# ICES SGHERWAY REPORT 2010

SCICOM STEERING GROUP ON SUSTAINABLE USE OF ECOSYSTEMS

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# Report of the Study Group on the evaluation of assessment and management strategies of the western herring stocks (SGHERWAY)

14-18 June 2010

Dublin, Ireland

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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## Contents

## Executive summary

The final meeting of the ICES Study Group on the evaluation of assessment and management strategies of the western herring stocks [SGHERWAY] took place in Dublin, Ireland, 14–18 June, 2010. The Chair was Emma Hatfield (UK) and 8 people in total attended, from five nations.

This is the final report of SGHERWAY.

SGHERWAY was convened in 2008 to explore and evaluate the series of recommendations produced by the EU funded WESTHER project which suggested that, in the current stock assessment setup for herring to the west of the British Isles, two of the basic assumptions of stock assessment are violated.

Currently the herring to the west of the British Isles are fished, managed and assessed separately as four ICES stocks 1: VIa North; 2: VIaS and VIIb,c; 3: VIIaN and 4: Celtic Sea and VIIj. Analytical assessments for VIa North are accepted by ICES in most years and have been accepted for the Celtic Sea and VIIj ICES stock for the last two. Analytical assessments have been rejected by ICES for VIaS and VIIb,c or VIIaN for many years.

A combined assessment of the three stocks VIaN, VIaS/VIIb,c and VIIaN (the Malin Shelf metapopulation) 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 because it does not provide sufficient information on the status of the individual components.

Alternative management strategies for the Malin shelf metapopulation were investigated to show how it could be sustainably managed, approaching MSY levels. The tools evaluated did not, under all conditions, suffice to manage the components of the metapopulation sustainably. The results showed that managing metapopulations is only possible with detailed information on fisheries independent data. However, whenever subcomponents of the metapopulation differ considerably in abundance, sustainable management is impossible for the smallest subcomponent. The VIIaN ICES stock should therefore continue to be assessed and managed separately. Where there is uncertainty of stock identification fishing mortality should be kept at low levels. Should identification rates increase, fishing mortality may also be increased.

The evaluation of the utility of a synoptic acoustic survey in the summer for the Hebrides, Malin and Irish shelf areas 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 survey covers all areas in which mixing of the various western herring stocks is likely to occur at that time and could be used to establish time-series for the constituent components of the Malin Shelf stock complex. However, such time-series will not be available for a number of years. The amount of mixing between stocks cannot be estimated by the current sampling regime in the Malin Shelf survey. Consequently, a sampling programme has been developed to allow proper identification of fish population origins, making use of otolith and body shape techniques. Analyses will be compared to fish of known spawning origin collected during the EU project WESTHER. This sampling programme has been initiated in the 2010 synoptic acoustic survey.

# 1 Participation and Terms of Reference

The final meeting of the ICES SGHERWAY met in Dublin, Ireland from 14–18 June 2010. The participants were:

| | |
|---|---|
| Steven Beggs | UK [Northern Ireland] |
| Maurice Clarke | Ireland |
| Afra Egan | Ireland |
| Clementine Harma | Ireland (part time) |
| Emma Hatfield [Chair] | UK [Scotland] |
| Niels Hintzen | the Netherlands |
| Norbert Rohlf | Germany |
| John Simmonds | Italy |

Contact details for each participant are given in Annex 1.

SGHERWAY has met five times since 2008: 8–12 December 2008, in Aberdeen, Scotland; 18 March 2009, prior to the HAWG, in Copenhagen, Denmark; 7 to 11 December 2009, in Aberdeen, Scotland; 24 to 26 March 2010 in Copenhagen, Denmark and 14 to 18 June 2010. Reports were produced, after the meetings in December 2008 and 2009 (ICES, 2008 and 2009a).

# 2 Introduction

## 2.1 Current assessments

Currently (see ICES, 2007) the herring to the west of the British Isles are fished, managed and assessed separately as four stocks 1: VIa North; 2: VIaS and VIIb,c; 3: Irish Sea (VIIaN) and 4: Celtic Sea and VIIj (Figure 2.1). In addition, 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. The assessments are carried out with Integrated Catch Analysis (ICA), or separable VPA (for VIaS and VIIb,c; see ICES, 2007) using annual data on landings, catch- and weight-at-age data along with a variety of survey tuning indices. In all cases, landings data are assigned to the area (stock) and statistics formulated by area.

In each area there are a number of survey datasets (tuning indices) that are, or could be, used within an assessment. In the case of VIa North, there are acoustic survey data (1991-present) on the summer (July) distribution, biomass and abundance of the stock. This survey covers the area west of 4°W around the shelf southwards to 56°N. In the case of the Celtic Sea and VIIj there are acoustic survey data on spawning-stock biomass at or close to spawning (autumn/winter, since 1990, with the exception of 1997). For the Irish Sea acoustic survey data are available, again close to spawning time, on spawning-stock biomass. For each acoustic survey biological data are available to determine size-at-age, numbers-at-age etc. In addition there is a larvae production series that also serves as an indicator of the dynamics of the spawning stock. Data exist on the numbers of juvenile herring in the Irish Sea area but this has never been used as a recruitment index due to the known mixing of, at least, Irish Sea and Celtic Sea juveniles (see, e.g. Brophy and Danilowicz, 2002; Burke *et al.,* 2008). In VIaS and VIIb,c an acoustic survey of the spawning biomass of herring (at spawning time) was initiated in 1999, however, it became apparent that synchronization of the survey with the peak spawning event to ensure containment of the stock was problematic. Winter surveys carried out from 2004–2007 produced variable age profiles and biomass estimates between years, and were not considered reliable. Bad weather often affected the survey as it took place in January. It was recognized that synoptic coverage of a stock that spawns over a period from October to February in an area spanning all of Divisions VIaS and VIIb cannot be achieved with a winter survey. Thus the series was discontinued in 2007. The review group of the 2007 assessment highlighted that although there is an acoustic abundance estimate, the historical series is too short to consider it as a tuning survey in an analytical assessment.

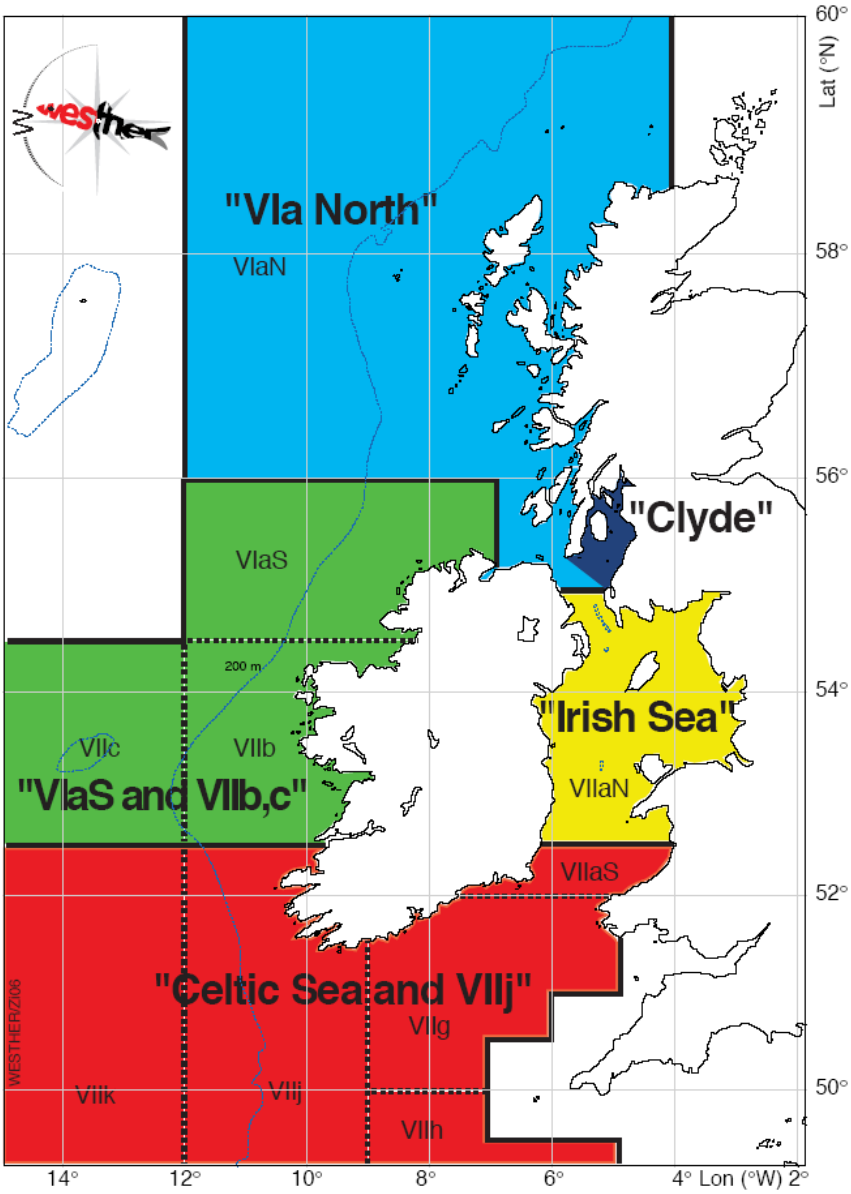



**Figure 2.1. Current defined assessment and management areas for herring stocks to the west of the British Isles.**

Larvae surveys were carried out in the Celtic Sea (1978 to 1985 and in 1990), northwest Ireland (1981 to 1988), and off the west coast of Scotland (1973 to 1993; see ICES, 1994 and section 6 in this report). Each of these was discontinued for a variety of reasons. In the Irish Sea larvae surveys on the Douglas Bank (1974 to 1988 and 1989 to

1999) were discontinued, while a more extensive survey still continues (1993 – present). In the Celtic Sea multiple cruises throughout the spawning season resulted in reliable indicators of spawning stock (ICES, 1990), and these surveys were replaced with acoustic estimates of spawning stock size. The northwest of Ireland surveys were discontinued because they did not give a realistic estimate of stock size probably because of several factors: the influx of larvae from adjacent areas; the survey occasionally missed part of the autumn spawning production because of survey timing; and no account was taken of the winter/spring-spawning component that in some years comprised a major component of the commercial catches. The Irish Sea Douglas Bank surveys were discontinued because they did not reflect the dynamics of the spawning stock, probably because the surveys were too limited spatially or temporally and susceptible to variability caused by relatively minor shifts in peak spawning/hatching time. The west of Scotland acoustic surveys were deemed to give better data on stock biomass and information on abundance-at-age so the larvae surveys were discontinued in 1993. While in use, a Larvae Abundance Index (LAI) and Larvae Production Estimate (LPE) were calculated for the west coast of Scotland larvae surveys. Although the survey ceased in 1993 the LAI values were used in the assessment until 2001. However, in 2002 it was decided that the LAI no longer had any influence on the assessment and it has not been used since.

Over the years there have been problems with the assessment of the various stocks to the west of the British Isles. There has been a series of analytical assessments for VIa North, which have been accepted in most years but 2000 and 2006 where there were conflicts between the acoustic survey index and catch data (ICES, 2006). In 1992 the assessment of the Clyde ceased due to the lack of landings and fishery-independent survey data. Analytical assessments for VIaS and VIIb,c have not been possible due to the lack of fishery-independent survey data; exploratory assessments to show the 'development of the stock' have usually been presented at the HAWG but have not been accepted for the provision of catch options for the next year. The survey data for the Celtic Sea and VIIj stock have allowed analytical assessments. Historically there have been conflicting signals present in the catch and survey data, resulting in unstable assessment on occasions, but more recently the survey has been redesigned and the analytical assessment has been accepted for the last 2 years. The redesigned survey has been performing better in the assessment with smaller residuals and no clear age or year effects. The assessment of the Irish Sea stock has been unstable resulting in no analytical assessment being accepted by the HAWG for many years.

## 2.2 Current management and fisheries

At present the management is based on the four main fisheries, i.e. VIa North, VIaS and VIIb,c, Irish Sea, and Celtic Sea and VIIj. In all cases annual TACs are agreed for each of the fisheries. These are ideally based on scientific advice which has been given in accordance with the Precautionary Approach (until 2009) and aimed at maintaining the stocks above $B_{pa}$ wherever possible (if this reference point is defined). An annual TAC is also set for the Clyde, though the fishery is sporadic and the quota has been taken in other areas in some years.

The VIa North fishery has, in the past, operated throughout the year, with a peak in the summer but (since 2005) is now almost exclusively a summer fishery, i.e. targeting pre-spawning, feeding, aggregations. This fishery is now mostly linked to the North Sea herring fishery in the adjacent management area to the east. The fishery in the Celtic Sea and VIIj is primarily a fishery prosecuted on spawning aggregations. More recently there has been the addition of a summer, 'offshore' fishery, but this has now declined. In the Irish Sea the fishery has traditionally been on fish that spawn in the vicinity of the Isle of Man. In more recent years the fishery has focused increasingly on pre-spawning aggregations to the west of the Isle of Man, with limited catches on the Douglas Bank spawning ground prior to its annual closure. In VIaS and VIIb,c the fisheries tend to be on spawning and pre-spawning aggregations.

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) and in general these fisheries are managed at the regional level and prosecuted by discrete 'local fleets'. The exception is the VIa North fishery (and the VIIj offshore fishery in the past) where international fleets are important. In most cases the fleet sizes vary between years, both in terms of the numbers of vessels taking part in the various fisheries and the size and capacity of those vessels.

In addition to TAC constraints there are a number of other management measures currently enforced in the Celtic and Irish Seas. The Republic of Ireland's fisheries for both the VIaS and VIIb,c and Celtic Sea and VIIj stocks are managed by local committees. These committees each have a set of local management objectives (ICES, 2007).

In the Celtic Sea and VIIj the fishing season is considered as running from 1 April to the 31 March the following year. The fishery generally opens around 1 October each year to target the fish when inshore for spawning. Recently, the fishery has remained open throughout to allow vessels to target fish outside the spawning seasons when the fish are of better quality and marketability. The spawning grounds are protected by rotating box closures implemented under EU legislation. In addition to these, one box was voluntarily closed in the recent seasons. This initiative was instigated by the Irish Southwest Pelagic Management Committee to afford extra protection to first time spawners. The Irish Southwest Pelagic Management Committee was established to manage the Irish fishery for this herring stock. It therefore has responsibility for management of the entire fishery for this stock at present. It proposed a rebuilding plan which incorporates scientific advice with the main elements of the EU policy statement on fishing opportunities for 2009, local stakeholder initiatives and Irish legislation. It was adopted by the Pelagic RAC and used as a basis for the 2010 TAC. In 2009, the plan was evaluated by ICES and found to be in accordance with the precautionary approach, within the estimated stock dynamics.

In the Irish Sea the area around the Mourne coast is permanently closed to herring fishing from the 21 September to the 31 December, with a derogation for a gillnet fishery; this is designed to protect the Mourne spawning component. There is a spawning ground closure (annually 21 September to 15 November) to the east of the Isle of Man (Douglas Bank) to protect the Manx spawning component. The final measure is a year round closed area for fishing juvenile herring in the eastern Irish Sea, up to 12 nautical miles from the coastline. This is a closure designed to protect the juveniles. Republic of Ireland boats are also banned from fishing for herring to the east of the Isle of Man.

The management of herring in the Clyde is complicated by the presence of two spawning components that are not separated currently; a resident spring-spawning component and the immigrant autumn spawning component. Management strategies have been directed towards rebuilding the highly depleted spring-spawning component to historical levels. The measures which remain in force in order to protect the indigenous spring-spawning component are: a complete ban on herring fishing from

1 January to 30 April; a complete ban on all forms of active fishing from 1 February to 1 April on the Ballantrae Bank spawning grounds, to protect the demersal spawn and prevent disturbance of the spawning shoals; a ban on herring fishing between 00:00 Saturday morning and 24:00 Sunday night.

In VIaS and VIIb,c the fishing season is considered to run from late autumn into the spring. It opens on the 1 October and closes around the end of March the following year. Here individual vessels have individual quotas. In 2000 the Irish Northwest Pelagic Management Committee was established to deal with the management of the VIaS and VIIb,c stock. In recent year 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. In 2009, the Federation of Irish Fishermens' Organisations and the Pelagic RAC developed a rebuilding plan for this stock. The plan was for *status quo* TAC in 2010, and, in subsequent years a TAC set at $F_{0.1}$. However, this plan was not adopted.

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.

### 2.3 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'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.

The project's scientific results, summarized in Hatfield *et al.* (2007), provided little evidence of discreet structuring of juvenile and adult herring west of the British Isles, outside the spawning seasons. However, high classification success of spawning aggregations for several of the methods used (e.g. Campbell *et al.*, 2007) provided evidence of population structuring by spawning time and spawning sites, indicating a high degree of natal fidelity. Evidence suggested significant migration and mixing of herring that originate in different spawning areas, especially to and from feeding grounds and by repeat spawners to spawning grounds (Figure 2.2). The degree of mixing of juvenile and first time spawners is more area specific, but still significant in some areas, e.g. mixing of Celtic and Irish Sea juveniles in the Irish Sea. Overall there is considerable mixing of spawning components in both the juvenile and adult phases.

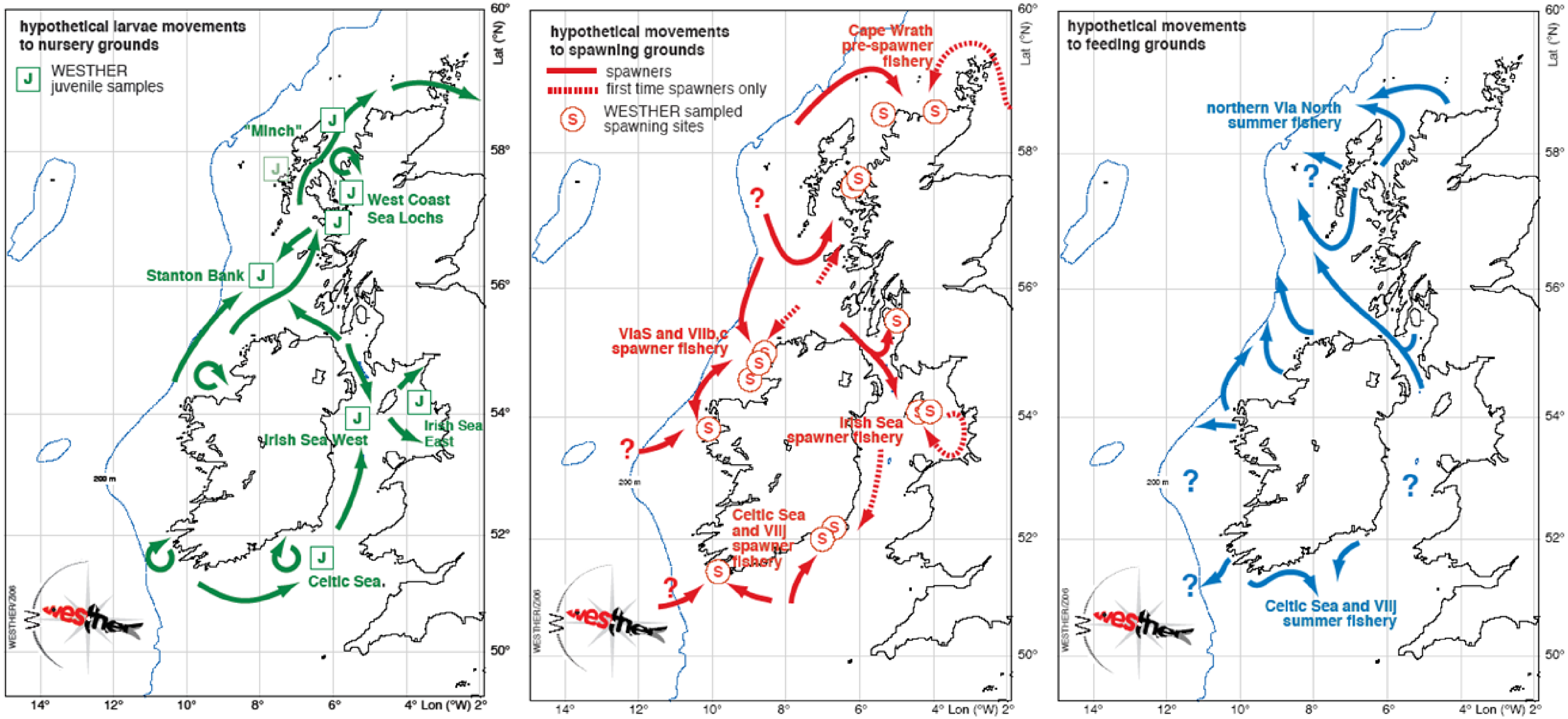



**Figure 2.2. Hypothetical movements of juveniles and adults to feeding and spawning grounds based on historical evidence and WESTHER results.**

## 2.4 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 and VIIb,c, Irish Sea, and Celtic Sea and VIIj. The results from WESTHER suggested that under the current stock assessment units (ICES, 2007), 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 summer acoustic survey and commercial fishery which, in some years, target feeding aggregations that are suggested to be a mixture of fish originated from several spawning sites outside VIa North (i.e. adults from VIaS and VIIb,c, Irish Sea and possibly even the Clyde).

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

1. **assess the herring to the west of the British Isles as two stock units** - Malin Shelf (including the current ICES stocks VIa North, VIaS and VIIb,c, Clyde and Irish Sea (VIIaN)) and Celtic Sea (the current Celtic Sea and VIIj stock; Figure 2.3). In the area studied in WESTHER we can hypothesize 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 here for convenience
2. **survey effort should be increased or diverted to a combined survey** on non-spawner distributions mixing on the Malin Shelf
3. **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
4. **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 and VIIb,c
5. **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.**

6. **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.**

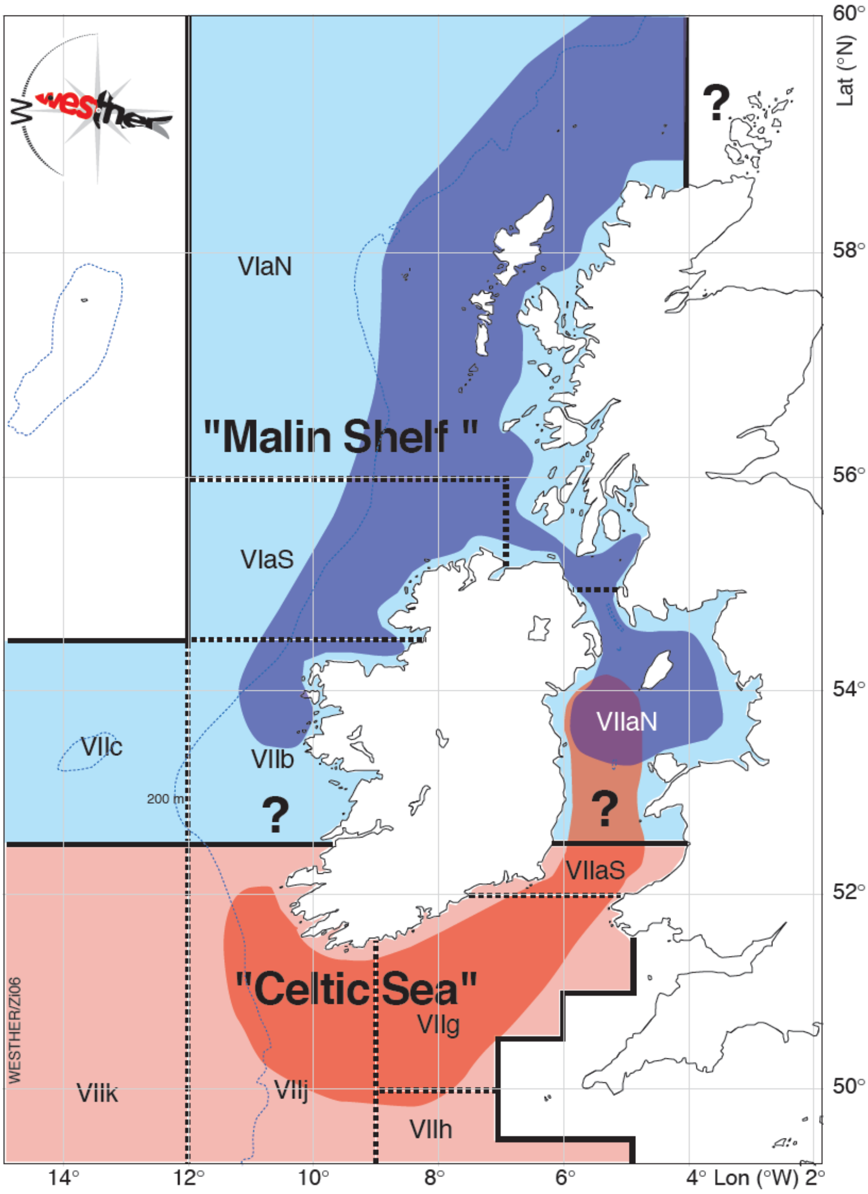



**Figure 2.3. Proposed assessment units for assessments of western stocks, based on grouping suggested from WESTHER. Darker colours indicate known distribution of herring in those areas.**

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.

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:-

- 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
- replacement of existing or development of new cost-effective assessment and data collection schemes which will be required to support this management
- movement to coordinated management for the region

Additionally, the 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))".*

The 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 (VIa(N), VIa(S)/VIIb,c Irish Sea and Celtic Sea) affords the best possible protection for local spawning stocks. However it does not afford protection to the fish of one stock distributed in another management area at feeding time.

Provided both the spawning fisheries (VIa(S)/VIIb,c, Irish Sea and Celtic Sea) and the fishery in the mixing area (predominantly VIa(N)) are 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

Taking into account the results of WESTHER in relation to VIaN, VIaS and VIIaN stocks then, SGHERWAY met initially to:

a ) evaluate the utility of a synoptic acoustic survey in the summer for the Hebrides, Malin and Irish shelf areas, in conjunction with PGHERS surveys of VIaN and the North Sea

b ) explore a combined assessment of the three stocks and investigate its utility for advisory purposes

c ) evaluate, through simulation, alternative management strategies for the metapopulation of VIaN, VIaS and VIIaN

d ) comment on the best way to maintain each spawning component in a healthy state, whilst managing the fish of that component when they are in a neighbouring area.

SGHERWAY modified these terms of reference slightly during its term but the essential work remained the same.

# 3 Exploration of a combined assessment

## 3.1 Development of a Combined Assessment

An exploratory combined assessment was conducted in 2008, based on a data series that included VIaN catch-at-age data from 1961–1976 (ICES, 2008). In 2009, SGHERWAY identified a problem with this approach (ICES, 2009a). This problem related to reconciling the VIaN data with those for the remainder of the combined Malin Shelf, over the period 1957–1976.

A question was identified when examining the revised VIaN data. A comparison was made of VIa (incl. Moray Firth) historical catch in numbers-at-age (canum) with the revised VIaN canum. Indices were derived by subtracting, for the relevant year and age, the VIaN revised catch from the VIa (incl. Moray Firth) catch. It could be seen that there are many instances where the revised VIaN value is greater than the historic VIa (incl. Moray Firth) value. These anomalies occur from 1971–1980, with one exception.

Based on this analysis it was thought the best approach was to ignore data that were derived from revisions, and instead to use the most complete set of data for the whole of VIa. A complete set of data for the whole of VIaN exists for the years 1961–1980 (ICES HAWG, 1974–1981). The combined assessment presented by SGHERWAY 2010 is based on these original data for the entire VIa, combined with data for the Clyde, Irish Sea and VIIb,c.

### 3.1.1 Data Combinations

In order to produce a combined dataset for the Malin Shelf, data from the following current or historic stock units were used:

- VIa, including Moray Firth juvenile fishery (historic)
- VIaN (current)
- VIIb,c (historic)
- VIa, Firth of Clyde only (mainly historic)
- VIIaN (current)

Catch in tonnes and catch in numbers were taken from data presented in ICES HAWG reports. Mean weights in the catch for the appropriate years and ages were taken from these reports, where available. In the remainder of cases, constant values-at-age were taken from adjacent years. A combined mean weight in the catch matrix was constructed by re-weighting by the combined catch numbers. The sources of these data are explained in Table 3.1.1.1.

**Table 3.1.1.1. Malin Shelf Herring metapopulation. Sources of data used in the combined assessment; Catch in tonnes (CATON), catch in numbers (CANUM) and mean weight in the catch (WECA). Numbers refer to footnotes, below table.**

| CATON | VIa (incl. Moray) | VIaN | VIaS | VIIb,c | VIIaN | Firth of Clyde |
|---|---|---|---|---|---|---|
| 1961–1969 | 1 | - | - | 3 | 2 | 5 |
| 1970–1980 | 1 | - | - | 4 | 2 | 5 |
| 1981-present | - | 8 | 2 | - | 2 | 5 |
| **CANUM** | | | | | | |
| 1961–1969 | 1 | - | - | 3 | 2 | 5 |
| 1970–1980 | 1 | - | - | 4 | 2 | 5 |
| 1981-present | - | 8 | 2 | - | 2 | 5 |
| **WECA** | | | | | | |
| 1961–1969 | 7 | - | - | 3 | 2 | 5 |
| 1970–1980 | 7 | - | - | 6 | 2 | 5 |
| 1981-present | - | 8 | 2 | - | 2 | 5 |

**Footnotes**

**[1]ICES HAWG (1974–1981).**

**[2]ICES HAWG (2010).**

**[3]Assumed to be included in VIa (incl. Moray Firth).**

**[4]ICES HAWG (1981).**

**[5]SGHERWAY (2009).**

**[6]Constant values, based on VIaS/VIIb,c, HAWG (2010).**

**[7]Constant values, based on VIaN, HAWG (2003).**

**[8]ICES HAWG (2010); 2009 data revised after WG.**

This combined dataset is faithful to the original VIa time-series (1957–981) and does not contain any data from the revision of the VIaN (ICES, 2004) nor the combination of VIaS and VIb,c data (ICES, 1982).

Most of the stocks had the same plus group (9+). However, for VIIaN it is 8+ and for Clyde, 10+. For VIIaN, 50% of the catch numbers at 8+ were allocated to 9+. For Clyde, the numbers at 10+ were added to the 9 ring to produce a plus group of 9+.

All input files for the combined assessment are described in Table 3.1.1.2. The exploratory assessment was run for 1961–2008. The 2009 data were excluded because no age structure was available for Irish Sea or Clyde.

**Table 3.1.1.2. Malin Shelf Herring metapopulation. Description of input files for Malin Shelf metapopulation exploratory assessment.**

| TYPE | NAME | AGE | SOURCE | NOTES | VARIABLE BY YEAR |
|---|---|---|---|---|---|
| Caton | Catch in tonnes | 1–9 + | Table 3.1.1.1 | | Yes |
| Canum | Catch-at-age in numbers | 1–9 + | Table 3.1.1.1 | No data for VIIaN or Clyde in 2009 | Yes |
| Weca | Weight-at-age in the commercial catch | 1–9+ | Table 3.1.1.1 | No data for VIIaN or Clyde in 2009 | Yes |
| West * | Weight-at-age of the spawning stock at spawning time. | 1–9+ | As for VIaN (ICES, 2009b) | Recent values based on VIaN survey data | Yes (1992 onwards) |
| Mprop | Proportion of natural mortality before spawning | 1–9 + | As for VIaN (ICES, 2009b) | 0.67 all years | No |
| Fprop | Proportion of fishing mortality before spawning | 1–9 + | As for VIaN (ICES, 2009b) | 0.67 all years | No |
| Matprop | Proportion mature-at-age | 1–9 + | As for VIaN (ICES, 2009b) | Recent values based on VIaN survey data | Yes (1992 onwards) |
| Natmor | Natural mortality | 1–9 + | As for VIaN (ICES, 2009b) | From North Sea MSVPA | No |
| Fleet | Tuning index | | As for VIaN (ICES, 2010) | VIaN survey values | Yes |

### 3.1.2 Data explorations

Trends in the catch numbers-at-age for the Malin Shelf stock complex are shown in Figure 3.1.2.1. Several strong year classes are apparent: 1963, 1969, 1981, 1985 and, most recently, 1998. Log catch ratios show upward trends in the mortality signal in the 1970s and 1990s (Figure 3.1.2.2). Catch curves (Figure 3.1.2.3) show this trend also, with recent (incompletely represented cohorts) experiencing higher mortality too (Table 3.1.2.1). Total mortality increased from low levels (1950s - mid 1960s) to a peak of over 1.0 in 1973. Since the late 1990s mortality has varied widely up to 0.68. Trends over time in total mortality (3–6 winter rings) are presented in Figure 3.1.2.4 and show a peak in the early 1970s.

**Table 3.1.2.1. Malin Shelf Herring metapopulation. Total mortality (Z per year) by 5-year group of year classes.**

| YEAR CLASS GROUPS | Z 3–6 |
|---|---|
| 1960–1965 | 0.3 |
| 1965–1971 | 0.7 |
| 1971–1975 | 0.6 |
| 1976–1980 | 0.5 |
| 1981–1985 | 0.4 |
| 1986–1990 | 0.3 |
| 1991–1995 | 0.5 |
| 1996–2001 | 0.4 |
| 2002–present (incomplete information) | 0.5 |

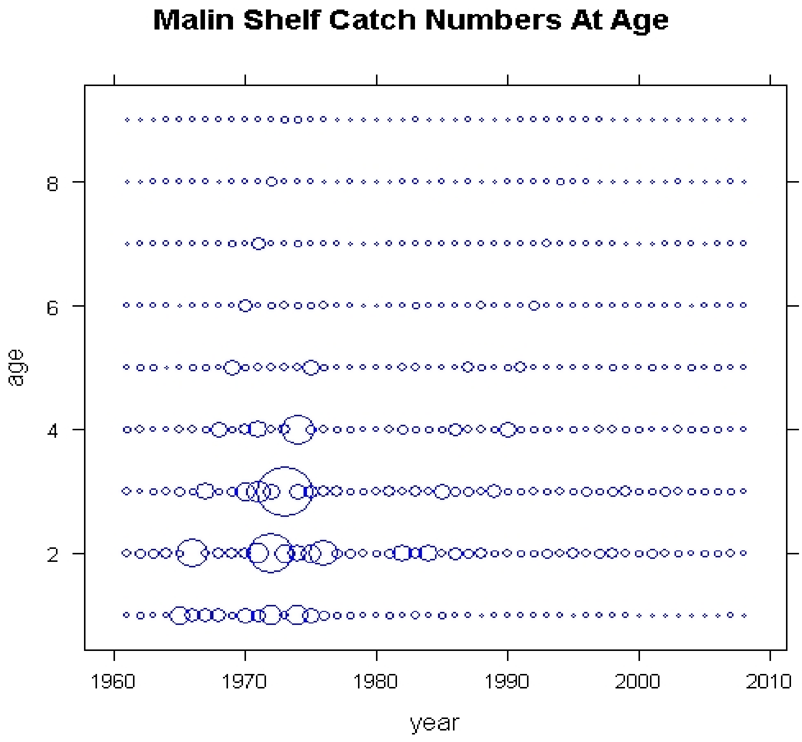



**Figure 3.1.2.1. Malin Shelf Herring metapopulation. Catch numbers-at-age, from combined data 1961–2008.**

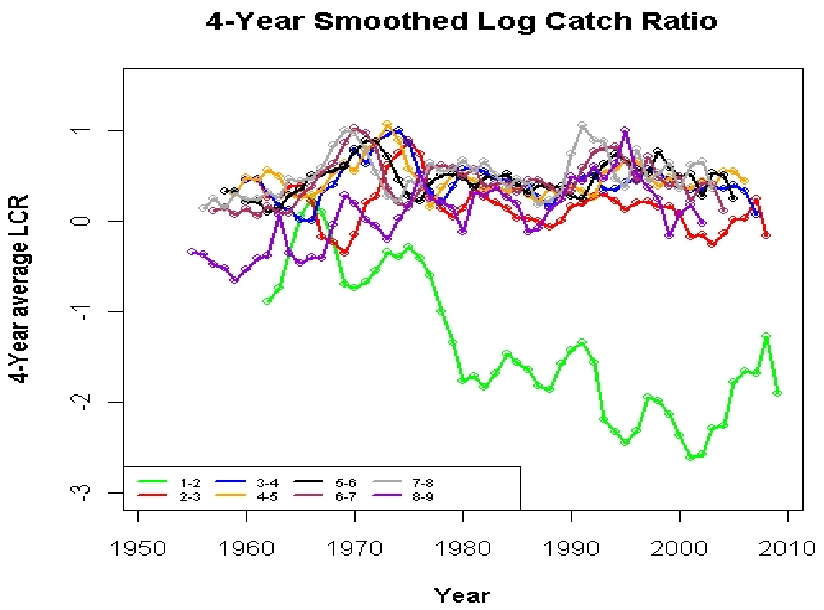
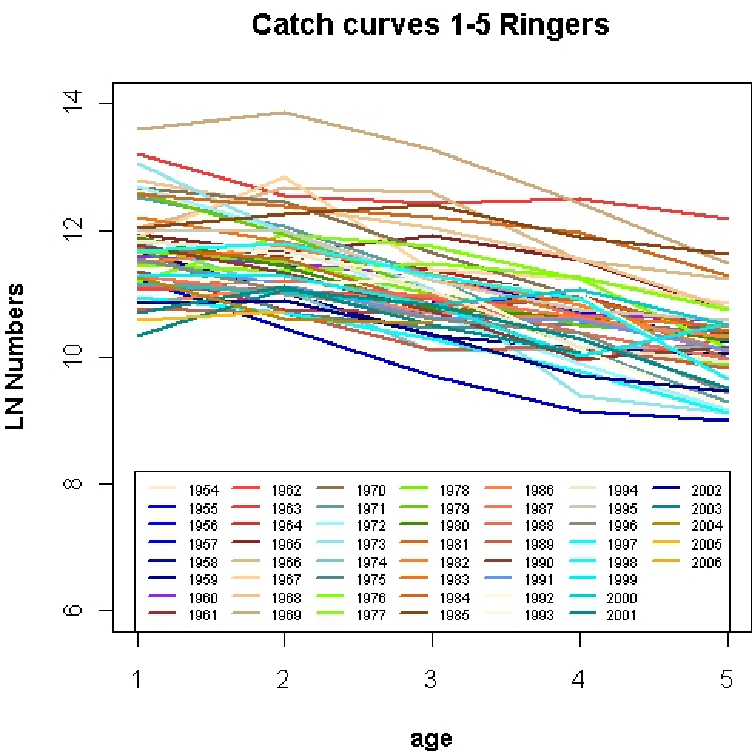



**Figure 3.1.2.2. Malin Shelf Herring metapopulation. Four-year smoothed average log-catch ratios, by year class.**



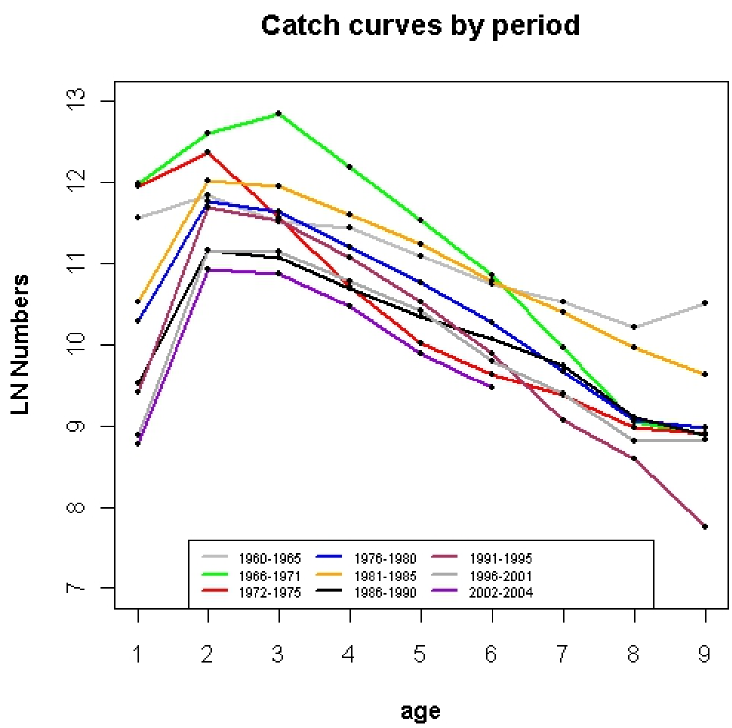




**Figure 3.1.2.3. Malin Shelf Herring metapopulation. Catch curves for Malin Shelf metapopulation, by year class. Catch curves by year class (upper panel) and averaged over 5-year periods (lower panel).**

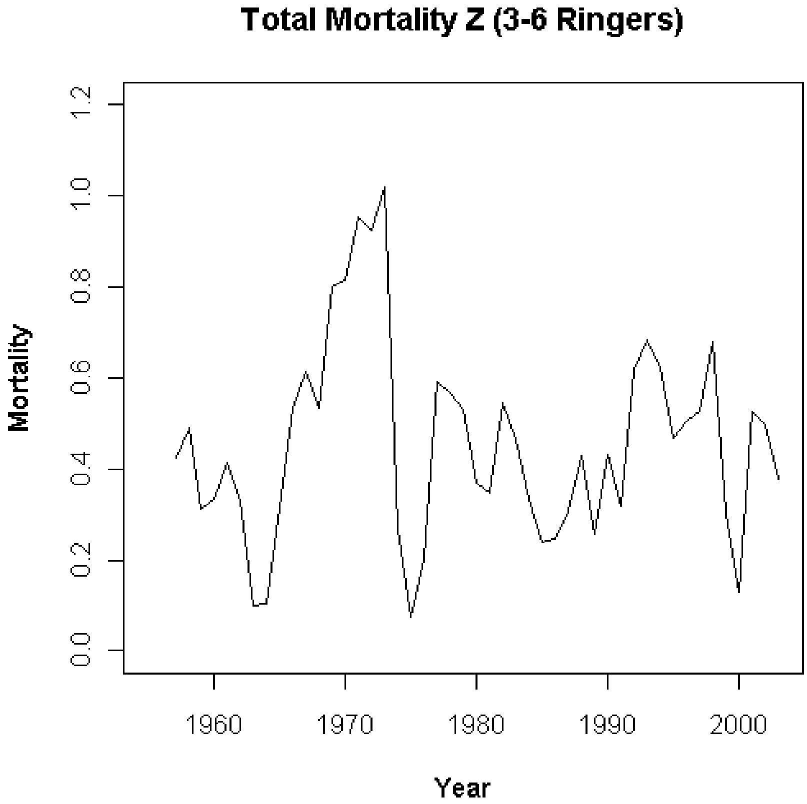



**Figure 3.1.2.4. Malin Shelf Herring metapopulation. Trends over time in catch curve total mortality (3–6 winter rings), from cohort catch curves.**

A comparison of the age compositions between the commercial catches for each stock individually, the combined dataset and for the VIaN acoustic survey is presented in Figure 3.1.2.5. Agreement between catch and survey data has varied between years with agreement in recent years being lower overall. In general there is poor agreement between the VIIaN catch numbers-at-age (CNAA) and the survey and catch data for the other stocks. The strong 1981 year class present in VIaS/VIIb,c can be seen in the VIaN survey and the CNAA. The strong 1985 year class also present in VIaS/VIIb,c was evident in the combined CNAA. It was also picked up by the VIaN survey but not to the same extent. Interestingly, both the strong 1981 and 1985 year classes from VIaS/VIIb,c were also strongly evident in the catch numbers-at-age for VIaN from 1987 to 1994 (data in ICES files). Either these cohorts were also strong in the VIaN stock, or they were mixing with local fish in the fishery in that area. These comparisons illustrate that there is not full coherence between the existing VIaN survey and the VIaN catch numbers-at-age. However, the coherence with the survey and combined Malin Shelf CNAA is lower. There is evidence that fish from the more southern stocks occur in the VIaN area. Further work is required to quantify the extent of this mixing and this has begun in 2010 during the combined Malin Shelf surveys.

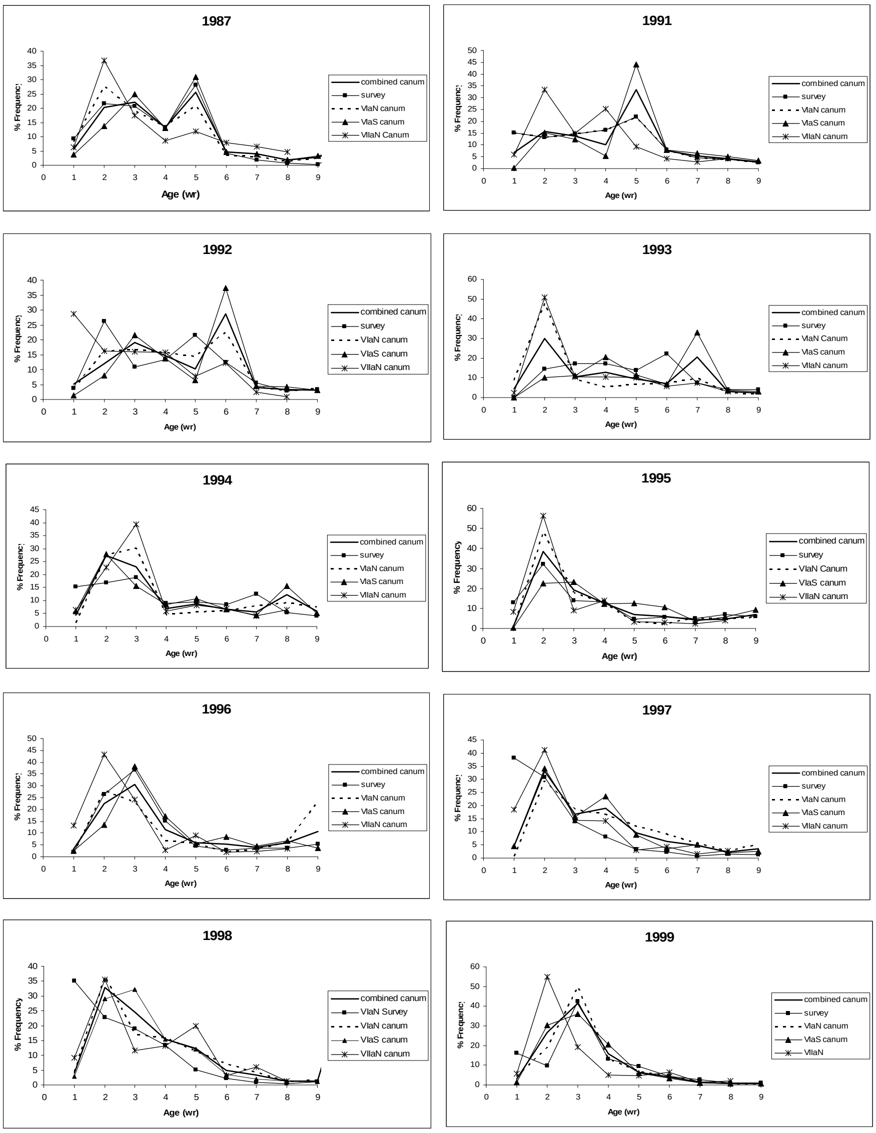



**Figure 3.1.2.5. Percentage age composition in VIaN acoustic survey, VIaN and VIaS/VIIb.c and VIIaN catch numbers-at-age (CNAA) and combined Malin Shelf CNAA. Age in winter rings.**

## 3.2 Exploratory Assessments

A number of different assessment runs were carried out prior to the SGHERWAY meetings in December 2008 and 2009 and June 2010 to explore the combined dataset. Full details of the settings tested are presented in the text table below (page 19).

### 3.2.1 SPALY Run

A SPALY run was carried out each year using the same settings as the current VIaN assessment. The assessment was run using FLICA (R Development Core Team, 2008). The diagnostics from the 2010 SPALY run are presented in Figures 3.2.1.1 to 3.2.1.10 below. The separable period was 8 years and selection was fixed at 1.0 relative to age 4. The diagnostics are similar in the SPALY runs carried out each year.

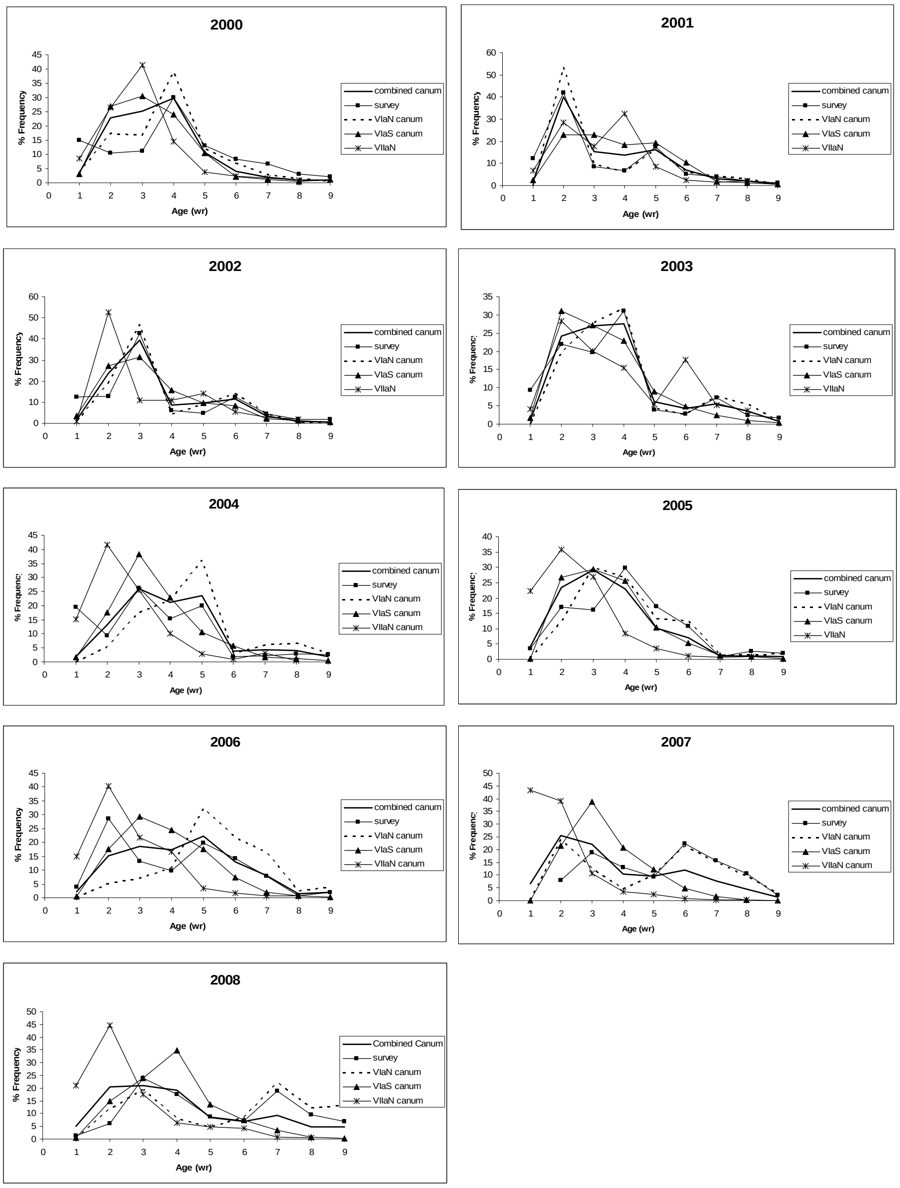



**Figure 3.1.2.5 Continued. Percentage age composition in VIaN acoustic survey, VIaN and VIaS/VIIb.c and VIIaN catch numbers-at-age (CNAA) and combined Malin Shelf CNAA. Age in winter rings.**

Examination of the diagnostics (Figures 3.2.1.2–3.2.1.6) shows that the observed and fitted time-series are noisy for younger ages. It can also be seen that from age 5 to age 9 there is a mismatch between the fitted index and the observed index. This may be because the acoustic survey did not fully pick up the strong 1985 year class evident in the combined catch data (Figure 3.1.2.1). The VIaN survey in 2008 had a greater spread of ages than in previous years with higher amounts of older ages. This leads to low agreement in the diagnostics from the older ages in 2008.

| Year | Run | Catch Data | Survey Time Series | Survey ages | Separable Period | Reference Age | Selection at oldest age |
|---|---|---|---|---|---|---|---|
| **2008** | SPALY Run 1 | 1961-2007 | 1987-2007 | 1-9 | 8 | 4 | 1 |
| **2008** | 2 | 1961-2007 | 1987-2007 | 1-9 | 6 | 4 | 1 |
| **2008** | 3 | 1996 -2007 | 1987-2007 | 1-9 | 10 | 4 | 1 |
| **2008** | 4 | 1961-2007 | 1987-2007 | 1-9 | 8 | 4 | 1 |
| **2008** | 5 | 1961-2007 | 1987-2004 2006-2007 | 1-8 | 8 | 4 | 1 |
| **2009** | SPALY Run 1 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 1 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 0.7 |
| **2009** | 2 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 0.85 |
| **2009** | 3 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 4 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 1.15 |
| **2009** | 5 | 1961-2008 | 1987-2008 | 1-9 | 8 | 4 | 1.3 |
| **2009** | 6 | 1961-2008 | 1987-2008 | 1-9 | 8 | 3 | 1 |
| **2009** | 7 | 1961-2008 | 1987-2008 | 1-9 | 8 | 3 | 0.7 |
| **2009** | 8 | 1961-2008 | 1991-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 9 | 1961-2008 | 1992-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 10 | 1961-2008 | 1993-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 11 | 1961-2008 | 1994-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 12 | 1961-2008 | 1995-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 13 | 1961-2008 | 1996-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 14 | 1961-2008 | 1997-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 15 | 1961-2008 | 1997-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 16 | 1961-2008 | 1998-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 17 | 1961-2008 | 1999-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | survey run* | 1961-2008 | 1998-2008 | 3-6 | 8 | 4 | 1 |
| **2009** | 19 | 1961-2008 | 1998-2008 | 2-7 | 8 | 4 | 1 |
| **2009** | 20 | 1961-2008 | 1998-2008 | 2-6 | 8 | 4 | 1 |
| **2009** | 21 | 1961-2008 | 1987-2008 | 3-6 | 8 | 4 | 1 |
| **2009** | 22 | 1970-2008 | 1987-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 23 | VIaS and VIaN only | 1987-2008 | 1-9 | 8 | 4 | 1 |
| **2009** | 24 | VIaS VIaN and Clyde only | 1987-2008 | 1-9 | 8 | 4 | 1 |
| **2010** | SPALY Run* | 1961-2008 revised data | 1991-2008 | 1-9 | 8 | 4 | 1 |
| **2010** | 2 | 1961-2008 revised data | 1991-2008 | 1-9 | 8 | 4 | 1 |
| **2010** | 3 | 1961-2008 revised data | 1994,1995, 2008,2009 | 1-9 | 8 | 4 | 1 |
| **2010** | 4 | 1961-2008 revised data | 1991-2008 | 1-9 | 8 | 4 | 1 |

* Assessment output presented

A range of model settings and data options were evaluated including

- which surveys to include
- survey ages
- weighting on survey data
- Separable Period
- Reference Age
- Selection in the terminal year

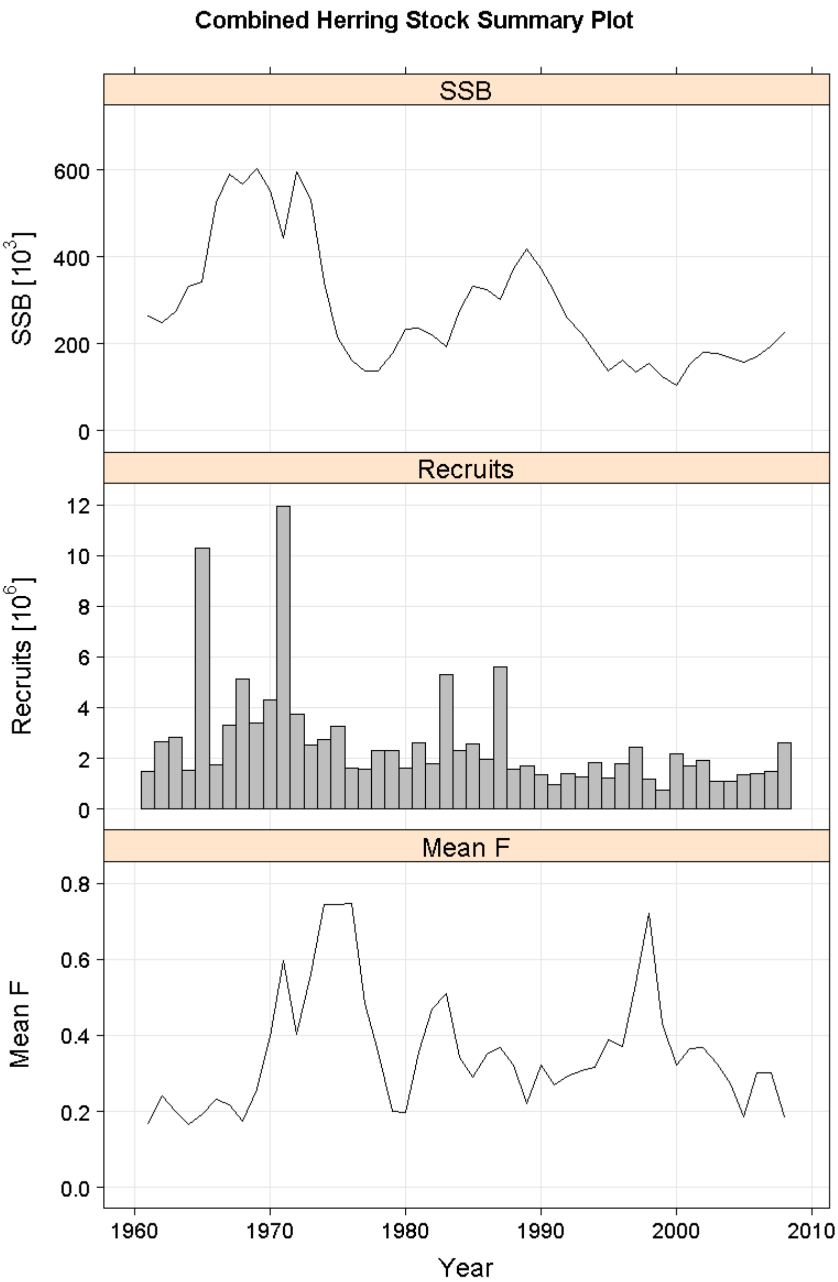



**Figure 3.2.1.1. Combined Assessment SPALY run 2010. SSB, Recruits and Mean F ages 3–6.**

The catch and survey residuals are presented in Figures 3.2.1.7 and 3.2.1.8 and do not show any clear year or age effects, other than the 2005 effect in the log catch residuals. Figure 3.2.1.9 shows the otolith plot which shows the results of parametric bootstrapping and represents the uncertainty of the fit to the assessment model. An analytical retrospective was carried out which shows a poor retrospective pattern between years (Figure 3.2.1.10). Overall the retrospective bias is much lower in the recent period than in the early 2000s, and is comparable to many other ICES assessments.

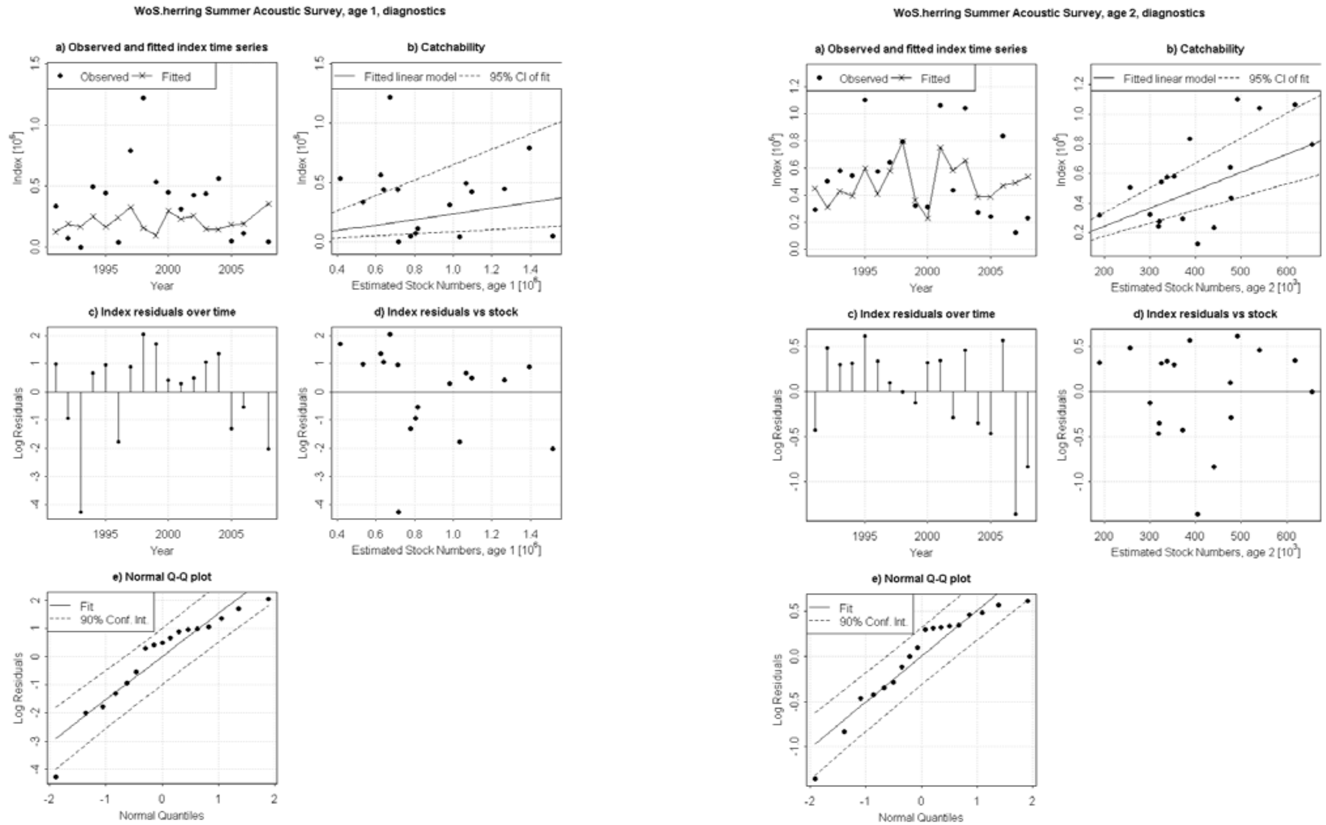



**Figure 3.2.1.2. Combined Assessment SPALY run. Diagnostics of the VIaN acoustic survey fit at 1 wr (left) and 2 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

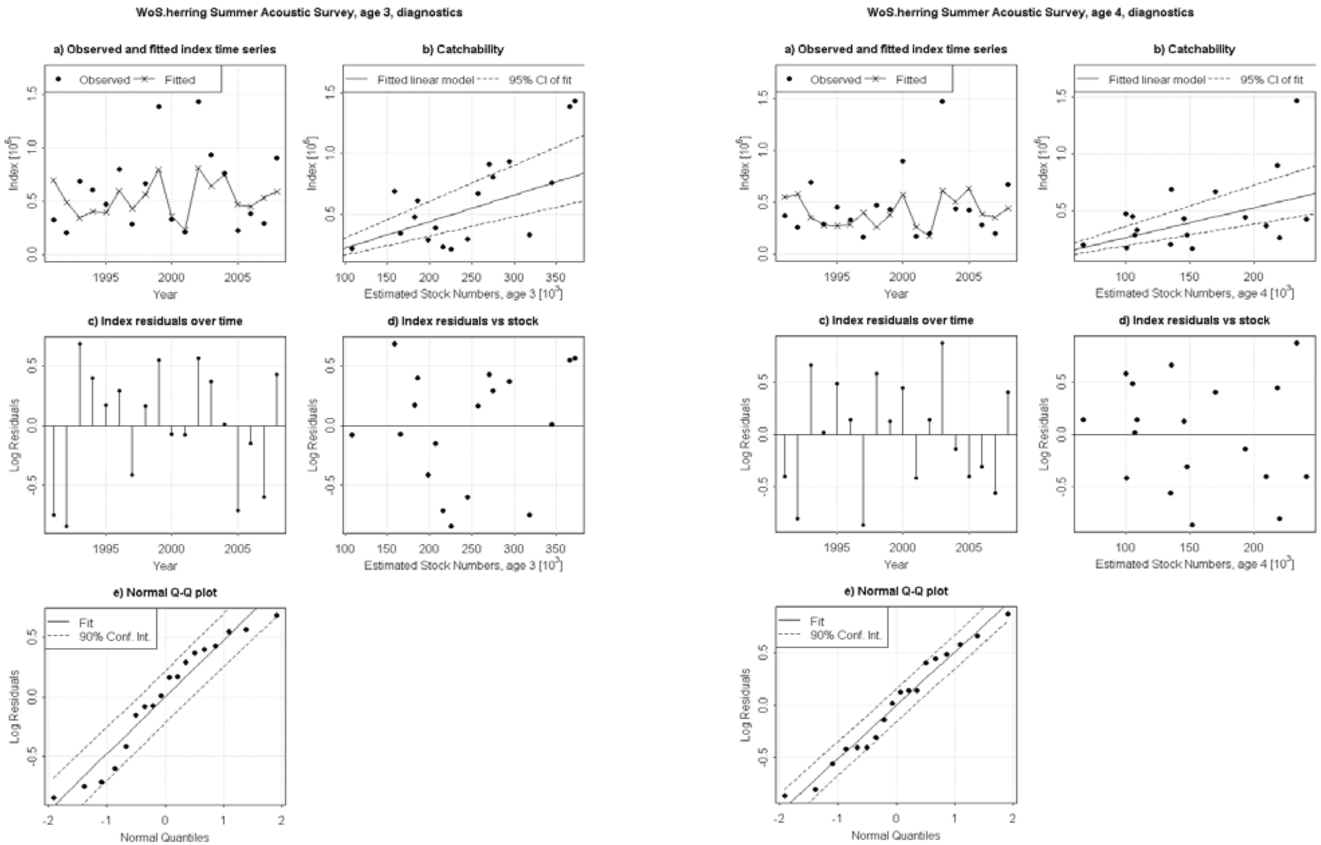



**Figure 3.2.1.3. Combined Assessment SPALY run. Diagnostics of the VIaN acoustic survey fit at 3 wr (left) and 4 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

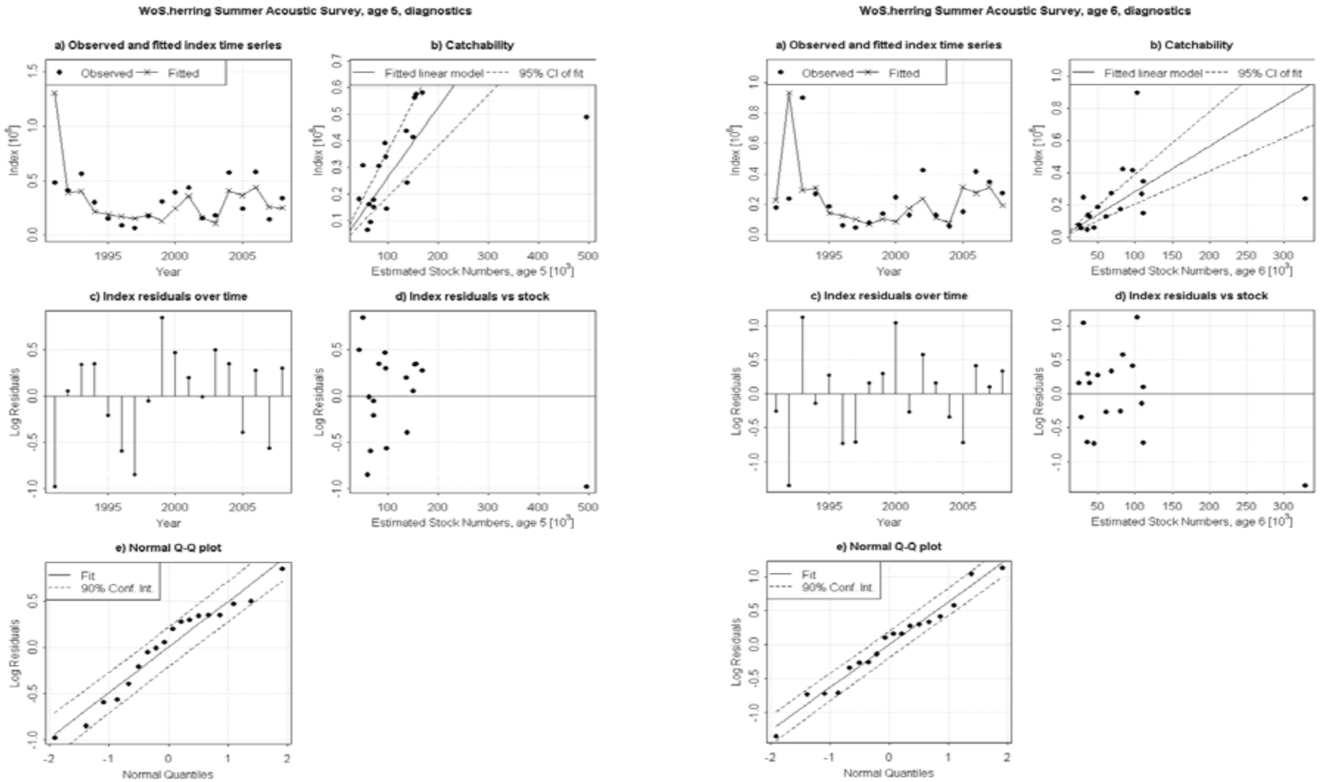



**Figure 3.2.1.4. Combined Assessment SPALY run. Diagnostics of the VIaN acoustic survey fit at 5 wr (left) and 6 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

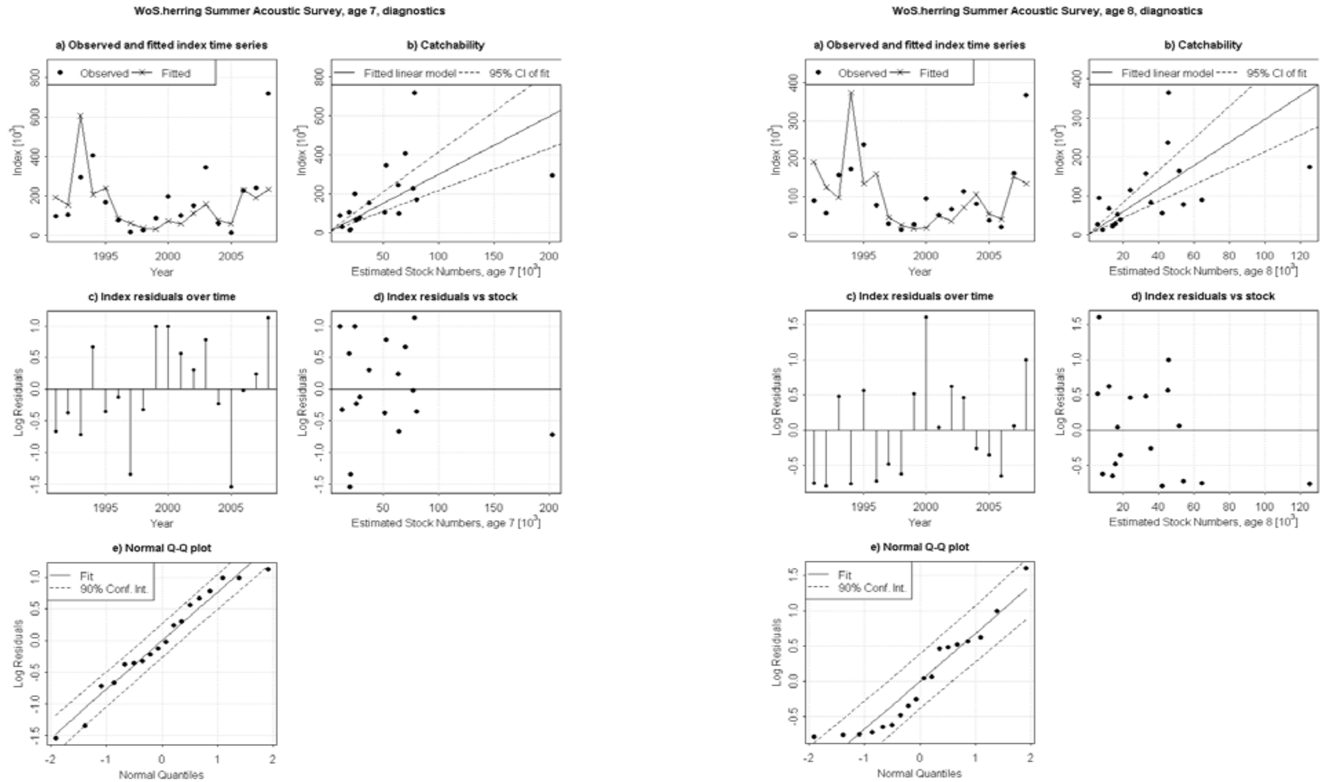



**Figure 3.2.1.5. Combined Assessment SPALY run. Diagnostics of the VIaN acoustic survey fit at 7 wr (left) and 8 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

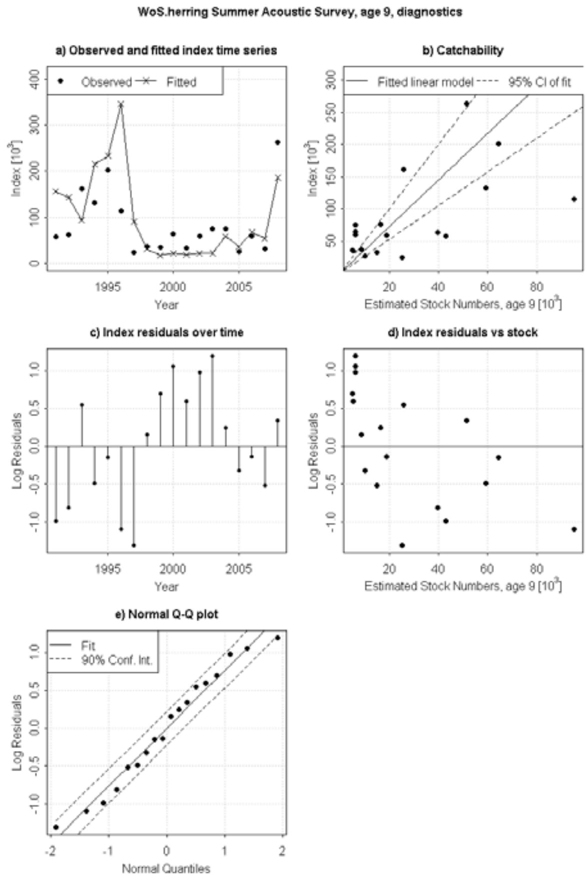



**Figure 3.2.1.6. Combined Assessment SPALY run. Diagnostics of the VIaN acoustic survey fit at 9 wr from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatterplot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

### 3.2.2 Survey Data

The assessment was tuned using the VIaN survey which is carried out annually in July. The survey age classes encountered on this survey vary from year to year, with year class estimates one year higher than the previous year. Oscillations in the biomass estimate are also seen. The imprecision is almost certainly driven by the year to year variability of the distribution of the stock and the contagious distribution of herring within the survey area (Fernandes *et al.*, 2003). This survey is part of the combined Malin Shelf survey which, by July 2010, will have a time-series of three years.

In order to see if an improved retrospective pattern could be attained a number of data combinations were tested by removing surveys one year at a time and also removing ages one at a time. It was found that the only way to improve the retrospective pattern was to remove survey years prior to 1998. The assessment was run using surveys from 1998–2008 and tuned only using ages 3–6. The diagnostics from this run (survey run) are presented in Figures 3.2.2.1 – Figure 3.2.2.7. The main reasons why data may be excluded from a time-series would be if the survey timing changed between years and only certain years were comparable, or specific ages were not picked up by the survey. The VIaN assessment uses all ages and all years from the VIaN survey time-series and there is no basis for excluding data from the combined assessment.

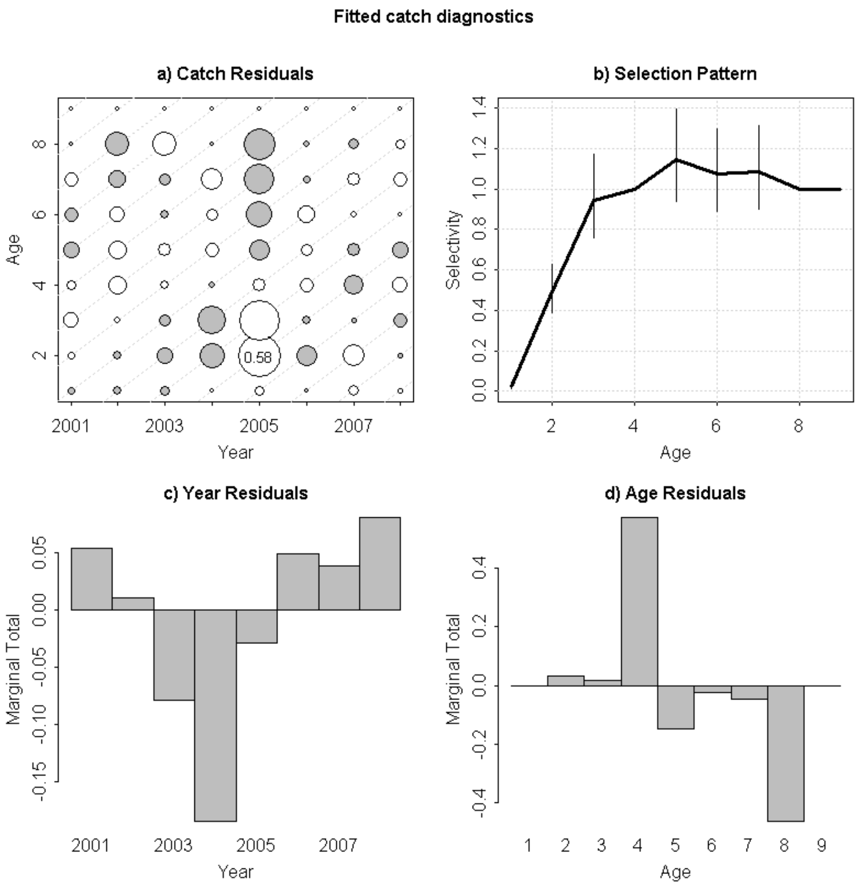



**Figure 3.2.1.7. Combined Assessment SPALY run. Catch diagnostics from FLICA. a) Bubble plot of log catch residuals by age (weighting applied) and year. Grey bubbles correspond to negative log residuals. The largest residual is given. b) Estimated selection parameters (relative to 4 wr) with 95% confidence intervals. c): Marginal totals of residuals by year. d). Marginal totals of residuals by age (wr).**

The poor retrospective pattern produced in each scenario may be as a result of the partial coverage of the single tuning series used. In most years this survey does not extend as far as VIaS. In 1994, 1995 and 1996 a summer survey was carried out in VIaS/VIIb, c. In 2008 the first synoptic survey covering the whole area was carried out and its utility will be further investigated once a sufficient time-series becomes available. This survey was again carried out in 2009 and a total biomass estimate produced by WGIPS. A further exploratory assessment run was carried out using data from the surveys that covered the distribution area (1995, 1996, 2008 and 2009). The lack of data available led to deterioration in the assessment diagnostics.

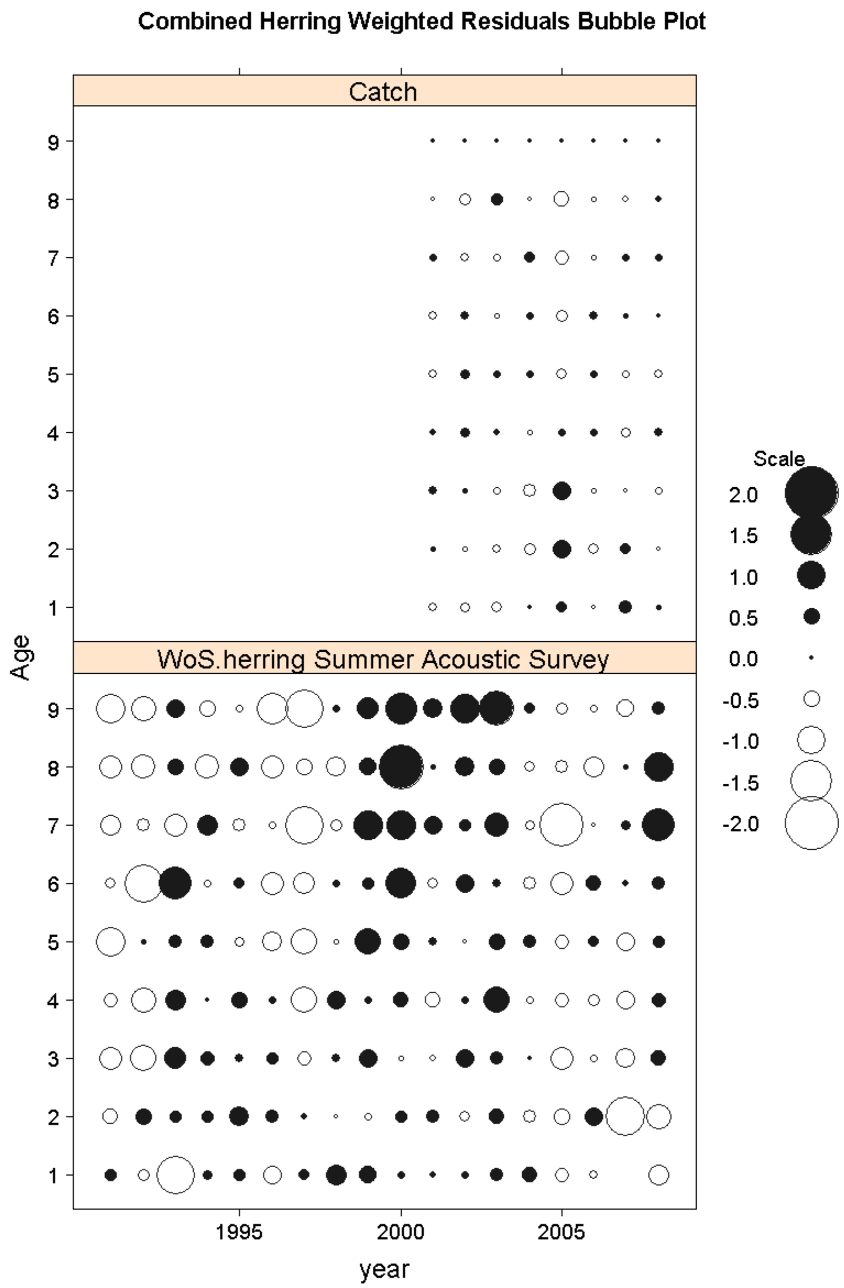



**Figure 3.2.1.8. Combined Assessment SPALY run. Catch and survey residuals from the VIaN Summer acoustic survey.**

Finally, the use of alternative weighting options on the survey data was examined. The use of flat or inverse variance was examined following the procedure carried out for west of Scotland herring at the 2009 HAWG. (ICES, 2009b). This did not change the diagnostics or improve the overall assessment.

