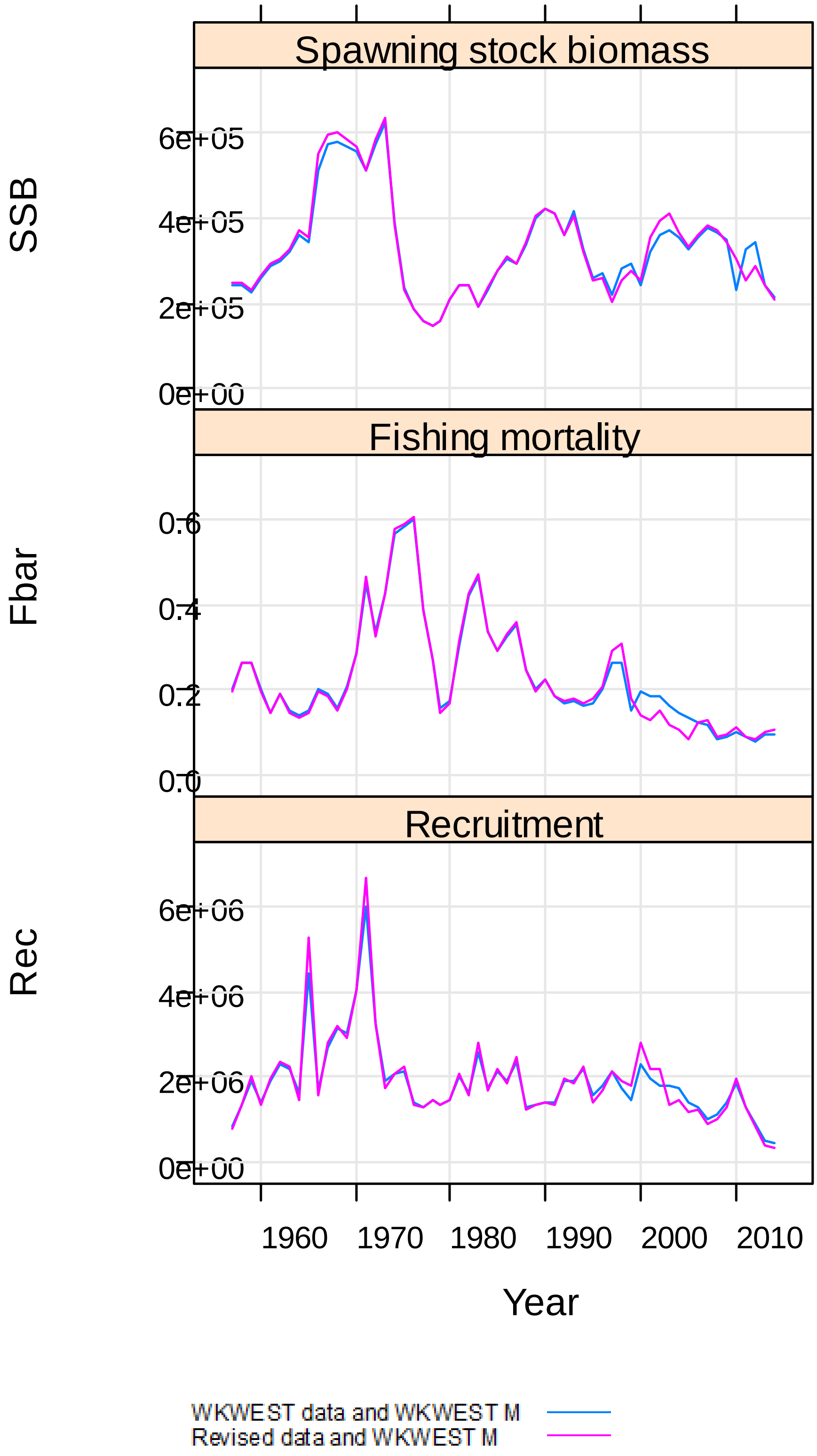


Figure 3.Overlaid stock summary trajectories for the assessments with WKWEST data and the revised input data.

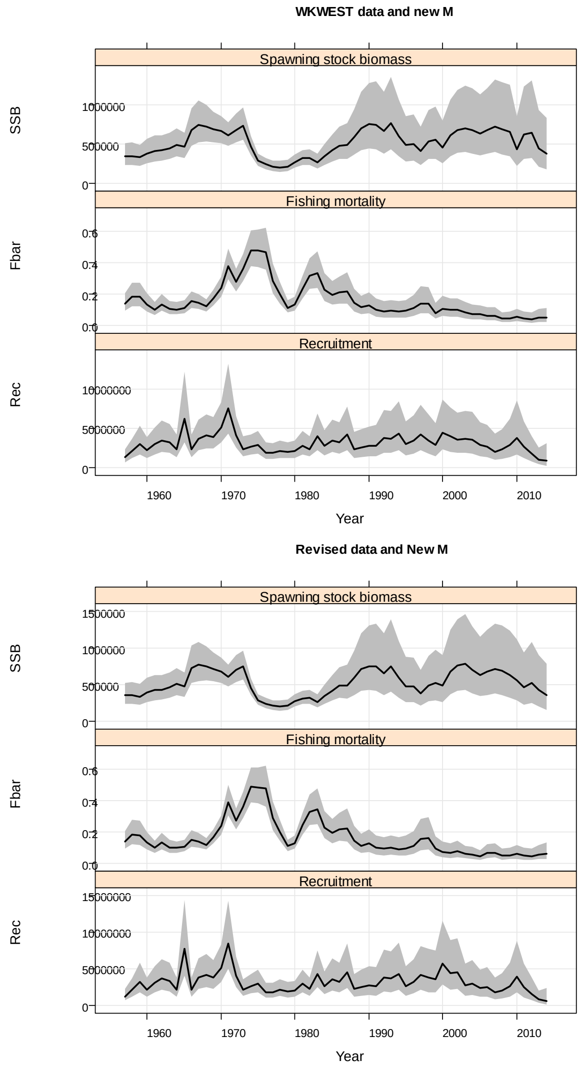


Figure 4. Summary plots for assessments performed with new natural mortality introduced at HAWG 2015 with WKWEST input data on the left and revised input data on the right.

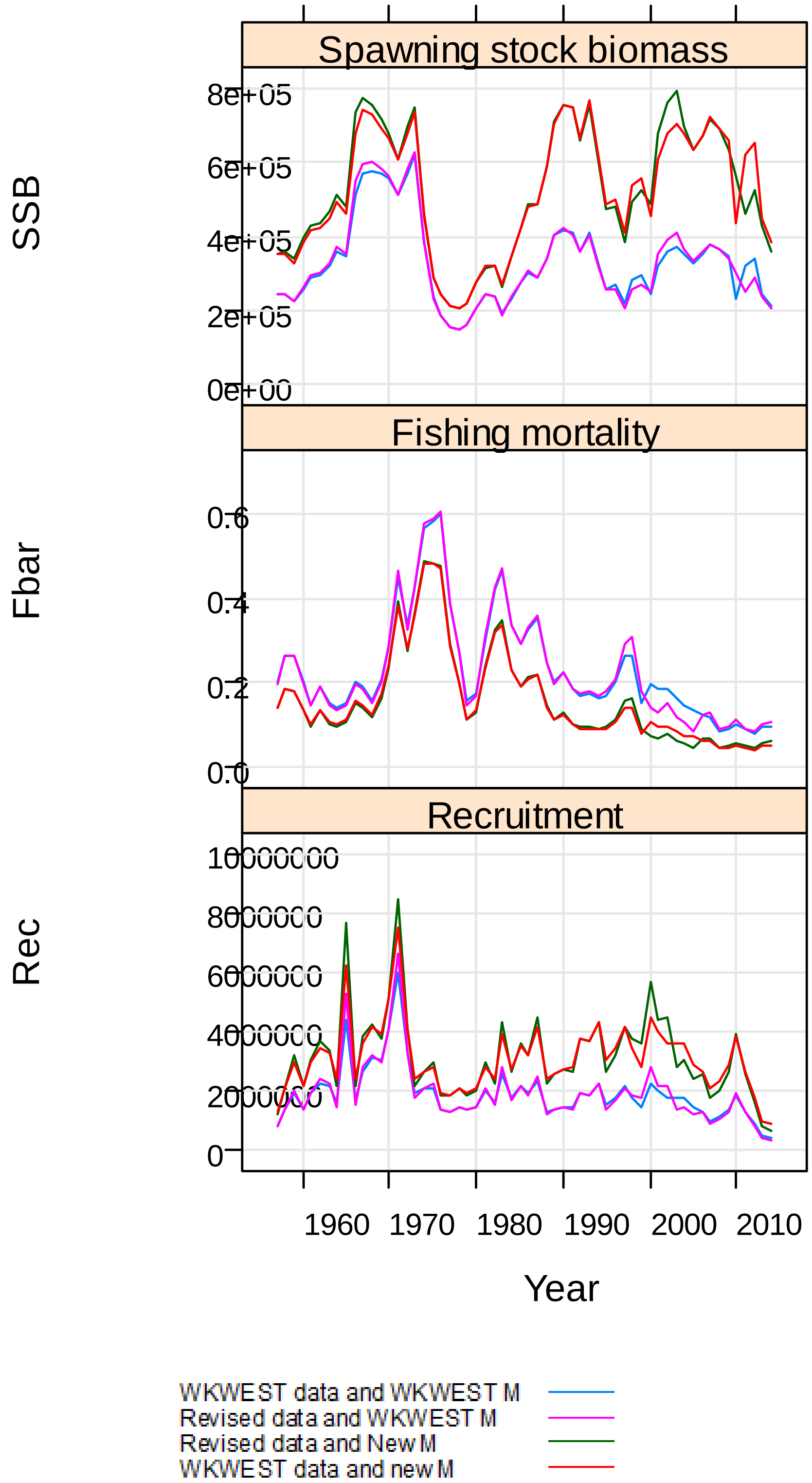


Figure 5. Stock summary plots for the VIa assessment demonstrating the effect of revising the input data (two lowest lines) and changing natural mortality (two upper lines).

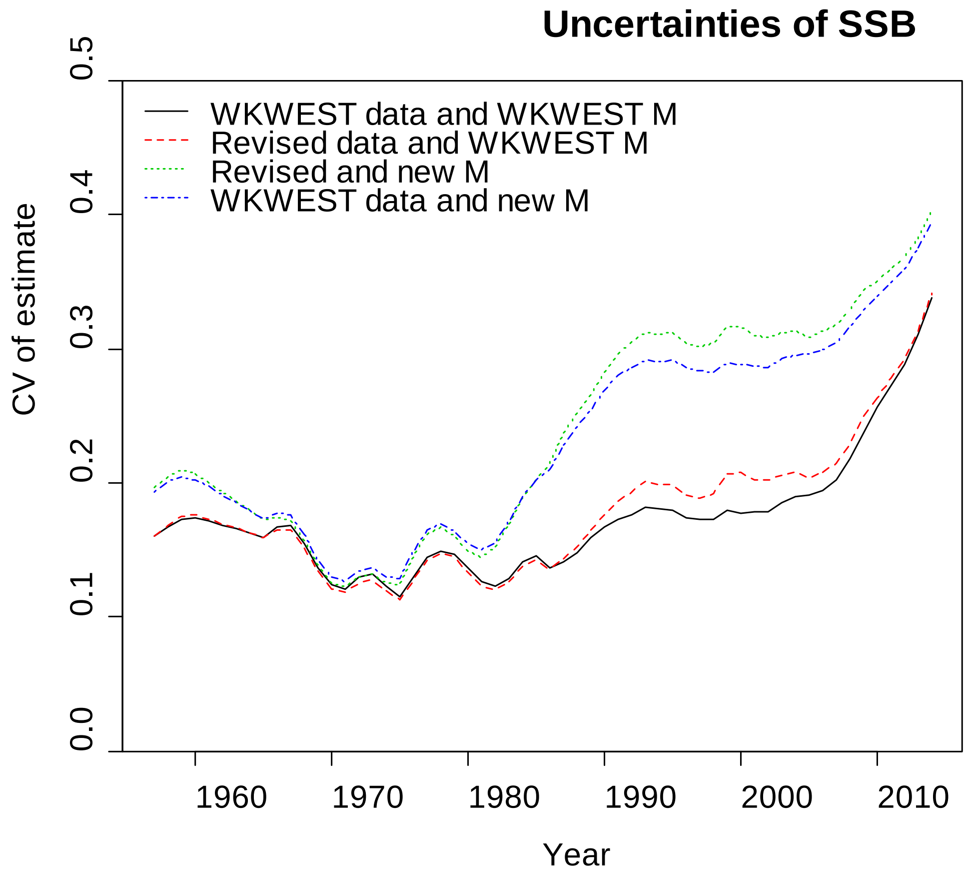


Figure 6. CV around the estimate of SSB from assessment runs using for the WKWEST data and revised input data and with the new and the WKWEST 2015 natural mortality.

