Stock Annex: Tusk (*Brosme brosme*) in Subarea 14 and Division 5.a (East Greenland, and Iceland grounds)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Tusk
Working Group:	Working Group on Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP)
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A. General

A.1. Stock definition

Tusk in Icelandic and Greenland waters (ICES Divisions 5.a and 14 respectively) is considered as one stock unit and is separated from the tusk found on the Mid-Atlantic Ridge, on Rockall (VIb), and in Divisions 1 and 2. This stock discrimination is based on genetic investigation (Knutsen *et al.*, 2009) and was reviewed at the WGDEEP meeting in 2007.

A.2. Fishery

The tusk in ICES Division 5.a is mainly caught by Iceland (75—85% of the total annual catches in recent years), but the Faroe Islands and Norway also important fishing nations. Foreign catches of tusk in 5.a, mainly conducted by the Faroese fleet, has always been considerable but have decreased since 1990, whereas the Icelandic catches have increased.

Over 95% of the Icelandic tusk catch in 5.a comes from longliners and mainly caught as either bycatch in other fisheries or in mixed fishery. The Icelandic longline fleet mainly targets cod and haddock where tusk is often caught as bycatch. The directed fishery for tusk has traditionally been little but has increased in recent years. Tusk is then often caught with ling and blue ling along the south and southwest coast of Iceland.

In recent years between 150–250 longliners have annually reported tusk catches, whereof 80–85% have been caught by about 20–25 vessels (annual catch of each vessel from about 50 tonnes up to 800 tonnes).

Since 1991, 60–80% of the catches have been taken within the depth range of 100–300 m, with 80–95% of the catches taken at depth less than 400 m. In some years, about 20% of the annual tusk catch has been taken at depths between 600–700 m.

The longline fleet in Icelandic waters is composed of both small boats (<10 GRT) operating in shallow waters as well as much larger vessels operating in deeper waters. Cod and haddock are the main target species of this fleet but tusk, ling and blue ling are also caught, sometimes in directed fisheries. The ten longline vessels that fish about 65% of the total tusk catch in 5.a are vessels between 300–600 GRT.

Tusk fishery in ICES Division 14 has traditionally been very little, with less than 100 t caught annually. The tusk is caught as bycatch in other fisheries.

A.3. Ecosystem aspects

Tusk in Icelandic waters is mainly found on the continental shelf and slopes of south-east, south, and west of Iceland at depths of 0–1000 m, but mainly at depths between 100–500 m.

A.4. Management

The Ministry of Fisheries is responsible for management of the Icelandic fisheries and implementation of the legislation. The Ministry issues regulations for commercial fishing for each fishing year, including an allocation of the TAC for each of the stocks subject to such limitations. Below is a short account of the main feature of the management system and where applicable emphasis will be put on tusk.

A system of transferable boat quotas was introduced in 1984. The agreed quotas were based on the Marine Research Institute's TAC recommendations, taking some socio-economic effects into account, as a rule to increase the quotas. Until 1990, the quota year corresponded to the calendar year but since then the quota, or fishing year, starts on September 1 and ends on August 31 the following year. This was done to meet the needs of the fishing industry. In 1990, an individual transferable quota (ITQ) system was established for the fisheries and they were subject to vessel catch quotas. The ITQ system allows free transferability of quota between boats. This transferability can either be on a temporary (one year leasing) or a permanent (permanent selling) basis. This system has resulted in boats having quite diverse species portfolios, with companies often concentrating/specializing on particular group of species. The system allows for some but limited flexibility with regards converting a quota share of one species into another within a boat, allowance of landings of fish under a certain size without it counting fully in weight to the quota, and allowance of transfer of un-fished quota between management years. The objective of these measures is to minimize discarding, which is effectively banned. Since 2006/2007 fishing season, all boats operate under the TAC system.

In the beginning, only few commercial exploited fish species were included in the ITQ system, but many other species have gradually been included. Tusk was included into the ITQ system in the 2001/2002 quota year.

Landings in Iceland are restricted to particular licensed landing sites, with information being collected on a daily basis time by the Directorate of Fisheries in Iceland (the enforcement body). All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on each landing is stored in a centralized database maintained by the Directorate and is available in real time on the internet (www.fiskistofa.is). The accuracy of the landings statistics are considered reasonable.

All boats operating in Icelandic waters have to maintain a logbook record of catches in each haul/set. The records are available to the staff of the Directorate for inspection purposes as well as to the stock assessors at the Marine Research Institute.

With some minor exceptions it is required by law to land all catches. Consequently, no minimum landing size is in force. To prevent fishing of small fish various measures such as mesh size regulation and closure of fishing areas are in place.

A system of instant area closure is in place for many species, including tusk. The aim of the system is to minimize fishing on juveniles. For tusk, an area is closed temporarily (for two weeks) for fishing if on-board inspections (not 100% coverage) reveal that more than 25% of the catch is composed of fish less than 55 cm in length. Since tusk is often bycatch in other fisheries, this rule does only apply when the tusk catch is more than 30% of the total catch in a set/haul. Because of repeated instant area closures off the south and southeast coast of Iceland in 2003, four areas were closed permanently for longline fishery in order to protect juvenile tusk (Figure 1).

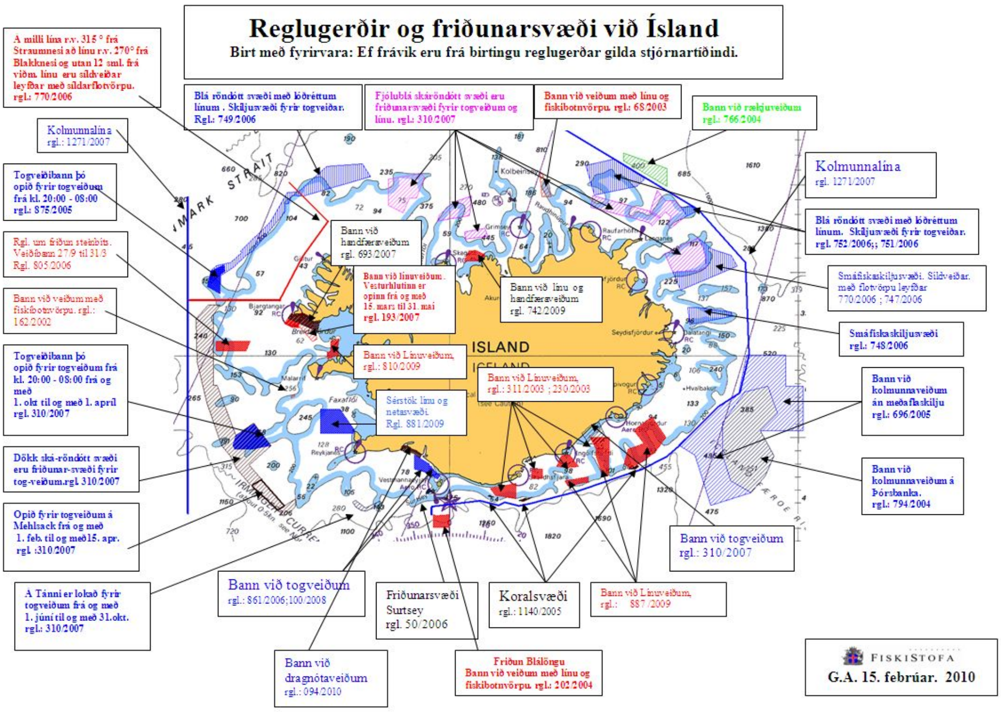

Figure 1. Marine protected areas in Icelandic waters. These areas are closed for various types of fisheries and may be closed permanently (all year around) or temporarily (closed part of the years. Four areas marked red south and southeast of Iceland (reference to the box *Bann við Línuveiðum, rgl.: 311/2003; 230/2003*) are areas permanently closed for longline fisheries in order to protect juvenile tusk. Trawling does not occur within these areas. Figure provided by Directorate of Fisheries in Iceland.

