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Stock Annex: Blue whiting (*Micromesistius poutassou*) in subareas 1–9, 12, and 14 (Northeast Atlantic and adjacent waters)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Blue Whiting
Working Group:	Working Group for Widely distributed stocks
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Revised by

- Inter-Benchmark Protocol on Blue Whiting, 14 June 2016
- WGWIDE 2019. Mainly Section A.2-A.3, B.1 and B.2
- WGWIDE 2020. Mainly Section A.1, A.2, B.2, G., H.1 and some of the tables and figures updated.
- WGWIDE 2021. Mainly Section B.2.

A. General

A.1. Stock definition

Blue whiting (*Micromesistius poutassou*) is a pelagic gadoid that is widely distributed in the eastern part of the North Atlantic. The highest concentrations are found during spawning along the edge of the continental shelf in areas west of the British Isles and on the Rockall Bank plateau where it occurs in large schools at depths ranging between 300 and 600 meters, but is also present in almost all other management areas between the Barents Sea and the Strait of Gibraltar and west to the Irminger Sea. Adults reach maturation at 2–7 years old and undertake long annual migrations from the feeding grounds to the spawning grounds (Bailey, 1982). Most of the spawning takes place between March and April, along the shelf edge and the banks west of the British Isles. Juveniles are abundant in many areas, with an important nursery area believed to be the Norwegian Sea, at least in times of high abundance. Morphological, physiological, and genetic research has suggested that there may be several components of the stock which mix in the spawning area west of the British Isles. Due to the large population size, its considerable migratory capabilities and wide spatial distribution, the stock composition and dynamics require continued monitoring. The migration routes of blue whiting in the North Atlantic are shown in Figure A1.

Blue whiting stock identity

Prior to 1993, for the purposes of assessment, it was assumed that blue whiting had two components, a northern and a southern component. The northern stock was known to feed in the Norwegian Sea and spawn to the west of the British Isles. The southern stock was found along the continental shelf off the coast of Spain and Portugal with the main spawning areas towards the Porcupine Bank. The Porcupine Bank was considered a transitional area between the two main stocks (ICES, 1990). In 1993 it was argued that there was no strong evidence to maintain this division between the two stocks. Results from an otolith age reading workshop at that time showed no significant difference in mean annual ring diameter between northern and southern stocks. It was agreed by ACFM in 1993 that the two stocks should be combined for assessment purposes (ICES, 1995). Since then this stock has been assessed as one unit.

Several approaches have been employed to investigate the stock structure of blue whiting. The details of studies relating to genetics: larval otolith growth patterns, the movements of eggs and larvae and otoliths shape analysis, have been published in recent years. An overview of these is given below.

Blue whiting has a wide geographic distribution and large population size, which is generally advantageous for the accumulation and preservation of genetic variability (Mork and Giaever, 1995). The first genetic work was carried out in the early 1990s. A study was carried out by Mork and Giaever, 1995 included samples from most of the eastern Atlantic but the amount of samples from the southern part of this area was generally low. Further work revealed significant geographic heterogeneity with reproductive units found at the fringes of the distribution range. A genetically distinct population was found in the Barents Sea and potential populations identified in the Mediterranean and Romsdalsfjord area of Norway. Samples taken from the area west of the British Isles and from the Norwegian Sea were genetically similar, which suggests a single blue whiting stock throughout the area (Giaever and Stein, 1998). Genetically distinct populations were also found in the Barents Sea and Mediterranean by Ryan *et al*., 2005 by using one mini satellite and five microsatellite loci. Temporal variation was also seen between samples collected on the main spawning area. In this case there was insufficient data to identify explicitly the geographic range of these possible stocks. A study conducted by Was *et al*., 2008 used a landscape genetics approach which combines spatial and genetic information to detect barriers to gene flow. This microsatellite analysis found that samples collected and analysed from along the south flowing current from the Porcupine Bank i.e. the Celtic Sea and Bay of Biscay were genetically different from those in the north-flowing current. Temporal variation was seen in samples collected in the Rockall Bank area and the reasons for this are inconclusive.

Oceanographic modelling has been used to examine movements of blue whiting eggs and larvae. Larval drift is an important factor in recruitment. A hypothesis put forward by Skogen *et al*., 1999, was that the southern stock will spawn in an area where the eggs and larvae are likely to drift southwards and the northern stock where the eggs and larvae will drift northwards. Based on modelled drift patterns they found that a possible separation line was located at 54.5ºN but this was subject to significant interannual variability over the twenty years studied. Work conducted by Bartsch and Coombs (1997) used a three-dimensional baroclinic model suggests that particles released on the Porcupine Bank drifted southwards with a separation at about 53–54ºN. This work gave some additional information about stock separation but suggested that the division might be more southerly. Additional testing of the use of this type of model was recommended.

An investigation of larval growth histories was carried out in 2007 (Brophy and King, 2007). Groups that are spatially or temporally distinct after hatching show measurable differences in the larval portion of the otolith. This study has shown that larvae from the Bay of Biscay grow faster than those from more northerly spawning areas. It also confirmed that fish spawning to the west of Ireland and Scotland, do not form a randomly mixing unit and that subunits within this aggregation have experienced differences during the larval phase. It was hypothesised that the dispersal of larvae could influence the subsequent dispersal of spawning adults. The fish that are found in the feeding assemblages throughout the distribution may not contribute equally to the spawning assemblages in the north and south of the spawning grounds.

In 2009 the stock identification methods working group (SIMWG) stated that the perception of blue whiting in the NE Atlantic as a single unit stock is not consistent with recently observed differences in genetics and growth and should be revised; based on current available data. They recommended that a precautionary approach should initially treat blue whiting populations in Areas 8.k and 7.j and further south as a separate unit from all other NE populations. SIMWG is in support of an initial, precautionary delineation of "two main stocks" but also vigorously suggests that a large, interdisciplinary project on this species is needed in order to comprehensively understand blue whiting stock structure in the NE Atlantic so that SIMWG may provide more robust advice (ICES, 2009a).

Results from length-at-age and otholith shape analysis presented in at WKPELA in 2012 (ICES, 2012) did not provide evidence of two separate stocks but rather substantial mixing of individuals on the common spawning grounds. At this meeting following a full review of available studies on blue whiting stock structure in the Northeast Atlantic. The working group came to the conclusion that there is no scientific evidence in support of multiple stocks with distinct spawning locations or timings. The emerging picture is one of a single stock whose large-scale spatial distribution varies as a function of hydrographic conditions and total abundance; this is commonly described as an abundance-occupancy relationship. Further, there seem to be a number of core nursery and feeding areas with marginal areas being occupied at times of high stock abundance. As a result, the working group decided to recommend treating blue whiting in ICES Subareas 27.1–9, 12 and 14 as a single stock for assessment purposes.

A study based on Continuous Plankton Recorder (CPR) data from 1948–2005 using modern statistical techniques indicated a clear spatial separation between a northern spawning area, in the Rockall Trough, and a southern one, off the Porcupine Seabight. In addition, the results showed that spawning started earlier in the southern area (by at least one month), with peak spawning occurring later moving north (Pointin and Payne, 2014).

Otolith-shape analysis has recently been shown to be able to reliably identify the stock origin of sampled fish (Mahé *et al.*, 2016; Keating *et al.*, 2014). Those studies revealed distinct morphotypes, from fish occupying distinct geographical distribution areas. These findings support the hypothesis of northern and southern components in the blue whiting population which may overlap to varying degrees in the centre of the spawning distribution.

In 2014 the ICES Stock Identification Methods Working Group (SIMWG) reviewed again the evidence of separate stocks in 2014 based on the new scientific evidences (ICES, 2014) and concluded that the perception of blue whiting in the NE Atlantic as a single-stock unit is not supported by the best available science. SIMWG further recommended that blue whiting be considered as two units. However, there is currently no information available that can be used as the basis for generating advice on the status of the individual stocks. There is still a need for more information regarding population structure in these stocks.

A.2. Fishery

Since 1988, fleets from 19 nations have been involved in the blue whiting fisheries. The highest landings have been reported by Norway, followed by Iceland, the Faroes and the USSR/Russia. The highest concentrations of catches are generally found along the edge of the continental shelf in the area west of the British Isles, on the Rockall and Hatton Banks and around the Faroe Islands and the last decade or so, 80-90% of these catches have been taken in quarters one and two. In the following quarters catches are generally taken further north in the Norwegian Sea and also in the North Sea with lesser quantities of blue whiting caught in the southern area off Spain and Portugal.

Most of the catches are taken in the directed pelagic trawl fishery in the spawning and post-spawning areas (Divisions 27.5.b, 27.6.a, 27.6.b ,27.7.b, 27.7.c and 27.7.k). Catches are also taken in the directed and mixed fishery in Subarea 27.4 and Division 27.3.a, and in the pelagic trawl fishery in the Subareas 27.2.a and in Divisions 27.5.a and 27.14.b. These fisheries in the northern areas have taken between 100000–2300000 tonnes per year in the last 15 years, while catches in the southern areas (Subarea 27.8, 27.9.a, Divisions 27.7.d, 27.7.e and 27.7.g–k) have been in the range of 3000–305 000 tonnes. The proportion of landings originating in the Norwegian Sea fluctuates greatly, having increased from 5% of the total in the mid-1990s to around 30% in 2003–2004, after which the proportion decreased again to below 10%. These fluctuations are thought to be linked to fluctuations in recruitment.

A.3. Ecosystem aspects

The blue whiting spawning stock increased in abundance by a factor four during the period 1990-2003. The spawning stock reached a minimum in 2010 and again reached a peak in 2017, after which it again has decreased. The strong year classes in 2013-15 were followed by weak year classes in 2016-18. During the period 2005-2008, the recruitment strength was low in the spawning areas west of Ireland and the British Isles and high in the Bay of Biscay and Celtic Sea, indicating a negative correlation pattern between the northern and southern regions. The early life stages have a significant influence on the reproductive success of this stock. The main blue whiting spawning areas are located along the shelf edge and banks west of the British Isles and Ireland. The eggs and larvae spawned on the Porcupine Bank area (west of Ireland) can drift both towards the south and towards the north, depending on the spawning location, oceanographic conditions and the effects from wind force, while the spawning products from the northern spawning area west of the Hebrides always drift northwards. The northward drift spreads the major part of the juvenile blue whiting to the Norwegian Sea and adjacent areas from Iceland, Faroes and North Sea to the Barents Sea. The larvae usually settle on the deeper areas of the various shelf edges in autumn and stay more or less associated with bottom the first winter or more, gradually becoming part of the mature stock after two or three years. Adult blue whiting carries out active feeding and spawning migrations in the same area as herring. Blue whiting consequently has an important role in the pelagic ecosystems of the area, both by consuming zooplankton and small fish, and by providing a food resource for larger fish and marine mammals (ICES, 2009b). Overlapping distribution of feeding mackerel within the blue whiting spawning grounds has been observed (PGNAPES, ICES RMC/06, 2009) and an ecologic interaction, where mackerel preys on blue whiting egg and larvae is plausible. This possible interaction may have increased, both with the growth in the mackerel stock and with the changes observed in mackerel distribution, in recent years. A study by Utne *et al*. (2012) however suggest that the vertical overlap between blue whiting and herring/mackerel in the Norwegian Sea during the summer feeding period is limited as blue whiting prefer to stay in deeper waters than the other two species. This indicates that the food competition might be limited between blue whiting and mackerel/herring during summer in certain areas. Nevertheless, it is strongly suggested that the relationship between mackerel predation and blue whiting recruitment is carried out.

Environmental conditions in the main spawning areas have undergone significant changes during the last three decades. Changes in temperature, salinity and circulation have been recorded in long-term trend data. Blue whiting is sensitive to temperature and salinity and will only spawn in waters with suitable ranges. Hatun *et al.* (2009a) suggests a temperature range of 9°–10°C and salinity ranges of between 35.35 and 35.45 psu, which is further confirmed by Miesner & Payne (2018), who reported 35.3-35.5 psu as optimal spawning salinities and also outlined the spatial range and the temporal window of spawning along the European Shelf – with larger spawning areas peaking in March in periods with optimal salinities and more confined spawning areas but temporally more dispersed in periods with not optimal salinities.

The ICES (2020) report on ocean climate documents increases in temperature and salinity in the blue whiting distribution area since early 1990-ties. However, since 2016 a freshening of the eastern Subpolar Atlantic has been observed. Notably, the freshening was accompanied by above-average temperatures.

The circulation of the North Atlantic is characterized by two large gyres: the subpolar and subtropical gyre. Some of the water in the subtropical gyre is recirculated to the west of the Mid-Atlantic Ridge (MAR) and some water continues east and crosses the MAR in the Azores Current and the remainder forms the North Atlantic Current (NAC) (ICES, 2008). The Subpolar Gyre controls the flow trajectory of the NAC in the Northeastern Atlantic. When the gyre is strong, it extends eastwards, branches off and carries cold and less saline water to the Rockall Trough and over the Rockall plateau (Figure A2a). When the gyre is weak, it moves west and allows subtropical water to spread north and west and this results in warmer more saline conditions (Figure A2b) (Hatun, *et al*., 2009a).

Work carried out by Hatun, *et al*., 2007 used a gyre index value which is obtained from the simulated sea surface height over the entire North Atlantic Ocean and it reflects the shape and strength of the Subpolar Gyre. Since blue whiting are known to spawn in water masses with a relatively narrow temperature and salinity range the strength of the gyre index influences their spawning distribution. A strong gyre index is associated with cold and fresh conditions in the Northeast Atlantic and this seems to coincide with spawning to the east, along the continental slope and the Porcupine Bank area. The post-spawning migration these years is through the Faroe Shetland channel and is possibly associated with a smaller total fish stock. When the gyre index is weak, spawning takes place in a wider area on the western slope of the Faroe plateau and over the Rockall plateau. The post-spawning migration is also more westerly, through the Faroe Bank channel and is possibly also associated with larger stock size. The estimated threefold increase in blue whiting biomass coincided with major changes in the marine climate and this shift between east and west during the mid-1990s indicates a possible connection.

