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Review of the fishery, biological research, assessment and management of Golden redfish (*Sebastes marinus*) in Icelandic waters

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Golden redfish (*Sebastes marinus*) is one of the most important fishery resources in Icelandic waters. It has been exploited since early 1920's, but it was not until after World War II that the fishery expanded. There were quickly signs of overfishing as redfish species are in general vulnerable to overfishing. In large part, their vulnerability is a product of their life history. A life history that is characterized by a long-lived, slow-growing, and late-maturing cycle. Available survey indices (since 1985) showed a decline in stock size until mid 1990's but a slow increase since then. With various protection measures and reduction in fishing effort since the mid 1990s the golden redfish stock is now considered within safe biological limits. We review the fishery of golden redfish, assessment, the status of the stock, advice, and the management. We also review the protection measures taken to protect juvenile redfish and the relationship of golden redfish between Icelandic and East-Greenland waters.

1. Introduction

Redfish species have been an important fishery resource in Icelandic waters and adjacent waters. There are three species exploited, i.e. golden redfish (*Sebastes marinus*), three stocks/management units of deep-water redfish (*S. mentella*), and Norway haddock (*S. viviparous*). One of the deep-waters redfish, named Icelandic slope stock, inhabits the demarsal habitats of the continental slope of Iceland. The other two stocks are found in the pelagic ocean of Irminger Sea and adjacent waters, including within the Icelandic 200 nautical miles EEZ, and are named shallow and deep pelagic stocks. There has been little fishing for *S. viviparous*, the smallest of the three species, although there has been some exploratory fishery in recent years, with the highest annual landings of 2,600 tonnes in 2010.

Historically, golden redfish has been the most important redfish species exploited in Icelandic waters and has been exploited since the early 1920s. It was not until after the Second World War that the redfish fishery expanded and at the same time the fishery for Icelandic slope deep-water redfish started. Deep-water redfish inhabits deeper water than golden redfish although those two species overlap to some extend in the depth distribution. There were quickly signs of overfishing of golden redfish as redfish is very vulnerable to overfishing. In large part, their vulnerability is a product of their life history. The life history is characterized by a long-lived, slow-growing, late-maturing cycle and low natural mortality. Such species can, therefore, only sustain low exploitation rate and a great deal of caution is needed when harvesting the stock. This is because recruitment to the fishable stock is slow.

In this paper we give an overview of the biology and ecology of golden redfish in Icelandic waters, its assessment, and status of the stock.

2. Geographical extent, stock definition and general biology

Golden redfish is found along the Norwegian coast up to Spitsbergen and in the western Barents Sea, in the northern North Sea, around Faeroe Islands and Iceland, along the Greenland coast, and along the North American east coast from Baffin Island and Labrador southward to the Flemish Cape, the Grand Banks and the Gulf of St. Lawrence (Tåning, 1949; Magnússon, 1956; Jónsson and Pálsson, 2006).

Golden redfish on the continental shelves of East-Greenland, Iceland and Faeroe Islands (EGIF) is considered one stock (ICES, 2011). There are at least two other stocks in the North Atlantic, i.e. in the Barents and Norwegian Seas and off the East coast of North America (Magnússon, 1956). 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 show however little genetic variation and that stock structure is complex (Nedreaas et al., 1994; Pampoulie et al., 2009).

The EGIF stock is most abundant in Icelandic waters 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 depth of 100-400 m. The main nursery areas are off East-Greenland and Iceland. No nursery grounds are known in the Faeroese waters (ICES, 1983; Einarsson, 1960; Magnússon and Magnússon, 1975; Pálsson et al., 1997).

Golden redfish is an ovoviviparous fish in which 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 fertilisation takes place in the ovary in winter (Raitt and Hall, 1967). Golden redfish produce many, small larvae (37-350 thousand larvae) that are extruded soon after they hatch from eggs and disperse widely as zooplankton (Einarsson, 1960; Magnússon, 1956; Jónsson and Pálsson, 2006).

Little is known about golden redfish breeding behaviour. Males mature in the autumn (September-January) when mating occurs (Magnússon, 1956). The eggs are fertilized in February-April, but mainly in March. Extrusion of larvae occurs in April-May. The main extrusion area is west and southwest of Iceland in the pelagic areas at depths from 200-550 m (Figure 2.1; Magnusson, 1980). Larval extrusion has also been observed south of Faroe Islands (ICES, 1983, but larval extrusion has not been observed in other areas, for example, along the east coast of Greenland.

Larvae are 5-7 mm at length when extruded and they remain in the pelagic areas for 4-5 months before the settle to the bottom. Larvae drift with general direction of currents west and north of Iceland and towards the shelf of East-Greenland (Figure 2.1; Einarsson, 1960; Manússon and Jóhannesson, 1997). In Icelandic waters, the nursery areas (golden redfish smaller than 30 cm) are found all around the country, but are mainly located off the west and along the north coast of Iceland at depths between 50 m and 350 m (Figure 2.1). As they grow, the juveniles migrate along the north coast towards the most important fishing areas the off the west and southwest coast, but also to the southeast fishing areas and to Faroese fishing grounds (Figure 2.1). There is a possible migration of golden redfish from East-Greenland back to Icelandic waters when they become mature (NWWG, 2011). However, the connection between these areas is unknown.

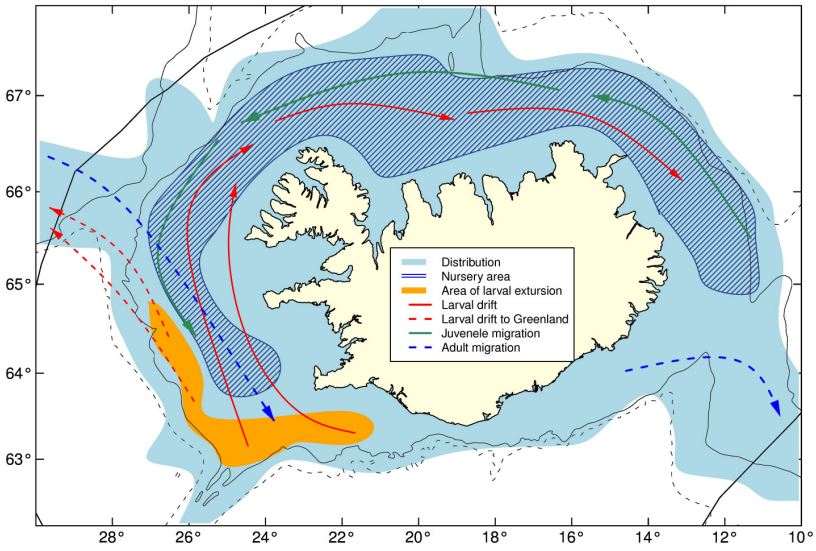

Fig. 2.1. Geographic range of golden redfish (*Sebastes marinus*) in Icelandic waters. The solid and dashed lines indicate the 500 m and 1000 m depth contour respectively.

Golden redfish is, as most redfish species, long-lived, slow-growing, and late maturing fish species with low natural mortality rate. Age determination of redfish has proven difficult (ICES, 1996; Stransky et al, 2005). Age determination of golden redfish shows, however, that it can reach more than 80 years (Nedreaas, 1990). Males mature both younger and smaller than females. On average, males mature at 31-33 cm length and 8-10 years, whereas females mature at the size of 35-38 cm at the age 10-14 years (Björnsson et al., 2007).

Based on the Icelandic grounfish survey in October, the growth rate of the redfish is about 2.5 cm per year in the first years but becomes slower thereafter. At age 6, the fish is on average around 20 cm and around 30 cm at age 10. However, there is a great variation in the growth between individuals (Björnsson and Sigurdsson, 2003).

The feeding habits of golden redfish are of pelagic nature and the food is dominated by plankton crustaceans (Pálsson, 1983). The main food item is Euphausids (krill), but other food includes Calanoida, Amphipods, and Calanoida (especially of smaller redfish). Golden redfish also feed on small fish species.

3. The fishery

Targeted fishery for golden redfish in Icelandic waters started in the early 1920s but was little until late 1930s when annual landings increased (Figure 3.1). 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. Little redfish fishery was conducted in Icelandic waters during World War II but increased rapidly after the war and to a record high of 167 thousand tonnes in 1951. At similar time exploitation of deep-sea redfish began on the continental shelf and slope of Iceland. Deep-sea redfish is found in deeper waters than golden redfish although there is some overlapping in the depth distribution. Reliable information on species composition in the redfish catches 1950-1965 is, however, limited as the catches of these two species were landed under the common name redfish.

