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Final report from the 3-year Russian-Norwegian research programme on Greenland halibut 2007-2009

By
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1 Introduction
Based on the decision of the 34th session of the Joint Russian-Norwegian Fisheries Commission (JRNFC), a joint research program aimed at improvement of Greenland halibut stock assessment methods and elaboration of optimal management strategy was developed at the meeting of PINRO and IMR scientists (21-27 March 2006). The research program was structured in six sub-projects and run for the three years 2007-2009, and final results were to be reported to the JRNFC by their meeting in October 2010. This final report gives a brief description of the main findings from the three-year program and summarizes the present level of knowledge within each of the six sub-projects.

The work has been organized in two main projects, one at each institution, led by O. Smirnov and O.T. Albert, respectively. In addition to the authors, the achievements of the research program are due to contributions from many scientists and technicians. We will especially mention Yuri Kovalev, Dmitry Prozorkevich, Andrey Sokolov, Andrey Dolgov, Evgeny Shamray, Evgeny Sentyabov, Alexsey Amelkin, Svetlana Glebova, Rifat Baimambetov, Åge Høines, Torild Johansen, Jon-Ivar Westgaard, Halvor Knutsen, Alf Habitz, Karl-Erik Karlsen, Merete Kvalsund, Thomas de Lange Wenneck, Kjell Gamst, Ronald Pedersen, Michael Polterman, Lisbet Solbakken, Yvan Lambert, Carla Freitas, Benjamin Planque, Arnt-Børre Salberg,

Some of the results are already published in international refereed journals, while other are intended for publication. This represents important quality controls of the conclusions that can be made on basis of the activities of the research program. Some of the conclusions presented in this report should therefore be considered as preliminary until final publication. Some of the research themes covered by the research program are also included in other scientific processes within ICES and NAFO, and these may lead to new or updated understanding on important aspects (e.g. on migration and connectivity, and on age and growth). Moreover, scientists and students in both countries will continue to use data sampled during the program period in future work. Even though this is called a "final report", we may therefore look forward to new insight on Greenland halibut ecology and behavior in the coming years.

2 Subproject on age determination
Age determinations of Greenland halibut have long been considered highly uncertain (ICES, 1997; Alpoim *et al.*, 2002; Treble and Dwyer, 2008) and recent results indicate a tendency to underestimate the age of older individuals (Gregg *et al.*, 2006; Treble *et al.*, 2008). Some laboratories have therefore ceased to age this species, and this has hampered analytical age structured assessments in several regions of the Northeast Atlantic (ICES, 2008a, b). Serious concerns have been raised that the annual production estimated with the current age estimates is too high (ICES, 2003; Albert *et al.*, 2005; Gregg *et al.*, 2006; Cooper *et al.*, 2007; Treble and Dwyer, 2008), and typically restricted to a maximum age well below 20 years. There are many examples from other species where systematic underestimation of age has resulted in failure to realize the stock's vulnerability to exploitation (Campana, 2001), and for many deep-water species this has led to sudden declines of stocks as well as the fishery that they supported. The question of correct age determination of Greenland halibut is therefore important for development of sustainable management of the fish stocks.

Based on tag-recapture experiments Albert *et al.* (2009) show that previous age determinations of Greenland halibut from whole otolith surfaces greatly underestimates the age of older individuals. They also show that the mean individual annual growth of adults is around one cm per year (Figure 1). Surface methods are much more effective than other more time-intensive methods, which is an important consideration for use in stock assessment. The paper therefore explores a new surface method that is in accordance with growth increments from tag-recaptures. The method relies on improved protocols relating to storing, imaging, choice of reading axis, and definition of seasonal zones. The definitions of the first two seasonal zones were validated by length frequencies of juveniles. The new reading axis and seasonal zones of older otoliths were validated by tagging experiments involving injection of OTC, a chemical tag that incorporates into the otolith as a visual band marking the otolith size at time of release (Figure 2). With the new method, several measures of otolith size were correlated with age, even for fish of equal length. This is expected for an accurate age determination method (Boehlert, 1985; Reznick *et al.*, 1989; Pawson, 1990; Worthington *et al.*, 1995; Choat and Axe, 1996; Butler and Folkvord, 2000; Cardinale *et al.*, 2000a,b; Labropoulou and Papaconstantinou, 2000; Pilling *et al.*, 2003; Lou *et al.*, 2005; Steward *et al.*, 2009), and was not apparent with the traditional method.

