Stock Annex: Herring (*Clupea harengus*) in Division 5.a, summer-spawning herring (Iceland grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Herring
Working Group	North Western Working Group (NWWG)
Created:	31 January 2011 at WKBENCH
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Last updated:	2 May 2017 at NWWG
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A. General

A.1. Stock definition

The Icelandic summer-spawning herring is constrained to Icelandic waters throughout its lifespan. Results from various researches including, tagging experiments around middle of last century, studies on larval transport, and studies on migration pattern and distribution, all suggest that the stock is local to Icelandic waters. Recent studies on stock structure on herring in Northeast Atlantic support this distinction, both on basis of otoliths shape analyses (Libungan et al. 2015) and micro-satellite analyses (Pampoulie et al. 2015). In catches and surveys, the maturity stage is used successfully to distinguish Her-5a from the other herring stocks.

A.2. Fishery

Since at least the year 2000, the herring fishery has been conducted by big vessels that in most cases have onboard both purse seines and mid-water-trawls that are used as needed in the fishery. Usually, most of the catch is taken by purse seine (ICES 2008). Bycatch in the herring fishery is normally insignificant as the fishing season is during the over-wintering period when the herring is in large dense schools. However, in the summers 2010-2014 some herring from the stock has been caught as bycatch in the mackerel fishery off the east-, southeast-, south- and west coast of Iceland and in the Norwegian spring-spawning fishery of the east coast in pelagic trawls. That has amounted to around 6-13 thousands tons annually.

A2.1. Prior to 1980

The catches of Icelandic summer-spawning herring increased rapidly in the early 1960s due to the development of the purse seine fishery off the south coast of Iceland. This resulted in a rapidly increasing exploitation rate until the stock collapsed in the late 1960s. A fishing ban was enforced during 1972–1975. The annual catches have since increased gradually to over 100 000 t.

A2.2. 1980 onwards

Until the autumn 1990, the herring fishery took place during the last three months of the calendar year. During 1990-2008 the autumn fishery continued until January or early February of the following year, and has started in September/October since 1994. In 2003 the season was further extended to the end of April and in the summers of 2002 and 2003 an experimental fishery for spawning herring with a catch of about 5 000 t each year was conducted at the south coast.

In the beginning of this period, the fleet consisted of multi-purpose vessels, mostly under 300 GRT, operating with purse-seines and driftnets. In recent 20 years, larger vessels (up to 1500 GRT) have been gradually taking over the fishery, and today they represent the whole herring fishing fleet. Consequently, the number of vessels participating in the fishery has shown decreasing trend in the 2000s from around 30 down to 15 in 2010. Simultaneously, the average size of the vessels has increased. These vessels are combination of purse-seiners and pelagic trawlers operating in the herring (Her.5a and Norwegian spring-spawners), capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*) fisheries, and in recent years also the NE-Atlantic mackerel (*Scombrus scombrus*) and Mueller's pearlside (*Maurolicus muelleri*) fisheries.

Since the 1997/1998 fishing season to around 2007/08, there was a fishery for Her.5a both west and east off Iceland, with gradual increase off the west coast. This west coast fishery of the stock had until then hardly taken place since the middle of the 1960s (Jakobsson 1980; Óskarsson et al. 2009a). In the period 2006 to 2012, most of the catches were taken in a small area off the west coast in the southern part of the bay Breiðafjörður (Fig. 1; e.g. ICES, 2008; 2009; 2012), while in 2014, the direct fishery took all place in offshore areas west of Iceland (in Kolluáll). The inshore fishing period, was nearly exclusive driven by purse seine fisheries, while the pelagic trawl fisheries, first introduced in 1997/98 and contributed earlier to around 20–60% of the catches for several years, is the most common gear in the offshore fishery, as in 2014.

A2.3. Fishery regulations

The fishery of the summer-spawning herring is currently regulated by regulations set by the Icelandic Ministry of Fisheries in 2006 (no. 770, 8. September 2006). According to it, fishery of juveniles herring (27 cm and smaller) is prohibited and to prevent such a fishery, area closures are enforced.

The fishery can take place from 1st September to 31st May each fishing season (1st September-31st August) in nets, purse seines and mid-water trawls. The mid-water trawling is only allowed outside of the 12 nautical miles zones with some additional areal restrictions. Use of sorting grids in the mid-water trawls can be required in some areas, if necessary to avoid bycatch.

If nets are used in the herring fishery, the minimum mesh size (stretched) is 63 mm.

The annual total allowable catch is decided by the Ministry of Fisheries. Since 1985, the decision has more or less been based on the advices given by the Marine Research Institute, with very small discrepancy (ICES 2010).

