HERRING
Clupea harengus

GENERAL INFORMATION

The Icelandic summer-spawning herring (*Clupea harengus*) is a pelagic fish that can be found all around the country. It lives in a wide range of depths from the surface down to a depth of 400m and at temperatures from 1-15°C (Jakobsson 2000). Its main wintering grounds have been either shallow or deep east or west of Iceland or shallow in the south (Jakobsson 1980, Óskarsson et al 2009). Herring spawns in July, and its spawning grounds can be found along the south and southwest coast of Iceland (Óskarsson and Taggart 2009, Jakobsson et al. 1969). After hatching of eggs at the bottom, larvae reach the north of the country by currents and the main nursery areas are found in fjords northwest and north of the country (Guðmundsdóttir et al. 2007).

SURVEYS

DESCRIPTION

The scientific data used for assessment of the Icelandic summer-spawning herring stock derives from annual acoustic surveys, which have been ongoing since 1973 (Table 1). Normally these surveys are conducted in the period of October–January, but also as late as end of March. The surveyed area each year is decided based on available information on the distribution of the stock in the previous and the current year, which include information from the fishery. Thus, the survey area varies spatially but is considered to cover the whole stock each year. The survey index for the stock in the winter of 2020/2021 derives from two dedicated acoustic surveys on RV Bjarni Sæmundsson: (1) A survey aiming at herring in the east, southeast and south of Iceland in November; (2) A survey in the end of March aiming at the main overwintering area of the stock west of Iceland. The biological sampling in the survey is detailed in Table 2. In addition to getting an acoustic estimate, the objective was also to get an estimate of the prevalence of the *Ichthyophonus* infection in the stock. The methods used to estimate the infection were the same as in previous years (Óskarsson and Pálsson 2018).

The *Ichthyophonus* infection has been persistent in the Icelandic summer-spawning herring since 2008. Mortality rate due to the infection was estimated using the NFT-ADAPT stock assessment model and was estimated that 30% of infected herring die annually (Óskarsson et al. 2018a). This assumption has been used in the stock assessment and infection mortality ($M_{infected}$) is added to the natural mortality (M=0.1) for each age group each year ($M_{age,\ year}$ = 0.1 + $M_{infected}$ × 0.3; Table 7). The number infected in the stock in 2020/21 was evaluated for each age group in the same way as has been done since the beginning of the infection in autumn of 2008 (Óskarsson and Pálsson 2018).

RESULTS

In the herring surveys in winter of 2020/21, herring was measured west of the country in the end of March 2021, and east, southeast, and south of the country in November 2020 (Figure 1). Survey estimates according to these two surveys amounted to 3.8 billion in number (two years and older) and the total biomass was estimated at 623 kt (Table 1). Part of the fishable stock (≥ 27 cm) was estimated at 50% of the total stock and 75% of the biomass, or 465 kt. The cohort from 2017 was the largest and accounted for 25% of the total biomass (177 kt), followed by the 2018 cohort with 17% (106 kt). Estimates of the infection rate caused by *Ichthyophonus* in the catch samples show a similar rate as last season, and new infections are still ongoing. The estimated infection rate was 8–29% for age 4 and older, but less than 4% for age 2 and 9% for age 3. The infection rate for the large 2017 year class was 5.4% west of the country and 15% in the southeast (Figure 2). There are still new infections taking place as seen with the younger ages, so infection mortality is assumed to take place in 2021, like in previous years.

FISHERY

The total catch in the 2020/2021 season was 36 100 tonnes (Table 3, Figure 4). This also includes the by-catch of herring in the mackerel and Norwegian spring-spawning herring fisheries in June - November 2020, and the part that was caught in June-August belongs to the previous fishing season. The recommended TAC for the 2020/2021 fishing season (September-August; ICES 2018) and the TAC (Regulation No. 672, 2 July 2020) were 35 490 tonnes (Table 3). Traditional catches in wintering grounds west of the country in November-February accounted for 44% (15 800 tonnes) of the total catch (Figure 4), while 56% (20 300 tonnes) were taken as bycatch in mackerel fishing in the south of the country in June-July (3 400 tonnes) and fishing for mackerel and Norwegian spring-spawning herring to the east in June-July (4 400 tonnes) and September-November (12 500 tonnes) (Figure 4).

All catches in the year 2020/2021 were caught in pelagic trawls (Figure 4). In the seasons 2007/2008 to 2012/2013, the majority of the catch (~90%) was caught in Breiðafjörður, but before that it was mainly caught off the south, southeast and east coasts. The year 2013/2014 was an indication of changes in this pattern, with a smaller proportion in Breiðafjörður, and since 2014/2015, most of the fishing has taken place in the west of the country. To protect juvenile herring (27 cm and smaller) in the fishery, area closures are enforced on the basis of a regulation on herring fishing issued by the Ministry of Fisheries (No. 376, 8 October 1992). No closure was enforced in this herring fishery in 2020/21. Normally, the age of first recruitment to the fishery is age-3, which is fish at length around 26–29 cm.

CATCH IN NUMBERS, WEIGHT AND MATURITY

The assessment of the age composition of the catch is based on samples from the catch of fishing vessels collected at sea by fishermen and catch information. This year, the calculations were accomplished by dividing the total catch into four cells confined by season and area. In the same way, weight-at-length relationships derived from the length and weight measurements of the catch samples were used. Based on difference in length-at-age between the summer months and the winter, two length-age keys were applied. The number of fish in the catch by age from 1975 is given in Table 4. The locations of the catch samples 2020/2021 are shown in Figure 4. The average weight by age obtained from the catch samples is given in Table 5. The fixed maturity ogives were used in this year's assessment, where proportion mature-at-age 3 is set 20% and 85% for fish at age 4, while all older fish is considered mature (Table 6).

ASSESSMENT

ANALYSIS OF INPUT DATA

Examination of catch curves from survey indices for the year classes 1989-2016 (Figure 5) indicates that the total mortality signal (Z) in the fully recruited age groups is around 0.4. It is under the assumption that the effort has been the same the whole time. In recent years, the effort has changed a lot because of the infection and spatial distribution of the stock, and the mass mortality in 2012/2013 (Óskarsson et al. 2018b), which makes any strong deductions from the catch curves for those years less meaningful. Catch curves from catch data were also plotted using year classes 1989-2016 (Figure 6). Even if the total mortalities look at bit noisy for some year classes, they seem to be close to 0.4. There is an indication that the fish is fully assessable at age 3–5. Increased mortality in the stock due to *Ichthyophonus* cannot be detected clearly from the catch curves. However, considering that F was reduced drastically in the beginning of the outbreak, similar Z means an increased M during that period, representing infection mortality.

ASSESSMENT MODELS AND INPUT DATA

To explore the data this year, two models were run, NFT-ADAPT (VPA/ADAPT version 3.3.0 NOAA Fisheries Toolbox) that has been used as the basis for the assessments since 2005 and a separable model (Muppet) also used in the Management Strategy Evaluation (MSE) in 2017 for the stock (ICES 2017; Björnsson 2018) as well as assessment of Icelandic saithe. NFT-ADAPT was evaluated at benchmark assessment in January 2011 (ICES, 2011a) and it was found to be appropriate as the principal assessment tool for the stock. The catch data used were from 1987/88–2020/21 (Table 8) and survey data from 1987/88–2020/21 (Table 1). Other input data consisted of: (i) mean weight at age (Table 5); (ii) maturity ogive (Table 6); (iii) natural mortality, M, that was set to 0.1 for all age groups in all years, except for 2009–2011 and 2017–2020 where additional mortality was applied because of the *Ichthyophonus* infection (Table 7; Óskarsson et al. 2018a); (iv) proportion of M before spawning was set to 0.5; and (v) proportion of F before spawning was set to 0. Thus, in comparison to last year's assessment, all the input data are the same with an additional year of data.

MODEL RESULTS

The NFT-ADAPT model estimates the number in the population at age 4-12 at the beginning of 2021, but the number in the population at age 3 was estimated based on survey data in 2019 (estimate from the index of 1-3 years according to Guðmundsdóttir et al. 2007 and ICES (2011a)) instead of using geometric mean, which is a standard setting in the model. The catchability at age in the survey, as estimated by NFT ADAPT, and the CV is shown in Figure 11.3.2.1. The age groups 3–10 were used for tuning (Table 11.1.1.1 as decided at the benchmark in ICES (2011a). In comparison to last year, the catchability of the survey is relatively the same with similar uncertainty. Sample data and settings of NFT-ADAPT are shown in Table 8. The numbers in the stock and fishing mortality are shown in Tables 9 and 10 and summarized in Table 11 and Figure 8. Deviations between the model and the underlying data from the survey are shown in Figure 8, 9 and Table 12 and show the effects of both cohorts and years. The pattern is the same as in recent years. Positive deviations, as the model gives lower values than the survey values, can be seen for the 1994 and 1999 cohorts for almost all age groups and negative deviations for the 2001 and 2003 cohorts. In 2000-2006, the deviations were positive (at the beginning of the year, 1 January). During these years, the population wintered in the east and west of the country, compared to a more easterly distribution before that time and wintered in coastal areas (from ~2006–2012). These positive deviations could therefore reflect changes in the expediency of the expedition this year. Analysis of the stability of the model over the last 6 years shows that its results on stock size estimates do not change much with the addition of one year of data (Figure 10). This indicates that there is consistency in the stock assessment. The measured values were considerably higher than those from the model (Figure 11), but otherwise there was good agreement.

COMPARISON OF MODELS

The results of the two models, NFT-ADAPT and Muppet, gave similar results, especially for the last years of the evaluation (Figures 8b-e). This indicates that what affects the results is the input data, not the model being used.

FINAL ASSESSMENT AND TAC ADVICE

In this updated assessment from the previous year, a new year of data was added on catch and survey results, as well as an estimation of mortality in 2020 due to the *Ichthyophonus* infection. The results from the analytical assessment model, NFT-ADAPT, indicate that the stock size has increased because of an upward revision in the stock size, due to a large 2017 year class entering the fishery at age 4 this autumn. Spawning stock biomass for 2021 is estimated 377.1 kt and the reference biomass of age 4+ (B_{Ref}) is 481.6 kt in the beginning of the year 2021. As the SSB will be above MGT $B_{trigger}$ = 200 kt, the advised TAC according to the Management Plan is $HR_{MGT} \times B_{Ref} = 0.15 \times 481\,594 = 72\,239$ tonnes.

REFERENCE POINTS AND THE MANAGEMENT PLAN

REFERENCE POINTS

The exploitation rate of $F_{0.1} = F_{MSY} = 0.22$ proved successful in managing the stock for about 30 years, despite biased assessments. At a Northwestern Working group meeting at ICES in 2016, where the catch rule for the stock was tested, the limit values for the stock were revised (ICES 2016). On the basis of stock-recruitment relationship, deriving from time-series ranging from 1947-2015, it was considered advisable to keep B_{lim} = 200 k. Other PA reference points were derived from B_{lim} and according to ICES guidelines: B_{pa} = 273 thous. tons ($B_{pa} = B_{lim} \times e1.645\sigma$, 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 $\sigma = 0.18$). Maximum Sustainable Yield: MSY was set in 2011 (Skagen 2012). The results of that work were that $F_{0.1}$ = 0.22 could be valid as F_{MSY}. During a MSE for the stock in April 2017 (ICES 2017), F_{MSY} = 0.22 was not significantly different from results of simulation giving 0.24. Thus, it was concluded adequate to keep F_{MSY} = 0.22.

MANAGEMENT PLAN

Five different catch rules (HCR) were tested for the stock in 2017 (ICES 2017) and all but the advisory rule used at the time ($F_{MGT} = 0.22$), passed the precautionary approach, and complied with the ICES MSY approach. One of these catch rules was then adopted by the Icelandic Government as a Management plan for the stock. This HCR is based on reference biomass of age 4+ in the beginning of the assessment years ($B_{ref,\ Y}$), a spawning stock biomass trigger (MGT $B_{trigger}$) is defined as 200 kt, and the harvest rate (HR_{MGT}) is set as 15% of the reference biomass age 4+ in the beginning of the assessment year. In the assessment year (Y) the TAC in the next fishing year (1 September of year Y to 31 August of year Y+1) is calculated as follows:

$TAC_{Y\ /\ Y\ +\ 1} = HR_{MGT} * B_{ref,\ Y}$

When SSB_Y is below MGT $B_{trigger}$:

$TAC_{Y\ /\ Y\ +\ 1} = HR_{MGT} * (SSB_y\ /\ MGT\ B_{trigger}) * B_{ref,\ Y}$

In the MSE simulation, the ongoing *Ichthyophonus* infection was considered to continue and was accounted for. Consequently, this HCR is independent of estimated level of *Ichthyophonus* mortality and requires no further action during such epidemics.