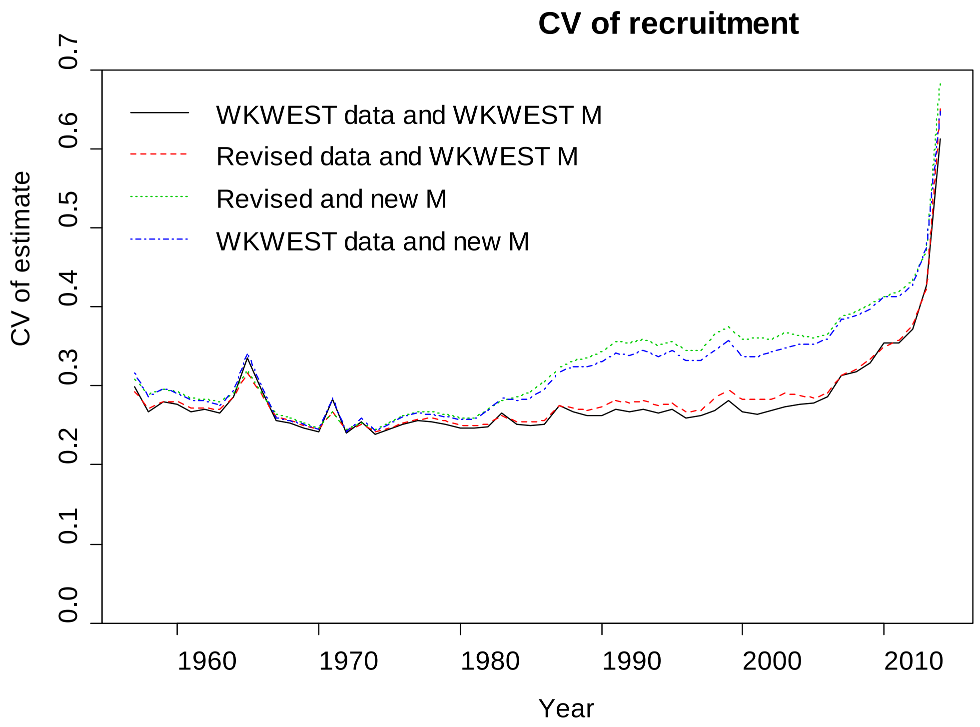


Figure 7. CV around the estimate of recruitment from assessment runs using for the WKWEST data and revised input data and with the new and the WKWEST 2015 natural mortality.

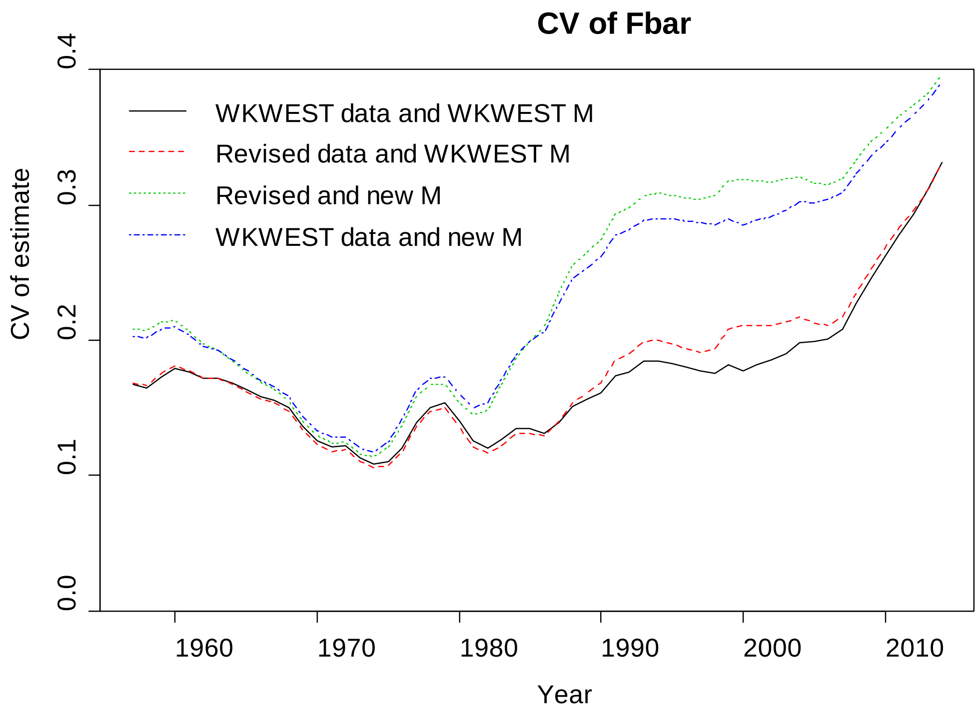


Figure 8. CV around the estimate of fishing mortality from assessment runs using for the WKWEST data and revised input data and with the new and the WKWEST 2015 natural mortality.

7.7 Working Document 4. An evaluation of tuning indices for the vombined VIaN/VIaS and VIIbc herring assessment

By Maurice Clarke and Dave Reid, Marine Institute, Galway, Ireland.

Introduction

The extension of the WKWEST benchmark into May 2015 allows for an in depth evaluation of the tuning indices being used. Such an evaluation would ideally have been conducted at the data preparatory meeting in November 2014, had data and sufficient time been available. Currently, four indices are available:

Malin Shelf Acoustic Survey	MSHAS	2008–2014	VIaN, VIaS and VIIbc
Scottish West Coast Acoustic Survey	WoSHERAS	1991-2007	VIaN, north of 56°N.
Scottish west coast IBTS Q4 trawl	IBTSq4	1996-2009	VIa
Scottish west coast IBTS Q1 trawl	IBTSq4	1986-2010	VIa

For a time series, or part of it, to be included in tuning it should:

1. Contain the stock
2. Provide a reliable index of abundance at that age
3. Not lead to double counting
4. Be free from bias
5. Track cohorts
6. Be free from year and age effects.
7. Be internally consistent in tracking of cohorts as they progress.
8. Have reasonably high precision
9. Generate positive mortality
10. Generate acceptable residual patterns about the model fit.

In addition, any differences in perception of stock development between surveys should be adequately explained.

Materials and methods

The input data were taken from the "fleet" file as revised, and used in the assessment work conducted in April and May, 2015, subsequent to HAWG 2015. Some of the analyses included IBTS data for subsequent years, though these represent a different sample design, and have not been used in tuning.

Criteria 1-4 are properties of the survey design and do not require data analyses. Criteria 5-9 are properties of the input data and are the subject of data analyses, whilst criterion 10 is a property of modelled outcomes, and is evaluated using these.

Bubble plots of the data were used to track cohorts over time and to check for year (vertical) effects and age (horizontal) effects. These plots also allowed for an evaluation of cohort tracking, cohort (diagonal) effects. Internal consistency, within individual indices, was examined by regressing observed abundance at age vs. age +1, and taking the coefficient of determination as a measure of goodness of fit.

The raw data were used to generate "log-catch ratios", to investigate instances of negative mortality, as follows:

$$LCR = \ln (A_{a,y}/A_{y+1,a+1})$$

where

A denotes abundance at age a and year y

and

LCR < 0.00 denotes a situation where $A_{y+1,a+1} > A_{y,a}$

The underlying trend in stock development from each survey was examined by multiplying the observed abundance with mean weight in the stock and proportion mature to generate "raw" observed total stock biomass (TSB) and spawning stock biomass (SSB).

Results and Discussion

A priori reasoning

The acoustic surveys were designed to provide herring abundance indices. The WOS HERAS has been used in the VIaN assessment for many years, and the survey design was for that management unit, although it is recognised that it contained fish from others stocks, e.g. herring in VIa(S). This effect would be reduced if the survey is used for the combined assessment of VIa (total) and VIIbc. The WOSHERAS doesn't fully contain the stockcomplex, but since 2008 it has been augmented with survey transects to the south to create the MSHAS survey. This new survey is thought to contain the stock, at least for older ages. Younger herring in VIa are believed to be mainly found in inshore areas of the Scottish west coast, particularly in the Minches and sea lochs. They may also be found in the Moray Firth (North Sea). In either case they will be at least partially unavailable to the acoustic surveys. For this *a priori* reason, it would seem prudent to exclude younger ages from survey indices used in the assessment. Ages less than 3 ring are probably not fully selected in the survey and should be excluded. Overall there is good reason to include the MSHAS and the WOSHERAS. The latter survey does not contain the stock. However as VIaS fish are likely to have been recorded in it, it is considered to be a reasonable index of the combined stock, albeit for a restricted geographic area. A precedent for inclusion of an historic index that only covers part of the stock is found in the blue whiting assessment, where the Norwegian acoustic survey was used in earlier years and augmented in recent years by including an international survey covering the whole stock area.

For IBTS data to be included in the assessment of combined herring stocks in VIa and VIIbc strong *a priori* reasons are required. IBTS surveys are not routinely used for herring assessment, except in certain circumstances. Herring is an aggregating species, and a catch per unit effort relationship is difficult to establish. The IBTS is based on the concept that the CPUE is proportional to the stock abundance. The western IBTS surveys were not designed as an abundance index for herring, and have been used mainly for demersal fish in recent years. IBTS data in the western area has been used in tuning the mackerel assessment, but only for age zero (0). CPUE indices for first and second winter juvenile mackerel have been used in stock projections as indices of recruitment. Juvenile mackerel are known to have a less pelagic habit than the adults. For herring, in general, IBTS CPUE data are only used as an abundance index for juvenile (age 1 ringer only) in the North Sea assessment, again based on a perception that juvenile herring are mainly demersal in habit. The North Sea IBTS started out as a young herring survey and was designed for that purpose. The IBTS surveys probably cannot be used in this way for young herring in the western area because as noted above in the context of the acoustic surveys, the juveniles are principally found in the sea lochs and in the North Sea. Older herring are also strong swimmers and could possibly avoid the trawl net, especially over short towing durations such as used (half hour). Together with the evidence from the North Sea for the poor performance of IBTS adult herring abundance indices, these factors suggest that the IBTS may not be able to provide a robust indicator for adult herring. Overall, there is not sufficient *a priori* reasoning to include either IBTS survey for tuning for VIa/VIIbc herring. However further investigations of the data are performed to attempt to find a basis for inclusion of these indices.

Raw year and age effects

All the surveys display year effects, where the abundances in that year show a vertical band that appears different to the adjacent years. The IBTSq4 survey (Figure 2) is most characterised by year effects with all years before 2003 appearing as such. Indeed there appears to be a change in selection subsequent to this, with greatly elevated observed abundance after this time. The quarter 1 IBTS survey displays fewer year effects, but 1992, 1998 and 2004 stand out. The WoS HERAS shows year effects in 1997 and 2005. There are no obvious year effects in the abundance at age in the MSHAS survey, though the series is short. Removing the mean-standardisation shows the 2010 is a year effect with greatly reduced abundance relative to adjacent years.

The IBTS surveys and the WoS HERAS survey display some obvious age effects, particularly at older ages. This may indicate age reading errors at older age, which appear as lack of progression from year to year. Examples of this are the years 1993-1996 for older ages in Figure 1 (lower) the bottom right hand side of Figure 2 (upper).

Cohort tracking

All the indices track certain obvious cohorts through the series (Figure 1 and 2). However the cohorts being tracked are not always the same ones. This is illustrated in the text table below. The 1999 and 2000 cohorts are picked up by each survey. There is consistency between the acoustic surveys in that they pick up the overlapping 1999 and 2000 cohorts. Good cohort tracking on its own is not considered a basis to include a survey. This can be illustrated by considering year-effect situations. In cases of a year effect, often an obvious cohort still is apparent in the effected year (see for instance, Figure 1, lower, age 4 wr in 2005). However the abundance at that year and age would not be considered reliable, though it still is apparent as an obvious cohort.

