Stock Annex: Herring (*Clupea harengus*) in subdivisions 30 and 31 (Gulf of Bothnia)

PLEASE NOTE THAT due to an error in input data the outcomes of the WKCLUB 2020 benchmark are not valid. Catch opportunities for 2021 were estimated based on landings data only (see WGBFAS 2020 report). The assessment method for the stock will be evaluated again prior to WGBFAS 2021.

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

Stock	Herring (*Clupea harengus*) in Subdivisions 30 and 31 (Gulf of Bothnia)
Working Group	Benchmark Workshop for Gulf Bothnia Herring (WKCluB)
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Main changes	Changed assessment model, updated survey indexes, catch forecast (method) and reference points.

A. General

A.1. Stock definition

Management units of Atlantic herring, *Clupea harengus*, have traditionally been based on geographic separation using meristic or morphological characteristics or as a result of stocks with different migration and spawning behaviour (ICES, 2002). The amount of genetic differentiation in Atlantic herring is generally small (Larsson, 2008), and spatial structure and morphological characters have not consistently coincided with genetic differences (Ryman *et al.*, 1984; Jørgensen *et al.*, 2008). Although previous studies did not find genetic differences between Atlantic and Baltic herring (Ryman *et al.*, 1984 and Koskiniemi and Parmanne, 1991), recent genetic research however, supports the need of spatially separate management units due to transoceanic genetic divergence between the Baltic and North Sea herring populations (Bekkevold *et al.*, 2005; Jørgensen *et al.*, 2005) as well as within the Baltic Sea between spatially distinct populations (Bekkevold *et al* 2005; Jørgensen *et al.*, 2005; 2008; Teacher *et al.*, 2013). Moreover, Jørgensen *et al*. (2005; 2008) found significant associations between genetic differentiation (using microsatellite loci), sea surface temperature and salinity. The variable results that are found depending on the method used to assess spatial and temporal variation of biological characteristics within the current management units (e.g. Rahikainen and Stephenson, 2004) highlight the complexity in the stock structure of herring and calls for future multivariate approaches to stock identification of herring in the Baltic Sea (Waldman, 1999). Recent full genome studies of North Sea and Baltic Sea herring indicate a metapopulation structure with reproductive mixing combined with strong environmental selection (Barrio *et al.*, 2016).

The Gulf of Bothnia, i.e. subdivisions 30 (Bothnian Sea) and 31(Bothnian Bay) is inhabited by the Gulf of Bothnia herring stock. The stock boundary is set at 60° 30′ N in the south (till 2016 regarded separately as Bothnian Sea and Bothnian Bay stocks). This area is also the Management Unit III of the International Baltic Sea Fishery Commission (IBSFC), which has included subdivisions 30 and 31 since 2005 (until the end of 2004, SD 29N was also included).

According to tagging studies, there are two spring-spawning coastal herring populations in the Bothnian Sea (Subdivision 30) (Hannerz, 1955, 1956; Otterlind, 1957, 1962, 1976; Sjöblom, 1961; Parmanne and Sjöblom, 1982, 1986), one is distributed along the west coast and the second along the east coast. Similarly, the migration pattern on both sides of the Bothnian Bay is the same and a mirror image of each other (Aro, 1989). Different spawning groups have been identified in the spring spawning herring (Ehnholm, 1951).

The autumn-spawning stock is very sparse (Sjöblom, 1966; Sjöblom, 1978). The separation into the coastal and open sea components is not applicable to these populations, although different spawning groups have been proposed (Ehnholm, 1951).

The spring-spawning coastal herring on the Swedish and Finnish coasts spawn in May–July in coastal areas starting in the shallowest areas and shifting to deeper waters following rising water temperatures (Neuman, 1982). Spawning occurs along the entire coastline (Aro, 1989), but some areas are more preferred than others (e.g. Bergström 2012).

The migration of the adult population from the open sea to the spawning grounds on the Swedish coast takes place in late autumn and early winter (Aro, 1989), which is also indicated by the concentration of large herring in the main spawning areas in autumn (Bergström, 2012). The new spawners, as well as immature fish, overwinter inside the Archipelago Sea and near the coast, and new spawners join the spawning stock during the spawning time. The feeding migration starts soon after spawning. The main feeding areas are the slopes of the Bothnian Sea Basin and the outer Archipelago Sea, and in the north the slopes of the Bothnian Bay Basin and archipelago, as well. The herring in the western side of the Bothnian Sea seem to be more bound to the coast than the southern Baltic stocks (Otterlind, 1976). The feeding migration occurs mainly along the coast and from the Bothnian Sea, there seems to be some migration to the Åland Sea and the Quark (Otterlind, 1957, 1962). The Åland Sea is a transition area with the Central Baltic stock. The proportion of the eastward migration to the Finnish coast is very low.

The spring-spawning coastal herring on the Finnish coast also spawn in May–July along the whole coastline, from the northern side of the Archipelago Sea up to the Quark. Some of the younger mature age groups also overwinter and feed near the coastline and in the Archipelago Sea (Sjöblom, 1961). The migration of the adult population to the spawning grounds from the feeding and overwintering areas in the open sea, the Archipelago Sea and in the Quark Archipelago, occurs during the winter, when the first spawning shoals are near the coast. After spawning, the feeding migration to the open sea near the slopes of the Bothnian Sea Basin and to the outer Archipelago Sea occurs quite rapidly. Herring is located in the feeding grounds usually during July–December. The feeding migration extends to southern parts of the Bothnian Sea and inside the Archipelago Sea, the Quark and the Bothnian Bay. There is also some exchange between the Finnish and Swedish coasts (Parmanne and Sjöblom, 1982; 1986). The spring-spawning coastal herring in the east coast of the Bothnian Sea has a clear philopatric behaviour as shown by tagging experiments where about 95% of the recaptures were obtained within 150 km from the tagging place (Parmanne and Sjöblom, 1986).

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The biological parameters such as mean weights, annual weight increase, condition and maturity of herring show similarities in the two basins (i.e. SD 30 and SD 31) suggesting they are the same stock (WKBALT; ICES, 2017). However, recruitment patterns and the dynamics in the occurrence of large year classes differed indicating they may be separate stocks. Differences in recruitment and year-class strength could however be due to differences in climate conditions in the two basins, for example SD 31 having longer ice covered periods and harsher winters. Genetics and tagging studies are recommended to further clarify if these stocks are similar. The vast majority of the combined stock in the Gulf of Bothnia inhabits the Bothnian Sea area.