Hatun *et al*., 2009a explored the hypothesis that the spawning distribution is predominantly controlled by the marine climate conditions west of Ireland, along the continental slope and west of Rockall when the Subpolar Gyre is weak and towards the Porcupine bank when the Subpolar Gyre is strong. This study used hydrographic, acoustic biomass and larval data as well as catch statistics and data from the regional gyre index. This study showed that the spawning distribution of blue whiting is determined by oceanographic conditions to the west of Great Britain and Ireland which in turn are regulated by the North Atlantic Subpolar Gyre.

Further work was carried out to examine large-scale bio-geographical shifts in the Northeast Atlantic from the Subpolar Gyre which used an ocean circulation model and data from four trophic levels including phytoplankton, zooplankton, blue whiting and pilot whales (Hatun *et al*., 2009b). This study found that changes in the distribution of blue whiting are caused by variable stock size and by shifts in the migration pattern. The Subpolar Gyre influences this process either by:

1) Directly regulating the currents and or hydrographic conditions that will influence the migration routes; or

2) Indirectly via trophodynamics.

This work suggests that recent advances in simulating the dynamics of the Subpolar Gyre may provide a potential for predicting the distribution of the main faunal zones in the Northeastern Atlantic a few years into the future. This in turn would facilitate more rational management of commercially important fish species.

Recruitment

A workshop was held in 2009 that examined blue whiting recruitment. The group reviewed and updated existing work on both the oceanography in the region and the distribution dynamics of blue whiting, particularly focusing on the most recent observations. A broad selection of hypotheses was examined that may explain the recruitment dynamics of this stock. The group focused on two potential mechanisms that may account for the hypothesized links between the oceanographic climate and the recruitment dynamics.

1) The predation hypothesis

This hypothesis examines the role of mackerel predation and changes in the spawning distribution of blue whiting. Changes in the spawning distribution lead to changes in the mackerel–blue whiting larvae overlap, and therefore the degree of predation.

2) The food hypothesis

This hypothesis is based on the amount and availability of food to the larvae and juveniles. Changes in the oceanographic conditions may change the food availability and ultimately impact larval/juvenile growth, survival and recruitment. More research is required to examine these topics (ICES, 2009c, RMC:09).

Finally, the workshop examined potential schemes that could be used for generating recruitment forecasts. A high degree of autocorrelation is present in the time-series, and indeed the assumption that recruitment in the following year is the same as the recruitment in the previous year was found to give relatively good predictions ($r2=0.57$). However, in the absence of a detailed process understanding, it was not possible to move beyond such basic schemes towards making genuine, knowledge-based, forecasts though qualitatively forecasts (high or low) might be feasible. Further research is required.

B. Data

B.1. Commercial catch

The procedure of the working group is to split length–frequency data into three areas, although it is recognised that the northern area comprises both spawning size fish and juveniles. The three areas are as follows:

1) The southern area around Spain and Portugal;
2) The northern area which includes the spawning grounds and the Norwegian Sea;
3) The North Sea and the Skagerrak.

SALLOCL

Commercial catch data are obtained from national laboratories of nations exploiting blue whiting. Data exchange spreadsheets are submitted to the stock coordinator. Prior to 2009 the data in the exchange spreadsheets were allocated samples to catch using the SALLOCL-application (Patterson, 1998). This programme produced the standard outputs on sampling status and biological parameters. It also clearly documented any decisions made by the stock coordinators for filling in missing data and raising the catch information of one nation/quarter/area with information from another dataset.

InterCatch

InterCatch, which is a web-based system for handling fish stock assessment data, was first used in 2009. Blue Whiting data are submitted using the 'Data Submission Workbook' spreadsheet and converted into the InterCatch format by the program "InterCatchFilemaker", developed by Andrew Campbell from Marine Institute, Galway, Ireland. The total International Catch-at-Age was available through the InterCatch web program. The allocations for those countries reporting catches without samples, were generally made using all available data for the same ICES Division and the same quarter. In cases where this was not possible, data from the nearest Divisions and the same quarter were used.

Estimating preliminary annual catches from Q1+Q2 data

Most of the blue whiting catches occur early in the year. It was therefore suggested at the benchmark (ICES, 2016a) that catches during the beginning of the assessment year (either Q1 or Q1+Q2) could be used to predict the annual catches in this year (Table B1). By incorporating these raised catches in the catch at age matrix used for the assessment, the model would have an additional source of information to confront with the most recent survey index, which might result in terminal year estimates being less sensitive to year effects in the survey.

The 2016 Benchmark concluded that the first semester (=first half year=quarter 1 and quarter 2) catch-at-ages for the preliminary year are raised to annual total catch-at-age from a 3 years average of the observed proportion of annual catches, taken in the first semester (Figure B1). This method was changed as the WGWIDE Advice Drafting Group in 2016 proposed to simply raise the preliminary first semester catches to "best available estimate" on the final catch weight (Figure B2). This approach is easier to communicate to the public as the raised catch is the same at the expected. The approach suggested by the ADG has been used since the 2016.

The mean weights at age for the preliminary in year catch data were derived from the average mean weights in the three previous years. Due to a decreasing trend in mean weight for the main age classes in the fishery, these values were an overestimate compared to the final mean weights obtained in the following year (see Figure B3). This gave an underestimate of the number of fish caught and thereby a tendency to overestimate SSB and underestimate F. For 2019, the observed preliminary mean weights were used in the assessment.

B.2. Biological data

Sampling protocol

In recent years all of the main countries participating in this fishery have provided sampling data to the working group. The European Commission Regulation 1639/2001 sets out the minimum and extended programmes for the collection of data in the fisheries sector and includes guidelines for blue whiting. This regulation requires EU Member States to take a minimum of one sample to be taken for every 1000 t landed in their country. Detailed information on the number of samples collected, number of fish aged and measured by year and by country is presented in the ICES working group report. This regulation applies to EU member states and there are currently no guidelines in place for other countries. Current precision levels of the sampling intensity are unknown and the group recommends reviewing the sampling frequency and intensity on a scientific basis and providing guidelines for sampling intensity.

Age reading

An age reading workshop took place in Hirtshals in Denmark in June 2005. Guidelines for ageing blue whiting are outlined in this report and all of the workshop participants agreed to follow these guidelines. The workshop found that overall there was a high level of agreement between age readers. The two main reasons for disagreement between age readers were, first the position of the first ring when the Bowers ring is clear and second true rings not counted by less experienced readers. Younger fish achieved better precision than older fish. This illustrates the problems associated with ageing older fish and is a common problem among many fish species (Worsøe Clausen *et al*., 2005).

An otolith exchange was carried out in 2009/2010 for a workshop in 2011. Age reading problems of 1 and 2 group blue whiting became evident during the 2011 May survey where small blue whiting was aged as 1, 2 or a combination of one and two years, pending on which country read the otoliths. This clearly demonstrates the need to calibrate the age readings by each institute participating in the surveys.

The quality of age readings of blue whiting was evaluated at a workshop (WKARBLUE) on age reading of blue whiting which took place in Bergen, Norway, in 2013 (ICES, 2013). Blue whiting otoliths have proven to be quite difficult to age, and though guidelines have been constructed, the experience of the reader determines the interpretation of the otolith structure. This strongly indicates that biased readings might have been present in many cases for the historical data used in the assessment, even for experienced age readers. It was therefore recommended to have regular exchanges and workshops in order to improve the agreement between readers. WKARBLUE recommended a new workshop in 2017, and the survey group recommended that the age readers look closer into a discrepancy problem for ages 1–3 in the 2014 blue whiting age reading material.

In 2017, took place in June the ICES second workshop on age reading of blue whiting (WKARBLUE2) (ICES, 2017). The workshop was preceded by an otolith exchange, which was undertaken using WebGR. The otoliths were also sent around to all participants. The exchanged collection included 245 otoliths spread by whole the distribution area. The overall agreement of the pre-workshop exercise was 64.1% considering all readers and 70% for the assessment readers. During the workshop 129 otoliths with annotations were discussed in plenary and 85% agreement was achieved. There were no clear signs of seasonal misinterpretations, but the Mediterranean and most northern areas (ICES area 27.14.b and NAFO 1C) proved to be quite difficult to interpret. Different methods to help age readers on classifications were discussed during the workshop. The burning of otoliths showed some potential in interpreting the inner ring, but not to be used as a routine. The sliced technique, besides being time consuming, do not show advantages on ring interpretation, and in turn can also introduce more misinterpretation on ageing. During the workshop some of the otoliths from the exercise were polished, to help readers in the cases were the age rings were not so evident, completely absent, or showing a growth pattern different from the expected. The polishing results revealed to be useful on the ring interpretation and to help during the plenary discussion, although we do not recommend this technique to be used as a routinely procedure, as it is very time consuming. Plug-in for ImageJ (OtoRing), which can detect variation in opacity in the otolith surface and be used as a tool on age rings identification as presented (Gonçalves *et al.* 2017a).

The last workshop on the age estimation of blue whiting (WKARBLUE3) was held in June 2021. In 2020, an age reading inter-calibration exchange using the SMARTDOTS platform was held and preceded the age reading workshop. In the 2020 exchange, the otolith collection included 407 otoliths from the entire stock distribution area, from which 190 otoliths where from the northern areas and 217 where from the southern areas of distribution. The otolith collection dataset enables a good coverage of samples by area and sex and took into account the differences in growth patterns by areas (northern and southern), and by sex due to the sexual dimorphism in blue whiting (Gonçalves *et al.* 2017b). The overall agreement results of the pre-workshop inter-calibration exchange were 66% considering all readers and 70% for the assessment readers (advanced readers). Considering only the otoliths samples from the northern areas and the readers from the northern that usually read the otoliths from those areas for the assessment, 69% of agreement was achieved. Otherwise, considering only the otoliths samples from the southern areas and the readers from the southern that usually read the otoliths from those areas for the assessment, 79% of agreement was achieved. During the workshop, a small exchange was also conducted with 55 otoliths in which 73% agreement between the advanced readers was achieved. When comparing those results with the ones obtained from the previous workshops (WKARBLUE, WKARBLUE2) an increase in precision amongst readers was observed, and this has been achieved from workshop to workshop.

During the workshop a continual effort is put to improve the age reading guidelines to increase the agreement between age readers and to use the same standards when handling the reoccurring problems on age identification, e.g, the otoliths from some areas proved to be more difficult to read, the position of the first annual growth ring, false rings and the interpretation of the edge. Considering the reoccurring problems on blue whiting age classifications, in order to overcome those and also increase the accuracy on ageing, age validations studies were further recommended and must be conducted. Furthermore, age reading exchanges and workshops are recommended to be held every 3 years, to monitor and mitigate the differences on age classifications between countries.

Age composition in the catch

The catch numbers-at-age were mean standardised by year and are presented in Figure B4. Strong year classes can be seen in the past as they moved through the fishery.

In recent years the numbers of fish at younger year classes are not as abundant and there are no signs of incoming strong recruitment.

Weight-at-age in the catch and weight-at-age in the stock

Mean weight-at-age in the catch data are calculated on an annual basis from data supplied by Denmark, the Faroes, Iceland, Ireland, the Netherlands, Norway, Portugal, Russia, Scotland and Spain. Figure B5 shows the mean weight-at-age for the total catch.

Maturity

Maturity-at-age used in the assessment was obtained by combining maturity ogives from the southern and northern areas, weighted by catch in numbers-at-age (ICES, 1995). These values have been used since 1994. Although the values of maturity-at-age may be too low, sufficient information for estimating new ogives is not available.

Natural mortality

It is known that blue whiting is a common prey among many different fish, cetacean and mammal predators. Defining how this impact varies over time is not a trivial issue for such a widely distributed stock that also exhibits notable changes in stock productivity over time. The current M of 0.2 was derived from investigations undertaken in the 1980s that examined the age distribution of the stock before the industrial fishery started. The possible need for revising the current estimate of instantaneous natural mortality rate *M* for blue whiting was discussed in detail by the 2002 WG (ICES, 2002). The value of M estimated from different methods was in the range of 0.38 to 0.60. Although it was acknowledged that the current estimate M=0.2 yr might be too low, there is not a strong basis for revision. At the WKPELA pelagic benchmark meeting, in 2012, various methods to attempt to estimate how M may vary over ages were explored. The relationship between natural mortality and body weight was applied to the blue whiting data to determine a variable M by age. The values ranged from around 1.1 at-age 0 to 0.7 at-age 10, which is considerably higher than the value used so far. Methodological work by WGMG (ICES, 2003a) emphasizes that natural mortality rate cannot be estimated reliably with information normally available for stock assessment models, so it is considered that further examination would be necessary in order to incorporate such values into the assessment. The effect of a change in the assumed natural mortality would have on assessment results also need to be explored. At present it is considered that there is no new information to support a revision of the current estimate of M.

Proportion of F and M before spawning

Both are set at 0, equivalent to spawning on the 1st January. This ignores the fact that the spawning period is later in the year (March–April).

Discards

Discards of blue whiting are thought to be small. Most of the blue whiting caught in directed fisheries are used for reduction to fishmeal and fish oil. However, some discarding occurs in the fisheries for human consumption and as bycatch in fisheries directed towards other species.

Reports on discarding from fisheries which catch blue whiting were available from the Netherlands for the years 2002–2007 and 2012–2014. A study carried out to examine discarding in the Dutch fleet found that blue whiting made a minor contribution to the total pelagic discards when compared with the main species mackerel, horse mackerel and herring (Figure B6). The length frequencies of landed and discarded fish caught were compared and from these data, it is clear that blue whiting are not selected and discarded for length reasons (Figure B7). It is more likely that in sorting and processing of mackerel small fish are commonly discarded (Borges *et al*., 2008).

Information on discards was available for Spanish fleets since 2006. Blue whiting is a bycatch in several bottom-trawl mixed fisheries. The estimates of discards in these mixed fisheries in 2006 ranged between 23% and 99% (in weight) as most of the catch is discarded, and only last day catch may be retained for marketing fresh. The catch rates of blue whiting in these fisheries are however low. In the directed fishery for blue whiting for human consumption with pair trawls, discards were estimated to be 13% (in weight) in 2006.

