Stock Annex: Tusk in ICES Subarea 14 and Division 5.a

Stock	Tusk in Subarea 14 and Division 5.a
Working Group	WGDEEP
Date	April 2017 (WKICEMSE)
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A. General

A.1. Stock definition

Tusk in Icelandic and Greenland waters (ICES Division 5.a and Subarea 14, respectively) is considered as one stock unit and is separated from the tusk found on the mid-Atlantic Ridge, on Rockall (6.b), 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

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 are also important fishing nations. Foreign catches of tusk in 5.a, mainly conducted by the Faroese fleet, have 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 is mainly caught as either bycatch in other fisheries or in mixed fisheries. The Icelandic longline fleet mainly targets cod and haddock, where tusk is often caught as bycatch. The directed fishery for tusk has traditionally been small 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 take about 65% of the total tusk catch in 5.a are vessels between 300–600 GRT.

The tusk fishery in the Greenland area of ICES Subarea 14 has traditionally been very small, with less than 100 t caught annually. The tusk is caught as bycatch in other fisheries. There are recent signs of increasing catches in the Greenland area, and this must be further investigated. For the time being, these catches are not included in the stock assessment.

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 features of the management system for Icelandic fisheries 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 of 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 to 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 towards the quota, and allowance of transfer of unfished quota between management years. The objective of these measures is to minimize discarding, which is effectively banned. Since the 2006/2007 fishing season, all boats operate under the TAC system.

At 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 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 is 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 and Freshwater 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 a mesh size regulation and closures of fishing areas, are in place.

A system of instant area closures 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 only applies 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 fisheries in order to protect juvenile tusk (Figure 1).

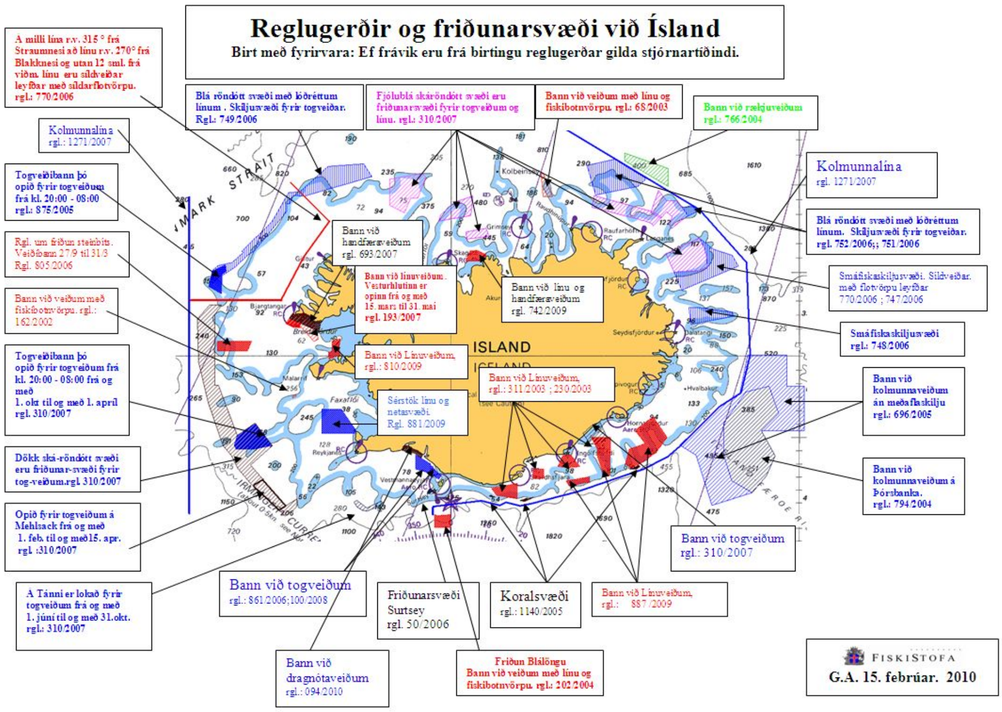

Figure 1. Marine protected areas in Icelandic waters. These areas are closed for various types of fisheries and may be closed permanently (all year around) or temporarily (closed for part of the year). Four areas marked red in the south and southeast of Iceland (reference to the box *Bann við Línuveiðum, rgl.: 311/2003; 230/2003*) are 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 are 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	Some years	Some years	Some 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 statistics, where the location of each haul, effort, depth of trawling and total catch of tusk, are given. Logbook statistics are available since 1991. Landings of Norwegian and Faroese vessels are provided 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. Based on limited data, discard rates in the Icelandic longline fishery for tusk are estimated very low (<1% in either numbers or weight) (WGDEEP, 2011:WD02). Measures in the management system such as converting quota share from one species to another are used by the fleet to a large extent and this is thought to discourage discards in mixed fisheries.

B.2. Biological

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 from which otoliths were collected were also weighed (to the nearest gramme). 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 from hauls containing tusk are taken from the commercial longline catch each year. Each sample consists of 150 tusk from a single haul. Otoliths are extracted from 20 randomly chosen fish, which are also length measured and weighed gutted. In most cases tusk is landed gutted, so it not possible to determine sex and maturity. If tusk is landed un-gutted, the un-gutted weight are measured and the sex and maturity of the fish are determined. The remaining 130 fish in the sample are only length measured.

Age reading of tusk from the commercial catch is done on a regular basis. A continuous time-series of age data is available for the survey since year 2000 and for the commercial catch since year 2008. 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.

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 estimates of natural mortality are available for tusk in Division 5.a and Subarea 14. In the Gadget stock assessment model (see below) natural mortality is assumed to be 0.15 $year^{-1}$.

The biological data from the fishery are stored in a database at the Marine and Freshwater 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 and Freshwater Research Institute in 5.a, are considered representative for tusk, namely 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 start of the Spring Survey the stated aim has been to estimate abundance of demersal fish stocks, particularly the cod stock, with increased accuracy, thereby strengthening the scientific basis of fisheries management. In other words, 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 a 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, which corresponds to 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 earlier 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" (Pálsson *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 built on the same plan and were considered identical for all practical purposes. The trawlers were expected 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, footrope 180 feet and the trawl weight 4200 kg (1900 kg submerged).

The length of each tow was set at 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).

