Stock Annex: Golden redfish (*Sebastes norvegicus*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Golden redfish
Working Group	North Western Working Group (NWWG)
Created:	
Authors:	
Last updated:	April 2019 (figures and tables inserted)
Last updated by:	Kristján Kristinsson, and Höskuldur Björnsson

A. General

A.1. Stock definition

Golden redfish (*Sebastes norvegicus*) on the continental shelves of East Greenland, Iceland and Faroe Islands (ICES Subareas 5 and Division 14.b) is considered one stock. This stock definition is based on the location of copulation and extrusion area (Magnússon and Magnússon, 1977; Magnússon, 1980; ICES, 1983). The few population genetic studies that have been conducted do not provide definitive results (Nedreaas *et al.*, 1994; Pampoulie *et al.*, 2009).

Geographical range of golden redfish in the East Greenland/Iceland/Faroe Islands region is shown in Figure A.1.1. Golden redfish is most abundant in Icelandic waters (ICES Division 5.a) and where most of the commercial catches are taken. Golden redfish is found all around Iceland, but the areas of the highest abundance are west, southwest, south and southeast of Iceland at depths of 100–400 m. The main nursery areas are off East Greenland and Iceland. In Icelandic waters they are found all around the country, but are mainly located off the west and north coasts at depths between 50 m and 350 m. No nursery grounds are known in the Faroese waters (ICES, 1983; Einarsson, 1960; Magnússon and Magnússon, 1975; Pálsson *et al.*, 1997). As they grow, the juveniles migrate along the north coast towards the most important fishing areas off the west and southwest coast, but also to the Southeast fishing areas and to Faroese fishing grounds in ICES Division 5.b.

A.2. Fishery

Exploitation of golden redfish of the East Greenland/Iceland/Faroe Islands stock (EGIF stock) started in the mid-1920s in Icelandic waters, and after the Second World War in the two other areas (Figure A.2.1).

The landings from the EGIF stock peaked in 1955 to 160 000 t (Figure A.2.1.), in the same year the fishery started in East Greenland waters. Between 1956 and 1978 the landings gradually decreased in all areas to 50 000 t but then increased again, especially in Icelandic waters. The total annual landings rose to a peak of 130 000 t in 1982. In the late 1980s the fishery collapsed in East Greenland waters and decreased in the two other areas. For the past 20 years the annual landings have been around 40 000 t and a 95–98% has been taken in Icelandic waters.

Annual landings and overview of the major fleet

Iceland

The fishery for golden redfish in Icelandic waters started in the early 1920s but annual landings started to increase in the late 1930s (Figure A.2.1). Annual landings in 1936–1939 varied between 40–65 thousand tonnes, compared to an average of 10 thousand tonnes in 1922–1935. During the interwar period redfish was mainly caught by foreign vessels operating in Icelandic waters. This fishery was unimportant during World War II but increased rapidly after the war and to a record high of 140 thousand tonnes in 1951. Annual landings in 1956–1977 ranged between 60–115 thousand tonnes. The majority of the catches were taken by foreign vessels, mainly from West-Germany. Since 1977, with the expansion of the EEZ to 200 nautical miles, mainly Icelandic vessels have fished for golden redfish in Icelandic waters. Landings declined from about 98 000 t in 1982 to 39 000 t in 1994. Since then, landings have oscillated between 32 000 and 49 000 t. Average annual landings in 2000–2011 have been around 40 000 tonnes.

The fishery for golden redfish in Icelandic waters is directed and predominantly conducted by the Icelandic bottom-trawl fleet, and accounts for more than 90% of the total catch. The rest is partly caught as bycatch in the gillnet, longline, and lobster fisheries. The most important fishing grounds are southwest and west of Iceland at 200–400 m depth.

The fishing fleet operating in Icelandic waters consists of diverse boat types and sizes, operating various types of gear. Golden redfish is mostly caught by the same vessels that are fishing for the pelagic and Icelandic slope *S. mentella* stocks. These are trawlers larger than 40 BRT equipped with bottom trawls.

Greenland

The fishery for golden redfish in East-Greenland waters (ICES Subarea 14) started in the early 1950s and annual landings have been more variable than in the other areas (Figure A.2.1). Until early 1980s the fishery was mainly conducted by West-Germany, except in 1976 when the former USSR exceeded the catches of West-Germany.

The landings peaked in 1955 to about 80 000 t shortly after the fishery commenced in the area. The annual landings then declined and ranged between 8000 and 41 000 t during the period 1957 to 1975, being on average 27 000 t. In 1976 the landings increased suddenly to 54 000 t mainly because of increased redfish fishery of the former Soviet Union. The annual landings immediately dropped to 15 000 t and were at that level for the next few years. After the landings reached 31 000 t in 1982, the golden redfish fishery drastically declined within the next three years. During the period 1985–1994, the annual landings from Subarea 14 varied between 600 and 4200 t, but from 1995 to 2008 there has been little or no direct fishery for golden redfish and landings were 200 t or even less, mainly taken as bycatch in the shrimp fishery. In 2009, a fishery targeting redfish was initiated in ICES 14. In 2010, landings of golden redfish increased considerable and were 1600 t, similar to early 1990s levels. This increase is mainly due to increased directed redfish fishery in the area.

Faroe Islands

Directed fishery for golden redfish in Faroese waters (ICES Division 5.b) was very little until 1978 (Figure A.2.1.). Landings rose to 9000 tonnes in 1985 but dropped gradually to 1500 t in 1999. Between 1999 and 2005 annual landings varied between 1500 and 2500 t, but afterwards they have oscillated between 460 to 690 t. Annual landings had never been so low.

The majority of the golden redfish caught in Division 5.b is taken by pair and single trawlers (vessels larger than 1000 HP), mainly as bycatch in other fisheries.

Management and regulations

Iceland

The Ministry of Fisheries and Agriculture in Iceland is responsible for the management of all Icelandic fisheries and law enforcement within the Icelandic Exclusive Economic Zone (EEZ). The Ministry issues regulations for commercial fishing for each fishing year (from September 1st to August 31st the following year), including 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, with emphasis on golden redfish when applicable. Further and detailed information on the management and regulations can be found at http://www.fisheries.is/.

A system of transferable boat quotas was introduced in 1984, but was changed to an individual transferable quota (ITQ) system in 1990. The fisheries are subjected to vessel catch quotas. The quotas represent shares in the national total allowable catch (TAC). Since the 2006/2007 fishing season, all boats operate under the TAC system. 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. The agreed quotas are based on the Marine Research Institute's TAC recommendations, taking some socio-economic effects into account.

Within this system, individual boat owners have substantial flexibility in exchanging quota, both among vessels within the same company and among different companies. The latter can be done via a temporary or permanent quota transfer. In addition, some flexibility is allowed to individual boats regarding the transference of allowable catch of one species to another. These measures, which can be acted on more or less instantaneously, are likely to reduce initiative for discards (which is effectively banned by law) and misreporting than can be expected if individual boats are restricted by TAC measures alone. They may, however, result in fishing pressures of individual species to be different than intended under the single species TAC allocation.

Furthermore, a vessel can transfer some of its quota between fishing years. There is a requirement that the net transfer of quota between fishing years must not exceed 10% of a given species (was changed from 33% in the 2010/2011 fishing year). This may result in higher catch in one fishing year than the set TAC and subsequently lower catches in the previous 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 (the native enforcement body). All fish landed has to be weighted, either at harbour or inside the fish processing factory. The information on landings is stored in a centralized database maintained by the Directorate and is available in real time on the Internet (www.fiskistofa.is). Between 5–10% of the golden redfish caught annually in Icelandic waters is landed in foreign ports. The accuracy of the landings statistics are considered reasonable although some bias is likely.

All boats operating in Icelandic waters have to maintain a logbook record of catches in each haul. For the larger vessels (for example vessels using bottom and pelagic trawls) this has been mandatory since 1991. 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.

Redfish (golden redfish (*S. norvegicus*) and Icelandic slope *S. mentella*) has been within the ITQ system since the beginning. Icelandic authorities gave a joint quota for these two species until the fishing year 2010/2011, although the MRI has provided a separate advice for the species since 1994. The separation of quotas was implemented in the fishing year that started September 1, 2010. Since the 1994/1995 fishing year, the total annual landings of golden redfish have exceeded the recommended TAC in most years.

Regulations

With some minor exceptions, it is required by law to land all catches. For golden redfish there is no formal harvest control rule. The minimum allowable mesh size is 135 mm in the trawl fisheries, with the exception of targeted shrimp fisheries in waters north of the island.

The minimum legal catch size for golden redfish is 33 cm for all fleets, with allowance to have up to 20% undersized (i.e. <33 cm) specimens of golden redfish (in numbers) in each haul. If the number of redfish <33 cm in a haul is more than 20%, fishing is prohibited for at least two weeks in those areas. Below is a sort description of area closures in Icelandic waters.

REAL-TIME AREA CLOSURE: A quick closure system has been in force since 1976 to protect juvenile fish. Fishing is prohibited up to two weeks in areas where the number of small fish in the catches has been observed by inspectors to exceed certain percentage (for example 25% or more of <55 cm cod and saithe, 25% or more of <45 cm haddock, and 20% or more of <33 cm redfish). If there are several consecutive quick closures in a given area the Minister of Fisheries can close the area for longer time with regulations, forcing the fleet to operate in other areas. Inspectors from the Directorate of Fisheries supervise these closures in collaboration with the Marine Research Institute.

PERMANENT AREA CLOSURES: In addition to allocating quotas on each species, there are other measures in place to protect fish stocks. Based on knowledge of the biology of various stocks, many areas have been closed temporarily or permanently aiming at juvenile protection. Figure 1 shows the map of such area closures that was in force in 2006. Some areas have been closed for decades.

TEMPORARY AREA CLOSURES: The major spawning grounds of cod, plaice and wolfish are closed during the main spawning period of these species. This measure was partly initiated by the fishermen.

Since 1991, when the first redfish closure took place, there have been another 68 quick closures in golden redfish fishing grounds (Table A.2.1 and Figure A.2.2). Quick closures have been fewer for small golden redfish since 2001, or three every year on average, because large areas southwest and west of Iceland are permanently or temporarily closed to trawling to protect juvenile golden redfish (Figure A.2.3). These areas were closed partly because quick closures on redfish fisheries happened very often during the period 1991–1995 (Schopka, 2007).

Faroe Islands

Management measures and regulations

Since 1 June 1996, a management system based on a combination of area closures and individual transferable effort quotas in days within fleet categories has been in force for the Faroese demersal fisheries. The individual transferable effort quotas apply to all fleets (from 2010), except for gillnetters fishing for Greenland halibut and monkfish, which are regulated by a fixed number of licences, by fishing depth and technical measures like maximum allowed number of nets, mesh size and maximum fishing time for each set. Pelagic fisheries for herring, blue whiting and mackerel are regulated by TACs. Trawlers are in general not allowed to fish within the 12 nautical mile limit and large areas on the shelf are closed to them. Inside the 6 nautical miles limit only longliners less than 110 GRT and jiggers less than 110 GRT are allowed to fish. The Faroe Bank shallower than 200 m is closed to all trawl and gillnet fisheries.

Technical measures such as area closures during the spawning periods, to protect juveniles and young fish, and mesh size regulations are a natural part of fisheries regulations.

Vessels from other nations are licensed to fish in Faroese waters through bilateral and multilateral agreements, regulated by TACs. Only Norway and EU have permission to fish deep-water species, but since no agreement has been reached in the negotiations on mutual fishing rights between the Faroese and Norway/EU since 2010, these parties, for the moment, are not allowed to fish in Faroese waters.

Greenland

Management measures and regulations

Management of golden redfish in the Greenland EEZ is managed by the Greenland Ministry of Fisheries, Hunting and Agriculture. There was no redfish directed fishery for more than a decade in east Greenland, but in 2009 an experimental fishery was successful, and the fishery was reopened. The fisheries are subjected to vessel catch quotas, which represents a share of the total allowable catch (TAC). The TAC is set by the Ministry of Fisheries, Hunting and Agriculture and is based on a mixed fishery, with no distinction being made between *S. norvegicus* and *S. mentella*. Hence, the mixed species TAC for 2010 was 6000 t, and this increased to 8500 t in 2011–2012 (assuming an 80:20 split between *S. mentella* and *S. norvegicus*).

All vessels are required to fill out logbooks records of the catch in each haul, and the information is made available to the Greenland Institute of Natural Resources. The fishery has since 2009 also been obligated to provide frozen samples of whole fish to the Greenland Institute of Natural Resources, with the objective to provide a species splitting factor and the collection of samples for a genetically based stock assignment study. Continued sampling from catches is necessary to allow for a continued monitoring of shifts in the species composition.

Catches of Golden redfish in the redfish directed fishery reached approximately 1700 t in 2011 (estimated from an 80:20 split of 8381 t mixed catches of *S. mentella* and *S. norvegicus*). The catches are taken in a small area just east of Kleine Banke (64°N 36°W and just northeast from here at 64°30′ N–65°N and 35°W). The fishery contracted from 2009–2011, and it appears that the fishery is taking place on a large local aggregation of redfish.