Herring in SDs 30 and 31 have been assessed separately historically, but were combined into one assessment unit at WKBALT (2017). The main arguments for combining these previously separate assessment units:

i) There is presently no strong biological evidence to conclude on whether to separate or combine SDs 30 and 31 in the stock assessment, based on biology alone.
ii) Data availability (lack of survey in SD 31) does not support a good quality assessment for SD 31 and this is unlikely to be possible to improve in future.
iii) There is no concern for overexploitation of the smaller stock component in SD 31 when merged together with a larger component in SD 30. This is because of natural conditions (ice and bottom features: difficulties in trawling) restrict fisheries in SD 31, and there is generally low economic interest in herring fisheries in SD 31.

A.2. Fishery

Since the mid-1970s the fishery has been dominated by pelagic and deep midwater trawl and trapnet fisheries. In 2017, the Finnish fishery accounted for 90% of the total catch, and trawl fisheries accounted for 96% of the Finnish catches. The trawling vessels in SD 31 are smaller than in SD 30, and this has not changed with time, probably because of the shallow and stony waters of SD 31, where it is difficult or even impossible for large trawlers to operate. The remaining Finnish catches (4%) were taken mainly by trapnets, which target the spawning component of the stock in May–June, and 0.1% were taken with coastal gillnets. The Swedish part of the fishery has been much smaller, e.g. 2–9% of the total catches in 2000–2010 and of a different gear composition. However, in recent years, the Swedish gear composition has changed and the share of Swedish catches has increased, being 10–17% in 2013–2017. In 2017, 94% of the Swedish catch came from trawls (71% from pelagic trawling and 23% from deep midwater trawling), 6% from gillnets, and <1% from other passive gears. Catches increased in the late 1990s because of an increased efficiency in the fishery and again since 2012 to record high levels due to stock growth and TAC increase. The fishery is regulated by a TAC.

In the herring fishery, pelagic and deep mid-water trawls overlap. Generally, the same vessels carry out pelagic and deep mid-water trawling and use the same gear for both. The pelagic trawl exploits the younger part of the stock and the deep midwater trawling is more directed towards the adult part of the stock. In autumn and early winter before the sea is covered with ice, pelagic pair trawling is used for industrial purposes. Many pelagic trawling vessels operate between the Bothnian Sea (SD 30) and the Åland Sea and northern Baltic proper (SD 29), depending on fishing possibilities and ice cover during winter. Deep-water trawling takes exclusively Baltic herring, whereas pelagic trawling catches sprat, as well. The trawlers operate in different fishing grounds depending on the fishing possibilities and ice cover.

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Sprat occurs in SD 30 in late autumn, winter and early spring but the sprat bycatches in herring fisheries are usually low. Sticklebacks are also caught in small, but growing numbers. Sprat and stickleback in the herring trawl fisheries are used for fodder along with the herring.

In the trapnet fishery for Baltic herring, a variety of trapnet types are used. This fishery is conducted near the coast and inside the archipelago and is mainly targeting the spawning component of Baltic herring stock in spring and early summer (May–June, in the Bothnian Bay, also July).

The herring discarding rates in Swedish fisheries was estimated to be 6–12% of Swedish herring catches in 2008–2010. Further analyses on discarding in the Swedish herring fisheries in SDs 30 and 31 are needed.

Discarding rates in the Finnish fisheries are negligible (estimated to be a few tons annually) and very small also in the Swedish fisheries but these have, however, been taken into account in recent assessments.

A.3. Ecosystem aspects

The increasing trend in stock size of the Bothnian Sea herring observed since the 1990s has been driven by good recruitment. The biomass dynamics of recruits (age 1) have been linked to increased abundance of *Bosmina* sp. (Lindegren *et al*., 2011), which is an important food source for both young of the year herring <5 cm in the northern Baltic Proper (Arrhenius, 1996), and for herring in the Bothnian Sea (Flinkman *et al*., 1992). Recruit abundance models also show that the number of recruits (age 1) is largely explained by *Bosmina* sp. abundance and sea temperature during the main growing season (July–September) for the young-of-the-year, while the best model did not identify an effect of the spawning stock size in recruitment (Gårdmark, Working Document 1 for WKPELA; ICES, 2012).

Among abiotic factors, climate change can be seen in increasing temperatures in the measurements conducted since 1980 (Kuosa *et al*., 2017). Increasing temperatures have probably increased the production in the ecosystem and improved the feeding conditions of herring larvae. Several especially abundant year classes of herring have developed in very warm years, which supports the effect of temperature. In addition to increase in temperature, the contents of dissolved inorganic phosphorus and dissolved inorganic nitrogen (winter values) have increased since 1980 (Kuosa *et al*., 2017), both possibly having additional effects besides the increase in temperature, regardless of the reason to increased nutrient levels. The increase of especially phosphorus is similar to the trends observed in herring abundance.

The Gulf of Bothnia herring is the prey of several predators, including cod (*Gadus morhua*) at least periodically in the southern areas, salmon (*Salmo salar*), coastal piscivores (pike, perch, pike-perch), grey seals, ringed seals, and birds such as cormorants (*Phalacrocorax carbo*). Grey seals can be regarded as the main predator for several reasons: cod and salmon are less abundant and herring makes up to about 70% of the biomass in the diet of an average grey seal (Lundström *et al*., 2010; Gårdmark *et al*., 2012). The proportion of herring in the food of cormorants is below 35% (J. Salmi, pers. comm.), and there are only a low number of ringed seals permanently in the Bothnian Sea (Anonymous, 2007).

Grey seals predate selectively on larger individuals of herring, and the mean length of prey was about 18 cm (Gårdmark *et al*., 2012). While grey seals have not been found to be a major driver of herring population dynamics (Lindegren *et al*., 2011), Östman *et al*.

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(2014) found that the size-selective removal of herring by grey seals may have decreased average weight at age of herring cohorts over the latest decades. The variation in length-specific body growth of cohorts was also explained by zooplankton resources (*Eurytemora* sp.), intra-specific density, and cohort-specific fishing mortality (Östman *et al*., 2014). Since the latter half of the 2000s, a gradual increase in mean weights-at-age has been observed.

B. Data

B.1. Commercial catch

Finnish commercial herring catch statistics is based on catch notifications submitted by fishermen at set intervals. The application of the Act (1139/94) on implementing the Common Fisheries Policy of the European Union obliges all commercial fishermen to submit catch notifications.

The discards are negligible in both countries' commercial fisheries and therefore not sampled either. Also, the information of discards from Finnish fishermen's reports is not used in assessment, but the Swedish reported discards are added to the total catches.

The fishing data of vessels ≥ 10 metres long are entered in the EU fishing logbook. The data entered are the dates of fishing by fishing trip, the size of the catch by species, the fishing (statistical) rectangle, the gear and number of gears used in fishing, and the trawling time in hours. A fisherman is obliged to keep an up to date logbook on board his vessel. The logbook must be returned to the regional authorities within 48 hours of the catch being landed.