Annual landings of golden redfish in 1956-1977 varied 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 of golden redfish declined from about 98,000 t in 1982 to 39,000 t in 1994 (Figure 3.1). Since then, landings have varied between 32,000 and 49,000 t. Average annual landings in 2000-2010 have been around 40,000 tonnes.

The fishery for golden redfish in Icelandic waters is predominantly conducted by the Icelandic bottom trawl fleet directed towards the species, and which accounts for more than 90% of the total catch. The remains are partly caught as by-catch in gillnet, long-line, and lobster fishery. Most of the catches are taken along the shelf west, southwest, and southeast of Iceland, mostly between 12°W and 27°W at depths between 200-450 m (Figure 3.2). More of the catch has in recent years been taken north-west of Iceland (Figure 3.2).

Golden redfish is fished all year around but the fishing is often best in the late winter.

The bottom trawl fishery for golden redfish is mainly a directed fishery. About 20-30% of the total catch is taken in mixed fishery, that is, in tows where golden redfish was less than 50% of the total catch. This means that 70-80% of the bottom trawl catch of golden redfish is a directed fishery. During the 2006-2010 period between 25-35% of the hauls were only golden redfish was caught.

The length distributions from the Icelandic commercial trawler fleet in 1955-1966 and 1975-2010 show that the majority of the fish caught is between 30 and 45 cm (Figure 3.3). The fish caught in 1955-1966 was on average larger than 1975-2010 and substantial amount of fish larger than 45 cm was caught. The modes of the length distributions for the past two decades ranged between 35 and 37 cm and much less were caught of fish larger than 45 cm compared to the 1950s and 1960s.

Catch-at-age data from the Icelandic fishery in Icelandic waters is available since 1995 and shows that the 1985-year class dominated the catches from 1995-2002 (Figure 3.4) and in 2002 this year class still contributed to about 25% of the total catch in weight. The strong 1990-year class dominated the catch in 2003-2007 contributing between 25-30% of the total catch in weight. This year class contributed about 14% of the total catch in weight in 2010 and the 1985-year class about 6%. The 1996-2001 year classes contributed in total about 40% of the total catch in 2010.

The average total mortality (Z), estimated from the catch-at-age data is about 0.23 for fish 15 years and older.

3.1 Discard

Comparison of sea and port samples from the discard sampling program does not indicate significant discard due to high grading in recent years (Pálsson et al., 2010), possibly due to area closures of important nursery grounds west off Iceland. Substantial discard of small redfish took place in the deepwater shrimp fishery prior to 1990 in Icelandic waters when sorting grids with bars spacing of 22 mm became mandatory (ICES, 2011). Since then the discard has been insignificant in the shrimp fishery due to the sorting grid, much less abundance of small redfish in the region, and less shrimp fishery.

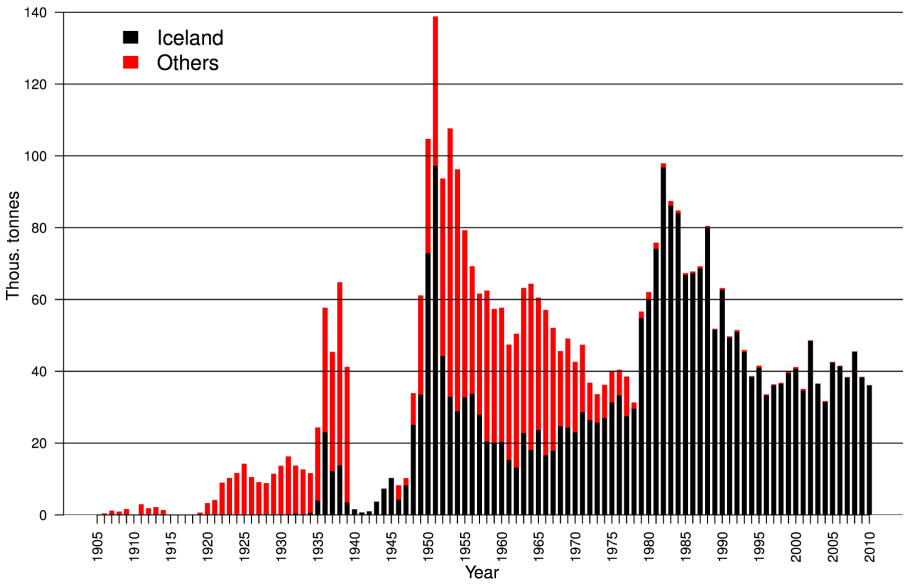

Figure 3.1. Nominal landings of golden redfish (*Sebastes marinus*) in tonnes in Icelandic waters 1906-2010.

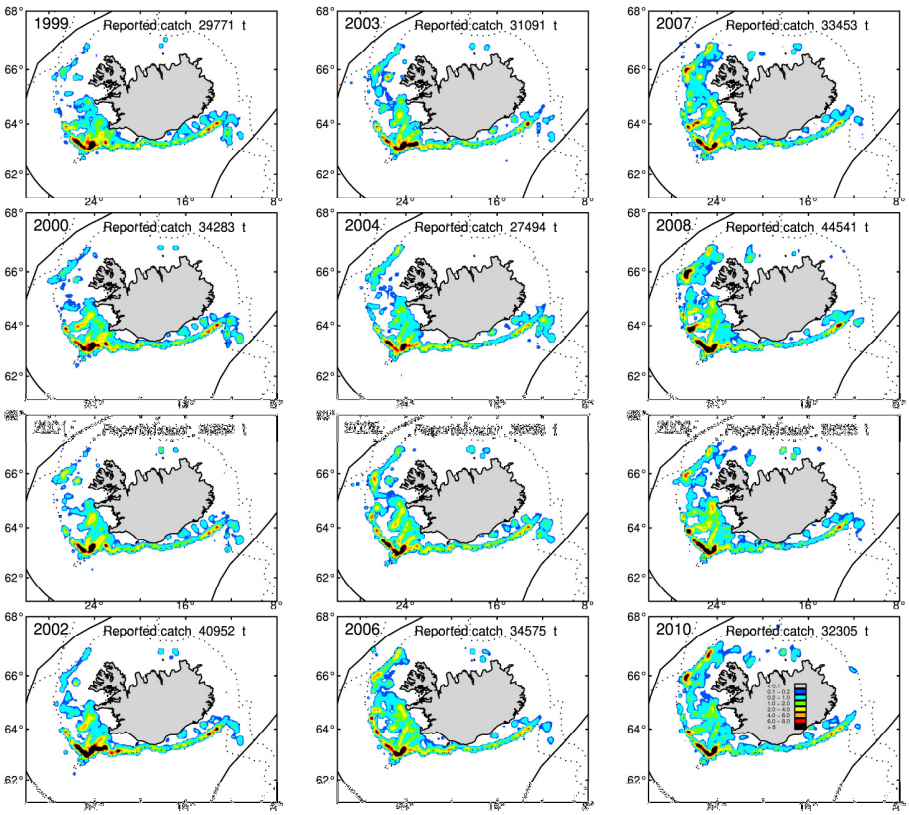

Figure 3.2. Geographical distribution of golden redfish catches in Icelandic waters 1999-2010.