Greenland opened an offshore cod fishery on the east coast of Greenland in 2008. To protect spawning aggregations of cod present management measures in Greenland EEZ prohibits trawl fishery for cod north of 63°N latitude. In 2009 and 2010 in this area was extended to 62°N. In 2012 this area closure was annulled, and instead all fishing directed for cod must take place after July 1st. This is done to protect spawning aggregations of cod in the Greenland EEZ. Due to the depth distribution of *S. norvegicus* (Hedeholm and Boje, 2012, WD#9) it is vulnerable to bycatch in the cod fishery, however, the current level of bycatch is considered insignificant (<1.5 t).

The introduction of grid separators in the shrimp fishery has reduced bycatch to very small amounts, and is not considered significant, especially since the shrimp fishery in the East Greenland area is limited (Sünksen, 2007).

A.3. Ecosystem aspects

Golden redfish is ovoviviparous, meaning that eggs are fertilized, develop and hatch internally. The male and female mate several months before the female extrudes the larvae. The females carry sperm and non-fecundated eggs for months before fertilization takes place in winter. Females are thought to have a determinate fecundity. Golden redfish produce many, small larvae (37–350 thousand larvae) that are extruded soon after they hatch from eggs and disperse widely as zooplankton (Jónsson and Pálsson, 2006). The extrusion of larvae may take place over several days or weeks in a number of batches. Knowledge of the biology, behaviour and dynamics of golden redfish reproduction is very scarce.

Growth and maturity

Golden redfish is, like most redfish species, long-lived, slow-growing and late-maturing. Males mature at age 8–10 at size 31–34 cm, whereas females mature age 12–15 at size 35–37 cm (Jónsson and Pálsson, 2006).

Diet

The food of golden redfish consists of dominant plankton crustaceans such as amphipods, copepods, calanoids, and euphausids (Pálsson, 1983).

B. Data

The text table below shows landings data supplied from each area.

	Kind of data				
Country/area	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 (5.a)	x	x	x	x	x
Faroe Islands (5.b)	x				x
Greenland (14)	x				x

B.1.1. Iceland

Icelandic commercial catch data, in tonnes by month, area and gear, are obtained from Statistical Iceland and the Directorate of Fisheries. The geographical distribution of catches (since 1991) is obtained from the logbooks, where location of each haul, effort, depth of trawling and total catch of golden redfish are recorded.

B.1.1.1 Splitting the redfish catches in ICES Division 5.a between S. norvegicus and Icelandic slope S. mentella

Until the 2010/2011 fishing season, Icelandic authorities gave a joint quota for *S. norvegicus* and Icelandic slope *S. mentella* in ICES Division Va. Icelandic fishermen were not required to divide the redfish catch into species. This was a problem when catch statistics of those two species were determined. Since 1993, a so-called *split–catch* method has been used to split the Icelandic redfish catches between the two species.

B.1.1.1.1. Data

The following data were used:

1) Data from logbooks of the Icelandic fleet (information on the location of each haul, how much was caught of redfish, and if available, the species composition of the catch).

2) Information on landed products from Icelandic factory (freezer) trawlers.

3) Biological samples from the Icelandic fresh-fish trawlers sampled by MRI and Icelandic Catch Supervision (ICS) personnel.

4) Landing statistics from Germany and UK if available.

5) Landing statistics from foreign vessels fishing in Icelandic waters.

6) Official landings by gear type provided by Directorate of Fisheries in Iceland.

B.1.1.1.2. Splitting the redfish catch from freezer trawlers

The redfish landings data of the freezer fleet are divided into species in landing reports and considered reliable. However, the official landings for each fishing trip are not divided by gear type if more than one was used (in this case bottom trawl and pelagic trawl), but set on one gear type (usually bottom trawl). The freezer trawlers mainly use bottom trawl in the redfish fishery, but in some years, especially in the 1990s, they also used pelagic trawls. Based on logbooks, the redfish caught with pelagic trawl was Icelandic slope *S. mentella*.

To get reliable species composition of the bottom-trawl catch, the total catch of the freezer trawler for each species was estimated. If for a given year redfish was caught with pelagic trawl (total catch was based on logbooks) the catch was subtracted from the total *S. mentella* catch.

B.1.1.1.3. Splitting the redfish catch from the fresh fish trawlers

The catch is first divided into defined strata and split into species according to the ratio of *S. norvegicus/S. mentella* observed in biological samples from each strata. Each stratum is a 15′ Latitude x 30′ Longitude rectangle.

1) **For each year:** The redfish catch from each year was divided into strata and scaled to the total un-split catch of the two species for each rectangle. It is assumed that the distribution of catch not reported in logbooks was the same as the reported catch. Catch taken by other gears was included (it usually represented about 2% of the total catch).

2) **For each stratum and each year:** The biological samples taken from the commercial catch were used to split the catch in each stratum into species. In this step, the average species composition in the samples in each stratum is estimated and then applied to the total catch of the fleet in that stratum (see previous step). If no information on species composition in a stratum

for any given year was available, the species composition one year before was used if available. If not, then the species composition two years before was applied, and so forth up to a maximum of five years before a given year. If no samples were available in a five year period, the splitting was done according to depth and the captain's experience. Only a small proportion of the catch was split into species using this last criterion.

3) The split into species of redfish landings in Germany and UK (containers or fresh landings) is based on landings reports and considered reliable.

4) For other nations operating in ICES Division 5.a, the catches are split according to information given by those nations. In 2009, only Faroe Islands and Norway operated in ICES Division 5.a.

B.1.1.1.4. Other gears

Between 92–98% of the annual redfish catch is caught with bottom trawls. The redfish caught with other gear types, i.e. longline, gillnet, hook and line, Danish seine, and lobster trawl is assumed to be *S. norvegicus*, because boats using these gear types mainly operate in shallow waters were only *S. norvegicus* is found.

B.1.2. Greenland

The Greenland authorities operate the quota uptake with three types of redfish:

- fish caught by bottom trawl and longlines on the bottom are named *Sebastes norvegicus*;
- fish caught pelagic in the Irminger Sea are named *Sebastes mentella*;
- fish caught as bycatch in the shrimp fishery are named *Sebastes* sp.

From the Greenland and German surveys we know that the demersal redfish found in the area is a mixture of *S. norvegicus* and *S. mentella*. All surveys report that *S. mentella* dominates the catch. According to survey background and one sample of fish from the commercial fishery, the amount of *S. mentella* caught in 14.b in 2009 and 2010 is estimated as 80% of the reported catch of demersal redfish derived from logbooks. This separation has been conducted with different proportions of *S. mentella* in years with significant catches (e.g. 1986), but it remains uncertain what have been done through the years with low catches.

B.1.3. Faroe Islands

Faroese commercial catch data are in tonnes by month, area and gear, and supplied by Statistics Faroe Islands and the Directorate of Fisheries. The geographical distribution of catches is obtained from the logbooks, where location of each haul, effort, depth of trawling and total catch of redfish are recorded.

Since golden redfish is landed just as redfish, there is a need to use all available information to split the catches into *S. norvegicus* and *S. mentella*, respectively.

For the Faroese catches, this split is based on data from Research Vessels surveys on horizontal and vertical distribution of the two species, from regular biological sampling of the redfish landings by fleet, and from logbooks (information on the location of each haul, effort, depth of trawling and how much redfish was caught).

For the catches from other nations, official landings statistics (STATLANT) and information from national laboratories are used to split catches into the two species.

B.1.4. Biological data from the commercial catch

Sampling from the Icelandic fleet

Biological data from the commercial catch were collected from landings by scientists and technicians of the Marine Research Institute (MRI) in Iceland and directly on board on the commercial vessels (mainly length samples) by personnel of the Directorate of Fisheries in Iceland. The biological data collected are length (to the nearest cm), sex, maturity stage and otoliths for age reading.

The general process of the sampling strategy by the MRI since 1999 is to take one sample of golden redfish for every 500 tonnes landed. Each sample consists of 200 individuals: otoliths are extracted from 30 fish which are also length measured, weighed, and sex and maturity determined; 70 fish are length measured, weighted, sex and maturity determined; the remaining 100 are length measured and sex and maturity determined.

Sampling data of size composition from the bottom-trawl fleet are available from 1956–1966 and 1970–2010, but sampling before 1976 is rather limited. Since 1999, 219–434 samples are taken annually and 35 000–74 000 individuals are length measured annually (Table B.1.2.1).

Sampling of age composition from the bottom-trawl fleet only started in 1995. For the first two years, age reading was scarce, but since 2000 the annual number of samples has been between 45 and 50 and 1600–1800 otoliths are age determined (Table B.1.2.1).

The data are stored in a database at the Marine Research Institute and are used to generate an age–length key (ALK) and as input data for the GADGET model.

Sampling from the Faroese fleet

Length samples from the Faroese fleet are available from 2001 and there are a few samples from the early 1990s.

Sampling from East Greenland

Length samples are available from the German commercial fleet operating in East Greenland waters 1975–1991, 1999, 2002 and 2004. Few length samples are available from the newly started Greenland fishery.

B.2. Biological

The total catch-at-age data in 5.a from 1995 is based on Icelandic otolith readings.

B.3. Surveys

Icelandic surveys in 5.a

Two bottom-trawl surveys, conducted by the Marine Research Institute in ICES Division 5.a, are considered representative for golden redfish: 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 it has a relatively dense station-grid (approximately 600 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 larger.

The text in the following description of the surveys is mostly a translation from Björnsson *et al*. (2007). The emphasis has been put on golden redfish where applicable. The report, written in Icelandic with English abstract and English text under each table and figure, can be found at the MRI website under the following link: http://www.hafro.is/Bokasafn/Timarit/rall_2007.pdf. An English version of the survey manual can be found at http://www.hafro.is/Bokasafn/Timarit/fjolrit-156.pdf.

B.3.1. Spring Survey in 5.a

The stated aim of the Spring Survey has been since the beginning the estimation of 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 based on their fishing experience. The other half was chosen randomly by the scientists at the MRI, but the captains were asked to decide the towing direction for all the stations.

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 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 those data it made sense to conduct the survey in the same month.

The total number of stations was decided to be 600 (Figure B.3.1), to decrease variance in indices and keep the survey within 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 of the survey area and the allocation of stations were 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 square size. There are up to 16 stations in each statistical square in the Northern area and up to seven in the southern area.

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 different area (NW, N, E, S, SW). The ten Japanese built trawlers were all built 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 a 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).

Length of each tow was set at 4 nautical miles and towing speed at approximately 3.8 nautical miles per hour. The 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).

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) and size (hull extended by several meters), larger engines, and some other minor alterations. These changes have most likely changed ship performance, but they are very difficult to quantify.

The trawlers are now considered old and it is likely that they will be decommissioned soon, so the search for replacements has started. In recent years, the MRI research vessels have taken part in the Spring Survey after carrying out 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 survey the SW area in 2010.

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, which 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 B.3.1). 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 to reduce costs. 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.

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. Icelandic Autumn Groundfish Survey

The Icelandic Autumn Groundfish Survey has been conducted annually in October since 1996 by the Marine Research Institute (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 conducted annually in March since 1985 does not cover the distribution of these deep-water species. The second aim of the survey is to have another fisheries-independent estimate on abundance, biomass and biology of demersal species, such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and golden redfish (*Sebastes norvegicus*), 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-water redfish. The research area is the Icelandic continental shelf and slopes within the Icelandic Exclusive Economic Zone (EEZ) 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 were 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 location of those stations was, 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. 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. For this reason, only the years from 2000 onwards can be compared for Icelandic slope *S. mentella*.

The number of stations in the deep-water area was reduced to 150, 100 of which 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 the 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 (Figure B.3.2).

In addition, 14 stations were randomly added in the deep-water area in areas where great variation had been observed in 1996–1999. 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 the number of stations in the shallow water area 162. The total number of stations taken in 2000–2009 has been around 381 (Table B.3.1).

In 2010, 16 stations were omitted in the deep-water area and the total number of stations in the area reduced from 219 to 203. All these stations have in common that they are in areas where stations are many and dense (close to each other), and with little variation. Four stations, aimed at deep-water redfish, were omitted southeast of Iceland. The rest or 12 stations were omitted west and northwest of Iceland, stations originally aimed at Greenland halibut.

B.3.2.3. Vessels

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" (Table B.3.1).

B.3.2.4. 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 shape of the trawls is the same but the trawl used in deep waters is larger. 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.

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.3.5. Data sampling

B.3.5.1. Length measurements and counting

All fish species are length measured. For the majority of species, including golden redfish, 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 is to measure at least four (Spring Survey) or five (Autumn Survey) times the length interval of golden redfish. Example: If the continuous length distribution of golden redfish 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 golden redfish 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.3.5.2. Otolith sampling

Otolith sampling of golden redfish only started in 1998 in the Spring Survey. Annually 3100–3800 otoliths are taken but, only otoliths from the year 2010 have been age read. Otolith of golden redfish from the Autumn Survey has on the other been sampled since the beginning of the survey in 1996. Annually 1000–1600 otoliths are sampled and all of them have been age read.

For golden redfish, a minimum of five are collected in both surveys, but the maximum differ between the surveys. In the Spring Survey the maximum number of otoliths collected are ten but 15 in the Autumn Survey. Otoliths are sampled at a 20 fish interval in the Spring Survey and ten fish interval in the Autumn Survey. This means that if in total 200 golden redfish are caught in the Autumn Survey in a single haul, 20 otoliths are sampled.

Each golden redfish taken in the otolith sampling is sex and maturity determined, weighed ungutted, and the stomach content is analysed onboard.