A.3. Ecosystem aspects

A3.1. Geographic location and timing of spawning

The spawning of the stock takes place in July off the SE, S and SW coast (Jakobsson and Stefansson, 1999) with the maximum activity around middle of July (Óskarsson and Taggart 2009). The nursery grounds are mainly in coastal areas off the NW and N coast, but occasionally also in coastal areas off the E, SE, and SW and W Iceland (Gudmundsdottir *et al*. 2007). The location of the overwintering of the mature and fishable stock has varied during the last 30 years (Óskarsson *et al*. 2009a). Prior to 1998 it was mainly off the SE and E Iceland but from 1998 to 2006, the overwintering took place both off the east and west coast, with increasing proportion being in the western part. Since then (winters 2006/07 to 2011/12), most of the stock has been located in high density in coastal waters in northern part of Breidafjördur in western Iceland.

A3.2. Diet

The variation in the diet composition of the Icelandic summer-spawning herring has been studied recently in comparison to diet of Northeast Atlantic mackerel and Norwegian spring spawning herring (Óskarsson et al. 2012). Stomach samples showed that the diet of the Icelandic summer-spawning herring consisted mostly of crustacea (86 to 100%) where copepoda, euphausiacea or hyperiidae weighed most of the identified prey groups. Euphausiacea was generally in more mass than copepoda. The only identified fish prey species in herring was capelin and sandeel (*Ammodytes* sp.). An older research made by MRI on stomach contents of herring in a relatively restricted area SW off Iceland in 2008 showed in addition that fish eggs and larvae could be a significant part of the diet (Óskarsson et al. 2008).

A3.3. Predators

Adult herring is food resource for various animals in Icelandic waters according to various researches. The animals include mink whale (*Balaenoptera acutorostrata*), humpback whale (*Megaptera novaeangliae*), several sea bird species, cod (*Gadus morhua*) and pollack (*Pollachius virens*), but the annual consumption of herring by the different predators is relatively unknown. An increased predation of herring by cod has been observed in stomach analyses in the Icelandic groundfish survey since the *Ichthyophonus* outbreak started in the herring stock in November 2008, even if it has not been quantified.

A3.4. Diseases and parasites

In November 2008, the Marine Research Institute in Iceland got the information from the commercial fleet fishing on Her.5a that the stock was seemingly infected by some parasite or had some disease. Within few days it was identified as a major outbreak of the protista parasite *Ichthyophonus hoferi*. A thorough examination of the fishable stock during the winter 2008/09 indicated that 32% of the stock was infected (Oskarsson et al. 2009; Oskarsson and Pálsson 2009) and 43% during the winter 2009/10 (Óskarsson et al. 2010). During the period from 1991 to 2000, the prevalence of *Ichthyophonus* infection in the stock was determined inter-annually but only a minor infection was observed during that period, or in around 1 per every 1000 individuals examined. The source of the infection outbreak is unknown (Oskarsson and Pálsson 2009) but the infection is transmitted with resting spores of the parasite that must be eaten in one way or another by the herring since they need an acid environment to be activated (Spanggard et al. 1995). Since the stock is not feeding during the overwintering period, the stock get the infection on the feeding grounds, which is also supported by the development of the infection in the stock as seen from an extensive sampling of the stock throughout the winters (Óskarsson et al. 2009; 2010). In the winter 2014/2015 the infection rate was still high in the older part of the stock, or year classes from 2007 and before while less in the younger ones (1-6%) (Óskarsson and Pálsson 2015). This pattern has been observed every years since 2008.

In juvenile herring the prevalence of infection was also high in most of the distribution area during the first two winters and the infection reached over a very extensive area, or all coastal areas around Iceland except for the east coast. Until in the assessment in

2013, the assumption was applied that all infected herring would die because of it within few months and maximum 12 months from getting infected on the feeding grounds. This assumption was used as this infection was believed to be fatal to all infected herring (Sinderman 1958).

A thorough exploration in 2013 of all available data since the infection started in 2008 led to changes on perception of infection mortality in the stock (Óskarsson and Pálsson 2013). The main conclusion was that the infection was only causing significant additional mortality in the first two years, despite a high prevalence of infection for five years. It means that the infection was considered to be less lethal for herring than had been assumed previously. This was based on several observations: (1) Development in the infection in both the first two winters was apparent where the infection was progressing from light to extreme infection, while no development was apparent the years after; (2) New infection was apparently occurring in the autumns 2008, 2009, and 2010 while not in the autumns thereafter where young age groups (< age 4) were almost without infection in all areas; (3) The proportion of the different year classes with light infection remained relatively constant since the autumn 2010; (4) Despite strong indications of no or insignificant new infection in the stock since the autumn 2010, the prevalence of the infection remained high, which strongly suggested a little or insignificant mortality in the stock because of the infection since 2010; (5) Constant prevalence of infection with no changes in the infection staging throughout the winter and spring 2012.