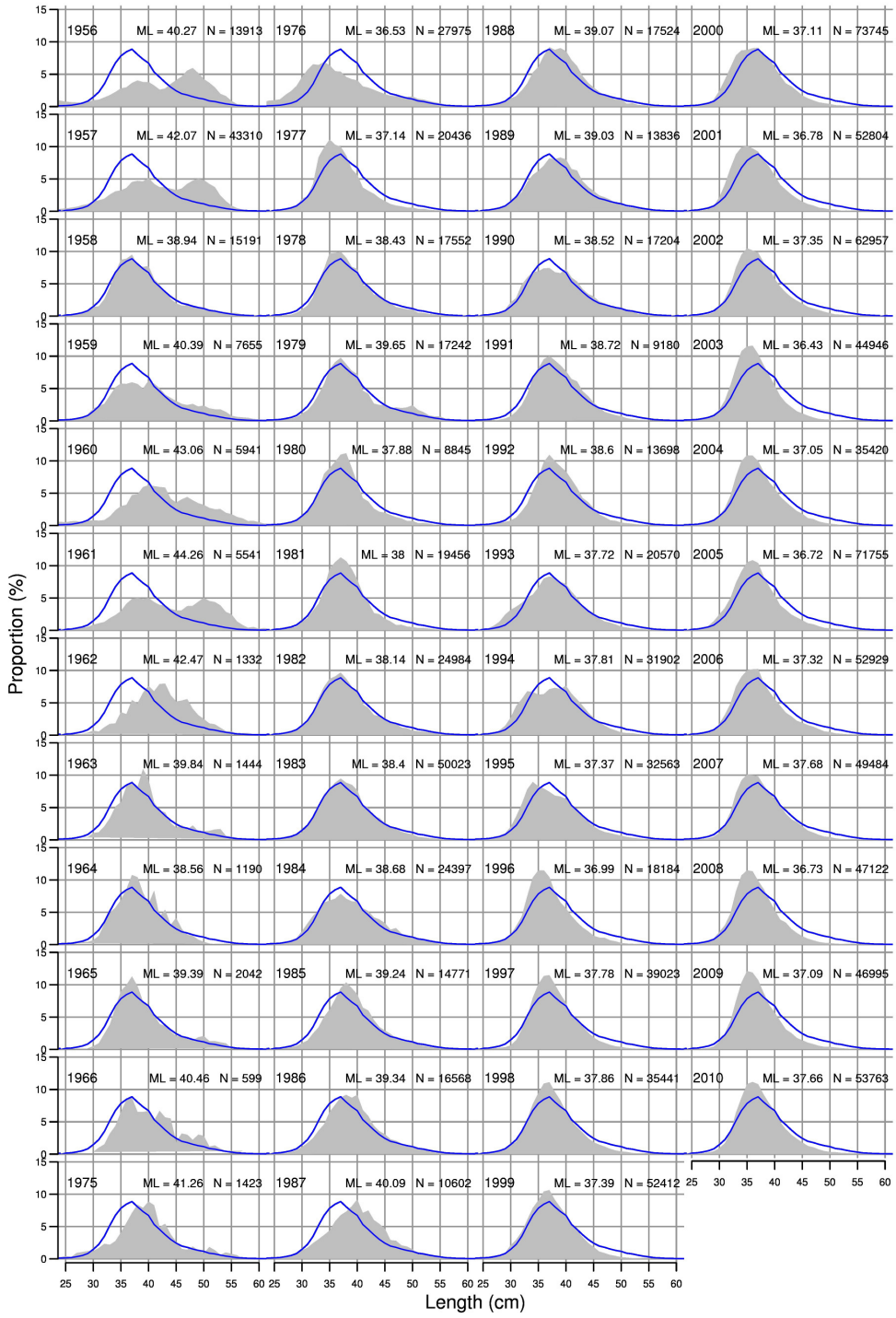

Figure 3.3. Length distributions of golden redfish in the commercial landings of the Icelandic bottom trawl fleet 1955-1966 and 1975-2010. The solid line is the mean of the years 1955-2010.

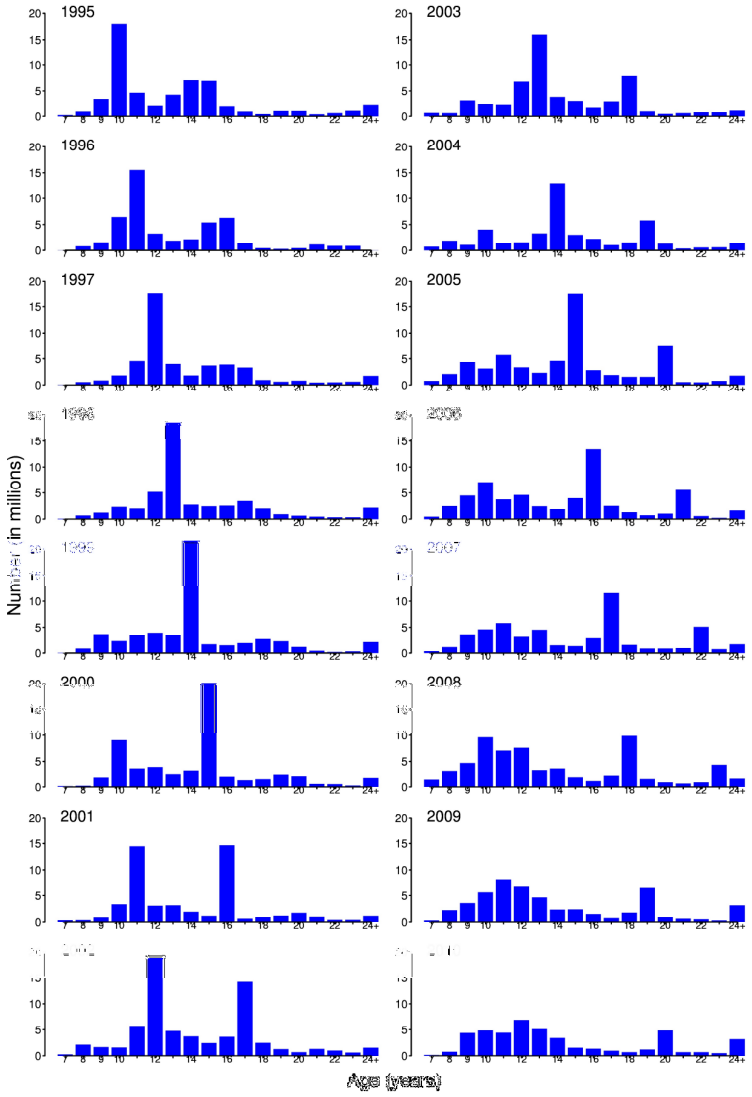

Figure 3.4. Catch-at-age (in numbers) of golden redfish in Icelandic waters 1995-2010.

4. Management

The Ministry of Fisheries and Agriculture in Iceland is responsible for management of the Icelandic fisheries, including the golden redfish fishery, and implementation of the legislation in the Icelandic Exclusive Economic Zone (EEZ). The Ministry issues regulations for commercial fishing for each fishing year (starts on September 1 and ends on August 31 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 2006/2007 fishing season, all boats operate under the TAC system. The agreed quotas are based on the Marine Research Institute's (MRI) 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 individual company as well as among different companies. The latter can be done via temporary or permanent transfer of quota. In addition, some flexibility is allowed by individual boats with regard to transfer 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. Finally, a vessel can transfer some of its quota between fishing years. This may result in higher catch in one fishing year than the set TAC and subsequently lower catches in the previous year.

All boats operating in Icelandic waters have to maintain a log-book 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 MRI.

Golden redfish has been within the ITQ system from the beginning. Icelandic authorities, however, gave a joint quota golden redfish and the Icelandic slope deep-water redfish until the fishing year 2010/2011, although MRI has provided a separate advice for the species since 1994. The separation of quotas was implemented in the 2010/2011 fishing year. Since 1994/1995 fishing year, the total annual landings of golden redfish has been in most years exceeded the recommended TAC. Figure 4.1 shows the MRI advice, the set TAC (joint quota for golden redfish and Icelandic slope deep-water redfish until the 2010/11 fishing year) and reported landings of golden redfish in Icelandic waters. The difference between the MRI advice and reported landings in the 2008/2009 fishing year is partly explained by transfer of allowable catch of one species to redfish and by transferring some of the redfish quota from the previous fishing year (see above).

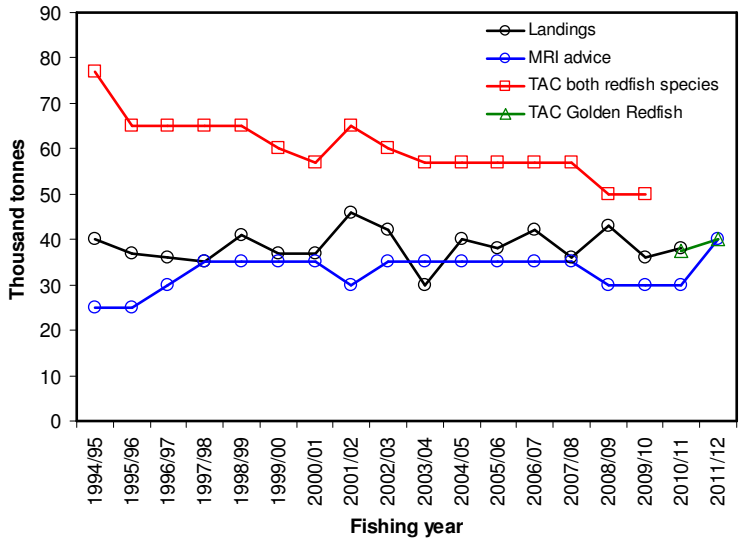

Figure 4.1. Marine Research Institute advice (blue line), set TAC for both golden redfish and Icelandic slope deep-water redfish (*S. mentella*) for the fishing years 1994/95-2009/10 (red line), set TAC for golden redfish in the 2010/11-2011/12 fishing years, and reported landings (black) of golden redfish in Icelandic waters. Landings statistics for the 2010/11 fishing year is preliminary. Fishing year is from September through August the following year.

5. Regulation

With some minor exceptions, it is required by law to land all catches. Consequently, no minimum landing size is in force. No formal harvest control rule exists for this stock. 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 and in the lobster fisheries south and southwest of Iceland.