Survey	Obvious cohorts
MSHAS	1999, 2000, 2001, 2007, 2008
WoS HERAS	1986, 1995, 1999, 2000
IBTS q1	1985 1998, 1999,2000
IBTS q4	1992, 1999, 2000

Internal consistency

For indices to be useful, they should display positive correlations between the main ages, as this demonstrates that the index is picking up a signal in abundance (Figure 4). The MSHAS survey displays positive correlations at a time lag of 1 for ages 3 onwards, though the relationship for age 6 is weak. The WoSHERAS has a similar pattern. However when all time lags are considered, only ages 6 onwards are positive for MSHAS. For the IBTSq1 survey, ages 2-9 and for IBTSq4 ages 5 and 7-9 are there positive correlations at a time lag of 1. Negative correlations are found throughout the time series for both IBTS surveys, at time lags greater than 1.

The coefficient of determination (r^2) provides a measure of goodness of fit of the observed regressions of abundance at age over various time lags (Figure 4). Weak (<0.5) values indicates poor goodness of fit and lack of internal consistency in abundance estimation. The IBTS q1 index has no r^2 greater than 0.48 for any time lag. The IBTS q4 index has only one r^2 that is greater than 0.5, and only marginally so (0.557 between ages 4 and 7). In contrast to the IBTS surveys, the acoustic surveys demonstrate strong abundance relationships ($r^2 > 0.7$) in many instances. The MSHAS shows moderate to high r^2 especially at ages of 6+. The WOSHERAS performs best at ages 6-7 in this regard.

Negative mortality

Figure 5 shows instances of negative mortality. The MSHAS displays the lowest degree of negative mortality, in 16 % of cases. This is followed by the WOSHERAS at 21% and each of the IBTS surveys at 33%. In the MSHAS Ages of 4 ring and more are generally free from negative mortality, with the exception of a band of values at older ages, representing the 2010 year. Similarly the WOSHERAS is relatively free from negative mortality at ages of more than 4 winter ring. In this survey, the exceptions are the 1992, 1997, 2002 and 2005 survey years. The IBTS surveys are characterised by negative mortality throughout. There is no obvious cut-off point in terms of years or ages that suggests itself in either case, that could be used to decide on what portion of the indices to include.

Stock development over time

Figure 6 shows an indicator of stock development over time as derived from the raw abundance data per survey. The acoustic series show a decline with lowest observations in each series towards the end. For the IBTS data, the full time series are used, including those years after the change in survey design. Taken together, the acoustic surveys show an overall downward trend since 2003. The IBTS surveys appear much noisier than the acoustic surveys, with wide fluctuations from year to year. The IBTS surveys as currently used in tuning do not include data post 2009/2010. Thus the series end in elevated estimates of abundance. When the series are extended, a strong decline is evident (Figure 7). The inconsistencies in stock trends from the acoustic and trawl surveys between 2003 and 2009 must be adequately explained. The upward trend in trawl surveys 2003-2009 is not supported by the previous assessment results for either stock, as conducted in previous assessments.

Though it is our a priori conclusion that the IBTS data should not used at all, we consider that there is no a priori basis to truncate the IBTS series to account for changing design. The first design change was the attachment of the ground gear. This is unlikely to lead to any major change in herring catches, because herring tend not to dive, but rather swim up to avoid the net. The other, more important design change was to change the survey stratification from rectangle to depth and geographical strata. This would also not be expected to have led to a change in selection for herring, mainly because they are not known to be associated with particular strata. The inclusion of truncated IBTS series which end with a marked increase requires strong reasoning, on the basis of the precautionary approach alone. Future investigations of the trawl surveys as tuning indices should begin with inclusion of all data to the end of the series.

Modelled year effects

The best case SAM model (run 86,) was used to evaluate the performance of each index in an assessment scenario. The MSHAS survey year effects in 2008 and 2013, but otherwise showed a reasonably balanced residual pattern (Figure 8). In the WOS HERAS the most obvious year effect was in 1994, 2005 and 2007. Overall, this survey displayed a well balanced residual pattern. The IBTSq1 survey showed several strong year effects in 1991, 1996, 1998 and 2004. There is also a tendency for a blocking of positive and negative residuals from 2004 onwards, either side of age 5. The IBTS q4 index had strong year effects in 2001, 2002 and 2009. In general the residual pattern for this index was poor with blocking or "chequered flag" effects.

Bias and double counting

A qualitative evaluation of both the acoustic and trawl surveys suggests that each is relatively free from bias. The acoustic surveys have been performed using a standard survey grid and design over time. Any changes due to vessel or environmental effects are not systematic over time, and hence would not lead to bias. Similarly the IBTS data are thought to be bias free, given that they have all been performed on one of two survey vessels, with intercalibration during the changeover. Similarly there is little chance of double counting within either of the survey types. The acoustic tracks are sufficiently wide to avoid this effect, and in the case of the trawl surveys, individual stations are reasonable dispersed.

Conclusions

Acoustic series

These are considered to be suitable for tuning, on an *a priori* basis. However, *post hoc* analyses suggest that the surveys perform better for older ages only, and this should be considered in subsequent model runs. These surveys are designed and used widely elsewhere for herring abundance estimation. They display consistent trends and pick up overlapping cohorts. The downward trend that is displayed by these surveys since 2003 must be considered to be the criterion against which other surveys are compared. If surveys other than those designed specifically for herring are showing a different trend, then there must be good reason to consider those trends as being trustworthy.

IBTS surveys

On an *a priori* basis, the IBTS q4 should not be used in tuning. However an attempt was made, using *post hoc* analyses of the data, to investigate if a basis could be found for its inclusion. No such basis could be found. There are many instances of negative mortality, throughout the abundance matrix, including a blocking effect (pre- and post- 2003) and it has poor cohort tracking ability (no cohorts in common with other surveys). Weakly positive or negative correlations between ages were found throughout the series. A trawl survey such as this would only be expected to be applicable for younger ages, yet it actually only performs moderately well for older ages. This contradictory finding further underlines that it is not a potential tuning index.

On an *a priori* basis, the IBTS q1 would not be expected to be a reasonable index of abundance for herring in VIa, and on that basis it should not be included. However *post hoc* analyses were used in an attempt to find support for including them. This survey suffers from the same data problems as the quarter 4 index, with weakly positive or negative correlations (poor internal consistency) and pervasive negative mortality. It does perform well in the model, with a reasonable residual pattern. However performance in a model is not a basis for inclusion of an index if there are strong *a priori* reasons for excluding it. The survey does perform well in cohort tracking, but that on its own is not an indicator that it can be used as an index of abundance, given that its internal consistency is so poor. hus no post hoc reasoning could be found to include the series. However based on our understanding of herring behaviour and the design of the survey, there is no a priori basis to truncate it at 2009/2010. If both trawl series are extended it does at least agree with the stock perceptions from the acoustic surveys.

Overall, the inclusion of the trawl surveys must be backed up by suitable behavioural or selectivity studies that demonstrate their utility for herring abundance estimation in VIa. Until such studies are available it would be prudent not to include these surveys. The upward trend they show from 2003 to 2009 is not supported in any other stock information and on the precautionary approach implies that they should not be included without strong corroboration.

Future work

At present there is insufficient basis for inclusion of the trawl surveys in tuning. However further work should be conducted that could lead to their inclusion in future benchmarks. Such work could include behavioural and selectivity studies. It could also focus on the North Sea IBTS which may provide an index for VIaN juveniles, if these fish can be shown to return to their natal area.

Table 2. Summary of survey evalution against various criteria.

Considerations	Criterion	MSHAS	WoS HERAS	IBTS Q1	IBTS Q4
Data	Track cohorts	Yes	Yes	Yes	Yes
	+ve correlations; lag 1	3-5;7-9	3-9	2-9	5; 7-9
	+ve correlations; lag all	6-9	3-9	none	None
	$r^2 > 0.5$, lag 1	6-9	6-7	none	None
	$r^2 > 0.5$, all lags	1-9	none	none	4 and 7 only
	$r^2 > 0.7$, lag 1	7-9	6-7	none	None
	$r^2 > 0.7$, all lags	2,4,5, 7-9	6-7	none	None
	Negative mortality	16%	27%	33%	33%
	Raw year effects	2008	2005	1992, 1998, 2003, 2004	every year pre- 2003
	Trend	Decrease 2008-2014	Decrease 2003-2007	Stable 2003-2006; Increase 2007-2010	Stable 2003-2007, Increase 2008-2010
Model	Acceptable residual patterns	Yes	Yes	Yes	No
	Model year effects.	2008, 2013	1994, 2005, 2008	1991, 1996, 1998, 2004	2001, 2002, 2009
A priori	Contains the stock	Yes, juveniles missing	No, only VIa	No, only VIa, juveniles missing	No, only VIa, juveniles missing
	Double counting	No	No	No	No
	Bias over time	No	No	No	No
	Provide a reliable index of abundance at that age	Yes	Yes	No	No

Figure 1. Abundance at age, standardised by the yearly mean, for MSHAS (above) and WOS HERAS (below) surveys.

Figure 2. Abundance at age, standardised by the yearly mean, for IBTSq1 (above) and IBTSq4 (below) surveys.

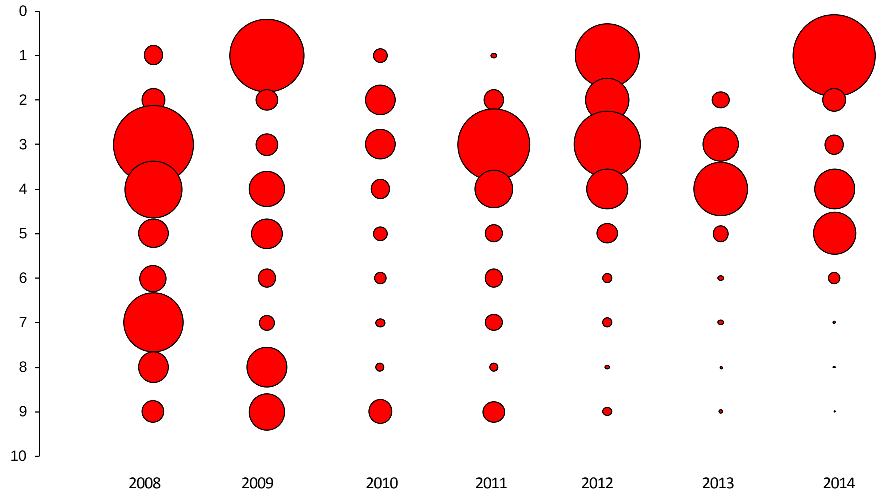


Figure 3. Abundance at age for MSHAS survey, without standardisation.

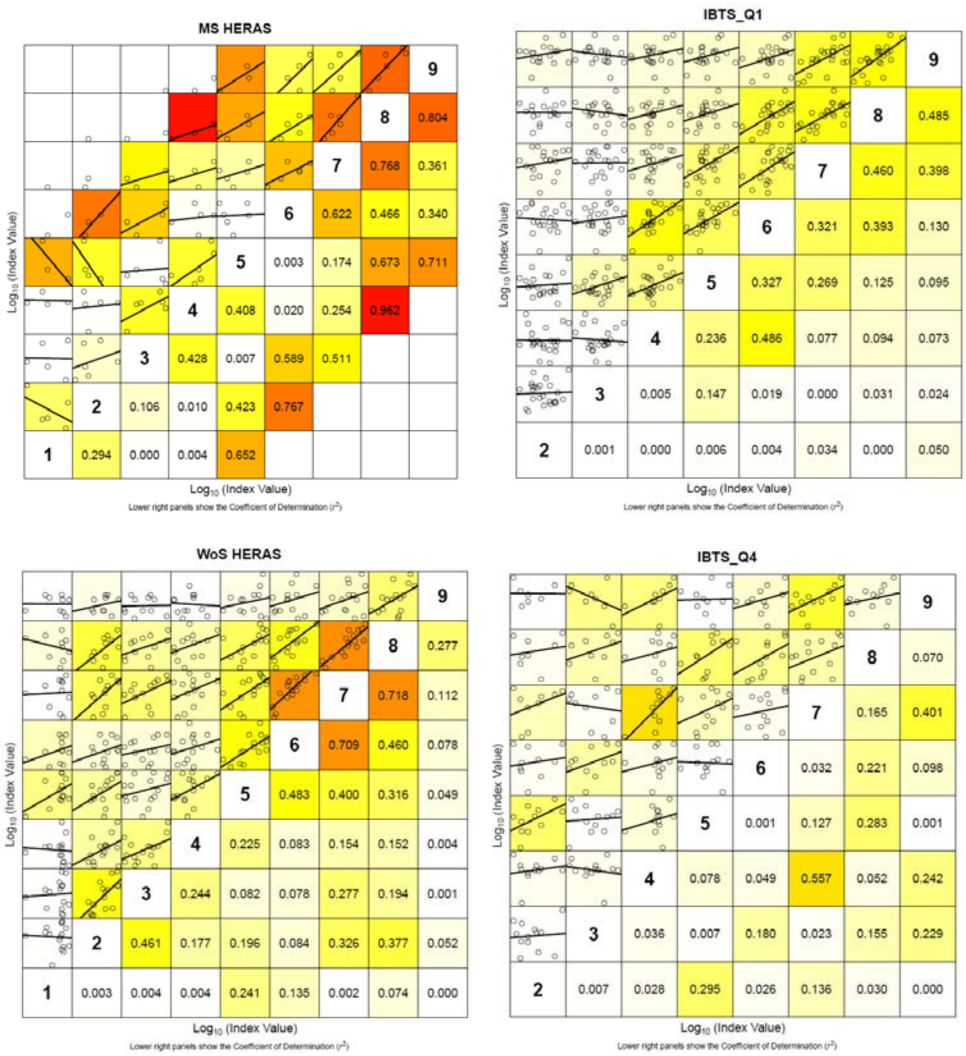


Figure 4. Internal consistency diagrams showing pairwise regressions by age and coefficient of variation values.