A3.5. Recruitment variation of the stock

The recruitment variation of the stock has been examined in two papers, first by Jakobsson et al. (1993)_and then more thoroughly by Óskarsson and Taggart (2010). The main conclusions from Jakobsson et al. (1993) by analysing the period from 1947 to 1991 was that the stock-recruitment relationship was most adequately fitted with a Cushing model and the recruitment increased strictly with increasing stock size with no signs of decreased recruitment at high stock level (i.e. a dome-shaped relation). Furthermore, environmental changes, and particularly the sea temperature affects the recruitment even if it was noted that two of the four largest year classes were produced in periods considered to be warm and two in periods considered to be cold.

Óskarsson and Taggart (2010) examined the recruitment variation of the stock during 1963-1999 with generalized linear models (GLM) with special focus on the impact of the maternal effects as well as various ecological and environmental factors. The best model explained 64% of the variation in the recruitment of the stock and incorporates total egg production constrained to the repeat spawners (40%), the NAO winter-index (18%), and ocean temperature (6%). The latter two represent the winter and spring period subsequent to year-class formation. Contribution of recruit spawners to the total egg production were of no significance in explaining variation in the recruitment despite the fact that they could contribute to as much as 55% of the egg production. The spawning potential of the repeat spawners was suggested to replace total SSB when determining recruitment potential in the stock assessment, which in addition to the incorporation of oceanographic factors, was considered to provide a more precautionary and risk-adverse approach. The ocean temperature off northern Iceland (Siglunes) was found to have a marginal effect on the recruitment of the stock; consistent with the results of Jakobsson et al. (1993) where average recruitment was reduced during the relatively cold period of 1965 through 1971. The primary nursery grounds for the stock are off northern Iceland (Fig. 1), though larvae and juveniles are also found elsewhere

(Gudmundsdottir et al., 2007). They concluded that oceanographic variability, as reflected in the positive effects of lagged winter NAO index and ocean temperature indices, influences recruitment through the survival of larvae during their first winter–spring. The conclusion is substantiated by the positive relation between age-3 recruitment and larval and post-larval abundance indices at age-1 and -2 in the ISS stock that indicate that the year class strength is determined during the first year of larval development (Gudmundsdottir *et al.,* 2007).

Similar to Jakobsson et al. (1993), Óskarsson and Taggart (2010) observed that the recruitment of the stock increased continuously with increases in total egg production of repeat spawners and there is no indication of density-dependence even as SSB and the egg production increased above historical estimates. In the end they conclude that it is more appropriate to use size structured estimates of fecundity as well a spawning experience (e.g. egg production of repeat spawners) in place of simply total egg production and SSB, especially, from a management perspective, at low SSB and when the size structure is truncated, and to do so prior to assessing potential oceanographic influences. Doing so should result in more accurate short-term predictions of the recruitment. Their best generalized linear model (GLM) explained 64% of the variation in the recruitment variation during 1963 to 1998 and incorporated total egg production constrained to the repeat spawners (40%), the North-Atlantic Oscillation (NAO) winter-index (18%), and ocean temperature (6%).

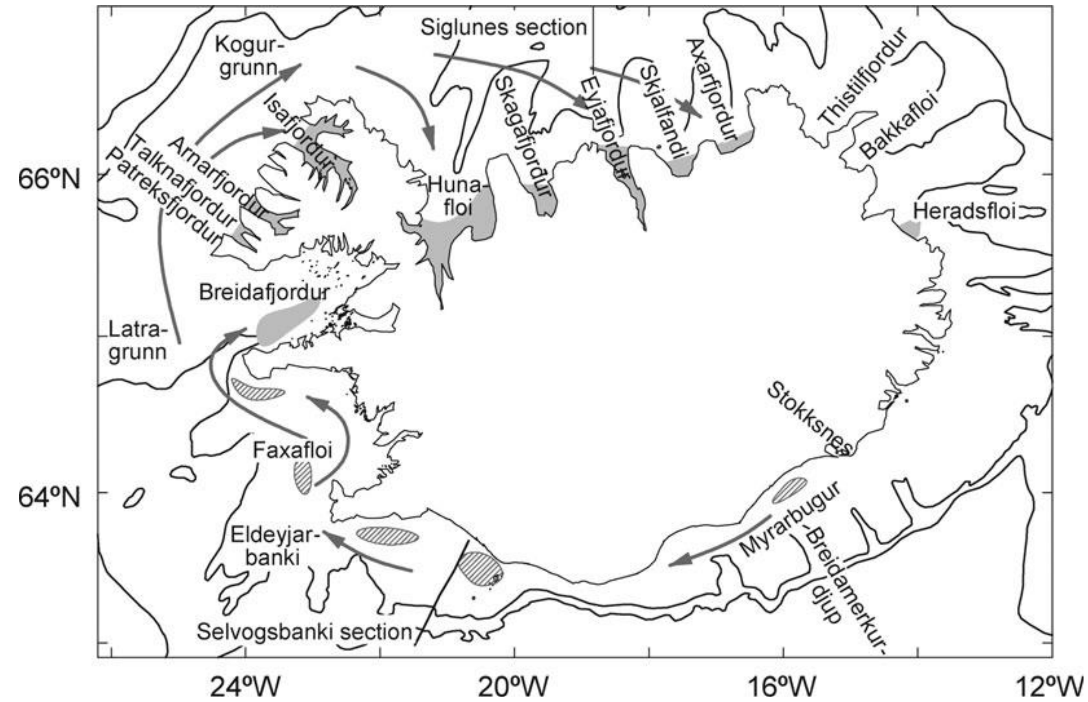

Figure 1. The names of some fjords and banks around Iceland referred to in the text. Grey shading indicates the nursery areas, and stripes the spawning areas, and the arrows show the directions of larval drift (adopted from Gudmundsdottir et al. 2007).