B.3.5.3. 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: Station, Vessel registry no., Cruise ID, Day/Month/Year, Statistical Square, Subsquare, Tow number, Gear type no., Mesh size, Briddles length (m).

Start of haul: Position North, Position West, Time (hour:min), Tow direction in degrees, Bottom depth (m), Towing depth (m), Vertical opening (m), Horizontal opening (m).

End of haul: Position North, Position West, Time (hour:min), Warp length (fm), Bottom depth (m), Tow length (nautical miles), Tow time (min), Tow speed (knots).

Environmental factors:

Wind direction, Air temperature (°C), Windspeed, Bottom temperature (°C), Sea surface, Surface temperature (°C), Cloud cover, Air pressure, Drift ice.

B.3.6. Data processing

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 L_i is length and α and β are coefficients of the length–weight relationship.

B.3.6.1. Index calculation

For calculation of indices the Cochran method is used (Cochran, 1977). The survey area is split into strata (see Section B.3.6.2). Index for each stratum is calculated as the mean number in a standardized tow, divided by the area covered multiplied with the size of the stratum. The total index is then a summed up estimate from the strata.

A "tow-mile" is assumed to be 0.00918 NM^2. 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:

$$\overline{Z}_i = \frac{\sum_i Z_i}{N_i}$$

where $\overline{Z}_i$ is the mean catch (number or biomass) in the *i*-th stratum, Z_i is the total quantity of the index (abundance or biomass) in the *i*-th stratum and N_i the total number of tows in the *i*-th stratum. The index (abundance or biomass) of a stratum (I_i) is:

$$I_i = \overline{Z}_i \left(\frac{A_i}{A_{tow}} \right)$$

And the sample variance in the *i*-th stratum:

$$\sigma_i^2 = \left(\frac{\sum_i (Z_i - \overline{Z}_i)^2}{N_i - 1} \right) \left(\frac{A_i}{A_{tow}} \right)^2$$

where A_i is the size of the *i*-th stratum in NM^2 and A_{tow} is the size of the area surveyed in a single tow in NM^2.

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

and the variance is

$$\sigma_{strata}^{2} = \sum_{region} \sigma_{i}^{2}$$

and the coefficient of variation is

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

B.3.6.2. Stratification

The strata used for survey index calculation for golden redfish in the Spring Survey are shown in Figure B.3.3 and for the Autumn Survey in Figure B.3.4. The stratification is the same in both surveys, but the area is larger in the Autumn Survey. The stratification is in general based on depth stratification and similar oceanographic conditions within each stratum.

The survey stratification and subsequent survey indices for golden redfish were re-calculated for the Autumn Survey in 2008 and for the Spring Survey in 2011. This was done because the majority of the total catch of golden redfish comes in few but large tows leading to high uncertainties in the estimates of the biomass/abundance indices (high CV). Many of these hauls are in a region with relatively long intervals between stations and gaps in the station grid can be seen near these hauls (Figures B.3.3 and B.3.4). After the changes, fewer and larger strata were used and the strata with the holes in the station net reduced. The aim of this revision was to reduce the weight of certain tows, to reduce the area weight and hence, to reduce CV in the indices.

The numbers of strata in the Autumn Survey were reduced from 74 to 33. Figure B.3.5 shows the stratification of the survey area that was used before 2008. The average size of stratum subsequently increased and number of tows within stratum increased. It should also be noted that some strata at the edge of the survey area were reduced in size. The number of strata in the Spring Survey went from 45 to 24. Figure B.3.6 shows the stratification of the survey area that was used before 2011.

Diurnal variation

Golden redfish is known for its diurnal vertical migration showing semi-pelagic behaviour. Usually the species is in the pelagic area during the night-time and close to the bottom during the daytime. There may also be a size or age difference in this pelagic behaviour. This causes great diurnal variation in the catch rates of golden redfish in both the spring and autumn bottom-trawl surveys conducted in Icelandic waters, and it has a large effect on the abundance indices.

The surveys are conducted both during the day and the night (24 hours). Few stations in a limited area account for a large part of the total catches of golden redfish. Besides, interannual variability caused by the time of day when the stations are taken becomes large and hence, can greatly influence the results.

The general model without taking into account length is a generalized model (GML):

$$\log(catch) = \alpha_{year} + \beta_{station} + \gamma_{time}$$

The model uses quasi family with log link and variance proportional to the mean. The factor α_{year} could be interpreted as abundance index. The factor γ_{time} does on the other hand describe the development during the day.

The data were divided into 17 length groups and fitted for each length group.

$$\log(catch) = \alpha_{year} + \beta_{station} + ps(time, df = 7)$$

where is the periodic spline with seven degrees of freedom.

Scaled predictions for each length group in the Spring and Autumn Surveys by the model are shown in Figure B.3.7. As may be seen the smallest redfish has opposite diurnal vertical migration compared to the usual one of larger fish. The model results do also show that much less is caught of the smallest redfish in the survey compared to medium size. This scaled diurnal variation by length as seen in Figure B.3.7 was used for calculating Cochran index for redfish. The only difference from the traditional method is that the numbers caught in each length group at each station will be divided by the appropriate multiplier shown in Figure B.3.7.

Comparison of total biomass index for golden redfish based on the old and new stratification, and taking into account the diurnal variation is shown in Figure B.3.8 for the Spring Survey and Figure B.3.9 for the Autumn Survey. In general, the measurement errors of the indices based on the new stratification and taking into account diurnal variation are lower than the ones based on the old stratification.

Faroese surveys in 5.b

Two annual groundfish surveys are conducted on the Faroe Plateau by the Faroe Marine Research Institute, the Spring Survey carried out in February–March since 1994 (100 stations per year down to 500 m depth, Figure B.3.10), and the Summer Survey in August–September since 1996 (200 stations per year down to 500 m depth, Figure B.3.11). Both surveys are bottom-trawl surveys and the same bottom trawl with 40 mm mesh size in the codend is used. Effort for both surveys is recorded in terms of minutes towed (60 min).

All stations are fixed stations. Half of the stations in the Summer Survey were the same as in the Spring Survey. The surveyed area is divided into 15 strata defined by depth and environmental conditions. For index calculation same method was applied as described in Section 2.4.3. The 'tow-mile' is assumed to be 0.0108 NM^2 and the width of the trawl is assumed to be 22 m. The tow length is set to 4 NM. It was not possible to calculate the sampling variance since the catch was aggregated by stratum, that is, only the total catch and number of tows per stratum was available.

Surveys in Greenland waters

Survey design

Abundance, biomass estimates and length structures have been derived using annual German groundfish surveys covering shelf areas and the continental slopes off West and East Greenland during 1982–2012. The survey was primarily designed for the assessment of cod, but it covers the entire groundfish assemblage down to 400 m depth (Rätz, 1999). Designed as a stratified random survey, the hauls are allocated to the strata off West and East Greenland according to both the area and the mean historical cod abundance at equal weights. Stations are randomly selected from successfully trawled grounds. Because of favourable weather and ice conditions and to avoid spawning concentrations, autumn was chosen for the time of the surveys.

The surveys were carried out by the research vessel RV Walther Herwig (II) 1982–1993 (except 1984 throughout RV Anton Dohrn was used) and since 1994 by RV Walther Herwig III.

Up to 2012, the surveyed area is the 0–400 m depth that is divided into seven geographical strata and two depth zones (0–200 m; 200–400 m, Figure B.3.12). The numbers of hauls were initially ca. 200 per year but were reduced from the early 1990s to 80–100 per year.

In 2013, the survey was re-stratified, with four strata in West Greenland resembling NAFO subarea structure, and five strata in East Greenland. Depth zones considered are 0–200 m and 200–400 m (Figure B.3.13). The time-series was recalculated accordingly.

For historical reasons strata with less than five hauls were not included in the annual stock calculations op to 2008. From 2009 on, all valid hauls have been included and the entire time-series have been corrected. For strata with less than five samples, GLM and quasi-likelihood estimates are recalculated based on year and stratum effects from the time-series. In some years (notable 1992 and 1994) several strata were not covered due to weather conditions/vessel problems, implying that the survey estimate implicitly refers to varying geographical areas.

Re-stratification of the survey in NWWG 2013 (NWWG WD 25)

The new stratification refers to 31 607 nm² excluding in particular areas for which no data were available (Table B.3.2), whereas the old stratification covered 37 463 nm² (Table B.3.3).

Stratification is undertaken to optimize sampling effort and design to obtain highly reliable estimates of a population, i.e. under minimizing sample variance.

Stratification on species level for Atlantic cod, golden redfish and deep-sea redfish was carried out according to the cumulative squared root frequency method by Dalenius and Hodges (Cochran, 1977, p.127–131; Dalenius and Hodges, 1959) based on average biomass per ICES rectangle.

Following the approach undertaken by Cornus (1986), survey samples were assigned to ICES rectangles prior to calculating stratum affiliations. Within ICES rectangles, the amount of trawlable area was estimated according to Cornus (1986).

Stratification on community level was undertaken with Ward’s minimum variance method by means of clustering. Many simulation studies comparing various methods of cluster analysis have been performed. In these studies, artificial datasets containing known clusters are produced using pseudo-random number generators. The datasets are analysed by a variety of clustering methods, and the degree to which each clustering method recovers the known cluster structure is evaluated. See Milligan (1981) for a review of such studies. In most of these studies, the clustering method with the best overall performance has been either average linkage or Ward’s minimum variance method. The method with the poorest overall performance has almost invariably been single linkage. However, in many respects, the results of simulation studies are inconsistent and confusing.

A six stratum design was analysed for community structure.

For each species, five strata were determined in terms of their assortment of ICES rectangles (Figure B.3.13). In a further step, adjacent ICES rectangles were combined into one stratum both defined through density level and geographic coherence.

Species stratification schemes were cross-checked with community schemes to outline general distribution patterns on the shelf.

In a third step, sampling frequency was checked, and strata 5 and 6 were joined to reach sufficient sample coverage.

Fishing gear

The fishing gear used was a standardized 140 feet bottom trawl, its net frame rigged with heavy groundgear because of the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the codend. The horizontal distance between wingends was 25 m at 300 m depth, the vertical net opening being 4 m. In 1994, smaller Polyvalent doors (4.5 m^2, 1500 kg) were used for the first time to reduce net damages due to overspread caused by bigger doors (6 m^2, 1700 kg), which have been used earlier.

Index calculation

All calculations of abundance and biomass indices were based on the modified 'swept-area' method using 22 m horizontal net opening as trawl parameter, i.e. the constructional width specified by the manufacturer, and standardized to a towing time of 30 minutes, yielding a distance swept of 2.25 nm as derived from a speed of 4.5 knots. Hauls, which received net damage or became hang-up after less than 15 minutes, were rejected. Some hauls of the 1987 and 1988 surveys were also included although their towing time had been intentionally reduced to ten minutes because of the expected large cod catches as observed from echosounder traces.

Stratified abundance estimates calculated from catch-per-tow data using the stratum areas as weighting factor (Cochran, 1977). Strata with less than five valid sets were included but are indicated. The coefficient of catchability was set at 1.0, implying that estimates are fair indices of abundance and biomass. Respective confidence intervals (CI) were set at the 95% level of significance of the stratified mean. The length–frequency distributions (LFDs) were compiled by stratum and year and raised to the respective abundance.

The assumption of the swept-area approach are certainly overestimating abundance, since herding effects through trawl doors and bridles are not considered (Dickson, 1993a; Dickson, 1993b). According to measurements undertaken with rock-hopper equipped BT140, door spread is about 60 m, and applying extension factors derived from nets of similar size, 0.5 of the door spread effectively contributes to the herding effect and thus to catch (Dickson, 1993b). This indicates that the naïve swept-area estimate based on the horizontal net opening only realistically overestimates catch by a factor of two.

Fitted SI

Following Venables and Dichmont (2004), a quasi-likelihood model was applied with loglink function and negative binomial-distributed errors.

Biological measurements

Fish were identified to species or lowest taxonomic level, and the catch in number and weight was recorded. Redfish inhabiting the survey area close to the bottom are believed to belong to the traditional stocks off Greenland, Iceland and the Faroe Islands (ICES, 1995). In the German surveys off Greenland, fish (>17 cm) were separated into *S. norvegicus* L. and *S. mentella* Travin, whereas juvenile redfish (<17 cm) were classified as *Sebastes* spp. due to difficult - and in most cases impossible - species identification. Total fish lengths were measured to cm below.

Stratification, index calculation, and inclusion of the German Survey in East Greenland in the GADGET model

Area definition

The German Survey does not cover the East Greenland continental shelf very well and only the edges of the shelf from 150–450 m are covered. The area used to compile abundance indices from the survey is approximately 45 000 km^2 (Figure B.3.13), a large area looking at the coverage.

For inclusion of the German Survey in East Greenland waters in the GADGET model (See Chapter C for the description and setup of the GADGET model) the survey area was reduced. Instead of using the five defined strata proposed in 2013 and shown in Figure B.3.13, only one stratum was used around the stations taken (Figure B.3.14). This approach was taken to avoid extrapolation to areas not covered by the survey and hence, to reduce the weight of each station. After the changes the area behind each station in the German Survey is 75% larger than of an average station in the Icelandic Spring survey.

The size of this region is 22 500 km^2. Outer boundary of the region follows the 500 m contour while the inner boundary is more *ad hoc*. Results from the Icelandic autumn survey indicate that golden redfish is not common below 500 m depth. Using larger areas in compilation of survey indices leads to substantial extrapolation to areas not covered by the survey.