With the exception of salmon catches, the Finnish fishing data of vessels ≤ 10 metres long are entered monthly in a coastal fishery form. The data entered are the size of the catch by species by the statistical rectangle, the type and number of gears used in fishing, and the number of fishing days. The forms must be returned to the regional authorities by the fifth day of the following month. All logbooks and most of the other catch notification forms are checked by national authorities.

The proportion of the Baltic herring catch, landed in Finland for the food and processing industry in relation to the total catch of that species, is estimated with the aid of the fish purchasing register that is maintained by the Ministry of Agriculture and Forestry.

Because all the main fisheries (pelagic trawling, deep midwater trawling and trapnets) have different exploitation patterns, their catches are also sampled separately. The sampling in the Gulf of Bothnia herring fishery is performed according to EU DCF requirements, covering 12 strata (three fleets and four year-quarters).

Since the study projects funded by DG XIV (International Baltic Sea Sampling Programs I & II) in 1998–2001, a length-stratified subsampling scheme has been applied to estimate age compositions of the Finnish catches of Baltic herring. This sampling scheme is designed to be compatible with international databases and uses standardized methodologies in data processing. Baltic herring samples are collected mainly in fishing harbours and, if necessary, also on board commercial fishing vessels. In the sampling scheme, the annual life cycle of Baltic herring and the presence of the ice coverage during the winter in the Gulf of Bothnia have been taken into account. Because of icing conditions, the three fishing gears are not in use year-round (e.g. trapnet

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fishery is usually conducted only in spawning time during quarters 2 and 3). The sampling effort is roughly based on the proportions of catches in different fisheries. Moreover, the sampling intensity in general is locally adjusted during the year according to temporal and regional changes in fisheries. The seasonal herring fishing intensity is predominantly dependent on the TAC, which may cause fishing restrictions in certain fisheries and/or seasons and may therefore change the sampling intensity from the original plan. A minimum coverage target is at least one sample by fishery per month (or three samples by fishery per year-quarter). The sampling strategy is to have age-length samples from all major gears in each quarter.

The Finnish and Swedish input files are uploaded to ICES InterCatch database. The data can also be found in the national laboratories and with the stock co-ordinator. The national data have been aggregated to international data in InterCatch.

Table B1. Description of the types of data available per country.

	Kind of data				
Country	Caton (catch in weight)	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Finland	x	x	x	x	x
Sweden	x	x	x		x

B.2. Biological sampling

The age and the individual weight data are obtained from both Finnish and Swedish landings from all year-quarters as well as from the catch samples in acoustic surveys in 3rd and 4th quarter. The annual weights-at-age are weighted by the year-quarterly catch numbers for WECA. The maturity ogives are based on the proportions of mature individuals of each age group before spawning time in the Finnish commercial data, and are updated every year.

B.2.1 Calculation of catch-at-age

In Finland, the calculation of catch-at-age is based on year-quarterly performed length-stratified random sampling of individual fish (at minimum 10 aged individual fish from all prevailing 0.5 cm length classes) and length samples of at least 300 specimens per sample from different commercial fisheries per quarter. The average number of individual-samples is 1100 from commercial fisheries and 2500 from surveys in SD 30 and 600 from commercial fisheries in SD 31 annually, and the average number of length measurements is 18 500 and 6000 respectively.

The quarterly collected length distributions (from length sampling) are converted into age distributions with year quarterly prepared age–length keys, ALKs, which are derived from the sampling of individuals.

The quarterly catches from the main herring fisheries (OTM + PTM carried out in midwater and deep midwater and trapnets, FPN + FYK) are divided by the mean weight of the herring from length samples of the respective fisheries in order to get the total catch number of fish for all strata (all fisheries, four quarters). The total catch numbers from each fishery and year quarter are then multiplied by the proportions of the age classes in the age distributions and summed up to get the annual catch-at-age.

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In Sweden, the length samples of at least 300 specimens per sample from two (main) commercial fisheries [bottom trawls (XTB) and gillnets (GNS)] in SD 30 and only from gillnets in SD 31 are collected quarterly each year. The catches of pelagic trawl (OTM and PTM) fisheries are not sampled. Length-stratified random sampling of individual fish (app. 20 aged individual fish from all prevailing 0.5 cm length classes per quarter) is performed only for gillnet fisheries. In SD 30 the average total number of annual length measurements is 5600 from bottom trawls and 2300 from gillnet fisheries, and the average total number of sampled fish individuals is 490, and in SD 31 the average total number of annual length measurements is 1700, and the average number of sampled fish individuals is 450.

The length distributions (from length sampling) are converted into age distributions with quarterly prepared age–length keys (ALKs). For that purpose, additionally Finnish ALK and mean weight-at-length data from trawl fisheries are borrowed.

The calculation of total annual catch-at-age follows the same procedure as in Finland.

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B.2.2 Calculation of mean weight

The mean weights-at-age are derived from the individual data collected from commercial catches all year round as well as from the individual data of acoustic survey trawl samples during September–October (2600 individuals annually), and averaged over year-quarters. The annual mean weights-at-age for assessment are derived by weighting the year quarterly mean weights by the year-quarterly catch numbers.

B.2.3 Maturity

The maturities are defined from the individual data that are collected all the year round from commercial catches with other so called “stock-related variables” as length, weight and age, and from the trawl samples of the acoustic survey. The data for the maturity ogive used in assessments are collected from samples before spawning (i.e. January to March in SD 30 and March to May in SD 31), because the idea is to get the proportion of spawners by age from the whole population, before the spawning part separates itself from non-spawners by approaching the coastline spawning areas.

The share of mature fish in each age group is calculated from annual data and the annual number of the individual samples for maturity definitions that are used for the maturity ogives has been on average (2010–2015) 283 in SD 30 and 212 in SD 31.

The maturity scale (Table B2) in use is the modified European standard nine-stage scale and the same scale is used both in Finland and Sweden. The stages II–VIII (VIII–A and VIII–B) are considered mature while stage I and IX are counted as “non-mature” although stage nine (abnormal) is usually mature, but not accounted to take part to spawning.

The maturities defined during a Swedish acoustic survey in 4th quarter and the maturities derived from Finnish 1st quarter sampling of commercial catches have showed very small differences.

In the WKPELA 2012 benchmark (ICES, 2012), the sensitivity of the annually changing proportions of spawners in age groups was tested (by several types of averages over time[1]) and even though there are clearly visible annual changes in mostly 2-year-olds,

[1] Four new combinations of maturity ogives were introduced to XSA (maturity ogive with 3 and 5 year running averages for the whole time-series, constant maturity ogive

there was only negligible impact to e.g. the estimates of SSB. It was concluded then that it was still better to have the latest real information on maturity-at-age than assume something else.