B. Data

B.1. Commercial catch

Landings and discards

The text Table below shows which data from landings is supplied from ICES Division 5.a.

ICES Division 5.a	Kind of data				
Country	Caton (Catch in weight)	Canum (catch-at-age in numbers)	Weca (weight-at-age in the catch)	Matprop (proportion mature-by-age)	Length composition in catch
Iceland	x	Two years	Two years		x
The Faroe Islands	x				x

Norway	x

Icelandic tusk catch in tonnes by month, area and gear are obtained from Statistical Iceland and Directorate of Fisheries. Catches are only landed in authorized ports where all catches are weighed and recorded. The distribution of catches is obtained from logbook statistic where location of each haul, effort, depth of trawling and total catch of tusk is given. Logbook statistics are available since 1991. Landings of Norwegian and Faroese vessels are given by the Icelandic Coast Guard and reported to the Directorate of Fisheries.

Discard is banned in the Icelandic demersal fishery and there is no information available on possible discard of tusk.

B.2. Biological

At 45 cm around 20% of tusk in 5.a is mature, at 58 cm 50% of tusk is mature and at 80 cm more or less every tusk is mature.

No information is available on natural mortality of tusk in 5.a. In the Gadget model it is assumed to be 0.2 but different variants of natural mortality are tested.

Biological data from the commercial longline catch are collected from landings by scientists and technicians of the Marine Research Institute (MRI) in Iceland. The biological data collected are length (to the nearest cm), sex and maturity stage (if possible since most tusk is landed gutted), and otoliths for age reading. Most of the fish that otoliths were collected from were also weighted (to the nearest gram). Biological sampling is also collected directly on board on the commercial vessels during trips by personnel of the Directorate of Fisheries in Iceland or from landings (at harbour). These are only length samples.

The general process of the sampling strategy is to take one sample of tusk for every 180 tonnes landed. This means that between 30–40 samples are taken from the commercial longline catch each year. Each sample consists of 150 fishes. Otoliths are extracted from 50 fish which are also length measured and weighed gutted. In most cases the tusk is landed gutted so it not possible to determine sex and maturity. If tusk is landed ungutted, the ungutted weight is measured and the fish is sex and maturity determined. The remaining 100 in the sample are only length measured.

Age reading of tusk from the commercial catch is not done on regular basis and otoliths from only two years have been age read.

Earlier observations indicates that tusk becomes mature-at-age of about 8–10 years or at around the length of 56 cm. However, new ageing of tusk otoliths from 1995 and 2009 suggest that tusk grows considerably faster than previously assumed. The new age readings are considered more plausible than the older estimates as they results in more similar estimates of growth of tusk in 5.a as has been reported in other management units.

The mean length-at-maturity is close to the mean length of tusk in the commercial catches. This means that a large proportion of the tusk is caught as immature.

No estimates of natural mortality are available for tusk in 5.a and 14. In the Gadget model (see below) natural mortality is assumed to be 0.2 year^{-1}.

The biological data from the fishery are stored in a database at the Marine Research Institute. The data are used for description of the fishery and as input data for the GADGET model.

B.3. Surveys

Iceland

Two bottom-trawl surveys, conducted by the Marine Research Institute in 5.a, are considered representative for tusk are the Icelandic Groundfish Survey (IGS or the Spring Survey) and the Autumn Groundfish Survey (AGS or the Autumn Survey) The Spring Survey has been conducted annually in March since 1985 on the continental shelf at depths shallower than 500 m and has a relatively dense station-net (approximately 550 stations). The autumn survey has been conducted in October since 1996 and covers larger area than the spring survey. It is conducted on the continental shelf and slopes and extends to depths down to 1500 m. The number of stations is about 380 so the distance between stations is often greater. The main target species in the autumn survey are Greenland halibut (*Reinhardtius hippoglossoides*) and deep-water redfish (*Sebastes mentella*).

The text in the following description of the surveys is mostly a translation from Björnsson *et al*. (2007). Where applicable the emphasis has been put on tusk.

B.3.1. Spring survey in 5.a

From the commencing of the spring survey the stated aim has been to estimate abundance of demersal fish stocks, particularly the cod stock with increased accuracy and thereby strengthening the scientific basis of fisheries management. That is, to get fisheries-independent estimates of abundance that would result in increased accuracy in stock assessment relative to the period before the spring survey. Another aim was to start and maintain dialogue with fishermen and other stakeholders.

To help in the planning, experienced captains were asked to map out and describe the various fishing grounds around Iceland and then they were asked to choose half of the tow-stations taken in the survey. The other half was chosen randomly.

B.3.1.1. Timing, area covered and tow location

It was decided that the optimal time of the year to conduct the survey would be in March, or during the spawning of cod in Icelandic waters. During this time of the year, cod is most easily available to the survey gear as diurnal vertical migrations are at minimum in March (Pálsson, 1984). Previous survey attempts had taken place in March and for possible comparison with that data it made sense to conduct the survey in March.

The total number of stations was decided to be 600 (Figure 2). The reason of having so many stations was to decrease variance in indices but was inside the constraints of what was feasible in terms of survey vessels and workforce available. With 500–600 tow-stations the expected CV of the survey would be around 13%.

The survey covers the Icelandic continental shelf down to 500 m and to the EEZ-line between Iceland and Faroe Islands. Allocation of stations and data collection is based on a division between Northern and Southern areas. The Northern area is the colder part of Icelandic waters where the main nursery grounds of cod are located, whereas the main spawning grounds are found in the warmer Southern area. It was assumed that 25–30% of the cod stock (in abundance) would be in the southern area at the survey time but 70–75% in the north. Because of this, 425 stations were allocated in the colder northern area and 175 stations were allocated in the southern area. The two areas were then divided into ten strata, four in the south and six in the north.

Stratification in the survey and the allocation of stations was based on pre-estimated cod density patterns in different "statistical squares" (Palsson *et al.*, 1989). The statistical squares were grouped into ten strata depending on cod density. The number of stations allocated to each stratum was in proportion to the product of the area of the stratum and cod density. Finally the number of stations within each stratum was allocated to each statistical square in proportion to the size of the square. Within statistical squares, stations were divided equally between fishermen and fishery scientist at the MRI for decisions of location. The scientist selected random position for their stations, whereas the fishermen selected their stations from their fishing experience. Up to 16 stations are in each statistical square in the northern area and up to seven in the southern are. The captains were asked to decide the towing direction for all the stations.