Survey indices calculations

The Icelandic data are converted to abundance by assuming 17 m width of the survey trawl. Also diurnal variability is taken into account and the results calibrated to the average of day and night but the survey is conducted 24 hours per day. Results from the German survey are converted to abundance per km^2 by assuming 22 m width of the survey trawl but not correcting for time of day as the German survey is only conducted during the day.

The Icelandic indices are compiled using stratified mean as described in Chapter B.3.6. The Greenland indices used in the GADGET setup are compiled by taking the average over the abundance/km^2 of the stations each year multiplied by $\frac{22m}{16m}$ (to account for different trawl width in the German and the Icelandic Spring Surveys respectively) and then by the size of the survey area, in this case 22 500 km^2.

Combination of the Icelandic Spring Survey and the German East Greenland Survey

The German survey in East Greenland waters is conducted in the autumn (September–October) or 4–5 months earlier than the Icelandic Spring survey the following year. When the survey indices were combined, the German survey in year y was added to the Icelandic Spring Survey conducted the year after (y+*1*). During this period of 4–5 months between the surveys, the fish grows. Furthermore, it might also migrate between areas. The former problem is taken care of by adding one cm to the length of all fish caught in the German survey but the latter problem is not considered specifically.

B.4. Commercial CPUE

Iceland

Catch per unit of effort is routinely calculated during the annual assessment process. Data used to estimate cpue for golden redfish in Division 5.a since 1978 were obtained from logbooks of the Icelandic bottom-trawl fleet. Only those hauls were used that were taken above 450 m depth (combined golden redfish and Icelandic slope *S. mentella*) and that were comprised of at least 50% golden redfish (assumed to be the directed fishery towards the species; between 70–80% of the total annual catch were from those hauls). Non-standardized cpue and effort is calculated for each year:

$$E_y = \frac{Y_y}{CPUE_y},$$

where E is the total fishing effort and Y is the total reported landings.

Cpue indices were also estimated from this dataset using a GLM multiplicative model (generalized linear models). This model takes into account changes in vessels over time, area (ICES statistical square), month and year effects:

glm(log(catch) ~ log(effort) + factor(year) + factor(month) + factor(area) + factor(vessel), family=gaussian())

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, has been used for assessment of golden redfish in ICES Division 5.a since 1999 (Björnsson and Sigurdsson, 2003).

GADGET is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimization 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 multispecies, multiarea, multifleet model, capable of including predation and mixed fisheries issues; however it can also be used on a single species basis. Worked examples, 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 (2003), 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 that it is length based and takes into account the fact that fisheries are often targeting the largest individuals of age groups partly recruited to the fisheries thereby reducing the mean weight of the survivors.

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. Optimization routines then attempt to find the best set of parameter values.

Growth

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 golden redfish model a von Bertalanffy function has been employed to calculate this mean growth. At each time-step 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:

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

and

$$\sum i p_{il} = \mu_i$$

Here μ is the calculated mean growth and p_{il} is the proportion of fish in length group l growing i length groups. The proportions are selected from a beta-binomial distribution, that is a binomial distribution $f(n,p)$ where n is the maximum number of length groups that a fish can grow in one time interval. The probability p in the binomial distribution comes from a beta distribution described by α and β (Stefansson, 2001). As in all discrete probability distributions the condition $\sum p_{il} = 1$ is automatically satisfied. The mean of the distribution is given by:

$$\mu_l = \frac{n\alpha}{\alpha + \beta} = \sum_{i=0}^{n} p_{il} i$$

For a given value of β, a value of α is selected so that $\mu_l = G_l$ where G_l is the calculated mean growth from the parametric growth equation. β, which can either be estimated or specified in the input files, affects the spread of the length distribution.

Fleets

All fleets or predators in the model work on size. To be specific the predators have size preference for their prey and through predation can affect mean weight and length-at-age in the population. A fleet (or predator) is modelled so that either the total catch or the total effort in each area and time interval is specified. In the golden redfish assessment described here the commercial catch is given in weight but the survey is modelled as a fleet with a constant effort.

The first step in estimating catch in numbers by age and length in the model is to calculate the 'modelled cpue' for each fleet:

$$CPUE_{\text{mod}} = \sum_{prey} \sum_{l} S_{prey,l} N_{prey,l} W_{prey,l}$$

where $S_{prey,l}$ is the selection of prey length l, $N_{prey,l}$ is the number of fish and $W_{prey,l}$ is the mean weight of prey of length l. The total catch of each length group of each prey is then calculated from:

$$C_{prey,l} = C \frac{S_{prey,l} N_{prey,l} W_{prey,l}}{CPUE_{\text{mod}}}$$

where $C_{prey,l}$ is the amount caught by the predator of length group l of prey (in this case golden redfish) and C is the total amount caught by the fleet, either specified or calculated from:

$$C = E \times CPUE_{\text{mod}}$$

where E is the specified effort.

In the golden redfish assessment described here the commercial catches are set (in kg per six months), and the survey is modelled as fleet with small total landings. The total catch for each fleet for each six month period 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 major advantage of using an age–length structured model is that the modelled output can be compared directly to 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 such as golden redfish where time-series of age data is relatively short compared to the lifespan of the species). Length data can be used directly for comparison to model output. 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.

Optimization

The model has three alternative optimizing algorithms linked to it: a wide area search Simulated Annealing (Corona *et al*., 1987), a local search Hooke-Jeeves algorithm (Hooke and Jeeves, 1961) and finally one based on the Boyden-Fletcher-Goldfarb-Shanno algorithm hereafter termed BFGS (Bertsekas, 1999).

The simulated annealing and Hooke-Jeeves algorithms are not gradient based, and there is therefore no requirement for the likelihood surface to be smooth. Consequently neither of these two algorithms returns estimates of the Hessian matrix. Simulated annealing is more robust than Hooke-Jeeves and can find a global optimum where there are multiple optima, but needs about 2–3 times the number of iterations compared to the Hooke-Jeeves algorithm.

BFGS is a quasi-Newton optimization method that uses information about the gradient of the function at the current point to calculate the best direction in which 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-Jeeves algorithm. However the gradient search in BFGS is more accurate than the stepwise search of Hooke-Jeeves and may therefore give a more accurate estimate 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 optimization run, attempting to utilize the strengths of all. Simulated annealing is used first to attempt to reach the general area of a solution, followed by Hooke-Jeeves to rapidly home in on the local solution, and finally BFGS is used for fine-tuning the optimization. This procedure is repeated several times to attempt to avoid converging to a local optimum.

Likelihood weighting

The total objective function to be minimized is a weighted sum of the different components. Selection of the weights follows 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 (***rgadget***.*r-forge.r-project.org/*) which is written and maintained by B. Th. Elvarsson at MRI.

Conceptually the log-likelihood components can roughly be thought of as residual sums of squares (SS), and as such their variances can be estimated by dividing the SS concerned by the associated 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:

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

6) For each likelihood component, perform an optimization with the initial score for that component set to 10 000. Then estimate the residual variance using the resulting SS of that component divided by the effective number of datapoints, that is, all non-zero data-points.

7) 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 a 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 measurements for each yearly recruit. In general problems 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:

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

where t 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 referenced. The inverses of the estimated residual variances 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 golden redfish assessment in GADGET

Below is the description of the GADGET settings for the golden redfish assessment as accepted by WKREDMP 2014. Changes from the previous settings are described.

Age and length range and growth: In the assessment one cm length groups are used, 10.5–68.5 cm. The year is divided into two time-steps. The age range is five to 30 years, with the fish 30 years and older treated as a plus group. The length at recruitment (age 5) is estimated and mean growth is assumed to follow the von Bertalanffy growth function. Mean length at recruitment (age 5) was estimated separately for year classes before 1996, for year classes 1996–2000 and year classes 2001 and later. This was done to take into account increase in mean weight-at-age that has been observed since year class 1996. As selection to the survey and catches is size based, faster growth will lead to cohorts recruiting earlier to the surveys and the fisheries and hence, leading to overestimation if changed growth was not taken into account. Weight–length relationship is obtained from spring survey data. Before the 2012 assessment, age range in the model was 0–30 years old but the youngest age groups were excluded from the model as recruitment data were not considered usable in assessment due to changes in spatial distribution of recruits.

Natural Mortality (*M*): Natural mortality for this long-lived species is assumed to be low but has to be guessed like for most other stock. Since the 2012 assessment, *M* of all age groups, except the plus group, is 0.05 but 0.1 for the plus group. Before that *M* for 0 years old was 0.20 and then reducing gradually to 0.05 for age 5. *M* for age 5–29 was 0.05 but 0.1 for the plus group (30+). Changing *M* for ages 0–4 does not affect the results as they do not appear in the fisheries.

Time-Steps: The model starts in 1970 and the time-step is six months. The last tuning and catch data used are for the first half of the assessment year. Short-term predictions 5–8 years ahead are done with fixed effort and fixed catch. Landings data are available for all the period but biological data are scarce before 1985 and scarcer the further back in time we go. In the model all available data are used for tuning. One reason for starting the model so early is to have the burn in period of the model before the most important tuning data are sampled, but also try to have the time period comparable to the lifespan of the species.

Commercial Landings: The commercial landings are since the spring 2012 modelled as three fleets (Greenland, Iceland and the Faroese), each with selection patterns described by a logistic function and the total catch in tonnes specified for each six month period.

Surveys: Two surveys are used, the Icelandic Spring Survey (IS-SMB) and the German autumn groundfish survey in East Greenland waters (GER(GRL)-GFS-Q4). The indices are combined into one survey index.

The German autumn groundfish survey is conducted in the autumn (September–October) or 4–5 months earlier than the Icelandic Spring Survey (March) the following year. When the survey indices were combined, GER(GRL)-GFS-Q4 in year *y* was added to the IS-SMB conducted the year after (*y+1*). To compensate for growth during the period of 4–5 months that are between the surveys, one cm was added to the length of all fish caught in GER(GRL)-GFS-Q4. The length groups division used in the tuning are two cm length groups from 19 to 54 cm.

The combined surveys (1985-onwards) are modelled as one fleet with constant effort and a nonparametric selection pattern that is estimated for each length group.

In previous settings only the Icelandic Spring Survey (IS-SMB) was used.

General changes

Changes made in 2012

Some important changes have been done to the model setup in recent years, most of them due to problems with recruitment estimation but reasonably large year classes seen in recent years were not seen in Icelandic surveys as small fish. This has led to consistent underestimation of recruiting year classes in recent years.

Changes made in 2014

- Changes in growth, now modelled for three periods, before 1996 year class, 1996–2000 year class and 2001 and later year classes.
- Inclusion of the German Groundfish Survey in East Greenland waters (GER(GRL)-GFS-Q4). The survey biomass of the German survey at year *y* was added to the Icelandic spring survey the year after or *y+1*. The German survey did get half weight to avoid extrapolation to areas not surveyed, and hence reduce noise.
- Length range of tuning data 19–54 cm.

In addition development of the model has been ongoing. Among the things developed in 2011–2014 is the likelihood weighting that was changed somewhat in the latter half of 2012.

Current setup

Data/constraints used in the objective function to be minimized are as follows:

Data used for tuning are:

- Length distributions from the commercial catches (Greenland, Iceland and the Faroese) and the surveys (the Icelandic Spring survey (IS-SMB) and German Groundfish Survey in East Greenland combined) in two cm length groups, using multinomial likelihood functions.
- Length disaggregated survey indices in two cm length group 19–54 cm using lognormal errors.
- Age–length keys and mean length-at-age from the Icelandic groundfish survey in October (IS-SMH): 1996–recent year. Based on two cm length groups using multinomial likelihood function.

- Age–length keys and mean length-at-age from the Icelandic commercial catch 1995–recent year. Based on two cm length groups using multinomial likelihood function.
- Mean length-at-age in IS-SMH. Based on sum of squares.
- Mean length-at-age in Icelandic commercial catches. Based on sum of squares.
- Landings by six month period.
- Understocking, i.e. too small biomass to cover the specified catch in tonnes.
- Bounds, a penalty function restricting the optimizing algorithms to the bounds specified for the estimated parameters.

The total objective function to be minimized is a weighted sum of the different components. Understocking and bounds are zero in the final solution they are only tools for guidance during the optimization process. Weights for the various log-likelihood components are assigned according to the reweighting procedure described above.

The parameters estimated are:

- The number of fish when simulation starts.
- Recruitment each year.
- Two parameters for the growth equation.
- Parameter β of the beta-binomial distribution controlling the spread of the length distributions.
- The selection pattern of the commercial catches. Two parameters for each fleet.
- Average size at recruitment. Three parameters estimated separately for year classes before the 1996 year class, year classes 1996–2000 and year classes 2001 and onwards.

The estimation can be difficult because some groups of parameters are correlated, and therefore the possibility of multiple optima cannot be excluded.