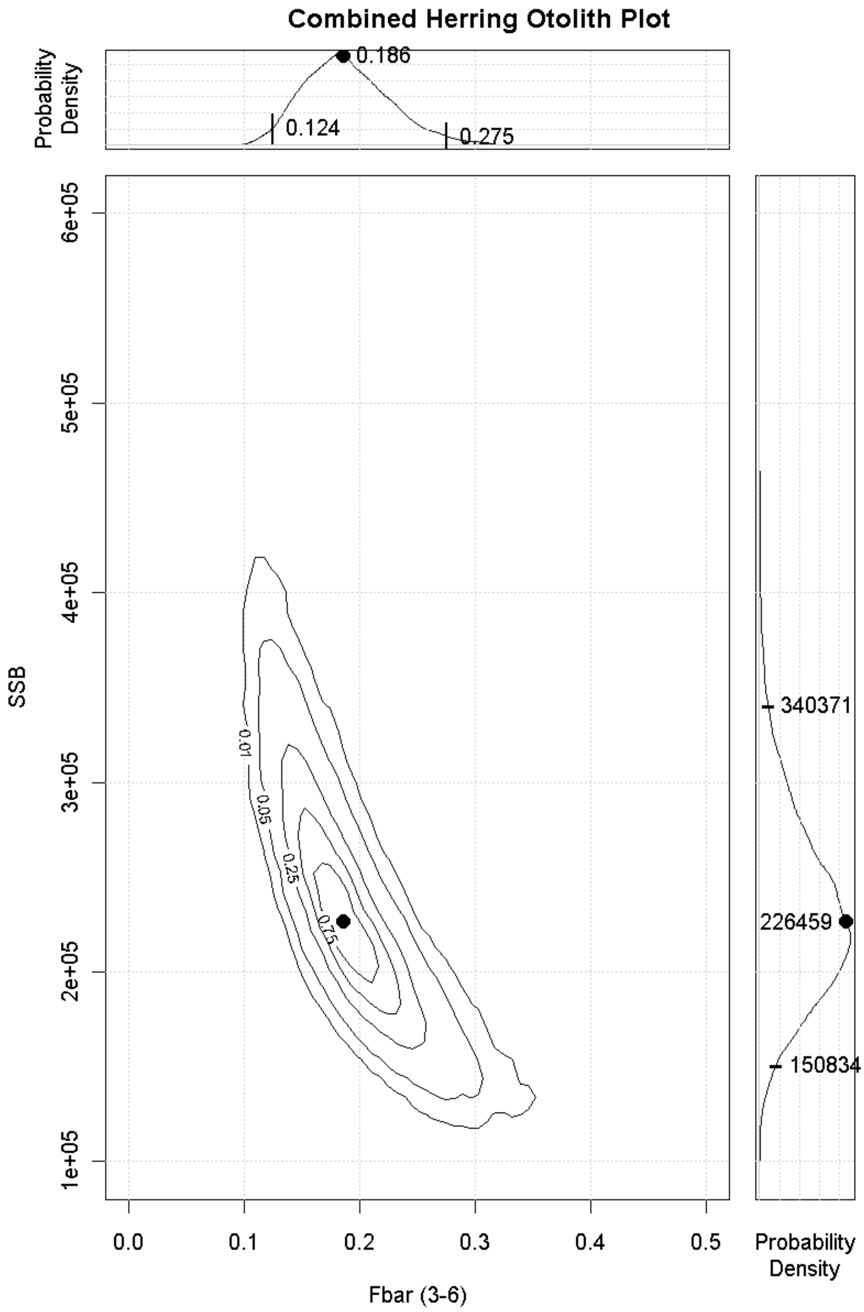



**Figure 3.2.1.9. Combined Assessment SPALY run "Otolith" plot. Results of parametric bootstrapping from FLICA. The main figure depicts the uncertainty in the estimated spawning-stock biomass and average fishing mortality, and their correlation. Contour lines give the 1%, 5%, 25%, 50% and 75% confidence intervals for the two estimated parameters and are estimated from a parametric bootstrap based on the variance covariance matrix in the parameters returned by FLICA. The plots to the right and top of the main plot give the probability distribution in the SSB and mean fishing mortality respectively. The SSB and fishing mortality estimated by the method is plotted on all three plots with a heavy dot. 95% confidence intervals, with their corresponding values, are given on the plots to the right and top of the main plot.**

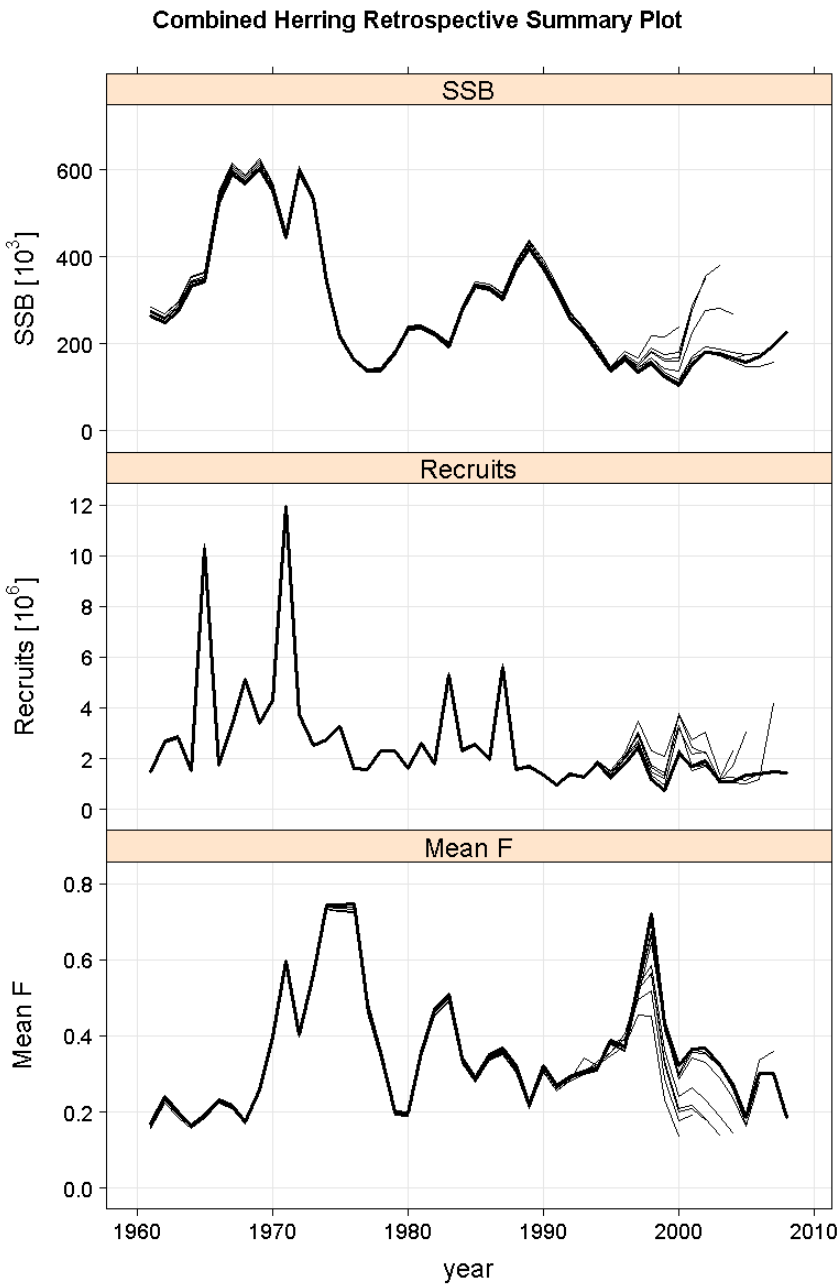



**Figure 3.2.1.10. Retrospective pattern in the combined assessment SPALY run.**

### 3.2.3 Other assessment settings

The selection on the oldest age and the choice of reference age were examined. Examination of catch curves (Figure 3.1.2.3) shows that the main ages for full recruitment are 2 and 3 winter ring; therefore reference ages of 3 and 4 were tested in the assessment. Selection on the oldest age was also examined with values ranging from 0.7 to 1.3 used. A range of values was examined because it is believed that the stocks in VIaN, VIaS/VIIb, c and VIIaN are exploited at different levels which would equate to a dome-shaped selection in a combined assessment. The reason for this is that fish exploited at a higher level would only form a small component of the exploited stock at older ages, whereas fish exploited at a lower level would form a larger component of the exploited stock at older ages. Changes could be seen in the catch diagnostics with a selection value of 0.7 and a reduced reference age of 3. This gave the most dome shaped pattern. An upward facing selection can be seen if a higher value for selection (1.3) and a reference age of 4 is chosen. A flat topped selection pattern can be seen if selection is set at 1.3 and the reference age is 3. However, these runs did not change the remaining diagnostics with a poor retrospective pattern observed each time.

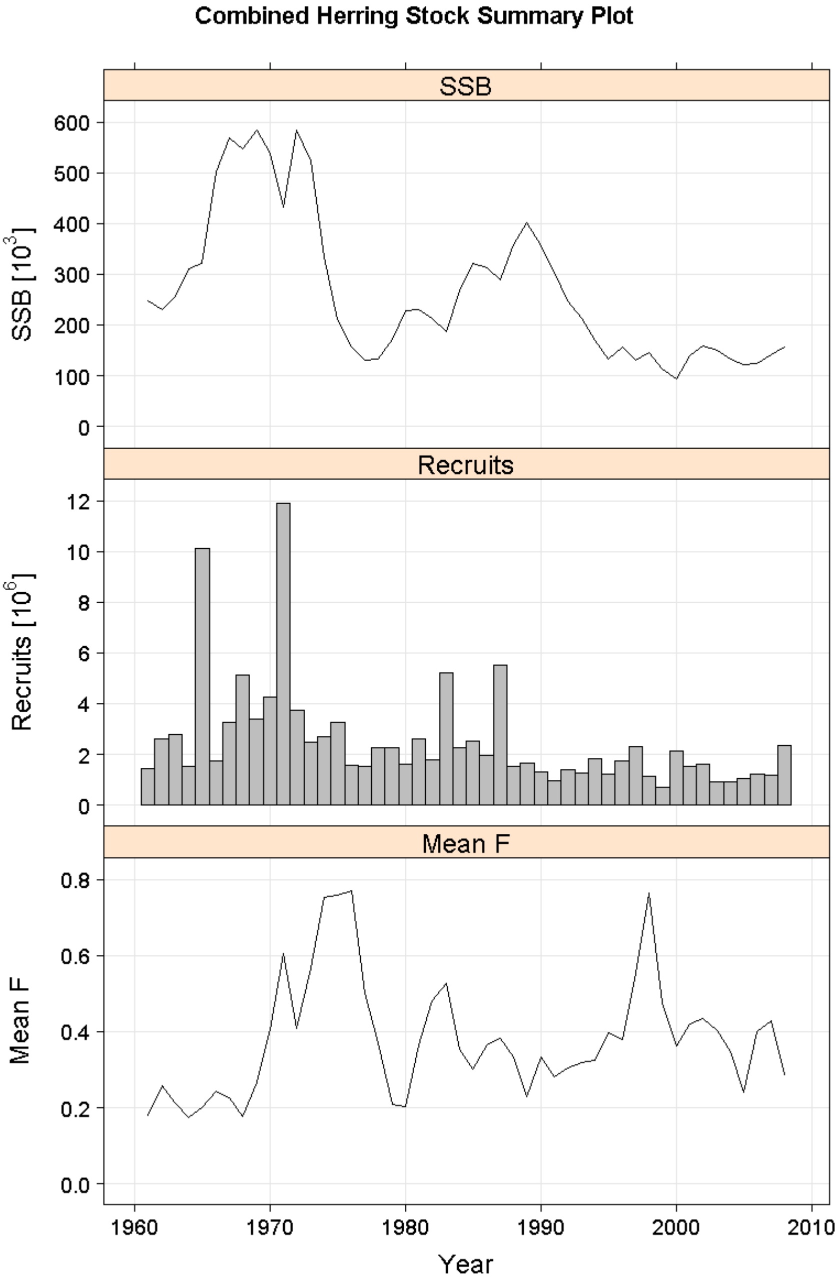



**Figure 3.2.2.1. Combined Assessment survey run. SSB, Recruits and Mean F ages 3–6.**

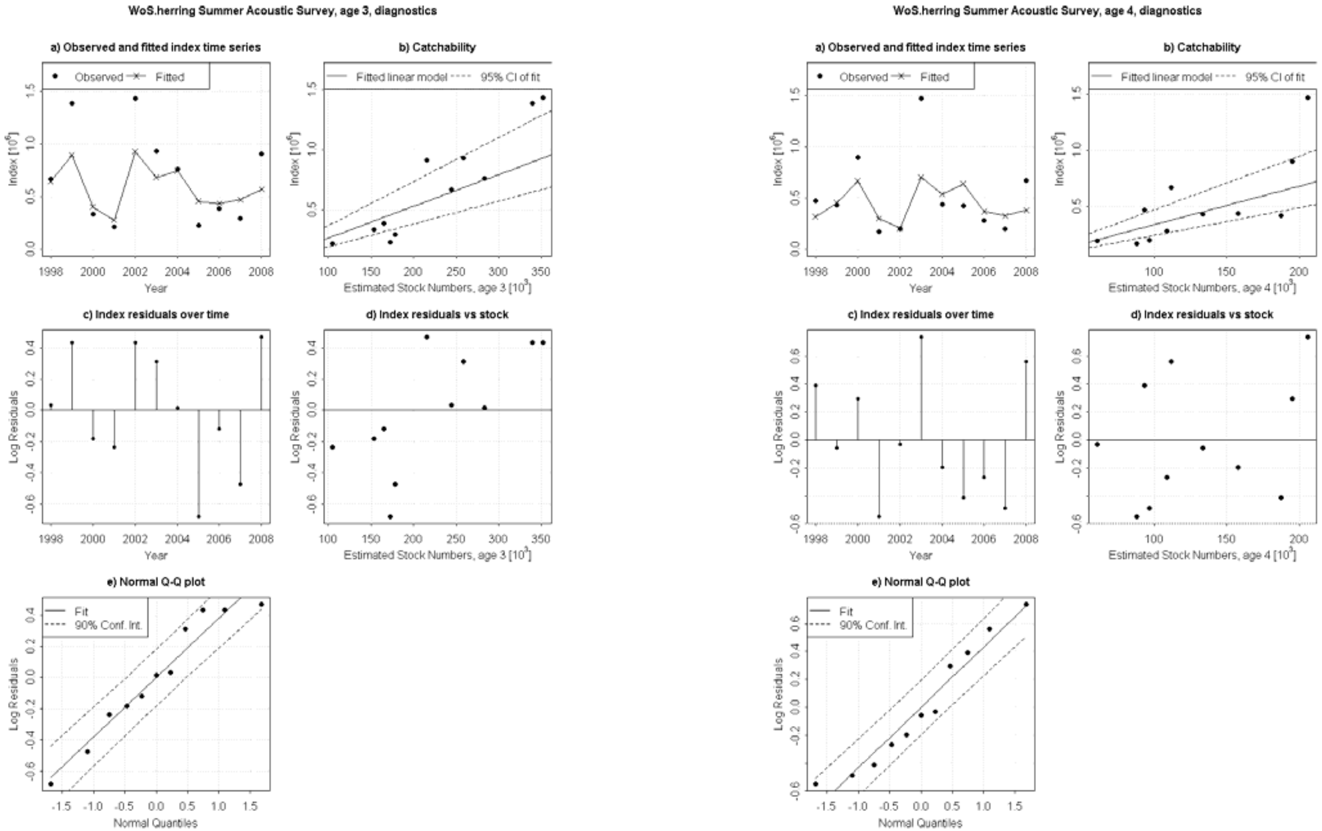



**Figure 3.2.2.2. Combined Assessment survey run. Diagnostics of the VIaN acoustic survey fit at 1 wr (left) and 2 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

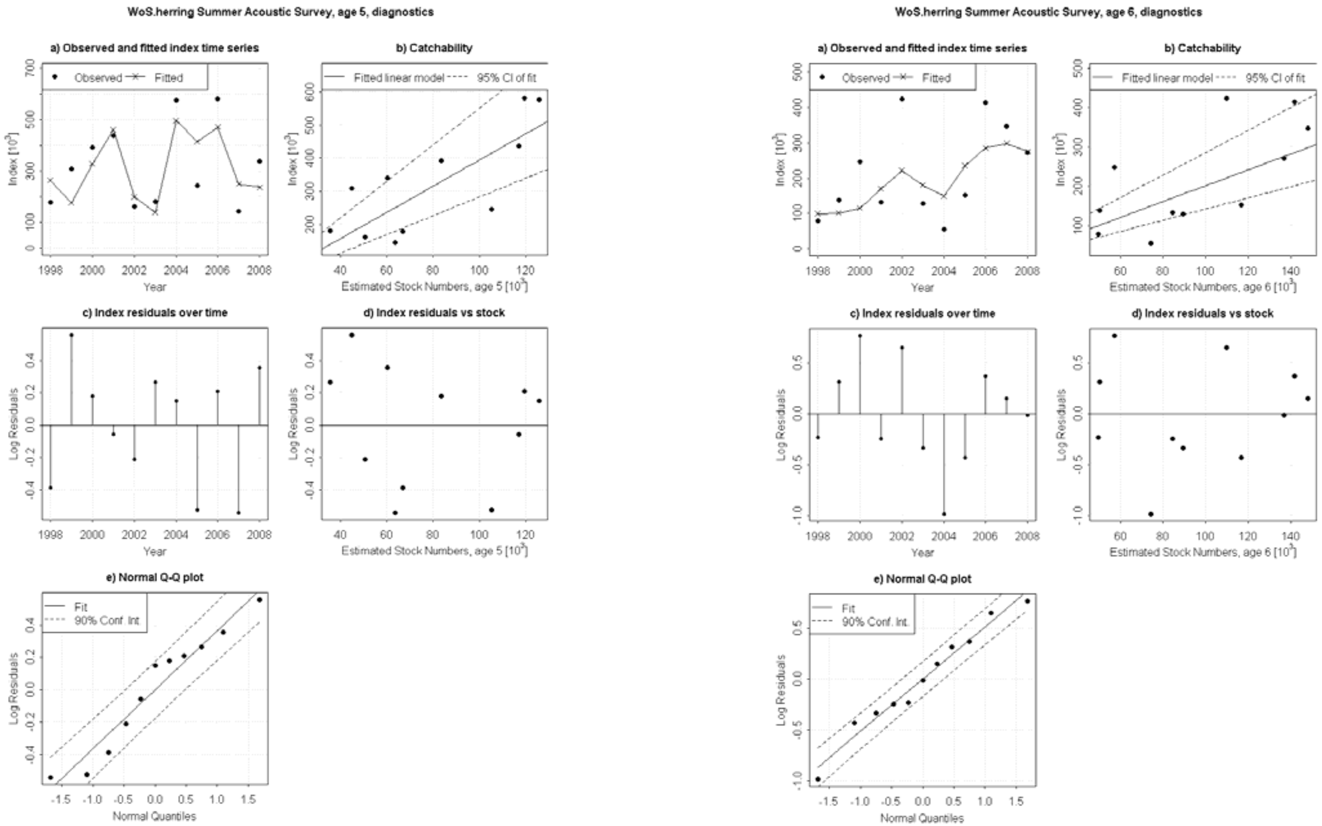



**Figure 3.2.2.3. Combined Assessment survey run. Diagnostics of the VIaN acoustic survey fit at 3 wr (left) and 4 wr (right) from the FLICA assessment. a) Comparison of observed (points) and fitted (line) index value. b) Scatter plot of index observations vs. FLICA estimates of stock numbers-at-age. Fitted catchability (linear model – solid line), with 95% confidence interval (dotted line). c) Log residuals of catchability model fitted by FLICA as a function of time. d). Log residuals from the catchability model against stock size at age estimated by the FLICA assessment method. e). Normal Q-Q plot of log residuals (points) with fitted linear regression (solid line) and 90% confidence interval for predication (dotted line).**

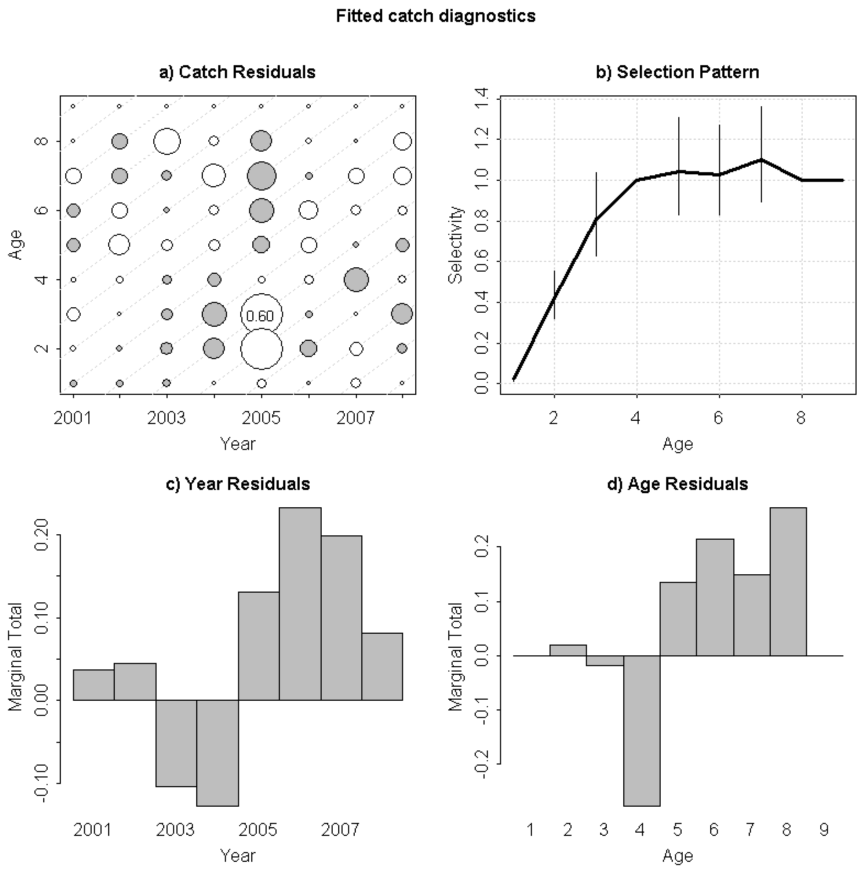



**Figure 3.2.2.4. Combined Assessment survey run. Catch diagnostics from FLICA. a) Bubble plot of log catch residuals by age (weighting applied) and year. Grey bubbles correspond to negative log residuals. The largest residual is given. b) Estimated selection parameters (relative to 4 wr) with 95% confidence intervals. c): Marginal totals of residuals by year. d). Marginal totals of residuals by age (wr).**

### 3.2.4 Possible Reasons for Retrospective bias

Adjusting the settings of the assessment had little impact on the diagnostics and we can conclude that the assessment is not sensitive to the choice of setting.

The survey that is used to tune this exploratory assessment does not cover the entire area. It will be a number of years before a full time-series of data from the combined survey with information on splitting to the various known populations becomes available.

The estimated fishing mortality-at-age by year as calculated from the assessment was examined in more detail and is presented in Figure 3.2.4.1. This shows a clear change in selection in 1997 and 1998. This change in selection may influence the analytical retrospective and contribute to the poor pattern that is produced. The estimated fishing mortality-at-age was also scaled to mean F over ages 3–6. This also shows changes in 1997 and 1998 but they are not as pronounced (Figure 3.2.4.2).

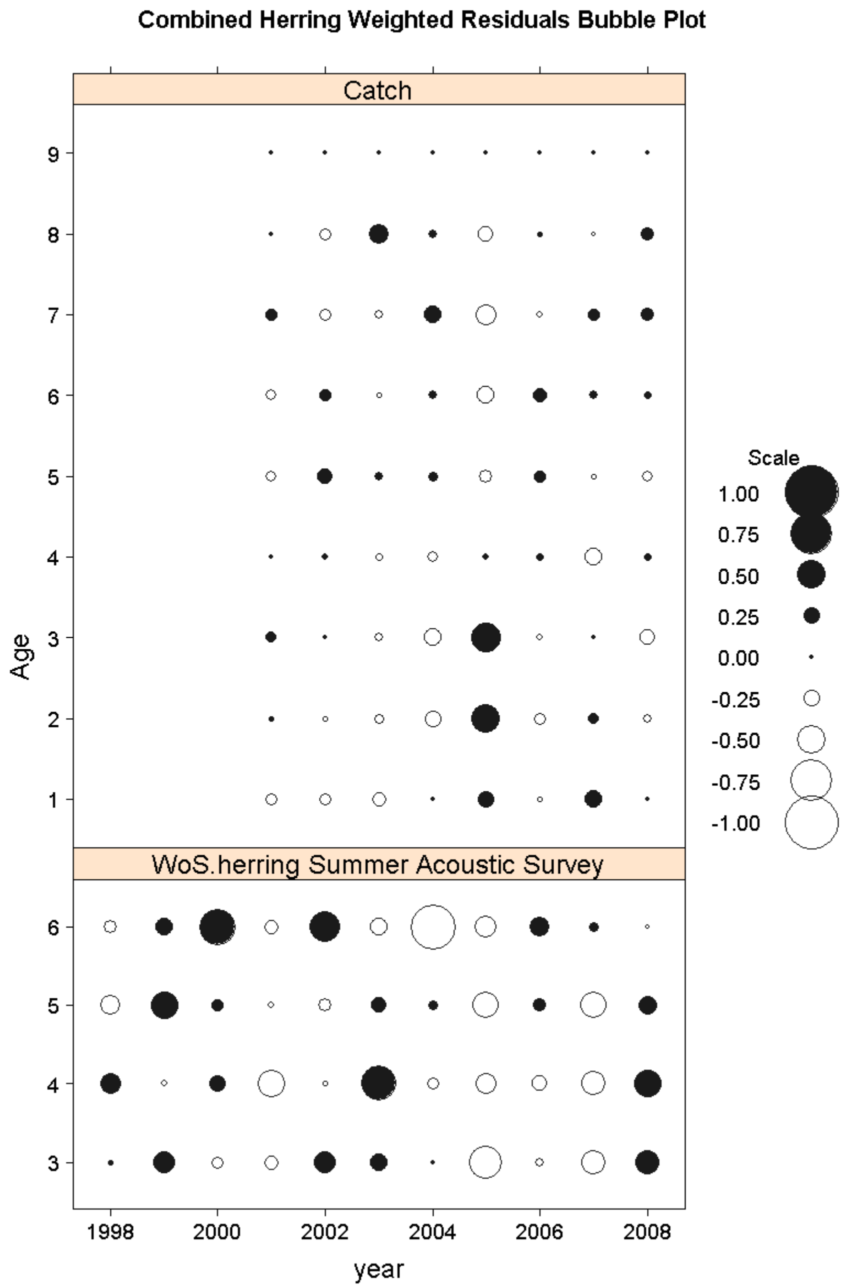



**Figure 3.2.2.5. Combined Assessment survey run. Catch and survey residuals from the VIaN Summer acoustic survey.**

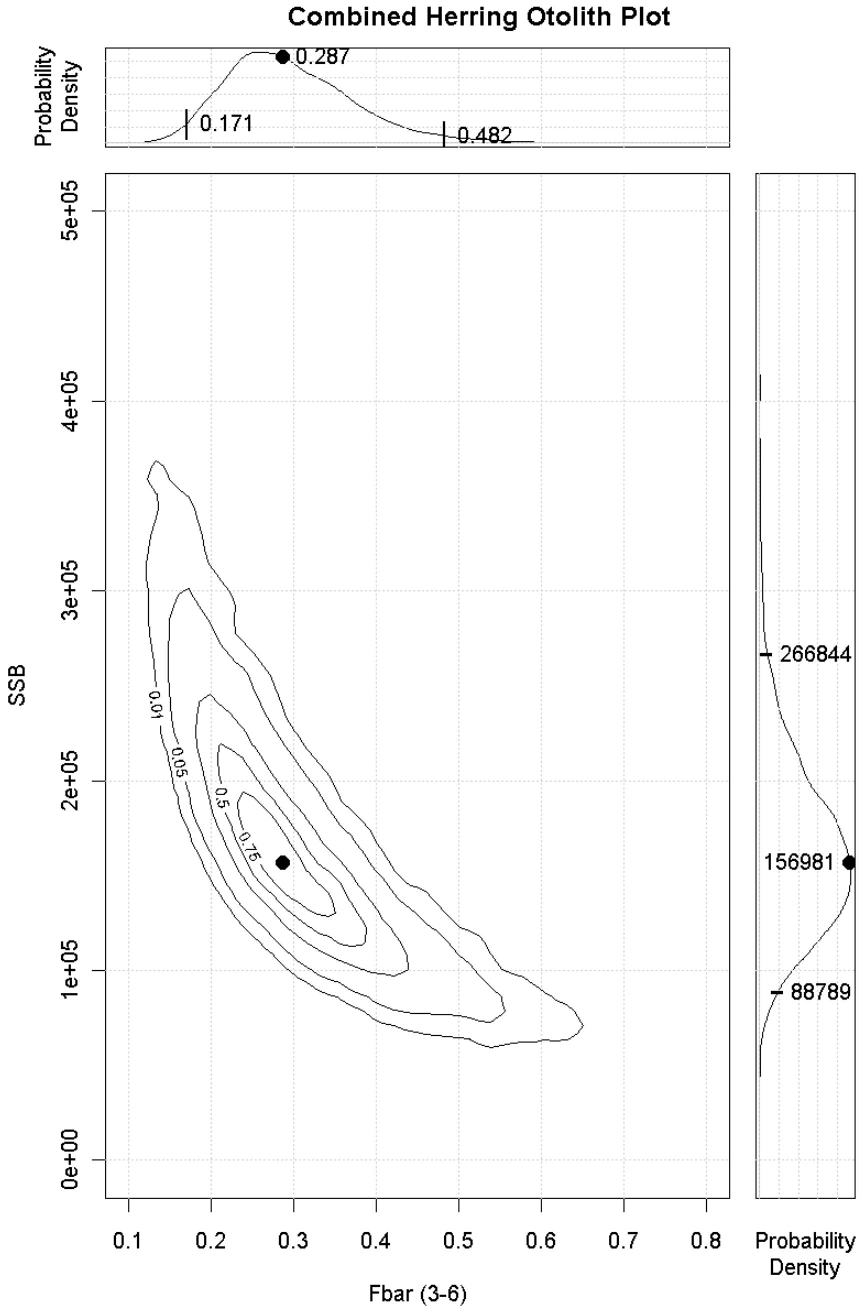



**Figure 3.2.2.6. Combined Assessment survey run "Otolith" plot. Results of parametric bootstrapping from FLICA. The main figure depicts the uncertainty in the estimated spawning-stock biomass and average fishing mortality, and their correlation. Contour lines give the 1%, 5%, 25%, 50% and 75% confidence intervals for the two estimated parameters and are estimated from a parametric bootstrap based on the variance covariance matrix in the parameters returned by FLICA. The plots to the right and top of the main plot give the probability distribution in the SSB and mean fishing mortality respectively. The SSB and fishing mortality estimated by the method is plotted on all three plots with a heavy dot. 95% confidence intervals, with their corresponding values, are given on the plots to the right and top of the main plot.**

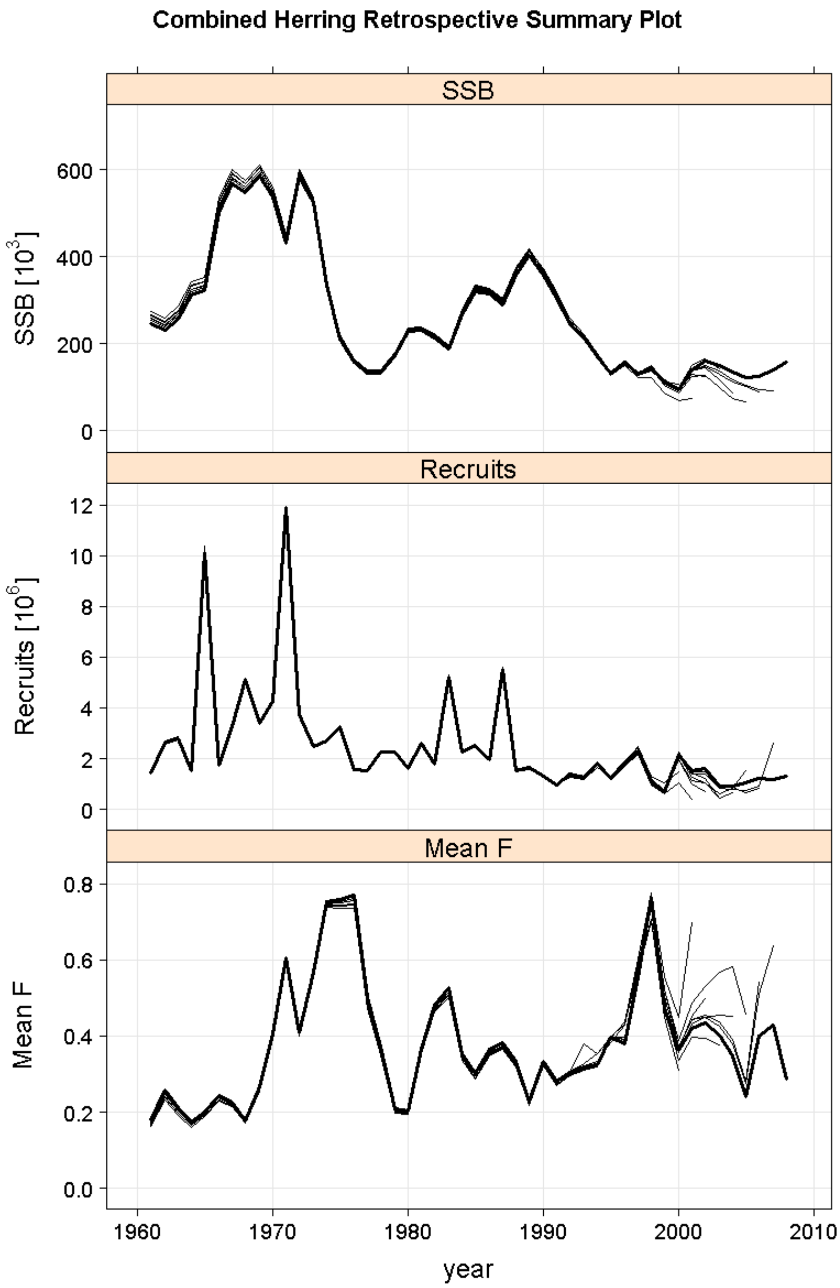



**Figure 3.2.2.7. Retrospective pattern in the combined assessment survey run.**

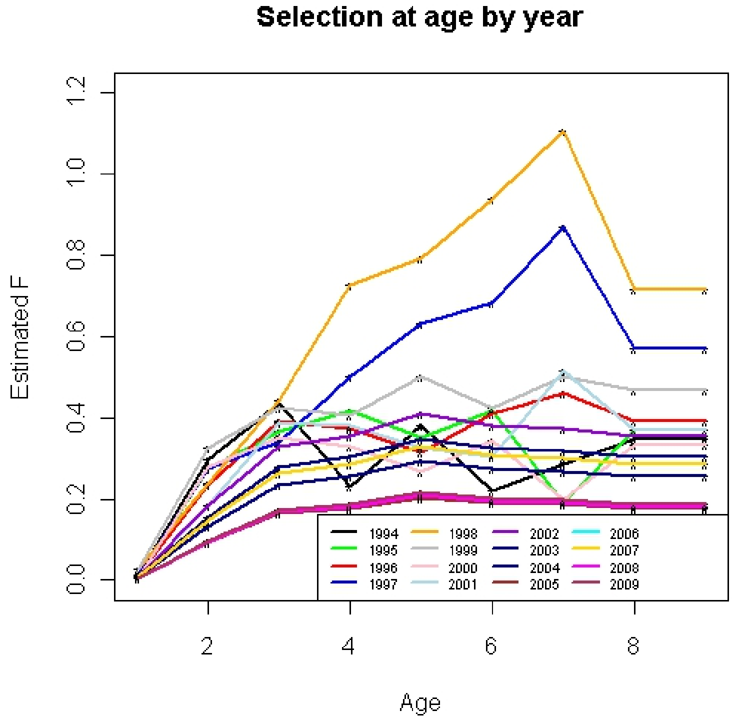



**Figure 3.2.4.1. Selection-at-age by year.**

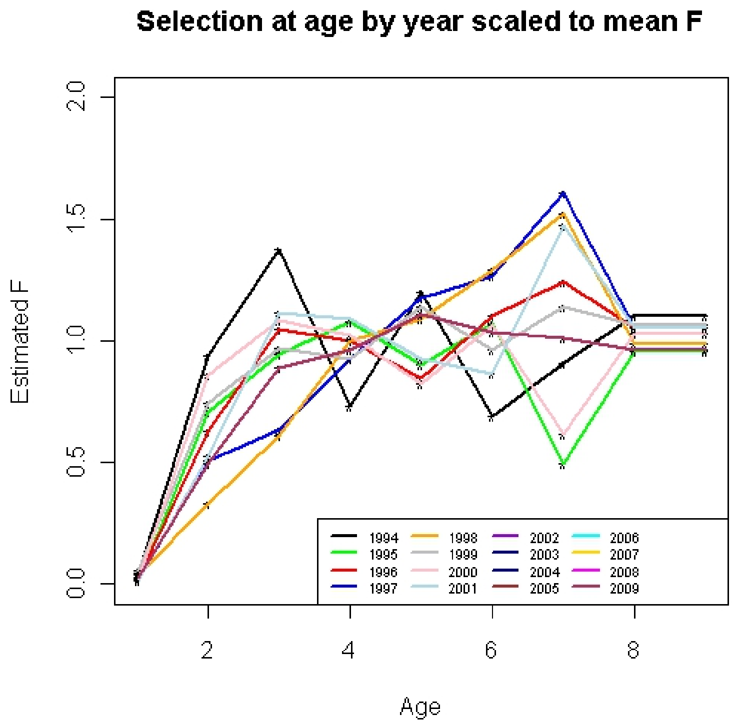



**Figure 3.2.4.2. Selection-at-age by year scaled to mean F over ages 3–6.**

### 3.3 Conclusions

The combined assessment does give important information on the Malin Shelf meta-population, though it is unlikely to be useful for management advice purposes. The difference between the survey and modelled abundances (the catchability) calculated in the combined assessment is less than for the VIaN assessment. The catchability of the VIaN acoustic survey in the combined assessment SPALY run was around 2 which is more in line with other herring assessments (Celtic Sea, North Sea and Irish Sea). The combined assessment could be expected to encompass more of the interstock variability. When survey data are removed, the catchability increases because less of the variability is accounted for. This suggests that the VIaN assessment currently performed by ICES (ICES, 2010) is using a tuning index that represents a population larger than the VIaN population alone. Therefore some means of segregating the VIaN tuning series according to constituent populations is required.

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 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.

Each SPALY exploratory assessment run shows a similar pattern for SSB, Mean F and Recruitment. The magnitude and location of the catch residuals is similar also with 2005 showing the largest residuals in each scenario. The residuals produced are smaller overall than from single-stock assessments with clear improvements seen since 2005.

Figure 3.3.1 shows the stock/recruitment estimates from the SPALY FLICA run (1961–2008). The data series is dominated by the strong year classes in the 1960s-1980s, and is broadly similar in pattern to those shown for VIaN and VIaS/VIIbc. Productivity over time, in terms of recruits per spawner (Figure 3.3.2), varies widely over time, with a distinct trough in the early 1990s.

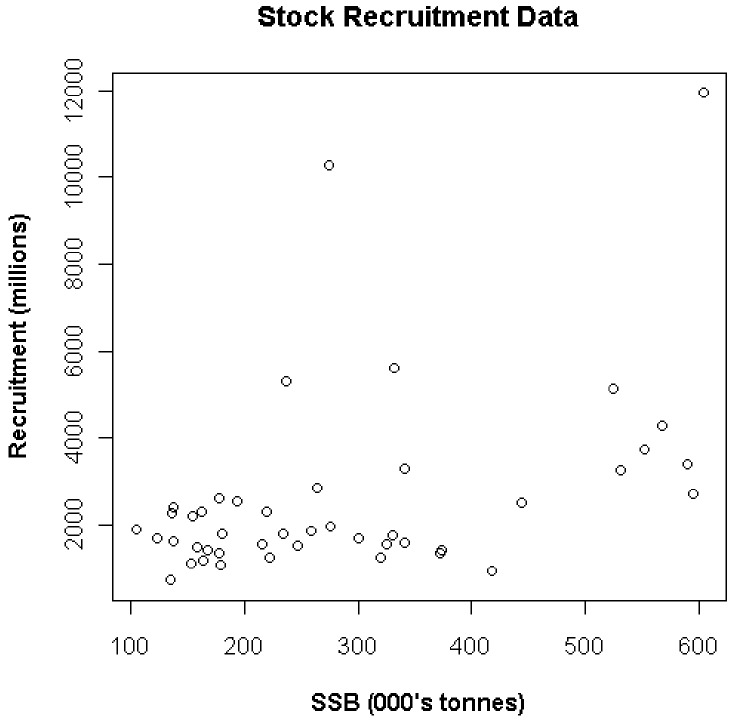



**Figure 3.3.1. Malin Shelf Herring metapopulation. Stock recruit data for the Malin Shelf metapopulation, from SPALY run in 2010.**

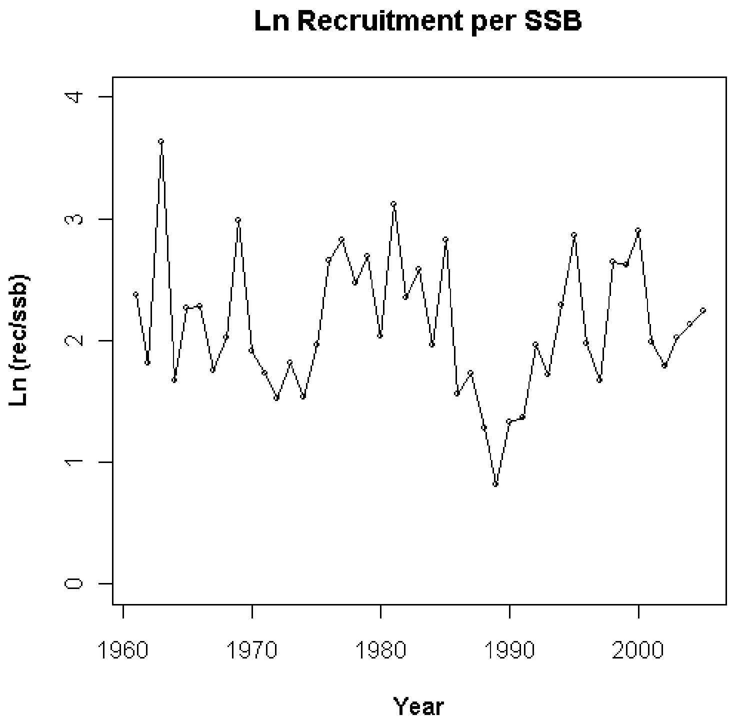



**Figure 3.3.2. Malin Shelf metapopulation productivity over time. Recruitment per spawner (natural log (ln) transformed data).**

Figure 3.3.3 illustrates some key features of assessing the three stocks together as a metapopulation, rather than individually (the current procedure). Metapopulation SSB and recruitment are roughly the sum of those of the three individual stocks. However, the metapopulation historic F trajectory occupies a centralized position among the individual F trends. The F signal from the combined assessment is not a good indication of the F that was experienced by the individual stocks. Thus the combined F masked peaks and troughs in F for the individual stocks. An individual stock could suffer very high F that would be masked in the combined assessment. Similarly, the combined F may tend to mask a low F that could be being experienced by a constituent stock. Thus the combined assessment does not offer good information on the individual stocks, especially the exploitation rates they are experiencing. If a target F strategy were being implemented for this metapopulation, the combined assessment would not deliver sufficient information on realized F on individual stocks.

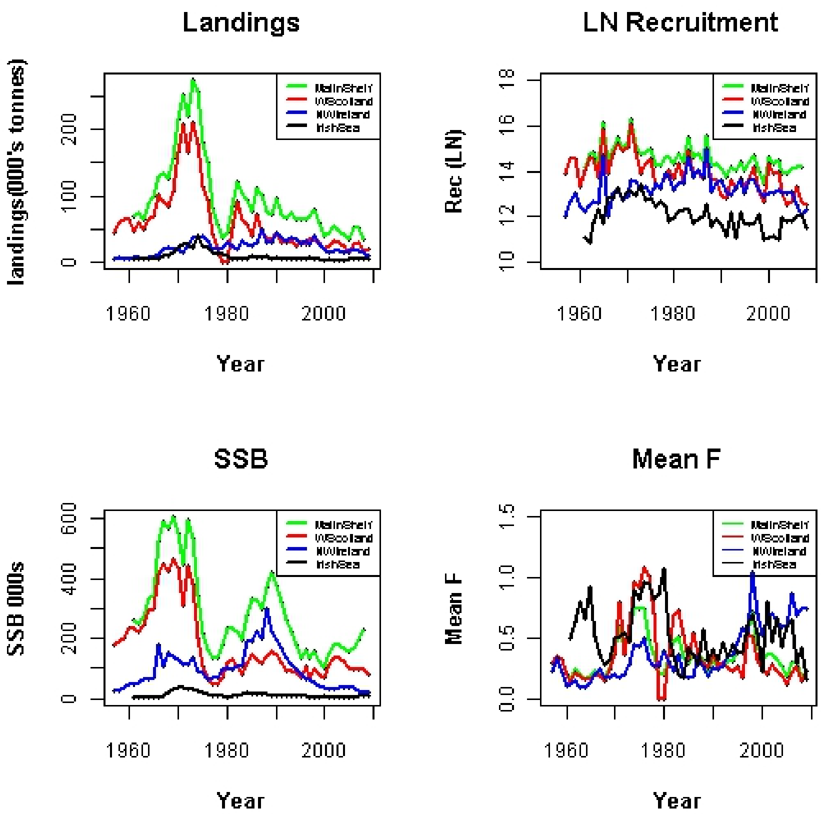



**Figure 3.3.3. Malin Shelf Herring metapopulation. Comparisons of Malin Shelf exploratory assessment with constituent stocks, as presented in ICES HAWG (2010). F per year, landings ('000s tonnes), SSB ('000s tonnes) and recruitment (ln). For NW Ireland the separable VPA run with F=0.5 was chosen as the best estimate of stock development. Malin Shelf (green); west of Scotland-VIaN-(red); NW Ireland–VIaS/VIIb,c-(blue); Irish Sea–VIIaN-(black).**

The failure to recognize and account for population structure may lead to depletion of spawning components and have unexpected ecological consequences. Appropriate management to preserve this complexity remains a challenge (Stephenson, 1999). Whilst we have learned a lot about the metapopulation from the combined assessment exercise, it is unlikely that it will replace individual assessments of the constituent stocks. However, it is necessary to segregate these stocks in the Malin Shelf acoustic surveys, and work on this has begun in 2010.

# 4 Management strategy evaluation modelling

## 4.1 Introduction

Managing economically important fish stocks at sustainable levels is the aim of natural resource managers. However, due to uncertainty in the advice and the use of methodologies that are not specifically designed to give accurate advice (Piet *et al.*, 2010), correct advice is given for only slightly over half of the stocks in the North Sea (Piet and Rice, 2004) which makes sustainable management difficult. Stocks that mix at different life stages in their life cycle (e.g. metapopulations) pose problems for providing accurate advice (Stephenson, 1999; Kell and Bromley, 2004; Kell *et al.*, 2009). Developing complex assessment methods as a possible remedy might be difficult and does not guarantee to accurately represent the states of nature. However, they can be used to evaluate hypotheses on stock structure and dynamics (Hilborn, 2003) and provide insight into the most sustainable management actions. The information obtained from fishery-independent sources plays a major role in such complex models (Beare *et al.*, 2005; Mesnil *et al.*, 2009) which could support alternative ideas on managing metapopulations.

The herring populations to the west of the British Isles, in ICES areas VIaN, VIaS/VIIb.c and VIIaN, have been found to mix during the feeding season (Campbell *et al.*, 2007; Geffen *et al.*, Submitted) and can hence be considered a metapopulation (Kritzer and Sale, 2004). However, in contrast, they are currently each managed as single stocks. It is unknown if the fisheries currently catch mixtures of fish. However, if they do, the stock definitions (Begg and Waldman, 1999) are violated (Reiss *et al.*, 2009; Geffen *et al.*, Submitted.). Additionally, the survey carried out in VIaN as a tuning index for the VIaN ICES stock catches mixtures of the different populations. Therefore, the data used to tune the VIaN assessment is representative of more than one, currently unquantified, stock (Hatfield *et al.*, 2007). This setup makes these populations an interesting case study to evaluate the effects of mixing on stock management. Many authors have already simulated metapopulations, either in a management strategy evaluation framework (Kell and Bromley, 2004) or a generalized model framework (Secor *et al.*, 2009; Kerr *et al.*, 2010), and evaluated management scenarios (Powers and Porch, 2004; Kell *et al.*, 2009). Where Secor *et al.* (2009) and Kerr *et al.* (2010) took a biological perspective evaluating the effects of, among other issues, straying and entrainment, Kell *et al.* (2009) primarily focused on the misperception of population structure obtained from assessment setups. However, both novel approaches lacked the experimental realism to quantify the effects of mixing populations on management. Primarily, when dealing with mixing hypothesis within a management framework, historical trends are important, as these, among others, indicate the boundaries to possible mixing scenarios. That is, correcting for mixing may not result in the back transferring of fish from one into the other area by more than its perceived size. Part of correcting for mixing relates to revising the stock–recruitment models, which are most often seen as drivers of population development (De Lara *et al.*, 2007; Piet *et al.*, in prep,) and are key to such analyses. Thereby, issues encountered in gathering fisheries independent information are not often extensively dealt with.

In a fishery where different spawning populations are caught simultaneously, proportions by spawner type in the catch can be identified to support management actions (Gröger and Gröhsler, 2001; Bierman *et al.*, 2010). However, in situations where populations mix that are morphologically or genetically similar, it is difficult to accurately allocate fish to spawning components. Consequently, misidentifications might result in a biased pattern in either the catch or the survey indices. 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 west of the British Isles study (the WESTHER project, Anon, 2006) 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 (Hatfield, Pers. Comm.) an average success rate of 0.85 can be achieved, with the success rate for some spawning groups achieving 0.95 or greater.

In methods deployed looking solely at the characteristics of the catch under different effort and productivity regimes, it was apparent that preventing population decline only based on catch information would not be sufficient as variability of the simulated data were too large to identify problems (ICES, 2008). A similar approach was undertaken by (Kell *et al.*, 2009), and showed very similar results. However, Kell *et al.*'s (2009) study minimized process variability whereby they were able to see the effects of such effort and productivity changes more clearly. In evaluating sustainable management scenarios within a management strategy evaluation framework designed for this study, it became evident that fishery-independent data would be needed in addition to the available catch data, to support the advice obtained from assessment results.

Hence, this study primarily focuses on the effects of survey design and the success of implementing management dealing with mixing populations in both the catch and in the fishery-independent information source. Therefore, we focus on identification success rates and on sample sizes taken in surveys. Additionally, mixing effects will be discussed in the light of a more realistic approach to management strategy evaluation. The aim of this study is to show how metapopulations can be sustainably managed, approaching MSY levels (Mace, 1994; 2001), either by taking a very precautionary approach or investing in more reliable survey information.

## 4.2 Material and Methods:

The ability to manage metapopulations is evaluated within a simulation framework. Here we coherently model: [1] the biological populations of herring to the west of the British Isles, each spawning within three respective ICES areas: VIaN, VIaS/VIIb,c and VIIaN; [2] the three different fisheries targeting these populations; [3] the collection of fisheries independent data based on surveys; [4] the stock assessment procedure to identify the perceived status of the three biological populations which are used to [5] set management targets. These procedures are modelled including feedback loops where, over time, the outcomes of management actions affect the biological population the year after which, in its turn, affects the fishery and management.

Within the simulation we make a distinction between the concept of an ICES stock and a grouping of biological components, i.e. population. We assume that the biological population represents the truth while an ICES stock is a perceived view of the truth generated through the catches of a fishery and survey indices, which might be inaccurate or biased due to uncertain survey measures or population mixing.

### 4.2.1 Populations

The populations of the three different ICES areas, VIaN, VIaS/VIIb,c and VIIaN are assumed to each represent a spawning population. During spawning they only occupy the area they are named after, while during the feeding season parts of a population can migrate to other areas where they are susceptible to the fishery active within the area. The age-structured populations are assumed not to immigrate/emigrate between spawning components (Anon., 2006) Each year, recruits are added to the population, based on a segmented regression function, which represents the relationship between the potential spawning biomass and the number of offspring produced (see Eqn 1, Annex 2).It is assumed that the amount of recruits produced depends on the productivity of the system. As productivity is known to change considerably over time (Payne *et al.*, 2009), the magnitudes in recruitment vary as well. Hence, specific year ranges (see Table 4.2.1.1) have been selected which are thought to be similar to the current productivity levels. This should prevent the prediction of overly optimistic or pessimistic offspring productions. However, the simulated extent of mixing has implications for recruitment prediction. If (e.g.) the VIaS/VIIb,c population has always contributed to the VIaN catch, it is likely that the VIaN population has always been overestimated. To account for this overestimation, the Stock-Recruitment Relationship (SRR) has to be adapted as lower Spawning Stock Biomasses (SSB) produced the Recruitment (R) observed in the surveys (Eqn 1, Annex 2; see also Figure 4.3.1.1).

Within a cohort, survival from one year to the next depends on natural mortality and fishing mortality generated by the different fleets the populations are susceptible to (see Eqn 2, Annex 2). It is assumed that the catches of the fleets are exactly taken and that fishing mortality can be calculated without error. Natural mortality, fecundity, time of spawning, and weight-at-age are taken from the 2008 assessment results (ICES HAWG reports), except for VIaS/VIIb,c where the 2007 assessment results have been used. Starting numbers-at-age in 1977, the start of the simulations, are taken from the 2005, 1998 and 2000 stock assessments for VIaN, VIaS/VIIb,c and VIIaN respectively. These years were assumed to represent the last year in which there was confidence on the accuracy of estimated stock numbers. All timelines of the populations are aligned to range from 1977 to 2005. Note that due to the shift in timelines, the starting values in 1977 were set as those from 1970 and 1972 for VIaS/VIIb,c and VIIaN respectively.

**Table 4.2.1.1. Year classes assumed to be produced during system productivity levels similar to current levels.**

| POPULATION | YEAR CLASSES |
|---|---|
| VIaN | 1989–2006 |
| VIaS/VIIb,c | 1970–1980,1986–1998 |
| VIIaN | 1963–2005 |

The dynamics of the biological populations are projected from 1977 forward in time to study the difference in perception of the stock vs. the simulated biological truth.

### 4.2.2 The fishery

Within each of the three management areas, the fishery is targeting the biological populations during the feeding season when mixing between populations occurs. Hence, each fishery only has the fish occurring in the management area they are active in available to it. Due to mixing, it can occur that a fishery has more than one population available to it while others have less than one population available. The combination of the three fisheries targets, in total, 100% of each population. The catches of the fisheries are defined by the Baranov catch equation (Eqn 3, Annex 2) and depend on the available numbers-at-age, selectivity pattern of the catch, the catchability of the fishery, natural mortality and the amount of effort allocated during a year. Landings are assumed to equal the catches as discarding is not simulated. Landing weights for the projected period are taken as the mean weight-at-age over 10 historic years. Selectivity for the projected period of 20 years is assumed to be similar to the pattern as fitted by the assessment in the last appropriate year. Error has been added to vary selectivity from year to year. These errors are obtained from selectivity residuals in the 2008 (VIaN, VIIaN) and 2007 (VIaS/VIIb,c) assessments. The residuals represent observed vs. fitted ratios (trimmed to two standard deviations from the mean), where final selectivity equals the selectivity-at-age times error-at-age. Catchability is assumed to be 1 for the whole time-series for all fleets.

Catches are projected from 1977 forward in time, similar to the biological population, assuming exploitation levels as observed in the ICES stock assessments.

#### 4.2.3 The surveys

Within the simulation framework only one survey is designed and this is an acoustic survey over the Malin/Hebrides Shelf, targeting the combined population of VIaN, VIaS/VIIb,c and, depending on the scenario investigated, VIIaN, and it reports on all ages. This survey estimates a relative abundance of the populations (see Eqn 4, Annex 2). As the VIaN, VIaS/VIIb,c and VIIaN ICES stocks are separately managed, the Malin Shelf survey has to be split into proportions allocating survey samples to the different stocks. However, due to the difficulty in distinguishing spawning origin, the splitting procedure has the potential to incorrectly allocate a sample to (e.g.) the VIaS/VIIb,c population while it actually belonged to the VIaN population, and vice versa. This process is described by the confusion matrix. Within this matrix (Table 4.2.3.1), the proportion correctly identified per ICES stock, and the transfers from each ICES stock to the two others is given. In addition to the accuracy of allocation, the number of samples taken during the survey to determine the age structure of the individual populations is also important. Where there are many samples, the number-at-age patterns will approximate the true age pattern in the populations rather well. However, when a small number of samples are taken, the age structure might be distorted (De Oliveira *et al.*, 2006). Error is added to the derived age structures for each survey. These errors are obtained from an assessment in 2005 on the forward projected population and catches. The residuals represent observed vs. fitted ratios (trimmed to two standard deviations from the mean), where the final survey index equals the numbers-at-age times error-at-age. Similar to the rebuild of the populations, survey time-series are generated in retrospect according to the methods described above.

**Table 4.2.3.1. Confusion matrix. Values on the diagonal indicate the proportion of samples that is correctly identified (in this case 0.8). All other values indicate the proportion of incorrectly identified samples and which are allocated to another spawning component.**

| | | Allocation | | |
|---|---|---|---|---|
| | Population | VIaN | VIaS/VIIb,c | VIIaN |
| Origin | VIaN | 0.8 | 0.1 | 0.1 |
| | VIaS/VIIb,c | 0.1 | 0.8 | 0.1 |
| | VIIaN | 0.1 | 0.1 | 0.8 |

The effects on management of both the incorrect splitting as well as the number of samples taken during a survey will be evaluated by varying levels of 'confusion' and sampling size.

#### 4.2.4 The stock assessment procedure

The perception of the ICES stock status is generated through the explicit inclusion of a stock assessment in the simulation, which is based on fishery-independent (surveys) and -dependent (landings) data. By combining population parameters, catches and survey indices, all information sources necessary to perform an assessment are available. The biological parameters contributing to the perception of the ICES stock is management area specific. Hence, only population $x$ contributes to the biological parameters of ICES stock $x$ whereas the catches of ICES stock $x$ can originate from different populations. To what extent the survey indices originate from different populations depends on the accuracy of the splitting procedure and sample size from the surveys. The assessment performed uses an Integrated Catch at Age analysis method (ICA), embedded within the FLR software, using the R platform (R Development Core Team, 2009). Within the assessment, stock numbers-at-age, as well as the harvest patterns, are estimated by minimizing the likelihood function (for a more technical description, see Patterson and Melvin (1996)).

#### 4.2.5 Management

The results of the assessment are used within the management routine. For this, the ICES stock is projected forward 2 years in time, assuming constant recruitment (geometric mean of recruitment over the most recent 5 years) and weights-at-age equal to the moving average over 2 years. Management targets are set to the proposed TAC for the intermediate year as obtained from the projections the year before, and to an F-target for the forecast year. Three different management targets have been evaluated: maintain harvest mortality over the targeted age-groups at 0.2, 0.3 or 0.4. In 2006, at the transition from the historic to the future period, no TACs have been imposed. Hence, in this situation for the intermediate year a management target equal to the management target for the forecast year has been used. In all other future years, for the intermediate year the TAC imposed the year before is used while for the forecasted year the allowed catches are calculated based on the harvest level set. Hereafter, the effort necessary to actually catch the TAC can be calculated. However, where the TAC has been based on the ICES stock dynamics, the effort is calculated based on the numbers available to the fishery, and hence is directly linked to the population sizes and the level of mixing during feeding season.

The effort projected for year *year+1* is deployed the year after to generate a catch and cause fishing mortality. This allows a full-feedback analysis of the management strategy evaluation. In total each scenario is repeated 100 times as the uncertainty in the different processes might encompass a range of possible outcomes. These repetitions are used to evaluate the risk of certain management scenarios to sustainable exploitation.

#### 4.2.6 Scenario descriptions

In total, four different processes are varied to evaluate whether management of the ICES stocks is precautionary or not.

- the number of samples taken in the Malin Shelf survey
- the accuracy of correctly splitting the Malin Shelf survey into three different survey indices as given in the confusion matrix

the level of mixing between populations (see Table 4.2.6.1 for a detailed description)

the management target for the forecasted year

[1] As a baseline, 1500 samples are taken during one survey season. This number approximates the number of samples taken in the synoptic acoustic Malin Shelf survey executed in 2008. Furthermore, a doubling of this number will be used to evaluate management.

[2] When new methods might become available, or more spawning herring sites are available to inform the mixture, the accuracy of correctly splitting the survey and fisheries catches might increase. For the survey splitting this implies that the diagonal values in the confusion matrix might increase towards 1. Hence, three extra scenarios are executed: with diagonal values of 0.9 and 1, and also a worst case scenario with diagonal values up to 0.7.

[3] The level of mixing is unclear, hence, assumptions have to be made to what extent VIaS/VIIb,c, VIaN and VIIaN fish mix during the feeding season. As low levels of mixing already have major implications for the restructuring of the SRR, values up to 25% mixing belong to the highest chosen during these scenarios, complemented with a 12.5%, 5% and no mixing scenario.

[4] Three different management targets have been chosen to evaluate management. Fishing mortalities of 0.2, 0.3 and 0.4 have been selected as it is assumed that these levels approximate respectively very precautionary to rather non-precautionary management targets.

**Table 4.2.6.1. Availability of populations to fisheries under different population mixing regimes expressed as percentages of the total population. Same percentages apply across all ages.**

| | VIaN Fishery | | |
|---|---|---|---|
| Mixing scenario | VIaN Population | VIaS/VIIb,c Population | VIIaN Population |
| 25% | 100 | 25 | 25 |
| 12.5% | 100 | 12.5 | 12.5 |
| 5% | 100 | 5 | 5 |
| 0% | 100 | 0 | 0 |

| | VIaS/VIIb,c Fishery | | |
|---|---|---|---|
| | VIaN Population | VIaS/VIIb,c Population | VIIaN Population |
| 25% | 0 | 75 | 0 |
| 12.5% | 0 | 87.5 | 0 |
| 5% | 0 | 95 | 0 |
| 0% | 0 | 100 | 0 |

| | VIIaN Fishery | | |
|---|---|---|---|
| | VIaN Population | VIaS/VIIb,c Population | VIIaN Population |
| 25% | 0 | 0 | 75 |
| 12.5% | 0 | 0 | 87.5 |
| 5% | 0 | 0 | 95 |
| 0% | 0 | 0 | 100 |

## 4.3 Results

Three different sets of results were obtained from the scenarios described above. Firstly we show the results of changing mixing scenarios, within calculated upper and lower bounds of feasible mixing levels. Secondly, the effects of identification problems in the survey (i.e. varying the confusion matrix) on management are described and, third, the outcomes of the design of the Malin Shelf survey are presented.

### 4.3.1 Effects of mixing scenarios

If populations mix during the fishing season, a fishery may catch a mixture of different populations, instead of only one. ICES stock definitions rely on the catch information provided through the fishery, and hence a discrepancy between ICES stock and populations occurs if the ICES stock consists of a mixture while the population does not (Kell *et al.*, 2009). This discrepancy carries into the stock–recruitment relationship where the spawning stock size is linked to recruitment it produces. With population mixing in a fishery, the abundance in the population does not equal the abundance estimate in the ICES stock and the productivity level of the ICES stock is different from the actual population.

When simulating mixing of populations, this difference in productivity should be accounted for. Within the simulation framework a Hockey-Stick stock recruitment model is used (Barrowman, 2000). The adjustment in productivity is shown graphically in Figure 4.3.1.1. For example, under mixing scenario 12.5%, the VIaN fishery has access to the full VIaN population and to 12.5% of both VIaS/VIIb,c and VIIaN populations. The catches derived from these populations all contribute to the perception of the VIaN ICES stock. Based on these catches, SSB has been estimated and linked by year to the recruitment produced. However, part of the recruits allocated to VIaN belonged in reality to the VIaS/VIIb,c or VIIaN populations. Hence, adjustments to the stock recruitment relationship for the VIaN ICES stock have to be made.

We distinguish three different ways to rescale the stock–recruitment relationship (see also Figure 4.3.1.1):

1) rescaling the asymptotic recruitment for each area. This implies that the carrying capacity of the populations is different. Overall, the carrying capacity and resilience of the whole area are maintained but populations available to fisheries other than within the ICES area they are named after will have a higher resilience and hence $F_{crash}$. Here it is assumed that a proportion of the recruits estimated in, e.g. VIaN in reality belonged to the VIaS/VIIb,c or VIIaN population, while spawning adults were accurately estimated. This option is considered to be more precautionary.
2) rescaling both SSB and recruitment parameters together, implying a proportional change in carrying capacity while maintaining the resilience within each area. This assumes that the number of recruits was estimated with a bias, hence the change in carrying capacity. As the number of spawning fish due to the mixing was estimated incorrectly too, the number of spawning adults producing the recruitment shifts as well.
3) rescaling the resilience of the population while maintaining carrying capacity. Here it is assumed that the recruitment estimated outside the mixing season is without bias and hence represents the actual recruits produced by a population. However, as SSB is estimated based on the catch, consisting of a mixture of populations, the inflection point of the

curve is shifted leftwards. This shift indicates a higher resilience for the population in the ICES area where mixing occurs.

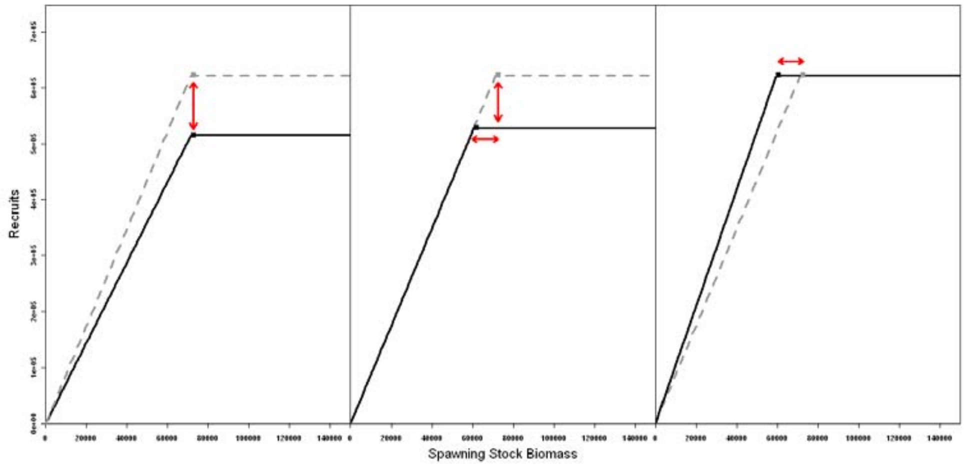



**Figure 4.3.1.1. Grey dashed line represents original Stock-Recruitment relationship while the black solid line represents the adjusted Stock-Recruitment relationship. Red arrows indicate the transition. Left panel: Graphical representation of productivity adjustment under mixing scenario 12.5% where the VIaN fishery has access to 12.5% of both the VIaS/VIIb,c and VIIaN population. As the VIaN fishery has access to more fish than solely the VIaN population, the productivity has consistently been overestimated. This because many recruits considered to be VIaN recruits were actually produced by the VIaS/VIIb,c and VIIaN populations. To compensate for this, the original stock recruitment model (grey dotted line) is lowered as is presented by the black solid line. Note however that due to this change the slope of the lines from the origin has altered as well, indicating a loss in resilience. Mid panel: Productivity adjustment under mixing scenario 12.5% including resilience correction. This correction also implies an SSB adjustment. Right panel: The adjustments made to the curve imply an adjustment in SSB, which reflects the correction of the extra catch in VIaN due to the availability of VIaS/VIIb,c and VIIaN fish to the VIaN fishery. However, recruits are estimated outside the feeding season, when populations do not mix, and are hence estimates without bias.**

In this study only option 1 was used. The increase in resilience for the VIaS/VIIb,c and VIIaN populations, and the decline in resilience in the VIaN population was specifically chosen to represent a more precautionary approach.

Using the population estimates for VIaN, VIaS/VIIb,c and VIIaN from the 2010 HAWG, estimates of the maximum proportions mixing with VIaN spawners and contributing to catches in the VIaN ICES stock have been made. As VIaS/VIIb,c and VIIaN ICES stocks do not have an agreed assessment the converged parts of exploratory assessments of these components were used up to 2005. The earliest common year available is 1970, so the period evaluated was 1970 to 2005 inclusive. The minimum mixing can always be zero, and if year on year variability of the proportion mixing is allowed, no estimate of the maximum can be made (below zero recruitment in VIaN). However, if we constrain the mixing to be two fixed factors, one for VIaS/VIIb,c and one for VIIaN, it is possible to obtain an estimate of the maximum transfer. The basis of this is to maximize the total number of herring transferred in all years based on a condition to not exceed the total population of VIaN in any year. Such a maximum implies zero indigenous herring in VIaN in that year. Two ways of doing this were tested, one based on the recruiting year class at age 1 winter ring (wr), which ignores mortality in the fisheries and one based on the ages contributing most (>60%) to the catch in VIaN , ages 2–4 wr. The resulting factors are very similar and are given in Table 4.3.1.1. Figure 4.3.1.2a shows the numbers of recruits (age 1 wr) in VIaS/VIIb,c, VIIaN and VIaN along with the maximum fixed ratio transfer. Figure 4.3.1.2.b shows the resulting maximum proportions of all immigrant herring contributing to catches in VIaN by year. The limiting maximum occurs in two years, 1990 and 1993.

**Table 4.3.1.1. Range of constant fractions of herring (by number) that could be contributing to catches in VIaN, Based on recruitment-at-age 1 wr or on catches ages 2–4 wr**

| | Minimum fraction | Maximum fraction | |
|---|---|---|---|
| | | Recruits (1wr) | Ages 2–4 wr |
| VIIaN | 0 | 0.17 | 0.15 |
| VIaS/VIIb,c | 0 | 0.31 | 0.30 |

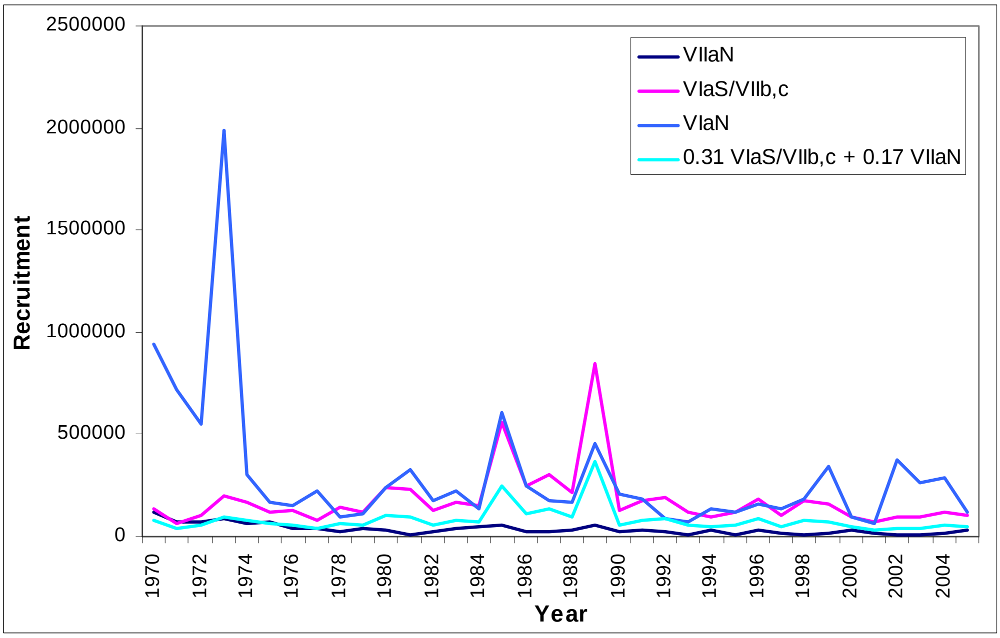
The effects of population mixing on ICES stock management is best evaluated over a range of mixing levels while other processes, such as survey confusion or change in exploitation level, are kept constant. Figure 4.3.1.3 gives an overview of the four different mixing scenarios and the development of SSB in the ICES stocks related to the development in SSB in the populations. These 'standardized' plots show that whenever there is no mixing between populations (0% column), each ICES stock's SSB development is nearly the same as its population's and is hence positioned on top of the y=1 line. However, when mixing levels increase (from column 5% to 25%), the divergence between the ICES stocks and the populations increases too, i.e. the lines do not remain on top of the y=1 line.

The VIaN ICES stock is assessed to be bigger than the VIaN population, which is mainly driven by the catch-at-age matrix. The catch of the VIaN fishery comprises a mixture of VIaN, VIaS/VIIb,c and VIIaN fish and follows the cohort decays in numbers-at-age in the populations, as they are all targeted at a similar fishing mortality. Therefore, the assessment estimates the VIaN ICES stock fishing mortality to be similar to the realized population fishing mortality. However, due to the larger catch in VIaN, which is bigger than the catch that could have been realized when fishing only on the VIaN population with similar fishing mortality, the productivity of the ICES VIaN stock is overestimated as well. Therefore, estimated recruitment in the VIaN ICES stock is larger than in the VIaN population. The opposite is true for the VIaS/VIIb,c and VIIaN ICES stocks that are estimated to be smaller than the actual population size. Here the catches of the VIaS/VIIb,c and VIIaN fisheries only account for either 95, 87.5 or 75% of the total population sizes, while again fishing mortality estimates in the assessments are similar to the realized fishing mortality on the populations.

### 4.3.2 Effects of identification problems

Some samples of fish in the survey catch are difficult to allocate to their spawning population and, consequently, may be incorrectly allocated to another spawning population. Accordingly, the age composition obtained from the survey might be biased. These identification problems have been evaluated for four different levels: an identification success rate of 0.7, 0.8, 0.9 and 1 per fish. That is to say, if a fish belongs to the VIaN population, there is, under a success rate of 0.8, a 10% chance that it is identified as being a VIaS/VIIb,c fish or a 10% chance that it is identified as a VIIaN fish. The effect of misidentification in the survey is shown graphically in Figure 4.3.2.1a.

a)




b)

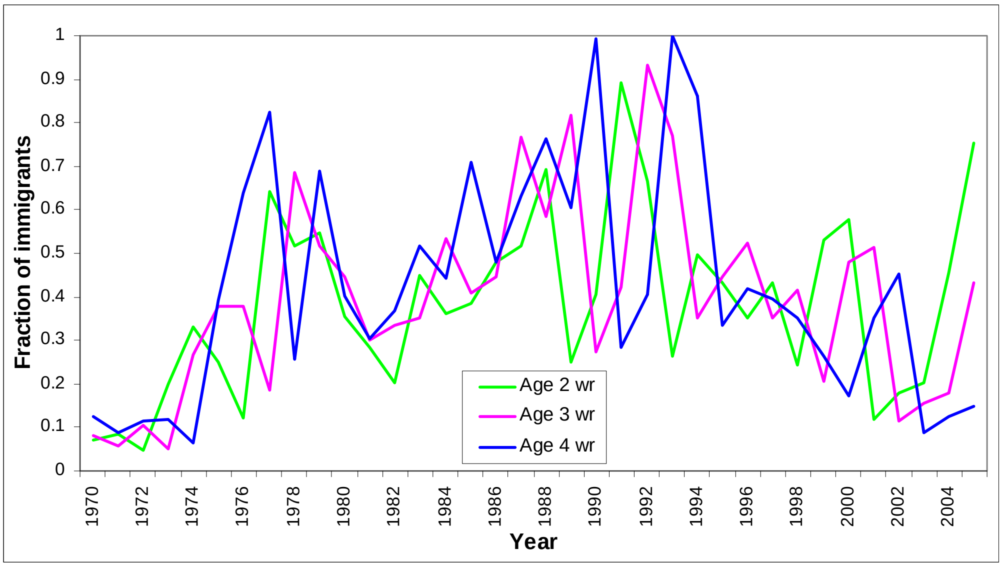



**Figure 4.3.1.2. Maximum fixed ratio movement of herring from VIaS/VIIb,c and VIIaN populations into VIaN ICES stock based on maximizing the total but not exceeding the VIaN population. a) maximum based on recruits (1 winter ring (wr)). b) maximum of catch-at-ages most important ages contributing to catch (ages 2,3 and 4 wr).**

Higher levels of misidentification result in less distinct age patterns per population in the survey. These errors propagate through to the assessment. Populations are especially prone to these errors when their abundances differ considerably. In the case of the VIaN population which, under the model parameters here, is approximately twice as small as the VIaS/VIIb,c population (see Figure 4.3.2.1b), high misidentification rates (0.7) result in a survey view dominated by the dynamics of the VIaS/VIIb,c population. After splitting the Malin Shelf survey catch into a VIaN and a VIaS/VIIb,c age composition index, the VIaN index contains 30% of VIaS/VIIb,c fish due to the misidentification in the survey. The 30% of VIaN fish accounted for in the VIaS/VIIb,c index however, is much smaller. Hence, the VIaN index is driven by the VIaS/VIIb,c abundance in the survey catch, while the opposite is not true. The effect of misidentification becomes apparent because the VIaN population is exploited at an unsustainable level (fishing mortality of 0.3), while the VIaS/VIIb,c population stabilizes in the future period. The VIaN survey index communicates a stabilizing population for the VIaN population, as this is the pattern in the VIaS/VIIb,c population. However, as the VIaN population is overexploited, it rapidly declines resulting in a diverging pattern between VIaN population trends and VIaN ICES stock trends. When misidentification levels drop, as in columns 0.8 and 0.9, the trends of the VIaN population become clearer which results in better management and hence less rapid declines in the population. If population abundances, sampled in a combined survey, are of similar size, misidentification will have less effect as the total number of misidentified fish is equal in all survey indices and the displacement of misidentified fish from one to the other index equals out (and vice versa). The VIIaN population has its own survey in this specific case (discussed below), and hence is not affected by the misidentification problem.

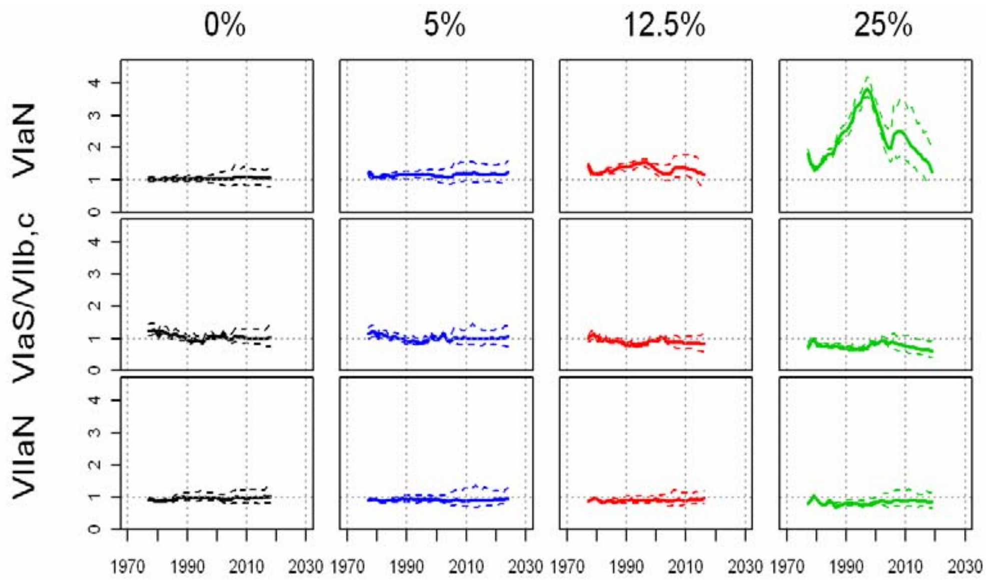
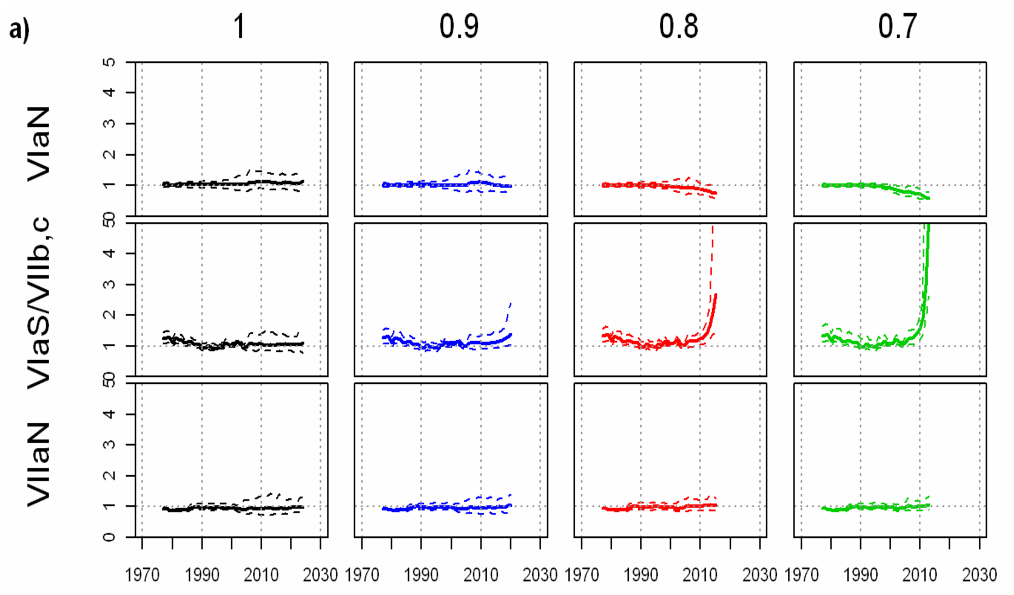



**Figure 4.3.1.3. Observed development in SSB relative to simulated development for the three ICES stocks (by row VIaN, VIaS/VIIb,c and VIIaN respectively) under different percentages of mixing (with the fishery in VIaN mixed with 0, 5, 15 and 25% of VIaS/VIIb,c and VIIaN respectively by column). Medians are solid lines and 2.5 and 97.5 percentiles dotted lines. Values above the y=1 line indicate overestimation of the observed ICES stock in relation to the simulated population, while values below 1 indicate an underestimation. The surveys used for tuning the stock assessments in these simulations were based on two surveys; a Malin Shelf survey split for VIaN and VIaS/VIIb,c ICES stocks; and a separate VIIaN survey. Exploitation levels were at a sustainable level of F3–6 =0.2. The accuracy of splitting the Malin Shelf survey between stocks was based on a 100% identification success and a sampling total of 1500 fish.**



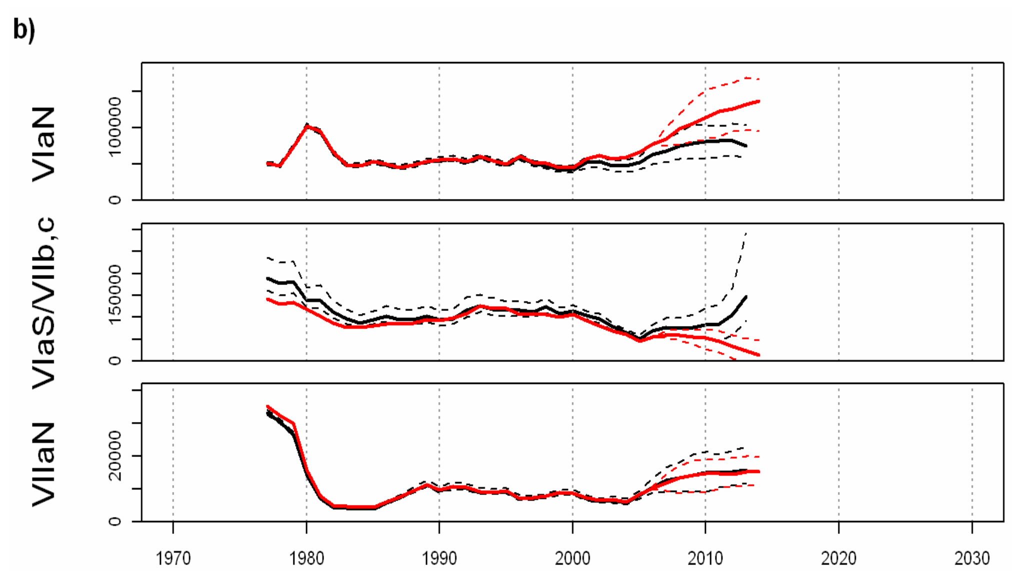




**Figure 4.3.2.1.a. Observed development in SSB relative to simulated development for the three ICES stocks (by row VIaN, VIaS/VIIb,c and VIIaN) under different identification success rates (with identification success to split the survey catch into spawning population of 1, 0.9, 0.8 and 0.7 respectively by column). Showing median (solid lines) and 2.5 and 97.5 percentiles (dotted). Values above the y=1 line indicate overestimation of the observed ICES stock in relation to the simulated population, while values below 1 indicate an underestimation. The surveys used for tuning the stock assessments in these simulations were based on two surveys; a Malin Shelf survey split for VIaN and VIaS/VIIb,c ICES stocks; and a separate VIIaN survey. Exploitation levels were at a sustainable level of F3–6 =0.3. The level of mixing between stocks was set to 0 and a sampling total of 1500 fish was used.**

**Figure 4.3.2.1.b. Panels show the development in SSB according to the ICES stock (in black, 95% CI in black dashed lines) and the populations (in red, 95% CI in red dashed lines). Scenario settings are similar to Figure 3a column 0.7.**

### 4.3.3 Malin Shelf survey design

The simulated Malin Shelf survey within this study sampled either the combination of the VIaN and VIaS/VIIb,c populations or the combination of the VIaN, VIaS/VIIb,c and VIIaN populations at the same time in the year. A fraction of the total abundance of all populations was sampled and split into three different index series which were used within the assessment. In reality sample size is relatively small, i.e. 1500 age samples within a year. These 1500 samples are identified and hence binned into three index series each containing 9 age groups. The number of samples taken from one spawning population is related to the abundance of that spawning population, and hence, smaller numbers of samples are taken from the smaller spawning populations (note that this survey design assumes perfect spatial and temporal mixing combined with random sampling). This in turn distorts the age composition in the survey indices. The distortion has most effect on the index of the smallest population being surveyed, as the survey catch will be dominated by the bigger populations, as a result of which only a few samples remain to derive an age composition for the smaller populations. However, within the current framework, the survey implementation error was obtained directly from the assessments. Within the VIIaN assessment in particular this error was highly skewed towards 1-year olds and hence distorted the age pattern in the survey. Therefore, hardly any difference can be observed in Figure 4.3.3.1a where the effect on management of four different sample sizes has been evaluated. An alternative evaluation of sample size was undertaken and is shown in Figure 4.3.3.1c; this indicated that the age pattern in the VIIaN survey index is highly variable at low sample sizes and reduces towards higher sample sizes. In the VIaN and VIaS/VIIb,c survey index, variation is already much lower at low sample sizes.