B. Data

B.1. Commercial catch

B1.1. Landings

Information about landings of the fishery fleet is collected by the Icelandic Directorate of Fisheries. They have access to both landings in the harbours (the official landing) and the registered catch in the digital logbook kept by all the vessels. The logbooks keep information about timing (day and time), location (latitude and longitude), fishing gear, catch size, and species composition in the catch of each fishing operation for each vessel.

Biological samples from the catch are taken at sea by the fishermen or in the harbours by people from MRI and/or inspectors from the Directorate of Fisheries and then analysed by MRI (record at least the fish length, weight, age (from scales), sex, maturation, and weight of sexual organs). The information from the samples is then used along with the total landing data and the logbook data to estimate the composition of the total landings. It includes estimating **Caton** (catch-in-weight), **Canum** (catch-at-age-in numbers), **Weca** (weight-at-age-in-the-catch), and length composition in the catch.

The annual estimations of the composition of the total landings (e.g. the catch at age matrix) are based on dividing the annual landings into cells according to the fishing gear, geographical location and month of fishing. The number of cells used in the calculation each year depends on number of factors, including the spatial and temporal distribution of the fishery, the fishing gear used and intensity of biological sampling, and has ranged from 3 to 10 during the years 2004 to 2014. The number of weight-at-length relationships and length-at-age relationships applied differs between years and is in the range of 1-2 in both cases. Since 1990 to present, all available length measurements are used for the estimations in the cells, while length of aged fish was only used in earlier estimations. Length measurements done by inspectors of the Directorate of Fisheries are though usually omitted as inspectors tend to focus on catches that are suspected to consist of small herring and give therefore often biased length distributions.

A planed re-aging of herring from the catch samples in the fishing seasons 1994/95 through 1997/98 was not finished in February 2010 and because of limited manpower at the Marine Research Institute it will be postponed further. When the re-aging is accomplished the number at age in the catch will be re-estimated. Previous work suggests though that only small changes can be expected.

B1.2. Discards

Discards are illegal in Icelandic waters. Normally, discards are considered to be insignificant in the fishery of Icelandic summer-spawning herring. There are few exceptions in the past 35 years where discards were estimated to be significant (1990-95; ICES 2008). These exceptions are related to large year classes being entering the fishery and juveniles have been numerous in the catch. Surveillance by inspectors from the Directorate of Fisheries during each fishing season is considered adequate in verifying if a discard is ongoing.

B.2. Biological

B.2.1. Weight at age of the stock

The weight at age in the stock is estimated from the commercial catch samples combined over the whole fishing area. Since the fishery takes place in the autumns and the winters (around September through January), the weight at age represents that period.

B.2.2. Natural mortality, M

Natural mortality is assumed to be constant, M=0.1, for the whole range of ages and years. There are no direct estimates of M but the estimate of M=0.1 has been evaluated numerically by Jakobsson *et al.* (1993). They concluded, through comparison of acoustics- and VPA based stock size estimations that the assessed level of M ranged from 0.1 to 0.15. Because of the *Ichthyophonus* infection in the stock first observed in 2008 and still existing in 2017, a higher M has been applied in the analytical assessment. In a working document to NWWG 2013, Óskarsson and Pálsson (2013) addressed the development and nature of the massive and long-lasting *Ichthyophonus hoferi* outbreak in Icelandic summer-spawning herring since the autumn 2008 to 2013. Their main conclusions were that the infection was only causing significant additional mortality in the first two years, despite a high prevalence of infection for five years. These data have been revisted recently with updated data and lead to different estimates of the infection mortality (Óskarsson et al. 2017). These new results are considered to be more robust than previous estimates and were decided to be used in the analytical assessment from 2017 and onwards (ICES 2017). The results imply that significant infection mortality took place in the first three years after the outbreak started (2009-2011) but not the years after (2012-2016). The level of the mortality was estimated with series of runs of the NFT-adapt assessment model, which gave the best fit to the data when applying infection mortality equivalent to 30% of the infected herring (heart inspection and survey abundance estimates provided $M_{infected}$) died annually in the first three years of the outbreak ($M_{year, age} = M_{fixed} + M_{infected, year, age} \times 0.3$; see Table B.2.2.1, year referring to autumns).