Description	Period	Half–year	Area	Likelihood component
Length distribution of landings	1970+	YES	Iceland East Greenland Faroese	ldist.catch
Combined survey length distribution of IS-SMB and GER(GRL)-GFS-Q4	1985+	-	Iceland East Greenland	ldist.survey
Abundace index of IS-SMB and GER(GRL)-GFS-Q4 of 19–24 cm individuals	1985+	-	Iceland	si1924
Abundace index of IS-SMB and GER(GRL)-GFS-Q4 of 25–54 cm individuals	1985+	-	Iceland	si2524
Age–length key of the landings	1995+	-	Iceland	alkeys.catch

Age–length key of the IS-SMH	1996+	-	Iceland	alkeys.survey
Mean length by age of landings	1995+	-	Iceland	meanl.catch

The **diagnostics** considered when reviewing the model's results are:

- Likelihood profiles plot. To analyse convergence and check for problematic parameters.
- Plots comparing observed and modelled proportions by fleet (catches). To analyse how estimated population abundance and exploitation pattern fits observed proportions.
- Plots of residuals in catchability models. To analyse precision and bias in abundance trends.
- Retrospective analysis. To analyse how additional data affects the historical predictions of the model.

Model setup

This file contains some information about the GADGET setup for golden redfish.

The selected base run is stored in the directory Baserun2014_2019. The most important files are:

TIME (first and last year of simulation and the number of time-step). Last year's file looked like. (In GADGET; means comment in similar way as # is used in R. # is on the other hand used to identify estimated variable in GADGET.)

```
;Optimisation  Time file for the redfish example in 2013 assessment
;
firstyear      1970
firststep      1
lastyear       2013
laststep       1
notimesteps    2 6 6
;
```

The simulation time ends in first half of the assessment year to be able to use the tuning data in that quarter (Icelandic Spring survey). Catches in the first half of the assessment year are gestimated and part of the input to the model.

Another time file **TIME.SIMU** is used for prognosis six years ahead.

```
;
; Simulation Time file for the redfish example
;
firstyear      1970
firststep      1
lastyear       2019
laststep       2
notimesteps    2 6 6
;
```

The final year in those file is incremented by 1 each year.

AREA is a file required by the program. The file contains size of each area and temperature. These data are not needed in the redfish example so the values in this file do not matter, but the file must be there with the right "number of numbers". This file is in the directory and does not need to be updated.

Description of the stock is in the file **SMARINUS** and that file is not changed between years while same settings are used.

Three files are with the name **sebmar.rec, sebmar.init** and **sebrefw.dat** are stored in the directory InitFiles. Of those sebmar.rec is the only one that needs to be changed each assessment year.

Initial conditions are stored in the file **sebmar.init**. In this file there are ten estimated parameters but the data are not sufficient to estimate the number in each age group in 1970. This file will not be changed annually if the assessment settings are not changed.

The file **sebrefwt.dat** stores the length–weight relationship used in the simulations.

The file **sebmar.rec** contains information about recruitment. Recruitment is at age 5 in step 1. Recruitment is estimated for each year from 1970. Mean length-at-age is estimated separately for three time periods, 1970–2000, 2001–2005 and 2006 onwards. The last year class estimated is the year class that is eight years old in the assessment year. In the 2013 assessment year it is the year class 2005. In simulations other year classes are assumed as average (the name of the switch is #**recfuture** and the average value **0.8** and the minimum over five years is **0.45**). Assumptions about these year classes do not have much effect on the advice but substantial on short-term simulations (six years). Next year the first line with #**recfuture** will be replaced with #**rec2011**. Every year possible changes in growth should be investigated. This investigation is similar to checking if selection pattern has changed in separable age-based model but changes in growth do often lead to change in selection by age.

The file **FLEET** in the top directory describes the fleets catching the fish. Each fleet has a type, specified catches in kg (totalfleet) or specified effort (linearfleet). Each fleet also has a name, selection function and a multiplier that can be used to scale up or down the effort or catches. Data files where catch or effort data are stored are also specified.

The directory **DataFiles** contains a number of files that will all have to be changed (or appended) every year. The files are:

FarCommLD.dat
IceCommLD.dat
GreenCommLD.dat
sebmar.meanlength.catch
fleet.data
IceMarGrlOctIndices.dat
sebmar.meanlength.surveys
fleet.predict
IceMarGrlOctLdr.dat
sebmar.surveys.alkeys
sebmar.catch.alkeys

The files **IceMarGrlOctIndices.dat** and **IceMarGrlOctLdr.dat** contain the combined survey indices for Iceland and Greenland. The difference between those files is just one column with the fleet name that is not in **IceMarGrlOctIndices.dat.** These files describe the use of the same data in two different ways.

All of the files in the **DataFiles** directory can be read in **R** with the command

read.table(file,comment.char=";")

fleet.data contains the catch per time period and fleet. There are four fleets defined, three commercial fleets and one survey, contains the landings in kgs per time-step (six months).

The three commercial fleets (column 4) used in this assessment are **Faroe, Greenland, Iceland.** The last catch data of those fleets are in the first half of the assessment year. The catch after that should be zero. A missing line is interpreted as 0. Each year, catch for the year before the assessment year is entered. The catch for the first half is already there, but as it was an estimate it has to be updated. An estimate for the first half of the assessment year will then be added. The exact division between the year halves does not matter as long as the total catches are correct.

The fourth fleet is the survey **IcelandMarchSurvey** with small amount caught every time-step (10 tons). When the Greenland survey data are added the fleet is still called **IcelandMarchSurvey**. Nothing needs to be changed for **IcelandMarchSurvey** for the next six years in the file **fleet.data**.

The file **fleet.predict** contains information about prediction with fixed effort. The effort is one but a multiplier is specified in the file **FLEET** in the top directory. There it is also specified that the fleet future is with specified effort and is called **linearfleet** but the others where the catch is specified are called **totalfleet**. The proposed HCR corresponds to the multiplier being *0.127.* Care should be taken to have the effort 0 in all time intervals where commercial catch in kg is given, **step 1 2013** and earlier in the **2013** assessment.

Other files in the folder **DataFiles** are likelihood data, all of them specified in the file **LIKELIHOOD** in the base directory where they are related to certain likelihood types (penalty, understocking, surveyindices, catchdistribution, catchstatistics). So-called aggregation files specify how the data are aggregated. Possible methods for aggregation are large, both across lengths, ages and areas. For example, the length distribution from the Icelandic commercial fleet, the file **LIKELIHOOD** looks like:

[component]
name Ice.CommLD
weight 0.0421227197
type catchdistribution
datafile DataFiles/IceCommLD.dat
function multinomial
overconsumption 1
minimumprobability 20
areaaggfile AggFiles/allarea.agg
ageaggfile AggFiles/allage.agg
lenaggfile AggFiles/len.agg
fleetnames Iceland
stocknames sebmar
;

Below are few lines from the file **IceCommLD.dat**. Order does not matter in that file

2011	**1**	**allareas**	**allages**	**len19–20**	**2**
2012	**1**	**allareas**	**allages**	**len19–20**	**22**

What does len19–20 and allages mean? For that we look at the files **AggFiles/allage.agg** and **AggFiles/len.agg**

allage.agg

.agg

;

; Age aggregation file - all ages aggregated together

;

allages 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

len.agg one line

;name	*minl*	*maxl*
len19–20	*18.5*	*20.5*

The number **weight** is what is later changed by the reweighting algorithm.

Generation of the likelihood data files will not be described here but the Icelandic data are generated by **R** scripts accessing the Icelandic databases. The German survey data from East Greenland are provided on cm basis for every station. Generation of the data file is just summing up available length and age measurements by length, age, and time interval, compiling survey indices by length or calculating mean length-at-age, standard deviation and number of aged fishes per age group and time interval. The only complication in the generation of likelihood data is the combination of the survey indices from Iceland and Greenland. Generally compiling data for GADGET is simpler than calculating, catch in numbers per age and survey indices by age.

After running the program large number of files will be generated as specified in **PRINTFILE**. The **rgadget** library (http://r-forge.r-project.org/projects/rgadget/) has a number of functions to read and plot these files.

The last thing to be done before starting a new run is to add the switch corresponding to the most recruitment to the most recent parameter file. This step can also be skipped but then the parameter starts with the value 0 and wide bounds, for example from **-9999** to **9999**. The negative bound might become a problem in optimization so setting the line in manually is recommended. Not starting from the best solution from the last year is recommended procedure if time allows. This can be achieved by randomly changing some of the value in the starting parameter file (**params.in** is the default name).

The order of things is as follows.

- Set up the data and likelihood files.
- Run the model with the final parameter file from last year *gadget -s -i params.final*.
- Look at the file *params.out* generated in each gadget run. If the data entered are correct the likelihood value (line 2) in *params.out* should not have increased by more than 50%.
- Copy *params.final* to *params.in*. Add the line with the most recent recruitment.
- Run the reweighing script. See below this list.
- Copy the file params.final from the **WGTS** directory and change #**recfuture** to the average value (0.8). Change the multiplier of the future fleet in the file FLEET to 0.127.

- Run the simulations with *gadget -s -i params.final -main main.simu*. The catch obtained for the year after the assessment year is the advice for that year.
- Plot results.

In reweighting data from the same source are combined so the command used is:

grouping<-
list(sind=c("si1924","si2548"),survey=c("alkeys.sur","IceSurMar.LD","meanl.sur"),comm=
c("Ice.CommLD","meanl.catch","alkeys.catch"),foreign=c("Far.Co

mmLD","Green.CommLD"))

gadget.iterative(rew.sI=TRUE,grouping=grouping)

gadget.iterative is obtained from the rgadget package.

D. Short-Term Projection

Short and medium-term forecasts for golden redfish in 5.a and 14 can be obtained from GADGET using the settings described below.

Model used: Age–length forward projection

Software used: GADGET (script: run.sh)

Initial stock size: abundance-at-age and mean length for ages 5 to 30+

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 and selection by size

Exploitation pattern:

Landings: logistic selection parameters estimated by GADGET for the Icelandic fleet.

Intermediate year assumptions: First half, TAC constraint based on the TAC left from last year. Second half, F according to the Harvest Control Rule

Stock–recruitment model used: None

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

E. Medium-Term Projections

See Section D.

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 by size

F and M before spawning: NA

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

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 for the Icelandic commercial fleet

Procedures used for splitting projected catches:

Driven by selection functions and provided by GADGET.

Yield-per-recruit is calculated by following one year class started at age 5 in 2002 of million fishes for 53 years through the fisheries calculating total yield from the year class as function of fishing mortality of fully recruited fish. Yield-per-recruit is then the total amount caught divided by the initial number of fish at age 5. 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.

G. Biological Reference Points

Investigation of spawning stock–recruitment data do not show any apparent relationship from 1975–2003 that is approximately the period where reasonable estimates on those data can be obtained. Therefore B_{loss} was suggested in 2012 as candidate for B_{lim}. Then B_{loss} was 160 thousand tonnes that while it is now closer to 150 thousand tonnes due to changes in parameter settings. Still the proposed B_{lim} is 160 thousand tonnes, but will be revisited is changes are done to the assessment that lead to major change in stock size. (Changes in M).

$B_{trigger}$ was defined as 220 thousand tonnes in 2012 (160*exp(0.2*1.645)) where 0.2 was at that time estimated standard error of the biomass in the assessment year from a TSA assessment. This point does not have any biological meaning, it is just a trigger point in the harvest control rule and according to the simulations probability of SSB $<B_{trigger}$ should be low and in the simulations the trigger action is not included but it will lead small reduction in average fishing mortality. Without any $B_{trigger}$ the probability of SSB $<B_{lim}$ is still very low (<1%). Long periods of poor recruitment (not observed in those 30 years where data on recruitment are available) would be the scenario most likely leading to SSB $<B_{trigger}$. 30 years is short time for redfish so things not seen there are relatively likely to happen in the near future.

I. References

Ansley, C.F. and Kohn, R. 1986. Prediction mean squared error for state space models with estimated parameters. Biometrica, 73, 467–473.

Begley, J., and Howell, D. 2004. An overview of Gadget, the Globally applicable Area-Disaggregated General Ecosystem Toolbox. ICES C.M. 2004/FF:13, 15 pp.

Bertsekas, D. 1999. Nonlinear programming. Athena Scientific, 2nd edition.

Björnsson, H. And Sigurdsson, T. 2003. Assessment of golden redfish (*Sebastes marinus* L.) in Icelandic waters. Scientica Marina, 67 (Suppl. 1): 301:304.

Björnsson, Höskuldur, Jón Sólmundsson, Kristján Kristinsson, Björn Ævarr Steinarsson, Einar Hjörleifsson, Einar Jónsson, Jónbjörn Pálsson, Ólafur K. Pálsson, Valur Bogason and Þorsteinn Sigurðsson. 2007. The Icelandic groundfish surveys in March 1985–2006 and in October 1996–2006 (*in Icelandic with English abstract*). Marine Research Institute, Report 131: 220 pp.

Corona, A., M. Marchesi, M. Martini, and S. Ridella. 1987. Minimizing Multimodal Functions of Continuous Variables with the Simulated Annealing Algorithm. ACM Trans. Math. Software, 13(3): 262–280.

Einarsson, H. 1960. The fry of *Sebastes* in Icelandic waters and adjacent seas. Journal of the Marine Research Institute 2(7): 68 pp.

Fock, H. 2011. Abundance and length composition for *Sebastes marinus* L., deep sea *S. mentella* and juvenile redfish (*Sebastes* spp.) off Greenland based on groundfish surveys 1985–2010. ICES NWWG 2011: WD 16.

Frøysa, K. G., Bogstad, B., and Skagen, D. W. 2002. Fleksibest -an age–length structured fish stock assessment tool with application to Northeast Arctic cod (*Gadus morhua* L.). Fisheries Research, 55: 87–101.