The minimum legal catch size golden redfish is 33 cm for all fleets, with allowance to have up to 20% undersized (i.e. less than 33 cm) specimens of golden redfish (in numbers) in each haul. If the number of redfish smaller than 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 with the objective to protect juvenile fish, such as cod, haddock, saithe, and golden redfish. 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, if 20% or more of <33 cm redfish is in one haul). If there are several consecutive quick closures in a given area, the Minister of Fisheries can with regulations close the area for longer time forcing the fleet to operate in other areas. Inspectors from the Directorate of Fisheries supervise these closures in collaboration with the Marine Research Institute. Since 1991, when the first redfish closure took place, a total of 66 closures on redfish have taken place (Figure 5.1). On average, around 100 closures takes place annually where most dominant species closed for are cod and haddock.

PERMANENT AREA CLOSURES: Based on knowledge on the biology of various stocks, many areas have been closed temporarily or permanently aiming at protection of juveniles.

TEMPORARY AREA CLOSURES: The major spawning grounds of cod, plaice and wolfish are closed during the main spawning period of these species. The general objectives of these

measures, which were in part initiated by the fishermen, are to reduce fishing during the spawning activity of these species.

Few quick closures have been on small redfish since 2001 or on average 3 every year (Table 1). The reason for few quick closures on small redfish is because large areas southwest and west of Iceland are closed permanently or temporarily for trawling to protect juvenile golden redfish (Figure 5.2). These areas were closed partly because of frequent quick closures on redfish fisheries in 1991-1994 (Schopka, 2007).

Table 1. Number of quick closures on golden redfish in Icelandic waters 1991-2010. See text for further description.

YEAR	NO. CLUOSURES
1991	1
1992	1
1993	2
1994	8
1995	3
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

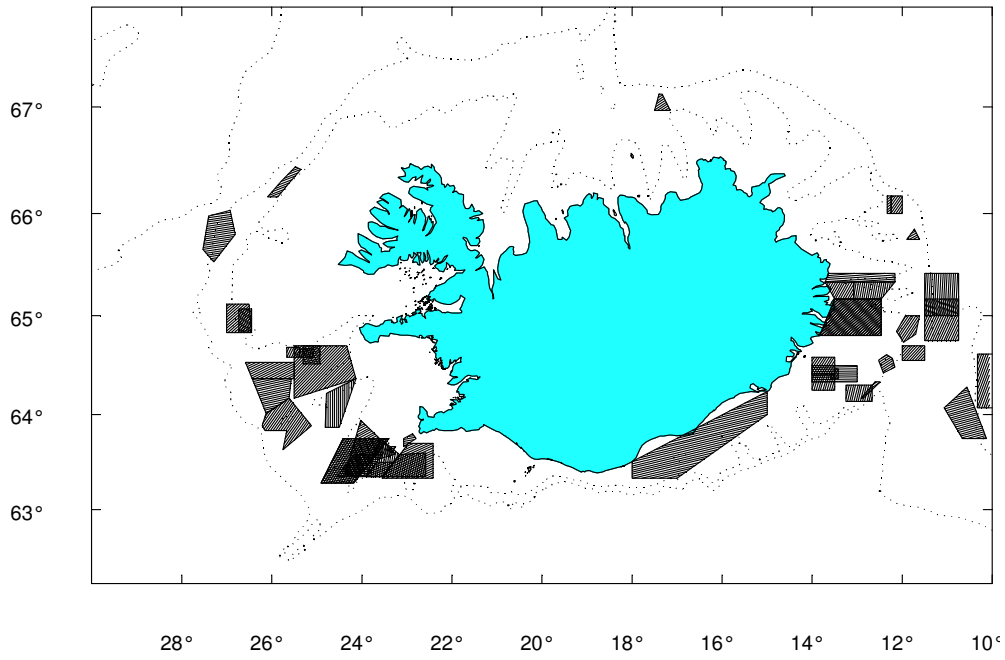

Figure 5.1. The locations of quick closures on juvenile redfish 1991-2008.

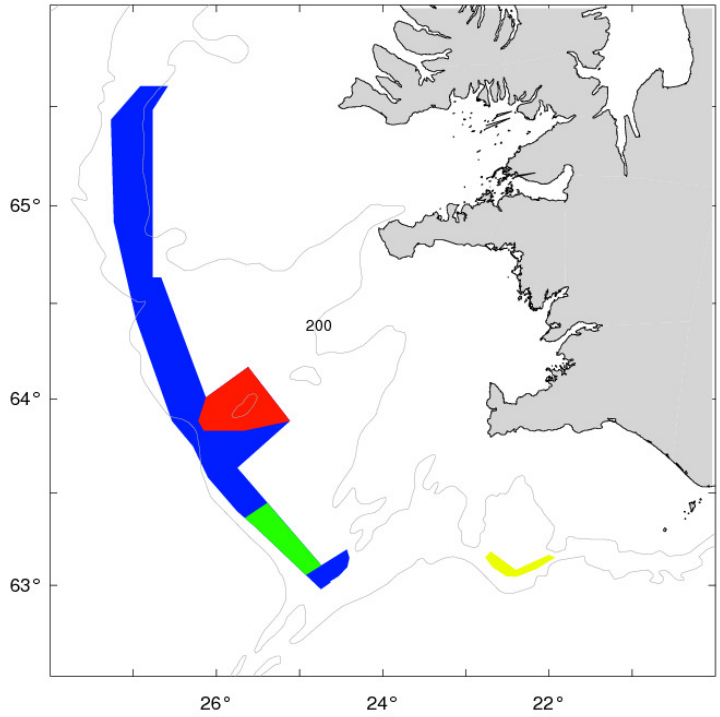

Figure 5.2. Schematic overview of closed areas for protection of juvenile golden redfish. These areas are either closed permanently or temporarily and during closure bottom trawling is prohibited. The blue area is closed all year long; the red area is only open during the night or from 20:00-08:00 from October 1 to April 1 to allow fishing for saithe; the 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.

6. Research on golden redfish

Although the fishery for golden redfish Icelandic waters started in the 1920s, research on the species was limited during the first decades of the fishery. It was not until after the Second World War that systematic research started in order to describe various life history stages, such as on larvae and larvae distribution (Magnússon, 1956; Einarsson, 1960) and on the distribution of adult fish and mapping the location of breeding places (Tåning, 1949). Often the aim of the research on the adult population was to find new redfish fishing grounds for the Icelandic fishing fleet (*heimildir eftir J. Magnússon*).

The distribution and abundance 0-group fish in Icelandic and East Greenland waters was investigated annually in August in a 0-group survey 1970-2003 (Magnússon and Magnússon, 1977; Magnússon and Jóhannesson, 1997; Sveinbjörnsson and Hjörleifsson, 2003). The purpose to of the survey was to obtain an indication of the relative year-class strength of larvae of commercially important fish species inhabiting these waters. The survey was discontinued in 2003. One problem regarding these larvae research on redfish was that it was difficult to distinguish the golden redfish and deep-water fish larvae from each other although attempts were made (Magnússon and Magnússon, 1977; Magnússon, 1981). The results from these surveys indicate that the distribution and abundance of 0-group redfish is variable (Figure 6.1*a,b*). Low abundance is found in Icelandic waters whereas the main distribution both at East Greenland and in the Central Irminger Sea (Magnússon and Jóhannesson, 1997). It has, however, been difficult it is to use the 0-group survey indices as an indicator of year class strength of golden redfish.

In recent year, the main focus of the golden redfish research has been on age reading and development of appropriate method to age determine redfish, how fishery independent surveys can be used in determine the stock status and , and on the developing of appropriate assessment model for the species.

6.1 Age reading

Accurate age determination of redfish species is difficult. This is because of slow growth and longevity (Nedreaas, 1990; Stransky et al., 2005; ICES, 2009). Age determination data are the basis for age-based analytical assessment and because of the problem of age reading, such assessment models are seldom conducted on redfish stocks. Alternative assessment models could be length or age-length based models but they require reliable data on growth (ICES, 2009).

Several workshops have been held to resolve the problem of age reading of redfish (e.g. ICES 1996; 2006; 2009). The aim of those workshops are to find the most appropriate method to age determine redfish and to standardize the method across laboratories. This is because different countries are using different aging methods for different redfish, resulting in large difference in age per length class (ICES, 2009). Another aim of the workshops was to analyse the sources of age determination errors to get more accurate age determination. The main result of these workshops is that the most appropriate method used age determination of redfish, including golden redfish, was the break-and-burn method of otholiths.