Figure 4.3.3.1b shows clearly that the trends in the VIIaN population are not captured at all by the VIIaN assessment when only 1500 samples are taken within the survey; this is also partly due to the survey implementation error. The VIIaN assessment is almost completely driven by the dynamics of the VIaN and VIaS/VIIb,c populations which indicate a stable development of SSB over time. As the VIaN and VIaS/VIIb,c population are, under the model parameters here, approximately of the same size, trends in both the VIaN and VIaS/VIIb,c populations are picked up which result in accurate assessments. However, the VIIaN population does not stabilize, although its survey index communicates this development as it is driven by the VIaN and VIaS/VIIb,c survey catch, and hence the VIIaN assessment estimate is different from the VIIaN population. The rapid increase in VIIaN population size can partly be explained by the resilient population dynamics combined with low fishing pressure which allows the population to expand in size over time. However, if the population would be harvested at higher rates the population might decline markedly without it being noticed.

The scenarios described in the results section most clearly indicated the dynamics of the metapopulation when we tried to manage the stocks sustainably at different levels of fishing mortality, levels of mixing or survey design and sample size in the survey. These scenarios were designed in such a way that only one of these aspects was varied, resulting in distinct results. However, all combinations of the four scenario aspects have been evaluated as well. As they do not contribute any further to the understanding of the metapopulation dynamics, they are not included or discussed in the results section. They are, however, listed in Annex 4 for reference purposes.

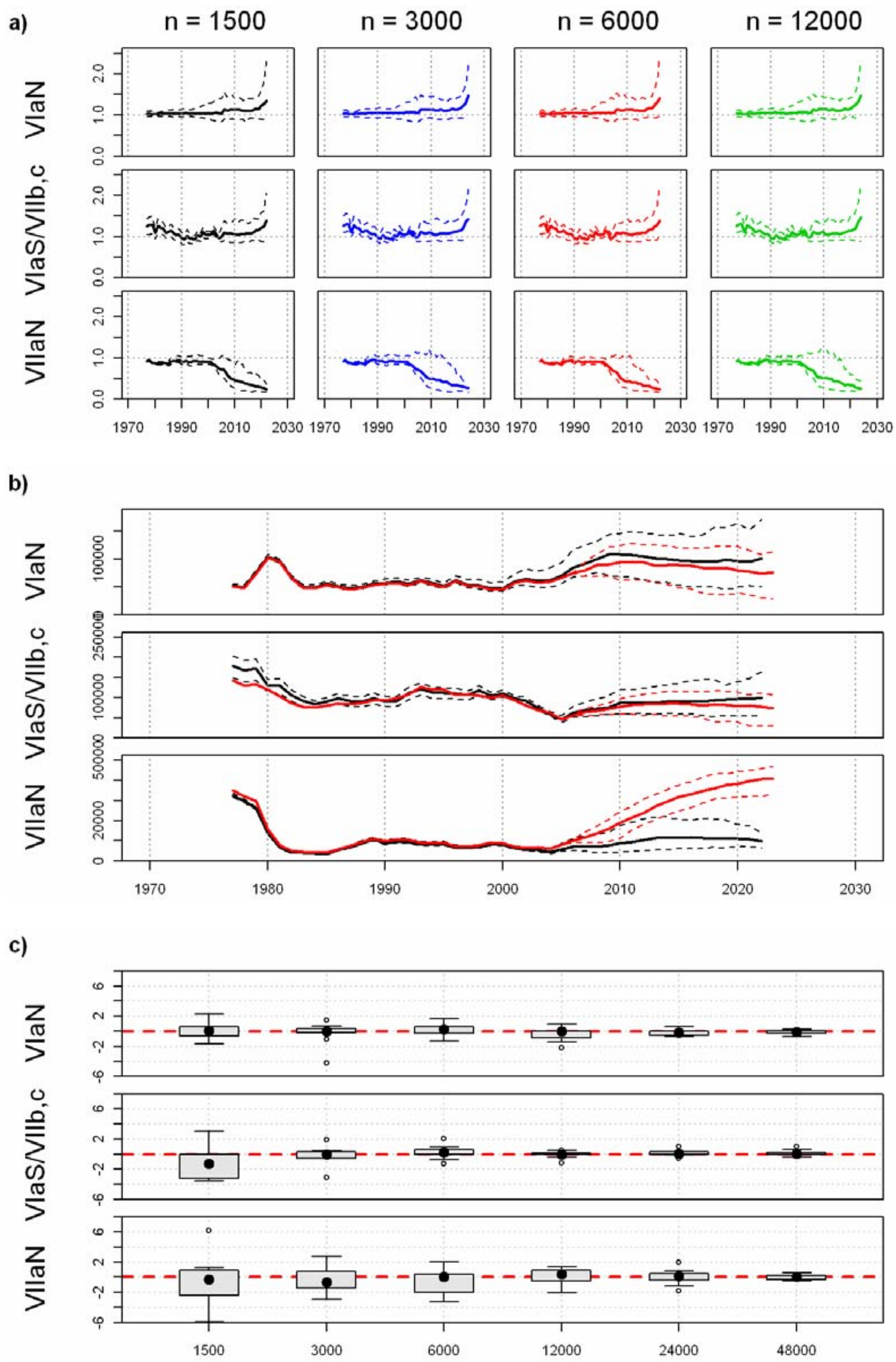



**Figure 4.3.3.1a. Observed development in SSB relative to simulated development for the three ICES stocks (by row VIaN, VIaS/VIIb,c and VIIaN) under different sample sizes in the survey (with sample sizes of 1500, 3000, 6000 and 12000 respectively by column). Showing median (solid lines) and 2.5 and 97.5 percentiles (dotted). Values above the y=1 line indicate overestimation of the observed ICES stock in relation to the simulated population, while values below 1 indicate an underestimation. The surveys used for tuning the stock assessments in these simulations were based on one survey; a Malin Shelf survey split for VIaN, VIaS/VIIb,c and VIIaN ICES stocks. Exploitation levels were at a sustainable level of F3–6 =0.2. The level of mixing between stocks was set to 0 and identification success was set to 1.**

**Figure 4.3.3.1b. Panels show the development in SSB according to the ICES stock (in black, 95% CI in black dashed lines) and the populations (in red, 95% CI in red dashed lines). Scenario settings are similar to Figure 4a column n=1500.**

**Figure 4.3.3.1c. Boxplots show the deviance of the true age-pattern for all age groups within the Malin Shelf survey. The x-axis indicates the number of samples taken in the Malin Shelf survey. Exploitation levels were at a sustainable level of F3–6 =0.2. The level of mixing between stocks was set to 0 and identification success was set to 1.**

**Red lines indicate no average deviance from the true age-pattern in the survey. The first and third quantile at each sample size are represented by the shaded boxes, while minimum and maximum observations, not being outliers, are represented by the dotted vertical lines. Outlying results (more than 1.5 times the interquantile distance away from the 1st or 3rd quantile) are represented by open circles.**

## 4.4 Discussion

The successful management of populations that are caught as a mixture in both landings and surveys poses several problems. That is, the information obtained from the fisheries does not represent the actual population sizes and the fisheries independent data might have a similar bias too. In the latter situation, due to identification problems, the population estimates might be distorted even more. This study identifies how, under these circumstances, sustainable management is still possible (see Figure 4.4.1).

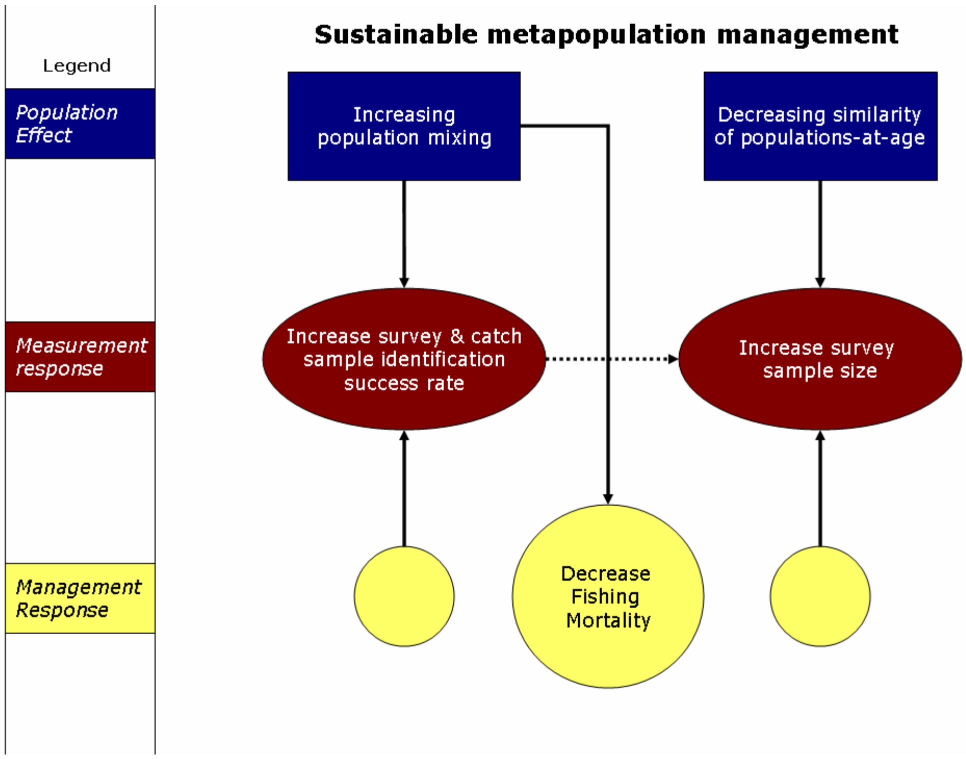



**Figure 4.4.1. Population and management relationships for sustainable metapopulation management. Square boxes represent the biological subcomponents of the metapopulations. The ovals represent measurements taken from the metapopulation while the circles indicate possible management responses. Solid arrows represent direct cause-and-effect relationships while dashed arrows indicate possible cause-and-effect relationships to improve sustainable metapopulation management. The multiple arrows originating from the 'increasing population mixing' box can exist next to each other.**

Managing populations that are caught as a mixture by the fisheries does not pose many problems as fishing mortalities are estimated to be very similar to the realized fishing mortality on the populations. However, stock abundances will be incorrectly estimated, which could have implications when stocks are managed by biomass reference levels (Bartley *et al.*, 1996). The determination of these reference levels, and the precautionary approach they are related to (Garcia, 1994), largely depends on the current understanding of the productivity of these stocks. Due to population mixing both the spawning-stock biomass and recruitment might be incorrectly estimated, as a result of which population productivity changes. When left uncorrected, this results in the determination of inaccurate reference points. If only SSB or recruitment are estimated incorrectly this could have major implications, as resilience of the populations (Holling, 1973; Scheffer *et al.*, 2001) is under- or overestimated. When proposing TACs for these mixed populations, productivity needs to be known, especially if MSY is set as a management target.

In the herring to the west of the British Isles case study, however, further issues for management arise because, as well as the emerging mixture of the catch there is also difficulty in identifying spawner type from the fisheries independent data. Although using different techniques (Campbell *et al.*, 2007; Clausen *et al.*, 2007; Burke *et al.*, 2008; Geffen *et al.*, Submitted) can result in an identification success of nearly 90% (sensitivity and specificity of 0.9 – Altman and Bland (1994); the WESTHER project, Anon. (2006); Bierman *et al.* (2010)), the remaining incorrectly identified 10% could cause serious management problems. These problems become especially apparent when population abundance differs greatly within the metapopulation, or if the age composition between populations is significantly different. In these situations, the inability to perfectly classify all fish results in a survey index driven by the more abundant year classes or populations covered by the survey. Accordingly, the individual stock assessments will only provide accurate information on the most abundant populations, whereas even a small misidentification rate can result in the complete misperception of population abundance by the assessment method. This has the potential to result in the extinction of one of the subcomponents of the metapopulation. However, when population abundance is approximately half the size of the most abundant population, management under an identification success rate of 0.9 is possible, even when exposed to higher fishing mortalities. When identification levels drop from e.g. 0.9 to 0.8, fishing mortality has to come down by more than 0.1.

Population-at-age dissimilarity in a metapopulation can already distort individual population trends when these are obtained from metapopulation fisheries dependent (Kell and Bromley, 2004) or independent surveys with low sample sizes. As the survey samples are dominated by the more abundant populations, assuming temporal and spatial homogeneity of the survey, under low sample sizes proportions-at-age of the smaller populations are estimated with very low precision due to the low amount of samples allocated to the smaller populations.

However, sample size is not able to counter the effects of misidentification in the survey as long as there is spatial and temporal homogeneity in the survey. This is because the fraction of misidentified fish remains the same and hence causes the indices of smaller populations to be dominated by the larger populations as the flow of misidentified fish from the large into the small population index is greater that the opposite direction. However, under larger sample sizes it becomes possible to neglect fish where no distinct identification is possible, and hence increases the identification rate while population-at-age patterns in the survey still resembles true population-at-age patterns.

In case neither the sample size can be increased nor the identification success improved, fishing mortality needs to decline to realize sustainable management. Fishing mortality should be reduced to levels which are appropriate to the least resilient population to prevent an increased risk for it to go extinct.

The model framework put in place here is a simplification of the real population dynamics of the herring stocks to the west of the British Isles. Although it resembles the characteristics used within current assessments for these ICES stocks, reconstruction of the historic part of the ICES stocks is based only on fishing patterns rather than on fishing patterns and catches. For the evaluations exhibited in this study, these reconstructions have proven to be helpful in determining sustainable management possibilities. Conversely, it makes it more difficult to give exact quantitative management suggestions for the near future, although this has never been the intention of this and related studies (Hilborn, 2003; Kell *et al.,* 2009; Kerr *et al.*, 2010). The simplifications also incorporate assumptions on levels of mixing and recruitment dynamics. Four different possible mixing levels have been evaluated. However, there are biological limits to the possible percentage of mixing. In this study, the VIaN ICES stock perception was fed by the VIaN, VIaS/VIIb,c and VIIaN populations. However, in the 25% mixing scenario, it is assumed that the VIaN population was at all times bigger than 25% of the VIaS/VIIb,c, and VIIaN population together. This was proven to be true for the current VIaN ICES stock perception; however, there is a potential risk that this assumption does not hold for the actual historic VIaN population. Additionally, the stock recruitment relationship can be reconstructed in different ways, such as the three options described in the results section (4.3 above). The potential of sustainable management relies, for a large part, on the assumed productivity of the populations (Piet *et al.,* in prep) and their behaviour at low spawning biomass estimates (Frank and Brickman, 2000; Nash *et al.,* 2009). These assumptions especially could alter the quantitative results described here.

This study has shown that managing metapopulations is only possible with detailed information on fisheries independent data. However, whenever subcomponents of the metapopulation differ considerably in abundance, sustainable management is impossible for the smallest subcomponent. Individual sustainable management of similar sized subcomponents is possible under high levels of mixing and survey misidentification rates. However, in these situations fishing mortality should be considerably reduced.

Neither mixing of populations nor population-at-age dissimilarity in metapopulations cannot be controlled. It is, therefore, essential to improve the identification of the populations from fish samples obtained from surveys. Only then, and in combination with the appropriate sample sizes of these surveys, metapopulation management will be possible.

## 4.5 Conclusions

The three main management tools evaluated in this study are: changing the target fishing mortality, altering the identification success and increasing the sample size taken in the Malin Shelf metapopulation survey. These tools do not, under all conditions, suffice to manage the metapopulation sustainably. In none of the scenarios where the VIIaN population is included in the Malin Shelf survey can the VIIaN ICES stock be sustainably managed. The population-at-age dissimilarity between populations in the Malin Shelf survey, where the VIIaN population is by far the smallest, causes the VIIaN ICES stock dynamics to be driven by the larger VIaN and VIaS/VIIb,c ICES stock dynamics. This is due to low sample sizes as well as the identification success rates being less than perfect (i.e. less than one). Even under low fishing pressure, the dynamics will not be clear enough to sustainably manage the VIIaN ICES stock and prevent it from extinction (Smedbol and Stephenson, 2001). The current setup of the framework, however, did not allow for an extensive testing of sample size on management success as the survey implementation error was completely driven by poorly estimated 1-year old fish and altered the survey index for VIIaN to such an extent that survey patterns obtained were not sensitive to an increase in sample size.

Managing the VIaN and VIaS/VIIb,c ICES stocks sustainably under different mixing scenarios and misidentification levels is possible. It should be noted, however, that although these stocks differ in their proportions-at-age, they are much closer to each other in total abundance than to the VIIaN ICES stock. This is of great importance for the ability to manage them. Under relatively high mixing levels of 12.5%, estimated SSB for both ICES stocks is close to reality while fishing mortality is estimated with a high level of accuracy. Even when identification success rates are as low as 0.7, both ICES stocks can be managed sustainably, although SSB estimates no longer approximate the true SSB. Hence, biomass reference levels will no longer be appropriate. Under these circumstances, however, fishing mortality should be kept at low levels (0.2) to manage sustainably as the VIaN population has lost part of its productivity and resilience due to mixing and cannot survive from constant high fishing pressure. Whenever identification rates increase, fishing mortality may also be increased. However, a 0.2 increase in identification success could be accompanied by an increase in F of approximately 0.1 while maintaining sustainable management.

When the VIaN and VIaS/VIIb,c populations only mix within the survey where they are prone to identification problems, and not in the fishery, fishing mortality can be as high as 0.3 and maintain sustainability within both the VIaN and VIaS/VIIb,c populations under identification success rates of 0.8. Whenever identification success rates drop below 0.8, e.g. to 0.7, fishing mortality has to be reduced by more than 0.1 year$^{-1}$.

# 5 Towards a Malin Shelf acoustic survey

The Study Group was asked to evaluate the utility of a synoptic acoustic survey in the summer for the Hebrides, Malin and Irish shelf areas, in conjunction with the WGIPS surveys of VIaN and the North Sea. This evaluation is based on results of a combined survey programme in 2008 and 2009, and an analysis of time-series of existing surveys in the area.

## 5.1 Malin Shelf acoustic survey results

The synoptic survey of what is currently considered the Malin Shelf metapopulation of herring was for the first time carried out in 2008 and again in 2009, with participating vessels from Scotland (FV *Chris Andra* and FV *Quantus*), Northern Ireland (RV *Corystes*) and Ireland (RV *Celtic Explorer*). The survey was an extension of the existing west of Scotland time-series to cover ICES divisions VIaS and VIIb (*Celtic Explorer*) and the Clyde and North Channel (*Corystes*). The VIaS/VIIb survey was a replacement to a winter spawning area survey. That winter survey was discontinued in 2007, being of no utility for tracking the development of the stock. The VIaN/North Channel/Firth of Clyde survey was completely new.

Transect interlacing was incorporated into the coordinated survey design in 2008 in the boundary regions of VIaN and VIaS and in the southern area of VIaN in the approaches to the Northern Channel. In the latter area all three vessels allocated survey effort. In 2009, planned transect interlacing between Scotland and Ireland (55.5°N - 56.5°N) and Ireland and Northern Ireland (east of 7°W in the North Channel) was not possible as Ireland was not granted permission to enter UK waters. Temporal synchrony was achieved between the Scottish and Irish vessels in the western area but a time-lag was again noted with the RV *Corystes* in the North Channel and its approaches. This time was addressed prior to the 2010 summer survey to ensure closer harmony between surveys.

**Table 5.1.1. Component surveys of the Malin Shelf metapopulation, conducted in 2008 and 2009.**

| VESSEL | AREA | RECTANGLES |
|---|---|---|
| Celtic Explorer (IR) | 2008: 52°30'-56°N, 12°-6°W<br>2009: 53°-56°N ,12°-7°W | 34D9-E0, 35D9-E0, 36D9-E0, 37D9-E1, 38D9-E1, 39E0-E3, 40E1-E3<br>35D8-D9, 36D8-D9, 37D9-E1, 38D9-E1, 39E0-E2, 40E0-E2 |
| Chris Andrea, Quantus (SCO) | 55°30'-60°30'N, 4°-10°W | 41E0-E3, 42E0-E3, 43E0-E3, 44E0-E3, 45E0-E4, 46E2-E5, 47E2-E5, 48E4-E5, 49E5 |
| Corystes (NIR) | Clyde/North Channel | 40E3–40E5, 39E3-E5, 38E4 |

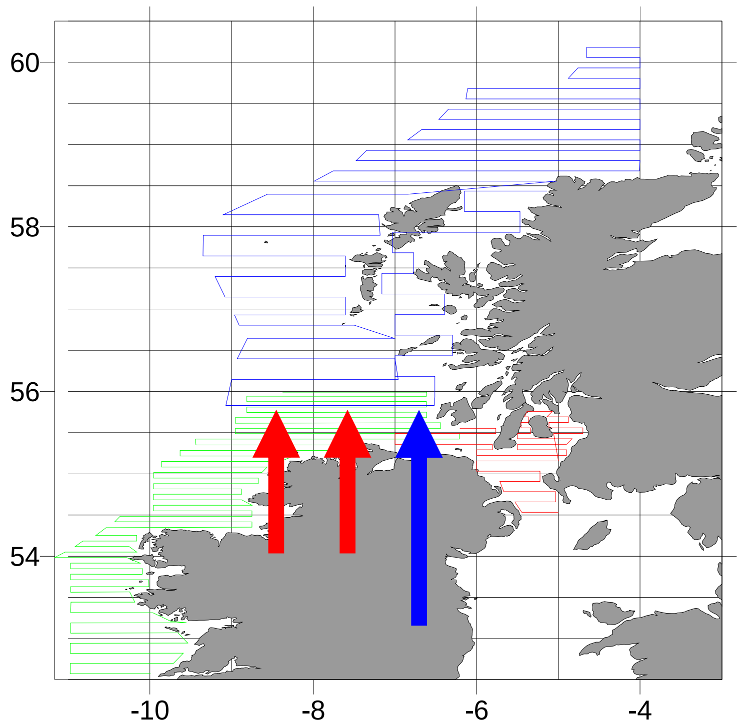



**Figure 5.1.1. Cruise tracks for the Malin shelf survey July 2008 (green RV Celtic Explorer (Republic of Ireland); red RV Corystes (Northern Ireland); blue MFV Chris Andra (Scotland)). Red arrow indicates 2 vessels transect interlacing, blue represents 3 vessel interlacing.**

The synoptic surveys in 2008 and 2009 provide estimates comprising four stocks to the west of the British Isles: the west of Scotland herring stock in Division VIaN (identified in ICES as her-vian); the Clyde stock (her-clyd); the stock in Division VIaS and VIIbc (her-irlw) and the Irish Sea stock (her-nirs). The Malin Shelf survey results were combined in the same manner as those in the North Sea, with weighting applied to individual survey estimates at ICES statistical rectangle according to the amount of survey effort in the rectangle measured in nautical miles (Figures 5.1.1 – 5.1.2).

The NASC density distribution of Malin Shelf herring in 2008 and 2009 from the three surveys is given in Figures 5.1.3 – 5.1.4.

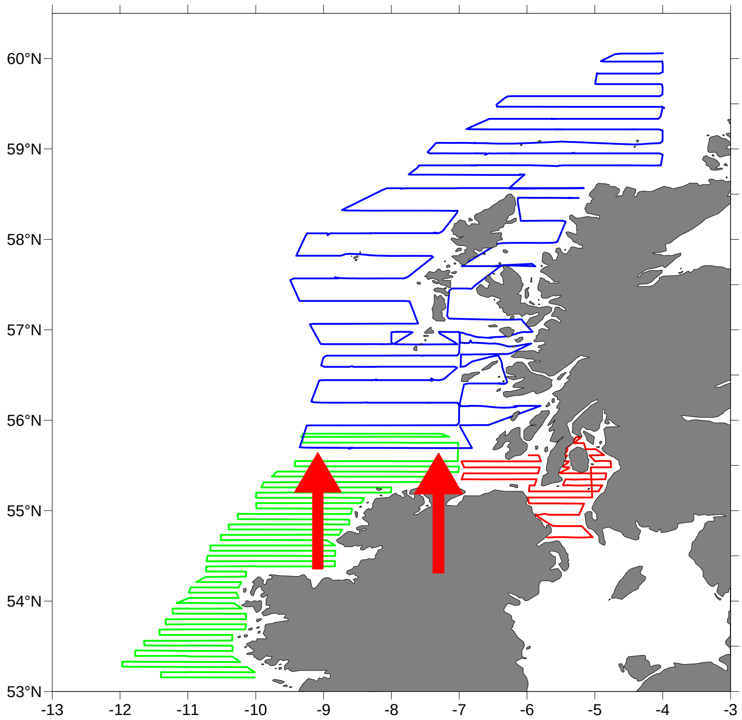



**Figure 5.1.2. Cruise tracks for the Malin Shelf survey June/July 2009 (green RV Celtic Explorer (Republic of Ireland); red FV Quantus (Scotland); blue RV Corystes (Northern Ireland)). Red arrow indicates 2 vessels transect interlacing.**

In 2008, the Malin Shelf estimate of SSB was 826 000 tonnes and 4 007 million fish (Table 5.1.2), largely dominated by the VIaN estimate (788 000 t). At the time of the WGIPS meeting in January 2010, no survey results were available from the RV *Corystes* survey. These survey results were added in March 2010. The SSB survey estimate in 2009 was 593 000 tonnes and 2 647 million fish and again dominated (98%) by the VIaN estimate (Table 5.1.3). In 2009, the VIaN estimate is lower compared to the previous year, which was the second highest in the time-series. In both years the VIaN survey did not detect many immature fish. The youngest year class observed in the survey in 2009 represents the strongest of the past four years. To ensure that the VIaN results were consistent with the time-series, they were derived from squares above 56°N only.

The spatial distribution of mature Malin Shelf herring in 2008 and 2009 is given in Figure 5.1.5. In general, the spatial distribution is highly comparable between both years, with a somewhat more pronounced preference of northern latitudes in 2009.

The 2008 RV *Corystes* survey caught only immature fish and therefore contributed no mature biomass to the SSB estimate. This was also the case in 2009. The corresponding distribution for immature herring is shown in Figure 5.1.6. While juveniles are still abundant in the North Channel, they also tend to migrate further west compared to the relative distribution in 2008. In both survey years, juvenile fish in the Malin Shelf survey were exclusively found south of 57°N.

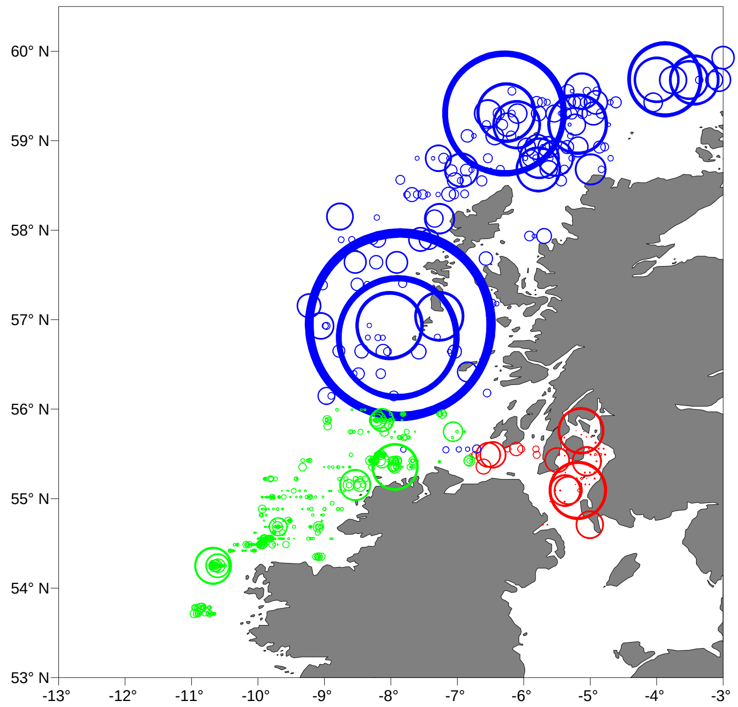



**Figure 5.1.3. Post plot of the distribution of total herring nautical area scattering coefficient (NASC) values (circle size is proportional to NASC but only within a survey) obtained from the three hydroacoustic surveys carried out in June/July 2008. Relative NASC comparisons are approximate and scaled to a maximum value of 7 500. Blue circles MFV Chris Andra, green circles RV Celtic Explorer and red circles RV Corystes.**

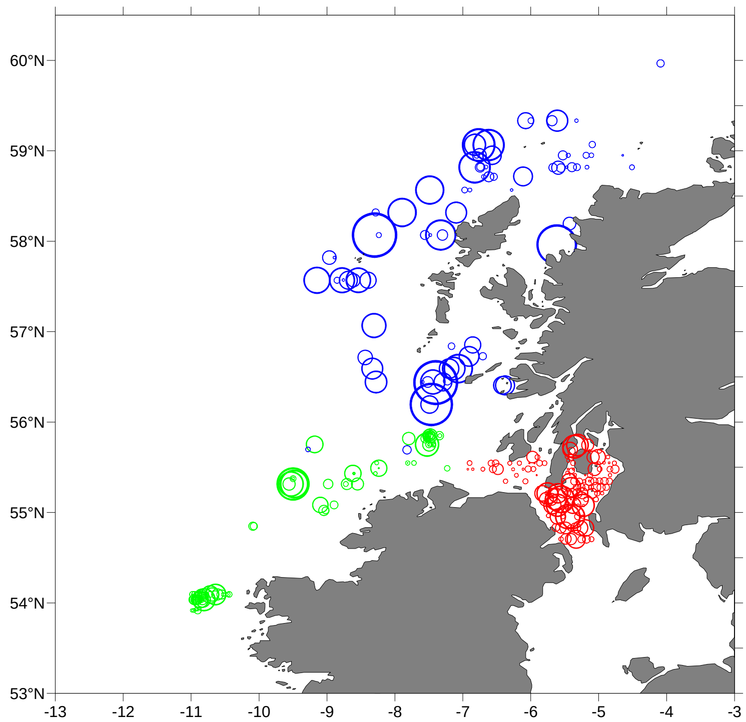



**Figure 5.1.4. Post plot of the distribution of total herring nautical area scattering coefficient (NASC) values (circle size is proportional to NASC but only within a survey) obtained from the three hydroacoustic surveys carried out in June/July 2009. Relative NASC comparisons are approximate and scaled to a maximum value of 7 500. Red circles FV Quantus, green circles RV Celtic Explorer and blue circles RV Corystes.**

**Table 5.1.2. Total numbers (millions of fish) and biomass (thousands of tonnes) of Malin Shelf herring in the area surveyed in the acoustic surveys July 2008, with mean weights, mean lengths and fraction mature by age ring.**

| AGE ( WINTER RING) | NUMBERS | BIOMASS | MATURITY | WEIGHT(G) | LENGTH (CM) |
|---|---|---|---|---|---|
| 0 | | | | | |
| 1 | 425 | 27 | 0.01 | 63.4 | 19.5 |
| 2 | 377 | 56 | 0.76 | 147.5 | 25.1 |
| 3 | 1000 | 189 | 1.00 | 188.7 | 27.1 |
| 4 | 718 | 149 | 1.00 | 207.0 | 27.9 |
| 5 | 362 | 77 | 1.00 | 213.6 | 28.2 |
| 6 | 286 | 61 | 1.00 | 214.9 | 28.1 |
| 7 | 721 | 159 | 1.00 | 220.6 | 28.5 |
| 8 | 366 | 82 | 1.00 | 224.2 | 28.6 |
| 9+ | 264 | 63 | 1.00 | 238.5 | 29.2 |
| Immature | 510 | 36 | | 70.6 | 20.1 |
| Mature | 4007 | 826 | | 206.2 | 27.8 |
| Total | 4517 | 862 | 0.89 | 190.9 | 27.0 |

**Table 5.1.3. Total numbers (millions of fish) and biomass (thousands of tonnes) of Malin Shelf herring in the area surveyed in the acoustic surveys July 2009, with mean weights, mean lengths and fraction mature by age ring.**

| AGE ( RING) | NUMBERS | BIOMASS | MATURITY | WEIGHT (G) | LENGTH (CM) |
|---|---|---|---|---|---|
| 0 | 4108 | 15 | 0.00 | 3.63 | 7.6 |
| 1 | 1299 | 68 | 0.00 | 52.0 | 18.1 |
| 2 | 265 | 38 | 0.67 | 143.3 | 24.5 |
| 3 | 274 | 56 | 0.99 | 204.1 | 27.4 |
| 4 | 444 | 98 | 1.00 | 222.1 | 28.2 |
| 5 | 380 | 89 | 1.00 | 233.0 | 28.6 |
| 6 | 225 | 52 | 1.00 | 231.5 | 28.6 |
| 7 | 193 | 45 | 1.00 | 232.4 | 28.6 |
| 8 | 500 | 116 | 1.00 | 232.3 | 28.6 |
| 9+ | 456 | 109 | 1.00 | 238.2 | 28.8 |
| Immature | 5 497 | 92 | | 16.7 | 10.3 |
| Mature | 2 647 | 593 | | 224.1 | 28.3 |
| Total | 8 144 | 685 | 0.32 | 84.1 | 16.2 |

## 5.2 Evaluation of the Malin Shelf Survey

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 a time-series for tuning assessments of the Malin Shelf stock complex constituents. However, such a time-series will not be available for a number of years. It should be noted that work in developing a new survey programme does not interfere with the tuning index time-series for any current stock. The current assessments can continue uninterrupted, until such a time-series is built up and until it was evaluated for its utility in tuning. This may need 4 or 5 years of continuous survey data.

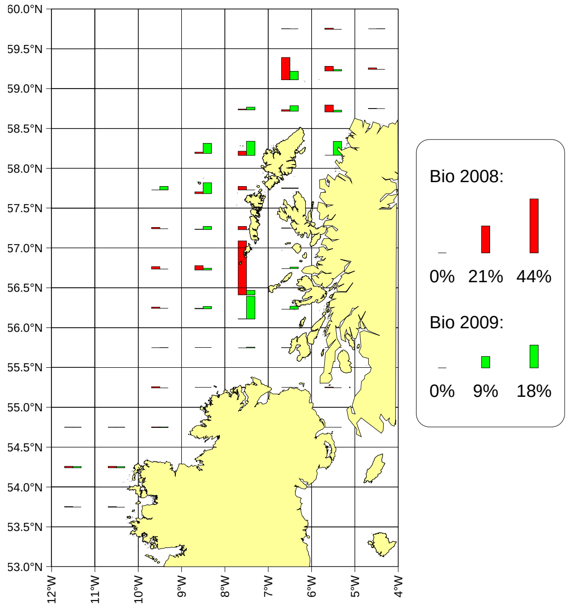



**Figure 5.1.5. Comparison of herring spawning biomass (1 000 t) per rectangle in 2008 and 2009. The biomass per rectangle is given as percentage of total SSB for each specific year.**

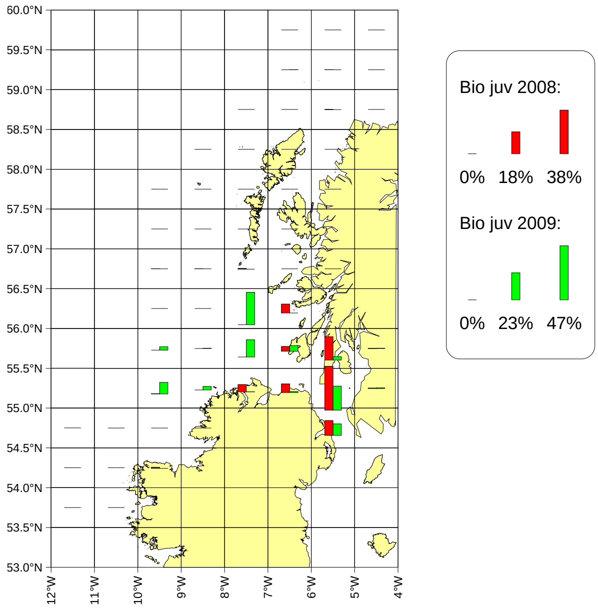



**Figure 5.1.6. Comparison of biomass of immature herring (1 000 t) per rectangle in 2008 and 2009. The biomass per rectangle is given as percentage of total biomass of immature fish for each specific year.**

The VIaS/VIIb,c sub-survey may also provide a separate tuning index for that stock component, in time. A summer survey is considered a better index, because the fish are less contagiously distributed. However, it is unclear what the spatial extent of that stock is during summer.

The amount of mixing between stocks cannot be resolved by the current sampling regime in the Malin Shelf survey. It is not possible to distinguish fish stock origin by simple meristic features and thus it remains unclear to what extent fish from one stock are being registered in another stock area. Consequently, a sampling programme has been developed to allow proper identification of fish stock origins, making use of otolith and body shape techniques and analyses that will be compared to the fish of known spawning origin collected during the EU project WESTHER (Anon., 2006). This sampling programme will be initiated in the 2010 summer surveys.

## 5.3 Time series of existing surveys

In 2008 and 2009 the Malin shelf survey was carried out extending the areas south of 56°N. This survey gives estimates of abundance in the area 53°N to 56°N on the shelf area to the west of Ireland and Scotland. The archive of acoustic survey data for the ICES coordinated surveys in North Sea, Kattegat, Skagerrak and VIa includes two years when the survey was carried out south to 53°N. The proportions of herring by age found south of 56°N in the four survey years (1995, 1996, 2008 and 2009) are compared below (Table 5.3.1). This shows that larger proportions of young fish are found south of 56°N compared with adults. There is considerable variability between years. Note that the 2008 and 2009 estimate includes North Channel results.

**Table 5.3.1. Percentage of estimate of area VIa found south of 56°N from acoustic surveys (Ages 1–9 by number, Biomass and SSB by weight).**

| Age | 1995 | 1996 | 2008 | 2009 |
|---|---|---|---|---|
| 1 | 74% | 92% | 89% | 73% |
| 2 | 26% | 15% | 38% | 29% |
| 3 | 28% | 2% | 9% | 4% |
| 4 | 15% | 1% | 7% | 3% |
| 5 | 5% | 5% | 6% | 2% |
| 6 | 11% | 1% | 5% | 3% |
| 7 | 8% | 3% | 0% | 3% |
| 8 | 4% | 5% | 0% | 0% |
| 9 | 30% | 10% | 0% | 0% |
| SSB | 25% | 3% | 6% | 2% |
| Biomass | 20% | 8% | 15% | 12% |

# 6 Towards the production of a spawning ground map

The SGHERWAY initiative provided a valuable opportunity to draw together several data sources to produce a map of spawning grounds for the herring stocks in VIaN, VIaS/VIIb,c, VIIaN and the Celtic Sea and VIIj. Several reviews of herring spawning grounds in the area (e.g. ICES, 1994; Breslin, 1998; Molloy, 2006) have been carried out. However, no synthesis has yet been presented for the area west of the British Isles as a whole. Indeed, to ensure adequate protection, the spawning grounds themselves should be adequately mapped and even designated as protected areas, according to Molloy and Kennedy (2002).

Spawning grounds have been defined using a number of data sources, including: grab surveys on spawning grounds (e.g. Parrish *et al.*, 1959; Bowers, 1969), presence of recently hatched larvae (reviewed in Heath, 1993), the presence of herring eggs in haddock stomachs (e.g. Bowman, 1922) and the capture of mature adult fish from both commercial boats and surveys.

To produce a map the data were restricted to time-series of survey data that could be built up as layers in ArcGIS.

The data investigated were:

i ) gravel bed distribution

ii ) time-series of larval surveys

iii ) "anecdotal" information

iv ) other surveys (acoustic, groundfish)

## 6.1 Gravel bed distribution

Sampling of eggs and/or herring larvae carried out in various areas and studies (e.g. Parrish *et al.* (1959) in the Firth of Clyde; Bowers (1969) in the Irish Sea; Holliday (1958) cited in Rankine (1986) in the Scottish waters) revealed particularly well-defined locations coinciding with a substrate of small stones and gravel only (boundaries occurred when large stones and rocks were present). This suggested that Atlantic herring in the area located west of the British Isles actively select gravel beds for their egg deposition (Napier, 1993). More recently, a RoxAnn survey conducted on spawning beds in the Celtic Sea, in the area adjacent to the Irish Sea (ICES, 2000), identified the spawning substrates in three of the four spawning beds effectively sampled, as typical of those identified by the previously cited authors. Therefore, for the purpose of the spawning ground map, available information on gravel and mixed sand/gravel bed distributions is presented as potential herring spawning ground habitat.

### Material and methods

The seabed mapping has been possible thanks to the data provided by three different projects:

#### 1. UKSeaMap project

Substrate information for the UK waters, data and information on the sediment nature made available by UKSeaMap project have been downloaded from the UKSeaMap WebSite (http://www.jncc.gov.uk/page-3663; (Connor *et al.*, 2006)). The data were electronically supplied as ESRI shapefiles (JNCC accepts no liability for the use of these data or for any further analysis or interpretation of the data).

This UK project aimed at producing simple, broad-scale and an ecologically relevant map of seabed features using geological, physical and hydrological data.

It was possible to extract the required information on substrate structure to inform potential favourable gravel habitat for herring to spawn, by creating new “gravel bed” and “mixed sediments” categories from the broad regional perspective on the distribution of the features. These new categories were chosen using the relevant substrate information for each category of interest, here coarse and mixed sediments, and adding information on tidal stress of the different regions so that the area would be likely, or not, to be used as a favourable herring spawning ground (see Table 6.1.3).

In this project, the whole UK continental shelf was surveyed (Figure 6.1.1) but information that appears in our sediment map is only related to the presence of gravel. When no gravel was found then, the area was left in white.

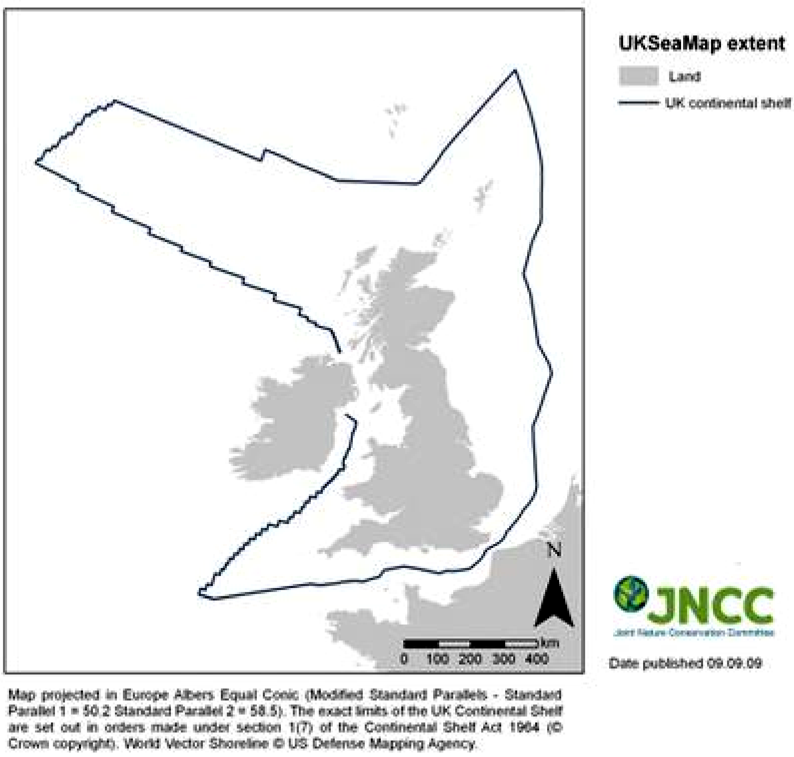



**Figure 6.1.1. Map showing the area covered by the UKSeaMap project (Source: Connor *et al.*, 2006)**

### 2. INFOMAR survey

The INFOMAR (the INtegrated mapping FOr the sustainable development of Ireland’s MARine resource) project is a joint seabed mapping project between the Geological Survey of Ireland and the Marine Institute, Ireland. Data from this survey (also available in the dedicated website: http://geos.marine.ie/infomar) have been provided by the Marine Institute Galway, Ireland) and supplied as ESRI shapefiles where the seabed classification grid has been used for the purpose of our map.

Covering some 125,000 km² of underwater territory, the INFOMAR project aims to produce integrated mapping products covering the physical, chemical and biological features of the seabed. Mapping of this ongoing project is mainly done in fine scale areas (e.g. embayment, well-defined and inshore coastal areas etc.) and so far has mapped the south coast of Ireland, with the Donegal coast being the follow up step to support coastal and inshore development (Figure 6.1.2).


**Figure 6.1.2. Map showing the area surveyed by INFOMAR project (Source: http://www.marine.ie/home/services/surveys/seabed/, 18 June 2010). Only some seabed classification features from the priority areas have been kept for the purpose of our map.**

### 3. IMAGIN project

Additionally in the Irish Sea, shapefiles have also been acquired from the European/Interreg IIIA Irish Sea Marine Aggregate Initiative (IMAGIN) project (O'Mahony *et al.*, 2008). IMAGIN is an ongoing research and development project aiming at providing improved knowledge of the seabed structure in order to give better support in managing activities and assessing impacts associated with marine aggregate extractions.

The surveyed areas are shown in Figure 6.1.3 and contribute to finer scale information of the previous UKSeaMap project in more localized areas.

### Results and discussion

The three projects cited above were not the only geological surveys dealing with seabed structure in the area. Most of the other mapping projects in the area were performed at a very small scale and it was decided not to include information from these projects in a broad scale map. Therefore, the IMAGIN, INFOMAR and UKSeaMap projects were the three seabed surveys used to produce this map since their large spatial scale covers the study area quite well.

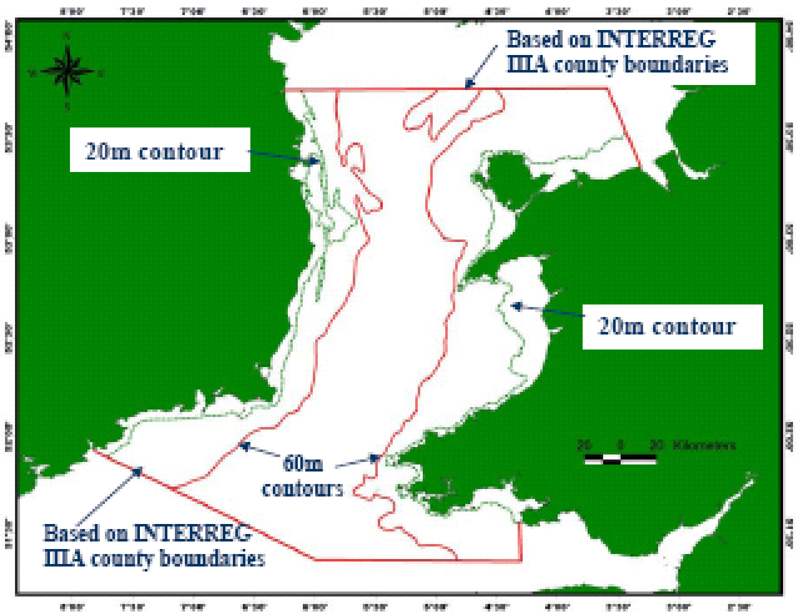



**Figure 6.1.3. Map showing the overall IMAGIN study area bounded to the north and south by seaward extensions of the designated county divides (Source: O'Mahony *et al.*, policy report (2008)).**

The map for sediment that is drawn includes both "gravel only" and "gravel and sand" beds, since they are potentially favourable spawning environments (Figure 6.1.4). For the determination of those substrates with the UKSeaMap project, several layers were combined to form the "gravel category" and "mixed gravel and sand category" (Table 6.1.3).

**Table 6.1.3. UKSeaMap substrate layers combined to form "gravel" and "mixed sand and gravel" categories.**

| Gravel sediment categories | Mixed gravel and sand sediment categories | Tide stress |
|---|---|---|
| Cold deep-water coarse | Cold deep-water mixed | NA |
| Warm deep water coarse | Warm deep-water mixed | NA |
| Shelf coarse plain | Shelf mixed plain | Strong |
| Shelf coarse plain | Shelf mixed plain | Moderate |
| Shelf coarse plain | Shelf mixed plain | Weak |
| Shallow coarse plain | Shallow mixed plain | Strong |
| Shallow coarse plain | Shallow mixed plain | Moderate |
| Shallow coarse plain | Shallow mixed plain | Weak |

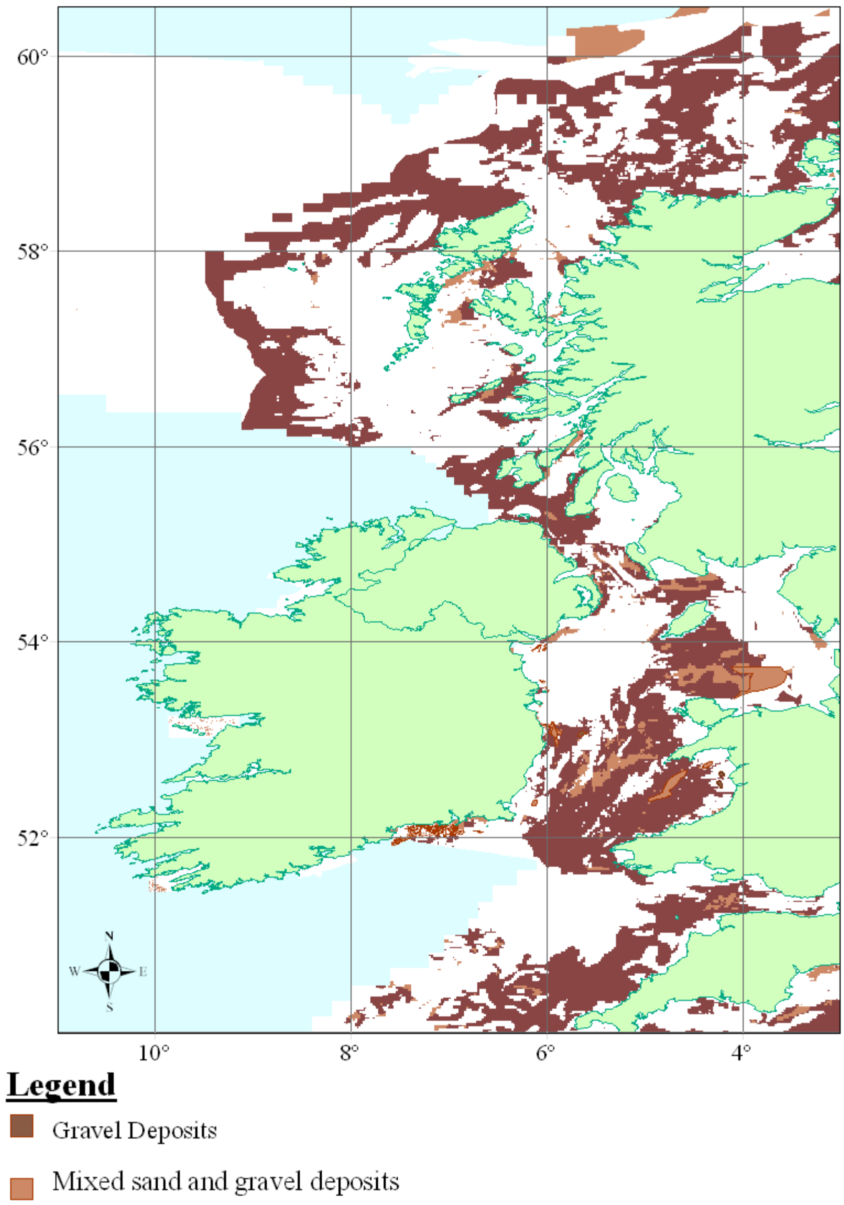



**Figure 6.1.4. Map showing the seabed structure distribution west of the British Isles (using data sources from IMAGIN, INFOMAR and UKSeaMap projects). The white areas are those surveyed once with no feature of interest for the determination of favourable spawning ground areas.**

## 6.2 Time series of larvae surveys and their spatio-temporal dynamics

Larvae surveys are important long-term surveys which have proven highly informative for the detection of both spatial and temporal dynamics of the spawning ground areas. Details of the time-series of larvae surveys are given in Table 6.2.1. These surveys aimed to collect newly hatched larvae to investigate their biological characteristics and also to locate the spawning areas.

### Material and methods

Three different larvae survey series have been prosecuted over the past 40 years or so (Table 6.2.1).

**Table 6.2.1. Summary of the different time-series collected by the three larvae surveys carried on the stocks to the west of the British Isles.**

| SURVEY AREA | YEARS SURVEYED |
|---|---|
| North West (VIaN and VIaS/VIIb) | From 1972 to 1994 |
| Irish Sea (VIIaN) | From 1996 to 2009 |
| Celtic Sea (Celtic Sea & Division VIIj) | From 1978 to 1985, and from 1989 to 1990 |

### Larvae survey time-series of VIaN and VIaS/VIIb:

Historic information on the distribution and abundance of herring larvae in areas VIaN and VIaS/VIIb (i.e. the northwestern area) is available from the ICES coordinated herring larvae surveys in the North Sea and adjacent waters, which were conducted from 1972 to 1989 (VIaS) and 1993 (VIaN). Surveys were carried out in specific time periods and areas, following the autumn spawning activity of herring from north to south (September to October). At a given station grid, oblique tows with plankton samplers were carried out at 5 knots ship speed. The number of herring larvae caught was estimated and all larvae were measured. Data were stored, giving information on the number of larvae in the size range of 5 – 24 mm.

The main purpose of the herring larvae surveys has been to provide quantitative estimates of the abundance of herring larvae which can be used as a relative index of changes in the spawning stock size of the specific herring stocks. Details of the survey methodology and the index calculation can be found in the manual of the IHLS programme (ICES, 2009c) and in Rohlf *et al.* (1998).

The temporal coverage for the period 1972 to 1993 is given in Figure 6.2.1.

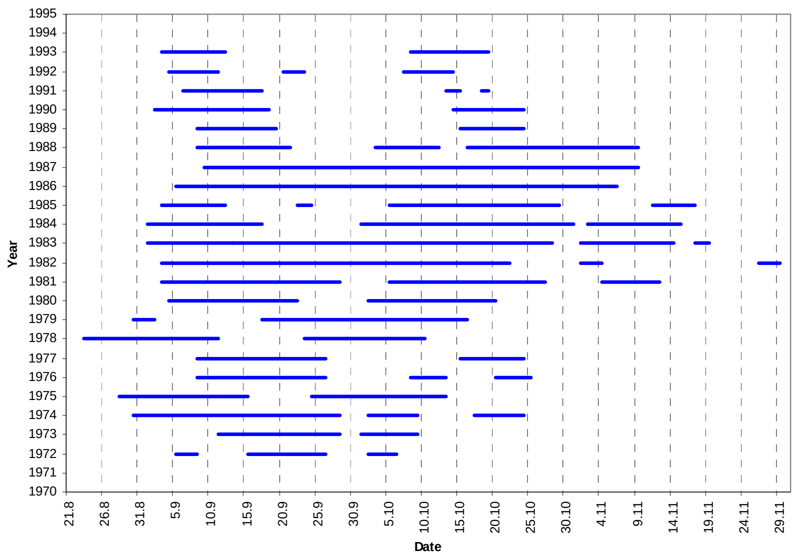



**Figure 6.2.1. Temporal coverage of the herring larvae surveys in VIaN and VIaS for the period 1972 – 1993. Dates are given where samples are available. This does not necessarily correspond to days-at-sea in the surveys.**

### 1. Larvae surveys of Celtic Sea, 1978 to 1985 and 1989 and 1990:

Surveys for larvae of autumn and winter spawning herring were conducted on a monthly basis, between October and February each season from 1978/1979 to 1984/1985 (Grainger, 1979; Grainger *et al.*, 1982; Grainger *et al.*, 1983; Grainger *et al.*,

1984) in the Celtic Sea and Division VIIj. However, winter coverage did not extend to the west of the survey area (i.e. VIIj). Further surveys were carried out in 1989 and partial surveys in 1990. These surveys provided information on the timing of spawning and on the location of the main spawning events as well as on the size of autumn and winter spawning components of the stock. The larvae surveys carried out after the fishery reopened in 1982 showed an increase in the spawning stock (Molloy, 1995). The surveys covered the south coast and stations were positioned 8 nautical miles apart in a grid formation. A Gulf III sampler, with 275 μm mesh was used to collect the samples (Grainger *et al.*, 1982).

**2. Larvae surveys in the Irish Sea (VIIaN)**

Herring larvae surveys of the northern Irish Sea (ICES area VIIaN) have been carried out by the Agri-Food and Biosciences Institute (AFBI), formerly the Department of Agriculture and Rural Development for Northern Ireland (DARD), in November each year since 1993. The surveys have been carried on onboard the RV *Corystes* since 2005 and prior to that on the smaller RV *Lough Foyle*.

Sampling is carried out on a systematic grid of stations covering the spawning grounds and surrounding regions in the NE and NW Irish Sea. Larvae are sampled using a Gulf-VII high-speed plankton sampler with 280 μm mesh net. Mean catch-rates (nos.$m^{-2}$) are calculated over stations to give separate indices of abundance for the NE and NW Irish Sea. Larvae production rates (standardized to a larva of 6 mm), and birth-date distributions, are computed based on the mean density of larvae by length class. A growth-rate of 0.35 mm $day^{-1}$ and instantaneous mortality of 0.14 $day^{-1}$ are assumed based on estimates made in 1993–1997.

**Results and discussion**

**I. Smaller larvae distribution**

Herring larvae distributions derived from surveys are influenced by drifting shortly after hatching, which complicates their use for the location of spawning grounds. Rankine (1986) suggested that a size of ≤7 mm length should be used to delineate spawning grounds off the Scottish coast as the larvae would be around one day old and not had the opportunity to drift away from the spawning grounds to any extent.

Therefore, the abundance of larvae ≤ 7mm is represented in Figure 6.2.2, to represent areas most likely to be herring spawning grounds, since these small larvae are likely to be fairly close to their spawning area. However, for the Celtic Sea survey (area south of Ireland), it has to be noted that larvae abundance was only available for larvae < 11mm.

It should be noted here that Figure 6.2.2 is indicative of trends in larval distribution over the time-series of these surveys. There is no information from winter or spring spawners included in the northwestern surveys. The hatching size of herring larvae is about 6–7 mm (Heath and McLachlan, 1987), and foraging larvae are subject to drift. The Celtic Sea survey results focus on larvae <11 mm, and thus the resulting distribution pattern may be influenced by drifted larvae to a certain degree. However, since Molloy and Corten (1975) demonstrated that winter larvae were bigger in the Celtic Sea than larvae hatched in autumn, it could be argued here that keeping larger sized larvae would keep the important winter larval component in the analysis which might not have been the case otherwise.

## II. Core spawning grounds and regions

Core spawning grounds are the areas where larvae were the most abundant and concentrated in each survey year. Identification of these grounds gives information on the more important spawning grounds in term of larval production and of their temporal dynamics, using small larvae density information.

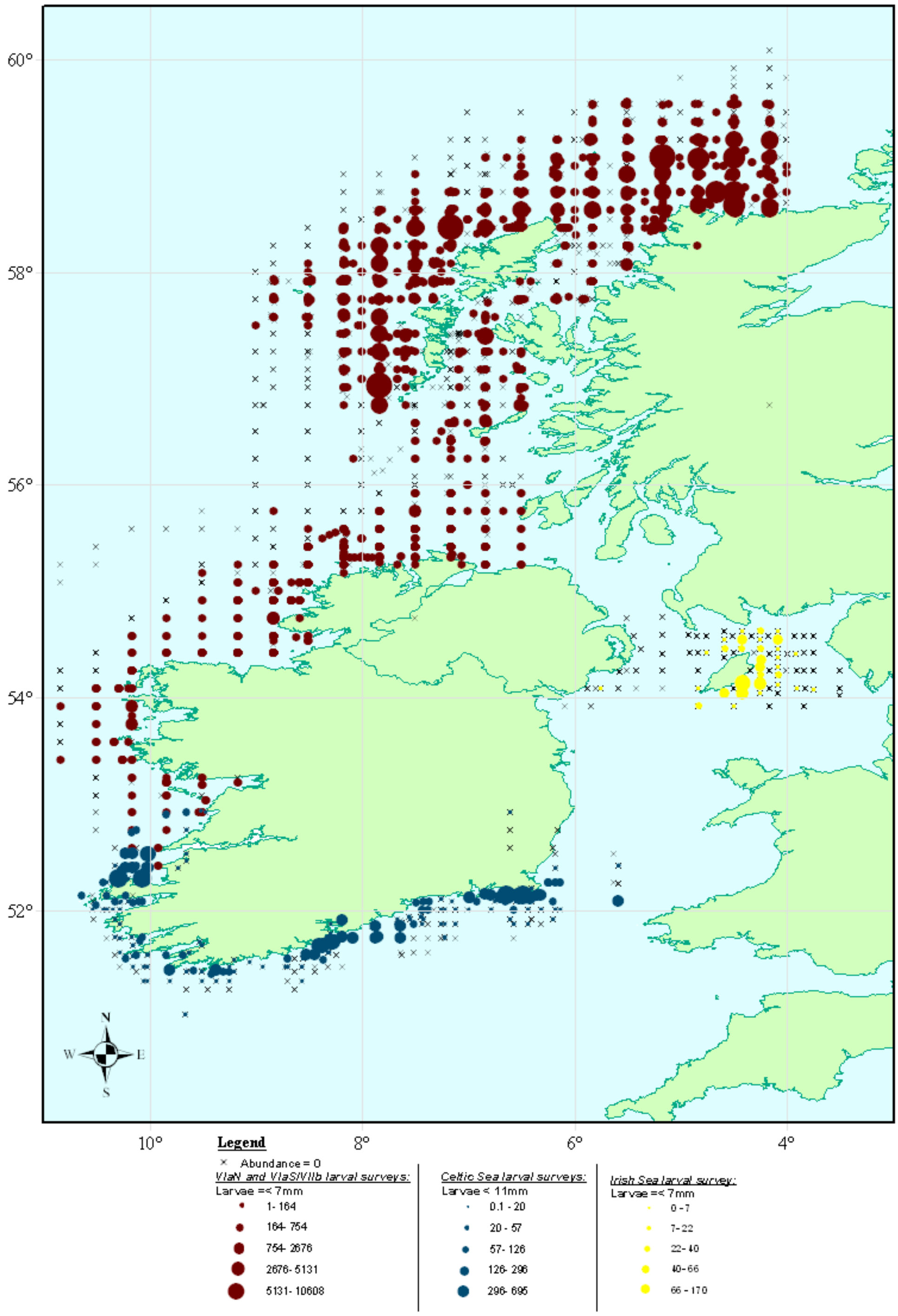



**Figure 6.2.2. Distribution of small larvae from the time-series of the three larvae surveys. Crosses represent null sampling events, red dots for the northwestern survey (VIaN and VIaS/VIIb), blue for the Celtic Sea and Division VIIj and yellow for the Irish Sea (VIIaN).**

Rankine (1986) suggested that densities of >500 larvae per square metre should be used to indicate the main spawning grounds around the Scottish coastal areas. Because the maximum density at a station in the Irish Sea larval survey was well below this threshold (182 larvae/m$^2$), it was thought that such a threshold could not be applied to the other stocks and that a specific-stock threshold should be established. A larval density threshold per area was calculated relative to the respective stock sizes. The respective estimates of SSB for the three stocks (ICES, 2010) were compared to each other in order to extract a ratio of the Celtic Sea stock to northwestern stocks and another one for the Irish Sea stock compared to the northwestern stocks. Finally, the well-established threshold of >500 larvae/m$^2$ (Rankine, 1986) was used as a starting and reference point for the northwestern larvae surveys, and applying the (above-explained) respective stocks ratios of the Celtic Sea and Irish Sea (compared to the northwestern), the Celtic Sea and Irish Sea thresholds were estimated. However, these limits were actually too low, allowing only very few data points to be taken into account with this new cut-off parameter (e.g. 4 points for the Celtic Sea). This idea was, therefore, not used, but led to another determination of core areas using the yearly density of larvae for each stock separately. Taking the different density distributions obtained per year for each of the stocks, only the upper 15$^{th}$ percentile of the distribution (i.e. representing the stations where the larvae were the most abundant, located in the upper tail of the graph of the probability distribution as shown in Figure 6.2.3) were plotted.

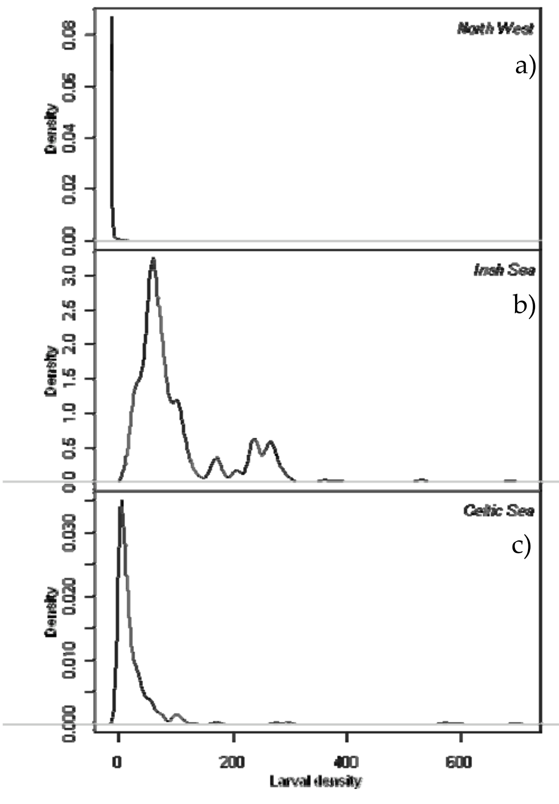



**Figure 6.2.3. Density curves of larval densities for a) the northwestern stock (VIaN and VIaS/VIIb), b) the Irish Sea stock (VIIaN) and c) the Celtic Sea and Division VIIj.**

The total larval density was summed by area and year. Then, according to the density distribution of these larval densities (Figure 6.2.3), it was decided to keep only the stations with a density larger than 85% of the distribution density curve as an arbitrary cut-off point to represent the core spawning area per year. In other words, for each year, all stations of an area were ranked according to the relative density of larvae sampled at each station. The stations with a density higher or equal to 85% of the density curve for the smallest size-group were kept to show the core extent of spawning areas described in Figure 6.2.2, in the following map (Figure 6.2.4).

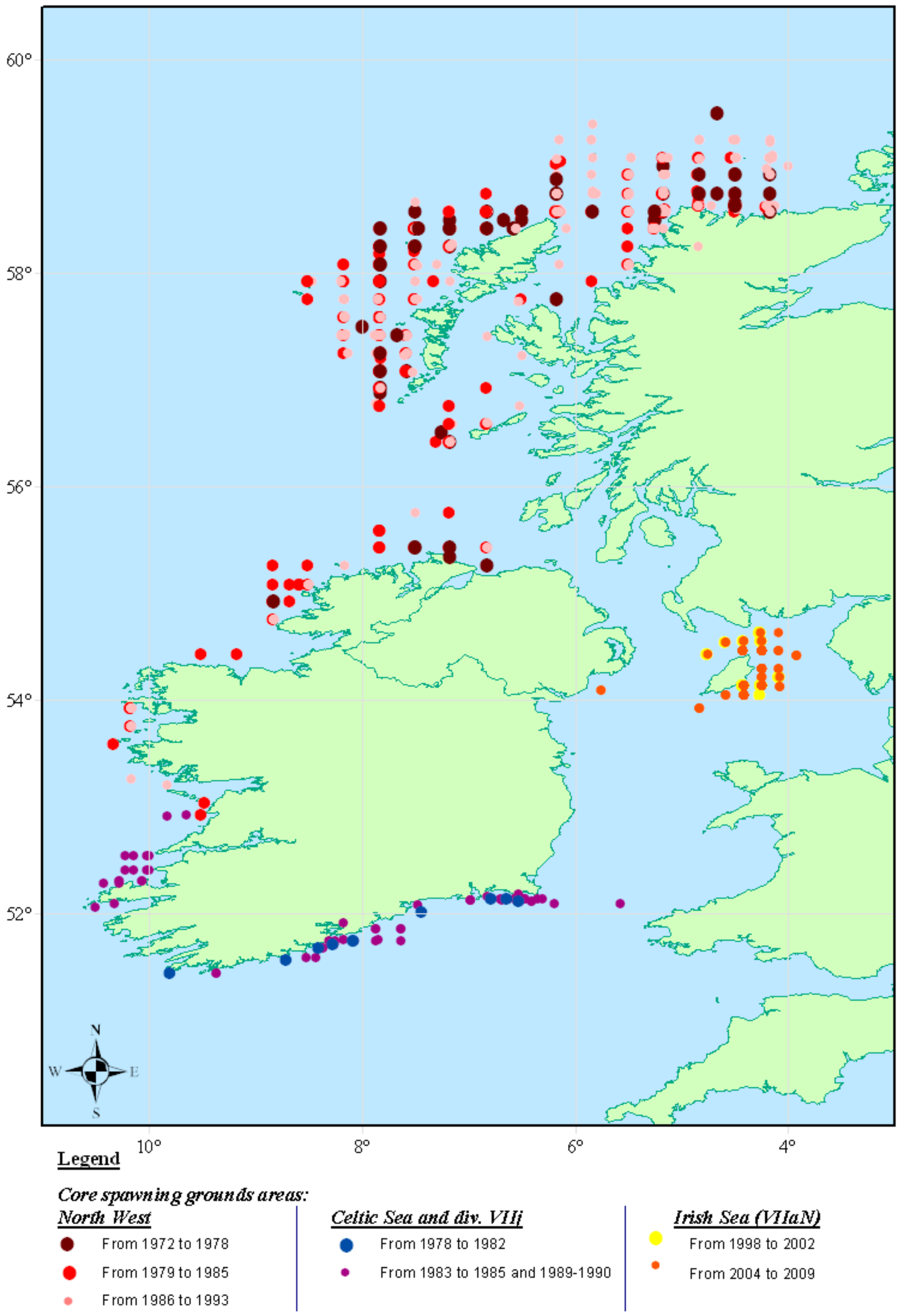



**Figure 6.2.4. Map representing the core areas of spawning grounds according to the different stock larval densities, keeping the stations that contained ≥ than 85% of the distribution of larval density per year. The different colours highlight the temporal dynamics of the different stocks.**

## 6.3 Anecdotal information

### Material and methods

Anecdotal information has been gathered in order to complete the pattern observed with the larvae surveys and sediment distributions. Information from various sources (mostly local fishermen) can be divided in two main groups:

- the position of catches of haddock or other fish which had been recently feeding on herring eggs (Bowman (1922) for the Scottish coasts; various anecdotal sources for the Celtic Sea (fishermen, pers. comm.)
- the position of roe fish or eggs caught during their fishing activity (fishermen, pers. comm.)

### Results and discussion

The information presented in Figure 6.3.1 is mostly anecdotal and should be regarded as a complementary indication to the location of potential spawning grounds.

The spawny haddocks collected by Bowman (1922) showed, in addition, the different spawning seasons of the fish in the Scottish coasts (reflected here as the blue polygons being spring-winter eggs and the red ones, autumn eggs). Here, also, the well-known Clyde component situated in Ballantrae Bank in the Firth of Clyde can be seen.

Concerning the north, south and west of Ireland, this additional information contributes to confirm the trends previously observed in the larval distributions in Figures 6.2.2 and 6.2.4.

## 6.4 Other surveys investigated

Additional sources of information that were thought to be useful for the SGHERWAY spawning map were checked by the members of the group, such as the potentially representative number of spawning fish in the two Irish acoustic surveys; the different groundfish surveys realized yearly by different countries in the area of interest, or the proportion of small herring larvae collected via the recent (2008 and 2009) Scottish west coast MIK surveys. However, for the latter three types of surveys, the conclusions were, in each case, that the scarce amount of data of interest was not sufficiently informative to warrant inclusion. Details for each survey series are given below.

### 6.4.1 Celtic Sea acoustic survey and Q1 VIaS and VIIb acoustic survey

Survey information from spawning herring occasionally caught during the Irish herring acoustic surveys either in the Celtic Sea or to the northwest of Ireland (the survey’s materials and methods used can be found in the respective surveys reports e.g. O’Donnell *et al.* (2009)). The Celtic Sea herring acoustic survey time-series currently used in the assessment runs from 2002 -2009. Acoustic surveys of this stock have been carried out since 1990, with the exception of 1997. Since 1998, usually only one winter survey has been conducted. The acoustic series was revised in 2006. Acoustic surveys have been conducted in Divisions VIaS and VIIb since 1994. In the mid 1990s, surveys were undertaken in summer. The timing changed in 1999 with the surveys being carried out in the winter. The series was discontinued in 2007 because it was recognized that synoptic coverage of a stock that spawns over a period from October to February in an area spanning all of Divisions VIaS and VIIb cannot be achieved with a winter survey. The number of maturity stage VI herring (running gonads) has been extracted from the time-series of the surveys and is included in Figure 6.3.1 represented as dots on the map.

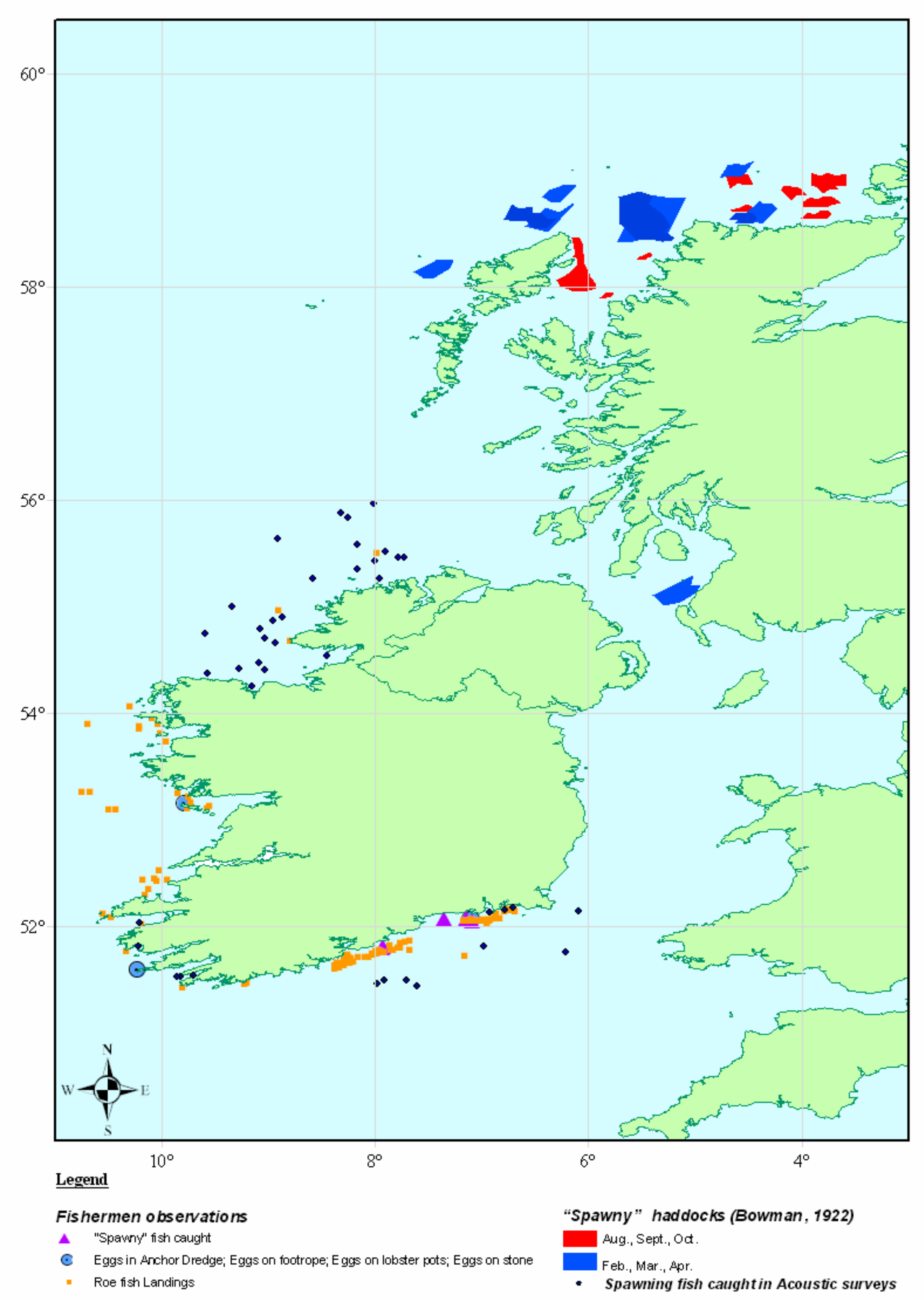



**Figure 6.3.1. Map showing the spread of other, mostly, anecdotal information gathered at different times showing the presence of spawning grounds in the areas under study.**

### 6.4.2 Scottish west coast IBTS time-series

International Bottom Trawl Surveys (IBTS) have been carried out by the Marine Laboratory, Aberdeen, off the west coast of Scotland and north of Ireland since 1986 in quarter 1 and since 1997 in quarter 4. Herring have been caught in 790 hauls across the 24 year time-series in Q1 (to 2009) and in 523 hauls across the 13 year time-series in Q4 (to 2008). It is known that herring spawn across the winter and spring in the area and it might therefore be possible to find evidence of this spawning activity in these surveys. However, these surveys do not catch many herring in each haul and fewer still are sampled for biological data (across the time-series, Q1 average 30 herring per haul, Q4 average 13 herring per haul).

An examination of maturity data showed that, for the IBTS time-series in both quarters, the maximum percentage mature (equivalent to stage 6 on the 8 stage scale) in any haul was 3.93. Using a cut off point of 1% mature gave one data point in the Q4 survey (1.02% mature in one haul) and four from the Q1 survey (1.24 to 3.93% mature in one haul). We know herring are benthic spawners in very specific areas and the IBTS survey does not necessarily fish in those areas. However, for example, the herring haul in the Clyde was taken on 14 March 1994. This is in the vicinity of the Ballantrae Bank spawning area, in the middle of the spawning period for Clyde spring-spawning herring (February to April: Bailey *et al.*, 1986) but only 3.5% of the herring within that haul were mature. The Scottish west coast IBTS always samples within the ICES statistical rectangle that contains Ballantrae Bank. However, the Bank area is only some 3 miles (east to west) by 9 miles (north to south) in area and extends from the coast seawards (Stubbs and Lawrie, 1962) with depths over the bank of 12 – 18 m. It is unlikely that surveys tows would be carried out so close to the coast. However, one might still expect to see reasonable aggregations of mature herring in the vicinity of a known spawning area though at spawning time and the fact that so few mature herring were present throughout the time-series would suggest that these surveys are not of use as an indicator of spawning grounds in the area.

#### 6.4.3 Q1 VIaS and Celtic Sea groundfish surveys

The current time-series of data from the Q4 Irish groundfish survey, conducted by the Marine Institute, Galway, runs from 2003 – 2009. Data from these surveys were examined for the occurrence of spawning herring to include in the spawning map. However, the inclusion of these data has been rejected due to the very small amount of spawning herring encountered, similar to the Scottish surveys. This is not surprising given the timing of the survey and the gear that is used.

#### 6.4.4 Scottish west coast MIK surveys 2008 and 2009

A MIK net survey was carried out in both 2008 and 2009, during the west coast 1$^{st}$ quarter IBTS on FRV *Scotia*, from 2–19 March 2008, and from 9–29 March 2009, from west of the Orkney Islands to the north of Ireland.

For the two west coast MIK surveys, if larvae were to be mapped on the same basis as the North Sea herring larvae survey where only herring <10 mm are used then 2.5% of larvae in 2008 and 11.1% of larvae in 2009 would be included as evidence of recently hatched herring. In 2008, only 0.2% of the larvae caught were hatched within the survey period. In 2009, however, 5% of those caught were hatched within the survey period. However, the MIK is designed to sample larger herring larvae. The North Sea MIK net survey samples overwintered herring larvae, not recently hatched ones. In 2009, in the Marine Lab. Aberdeen component of the North Sea MIK survey, no herring less than 11 mm were caught and the 11 mm larvae comprised less than 0.1% of the total larvae caught. The modal length was 23 mm. In contrast, the northern parts of the North Sea herring larvae survey in 2008 (in Orkney/Shetland (O/S) and Buchan (Bu)) that would contribute to the 2009 MIK in 2009 had modes of 7 mm

(O/S) and 8 mm (Bu). The proportion of 2008 O/S larvae <10 mm was 91% and of Bu larvae was 83%.