The reason for the "instability" was found to be the high interannual variation in the maturation of 2-year olds in the whole time-series and especially in 2010. The maturity calculations from raw data were examined carefully, and no mistakes were revealed.

Table B2. Maturity scale in use in Finland and Sweden.

Std Eur. Scale	Maturity stage (code)	Maturity stage
Ia	I	Immature, juvenile
Ib	II	Immature, early development
Iia	III	Maturing, early stage
Iib	IV	Maturing, late stage
IIIa	V	Spawning, prepared
IIIb	VI	Spawning, running
IV	VII	Spent
Va	VIII A	Regeneration, regressing
Vb	VIII B	Regenrating/skipped spawning
VI	IX	Abnormal

From 2002 to 2006, Finnish samples were age determined with two different methods in parallel, using traditionally whole otoliths and as a new method, neutral red stained slices of cut otoliths. The effects of the age determination method were presented at the WGBFAS meeting in 2006 (Raitaniemi and Pönni, 2006). The method affects the age distribution as well as the proportion of mature fish at age. Especially in old age groups (from age 5 or 6 on), determination from cut otoliths generally results in an older assessed age compared to whole otoliths. In the comparison, the numbers-at-age in the total catch differed about 2% on average, but ranged from 0.4% to 52% depending on year and age. On average the proportion of 4–8-year-olds in the catch was 11% lower, and the proportion of ages 9+ was 32% higher, when using neutral red stained slices compared to whole otoliths.

According to Peltonen *et al*. (2002), the agreement between the determinations of different age readers was better with the cut otoliths technique than with whole otoliths. A combination of age data from Finnish cut otoliths (representing 98% of the catch) and Swedish whole otoliths (representing 2% of the catch) was used between 2002–2006. The slicing method was calibrated between Finland and Sweden in 2007, and it has been applied also to Swedish catches as well as Bothnian Sea surveys since 2007. Since age determination using cut otoliths is considered to be more accurate (Raitaniemi and Pönni, 2006), this method is used as the standard method for ageing all

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for the whole time-series as an average of the whole time-series and two different averages over the time-series according to periods before and after the alleged regime shift (1973–1988 and 1989–2010)). Resulting estimates of SSB were compared to the annually updated maturity ogive in SPALY run, and the differences were found to be negligible with the exception of year 2010 only.

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the samples, and the time-series including ages from whole otoliths from 1980–2001 and cut otoliths from 2002 onwards is used in the assessments of this stock.

B.3. Surveys

Annual hydro-acoustic surveys have been conducted in SD 30 in October from 2007 until 2010 with Swedish RV Argos. In 2011 and in 2012 the survey was performed with the Danish RV Dana, 2013–2016 with Finnish RV Aranda, and in 2017 with RV Dana again. This survey is co-ordinated by ICES within the Baltic International Acoustic Surveys (BIAS). The annual survey-indices are collected and calculated with standardised methods within the international coordination of ICES WGBIFS and stored in international databases. The actual calculations have been performed in years 2007–2012 in the Swedish marine research institute (Havsfiskelaboratoriet) by Niklas Larson and from 2013 onwards in the Natural Resources Institute Finland by Juha Lilja.

Based on the implementation progress to development StoX software for calculations of WGBIFS acoustic stock indexes, it was decided that members of WGBIFS StoX task subgroup should analyse their national survey data with StoX software and compare the results with their official results. In SD 30, the comparison between StoX and official results showed significant difference between 2013 and 2015, but no differences were found between 2016–2018. Consequently, all official results (based on Excel spreadsheets) were recalculated and an error was discovered in calculations for 2013–2015 indexes. The error was corrected and new results were presented and accepted by WGBIFS??

The acoustic survey has been considered a reliable tuning fleet and has been included into the SD 30 assessment in 2013 after an independent review process (ICES, 2015a).

The SD 30 acoustic estimates are used as abundance indices (tuning fleet) for the assessment of Gulf of Bothnia herring stock (SDs 30 & 31) (see the text table in Section C, Assessment: data, method and settings). In the acoustic tuning fleet, age-groups 1–15 (true ages) are applied (Figure B1).

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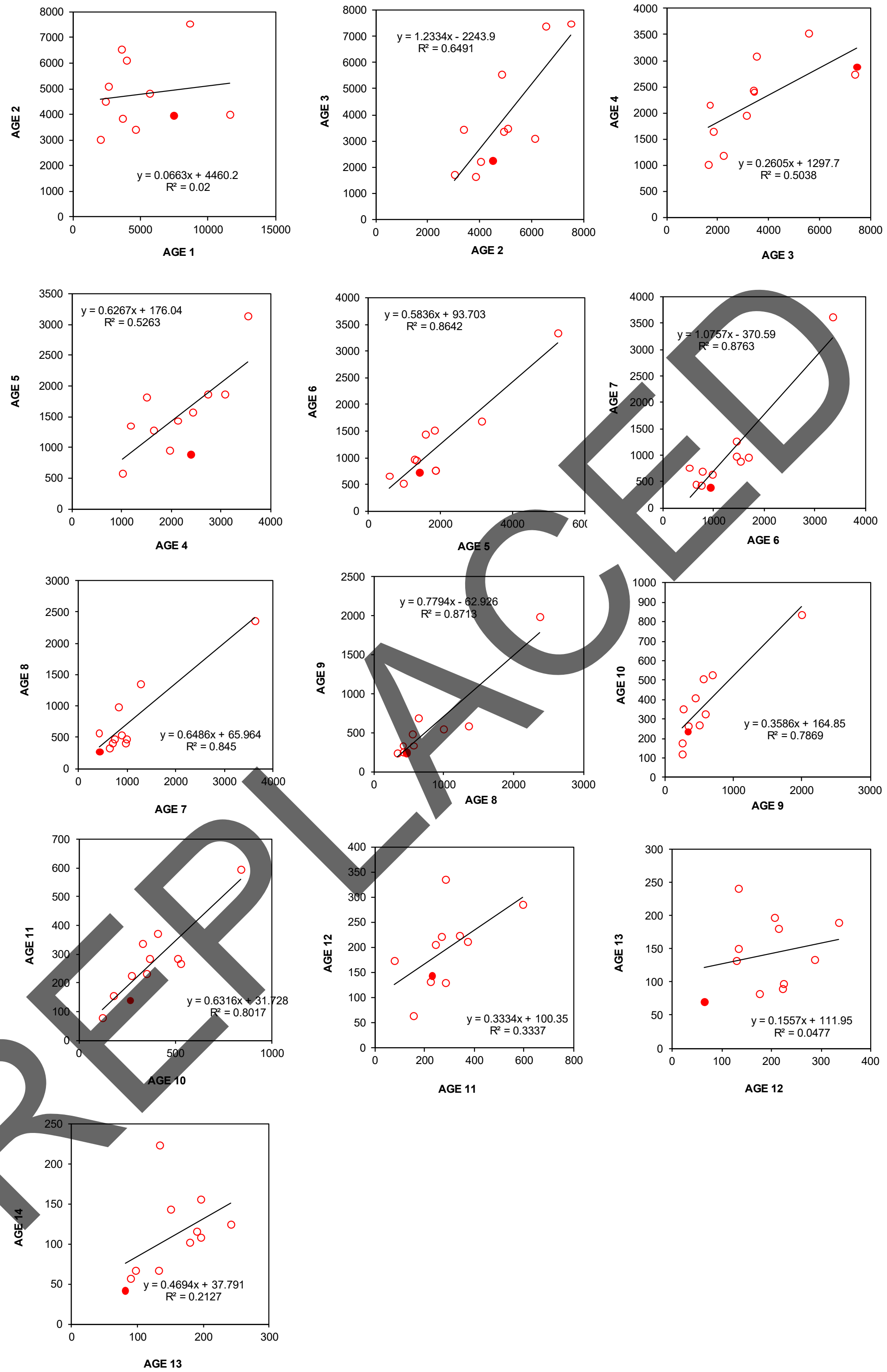