STATE OF THE STOCK

The stock was large around 2007 but steadily declined until 2017 despite small catches. This decrease was due to the *Ichthyophonus* infection mortality in 2009–2011 and 2016–2018 in addition to small year classes entering the stock since around 2005, particularly the 2011–2014 year classes. Survey indices in recent years indicate that the 2017 year class is large and will enter the fishery in the autumn of 2021.

SHORT TERM FORCAST

INPUT DATA

The final run of the NFT-ADAPT model, which gave the number-at-age on 1 January 2021, was used as a basis for projections of stock size development. All data used for the forecast are given in Table 13. Due to the expected *Ichthyophonus* mortality in the stock in spring 2021, the numbers from the NFT-ADAPT model were reduced in accordance with the estimated infection rate 2019/2020, which was multiplied by 0.3 (Table 7), or the same approach used in the 2009–2011 and 2018-2020 stock assessments (ICES, 2011b; 2018; Óskarsson et al. 2018a). Weight by age was determined from the average weight in last year's catch, and as in recent years, the average weight is expected to remain high, except for the youngest age groups (Figure 14). Weight for age 3 was set the same as used in 2020.

In summary, the basis for the stock projection is as follows: Spawning stock biomass (SSB 2021) = 377 kt; Biomass 4+ (1 January 2021) = 481.6 kt; Catch (2021/22) = 72 239 kt; and HCR (2021/22) = 0.15.

RESULTS

The spawning stock in 2022 is estimated at 421 kt, which is over MGT $B_{trigger}$ = 200 kt and the biomass of the reference stock at the beginning of 2022 is estimated at 441 kt. The results of different options are given in Table 14. Because of the increased uncertainty of the assessment in relation to the development of the *Ichthyophonus* infection in the coming months and years, and the uncertainty in size of the recruiting year classes, no medium-term prediction is provided.

UNCERTAINTIES IN THE ASSESSMENT AND FORECAST

UNCERTAINTY IN THE ASSESSMENT

There are many factors that could lead to uncertainty in the assessment. For example, there was a large uncertainty about *Ichthyophonus* mortality in the first years after the infection started, but as the years went by, it was possible to assess the mortality better (Óskarsson et al. 2018a), which is believed to have reduced this uncertainty. For the last few years, when new infections reappeared (2017–2020), it is possible to obtain a more accurate estimate of infection mortality, but until then the same approaches will be used. It has been shown that an increase in M in the input data for the stock assessment has the effect of increasing the historical size of the stock, but this has little effect on the assessment and advice. Another uncertainty factor related to the stock assessment is the size of year classes that are entering the stock, but the assessment of their size is based on sparse data as the herring is first caught and can be measured in acoustic surveys at the age of 3.

UNCERTAINTY IN THE FORECAST

The uncertainty in the projections is comparable to that mentioned above in the uncertainty in the stock assessment. In addition, the number of age 3 at the beginning of 2021 used in projections (572 million) is estimated with an acoustic survey of numbers at age 1 in 2019. No juvenile survey was gone in 2020 and there are no plans for such in 2021, which will cause even more uncertainty about the size of year classes that will enter the stock in the coming years.

ASSESSMENT QUALITY

The lack of stability between years in the herring stock assessment has often been a cause for concern. In particular, there was a tendency to overestimate the size of the stock. No assessment was made in 2005 due to data and model problems, and for the next two years ACFM rejected the assessment due to instability in the results of the assessment. The last five years have been more stable, and this year's assessments are stable for spawning stock size (SSB) and F (Figure 10), but the residuals also behave better (Figure 9). This together could be interpreted as evidence of a more reliable stock assessment.

CHANGES IN FISHING TECHNOLOGY AND FISHING PATTERNS

There are no recent changes in fishing techniques that could lead to different catch compositions. The fishing pattern in the seasons 2014/2015 to 2020/2021 was different from the previous nine seasons.

Instead of fishing near only in a small inshore area off the west coast in purse seine, the directed fishery took place in offshore areas west, south, southeast, and east of the country by pelagic trawls. These changes are not considered to affect the selectivity of the fishery because the fishery is still targeting dense schools of overwintering herring in large fishing gears, getting huge catches in each haul and is by none means size selective. The bycatch of Icelandic summer-spawning herring in the mackerel fishery (since 2006) and Norwegian spring-spawning herring (since 2004) has increased in recent years. It is mainly caught as bycatch in the east, southeast and south of the country, but not in the overwintering area west of the country, where the main fishery has taken place in recent years. Icelandic summer-spawning herring as bycatch has usually been less than 10% of the total catch but has increased in recent years and was 56% of the total catch this year. The fishing pattern varies annually, and it is related to variation in winter distribution of the different age classes of the stock. This variation can have consequences for the catch composition, but it is impossible to provide a forecast about this variation.

SPECIES INTERACTION EFFECTS AND ECOSYSTEM DRIVERS

Regarding relevant research on species interaction, the main work relates to the increasing amount of Northeast Atlantic mackerel (NEAM) feeding in Icelandic waters after 2006 (Astthorsson et al., 2012; Nøttestad et al., 2016). Surveys in the summers since 2010 indicate a high overlap in spatial and temporal distribution of NEAM and Icelandic summer-spawning herring (Óskarsson et al., 2016). Moreover, the diet composition of NEAM in Icelandic waters showed a clear overlap with those of the two herring stocks, i.e., Icelandic summer-spawning herring and Norwegian spring-spawning herring (Óskarsson et al., 2016). Even if copepoda was important diet group for all the three stocks its relative contribution to the total diet was apparently higher for NEAM than the two herring stocks. Considering former studies of herring diet, this finding was unexpected, and particularly how little the copepoda contributed to the herring diet. This difference in the stomach content of NEAM and the two herring stocks indicated that there could be some difference in feeding ecology between them in Icelandic waters, where NE-AM preferred copepoda, or feed in the water column where they dominate over other prey groups, while the opposite would be for the herring and the prey Euphausiacea. Recent studies in the Nordic Seas have shown similar results (Langøy et al., 2012; Debes et al., 2012). The indication for difference in feeding ecology of the species is further supported by the fact that the body condition of the two herring stocks showed no clear decreasing trend since the invasion of NEAM started into Icelandic waters. On the contrary the mean weights-at-age (and at-length) of the summer spawners have been high after 2010 (Óskarsson, 2019b) and for example record high in the autumn 2014 (Figure 11.6.1.1). It should though be noted that comparison of the diet composition of herring in recent years to earlier studies, mainly on NSS herring, indicate that the herring might have shifted their feeding preference towards Euphausiacea instead of Copepoda. That is possibly a consequence of increased competition for food with NEAM, where the herring is overwhelmed and shifts towards other preys. The Northwestern working group at ICES is not aware of documentations of strong signals from ecosystem or environmental variables that impact the herring stock and could possibly be a basis for implementing ecosystem drivers in the analytical basis for its advice. For example, recruitment in the stock has been positively, but weakly, linked to NAO winter index (North Atlantic Oscillation) and sea temperature (Óskarsson and Taggart 2010), while indices representing zooplankton abundance in the spring have not been found to impact the recruitment (Óskarsson and Taggart 2010) or body condition and growth rate of the adult part of the stock (Óskarsson 2008). Considering these relations derived from the historical data, relatively warm waters around Icelandic (Hafrannsóknastofnun 2016), and high positive NAO in recent years (NOAA 2021), which could have resulted in a large 2017 cohort and possibly also the 2018 cohort, although there is still uncertainty about its size.

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TABLES

Table 1. Acoustic estimates (in millions) in winters 1973/74–2020/21 (age refers to autumn). No surveys (and gaps in the time-series) were in 1976/77, 1982/83, 1986/87, 1994/95.

Year\age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
1973/74	154.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	154
1974/75	5.000	137.000	19.000	21.000	2.000	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	186
1975/76	136.000	20.000	133.000	17.000	10.000	3.000	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	322
1977/78	212.000	424.000	46.000	19.000	139.000	18.000	18.000	10.000	0.000	0.000	0.000	0.000	0.000	0.000	886
1978/79	158.000	334.000	215.000	49.000	20.000	111.000	30.000	30.000	20.000	0.000	0.000	0.000	0.000	0.000	967
1979/80	19.000	177.000	360.000	253.000	51.000	41.000	93.000	10.000	0.000	0.000	0.000	0.000	0.000	0.000	1004
1980/81	361.000	462.000	85.000	170.000	182.000	33.000	29.000	58.000	10.000	0.000	0.000	0.000	0.000	0.000	1390
1981/82	17.000	75.000	159.000	42.000	123.000	162.000	24.000	8.000	46.000	10.000	0.000	0.000	0.000	0.000	666
1983/84	171.000	310.000	724.000	80.000	39.000	15.000	27.000	26.000	10.000	5.000	12.000	0.000	0.000	0.000	1419
1984/85	28.000	67.000	56.000	360.000	65.000	32.000	16.000	17.000	18.000	9.000	7.000	4.000	5.000	5.000	689
1985/86	652.000	208.000	110.000	86.000	425.000	67.000	41.000	17.000	27.000	26.000	16.000	6.000	6.000	1.000	1688
1987/88	115.544	401.246	858.012	308.065	57.103	32.532	70.426	36.713	23.586	18.401	24.278	10.127	3.926	4.858	1965
1988/89	635.675	201.284	232.808	381.417	188.456	46.448	25.798	32.819	17.439	10.373	9.081	5.419	3.128	5.007	1795
1989/90	138.780	655.361	179.364	278.836	592.982	179.665	22.182	21.768	13.080	9.941	1.989	0.000	0.000	0.000	2094
1990/91	403.661	132.235	258.591	94.373	191.054	514.403	79.353	37.618	9.394	12.636	0.000	0.000	0.000	0.000	1733
1991/92	598.157	1049.990	354.521	319.866	89.825	138.333	256.921	21.290	9.866	0.000	9.327	0.000	0.000	1.494	2850
1992/93	267.862	830.608	729.556	158.778	130.781	54.156	96.330	96.649	24.542	1.130	1.130	3.390	0.000	0.000	2395
1993/94	302.075	505.279	882.868	496.297	66.963	58.295	106.172	48.874	36.201	0.000	4.224	18.080	0.000	0.000	2525
1995/96	216.991	133.810	761.581	277.893	385.027	176.906	98.150	48.503	16.226	29.390	47.945	4.476	0.000	0.000	2197
1996/97	33.363	270.706	133.667	468.678	269.888	325.664	217.421	92.979	55.494	39.048	30.028	53.216	18.838	12.612	2022
1997/98	291.884	601.783	81.055	57.366	287.046	155.998	203.382	105.730	35.469	27.373	14.234	36.500	14.235	11.570	1924
1998/99	100.426	255.937	1081.504	103.344	51.786	135.246	70.514	101.626	53.935	17.414	13.636	2.642	4.209	8.775	2001
1999/00	516.153	839.491	239.064	605.858	88.214	43.353	165.716	89.916	121.345	77.600	21.542	3.740	11.149	0.000	2823
2000/01	190.281	966.960	1316.413	191.001	482.418	34.377	15.727	37.940	14.320	15.413	14.668	1.705	3.259	0.000	3284
2001/02	1047.643	287.004	217.441	260.497	161.049	345.852	62.451	57.105	38.405	46.044	38.114	21.062	3.663	0.000	2586
2002/03	1731.809	1919.368	553.149	205.656	262.362	153.037	276.199	99.206	47.621	55.126	18.798	24.419	24.112	1.377	5372
2003/04	1115.255	1434.976	2058.222	330.800	109.146	100.785	38.693	45.582	7.039	6.362	7.509	10.894	0.000	2.289	5268
2004/05	2417.128	713.730	1022.326	1046.657	171.326	62.429	44.313	10.947	23.942	12.669	0.000	1.948	11.088	0.000	5539
2005/06	469.532	443.877	344.983	818.738	1220.902	281.448	122.183	129.588	73.339	65.287	10.115	9.205	3.548	12.417	4005
2006/07	109.959	608.205	1059.597	410.145	424.525	693.423	95.997	123.748	48.773	0.955	0.000	0.000	0.000	0.480	3576
2007/08	90.231	456.773	289.260	541.585	309.443	402.889	702.708	221.626	244.772	13.997	22.113	68.105	10.136	2.800	3376