Observations of an ongoing new infection in the winter 2016/17 are considered to result in significant infection mortality in the spring 2017. It called for applying additional infection mortality for 2017, and applying the results by Óskarsson et al. (2017) was considered to be the most reasonable approach. It means that the estimates of $M_{infected}$ in 2016/17 should be multiplied by 0.3 and added to the fixed M. The resulting values (Table B.2.2.1) were used in the prognosis in 2017 and should be applied in the future analytical assessment as M in 2017 until better more reliable estimates become available. For future assessments, the prevalence of infection will need to be monitored.

Table B.2.2.1. The applied natural mortality in analytical assessment for Icelandic summer-spawning herring in the winter 1987-2017, which represent the fixed value (0.1 in addition to additional M caused by *Ichthyophonus* infection in 2008/09 to 2010/11 and 2016/2017 (years referring to the autumns) for age groups 3 to 13+.

Year\age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1987-2008	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2009*	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
2010*	0.29	0.29	0.28	0.26	0.25	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23
2011*	0.13	0.26	0.26	0.25	0.23	0.24	0.25	0.24	0.20	0.21	0.21	0.21	0.21	0.21
2012-2016	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
2017**	0.11	0.12	0.13	0.17	0.18	0.21	0.19	0.26	0.29	0.21	0.18	0.19	0.10	0.10

* Based on prevalence of infection estimates and acoustic measurements ($M_{infected}$multiplied by 0.3 and added to 0.1; Óskarsson et al. 2017).

**Based on prevalence of infection estimates in the winter 2016/17 (multiplied by 0.3 and added to 0.1) and should by applied in the prognosis in the 2017 assessment.

B.2.3. Age at maturity

The age at maturity of the Icelandic summer-spawning stock was until 2006 estimated annually from the commercial catches alone (ICES 2008). Such estimates are a subject to various source of errors including that the year classes that are becoming mature might have spatial distribution that is linked to if they are mature or not. For example, mature individuals of a given year class would be more likely to join the older fully mature age groups than the immature individuals. It indicates also that the estimate of age at maturity from the catch samples can be incorrect because the most important age groups are poorly representative in the commercial catches. That was the main reason for the decision taken in 2006 that the maturity-at-age from 2006 and onwards was assumed to be constant (Óskarsson and Guðmundsdóttir 2006), which was based on analyses of catch and survey data and is as follows:

Age	<3	3	4	5+
Proportion mature	0.00	0.20	0.85	1.00

Analyses and comparison of estimates from commercial catch data, survey data and estimates based on fish scale growth layers indicate, however, that the maturity ogive of the non-fishable part of each age class in the stock is equivalent to the fishable part for the years 1962 to 2002 (Óskarsson and Guðmundsdóttir 2011). It gives support to the age at maturity values used in the assessment of the stock until 2006, originating from the traditional method in estimating the age at maturity from simply commercial catch samples. However, since the spatial distribution of the stock is completely different in recent years, where most of the fishable stock is overwintering in a small area off the west coast (Óskarsson et al. 2009a), compared to the period which the analyses cover, using the commercial catch samples to estimate the age at maturity cannot be recommended for the most recent years. Thus, to get reliable estimates of age at maturity that is independent of the stock distribution, Óskarsson and Guðmundsdóttir (2011) recommend a re-establishment of determination of age of first spawning from the fish scales growth layer, which took place during the period 1964 to 1992. Until then and following analyses of those data, the maturity ogive of the stock in the assessment should be fixed as shown in the table above.

B.2.4. Ageing of the stock

The age of the stock is determined from the fish scales and the number of annual winter-rings +1 gives the age in years

B.2.5. Fecundity of the stock

The fecundity variation of the Icelandic summer-spawning herring has been estimated in two papers, by Jakobsson et al. (1969) and later more thoroughly by Óskarsson and Taggart (2006). The latter paper indicates that the fecundity at length relation to be: Fecundity [$\times 10^3$] = 15.9 × Length [cm] - 382.2. It indicates that herring at average length in the catch (32 cm) spawns around 127 thousands eggs in a season and release all the eggs at once. Furthermore, Fulton's condition factor K ($=100\times\text{Weight}\times\text{Length}^{-3}$) explains a trivial (1.5%) but significant amount of the residual variation in potential fecundity of the stock, and appears to have the greatest effect among smaller length classes.

B.3. Surveys

A. Autumn/winter survey (IS-Her-Aco-Q4/Q1)

Currently, one survey is available and applied as a tuning series for the analytical assessment of the Icelandic summer-spawning herring stock. It is an acoustic research survey, which has been ongoing annually since 1974 except for the winters 1976/77, 1982/83, 1986/87, and 1994/95. These surveys have been conducted in October-December and/or January. The survey area varies spatially as the survey is focused on the adult and incoming year classes. The surveyed area is decided on the basis of all available information on the distribution of the stock in previous and the current year, which include information from the fishery. Thus, the survey area varies spatially as the survey is focused on the adult and incoming year classes. As normally practiced in acoustic surveys, trawl samples are used to get information about the schools species- and length composition. Detailed information and the results of the surveys are given inter-annually in internal reports at MRI, and later summarized in the assessment reports.