Figure B1. Consistency between consecutive age classes in acoustic tuning fleet.

The coverage of the acoustic transects and trawl samples has mostly been good. In 2012, the coverage was only half of the "normal" because of a sudden 50% reduction in funding. In 2014, there were problems with the fishing gear, which reduced the trawl hauls, but the spatial acoustic coverage was not affected that much. In 2015, a storm damaged the ship so that the most northern part of the area had to be skipped due to lack of time after fixing the damage in harbour.

The 2012, 50% reduction in the survey effort, as well as the 2014 and 2015 results were, however, considered acceptable for the index by the survey expert working group, WGBIFS (ICES, 2013; 2015; 2016, 2017; 2018).

The survey is based on Baltic International Acoustic Surveys (BIAS) manual (ICES, 2016) with the aim of 60 Nm of acoustic transect and two trawl hauls per statistical rectangle. In the catch sampling, at least 300 fish are measured in 0.5 cm length classes for length distributions, and ten individuals from all prevailing length classes are aged per rectangle, comprising normally about 20 000 length-measurements and 2600 age readings annually.

B.4. Commercial CPUE

Trapnet fishing that takes place during the spawning period in second year-quarter is used as a tuning fleet in the stock assessment (see the text table in Section C, Assessment: data and method). The main commercial fleets, i.e. pelagic trawling (single- and pair-trawling) and deep midwater trawling are not used.

The reason for not using commercial trawl fishery fleets in the stock assessment is the change in trawls. There has been an increase in trawl gear size and changes in gear characteristics since the early 1980s. In the past, reported fishing effort data (trawling hours) may not have been accurate.

The trapnet tuning fleet was revised in 2012. Before 2012, the total number of trapnets set in SD 30 was used as effort for the herring catch caught. Throughout the 1980s, the total number of trapnets decreased, but since 1990s, it has remained more or less stable. Due to reduction in effort in years 1974–1989, the revised dataset starts at 1990.

The revised dataset is considered geographically representative and only includes trapnets that are used for catching herring in spawning time (April–June). The 1990–2006 dataset used in the assessment includes only those areas (statistical rectangles) that have continuous time-series for the catches and the corresponding effort (number of herring trapnets). The CPUE taking into account the difference in catchability between sites is used as an index for stock size (numbers-at-age) in the assessment.

In 2015, the trapnet index was, however, not considered sufficiently reliable by the working group, as it is introducing increasing uncertainties to the assessment.

After a review process (ICES, 2015a) it was decided that the trapnet tuning series should be truncated and the last years of data (2007 onwards; overlap period between the acoustic and the trapnet tuning series) were not included in the assessment (ICES, 2015a). In the benchmark of 2017 and inter-benchmark of 2018, this practice was continued, excluding trapnet data from the years 2007 onwards in the assessment.

The trapnet abundance indices standardization model was changed from previously used GLM to the multi-layer perceptron (MLP) algorithm (ICES, 2017). The statistical model performances of MLP and GLM models were roughly comparable. However, in very high abundance years the MLP based model fit against observed data was better than that of GLM. Hence, the MLP model was updated with additional age groups (3–

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14, previously 3–9). The statistical performance of the MLP model with age groups 3–14 was better than using age groups 3–9. Therefore (and altogether), the working group used MLP based CPUE estimates of age groups 3–14 in 1990–2006 in stock assessment of the combined Gulf of Bothnia stock.

C. Assessment: data,method and settings

Assessment of Gulf of Bothnia herring (SD30–31) was conducted using the Stock Synthesis (SS) model (Methot and Wetzel, 2013). Stock Synthesis is programmed in the ADMB C++ software and searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. The assessment was conducted using the 3.30 version of the Stock Synthesis software under the windows platform.

The assessment model of herring in SDs 30–31 is a one area, annual, age-based model where the population is comprised of 20+ age-classes (with age 20 representing a plus group) with sexes combined (male and females are modelled together).

The model starts in 1963 and the initial population age structure was assumed to be in an exploited state, so that the initial catches were assumed to be the average of last three years (1963–1965) in the time-series. Fishing mortality was modelled using hybrid F method (Methot and Wetzel, 2013). Option 5 was selected for the F report basis; this option represents a recent addition to Stock Synthesis and corresponds to the fishing mortality requested by the ICES framework (i.e. simple unweighted average of the F of the age classes chosen to represent the F_{bar} (age 3–7)).

Spawning–stock biomass and recruitment

Spawning biomass was estimated at the beginning of the year and it was considered proportional to fecundity. In the model, the recruitment was assumed to be only a single event occurring at the beginning of the year. Recruitment was derived from a Beverton and Holt (BH) stock–recruitment relationship (SRR) and variation in recruitment was estimated as deviations from the SRR. Recruitment deviates were estimated for 1963 to 2018 (55 annual deviations). Recruitment deviates were assumed to have a standard deviation (σR) of 0.6, which was derived using the likelihood profile function in r4ss. The reference model estimates steepness (h) for the SRR within the model using with a full Beta prior of 0.74 with a standard deviation of 0.113 as derived for herring in Myers *et al*. (1999).

Growth, weights and maturity

Empirical weight-at-age matrices for both commercial fleet and survey indices are provided as input for the model and are estimated using commercial and survey data. Maturity-at-age matrix is also provided as input and derived from commercial data.