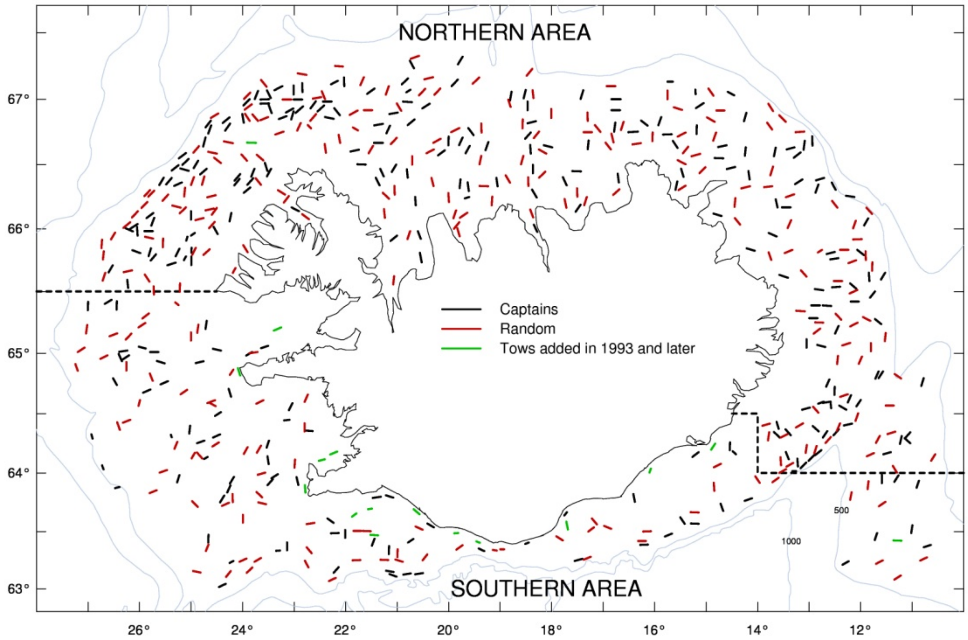

Figure 2. Stations in the Spring Survey in March. Black lines indicate the tow-stations selected by captains of commercial trawlers, red lines are the tow-stations selected randomly, and green lines are the tow-stations that were added in 1993 or later. The broken black lines indicate the original division 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 conducting 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 has since 2010 surveyed 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. On the first survey 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 in response to criticism from fishermen.

In short, until 1995 between 596 and 600 stations were surveyed annually. In 1996 14 stations that had been 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. Another 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 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 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 during 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 a total of 162 stations in the shallow-water area. The 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 during 1996–1999, but in 2000 the commercial trawler was replaced by the RV "Árni Friðriksson".

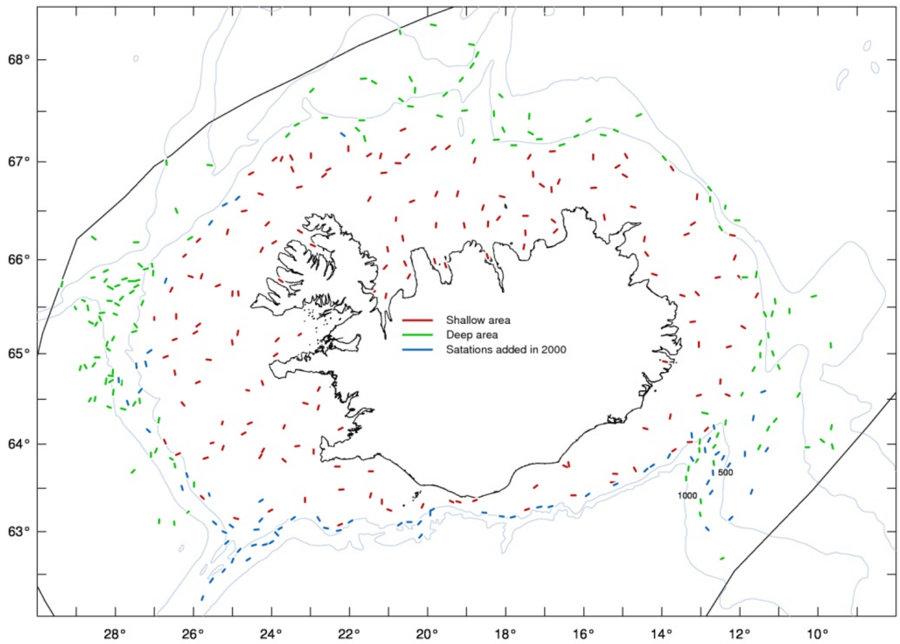

Figure 3. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

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 66.6 m" 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 66.6 m" 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 that tusk is weighed un-gutted 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 un-gutted 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 in a survey haul when encountered. When more than one tusk is caught otoliths are sampled at a four fish interval. This means 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, Sub-square, 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, Windspeed, 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 few tusks are 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 in a given station 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_i is the number of fish of length Li among those measured for length, $n_{measured}$ is the number of fished measured for length, and $n_{counted}$ is the number of fish counted but not measured for length.

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 the coefficients of the length–weight relationship.

B.3.2.4.2. Index calculation

Two types of indices are calculated for tusk in 5.a and 14, one is for describing the general status of the population and the other one for tuning in the GADGET model.

Presentational index

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 the sum of the 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.

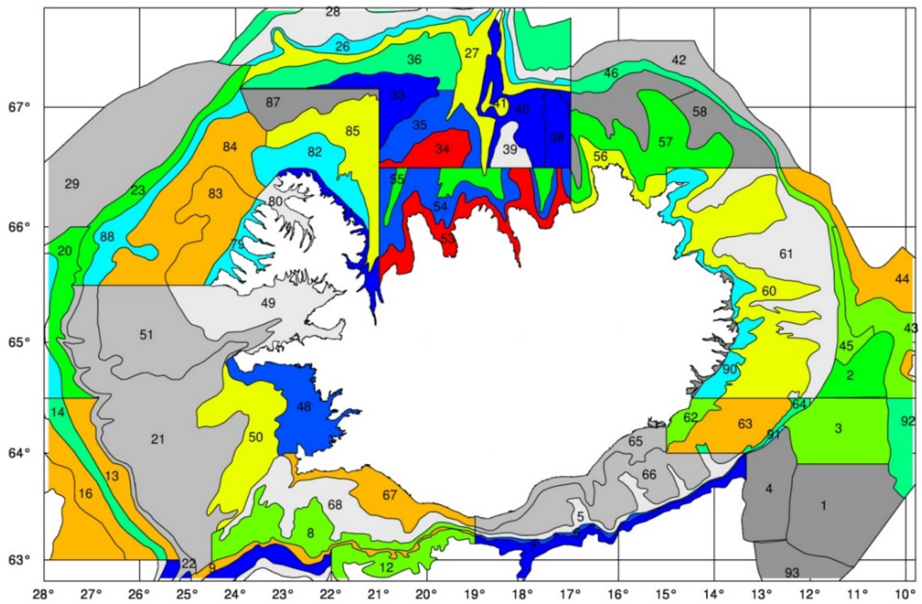

Figure 4. Subareas or strata used for calculation of survey indices in Icelandic waters.