Since 2004, the blue whiting discards data produced by Portuguese vessels operating with bottom otter trawl within the Portuguese reaches of ICES Division 27.9.a were available. The discards data are from two fisheries: the crustacean fishery and the demersal fish fishery. The blue whiting estimates of discards in the crustacean fishery for the period of 2004–2019 ranged between 23% and 40% (in metric tonnes). For the same period the frequency of occurrence in the demersal fish fishery was around zero for the most of the years, in the years were it was significant (2004, 2006, 2010) was ranged between 43% and 38% (in metric tonnes). In 2014, discards were 39% of the total catches for blue whiting in the Portuguese coast.

The total discards from Portugal and Spain were included in the assessment, since 2014.

In general, discards are assumed to be minor in the blue whiting directed fishery. Currently, all discard data provided to the working group, by the Denmark, Ireland, UK (Scotland), Sweden, Spain and Portugal, are included in the assessment.

B.3. Surveys

A number of surveys are (or have been) carried out which provide data on blue whiting abundance in different areas of their distribution. One survey is used to tune the assessment. The remaining surveys are not used in the assessment, but data are updated on an annual basis and could be incorporated at a later stage should further work suggest that their inclusion would lead to an improved assessment.

Surveys used in the assessment

1. International Blue Whiting spawning-stock survey (IBWSS)

The IBWSS is carried out in March–April on the spawning grounds to the west of the British Isles and was established in its current form in 2004. Five countries participate annually in the survey; the Russian Federation, Norway, Faroes, the Netherlands and Ireland. The survey is internationally coordinated through the Working Group of International Pelagic Surveys (WGIPS).

The design of the IBWSS has traditionally been aimed at reducing the effects of double counting of the northward migrating spawning aggregation. Consideration is also given to the start and end times of the survey window to assure a synoptic coverage while taking into account vessel availability in the different countries and temporal occurrence of spawning aggregations. The spatial confines of the survey, although not fixed, are defined as core spawning areas and secondary target areas as suggested in 2005. The overall design uses stratified transects with a random start (random latitude) to ensure transect coverage is not replicated but randomised between years. The survey procedures are described in the "Manual for International Pelagic Surveys (IPS)" (ICES, 2021). The main problem affecting the outcome of the survey relates to adverse weather conditions encountered in the Northeast Atlantic at the time of the survey. This survey was first used as a tuning series in the assessment in 2007 with ages 3–8.

During the 2011 WGWIDE working group meeting it was decided to exclude the 2010 values from the IBWSSS time-series on the basis of a recommendation from WGNAPES. During the 2010 survey, poor weather and a mismatch between vessels led to a gap in coverage in north Porcupine and south Hebrides (ICES CM2010/SSGESST:20). It was agreed within WGNAPES in 2010 that the gap in area coverage occurred in an area of concentrated fishing effort and thus contained a high but unquantified biomass. Mean acoustic density for the unsurveyed rectangles within the core spawning area was determined by means of interpolation from surrounding surveyed rectangles following established methods. It was also agreed that the gap in coverage had no doubt resulted in an underestimate of the stock. However, the revised estimate was recommended to be accepted by WGWIDE in 2010 as the best available. In WGNAPES 2011 (ICES CM2011/SSGESST:16) the time-series was reviewed and the problems in the 2010 IBWSS was considered. The updated survey time-series, including the 2011 survey, show a decline in the observed stock but the rate of decline is not as abrupt if the 2010 estimate is excluded. Due to the large uncertainties in the estimate from 2010, WGNAPES recommended to exclude the 2010 data from the time-series in the assessment.

The original TS–length relationship applied for blue whiting was considered too low and tended to overestimate the abundance of fish. This original relationship was based on measurements taken from a juvenile cod in the 1970s and was applied as the best estimate available at the time. Acoustic abundance estimates of blue whiting have so far tended to be considerably higher than those based on the assessment. The workshop on implementing a new TS relationship for blue whiting abundance estimates (WKTSBLUES) met in 2012. The objectives of the workshop were to implement a new TS–length relationship proposed by Pedersen *et al*. (2011). This latest research used *in situ* acoustic measurements and was taken over several years, utilizing several different observation platforms. As the measurements were taken during the spawning–stock survey they are not only species-specific but also time and area specific, something which was not achieved with the old TS–length relationship. Recalculating the survey index resulted in an expected downward shift to around 32% of the original TSB. When recalculating the survey index all previous settings were retained to ensure continuity and comparability across the index. During the review of survey data an error was observed in the presented 2009 blue whiting estimate relating to abundance-at-age data. This error was corrected in the data in 2012.

At the Inter-Benchmark spring 2016, it was decided to also use the age groups 1–2 from the IBWSS in the default assessment (ICES, 2016a).

The indices of blue whiting from the spawning stock survey are presented in Table D1.

Surveys not used in the assessment but provide information

2. International ecosystem survey in the Nordic Seas (IESNS)

An international ecosystem survey is carried out annually in the Nordic Seas from late April to early June aimed at observing the pelagic ecosystem in this area. This survey focuses on Norwegian spring-spawning herring, blue whiting, zooplankton and hydrography. The survey area was split into three subareas which are as follows:

Area I - Barents Sea;

Area II - northern and central Norwegian Sea;

Area III - Southwestern area, i.e. Faroese and Icelandic zones and southwestern part of the Norwegian Sea.

The survey is coordinated by WGIPS. Ages 1–2 from this survey were used as recruitment indices, but WKPELA2012 decided not to use any recruitment series in the assessment.

At the Inter-Benchmark spring 2016, inclusion of ages 1–2 in the SAM assessment showed a very high observation uncertainty for both ages and it was decided not to use the survey in the default SAM assessment (ICES, 2016a).

The blue whiting indices of 1 and 2 age groups are presented in Table D2.

3. Norwegian survey on the spawning grounds

The Norwegian survey on the spawning grounds for blue whiting, west of the British Isles, provides the longest time-series covering a significant part of the blue whiting stock. This survey was carried out from 1991–2006. The time-series from 1991–2003, ages 3–8 was used to tune the assessment. This survey was replaced by the International spawning–stock survey in 2009.

The indices of are presented in Table D3.

4. Norwegian bottom-trawl survey in the Barents Sea

Norway has conducted bottom-trawl surveys targeting cod and other demersal fish in the Barents Sea since late 1970s. From 1981 onwards there have been systematically designed surveys carried out during winter (usually late January–early March) by at least two Norwegian vessels; in some years the survey has been conducted in cooperation with Russia. Blue whiting is a regular bycatch species in these surveys, and has in some years been among the numerically dominant species (Heino *et al*., 2003). This survey is currently giving the first reliable indication of year-class strength of blue whiting. The survey is not used in the assessment because of it coverage at the edge of the distribution area, but it is used for recruitment predictions. The indices of 1 group blue whiting are presented in Table D4.

5. Spanish bottom-trawl survey

Bottom-trawl surveys have been conducted off the Galician (NW Spain) coast since 1980, following a stratified random sampling design and covering depths down to 500 m. The survey is directed to a mixture of species. Since 1983, the area covered in the Spanish survey was extended to completely cover Spanish waters in Division 8.c. A new stratification has been established since 1997. The survey is not used in the assessments as it is only representative for a small part of the stock area. The mean catch and standard error of these bottom-trawl surveys are presented in Table D5.

6. Portuguese bottom-trawl survey

Bottom-trawl surveys have been conducted off the Portuguese coast since 1979, following a stratified random sampling design and covering depths down to 500 m. The area covered in the Portuguese survey was extended in 1989 to the 750 m contour. The survey is not used in the assessments as it is only representative for a small part of the stock area. The mean catch and standard error of these surveys is presented in Table D6.

7. French bottom-trawl survey

Bottom-trawl surveys have been carried out since 1987 in the Bay of Biscay and 1997 in the Celtic Sea following a random stratified sampling design and covering depths down to 700 m; both areas are covered in October–November. Estimates of aged 0 blue whiting using a cut off of 18 cm and raised to the total survey areas are presented in Table D7.

8. Icelandic bottom-trawl survey

The bottom-trawl survey has been conducted within the Icelandic exclusive economic zone annually in March since 1985 using a stratified random design with approximately 600 bottom trawl stations in total. Blue whiting juvenile index using a cut off of 21 cm and raised to the total survey area is presented in Table D8.

9. Other surveys

Several other surveys have in the past provided data to the working group. In recent years however these data have not been updated. Historical results from the following surveys are presented in WGNPBW working group reports.

- Norwegian Sea summer survey carried out in 1981–2001, 2005–2007. The stock estimates in numbers-at-age are given in the 2007 report.
- Faroes plateau spring bottom-trawl survey carried out in March 1996–2008. The survey is aimed at cod, haddock and saithe, but varying amounts of blue whiting are caught as bycatch each year (Table D9).
- Faroes plateau autumn bottom-trawl survey carried out in August–September 1994–2008. The survey is aimed at cod, haddock and saithe, but varying amounts of blue whiting are caught as bycatch each year.

B.4. Commercial cpue

No commercial cpue data are used in the assessment.

B.5. Other relevant data

None.

C. Assessment method and data

Model used:

The State–space Assessment Model (SAM), analytical assessment is used for the assessment.

At the Benchmark (WKPELA, 2012) the state–space models SAM model (Nielsen and Berg, 2014) was chosen as the assessment model for blue whiting. SAM offers a flexible way of describing the entire system, with relative few model parameters. Compared to the previously used SMS model (Lewy and Vinther, 2004), SAM models fishing mortality from random walk, whereas SMS assumes a separable model for fishing mortality and thereby a rather stable exploitation pattern. Model diagnostics from both models are similar; however, SAM gives a slightly better fit to catch data, as it allows variations in exploitation pattern from year to year. The assessment output from the two models is almost identical, such that the perception of the stock remains unchanged using SAM.

During the inter-benchmark protocol of blue whiting (IBPBLW) (ICES, 2016a) a version of SAM that accounted for correlated observations (Berg and Nielsen, 2016) was tested and found to be a better model to handle "year effects" in survey indices as observed in the 2015 IBWSSS, than the default SAM. This model was used in 2016.

Software used:

Source code for the SAM model and all scripts are freely available at https://www.stockassessment.org[Username: guest; Password: guest].

Assessment at **stockassessment.org**

The following assessments are available:

- BW-2014: The final 2014 assessment;
- bw-2015: The final 2015 assessment;
- WHB_IBPBLW_2016: The final assessment from the Inter-Benchmark spring 2016.

Model Options chosen:

The blue whiting assessment makes use of one survey index (International Blue Whiting Spawning–Stock Survey, IBWSSS) and the total catch-at-age data matrix. Fishing mortality random walks are allowed to be correlated.

The table below present the SAM configuration options (file model.cfg). In the file text following a hash-mark ("#") is a comment.

```
# SAM, Correlated Observations
# Min Age
1
# Max Age
10
# Max Age considered a plus group (0=No, 1=Yes)
1
# Coupling of fishing mortality STATES
# Rows represent fleets.
# Columns represent ages.
# 1  2  3  4  5  6  7  8  9  10  # Age
1  2  3  4  5  6  7  8  9  9   # Catch
0  0  0  0  0  0  0  0  0  0   # IBWSS
# Use correlated random walks for the fishing mortalities
```

```
 # ( 0 = independent, 1 = correlation estimated (compound symmetry), 2= AR(1))
 2
 # Coupling of catchability PARAMETERS
 # 1  2  3  4  5  6  7  8  9  10  # Age
0  0  0  0  0  0  0  0  0  0   # Catch
1  2  3  4  5  5  5  5  0  0   # IBWSS
 # Coupling of power law model EXPONENTS (if used)
 # 1  2  3  4  5  6  7  8  9  10  # Age
0  0  0  0  0  0  0  0  0  0   # Catch
0  0  0  0  0  0  0  0  0  0   # IBWSS
 # Coupling of fishing mortality RW VARIANCES
 # 1  2  3  4  5  6  7  8  9  10   # Age
1  1  1  1  1  1  1  1  1  1    # Catch
0  0  0  0  0  0  0  0  0  0    # IBWSS
 # Coupling of log N RW VARIANCES
 # 1  2  3  4  5  6  7  8  9  10  # Age
1  2  2  2  2  2  2  2  2  2
 # Coupling of OBSERVATION VARIANCES
 # 1  2  3  4  5  6  7  8  9 10   # Age
1  2  3  3  3  3  3  3  4  4   # Catch
5  6  7  8  8  8  9  9  0  0   # IBWSS
 # Stock recruitment model code (0=RW, 1=Ricker, 2=B&H)
0
 # Years in which catch data are to be scaled by an estimated parameter
0
# DefineFbar range
3  7
 # Observation correlation coupling (0 = uncorrelated)
 # Rows represent fleets, columns represent adjacent age groups,
 # i.e. the first column is the cor. between the first and 2nd age group.
 # NA in all non-empty age groups specifies unstructured correlation.
 # NA's and positive numbers cannot be mixed within fleets.
 # 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10  # Age
  1   1   1   1   1   2   2   2   2    # Catch
  3   3   3   4   4   4   4   0   0    # IBWSS
```

The options for “Coupling of fishing mortality STATES” show that random walk for F is independent by age for the ages 1–8, and combined for age 9 and 10. That means that F age 9 and F age 10 are the same.

It is assumed that F at-age is correlated to some degree estimated by the models. Therefore the option for “Use correlated random walks for the fishing mortalities” is set to 2 (using AR(1) correlation structures).

The “Coupling of catchability PARAMETERS” specifies the grouping of ages with respect to survey catchability. For the IBWSSS survey there is assumed an age-dependent catchability for age 1, age 2, age 3 and 4, and a combined (the same) catchability ages 5–8.

In the IBWSSS a linear relation between cpue and stock size is assumed, such that the options for “Coupling of power law model EXPONENTS”are all set to 0.

The variance for the random walk for F (“Coupling of fishing mortality RW VARIANCES “) is assumed the same for all ages.

The “Coupling of OBSERVATION VARIANCES” specifies the options for observation noise for both catches and survey indices. For catches the observation variance is age dependent for age 1 and 2. For ages 4–8 the variance is assumed the same, and different from the variance for ages 9–10. For the IBWSSS survey the variance is unique for age 1, age 2 and age 3; and the same within the groups ages, 4–6, and ages 7–8.

There is no obvious relation between SSB and recruitment, but recruitment seems to be correlated between years. To reflect this, the “Stock–recruitment model code” is set to 0=Random Walk.