	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9
MSHAS								
1998								
1999								-0.17
2000							0.40	0.52
2001						0.54	0.65	-0.97
2002					0.48	0.79	-0.11	0.08
2003				0.64	0.96	-0.34	1.29	0.41
2004			0.81	0.94	-0.27	0.71	1.36	0.79
2005		0.04	0.12	0.13	0.62	0.62	1.19	
2006	-0.10	-0.34	-0.26	0.67	1.26	0.77		
2007	0.90	-0.87	0.55	0.98	0.27			
2008	-0.39	-1.17	0.21	0.23				
2009	-2.17	0.23	-0.14					
2010	1.34	-0.13						
WoS HAS								
1982								0.35
1983							0.55	-1.05
1984						0.51	-0.40	0.18
1985					0.71	-0.21	0.53	-0.15
1986				-0.12	-0.78	0.79	0.54	0.72
1987			0.24	-0.78	0.75	0.46	0.77	1.16
1988		0.33	-1.18	0.81	0.49	0.88	0.98	-0.24
1989	-0.40	-0.31	0.88	0.62	0.93	1.31	0.16	-0.94
1990	-2.05	-0.05	0.30	1.55	0.66	0.57	0.02	-0.86
1991	-5.44	0.14	0.36	1.61	-0.18	-0.09	-0.09	1.01
1992	-0.80	0.32	1.57	-0.07	0.26	-0.36	1.34	-0.13
1993	-0.27	0.70	-0.50	0.42	0.22	0.88	0.42	-0.11
1994	-2.75	-0.04	0.43	0.09	1.09	-0.14	0.29	0.40
1995	0.00	-0.56	0.43	0.72	0.03	0.20	1.44	1.12
1996	1.33	-0.04	0.67	0.07	0.22	0.74	0.46	-0.42
1997	0.52	0.37	0.09	0.10	1.18	1.49	-0.54	-0.39
1998	-0.86	-0.30	-0.02	0.94	1.33	-0.40	0.33	
1999	-0.33	-0.76	0.75	0.59	-0.53	0.53		
2000	-0.90	0.31	0.59	-0.32	0.52			
2001	0.47	0.18	-0.21	0.67				
2002	0.84	-0.47	0.65					
2003	-2.81	1.04						
2004	-0.12							

	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9
IBTS q1								
1977								-0.61
1978							-0.53	1.88
1979						0.48	1.23	0.39
1980					-0.95	1.18	0.73	0.54
1981				-0.80	1.52	1.00	0.52	-0.79
1982			-1.55	0.93	0.21	0.02	-0.48	1.61
1983		-1.26	0.91	0.43	0.28	-1.04	1.75	0.63
1984	-1.25	-2.22	1.08	0.40	-1.10	1.85	-0.07	2.82
1985	-3.61	1.16	1.14	-1.06	2.00	-0.08	2.50	-0.26
1986	-1.14	-1.20	-1.92	1.32	-0.23	1.36	0.13	-0.21
1987	-0.99	-2.71	1.98	-0.33	0.91	0.59	0.33	-0.52
1988	-3.14	1.56	0.03	0.67	0.17	1.23	-0.85	0.96
1989	1.68	-1.71	1.04	1.00	0.34	0.22	1.45	-1.37
1990	-3.28	-1.12	1.17	0.92	-0.07	1.92	-0.56	-0.27
1991	-1.47	-0.38	1.36	-0.16	2.00	-1.21	0.89	-0.99
1992	-4.11	1.36	0.62	1.80	-0.33	-0.04	0.07	-0.65
1993	-4.76	0.00	2.23	-0.43	0.56	-0.65	0.30	0.39
1994	-3.03	1.30	-0.17	0.87	-0.50	0.23	0.92	-1.06
1995	-0.03	-3.25	1.06	-0.58	0.37	0.61	-0.34	0.51
1996	-4.41	0.60	0.10	0.41	0.21	-0.93	0.64	-0.28
1997	-1.41	1.83	0.16	0.56	-0.91	0.80	0.65	-0.45
1998	0.94	-2.01	0.62	-0.86	0.56	0.39	0.87	0.49
1999	-4.61	2.40	-0.92	0.29	0.20	0.56	0.32	-1.22
2000	-1.58	-0.93	0.82	0.15	0.23	0.91	-1.48	0.26
2001	-4.08	1.66	0.59	-0.11	0.59	-0.95	0.41	
2002	-1.61	-0.07	0.62	0.68	-0.82	0.23		
2003	-1.64	1.03	0.50	-0.98	1.18			
2004	-0.58	-0.84	-1.54	1.34				
2005	0.40	-1.65	1.09					
2006	0.14	-1.09						
2007	-2.79							
IBTS q4								
1987								-0.10
1988							-0.44	0.06
1989						0.66	0.77	-1.21
1990					0.29	1.32	0.60	-0.18
1991				-0.01	0.29	0.76	1.00	-0.75
1992			1.18	-0.04	0.55	1.29	-1.04	2.71
1993		0.59	0.29	0.74	0.56	-1.13	2.67	-1.35
1994	0.08	-0.25	0.46	0.91	-1.57	2.85	-1.05	-0.27
1995	-1.64	0.06	0.42	-1.46	2.99	-1.27	-0.22	1.05
1996	-1.48	0.32	-1.35	2.83	-1.65	-0.55	1.63	-1.00
1997	-0.19	-1.37	3.79	-1.84	-0.61	2.23	-1.26	0.48
1998	-2.82	2.85	-1.82	-0.48	1.89	-0.51	0.90	-0.37
1999	-0.27	-2.14	-0.38	1.31	-0.48	0.06	0.75	-0.37
2000	-4.25	1.03	1.58	-0.47	-0.08	0.22	0.42	
2001	2.02	1.41	-0.53	-0.67	0.87	0.19		
2002	-0.41	-0.50	-0.09	0.35	0.59			
2003	-1.08	-0.06	0.59	-0.14				
2004	-3.73	0.21	0.02					
2005	1.32	-1.26						
2006	-4.24							

Figure 5. Pictogram showing instances of negative mortality (in red) in log catch ratios from each survey index. Pairwise age comparisons are on the horizontal axis and cohort (by hatching year) on the vertical.

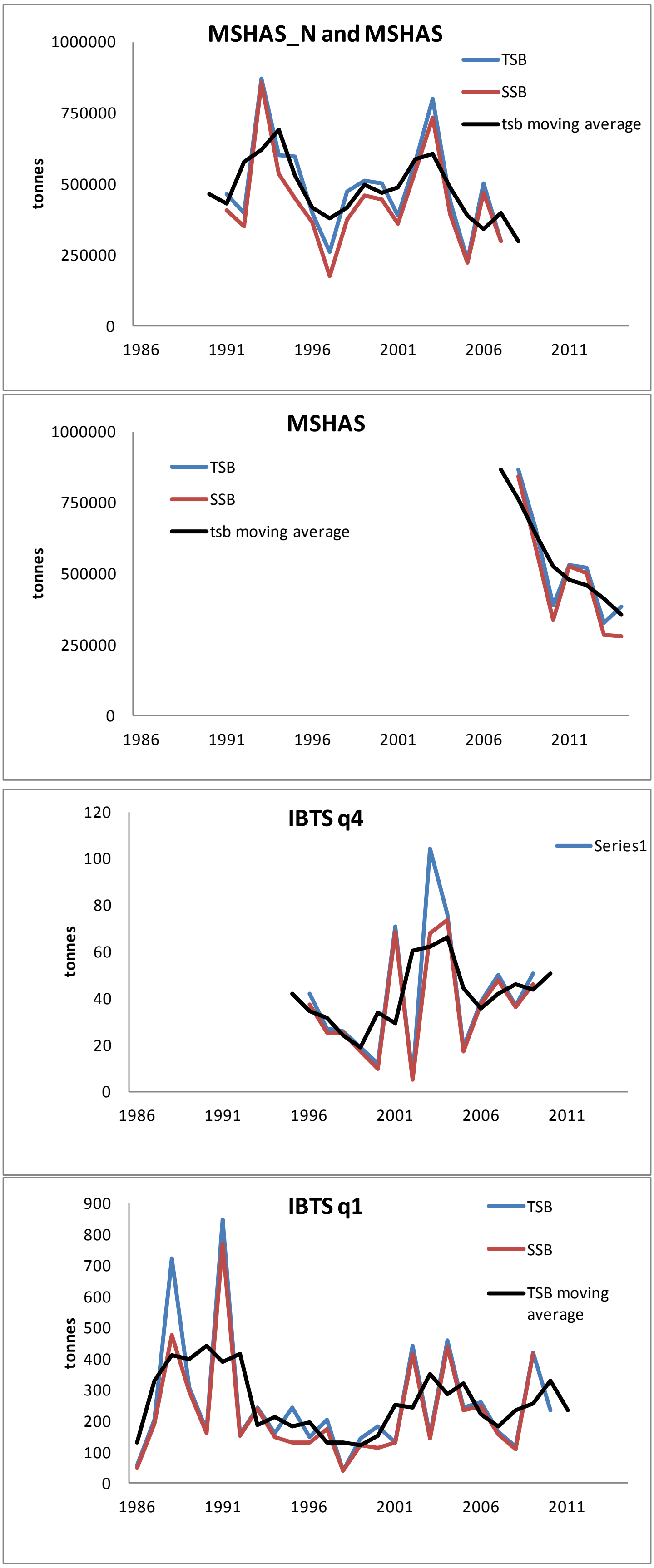
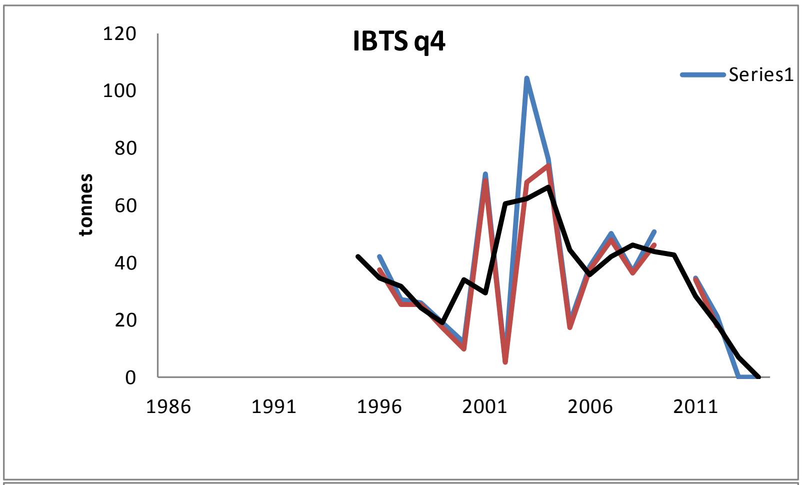


Figure 6. Total (TSB) and spawning (SSB) biomass as an indicator of survey tracking of abundance over time, with TSB moving average smoother.