Tuning indices

A different approach is taken in relation to the tuning series for the GADGET model. The spring survey abundance indices are aggregated into seven length intervals (Table 1, Figure 5). The survey indices are defined as the total number of fish caught in a survey within a certain length interval. 10 cm intervals are used for the indices, except for the smallest and the largest length intervals, which are wider so as to avoid getting a zero value for these length groups.

Table 1. Tusk in 5.a and 14: Length aggregation of survey indices used for tuning the GADGET model and the scaling applied between 1996 and 2005 to account for the missing Faroe ridge stations in those years.

Index	Range	Scaling	Index	Range	Scaling
Si.10–20	4–20 cm	1.05	Si.50–60	50–60 cm	1.16
Si.20–30	20–30 cm	1.25	Si.60–70	60–70 cm	1.14
Si.30–40	30–40 cm	1.25	Si.70–110	70–110 cm	1.05
Si.40–50	40–50 cm	1.17			

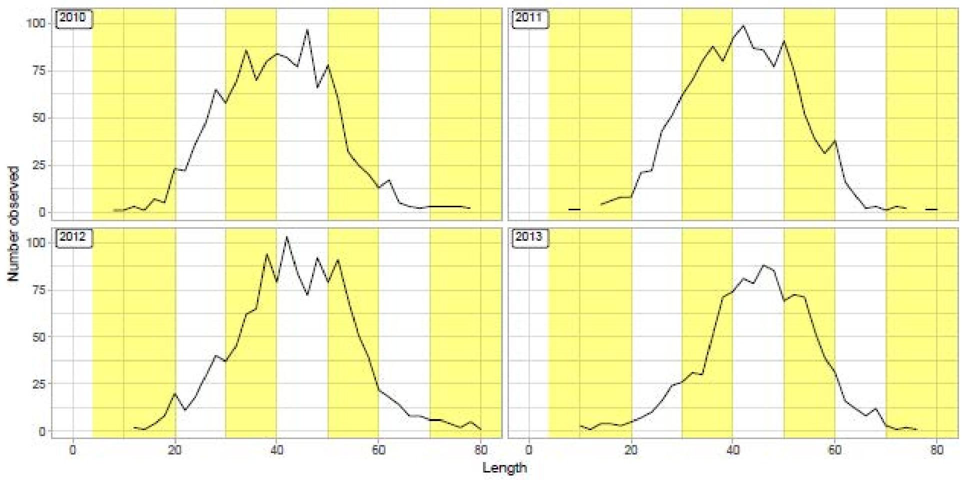

Figure 5. Tusk in 5.a and 14. Length distributions from the Icelandic Groundfish Survey. The yellow and white vertical bands represent the division into length aggregated abundance indices.

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). The tuning series for the GADGET model has been scaled to ensure comparability between years as listed in Table 1.

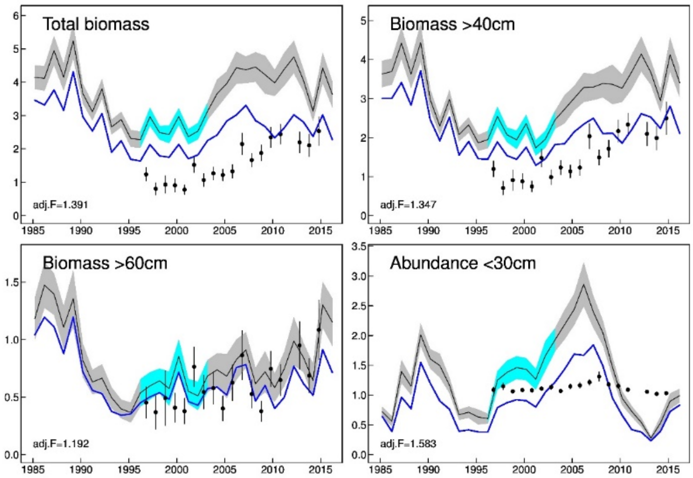

Figure 6. Tusk in 5.a and 14. Indices in the Spring Survey (March) since 1985 (line shaded area, where the years 1996–2005 have been scaled up analogously to scaling presented in Table 1) and the autumn survey (October) since 1996 (No autumn survey in 2011). The blue line is the Spring Survey index excluding the Faroe-Iceland Ridge throughout.

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. Sets were used only if catches of tusk were registered, but also for sets where tusk constituted to more than 10% and 30% of the catch.

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

The cpue estimates of tusk in 5.a are not considered representative of stock abundance.

B.5. Other relevant data

No other relevant data available.

C. Assessment: data and method

The modelling frameworks used in the assessment of tusk in 5.a is Gadget.

C.1. Description of GADGET

Gadget is a shorthand for the "Globally applicable Area Dis-aggregated General Ecosystem Toolbox", which is a statistical model of marine ecosystems. Gadget is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimisation routines for model fitting. 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 multiarea, multifleet, multistock 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 Stefánsson and Pálsson (1997) and Begley and Howell (2004), and a formal mathematical description is given in Frøysa *et al*. (2002).

Gadget is a forward simulation model and is structured around both age and length. It therefore requires direct modelling of growth within the model. 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.

C.1.1. 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 model-predicted 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 (Figure C.1).