Year\age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
2008/09	149.466	196.127	416.862	288.156	457.659	266.975	225.747	168.960	29.922	26.281	17.790	9.881	0.974	3.195	2258
2009/10	151.066	315.941	490.653	554.818	271.445	327.275	149.143	83.875	156.920	36.666	13.649	8.507	1.458	5.590	2567
2010/11	106.178	280.582	228.857	304.885	296.254	138.686	301.285	60.997	141.323	97.412	37.006	0.000	4.019	0.000	1997
2011/12	704.863	977.323	434.876	313.742	272.140	239.320	154.581	175.088	84.582	92.435	89.376	17.638	6.808	4,989	3676
2012/13	178.500	781.083	631.421	166.627	126.961	142.044	110.084	97.000	74.340	69.473	43.376	38.450	7.458	0.773	2468
2013/14	15.919	314.865	218.715	344.981	151.631	132.767	120.756	118.377	89.555	74.602	48.695	44.637	31.096	11.598	1718
2014/15	152.422	90,269	330.084	260.919	259.079	187.905	111.955	91.629	37.855	76.680	30.366	10.619	22.799	10.108	1667
2015/16	381.900	164.221	174.507	312.350	225.836	215.207	93.743	62.753	75.339	41.961	15.696	26.756	20.159	5.401	1816
2016/17	97.036	220.642	137.217	151.937	262.488	136.801	241.382	61.220	55.869	62.805	11.435	20.135	13.733	0.313	1473
2017/18	32.749	22.947	95.097	171.664	201.944	319.933	209.174	255.348	75.813	34.505	83.460	54.903	25.370	28.115	1611
2018/19	306.295	137.402	67.933	201.362	101.946	110.810	167.397	163.804	73.346	30.040	29.950	38.499	9.138	7.271	1445
2019/20	1525	229.841	158.605	103.631	211.106	98.785	53.723	59.527	42.221	37.186	21.341	15.089	10.393	0.986	2568
2020/21	1399.761	1114.743	424.292	138.193	81.983	127.703	66.488	102.847	82.755	63.522	56.970	22.767	11.122	21.563	3802

Table 2. Number of fish aged (number of scales) and number of samples taken in the annual acoustic surveys in the seasons 1987/88–2020/21 (age refers to the former year, i.e. autumns). In 2000 seven samples were used from the fishery.

	Number of scales															N of samples		
Year/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total	Total	West	East
1987/88	11	59	246	156	37	28	58	33	22	16	23	10	5	8	712	8	1	7
1988/89	229	78	181	424	178	69	50	77	42	29	23	13	7	12	1412	18	5	10
1989/90	38	245	96	132	225	35	2	2	3	3	2	0	0	0	783	8		8
1990/91	418	229	303	90	131	257	28	6	3	8	0	0	0	0	1473	15		15
1991/92	414	439	127	127	33	48	84	5	3	0	2	0	0	1	1283	15		15
1992/93	122	513	289	68	73	28	38	34	6	2	2	6	0	0	1181	12		12
1993/94	63	285	343	129	13	15	7	14	11	0	1	3	0	0	884	9		9
1994/95*																		
1995/96	183	90	471	162	209	107	38	18	8	14	18	2	0	0	1320	14	9	5
1996/97	24	150	88	351	141	137	87	32	15	10	7	14	4	2	1062	11	4	7
1997/98	101	249	50	36	159	95	122	62	21	13	8	15	8	5	944	14	7	7
1998/99	130	216	777	72	31	65	59	86	37	22	17	5	6	11	1534	17	10	7
1999/00	116	227	72	144	17	13	26	26	27	10	8	2	1	0	689	7	3	4
2000/01	116	249	332	87	166	10	7	21	8	14	11	3	1	0	1025	14	10	4
2001/02	61	56	130	114	62	136	25	24	17	21	17	10	3	0	676	9	4	5
2002/03	520	705	258	104	130	74	128	46	26	25	13	15	10	1	2055	22	12	10
2003/04	126	301	415	88	35	32	15	17	3	4	4	6	1	1	1048	13	8	5
2004/05	304	159	284	326	70	29	17	5	8	4	0	3	3	0	1212	13	4	9
2005/06	217	312	190	420	501	110	40	38	26	18	5	5	5	7	1894	22	14	8
2006/07	19	77	134	64	71	88	22	4	2	2	0	0	0	1	484	6	4	2
2007/08	58	288	180	264	85	80	104	19	15	2	2	6	1	3	1107	17	13	4
2008/09	274	208	213	136	204	123	125	97	18	13	9	7	4	17	1448	29	19	10
2009/10	104	100	105	116	60	74	34	19	36	8	3	4	2	2	667	17	10	7
2010/11	35	74	102	157	139	61	119	22	52	36	13	0	1	0	811	11	8	3
2011/12	229	330	134	115	100	106	74	87	45	48	51	10	3	3	1335	15	9	6
2012/13‡	42	266	554	273	220	252	198	165	126	114	69	61	12	2	2370	60	55‡	5
2013/14	26	472	275	414	199	200	199	208	163	138	90	85	60	23	2552	45	37‡	8
2014/15	83	50	96	71	72	53	32	26	11	22	8	3	6	4	534	10	8	2
2015/16	229	112	131	208	148	123	47	32	32	22	13	7	12	4	1120	14	7	7§
2016/17§	66	164	122	137	202	117	169	43	50	44	14	15	9	4	1162	14	12	2
2017/18	35	58	82	77	75	101	65	77	29	11	27	18	8	9	672	10	5	5
2018/19	28	39	31	98	50	53	77	75	36	15	15	21	5	4	547	7	5	2
2019/20	265	143	94	48	101	60	43	54	45	43	27	26	20	6	975	10	5	5
2020/21	248	215	116	68	59	104	52	79	55	44	35	13	6	8	1102	13	5	8

*No survey

‡Samples in the western part were mainly from the commercial catch as there was impossible to secure a usable research survey samples from Kolgrafafjörður where most of the herring was observed.

§Three samples were taken in the east and south in this survey (B1-2016), while four were taken in the west and used also in the age-length key.

Table 3. Landings, catches, recommended TACs, and set National TACs in thousand tonnes.

Year	Landings	Catches	Recom. TACs	Nat. TACs	Year	Landings	Catches	Recom. TACs	Nat. TACs
1972	0.31	0.31			2007/2008	158.9	158.9	130	150
1973	0.254	0.254			2008/2009	151.8	151.8	130	150
1974	1.275	1.275			2009/2010	46.3	46.3	40	47
1975	13.28	13.28			2010/2011	43.5	43.5	40	40
1976	17.168	17.168			2011/2012‡	49.4	49.4	40	45
1977	28.925	28.925			2012/2013‡	72.0	72.0	67	68.5
1978	37.333	37.333			2013/2014‡	72.0	72.0	87	87
1979	45.072	45.072			2014/2015‡§	95.0	95.0	83	83
1980	53.268	53.268			2015/2016‡	69.7	69.7	71	71
1981	39.544	39.544			2016/2017‡	60.4	60.4	63	63
1982	56.528	56.528			2017/2018‡	35.0	35.0	39	39
1983	58.867	58.867			2018/2019‡	40.7	40.7	35.1	35.1
1984	50.304	50.304			2019/2020‡	30.0	30.0	34.6	34.6
1985	49.368	49.368	50	50	2020/2021‡	36.1	36.1	35.5	35.5
1986	65.5	65.5	65	65	2021/2022			72.2	
1987	75	75	70	73					
1988	92.8	92.8	90	90					
1989	97.3	101	90	90					
1990/1991	101.6	105.1	80	110					
1991/1992	98.5	109.5	80	110					
1992/1993	106.7	108.5	90	110					
1993/1994	101.5	102.7	90	100					
1994/1995	132	134	120	120					
1995/1996	125	125.9	110	110					
1996/1997	95.9	95.9	100	100					
1997/1998	64.7	64.7	100	100					
1998/1999**	87	87	90	70					
1999/2000	92.9	92.9	100	100					
2000/2001	100.3	100.3	110	110					
2001/2002	95.7	95.7	125	125					
2002/2003*	96.1	96.1	105	105					
2003/2004*	130.7	130.7	110	110					
2004/2005	114.2	114.2	110	110					
2005/2006	103	103	110	110					
2006/2007	135	135	130	130					

*Summer fishery in 2002 and 2003 included.

** TAC was decided 70 thousand tonnes but because of transfers from the previous quota year the national TAC became 90 thousand tonnes.

‡ Landings and catches include bycatch of Icelandic summer-spawning herring in the mackerel and NSS herring fishery during the preceding summer (i.e. from the fishing season before in June–August).

§ The landings and catches in 2014/2015 consist of transfer of 7 kt from the year before and 5 kt from the year to come, which explains the discrepancy to the TACs.

Table 4. Catch in numbers (millions) and total catch in weight (thousand tonnes) (1981 refers to season 1981/1982 etc).

Year\ age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Catch
1975	1.518	2.049	31.975	6.493	7.905	0.863	0.442	0.345	0.114	0.004	0.001	0.001	0.001	0.001	13.280
1976	0.614	9.848	3.908	34.144	7.009	5.481	1.045	0.438	0.296	0.134	0.092	0.001	0.001	0.001	17.168
1977	0.705	18.853	24.152	10.404	46.357	6.735	5.421	1.395	0.524	0.362	0.027	0.128	0.001	0.001	28.925
1978	2.634	22.551	50.995	13.846	8.738	39.492	7.253	6.354	1.616	0.926	0.4	0.017	0.025	0.051	37.333
1979	0.929	15.098	47.561	69.735	16.451	8.003	26.04	3.05	1.869	0.494	0.439	0.032	0.054	0.006	45.072
1980	3.147	14.347	20.761	60.727	65.328	11.541	9.285	19.442	1.796	1.464	0.698	0.001	0.11	0.079	53.268
1981	2.283	4.629	16.771	12.126	36.871	41.917	7.299	4.863	13.416	1.032	0.884	0.760	0.101	0.062	39.544
1982	0.454	19.187	28.109	38.280	16.623	38.308	43.770	6.813	6.633	10.457	2.354	0.594	0.075	0.211	56.528
1983	1.475	22.499	151.718	30.285	21.599	8.667	14.065	13.713	3.728	2.381	3.436	0.554	0.100	0.003	58.867
1984	0.421	18.015	32.244	141.354	17.043	7.113	3.916	4.113	4.517	1.828	0.202	0.255	0.260	0.003	50.304
1985	0.112	12.872	24.659	21.656	85.210	11.903	5.740	2.336	4.363	4.053	2.773	0.975	0.480	0.581	49.368
1986	0.100	8.172	33.938	23.452	20.681	77.629	18.252	10.986	8.594	9.675	7.183	3.682	2.918	1.788	65.500
1987	0.029	3.144	44.590	60.285	20.622	19.751	46.240	15.232	13.963	10.179	13.216	6.224	4.723	2.280	75.439
1988	0.879	4.757	41.331	99.366	69.331	22.955	20.131	32.201	12.349	10.250	7.378	7.284	4.807	1.957	92.828
1989	3.974	22.628	26.649	77.824	188.654	43.114	8.116	5.897	7.292	4.780	3.449	1.410	0.844	0.348	101.000
1990	12.567	14.884	56.995	35.593	79.757	157.225	30.248	8.187	4.372	3.379	1.786	0.715	0.446	0.565	105.097
1991	37.085	88.683	49.081	86.292	34.793	55.228	110.132	10.079	4.155	2.735	2.003	0.519	0.339	0.416	109.489
1992	16.144	94.86	122.626	38.381	58.605	27.921	38.42	53.114	11.592	1.727	1.757	0.153	0.376	0.001	108.504
1993	2.467	51.153	177.78	92.68	20.791	28.56	13.313	19.617	15.266	4.254	0.797	0.254	0.001	0.001	102.741
1994	5.738	134.616	113.29	142.876	87.207	24.913	20.303	16.301	15.695	14.68	2.936	1.435	0.244	0.195	134.003
1995	4.555	20.991	137.232	86.864	109.14	76.78	21.361	15.225	8.541	9.617	7.034	2.291	0.621	0.235	125.851
1996	0.717	15.969	40.311	86.187	68.927	84.66	39.664	14.746	8.419	5.836	3.152	5.18	1.996	0.574	95.882
1997	2.008	39.24	30.141	26.307	36.738	33.705	31.022	22.277	8.531	3.383	1.141	10.296	0.947	2.524	64.682
1998	23.655	45.39	175.529	22.691	8.613	40.898	25.944	32.046	14.647	2.122	2.754	2.15	1.07	1.011	86.998
1999	5.306	56.315	54.779	140.913	16.093	13.506	31.467	19.845	22.031	12.609	2.673	2.746	1.416	2.514	92.896
2000	17.286	57.282	136.278	49.289	76.614	11.546	8.294	16.367	9.874	11.332	6.744	2.975	1.539	1.104	100.332
2001	27.486	42.304	86.422	93.597	30.336	54.491	10.375	8.762	12.244	9.907	8.259	6.088	1.491	1.259	95.675
2002	11.698	80.863	70.801	45.607	54.202	21.211	42.199	9.888	4.707	6.52	9.108	9.355	3.994	5.697	96.128
2003	24.477	211.495	286.017	58.120	27.979	25.592	14.203	10.944	2.230	3.424	4.225	2.562	1.575	1.370	130.741
2004	23.144	63.355	139.543	182.45	40.489	13.727	9.342	5.769	7.021	3.136	1.861	3.871	0.994	1.855	114.237
2005	6.088	26.091	42.116	117.91	133.437	27.565	12.074	9.203	5.172	5.116	1.045	1.706	2.11	0.757	103.043
2006	52.567	118.526	217.672	54.800	48.312	57.241	13.603	5.994	4.299	0.898	1.626	1.213	0.849	0.933	135.303
2007	10.817	94.250	83.631	163.294	61.207	87.541	92.126	23.238	11.728	7.319	2.593	4.961	2.302	1.420	158.917
2008	10.427	38.830	90.932	79.745	107.644	59.656	62.194	54.345	18.130	8.240	5.157	2.680	2.630	1.178	151.780
2009	5.431	21.856	35.221	31.914	18.826	22.725	10.425	9.213	9.549	2.238	1.033	0.768	0.406	0.298	46.332
2010	1.476	8.843	22.674	29.492	24.293	14.419	17.407	10.045	7.576	8.896	1.764	1.105	0.672	0.555	43.533
2011	0.521	9.357	24.621	20.046	22.869	23.706	13.749	16.967	10.039	7.623	7.745	1.441	0.618	0.785	49.446
2012*	0.403	17.827	89.432	51.257	43.079	51.224	41.846	34.653	27.215	24.946	15.473	13.575	2.595	0.253	125.369
2013	6.888	46.848	24.833	35.070	17.250	18.550	19.032	21.821	15.952	15.804	10.081	9.775	6.722	2.486	72.058
2014	0.000	3.537	53.241	50.609	70.044	34.393	22.084	22.138	13.298	17.761	7.974	4.461	2.862	1.746	94.975
2015	0.089	6.024	29.89	53.573	43.501	43.015	15.533	10.76	8.664	8.161	6.981	2.726	2.467	1.587	69.729
2016	0.072	10.740	25.575	29.908	41.952	25.823	24.925	9.516	7.734	6.088	4.284	7.154	3.108	0.827	60.403
2017	1.262	5.236	31.855	18.113	10.239	15.506	10.223	8.830	5.676	3.399	1.616	2.220	1.533	1.596	35.034
2018	0.000	8.911	19.642	34.284	16.847	12.376	17.161	6.978	7.379	3.482	1.713	1.153	2.159	0.489	40.683
2019	0.461	4.601	15.845	12.970	16.084	12.244	6.944	9.531	6.167	4.732	2.983	2.808	2.200	1.866	30.038
2020	0.384	23.603	15.956	22.572	16.333	19.385	11.071	7.098	6.241	3.035	3.359	1.809	1.567	1.129	36.100