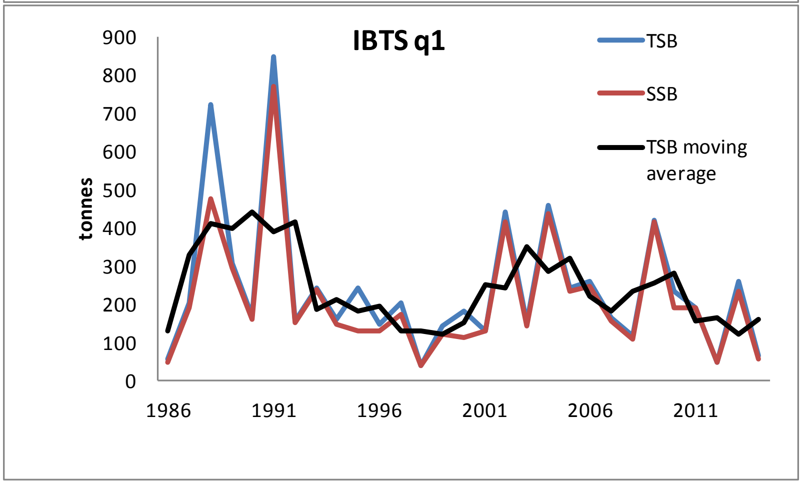


Figure 7. Total (TSB) and spawning (SSB) biomass as an indicator of IBTS surveyed abundance over time, extended for years after change of design, with TSB moving average smoother.

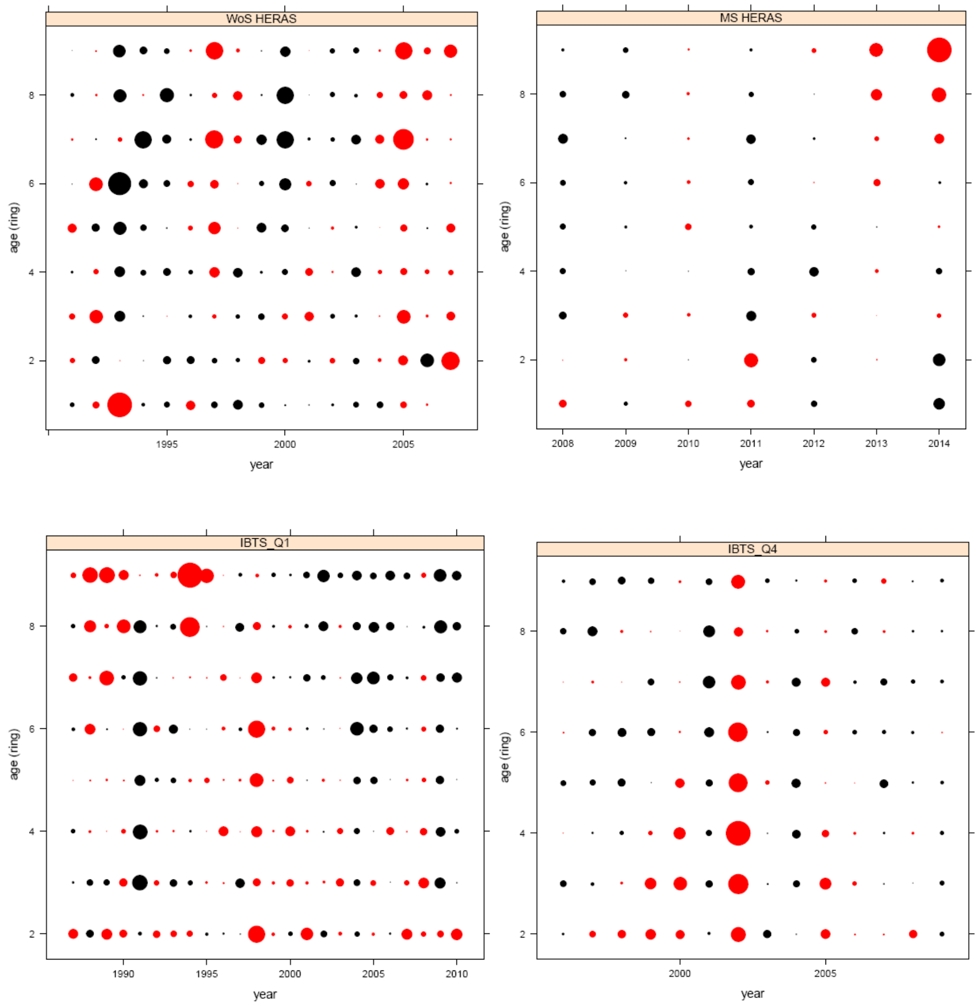


Figure 8. Residuals about the best case SAM model fit to each of the survey indices.

7.8 Working Document 5. ASAP assessment of Herring in VIa, VIIb,c

By Afra Egan, May 2015

Introduction

Separate stock assessments have previously been carried out on the herring stocks in VIaS, VIIb,c and VIaN. It has been recognized that mixing occurs between these stocks and it was decided to benchmark these stocks together at WKWEST in 2015. WKWEST recognized the conclusions and recommendations of previous studies WESTHER and SGHERWAY that were conducted on these herring stocks that considered the meta-population structure of herring in these ICES divisions. Despite the efforts to apply a splitting procedure using updated baseline information on body morphometry and otolith shape analysis, estimates of stock composition are not currently sufficient for splitting the mixed-stock survey data. WKWEST determined that the assessment of the meta-population of herring in ICES Divisions VIa and VIIb,c combined is the best available scientific information for determining stock status and offering catch advice for the fisheries in the areas (ICES, 2015 WKWEST).

A final assessment has not yet been presented for this combined stock in 2015 and further explorations have been carried out. These explorations involve applying different assessment models to the data. This document outlines the exploratory assessment using the ASAP model.

Materials, methods and results

Input data

The catches in tonnes (caton) were combined from the two areas VIaS, VIIb,c and VIaN for the years 1957 – 2014. The catch in numbers age (canum) from 1957-1969 were taken from ICES HAWG 1974, as these figures were used in the pre 1981 joint assessment of VIa. These included catch in numbers for VIIbc, and the juvenile fishery in the Moray Firth (IVa) that were considered to be from the VIa stock. For 1970 to present, catch numbers were summed from the two assessments. Mean weights in the catch were compiled from the separate assessments and weighted by the combined catch in numbers. Weights at age in the stock at spawning time were taken from the VIaN acoustic survey. The maturity ogive is taken from observed maturity at age in the Malin Shelf survey 2008-2014, following the procedure used for the separate VIaN assessment. For earlier years, the maturity ogive is as per the VIaN stock, and is taken from the geographic split VIaN old acoustic tuning series. The proportions of F and M before spawning were the same in each separate assessment, and have not changed.

Natural Mortality

In 2014, WGSAM provided updated estimates of natural mortality for North Sea herring through a new SMS key run (ICES, WGSAM 2014). These values were also used for the VIa, VIIb,c herring assessment. During the Herring assessment working group in 2015, it was discovered that there was an error in the 2014 SMS key run. As a consequence of this, it was decided apply the average natural mortalities from the 2011 SMS key run (ICES, 2015 HAWG). This data change had an impact on the SAM assessment and further investigations were then required.

Survey Data

Four possible survey indices can be used in the assessment of Herring in VIa, VIIb,c.

1. **The Malin Shelf Acoustic survey** has been carried out annually since 2008 and covers the stock area of VIIb, and VIa. The current survey has two participating vessels, one from Scotland (chartered fishing vessel) and one from Ireland (RV "Celtic Explorer"). The survey covers the continental shelf west of Scotland and Ireland from 53.5°N up to a northern limit of 62°N. The survey area is bound to the west by the 200m depth contour on the shelf edge and to the east by the 30m depth contour on the Irish and Scottish coasts and the 4°W line (ICES, WGIPS 2015).
2. **The West of Scotland acoustic survey** time series runs from 1991-2007 and mainly covered VIaN with coverage in VIaS in some years. It originally covered an area bounded by the 200 m depth contour and 4°W in the north and west and extended south to 56°N (Figure 3.6.2.1); it has provided an age-disaggregated index of abundance as the sole tuning index for the analytical assessment of VIaN herring since 2002 (ICES, WGIPS 2015).
3. **The Scottish West Coast Ground fish survey in quarter 1** (IBTS Q1) began in 1981. It has been carried out in a consistent manner from 1986 until 2010 when the survey was redesigned. The survey initially covered ICES Division VIa, but has since 1996 additionally covered the northern part of the Irish Sea and between 1996 and 2006 it extended into VIIb. The target species for this survey are cod, haddock, whiting, saithe and herring.
4. **The Scottish West Coast Ground fish survey in quarter 4** (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.

Different combinations of these indices will be explored using the ASAP assessment model.

Table 1: Assessment Input data summary

DATA (1–9)	YEAR RANGE	NOTES
Catch tonnes	1957-2014	Catch in tonnes
Catch numbers	1957-2014	Catch in numbers
Mean weight catch	1957-2014	Weighted by catch numbers
Mean weight stock	1957-2014	From VIaN survey sampling July
Natural mortality	1957-2014	From WGSAM 2011
Maturity ogive	1957-2014	Based on Malin shelf survey
Proportion of F before spawning	1957-2014	0.67
Proportion of M before spawning	1957-2014	0.67
Malin Shelf Scoustic Survey	2008-2014	
West Of Scotland Acoustic	1991-2007	
IBTS Q1	1986-2010	
IBTS Q4	1996-2009	

ASAP Version 3.0.1 7NOAA Fisheries toolbox[1]

The Age Structured Assessment Program (ASAP) (Legault and Restrepo, 1999) is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. The separability assumption is relaxed by allowing for fleet-specific selectivity at age that can change smoothly over time or in blocks of years. ASAP can handle years with missing data and uncertainty on catch and on recruitment can be specified1[1]. A summary of the ASAP settings used in the base run are presented in the table 1 below.

Table 2: Summary of ASAP setting used in the base run

DISCARDS INCLUDED	NO
Use likelihood constant	Yes
Mean F (Fbar) age range	3-6
Number of selectivity blocks	1
Fleet selectivity	By Age: 1-9: 0.3,0.5,1,1,1,-1,1,1,-1 Fixed at age and 9
Index units	2 (numbers)
Index 1 month Index 2 month Index 3 month Index 4 month	July (7) July (7) February (2) November (11)
Index selectivity linked to fleet	-1 (not linked)
Index 1 Years Index 2 Years Index 3 Years Index 4 Years	2008-2014 1991-2007 1986-2010 1996-2009
Index 1,2,3,4 age range	1-9
Index 1,2,3,4 Selectivity	0.5,0.5,0.5,0.5,1,1,1,1,1 Fixed from ages 5-9
Index 1,2,3,4 CV	0.2 all years
Sample size	No of herring samples collected per survey
Phase for F-Mult in 1st year	1
Phase for F-Mult deviations	2
Phase for recruitment deviations	3
Phase for N in 1st Year	1
Phase for catchability in 1st Year	1
Phase for catchability deviations	-5
Phase for Stock recruit relationship	1
Phase for steepness -	-5 (Do not fit stock-recruitment curve)
Recruitment CV by year	1
Lambdas by index	1
Lambda for total catch in weight by fleet	1
Catch total CV	0.1 for all years
Catch effective sample size	No of samples from Irish and Scottish sampling programmes where available. Averages used in other years

[1] http://nft.nefsc.noaa.gov

DISCARDS INCLUDED	NO
Lambda for F-Mult in 1st year	0 (freely estimated)
CV for F mult in the first year	0.5
Lambda for F-Mult deviations	0 (freely estimated)
CV for f mult deviations by fleet	0.5
Lambda for N in 1st year deviations	0 (freely estimated)
CV for N in the 1st year deviations	1
Lambda for recruitment deviations	1
Lambda for catchability in 1st year index	0
CV for catchability in 1st year by index	1
Lambda for catchability deviations	0
CV for catchability deviations	1
Lambda for deviation from initial steepness	0
CV for deviation from initial steepness	1
Lambda for deviation from unexpl. stock size	0
CV for deviation from unexpl. stock size	1

Other Settings Tested

ASAP has the option of allowing the model to be unconstrained with respect to estimating recruitment. This is not recommended, as solutions with one extremely large cohort often result. In this case a constraint on recruitment estimation was applied using different CV values to determine the level of the constraint i.e. a high CV leads to a minimal constraint and a lower CV will constrain recruitments more. In the base run the CV was set at 1. Further runs tested values of 0.5 and 0.75.