There is no year where catches are to be scaled (“Unallocated mortality”).

The options for observation correlation coupling is what Berg and Nielsen (2016) name “irregular lattice AR(1) observation correlation structure”. For the catch, observations are correlated within the ages 1–5 and within ages 6–10, and for the IBWSS within ages 1–3 and within ages 4–8.

Input data types and characteristics.

Type	Name	Year range	Age range	Variable from year to year Yes/No	Remarks
Caton	Catch in tonnes	1981–	1–10	Yes	Not used by SAM
Canum	Catch-at-age in numbers	1981–	1–10	Yes	
Weca	Weight-at-age in the commercial catch	1981–	1–10	Yes	
West	Weight-at-age of the spawning–stock at spawning time.	1981–	1–10	Yes	
Mprop	Proportion of natural mortality before spawning	1981–	NA	No	Set to zero, although spawning takes place March–April
Fprop	Proportion of fishing mortality before spawning	1981–	NA	No	Set to zero, See above
Matprop	Proportion mature-at-age	1981–	1–10	No	
Natmor	Natural mortality	1981–	NA	No	Constant 0.2

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	International Spawning–Stock Survey (IBWSS)	2004–assessment year	3–8 until 2015 1–8 after (ICES, 2016a)

The International Blue Whiting Spawning–Stock Survey (IBWSS) conducted since 2004 is used as cpue index. The IBWSS was not conducted in 2020 due to the covid pandemic.

The survey period used reflects the average timing of the survey, equivalent to 0.22–0.27 proportion of the year. This however, does not correspond to the average proportion of annual M and F before the survey takes place, as up to half of the annual catches are taken in the period January–March. The IBPBLW 2016 (ICES, 2016a) concluded that because only one survey period (proportion of Z before survey) can be given for the whole survey and all ages, the choice of survey period seems less critical and the survey period reflection the calendar data were used.

Models used for exploratory assessments

Previous WGWIDE working groups have conducted alternative assessments (e.g. TISVPA and XSA) in addition to the accepted assessment as a check on model assumptions and how the different model platforms handle the data. At future meetings exploratory analyses, potentially also including recruitment indices, will be encouraged. Advice will be based on the outputs of the SAM model.

D. Short-term projection

Model used, before 2014:

At the Benchmark in 2012 it was concluded that due to the uncertainty in the final year estimates of fishing mortality and stock numbers, the standard (deterministic) short-term forecast is considered inappropriate to this stock. Therefore, stochastic projections are performed, from which short-term projections are extracted. The stochastic projections are carried out by starting at the final year's estimates, using the variance-covariance matrix of those estimates. To run the short-term forecast 1000 samples are generated from the estimated distribution of the final year's estimates. Those 1000 replicates are then simulated forward according to the model and subject to different scenarios.

Issues with the stochastic forecast:

Compared to a deterministic forecast the stochastic forecast gives slightly higher estimates of TAC and SSB. For e.g. the TAC advice for 2015 is estimated 4–5% higher and SSB in 2016 8–9% higher. The difference is due to the assumed lognormal distributed stock number. The median of the projected stock N is unbiased compared to the stock N from a deterministic forecast, but the median of quantities like yield and SSB, which is the sum of several age groups N weighted by e.g. F, mean weight and proportion mature, will be higher. The difference increases by increasing uncertainty of the initial stock numbers used for the forecast.

Model used, since 2014:

Since 2014 a deterministic version of the short-term forecast has been applied for advice. The MSE evaluation (ICES advice 2014, ICES advice 2015) used a deterministic forecast in the evaluation. The conclusion, that a given HCR is precautionary is sensitive to the choice of forecast model. With a TAC estimated 4–5% lower in the MSE than actually applied in the MSE will give a too high target F for precautionary management. Therefore, the WGWIDE concluded in 2014 to use to use a deterministic forecast.

Software used:

Source code for the SAM model and all scripts including forecast script are freely available at https://www.stockassessment.org [Username: guest; Password: guest].

The default forecast.R script has been modified to handle both stochastic and deterministic forecast: The top two lines

determenistic<-TRUE

if (determenistic)nosims<-2 else nosims<-1000

have been inserted, which allow setting deterministic<-TRUE or FALSE. The script has further been modified such that when deterministic==TRUE, the variance - covariance matrix is set to 0 (deterministic forecast). The number of simulations (nosims) is maintained at 2 (1 would be sufficient) such that the same data structure can be used for both types of forecast.

In the plotscript.R the following lines have been inserted and source code changed accordingly

TAC.year<-2016 # used for meaning full labels in forecast output

Blim<-1500000

Bpa<- 2250000

outFac<-0.001 # factor used for output tables, N, Recruits, SSB

By setting the TAC.year variable it is possible to use an "intermediate year" in the forecast (as normally done for most species) or using make a forecast without an intermediate year in case of preliminary catch data (raised first half-year data) are used.

Initial stock size: Final year's estimates of N are used.

The benchmark in 2012 concluded that the available survey indices should be used in a qualitative way to estimate recruitment, rather than using them in a strict quantitative model framework.

The IBPBLW, 2016 concluded that the IBWSS ages 1 and 2 are likely the most suitable recruitment indices. More work is however needed before it can be decided.

At WGWIDE 2021, it was decided to use geometric mean of available survey indices for the period 1996 onward to calculate recruitment index (R_{age1}) to use in the forecast, except for the intermediate year. Previously the whole timeseries beginning in 1981 had been included in index calculations. The timeseries was shortened to 1996 onward as there was limited fluctuation in the survey indices prior to 1996, only one of seven surveys has measurements prior to 1993, and there is limited annual variability in the index prior to 1996 but after 1996 there are obvious periods of low and high recruitment. The assessment recruitment value is used for the intermediated year.

Maturity: The proportion mature for this stock is assumed constant over the years. The maturity ogive used in the short-term forecast is the same as the ogive used in the assessment.

F and M before spawning: These values are both 0, spawning is assumed to take place the 1st January.

Weight-at-age in the stock and weight-at-age in the catch: Weight-at-age in the catch and weight-at-age in the stock are the same and for the short-term forecast are calculated as three years' averages.

Exploitation pattern: This is based on F in the year where the final three years of data calculated from the most recent assessment.

Natural Mortality: Natural mortality is assumed to be 0.2 across all ages.

Maturity: As used in the SAM assessment (independent of year).

Intermediate year assumptions: Intermediate year's F is estimated from TAC constraint with the default assumption is that TAC is landed fully. More work is needed however, to evaluate if an assumption of using *F status quo* in the intermediate year would be a better alternative.

E. Medium-term projection

Medium-term projections are not used routinely for this stock.

F. Long-term projections

Long-term projections are not carried out for this stock.

G. Biological reference points

The Workshop on Limit and Target Reference Points (WKREF) considered the biological reference points for Blue Whiting at a meeting in Gdynia, Poland in January in 2007 (ICES, 2007b). The original reference points for this stock were set in 1998, before the era of high productivity became apparent. The group examined the consequences of these new observations on the reference points by first splitting the time-series into two productivity regimes (low productivity from 1981–1994, and high productivity from 1995–2005). Standard methods (i.e. using the guidelines from the Study Group on Precautionary Reference points, SGPRP (ICES, 2003b) were then used to re-estimate the reference points, which were found to be comparable to the current values. A new probabilistic approach for estimating B_{lim} was also employed, but again, the result was found to be comparable with the current values. The group concluded that there was no basis for revising the current reference points. WKREF also noted that there may be no need for different B_{lim} values in different productivity regimes.

A stochastic equilibrium analysis made during the Working Group established by the Blue Whiting Coastal States on Blue Whiting management strategies (Anon, 2008) indicates a high risk of stock collapse with an F from approximately 0.3 and upwards given the "low recruitment" regime as observed in 1981–1996. F_{MAX} is poorly defined and a very limited increase in yield is obtained for F in the range 0.18 to 0.30. $F_{0.1}$ was estimated at 0.18. Sensitivity analysis of a change in exploitation pattern showed that these conclusions are robust with respect to the choice of exploitation pattern. A yield-per-recruit analysis was conducted using MFYPR which also calculated $F_{0.1}$ as 0.18.

At the WKPELA 2012 meeting the precautionary approach fishing mortality reference points for this stock were removed. A major problem was that fishing at F_{pa} implied a high probability of bringing the stock below B_{pa}, in other words the present combination of F_{pa} and B_{pa} is inconsistent, likewise for F_{lim} and B_{lim}.

As a response to a special request from NEAFC, ICES re-evaluated in May 2013 (ICES advice, 2013) the reference points for the stock. ICES concluded that B_{lim} and B_{pa} should remain unchanged. F_{pa} and F_{lim} were undefined. Equilibrium stochastic simulations have been used to give a new value for F_{lim} = 0.48. On the basis of this and the uncertainty in the assessment, a corresponding value for F_{pa} = 0.32 was derived. Currently MSY advice is based on a management strategy evaluation which used $F_{0.1}$ as a proxy for F_{MSY} and an MSY $B_{trigger} = B_{pa}$. The new simulations provide estimates of F_{MSY} = 0.30. There are no scientific reasons to reduce MSY $B_{trigger}$ below B_{pa}, and no estimates of MSY $B_{trigger}$ are above B_{pa}. Under these circumstances it is proposed that B_{pa} be retained as MSY $B_{trigger}$ for the MSY framework.

In a request from NEAFC, June 2013, ICES was requested to confirm the suggested reference points, more specifically to confirm:

a) That the value of $F_{0.1}$ is considered to be 0.22 rather than 0.18, as stated in the advice of September 2012;

b) That the value of F_{MSY} is considered to be 0.30 rather than 0.18, as stated in the advice of September 2012.

ICES confirmed (ICES advice October 2013) that the value of $F_{0.1}$ is currently estimated to be 0.22. ICES advised that the value of F_{MSY} is considered to be 0.30 and this replaces the $F_{0.1}$ proxy for F_{MSY} of 0.18 from the advice of September 2012.

In 2016, ICES hosted a workshop to re-evaluate biological reference points and evaluate a proposed longterm management strategy (LTMS) (ICES, 2016b) for the Northeast Atlantic blue whiting (BW, *Micromesistius poutassou*) stock (whb-comb; Subareas 1–9, 12 and 14). This was done in a response to a recommendation from the Inter-Benchmark Protocol of Blue Whiting (ICES, 2016a), where a new assessment of the stock was produced, and a NEAFC request to ICES.

Main results from the executive summary of the report (ICES, 2016b): a stochastic simulation model, R-package called "EQSIM", was used to evaluate the biological reference points and the LTMS. Two characteristics of the input data were identified that could influence the simulations: highly variable recruitment, with periods of high and low productivity, and high uncertainty in the stock assessment. Recruitment is a keystone variable in LTMS as it has a large impact on the potential yield that can be taken from a fish stock. There is no relationship between BW spawning stock biomass (SSB) and recruitment, but there is relationship between recruitment and SSB two years later. BW recruitment, from 1981 to 2016, is highly variable (the highest value is 17x the lowest value) and has one period of high recruitment, from 1996 to 2005, causing high auto-correlation in estimated recruitment. WKBWMSE agreed that in the LMTS evaluation the whole recruitment time series should be used as there is no scientific reason to reject some years and accept others. The stock assessment depends primarily on a single acoustic index of abundance that in the past has had obvious year effects. This has led to notable retrospective revisions in estimates of stock size and fishing mortality (F). Past advice uncertainty, rather than parametric model uncertainty, was estimated and used to simulate error in the perceived state of the stock and the fishery.

EQSIM was amended to conduct a long term simulation of the blue whiting stock, rather than simply estimating equilibrium conditions. The amended model is called 'SimpSIM' and is R package. WKBWMSE concluded that a B_{lim} of 1.5 million tonnes and a B_{pa} of 2.25 million tonnes was still appropriate and should remain unchanged but reevaluated F_{msy} (= 0.32), F_{pa} (= 0.58) and F_{lim} (= 0.88). The proposed LTMS included a harvest control rule (HCR) with two breakpoints (at B_{pa} and B_{lim}), a 10% interannual quota flexibility ("banking and borrowing"), and a 20% TAC change limits. This HCR was evaluated to ensure that the probability of SSB going below B_{lim} in any given year should be less than 5%. WKBWMSE concluded that the proposed HCR was precautionary for the re-evaluated estimates of B_{lim} (1.5 million tonnes), B_{pa} (2.25 million tonnes) and F_{msy} (= 0.32). Including a 10% interannual quota flexibility in the LTMS had an insignificant effect on the performance of the HCR. The HCR was precautionary both with and without the 20% TAC change limits above B_{pa}. However, not applying TAC change limits can lead to advised TAC being lowered considerablyif the stock is estimated to be below B_{pa}, and it limits how quickly advised TAC can increase once the stock is estimated to have recovered above B_{pa}.

The present reference points and their technical basis are:

FRAMEWORK	REFERENCE POINT	VALUE	TECHNICAL BASIS	SOURCE
MSY approach	MSY $B_{trigger}$	2.25 million t	B_{pa}	ICES (2013a, 2013b, 2016b)
	F_{MSY}	0.32	Stochastic simulations with segmented regression stock–recruitment relationship	ICES (2016b)
Precautionary approach	B_{lim}	1.50 million t	Approximately B_{loss}	ICES (2013a, 2013b, 2016b)
	B_{pa}	2.25 million t	B_{lim} exp(1.645 × σ), with σ = 0.246	ICES (2013a, 2013b, 2016b)
	F_{lim}	0.88	Equilibrium scenarios with stochastic recruitment: F value corresponding to 50% probability of (SSB< B_{lim})	ICES (2016b)
	F_{pa}	0.53	Based on F_{lim} and assessment uncertainties. F_{lim} exp(−1.645 × σ), with σ = 0.299	ICES (2016b)

H. Other issues

Changes in blue whiting mean weights over time

Possible causal relations for the visible reductions in mean weight-at-age were investigated by WGWIDE in 2008. Several aspects relating to the biology of fish stocks such as recruitment, growth or natural mortality, are influenced by ecosystem conditions. Some of these conditions were suggested as possible reasons for the change in mean weight-at-age. These include the following:

Density-dependant competition. Too many fish competing for the same food resource.

Changes in plankton abundance would impact on the amount of food available for blue whiting.