Natural mortality

An age-varying natural mortality is assumed to be constant for the entire time-series (Figure C1, Table C1). M was estimated based on the methods described in Then *et al*. (2015) and Lorenzen (1996). Then *et al*. (2015) estimation of M is based on maximum age (tmax = 25) and parameters of the von Bertalanffy growth curve as derived from www.fishbase.org for the same area. The Lorenzen type (Lorenzen, 1996) of M-at-age function assumes a declining relationship between M and the mean weight of fish in successively older age classes. The growth and the length–weight parameters used for

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the M estimation are reported in Table C2. In all model configurations tested, M gradually decrease from 0.563 to 0.257 for ages 0 to 20. In order to reduce the number of parameters to be used in the model, natural mortality was set using six breaks: age 0.5, 1, 3, 5, 8 and 15., where M for the adjacent ages is simply linearly interpolated using the values estimated for the age breaks.

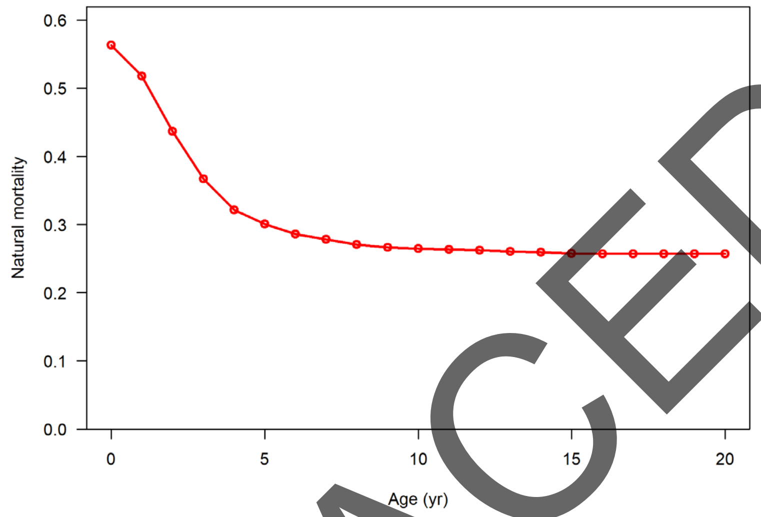

Figure C1. Herring SDs 30–31. The age-specific natural mortality used in the model.

Table C1. Herring SDs 30–31. Natural mortality vector by breaks used in the model.

Age 0.5	Age 1	Age 3	Age 5	Age 8	Age 15
0.563	0.472	0.332	0.290	0.267	0.257

Table C2. Herring SDs 30–31. Parameters used to estimate the natural mortality vector by age.

Life-history parameters		
k (combined sex)	0.34	From Fishbase
L_{inf} (combined sex)	21	From Fishbase
t_0 (combined sex)	-1.1	From Fishbase
A	3.99E-03	Estimated from LW BIAS survey data
B	3.145258	Estimated from LW BIAS survey data

Uncertainty measures and likelihood

The total likelihood of the model is composed of a number of components, including the fit to the survey and CPUE indices, tag recovery data (when tagging data are used), fishery length–frequency data, age compositions and catch data. There are also contributions to the total likelihood from the recruitment deviates and priors on the individual model parameters (if any). The model is configured to fit the catch almost exactly

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so the catch component of the likelihood is generally small (although catch penalties might be created and catches are entered with uncertainty). Details of the formulation of the individual components of the likelihood are provided in Methot and Wetzel (2013).

Samples sizes, CVs, data weighting

For the commercial fleet the CV of the catches was set to 0.05. The CV of the initial catches of the commercial fleet was set to 0.1 to add extra variability. The annual sample size associated with the age distribution data for commercial catches is reported as number of trips sampled. The CV of both the acoustic and trapnet survey indices are not available. Therefore, a value of 0.1 is assumed for all years. The relative weighting of the age compositions of the reference model were estimated using Francis method as implemented in r4ss package. The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix, which was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

Fishery dynamics

Fishery selectivity of the reference model is assumed to be age-specific and time-invariant. For both commercial fleet and surveys, a random walk selectivity was used. This selectivity pattern provides for a random walk in ln(selectivity). For each age a ≥ Amin, where Amin is the minimum age for which selectivity is allowed to be non-zero, there is a selectivity parameter, pa, controlling the changing selectivity from age a − 1 to age a. All data inputs are summarised in Table C3 while in Table C4 the configuration of the reference model is reported.

Table C3. Herring SDs 30-31. Input data used in the Stock Synthesis models.

Type	Name	Year range	Range
Catches	Catches in tonnes for each year	1963–2018	
Age compositions	Catch in numbers(thousand) per age class	Commercial fleet: 1980–2018 Acoustic survey: 2007–2018 Trapnet survey: 1990–2006	0–15+
Maturity ogives	Empirical maturity-at-age estimated from surveys		
Natural mortality	Natural mortality by age class costant for the entire time-series derived from Then *et al*., 2015		0–20+

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Type	Name	Year range	Range
Surveys indices	Density index from acoustic survey and biomass index from trapnet survey	Acoustic survey: 2007–2018 Trapnet survey: 1990–2006	
SSB index	SSB proportional to fecundity		

Table C4. Herring SDs 30–31. Settings of the Stock Synthesis assessment reference model. The table columns show: number of estimated parameters, the initial values (from which the numerical optimization is started), the intervals allowed for the parameters, the priors used, the value estimated by the model and its standard deviation. Parameters in bold are set and not estimated by the model.

Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)	Standard deviation
Natural mortality (age classes 0.5, 1, 3, 5, 8, 15)		**0.563, 0.472, 0.332, 0.290, 0.267, 0.257**				
Stock and recruitment						
Ln(R_0)	1	18.03	(16, 25)	No_prior	17.36	0.07
Steepness (h)	1	0.66	(0.1, 1)	0.74	0.77	0.10
Recruitment variability (σ_R)		**0.60**				
Ln (Recruitment deviation): 1963–2018	55					
Recruitment autocorrelation		**0**				
Initial catches		Average of 1963–1965				
Commercial fleet	1	0.2	(0.001, 1)	No_prior	0.034	0.006
Selectivity (random walk)						
Commercial fleet						
Change from age1 to age2	1	1.45	(-5, 9)	No_prior	1.31	0.07
Change from age2 to age3	1	0.4	(-5, 9)	No_prior	0.37	0.06
Change from age3 to age4	1	0.15	(-5, 9)	No_prior	0.14	0.06