The selection pattern of the fishery was also examined. A flat topped selection was applied by fixing selection at ages 6 and 9. The possibility of increasing selection with age was also investigated by fixing selection at the oldest age which in this case is 9. When selection is fixed at age 6 the selection is estimated to be flat topped before dropping off at age 9.

Four different combinations of survey data listed below were also tested.

- Option 1: 4 surveys - The Malin Shelf and West of Scotland Acoustic Survey, IBTS Q1 and IBTS Q4
- Option 2: 1 acoustic survey – The Malin Shelf Acoustic Survey
- Option 3: 2 acoustic surveys – The Malin Shelf and West of Scotland Acoustic Survey
- Option 4: 4 surveys in option 1 but with 1986 removed from the IBTS Q1 time series.

CVs are not currently available for each of the survey time series. Two different options were explored 0.2 and 0.5.

Results

Base Run

The outputs from the base run are presented in Figures 1-4 below. Figure 1 shows the catch proportions-at-age residuals. The residuals are large for the young ages, which is to be expected because these are estimated with low precision. There are no clear patterns in the residuals. Figure 2 shows the residuals of the index proportions-at-age. Some age effects can be seen in the survey indices at the youngest and oldest ages. Figure 3 shows the observed and predicted catches. In general, the model followed the observed catches quite closely. The stock summary plots showing the trajectories for landings, recruitment, SSB and mean F with the associated standard deviations are shown in Figure 4.

Changing the CV on recruitment deviation

Using a CV of 1 (applying a minimal constraint on recruitment) leads to high uncertainty in the estimation of recruitment in the terminal year. Using a lower CV on recruitment constrains the estimate more and improves the uncertainty. The plots for each of the key parameters are presented in Figure 5.

Selection Pattern in the fishery

For these initial ASAP runs one selection pattern was applied over the whole time series (1957-2014). In the base run selection was fixed at age 6 with selection at remaining ages estimated by the model. This gave a slightly dome shaped pattern. Two other options were tested by fixing selection at age 9 which showed increasing selection up to age 8. A third option was also tested by fixing selection at age 6 and 9 to give a more flat topped selection pattern. Each of the selection patterns are presented in Figure 7. It is though that a flat topped selection pattern may be most appropriate for this fishery but further investigations would be required to confirm this.

Survey Combinations

Subsequent runs were carried out using a CV of 0.5 on the recruitment deviation and fixing selection at ages 6 and 9. Runs were carried out using survey data options 1-4 outlined above. Option 4 which uses the 4 surveys but with 1986 IBTS Q1 1986 survey removed led to improved diagnostics in the SAM model and was tested in ASAP also. The removal of this data has little impact on the ASAP assessment. The retrospectives from each run are presented in Figure 8 - Figure 11. The best retrospective can be seen when only the Malin Shelf acoustic survey is used. The uncertainty of the key parameters of recruitment, SSB and Mean F from the different survey combinations are presented in Figure 12. The uncertainty on SSB and Mean F is reduced slightly in the most recent years when the 4 surveys are included. The stock trajectories from survey combination options 1-3 are presented in Figure 13. Tuning the assessment using the 4 surveys shows a higher SSB and lower mean F in the most recent part of the time series.

ASAP/SAM comparison

A comparison of the stock trajectories from ASAP and SAM is presented in Figure 14. Both runs use the same survey data – the Malin shelf acoustic survey, West of Scotland acoustic survey, IBTS Q1 without the 1986 data point and the IBTS Q4 survey. Both models show reasonable agreement. SAM estimates higher SSB and lower mean F than ASAP throughout the time series. The agreement between both models is best for recruitment.

Survey CVs

ASAP has the option to set CVs for each of the indices. As this information is not easily available the assessment was run using CVs of 0.2 and 0.5 on all indices. Changing the CV on the indices had little impact on diagnostics.

Conclusions

The results presented here are from initial exploratory assessments using the ASAP model. ASAP has potential for use in the assessment of herring in VIa, VIIb,c and if this model was selected as the final assessment model for this stock further settings and data options could be tested.

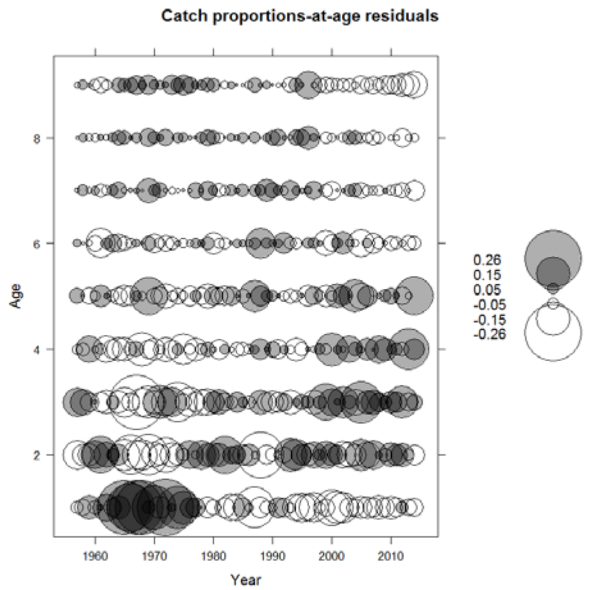


Figure 1: Catch proportions at age residuals for the base case ASAP run.

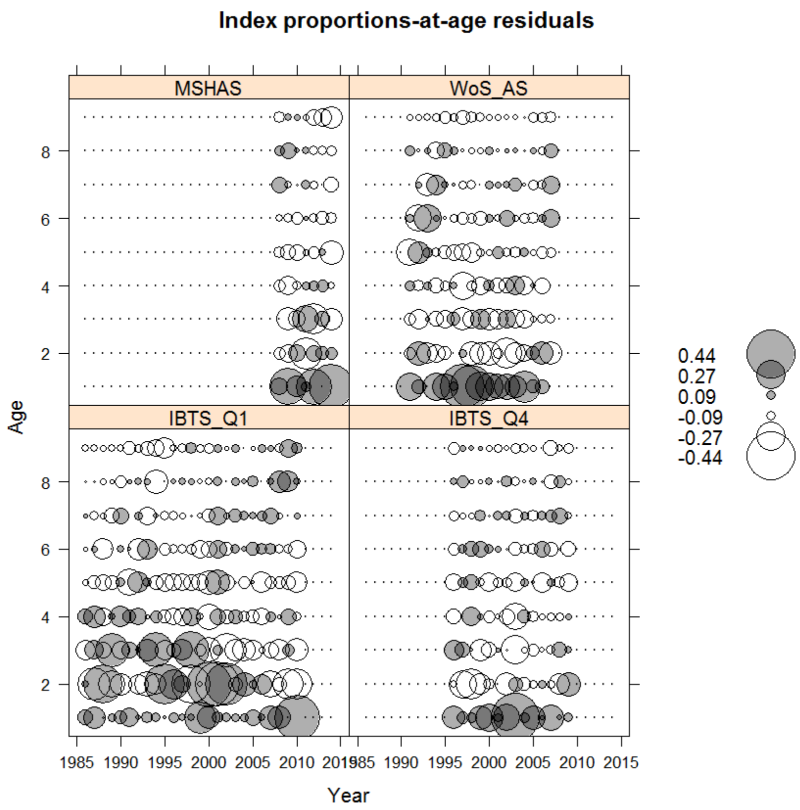


Figure 2: Index proportions-at-age residuals (observed–predicted) for the base case ASAP run.

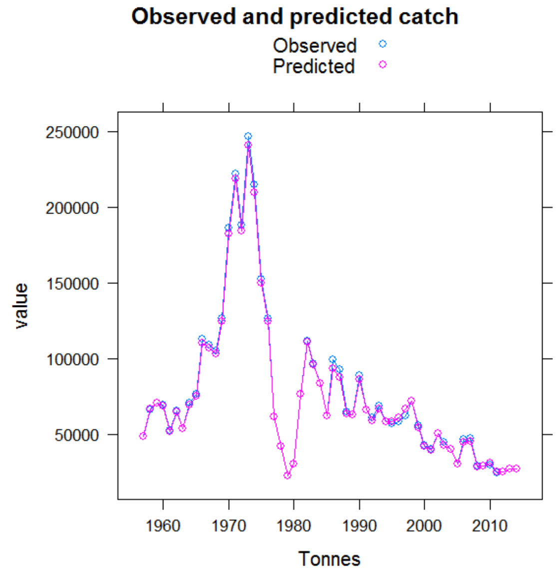


Figure 3. Observed catch and predicted catch for the base case ASAP run.

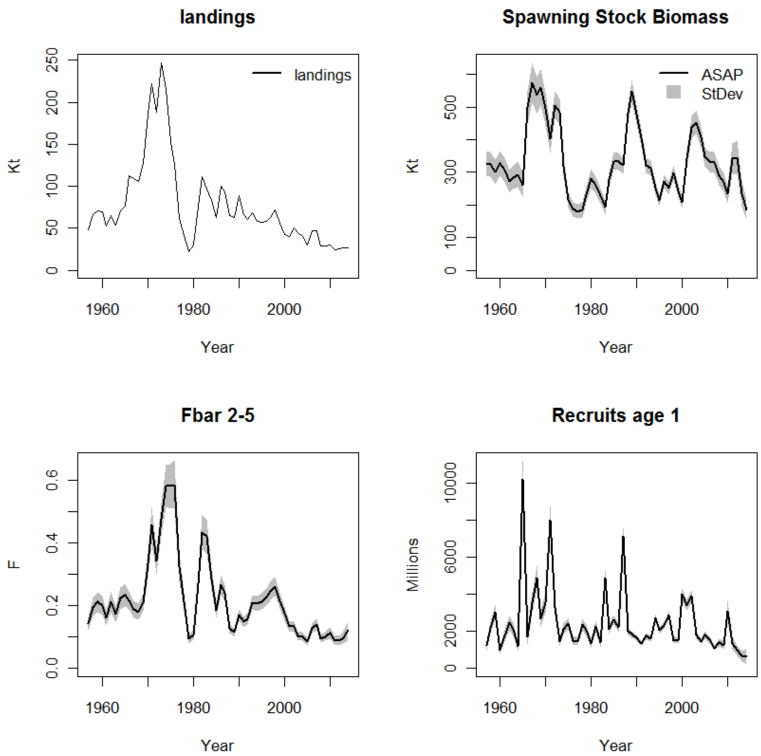


Figure 4: Stock summary plot with standard deviations for the base case ASAP run

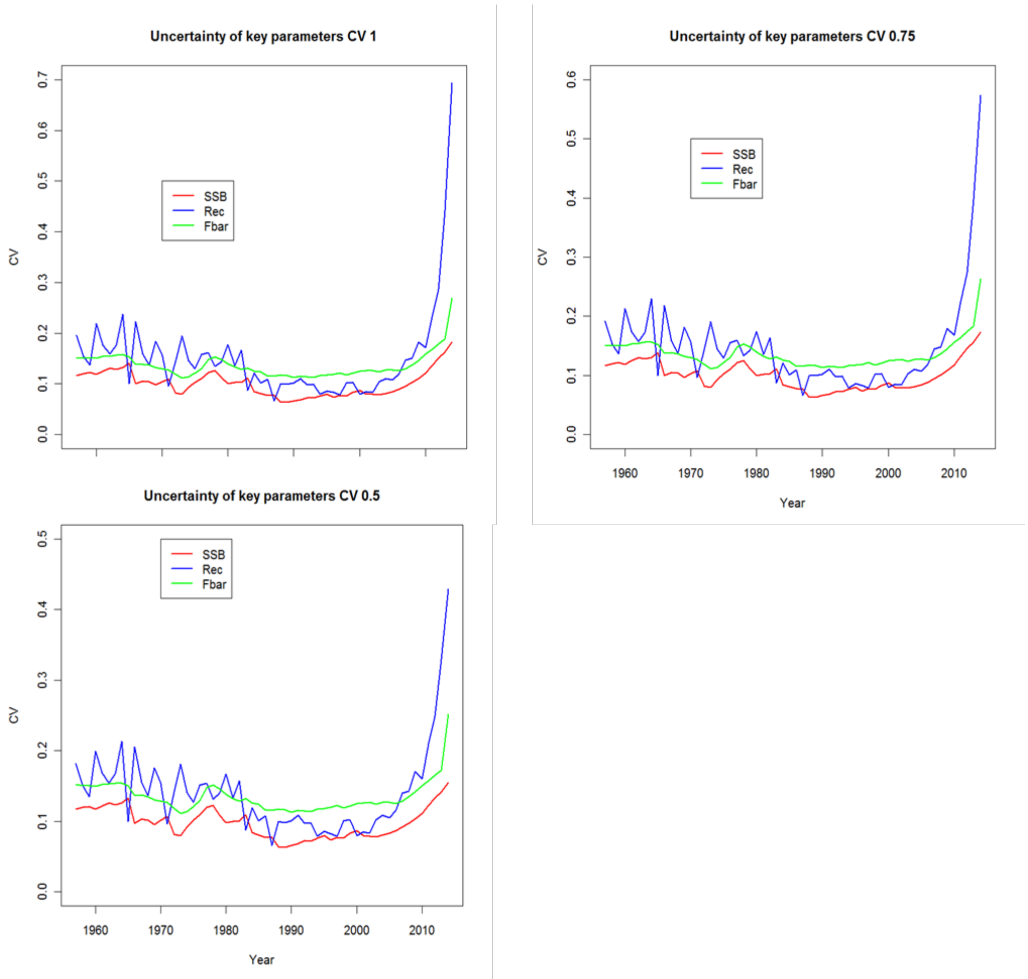


Figure 6: Uncertainty of key parameters when the CV on recruitment deviation is adjusted