B. Spawning survey (IS-Her-Aco-Q3)

In the summer 2009, 2010 and 2011, acoustic surveys were conducted on the spawning grounds of the Icelandic summer-spawning herring. The surveys, which took place in a ten day period in the beginning of July, just before the maximum of the spawning activity, around the middle of July (Óskarsson and Taggart 2009), covered all the known spawning grounds of the stock. The main purpose of these surveys was to get estimates of the prevalence of *Ichtyhophonus* infection in the stock, but also to get acoustic abundance estimates of the stock. The working group involved in the assessment of the stock considers that the results of this acoustic survey can be used as a tuning series within an analytical assessment when and if the time series becomes sufficiently long. The main advantage of this survey above the traditional autumn/winter survey (above) is that its spatial and temporal coverage is consistent and fixed between years. Thus, hopefully this survey will continue for some years, so the quality and reliability can be verified including how well it is following the stock trend according to the assessment and the autumn/winter survey.

C. Juvenile survey (IS-Her-Aco-Juv-Q4/Q1)

In addition to the acoustic survey aimed at the fishable part of the stock, there have been occasionally acoustic surveys off the NW, N, and NE coast of Iceland aimed to estimate the year class strength of the juveniles. This survey was undertaken in November to December in most years during 1980 to 2003, but had not taken place since 2003, until it was resurrected in January 2009. Since then they have been undertaken every years. The results of these measurements had until 2011 not been used in the assessment or stock projection directly, even if the year class indices at age-1 herring derived from the survey showed a significant relationship to recruitment of the stock at age 3 (Gudmundsdóttir *et al.* 2007). However, because of this obtained relationship, and to utilize the information from this survey, the survey abundance index of age 1 herring have been used since 2011 to predict the number at age 3 for the stock in the short-term projections (see section D below).

B.4. Commercial CPUE

The commercial CPUE data is not considered relevant to the assessment because of the nature of the fishery and due to the continuous development of the vessels and the equipment used in the fishery.

B.5. Other relevant data

None

C. Assessment: data and method

Model: Age structured

Software: NFT-ADAPT (VPA/ADAPT version 3.3.0 NOAA Fisheries Toolbox)

Alternatives evaluated and available for future comparisons include a new version of TSA (older version, see Gudmundsson 1994). Also, a statistical catch-at-age was presented (Coleraine) and it was consistent with other models and may be useful for presenting and comparing uncertainty estimates in the future.

The NFT-ADAPT has been used for point estimate and final assessment of the stock since 2005 to 2010.

Model Options: The model options differ slightly between years, but are given in tables or text in the WG assessment reports (e.g. ICES 2008).

The youngest age groups in the assessment runs from catchdata is age 3 and oldest age 13+.

The data used from the tuning series (IS-Her-Aco-Q4/Q1) are age groups 4-11 (or age 3-10 in the assessment year-1).

Years used are 1987 onwards.

The IMSL parameters used are the defaults except the following three:

Scaled gradient tolerance of 6.055454E-05

Scaled step tolerance of 1.0E-18

Relative function tolerance of 1.0E-18

Survey weighting factors were 1.0 for each age except:

In 1989 weighting factors used as 0.01 for 8 years and older

In 1990 and 1991 weighting factors used as 0.01 for 9 years and older

In 1992 weighting factors used as 0.01 for 10 years and older

In 1993 weighting factor used as 0.01 for age 11 year

In 2004 weighting factor used as 0.01 for age 10 year and older

In 2005 and 2007 weighting factor used as 0.01 for age 11

Earliest age in Terminal Year+1: Geometric mean over 1987-2006

Calculation Method Full-F in Terminal Year: Classic Method

F at oldest age in Terminal Year: Use F at oldest true age calculation method

F at oldest true age calculation method: Use arithmetic average

F oldest age calculation method: Use ages 8-11

Plus group calculation: Forward

F-plus group ration: 1 for all years.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1947-last data year	2-15+	Yes
Canum	Catch at age in numbers	1947-last data year	2-15+	Yes
Weca	Weight at age in the commercial catch	1947-last data year	2-15+	Yes
West	Weight at age of the stock .	1947-last data year	2-15+	Yes
Mprop	Proportion of natural mortality before spawning	1947-last data year	2-15+	No –set to 0.5 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1947-last data year	2-15+	No –set to 0 for all ages in all years
Matprop	Proportion mature at age	1947-last data year	2-15+	No- since 2005 set 0.2 for age-3 and 0.85 for age-4
Natmor	Natural mortality	1947-last data year	2-15+	No – set to 0.1 for all ages in all years*

*Because of the *Ichthyophons* outbreak in the stock, M that accounted for the infection mortality is added to 0.1 for the years 2009-2011 and 2017 (see section B.2.2.).