* Includes both the landings (73.4 kt) and herring that died in the mass mortality (52.0 kt) in the winter 2012/13 in Kolgrafafjörður.

Table 5. The mean weight (g) at age from the commercial catch (1981 refers to season 1981/1982 etc.).

Year\age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1975	110	179	241	291	319	339	365	364	407	389	430	416	416	416
1976	103	189	243	281	305	335	351	355	395	363	396	396	396	396
1977	84	157	217	261	285	313	326	347	364	362	358	355	400	420
1978	73	128	196	247	295	314	339	359	360	376	380	425	425	425
1979	75	145	182	231	285	316	334	350	367	368	371	350	350	450
1980	69	115	202	232	269	317	352	360	380	383	393	390	390	390
1981	61	141	190	246	269	298	330	356	368	405	382	400	400	400
1982	65	141	186	217	274	293	323	354	385	389	400	394	390	420
1983	59	132	180	218	260	309	329	356	370	407	437	459	430	472
1984	49	131	189	217	245	277	315	322	351	334	362	446	417	392
1985	53	146	219	266	285	315	335	365	388	400	453	469	433	447
1986	60	140	200	252	282	298	320	334	373	380	394	408	405	439
1987	60	168	200	240	278	304	325	339	356	378	400	404	424	430
1988	75	157	221	239	271	298	319	334	354	352	371	390	408	437
1989	63	130	206	246	261	290	331	338	352	369	389	380	434	409
1990	80	127	197	245	272	285	305	324	336	362	370	382	375	378
1991	74	135	188	232	267	289	304	323	340	352	369	402	406	388
1992	68	148	190	235	273	312	329	339	355	382	405	377	398	398
1993	66	145	211	246	292	324	350	362	376	386	419	389	389	389
1994	66	134	201	247	272	303	333	366	378	389	390	412	418	383
1995	68	130	183	240	277	298	325	358	378	397	409	431	430	467
1996	75	139	168	212	258	289	308	325	353	353	377	404	395	410
1997	63	131	191	233	269	300	324	341	355	362	367	393	398	411
1998	52	134	185	238	264	288	324	340	348	375	406	391	426	456
1999	74	137	204	233	268	294	311	339	353	362	378	385	411	422
2000	62	159	217	268	289	325	342	363	378	393	407	425	436	430
2001	74	139	214	244	286	296	324	347	354	385	403	421	421	433
2002	85	161	211	258	280	319	332	354	405	396	416	433	463	460
2003	72	156	189	229	260	283	309	336	336	369	394	378	412	423
2004	84	149	213	248	280	315	331	349	355	379	388	412	419	425
2005	106	170	224	262	275	298	324	335	335	356	372	394	405	413
2006	107	189	234	263	290	304	339	349	369	416	402	413	413	467
2007	93	158	221	245	261	277	287	311	339	334	346	356	384	390
2008	105	174	232	275	292	307	315	327	345	366	377	372	403	434
2009	113	190	237	274	304	318	326	335	342	360	372	394	409	421
2010	87	204	243	271	297	315	329	335	341	351	367	366	405	416
2011	97	187	245	283	309	328	343	352	356	364	375	386	378	432
2012	65	206	244	282	301	320	333	344	350	359	364	367	373	391
2013	95	182	238	271	300	322	337	349	360	365	362	375	377	394
2014		202	259	288	306	328	346	354	362	366	367	380	383	403
2015	107	203	249	275	299	313	329	347	352	358	361	368	380	378
2016	129	202	242	281	303	322	336	355	359	368	369	379	386	402
2017	95	192	252	281	303	324	341	350	367	376	384	389	395	402
2018		191	252	293	317	333	347	350	366	375	389	388	392	383
2019	103	175	244	282	305	308	328	340	349	357	360	366	374	374
2020	81	140	229	267	288	311	329	345	351	367	372	370	382	398

Table 6. Proportion mature at age (1981 refers to season 1981/1982 etc.).

Year\age	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1975	0	0.27	0.97	1	1	1	1	1	1	1	1	1	1	1
1976	0	0.13	0.9	1	1	1	1	1	1	1	1	1	1	1
1977	0	0.02	0.87	1	1	1	1	1	1	1	1	1	1	1
1978	0	0.04	0.78	1	1	1	1	1	1	1	1	1	1	1
1979	0	0.07	0.65	0.98	1	1	1	1	1	1	1	1	1	1
1980	0	0.05	0.92	1	1	1	1	1	1	1	1	1	1	1
1981	0	0.03	0.65	0.99	1	1	1	1	1	1	1	1	1	1
1982	0.02	0.05	0.85	1	1	1	1	1	1	1	1	1	1	1
1983	0	0	0.64	1	1	1	1	1	1	1	1	1	1	1
1984	0	0.01	0.82	1	1	1	1	1	1	1	1	1	1	1
1985	0	0	0.9	1	1	1	1	1	1	1	1	1	1	1
1986–2020	0	0.2	0.85	1	1	1	1	1	1	1	1	1	1	1

Table 7. Natural mortality at age for the different years (refers to the au-tumn) where the deviation from the fixed M = 0.1 is due to the Ichthyophonus infection (1981 refers to season 1981/1982 etc.). The estimate of, for example, M for age 4 in 2020 represents estimated infection rate of age 3 in 2019.

Year\age	3	4	5	6	7	8	9	10	11	12	13	14	15	13+
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	0.111	0.118	0.124	0.173	0.175	0.175	0.207	0.187	0.256	0.279	0.210	0.180	0.191	0.183
2018	0.116	0.112	0.172	0.162	0.175	0.228	0.226	0.247	0.275	0.338	0.307	0.184	0.186	0.250
2019**	0.111	0.135	0.144	0.168	0.216	0.169	0.171	0.183	0.245	0.189	0.243	0.182	0.140	0.189
2020***	0.119	0.146	0.122	0.155	0.191	0.164	0.193	0.159	0.230	0.100	0.146	0.151	0.100	0.275

* Based on prevalence of infection estimates and acoustic measurements ($M_{infected}$ multiplied by 0.3 and added to 0.1; Óskarsson *et al.* 2018).

** Based on prevalence of infection estimates in the winter 2019/20 and 2020/21 (multiplied by 0.3 and added to 0.1; Óskarsson and Pálsson, 2018).

*** Based on prevalence of infection estimates in the winter 2020/21 (multiplied by 0.3 and added to 0.1) and should be applied in the prognosis in the 2021 assessment.

Table 8. Model settings and results of model parameters from the final NFT-ADAPT run in 2021.

```
VPA Version 3.3.0
 Model ID: RUN1 2021
 Input File: C:\HAFRONET_GOGN\NWWG OG UTTEKTIR\NWWG2021\VPA\RUN1_2021_R_00.DAT
 Date of Run: 26-APR-2021                        Time of Run: 13:27

 Levenburg-Marquardt Algorithm Completed     7 Iterations
 Residual Sum of Squares =     59.4232

 Number of Residuals     =    264
 Number of Parameters    =      9
 Degrees of Freedom      =    255
 Mean Squared Residual   =     0.233032
 Standard Deviation      =     0.482734


 Number of Years =    34
 Number of Ages  =    11
 First Year      =  1987
 Youngest Age    =     3
 Oldest True Age =    12

 Number of Survey Indices Available       =    10
 Number of Survey Indices Used in Estimate =     8


 VPA Classic Method - Auto Estimated Q's


 Stock Numbers Predicted in Terminal Year Plus One (2021)
 Age    Stock Predicted     Std. Error      CV

   4        1130123.745   0.554399E+06   0.490565E+00
   5         257398.668   0.918374E+05   0.356791E+00
   6          88145.395   0.293167E+05   0.332595E+00
   7          29378.669   0.103832E+05   0.353427E+00
   8          64413.772   0.196232E+05   0.304643E+00
   9          39228.065   0.111259E+05   0.283621E+00
  10          34522.515   0.900332E+04   0.260795E+00
  11          43267.578   0.109880E+05   0.253954E+00
  12          31864.455   0.865457E+04   0.271606E+00

 Catchability Values for Each Survey Used in Estimate
 INDEX     Catchability    Std. Error      CV

   1       0.986382E+00   0.940359E-01   0.953342E-01
   2       0.127444E+01   0.106471E+00   0.835434E-01
   3       0.138258E+01   0.797671E-01   0.576942E-01
   4       0.150767E+01   0.959402E-01   0.636346E-01
   5       0.159940E+01   0.113761E+00   0.711275E-01
   6       0.178267E+01   0.144659E+00   0.811474E-01
   7       0.189357E+01   0.201581E+00   0.106456E+00
   8       0.177107E+01   0.187207E+00   0.105703E+00


 -- Non-Linear Least Squares Fit --

 Maximum Marquadt Iterations    =       100
 Scaled Gradient Tolerance      =    6.055454E-05
 Scaled Step Tolerance          =    1.000000E-18
 Relative Function Tolerance    =    1.000000E-18
 Absolute Function Tolerance    =    4.930381E-32

 Reported Machine Precision     =    2.220446E-16


 VPA Method Options

 - Catchability Values Estimated as an Analytic Function of N
 - Catch Equation Used in Cohort Solution
 - Plus Group Forward Calculation Method Used
 - Arithmetic Average Used in F-Oldest Calculation
 - F-Oldest Calculation in Years Prior to Terminal Year
   Uses Fishing Mortality in Ages  8 to 11
 - Calculation of Population of Age 3 In Year 2021
   =  Geometric Mean of First Age Populations
      Year Range Applied =  1991 to  2014
 - Survey Weight Factors Were Used

 Stock Estimates

 Age   4
 Age   5
 Age   6
 Age   7
 Age   8
 Age   9
 Age  10
 Age  11
 Age  12

 Full F in Terminal Year               =   0.2098

 F in Oldest True Age in Terminal Year =   0.1512

 Full F Calculated Using Classic Method

 F in Oldest True Age in Terminal Year has been
 Calculated in Same Manner as in All Other Years

 Age  Input Partial  Calc Partial   Fishing     Used In
      Recruitment    Recruitment    Mortality   Full F    Comments

   3      0.500          0.048       0.0196      NO      Stock Estimate in T+1
   4      0.800          0.139       0.0568      NO      Stock Estimate in T+1
   5      1.000          0.521       0.2123      YES     Stock Estimate in T+1
   6      1.000          1.000       0.4073      YES     Stock Estimate in T+1
   7      1.000          0.600       0.2444      YES     Stock Estimate in T+1
   8      1.000          0.568       0.2313      YES     Stock Estimate in T+1
   9      1.000          0.418       0.1702      YES     Stock Estimate in T+1
  10      1.000          0.301       0.1225      YES     Stock Estimate in T+1
  11      1.000          0.199       0.0809      YES     Stock Estimate in T+1
  12      1.000          0.371       0.1512              F-Oldest
```

Table 9. Icelandic summer spawners stock estimates (from NFT-ADAPT in 2021) in numbers (millions) by age (years) at 1 January during 1987–2021.