B.3.1.2. Vessels, fishing gear and fishing method

In the early stages of the planning it was apparent that consistency in conducting the survey on both spatial and temporal scale was of paramount importance. It was decided to rent commercial stern-trawlers built in Japan in 1972–1973 to conduct the survey. Each year, up to five trawlers have participated in the survey each in a dedicated area (NW, N, E, S, SW). The ten Japan-built trawlers were all build on the same plan and were considered identical for all practical purposes. The trawlers were thought to be in service at least until the year 2000. This has been the case and most of these trawlers still fish in Icelandic waters but have had some modifications since the start of the survey, most of them in 1986–1988.

The survey gear is based on the trawl that was the most commonly used by the commercial trawling fleet in 1984–1985. It has relatively small vertical opening of 2–3 m. The headline is 105 feet, fishing line is 63 feet, foot-rope 180 feet and the trawl weight 4200 kg (1900 kg submerged).

Length of each tow was set 4 nautical miles and towing speed at approximately 3.8 nautical miles per hour. Minimum towing distance so that the tow is considered valid for index calculation is 2 nautical miles. Towing is stopped if wind is more than 17–21 m/sec, (8 on Beaufort scale).

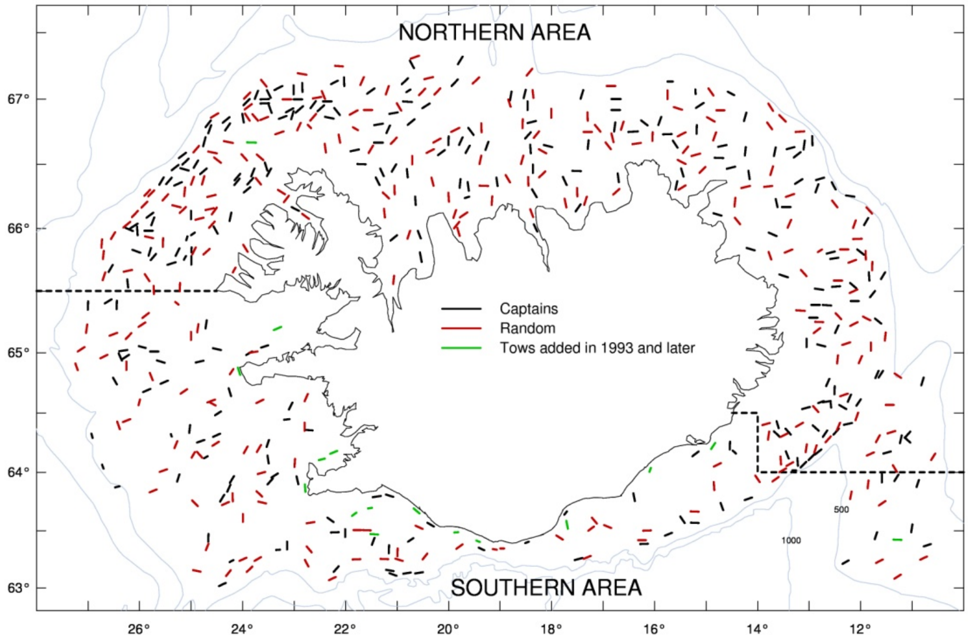

Figure 2. Stations in the spring survey in March. Black lines indicate the tow-stations selected by captains of commercial trawlers, red lines are the tow-stations selected randomly, and green lines are the tow-stations that were added in 1993 or later. The broken black lines indicate the original division of the study area into northern and southern area. The 500 and 1000 m depth contours are shown.

B.3.1.3. Later changes in vessels and fishing gear

The trawlers used in the survey have been changed somewhat since the beginning of the survey. The changes include alteration of hull shape (bulbous bow), the hull extended by several meters, larger engines, and some other minor alterations. These alterations have most likely changed the qualities of the ships but it is very difficult to quantify these changes.

The trawlers are now considered old and it is likely that they will soon disappear from the Icelandic fleet. Some search for replacements is ongoing. In recent years, the MRI research vessels have taken part in the spring survey after elaborate comparison studies. The RV Bjarni Sæmundsson has surveyed the NW-region since 2007 and RV Árni Friðriksson has surveyed the Faroe-Iceland Ridge in recent years and will in 2010 survey the SW area.

The trawl has not changed since the start of the survey. The weight of the otter boards has increased from 1720–1830 kg to 1880–1970 kg. The increase in the weight of the otter boards may have increased the horizontal opening of the trawl and hence decreased the vertical opening. However, these changes should be relatively small as the size (area) and shape of the otter boards is unchanged.

B.3.1.4. Later changes in trawl-stations

Initially, the numbers of trawl stations surveyed was expected to be 600 (Figure 2). However, this number was not covered until 1995. The first year 593 stations were surveyed but in 1988 the stations had been decreased down to 545 mainly due to bottom topography (rough bottom that was impossible to tow), but also due to drift ice that year. In 1989–1992, between 567 and 574 stations were surveyed annually. In 1993, 30 stations were added in shallower waters as an answer to fishermen's critique.

In short, until 1995 between 596 and 600 stations were surveyed annually. In 1996 14 stations that were added in 1993 were omitted. Since 1991 additional tows have been taken at the edge of the survey area if the amount of cod has been high at the outermost stations.

In 1996, the whole survey design was evaluated with the aim of reduce cost. The number of stations was decreased to 532 stations. The main change was to omit all of the 24 stations from the Iceland-Faroe Ridge. This was the state of affairs until 2004 when in response to increased abundance of cod on the Faroe-Iceland Ridge nine stations were added. Since 2005 all of the 24 stations omitted in 1996 have been surveyed each year.

In the early 1990s there was a change from Loran C positioning system to GPS. This may have slightly changed the positioning of the stations as the Loran C system was not as accurate as the GPS.

B.3.2. Autumn survey in 5.a

The Icelandic autumn survey has been conducted annually since 1996 by the MRI. The objective is to gather fishery independent information on biology, distribution and biomass of demersal fish species in Icelandic waters, with particular emphasis on Greenland halibut (*Reinhardtius hippoglossoides*) and deep-water redfish (*Sebastes mentella*). This is because the spring survey does not cover the distribution of these deep-water species. Secondary aim of the survey is to have another fishery independent estimate on abundance, biomass and biology of demersal species, such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and golden redfish (*Sebastes marinus*), in order to improve the precision of stock assessment.

B.3.2.1. Timing, area covered and tow location

The autumn survey is conducted in October as it is considered the most a suitable month in relation to diurnal vertical migration, distribution and availability of Greenland halibut and deep-sea redfish. The research area is the Icelandic continental shelf and slopes within the Icelandic Exclusive Economic Zone to depths down to 1500 m. The research area is divided into a shallow water area (0–400 m) and a deep-water area (400–1500 m). The shallow water area is the same area covered in the spring survey. The deep-water area is directed at the distribution of Greenland halibut, mainly found at depths from 800–1400 m west, north and east of Iceland, and deep-water redfish, mainly found at 500–1200 m depths southeast, south and southwest of Iceland and on the Reykjanes Ridge.