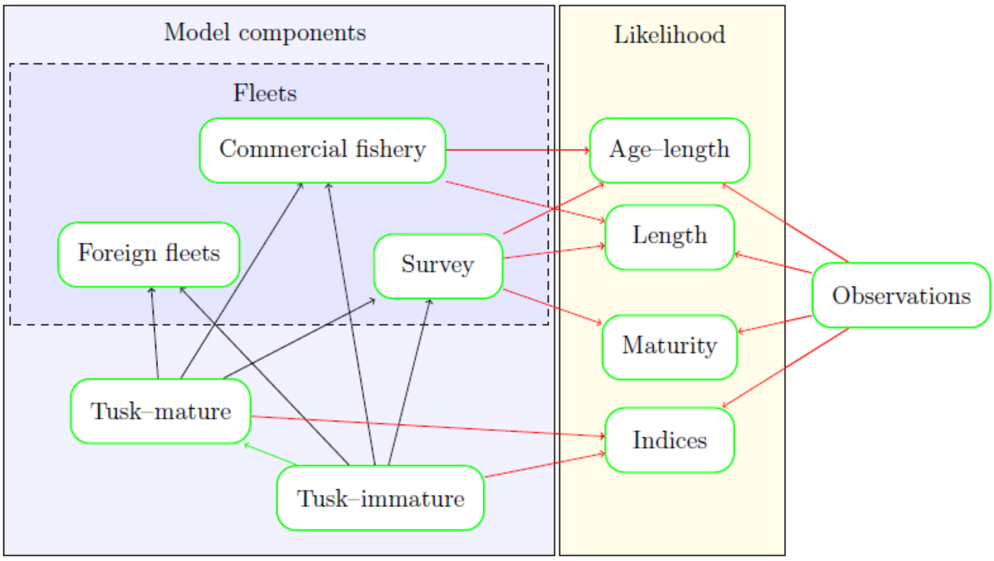

Figure 7. Schematic description of the Gadget model for Tusk in 5a. Lines indicated flow from one model component to the other. Black lines indicate consumption by predators (fleets), red lines the modelled predictions/observations sent to the likelihood and green lines movement between stock components.

C.1.2. Simulation model

In a typical Gadget model the simulated quantity is the number of individuals, N_{alsyt}, at age $a = a_{min} \ldots a_{max}$, in a length-group l, representing lengths ranging between l_{min} and l_{max} cm in Δl cm length-groups, at year y which is divided into time-steps, usually quarters, $t = 1 \ldots T$. The length of the time-step is denoted Δt. The population is governed by the following equations:

$$
\begin{aligned}
N_{alsy,t+1} &= \sum_{l'} G_{l'}^{l} \left[(N_{al'syt} - \textstyle\sum_f C_{fal'st}) e^{-M_a \Delta t} + I_{al'lsyt} \right] && t < T \\
N_{a,ls,y+1,1} &= \sum_{l'} G_{l'}^{l} \left[(N_{a-1,l'sy,T} - \textstyle\sum_f C_{fa-1,l's,T}) e^{-M_a \Delta t} + I_{al'lsy,T} \right] && t = T, a < a_{max} \\
N_{a,ls,y+1,1} &= \sum_{l'} G_{l'}^{l} (N_{al'sy,T} - \sum_f C_{fal'sy,T} + \\
&\qquad N_{a-1,l'sy,T} - \sum_f C_{f,a-1,l'sy,T}) e^{-M_a \Delta t} && t = T, a = a_{max}
\end{aligned}
\tag{1}
$$

where $G_{l'}^{l}$ is the proportion in length group l that has grown $l-l'$ length groups in Δt, C_{falsyt} denotes the catches by fleet $f \in \{S,C,F\}$, i.e. the survey[1], commercial and foreign[2] vessels, M_a the natural mortality-at-age a and $I_{al'lsyt}$ denotes the movement of fish at length l' from the immmature to the mature stock component at length l [3].

C.1.2.1. Growth

Growth in length is modelled as a two–stage process, an average length update in Δt and a growth dispersion around the mean update (as described in Stefansson *et al.*, 2005). Average length update is modelled by calculating the mean growth for each length group for each time-step, using a parametric growth function. In the current model a simplified form of the von Bertanlanffy function has been employed to calculate this mean length update.

$$\Delta l = (l_\infty - l)(1 - e^{-k\Delta t}) \tag{2}$$

where l_∞ is the terminal length and k is the annual growth rate.

Then the length distributions are updated according to the calculated mean growth by allowing some portion of the fish to have no growth, a proportion to grow by one length group and a proportion two length groups, etc. How these proportions are selected affects the spread of the length distributions but these two equations must be satisfied:

$$\sum_i p_{il} = 1$$

and

$$\sum_i i p_{il} = \Delta l$$

Here Δl is the calculated mean growth and p_{il} is the proportion of fish in length group l growing i length groups. Here the growth is dispersed according to a beta–binomial distribution parametrised by the following equation:

$$G_l^{l'} = \frac{\Gamma(n+1)}{\Gamma((l'-l)+1)} \frac{\Gamma((l'-l)+\alpha)\Gamma(n-(l'-l)+\beta)}{\Gamma(n-(l'-l)+1)\Gamma(n+\alpha+\beta)} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \tag{3}$$

where α is subject to:

---

1 The survey fleet catches are given a nominal catch to allow for survey age and length distribution predictions.

2 In the case of tusk foreign vessels are assumed to have the same suitability function as the commercial fleet, however this does however simplifies the data entry.

3 A short note on notation, here l is used interchangeably as either the length group or the midpoint of the length interval for that particular length group, depending on the context.

$$\alpha = \frac{\beta \Delta l}{n - \Delta l} \tag{4}$$

where n denotes the maximum length group growth and $(l' - l)$ the number of length groups grown.

The weight, W_{sl}, at length group l is calculated according to the following stock component specific length–weight relationship:

$$W_{sl} = \mu_s l^{\omega_s} \tag{5}$$

C.1.2.2. Recruitment and initial abundance

Gadget allows for a number of relationships between stock–recruitment and the size of the spawning stock to be defined. However in this model the number of recruits each year, R_y, is estimated within the model as a.

Recruitment enters the population according to:

$$N_{a_{min} l 0 y t'} = R_y p_l \tag{6}$$

where t' denotes the recruitment time-step and p_l is the proportion in length group l that is recruited. p_l is determined by a normal density with l_0, which has a one to one mapping with t_0 used in a typical von Bertalanffy growth model, and variance σ_y^2.

A simple formulation of initial abundance in numbers is used for each age group a, of stock s and in length-group l:

$$N_{als11} = \nu_{as} q_{al} \tag{7}$$

where ν_a is the initial number-at-age a in stock s in the initial year and q_l the proportion at length group l which is determined by a normal density with a mean according to the growth model in equation 2 and variance σ_a^2, with a starting length, at age 1, as l_0.