Gudmundsson, G. 1994. Time-series analysis of catch-at-age observations. Applied Statistics 43 (1), 117–126.

Gudmundsson, G. 1995. Time-series analysis of catch-at-length data. ICES Journal of Marine Science, 52, 781–795.

Gudmundsson, G. 2004. Time-series analysis of abundance indices of young fish. ICES Journal of Marine Science, 61, 176–183.

Gudmundsson, G. 2005. Stochastic growth. Can. J. Fish. Aquat. Sci. 62, 1746–1755.

Harvey, A.C. 1989. Forecasting structural time-series models and the Kalman filter. Cambridge University Press, Cambridge UK

Hedeholm R. and Boje J. 2011. Survey results for Redfish in East Greenland offshore waters in 2008–2010. ICES NWWG WD#9.

Hendry, D. F., and Krolzig, H.-M. 2005. The properties of automatic Gets modelling. Economic Journal, 115, C32–C61.

Hooke, R. and Jeeves, T.A. 1961. 'Direct search' solution of numerical and statistical problems. Journal of the Association for Computing Machinery 8 (2): 212–229.

ICES. 1983. Report on the NAFO/ICES Study Group on biological relationships of the West Greenland and Irminger Sea redfish stocks. ICES CM 1983/G:3, 11 pp.

ICES. 1995. Report of the North Western Working Group (NWWG). ICES CM 1995/Asess:19, 361 pp.

ICES. 2011. Report of the North Western Working Group (NWWG). ICES CM 2011/ACOM:7, 975 pp.

Jónsson, G. and Pálsson, J. 2006. Icelandic fishes (*in Icelandic*). Vaka-Helgafell, Reykjavík, Iceland.

Magnússon, J. and Magnússon, J.V. 1975. On the distribution and abundance of young redfish at Iceland 1974. Journal of the Marine Research Institute 5(3): 22 pp.

Marine Research Institute. 2010. Manuals for the Icelandic bottom trawl surveys in spring and autumn (*edt.* Jón Sólmundsson and Kristján Kristinsson). Marine Research in Iceland, Report Series no. 156.

Nielsen, H.B. 2000. UCMINF- An algorithm for unconstrained nonlinear optimization. Technical Report, IMM-REP-2000-19.

Pálsson, Ó. K. 1983. The feeding habits of demersal fish species in Icelandic waters. Journal of the Marine Research Institute 7(1): 60 pp.

Pálsson, Ó. K. 1984. Studies on recruitment of cod and haddock in Icelandic waters. ICES CM 1984/G:6, 16p.

Pálsson, Ó. K., Jónsson, E. Schopka, S. A., and Stefánsson, G. 1989. Icelandic groundfish survey data used to improve precision in stock assessments. Journal of Northwest Atlantic Fishery Science, 9: 53–72.

Pálsson, Ó. K., Björnsson H., Björnsson E., Jóhannesson G., and Ottesen, Þ. 2010. Discards in demersal Icelandic fisheries 2010. (*In Icelandic with English abstract*). Marine Research Institute, Report series no. 154.

Rätz, H.-J. 1999. Structures and changes of the demersal fish assemblage off Greenland, 1982–1996. NAFO Sci. Coun. Studies, 32: 1–15.

Saville, A. 1977. Survey methods of appraising fishery resources. FAO Fisheries Technical Paper 171. 81 pp.

Schopka, S. A. 2007. Area closures in Icelandic waters and the real-time closure system. A historical review. (*In Icelandic with English abstract*). Marine Research Institute, Report 133: 86 pp.

Sünksen, K. 2007. Discarded by-catch in shrimp fisheries in Greenlandic offshore waters 2006–2007. NAFO SCR doc. 07/88.

Taylor, L., Begley, J., Kupca, V. and Stefánsson, G. 2007. A simple implementation of the statistical modelling framework Gadget for cod in Icelandic waters. African Journal of Marine Science, 29:223–245.

Table A.2.1. Number of quick closures on golden redfish in Icelandic waters 1991–2011. See text for further description.

Year	Number of Closures
1991	1
1992	1
1993	2
1994	8
1995	3
1996	0
1997	0
1998	3
1999	6
2000	12
2001	3
2002	3
2003	1
2004	1
2005	6
2006	3
2007	4
2008	5
2009	2
2010	2
2011	2
Total	68

Table B.1.2.1. Biological sampling of golden redfish from the commercial catch in Icelandic waters 1995–2011. The table shows number of samples, how many individuals were sampled for length measurement and age determination.

	Length Measurements		Age Determination	
Year	# Samples	# Measured	# Samples	# Age Read
1995	177	38,403	7	596
1996	100	19,747	3	209
1997	172	38,990	23	1424
1998	174	35,336	26	1404
1999	253	52,407	37	1218
2000	323	73,965	49	1611
2001	269	52,833	46	1600
2002	341	62,926	48	1627
2003	260	45,568	48	1676
2004	219	35,741	48	1669
2005	434	71,681	44	1629
2006	336	52,873	46	1681
2007	311	49,673	45	1723
2008	327	47,122	48	1704
2009	283	46,995	52	1838
2010	328	56,807	47	1721

Table B.3.1. Vessels used in the Autumn Groundfish Survey in ICES Division Va, their survey area, and the number of station taken.

Year	Shallow waters		Deep waters		Total stations
	Vessel name	No.Stations	Vessel name	No.Stations	
1996	r/v Bjarni Sæmundsson	146	Múlaberg ÓF32	144	290
1997	r/v Bjarni Sæmundsson	150	Brettingur NS50	149	299
1998	r/v Bjarni Sæmundsson	153	Brettingur NS50	144	297
1999	r/v Bjarni Sæmundsson	166	Brettingur NS50	149	315
2000	r/v Bjarni Sæmundsson	163	r/v Árni Friðriksson	219	382
2001	r/v Bjarni Sæmundsson	161	r/v Árni Friðriksson	219	380
2002	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	221	383
2003	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	220	382
2004	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	220	382
2005	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2006	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2007	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2008	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2009	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	219	381
2010	r/v Bjarni Sæmundsson	162	r/v Árni Friðriksson	203	365

Table B.3.2. The survey area (nm^2) based on the old stratification (used up to 2012) in the German Greenland groundfish Survey by stratum (see Figure B.3.12).

	Depthstrata (m)	Area (nm2)
1.1	1–200	6805
1.2	201–400	1881
2.1	1–200	2350
2.2	201–400	1018
3.1	1–200	1938
3.2	201–400	742
4.1	1–200	2568
4.2	201–400	971
5.1	1–200	2468
5.2	201–400	3126
6.1	1–200	1120
6.2	201–400	7795
7.1	1–200	92
7.2	201–400	4589
Total		37 463

Table B.3.3. The survey area (nm²) based on the new stratification (applied in 2013) in the German Greenland groundfish Survey by stratum (see Figure B.3.13).

In West GLD stratification equals NAFO stratification, in East GLD based on assignment to ICES rectangles, therefore geographic boundaries given as ca. values.

Stratum	boundaries				depth	area
	south	north	east	west	(m)	(nm²)
1.1	64°15'N	67°00'N	50°00'W	57°00'W	1–200	6805
1.2	64°15'N	67°00'N	50°00'W	57°00'W	201–400	1881
2.1	62°30'N	64°15'N	50°00'W	55°00'W	1–200	2350
2.2	62°30'N	64°15'N	50°00'W	55°00'W	201–400	1018
3.1	60°45'N	62°30'N	48°00'W	53°00'W	1–200	1938
3.2	60°45'N	62°30'N	48°00'W	53°00'W	201–400	742
4.1	59°00'N	60°45'N	44°00'W	50°00'W	1–200	2568
4.2	59°00'N	60°45'N	44°00'W	50°00'W	201–400	971
5&6.1	59°00'N	ca 63°50'N	40°00'W	44°00'W	1–200	1562
5&6.2	59°00'N	ca 63°50'N	40°00'W	44°00'W	201–400	2691
7.1	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1–200	298
7.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	4615
ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	1-200	49	
8.2	ca 63°50'N	66°00'N	ca 33°00'W	41°00'W	201–400	2173
9.1	64°45'N	67°00'N	29°00'W	33°00'W	1–200	0
9.2	64°45'N	67°00'N	29°00'W	33°00'W	201–400	1946
Sum						31 607

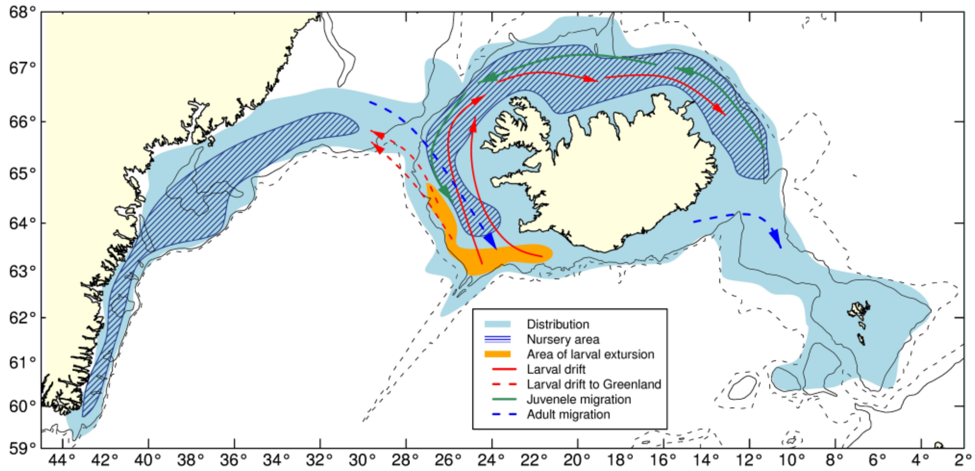

Figure A.1.1. Geographic range of golden redfish (*Sebastes norvegicus*) in East Greenland, Icelandic and Faroese waters, area of larval extrusion, larval drift and possible migration routes. The solid and dashed lines indicate the 500 m and 1000 m depth contour respectively.

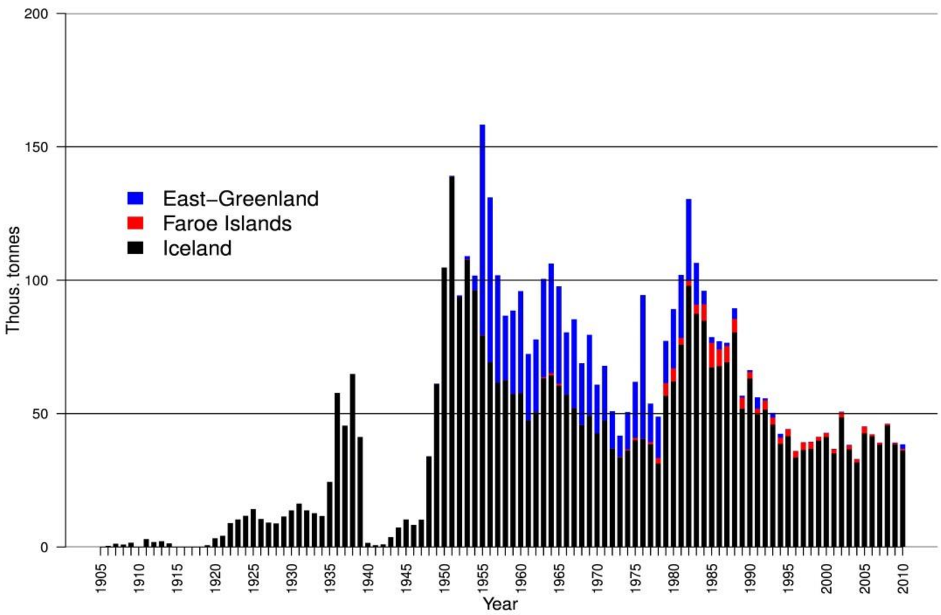

Figure A.2.1. Nominal landings (in tonnes) of golden redfish from Icelandic waters (ICES Division Va), Faroese waters (ICES Division Vb) and East-Greenland waters (ICES Division X

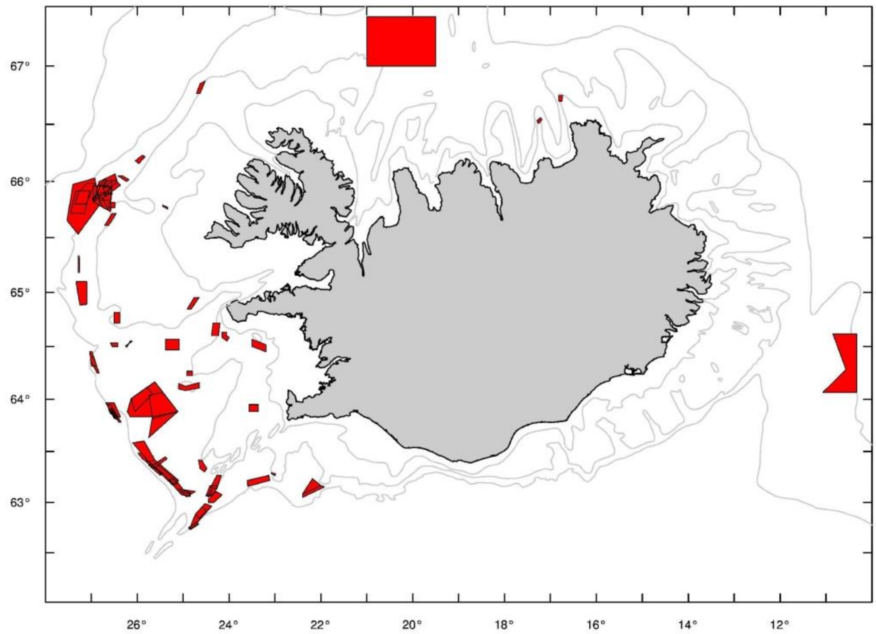

Figure A.2.2. Schematic overview of quick closures on golden redfish in Icelandic waters (ICES Division Va) 1991–2011.