It may be that a cut-off greater than <10 mm could be used to define to define spawning grounds for spring-spawning herring. Certainly, in the North Sea calculations, <11 mm is used for the winter spawning component because they grow slightly more quickly than autumn spawned larvae. However, the small larvae from the two MIK surveys, hatched in March, appear to have originated from spawning areas already identified during the larvae surveys off the north coast of Ireland, suggesting that the areas used by spring-spawning herring as spawning grounds are the same as those used by the autumn spawners.

## 6.5 Spawning area delineation

In this explanatory section, the names used to describe the respective locations of the main spawning areas in accordance with the literature are shown on Figure 6.5.

### 6.5.1 North-western main spawning grounds

Larger quantities of newly hatched larvae are found over the banks north of Scotland, around Rona, the Outer Hebrides, at Donegal Bank and west of Achill Island (Figure 6.2.4).

#### North-west of Ireland (VIaS/VIIb)

The maps support earlier studies of spawning areas / sites.

Evidence of autumn spawners in the area of Galway Bay has been highlighted by Grainger (1976). Bracken (1962) also found spawners in autumn in Keem Bay off Achill, evidence proved by the occurrence of roe herring in October and November during the 1980s and 1990s.

Further north, along the coasts of the Donegal, spawning occurs in a few locations from Rosbeg to Tory Island (offshore from Tory Island to Inishtrahull, out as far as the Stanton Bank).

While no scientific investigations were conducted in the northwest of Ireland from 1941 to 1960, surveys and studies carried out later in the time-series showed the occurrence of both autumn and winter-spring-spawning herring in the spawning grounds. There is an autumn spawning component in the western areas and further along the north coast, from Rosbeg to Tory Island (Molloy, 2006) and it is thought that spring spawners are an important component.

#### Scottish coasts (VIaN):

Approximately half of the west of Scotland stock has been demonstrated to spawn to the west of the Hebrides (Heath and MacLachlan, 1987), which indeed appears in Figure 6.2.4 as the most abundant area in term of stations mapped. Another important and temporally consistent spawning ground can be found between Cape Wrath and the Orkney Islands. Most of the remainder seemed to spawn well inshore of the main current stream off the north coast of Scotland, as discussed in Rankine (1986).

The Ballantrae Bank spawning area in the Firth of Clyde, first showed by Ewart (1884) was not included in the larvae surveys. Nevertheless, the existence of this small but well-known spawning location has been confirmed by several authors (e.g. Hemmings, 1965), thanks to underwater observations of herring spawning; and Morrison *et al.* (1991) who carried out a detailed survey on a spawning bed using divers, ROV and grab samplers (in Morrison and Bruce, 1981).

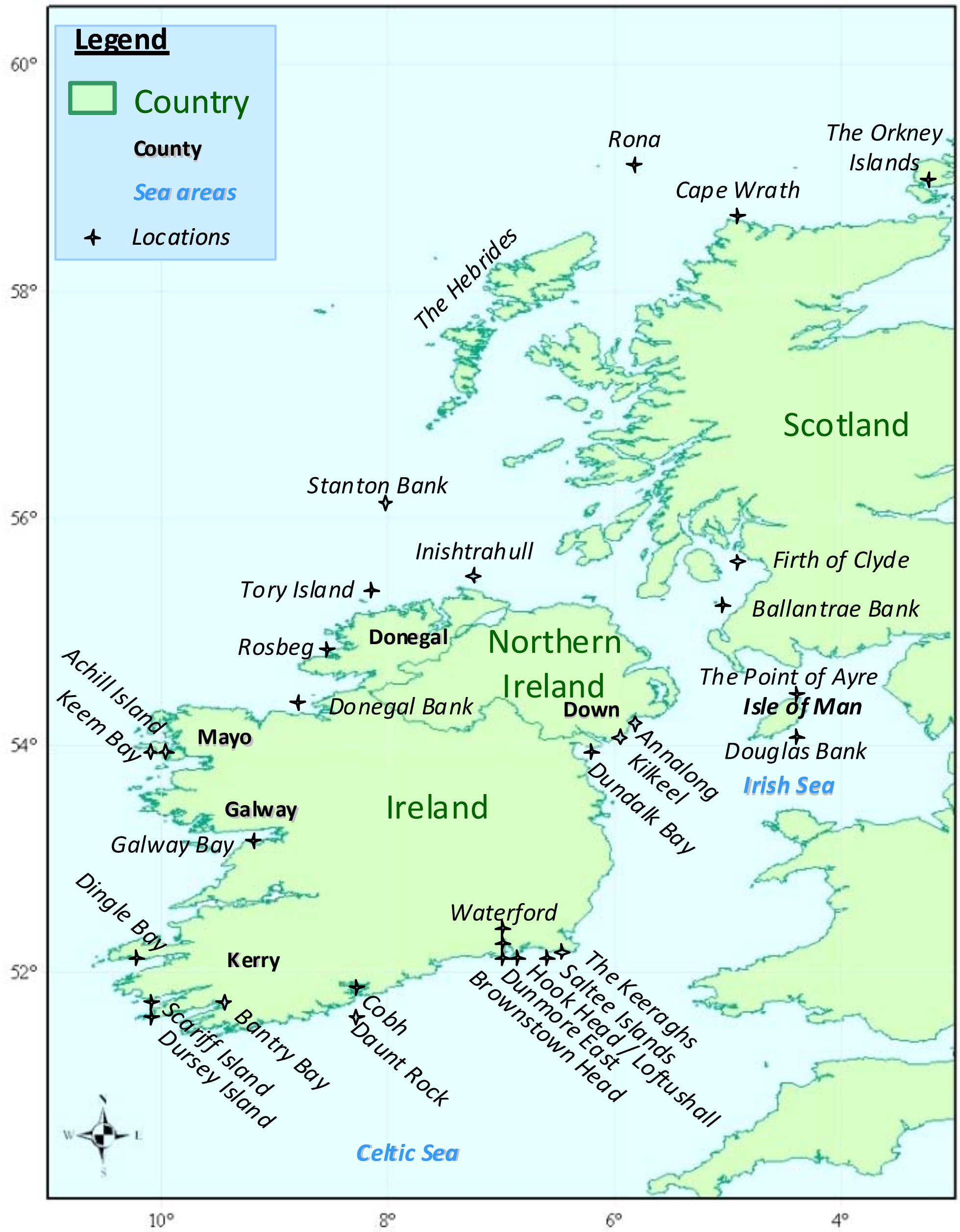



**Figure 6.5. Location of the different names to describe the nearshore herring spawning grounds in the text.**

### 6.5.2 Celtic Sea and Division VIIj

The main spawning grounds shown in Figure 6.2.4 are fairly consistent with the ones described by Breslin (1998). They are between the Keeraghs and Saltee Islands, off Cobh around the Daunt Rock and the area from Brownstown Head to Hook Head (around Dunmore East) and have been very well documented in the literature (Bracken, 1961; Burd and Bracken, 1965; Molloy, 1966). Moreover, four RoxAnn surveys, combined with grab sampling, performed from 1996 to 1998 (cited in Breslin 1998), in areas where fishers observed spawning herring, collected eggs efficiently and proved the well-known spawning areas demonstrated in Figure 6.2.4 for the Celtic Sea. Anecdotal information from fishers referring to catches of spawning herring off the mouth of Waterford harbour, near Loftushall, confirmed the eastern Celtic Sea spawning ground shown in Figure 6.2.4. Nevertheless, even if Figure 6.2.4 seems to describe the core spawning regions well, it has to be noted, for example, that the historically important Bantry Bay autumn spawning component (Farran, 1944) off County Kerry is not represented on this map. Therefore, Figure 6.2.4 should be taken carefully as indicative of the main spawning regions in the time-series represented by the respective larval surveys.

With respect to temporal patterns, although spawning to the west coast of Ireland is known to happen in autumn (from September to November), some winter spawning events have been recorded in January/February around the Dingle area (ICES, 1997). Winter is currently the dominant spawning season in the Celtic Sea (Brophy and Danilowicz, 2002) and the relative proportions of autumn-spawners and winter spawners have been fluctuating from 1959 to present (Harma *et al.*, unpublished data).

In order to see if changes in spawning time had an impact on spawning grounds, two different time periods were chosen for the Celtic Sea and were set as: Period 1, from 1978 to 1982; Period 2, from 1983 to 1990. In 1982, the survey area for the Celtic Sea was extended to include Division VIIj. However, even though the survey area extended to the west for the second period drawn on Figure 6.2.4, it was still possible to compare the previously called Celtic Sea area potential temporal dynamics. It can be concluded that the location of the main spawning grounds in the Celtic Sea did not change greatly during the two periods under study.

### 6.5.3 Irish Sea main spawning grounds (VIIaN)

Wood and Howlett (1976), who studied the distribution and abundance of larvae and juvenile herring in the north of the Irish Sea, came to the same conclusion as SGHERWAY concerning the core of spawning grounds in the Irish Sea. They showed that the most important spawning area of the Manx stock is located some 3 to 10 miles south of Douglas (southeast of the Isle of Man), while the smaller but well-known Mourne component spawned on nearby inshore grounds situated between Annalong and Dundalk Bay. This latter Mourne stock located off the east coast of Northern Ireland, near Kilkeel (County Down) has been well documented (Anon., 1977; 1979 and ICES, 1994) and is known to be an autumn spawning stock. In addition, Bowers (1969) using grab surveys to describe spawning beds on the Douglas Bank, the so-called Manx stock, proved they were mainly autumn-spawning fish. However, even though it has largely been proved that the Manx and Mourne stocks were autumn spawning stocks, a few occurrences of winter spawners have been documented in some years (ICES, 1994).

Furthermore, quite a large number of small larvae were found to the north of the Isle of Man, off the Point of Ayre. Dickey-Collas *et al.* (2001) confirmed that these larvae (caught with yolk-sac still attached) were indeed spawned locally.

## 7 SGHERWAY Conclusions

Currently the herring to the west of the British Isles are fished, managed and assessed separately as four ICES stocks 1: VIa North; 2: VIaS and VIIb,c; 3: VIIaN and 4: Celtic Sea and VIIj. There has been a series of analytical assessments for VIa North, which have been accepted in most years. Analytical assessments have not been accepted for the VIaS and VIIb,c or VIIaN ICES stocks for many years. Analytical assessments for the Celtic Sea and VIIj ICES stock have been accepted for the last 2 years.

The results from 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) suggested that under the current stock assessment units two of the basic assumptions of stock assessment are violated and that the Celtic Sea and VIIj ICES stock should continue to be assessed and managed separately. SGHERWAY was therefore convened, in 2008, to explore and evaluate the series of recommendations produced by the WESTHER project.

A combined assessment of the three stocks VIaN, VIaS/VIIb,c and VIIaN (called the Malin Shelf metapopulation) was explored and its utility for advisory purposes investigated. Adjusting the settings of the assessment in the various scenarios tested had little impact on the diagnostics and we can conclude that the assessment is not sensitive to the choice of setting. 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. The combined assessment suggested that the VIaN assessment currently performed by ICES is using a tuning index (the VIaN acoustic survey) that represents a population larger than the VIaN population alone, as suggested in the WESTHER project results. The failure to recognize and account for population structure may lead to depletion of spawning components and have unexpected ecological consequences. Appropriate management to preserve this complexity remains a challenge. Whilst we have learned a lot about the metapopulation from the combined assessment exercise, it is unlikely that it will replace individual assessments of the constituent stocks. However, it is necessary to segregate these stocks in the Malin Shelf acoustic surveys, and work on this has begun in 2010.

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, VIaS and VIIaN were investigated. The study aimed to show how metapopulations 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 VIIaN population was included in the modelled Malin Shelf survey (assumed to comprise herring from the VIaN, VIaS/VIIb,c and VIIaN populations) can the VIIaN ICES stock be sustainably managed. Even under low fishing pressure, the dynamics will not be clear enough to sustainably manage the VIIaN ICES stock and prevent it from extinction. However, managing the VIaN and VIaS/VIIb,c ICES stocks sustainably under different mixing scenarios and misidentification levels is possible. This study has shown that managing metapopulations is only possible with detailed information on fisheries independent data. However, whenever subcomponents of the metapopulation 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.

The Study Group was asked to evaluate the utility of a synoptic acoustic survey in the 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 will 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 has been developed to allow proper identification of fish population origins, making use of otolith and body shape techniques. Analyses will be compared to the fish of known spawning origin collected during the EU project WESTHER. This sampling programme has been initiated in the 2010 synoptic acoustic survey.

In addition, the SGHERWAY initiative provided a valuable opportunity to draw together several data sources to produce a map of spawning grounds for the herring stocks in VIaN, VIaS/VIIb,c, VIIaN and the Celtic Sea and VIIj. Maps are included within the report.

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## Annex 1: List of participants

| Name | Address | Phone/Fax | Email |
|---|---|---|---|
| Emma Hatfield (Chair) | Marine Scotland – Science<br>Marine Laboratory<br>375 Victoria Road<br>Aberdeen AB11 9DB<br>UK | +44 1224 295434 | e.hatfield@marlab.ac.uk |
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| Norbert Rohlf | Johann Heinrich von Thünen-Institut (vTI)<br>Institut für Seefischerei<br>Palmaille 9<br>D- 22767 Hamburg<br>Germany | +49 40 38905 166 | norbert.rohlf@vti.bund.de |
| John Simmonds | European Commission - Joint Research Centre (JRC)<br>Maritime Affairs Unit<br>21027 Ispra, VA<br>Italy | +39 0332 785311 | john.simmonds@jrc.ec.europa.eu |

## Annex 2: Model equations for the Management Strategy Evaluation

**Eqn 1**:

$$R = \begin{cases} SSB \le \beta : \alpha \cdot SSB \\ SSB > \beta : \alpha \cdot \beta \end{cases} \quad \alpha_x = \frac{\sum_{z \ne x} \left( \frac{A_z \cdot \alpha_z \cdot \beta_z}{1 - A_z} \right) + \frac{\alpha_x \cdot \beta_x}{A_x}}{\beta_x}$$

**Eqn 2**:

$$\begin{aligned}
N_{1,y,x} &= \Phi(\theta, SSB_{y-2,x}) \cdot \varepsilon_{SRR} \\
N_{2,y,x} &= \sum_f \left[ N_{1,y-1,x} \cdot A_{x,f} \cdot \exp(-M_{1,y-1,x} - S_{1,y-1,f} \cdot F_{1,y-1,f}) \right] \\
&\vdots \\
N_{a,y,x} &= \sum_f \left[ N_{a-1,y-1,x} \cdot A_{x,f} \cdot \exp(-M_{a-1,y-1,x} - S_{a-1,y-1,f} \cdot F_{a-1,y-1,f}) \right] \\
N_{a+,y,x} &= \sum_f \left[ N_{a-1,y-1,x} \cdot A_{x,f} \cdot \exp(-M_{a-1,y-1,x} - S_{a-1,y-1,f} \cdot F_{a-1,y-1,f}) \right] + \\
&\sum_f \left[ N_{a+,y-1,x} \cdot A_{x,f} \cdot \exp(-M_{a+,y-1,x} - S_{a+,y-1,f} \cdot F_{a+,y-1,f}) \right]
\end{aligned}$$

$$SSB_{y,x} = \sum_{a=1:9} N_{a,y,x} \cdot W_{a,y,x} \cdot Mat_{a,y,x}$$

**Eqn 3**:

$$C_{a,y,f} = \sum_x N_{a,y,x} \cdot W_{a,y,x} \cdot A_{x,f} \cdot \frac{F_{a,y,f}}{F_{a,y,f} + M_{a,y,x}} \cdot \left(1 - \exp(-M_{a,y,x} - S_{a,y,f} \cdot F_{a,y,f})\right)$$

**Eqn 4:**

$$\begin{aligned}
n_y &= \sum_a \sum_x SI_{a,y} \cdot SI_{x,y} \\
P_{a,y,x} &= \frac{SI_{a,y,x}}{n_y} \\
I_{a,y,x} &= n_y \cdot P_{a,y,x} \cdot CS_{a,x} + \sum_{g \ne x} n_y \cdot P_{a,y,g} \cdot (1 - CS_{a,g}) \cdot \varepsilon_I
\end{aligned}$$

Where $SI_a$ and $SI_x$ are indicator variables where $SI_a = 1$ if a fish is of age $a$, $SI_x = 1$ if a fish is of population $x$ and 0 otherwise

Symbol explanations:

| PARAMETER | EXPLANATION |
|---|---|
| $\alpha$ | *Slope parameter of segmented regression Stock-Recruit curve* |
| $\beta$ | *Inflection point parameter of segmented regression Stock-Recruit curve* |

| *Identifier* | *Explanation* |
|---|---|
| $x$ | *Identifier of biological population* |
| $z$ | *Identifier of biological population other than itself* |
| $y$ | *Identifier of years* |
| $f$ | *Identifier of fleets* |
| $a$ | *Identifier of age* |

| VARIABLE | EXPLANATION |
|---|---|
| $R$ | *Recruitment* |
| $SSB$ | *Spawning Stock Biomass* |
| $N$ | *Numbers* |
| $C$ | *Catch* |
| $I$ | *Survey index* |
| $F$ | *Fishing mortality* |
| $S$ | *Fishery selectivity* |
| $M$ | *Natural mortality* |
| $W$ | *Weight of the biological population* |
| $Mat$ | *Maturity of the biological population* |
| $A$ | *Availability to the fisheries* |
| $n$ | *Sample size* |
| $SI$ | *Identicator variable* |
| $CS$ | *Identification success in survey* |
| $\varepsilon_{SRR}$ | *Error structure on Stock-Recruit relationship* |
| $\varepsilon_{I}$ | *Error structure on survey* |

## Annex 3: Recommendations

| Recommendation | For follow up by: |
|---|---|
| 1. That the Malin Shelf synoptic acoustic survey be continued to allow provision of acoustic and biological data and splitting of the constituent population components. | WGIPS |
| 2. That sampling for the provision of population ID be carried out on each of the component Malin Shelf surveys to allow otolith and body morphology analysis. | WGIPS; Marine Scotland-Science, Aberdeen; Marine Institute, Galway; AFBINI, Belfast. |
| 3. That the Irish Sea herring stock should undergo a benchmark assessment in 2011. | ACOM for HAWG |

## Annex 4: Figures showing results of all scenarios tested in the management strategy evaluation

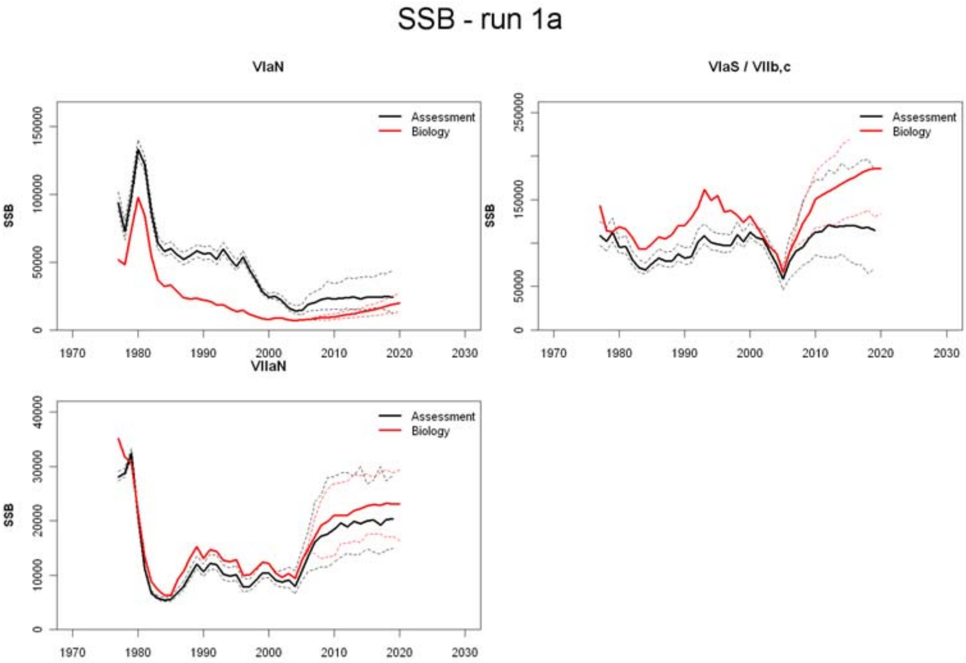
In addition to the scenario results described in the result section, many others have been performed where combinations of the scenario settings were evaluated. These results are listed below, each consisting of an SSB, Fbar, Recruitment and Survey Index plot. The text table below shows which run can be identified with which scenario setting.

- the Ftarget column represents the absolute target set in the short term forecast;
- the availability scenario refers to the levels of mixing (1 = 25%... 4=0% mixing). The Malin Shelf survey was either executed on only the VIaN and VIaS/VIIb,c population (1–2), or also in combination with the VIIaN population (1–3). As the latter situation hardly made any difference to the results for the VIaN and VIaS/VIIb,c populations, they have been excluded.
- the Identification Success rate is given in the second row of the table below. Four runs have been included under the 10e runID, where an evaluation of an increase in sample size was evaluated.

The figures below show median results in solid lines while the 95% quantile of the runs is given in dashed lines. Target lines are shown in dotted lines.

Note: Sudden drops and peaks in the recruitment plots are an artifact of the assessment method used and have not been used within the simulations.

| | | Malin Shelf Survey | 1-2 | 1-2 | 1-2 | 1-2 | 1-3 |
|---|---|---|---|---|---|---|---|
| | | Identification Success | 1 | 0.9 | 0.8 | 0.7 | 1 |
| Ftarget | Availability Scenario | *RunID* | | | | | |
| 0.2 | 1 | | 1a | 1b | 1c | 1d | |
| 0.3 | 1 | | 2a | 2b | 2c | 2d | |
| 0.4 | 1 | | 3a | 3b | 3c | 3d | |
| 0.2 | 2 | | 4a | 4b | 4c | 4d | |
| 0.3 | 2 | | 5a | 5b | 5c | 5d | |
| 0.4 | 2 | | 6a | 6b | 6c | 6d | |
| 0.2 | 3 | | 7a | 7b | 7c | 7d | |
| 0.3 | 3 | | 8a | 8b | 8c | 8d | |
| 0.4 | 3 | | 9a | 9b | 9c | 9d | |
| 0.2 | 4 | | 10a | 10b | 10c | 10d | 10e |
| 0.3 | 4 | | 11a | 11b | 11c | 11d | |
| 0.4 | 4 | | 12a | 12b | 12c | 12d | |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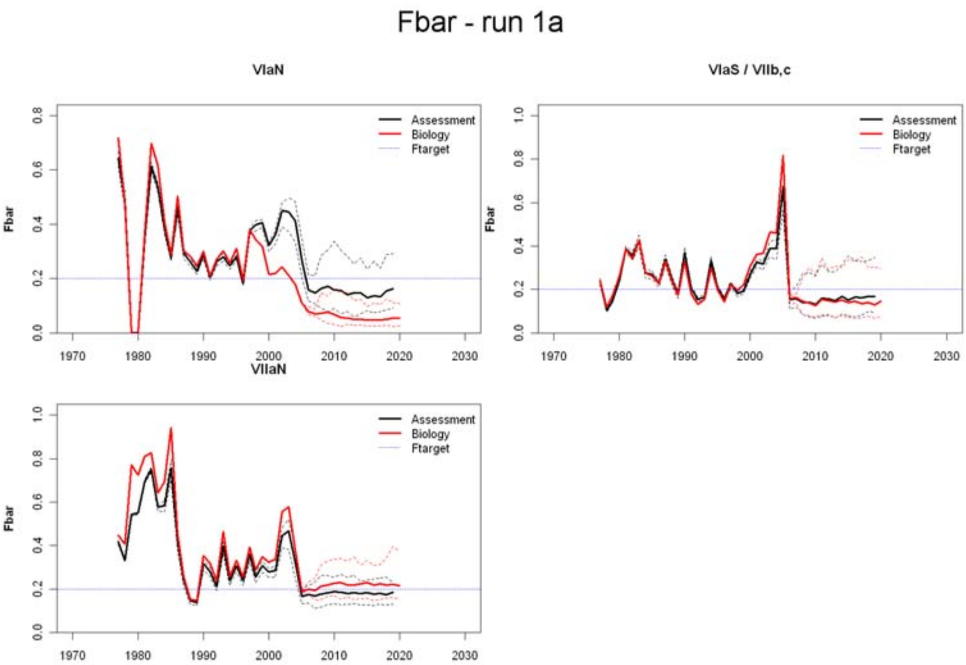
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology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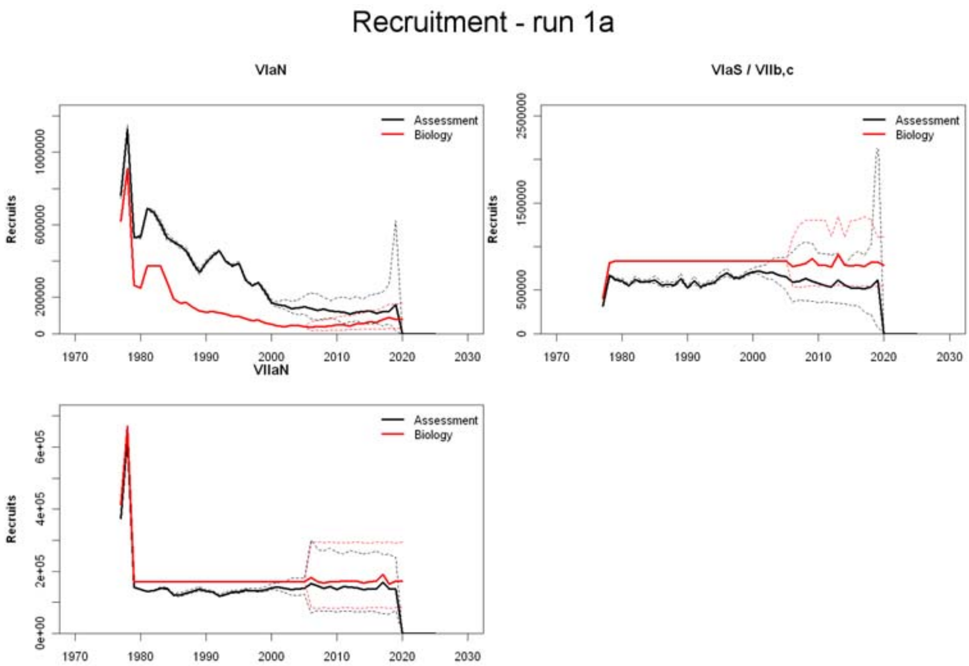
Biology
Ftarget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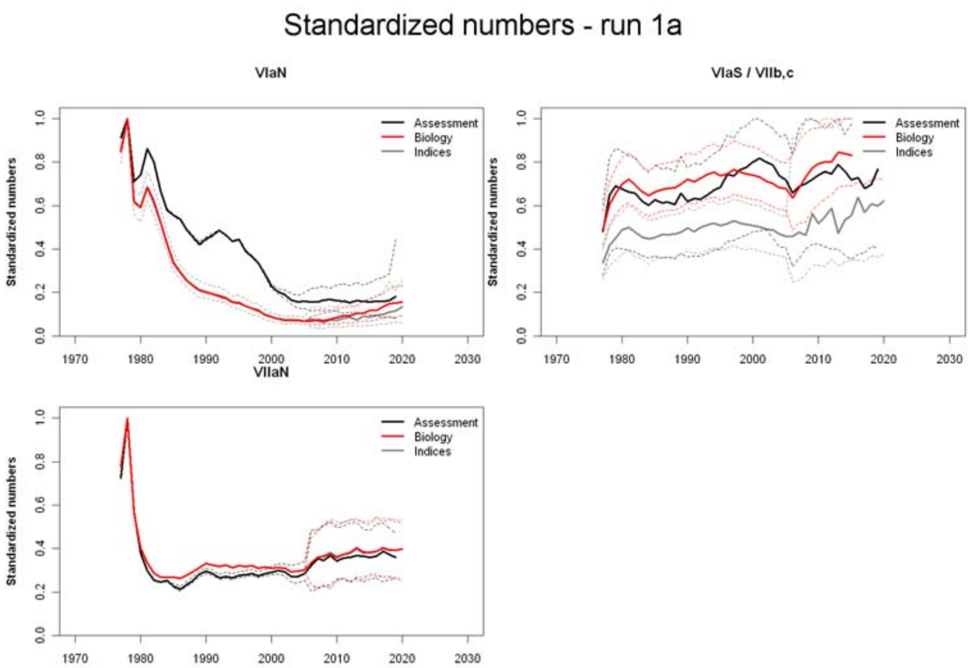
Recruits
Assessment
Biology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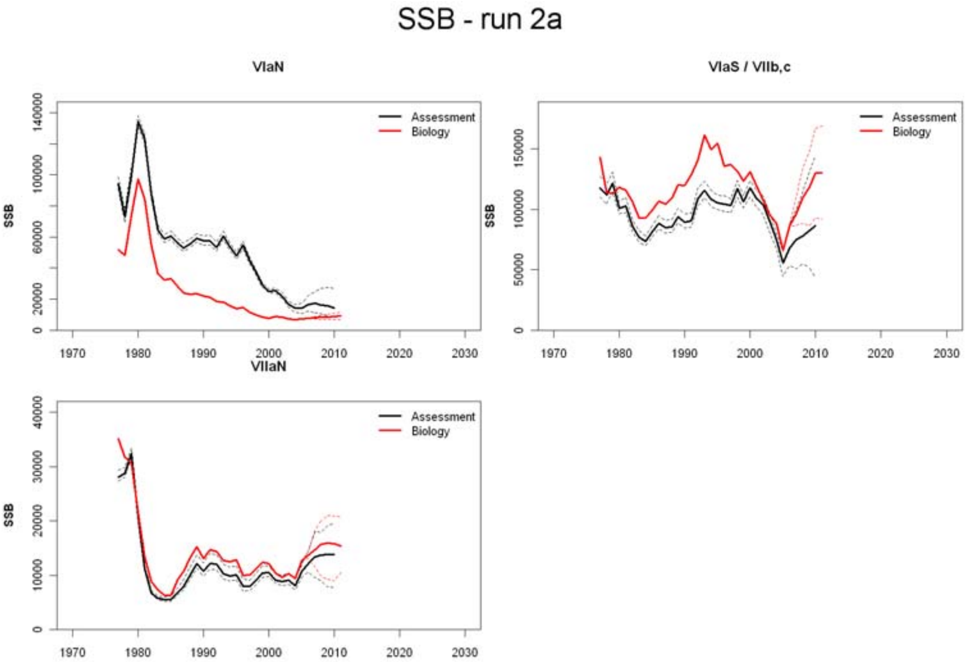
VIIaN
Standardized numbers
Assessment
Biology
Indices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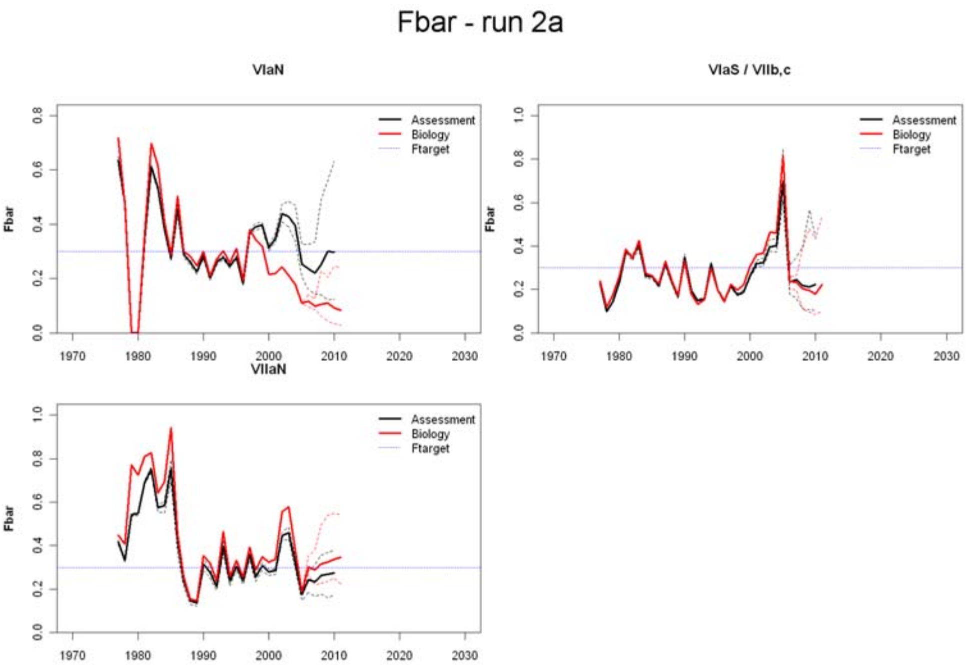
Biology
SSB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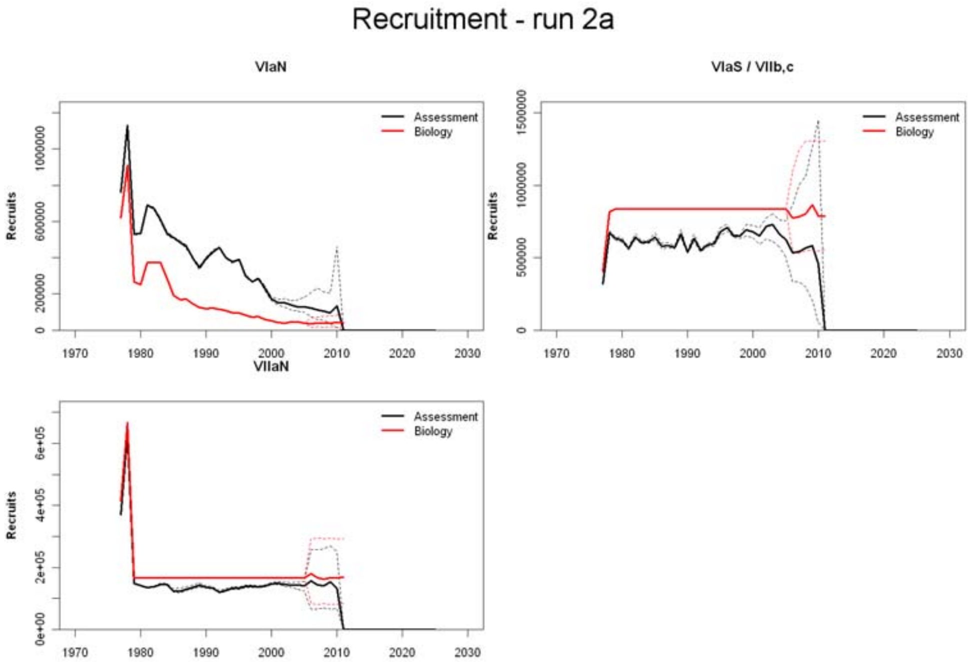
Ftarget
Fbar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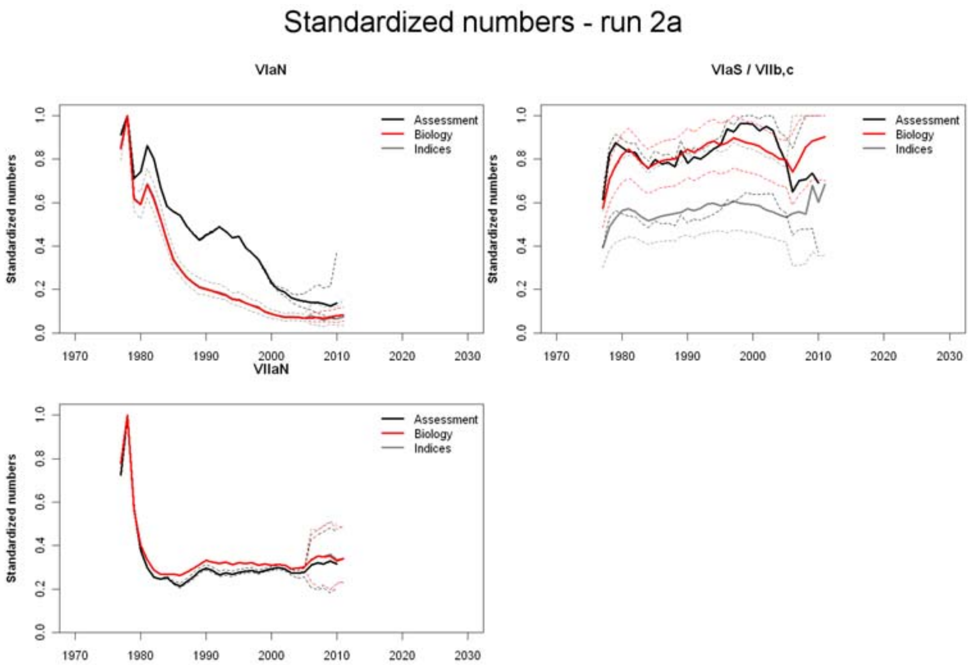
Assessment
Biology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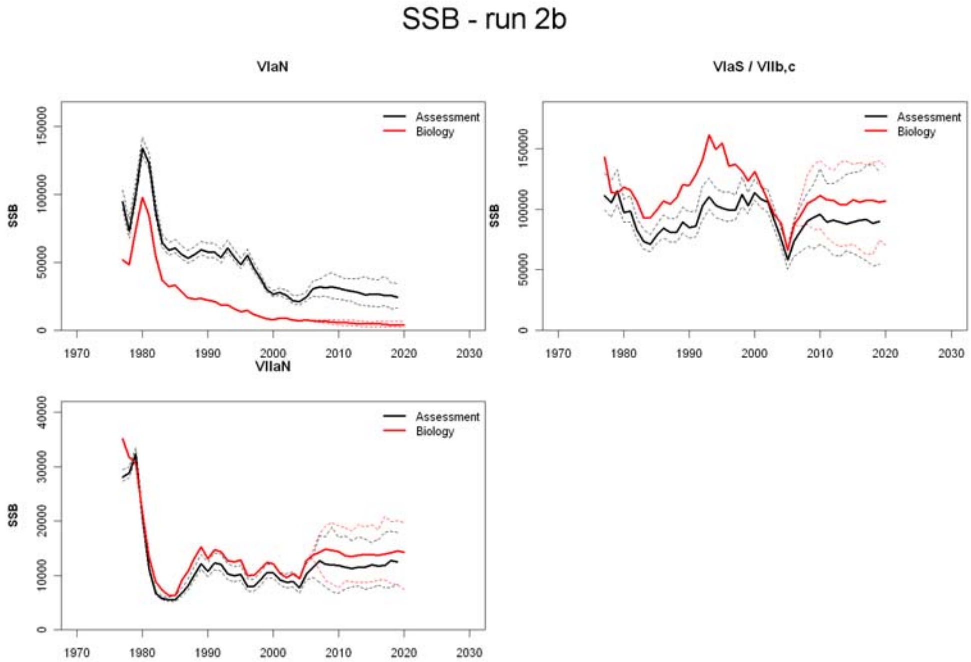
Biology
Indices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VIaN
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SSB
Assessment
Biology
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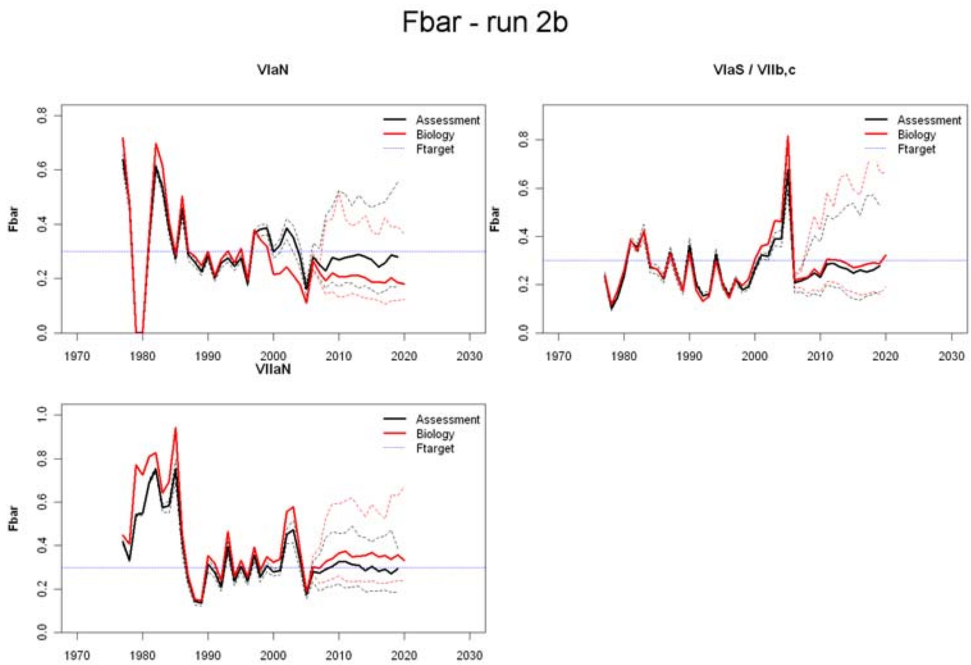
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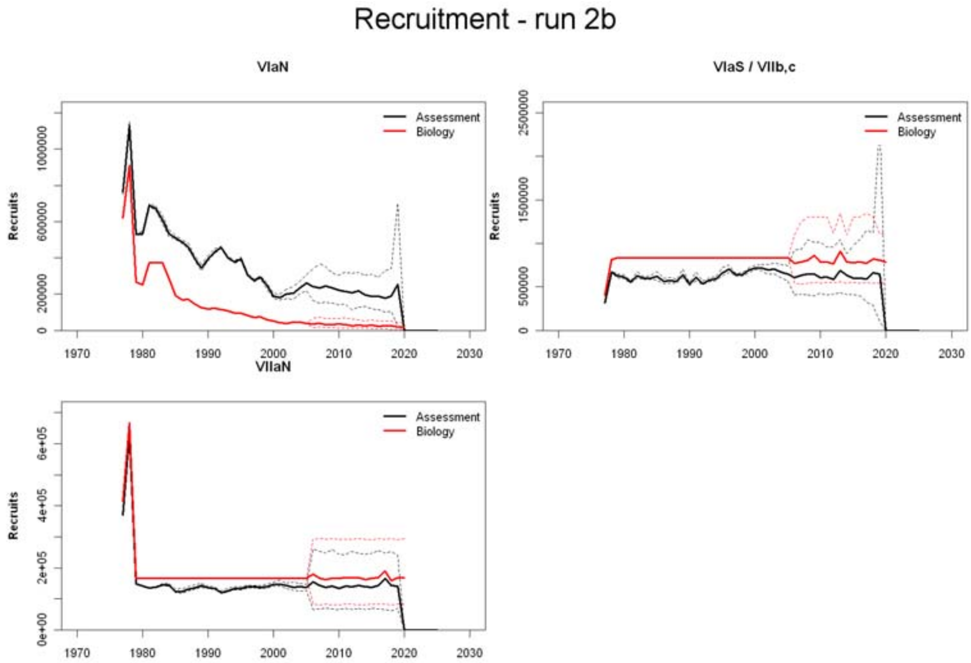
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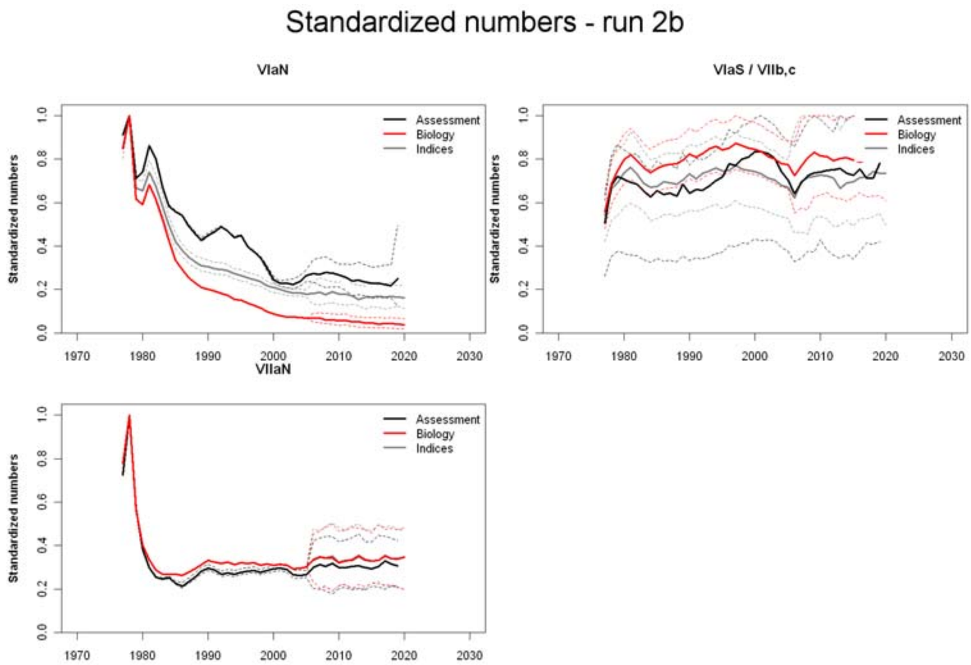
Recruits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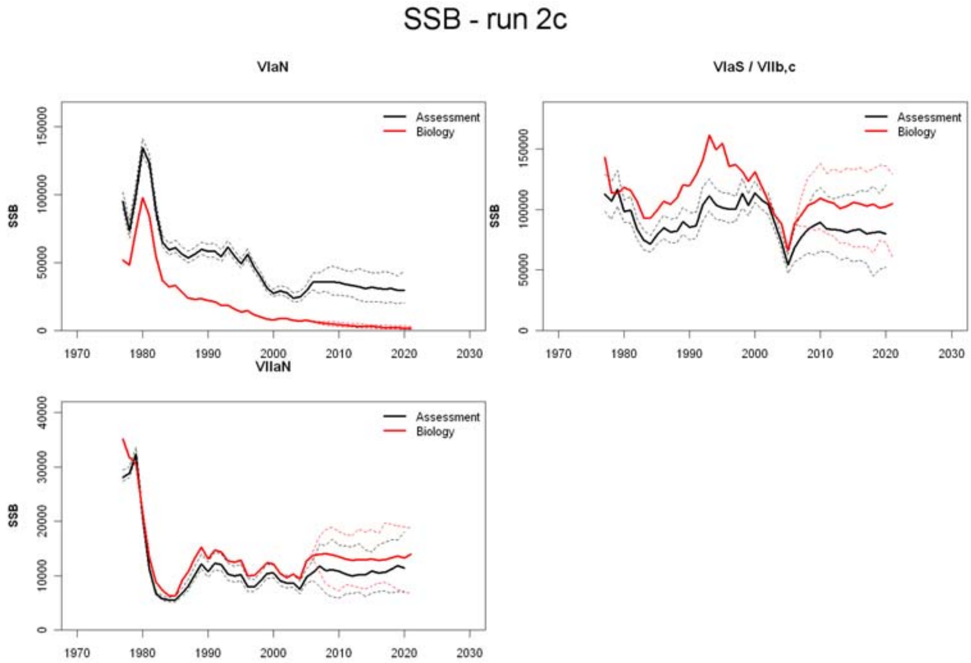
Standardized numbers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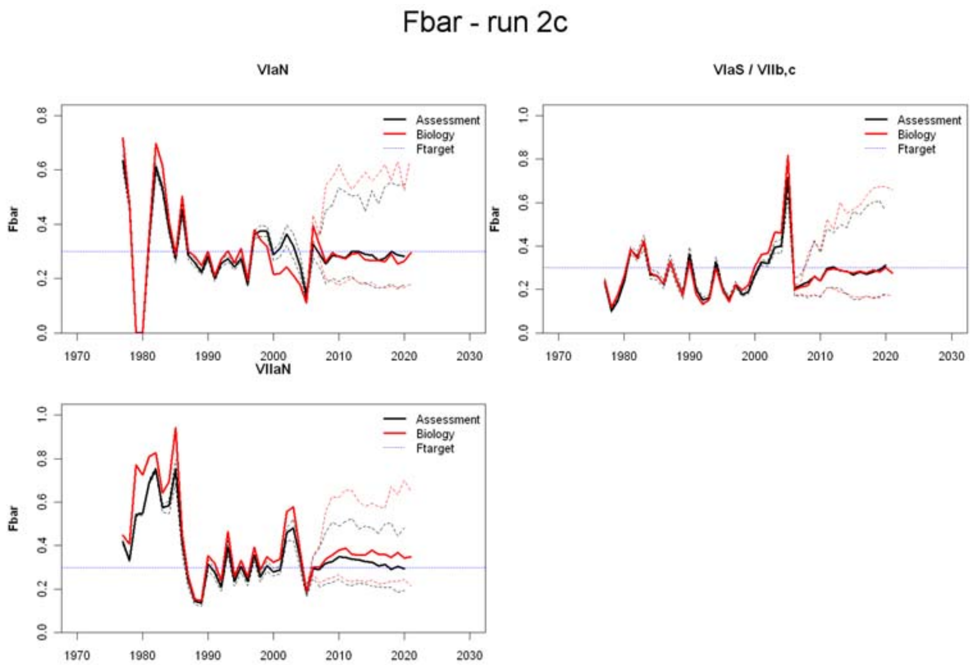
SSB
Assessment
Biology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Fbar
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Biology
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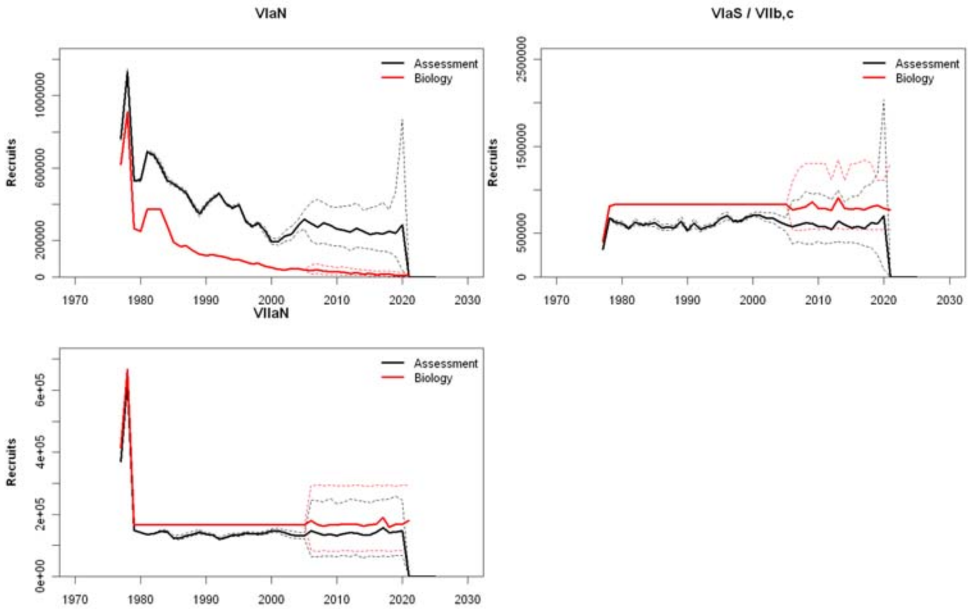
Recruitment - run 2c

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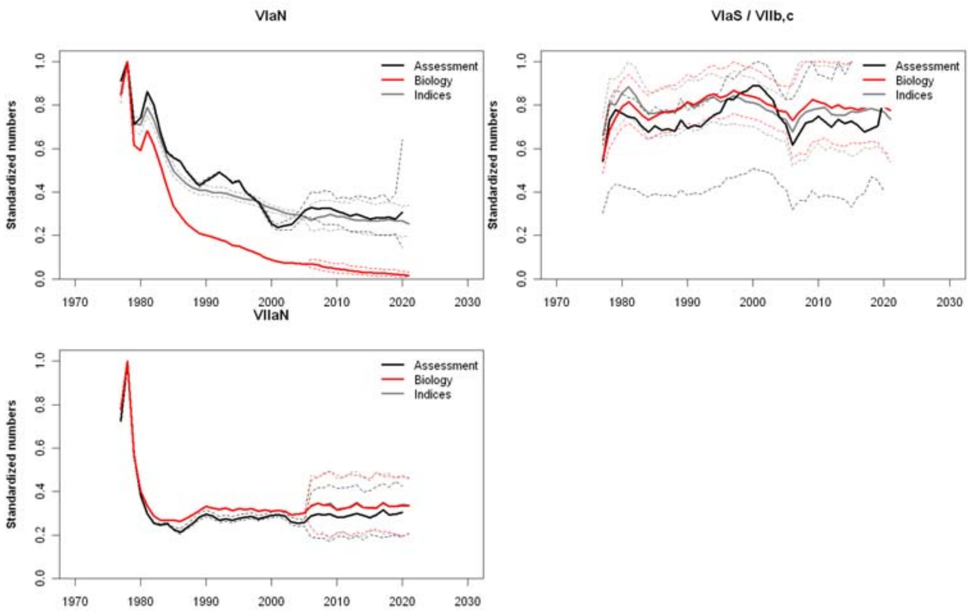

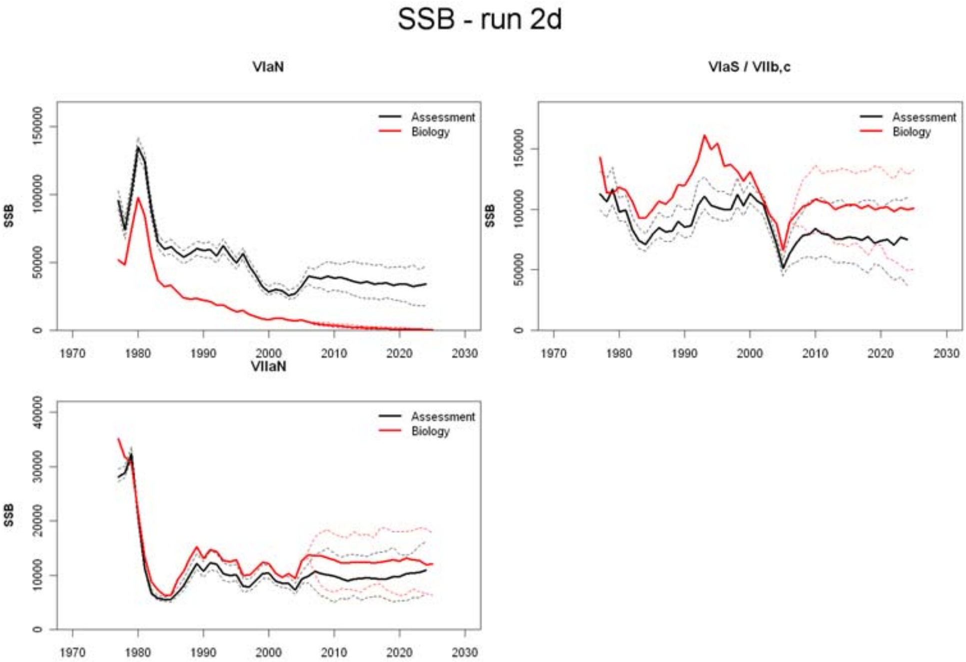
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Assessment
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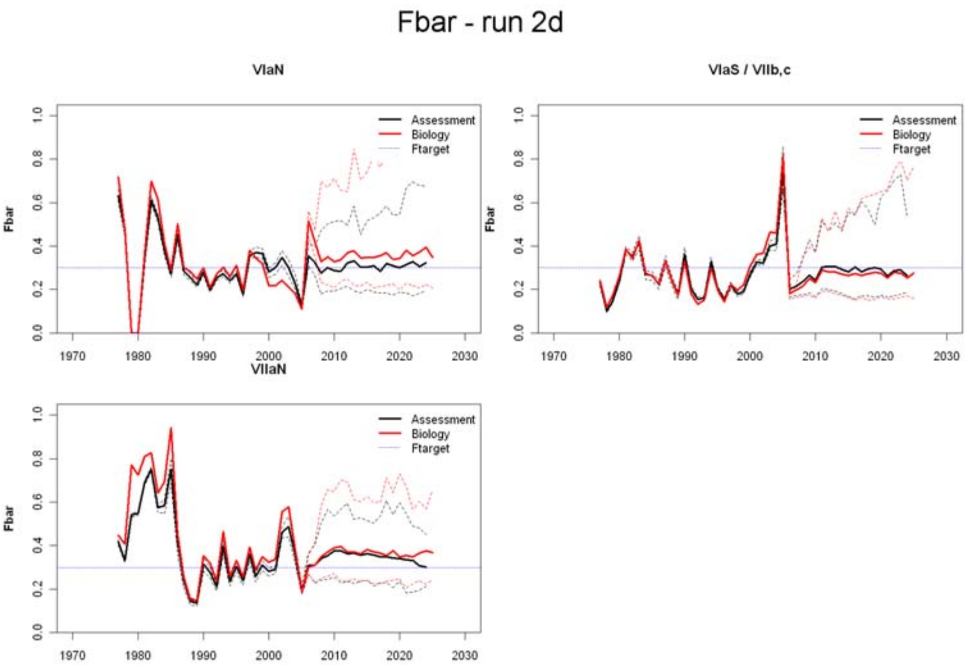
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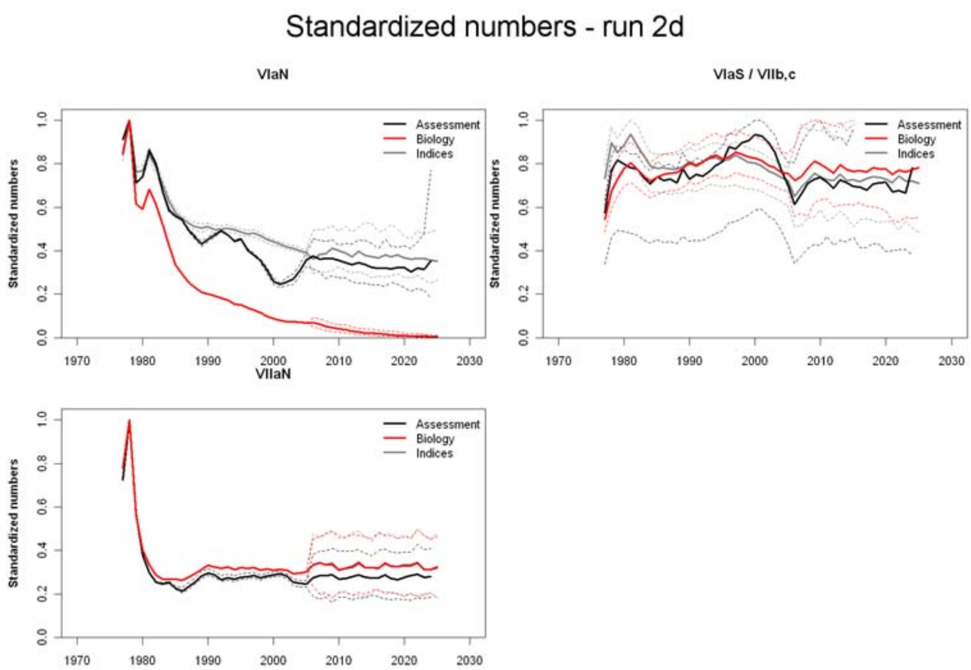
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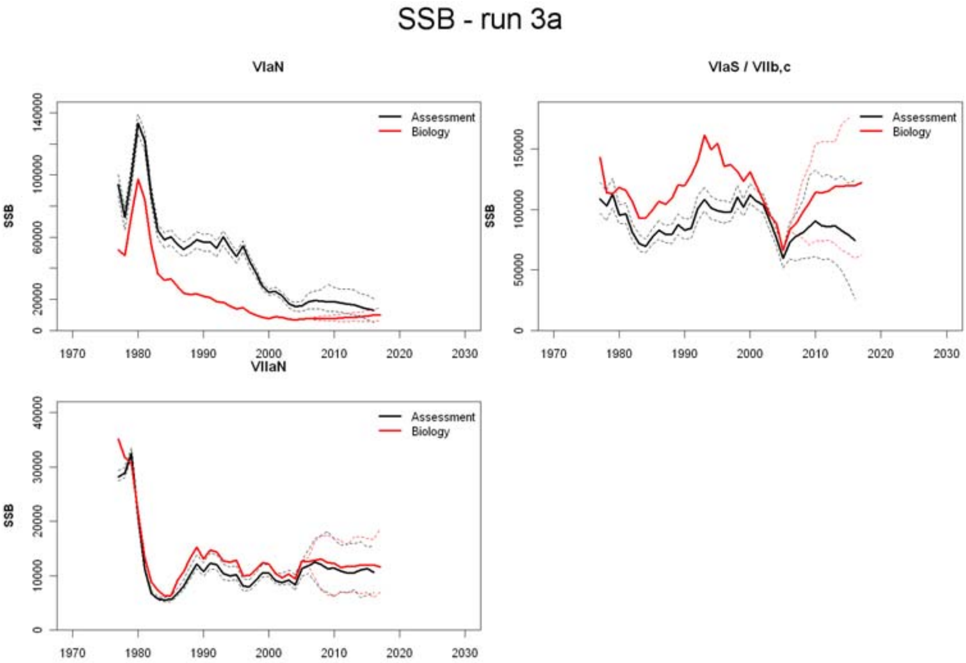
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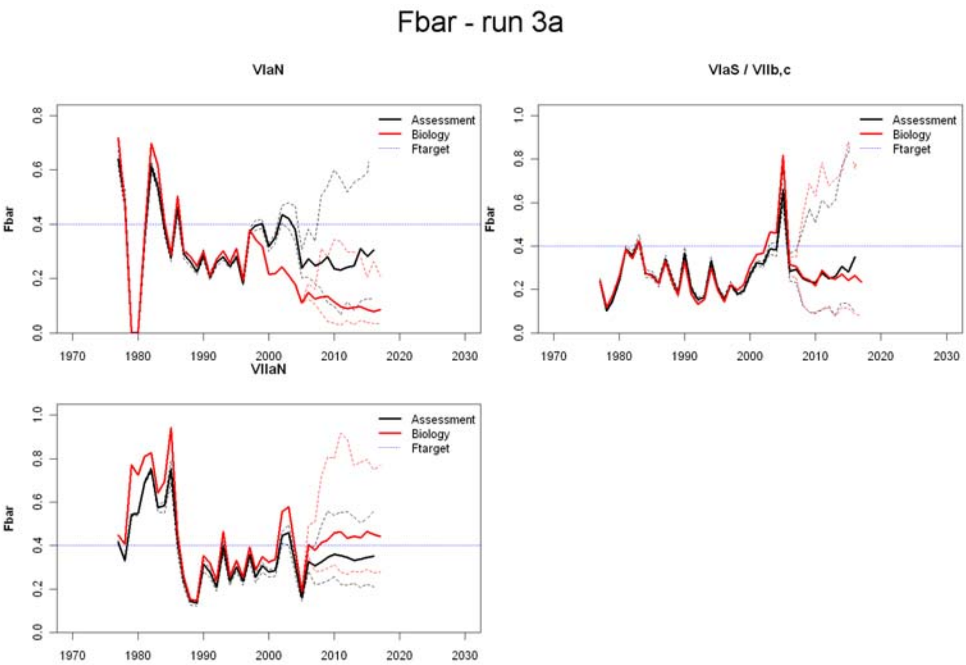
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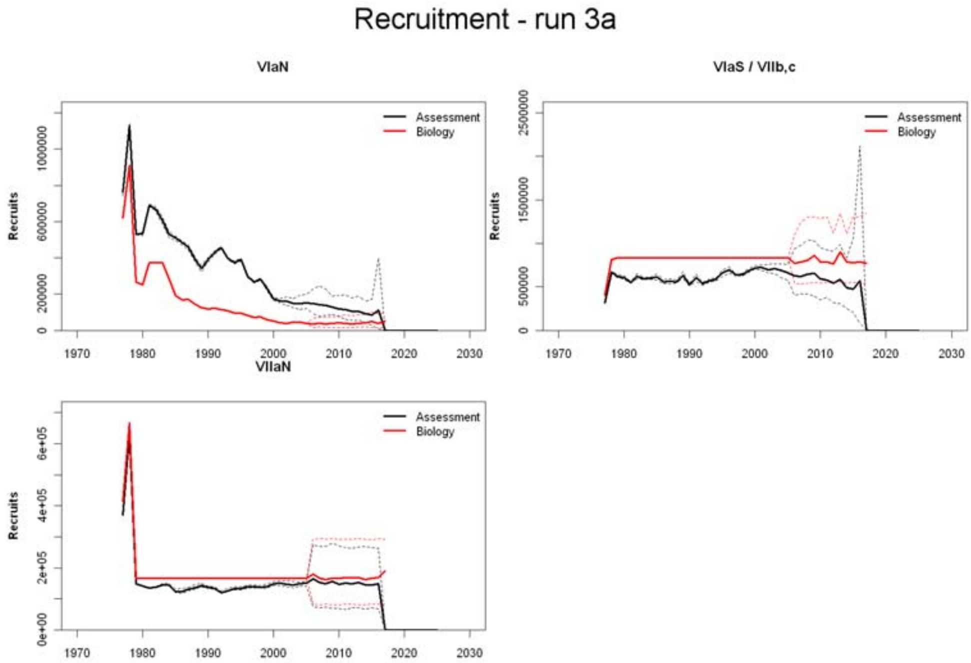
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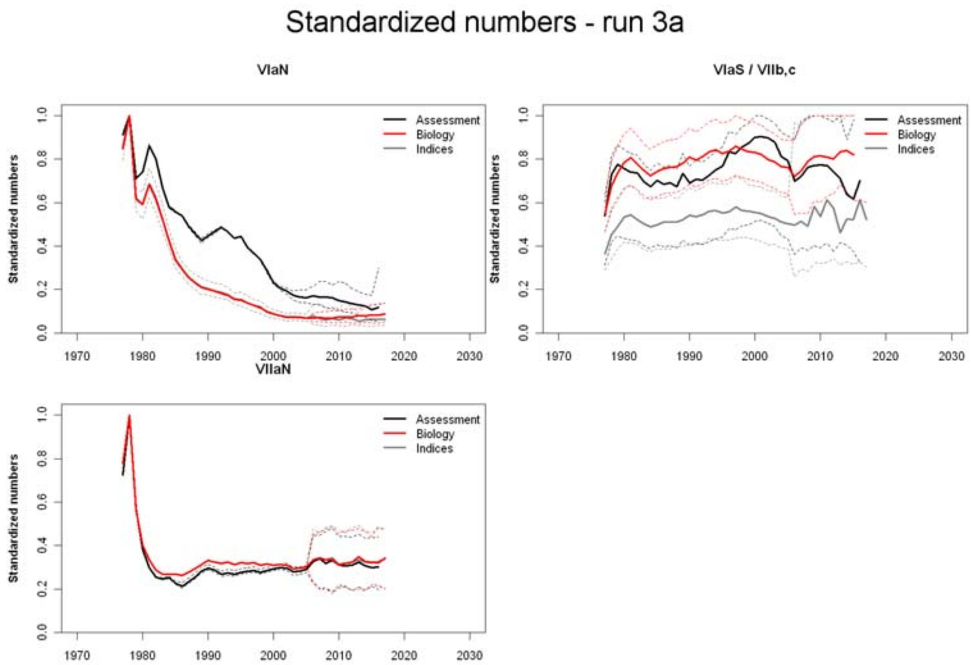
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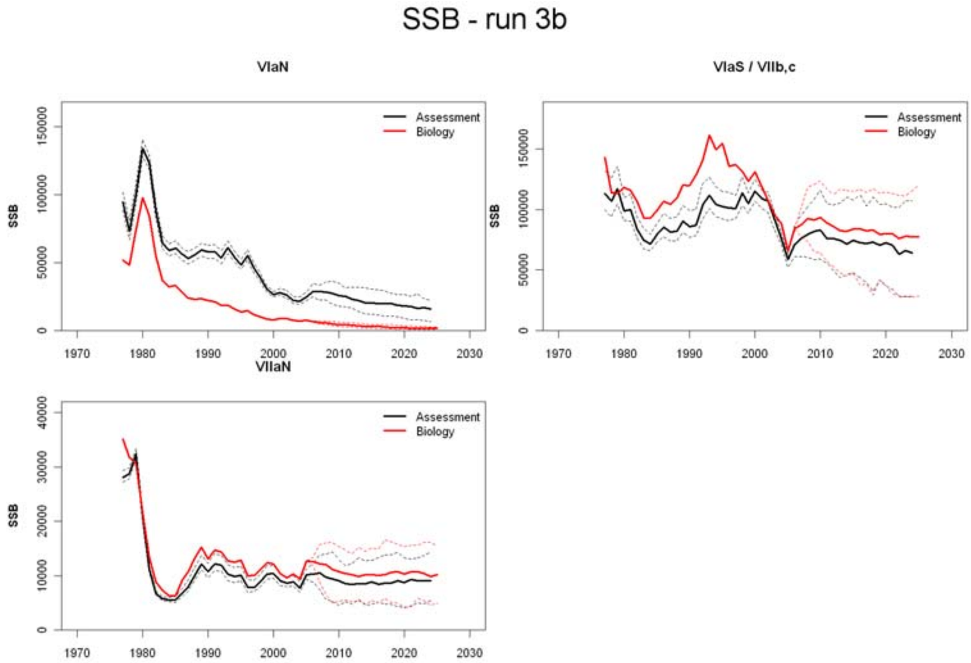
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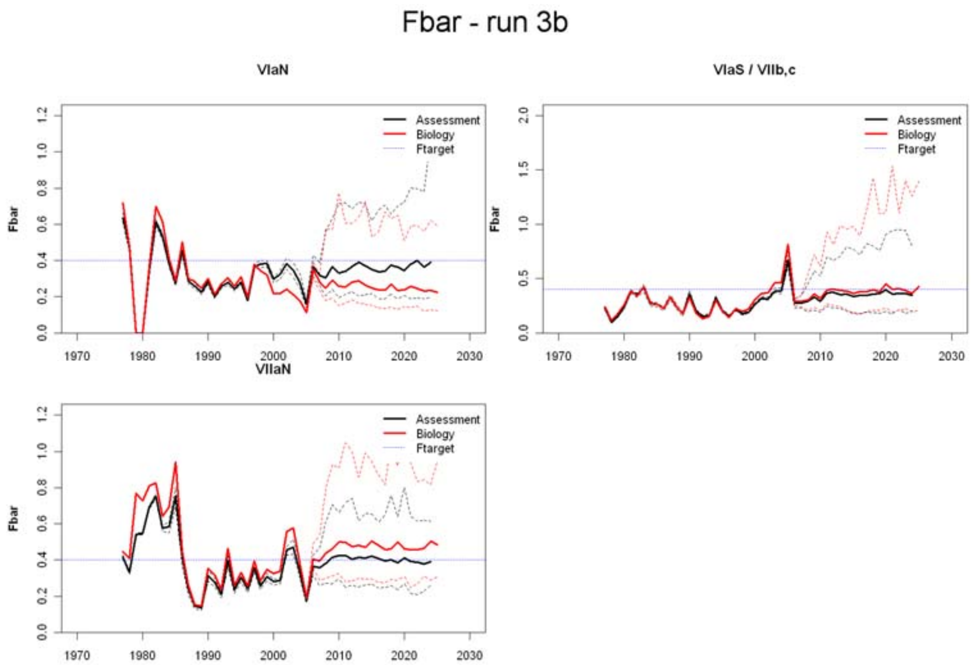
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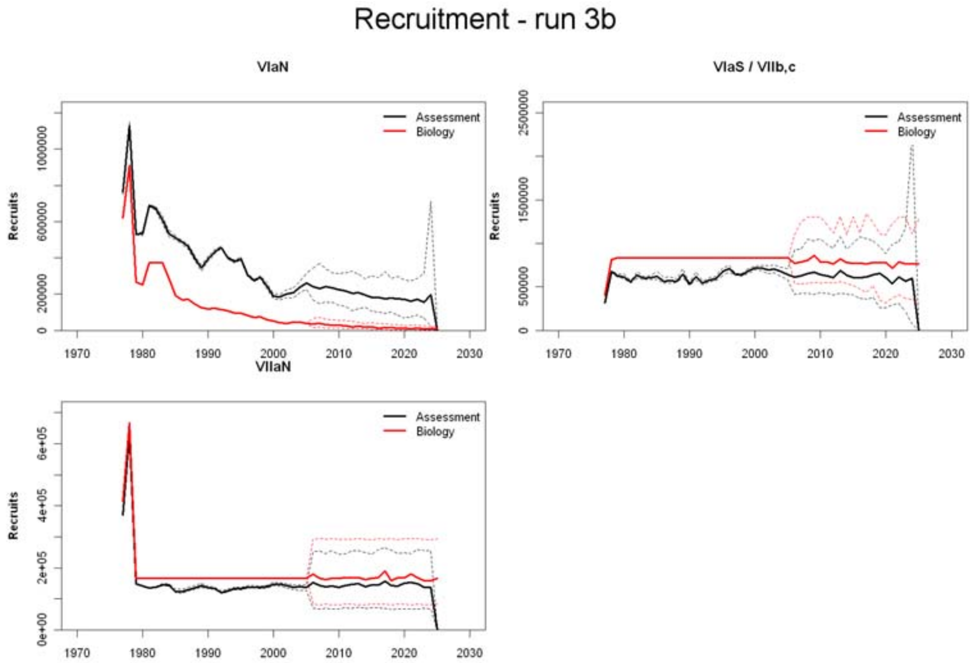
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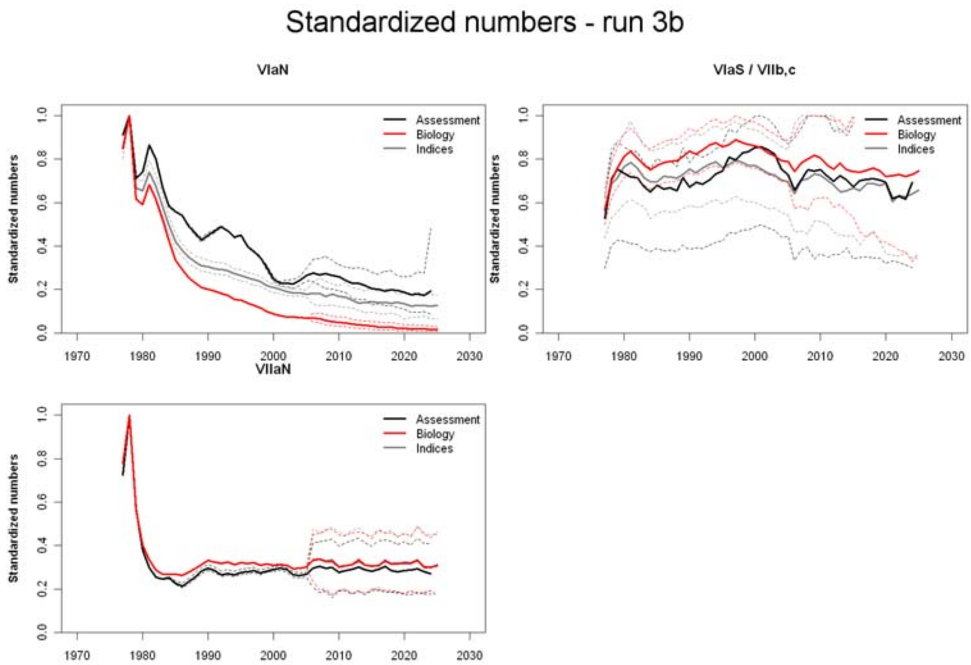
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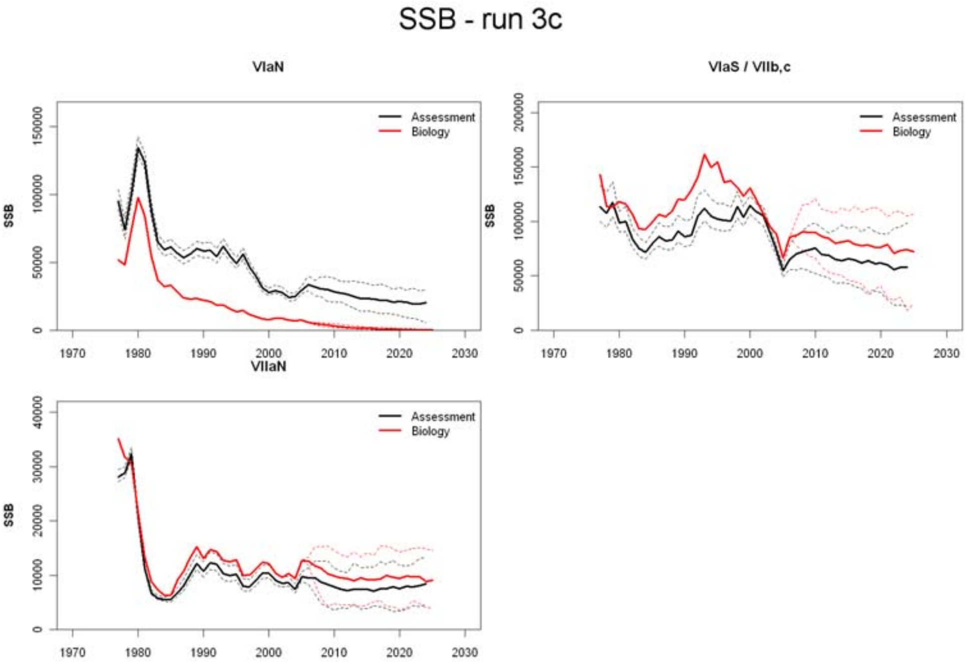
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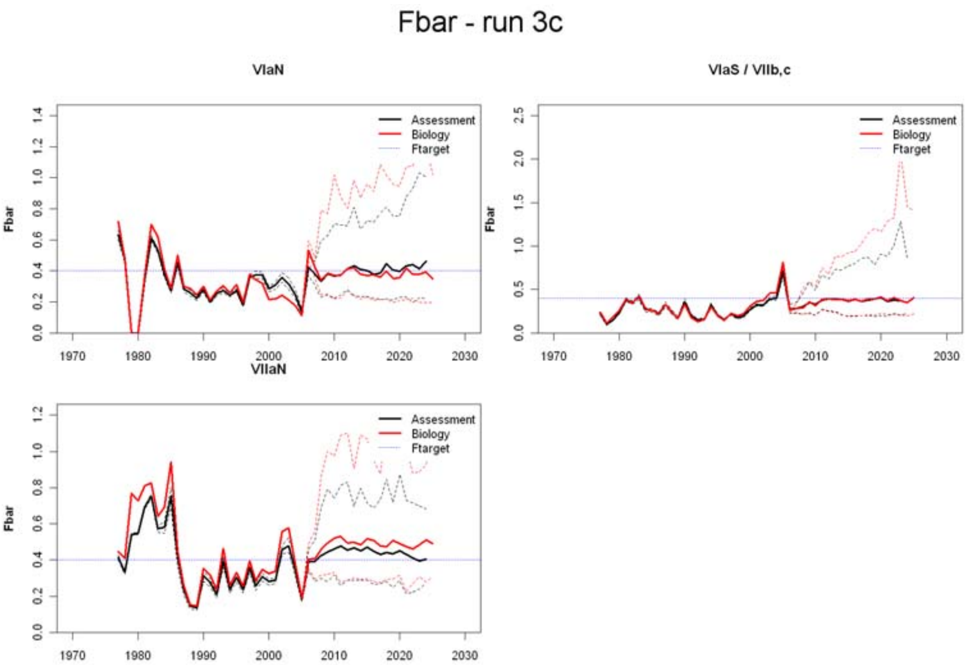
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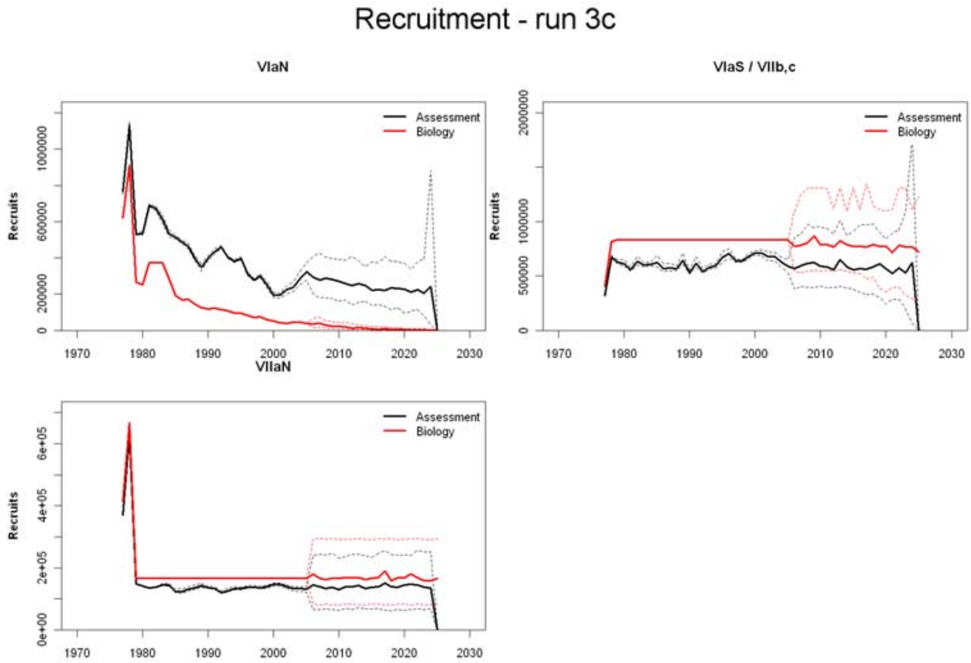
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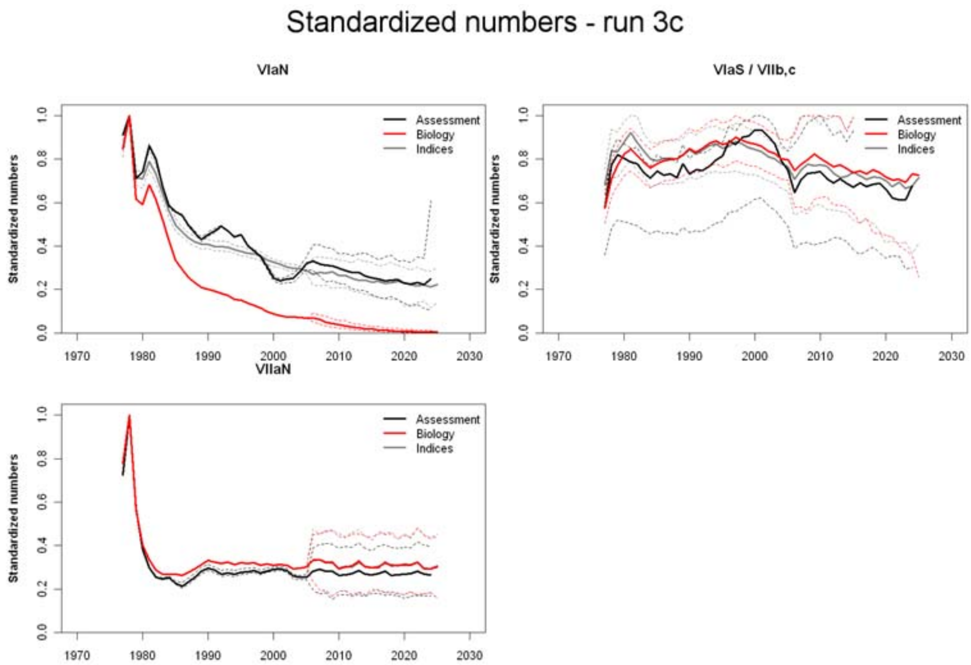
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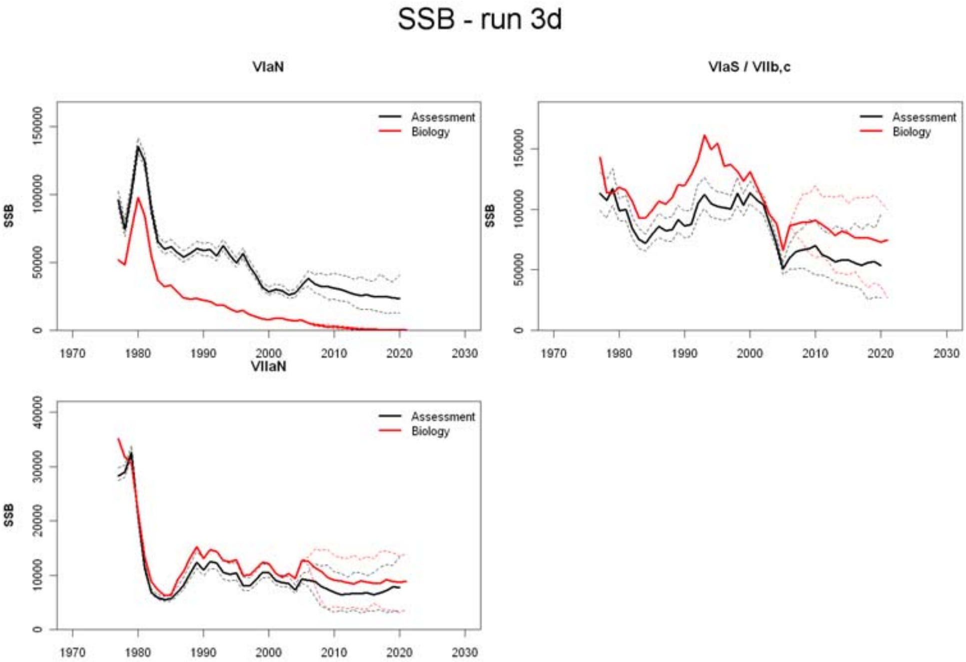
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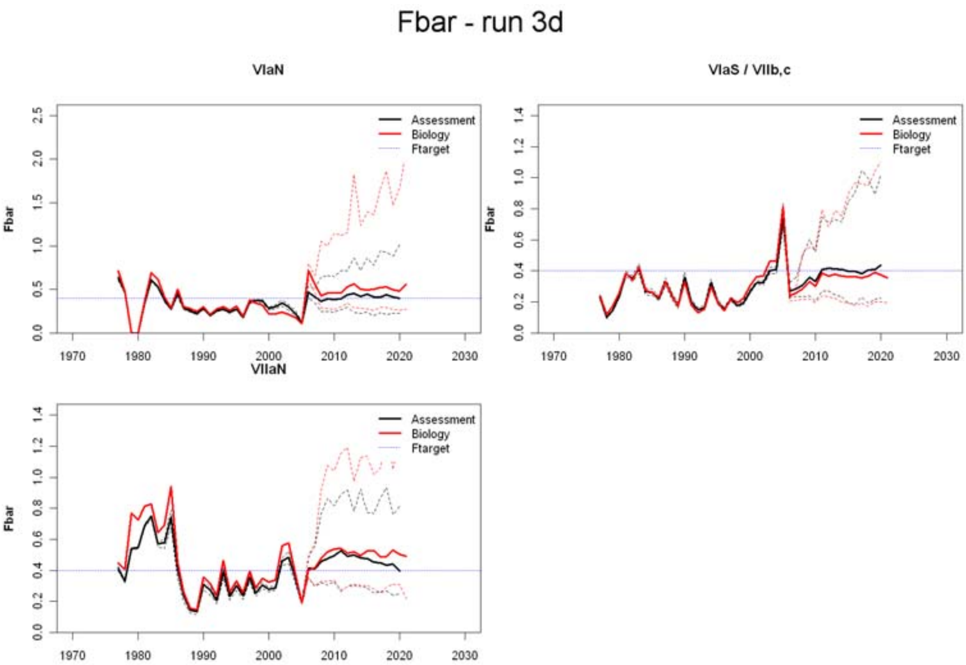
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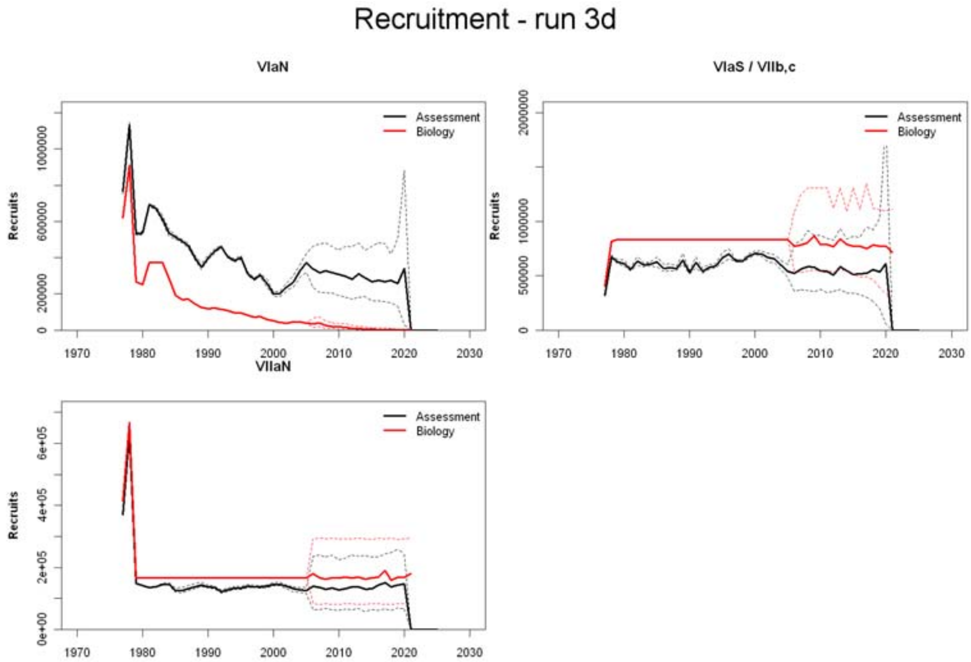
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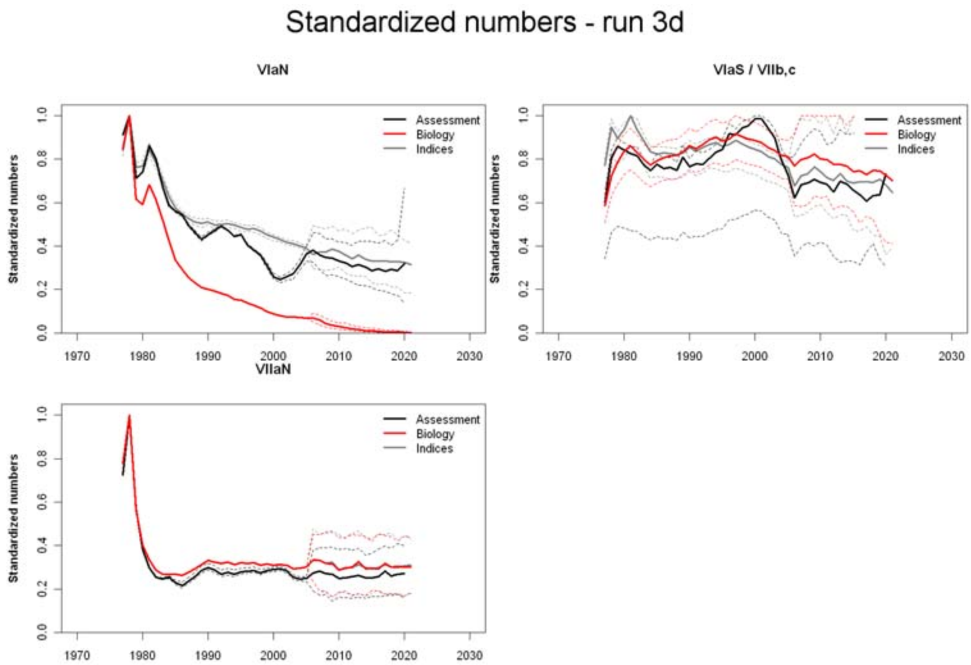
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1980
1990
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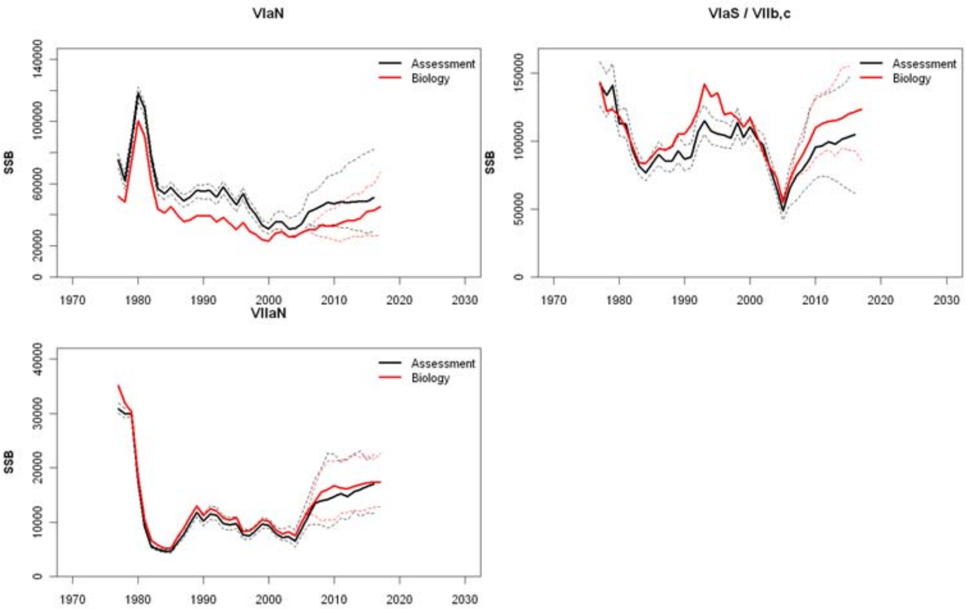
2010
2020
2030