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	IS-Her-Aco-Q4/Q1	1974-last data year	2-15+ (age 3-10 used in tuning)
Tuning fleet 2			
Tuning fleet 3			
….			

D. Short-Term Projection

Model used: Age structured

Software used: An Excel spreadsheet prepared in MRI, which has been compared to results from a Fortran script used at MRI for years for herring and other species, and they have giving identical results.

Initial stock size: Taken from NFT-Adapt in most recent years. The number of the youngest age groups (age 3) is determined as described below (in *recruitment prediction model used)*.

Until in the stock assessment in 2013, this procedure was followed: *If and when the stock is found to be infected by Ichthyophonus hoferi in the autumn of the most recent year in the assessment, the number-at-age for that year should be decreased according to the estimation of the infection prevalence before doing the projection (ICES, WKBENCH 2011). The reason is that all infected fish at that time is considered to die because of it in the spring, or before the spawning occur and can therefore be considered to be ineffective.* From 2013 and on, it was however suggested, and adopted, to ignore the estimates of the infection prevalence in the stock projection on basis of conclusive explorations indicating that the infection was less lethal than assumed earlier (Óskarsson and Pálsson 2013). The approach used prior to 2013 was however, reinstated in 2017 because of intense new infection in the stock (see section B2.2. above).

Maturity: The same ogive as in the assessment for the year 2006 to present.

Natural mortality: Set to 0.1 for all ages in all years.

F and M before spawning: Set to 0 for F and to 0.5 for M.

Weight at age in the stock: The weight at age (W_{y+1}) is predicted from the mean weight of the same year class a year earlier (W_y) by applying the relationship obtained by Óskarsson (2011): $W_{y+1} - W_y = -0.2229 \times W_y + 90.27$.

Weight at age in the catch: Same as used for the stock

Exploitation pattern: Average of three last years for age-3 and 4, but set 1.0 for age-5+ (ICES, WKBENCH 2011).

Intermediate year assumptions: Not relevant

Uncertainty: Estimated by using *the upper and lower 95% confidence interval* of the estimation of the initial stock size as estimated with NFT-Adapt for the most recent year.

Recruitment predictions model used: Number at age 3 (N_{age3}, i.e. recruitment) is derived from index of number at age 1 in the Juvenile survey ($N_{age-1, survey}$; Survey C) two years earlier if available by applying the relationship obtained by Gudmundsdottir et al. (2007):

$\log N_{age\,2} = 0.390 \times \log N_{age\text{-}1,\,survey} + 5.34$

Then N_{age3} is calculated as ln (N_{age2})–Z= ln (N_{age3}), where Z=M=0.1. If the survey index is not available, then the number at age 3 is equal to the geometrical mean over the whole assessment period, as done previously.

Procedures used for splitting projected catches: Not relevant

E. Medium-Term Projections

Medium-term projections have not been completed in recent assessments for this stock. The reason was reliance of the fishery on intermittent large year-classes, and the fluid nature of the fishery and related assessment, which was considered to make the usefulness of medium-term projections questionable.

At WKBENCH (ICES 2011a), it was considered relevant to include also a medium-term projection (~five years) for the stock. The model used and input data are the same as described above for the short-term projection concerning, *initial stock size, maturity, F and M before spawning, weight-at-age in the stock and catch, and exploitation pattern*. The *number of recruits* (age-3) for each year is derived from the index of number at age 1 in the Juvenile survey if available (see above in short-term projections), but otherwise it is set equal to the geometric mean over the whole assessment period.

F. Long-Term Projections

It has not been completed in recent assessments.

G. Biological Reference Points

Precautionary approach reference points:

The working group points out that managing this stock at an exploitation rate at or above $F_{0.1}$=F_{MSY}=0.22 has been successful in the past, despite biased assessments. At the 2016 NWWG meeting, the PA reference points for the stock were verified and revised (ICES 2016). On basis of the stock-recruitment relationship deriving from time-series ranging from 1947-2015, keeping B_{lim}=200 kt was considered reasonable as the Study Group on Precautionary Reference Points for Advice on Fishery Management concluded also in February 2003. Other PA reference points were derived from B_{lim} and these data in accordance to the ICES Advice Technical Guidelines and became these: B_{pa}= 273 kt ($B_{pa} = B_{lim} \times e^{1.645\sigma}$, where $\sigma = 0.19$); F_{lim} = 0.61 (F that leads to SSB = B_{lim}, given mean recruitment); F_{pa}= 0.43 ($F_{pa} = F_{lim} \times \exp(-1.645 \times \sigma)$, where $\sigma = 0.18$).

MSY based reference points:

The MSY based reference points have not been set for Icelandic summer-spawning herring, but exploratory work was present at the NWWG meeting in 2011 in a form as requested by ICES (ICES 2011b). The HCS program Version 10.3 (Skagen, 2012) was used to evaluate possible points based on the MSY framework that could be a basis for a management plan and Harvest Control Rule later.