Year\Age	3	4	5	6	7	8	9	10	11	12	13+	Total
1987	529.83	988.96	300.67	84.6	69.14	107.46	42.63	38.03	26.41	34.26	34.29	2256.28
1988	270.99	476.42	852.47	214.85	56.99	43.83	53.49	24.15	21.19	14.26	36.99	2065.62
1989	447.32	240.68	391.81	676.97	128.7	29.84	20.62	18.03	10.18	9.48	26.1	1999.74
1990	300.82	383.25	192.47	280.67	433.68	75.61	19.3	13.07	9.41	4.69	26.46	1739.43
1991	840.53	258.05	292.66	140.37	178.35	243.51	39.78	9.72	7.68	5.31	24.86	2040.81
1992	1033.07	676.3	186.91	183.01	94.01	109.04	116.17	26.44	4.86	4.36	24.19	2458.36
1993	635.4	844.64	495.55	132.7	110.06	58.6	62.27	54.88	12.95	2.76	23.67	2433.49
1994	691.69	526.33	595.58	360.43	100.33	72.5	40.39	37.75	35.19	7.69	22.92	2490.81
1995	202.69	498.11	368.75	403.38	243.41	67.16	46.36	21.12	19.31	17.95	23.14	1911.36
1996	181.37	163.46	320.6	251.26	261.5	147.48	40.52	27.52	11.03	8.38	27.53	1440.65
1997	772.48	148.94	109.67	208.36	162	156.4	95.84	22.7	16.92	4.46	22.16	1719.93
1998	320.43	661.68	106.16	74.28	153.66	114.6	112.07	65.59	12.46	12.1	10.03	1643.06
1999	552.47	246.83	432.26	74.53	59.03	100.26	79.08	71.03	45.45	9.26	13.4	1683.61
2000	391.18	446.4	171.37	257.61	52.17	40.6	60.9	52.74	43.39	29.17	11.67	1557.18
2001	468.43	299.56	274.75	108.34	160.47	36.25	28.87	39.58	38.35	28.51	25.24	1508.35
2002	1455.46	383.66	189.13	159.94	69.27	93.58	22.97	17.81	24.21	25.3	32.44	2473.75
2003	1074.87	1240.11	279.95	127.87	93.37	42.57	44.76	11.42	11.66	15.72	25.65	2967.95
2004	663.28	771.87	850.77	198.16	89.15	60.22	25.07	30.12	8.22	7.3	28.2	2732.36
2005	991.08	539.98	565.97	596.69	140.88	67.64	45.62	17.21	20.59	4.47	23.99	3014.11
2006	736.81	871.97	448.57	400.23	413.31	101.32	49.74	32.54	10.67	13.78	20.42	3099.35
2007	658.32	554.17	582.54	353.84	316.26	319.63	78.76	39.31	25.36	8.8	26.55	2963.54
2008	526.78	506.71	423.38	375.43	259.83	201.22	200.64	49.06	24.43	15.98	21.3	2604.75
2009	444.7	439.76	372.18	307.4	237.65	178.51	123.12	130.02	27.22	14.3	22.7	2297.55
2010	468.5	338.4	322.49	271.05	230.6	170.99	134.37	90.87	96.12	19.91	27.54	2170.83
2011	532.88	342.25	233.22	218.93	187.97	166.92	118.63	96.72	64.93	68.33	34.04	2064.82
2012	394.18	459.16	242.63	162.99	150.43	128.05	119.41	77.77	67.37	46.19	73.87	1922.04
2013	478.67	339.72	330.59	170.9	106.63	87.59	76.21	75.2	44.59	37.33	78.39	1825.83
2014	240.45	388.62	283.8	265.82	138.25	78.88	61.19	48.27	52.91	25.37	77.15	1660.71
2015	223.09	214.21	301.08	208.75	174.1	92.48	50.43	34.4	31.07	31.05	76.59	1437.25
2016	288.88	196.13	165.44	221.58	147.61	116.73	68.93	35.42	22.91	20.38	84.33	1368.34
2017	122.79	251.18	153.18	121.31	160.67	109.05	81.98	53.33	24.72	14.96	80.15	1173.31
2018	191.51	104.94	193.25	118.33	92.67	120.71	82.2	58.72	39.09	16.16	71.16	1088.74
2019	346.73	162.14	75.3	131.39	85.15	66.49	80.87	59.37	39.38	26.67	62.17	1135.65
2020	1286.45	305.95	126.88	53.17	96.33	57.67	49.79	59.44	43.83	26.66	64.56	2170.73
2021	572	1130.12	257.4	88.15	29.38	64.41	39.23	34.52	43.27	31.86	65.33	2328.37

Table 10. Estimated fishing mortality at age of Icelandic summer-spawning herring (from NFT-ADAPT in 2021) by age (years) during 1987–2020 (referring to the autumn of the fishing season) and weighed average F by numbers for age 5–10.

Year\Age	3	4	5	6	7	8	9	10	11	12	13+	WF_{5-10}
1987	0.006	0.049	0.236	0.295	0.356	0.598	0.468	0.485	0.516	0.517	0.517	0.347
1988	0.019	0.096	0.131	0.412	0.547	0.654	0.988	0.764	0.704	0.777	0.506	0.266
1989	0.055	0.124	0.234	0.345	0.432	0.336	0.356	0.550	0.674	0.479	0.111	0.322
1990	0.053	0.170	0.216	0.353	0.477	0.542	0.586	0.431	0.472	0.508	0.071	0.400
1991	0.117	0.223	0.370	0.301	0.392	0.640	0.309	0.593	0.466	0.502	0.055	0.436
1992	0.101	0.211	0.243	0.409	0.373	0.460	0.650	0.613	0.465	0.547	0.023	0.415
1993	0.088	0.249	0.218	0.180	0.317	0.272	0.400	0.345	0.421	0.360	0.011	0.248
1994	0.228	0.256	0.290	0.293	0.302	0.347	0.549	0.571	0.573	0.510	0.090	0.312
1995	0.115	0.341	0.284	0.333	0.401	0.405	0.422	0.550	0.735	0.528	0.154	0.343
1996	0.097	0.299	0.331	0.339	0.414	0.331	0.479	0.386	0.804	0.500	0.350	0.361
1997	0.055	0.239	0.290	0.205	0.246	0.233	0.279	0.500	0.235	0.312	1.042	0.250
1998	0.161	0.326	0.254	0.130	0.327	0.271	0.356	0.267	0.197	0.273	0.582	0.280
1999	0.113	0.265	0.418	0.257	0.274	0.399	0.305	0.393	0.344	0.360	0.735	0.377
2000	0.167	0.385	0.359	0.373	0.264	0.241	0.331	0.219	0.320	0.278	0.700	0.335
2001	0.100	0.360	0.441	0.347	0.439	0.357	0.383	0.392	0.316	0.362	0.457	0.415
2002	0.060	0.215	0.291	0.438	0.387	0.638	0.598	0.324	0.332	0.473	0.947	0.418
2003	0.231	0.277	0.246	0.261	0.339	0.430	0.296	0.229	0.368	0.331	0.255	0.280
2004	0.106	0.210	0.255	0.241	0.176	0.178	0.276	0.280	0.510	0.311	0.287	0.244
2005	0.028	0.086	0.247	0.267	0.230	0.207	0.238	0.378	0.302	0.281	0.223	0.253
2006	0.185	0.303	0.137	0.136	0.157	0.152	0.135	0.149	0.093	0.132	0.167	0.144
2007	0.162	0.169	0.339	0.209	0.352	0.366	0.373	0.376	0.362	0.369	0.419	0.322
2008	0.081	0.209	0.220	0.357	0.275	0.391	0.334	0.489	0.436	0.412	0.384	0.310
2009	0.056	0.093	0.100	0.071	0.112	0.067	0.087	0.085	0.096	0.084	0.075	0.088
2010	0.022	0.080	0.110	0.107	0.073	0.122	0.088	0.098	0.109	0.104	0.100	0.101
2011	0.019	0.085	0.102	0.125	0.152	0.097	0.175	0.124	0.139	0.134	0.097	0.126
2012*	0.049	0.229	0.250	0.324	0.441	0.419	0.362	0.456	0.490	0.432	0.265	0.354
2013	0.108	0.080	0.118	0.112	0.202	0.259	0.357	0.252	0.464	0.333	0.293	0.175
2014	0.016	0.155	0.207	0.323	0.302	0.347	0.476	0.341	0.433	0.399	0.132	0.296
2015	0.029	0.158	0.207	0.247	0.300	0.194	0.253	0.307	0.322	0.269	0.098	0.240
2016	0.040	0.147	0.210	0.221	0.203	0.254	0.157	0.260	0.326	0.249	0.149	0.216
2017	0.046	0.144	0.134	0.096	0.111	0.108	0.127	0.124	0.169	0.132	0.076	0.116
2018	0.051	0.220	0.214	0.167	0.157	0.173	0.099	0.152	0.107	0.133	0.062	0.171
2019	0.014	0.110	0.204	0.142	0.174	0.120	0.137	0.120	0.145	0.131	0.129	0.151
2020	0.020	0.057	0.212	0.407	0.244	0.231	0.170	0.123	0.081	0.151	0.081	0.228

* Derived from both the landings ($WF_{5–10}$ ~0.209) and the herring that died in the mass mortality (0.148) in the winter 2012/13 in Kolgrafafjörður (Óskarsson et al., 2018b). $WF_{5–10}$ without the mass mortality was 0.214.

Table 11. Summary table from NFT-ADAPT run in 2021 for Icelandic summer spawning herring.