Regarding the remaining uncertainty, we consider that identification of the zones between four and eight years in otoliths of older specimen is still quite uncertain. In this adolescent phase there is no guidance from the length distributions, and the zonation pattern is typically characterized by several checks and false seasonal zones, especially in the right otoliths. The smallest OTC-tagged and recaptured individual suggests that the zonation pattern may possibly be clearer in the left otoliths in these young fish. This phase also represents the ages of transition between the juvenile and adult distribution area, which is a length structured process involving the largest individuals of the younger age groups (Albert, 2003). It is also the size groups where the sampling trawl is clearly size selective (Albert *et al.*, 2003) thus further biasing any attempt to estimate growth in length from the catches. Unfortunately, these size groups were under-represented in the tag-recapture data. Future tagging experiments, shedding light on this adolescent phase, may therefore further improve age

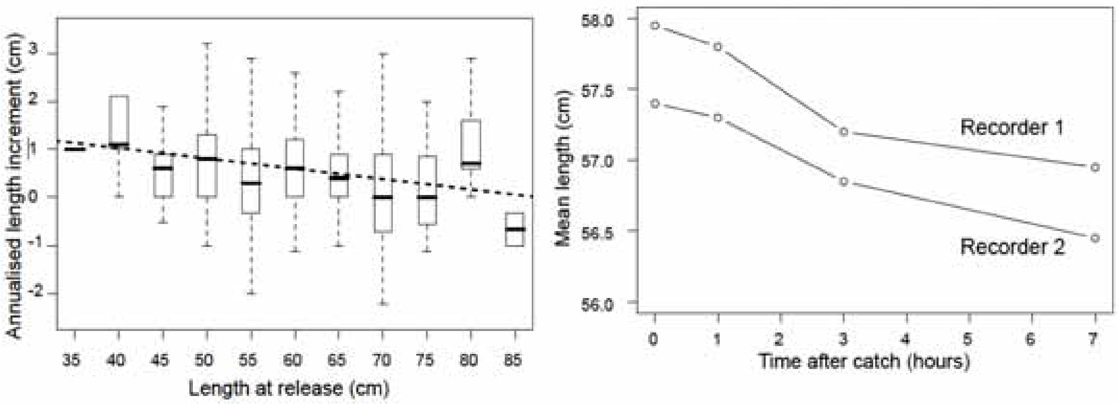


Figure 1. Left: Mean annual length increments of Greenland halibut from release to recapture versus length at release. Box-plots show median, 25 and 75 percentiles and main range. Dotted line represents a linear regression through all data points. Right: Mean length of 20 Greenland halibut measured by two technicians at varying times after catch. Recaptured fish were usually put aside during production in the fabric and was measured several hours after catch. Length at recapture may therefore be negatively biased by approximately one cm due to post mortem shrinkage. In addition, the figure illustrates that between-person precision is at the same level as estimated annualized length increments.

estimations of Greenland halibut.

Despite the above-mentioned uncertainty with the fourth to eighth seasonal zones, the interpretation followed widely accepted interpretation rules (Williams and Bedford, 1974; Beamish and McFarlane, 1987), and the uncertainty within this section of the otoliths should probably not be expected to be more than a few years. But even if the new method can be considered as reasonably accurate, it is still relatively imprecise, with a mean CV of 12% between age readers. This is at the same level as that found for many other long lived fish species (Kimura and Lyons, 1991; Bergstad *et al.*, 1998; Stransky *et al.*, 2005) and experience has shown that this precision may be significantly improved by systematic exchange programs and agreement on specific interpretation principles (Bergstad *et al.*, 1998).

Recommendations:

1. Future work should focus on increasing precision by finding aging structures, reading axes and preparation techniques that may enhance readability for intermediate ages, as well as capturing the full age of older individuals. As more OTC marked fish are recaptured, it may be possible to better describe the full variability of otolith growth throughout the ontogeny of the fish. This may also warrant further exploration of axes in the 3D otolith structure (as well as of alternative structures such, as scales and vertebrae) that most consistently represent the true age of the individuals.