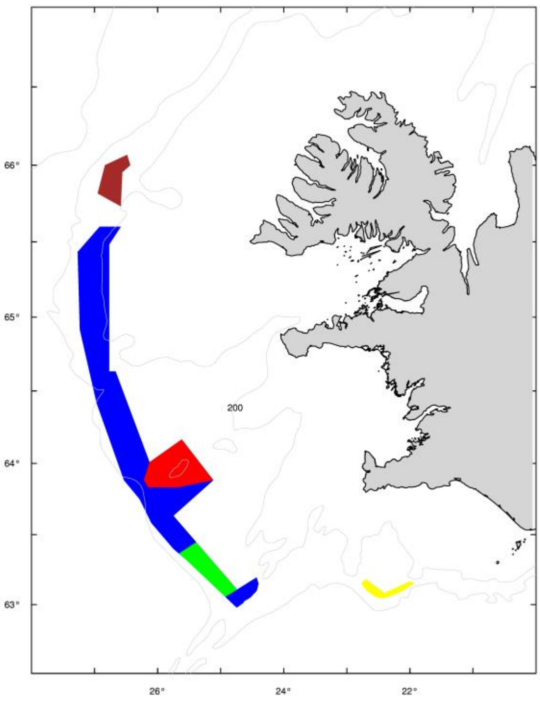

Figure A.2.3. Schematic overview of closed areas for protection of juvenile *S. norvegicus* in Icelandic waters (ICES Division Va). These areas are either closed permanently or temporarily. During closure bottom trawling is prohibited. The blue area is closed all year long; the red area is only open during the night or from 20:00–08:00 from October 1 to April 1 to allow fishing for saithe; the brown area is open for bottom trawling during the night or from 20:00 to 08:00; the green area is open for bottom trawling February 1 to April 15; the yellow area is closed for bottom-trawl fishery from June 1 to October 31.

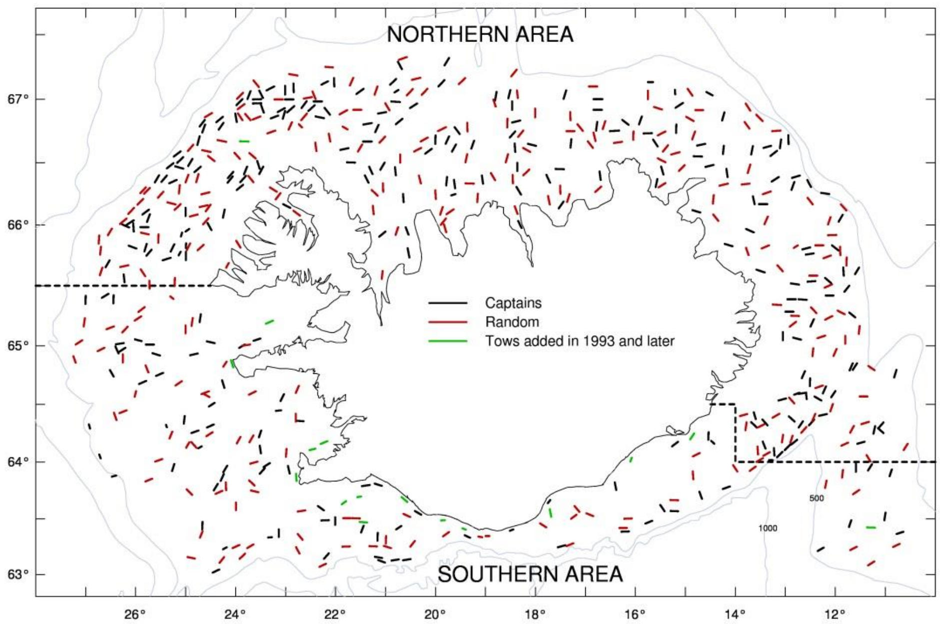

Figure B.3.1. Stations in the Spring Survey in March. Black lines indicate the tow-stations selected by captains of commercial trawlers, red lines are the tow-stations selected randomly, and green lines are the tow-stations that were added in 1993 or later. The broken black lines indicate the original division of the study area into Northern and Southern area. The 500 and 1000 m depth contours are shown.

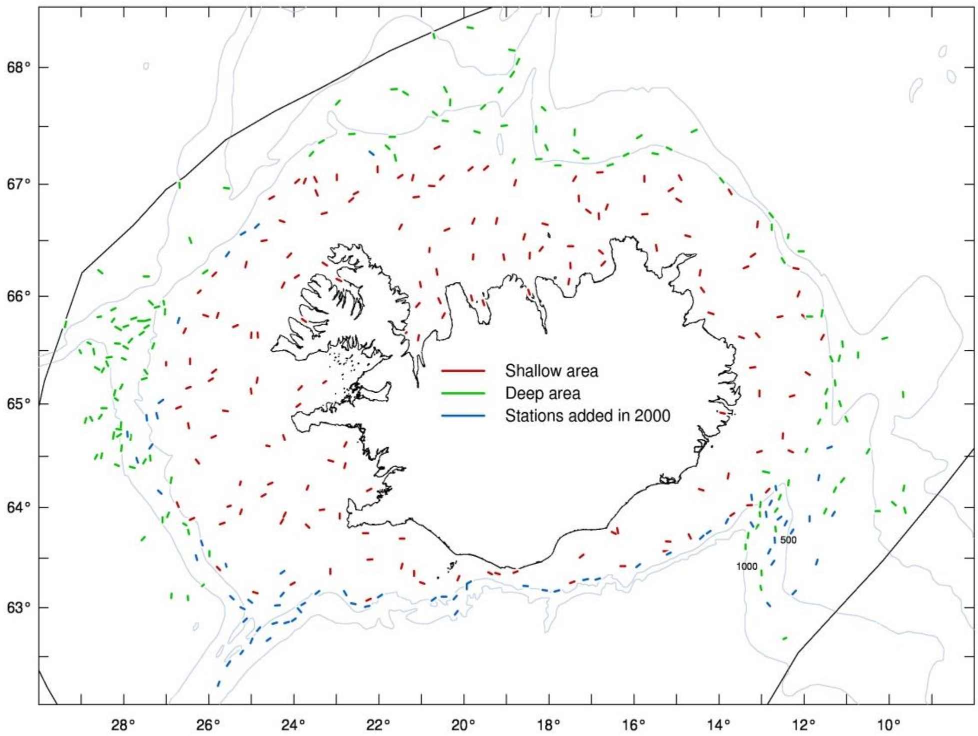

Figure B.3.2. Stations in the Autumn Groundfish Survey (AGS). RV "Bjarni Sæmundsson" takes stations in the shallow-water area (red lines) and RV "Árni Friðriksson" takes stations in the deep-water areas (green lines), the blue lines are stations added in 2000.

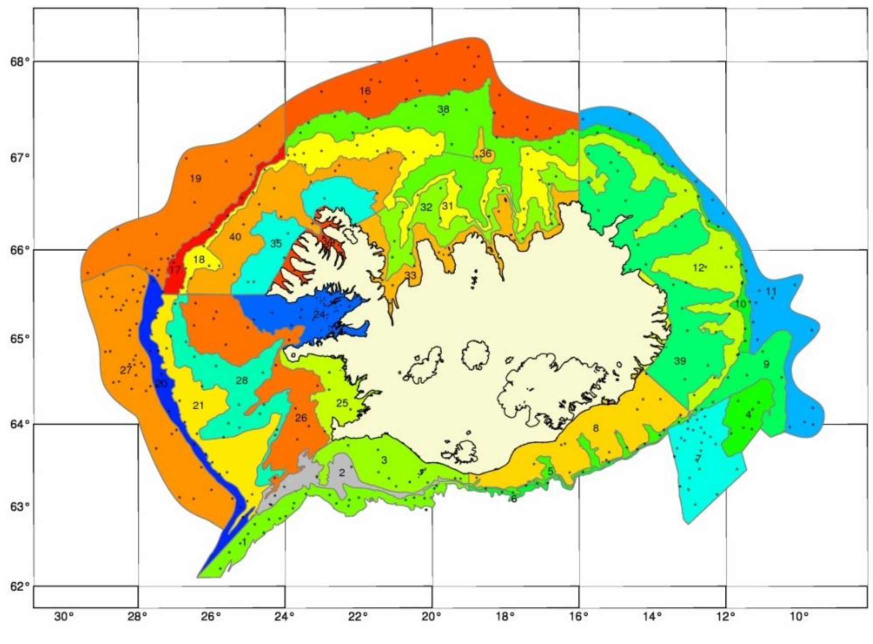

Figure B.3.3. Subareas or strata used for calculation of survey indices for golden redfish from the Autumn Survey in Icelandic waters. This stratification was applied in 2008.

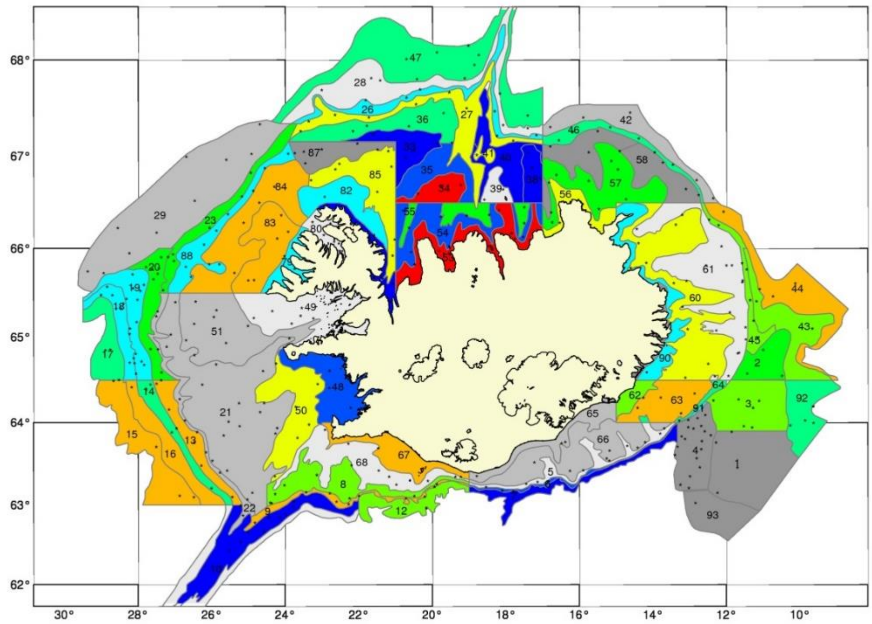

Figure B.3.4. The old stratification (before 2008) that was used for calculation of golden redfish indices from the Autumn Survey in Icelandic waters.

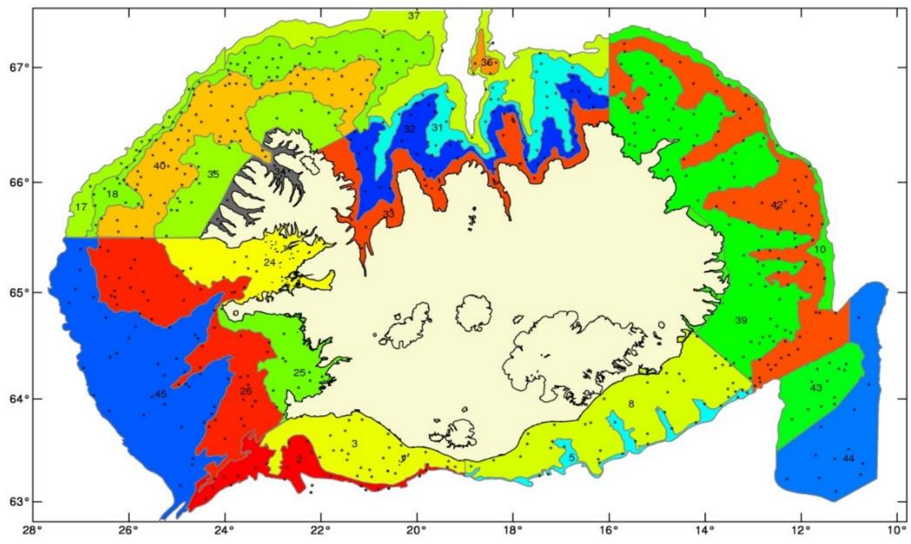

Figure B.3.5. Subareas or strata used for calculation of survey indices for golden redfish from the Spring Survey in Icelandic waters. This stratification was applied in 2011.