B.3.2.2. Preparation and later alterations to the survey

Initially, a total of 430 stations were divided between the two areas. Of them, 150 stations were allocated to the shallow water area and randomly selected from the spring survey station list. In the deep-water area, half of the 280 stations were randomly positioned in the area. The other half were randomly chosen from logbooks of the commercial bottom-trawl fleet fishing for Greenland halibut and deep-water redfish in 1991–1995. The locations of those stations were, therefore, based on distribution and pre-estimated density of the species.

Because MRI was not able to finance a project in order of this magnitude, it was decided to focus the deep-water part of the survey on the Greenland halibut main distributional area. For this reason, important deep-water redfish areas south and west of Iceland were omitted. The number and location of stations in the shallow water area were unchanged.

The number of stations in the deep-water area was therefore reduced to 150. A total of 100 stations were randomly positioned in the area. The remaining stations were located on important Greenland halibut fishing grounds west, north and east of Iceland and randomly selected from a logbook database of the bottom-trawl fleet fishing for Greenland halibut 1991–1995. The number of stations in each area was partly based on total commercial catch.

In 2000, with the arrival of a new research vessel, MRI was able finance the project according to the original plan. Stations were added to cover the distribution of deep-water redfish and the location of the stations selected in a similar manner as for Greenland halibut. A total of 30 stations were randomly assigned to the distribution area of deep-water redfish and 30 stations were randomly assigned to the main deep-water redfish fishing grounds based on logbooks of the bottom trawl fleet 1996–1999.

In addition, 14 stations were randomly added in the deep-water area in areas where great variation had been observed in 1996–1999. However, because of rough bottom which made it impossible to tow, five stations have been omitted. Finally, 12 stations were added in 1999 in the shallow water area, making total stations in the shallow water area 162. Total number of stations taken since 2000 has been around 381 (Figure 3).

The RV "Bjarni Sæmundsson" has been used in the shallow water area from the beginning of the survey. For the deep-water area MRI rented one commercial trawler 1996–1999, but in 2000 the commercial trawler was replaced by the RV "Árni Friðriksson".

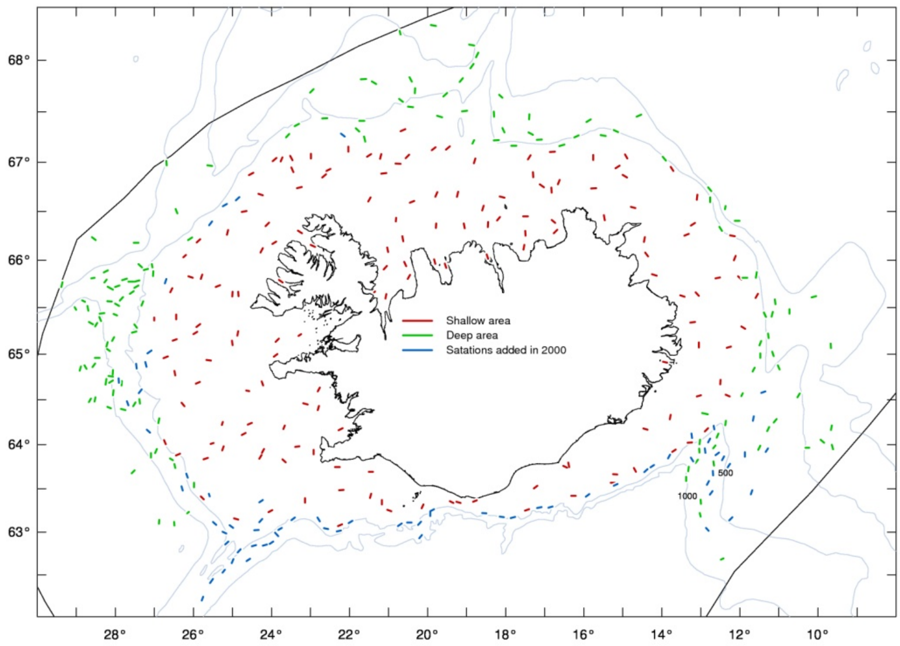

Figure 3. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

B.3.2.3. Fishing gear

Two types of the bottom survey trawl "Gulltoppur" are used for sampling: "Gulltoppur" is used in the shallow water and "Gulltoppur 66.6m" is used in deep waters. The trawls were common among the Icelandic bottom-trawl fleet in the mid 1990s and are well suited for fisheries on cod, Greenland halibut and redfish.

"Gulltoppur", the bottom trawl used in the shallow water, has a headline of 31.0 m, and the fishing line is 19.6 m. The deep-water trawl, "Gulltoppur 66.6m" has a headline of 35.6 m and the fishing line is 22.6 m.

The towing speed is 3.8 knots over the bottom. The trawling distance is 3.0 nautical miles calculated with GPS when the trawl touches the bottom until the hauling begins (i.e. excluding setting and hauling of the trawl).

B.3.3. Data sampling

The data sampling in the Spring and Autumn surveys is quite similar. In short there is more emphasis on stomach content analysis in the autumn survey than the spring survey. For tusk, the sampling procedure is the same in both surveys except tusk is weighed ungutted and stomach content analysed in the autumn survey.

B.3.3.1. Length measurements and counting

All fish species are measured for length. For the majority of species including tusk, total length is measured to the nearest cm from the tip of the snout to the tip of the longer lobe of the caudal fin. At each station, the general rule, which also applies to tusk, is to measure at least four times the length interval of a given species. Example: If the continuous length distribution of tusk at a given station is between 15 and 45 cm, the length interval is 30 cm and the number of measurements needed is 120. If the catch of tusk at this station exceeds 120 individuals, the rest is counted.

Care is taken to ensure that the length measurement sampling is random so that the fish measured reflect the length distribution of the haul in question.

B.3.3.2. Recording of weight, sex and maturity stages

Sex and maturity data have been sampled for tusk from the start of both surveys. Tusk is weighted as ungutted in the autumn survey.

B.3.3.3. Otolith sampling

For tusk a minimum of one otolith in the spring and autumn surveys is collected and a maximum of 25. Otoliths are sampled at a four fish interval so that if in total 40 tusks are caught in a single haul, ten otoliths are sampled.

B.3.3.4. Stomach sampling and analysis

Stomach samples of tusk are routinely sampled in the autumn survey.

B.3.3.5. Information on tow, gear and environmental factors

At each station/haul relevant information on the haul and environmental factors, are filled out by the captain and the first officer in cooperation with the cruise leader.