C.1.2.3. Maturation

Two stage maturity is modelled and represented by the two stock components. First the movement between the two components is formulated as:

$$I_{al'lsyt} = \begin{cases} N_{al'0y,t-1} \times m_{l'}^{l} & s = 1, t > 1 \\ N_{al'0y-1,T} \times m_{l'}^{l} & s = 1, t = 1 \\ -N_{al'0y,t-1} \times m_{l'}^{l} & s = 0, t > 1 \\ -N_{al'0y-1,T} \times m_{l'}^{l} & s = 0, t = 1 \end{cases} \tag{8}$$

where $s = 0$, as noted above, denotes the immature stock component and $m_{l'}^{l}$ is the proportion of immatures that mature between the lengths l and l' defined as:

$$m_{l'}^{l} = \frac{\lambda(l-l')}{1+e^{-\lambda(l-l_{50})}} \tag{9}$$

The second when individuals of the immature stock component reach a certain age those individuals are all moved to the mature stock component.

C.1.2.4. Fleet operation

Catches are simulated based on reported total landings and a length-based suitability function for each of the fleets (commercial fleets and surveys). Total landings are assumed to be known and the total biomass is simply offset by the landed catch. The catches for length group l, fleet f at year y and time-step t are calculated as:

$$C_{falsyt} = E_{ft} \frac{S_f(l) N_{alsyt}}{\sum_{s'}\sum_{a'}\sum_{l'} S_f(l') N_{a'l's'yt} W_{l's'}} \tag{10}$$

where E_{ft} is the landed biomass at time t and $S_f(l)$ is the suitability of length group l by fleet f defined as[4]:

$$S_f(l) = \frac{1}{1+e^{-b_f(l-l_{50,f})}} \tag{11}$$

The effective fishing mortality-at-age and at time-step t is calculated according to the following equation:

$$F_{asyt} = \frac{-\log(1.0 - \frac{C_{asyt}}{N_{asyt}})}{\Delta t} \tag{12}$$

where $C_{asyt} = \sum_{fl} C_{falsyt}$ and $N_{asyt} = \sum_{l} N_{alsyt}$. For tusk the reported F_y is the average F_a for fully recruited ages, i.e. age 15 and above, for that year.

Harvest rate in terms of the reference biomass is calulated as:

$$H_y = \frac{C_y}{B_{ref,y}} \tag{13}$$

where $B_{ref,y} = \sum_{alst} N_{alsyt} W_{s,l}$ and $C_y = \sum_{falst} C_{falsyt} W_{s,l}$.

---

[4] Other functional forms for the selection are defined in Gadget.

For tusk the reported reference biomass is the biomass of fish larger than or equal to 40 cm, denoted $B_{40cm^+,y}$.

C.1.3. Observation model

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 data directly means that the model can be used for stocks where age data are sparse, as is the case with tusk in 5.a and 14. 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 datasets.

In Gadget, data are assimilated using a weighted log-likelihood function. Typically three types of data enter the likelihood, length-based survey indices, length distributions from survey and commercial fleets and age–length distribution from the survey and commercial fleets. Additionally other types of data, and other likelihood functions, could be used, see Begley (2005) for further details.

In formulations below it is assumed that the compositional data are sampled at random, both from the fishery and surveys, as this is how the sampling protocol is Icelandic waters is set up. Other forms of likelihoods are implemented in Gadget that can be used to address other types of sampling, e.g. length-stratified sampling of maturity.

C.1.3.1. Survey indices

For each length range g the survey index is compared to the modelled abundance at year y and time-step t using:

$$l_g^{SI} = \sum_y \sum_t (\log I_{gy} - (\log q_g + b_g \log \tilde{N}_{gyt}))^2 \tag{14}$$

where

$$\tilde{N}_{gyt} = \sum_{l \in g} \sum_a \sum_s N_{alsyt}$$

C.1.3.2. Fleet data

Length distributions are compared to predictions using

$$l_f^{LD} = \sum_y \sum_t \sum_l (\pi_{flyt} - \hat{\pi}_{flyt})^2 \tag{15}$$

where f denotes the fleet where data were sampled from and

$$\pi_{flyt} = \frac{\sum_a \sum_s O_{falsyt}}{\sum_a \sum_{l'} \sum_s O_{fal'syt}}$$

and

$$\hat{\pi}_{lyt} = \frac{\sum_a \sum_s C_{falsyt}}{\sum_a \sum_{l'} \sum_s C_{fal'syt}}$$

i.e the observed and modelled proportions in length group l respectively at year y and time-step t. Similarly age–length data are compared:

$$l_f^{AL} = \sum_y \sum_t \sum_a \sum_l \sum_s (\pi_{falsyt} - \hat{\pi}_{falsyt})^2 \tag{16}$$

where

$$\pi_{alyt} = \frac{\sum_s O_{falsyt}}{\sum_{a'} \sum_{l'} \sum_s O_{fa'l'syt}}$$

and

$$\hat{\pi}_{falyt} = \frac{\sum_s C_{falsyt}}{\sum_{a'} \sum_{l'} \sum_s C_{fa'l'syt}}$$

Length-at-maturity comparison uses the number fish of which maturity status has been assigned that are observed in a given fishery or a survey. The observed proportions are compared to the modelled proportion using sum of squares:

$$l_f^{M} = \sum_y \sum_t \sum_l (\pi_{flyt} - \hat{\pi}_{flyt})^2 \tag{17}$$

where

$$\pi_{flyt} = \frac{\sum_a O_{fal1yt}}{\sum_{a'} \sum_{l'} \sum_s O_{fa'lsyt}}$$

and

$$\hat{\pi}_{lyt} = \frac{\sum_a C_{fal1yt}}{\sum_a \sum_{l'} \sum_s C_{fal'syt}}$$

i.e. the observed and modelled proportions immmature and mature respectively in length group l, year y and time-step t.

C.1.3.5. Order of calculations

The order of calculations is as follows:

1) **Printing**: model output at the beginning of the time-step;
2) **Consumption**: mainly fleet harvesting;
3) **Natural mortality**: Natural mortality is applied after consumption;
4) **Growth**: length update is applied;
5) **Maturation**: maturing fish moved from one stock component to the other;
6) **Spawning and recruitment**: New individuals enter the immature stock component;
7) **Likelihood comparison**: likelihood score is calculated here, note that the comparison is based on the modelled processes in previous steps;
8) **Printing**: model output at the end of the time-step;
9) **Ageing**: if this is the end of year the age is increased.