External environmental factors, such as temperature and salinity. Spawning is effected by both of these environmental variables.

An in depth analysis of the causes of these changes in mean weights, which would be needed for any kind of forecast is outside the scope of this working group (ICES, 2008).

Possible effects of protecting juvenile blue whiting

The modern blue whiting fishery developed during the second half of the 1970s when the landings increased from around 100 000 tonnes to above 1 million tonnes. The majority of the catches have since been taken on the spawning grounds west of the British Isles. A small but fairly constant fraction of the catches are taken in the southern areas and in the North Sea (Norwegian trench) and a variable fraction in the Norwegian Sea (Figure H1). The proportion of landings taken in the Norwegian Sea increased after the strong year classes from 1995 onwards led to increased densities of (young) blue whiting in this area, but is now decreasing and was in 2007 around the pre-2000 level.

Landings from the Norwegian Sea and the North Sea are generally comprised of a larger proportion of juvenile fish compared to landings from the spawning area, though this proportion varies between years. A measure to reduce the exploitation of juveniles could therefore, in theory, be to close the fishery in these areas (or a temporal closure of the fishery outside the spawning season). However, it is impossible to estimate the resulting reduction in juvenile fishing mortality of such measures since juveniles are also exploited in the spawning ground fishery.

The effects on the yield-per-recruit curve of applying three different exploitation patterns on ages 1–2 were explored using the standard ICES software MFYPR; (1) zero exploitation, (2) "high" exploitation and (3) the constant F selection pattern used in SMS from 1999 onwards. The "high" exploitation pattern which gave the highest relative fishing mortality on ages 1–2 during the last 15 years was derived from the XSA assessment. The SMS exploitation pattern was used on ages older than two years. Figure H2 shows the three F selection patterns used and the resulting yield-per-recruit curves. The difference between the curves is marginal with similar values for $F_{0.1}$ derived. The conclusion is that the effect on yield of protecting juveniles is likely to be very small. A separate clause for the protection of juveniles in the management plan is not needed (ICES, 2008).

H.1. Management and ICES advice

Management plans

A management plan was agreed for this stock between the four coastal states (Norway, Faroe Islands, Iceland, and EU) in December 2005. The text for the agreed plan is given below. This management agreement aims to maintain the SSB of the blue whiting stock at levels above 1.5 million tonnes (B_{lim}) and the fishing mortality rates at levels of no more than 0.32 (F_{pa}). To achieve this, the TAC is reduced by at least 100 000 tonnes a year until the fishing mortality is reduced to 0.32 (F_{pa}). The plan states that if the spawning stock falls below 2.25 million tonnes, unspecified actions to obtain a safe and rapid recovery to this level should be taken. ICES has evaluated this management plan in 2006 and found it not to be in accordance with the precautionary approach in a period of low recruitment.

Text for the 2005 management plan for blue whiting

1) The Parties agree to implement a multiannual management arrangement for the fisheries on the blue whiting stock which is consistent with the precautionary approach, aiming at constraining harvest within safe biological limits, protecting juveniles, and designed to provide for sustainable fisheries and a greater potential yield, in accordance with advice from ICES.

2) The management targets are to maintain the Spawning–Stock Biomass (SSB) of the blue whiting stock at levels above 1.5 million tonnes (B_{lim}) and the fishing mortality rates at levels of no more than 0.32 (F_{pa}) for appropriate age groups as defined by ICES.

3) For 2006, the Parties agree to limit their fisheries of blue whiting to a total allowable catch of no more than 2 million tonnes.

4) The Parties recognise that a total outtake by the Parties of 2 million tonnes in 2006 will result in a fishing mortality rate above the target level as defined in Paragraph 2. Until the fishing mortality has reached a level of no more than 0.32, the Parties agree to reduce their total allowable catch of blue whiting by at least 100 000 tonnes annually.

5) When the target fishing mortality rate has been reached, the Parties shall limit their allowable catches to levels consistent with a fishing mortality rate of no more than 0.32 for appropriate age groups as defined by ICES.

6) Should the SSB fall below a reference point of 2.25 million tonnes (B_{pa}), either the fishing mortality rate referred to in paragraph 5 or the tonnage referred to in paragraph 4 shall be adapted in the light of scientific estimates of the conditions then prevailing. Such adaptation shall ensure a safe and rapid recovery of the SSB to a level in excess of 2.25 million tonnes.

7) This multiannual management arrangement shall be reviewed by the Parties on the basis of ICES advice.

The stock is currently in a period of low recruitment. In July 2008 a new draft management plan was proposed by the Coastal States. ICES has evaluated the draft management plan and considers it precautionary, if fishing mortality in the first year is immediately reduced to the fishing mortality that is implied by the HCR. The text of this plan is also presented below.

Text for the 2008 management plan for blue whiting

1) The Parties agree to implement a long-term management plan for the fisheries on the blue whiting stock, which is consistent with the precautionary approach, aiming at ensuring harvest within safe biological limits and designed to provide for fisheries consistent with maximum sustainable yield, in accordance with advice from ICES.

2) For the purpose of this long-term management plan, in the following text, "TAC" means the sum of the coastal State TAC and the NEAFC allowable catches.

3) As a priority, the long-term plan shall ensure with high probability that the size of the stock is maintained above 1.5 million tonnes (B_{lim}).

4) The Parties shall aim to exploit the stock with a fishing mortality of 0.18 on relevant age groups as defined by ICES.

5) While fishing mortality exceeds that specified in paragraphs 4 and 6, the Parties agree to establish the TAC consistent with reductions in fishing mortality of 35% each year until the fishing mortality established in paragraphs 4 and 6 has been reached. This paragraph shall apply only during 2009 and 2010.

6) For the purposes of this calculation, the fishing percentage mortality reduction should be calculated with respect to the year before the year in which the TAC is to be established. For this year, it shall be assumed that the relevant TAC constrains catches.

7) When the fishing mortality in paragraph 4 has been reached, the Parties agree to establish the TAC in each year in accordance with the following rules:

7.1) In the case that the spawning biomass is forecast to reach or exceed 2.25 million tonnes (SSB trigger level) on 1 January of the year for which the TAC is to be set, the TAC shall be fixed at the level consistent with the specified fishing mortality.

7.2) In the case that the spawning biomass is forecast to be less than 2.25 million tonnes on 1 January of the year for which the TAC is to be set (B), the TAC shall be fixed that is consistent with a fishing mortality given by:

$$F = 0.05 + [(B-1.5)(0.18-0.05) / (2.25-1.5)]$$

7.3) In the case that spawning biomass is forecast to be less than 1.5 million tonnes on 1 January of the year for which the TAC is to be set, the TAC will be fixed that is consistent with a fishing mortality given by F = 0.05.

8) When the fishing mortality rate on the stock is consistent with that established in paragraph 4 and the spawning stock size on 1 January of the year for which the TAC is to be set is forecast to exceed 2.25 million tonnes, the Parties agree to discuss the appropriateness of adopting constraints on TAC changes within the plan.

9) The Parties, on the basis of ICES advice, shall review this long-term management plan at intervals not exceeding five years and when the condition specified in paragraph 4 is reached.

The ICES TAC advice given in 2015 was based on the MSY approach as there was no management plan agreed for blue whiting.

Text for the 2016 management plan for blue whiting (ICES, 2016b)

Long-Term Management Strategy for Blue Whiting

1) The Parties agree to implement a long-term management strategy for the fisheries on the Blue Whiting stock, which is consistent with the precautionary approach and the MSY approach, aiming at ensuring harvest rates within safe biological limits.

2) For the purpose of this long-term management strategy, in the following text, “TAC” means the sum of the Coastal State quotas and the NEAFC allowable catches.

3) As a priority, the long-term strategy shall ensure with high probability that the size of the stock is maintained above B_{lim}.

4) In the case that the spawning biomass is forecast to be above or equal to $B_{trigger}$ ($=B_{pa}$) on 1 January of the year for which the TAC is to be set, the TAC shall be fixed to a fishing mortality of F_{msy}.

5) Where the rules in paragraph 4 would lead to a TAC, which deviates by more than 20% from the TAC of the preceding year, the Parties shall fix a TAC that is no more than 20% greater or 20% less than the TAC of the preceding year.

6) In the case that the spawning biomass (SSB) is forecast to be less than the precautionary biomass ($B_{trigger}$) on 1 January of the year for which the TAC is to be set, the TAC shall be fixed that is consistent with a fishing mortality given by:

Target $F = 0.05 + [(SSB - B_{lim})*(F_{msy} - 0.05) / (B_{trigger} - B_{lim})]$

7) In the case that the spawning biomass is forecast to be less than B_{lim} on 1 January of the year for which the TAC is to be set, the TAC will be fixed corresponding to a fishing mortality F=0.05.

8) Each Party may transfer to the following year unutilised quantities of up to 10% of the quota allocated to it. The quantity transferred shall be in addition to the quota allocated to the Party concerned in the following year.
9) Each Party may authorise fishing by its vessels of up to 10% beyond the quota allocated. All quantities fished beyond the allocated quota for one year shall be deducted from the Party's quota allocated for the following year.
10) The inter-annual quota flexibility scheme in paragraphs 8 and 9 should be suspended in the year following the TAC year, if the stock is forecast to be under $B_{trigger}$ at the end of the TAC year.
11) The Parties, on the basis of ICES advice, shall review this long-term management strategy at intervals not exceeding five years.

ICES advice

In 2003, ICES stated that both estimates of SSB and fishing mortality were high but uncertain. Nevertheless, the spawning–stock biomass in 2003 was likely to be above B_{pa}. Therefore, based on the most recent estimates of fishing mortality and SSB, ICES classified the stock as likely to be harvested outside safe biological limits ($F>F_{lim}$). The incoming year classes seemed to be strong. ICES recommended that catches should be less than 925 000 tonnes in 2004 in order to achieve a 50% probability that the fishing mortality in 2004 is less than F_{pa} (=0.32). This would also assure a high probability that the spawning–stock biomass in 2005 to be above B_{pa} (ICES, 2005).

In 2004 ICES concluded from the most recent estimates of fishing mortality and SSB that the stock had full reproductive capacity, but was harvested unsustainably. Although the estimates of SSB and fishing mortality were not considered precise, it was certain that SSB was above B_{pa} and the estimated fishing mortality well above F_{lim}. Recruitments in the last decade appeared to be at a much higher level than earlier. The unimplemented management plan implied catches of less than 1.075 million tonnes in 2005 which was expected to keep fishing mortality less than 0.32 with 50% probability. This would also have assured a high probability that the spawning–stock biomass in 2006 would be above B_{pa}. ICES recommended that measures be taken to protect juveniles (ICES, 2005).

In 2005 ICES advised that fishing within the limits of the management plan (F=0.32) implied catches of less than 1.5 million tonnes in 2006. This would result in a high probability that the spawning–stock biomass in 2007 would be above B_{pa}. The present fishing level was well above levels defined by the management plan and should be reduced. The primarily approach to reduce catch of juveniles is to reduce overall fishing mortality. Catches of juveniles in the last four years were much greater than in earlier periods. If an overall reduction of fishing mortality cannot be achieved then specific measures should be taken to protect juveniles (ICES, 2006).

In 2006 ICES stated that the maximum catch in 2007 corresponding to a new agreed management plan is 1.9 million tonnes, which is expected to leave the spawning–stock biomass at 2.86 million tonnes, i.e. above B_{pa} in 2008, but would lead to an F above F_{lim} in 2007.Fishing mortality is estimated at 0.48 and was above the fishing mortalities expected to lead to high long-term yields and low risk of depletion of production potential. Fishing at F_{pa} implies catches of less than 980 thousand tonnes in 2007. This was expected to result in a spawning–stock biomass in 2008 well above B_{pa}. The newly agreed management plan was evaluated by ICES and was not considered in accordance with the precautionary approach. ICES concluded that the exploitation boundaries for this stock should be based on the precautionary limits (ICES, 2007a).

In 2007 ICES classified the stock as having full reproductive capacity, but being harvested at increased risk. SSB increased to a historical high in 2003, but has decreased since then. The estimated fishing mortality was well above F_{pa}. Recruitment in the last decade appears to be at a much higher level than prior to 1996. The 2005 and 2006 year classes were estimated at the pre-1996 level. ICES has evaluated the present management plan in 2006 and found it not to be in accordance with the precautionary approach. ICES concluded that the exploitation boundaries for this stock should be based on the precautionary limits. The advice for 2008 is a maximum TAC at 835 000 tonnes based on an F at F_{pa} (ICES, 2008).

The 2008 advice for Blue whiting states that based on the most recent estimates of fishing mortality and SSB, ICES classifies the stock as having full reproductive capacity, but being harvested at increased risk. SSB increased to a historical high in 2003, but has decreased since then and is expected to be just above B_{pa} in 2009. The estimated fishing mortality is well above F_{pa}. Recruitment of the 2005 and 2006 year classes are estimated to be in the very low end of the historical time-series. Surveys indicate that the 2007 year class could also be low.

In 2009 ICES advised that based on the most recent estimates of SSB (in 2009) and, fishing mortality (in 2008), ICES classifies the stock as having full reproductive capacity and being harvested sustainably (F=0.29). Year classes 2005–2008 are among the lowest observed. Due to recent low recruitment, SSB has declined from its historical peak in 2003–2004 of more than 7 million tonnes to 3.6 million tonnes at the beginning of 2009, and the decline is expected to continue in the short term.

In 2010, following a sharp downward revision in the perceived abundance of the stock in the assessment, the TAC for blue whiting in 2011 was significantly lower than in 2010. This downward revision in the assessment estimates of abundance was driven predominantly by the low values of the 2010 IBWSSS acoustic survey. In 2011 these values were removed from the assessment of the stock (see Section B.3) resulting in an upward revision of abundance estimates. This led in turn to a sharp increase in the TAC for 2012 compared with the low 2011 TAC.

In 2011, ICES estimates the SSB (in 2011) to be above B_{pa} and F (in 2010) to be below F_{MSY}. Year classes 2005–2010 are among the lowest observed. Due to recent low recruitment, SSB has declined from its historical peak in 2003–2004 of more than 6 million tonnes to just above B_{pa} at the beginning of 2011. Based on the management plan ICES calculated a TAC for 2012 at 391 000 tonnes. This TAC advice was later followed by NEAFC. This TAC was significantly higher than that advised for 2011 and was the first increase in TAC since TACs were first agreed in 2006.