Systematic sampling program for golden redfish otoliths in Icelandic waters started in 1995. Otoliths sampling from the commercial catch started in 1995, from the autumn survey in 1996, and from the spring survey in 1998. Annually, about 1,700 otoliths are age read from the commercial catch and approximately 1,500 from the autumn survey. Otoliths from the spring survey have not been age read.

6.2 Fisheries independent surveys

Fishery independent surveys are one of the methods to obtain information on stock size, stock status and general biology of various fish species, such as distribution of various life history stages, maturity, growth and feeding. Several surveys are or have been conducted annually in Icelandic waters. Here, we focus on two bottom trawl surveys which are considered representative for golden redfish: the Icelandic Groundfish Survey (the spring survey) and the Autumn Groundfish Survey (the autumn survey). The spring survey has been conducted annually in March since 1985 on the continental shelf at depths shallower than 500 m and has relatively dense station-net or approximately 600 stations (Pálsson et al., 1989). 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 than in the spring survey. Detailed description of the surveys is found in Pálsson et al. (1989), Björnsson et al. (2007) and in MRI (2010).

6.2.1 Results form the bottom trawl surveys

Golden redfish is found in 92-96% of the tows conducted in the spring survey and between 51-62% of the tows in the autumn survey. The difference is because the autumn survey extends to deeper waters than the spring survey and where golden redfish is less abundant. Golden redfish is found in 93% of the tows conducted in shallower waters (less than 500 m) in the autumn survey, which is the same area as in the spring survey, and in 30% of the tows conducted in deeper waters than 500 m.

Survey indices are calculated from these surveys and used in the assessment of golden redfish in Icelandic waters. Length disaggregated indices from the March survey are used in the Gadget model (see Chapter 7). Another index that is calculated is the index of fishable biomass from the spring survey (U), but the relative state of the stock has been assessed through this index.

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

Figure 6.2*a* show shows the total biomass index from the Icelandic spring and autumn groundfish surveys with ±1 standard deviation in the estimate (68% confidence interval). The total biomass of golden redfish as observed in the spring survey decreased from 1988 to a record low in 1995. Between 1996 and 2002 the stock showed signs of improvement but was low compared to the beginning of the series. In 2003 the biomass increased significantly and has since then been high. The 2011 estimate is the highest in the time series. The CV of the measurement error is considerably higher since 2003 than before that. The high CV is because the majority of the total catch of golden redfish comes in a few large tows leading to high uncertainties in the estimates of the biomass/abundance indices (high CV).

The trend in the biomass index of the fishable biomass (fish larger than 32 cm) is similar to the total biomass in both surveys (Figure 6.2*b*).

The biomass of fish bigger than 40 cm accounted for a large part of the total biomass index in the beginning of the time series or 1/3 of the total biomass (Figure 6.2*c*). The biomass of the largest fish decreased drastically from 1989-1992 and has since then been stable at low level. The 1985- and 1990-year classes, that were large, should have contributed to this size group but has not been observed in the surveys.

The recruitment index (redfish 11 cm and smaller) shows peaks in 1987 and 1992 which represent the large 1985- and 1990 year classes (Figure 6.2*d*). The peaks observed around 2000 are much smaller but there is indication that these year classes are recruiting to the fishable stock in greater manner (see Section 7). The abundance estimation of small redfish in 2011 was the lowest in the time series.

The total biomass index from the autumn survey is difficult to interpret partly because the time series is shorter (Figure 6.2*a*). There is also large measurement errors, especially in 2006 and 2008 and great variation in the estimates in 2006-2010 without any clear trend. Recruitment index is lower than in the spring survey. Possible explanations for this difference are that the autumn survey does not cover the distribution of juvenile redfish, that the selectivity of the trawl used is less than the one used in the spring survey or juveniles are less at the bottom than in the spring. The recruitment index shows though spikes in 1998 and 1999 that is then observed in the spring survey in 2000 and 2001 (Figure 6.2*d*).

Length distribution of golden redfish shows that the majority of the fish caught is 25 cm and larger. The modes of the distribution in recent years have been between 33 and 35 cm whereas the fish was on average larger at the beginning of the time series.

Length distribution from spring survey in shows that the peaks, which can be seen in 1987-1988 and in 1991-1993, reached the fishable stock approximately 10 years later (Figure 6.3). The increase in the survey index since 1995, therefore, reflects the recruitment of a relatively strong year classes (1985-year class and then the 1990-year class). This has been confirmed by age readings (Figure 6.4). There is an indication of considerable recruitment (fish less than 12 cm) observed in both groundfish surveys in 1998-2000 (Figures 6.2*d*) and can be seen as 9-14 years old fish in the 2010 autumn survey (Figure 6.3).

From the length distribution in the spring survey it can be seen that recruitment is highly variable with years with very low recruitment. Growth rate from these length distributions is approximately 2-2.5 cm/year for the youngest year classes. It is not possible to follow year classes longer than 4-5 years. It seems that golden redfish disappears to some extend from the juvenile areas north and northwest of Iceland and does not reappear in the spring survey until it reaches size of about 25 cm.

Golden redfish first appears in the autumn survey as one year old but is not prominent until it reaches the age of 4-5 years. Age disaggregated abundance indices show that the 1985 year class was the most abundant year class until 1999, but between 2000 and 2007 the 1990 year class was the most abundant one. Since the abundance of these two large year classes has decreased although they are still relatively prominent in the survey.

Age disaggregated abundance indices indicate that the year-classes 1996-2001, observed as 9-14 years old fish in 2010, are now similar to the indices of year-class 1990 at same age (Figure 6.4). Individually these year classes are not as large as the 1985 and 1990 year classes but combined they may be larger than the big year-classes.

Golden redfish in both surveys is found all around Iceland on the continental shelf down to 500 m depth. It is most abundant south, south-west, west and north-west of Iceland at 100-400 m depth.

Considerable change has been in the distribution of golden redfish as observed in the Spring Survey since 1985 (Figure 6.5). In the beginning of the time series, golden redfish was most abundant along the south coast and west and northwest of Iceland. In 1990-1998 much less was caught in all areas, except in the cold waters east of Iceland where golden redfish is least abundant, and this is related to the decrease of the total biomass 1990-1994 (Figure 6.5). As the biomass rose in the early 2000's, golden redfish has mainly been distributed southwest of Reykjanes Ridge, west and northwest of Iceland. A notable change is an increase in biomass

southwest of Iceland in an area that has been protected for commercial trawling since 1994. However, much less of golden redfish was caught in warmer waters south and south-west of Iceland (along the Reykjanes Ridge) in 2007-2011 than in 1985-1989.

Proportionally more of golden redfish is caught in south-west and west of Iceland in the Autumn Survey than in the Spring Survey. The distribution in the autumn survey shows though similar trend as in observed in the spring survey, which is an increase of abundance of golden redfish north-west and north of Iceland and a decrease along the south coast.

In general, the main distribution areas of golden redfish have in recent years moved more northerly and much less is now caught along the south and southeast coast of Iceland.

Nursery areas for golden redfish (here, smaller than 12 cm) are found northwest, north, and northeast of Iceland, but it varies between years where the main nursery areas are located. In 1987, when the magnitude of small redfish was great because of the strong 1985 year class, small redfish was mainly distributed north and northwest of Iceland. In 1992, because of the 1990 year class, juvenile redfish were mainly distributed northwest and north of Iceland. After that, small redfish have mainly been found west and northwest of Iceland.