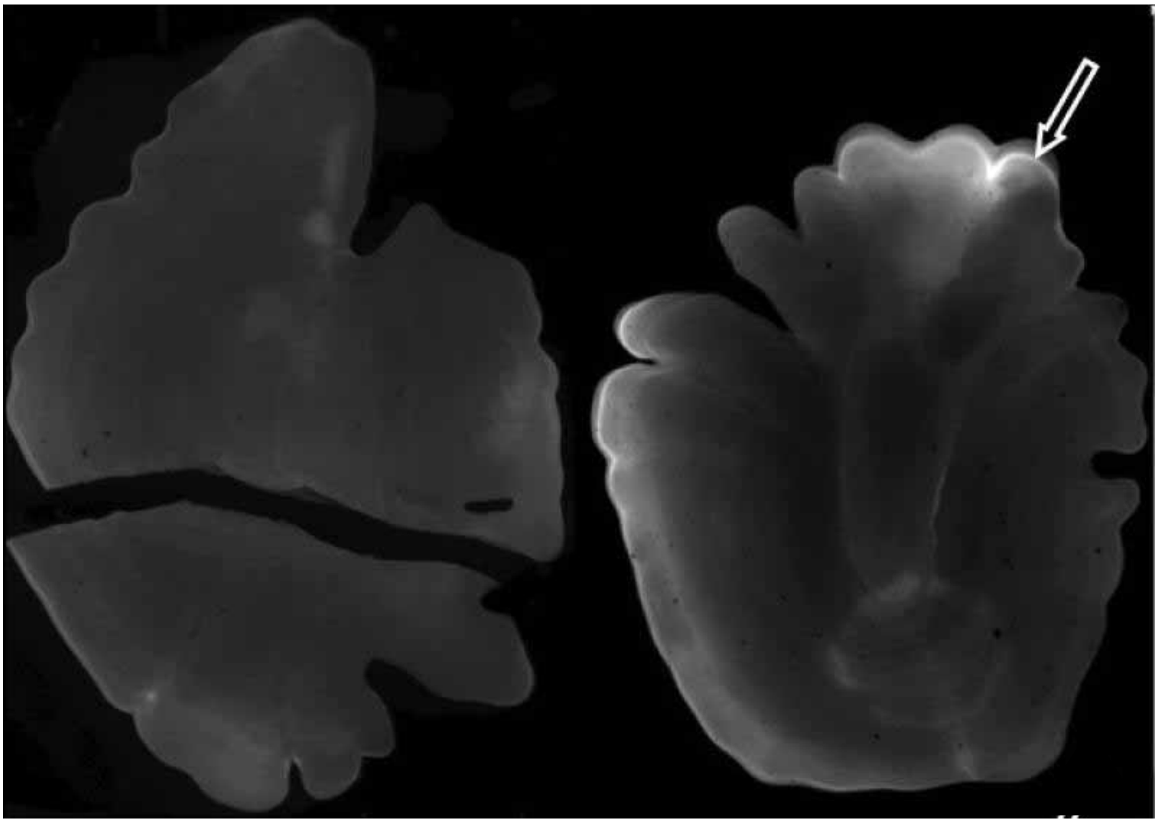


Figure 2. Left and right otoliths of a recaptured Greenland halibut injected with fluorescent OTC at time of release. The fluorescent band indicates otolith size at time of release and subsequent otolith growth until recapture. The fish had grown from 45 to 46 cm during two years at large, and otolith growth is only seen in the right otolith. An important difference between the old and the new Norwegian age reading method is that the new one relies on the right otolith (especially for older specimens), whereas the old method mainly used the left otoliths for all ages. Another difference is that with the new method, fish length is not known to the age reader, so the age estimates are more independent on previously assumed relationship between fish length and age.

2. ICES organize an age interpretation workshop on Greenland halibut (WKARGH) in Vigo, Spain, 13-16 February 2011. It is recommended that future assessments and management-oriented research on Northeast Arctic Greenland halibut be based on results and conclusions reached by that workshop. It is therefore important that relevant Russian and Norwegian scientists fully participate in this process.

Activities of the subproject:

- OTC-Tagging survey off King Karl Land, Sep-Oct 2006. *9762 fish released.*
- OTC-Tagging survey off King Karl Land, Jul-Aug 2007. *9045 fish released.*
- OTC-Tagging survey to NW Spitsbergen, Sep 2008. *5474 fish released.*
- Tank experiment on OTC tagging mortality, Sep 2006 and Sep 2007.
- Master thesis on back-calculated juvenile growth (Sivarajah, 2007).
- Paper on validation of new age determination method (Albert *et al.,* 2009)
- Lab-comparison of American and Norwegian ageing methods, AFSC, Seattle, March 2010.
- Planning meeting of age validation workshop, St. Johns, May 2010.