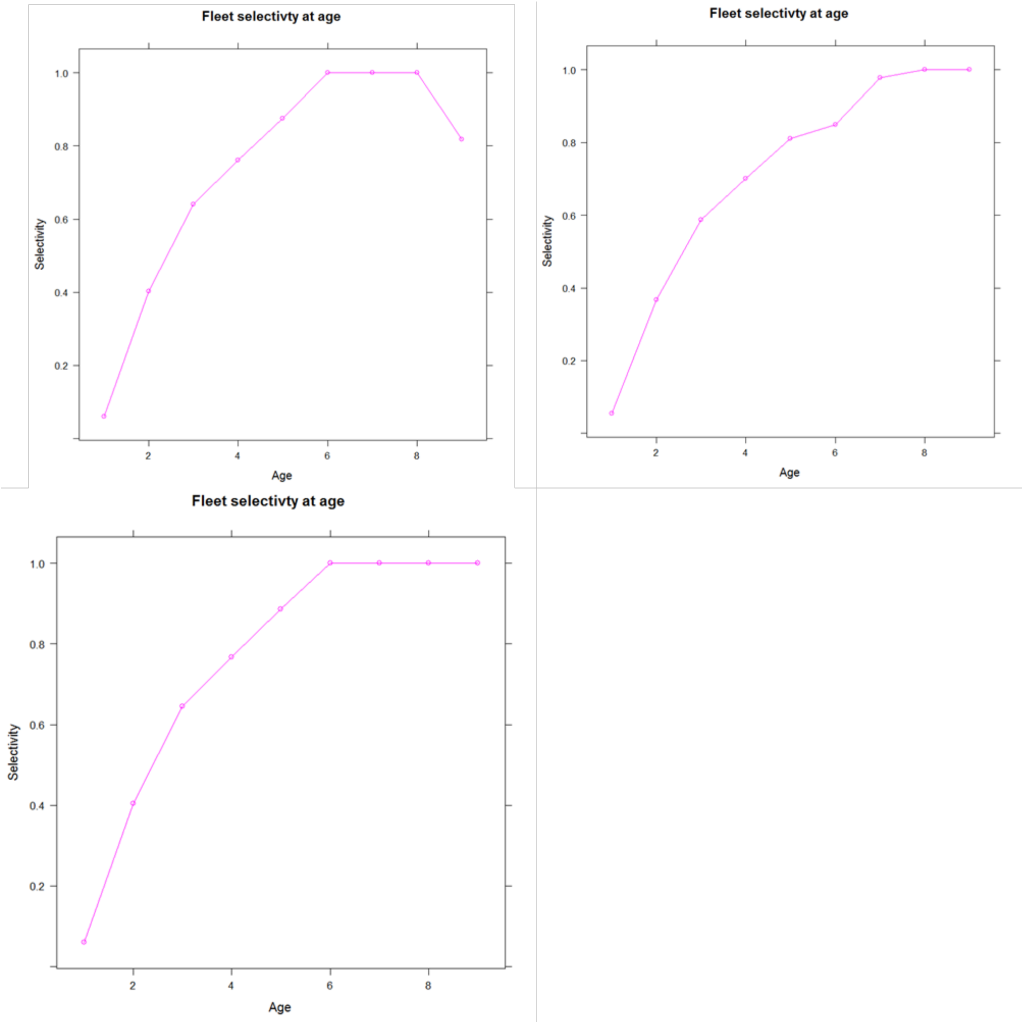


Figure 7: Selection pattern estimated by ASAP when selection is fixed at different ages

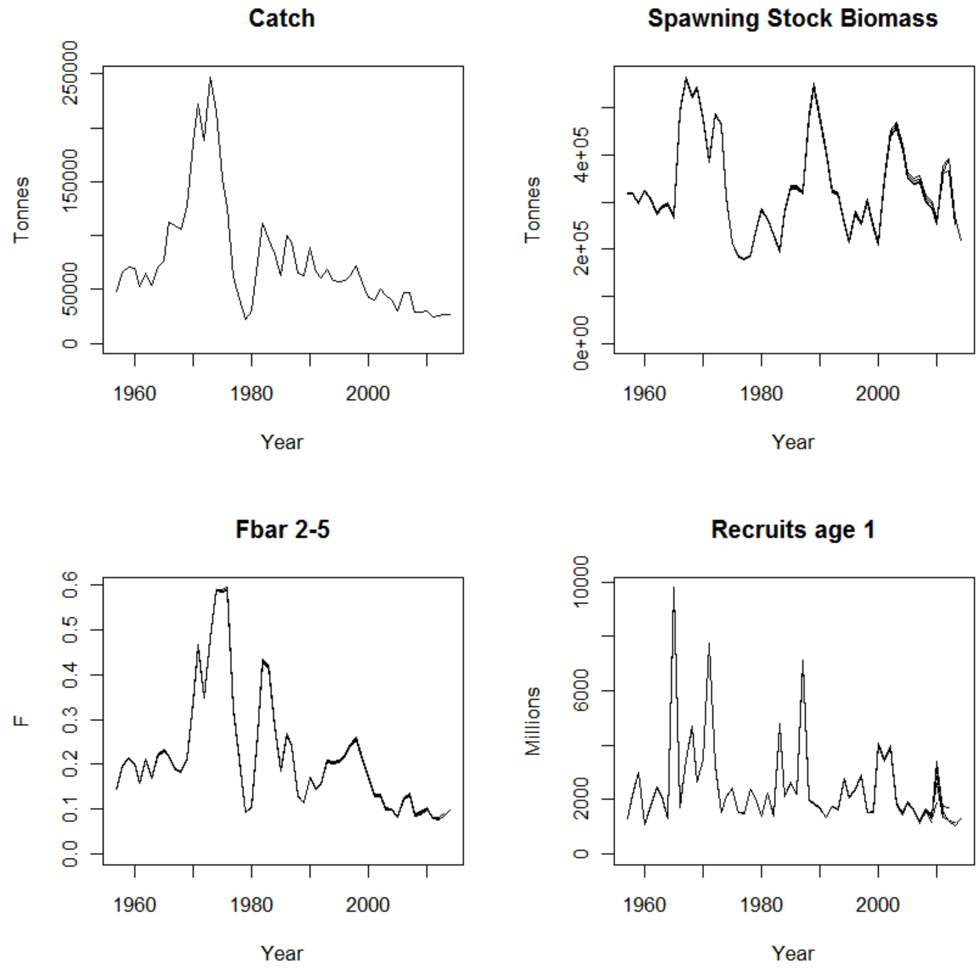


Figure 8: Retrospective pattern when four surveys are included in the assessment

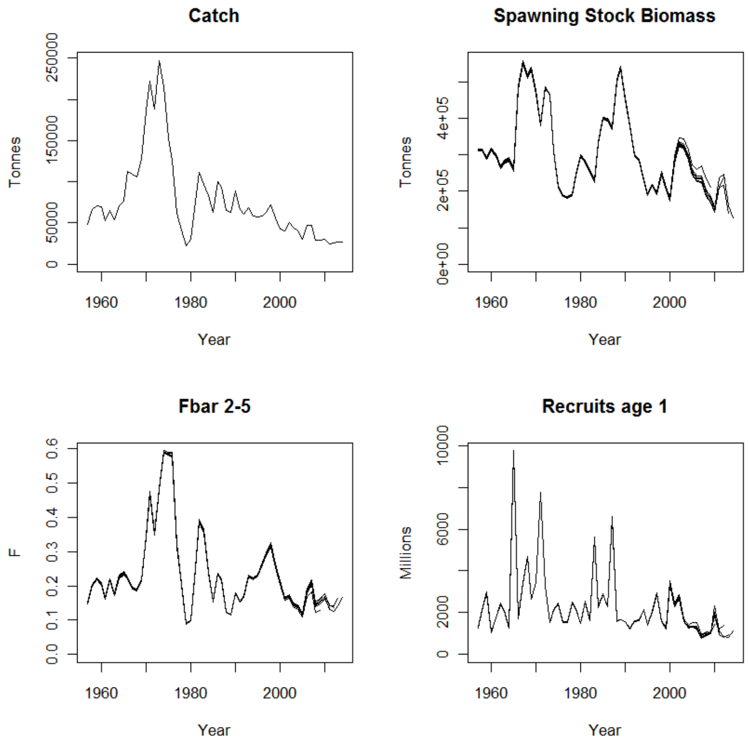


Figure 9: Retrospective pattern when 1 survey (Malin shelf acoustic) is included in the assessment

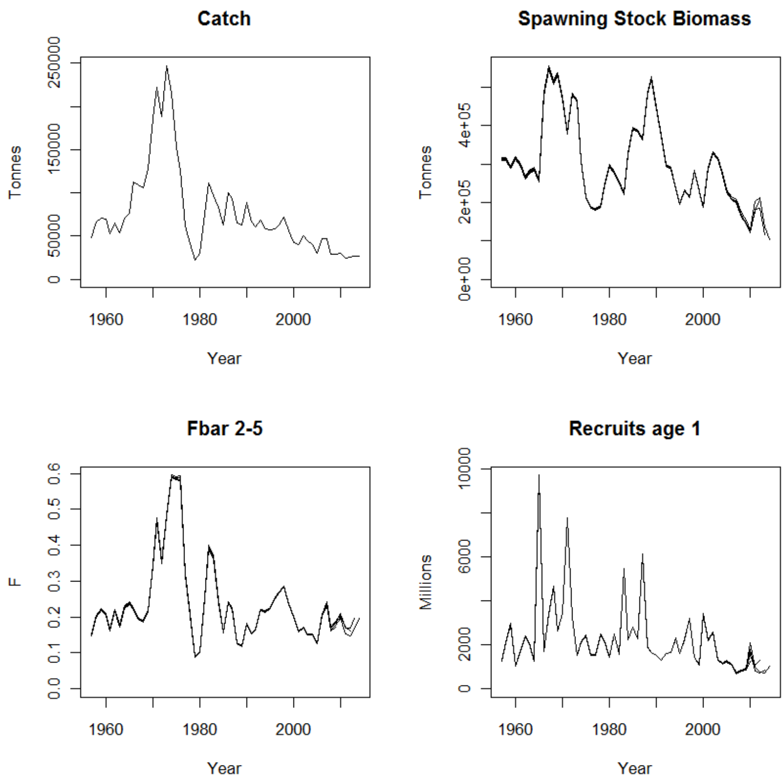


Figure 10: Retrospective pattern when 2 surveys (Malin shelf acoustic and West of Scotland acoustic surveys) are included in the assessment