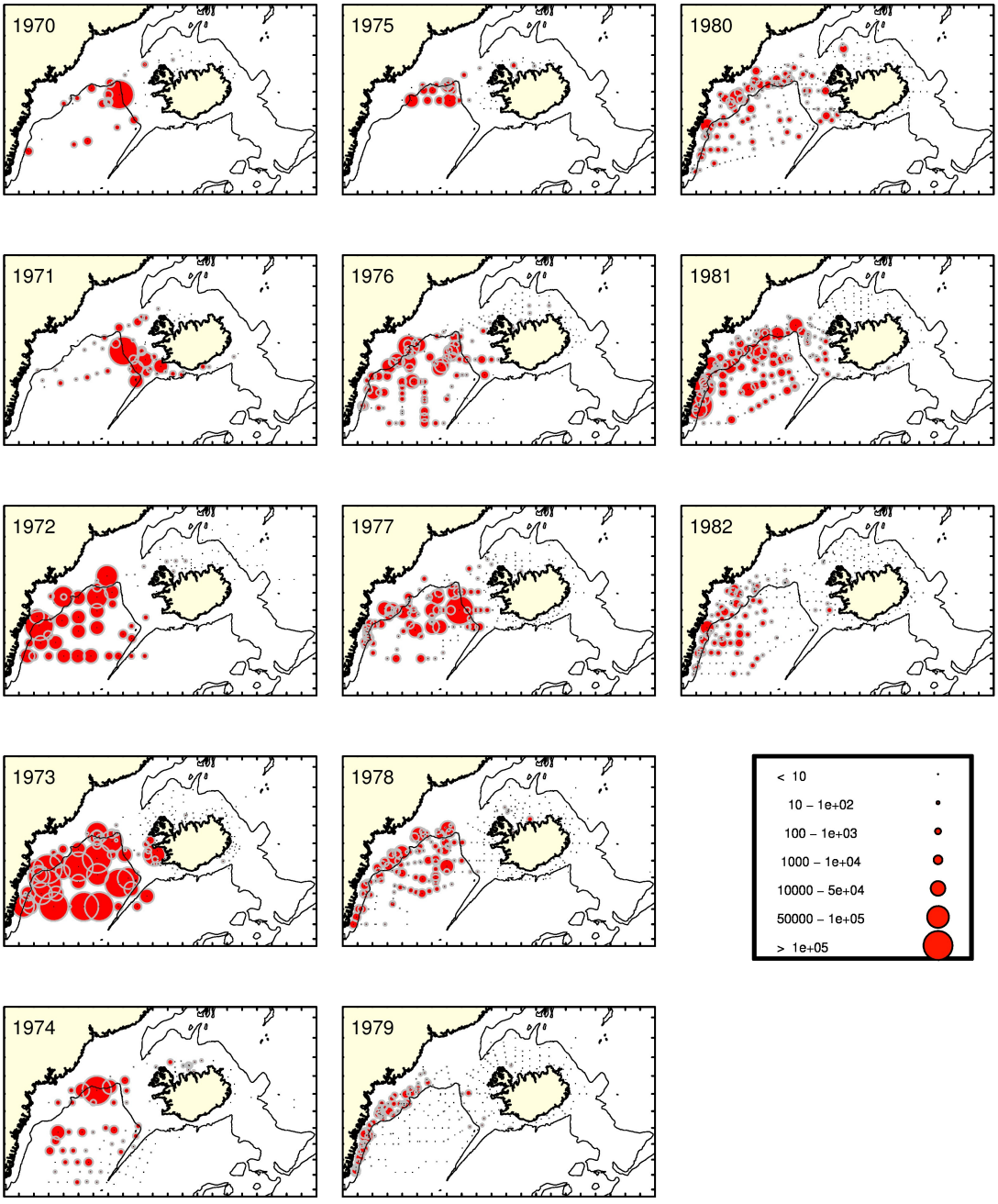

Figure 6.1. Annual distribution and density (number/tow) of 0-group redfish (a) 1970-1982 and (b) 1983-1995.

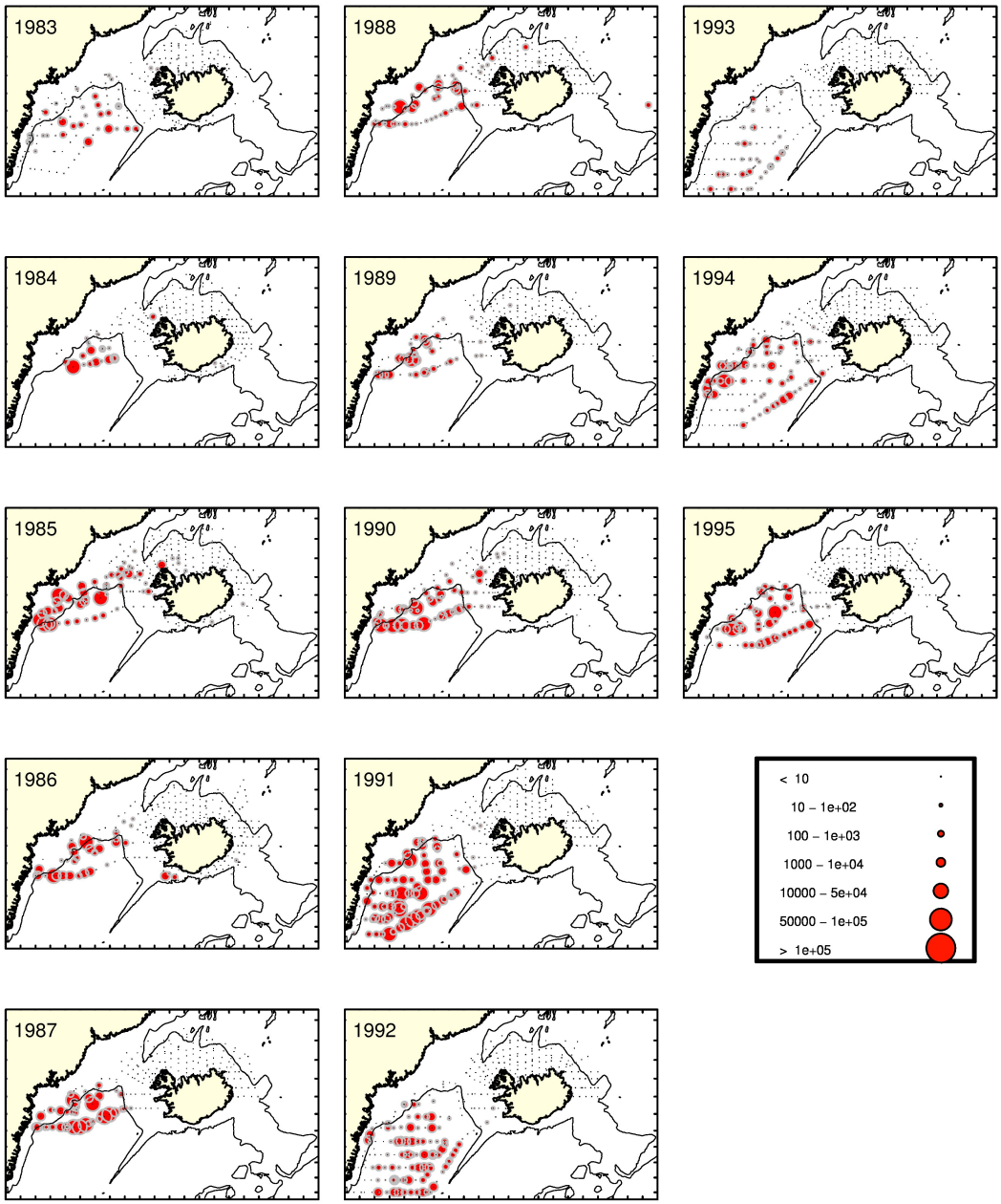

Figure 6.1b. Continued.

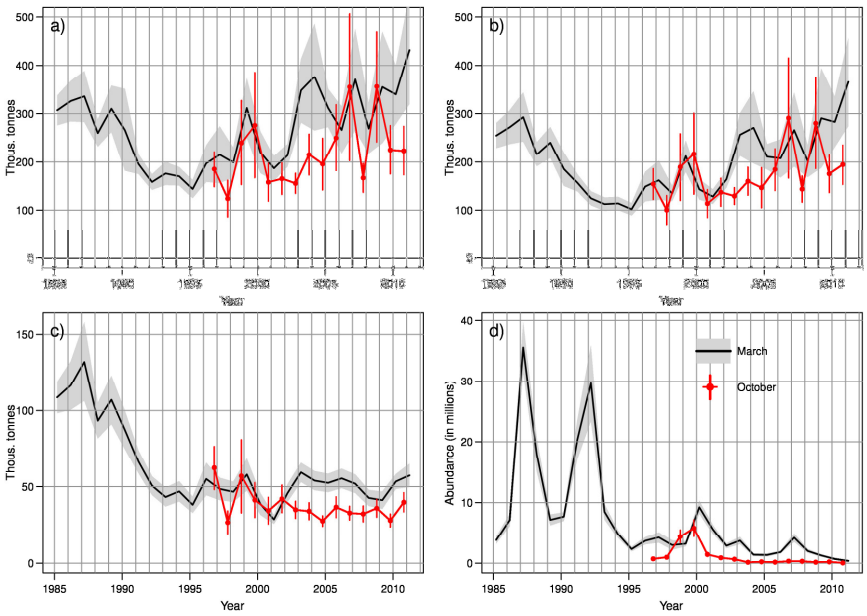

Figure 6.2. Indices of golden redfish from the groundfish surveys in March 1985-2011 (line, shaded area) and October 1996-2010 (red points, vertical lines). a) Total biomass; b) biomass of fish larger than 32 cm; c) biomass of fish larger than 40 cm; d) indices of juvenile golden redfish (4-11) cm in millions. The shaded area and the vertical bar show ±1 standard error of the estimate.