Year	Recruits age 3 (millions)	Biomass age 3+ (kt)	Biomass age 4+ (kt)	SSB (kt)	Landings age 3+ (kt)	Yield/SSB	WF_{5-10}	HR 4+
1987	530	504	415	384	75	0.20	0.35	0.182
1988	271	495	452	423	93	0.22	0.27	0.205
1989	447	459	401	386	101	0.26	0.32	0.251
1990	301	410	371	350	104	0.30	0.40	0.281
1991	841	424	310	310	107	0.34	0.44	0.344
1992	1033	502	349	343	107	0.31	0.42	0.307
1993	635	546	454	424	103	0.24	0.25	0.226
1994	692	553	461	441	134	0.30	0.31	0.290
1995	203	462	435	406	125	0.31	0.34	0.288
1996	181	347	322	307	96	0.31	0.36	0.297
1997	772	368	267	269	65	0.24	0.25	0.243
1998	320	366	323	298	86	0.29	0.28	0.266
1999	552	373	297	290	93	0.32	0.38	0.312
2000	391	386	324	306	100	0.33	0.34	0.308
2001	468	347	282	272	94	0.34	0.41	0.332
2002	1455	512	278	297	96	0.32	0.42	0.346
2003	1075	579	411	389	129	0.33	0.28	0.313
2004	663	615	516	486	112	0.23	0.24	0.218
2005	991	705	537	526	102	0.19	0.25	0.191
2006	737	785	646	612	130	0.21	0.14	0.201
2007	658	699	595	569	158	0.28	0.32	0.265
2008	527	684	593	564	151	0.27	0.31	0.254
2009	445	628	543	489	46	0.09	0.09	0.084
2010	469	602	507	451	43	0.10	0.10	0.086
2011	533	575	476	429	49	0.12	0.13	0.104
2012	394	538	457	434	72	0.16	0.21	0.158
2013	479	486	399	384	71	0.19	0.18	0.179
2014	240	482	434	408	95	0.23	0.30	0.219
2015	223	409	364	347	70	0.20	0.24	0.192
2016	289	392	333	321	60	0.19	0.22	0.181
2017	123	350	326	296	35	0.12	0.12	0.107
2018	192	329	292	268	41	0.15	0.17	0.139
2019	347	305	244	229	30	0.13	0.15	0.123
2020	1286	437	257	260	36	0.14	0.23	0.140
2021	572	578	482	377				

* The mass mortality of 52 thousand tonnes in Kolgrafafjörður in the winter 2012/13 is not included in the landings, yield/SSB, or WF, but is included as landings in the analytical assessment.

Table 12. The residuals from survey observations and NFT-Adapt 2021 results for Icelandic summer spawning herring (no surveys in 1987 and 1995) on 1 January.

Year\Age	4	5	6	7	8	9	10	11
1987								
1988	-0.158	-0.236	0.036	-0.409	-0.768	-0.303	-0.220	-0.464
1989	-0.165	-0.763	-0.898	-0.029	-0.027	-0.354	-0.039	-0.034
1990	0.550	-0.313	-0.331	-0.098	0.396	-0.439	-0.128	-0.242
1991	-0.655	-0.366	-0.721	-0.342	0.278	0.112	0.715	-0.371
1992	0.454	0.398	0.234	-0.456	-0.232	0.216	-0.855	0.136
1993	-0.003	0.144	-0.145	-0.238	-0.548	-0.142	-0.073	0.067
1994	-0.027	0.151	-0.004	-0.815	-0.688	0.388	-0.380	-0.543
1995								
1996	-0.186	0.623	-0.223	-0.024	-0.288	0.307	-0.072	-0.185
1997	0.611	-0.045	0.487	0.100	0.264	0.241	0.771	0.616
1998	-0.081	-0.512	-0.582	0.214	-0.161	0.018	-0.161	0.474
1999	0.050	0.675	0.003	-0.541	-0.170	-0.693	-0.280	-0.400
2000	0.645	0.090	0.531	0.115	-0.404	0.423	-0.105	0.457
2001	1.186	1.324	0.243	0.690	-0.523	-1.185	-0.681	-1.557
2002	-0.277	-0.103	0.164	0.433	0.838	0.422	0.526	-0.110
2003	0.451	0.439	0.151	0.623	0.810	1.242	1.523	0.836
2004	0.634	0.641	0.188	-0.208	0.045	-0.144	-0.224	-0.727
2005	0.293	0.349	0.238	-0.215	-0.550	-0.607	-1.091	-0.421
2006	-0.661	-0.505	0.392	0.673	0.552	0.321	0.743	1.356
2007	0.107	0.356	-0.176	-0.116	0.305	-0.380	0.508	0.082
2008	-0.090	-0.623	0.042	-0.236	0.225	0.675	0.869	1.733
2009	-0.794	-0.129	-0.389	0.245	-0.067	0.028	-0.376	-0.477
2010	-0.055	0.177	0.392	-0.248	0.180	-0.474	-0.719	-0.081
2011	-0.185	-0.261	0.007	0.044	-0.655	0.354	-1.099	0.206
2012	0.769	0.341	0.331	0.182	0.156	-0.320	0.173	-0.344
2013	0.846	0.405	-0.349	-0.236	0.014	-0.210	-0.384	-0.061
2014	-0.197	-0.503	-0.063	-0.318	0.051	0.102	0.259	-0.045
2015	-0.850	-0.151	-0.101	-0.013	0.239	0.219	0.341	-0.374
2016	-0.164	-0.189	0.019	0.015	0.142	-0.271	-0.067	0.619
2017	-0.116	-0.353	-0.099	0.080	-0.243	0.502	-0.501	0.244
2018	-1.507	-0.952	0.048	0.368	0.505	0.356	0.831	0.091
2019	-0.152	-0.345	0.103	-0.230	0.041	0.149	0.376	0.050
2020	-0.272	-0.019	0.343	0.374	0.069	-0.502	-0.637	-0.609
2021	0.000	0.257	0.126	0.616	0.215	-0.050	0.453	0.077
Max residuals	1.186	1.324	0.531	0.690	0.838	1.242	1.523	1.733

Table 13. The input data used for prognosis of the Icelandic summer-spawning herring in the 2021 assessment: the predicted weights, the selection pattern, M, proportion of M before spawning, and the number-at-age derived from NFT-Adapt run.

Age (year class)	Mean weights (kg)	M	Maturity ogive	Selection pattern	Mortality prop. before spawning		Number at age
					F	M	1 January 2021
3 (2018)	0.153	0.11	0.200	0.207	0.000	0.500	572.0
4 (2017)	0.199	0.12	0.850	0.784	0.000	0.500	1130.1
5 (2016)	0.268	0.15	1.000	1.000	0.000	0.500	257.4
6 (2015)	0.297	0.12	1.000	1.000	0.000	0.500	88.1
7 (2014)	0.314	0.15	1.000	1.000	0.000	0.500	29.4
8 (2013)	0.332	0.19	1.000	1.000	0.000	0.500	64.4
9 (2012)	0.346	0.16	1.000	1.000	0.000	0.500	39.2
10 (2011)	0.358	0.19	1.000	1.000	0.000	0.500	34.5
11 (2010)	0.363	0.16	1.000	1.000	0.000	0.500	43.3
12 (2009)	0.375	0.23	1.000	1.000	0.000	0.500	31.9
13+ (2008+)	0.379	0.28	1.000	1.000	0.000	0.500	65.3

Table 14. Catch options table for the 2021/2022 season according to the Management plan where the basis is: SSB (1 July 2021) 377 kt (accounted for $M_{infection}$ in 2020); Biomass age 4+ (1 January 2021) is 481.6 kt; Catch (2020/21) 36.1 kt; HR (2020) 0.15, and WF_{5-10}(2020) 0.228. Other options are also shown.

Rationale	Catches (2021/2022)	Basis	F (2021/2022)	Biomass of age 4+ (2022)	SSB 2022	%SSB change *	% TAC change **
Management plan	**72.2**	**HR = 0.15**	**0.217**	**441**	**421**	**12**	**100**
MSY approach	73.0	F_{MSY}=0.22	0.220	440	420	11	2
Zero catch	0	F = 0	0	515	492	30	-100
F_{pa}	45.4	F_{pa} = 0.43	0.430	379	363	-4	29
F_{lim}	106.9	F_{lim} = 0.61	0.612	334	321	-15	204

*SSB 2022 relative to SSB 2021

**TAC 2021/22 relative to landings 2020/21

FIGURES

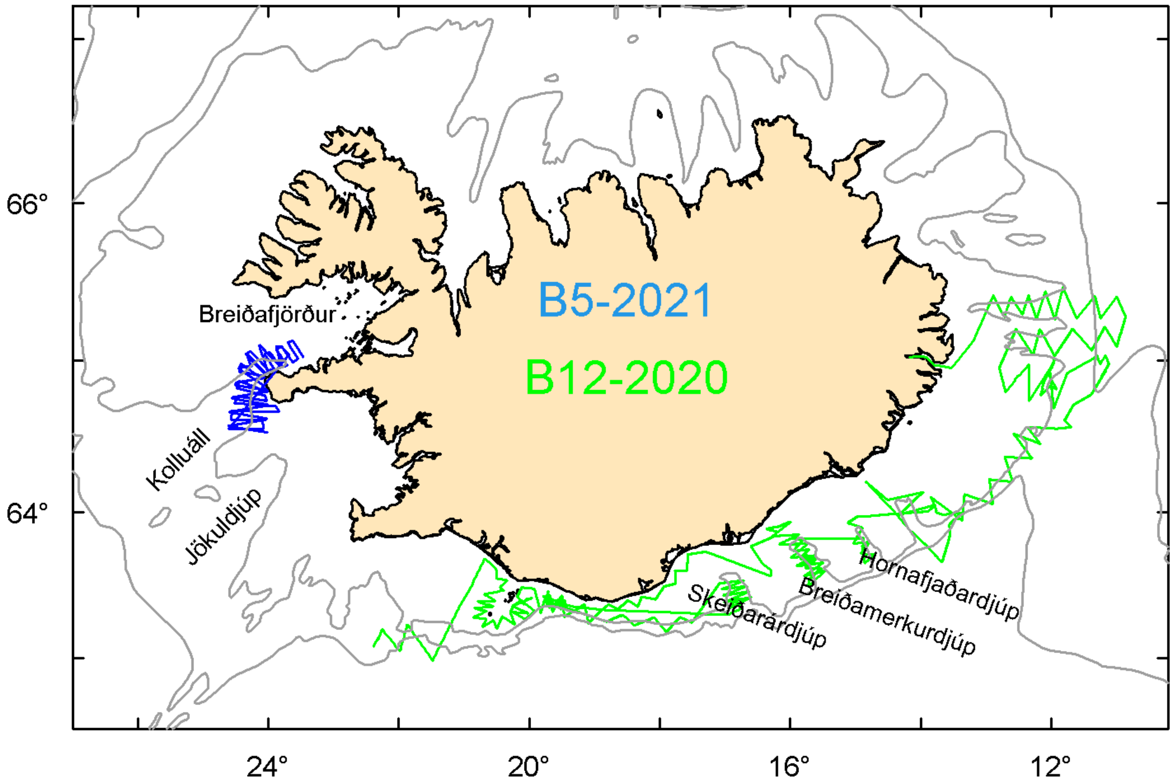

Figure 1. The survey tracks of two acoustic surveys in the east, southeast and south (B12-2020; green) and in the west (B5-2021; blue).

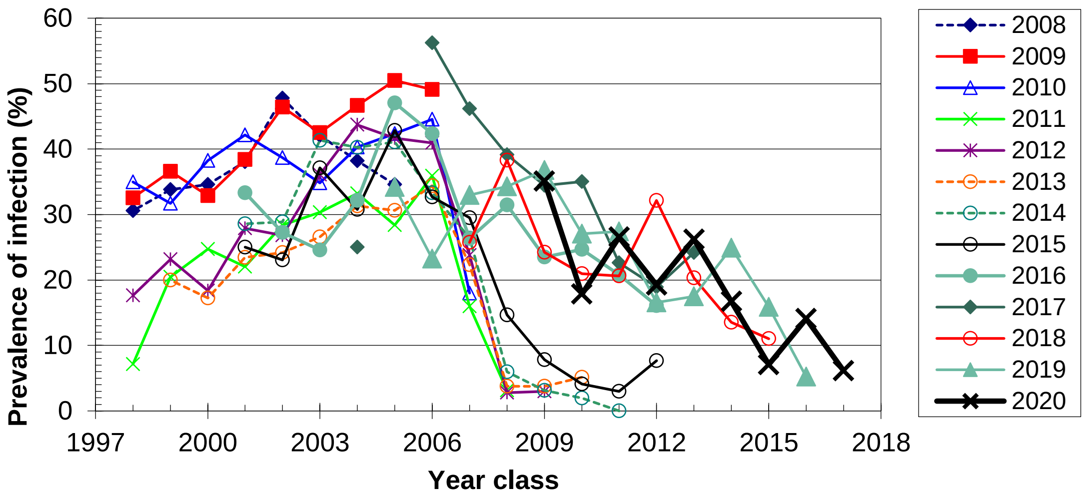

Figure 2. The prevalence of the *Ichthyophonus* infection for each year-class for the years 2008-2020. Estimated from catch samples west and east of Iceland.