In 2012, ICES estimates a historical low landings and fishing mortality at 0.04 in 2011, in combination with an increase in recruitment since 2010, have stopped the steep decline in SSB since 2004. SSB has increased by one million tonnes from 2011 to 2012 (3.8 million tonnes) and is above B_{pa} at the beginning of 2012. An increase in recruitment has been observed for the last two years, but the absolute recruitment strength is uncertain. ICES advises on the basis of the management plan agreed by Norway, the EU, the Faroe Islands, and Iceland, that catches in 2013 should be no more than 643 000 tonnes.

In 2013, ICES notes that SSB has almost doubled from 2010 (2.9 million tonnes) to 2013 (5.5 million tonnes) and is well above B_{pa} (2.25 million tonnes). This increase is due to the lowest Fs in the time-series in 2011 and 2012, in combination with increased recruitment since 2010. ICES advises on the basis of the management plan agreed by Norway, the EU, the Faroe Islands, and Iceland (target F=0.18) that landings in 2014 should be no more than 948 950 tonnes.

In 2014, ICES noted that SSB almost doubled from 2010 (2.9 million tonnes) to 2014 (5.5 million tonnes) and is well above B_{pa} (2.25 million tonnes). This increase is due to the lowest Fs in the time-series in 2011–2013, in combination with increased recruitment since 2010 (at-age 1). ICES advised on the basis of the management plan agreed by Norway, the EU, the Faroe Islands, and Iceland that catches in 2015 should be no more than 839 886 tonnes. All catches are assumed to be landed.

In 2015, ICES notes that F has increased from a historical low in 2011 to above F_{MSY} in 2014. SSB increased from 2010 to 2014 and is above MSY $B_{trigger}$. Recent recruitments are estimated above average, but with an uncertainty. Additional survey information indicates recruitment above average in 2014 and 2015 and this is taken into account in the short-term forecast. ICES advised on the basis of MSY approach that catches in 2016 should be no more than 776 391 tonnes. Currently there is no management plan for blue whiting in this area.

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Table B1. Proportion (%) of total annual catches number taken in quarter 1 (upper table) and in Quarter 1 & 2 (lower table).

Quarter 1			
age/year	2012	2013	2014
0	0.0	0.0	0.8
1	12.5	21.0	29.0

2	29.2	24.8	29.1
3	43.6	35.7	36.6
4	45.4	62.1	44.5
5	41.9	73.4	40.3
6	28.9	42.0	39.9
7	34.9	37.8	35.3
8	35.1	35.6	33.8
9	43.0	38.5	37.4
10	46.8	34.8	38.4

Quarter 1 & 2			
age/year	2012	2013	2014
0	6.9	0.2	2.3
1	68.6	67.2	64.3
2	83.3	72.7	71.8
3	90.4	80.9	92.7
4	93.0	91.4	94.4
5	96.6	97.8	93.8
6	96.8	98.6	94.3
7	96.9	97.0	94.9
8	97.7	97.2	97.1
9	98.8	98.2	97.3
10	99.3	97.5	95.2

Table D1. Blue whiting StoX abundance estimates (millions) from the International Blue Whiting spawning–stock survey (IBWSS) for 2004–2019.

	Age									
Year	1	2	3	4	5	6	7	8	9	10+	TSB
2004	1097	5538	13062	15134	5119	1086	994	593	164	0	3505
2005	2129	1413	5601	7780	8500	2925	632	280	129	23	2513
2006	2512	2224	10881	11695	4717	2719	923	352	198	39	3517
2007	468	706	5241	11244	8437	3155	1110	456	123	65	3274
2008	337	524	1455	6661	6747	3882	1719	1029	269	296	2647
2009	275	329	360	1292	3739	3458	1636	587	250	194	1599
2010*											
2011	312	1361	1135	930	1043	1713	2171	2423	1298	272	1827
2012	1140	1816	6454	1021	595	1415	2220	1777	1249	1085	2347
2013	582	1337	6175	7211	2938	1282	1308	1398	929	1807	3110
2014	4183	1491	5239	8420	10202	2754	772	577	899	2251	3761
2015	3255	4570	1891	3641	1797	466	174	108	206	365	1405
2016	2745	7893	10164	6274	4687	1539	413	133	235	361	2873
2017	262	2248	15682	10176	3762	1793	921	76	84	173	3135
2018	836	628	6615	21490	7692	2187	755	188	72	138	4035
2019	1129	1169	3468	9590	16979	3434	484	513	99	43	4198

*data from the 2010 survey was not used.

Table D2. Age 1 and age 2 indices of blue whiting from International ecosystem survey in the Nordic Seas (Total Area).

Year\Age	Age 1	Age 2
2003*	16127	9317
2004*	17792	11020
2005*	19933	7908
2006*	2512	5504
2007*	592	213
2008	25	17
2009	7	8
2010	0	280
2011	1613	0
2012	9476	3265
2013	454	6544
2014	3893	2048
2015	8563	2796
2016	4223	8089
2017	1236	2087
2018	441	1491
2019	3157	215
2020	2 822	481

Table D3. Cpue at-age from the Norwegian survey on the spawning grounds.

	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1991	6340	8497	7407	4558	2019	545
1992	26123	4719	1574	1386	810	616
1993	3321	26771	2643	1270	557	426
1994	2950	4476	11354	1742	1687	908
1995	9874	7906	6861	9467	1795	1083
1996	7433	8371	2399	4455	4111	1202
1997	-1	-1	-1	-1	-1	-1
1998	34991	4697	1674	279	407	381
1999	60309	26103	1481	316	72	153
2000	31011	41382	6843	898	427	228
2001	12843	13805	8292	718	175	51

2002	54740	12757	5266	8404	1450	305
2003	70303	28756	5735	2430	1708	260

Table D4. 1-group indices of blue whiting from the Norwegian winter survey (late January–early March) in the Barents Sea. (Blue whiting < 19 cm in total body length which most likely belong to 1-group).

Catch Rate		
Year	**All**	**< 19 cm**
1981	0.13	0
1982	0.17	0.01
1983	4.46	0.46
1984	6.97	2.47
1985	32.51	0.77
1986	17.51	0.89
1987	8.32	0.02
1988	6.38	0.97
1989	1.65	0.18
1990	17.81	16.37
1991	48.87	2.11
1992	30.05	0.06
1993	5.80	0.01
1994	3.02	0
1995	1.65	0.10
1996	9.88	5.81
1997	187.24	175.26
1998	7.14	0.21
1999	5.98	0.71
2000	129.23	120.90
2001	329.04	233.76
2002	102.63	9.69
2003	75.25	15.15
2004	124.01	36.74

Catch Rate		
Year	**All**	**< 19 cm**
2005	206.18	90.23
2006	269.2	3.52
2007	80.38	0.16
2008	17.97	0.04
2009	4.50	0.01
2010	3.30	0.08
2011	1.48	0.01
2012	127.71	125.93
2013	39.54	2.33
2014	31.48	24.97
2015	148.4	128.34
2016	86.99	11.31
2017	167.16	0.71
2018	9.19	0.03
2019	22.56	11.79
2020	20.96	16.20

Table D5. Stratified mean catch (Kg/haul and Number/haul) and standard error of Blue Whiting in bottom-trawl surveys in Spanish waters (Divisions 27.8.c and 27.9.a north). All surveys in September–October.

Kg/haul	30-100 m		101-200 m		201-500 m		TOTAL 30-500 m	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1985	9.50	5.87	119.75	45.99	68.18	13.79	92.83	28.24
1986	9.74	7.13	45.41	12.37	29.54	8.70	36.93	7.95
1987	-	-	-	-	-	-	-	-
1988	2.90	2.59	154.12	38.69	183.07	141.94	143.30	45.84
1989	14.17	12.03	76.92	17.08	18.79	6.23	59.00	11.68
1990	6.25	3.29	52.54	9.00	18.80	4.99	43.60	6.60
1991	64.59	34.65	126.41	26.06	46.07	18.99	97.10	17.16
1992	6.37	2.59	44.12	6.64	29.50	6.16	34.60	4.23
1993	1.06	0.63	14.07	3.73	51.08	22.02	22.59	6.44
1994	8.04	5.28	37.18	8.45	25.42	5.27	29.70	5.19
1995	19.97	13.87	36.43	4.82	15.97	4.10	28.52	3.66
1996	7.27	3.95	49.23	7.19	92.54	17.76	54.52	6.36
Kg/haul	70-120 m		121-200 m		201-500 m		TOTAL 70-500 m	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1997	17.87	7.35	44.68	10.52	57.14	16.60	42.62	7.29
1998	14.13	4.17	42.78	8.13	78.88	22.01	47.14	7.58
1999	93.01	14.60	112.39	19.92	169.21	50.26	124.66	17.85
2000	62.39	12.00	91.99	14.75	58.72	24.94	76.19	10.61
2001	8.35	3.31	50.18	10.09	52.41	16.71	42.02	7.02
2002	31.40	5.02	69.00	13.41	36.75	12.07	51.80	7.64
2003	42.52	12.22	71.40	11.01	46.43	11.42	58.13	6.92
2004	2.80	2.11	14.05	7.79	59.51	21.41	24.76	7.31
2005	50.63	16.15	95.17	19.28	40.06	8.88	69.94	10.57
2006	14.28	7.01	70.79	12.60	115.08	39.88	71.64	13.18
2007	4.76	3.75	39.10	23.21	21.69	4.41	26.86	11.74

Table D6. Stratified mean catch (Kg/haul) and standard error of bottom-trawl surveys in Portuguese waters (Division 27.9.a).

		20-100 m		100-200 m		200-500 m		500-750 m		TOTAL	
Year	Month	y	sy	y	sy	y	sy	y	sy	y	sy
1990	July	**2**	2	**153**	103	**242**	42	**50**	5	**96**	35
	October	**11**	5	**90**	28	**762**	234	**42**	10	**153**	35
1991	July	**1**	1	**140**	40	**268**	38	**64**	18	**98**	15
	October	**8**	5	**83**	18	**259**	53	**121**	27	**91**	11
1992	February	**7**	7	**43**	35	**249**	21	**73**	3	**68**	12
	July	**1**	1	**29**	18	**216**	43	**27**	5	**47**	9
	October	**1**	1	**22**	7	**208**	44	**80**	3	**54**	7
1993	February	**0**	0	**19**	14	**105**	31	**36**	0	**42**	10
	July	**0**	0	**3**	3	**151**	28	**55**	5	**34**	4
	November	**0**	0	**90**	0	**189**	43	**6**	1	**86**	9
1994	October	**0**	0	**374**	30	**283**	32	**49**	7	**174**	11
1995	July	**0**	0	**18**	14	**130**	20	**52**	3	**35**	5
	October	**18**	15	**103**	21	**328**	91	**31**	12	**94**	16
1996	October	**25**	24	**12**	2	**36**	6	**25**	7	**22**	8
1997	June	**0**	0	**3**	3	**116**	42	**45**	12	**27**	7
	October	**2**	1	**54**	20	**77**	13	**7**	2	**32**	8
1998	July	**0**	0	**8**	5	**105**	17	**38**	3	**25**	3
	October	**1**	1	**384**	87	**427**	101	**20**	2	**212**	36
1999	July	**1**	0	**60**	21	**66**	19	**25**	2	**37**	9
	October	**0**	0	**69**	16	**80**	20	**18**	8	**41**	7
2000	July	**23**	13	**109**	34	**116**	10	**63**	6	**75**	13
	October	**11**	4	**155**	53	**196**	22	**54**	4	**99**	19
2001	July	**18**	7	**238**	37	**305**	116	**57**	14	**152**	23
	October	**106**	6	**474**	224	**294**	66		0	**295**	97
2002	October	**19**	12	**176**	81	**180**	24		0	**116**	34
2003	October	**24**	10	**114**	14	**119**	30	**34**	6	**76**	8
2004	October	**0**	0	**44**	10	**380**	27			**84**	15
2005	October	**0**	0	**25**	7	**407**	239			**81**	42
2006	October	**1**	1	**154**	59	**196**	32			**95**	26
2007	October	**1**	1	**136**	66	**141**	25			**91**	32

Table D7. Stratified total numbers (aged 0 blue whiting using a cut off of 18 cm) of blue whiting in French bottom-trawl survey. NA no survey.

Year	Bay of Biscay	Celtic Sea	Variance (Biscay)	Variance (Celtic Sea)
1987	1.31E+09	NA	3.65E+16	NA
1988	1.23E+09	NA	1.04E+17	NA
1989	3.87E+08	NA	1.08E+16	NA
1990	9.40E+08	NA	2.87E+16	NA
1991	2.52E+08	NA	3.04E+15	NA
1992	5.89E+08	NA	9.51E+15	NA
1994	5.52E+09	NA	4.07E+17	NA
1995	2.20E+09	NA	8.79E+16	NA
1997	2.09E+09	7.56E+09	2.23E+17	3.27E+17
1998	2.43E+09	8.48E+08	2.70E+17	1.04E+16
1999	5.33E+09	4.40E+09	5.84E+17	8.49E+17
2000	3.96E+09	2.95E+09	2.81E+17	1.02E+17
2001	1.32E+09	1.06E+09	2.66E+16	3.01E+16
2002	3.05E+09	3.66E+09	2.09E+17	1.71E+17
2003	1.31E+09	1.42E+09	4.56E+16	1.30E+16
2004	1.75E+09	1.12E+09	1.87E+17	2.86E+17
2005	7.51E+08	7.09E+08	2.18E+16	1.60E+16
2006	7.65E+09	2.77E+09	1.03E+18	4.65E+17
2007	2.92E+09	1.24E+09	6.27E+16	7.15E+16
2008	3.10E+07	7.74E+08	1.58E+14	2.22E+17
2009	8.33E+09	9.04E+09	8.57E+17	2.46E+18
2010	3.32E+09	2.08E+09	1.60E+17	1.35E+17

Table D8. Stratified total numbers (one group is defined here as less than 22cm in March) of blue whiting in the Icelandic bottom-trawl surveys.