C.1.3.6. Iterative re-weighting

The total objective function used the modelling process combines equations 14 to 16 using the following formula:

$$l^T = \sum_g w_{gf}^{SI} l_{g,S}^{SI} + \sum_{f \in \{S,C\}} \left(w_f^{LD} l_f^{LD} + w_f^{AL} l_f^{AL} \right) + w^M l^M \qquad (18)$$

where $f = S$ or C denotes the spring survey, commercial fleets respectively. The weights, *wi*, are necessary for several reasons. First of all they are used to prevent some components from dominating the likelihood function. Another would be to reduce the effect of low quality data. It can be used as an a priori estimates of the variance in each subset of the data.

Assigning likelihood weights is not a trivial matter. Often this is done using some form of 'expert judgement'. For Gadget models the so called iterative re–weighting heuristic, introduced by Stefansson (2003), and subsequently implemented in Taylor *et al*. (2007), has become standard practice.

The general idea behind the iterative re-weighing is to assign the inverse variance of the fitted residuals as component weights. The variances, and hence the final weights, are calculated according the following algorithm:

1) Calculate the initial sums of squares (SS) given the initial parametrization for all likelihood components. Assign the inverse SS as the initial weight for all likelihood components.
2) For each likelihood component, do an optimization run with the initial SS for that component set to 10000. Then estimate the residual variance using the resulting SS of that component divided by the degrees of freedom (*df**), i.e. $\hat{\sigma}^2 = \frac{SS}{df^*}$.
3) After the optimization set the final weight for each component as the inverse of the estimated variance from the step above (weight $= 1/\hat{\sigma}^2$).

The number of non-zero datapoints (*df**) is used as a proxy for the degrees of freedom. While this may be a satisfactory proxy for larger datasets it could be a gross overestimate of the degrees of freedom for smaller datasets. In particular, if the survey indices are weighed on their own while the yearly recruitment is estimated they could be overfitted. In general problem such as these can be solved with component grouping, that is, in step 2, the likelihood components that should behave similarly, such as survey indices representing similar age ranges, should be heavily weighted and optimized together.

C.1.4. Optimisation

The model has three alternative optimising algorithms linked to it: a wide area search simulated annealing (Corana *et al.*, 1987), a local search Hooke and Jeeves algorithm (Hooke and Jeeves, 1961) and finally one based on the Boyden-Fletcher-Goldfarb-Shanno algorithm hereafter termed BFGS.

The simulated annealing and Hooke-Jeeves algorithms are not gradient based, and there is therefore no requirement on the likelihood surface being smooth. Consequently neither of the two algorithms returns estimates of the Hessian matrix. 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 algorithm.

BFGS is a quasi-Newton optimisation method that uses information about the gradient of the function at the current point to calculate the best direction to look for a better point. Using this information the BFGS algorithm can iteratively calculate a better approximation to the inverse Hessian matrix. Compared with the two other algorithms implemented in Gadget, BFGS is very local search compared to simulated annealing and more computationally intensive than the Hooke and Jeeves. However the gradient search in BFGS is more accurate than the stepwise search of Hooke and Jeeves and may therefore give a more accurate estimation of the optimum. The BFGS algorithm used in Gadget is derived from that presented by Bertsekas (1999).

The model is able to use all three algorithms in a single optimisation run, attempting to utilise the strengths of all. 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 and finally BFGS is used for fine-tuning the optimisation. This procedure is repeated several times to attempt to avoid converging to a local optimum.

The total objective function to be minimised is a weighted sum of the different components. The estimation can be difficult because some parameters or groups of parameters are correlated and, therefore, the possibility of multiple optima cannot be excluded. The optimisation was started with simulated annealing to make the results less sensitive to the initial (starting) values and then the optimisation was changed to Hooke and Jeeves when the 'optimum' was approached and then finally the BFGS was run in the end.

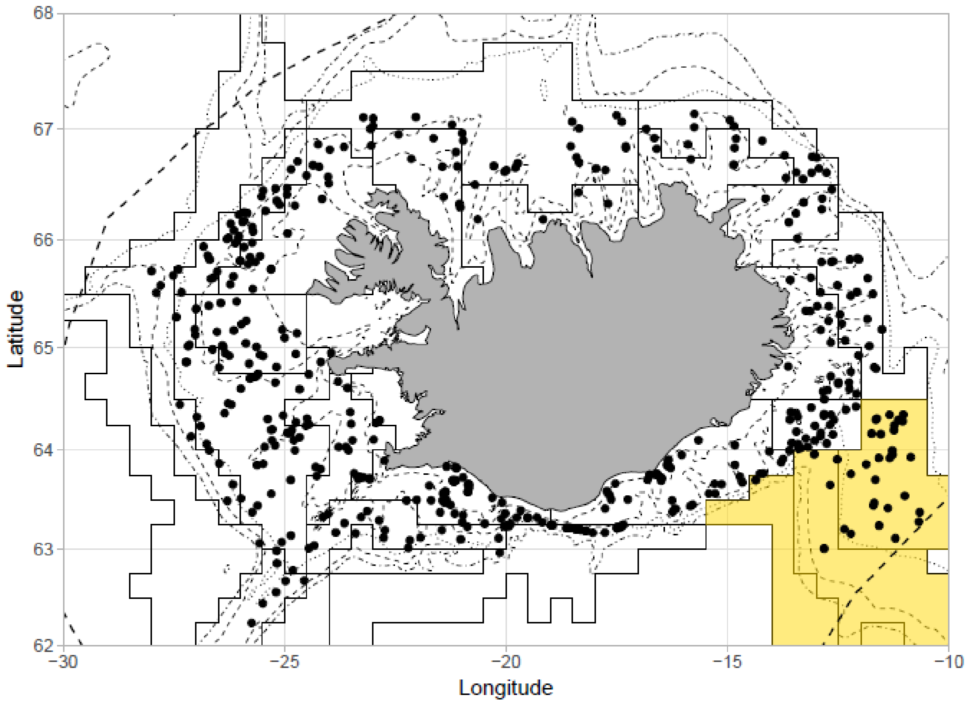

Figure 8. Locations of Tusk catches in 5.a by commercial and survey fleets in 2015 relative to the spatial subdivision on the Icelandic continental shelf area. The yellow shaded region indicates the area that was not covered in the Iceland spring survey in between 1996 and 2005.