Tow information

- **General:** Year, Station, Vessel registry no., Cruise ID, Day/month, Statist. Square, Subsquare, Tow number, Gear type no., Mesh size, Briddles length (m).
- **Start of haul:** Pos. N, Pos. W, Time (hour:min), Tow direction in degrees, Bottom depth (m), Towing depth (m), Vert. opening (m), Horizontal opening (m).
- **End of haul:** Pos. N, Pos. W, Time (hour:min), Warp length (fm), Bottom depth (m), Tow length (naut. miles), Tow time (min) , Tow speed (knots).
- **Environmental factors:** Wind direction, Air temperature °C, Wind speed, Bottom temperature °C, Sea surface, Surface temperature °C, Towing depth temperature °C, Cloud cover, Air pressure, Drift ice.

Greenland

Two research vessel series from Greenland waters are conducted annually, but very little tusk is caught.

B.3.2.4. Data processing

B.3.2.4.1. Abundance and biomass estimates at a given station

As described above the normal procedure is to measure at least four times the length interval of a given species. The number of fish caught of the length interval L_1 to L_2 is given by:

$$P = \frac{n_{measured}}{n_{counted} + n_{measured}}$$

$$n_{L_1-L_2} = \sum_{i=L_1}^{i=L_2} \frac{n_i}{P}$$

Where $n_{measured}$ is the number of fished measured and $n_{counted}$ is the number of fish counted.

Biomass of a given species at a given station is calculated as:

$$B_{L_1-L_2} = \sum_{i=L_1}^{i=L_2} \frac{n_i \alpha L_i^{\beta}}{P}$$

Where Li is length and alpha and beta are coefficients of the length–weight relationship.

B.3.2.4.2. Index calculation

For calculation of indices the Cochran method is used (Cochran, 1977). The survey area is split into subareas or strata and an index for each subarea is calculated as the mean number in a standardized tow, divided by the area covered multiplied with the size of the subarea. The total index is then a summed up estimates from the subareas.

A ‘tow-mile’ is assumed to be 0.00918 square nautical mile. That is the width of the area covered is assumed to be 17 m (17/1852=0.00918). The following equations are a mathematical representation of the procedure used to calculate the indices:

$$I_{strata} = \frac{\sum_{strata} Z_i}{N_{strata}}$$

$$\sigma^2_{strata} = \frac{\sum_{strata} (Z_i - I_{strata})^2}{N_{strata} - 1}$$

$$I_{region} = \sum_{region} I_{strata}$$

$$\sigma^2_{strata} = \sum_{region} \sigma^2_{strata}$$

$$CV_{region} = \frac{\sigma_{region}}{I_{region}}$$

Where *strata* refers to the subareas used for calculation of indices which are the smallest components used in the estimation, *I* refers to the stations in each subarea and region is an area composed of two or more subareas. *Zi* is the quantity of the index (abundance or biomass) in a given subarea. *I* is the index and sigma is the standard deviation of the index. CV refers to the coefficient of variation.

The subareas or strata used in the Icelandic groundfish surveys (same strata division in both surveys) are shown in Figure 3. The division into strata is based on the so-called BORMICON areas and the 100, 200, 400, 500, 600, 800 and 1000 m depth contours.

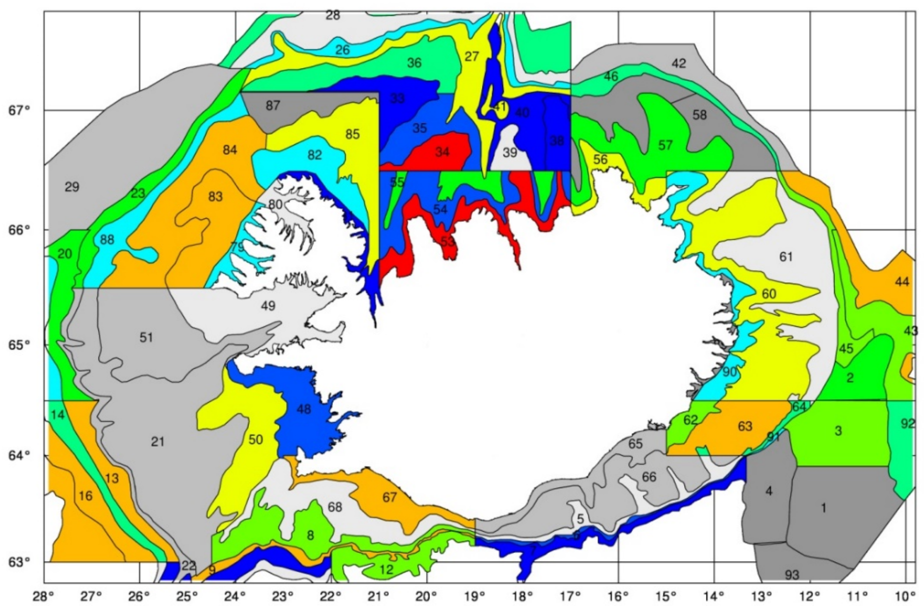

Figure 3. Subareas or strata used for calculation of survey indices in Icelandic waters.

B.3.2.4.3. Inclusion of the Iceland – Faroe ridge

In 2011 the 'Faroe Ridge' survey area was included into the estimation of survey indices. This topic was mentioned at the WKDEEP-2010 meeting but not acted upon (see: WKDEEP-2010-WD:TUSK-01). One of the problems when calculating spring survey indices for tusk in Icelandic waters is whether to use stations from the Iceland-Faroe Ridge. 24 stations on the Iceland-Faroe Ridge were omitted in 1996 from the survey. It was not until 2004 that nine of the stations were included again in the survey and all of the 24 stations in 2005. Inclusion of the Iceland-Faroe Ridge has some impact on the total survey index for the years when this area was surveyed (Figure 4).

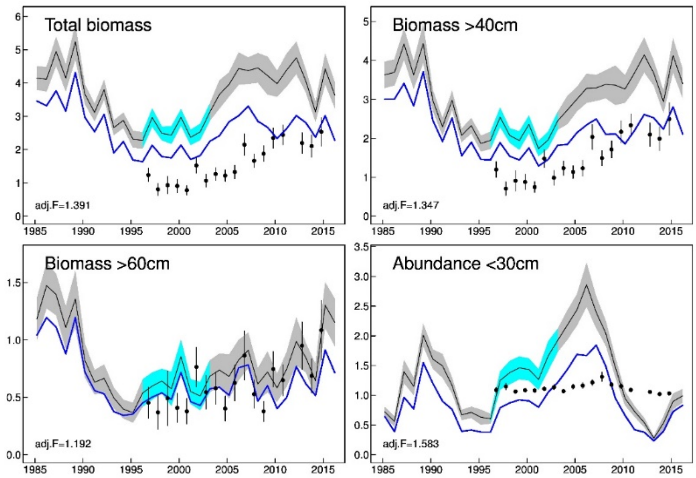

Figure 4. Tusk in 5.a and 14. Indices in the Spring Survey (March) 1985 and onwards (line shaded area) and the autumn survey (October) 1996 and onwards (No autumn survey in 2011). Green line is the index excluding the Faroe-Iceland Ridge.

B.4. Commercial cpue

Data used to estimate cpue for tusk in Division 5.a since 1991 were obtained from logbooks of the Icelandic longline fleet. Only sets were used where catches of tusk was registered, but also for sets where tusk constituted tom more than 10% and 30% of the catch.