SSB - run 4a

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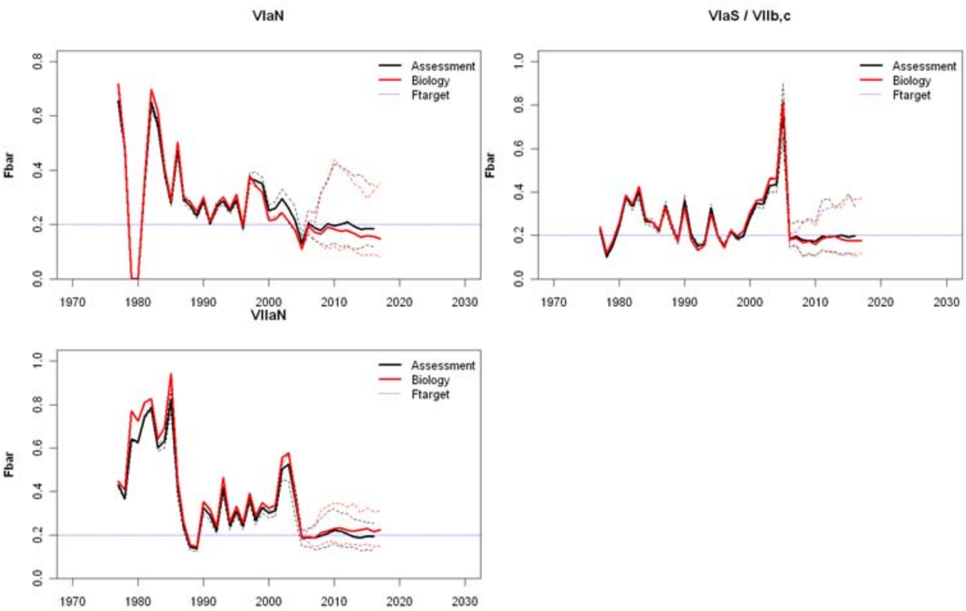

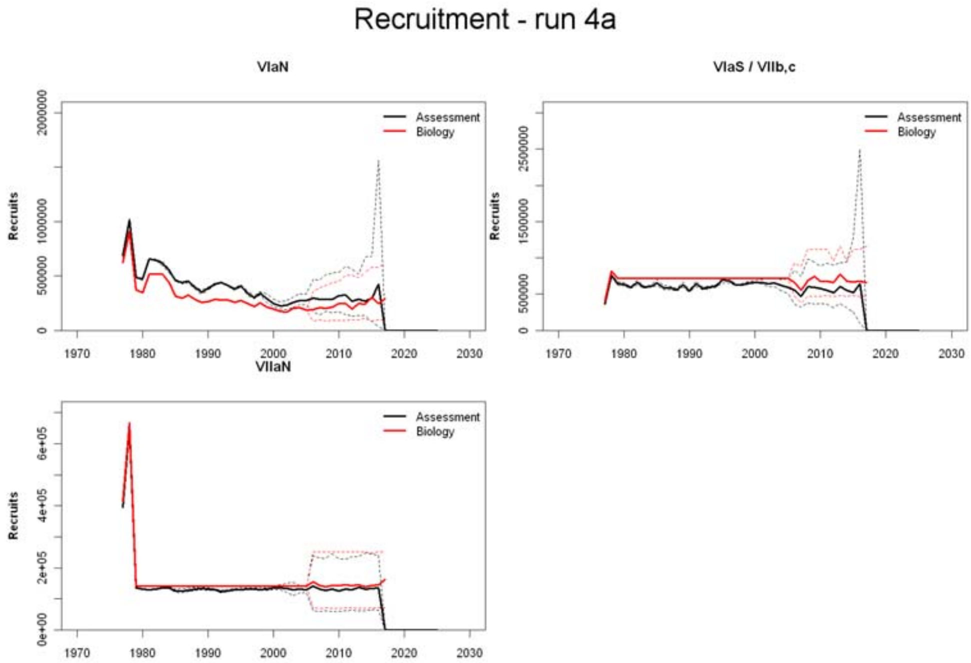
Recruitment - run 4a
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VIIaN
Assessment
Biology
Recruits
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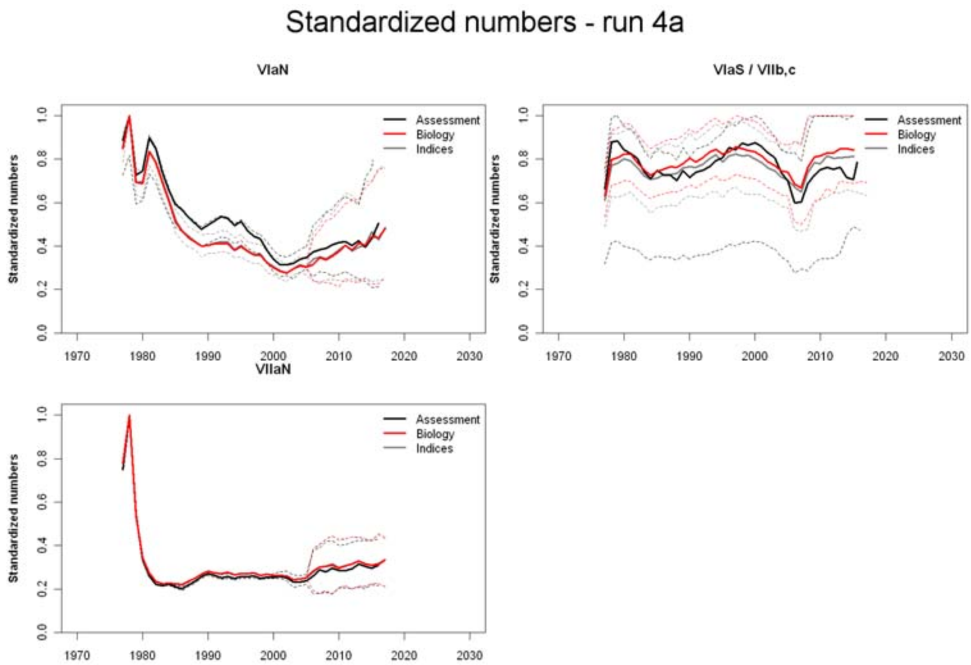
2010
2020
2030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Biology
Indices
Standardized numbers
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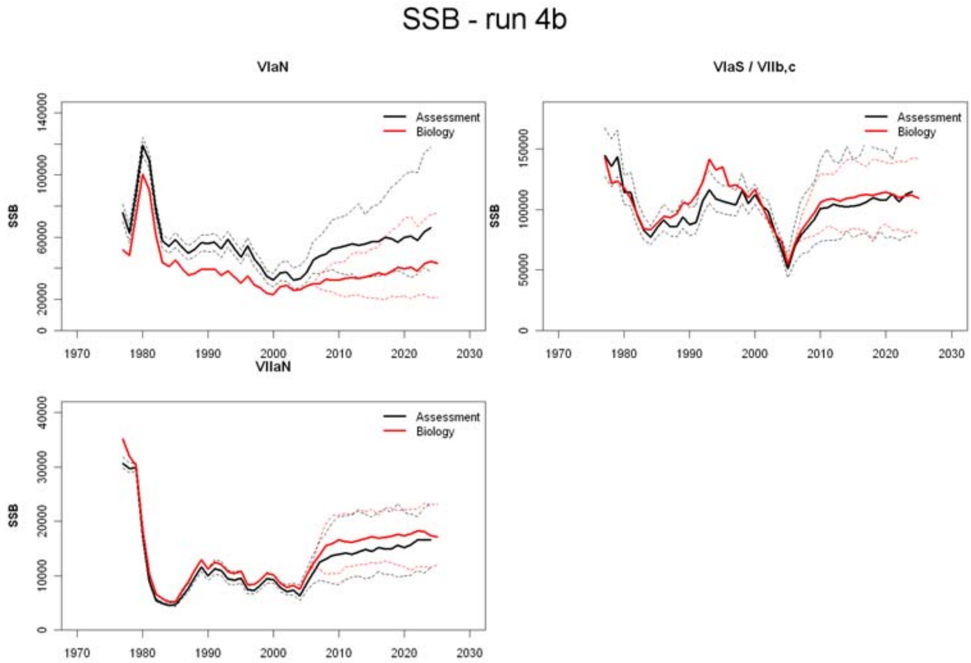
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Biology
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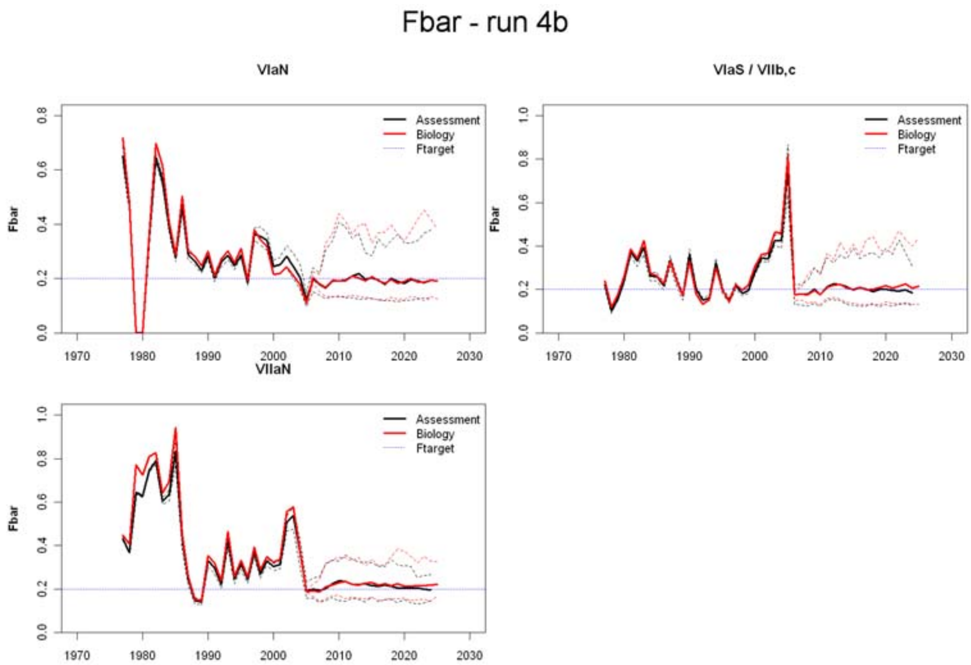
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Assessment
Biology
Ftarget
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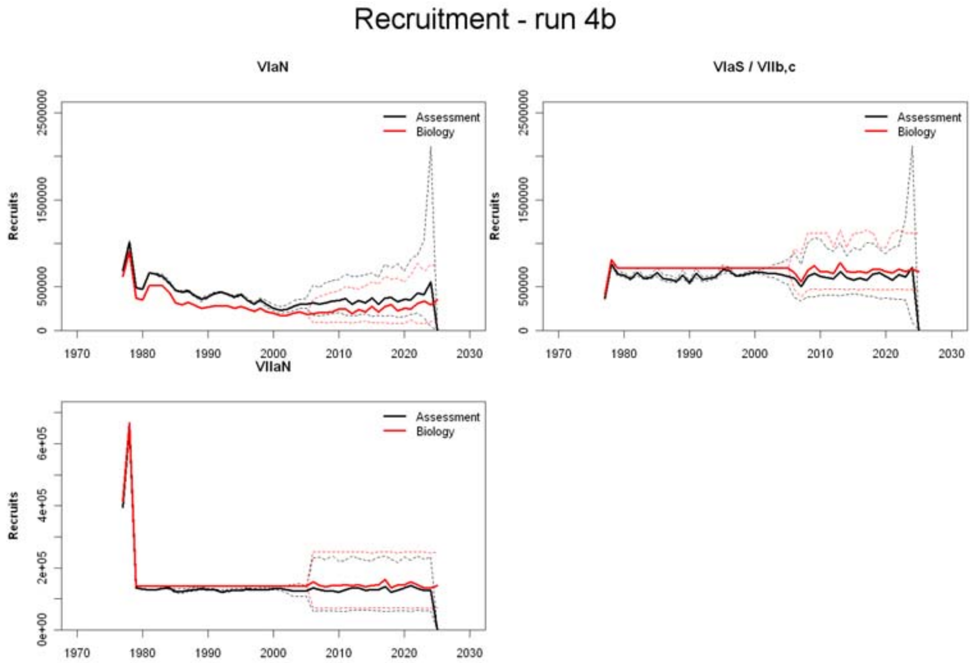
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Biology
Recruits
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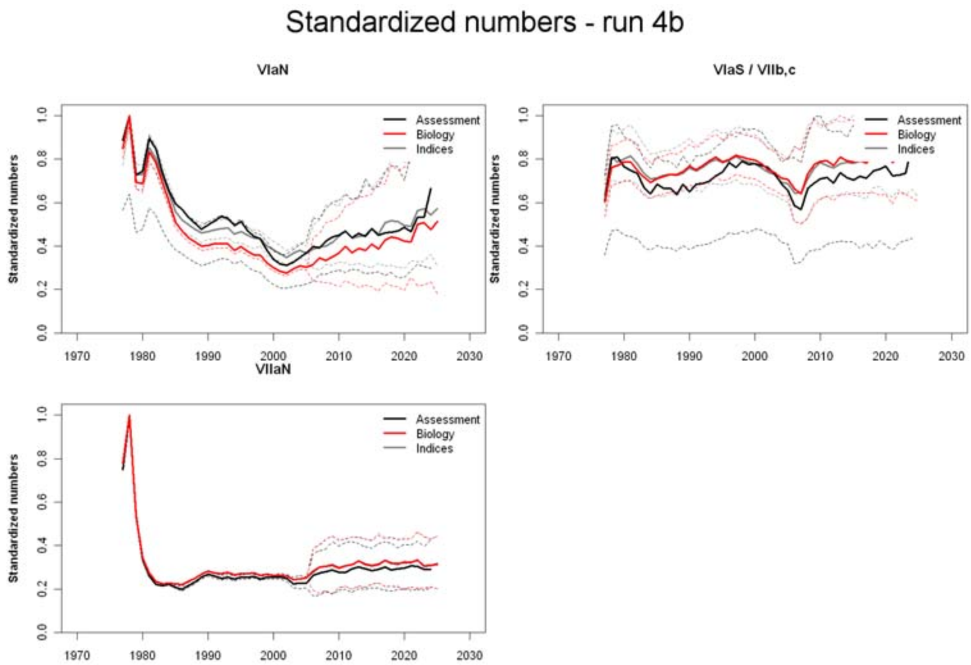
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Indices
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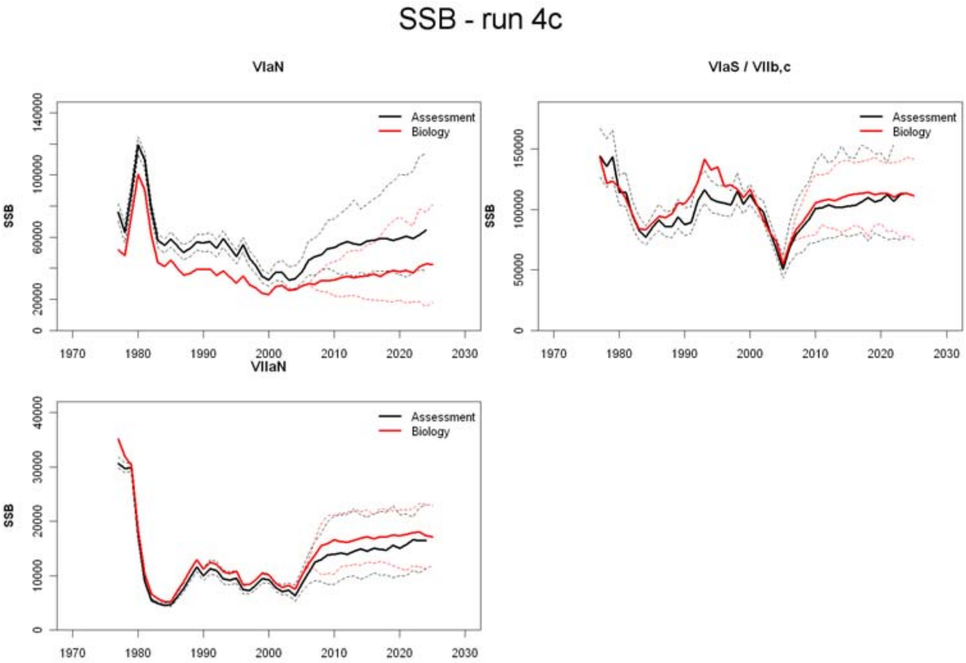
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VIaS / VIIb,c
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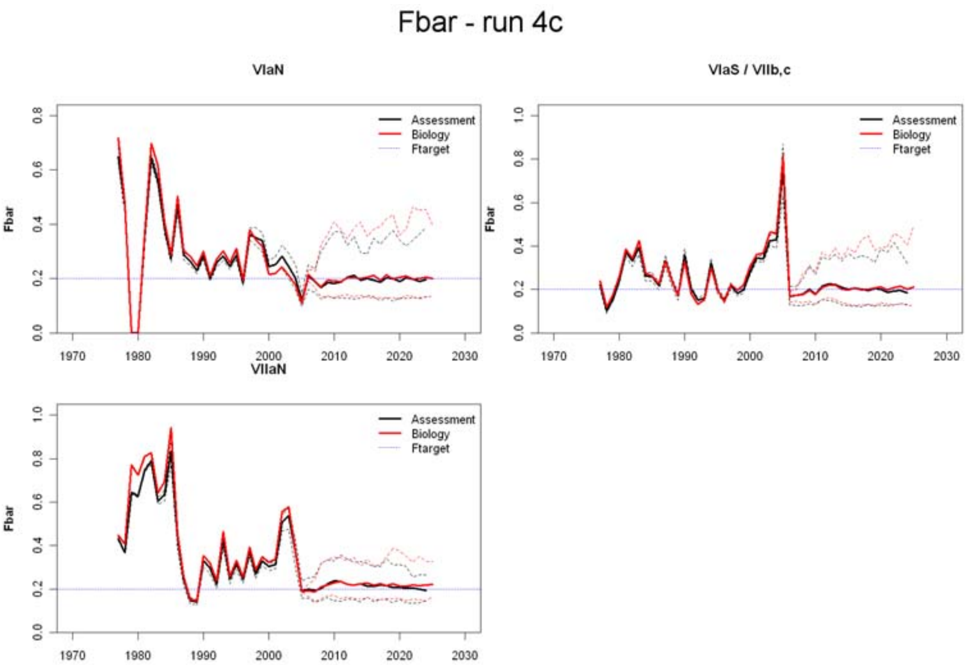
SSB
Assessment
Biology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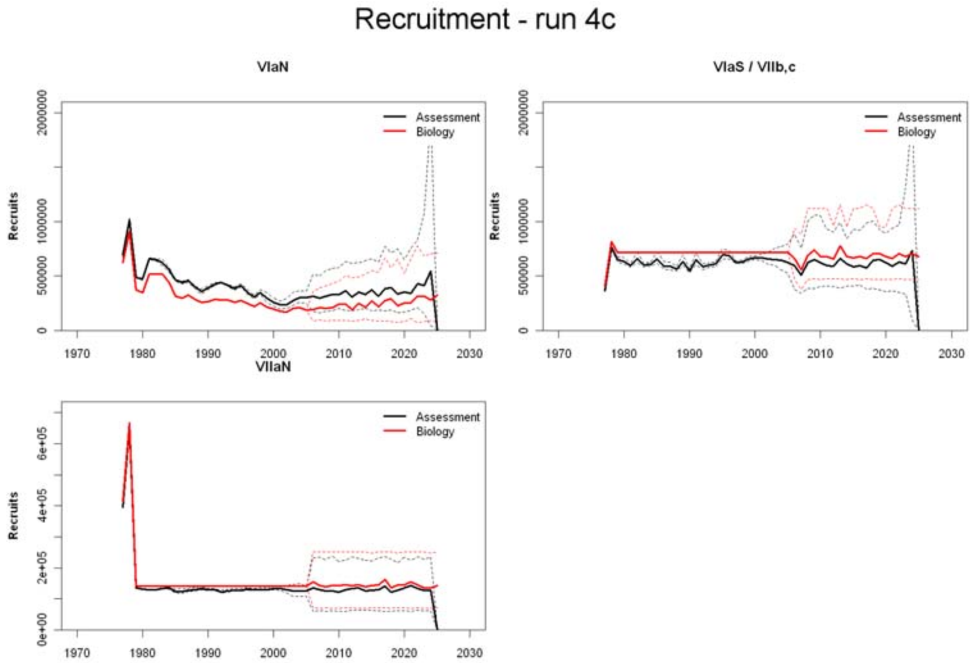
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Biology
Recruits
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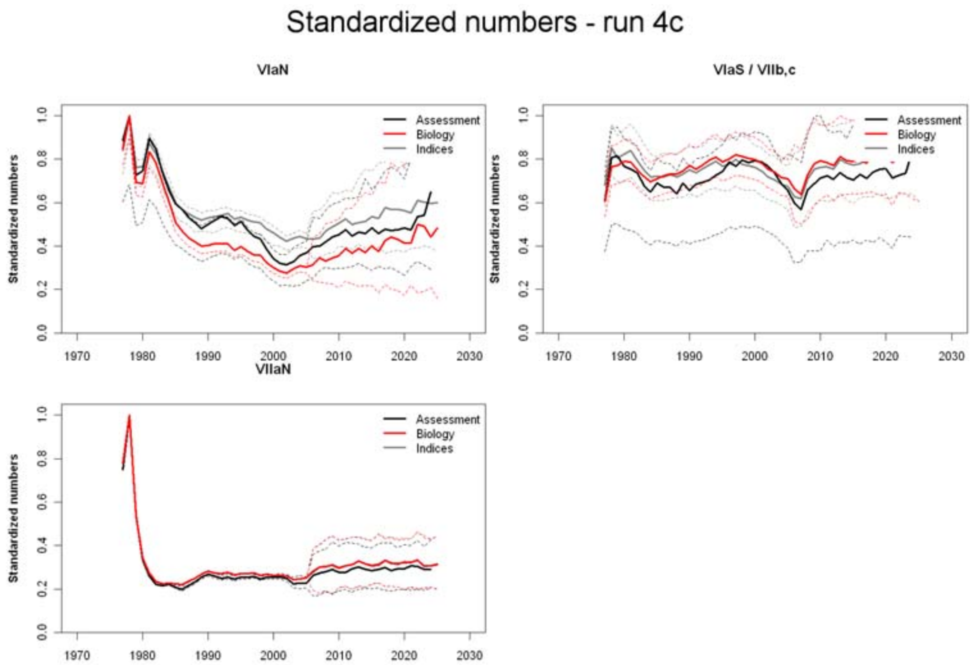
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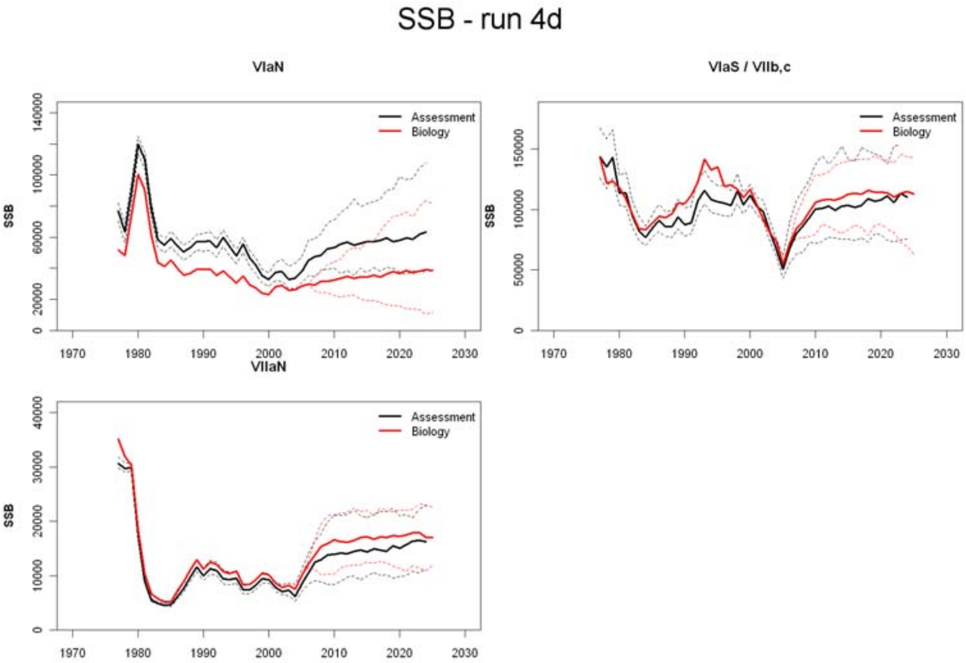
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VIaS / VIIb,c
VIIaN
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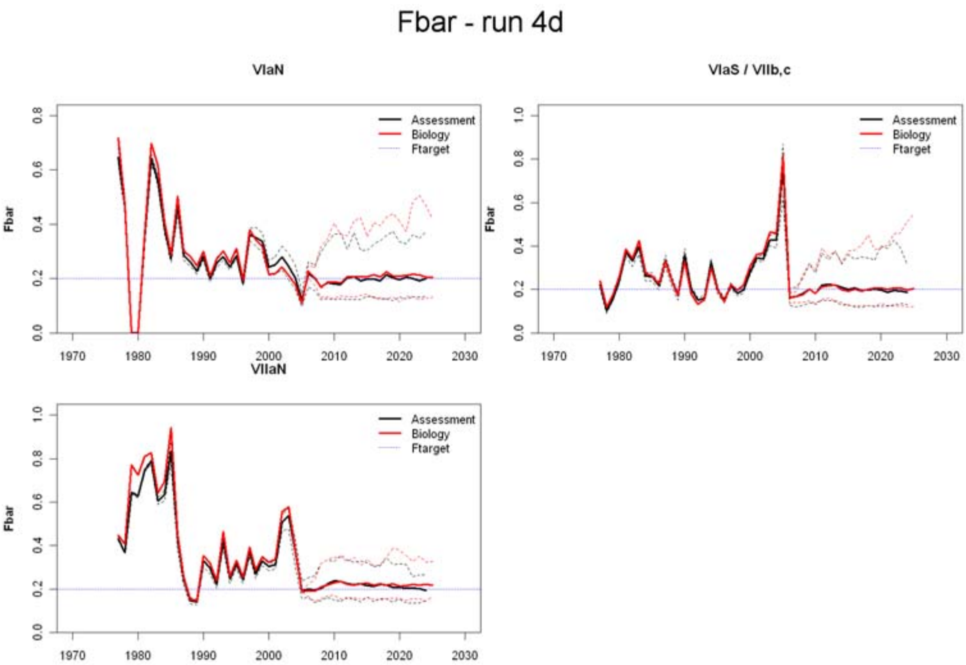
Assessment
Biology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VIIaN
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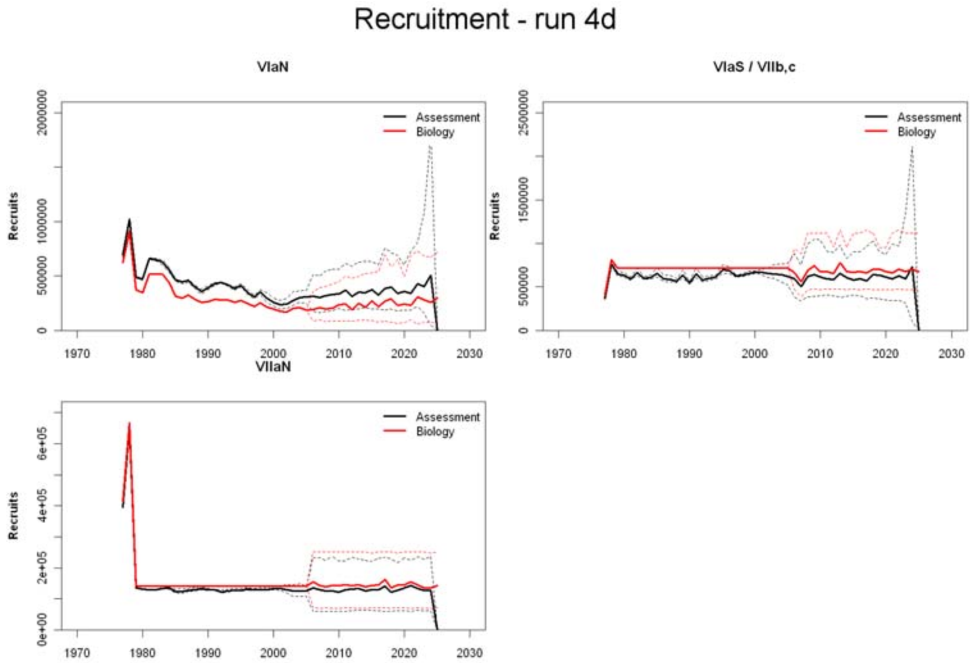
Biology
Ftarget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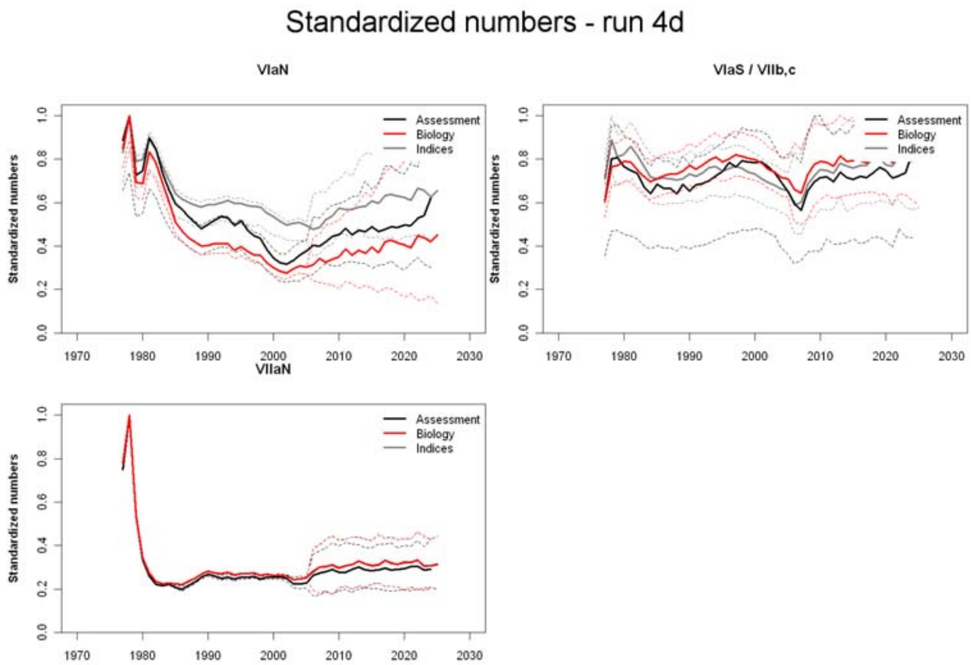
VIaS / VIIb,c
VIIaN
Assessment
Biology
Recruits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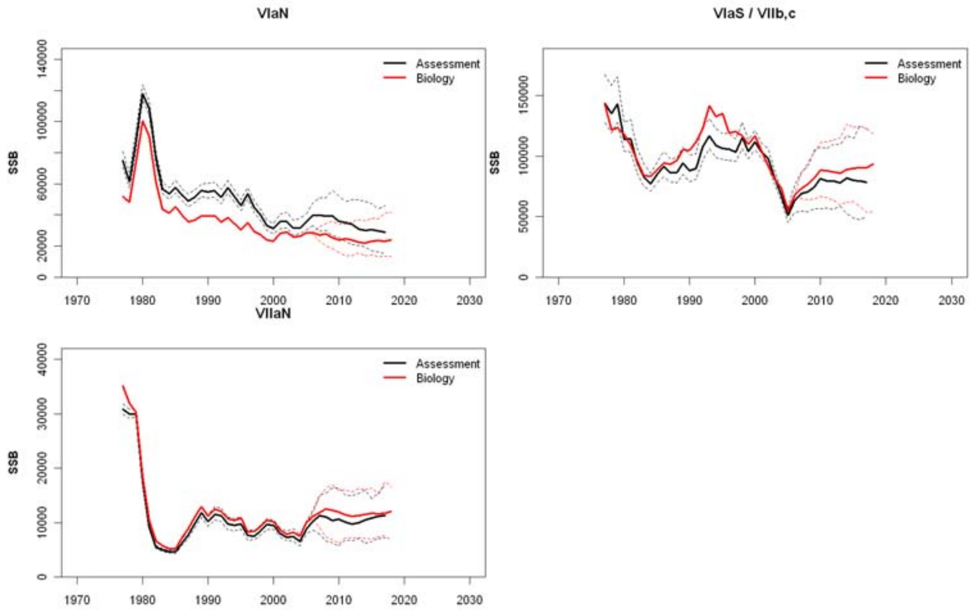
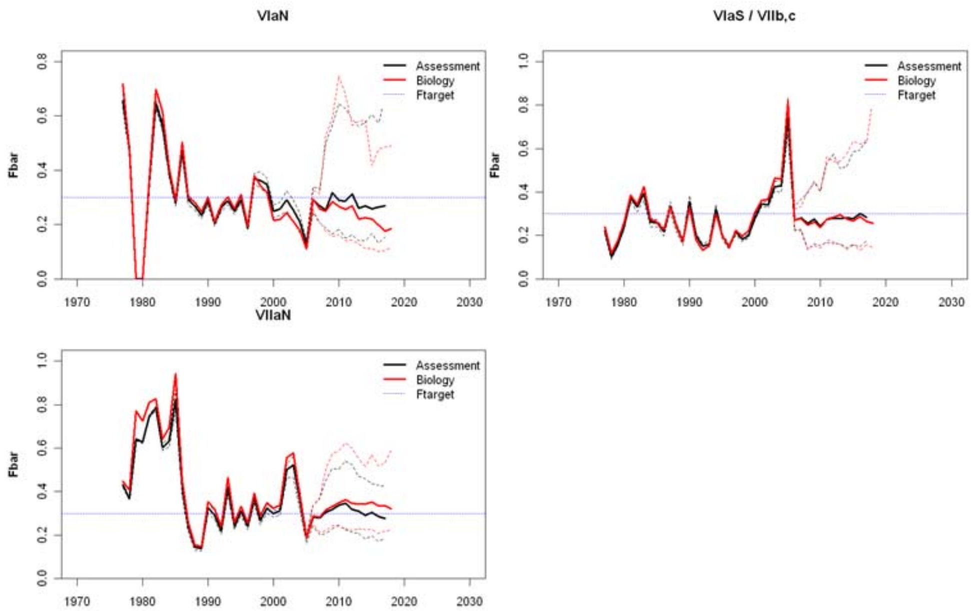
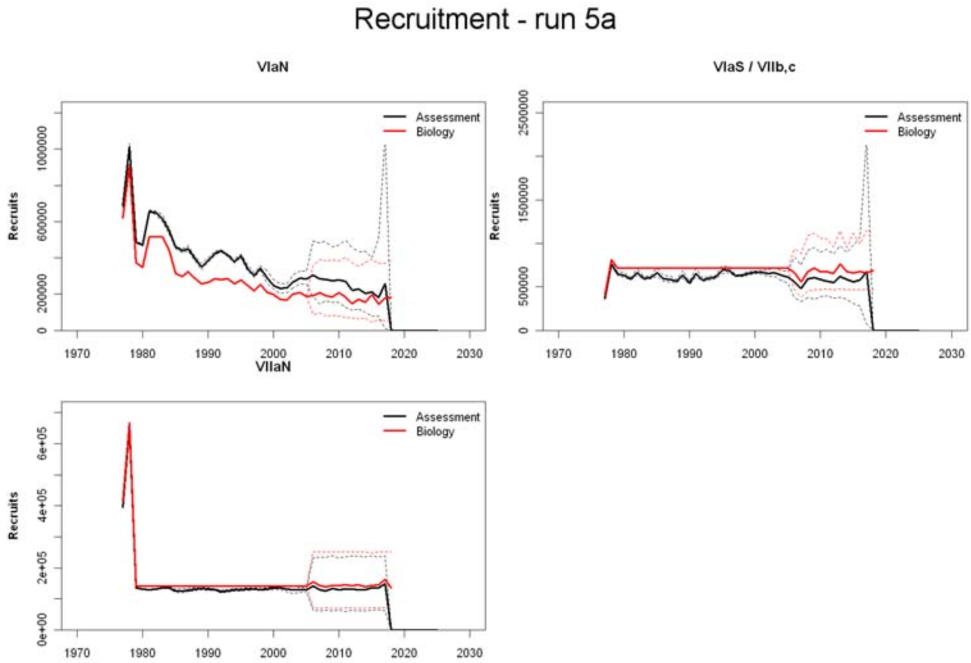
VIIaN
Assessment
Biology
Indices
Standardized numbers

SSB - run 5a




Fbar - run 5a

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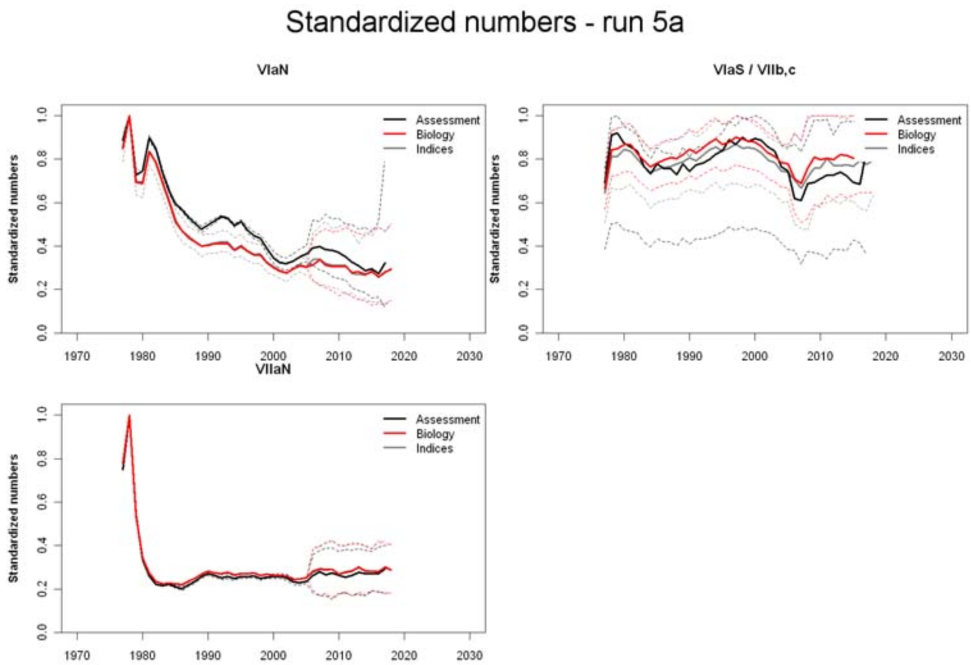
VIIaN
Recruits
Assessment
Biology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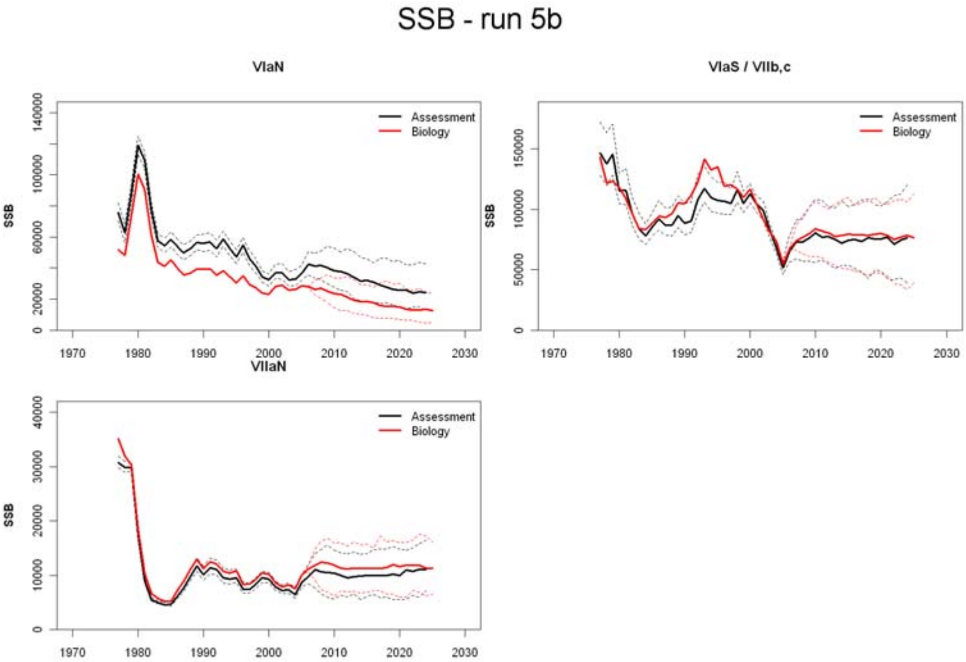
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices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VIaS / VIIb,c
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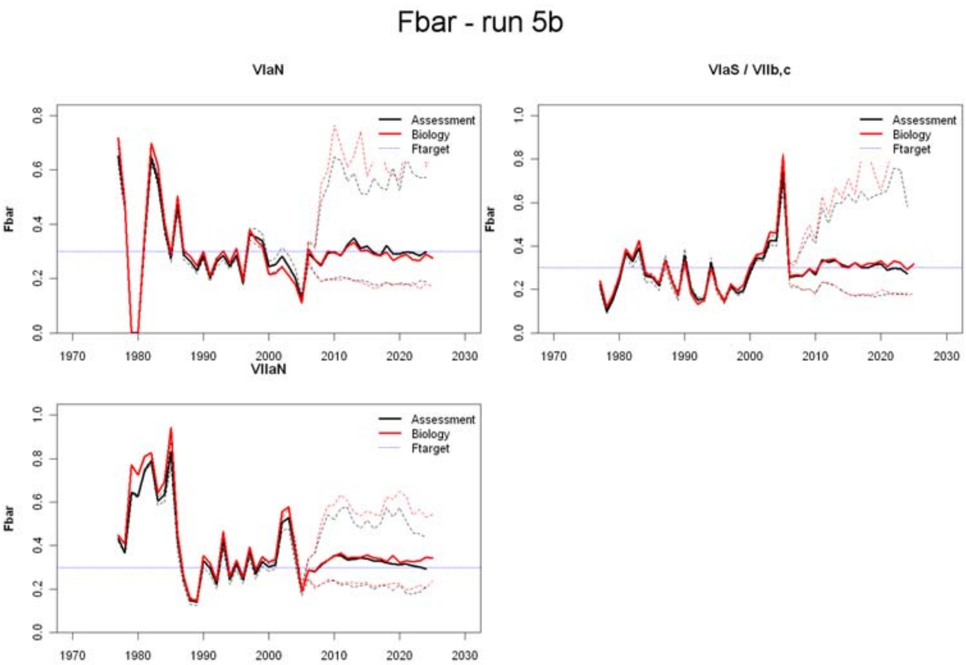
Assessment
Biology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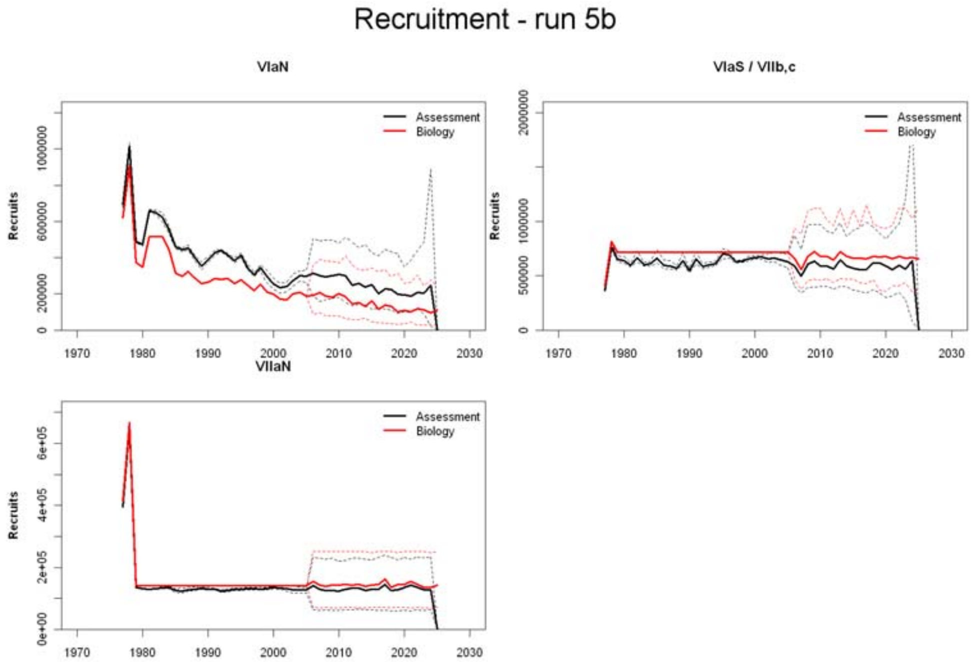
Biology
Ftarget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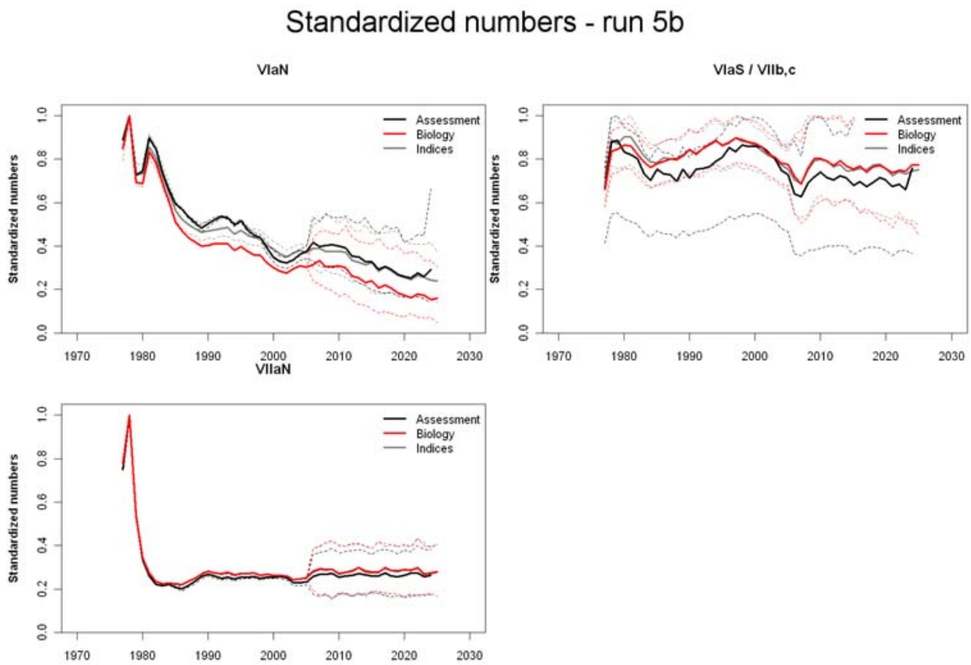
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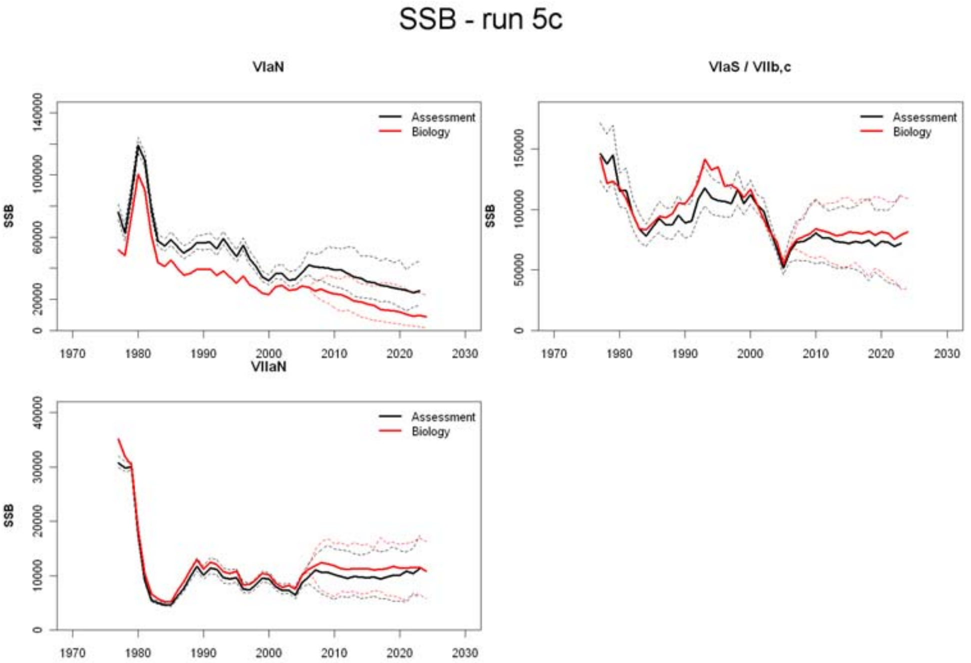
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Assessment
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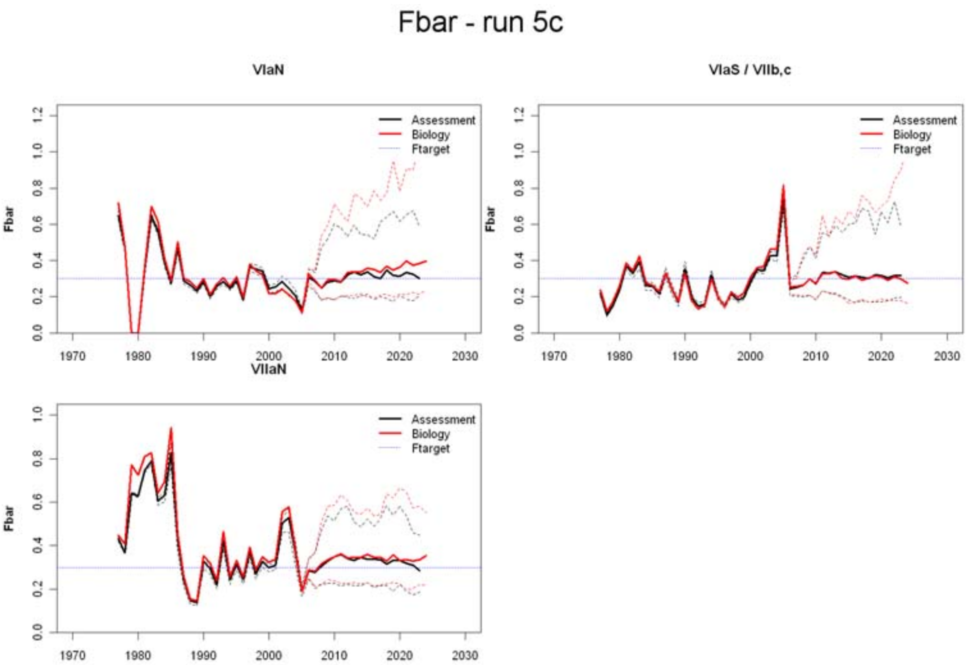
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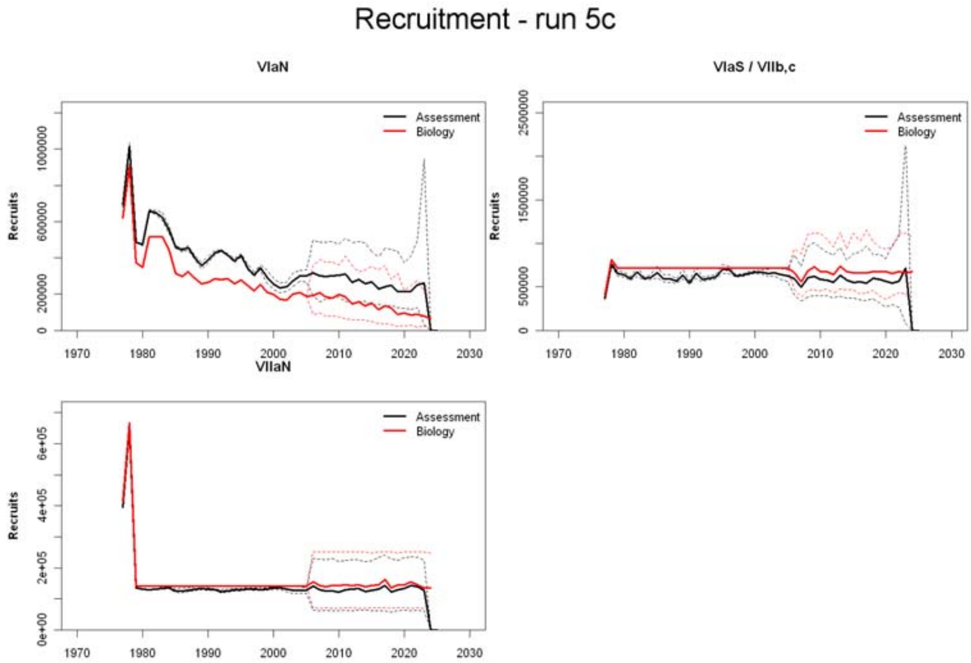
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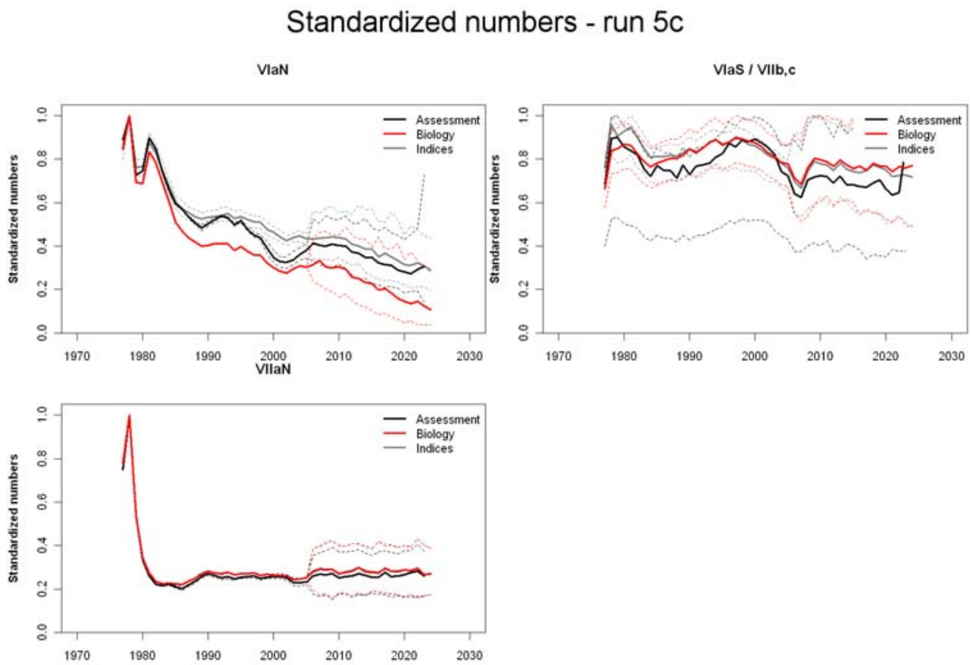
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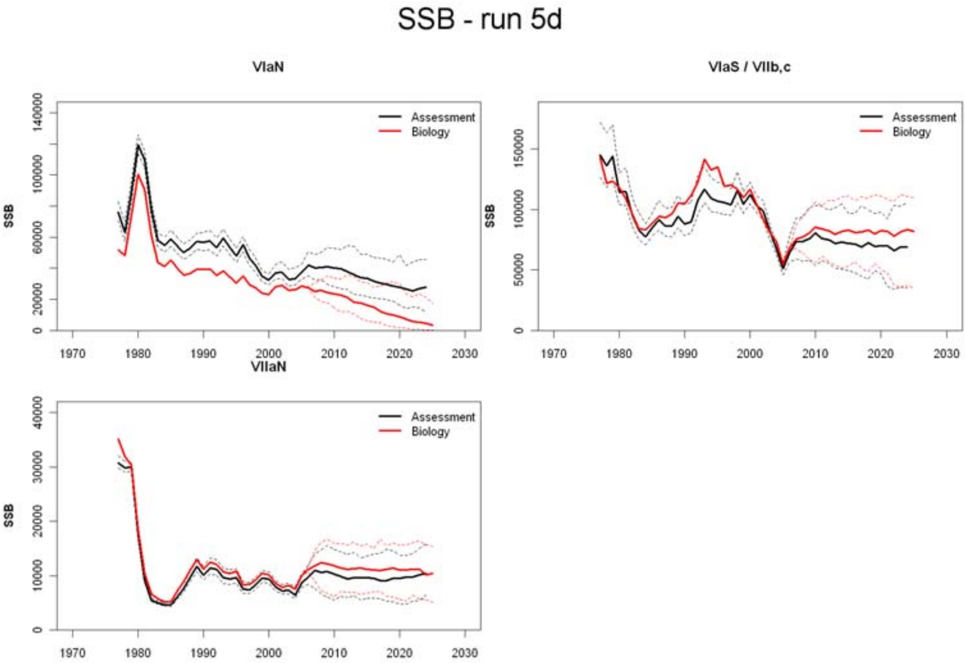
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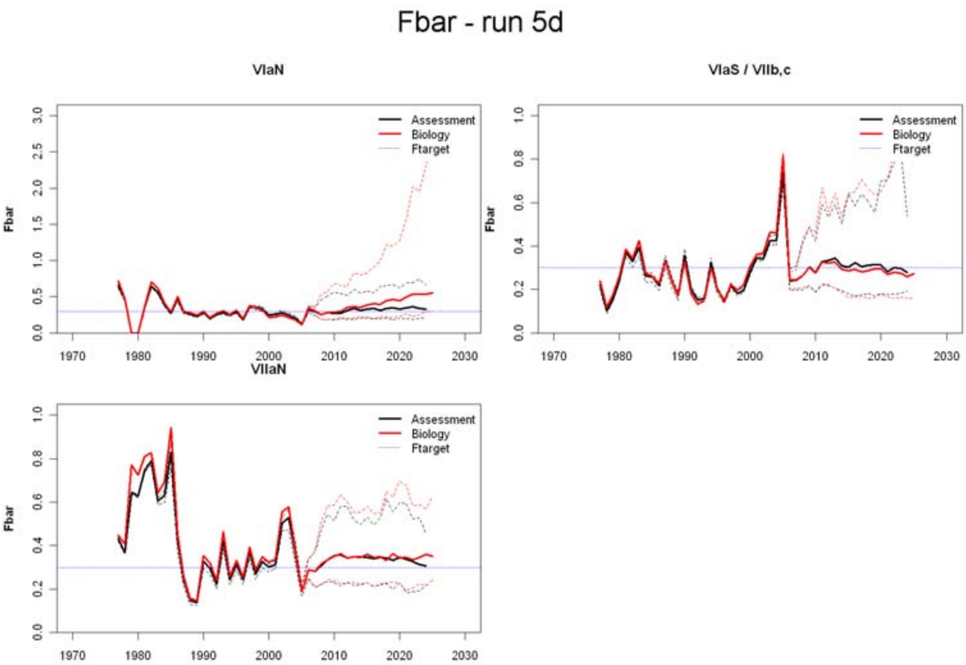
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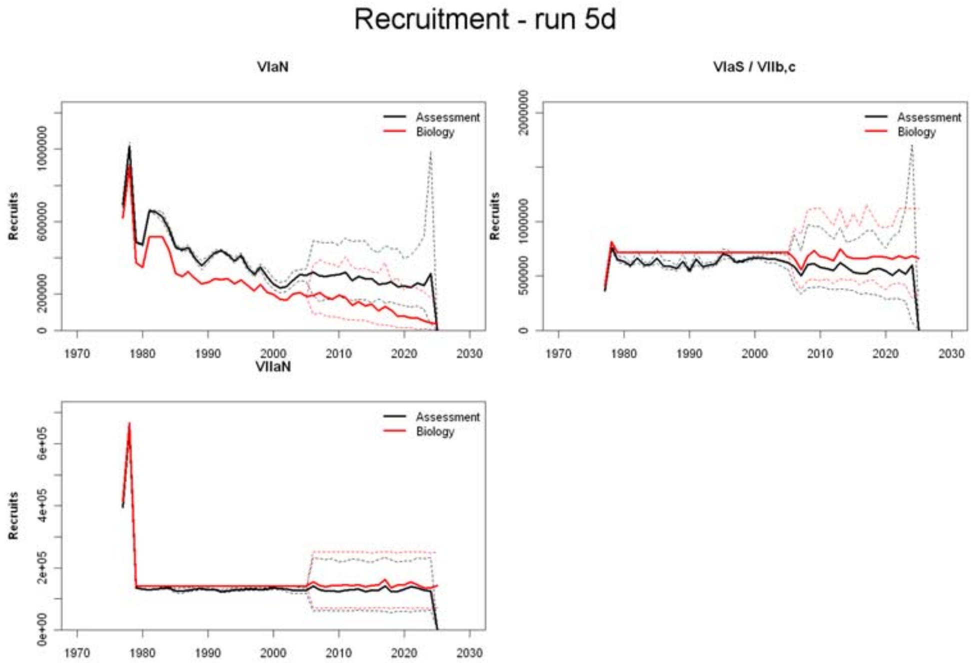
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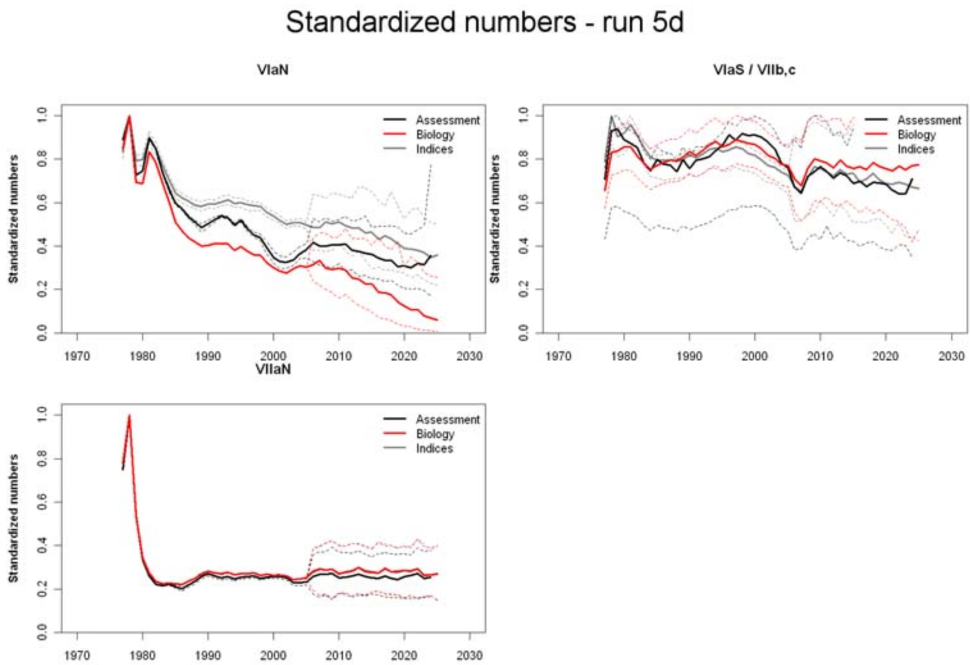
Biology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Indices

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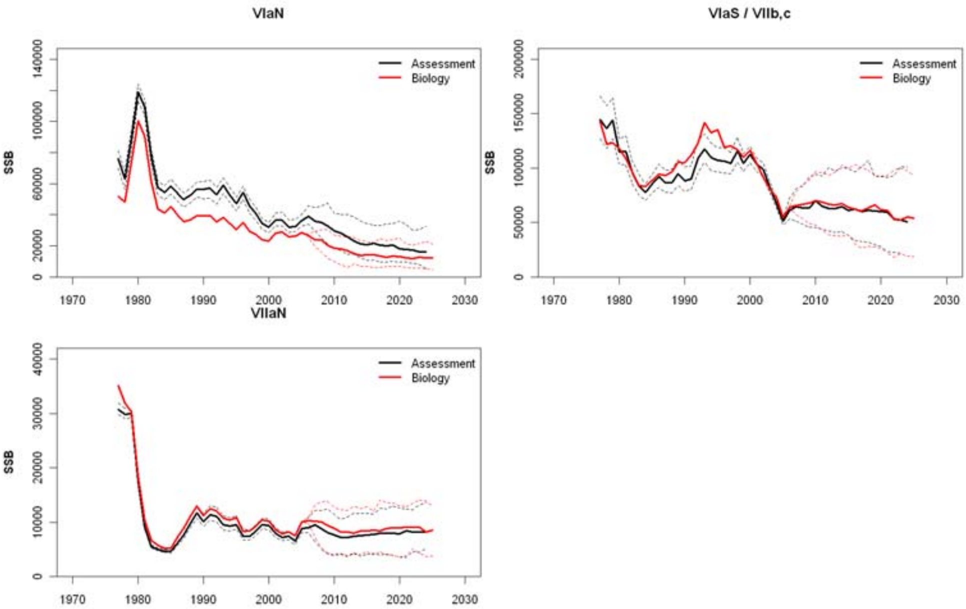
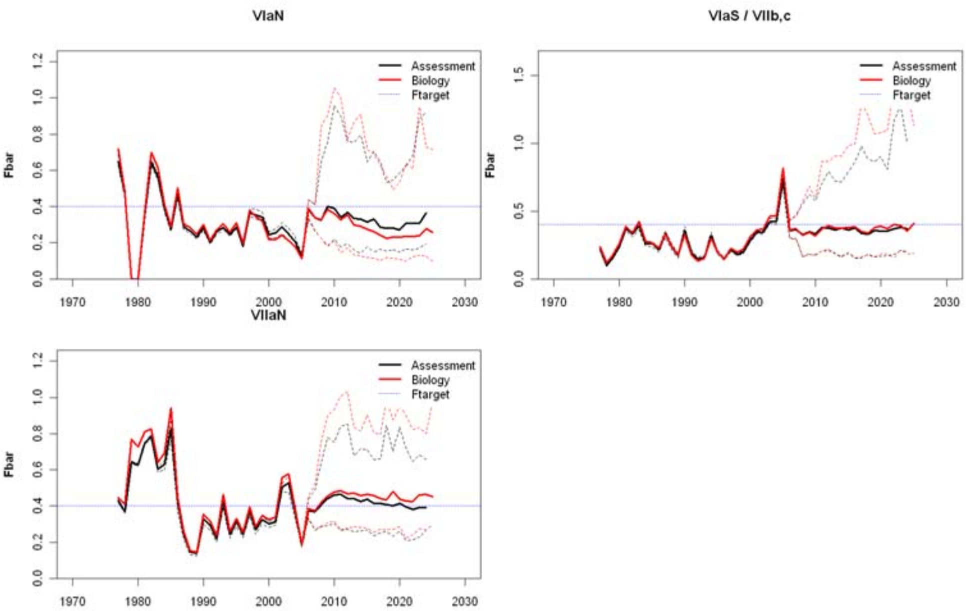
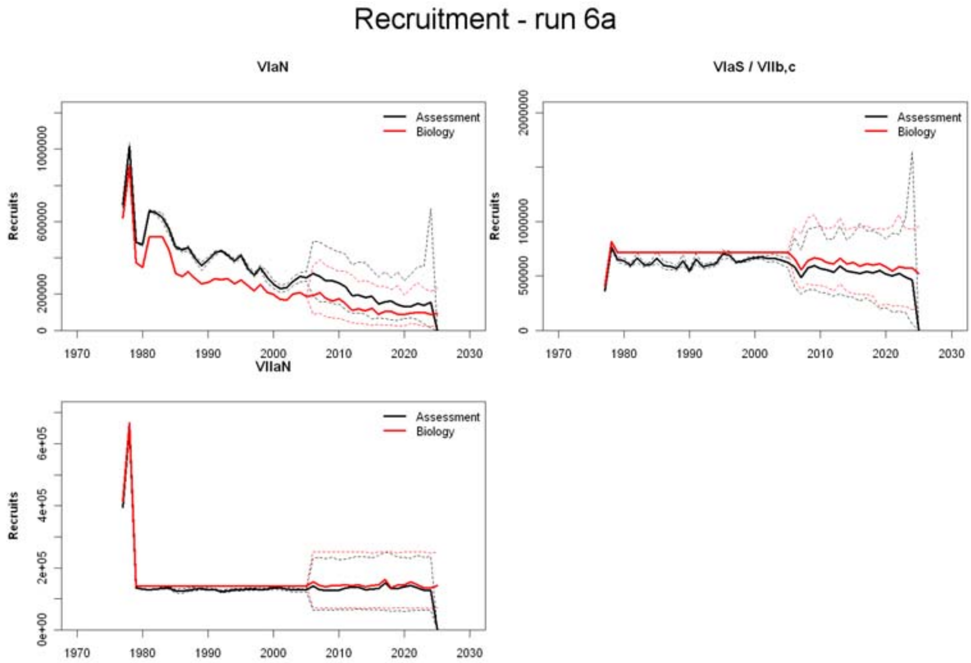