C.1.5. Bootstrap

To estimate the uncertainty in the model parameters and derived quantities a specialised boostrap for disparate datasets is used. The approach is based on spatial subdivisions that can be considered to be i.i.d. Refer to Elvarsson *et al*. (2014) and Lentin (2017) for further implementation details. The bootstrapping approach consists of the following:

- The base data are stored in a standardized database:
  - Time aggregation: three months;
  - Spatial aggregation: subdivision;
  - Further dis-aggregation is based on a range of categories including fishing gear, fishing vessel class, sampling type (e.g. harbour, sea and survey). A full listing of data types used in the case study can be found in Table 2, these data are stored subdivision dis-aggregated to allow for use in a bootstrap.
- To bootstrap the data, the list of subdivisions, depicted in Figure 8, required for the model is sampled (with replacement) and stored. For a multi–area model one would conduct the re-sampling of subdivisions within each area of the model.
- The list of resampled subdivisions is then used to extract data (with replacement so the same dataset may be repeated several times in a given bootstrap sample).

- For a single bootstrap Gadget model, the same list of resampled subdivisions is used to extract each likelihood dataset i.e. length distributions, survey indices and age–length frequencies are extracted from the same spatial definition.
- A Gadget model is fitted to the extracted bootstrap dataset using the estimation procedure described above.
- The re-sampling process is repeated until the desired number of bootstrap samples are extracted, which in this case the total sample size is 100.

When re-sampling, data are forced to remain in the correct year and time-step so re-sampling is based on sampling spatially the elementary data units within a given modelled unit of time and space. Thus, within a modelled spatial unit the bootstrap is a re-sampling of subdivisions. This implicitly assumes data contained within each area of the model to be independent and identically distributed. Independence is justified by the definition of subdivisions. Furthermore treating them as they were from the same distribution, i.e. bootstrap replicates, appears to have little negative effect when compared to more traditional methods (Taylor, 2002).

The entire estimation procedure is repeated for each bootstrap sample. In particular, since the estimation procedure includes an iterative re-weighting scheme, this re-weighting is repeated for every bootstrap sample. The point of this is that the bootstrap procedure is no longer conditional on the weights. The procedure as a whole is quite computationally intensive but can easily be run in parallel, e.g. on a computer cluster. Because of this the bootstrap routines are not run as part of the annual assessment but rather as a part of a benchmark process.

C.2. Settings for the tusk assessment

Tusk in 5.a is assumed to be fairly long-lived and the maximum age is set at 18, with 18 acting also as a plus group and simulation goes back to 1982, maturing at age 15 the latest. The minimum age of the immature substock is set as 1 and the mature is set to start at age 6. The length range in the model was between 4 and 110, in 2 cm length intervals, with the mature population starting at 20 cm. Recruitment is set to occur at the end of the first time-step. An overview of the datasets and model parameters used in the model study is shown in Tables 2 and 3 respectively.

Table 2. Overview of the likelihood data used in the model. Survey indices are calculated from the length distributions and are dis-aggregated ("sliced") into seven groups (Table 1). Number of data-points refer to aggregated data used as inputs in the Gadget model and represent the original dataset. All data from the Marine and Freshwater Research Institute, Iceland.

Origin	Time-span	Length group size	Num. data-points	Likelihood function	Weight group
	Age–length distributions:				
Commercial catches	All quarters, 1982–2016	2 cm	2187	See eq. 15	aldist.comm
March Survey	2^{nd}, 1985–2016	2 cm	1825	See eq. 15	aldist.igfs
	Length distributions:				
Commercial catches	All quarters, 1982–2016	2 cm	3329	See eq. 14	ldist.comm
March Survey	2^{nd}, 1985–2016	2 cm	1235	See eq. 14	ldist.igfs
	Ratio of immature:mature by length group:				
March Survey	2^{nd}, 1985–2016	4 cm	1404	See eq. 16	matp.igfs
	Survey indices:				
March Survey	1^{st}, 1985–2016	10 – 20 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	20 – 30 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	30 – 40 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	40 – 50 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	50 – 60 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	60 – 70 cm	32	See eq. 13	sind
March Survey	1^{st}, 1985–2016	70 – 110 cm	32	See eq. 13	sind

Natural mortality

M is assumed to be equal to 0.15, for all ages and years.

Weight–length relationship

The parameters of the weight–length relationship used in eq. 5 were estimate through the means of log-linear regression.

Fleets and selection

In the model there are two commercial fleets and one survey fleet. The commercial fleets are the Icelandic longline and foreign fleets. The selection is described by a logistic function and total catch in tonnes is specified for each time-step.

Table 3. An overview of the estimated parameters in the model.

Description	Notation	Comments	Formula
Natural mortality	M_a	Fixed at 0.15 for ages 1 to 18^+	See eq. 1
Growth function	k, L_∞	Estimated from age–length frequencies	See eq. 2
Growth implementation	β	n is fixed at 15 length-groups	See eq. 3
Fleet selection	b_f, $l_{50,f}$	One set for each of the fleets (Survey, Commerical and Foreign). The commercial and foreign fleet have the same selection	See eq. 11
Maturity ogive	λ, l_{50}		See eq. 8
Length at recruitment	l_0, σ_0	Mean length and std. deviation in recruitment length.	See eq. 6
Number of recruits by year	R_y	$y \in [1982, 2016]$. σ_0, i.e. std. deviation in recruitment length, based on length distributions obtained in the autumn survey.	See eq. 6
Initial abundance at ages 1 – 18 in 1982 by stock component	η_{sa}	$a \in [1, 18^+]$. σ_a^2, i.e. variance in initial length at age a, based on length distributions obtained in the spring survey.	See eq. 7 and table 3
Survey catch-ability	q_g	Intercept term in a log–linear relationship with abundance. The slope term, b_g, is assumed to be 1 for all indices.	See eq. 14
Length–weight relationship	μ_s, ω_s	Estimated outside of the model	See eq. 5
Scalars	R_c, $I_{c,s}$, F_0	Recruiment, initial numbers at age and initial fishing mortality (applied to all age groups)	

Table 4. Initial standard deviation in length by age.