Non-standardized cpue and effort are calculated for each year which is simply the sum of all catch divided by the sum of number of hooks.

B.5. Other relevant data

No other relevant data available.

C. Historical stock development

C.1. Description of gadget

Gadget is shorthand for the "Globally applicable Area Disaggregated General Ecosystem Toolbox", which is a statistical model of marine ecosystems. Gadget (previously known as BORMICON and Fleksibest). Gadget is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimisation routines. Processes are generally modelled as dependent on length, but age is tracked in the models, and data can be compared on either a length and/or age scale. The model is designed as a multi-area, multi-area, multi-fleet model, capable of including predation and mixed fisheries issues; however it can also be used on a single species basis. Gadget models can be both very data and computationally intensive, with optimisation in particular taking a large amount of time. Worked examples, a detailed manual and further information on Gadget can be found on www.hafro.is/gadget. In addition the structure of the model is described in Björnsson and Sigurdsson (2004), Begley and Howell (2004), and a formal mathematical description is given in Frøysa *et al*. (2002).

Gadget is distinguished from many stock assessment models used within ICES (such as XSA) in that Gadget is a forward simulation model, and is structured be both age and length. It therefore requires direct modelling of growth within the model. An important consequence of using a forward simulation model is that the plus groups (in both age and length) should be chosen to be large enough that they contain few fish, and the exact choice of plus group does not have a significant impact on the model.

Setup of a Gadget run

There is a separation of model and data within Gadget. The simulation model runs with defined functional forms and parameter values, and produces a modelled population, with modelled surveys and catches. These surveys and catches are compared against the available data to produce a weighted likelihood score. Optimisation routines then attempt to find the best set of parameter values. Growth is modelled by calculating the mean growth for fish in each length group for each time step, using a parametric growth function. In the tusk model a von Bertanlanffy function has been employed to calculate this mean growth. The actual growth of fish in a given length cell is then modelled by imposing a beta-binomial distribution around this mean growth. This allows for the fish to grow by varying amounts, while preserving the calculated mean. The beta-binomial is described in Stefansson (2001). The beta-binomial distribution is constrained by the mean (which comes from the calculated mean growth), the maximum number of length cells a fish can grow in a given time step (which is set based on expert judgement about the maximum plausible growth), and a parameter β, which is estimated within the model. In addition to the spread of growth from the beta-binomial distribution, there is a minimum to this spread due by discretisation of the length distribution.

Catches

All catches within the model are calculated on length, with the fleets having size-based catchability. This imposes a size-based mortality, which can affect mean weight and length-at-age in the population (Kvamme, 2005). A fleet (or other preditor) is modelled so that either the total catch in each area and time interval is specified, or this the catch per timestep is estimated. In the hake assessment described here the commercial catch and the discards are set (in kg per quarter), and the surveys are modelled as fleets with small total landings. The total catch for each fleet for each quarter is then allocated among the different length categories of the stock according to their abundance and the catchability of that size class in that fleet.

Likelihood data

A significant advantage of using an age–length structured model is that the modelled output can be compared directly against a wide variety of different data sources. It is not necessary to convert length into age data before comparisons. Gadget can use various types of data that can be included in the objective function. Length distributions, age–length keys, survey indices by length or age, cpue data, mean length and/or weight-at-age, tagging data and stomach content data can all be used. Importantly this ability to handle length date directly means that the model can be used for stocks such as hake where age data are sparse or considered unreliable. Length data can be used directly for model comparison. The model is able to combine a wide selection of the available data by using a maximum likelihood approach to find the best fit to a weighted sum of the datsets.

Optimisation

The model has two alternative optimising algorithims linked to it, a wide area search simulated annealing Corona *et al*. (1987) and a local search Hooke and Jeeves algorithim HookeJeeves1961. Simulated annealing is more robust than Hooke and Jeeves and can find a global optima where there are multiple optima but needs about 2–3 times the order of magnitude number of iterations than the Hooke and Jeeves algorithim. The model is able to use both in a single run optimisation, attempting to utilize the strengths of both. Simulated annealing is used first to attempt to reach the general area of a solution, followed by Hooke and Jeeves to rapidly home in on the local solution. This procedure is repeated several times to attempt to avoid converging to a local optimum. The algorithms are not gradient based, and there is therefore no requirement on the likelihood surface being smooth. Consequently neither of the two algorithims returns estimates of the Hessian.

Likelihood weighting

The total objective function to be minimised is a weighted sum of the different components. Selection of the weights estimated following the procedure laid out by Taylor *et al*. (2007) where an objective re-weighting scheme for likelihood components is described for Gadget models using cod as a case study. The iterative re-weighting heuristic tackles this problem by optimizing each component separately in order to determine the lowest possible value for each component. This is then used to determine the final weights. The iterative re-weighting procedure has now been implemented in the R statistical language as a part of the **rgadget** package which is written and maintained by B. Th. Elvarsson.

Conceptually the likelihood components can roughly be thought of as residual sums of squares (SS), and as such their variance can be estimated by dividing the SS by the degrees of freedom. Then the optimal weighting strategy is the inverse of the variance. The variances, and hence the final weights, are calculated according the following algorithm:

1) Calculate the initial SS given the initial parametrization. Assign the inverse SS as the initial weight for all likelihood components. With these initial weights the objective function will start off with value equal to the number of likelihood components.

2) For each likelihood component, do an optimization run with the initial score for that component set to 10000. Then estimate the residual variance using the resulting SS of that component divided by the effective number of datapoints, that is all non-zero datapoints.

3) After the optimization set the final weight for that all components as the inverse of the estimated variance from step 3 (weight =(1/SS) * df*).

The effective number of datapoints (df*) in 3) is used as a proxy for the degrees of freedom determined from the number of non-zero datapoints. This is viewed as satisfactory proxy when the dataset is large, but for smaller datasets this could be a gross overestimate. In particular, if the survey indices are weighed on their own while the yearly recruitment is estimated they could be over-fitted. If there are two surveys within the year Taylor *et al*. (2007) suggest that the corresponding indices from each survey are weighed simultaneously in order to make sure that there are at least two measurement for each yearly recruit. In general problem such as those mentioned here could be solved with component grouping, that is in step 2) above likelihood components that should behave similarly, such as survey indices, should be heavily weighted and optimized together.

Another approach for estimating the weights of each index component, in the case of a single survey fleet, would be to estimate the residual variances from a model of the form:

$$\log(I_{lt} = \mu + Y_t + \lambda_t + \varepsilon_{lt}$$

where *t* is denotes year, *l* length-group and the residual term, ε_{lt}, is independent normal with variance σ_s^2 where *s* denotes the likelihood component. The inverse of the estimated residual variance are then set as weights for the survey indices. In the RGadget routines this approach is termed **sIw** as opposed to **sIgroup** for the former approach.

C.2. Settings for the tusk assessment

Population is defined by 10 cm length groups, from 20–110 cm and the year is divided into four quarters. The age range is two to 20 years, with the oldest age treated as a plus group. Recruitment happens in the first and was set at-age 2. The length-at-recruitment is estimated and mean growth is assumed to follow the von Bertalanffy growth function estimated by the model.