Fbar - run 6a

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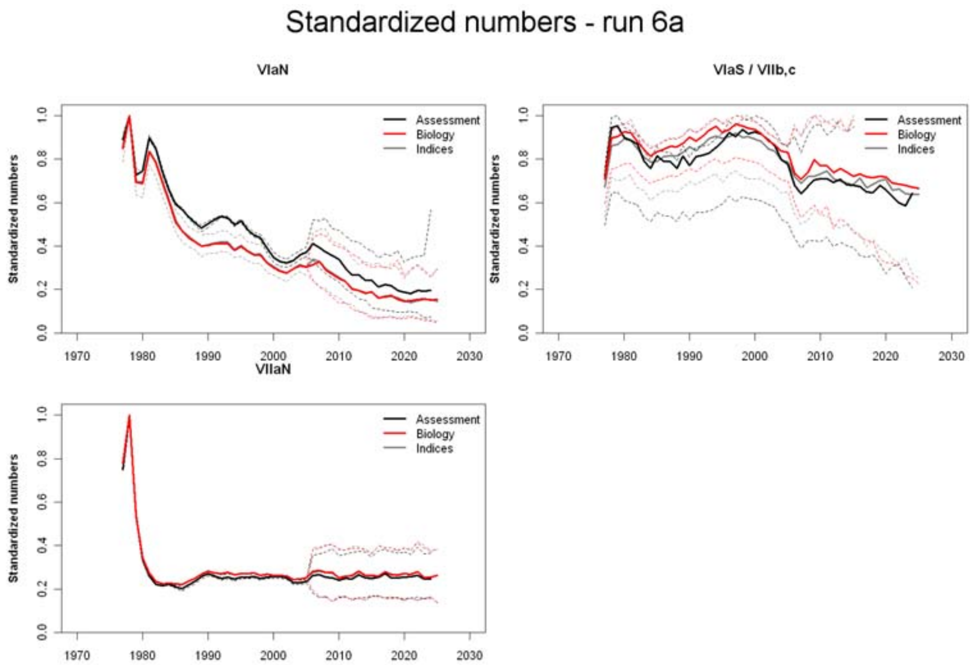
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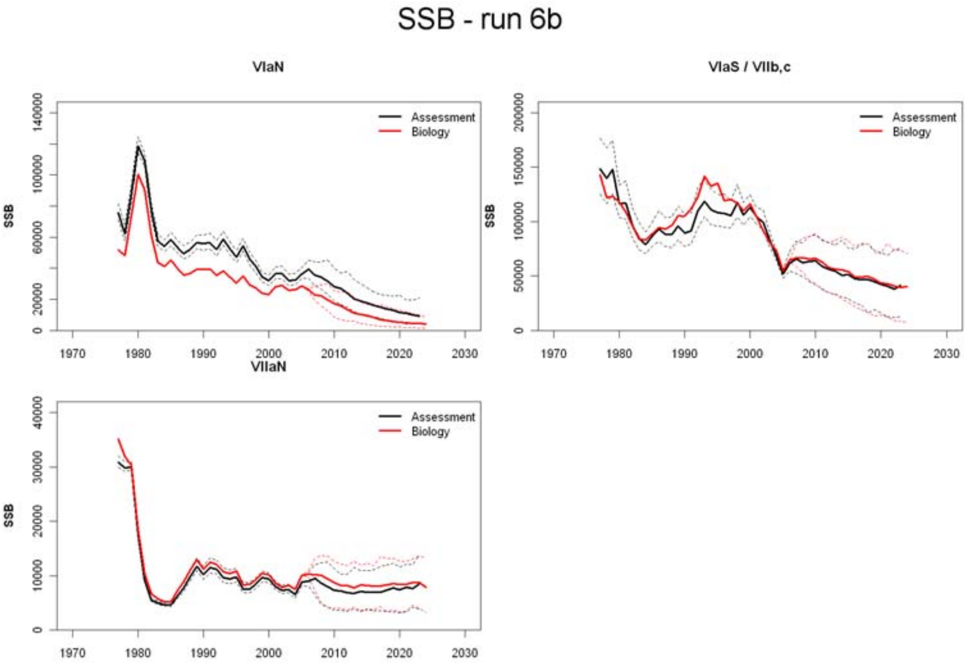
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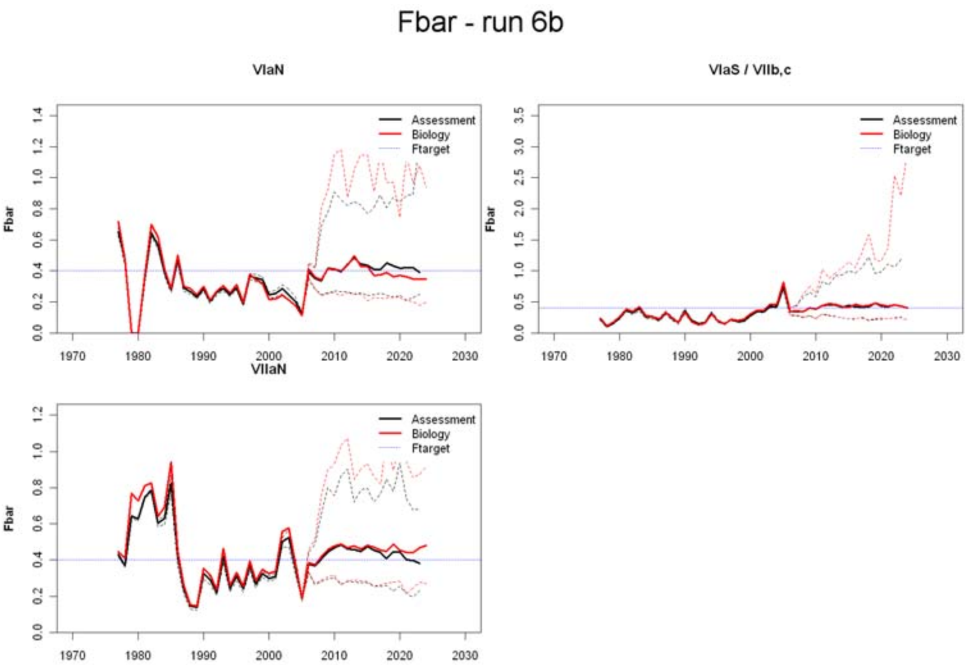
Biology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Biology
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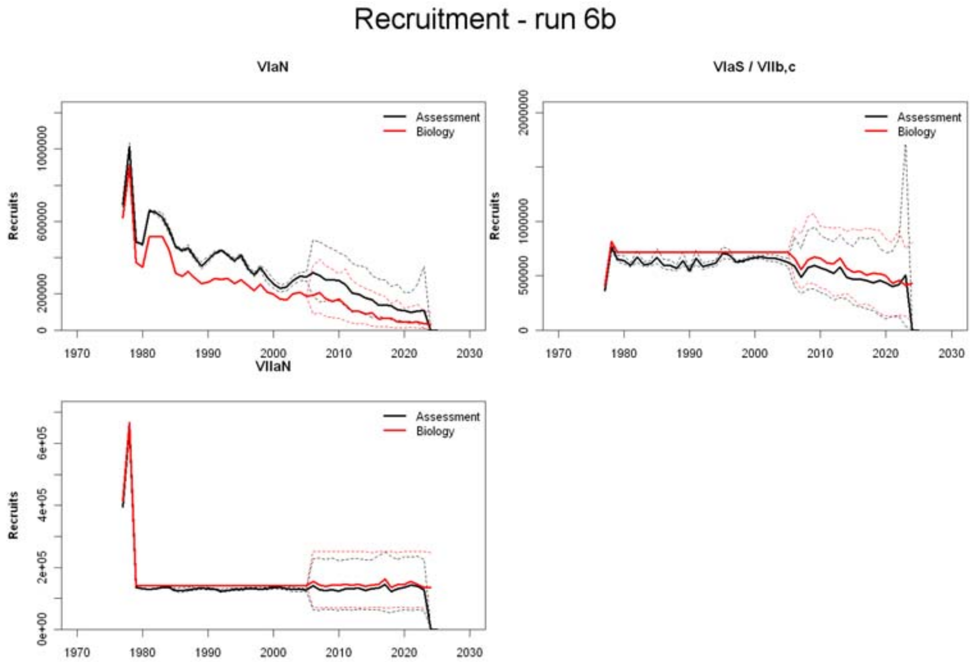
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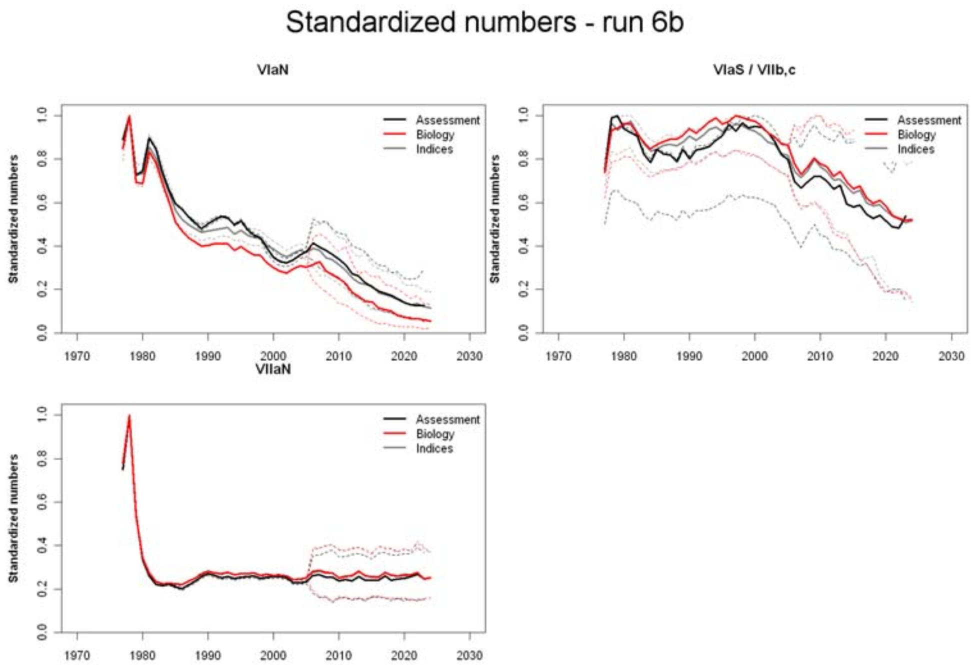
Recruits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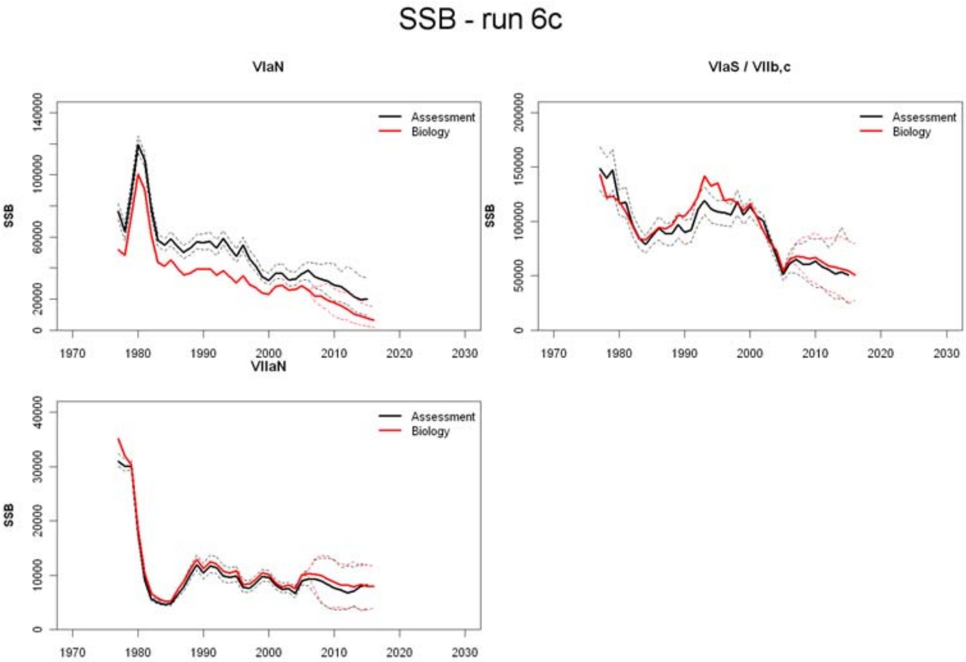
Standardized numbers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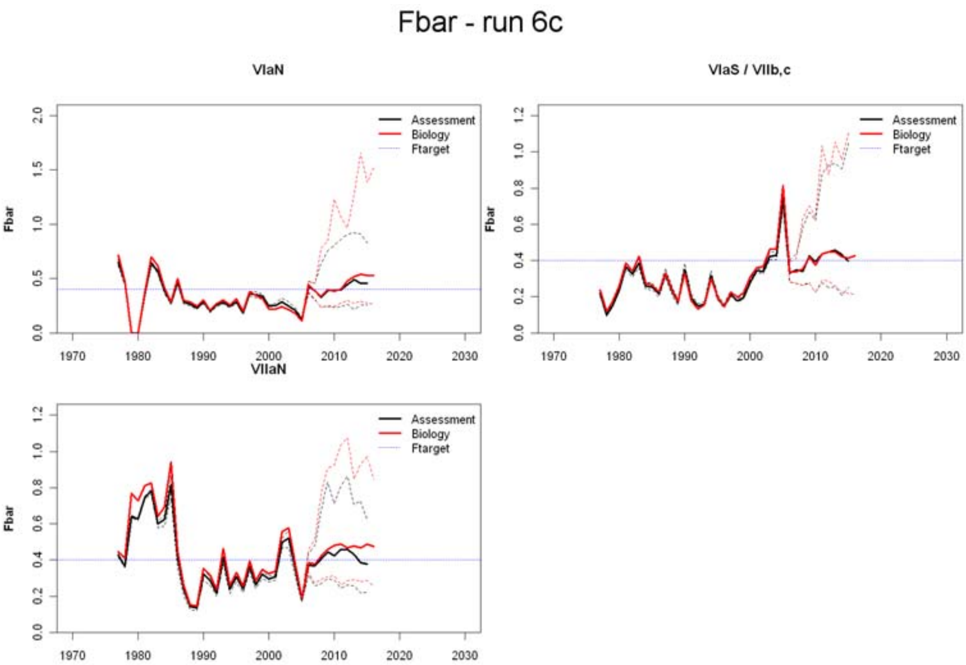
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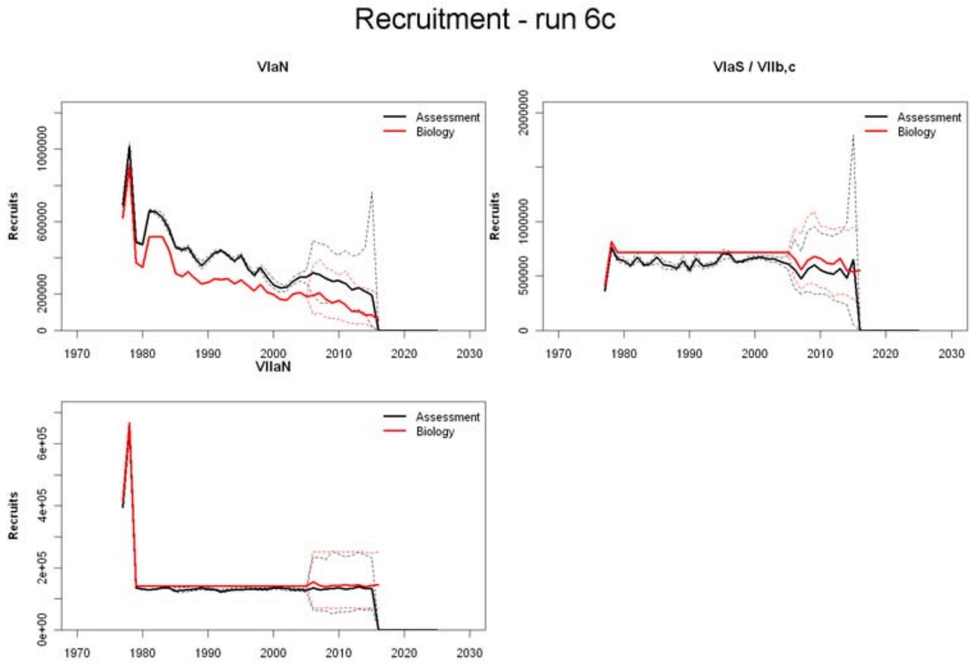
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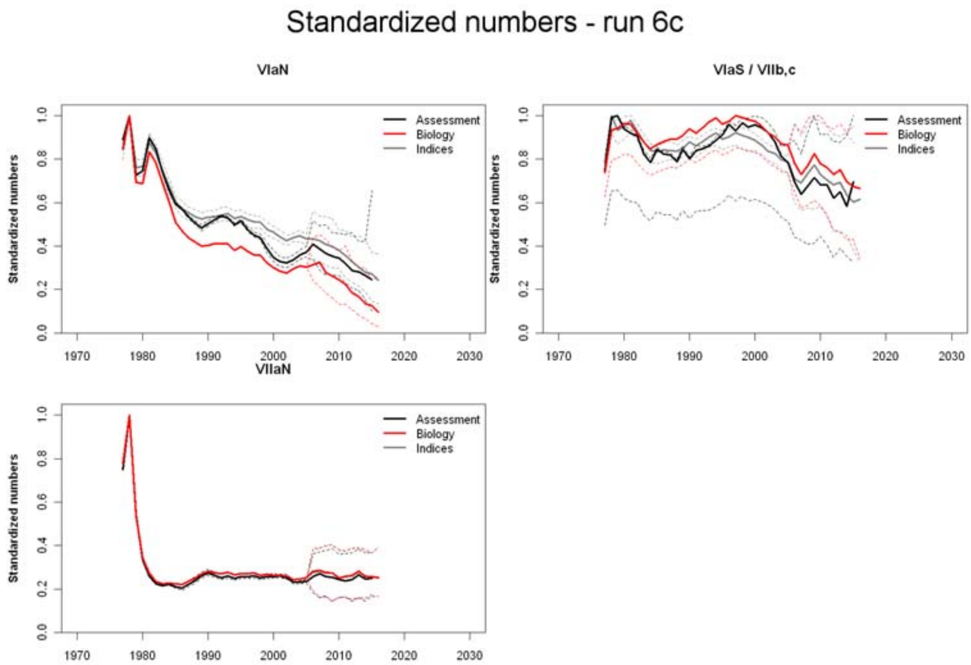
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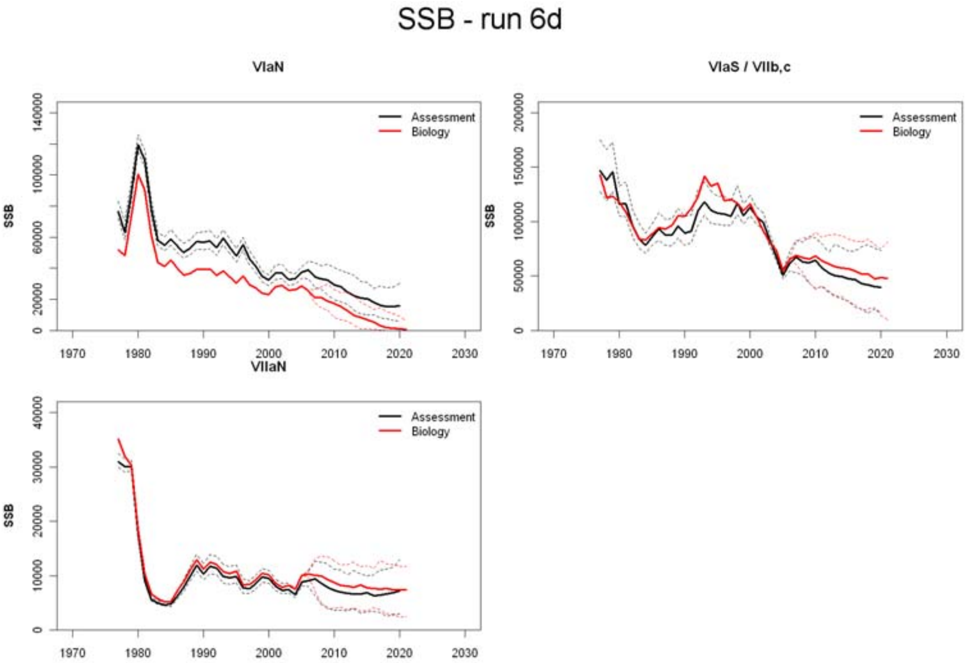
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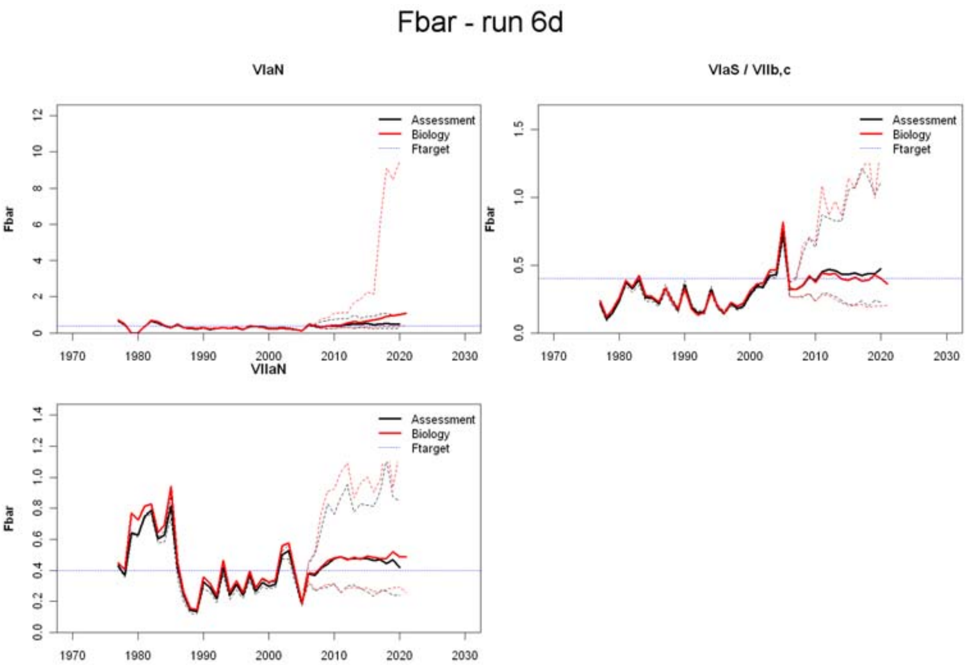
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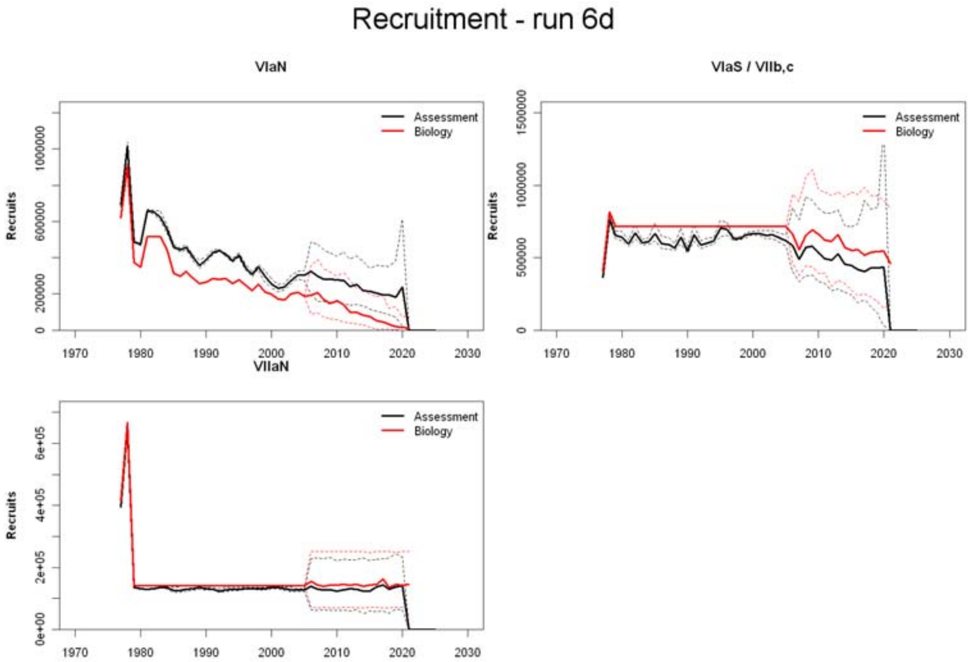
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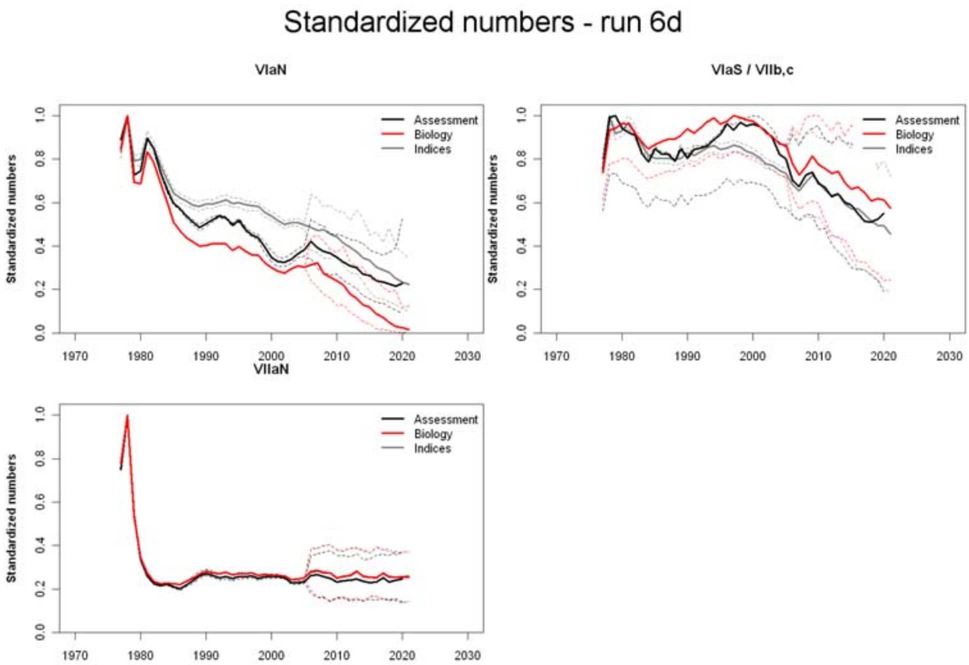
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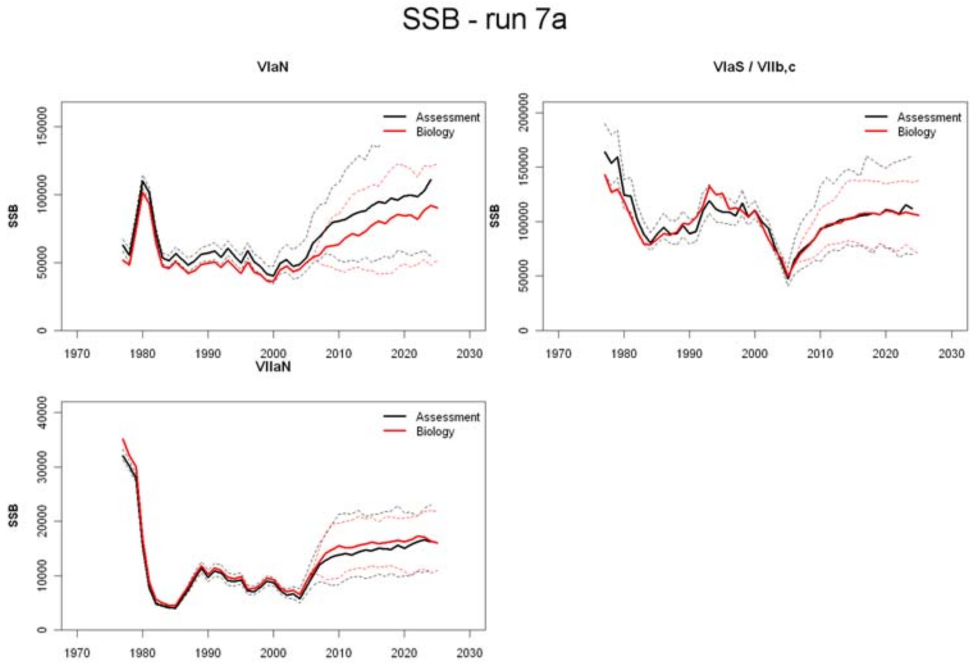
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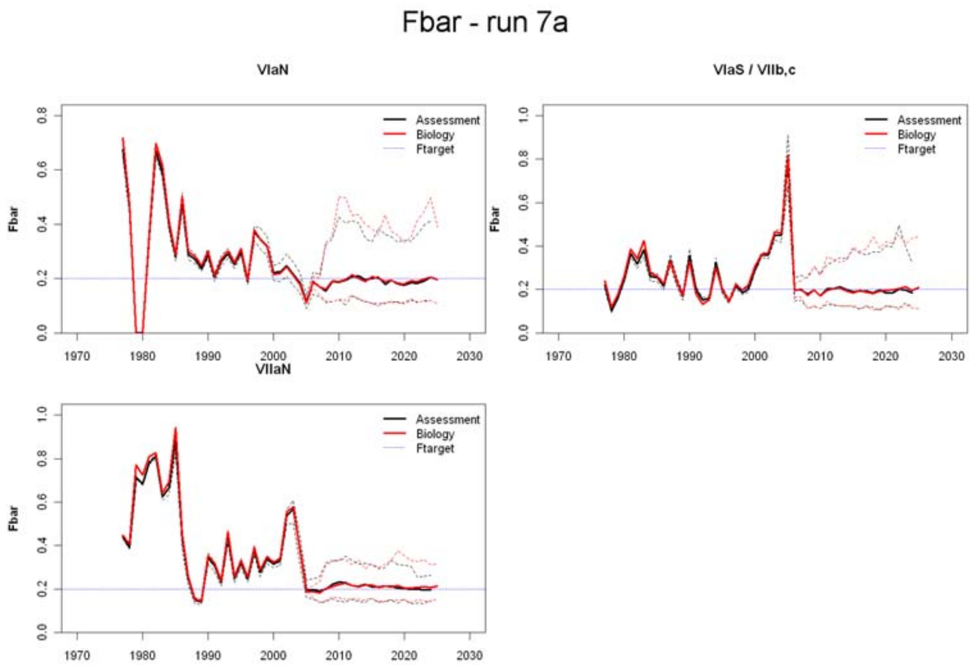
Biology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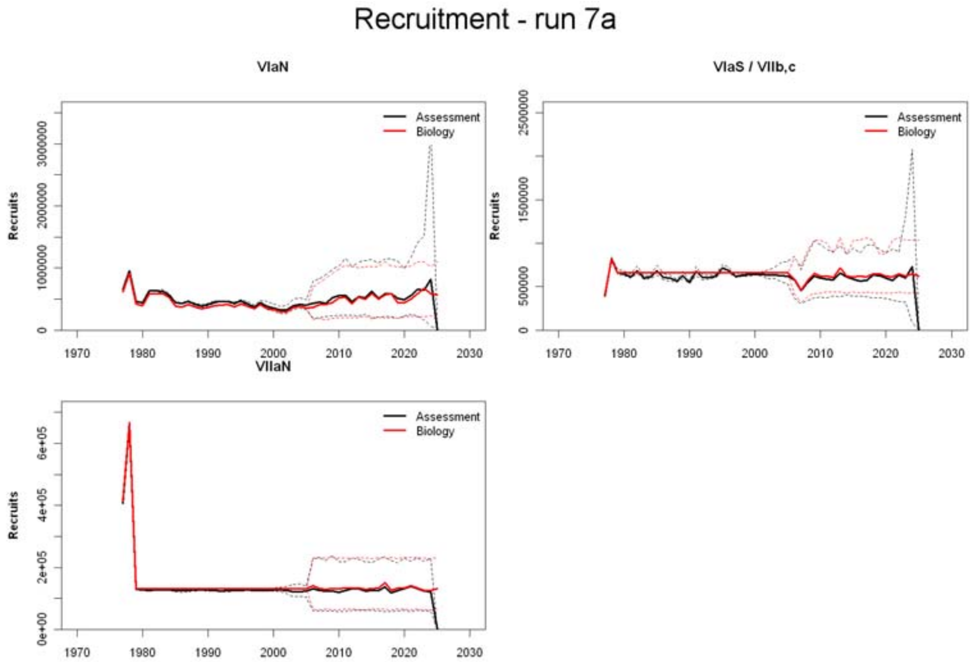
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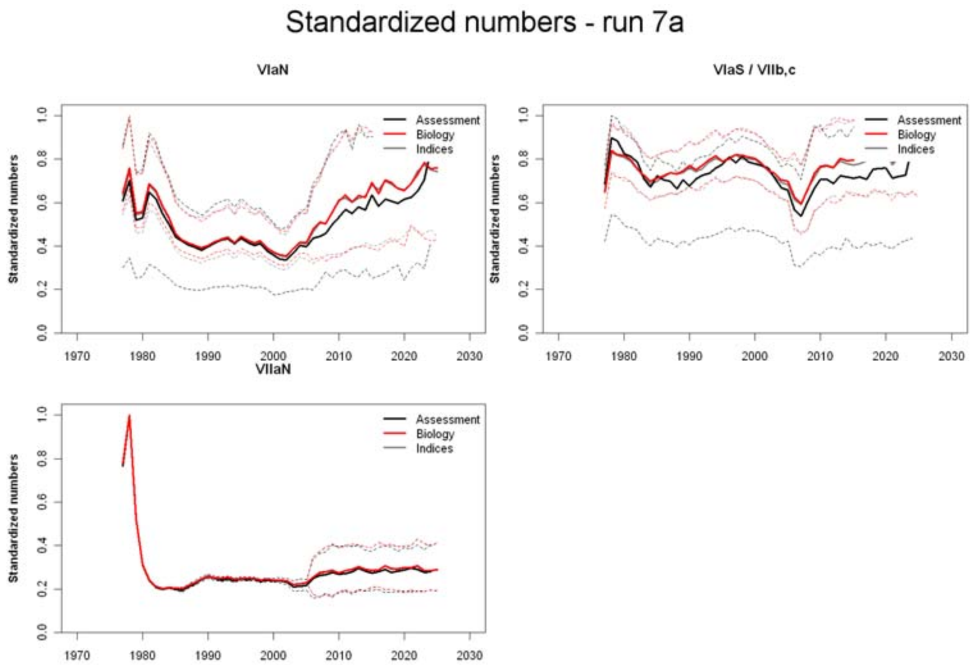
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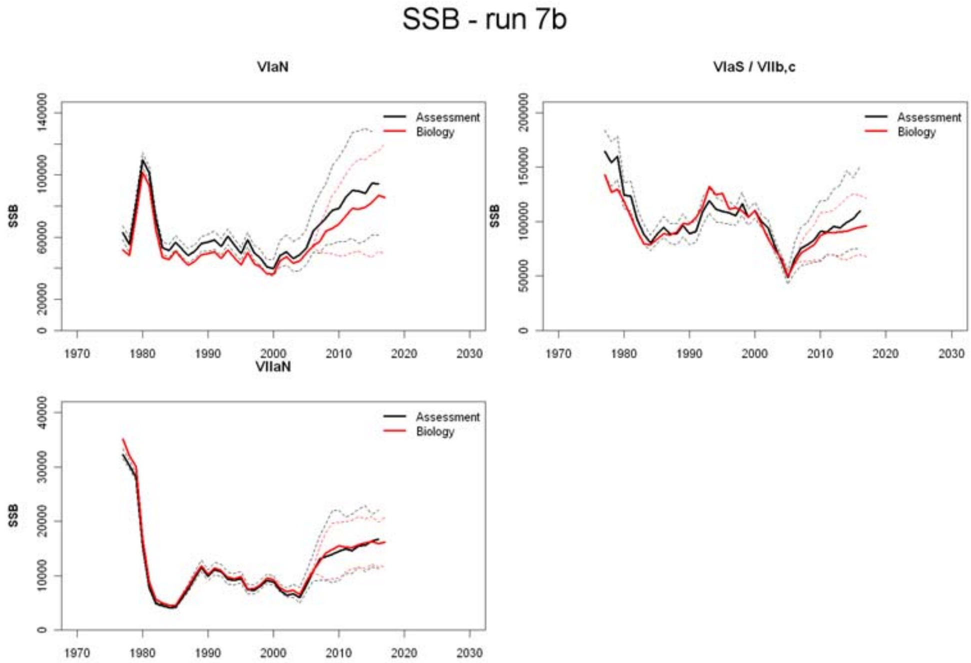
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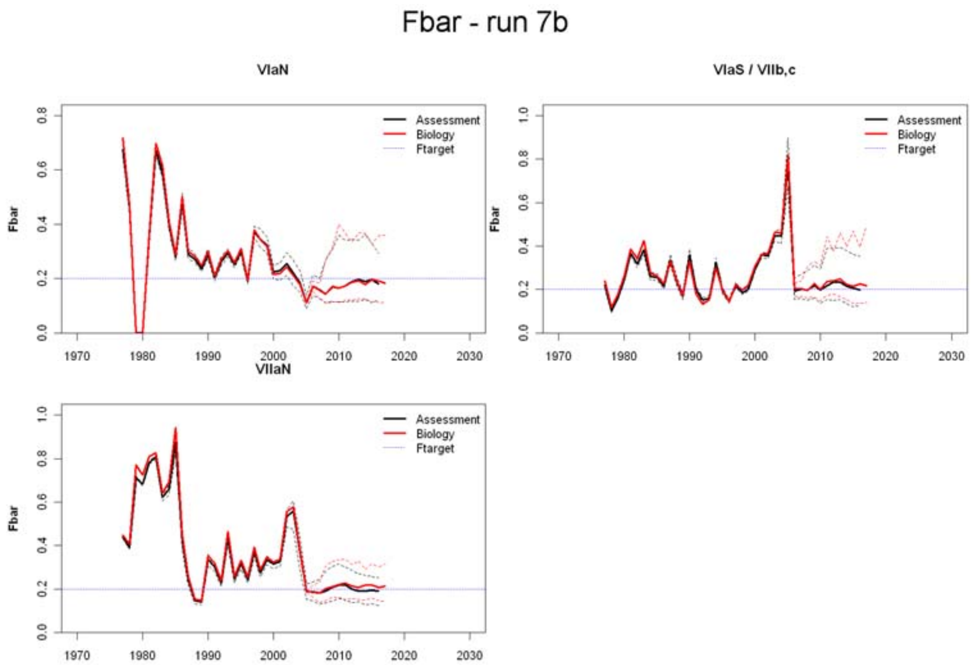
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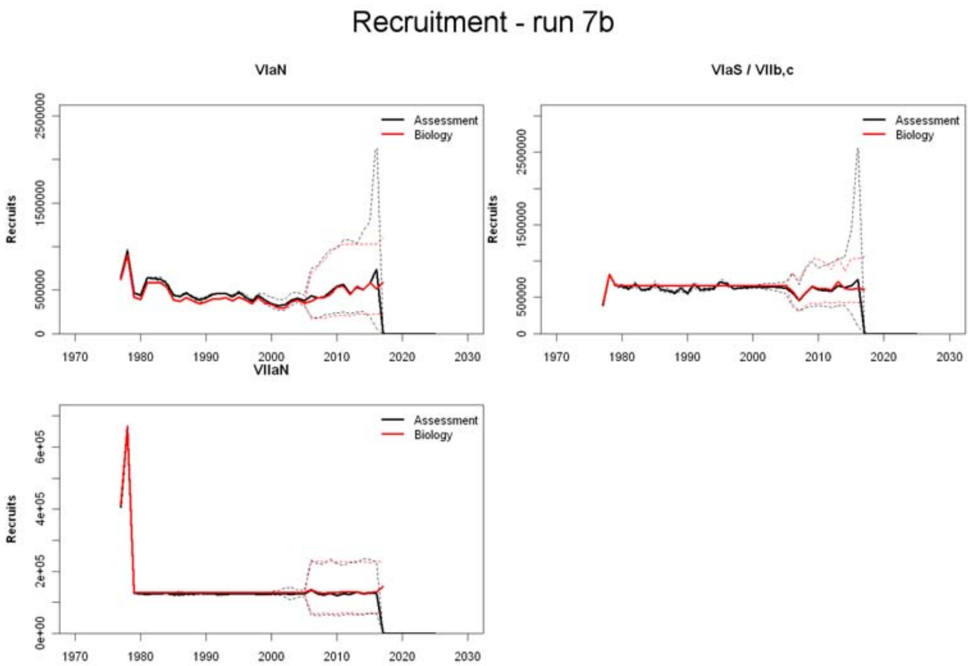
Biology
Ftarget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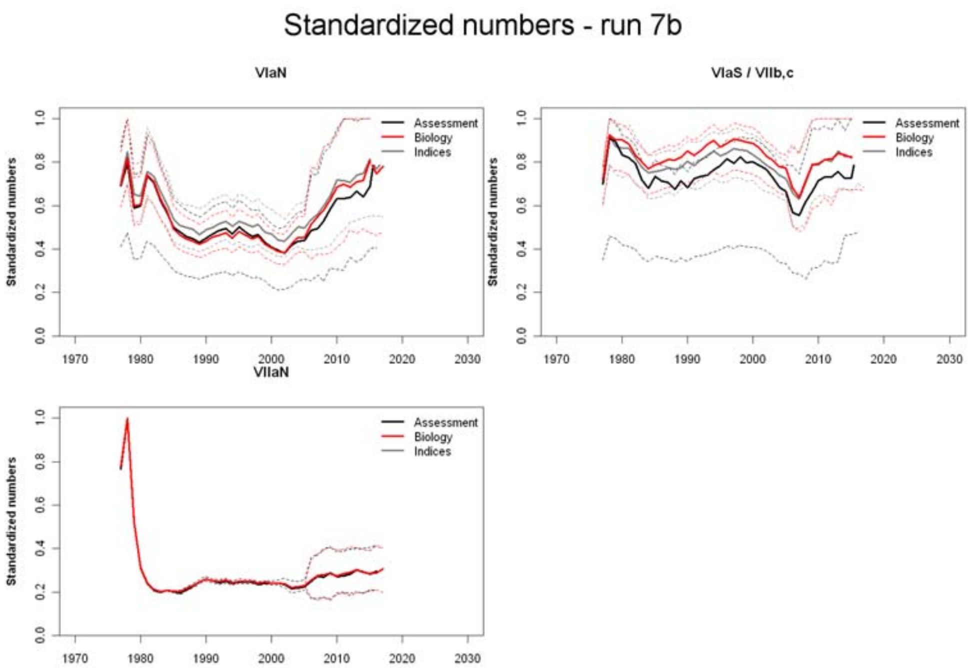
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology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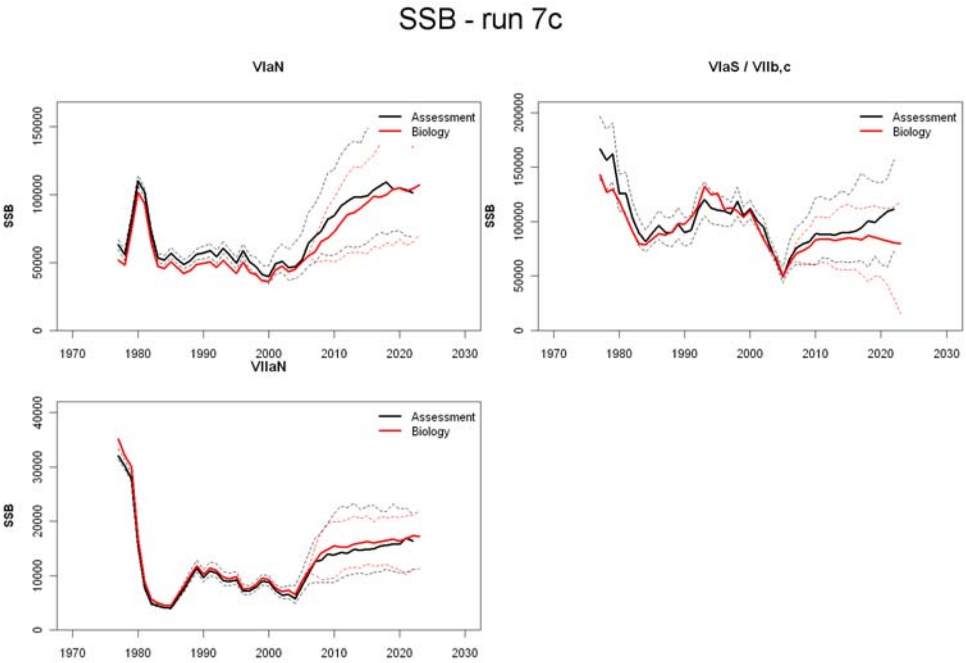
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices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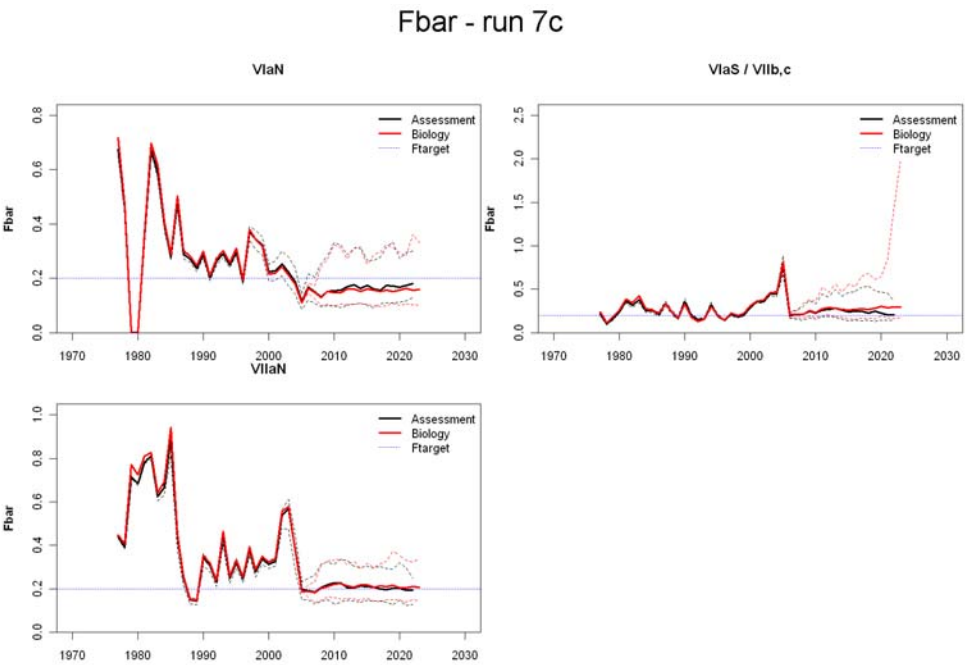
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology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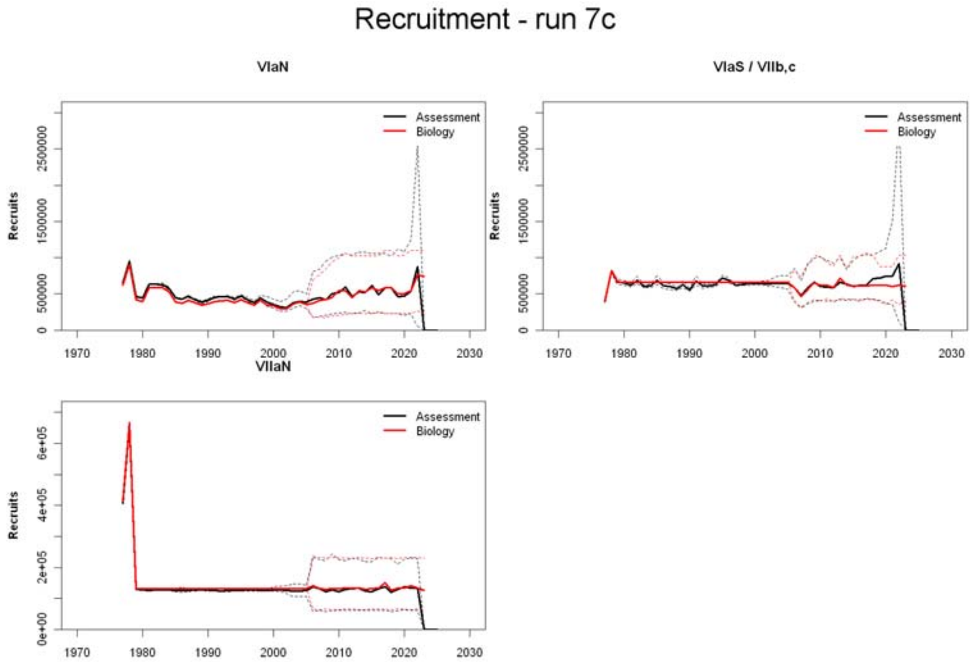
VIIaN
Fbar
Assessment
Biology
Ftarget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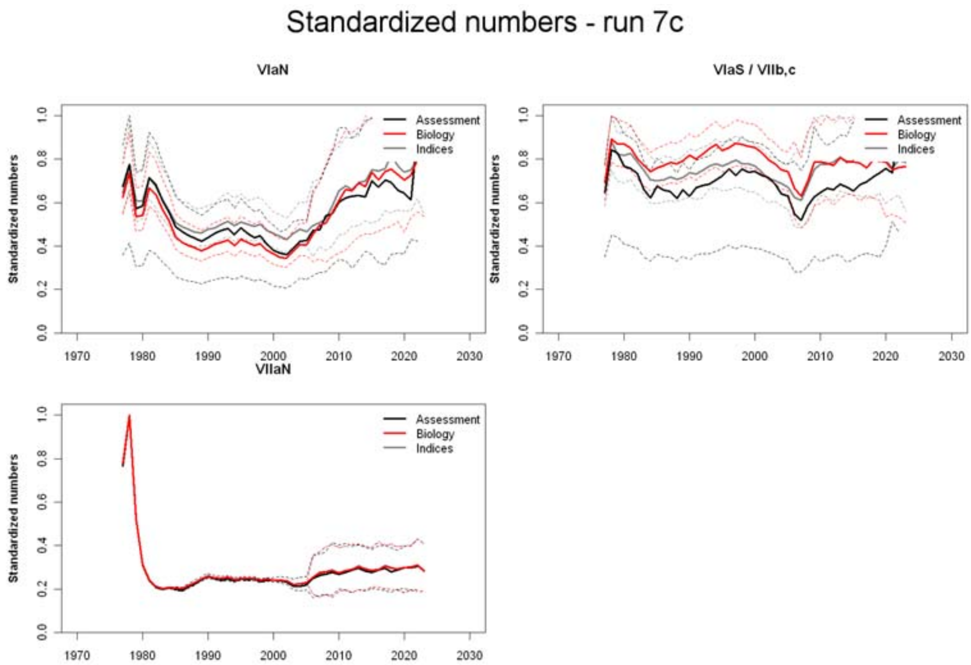
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology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Standardized numbers
Assessment
Biology
Indices

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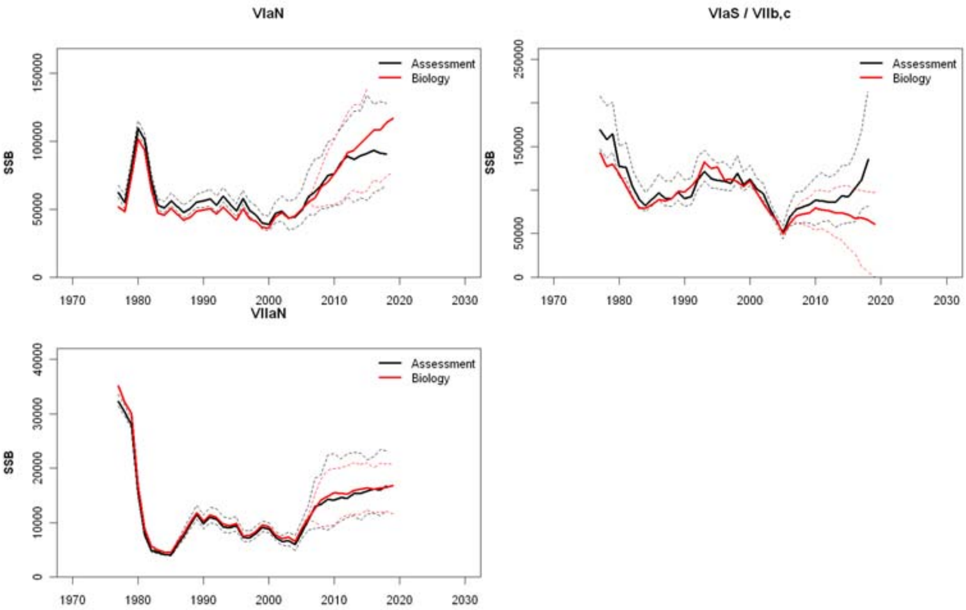


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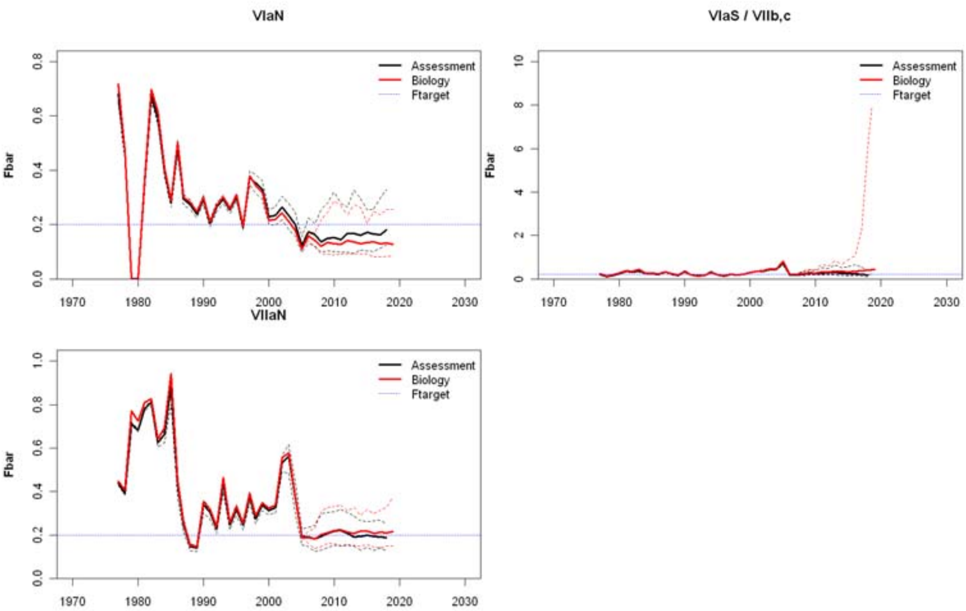

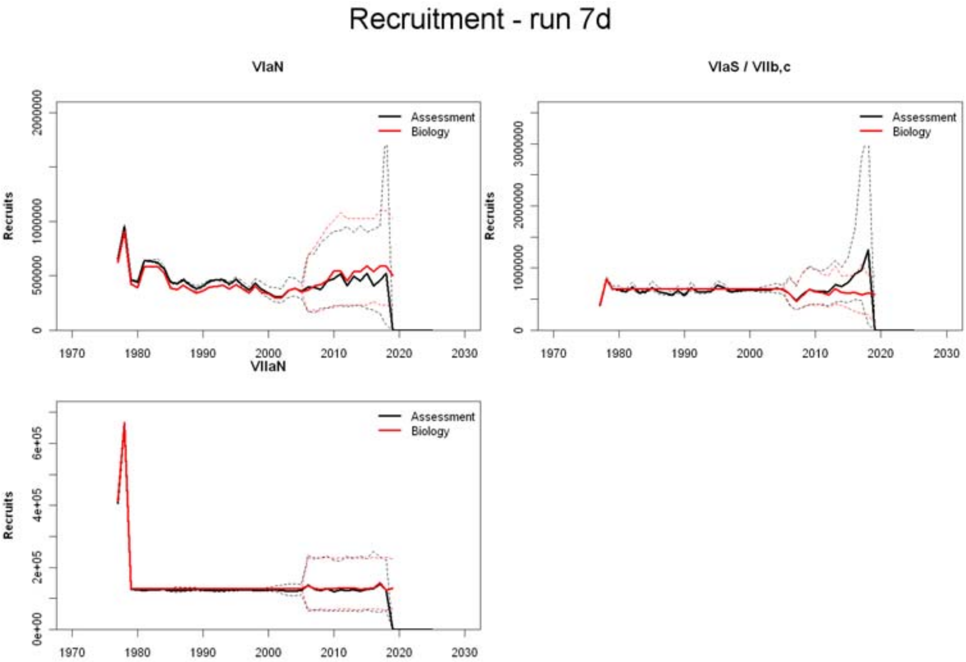
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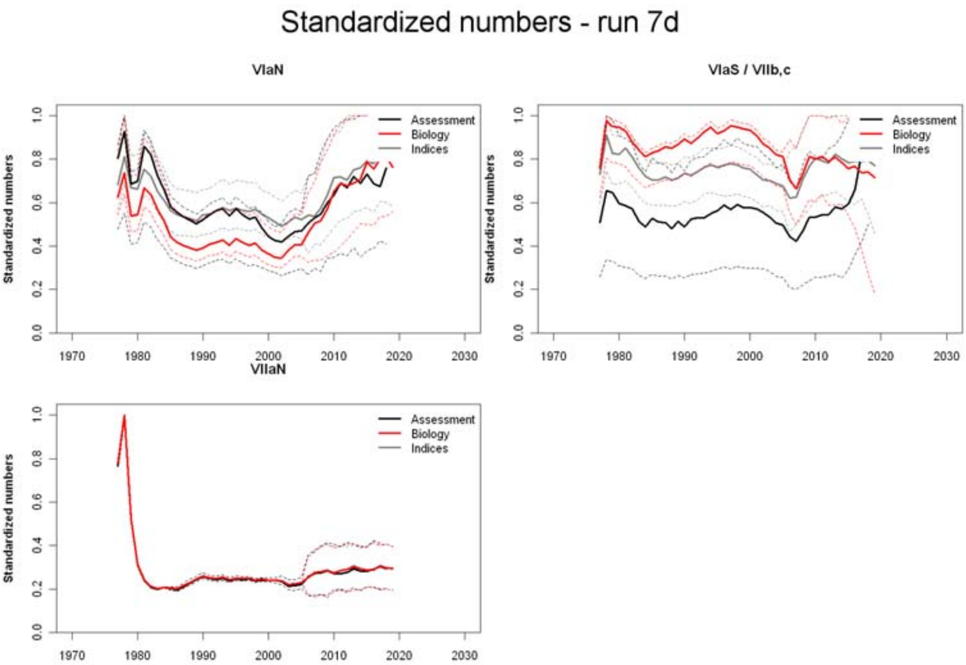
Recruits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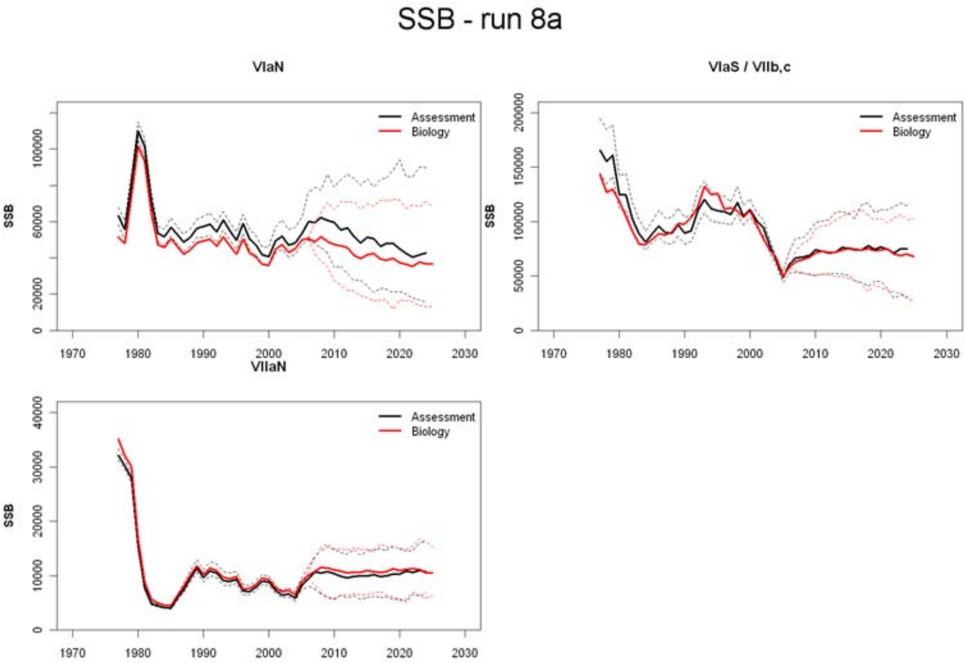
Biology
Indices
Standardized numbers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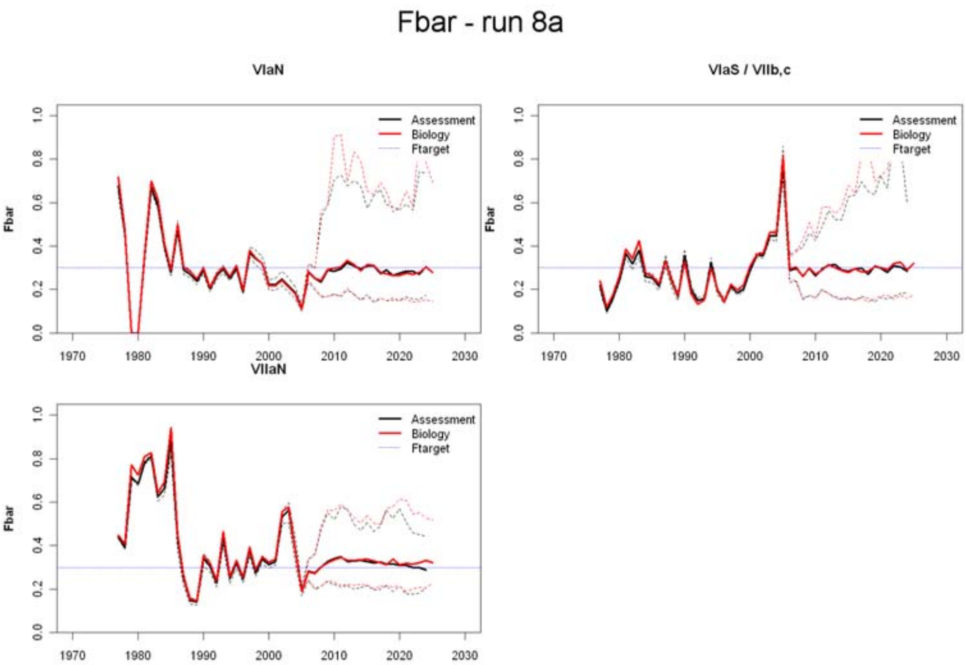
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology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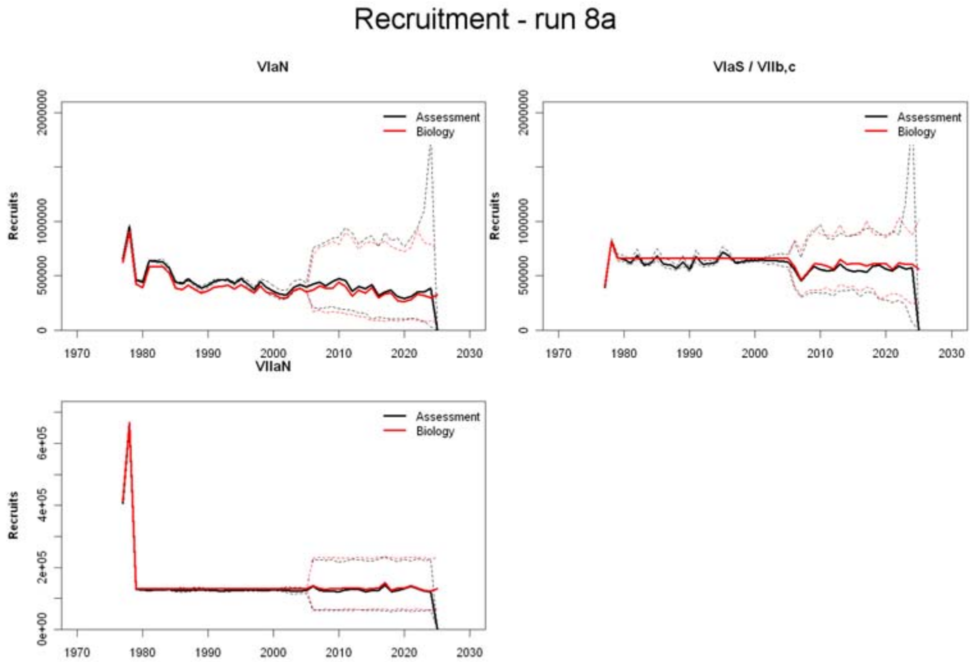
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VIaS / VIIb,c
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Recruits
Assessment
Biology
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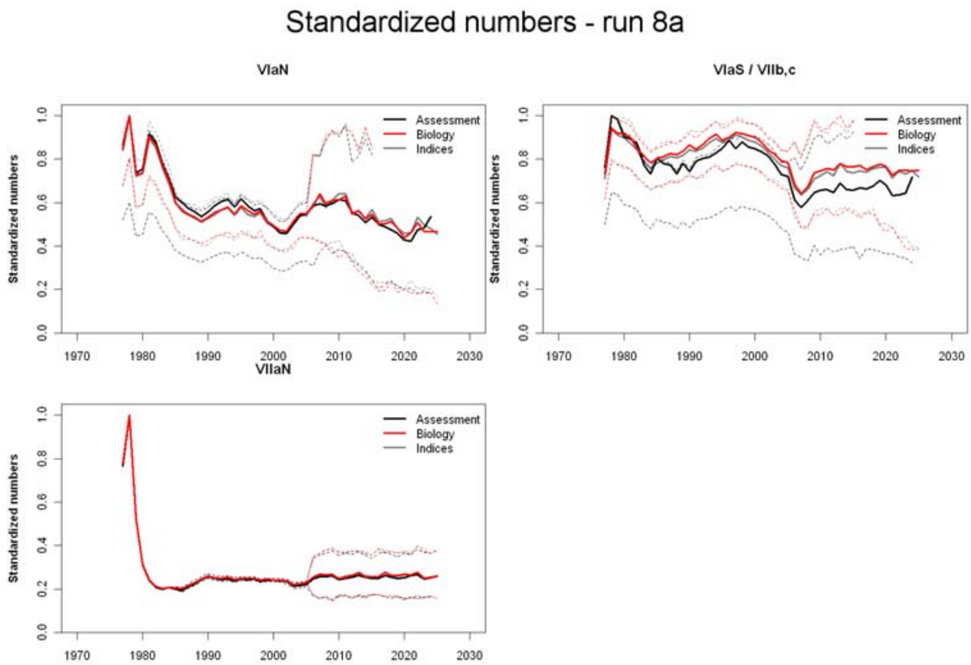
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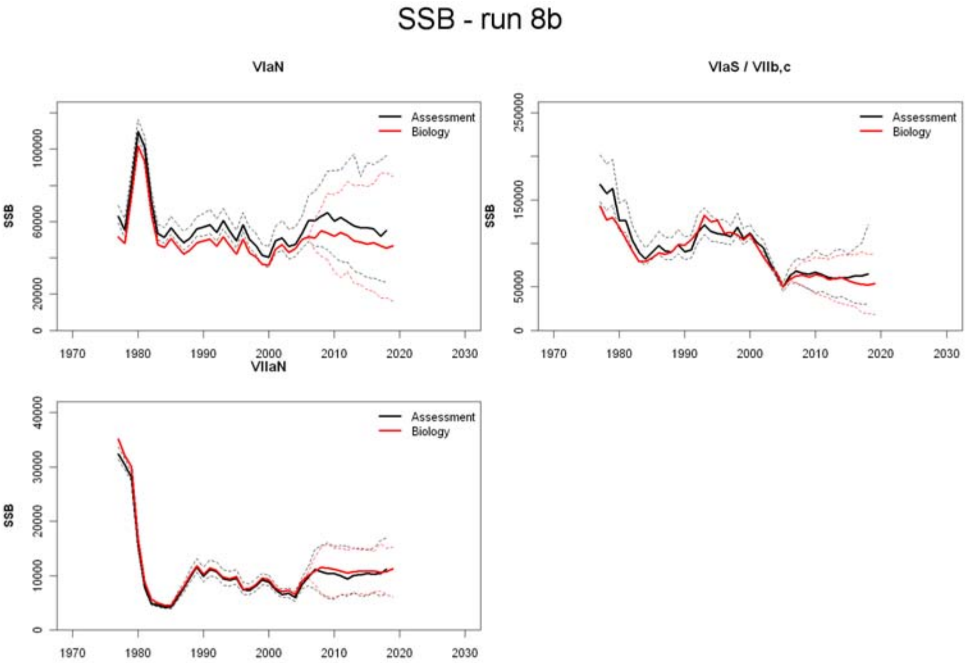
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VIaS / VIIb,c
VIIaN
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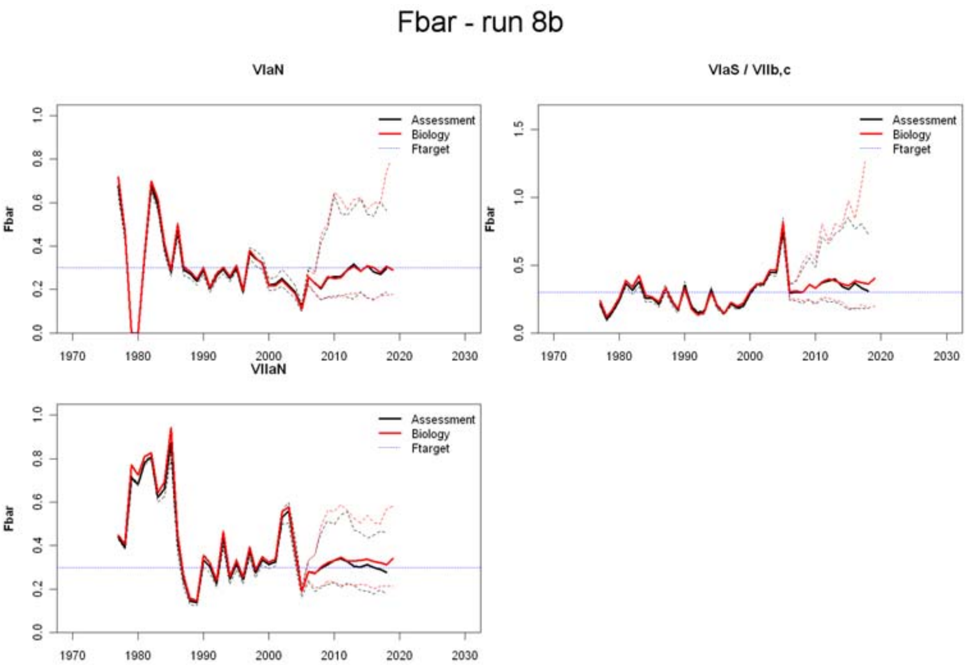
Assessment
Biology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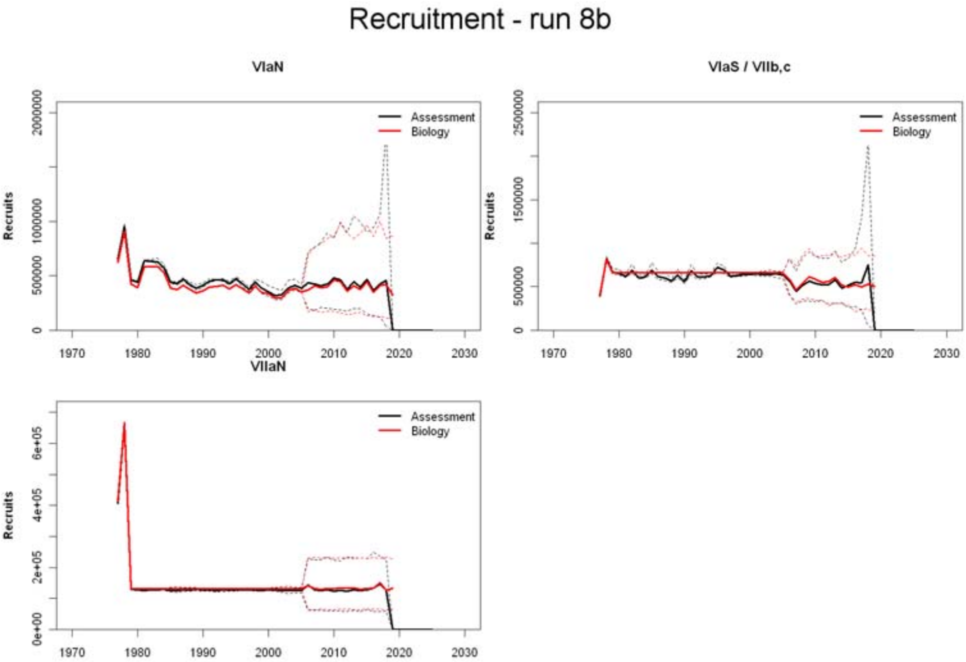
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VIaS / VIIb,c
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Recruits
Assessment
Biology
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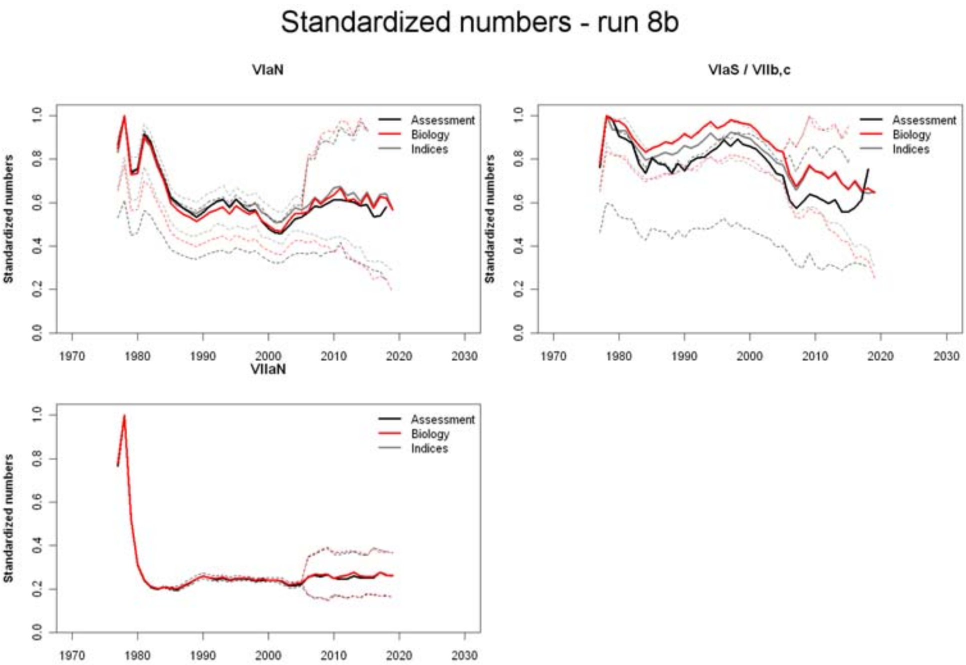
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VIaS / VIIb,c
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Standardized numbers
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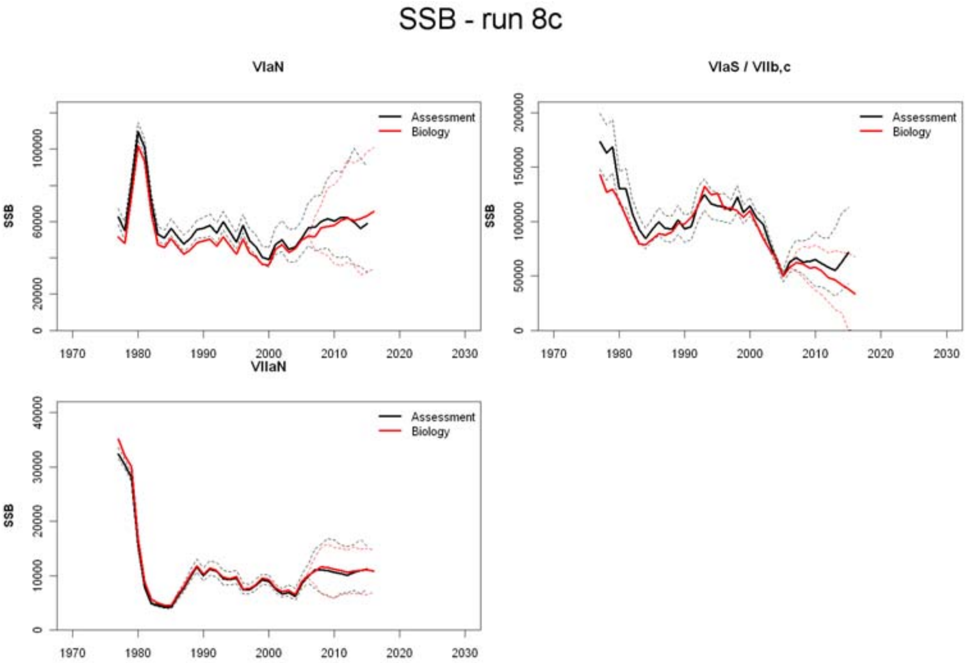
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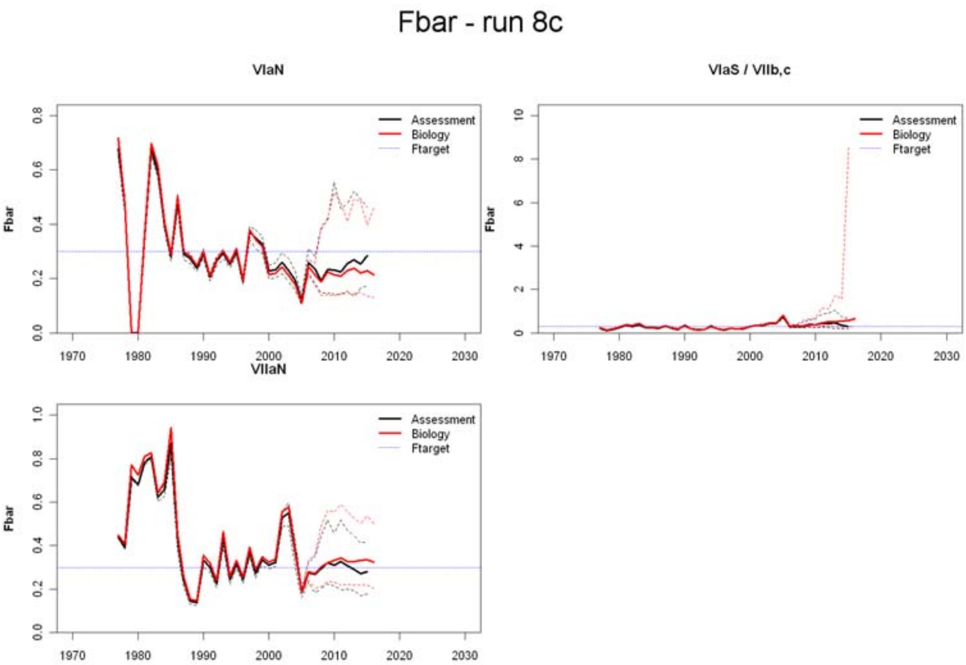
Assessment
Biology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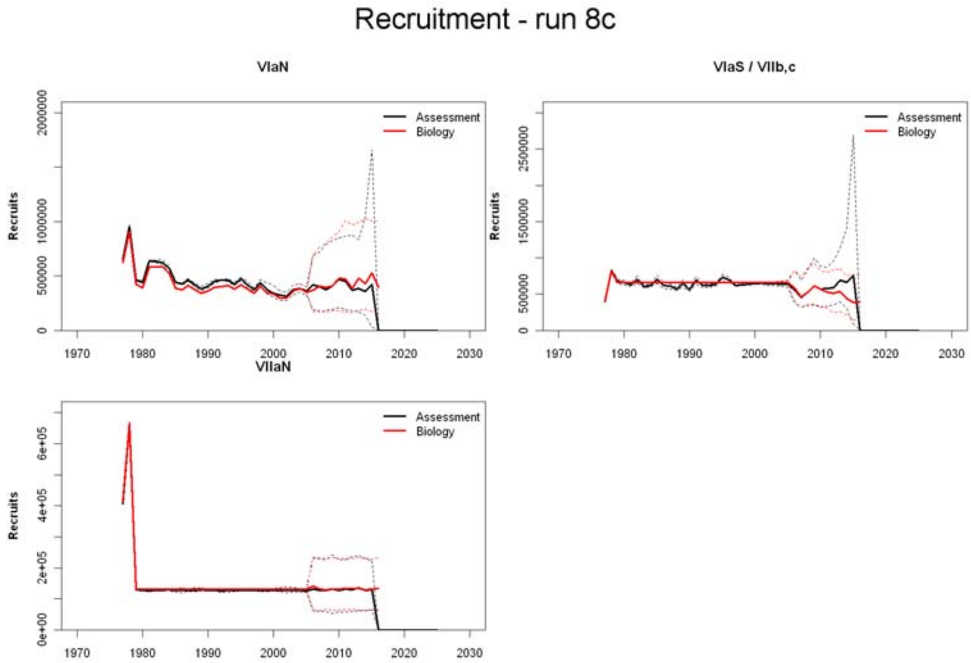
Ftarget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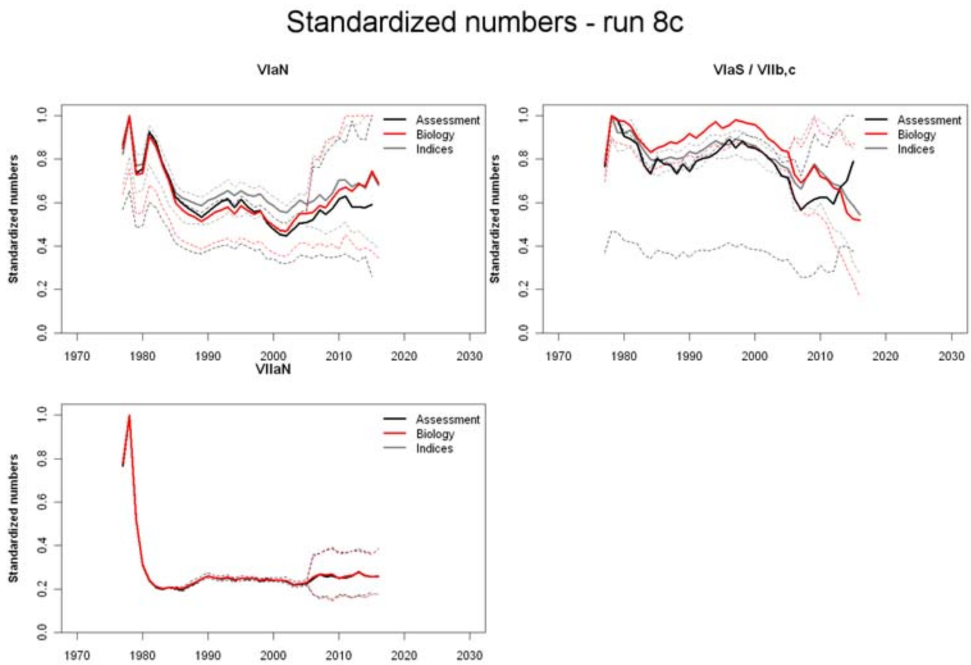
Recruits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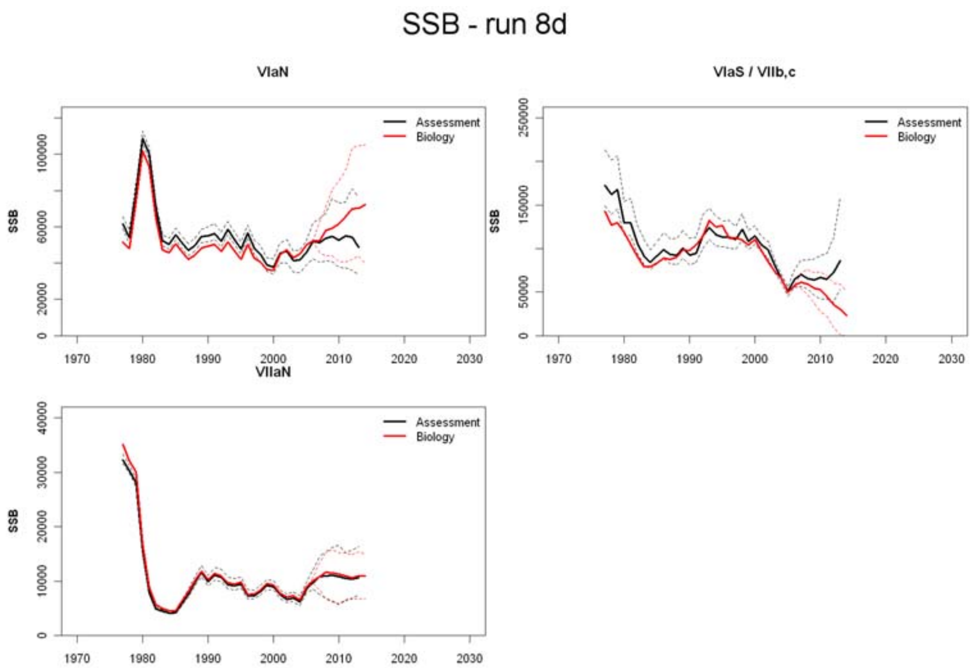
Indices
Standardized numbers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VIaS / VIIb,c
VIIaN
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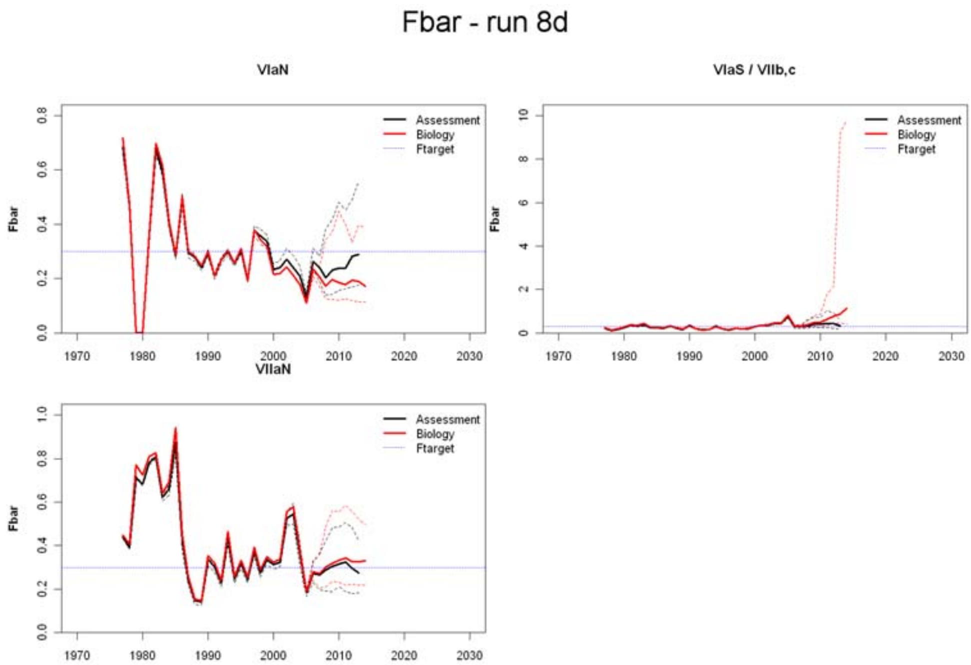
Assessment
Biology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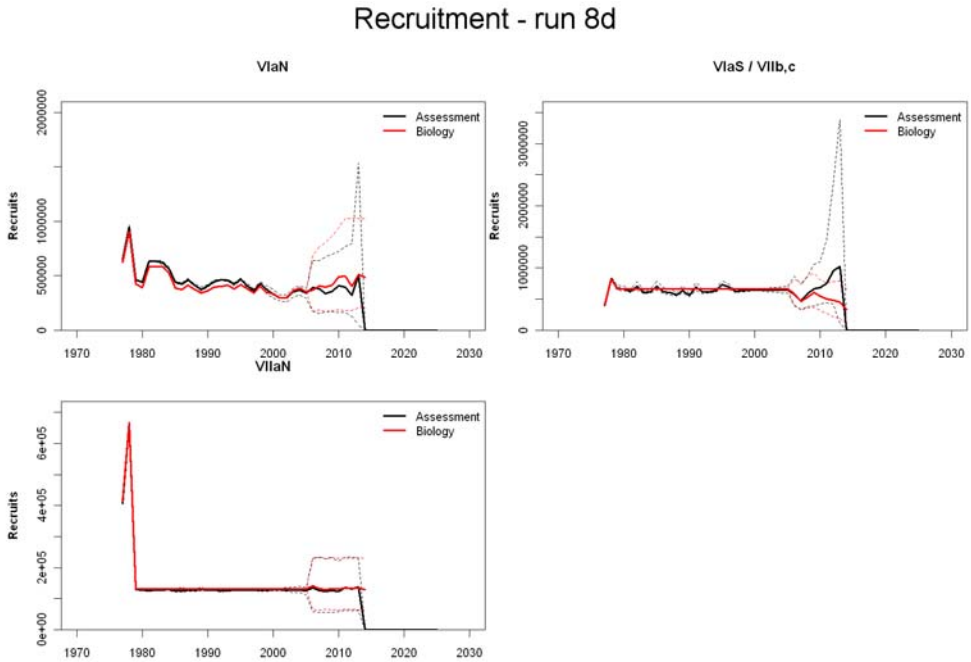
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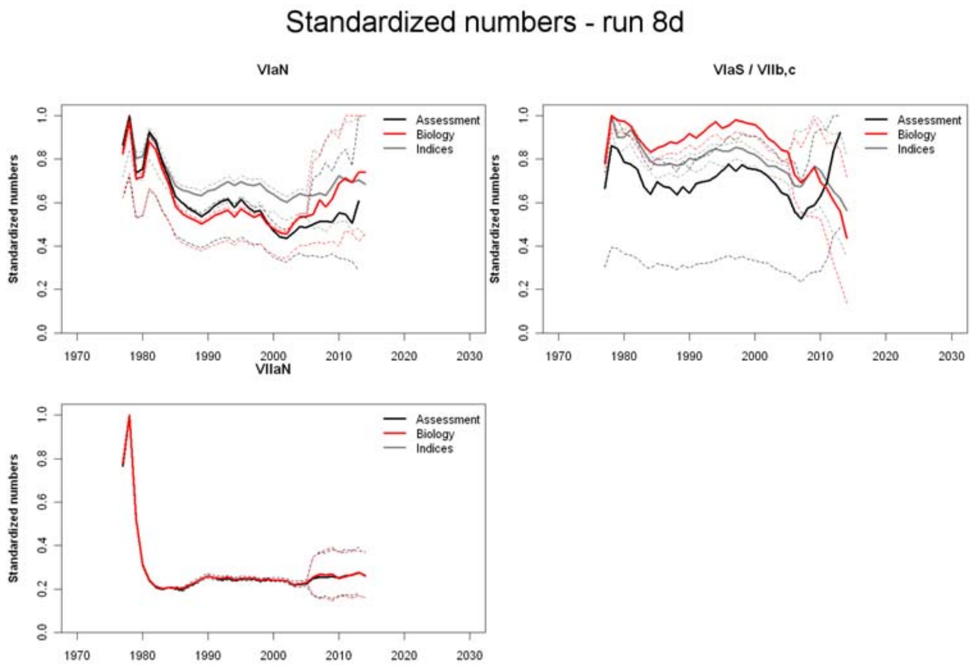
Biology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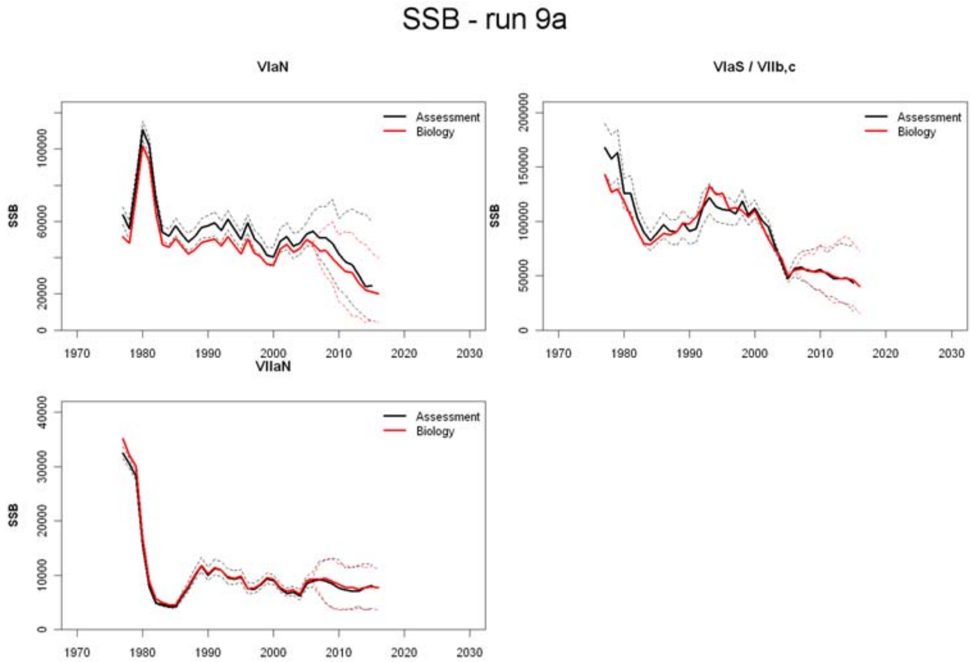
Biology
Indices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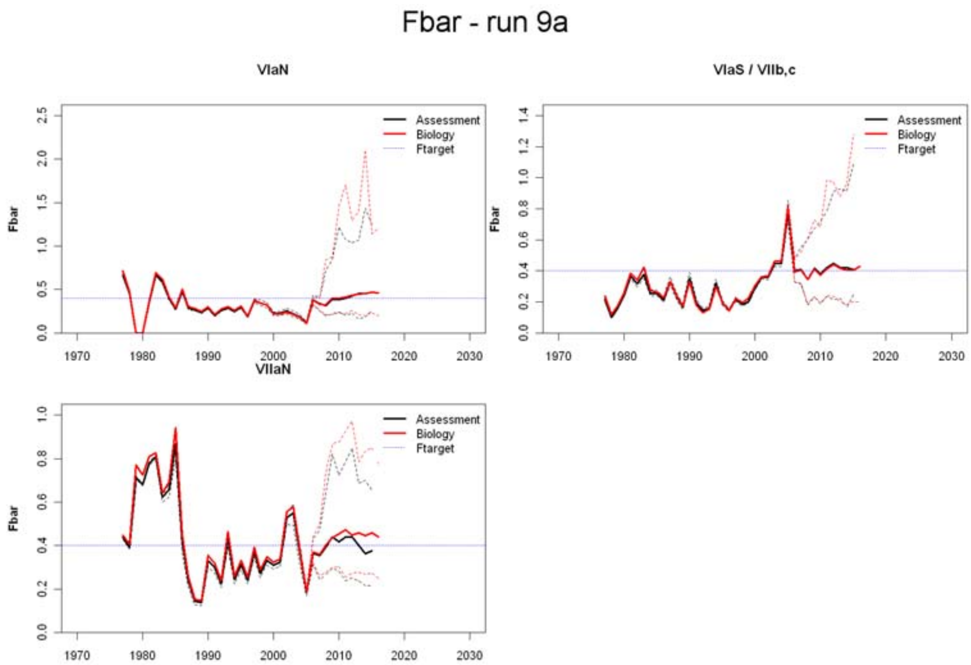
SSB
Assessment
Biology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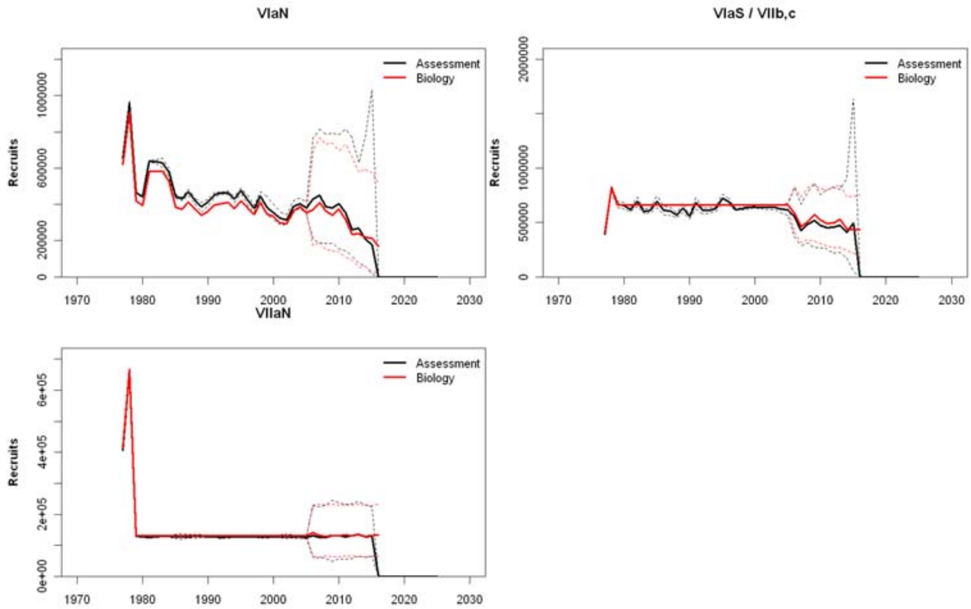
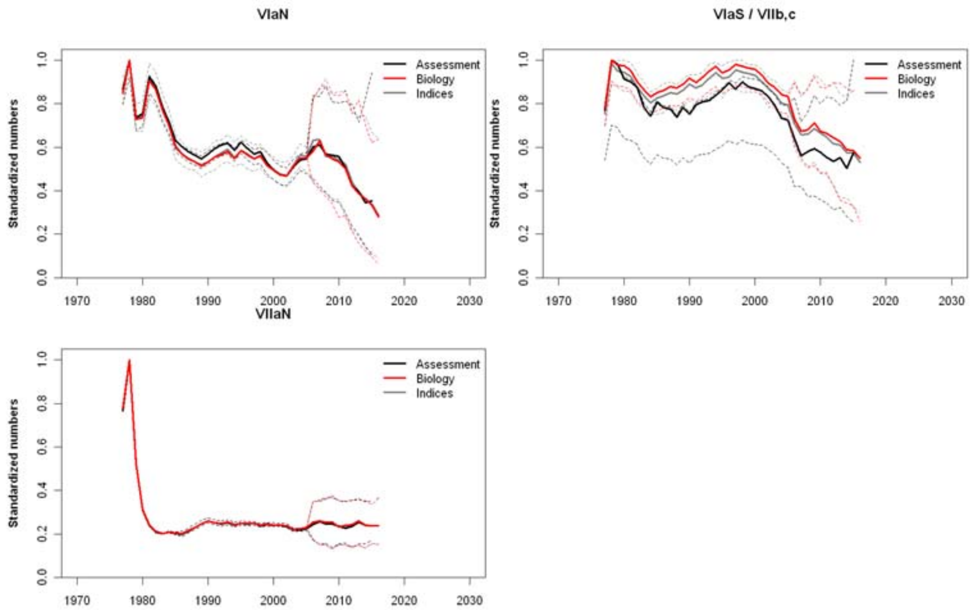
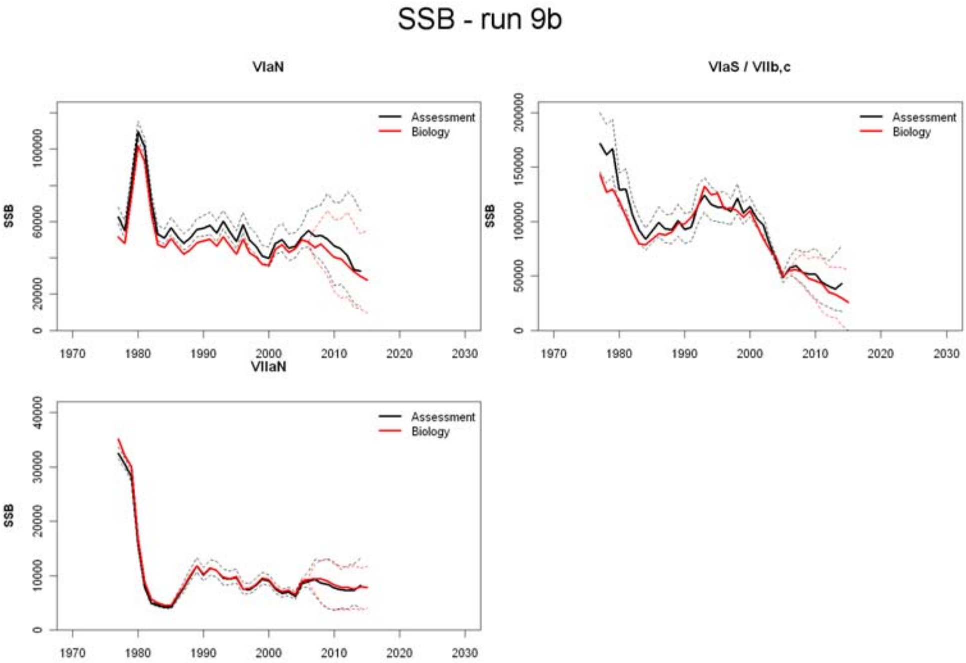
Fbar
Assessment
Biology
Ftarget