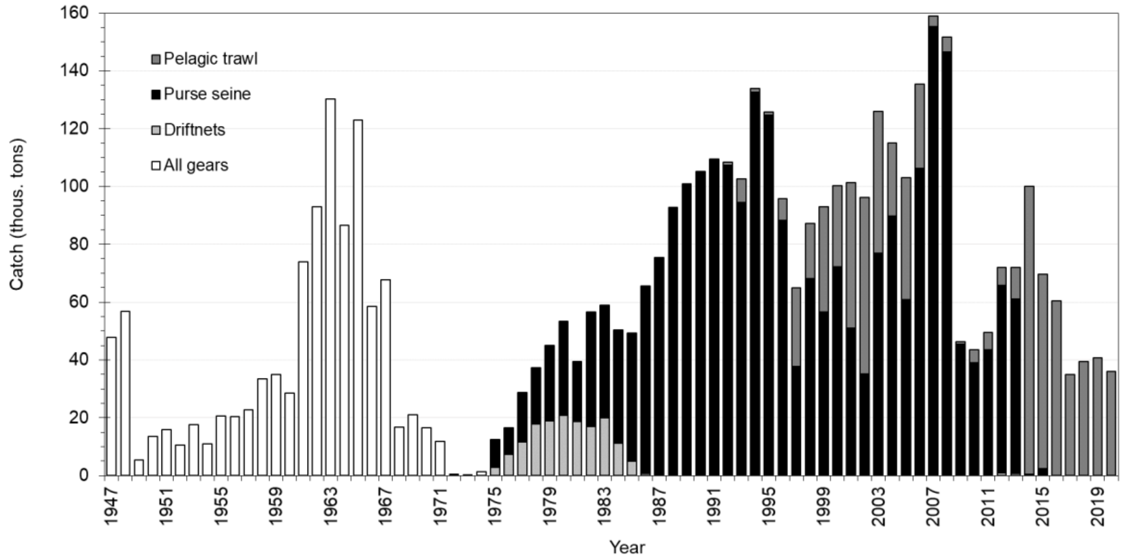

Figure 3. Seasonal total landings (in thousand tonnes) during 1947–2020, referring to the autumns, by different fishing gears from 1975 onwards.

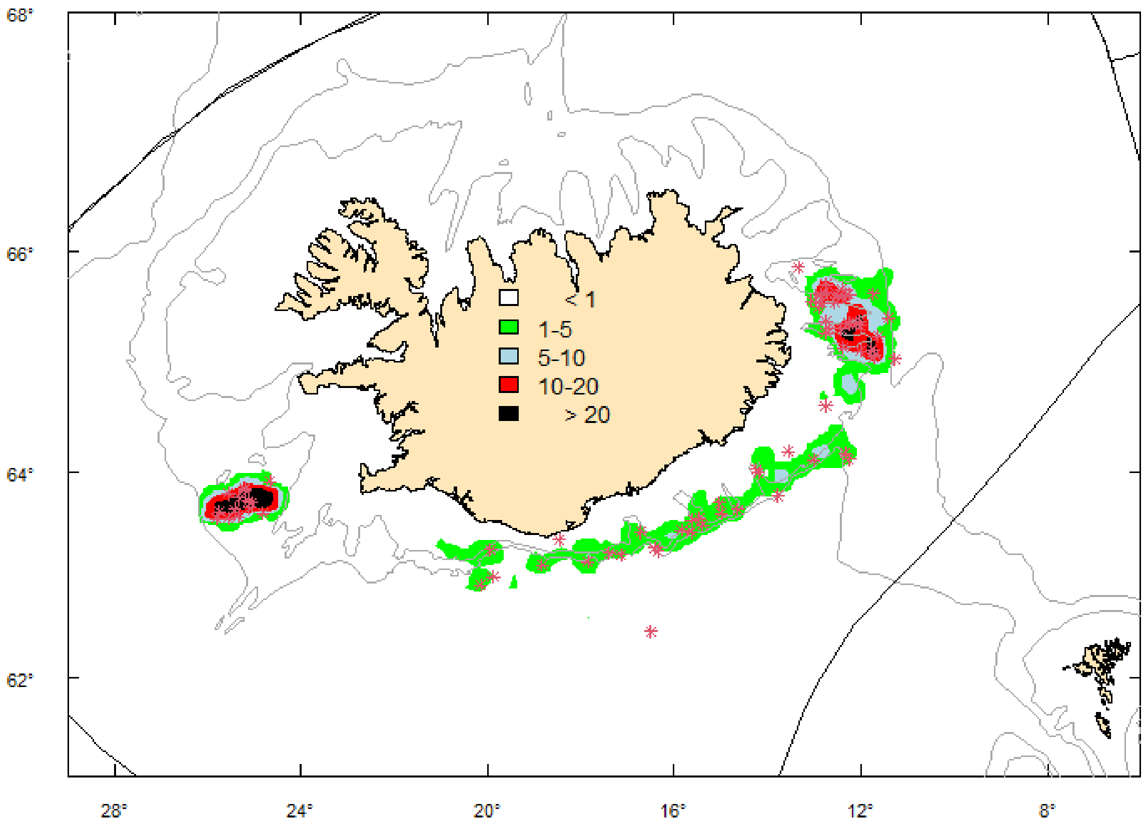

Figure 4. The distribution of the fishery (in tonnes) of Icelandic summer spawning herring during the fishing season 2020/21, including the bycatch in the mackerel fishery in July–November 2020. The stars indicate the location of catch samples.

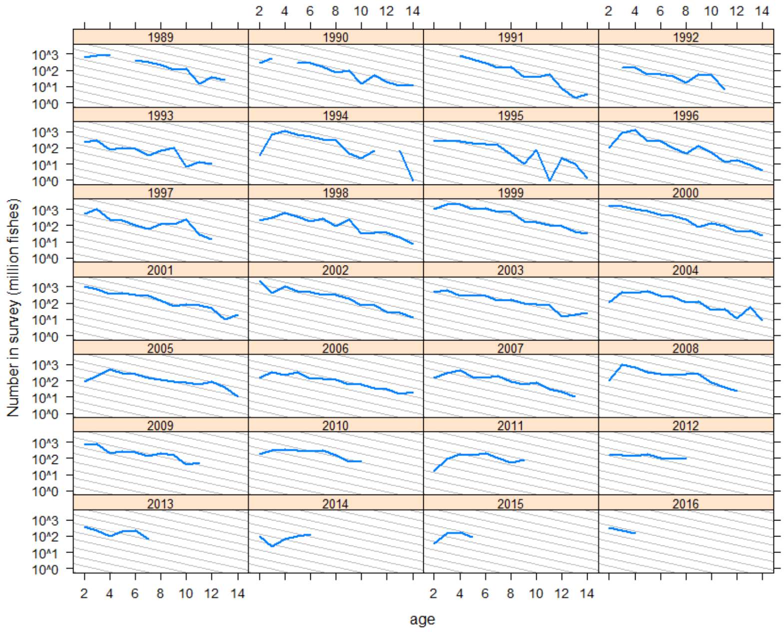

Figure 5. Catch curves (log2 of catches) from survey data by year classes 1989–2016. Grey lines correspond to Z = 0.4.

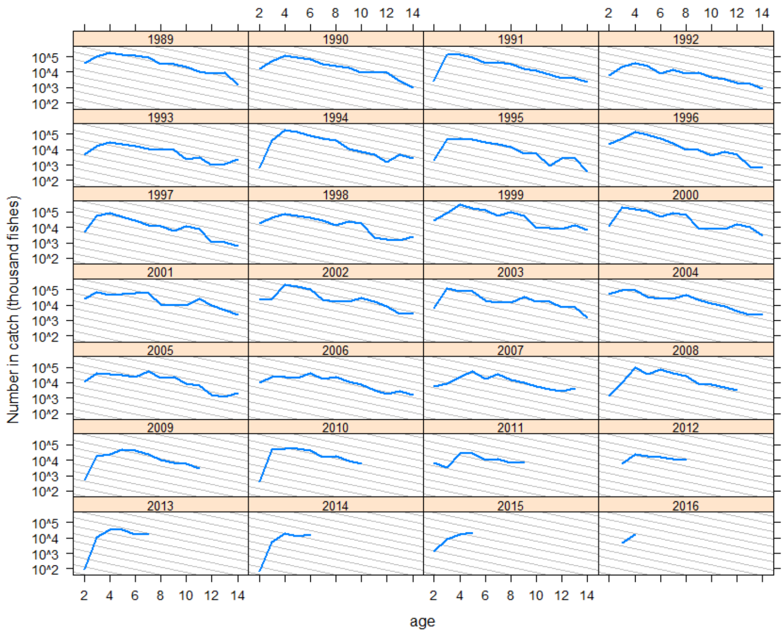

Figure 6. Catch curves (log2 of indices) from catch data by year classes 1989–2016. Grey lines correspond to Z = 0.4.

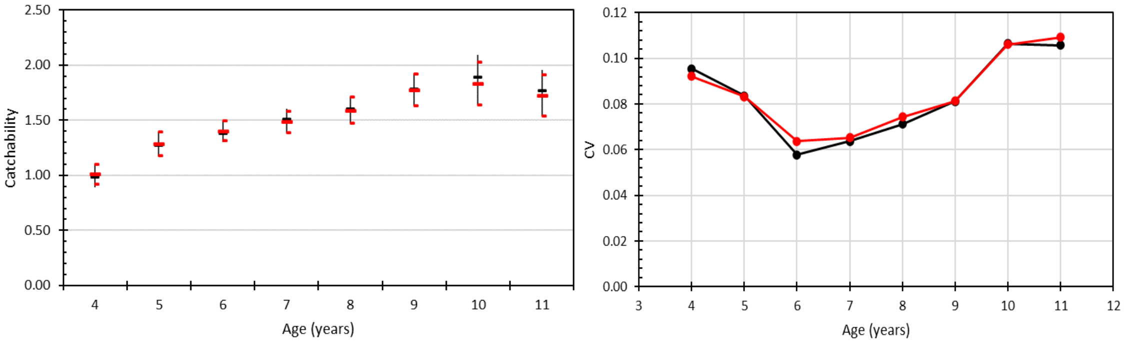

Figure 7. The catchability (± 2 SE; left graph) and its CV (coefficient of variation; right graph) for the acoustic surveys used in the final NFT-ADAPT modelrun in 2021 (1987–2020) compared to the assessment in 2020 (red lines).

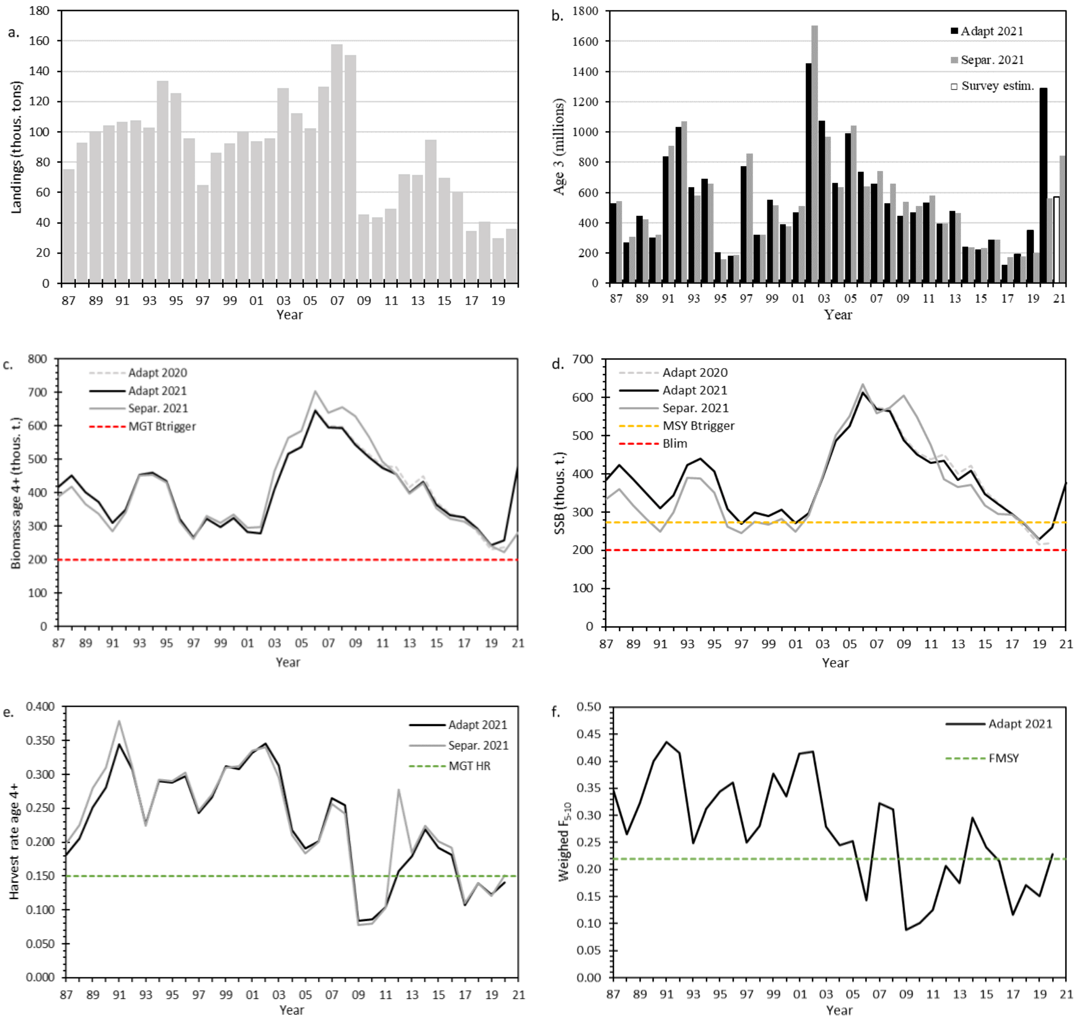

Figure 8. Comparisons of the final NFT-Adapt run in 2021, NFT-Adapt run in 2020 and a run from a separable model (Muppet) in 2021 concerning (a) landings, (b) number at age-3 (recruitment), (c) biomass of age 4+ (reference biomass) and (d) SSB. Harvest rate (e) of the reference biomass (HR_{MGT} shown) and (f) N-weighed F for age 5–10. Some reference points are also shown. Note that the mass mortality in Kolgrafafjörður in the winter 2012/13 is included in harvest rate (e) for Muppet but not in Adapt run 2021.