Catch Rate	
Year	**< 22 cm**
1996	6.5
1997	3.4
1998	1.1
1999	6.3
2000	9
2001	5.2
2002	14.2
2003	15.4
2004	8.9
2005	8.3
2006	30.4
2007	3.9
2008	0.1
2009	1.6
2010	0.2
2011	10.8
2012	29.9
2013	11.7
2014	66.3
2015	43.8
2016	6.3
2017	1.8
2018	0.4
2019	0.1
2020	9.8

Table D9. Stratified total numbers (one group is defined here as less than 23cm in March) of blue whiting in Faroese bottom-trawl survey.

Catch Rate	
Year	< 23 cm
1994	1382
1995	1105
1996	4442
1997	1764
1998	360
1999	1330
2000	782
2001	3357
2002	3885
2003	929
2004	15163
2005	23750
2006	13364
2007	11509
2008	840
2009	3754
2010	824
2011	11406
2012	5345
2013	8855
2014	51313
2015	14444
2016	22485
2017	5286
2018	1948
2019	285
2020	140

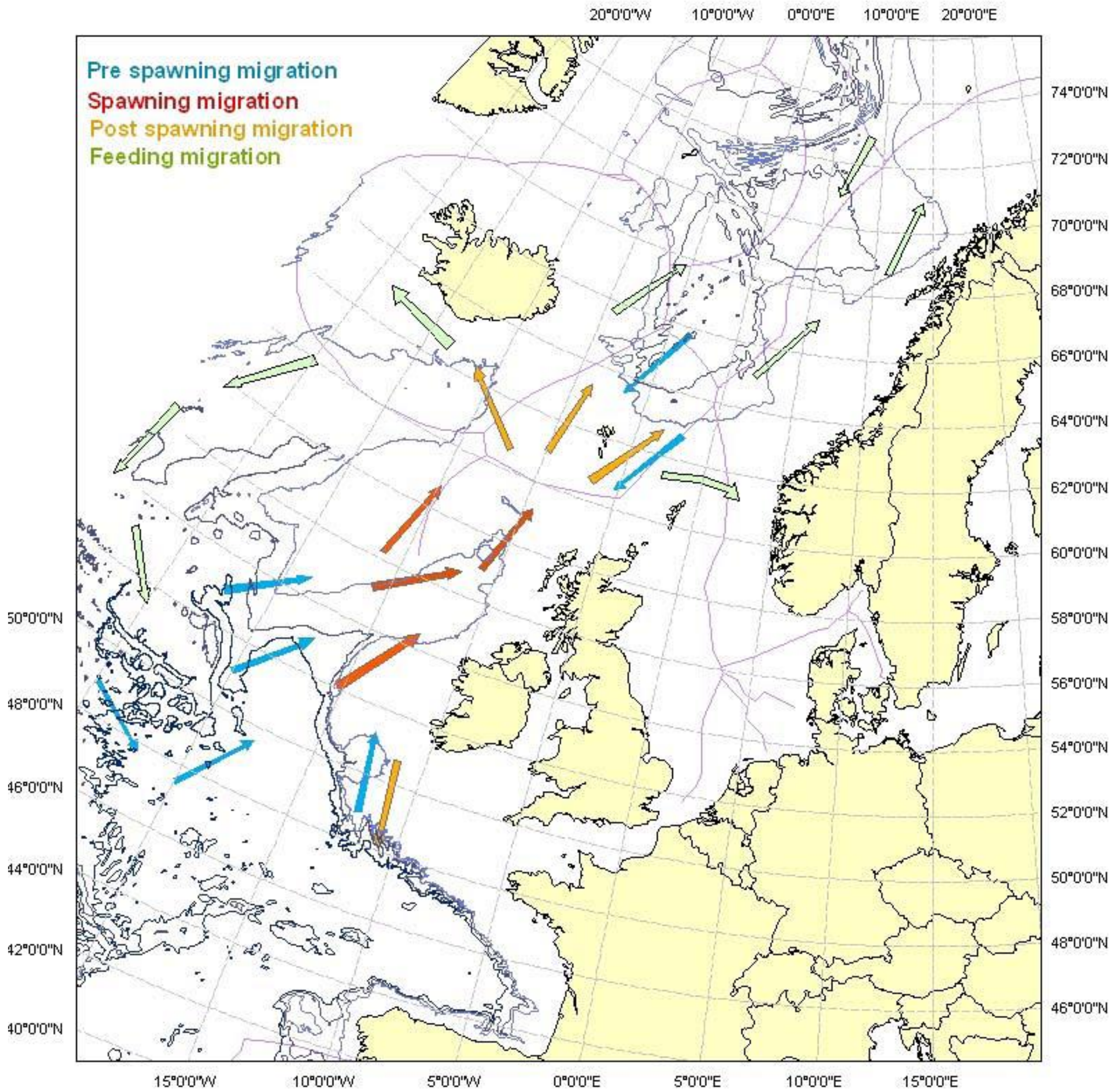

Figure A1. Migration routes for the blue whiting in the northern Atlantic. Tangen and Sveinbjörnsson (Source: Worsøe Clausen *et al.*, 2005).

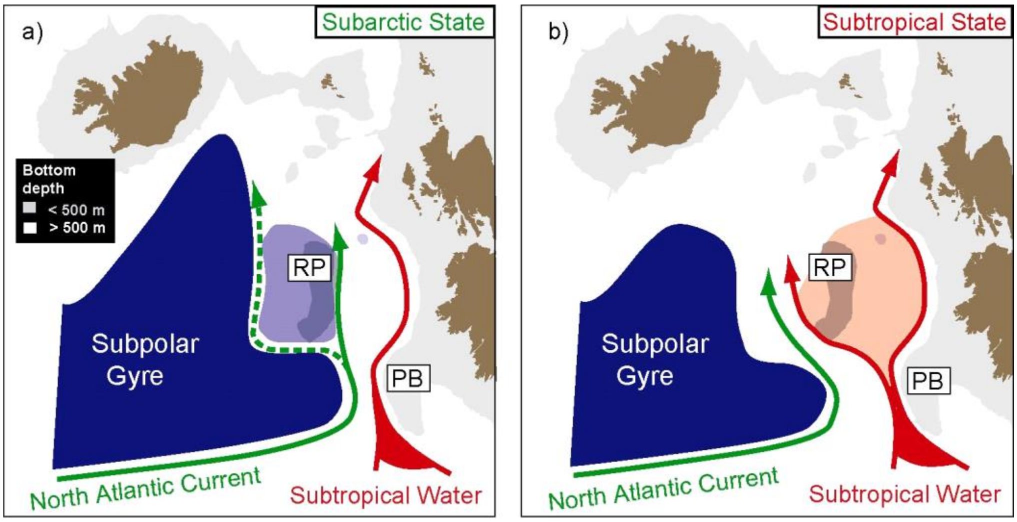

Figure A2. Outline of the source flows to the blue whiting spawning grounds in the Rockall Region. (a) A strong Subpolar Gyre (SPG) results in strong influence of cold Subarctic water near the Rockall Plateau. (b) A weak gyre results in warm subtropical dominance near the plateau (based on Hátún *et al.*, 2005). Abbreviations - RP: Rockall Plateau and PB: Porcupine Bank (Source: Hatun *et al.*, 2009a).

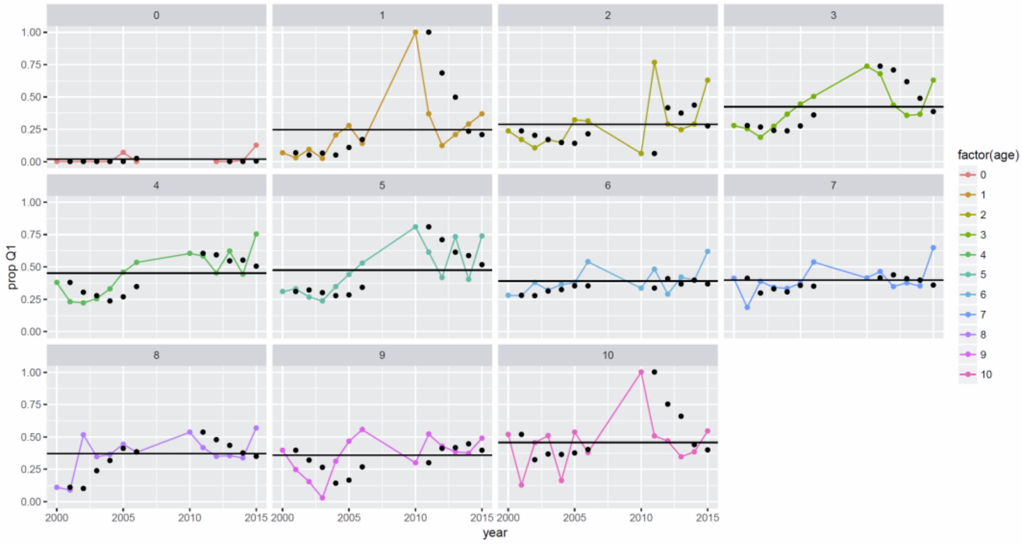

Figure B1. Proportion of the catches-at-age occurring in Q1 (colour lines with dots) and predicted proportion for the coming year based on the mean of the last 3 years (black dots) and overall mean (horizontal line).

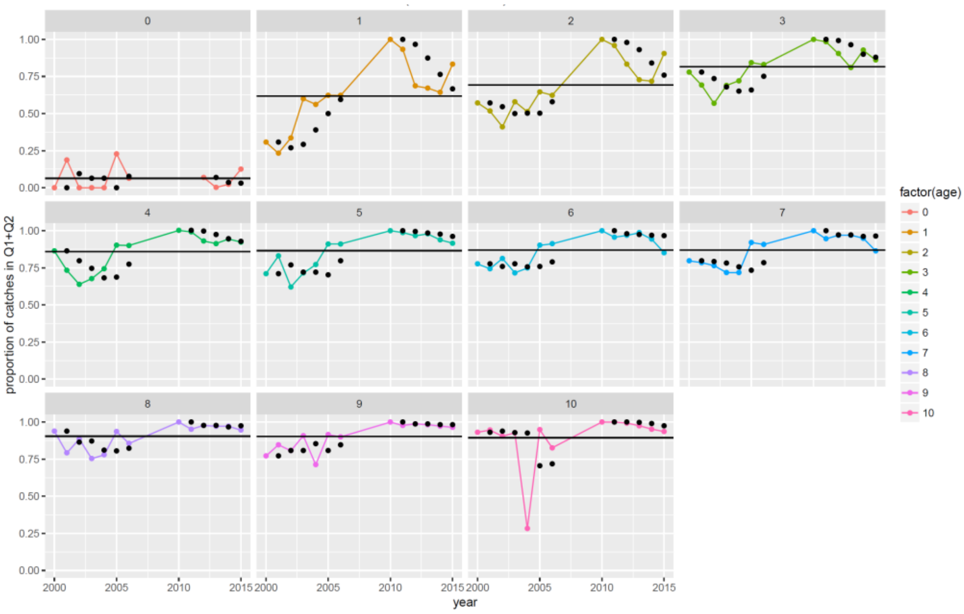

Figure B2. Proportion of the catches-at-age occurring in Q1+Q2 (colour lines with dots) and predicted proportion for the coming year based on the mean of the last 3 years (black dots) and overall mean (horizontal line).

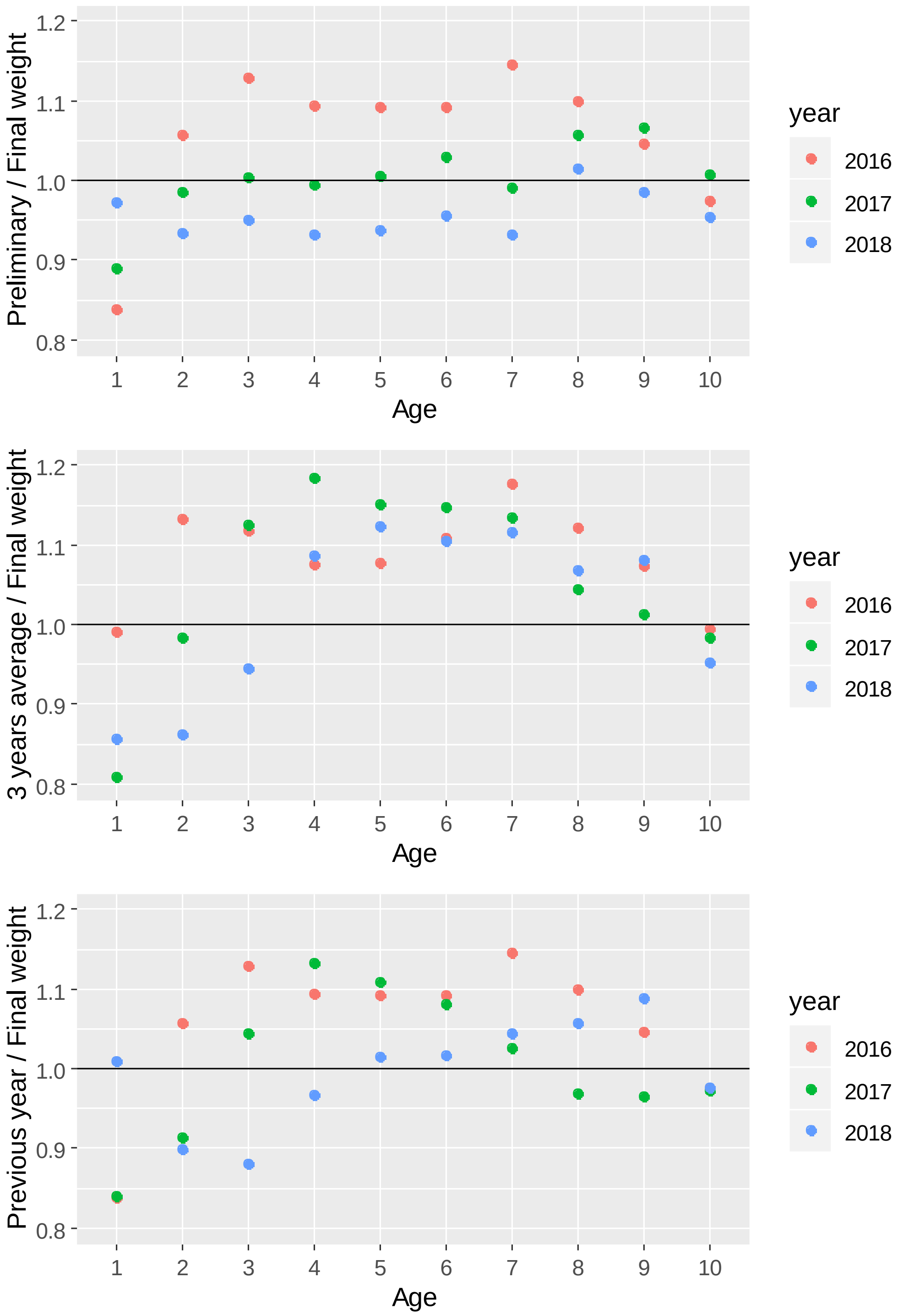

Figure B3. Comparison of preliminary mean weight at age for potential use in the assessment and final mean weight. The upper panel compares the preliminary weights with the final weights (obtained in the following year. The middle panel shows the average of the 3 preceding years weights compared with the final weights. Bottom panel shows previous years weights compared with the final year.