## Recruitment - run 9a




## Standardized numbers - run 9a

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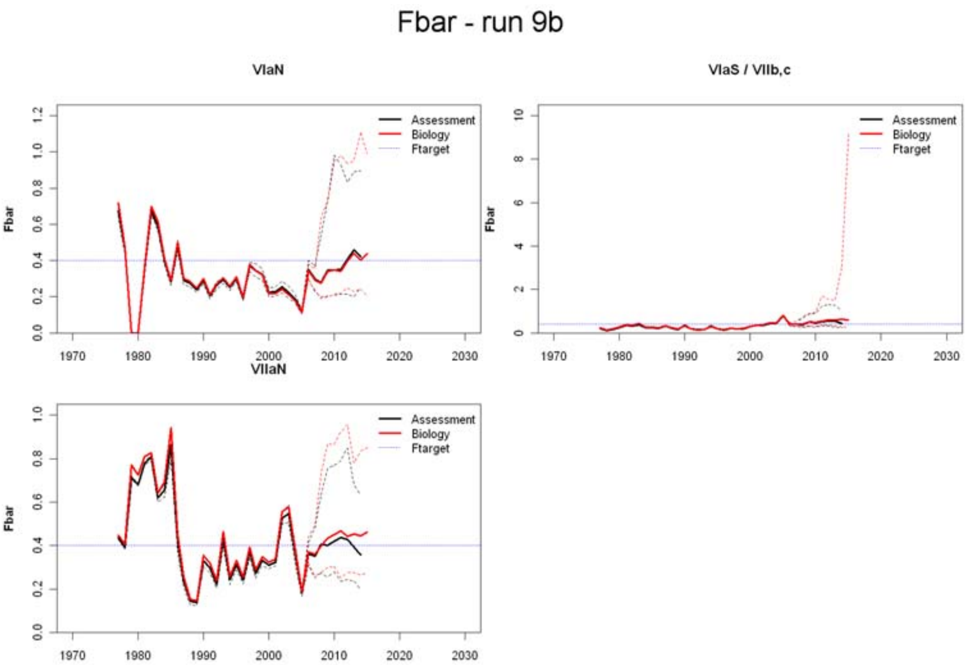
SSB
Assessment
Biology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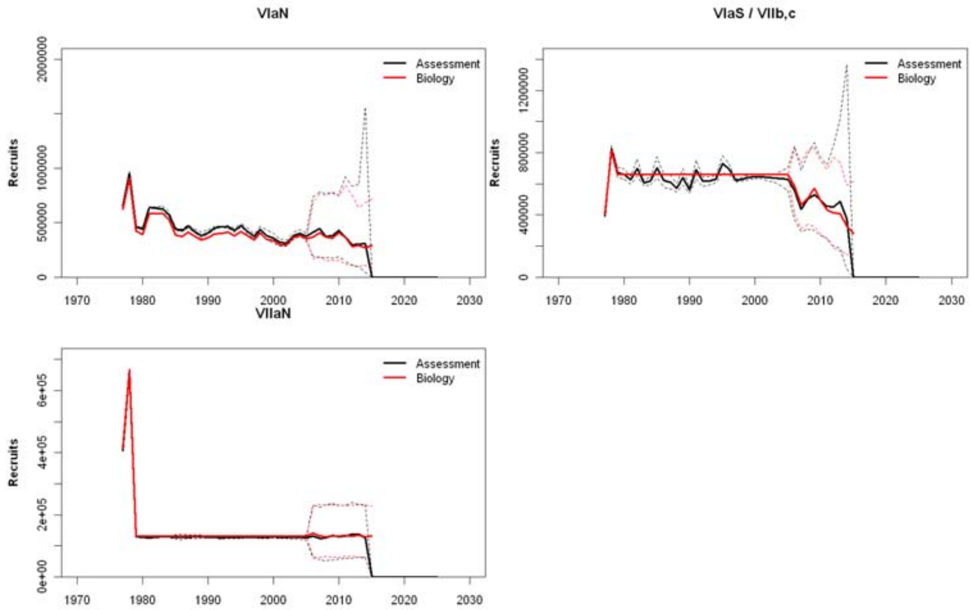
Ftarget

Recruitment - run 9b

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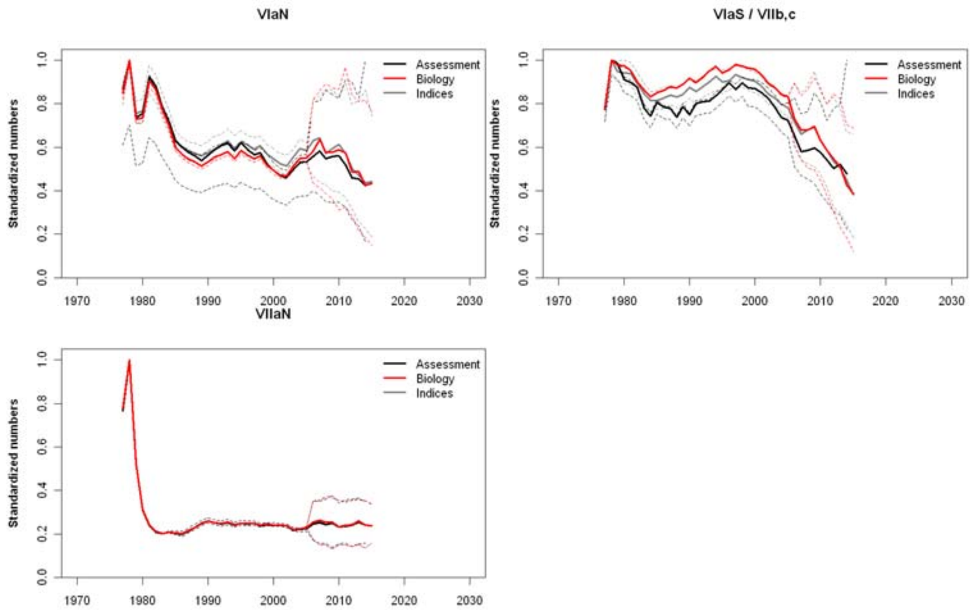

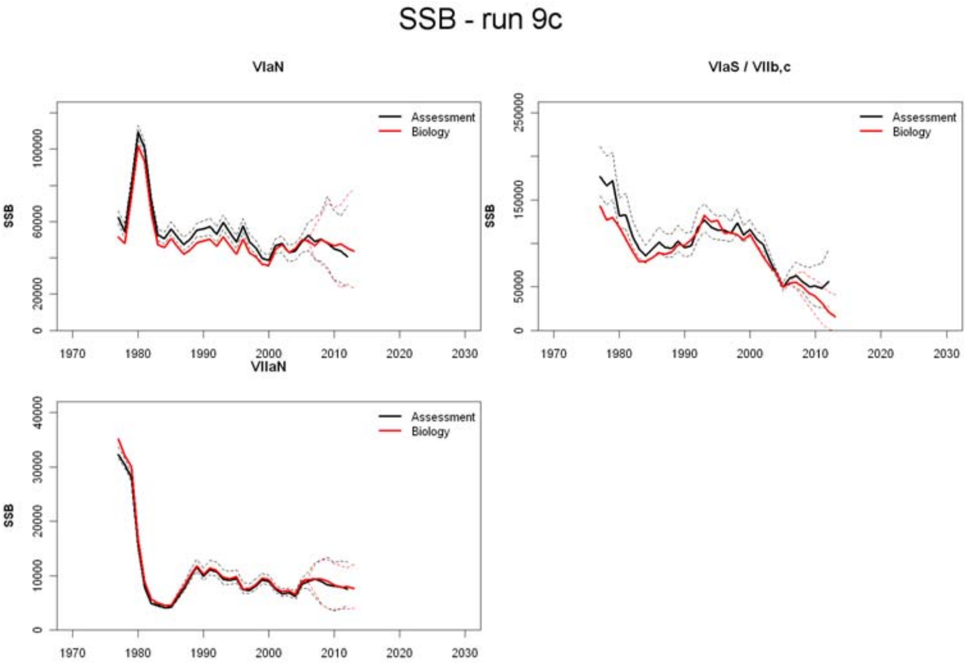
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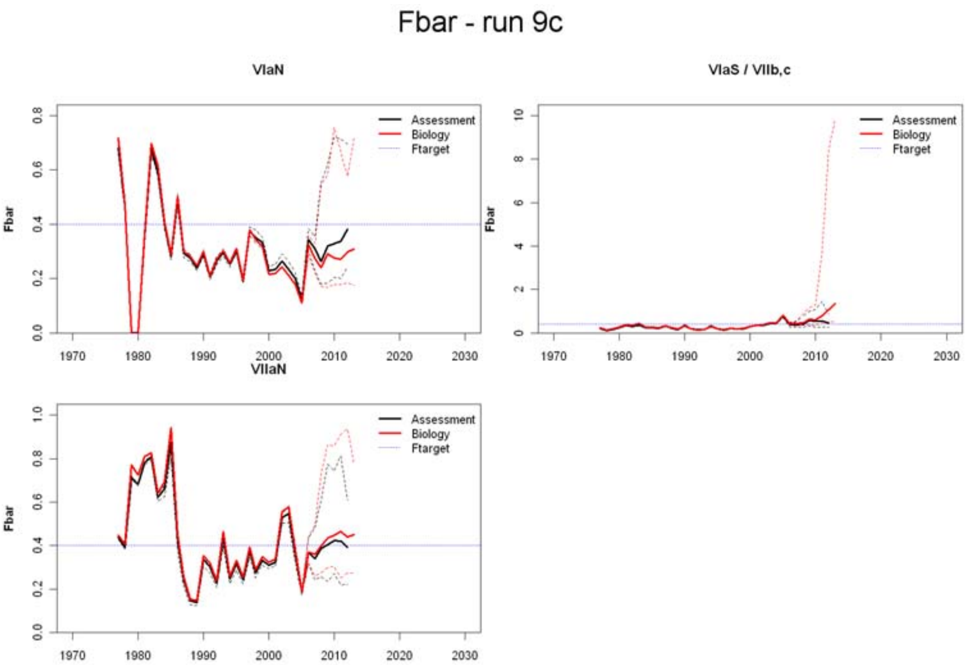
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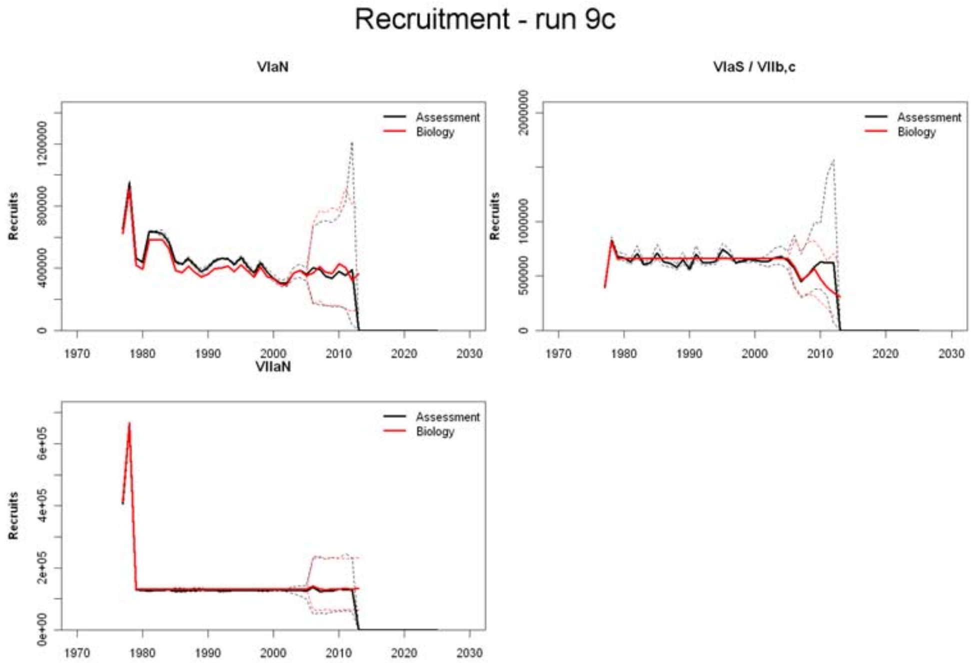
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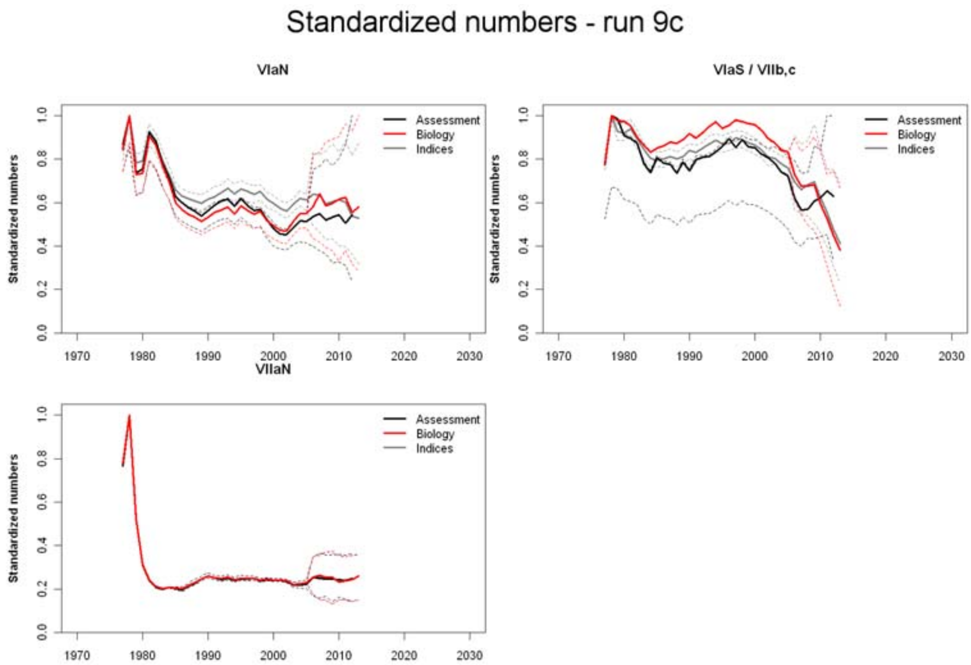
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Standardized numbers
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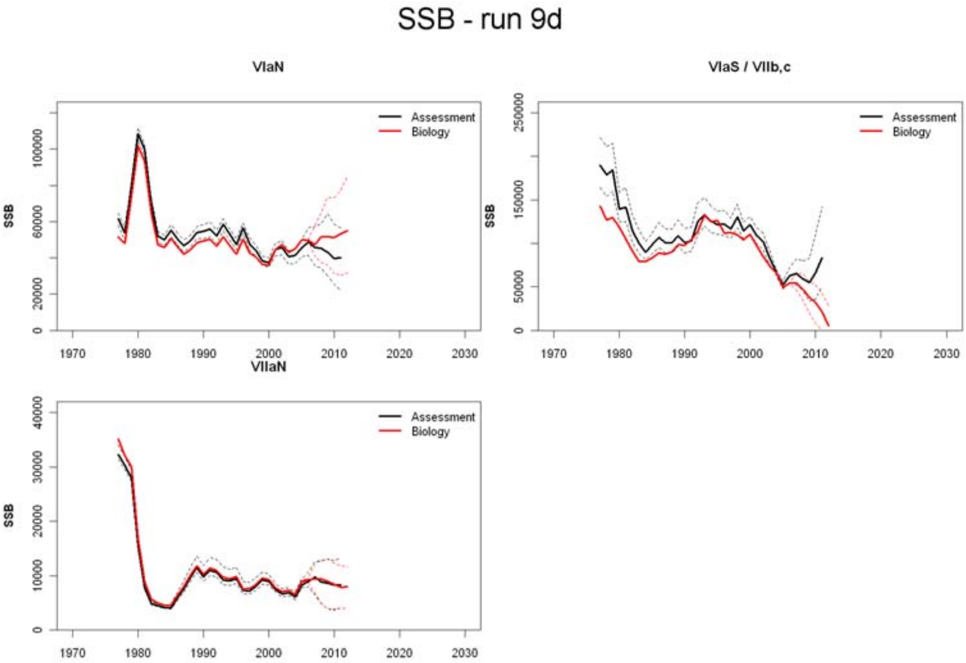
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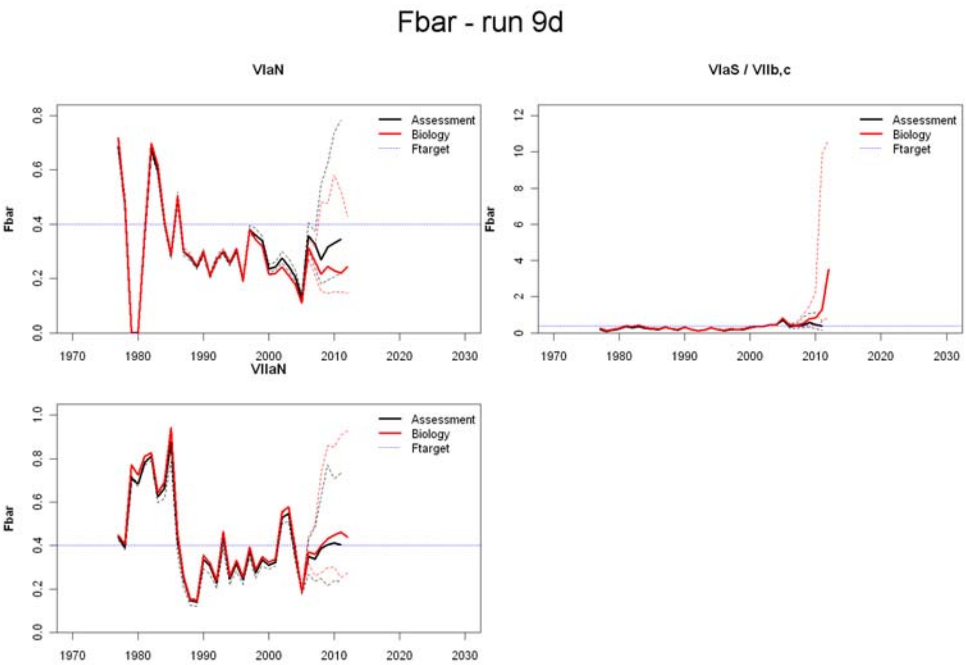
Biology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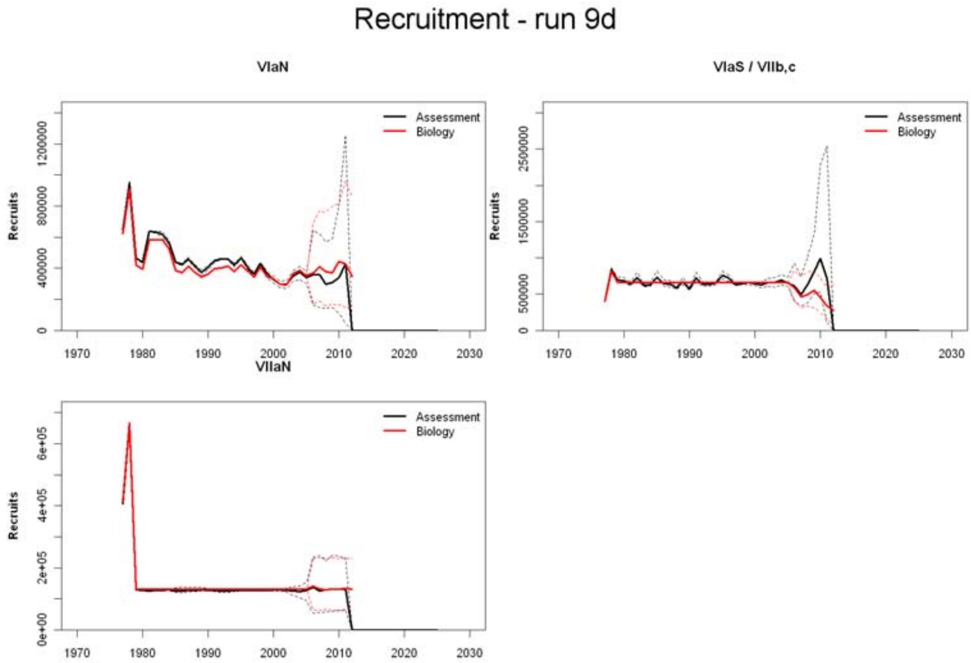
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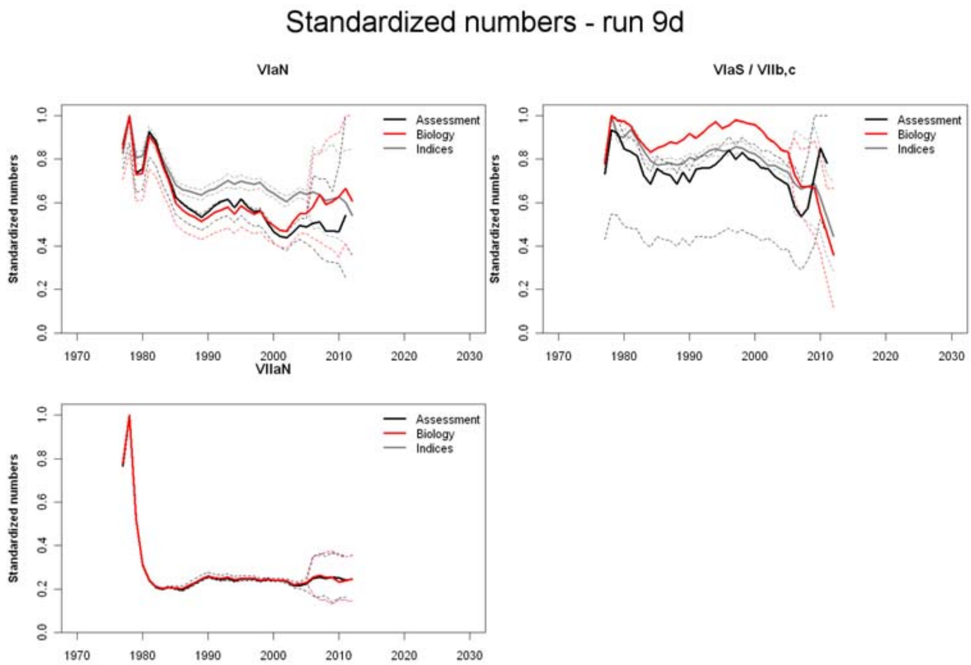
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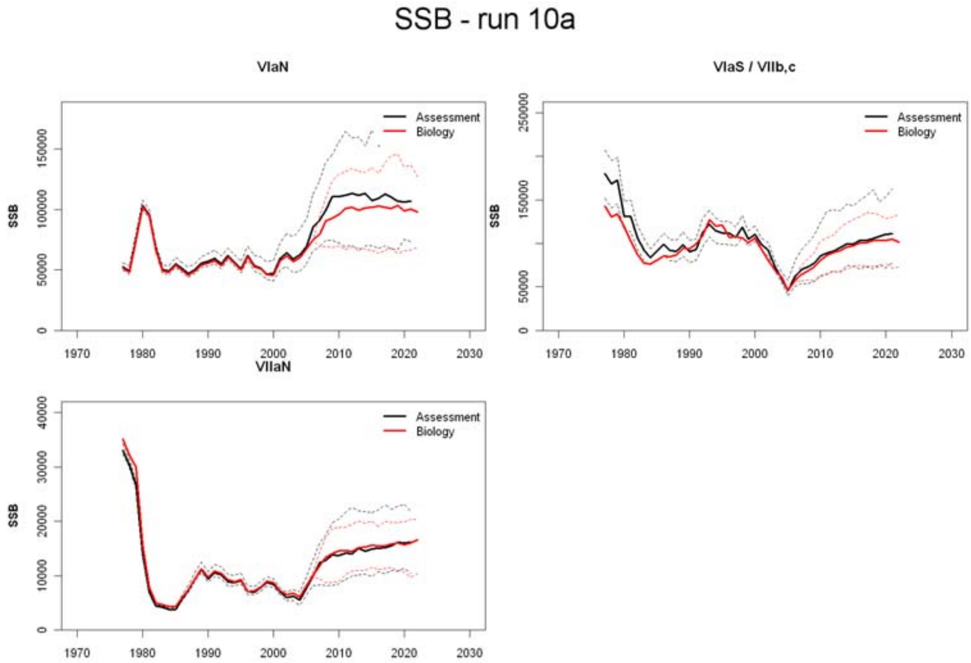
Standardized numbers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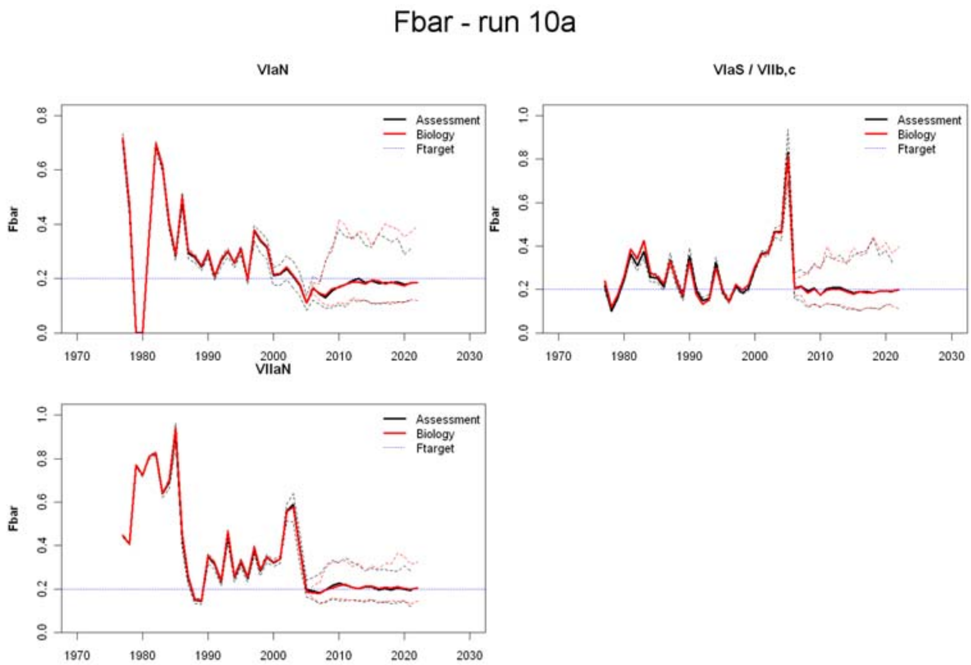
SSB
Assessment
Biology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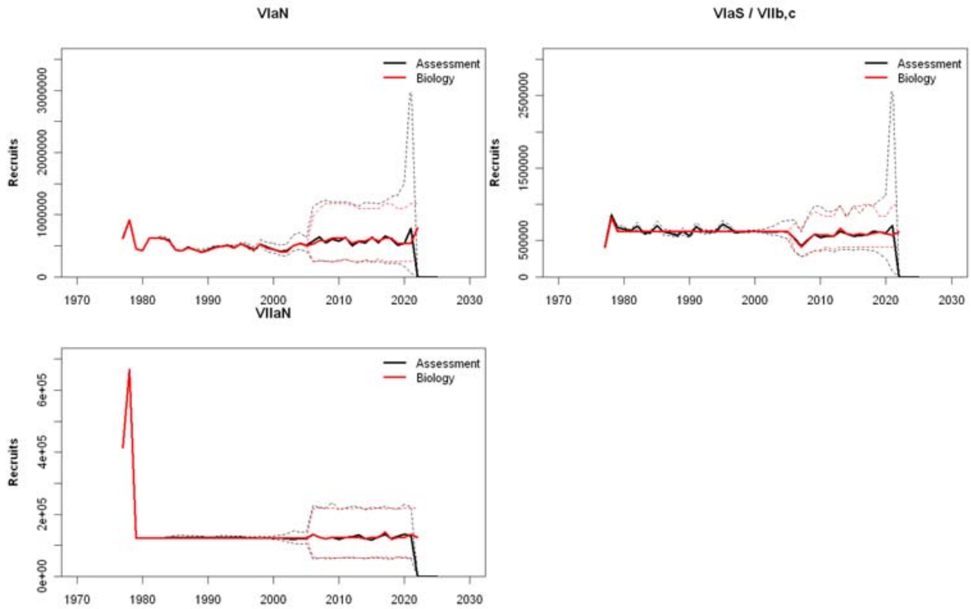
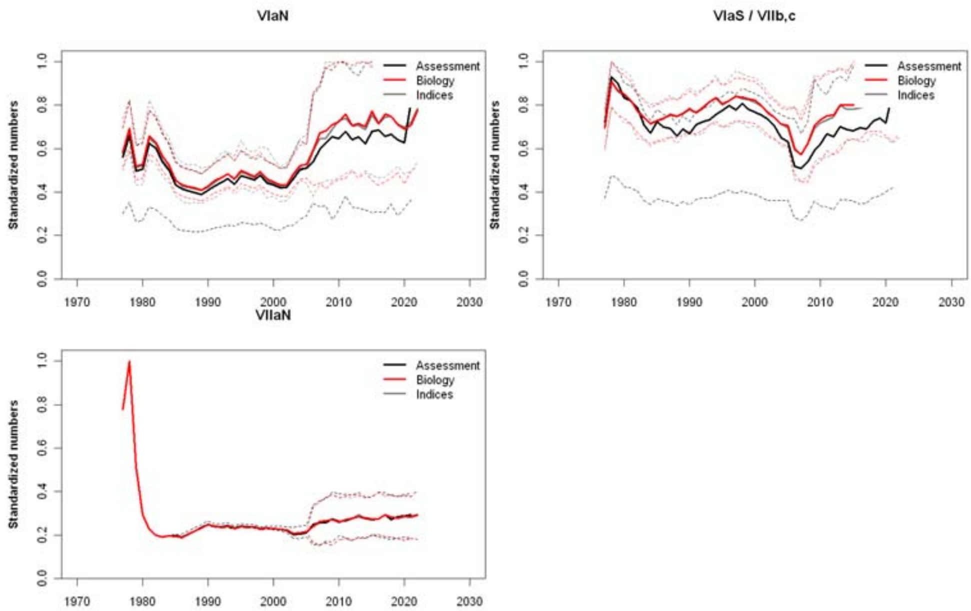
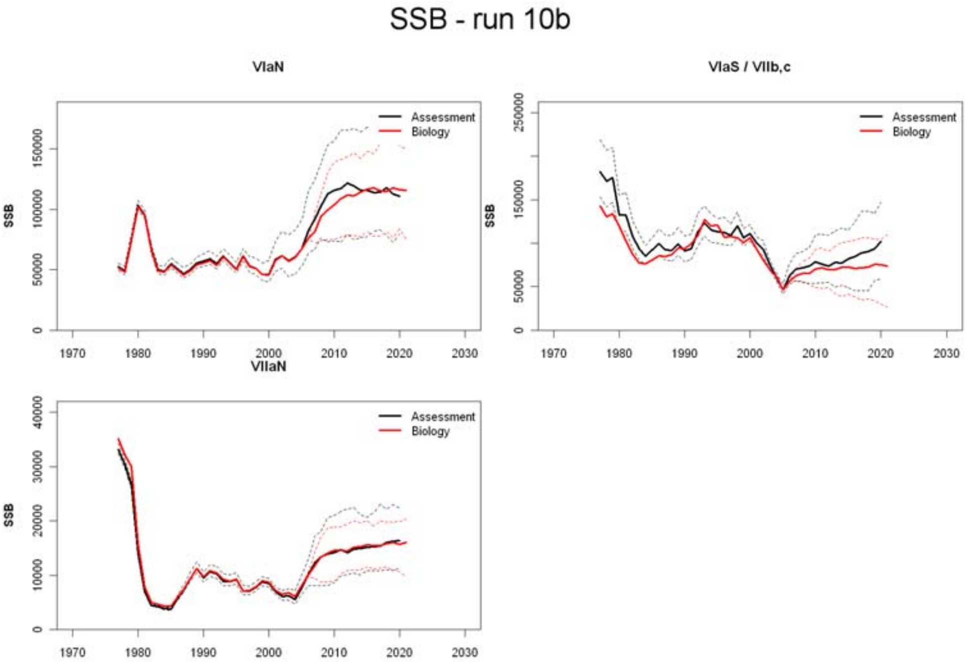
Assessment
Biology
Ftarget

Recruitment - run 10a




Standardized numbers - run 10a

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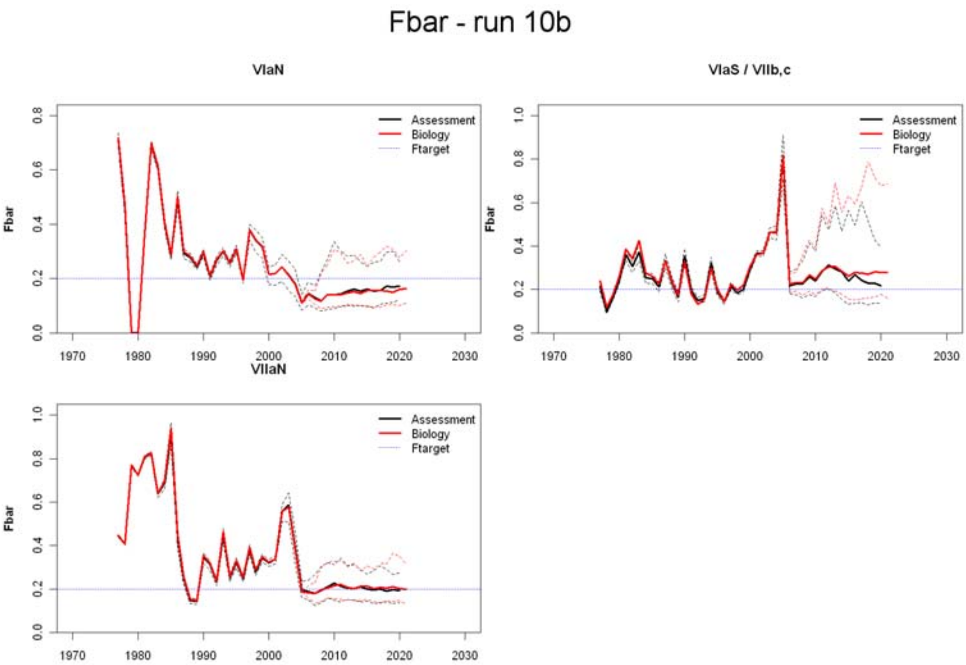
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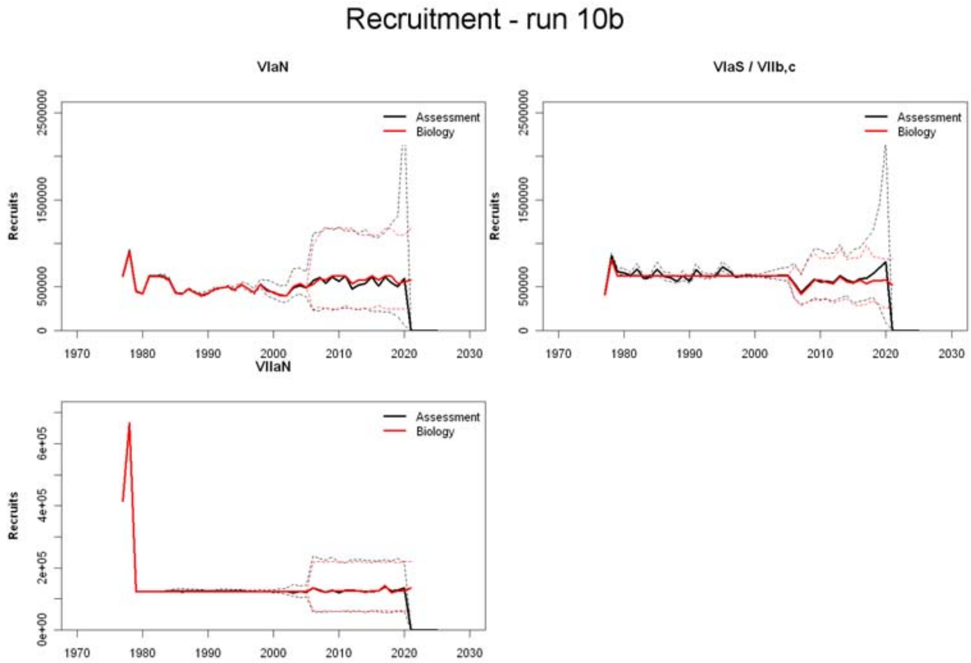
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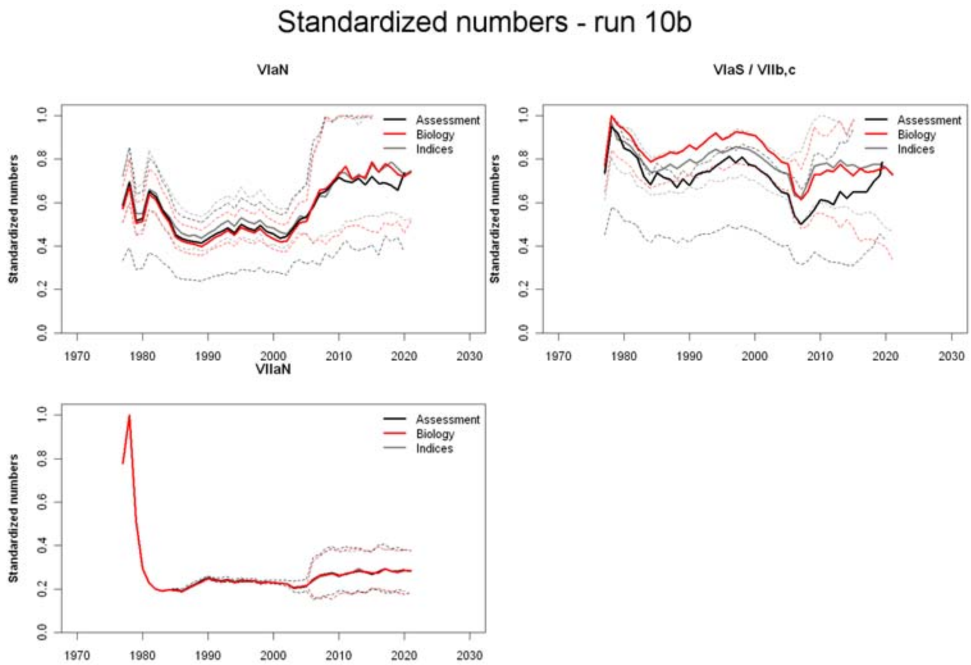
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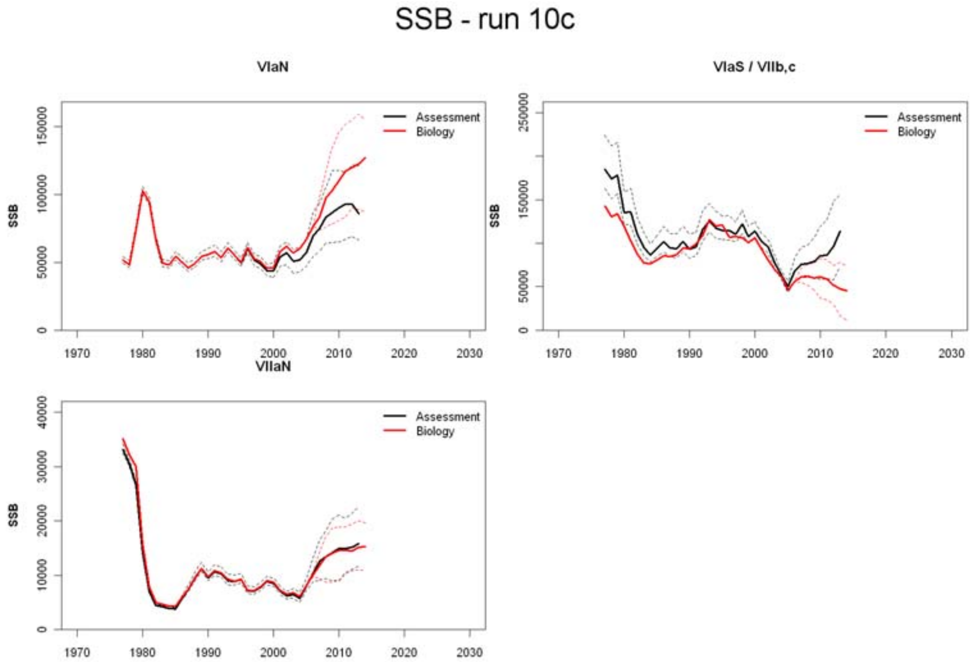
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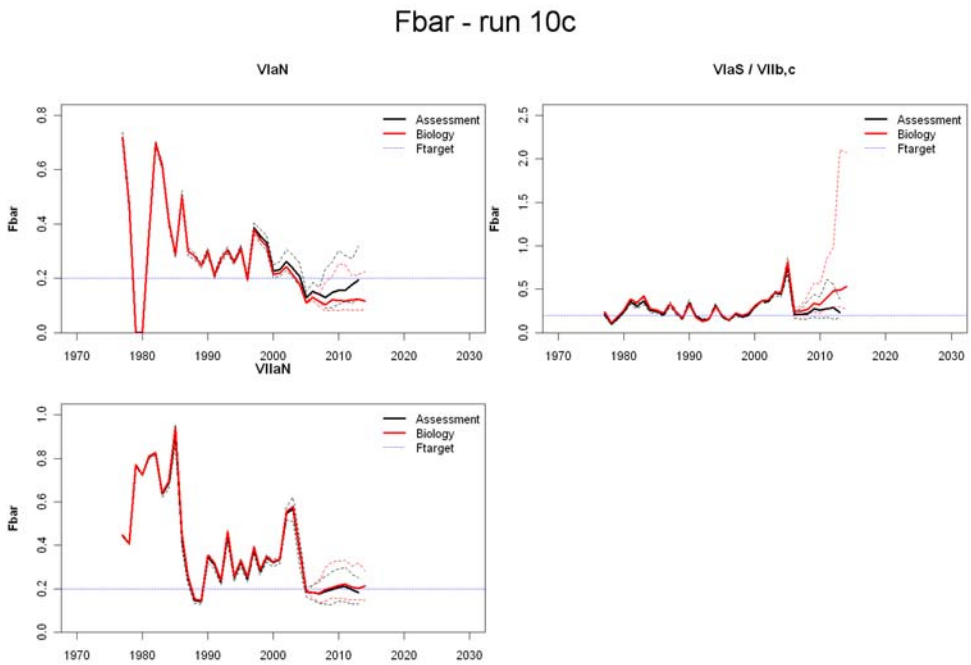
Biology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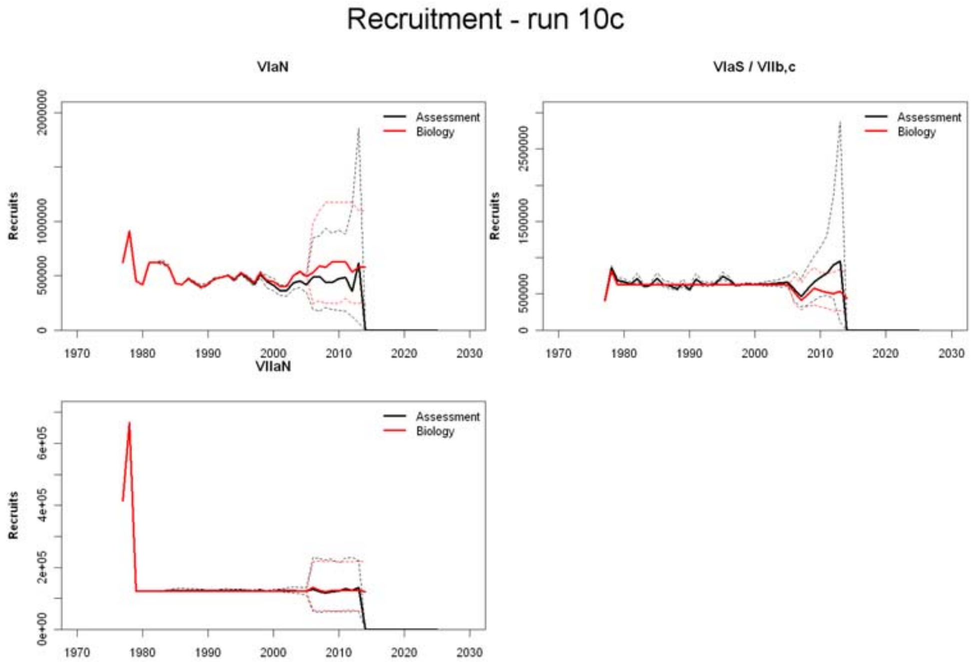
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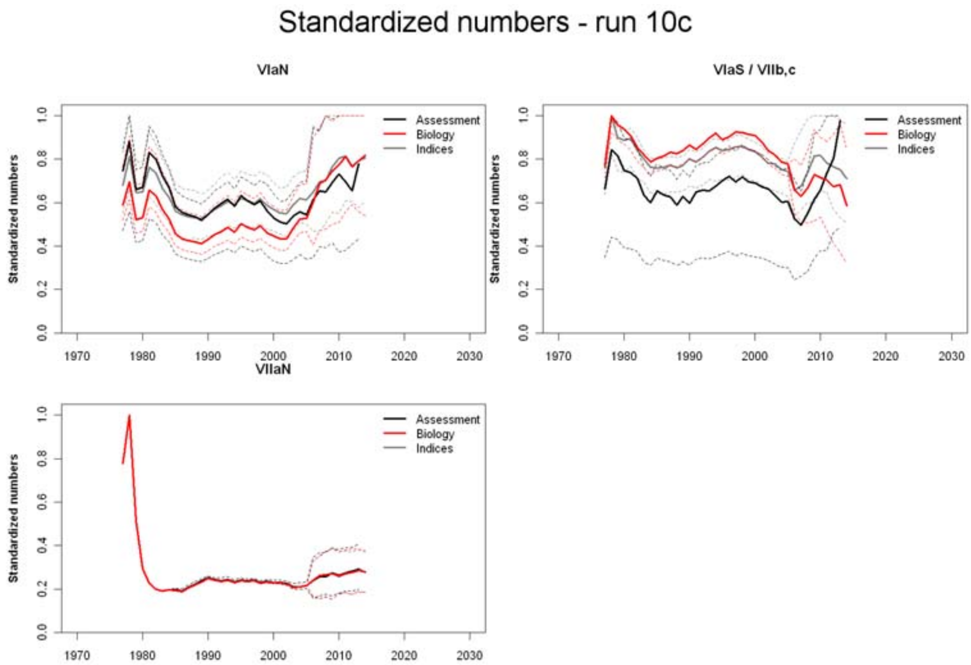
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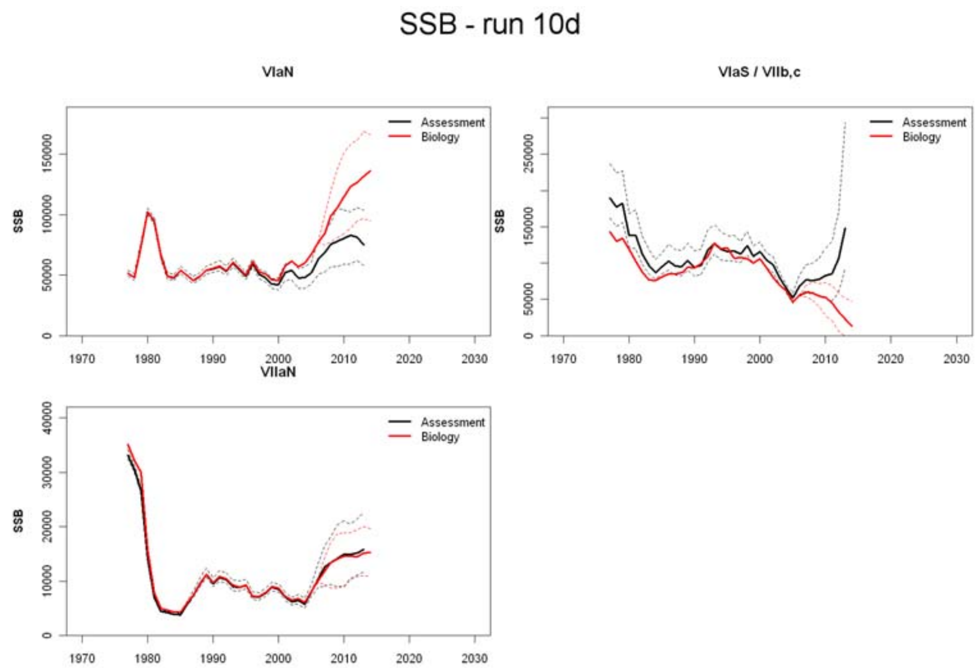
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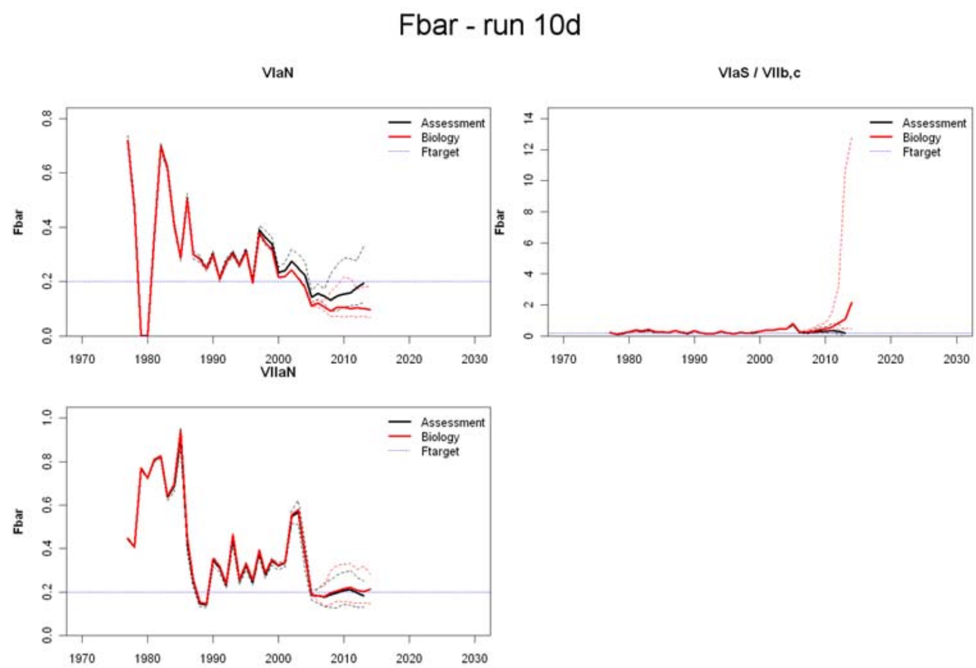
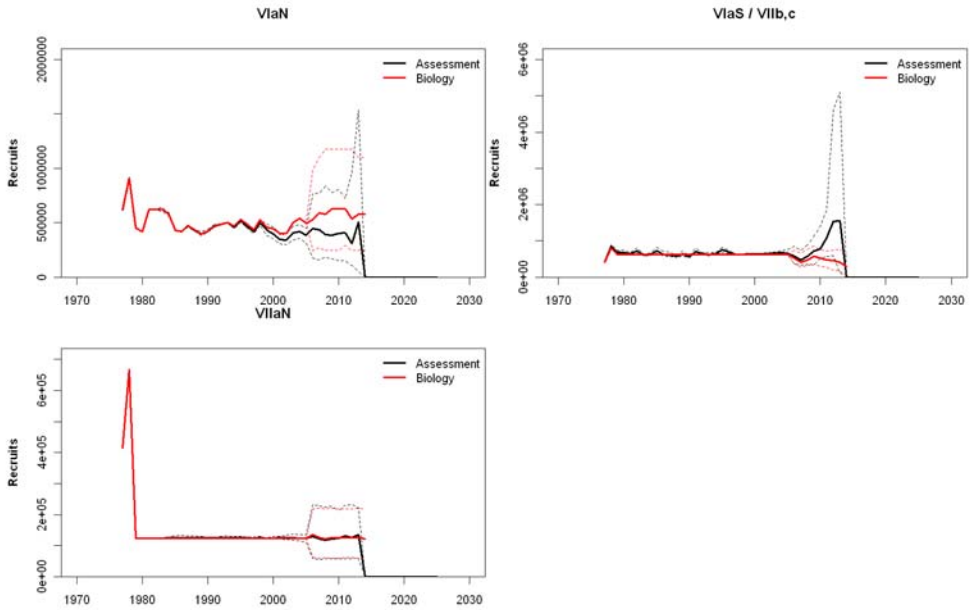
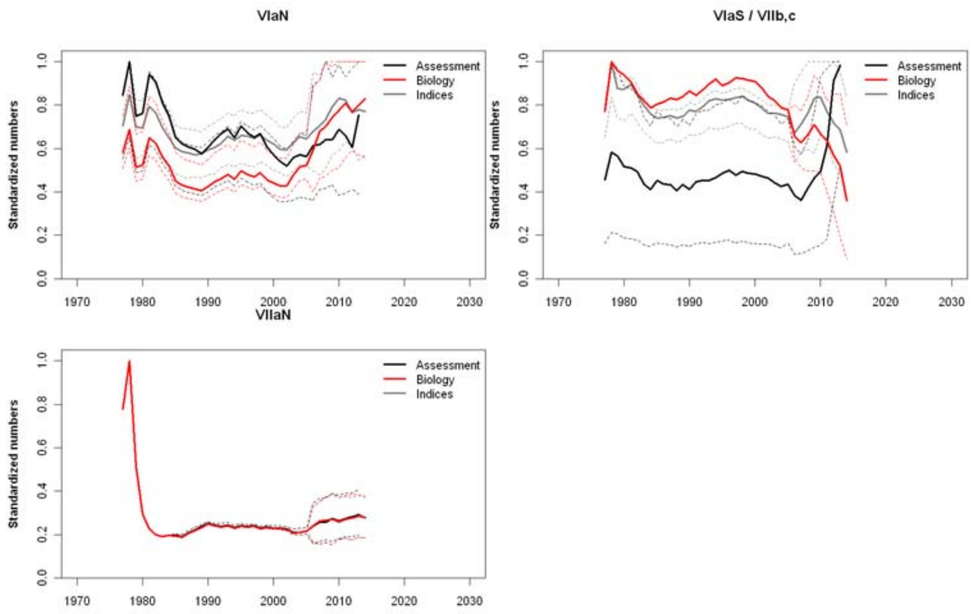
Biology
SSB

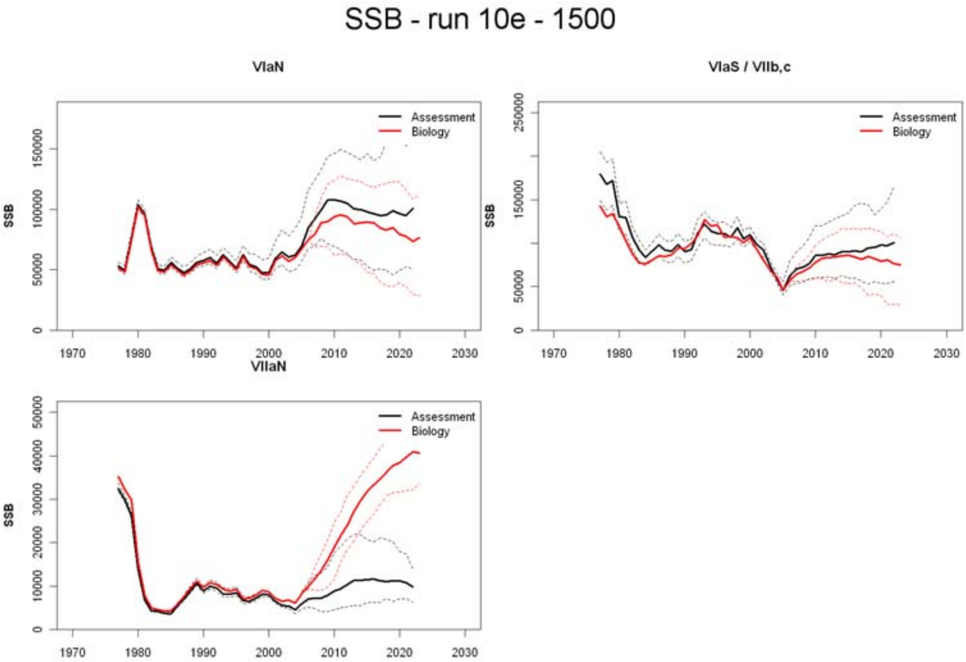

Fbar - run 10d
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Ftarget
Fbar

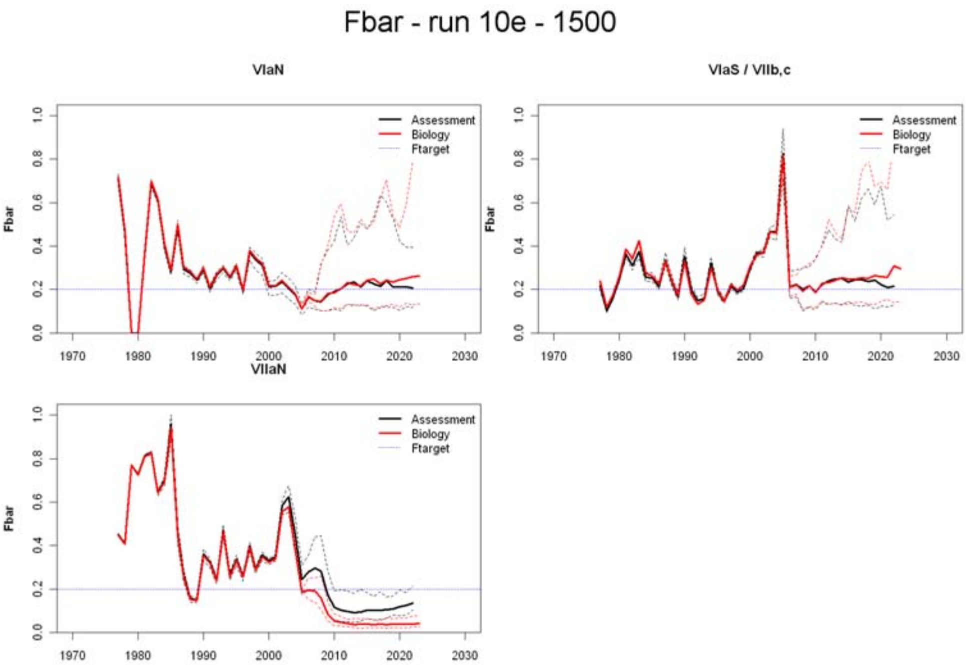
Recruitment - run 10d

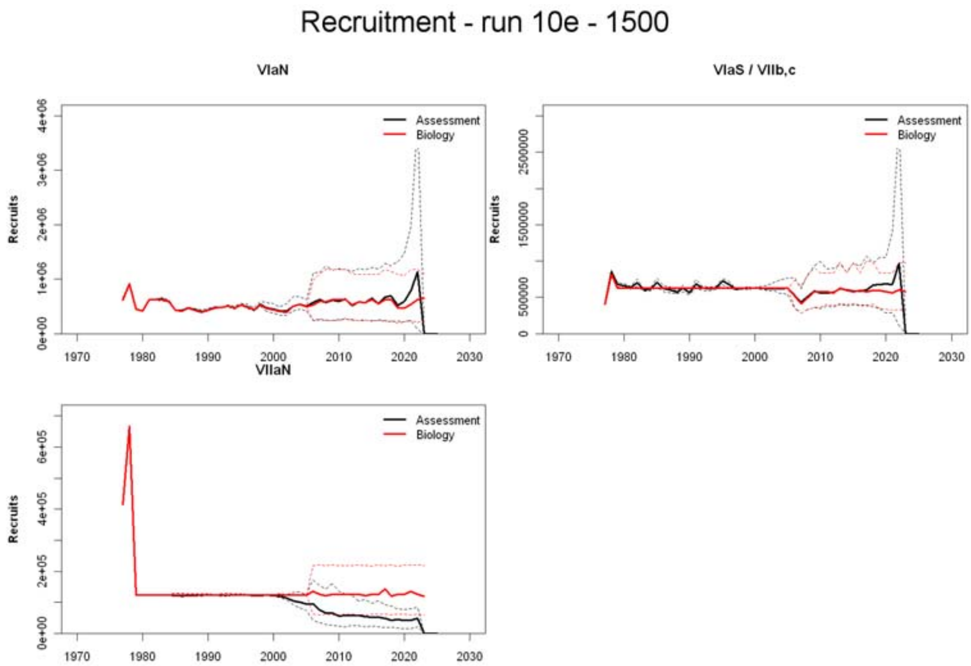


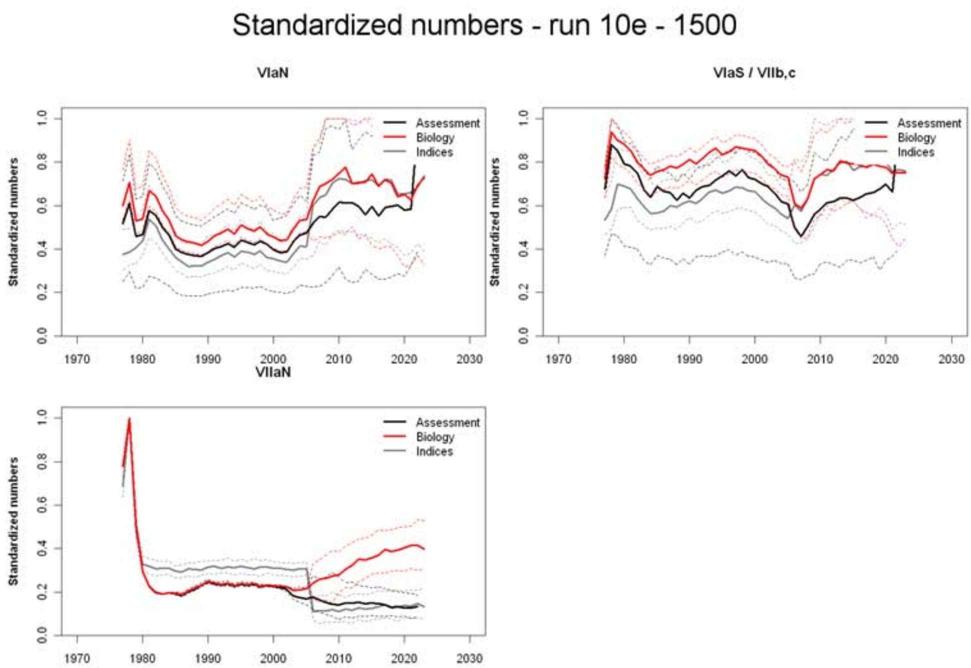

Standardized numbers - run 10d

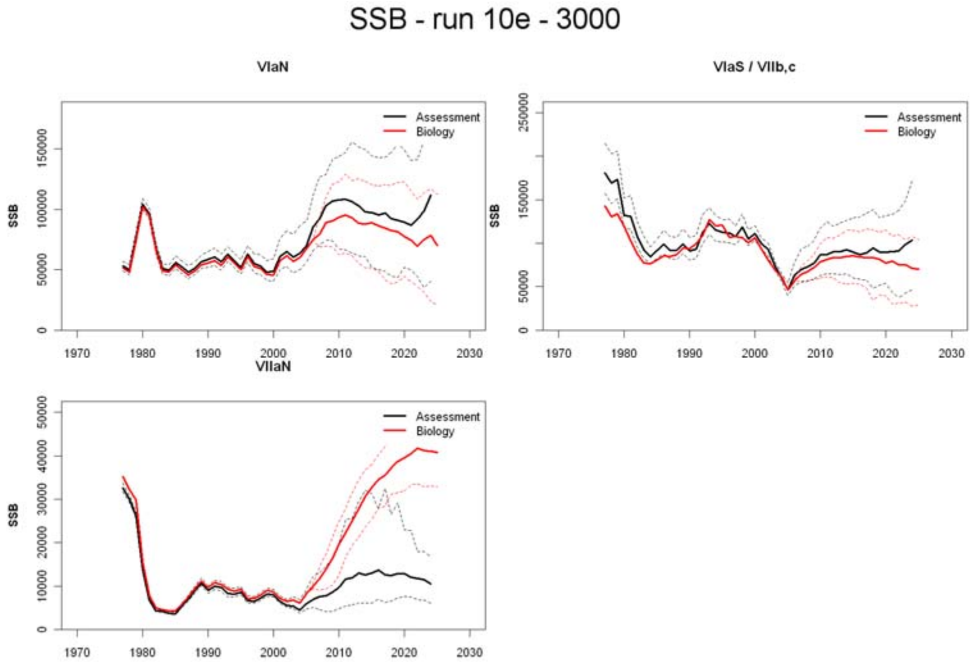


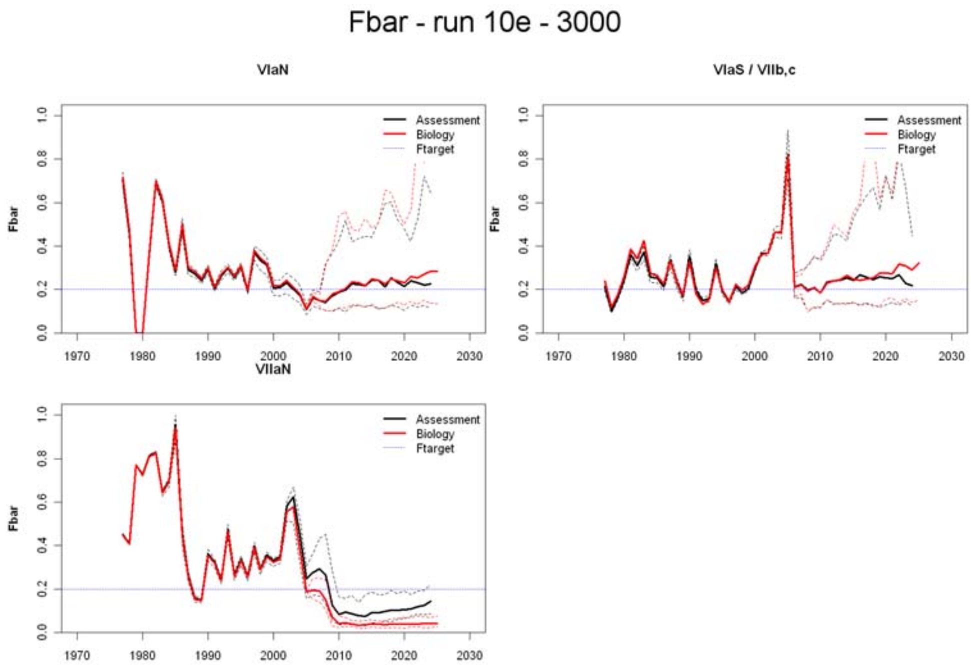

SSB - run 10e - 1500
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

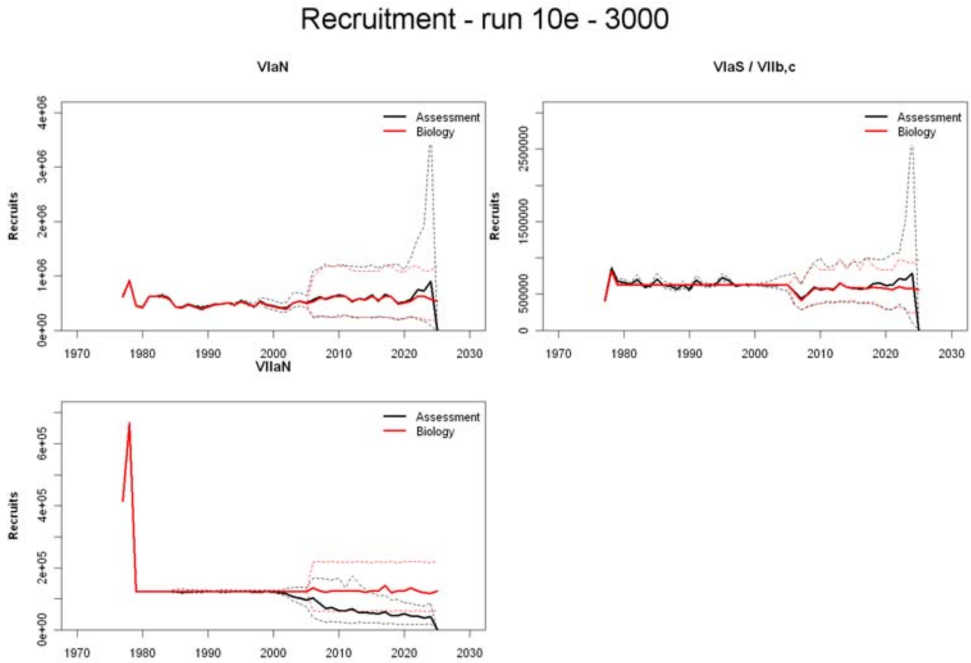

Fbar - run 10e - 1500
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

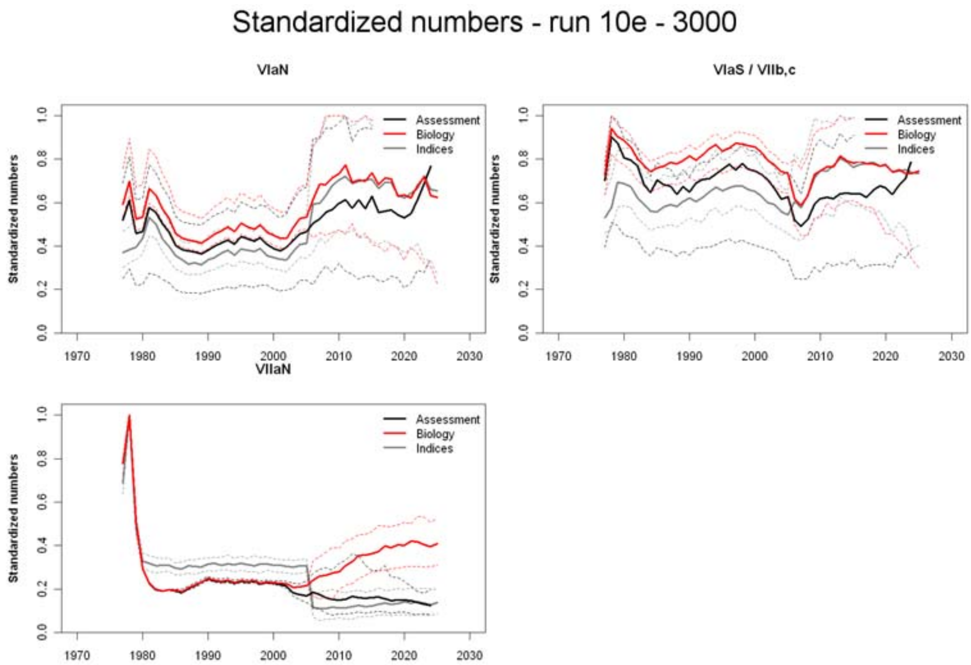

Recruitment - run 10e - 1500
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology

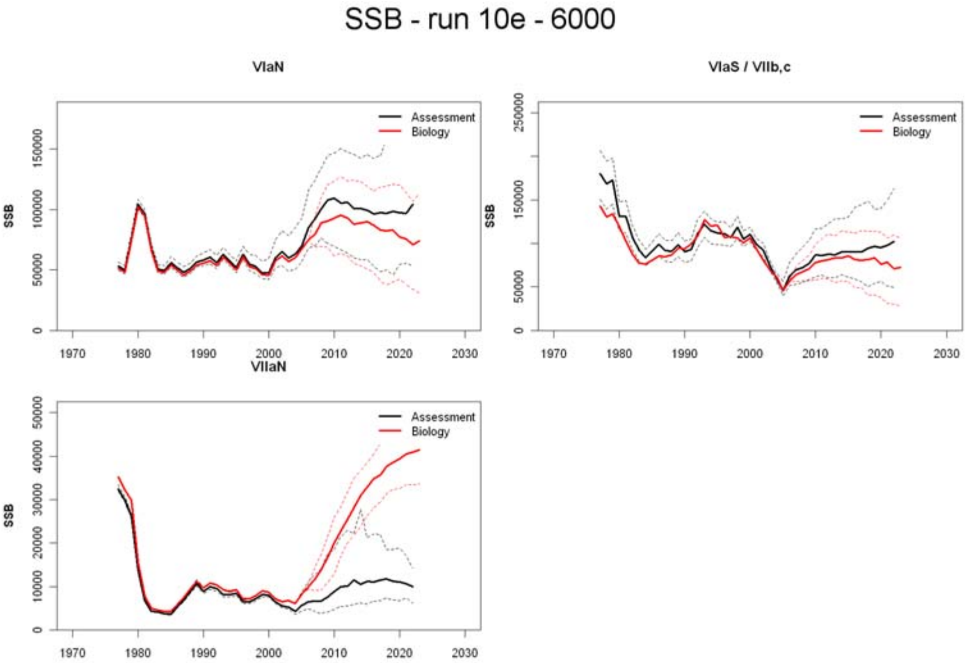

Standardized numbers - run 10e - 1500
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices

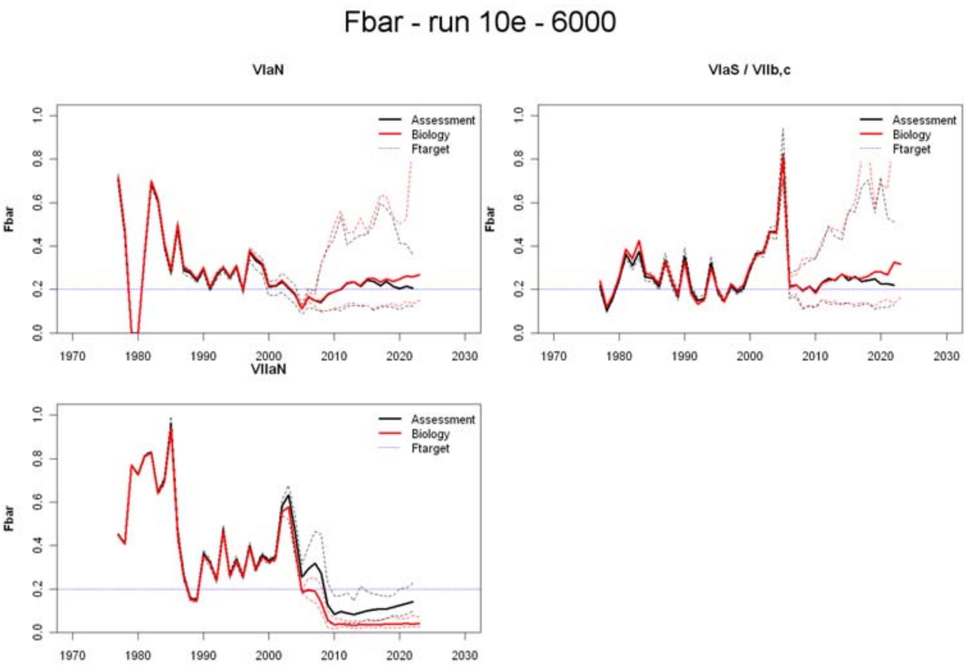

SSB - run 10e - 3000
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

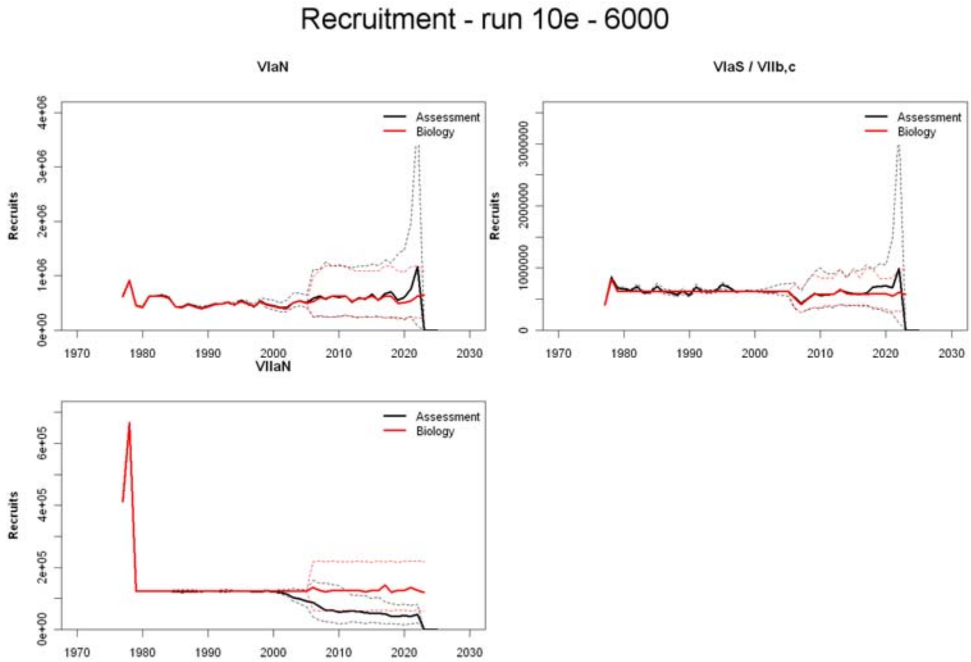

Fbar - run 10e - 3000
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget


Recruitment - run 10e - 3000
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology

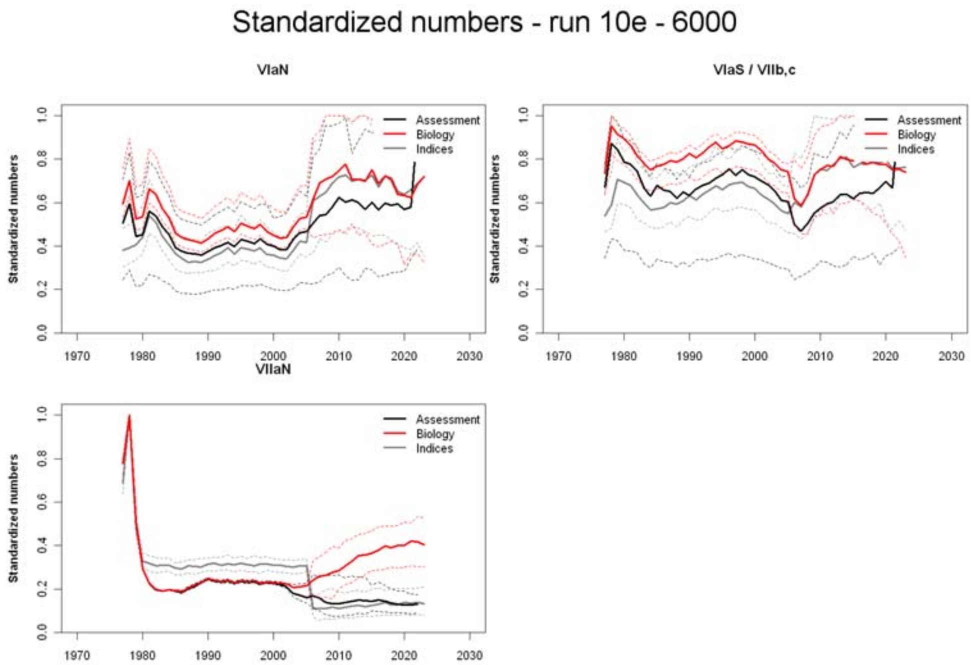

Standardized numbers - run 10e - 3000
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices


SSB - run 10e - 6000
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

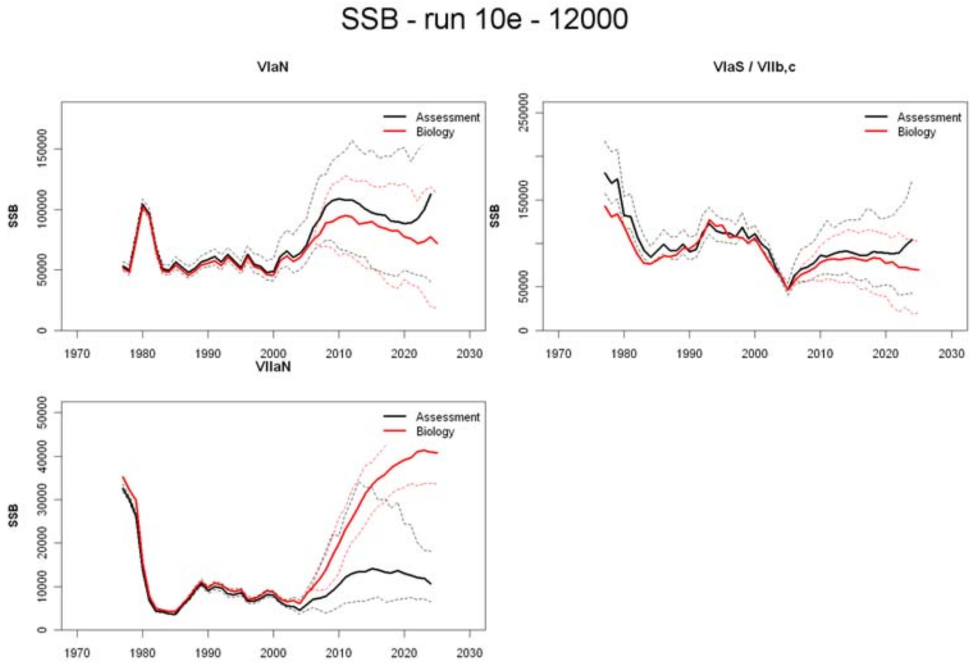

Fbar - run 10e - 6000
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

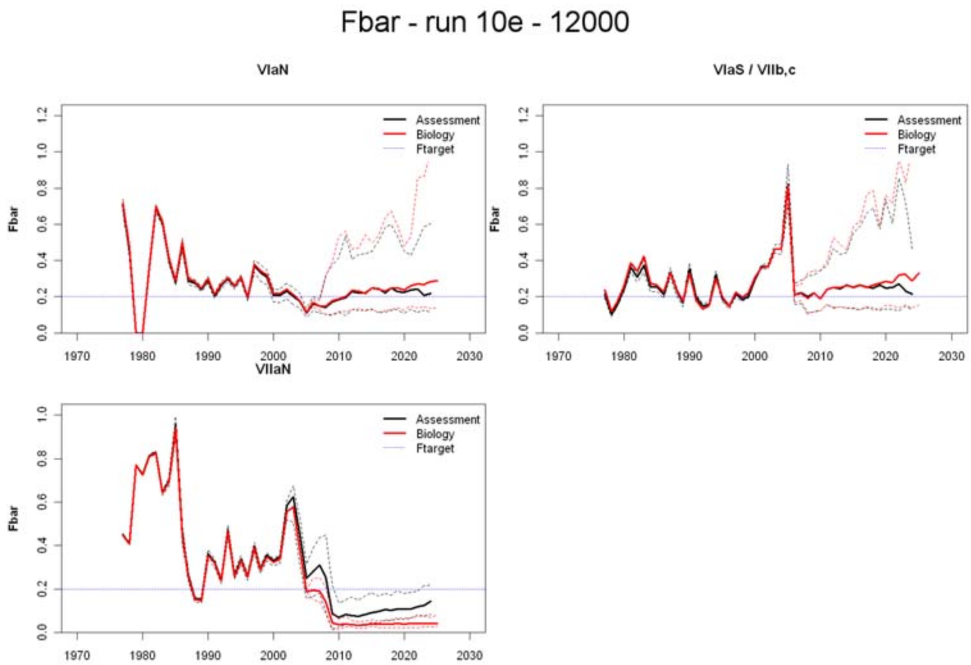


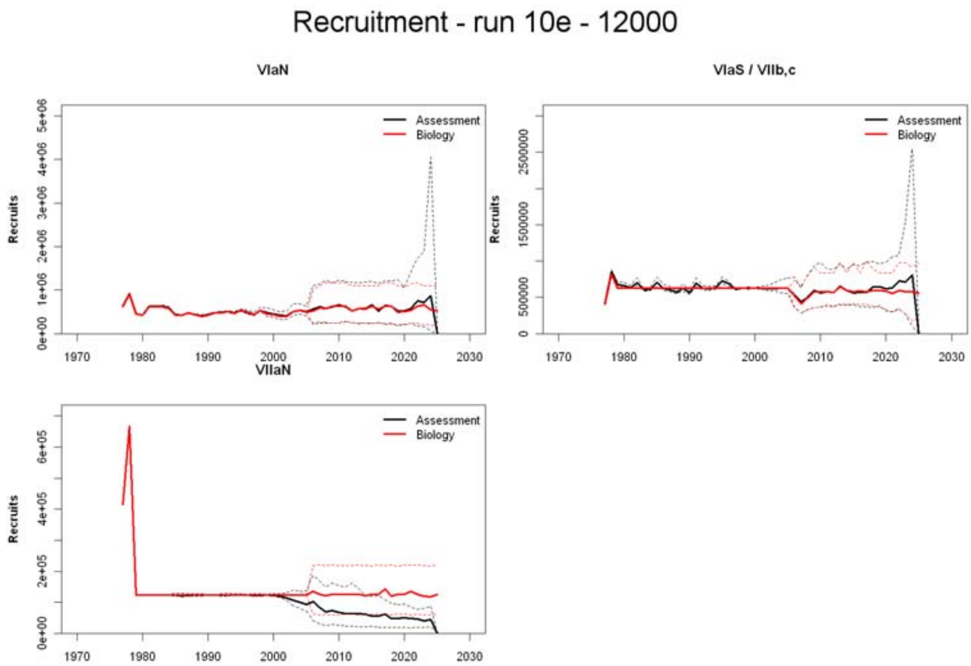
Recruitment - run 10e - 6000
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology

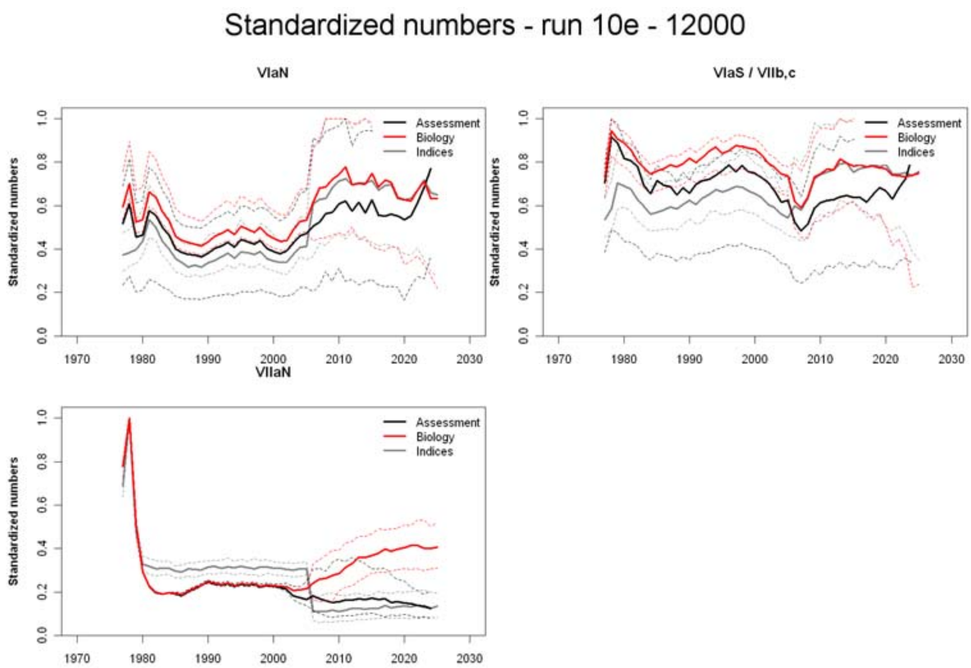



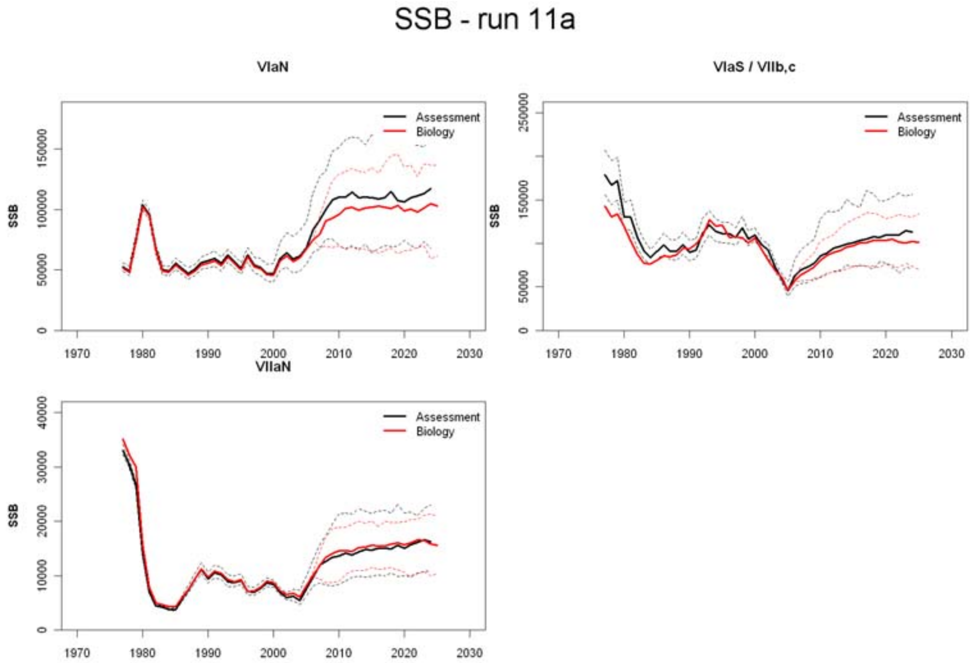
Standardized numbers - run 10e - 6000
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices

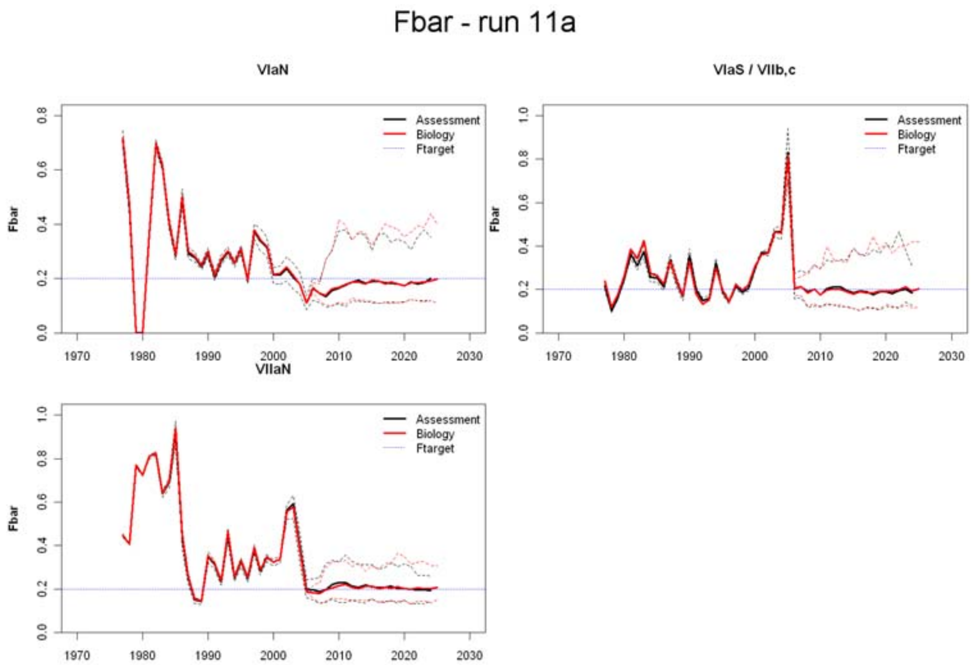

SSB - run 10e - 12000
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

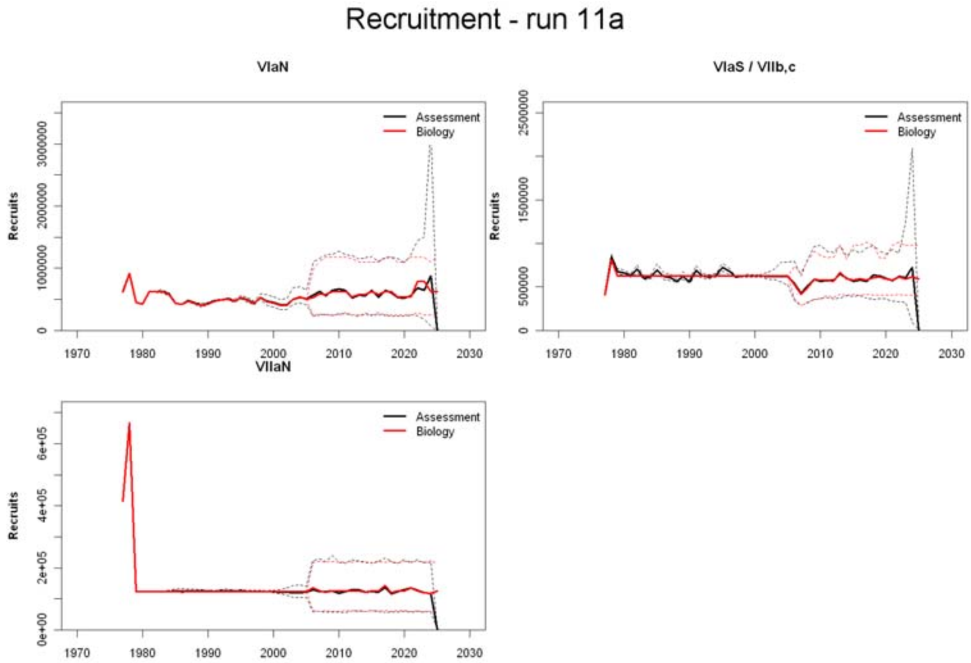

Fbar - run 10e - 12000
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

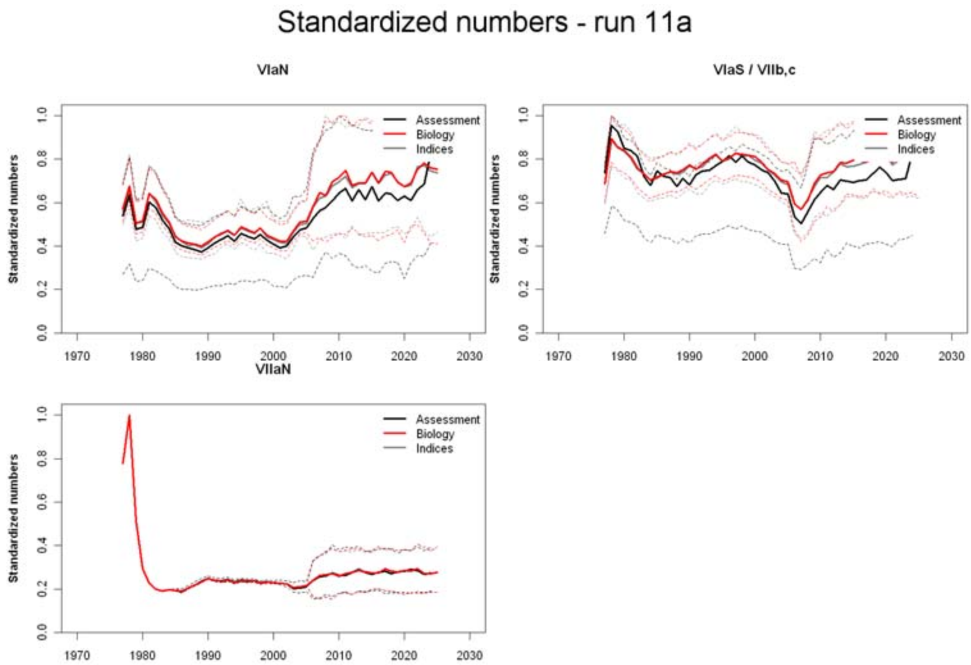

Recruitment - run 10e - 12000
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology

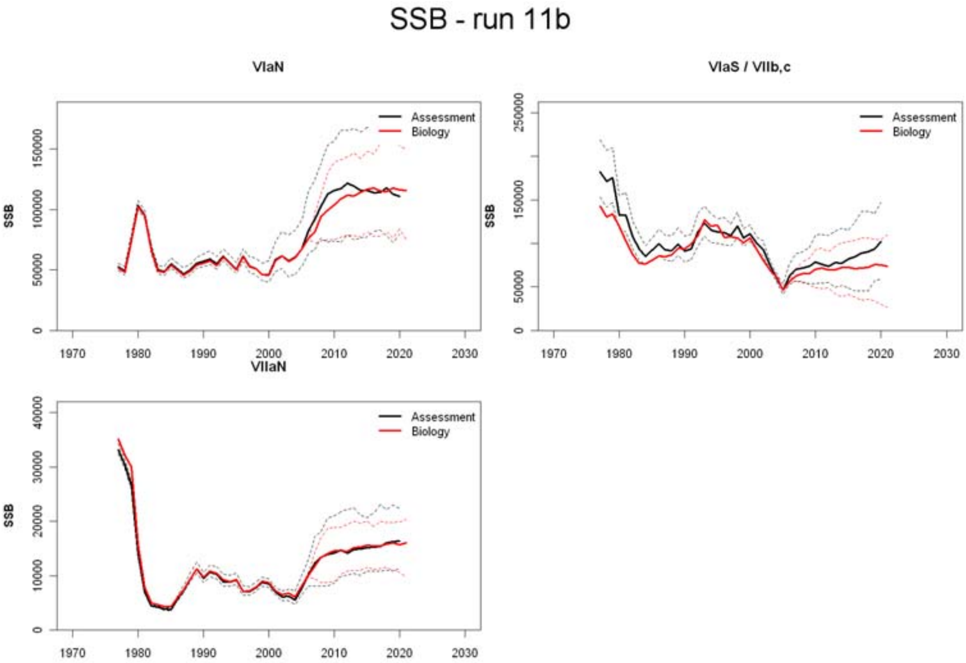

Standardized numbers - run 10e - 12000
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices

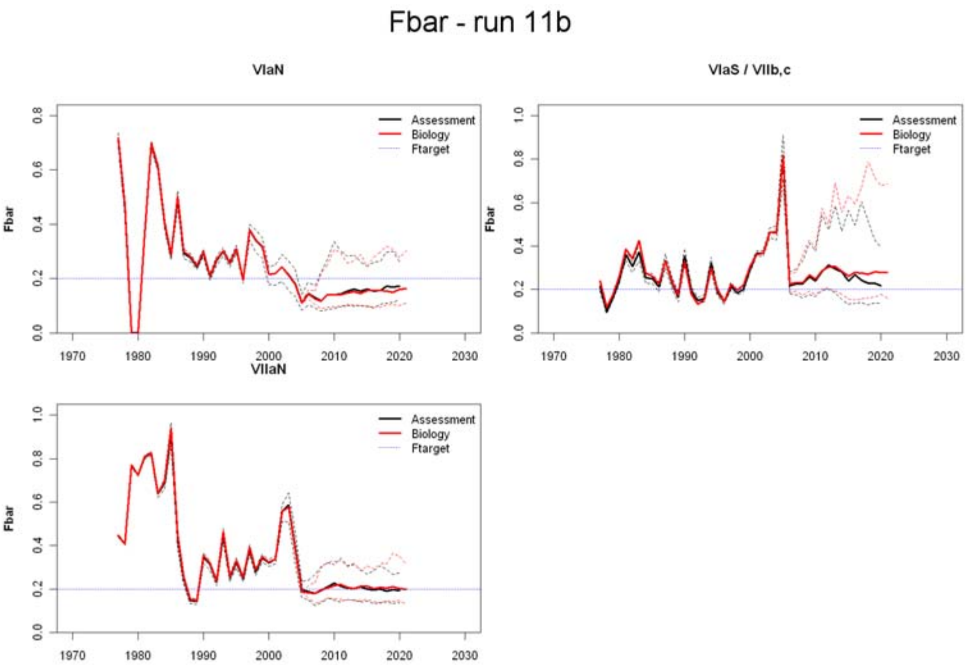

SSB - run 11a
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
SSB


Fbar - run 11a
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Ftarget
Fbar

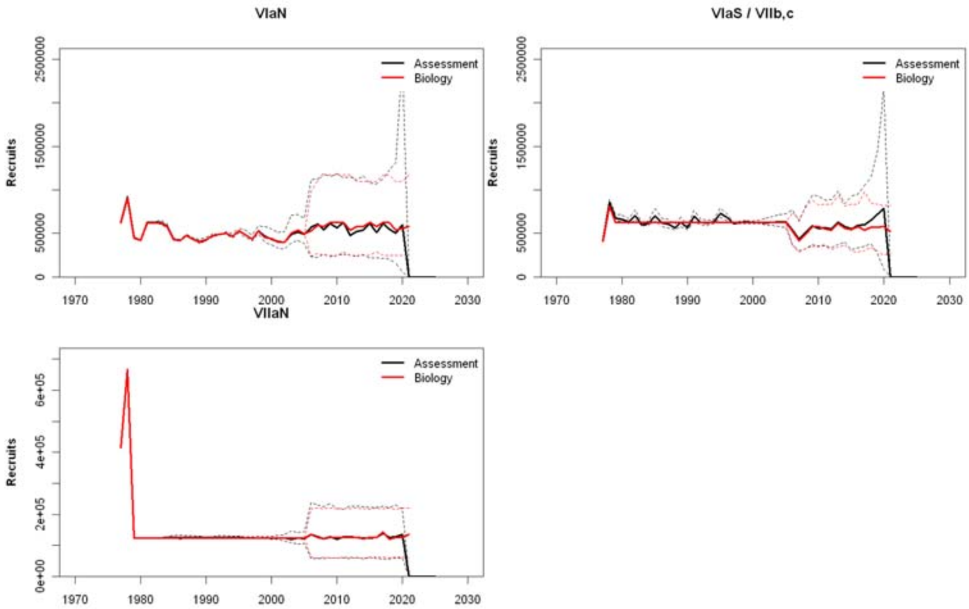

Recruitment - run 11a
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology


Standardized numbers - run 11a
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices

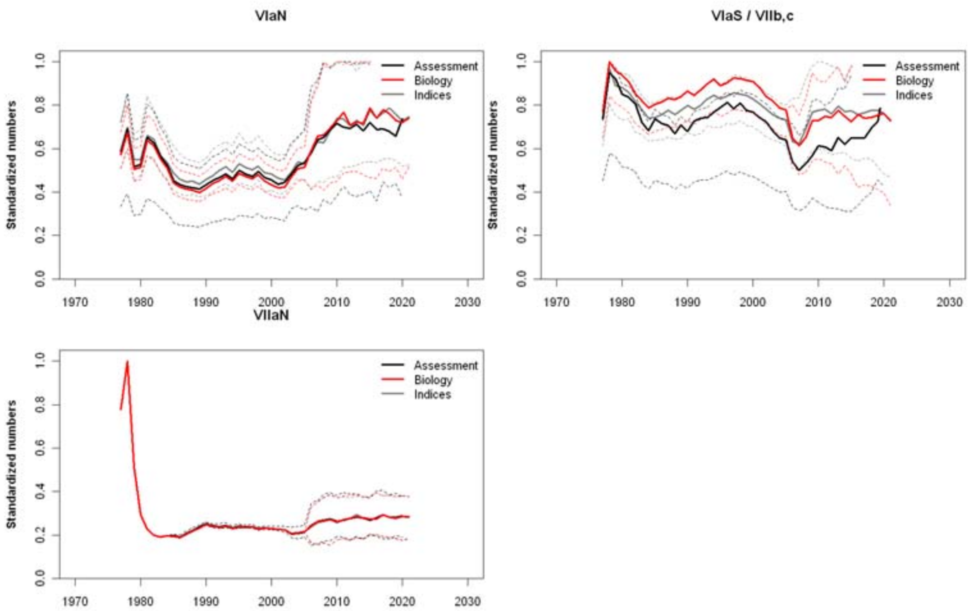

SSB - run 11b
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

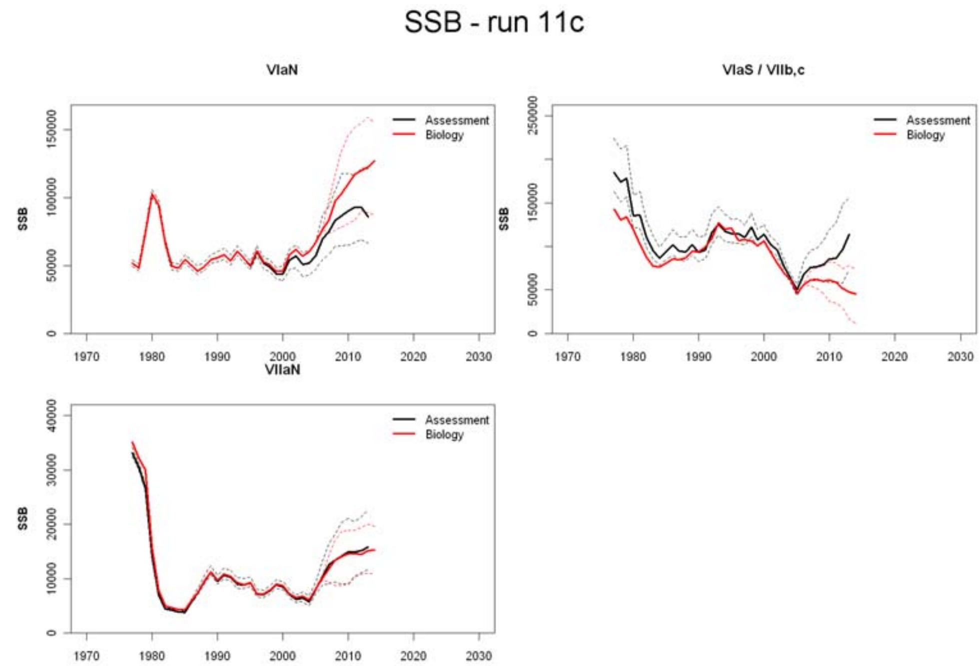

Fbar - run 11b
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

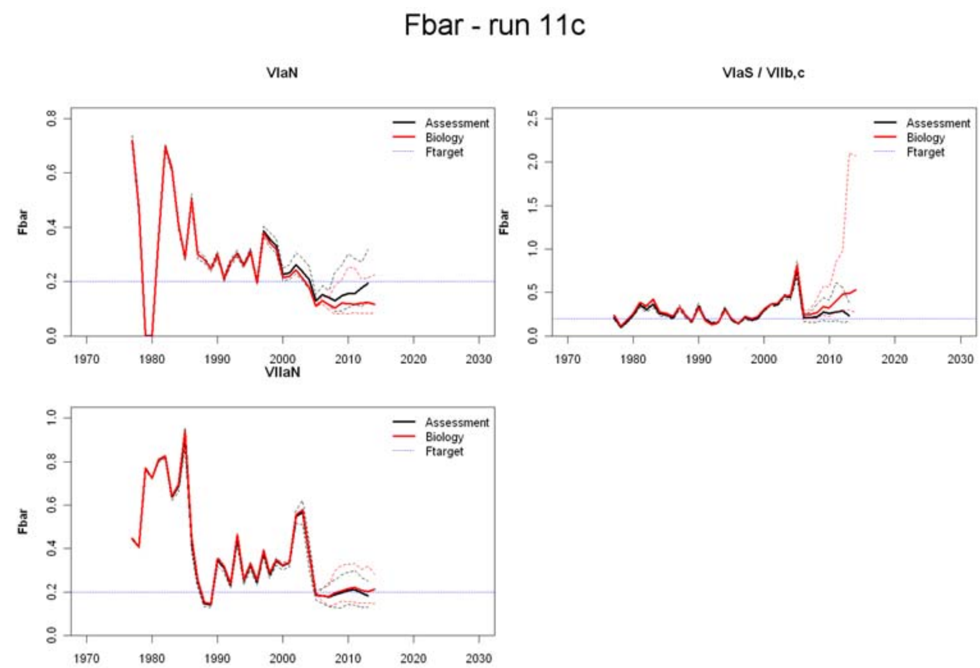
## Recruitment - run 11b

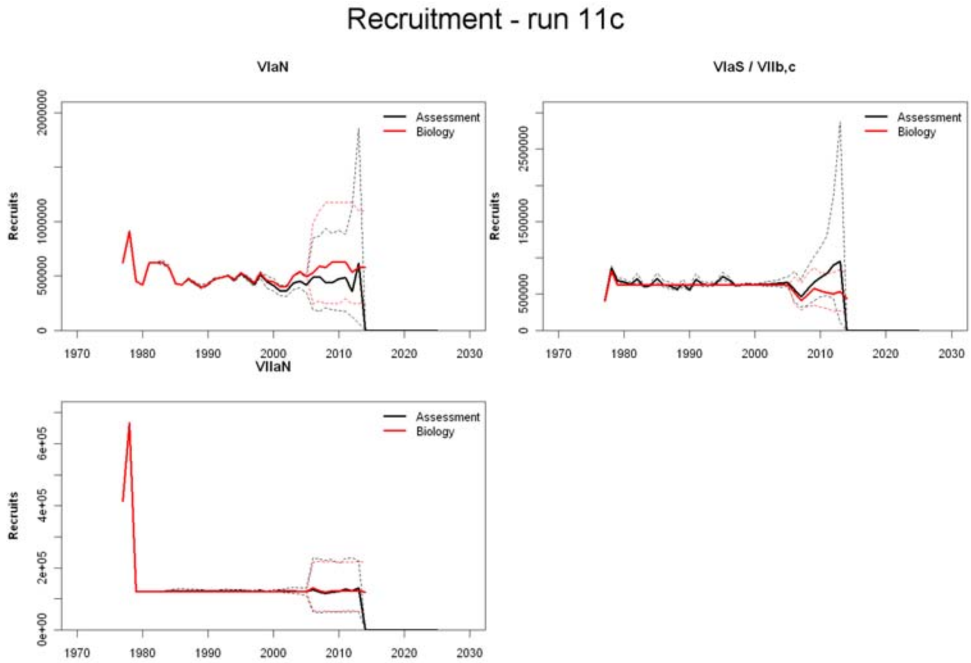


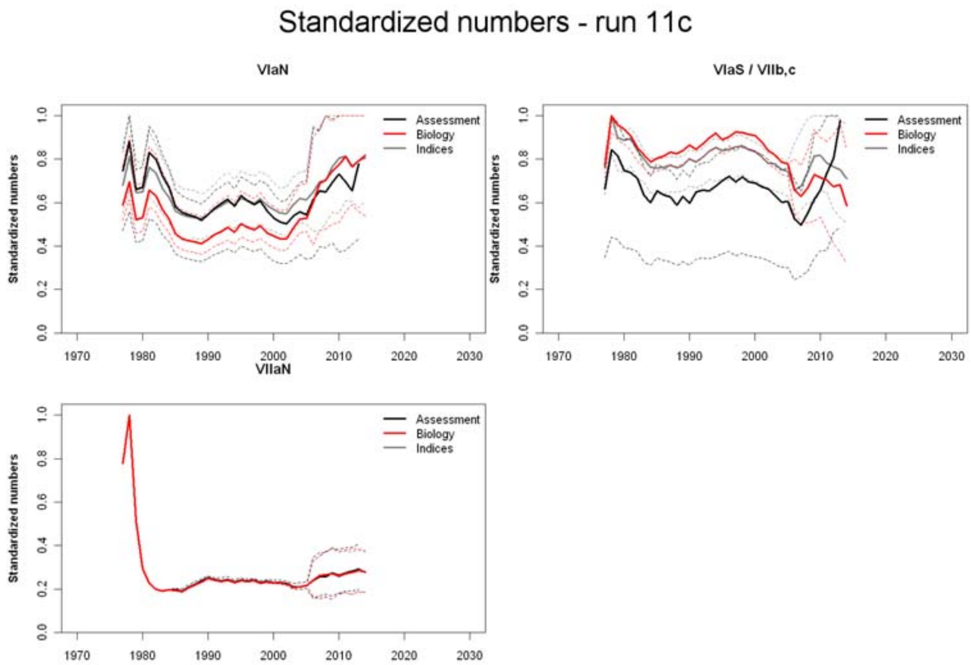

## Standardized numbers - run 11b



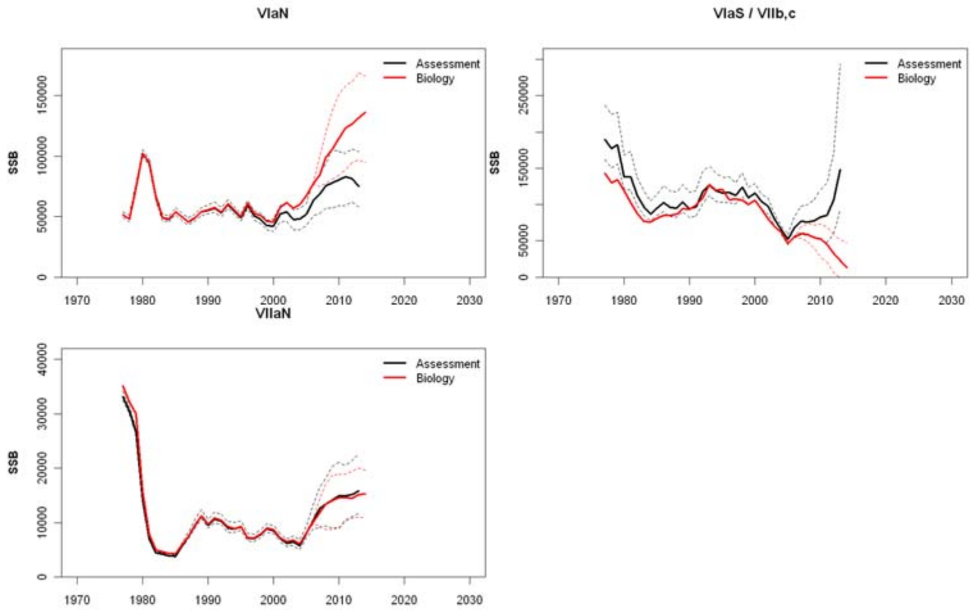

SSB - run 11c
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology


Fbar - run 11c
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

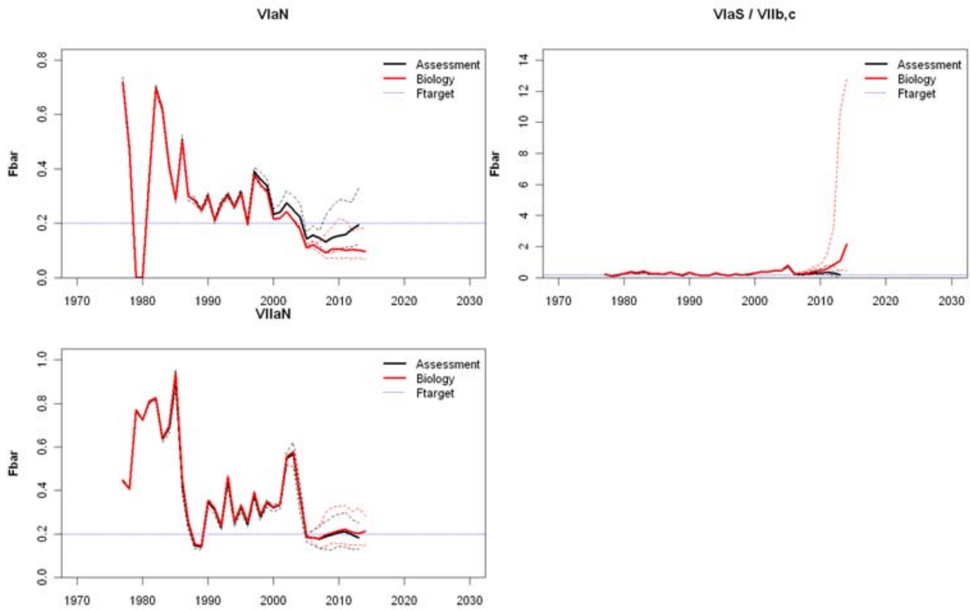

Recruitment - run 11c
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology
1970
1980
1990
2000
2010
2020
2030

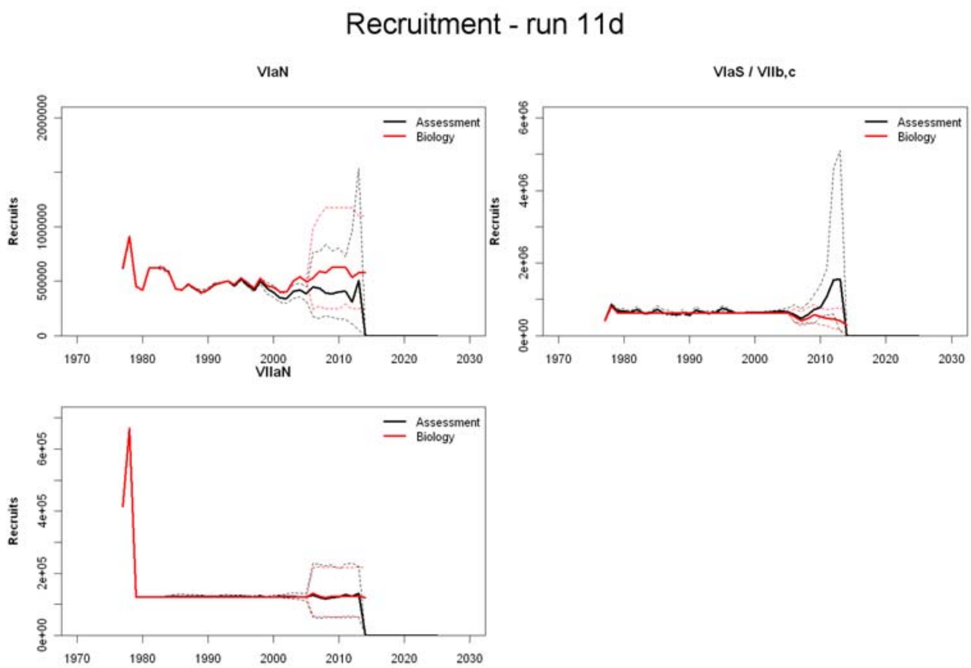

Standardized numbers - run 11c
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices
1970
1980
1990
2000
2010
2020
2030

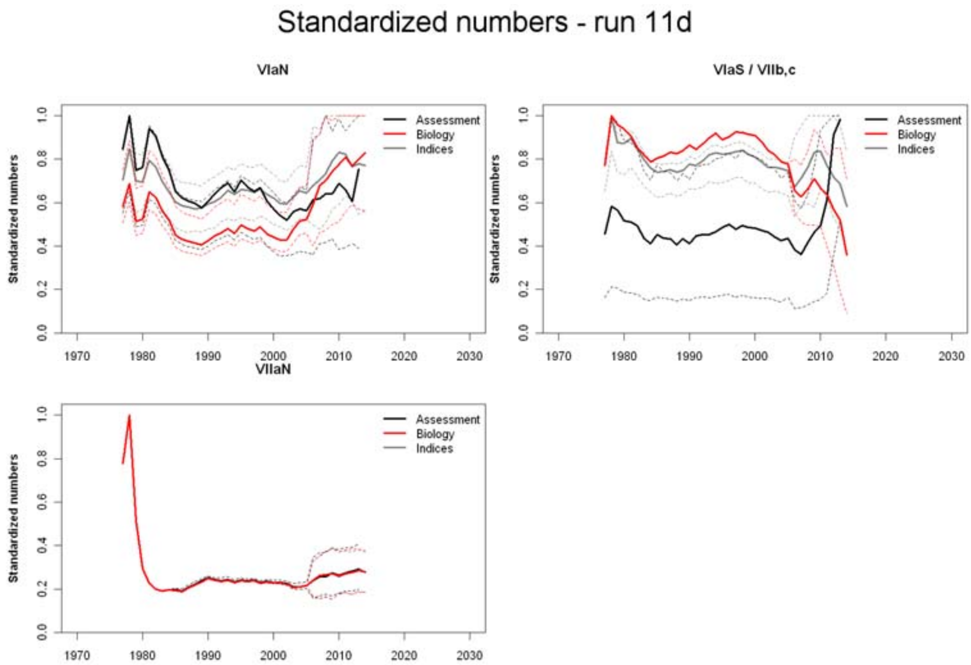
SSB - run 11d

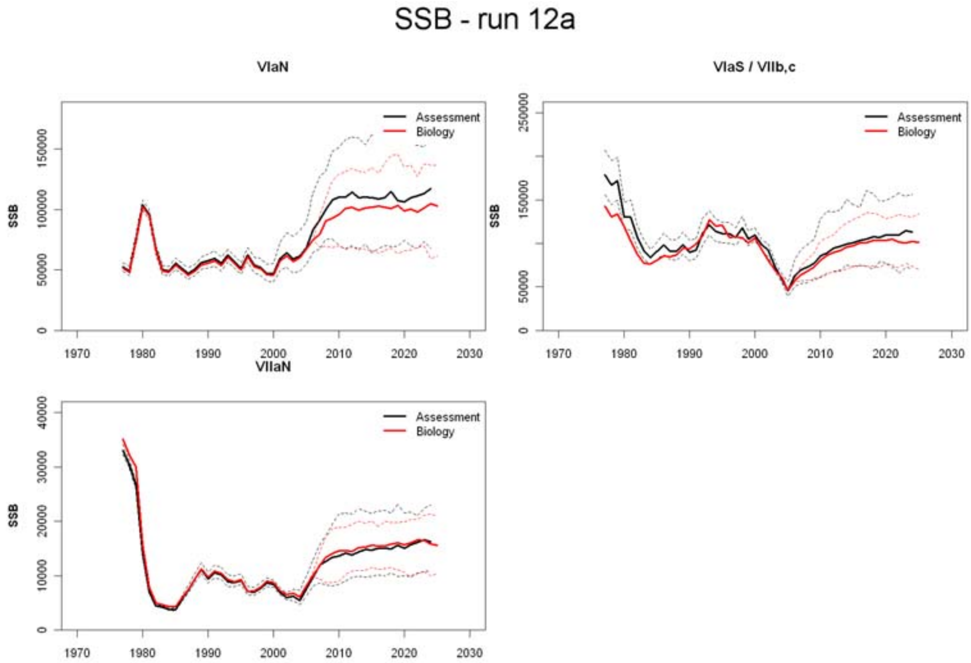


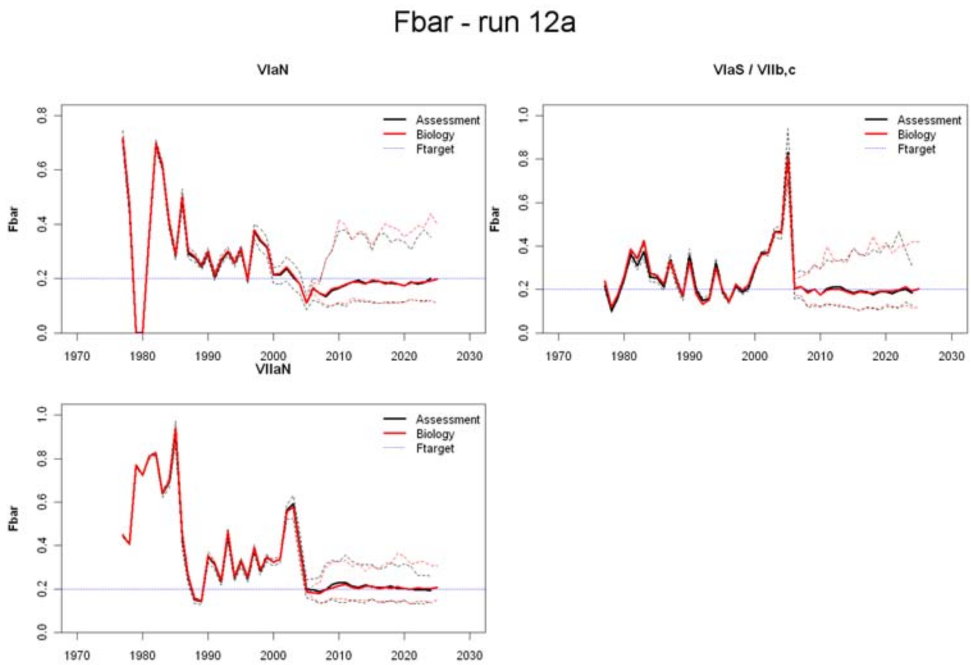

Fbar - run 11d

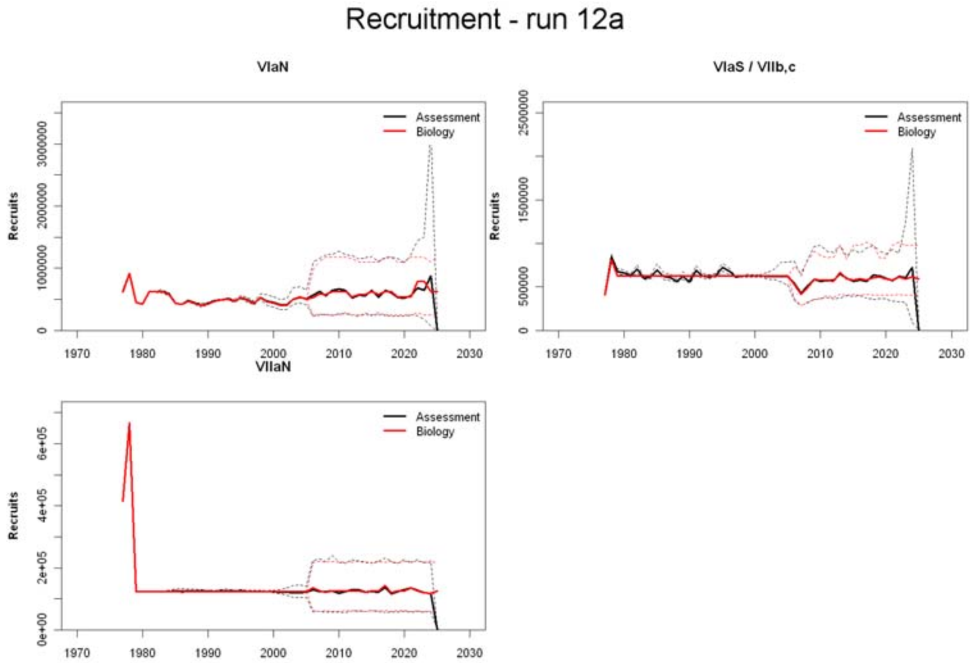


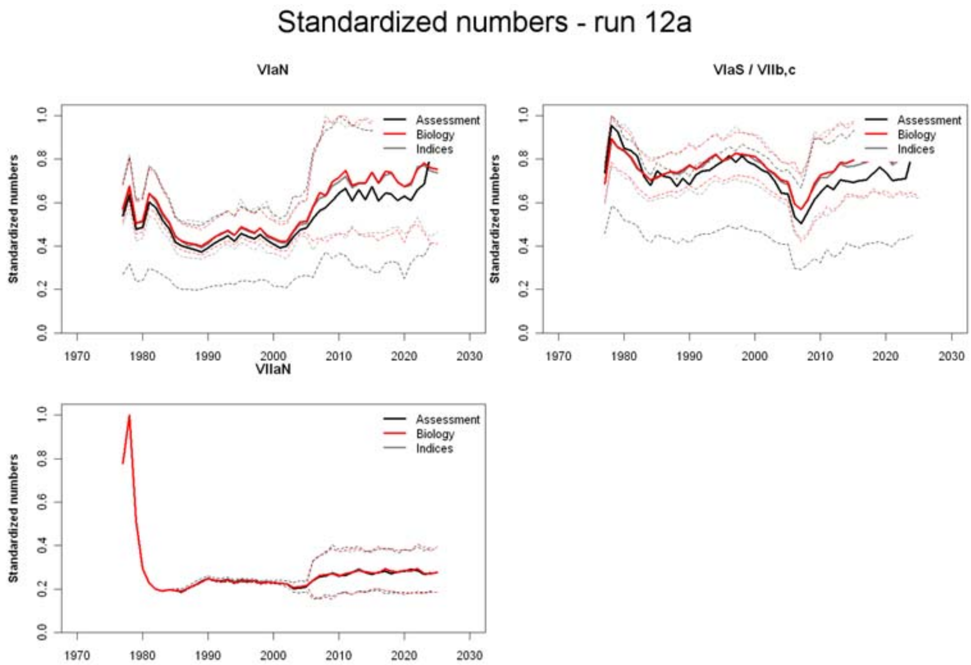

Recruitment - run 11d
VIaN
VIaS / VIIb,c
VIIaN
Recruits
Assessment
Biology

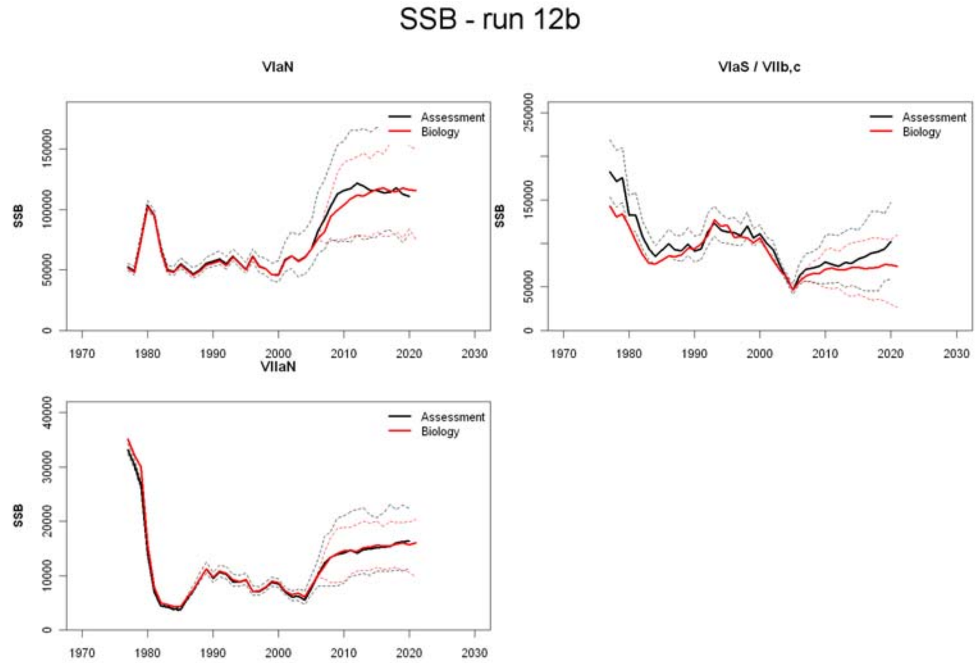

Standardized numbers - run 11d
VIaN
VIaS / VIIb,c
VIIaN
Standardized numbers
Assessment
Biology
Indices

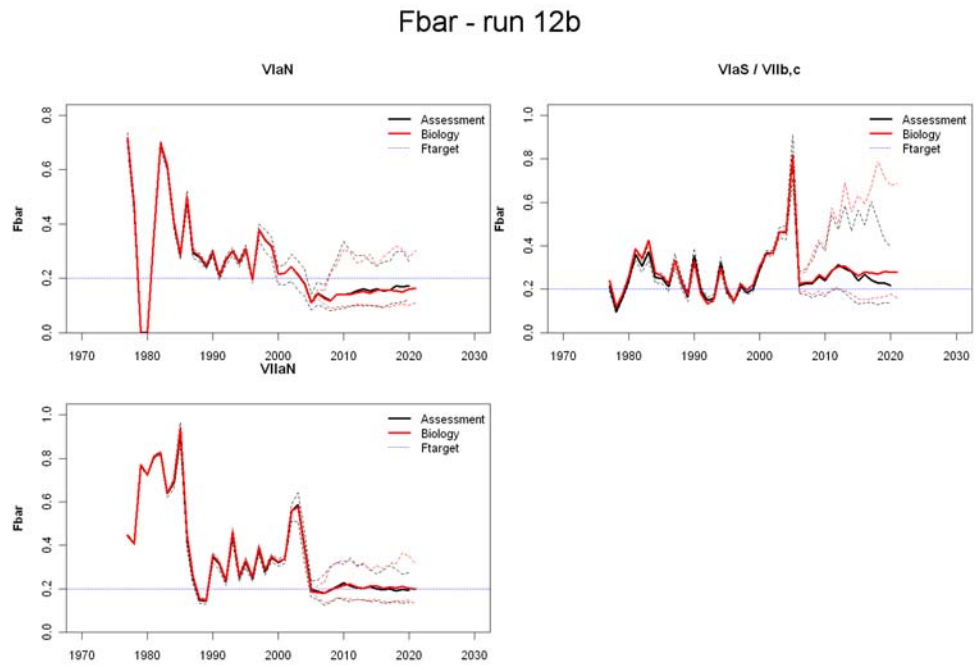

SSB - run 12a
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

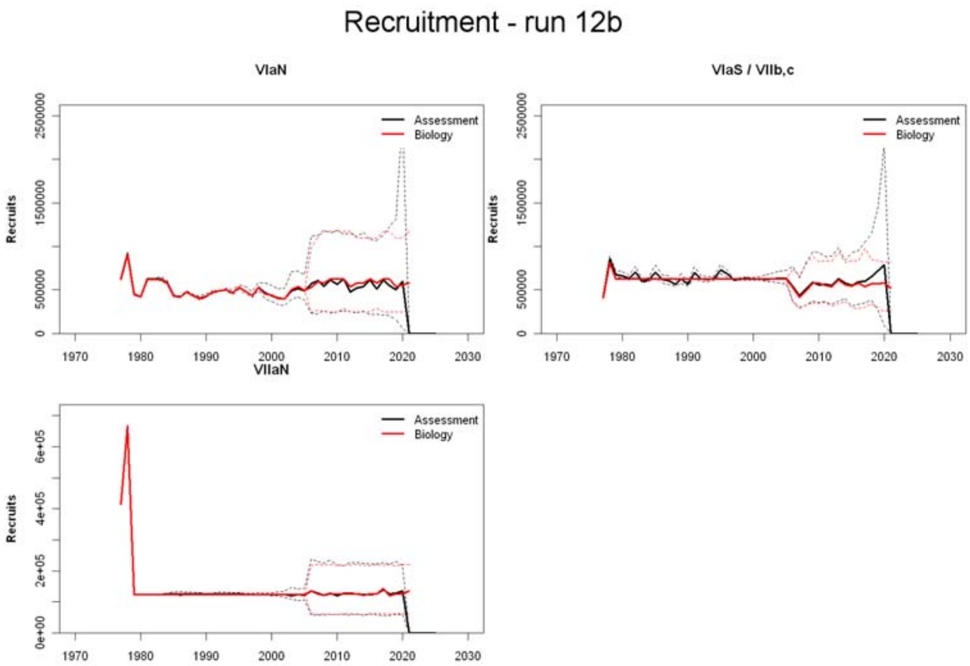

Fbar - run 12a
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

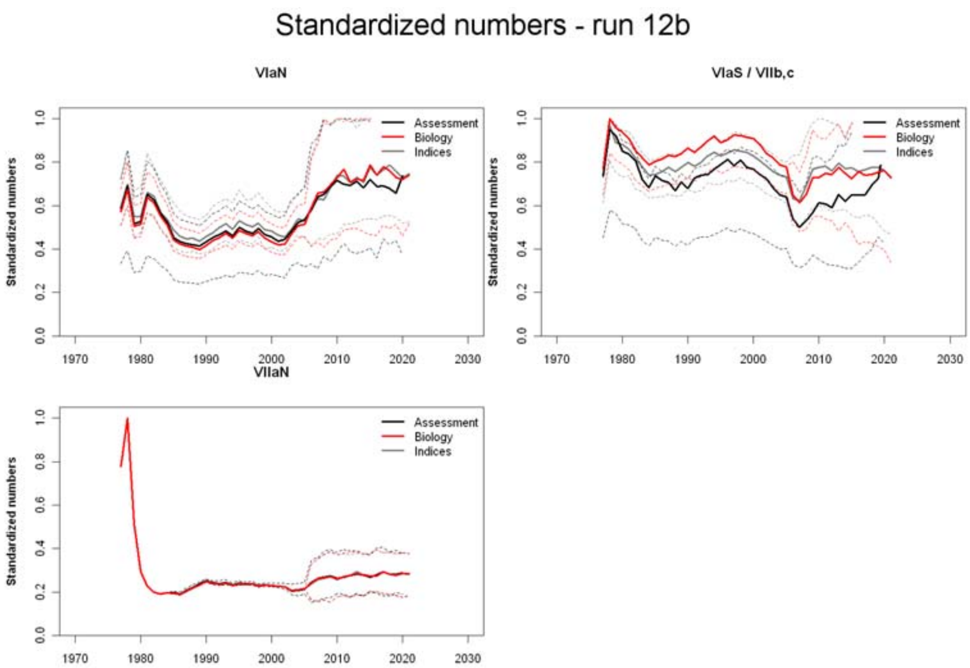

Recruitment - run 12a
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Recruits

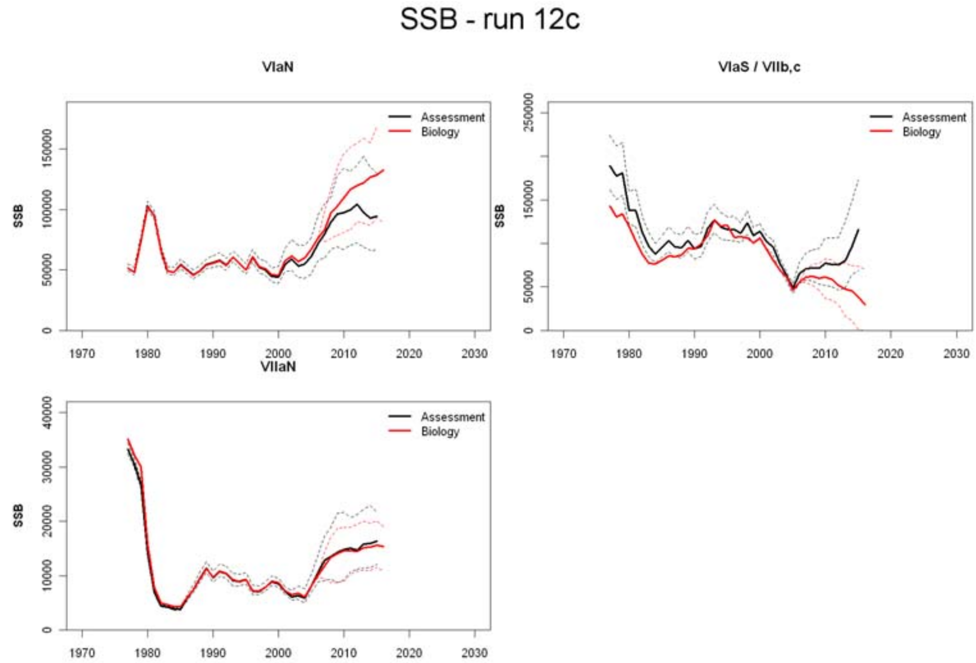

Standardized numbers - run 12a
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Indices
Standardized numbers

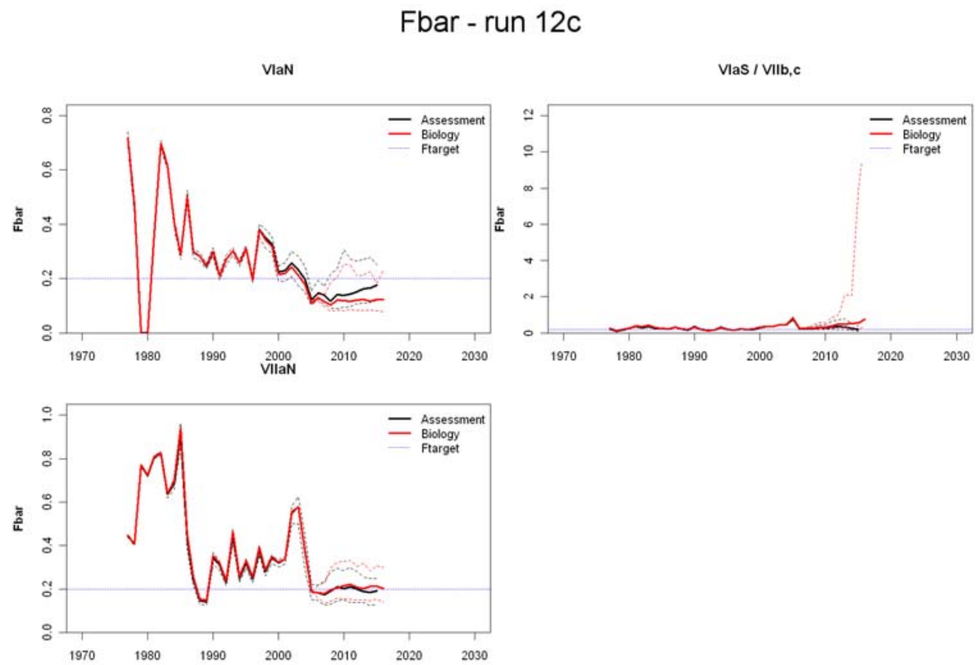

SSB - run 12b
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology


Fbar - run 12b
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

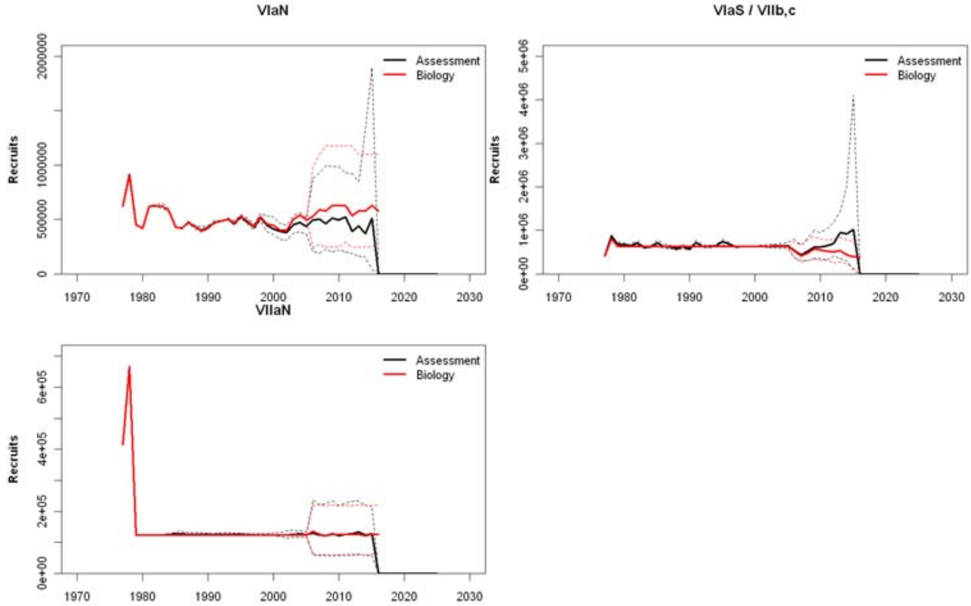

Recruitment - run 12b
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Recruits


Standardized numbers - run 12b
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Indices
Standardized numbers

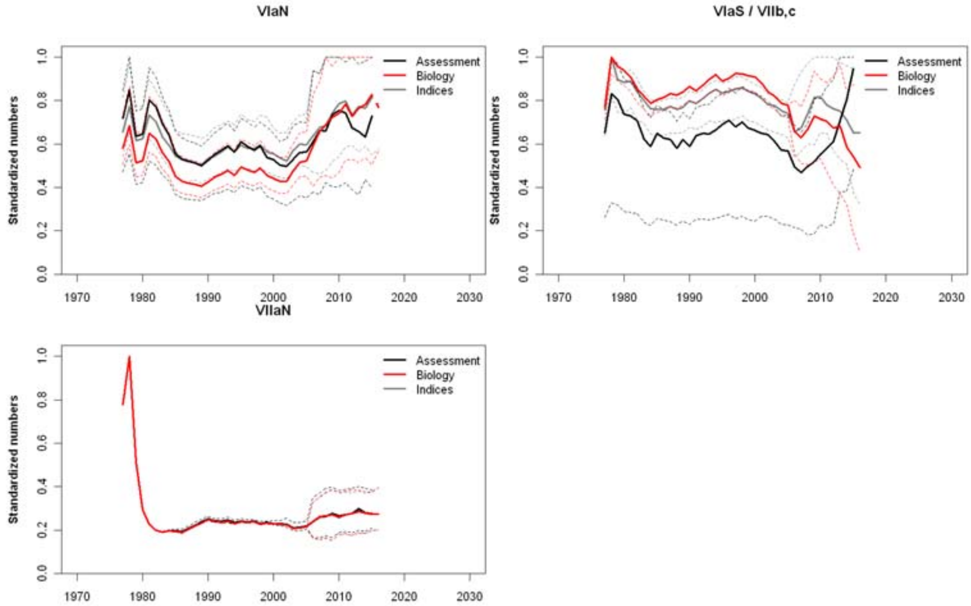

SSB - run 12c
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology

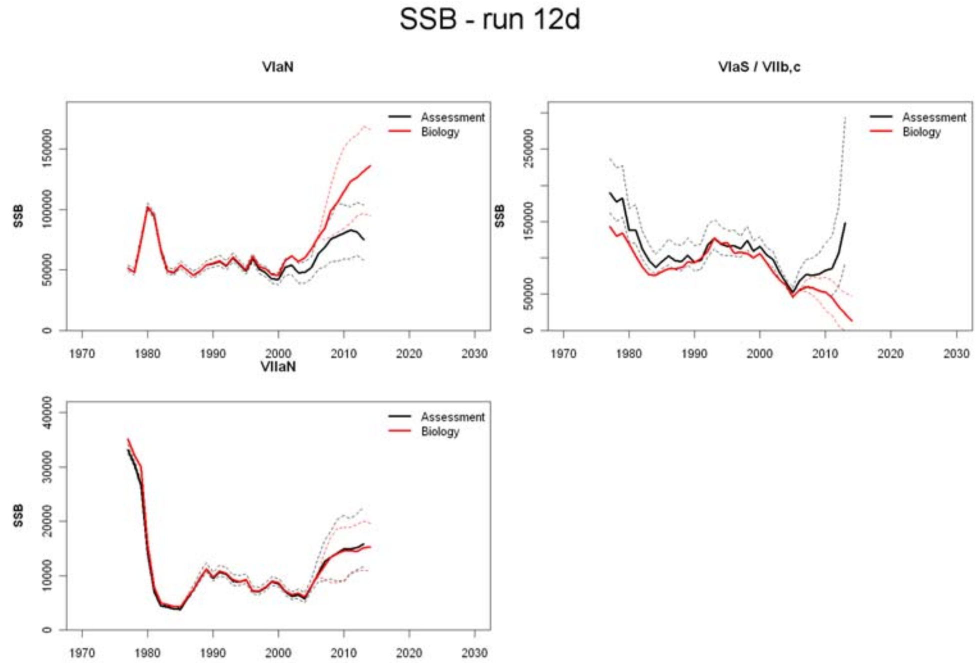

Fbar - run 12c
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget

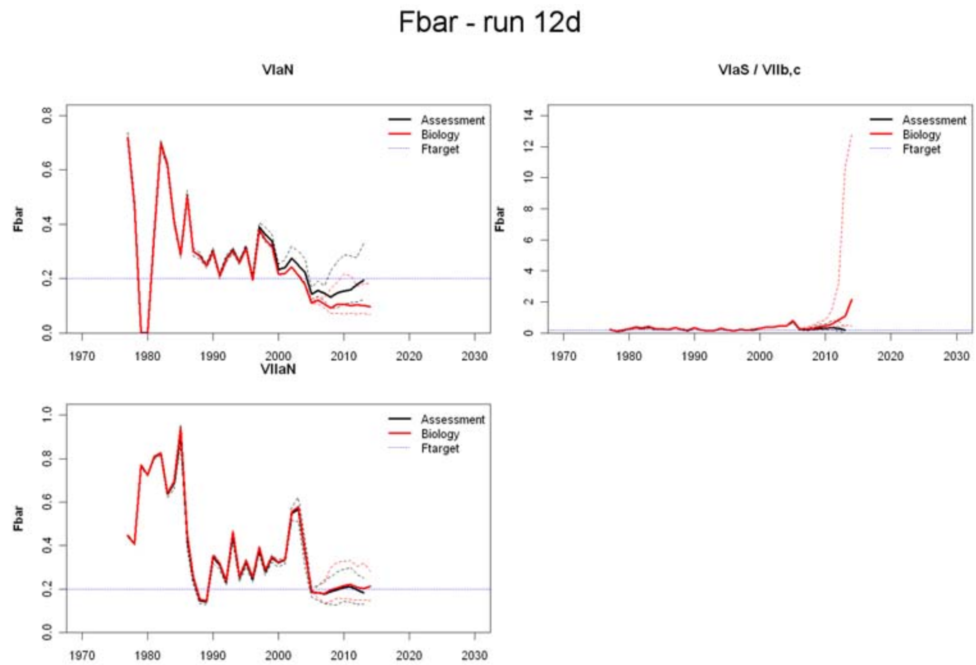
## Recruitment - run 12c

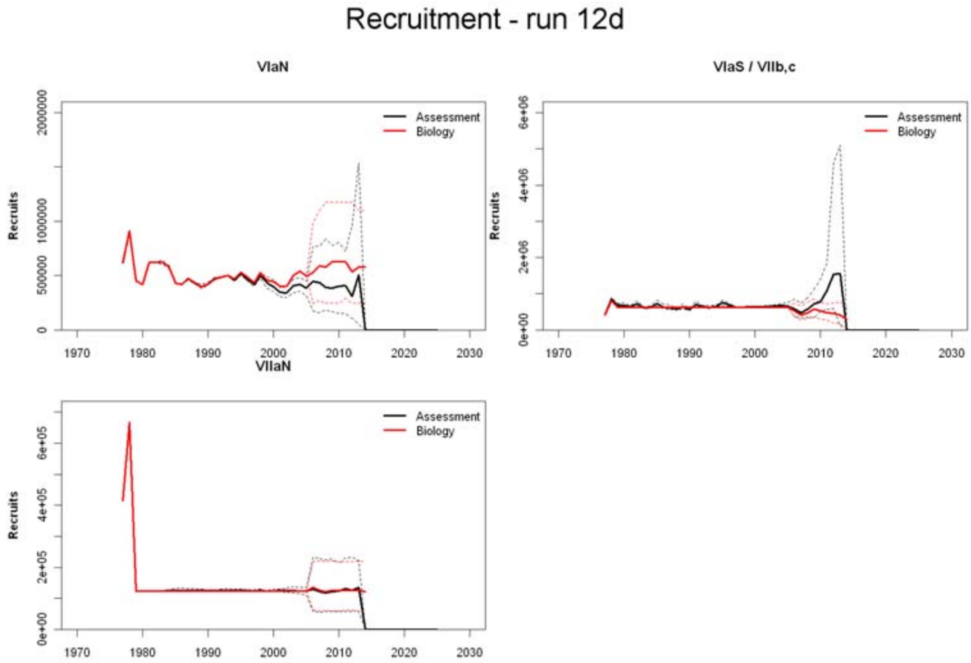


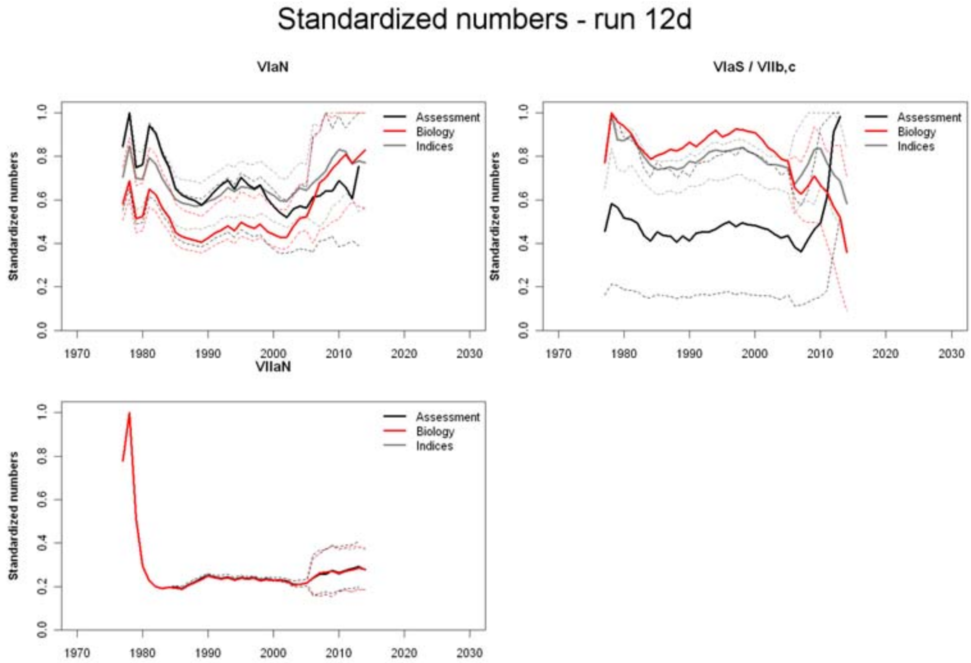

## Standardized numbers - run 12c




SSB - run 12d
VIaN
VIaS / VIIb,c
VIIaN
SSB
Assessment
Biology


Fbar - run 12d
VIaN
VIaS / VIIb,c
VIIaN
Fbar
Assessment
Biology
Ftarget


Recruitment - run 12d
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Recruits


Standardized numbers - run 12d
VIaN
VIaS / VIIb,c
VIIaN
Assessment
Biology
Indices
Standardized numbers