Number of different runs was made with varying settings. The results implied that the MSY framework was confirmative with the currently used precautionary reference points. It means that the currently used $F_{0.1}$=0.22 could be a valid candidate for F_{MSY}. During a Management Strategy Evaluation (MSE) for the stock in April 2017 (ICES

2017b), F_{MSY}=0.22 was not considered to be significantly different from results of simulation giving 0.24. Thus, it was concluded adequate to keep F_{MSY}=0.22. During a Management Strategy Evaluation for the stock in April 2017 (ICES 2017b) these reference points were evaluated and advised to be unchanged.

H. Other Issues

Two incidents of mass mortalities in the herring stock took place in a fjord off west Iceland (Kolgrafafjörður) where the stock had overwintered in the winter 2012/2013. On basis of fieldwork there, the causes of the mortalities are believed to very low levels of oxygen saturation there. Even if unexpected and particularly the first one, similar incidents in the future there can not be disregarded. If this has something to do with a road construction and a bridge crossing the fjord can not be concluded for the time being. The currents in the fjord and the impacts of the bridge will be explored in the coming months. Thus, the ecosystem in this fjord and the herring belongs to while there, could be threatened by this bridge and/or the topographic and oceanographic conditions as long as this huge biomass of herring decides to overwinter there. The numerical estimates of fish that died in these two incidents (i.e. number-at-age) were added to the catch matrix from 2012 in the 2014 assessment, and on. In that way, no additional M was required in the time series in the assessment.

H.1. Historical overview of previous assessment methods

The summer-spawning herring stock collapsed in late 1960s due to overfishing and environmental changes (Jakobsson *et al.* 1993). The spawning stock has increased from about 10 thous. tonnes in 1972 to about 700 thous. tonnes around the middle of the 2000s.

During the recovery period, the assessments were based on acoustic surveys. These surveys, during the early and mid-1970s, were considered very uncertain. During late 1980s and early 1990s the assessment tool used was a homemade Adapt type of VPA. The stock was consistently overestimated during the late 1980s and the early 1990s. The difference between the acoustic values and those obtained from VPA was about 30%. The most likely cause of this error was considered to be the use of too low target strength (TS) values in the acoustic surveys (Jakobsson *et al.,* 1993). The TS value was raised about 30% or to similar value as used for other herring stocks in the NE Atlantic and the old acoustic values in the tuning file corrected. Until 2002 the homemade Adapt-type of VPA was used for the final assessment of the Icelandic summer-spawning herring stock. Assessment tools like XSA and AMCI were run along as well for some years. In 2003-2004, AMCI runs were accepted as the final assessment. NFT-Adapt, which was first applied in the 2004 assessment, has been the main assessment tool since 2005, even if it was first in 2008 accepted as the final assessment. Both TSA (Gudmundsson, 1994) and XSA have been run along with NFT-Adapt for comparison as alternative tools. In all these assessments, one sided retrospective pattern is seen, especially in the years 2002-2005, but it has diminished in the last years. The reasoning for this pattern is not known.

In 2005 there was a large uncertainty regarding the assessment of the stock and no assessment was considered reliable enough by ACFM. The same happened in the 2006 and 2007 assessments. Assessments use to be consistently biased in overestimating the spawning stock for some years. Several reasons have been mentioned to account for this overestimation problem, including: (1) discrepancies in the catch and survey; (2) a possible higher natural mortality because of much more widespread spatial distribution of the stock since 1997, which means more accessibility for predators; (3) higher mortality related to the fishery with the pelagic trawl, but from 1997 to 2006 around 20-60% of the catch was taken by pelagic trawl; (4) the reduction of the part of the stock that was acoustically measured east of Iceland.

Summary of data ranges used in recent assessments:

Data	2007 assessment	2008 assessment	2009 assessment	2010 assessment
Catch data	Years: 1986–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+	Years: 1978–(AY-1) Ages: 3–12+
Survey: IS-Her-Aco-Q4/Q1	Years: 1986–(AY-1) Ages: 4–10	Years: 1986–(AY-1) Ages 4–10	Years: 1986–(AY-1) Ages 4–10	Years: 1986– (AY-1) Ages 4–10
Survey: B	Not used	Not used	Not used	Not used
Survey: C	Not used	Not used	Not used	Not used

Data	2011 assessment	2012 assessment	2013 assessment	2014–17 assessments
Catch data	Years: 1987–(AY-1) Ages: 3–13+	Years: 1987–(AY-1) Ages: 3–13+	Years: 1987–(AY-1) Ages: 3–13+	Years: 1987–(AY-1) Ages: 3–13+
Survey: IS-Her-Aco-Q4/Q1	Years: 1987–(AY-1) Ages: 3–10	Years: 1987–(AY-1) Ages 3–10	Years: 1987–(AY-1) Ages 3–10	Years: 1987–(AY-1) Ages 3–10
Survey: B	Not used	Not used	Not used	Not used
Survey: C	Not used	Not used	Not used	Not used

AY – Assessment year

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