Age	σ_a	Age	σ_a	Age	σ_a
1	5.00	7	6.45	13	7.82
2	3.34	8	6.34	14	7.40
3	3.74	9	6.26	15	7.50
4	5.70	10	6.76	16	7.50
5	6.92	11	7.44	17	7.50
6	6.73	12	7.96	18	7.50

Iterative re-weighting, initial parameter- and optimisation settings

In order to assign weights to the individual likelihood components the iterative re-weighting process described above was used. Survey indices were grouped when over-weighting them, the rationale is that similar datasets should contain similar information and to prevent issues related to overfitting.

Three types of scaling parameters are applied to the model parameters during the optimisation. First the recruitment level was scaled according to a common parameter, *Rc*, to allow the model to find the correct placement of the recruitment parameters. Similarly the initial number-at-age for each stock component was scaled with common parameters, first a plain scalar $I_{c;s}$ and secondly by a common fishing mortality, F_0. These parameters are estimated.

D. Short-term projection

Short-term forecasts for tusk in 5.a and 14 are done in gadget using the settings described below.

Model used: Age–length forward projection

Software used: GADGET

Initial stock size: abundance-at-age and length for ages 1 to 18+

Maturity: Estimated within the model as a logistic length-based process, with all fish of ages <6 assumed to be immature and all fish of ages >15 assumed to be mature.

F and M before spawning: NA

Weight-at-age in the stock: GADGET uses a weight–length relationship and von Bertalanffy growth (no weights-at-age are supplied to GADGET)

Weight-at-age in the catch: GADGET uses a weight–length relationship and von Bertalanffy growth (no weights-at-age are supplied to GADGET)

Exploitation pattern:

Landings: logistic selection-at-length, with parameters estimated within GADGET.

Intermediate year assumptions: Catch is set equal to the TAC in the assessment year and projections for the following year run at any selected harvest rate. Intermediate year assumptions are not necessary for advice according to the management plan as in that case the TAC for fishing year y/y+1 (September 1, year y, to August 31, year y+1) is set as a multiplier of $B_{40+\text{ cm},y}$.

Stock–recruitment model used: recruitment (age 1) estimates not needed for short-term prediction as tusk does not enter the fishery until the age of 6, approximately.

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

E. Medium-term projections

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

F. Long-term projections

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

G. Biological reference points

The biological reference points were calculated at the ICES workshop WKICEMSE (2017), and full details can be found there. They were set in accordance with ICES technical guidelines. B_{pa} was set equal to B_{loss} because the estimates from the stock assessment (starting in 1982) indicate a relatively narrow dynamic range of SSB, with no sign of lower recruitment at the lower end of the historically observed SSB values, whereas fishing pressure is not considered to have been overly high. B_{lim} was then calculated as B_{pa} /1.4, in line with the ICES technical guidelines. Reference points for fishing pressure were calculated in terms of harvest rates relative to B(40+ cm), i.e. HR_{lim}, HR_{pa} and HR_{MSY}. Equivalent fishing mortality values in equilibrium (F_{lim}, F_{pa}, F_{MSY}) were also calculated. As the stock has been fished historically above HR_{MSY}, the reference point MSY $B_{trigger}$ was set at B_{pa}.

ICES has been requested to evaluate a harvest control rule, according to which the TAC in year y/y+1 (September 1 of year y to August 31 of year y+1) is set as

$$TAC_{y/y+1} = HR_{MGT} * B_{40+\ cm,y} * \min(1, SSB_y/MGT\ B_{trigger}),$$

where HR_{MGT}=0.13 and MGT $B_{trigger}$ = 6.24 kt.

ICES has evaluated this rule and found it to be precautionary and in conformity with the MSY approach.

All reference points, including HR_{MGT} and MGT $B_{trigger}$ used in the harvest control rule, are presented in the table below.

Table 5. Tusk in 5.a and 14. Summary of reference points defined for tusk.

Framework	Reference point	Value	Technical basis
MSY approach	MSY $B_{trigger}$	6.24 kt	B_{pa}
	HR_{MSY}	0.17	The harvest rate that maximises the median long-term catch in stochastic simulations with recruitment drawn from a block bootstrap of historical recruitment scaled according to a hockey-stick recruitment function with B_{lim} as defined below.
	F_{msy}	0.23	The median fishing mortality when an harvest rate of H_{msy} is applied.
Precautionary approach	B_{lim}	4.46 kt	$B_{pa}/e^{1.645\sigma}$ where σ = 0.2
	B_{pa}	6.24 kt	SSB(2001), corresponding to B_{loss}
	HR_{lim}	0.27	HR corresponding to 50% long-term probability of SSB $>B_{lim}$
	F_{lim}	0.41	F corresponding to H_{lim}
	F_{pa}	0.27	$F_{lim}/e^{1.645\sigma}$ where σ = 0.25
	HR_{pa}	0.20	HR corresponding to F_{pa}
Management plan	HR_{MGMT}	0.13	HR such that $F \leq F_{msy}$, long-term yield is consistent with MSY while leading to high stock biomass
	MGMT Btrigger	6.24 kt	Set as B_{pa} as the stock has not been harvested at F_{msy}, or equivalents thereof

H. Other issues

H.1. Historical overview of previous assessment methods

Before the advice year 2008/2009 tusk in the NE-Atlantic was assessed as a single management unit.

Between 2008 and 2009 tusk in 5.a and 14 was assessed based on trends in survey indices from the Icelandic spring and autumn survey. Supplementary information included relevant information from the fishery such as length distributions, maturity data, effort, cpue and analysis of changes in spatial and temporal distribution.

In 2010 the stock was assessed as a category 1 stock following a benchmark. The basis for advice was $F_{0.1}$ for the advice years 2010/2011 and 2011/2012, F_{MAX} in 2012/2013 and 2013/2014 and from 2014/2015 onwards based on the ICES MSY approach

In the advice year 2017/2018 the following harvest control rule was implemented:

TAC in year y/y+1 (September 1 of year y to August 31 of year y+1) is set as

$$TAC_{y/y+1} = HR_{MGT} * B_{75+\,cm,y} * \min(1, SSB_y/MGT\ B_{trigger}),$$

where HR_{MGT}=0.18 and MGT $B_{trigger}$ = 6.24 kt.

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