Weight–length relationship is obtained from spring survey data.

Natural mortality was assumed to be 0.2 year^{-1}. In 2012 the EG decided to lower the value of natural mortality used in the assessment from 0.2 to 0.15 (See discussion in WGDEEP-2012 report) and this was subsequently adopted by the RG, ADG and ACOM.

The commercial landings are modelled as one fleet, starting in 1980 with a selection pattern described by a logistic function and the total catch in tonnes specified for each quarter. The survey (1985 onwards), on the other hand is modelled as one fleet with constant effort and a nonparametric selection pattern that is estimated for each length group (one 10 cm length group).

Data used for the assessment are described below:

- Length disaggregated survey indices (10 cm increments) from the Icelandic groundfish survey in March 1985–2009.
- Length distribution from the Icelandic commercial catch since 1979. The sampling effort was though relatively limited until the 1990s.
- Landings data divided into four month periods per year (quarters).
- Age–length keys and mean length-at-age from the Icelandic commercial fishery.

Description	Period	By quarter	Area	Likelihood component
Length distribution of landings	1981–1989, 1991+	YES	Iceland	ldist.catch
Length distribution of Icelandic GFS	1985+	-	Iceland	ldist.survey
Abundace index of Icelandic GFS of 20–39 cm individuals	1985+	-	Iceland	si2039
Abundace index of Icelandic GFS of 40-59 cm individuals	1985+	-	Iceland	si4059
Abundace index of Icelandic GFS of 60–110 cm individuals	1985+	-	Iceland	si60110
Age–length key of the landings	See stock section	YES	Iceland	alkeys.catch
Age–length key of the Icelandic GFS	See stock section	1st quarter	Iceland	alkeys.survey
Mean length by age of landings	1995, 2009	YES	Iceland	meanl.catch

Description of the likelihood components weighting procedure:

Component	Description	Quarters	Type
Bounds	Keeps estimates inside bounds	All	8
Understocking	Makes sure there is enough biomass	All	2
Si2039	Survey Index 20–39 cm	1	1
Si4049	Survey Index 40–59 cm	1	1
Si60110	Survey Index 60–100 cm	1	1
Si2080-2	Survey Index (To get a smoothed estimate of the survey selection curve	1	1
Ldist.catch	Length distribution commercial catches (Longlines)	All	3
Ldist.survey	Length distribution from the spring survey	1	3
Alkeys.catch	Age–length data from commercial catches	All	3
Meanl.catch	Mean length-at-age from commercial catches	All	4
ALK keys.survey	Age–length data from the spring survey	1	3

The parameters estimated are:

- The number of fish by age when simulation starts (ages 3 to 5) - 3 parameters. Older ages are assumed to be a fraction of age 5;
- Recruitment each year (1980 and onwards);
- Parameters in the growth equation; Linf is constant at 120 cm and K is estimated;
- Parameter β that models the transition from one length class to the next;
- Length-at-recruitment (mean length and SD);
- The selection pattern of:
    - The commercial catches (1980 and onwards - 2 params.

- Icelandic Spring survey - 1 parameter as the slope is kept constant.

The estimation can be difficult because of some or groups of parameters are correlated and therefore the possibility of multiple optima cannot be excluded. The optimisation is started with simulated anneling to make the results less sensitve to the initial (starting) values and then the optimisation was changed to Hooke and Jeeves when the 'optimum' was approached. The model runs presented at WGDEEP-2010 was started using the initial values and bounds below:

Inital parameter values used and the bounds assigned.

Switch	Value	Lower	Upper	Optimise
Linf	120	50	200	0
K	90	0.1	1000	1
Bbeta	0.1	0.001	15	1
Ic03	4	0.001	15	1
Ic04	3	0.001	15	1
Ic05	2	0.001	15	1
Recl	15	5	40	1
Recsdev	4	0.01	15	1
Rec1980	2	0.01	15	1
Rec1981	2	0.01	15	1
Rec1982	2	0.01	15	1
Rec1983	2	0.01	15	1
Rec1984	2	0.01	15	1
Rec1985	2	0.01	15	1
Rec1986	2	0.01	15	1
Rec1987	2	0.01	15	1
Rec1988	2	0.01	15	1
Rec1989	2	0.01	15	1
Rec1990	2	0.01	15	1
Rec1991	2	0.01	15	1
Rec1992	2	0.01	15	1
Rec1993	2	0.01	15	1
Rec1994	2	0.01	15	1
Rec1995	2	0.01	15	1
Rec1996	2	0.01	15	1
Rec1997	2	0.01	15	1
Rec1998	2	0.01	15	1
Rec1999	2	0.01	15	1
Rec2000	2	0.01	15	1
Rec2001	2	0.01	15	1
Rec2002	2	0.01	15	1
Rec2003	2	0.01	15	1
Rec2004	2	0.01	15	1
Rec2005	2	0.01	15	1
Rec2006	2	0.01	15	1
Rec2007	2	0.01	15	1

Switch	Value	Lower	Upper	Optimise
Rec2008	2	0.01	15	1
Alphacomm	0.9	0.03	10	1
L50comm	40	20	50	1
L50sur	15	5	100	1

However multiple optimisation cycles were conducted to ensure that the model had converged to an optimum, and to provide opportunities to escape convergence to a local optimum.

The **diagnostics** run to analyze the model are:

- Plots comparing observed data and modelled estimates these include survey indices, length and age distributions.
- Retrospective analysis. To analyse how additional data affects historical predictions of the model.

D. Short-term projection

Short and medium-term forecasts for tusk in 5.a and 14 can be done in gadget using the settings described below. However the model setup was not finalized at the Benchmark meeting (WKDEEP-2010). The Benchmark meeting concluded that the setup presented at the meeting as indicative of trends and suggested further improvements. If assessment improvements were addressed properly, WKDEEP agreed with the following parameters as input for short-term forecast. The ADGDEEP and subsequently ACOM decided to base the ICES advice for 2010 for tusk in 5.a and 14 based on projections from Gadget.

Model used: Age–length forward projection

Software used: GADGET (script: run.sh)

Initial stock size: abundance-at-age and mean length for ages 0 to 20+

Maturity: Fixed maturity ogive

F and M before spawning: NA

Weight-at-age in the stock: modelled in GADGET with VB parameters and length–weight relationship

Weight-at-age in the catch: modelled in GADGET with VB parameters and length–weight relationship

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET.

Intermediate year assumptions: Catch is set equal to set TAC in assessment year and projections run at F_{MSY}.

Stock–recruitment model used: Mean of years last three years

Procedures used for splitting projected catches: driven by selection functions and provide by GADGET.

E. Medium-term projections (NA)

F. Long-term projections

Model used: Age–length forward projection

Software used: GADGET

Initial stock size: one year class of 1 million individuals

Maturity: Fixed maturity ogive

F and M before spawning: NA

Weight-at-age in the stock: modelled in GADGET with VB parameters and length–weight relationship

Weight-at-age in the catch: modelled in GADGET with VB parameters and length–weight relationship

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET.