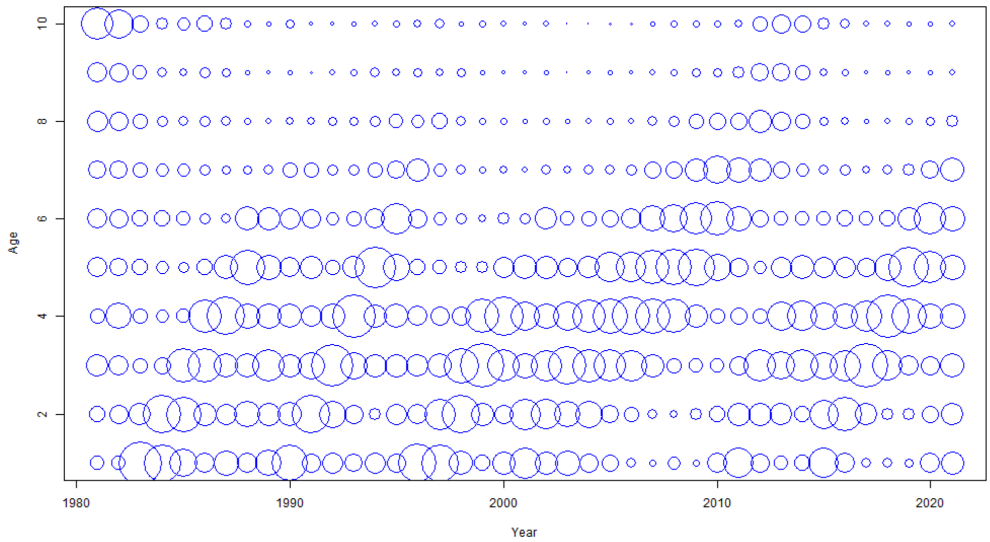

Figure B4. Catch proportion at age, 1981-2021. Preliminary values for 2021 have been used.

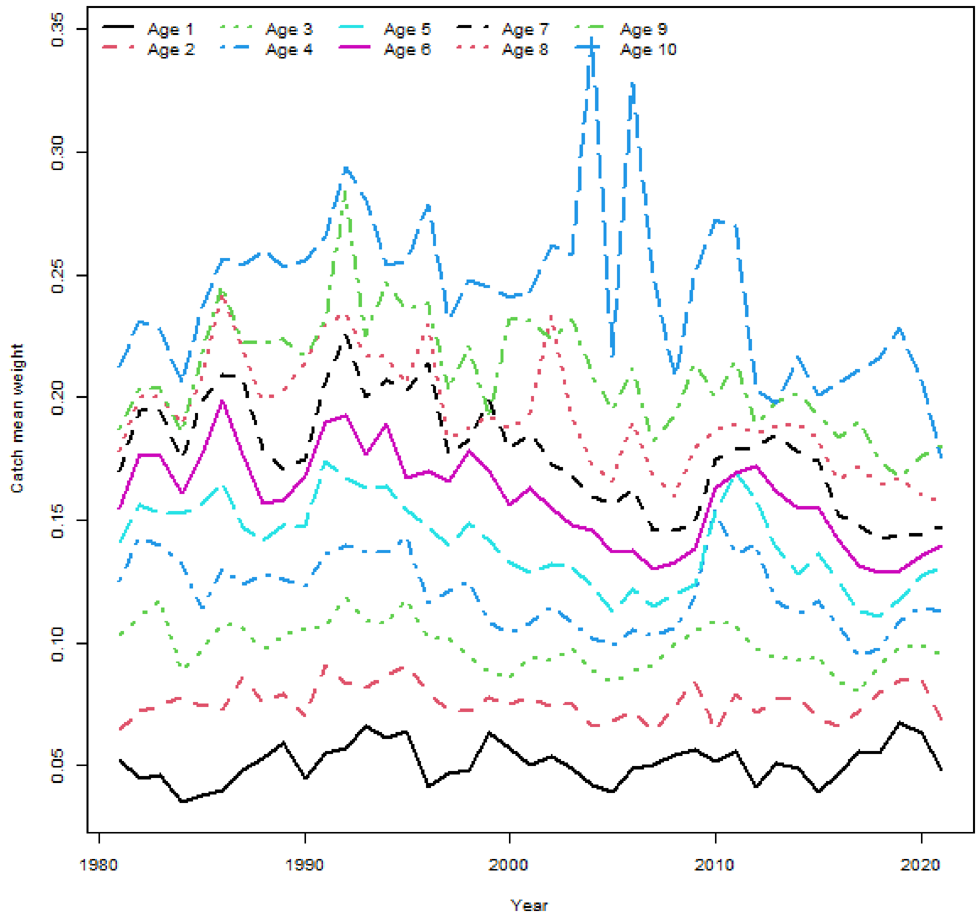

Figure B5. Blue whiting. Mean catch (and stock) weight (kg) at age by year. Preliminary values for 2021 have been used.

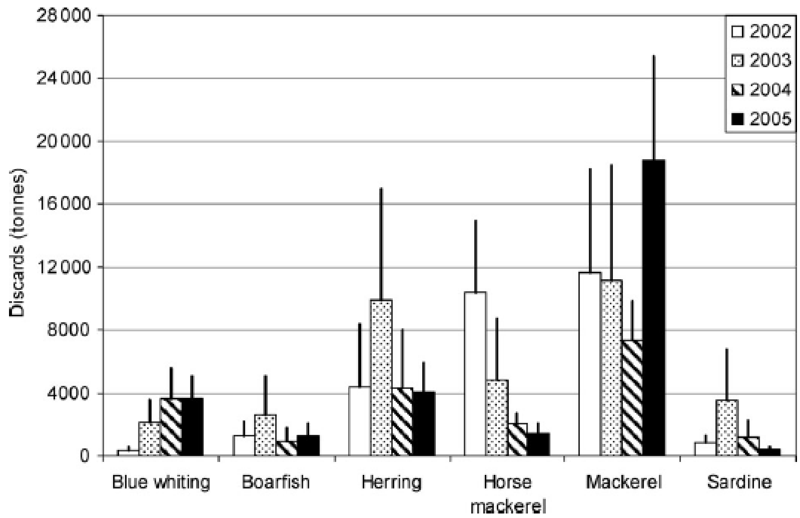

Figure B6. Biomass discarded by the Dutch freezer trawler fleet annually (raised using total number of trips) for the six most discarded species. The vertical lines represent the standard error on the estimates. (From Borges *et al.*, 2008).

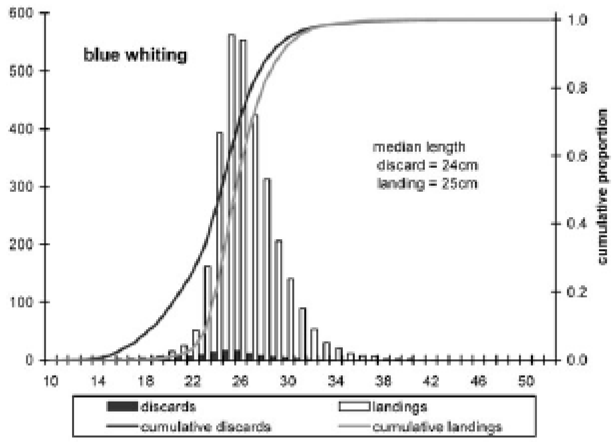

Figure B7. Length frequencies of discarded (filled histograms) and landed blue whiting (white histograms) by the Dutch fleet between 2002 and 2005. (From Borges *et al.*, 2008).

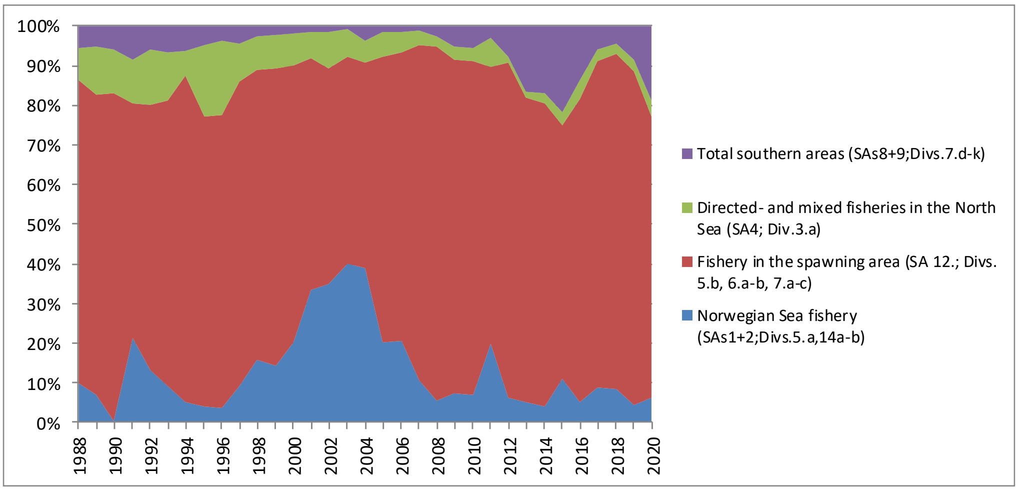

Figure H1. Development of Blue Whiting fisheries in different areas, from 1988–2020.

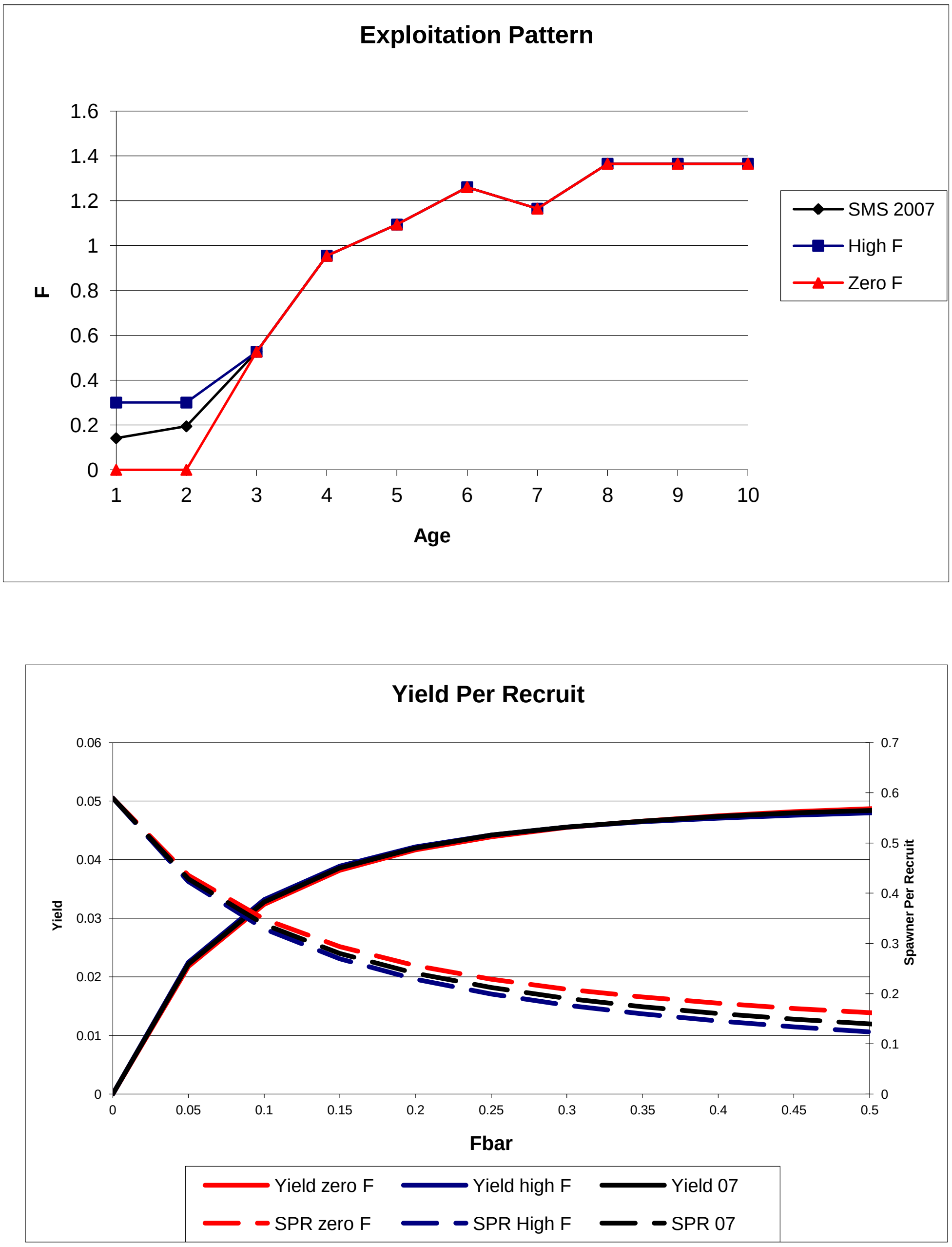

Figure H2. Blue Whiting exploitation pattern (upper) and yield-per-recruit curves (lower).