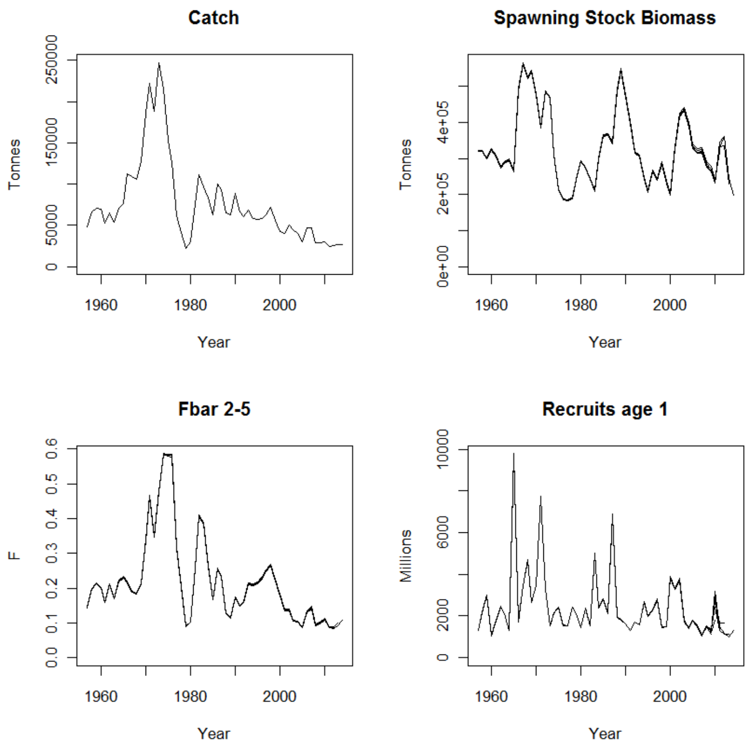


Figure 11: Retrospective pattern when four surveys are included in the assessment but 1986 is removed from the IBTS Q1 time series

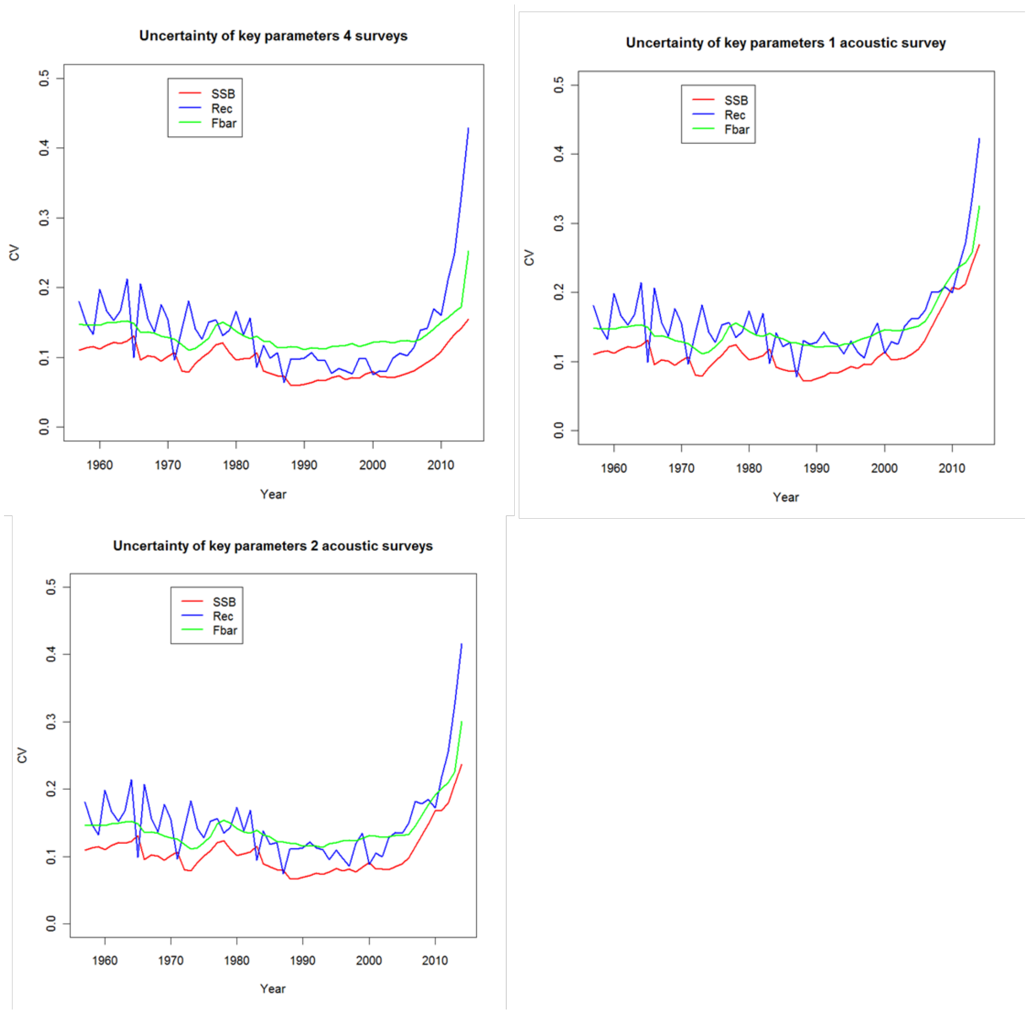


Figure 12: Uncertainties when different survey combinations are used.

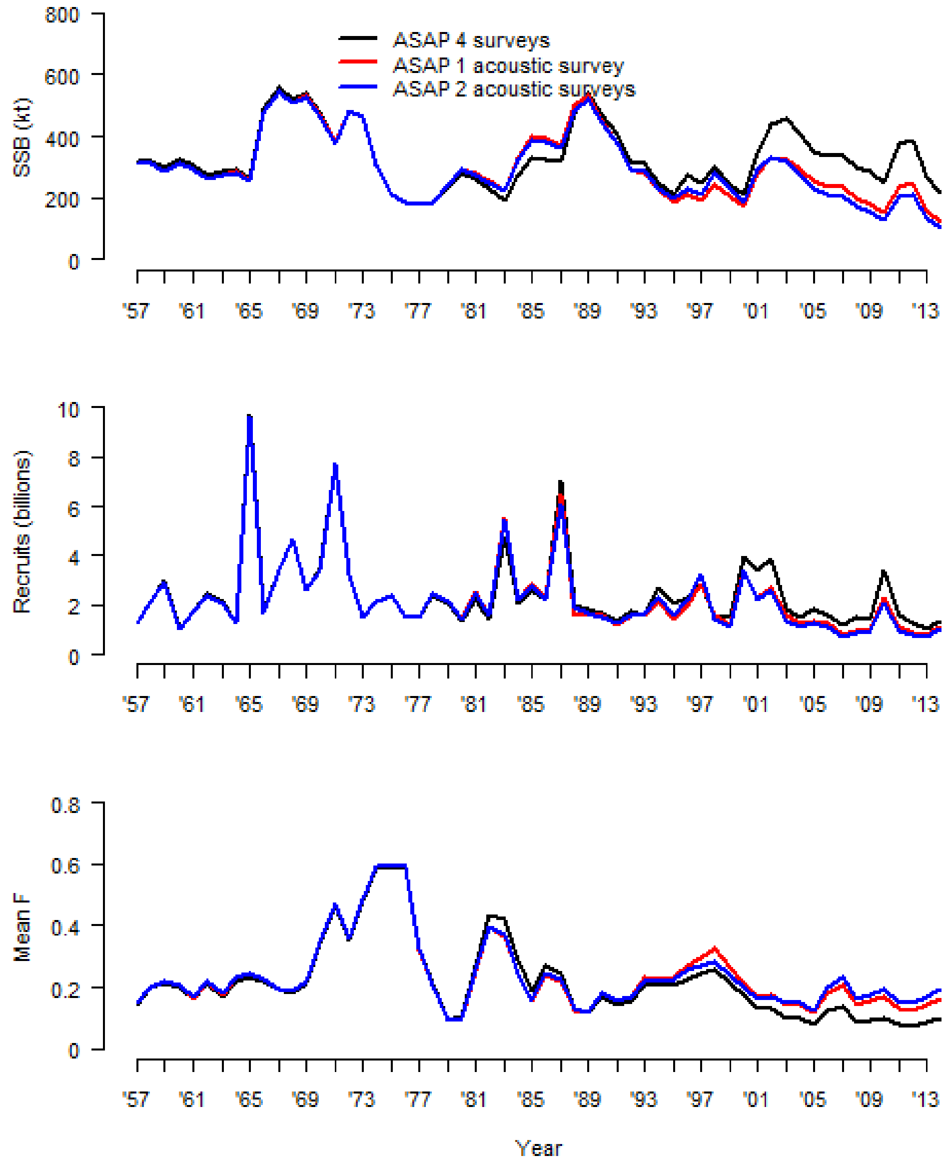


Figure 13: Comparison of the stock trajectories from ASAP when different survey combinations are used.

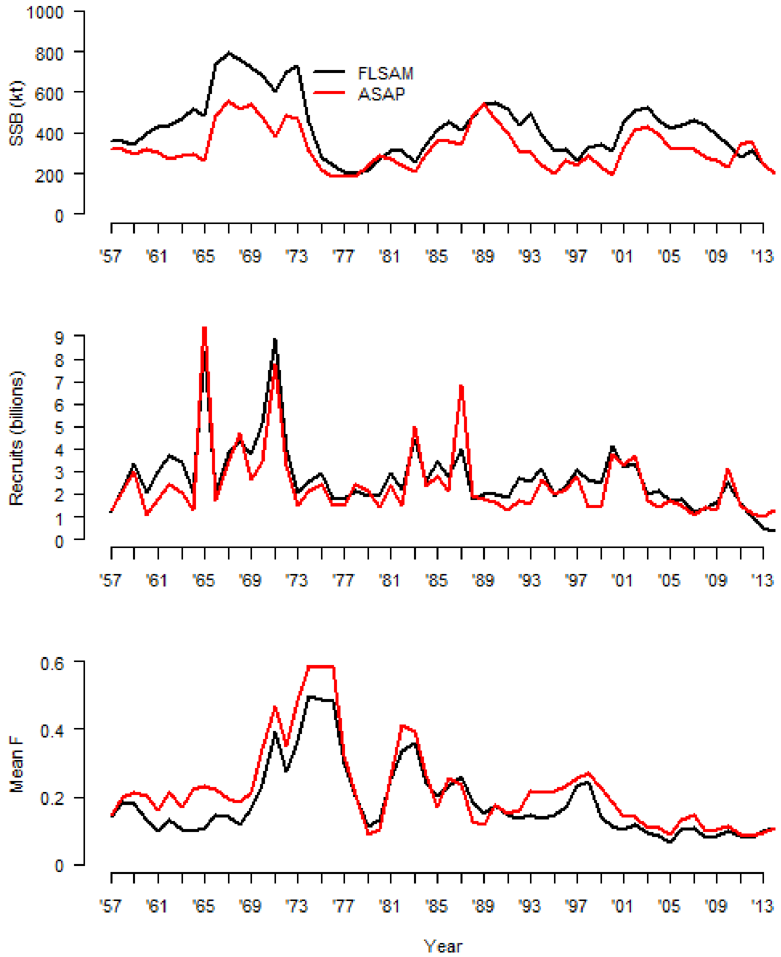


Figure 14: Comparison of the stock trajectories from ASAP and SAM

References

ICES.2011. Report of the Working Group on Multispecies Assessment Methods (WGSAM), 10–14 October 2011, Woods Hole, USA. ICES CM 2011/SSGSUE:10. 229 pp.

ICES. 2014. Interim Report of the Working Group on Multispecies Assessment Methods (WGSAM), 20–24 October 2014, London, UK. ICES CM 2014/SSGSUE:11. 104 pp.

ICES. 2015. Report of the Herring Assessment Working Group for the Area South of 62ºN (HAWG), 10-19 March 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/ACOM:06. 850 pp.

ICES. 2015. Report of the Working Group of International Pelagic Surveys (WGIPS), 19-23 January 2015, ICES HQ, Copenhagen, Denmark. ICES CM 2015/SSGIEOM:05. 279 pp.ICES 2015 WKWEST in prep. Report of the benchmark workshop on West Of Scotland Herring. ICES CM 2015/ACOM:34

Legault, C.M., Restrepo, V.R., 1999. A flexible forward age-structured assessment program. ICCAT Coll. Vol. Sci. Pap. 49, 246-253.

7.9 Lists of participants for DCWKWEST and WKWEST

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