Procedures used for splitting projected catches:

Driven by selection functions and provided by GADGET.

Yield-per-recruit is calculated by following one year class of million fishes for 29 years through the fisheries calculating total yield from the year class as function of fishing mortality of fully recruited fish. In the model, the selection of the fisheries is length based so only the largest individuals of recruiting year classes are caught reducing mean weight of the survivors, more as fishing mortality is increased. This is to be contrasted with age based yield-per-recruit where the same weights-at-age are assumed in the landings independent of the fishing mortality even when the catch weights are much higher as the mean weight in the stock.

G. Biological reference points

In the past Yield per recruit based reference points as estimated above have been used as proxies for F_{MSY}. F_{MAX} from a Y/R analysis is 0.24 and $F_{0.1}$ is 0.15 (Figure 5). As F_{MAX} is well defined and that there are no obvious limitations in the model in terms of fit to the data WGDEEP proposed in 2012 that F_{MAX} be adopted as proxy for F_{MSY}, ACOM subsequently used F_{MAX} as an proxy MSY reference point for the advice in 2012. According to bootstrap results presented in WGDEEP 2013 the estimated CV for F_{MAX} is 3% indicating that the 95% confidence interval of F_{MAX} are between 0.226 and 0.255.

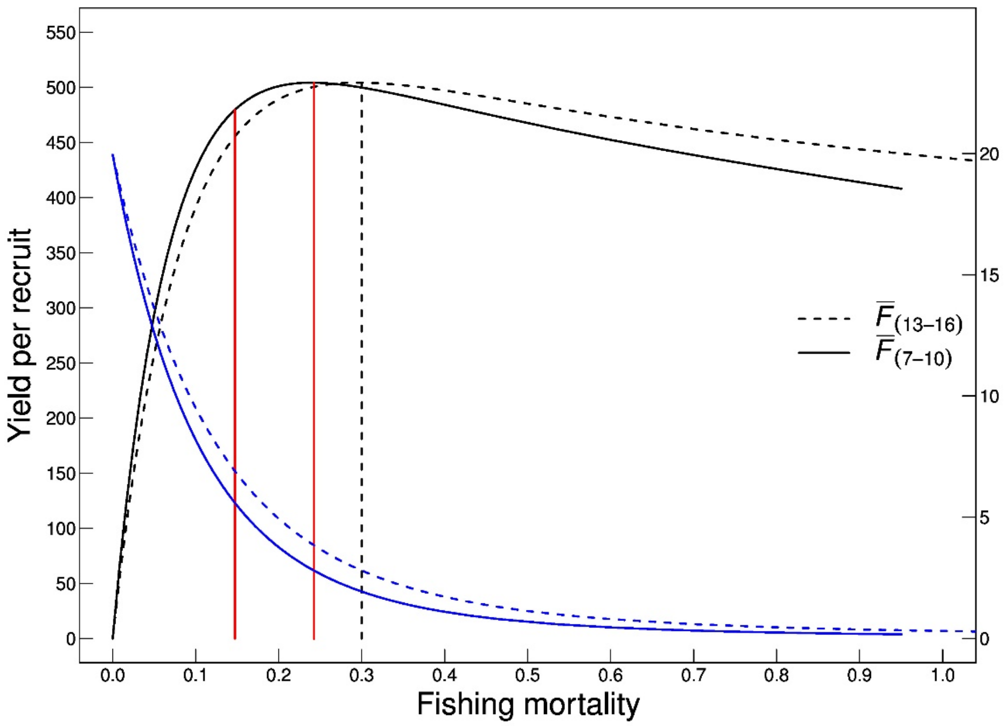

Figure 5. Tusk in 5.a and 14.b. Estimates of yield per recruit and S–R analysis using Gadget. The results are presented for the main age groups in the fishery (7 to 10) and for historical comparison for ages 13–16 or fully recruited to the fishery.

Stochastic simulations using the auto-correlation in recruitment (AR-1 model) were run until the year 2115 under fishing mortality ranging from 0 to 0.6. From these simulations an estimate of F_{MSY} of 0.20 is obtained. The equilibrium catch curve is rather flat at F_{MSY} indicating that the value is uncertain however using the F_{MSY} estimate would result in considerably larger biomass of the stock compared to fishing at F_{MAX} (Figure 6.). The confidence intervals for the F_{MSY} were 0.13 (5%), 0.16 (25%), 0.26 (75%) and finally 0.48 (95%).

WGDEEP 2014 recommended using F_{MSY}=0.2 as the target fishing mortality rather than F_{MAX}. This was subsequently used as the basis for the advice in 2014 by ICES.

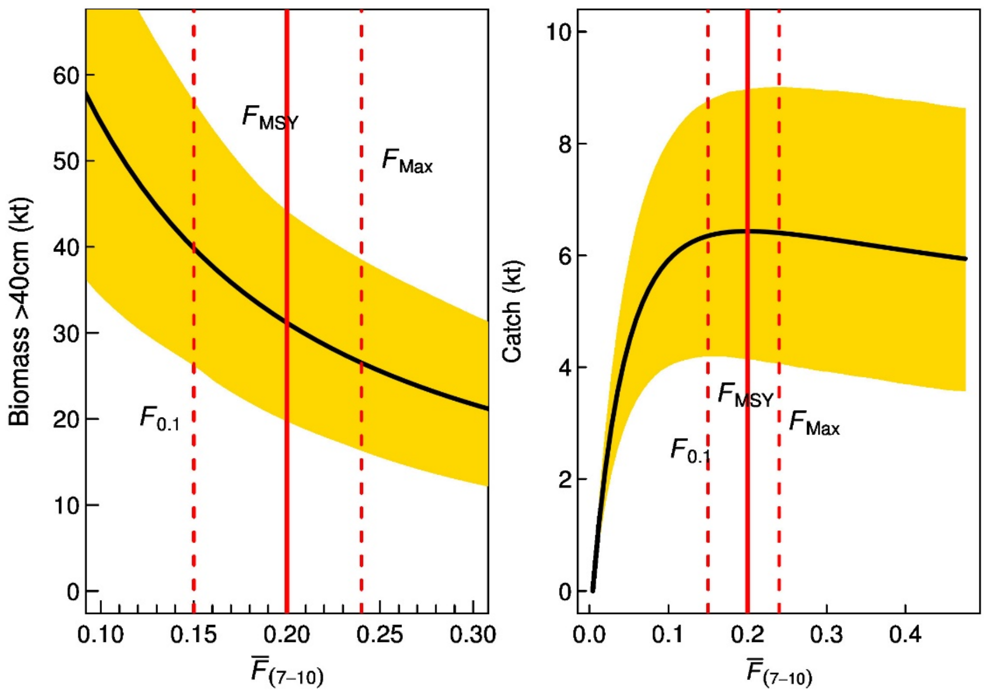

Figure 6. Tusk in 5.a and 14.b. Equilibrium stock biomass and catch from stochastic simulations.

H. Other issues

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