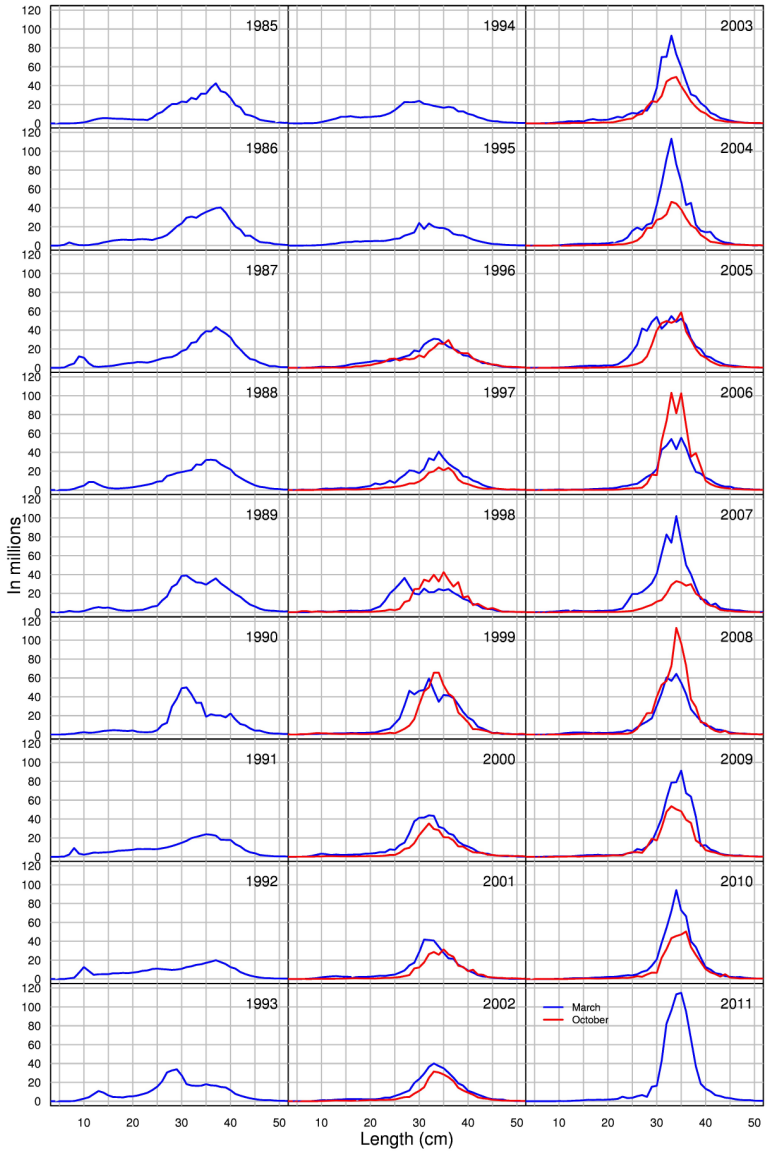

Figure 6.3. Length disaggregated abundance indices of golden redfish from the bottom trawl survey in March 1985-2011 (blue line) and October 1996-2010 (red line) conducted in Icelandic waters.

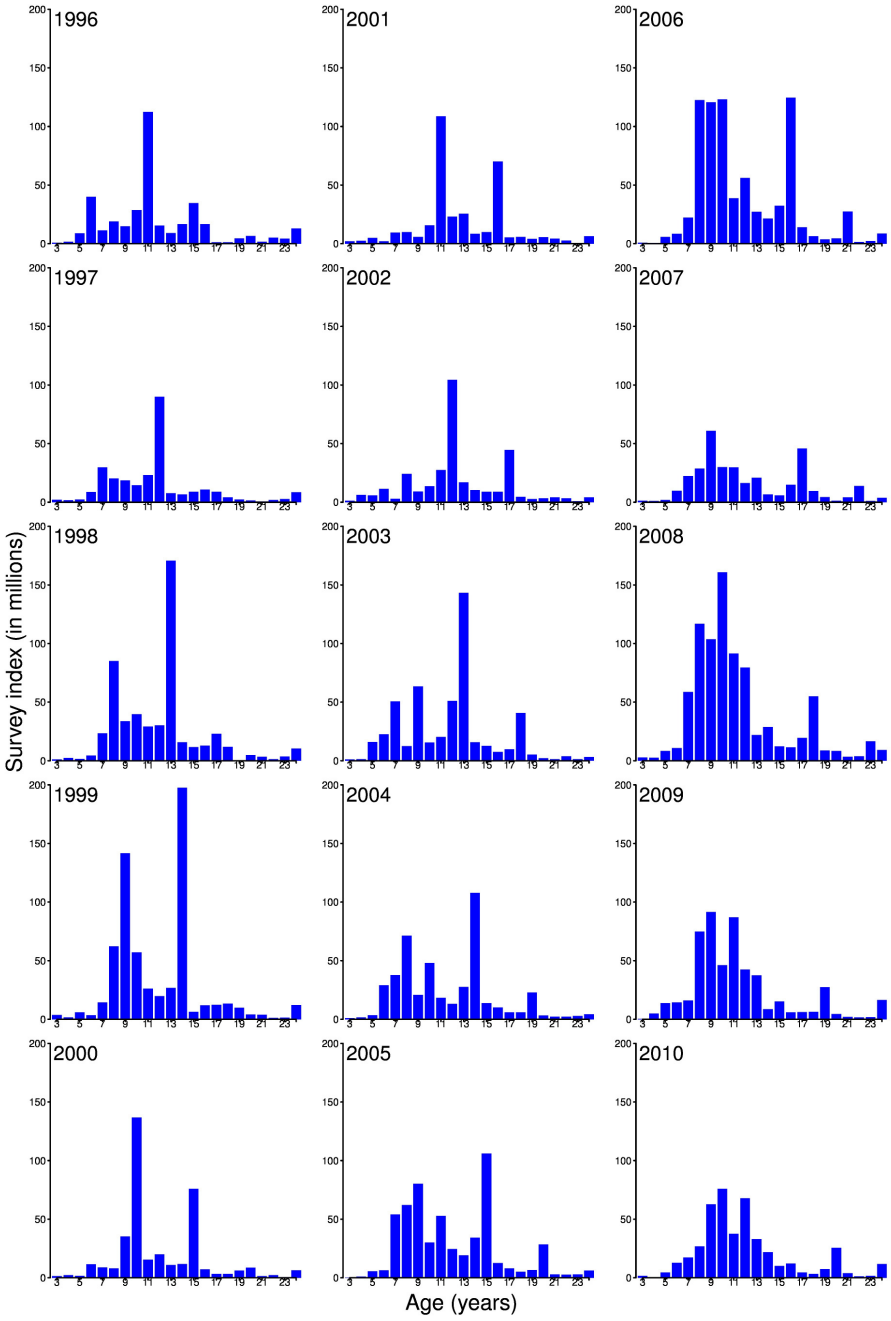

Figure 6.4. Age disaggregated abundance indices of golden redfish in the bottom trawl survey in October conducted in Icelandic waters 1996-2010.