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Parameter	Number estimated	Initial value	Bounds (low,high)	Prior	Value (MLE)	Standard deviation
Change from age4 to age5	1	0.14	(-5, 9)	No_prior	0.14	0.07
Change from age5 to age6	1	0.03	(-5, 9)	No_prior	0.07	0.08
Change from age6 to age7	1	0.01	(-5, 9)	No_prior	0.04	0.08
Acoustic Survey						
Change from age1 to age2	1	0.6	(-5, 9)	No_prior	0.50	0.17
Change from age2 to age3	1	0.2	(-5, 9)	No_prior	0.35	0.18
Change from age3 to age4	1	0.02	(-5, 9)	No_prior	-0.05	0.22
Change from age4 to age5	1	0.11	(-5, 9)	No_prior	0.07	0.25
Change from age5 to age6	1	0.14	(-5, 9)	No_prior	0.18	0.22
Trapnet Survey						
Change from age3 to age4	1	0.30	(-5, 9)	No_prior	0.13	0.15
<u>Catchability</u>						
Acoustic survey						
Ln(Q) – catchability		**-2.47811**				
Extra variability added to input standard deviation		**0.001**				
Trapnet survey						
Ln(Q) – catchability		**3.86604**				
Extra variability added to input standard deviation		**0.001**				

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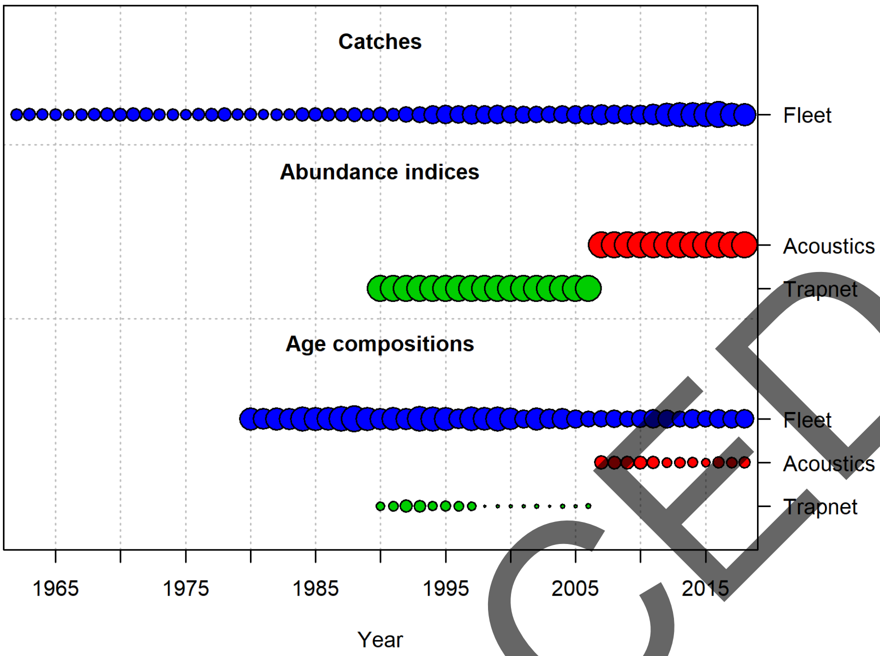

Figure C3. Herring SDs 30–31. Summary of the input time-series included in the model.

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D. Short-Term Projection

The short-term projections are made with Stock Synthesis using MCMC. Recruitment in the forecast period is set to the average of the last ten years for which recruitment deviations are estimated in the Stock Synthesis model. For maturity and weight-at-age an average of the last three years is used. Constant selectivity is used. Probabilistic forecasts were used. In this approach, catch and SSB levels corresponding to different catch options are calculated as in typical deterministic short-term forecast but using MCMC to make it possible to also include the most correct associated probability of the SSB to be below biomass reference points, for each year of forecast. Therefore, an MCMC with 1 100 000 iterations, 100 000 burn-in and 1000 thinning was run for the different levels of assumed F in the assessment year and assessment year+1, assuming F constraint in the intermediate year. It is important to note that the inputted F values for the forecast will sometime be different from the model realized F in the MCMC (but also in the MLE if this is used for the forecast). This is because the F used is an average across ages and those ages have different F because they are affected by selectivity. Each draw of the MCMC has different selectivity so the F produced for each draw will be slightly different due to the different selectivity. We have tested running three different MCMC with 110 000 iterations and compared the difference in F inputted and model realized F. The difference was on average 1.6% so that for the short-term forecast table to be included in the summary sheet the inputted F will be shown.

E. Medium-term projections

Not relevant.

F. Long-term projections

Not relevant.

G. Biological Reference Points

The reference points were re-estimated during the benchmark WKCluB 2020 (ICES, 2020) after the model was changed to Stock Synthesis. The Eqsim based reference point analysis used the newest (1980–2018) assessment results from the Stock Synthesis assessment. Reference points before the benchmark can be found in Table G5. Settings for the Eqsim can be found in Table G6.

Table G5. Summary table of stock reference points before the benchmark.

Reference point	Value	Technical basis
Current F_{MSY}	0.21	Eqsim
Current B_{lim}	202 272	Eqsim
Current B_{pa}	283 180	Eqsim
Current MSY $B_{trigger}$	283 180	Eqsim

Table G6. Data, parameters and settings for the Eqsim.

Data and parameters	Setting	Comments
SSB-recruitment data	1980–2018	
Exclusion of extreme values (option extreme.trim)	Used	
Mean weights, proportion mature and F at age pattern	2016–2018	
Exploitation pattern	2016–2018	
Assessment error in the advisory year. CV of F	0.212	ICES default value
Autocorrelation in assessment error in the advisory year	0.423	ICES default value
Autocorrelation in recruitment	Used	

The stock–recruitment fit using the three models (Ricker, B&H and segmented regression) weighted by the default "Buckland" method available in EqSim gave 86% of the points as derived from a segmented regression curve. However, the estimated breakpoint for this curve is at 710 748 tonnes, which is around 70% of the maximum observed values (Figures G1 and G2). This value was considered to be unrealistically high, which also resulted in rather low value of $F_{P.05}$ (i.e. 0.07) and F_{MSY} (0.15) without $B_{trigger}$, and $F_{P.05}$ (i.e. 0.08) and F_{MSY} (0.20) with $B_{trigger}$. Thus, a segmented regression model was used with a breakpoint set arbitrarily at the lowest observed SSB (i.e. $B_{lim} = B_{loss}$ = 375 610 t). B_{loss} was observed in the 1980s during a period of very low F and high M due to cod predation compared to today situation. This reinforce the idea that setting B_{lim} at B_{loss} would not impair recruitment also considering that current environmental conditions favour herring recruitment.

B_{pa} was set as B_{lim}*(exp(1.645*SSB_{var})) and MSY $B_{trigger}$ was set equal to B_{pa}. SSB_{var} was estimated as the uncertainty associated to the SSB in last assessment year (i.e. 2019; σ =

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0.126). After B_{lim}, B_{pa} and MSY $B_{trigger}$ were all defined, the ICES procedure for setting the reference points was used to estimate the remaining reference points. The SR relationship used for these runs was a hockey stick with the breakpoint set at the new B_{lim} (i.e. B_{loss}). The number of samples used to fit the SR relationship and the number of runs used in all EqSim simulations were 1000 and 200, respectively. Autocorrelation of recruitment was used in all EqSim simulations. F_{pa} was estimated using the ICES standard procedure (F_{pa}=F_{lim} x exp(-1.645 x F_{var}) with F_{var} estimated as the uncertainty associated to the F in last assessment year (i.e. 2018; σ = 0.131).