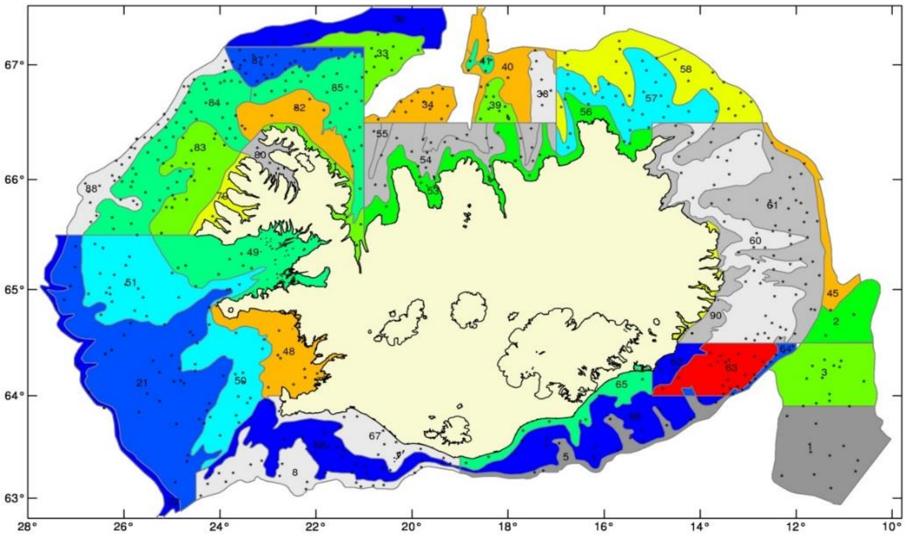

Figure B.3.6. The old stratification (before 2011) that was used for calculation of golden redfish indices from the Spring Survey in Icelandic waters.

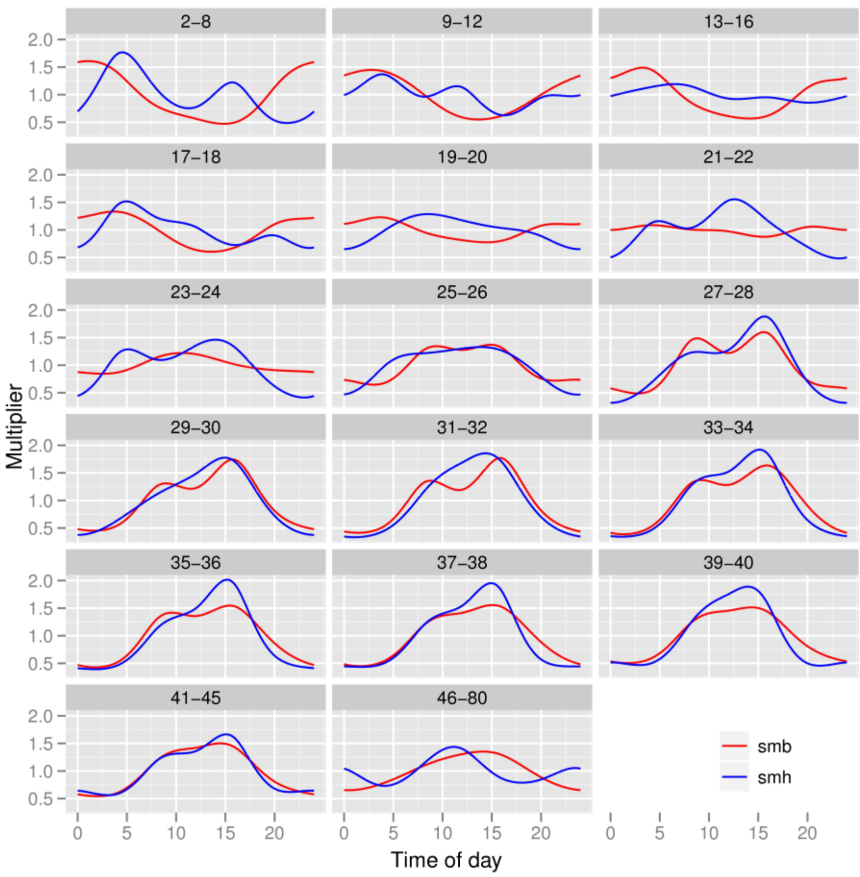

Figure B.3.7. Scaled multiplier for each length group in the Spring Survey (smb - red line) and the Autumn Survey (smh - blue line) based on the glm model with smoother applied to each length group.

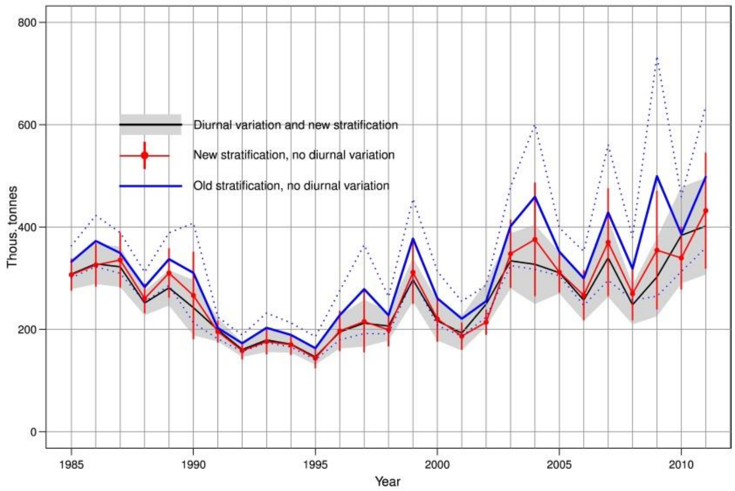

Figure B.3.8. Comparison in survey indices of golden redfish in the Spring Survey 1985–2011, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

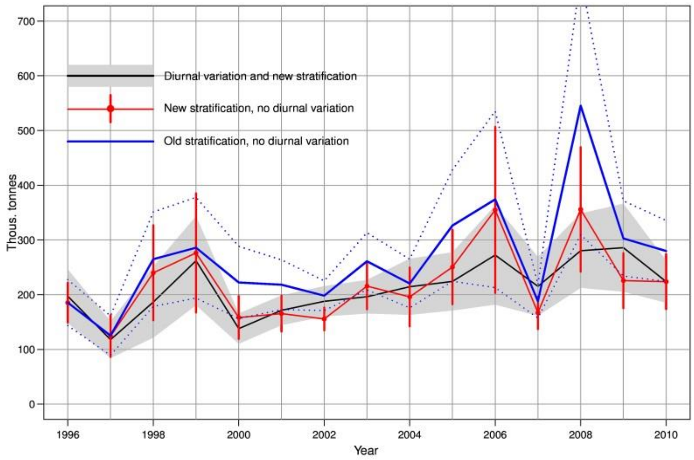

Figure B.3.9. Comparison in survey indices of golden redfish in the Autumn Survey 1996–2010, calculated using the new stratification scheme (Figure 3) with and without diurnal vertical migration, and the old stratification scheme (Figure 4).

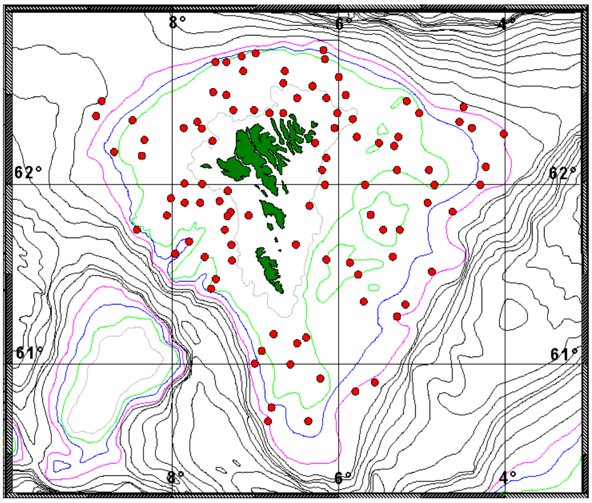

Figure B.3.10. Stations in the Spring Survey on the Faroe Plateau in March 2011.

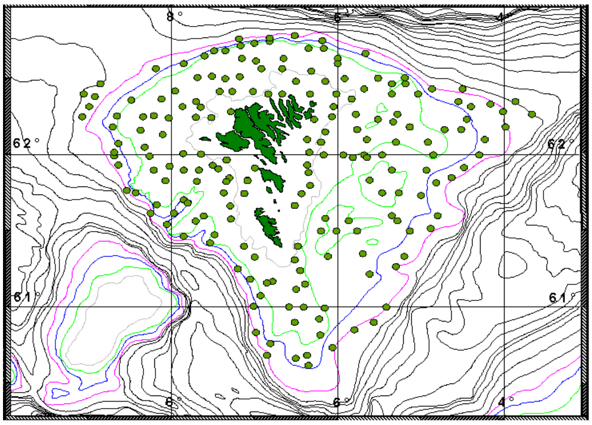

Figure B.3.11. Stations in the Summer Survey on the Faroe Plateau in August 2011.

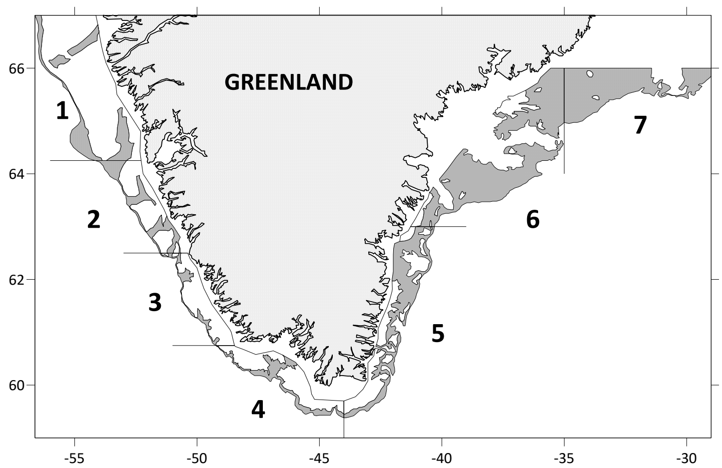

Figure B.3.12. Old stratification used for calculation of golden redfish survey indices of the German groundfish survey conducted on the Greenland shelf until 2012. Only strata off the East Greenland were used (strata 5–7).

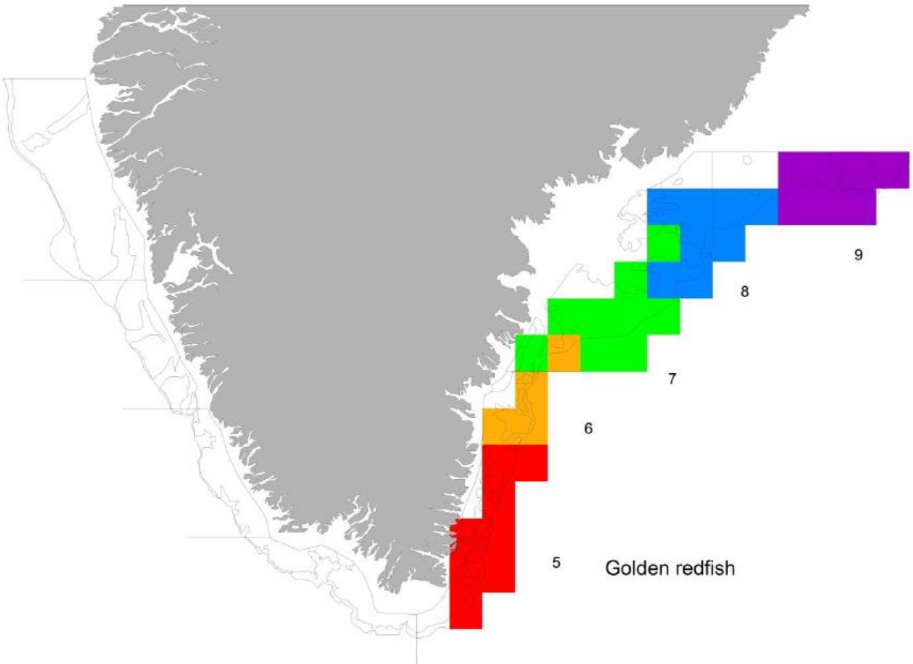

Figure B.3.13. The re-stratification in East Greenland undertaken in 2013. West Greenland strata remain unchanged. Each stratum is divided into two depth zones, 1–200 m and 201–400 m.

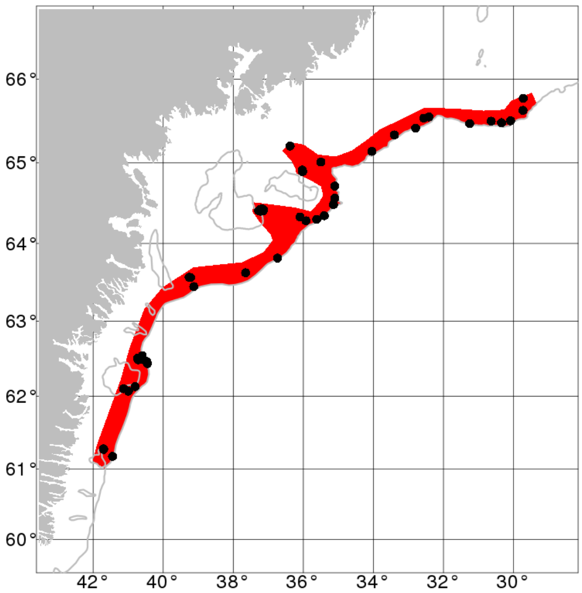

Figure B.3.14. The stratification of the German Survey conducted in East Greenland and used for calculation of survey indices of golden redfish to be used in the GADGET setup. The red area represents the proposed stratum (size = 22 500 km²) and the black points are the stations taken in the 2012 survey.