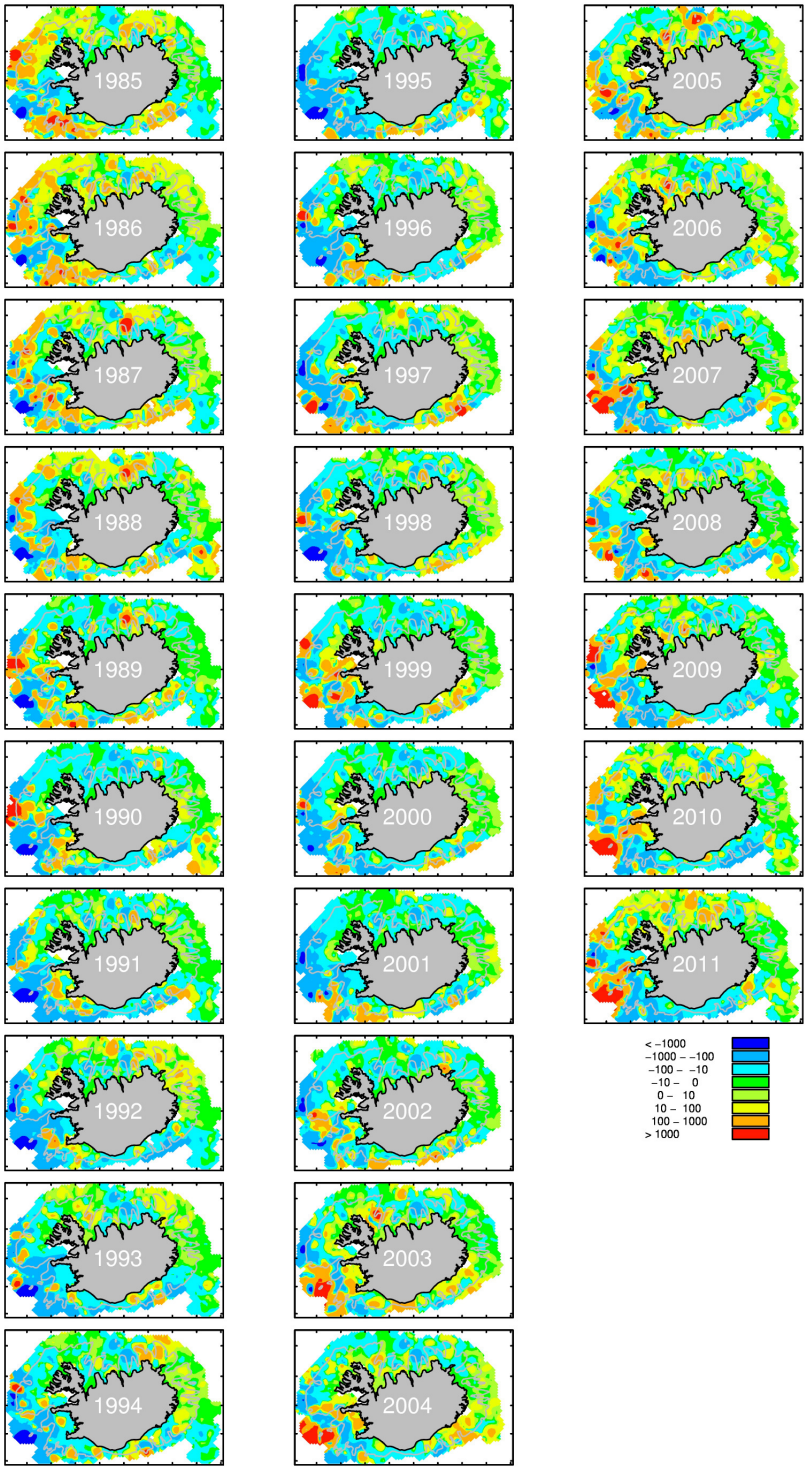

Figure 6.5. Deviation from mean geographical distribution (kg per NM²) of golden redfish in the Spring Survey 1985-2011.

7. Assessment

Analytical assessment is difficult for golden redfish, as is for many redfish species. This is because of the longevity of the species and it may take 30-40 years for a cohort to pass through the fishery. Time series data, such as from fishery independent data obtained from surveys, need therefore to be long. The spring survey was commenced in 1985 and the large 1985 year class, now 26 year old, is still abundant, both in the fishery and in the surveys. Age determination has also proven to be difficult and such data are the basis for age-based analytical assessment (see Chapter 6.1).

Until 1992, age based assessment (VPA) was used to assess the golden redfish stock in Icelandic waters but was abandoned (ICES, 1992). The reason was that age determination was inconsistent with information on recruitment variability seen in the length distribution from the surveys (Björnsson and Sigurdsson, 2004), possibly because of problems with age determination which was based on scales at that time. The stock was then assessed through CPUE series, which was later abandoned because CPUEs are not considered to reflect the stock status reliably (ICES, 2010).

Since the mid 1990s, ICES has assessed the golden redfish stock in Icelandic waters through index of fishable biomass from the Spring Survey (U) and the relative state of the stock has been assessed through this index

The noisy indices shown in Figure 6.1 are difficult to use when advice is based directly on indices. In 1998 an index was compiled from the March based on a selection curve rising sharply from 34-36 cm (L_{50} = 35 cm) and that area 0-400m. The survey extends down to 500 m depth but the stations between 400 and 500 m are few and show the largest CV´s. This index (Figure 7.1) and defined reference points (U_{pa}=60% and U_{lim}=20% of maximum value) have since then been used to classify the state of the stock. The index has been above U_{pa} since 2008 after having been below it for 18 years. The 2011 value of the index is the highest since 1987 but with relatively high measurement error compared to previous years.

Since 1999, Gadget model has been used for assessment of golden redfish in ICES Division Va (Björnsson and Sigurdsson 2003). Gadget model (**G**lobally applicable **A**rea **D**isaggregated **G**eneral **E**cosystem **T**oolbox, see www.hafro.is/gadget) is an age–length structured forward-simulation model, coupled with an extensive set of data comparison and optimisation routines. Processes are generally modelled as dependent on length, but age is tracked in the models, and data can be compared on either a length and/or age scale.

Worked examples, detailed manual, and further information on Gadget can be found on www.hafro.is/gadget. The structure of the model for golden redfish is described in Björnsson and Sigurdsson (2003). Additional description of the model is found in Begley and Howell (2004), and a formal mathematical description is given in Frøysa *et al*. (2002). Description of the model settings for the golden redfish in Icelandic waters and the results of the last run of the model are presented in Chapter 17 and in the Stock Annex for the species of the latest report of the North Western Working Group (ICES, 2011).

The results of the Gagdget model indicate both the fishable and spawning stock has gradually increased since 2000 and the fishable biomass is similar that it was in 1987 (Figure 7.1). Figure 7.1 also shows development of the harvestable biomass (fishing at F_{MAX}=0.15) for different catch options after 2011. The results indicate that landings near 40,000 tonnes will lead to stable fishable stock in coming years.

The model indicates that recruitment has been underestimated in recent years, i.e. some year classes in are considerably stronger than survey indices at small size indicated. This could

mean that recruitment is partly coming from other areas, most likely from East Greenland. Germany has conducted survey in East Greenland waters since 1982 and the survey indices from that survey indicate the biomass of the fishable stock has increased in recent years and there are also sign of improved recruitment (NWWG, 2011). The survey conducted in Icelandic waters might, therefore, not cover the nursery area of the stock.

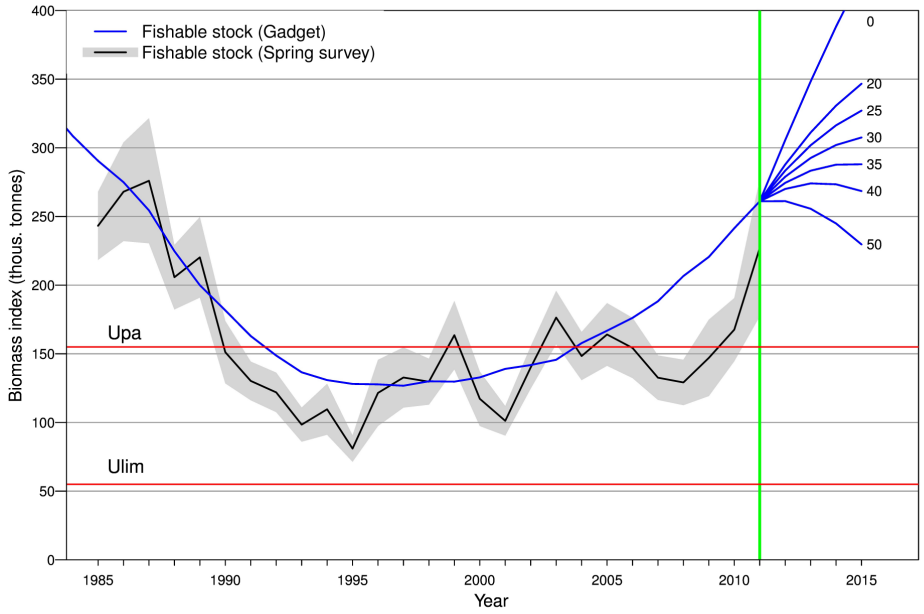

Figure 7.1. Development of the fishable biomass according to the Gadget model (blue line) using different catch options (0-50 000 t) after 2011. Also shown is the index of the fishable biomass (34 cm and larger) in the Icelandic groundfish survey in March 1985-2011 (black line and shaded area which is the ±1 standard error of the estimate).

8. Conclusion

In this paper, we have reviewed the past and ongoing research on golden redfish in Icelandic waters and described the current state of the stock. After the stock decreased from late 1980s to 1995 the stock has since then increased. Spawning stock and fishable stock have been increasing in recent years and are now the highest since. Furthermore, the Gadget stock assessment model indicates that fishing mortality has reduced in recent years and is now close to F_{MSY}.

Although research and management of golden redfish in Icelandic waters has been going on for decades there are some key difficulties regarding on the knowledge about the stock and life history characteristics of the species. These key difficulties include knowledge about mating and larval extrusion areas, migration pattern, the connection between areas (East Greenland – Iceland – Faroe Islands), stock identification, and recruitment pattern.

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