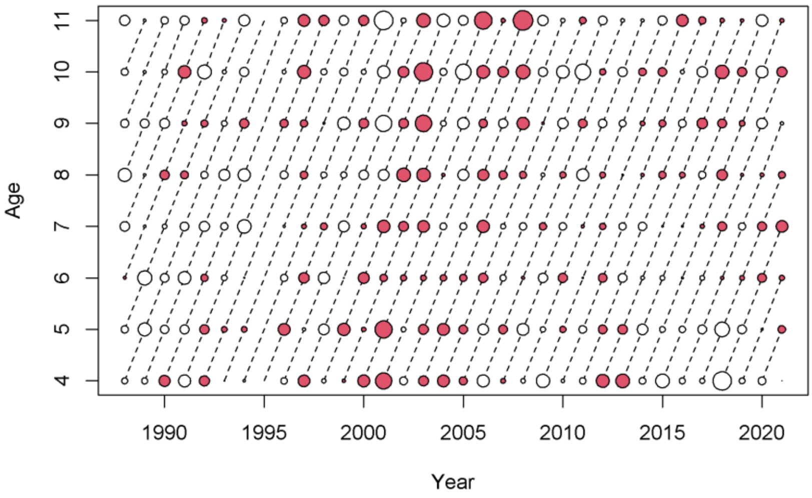

Figure 9. Icelandic summer spawning herring. Residuals of NFT-Adapt run in 2021 from survey observations (moved to 1 January). Filled bubbles are positive (i.e. survey estimates higher than the assessment) and open negative. Max bubble = 1.73.

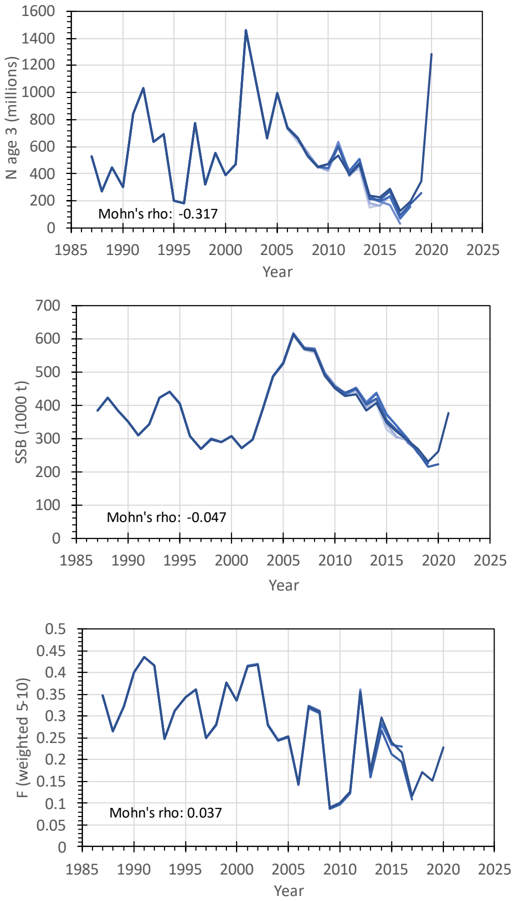

Figure 10. Icelandic summer spawning herring. Six years (2014–2021) retrospective pattern from NFT-Adapt in 2021 in recruitment as number at age 3 (the top panel), spawning stock biomass (middle panel) and N weighted F5–10 (lowest panel).

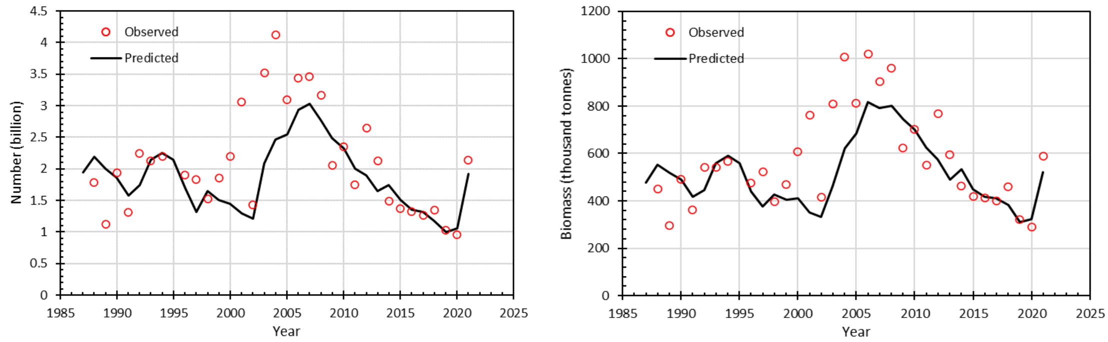

Figure 11. Observed versus predicted survey values from NFT-Adapt run in 2021 for ages 4–11 with respect to numbers (left) and biomass (right). Note that there was no survey in 1995.

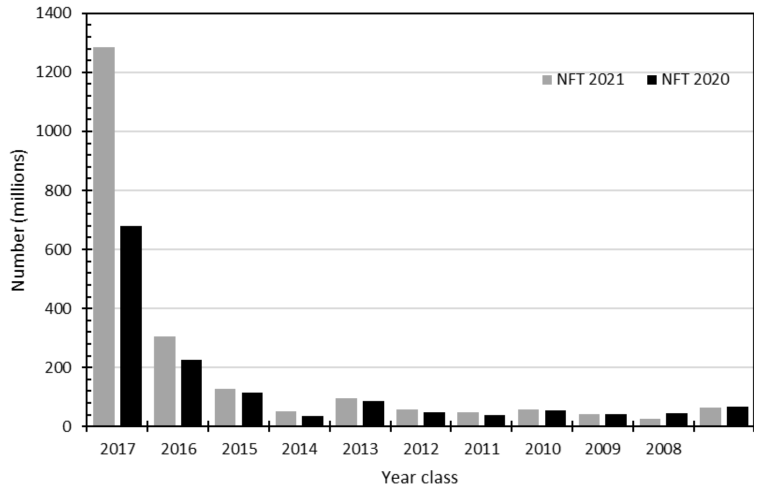

Figure 12. Icelandic summer-spawning herring. Comparison of number-at-age on 1 January from the final NFT model runs in 2020 and 2021 assessments.

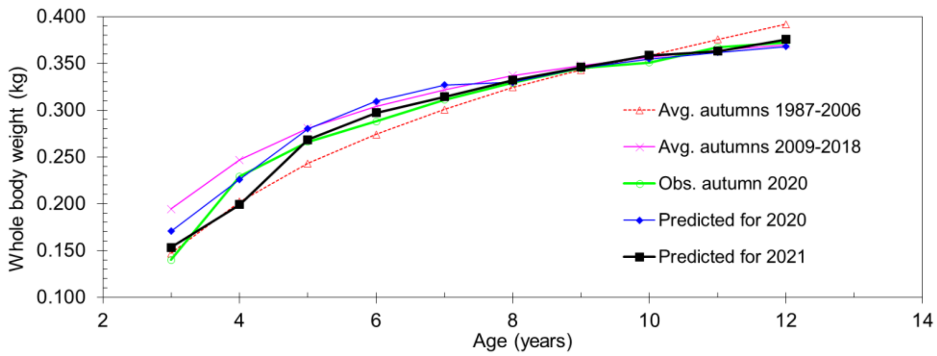

Figure 13. The mean weight-at-age for age groups 3 to 12 (+ group) in 1987–2006, 2009–2018, in the catches in the autumn 2019, predicted weights for autumn 2020 in the 2020 assessment (ICES, 2020) and finally predicted weights for the autumn 2021 from the weights in 2020, which was used in the stock prognosis.

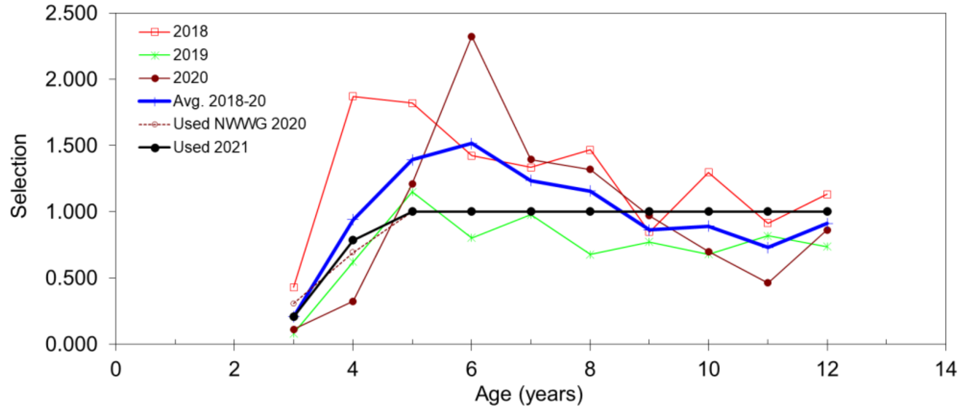

Figure 14. Estimate of selection pattern ($q=F_{age}/ WF_{5-10}$) in the fishery in the stock prognosis for age groups 3 to 12 (+ group) on basis of the Fs in 2018 to 2020, the average over these three years (used for the prognosis), the selection used in 2020 (ICES, 2020), and the selection used in the prognosis 2021.

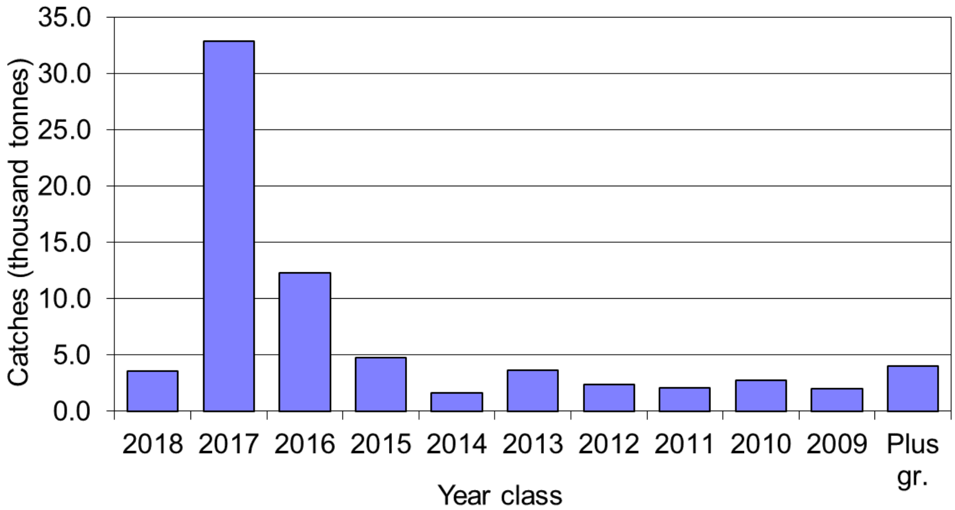

Figure 15. The predicted biomass contribution of the different year classes to the catches in the fishing season 2021/2022 (total catch of 72 239 tonnes).