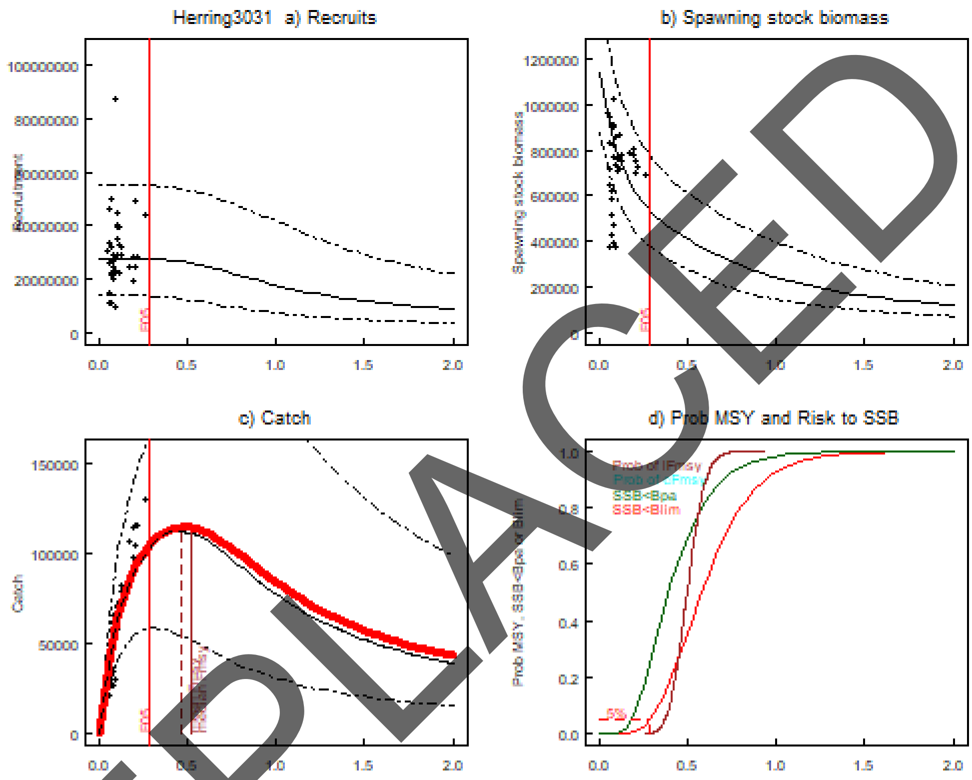

Figure G1. EqSim results for Herring in subdivisions 30 and 31 with $B_{trigger}$.

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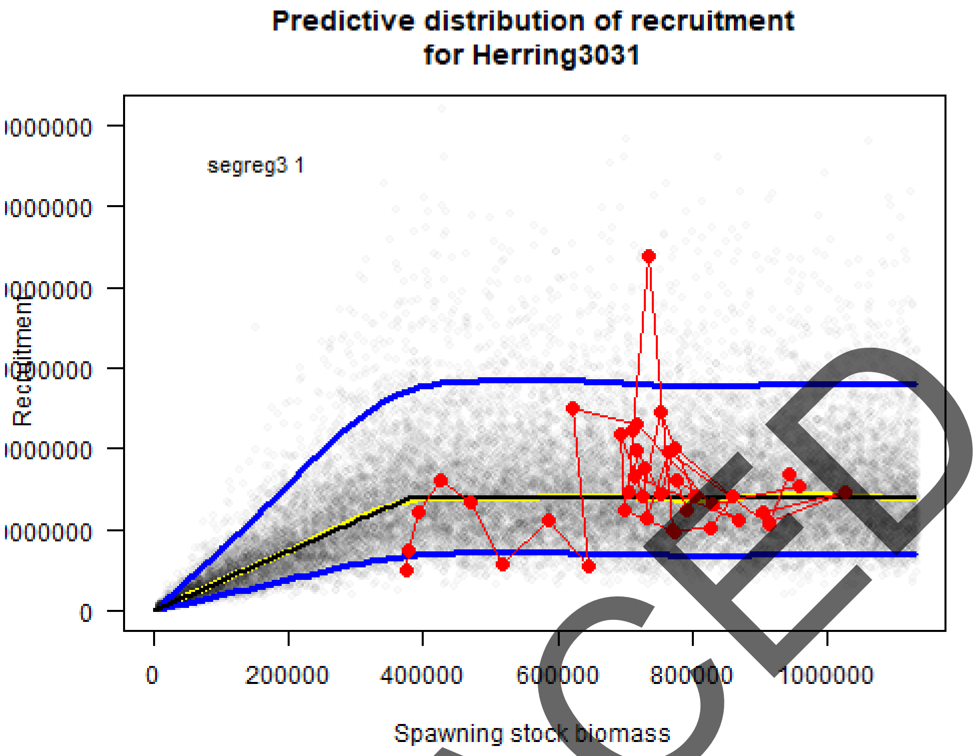

Figure G2. Stock–recruitment relationship (i.e. segmented regression with breakpoint at B_{lim}) for Herring in subdivisions 30 and 31 used in the EqSim simulations for the estimation of the F_{MSY} reference points.

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Table G7. Summary table of proposed stock reference points.

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Reference point	Value
$F_{P.05}$ (5% risk to B_{lim}) with MSY $B_{trigger}$	0.285
$F_{P.05}$ (5% risk to B_{lim}) without MSY $B_{trigger}$	0.257
F_{MSY}	0.285
F_{MSY} lower	0.285
F_{MSY} upper	0.285
F_{pa}	0.361
F_{lim}	0.448
F_{MSY} upper precautionary	0.285
F_{MSY} range with MSY $B_{trigger}$	0.285
F_{MSY} range without MSY $B_{trigger}$	0.257
MSY $B_{trigger}$	462 018 t
B_{pa}	462 018 t
B_{lim}	375 610 t

As explained above, the standard ICES procedure for setting B_{lim} reference point in this case would result in an unrealistically large value of B_{lim} and thus in an unrealistically low value of F_{MSY}. Thus, the procedure used to estimate the reference points for herring in SD 30 and 31 is not in strictly in accordance with the ICES reference point guidance but it has been modified to account for the specific SR relationship of this stock. Also, according to the EqSim estimations, $F_{P0.5}$ (0.285) is lower than F_{MSY} (0.462) estimated with $B_{trigger}$ and thus F_{MSY} and F_{MSY} range are dictated by precautionary considerations in this case.

H. Other Issues

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