3 Subproject on improving survey methods and aggregation of data from different surveys

Trawl surveys are one of the main sources of biological information on Greenland halibut. The importance of a survey is first of all defined by the period of observations and how the surveyed area covers the distribution range of the target species. In this respect the joint "ecosystem" surveys carried out by PINRO and IMR vessels in August-October are the most valuable surveys in the Barents Sea shelf area (mainly shallower than 500 m depth). In 2007-2009 PINRO initiated to expand the coverage of these investigations to the north-east (Prishchepa, 2008; Dolgov *et al.*, 2009). Owing to that Greenland halibut is known to be distributed not only in the Barents Sea and the adjacent waters of the Norwegian and Greenland Seas but also in meridian trenches of the Kara Sea (Figure 3, 4). Indexes of all parts of the ecosystem survey are standardized, giving a holistic view of Greenland halibut's living range on the shelf. While the continental slope of the Norwegian and Greenland Seas and the west and central area of the Barents Sea are inhabited by the adult specimen, the northern margin of the Eurasian shelf within the Barents and Kara Seas (and the Laptev Sea apparently) is a nursery ground according to the size composition of the aggregations (Figure 5).

The other important surveys on Greenland halibut are in the main adult distribution area along the continental slope of the eastern Norwegian Sea. While the shelf ecosystem survey use the standard research trawl Campelen (a relatively small modified shrimp trawl), the slope surveys use the larger Alfredo 5 ground fish trawl. Estimates of abundance and distribution are therefore not directly comparable between the two. Usually, the slope survey does not overlap spatially with the ecosystem survey, but in August 2005 a trawl survey was conducted, using three hired commercial vessels equipped with Alfredo 5 trawl. This survey also covered most of the shelf area where normally Campelen trawl is used in the surveys. Highest concentrations were observed in the western slope area, i.e. the main adult area. Also high concentrations were found northeast of Svalbard, mostly consisting of juveniles and young-of-the-year (Figure 6).

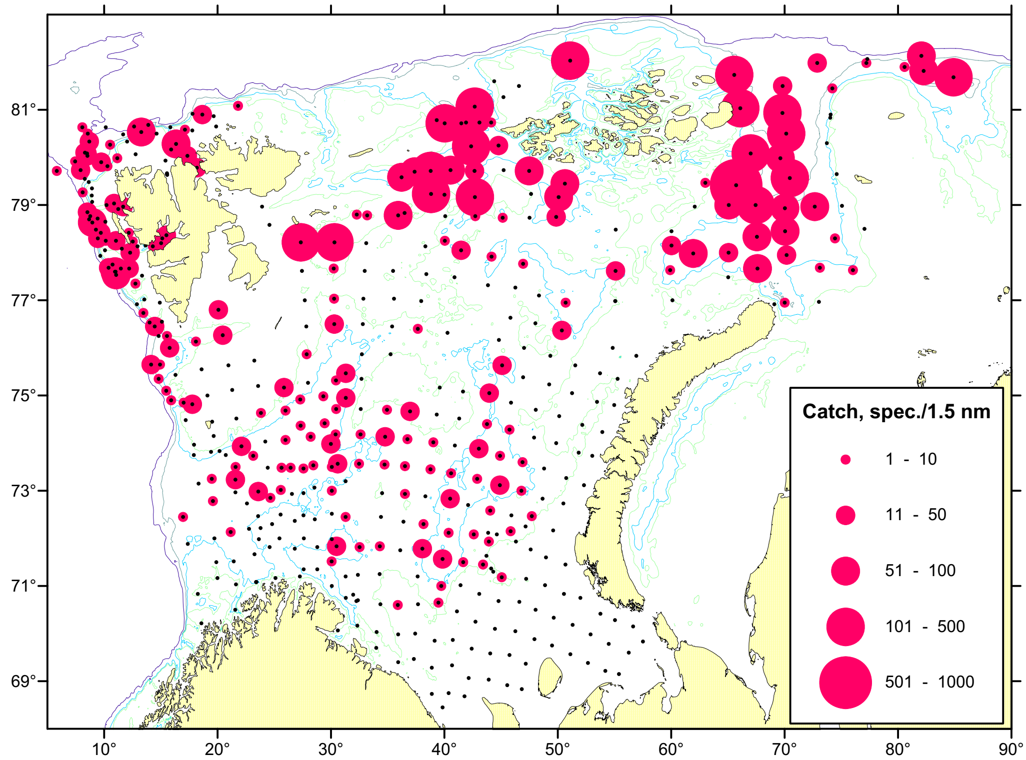


Figure 3. Greenland halibut catches (in numbers) in August-October 2008, spec./1.5 nm. Data from Barents Sea Ecosystem Survey using Campelen trawl.

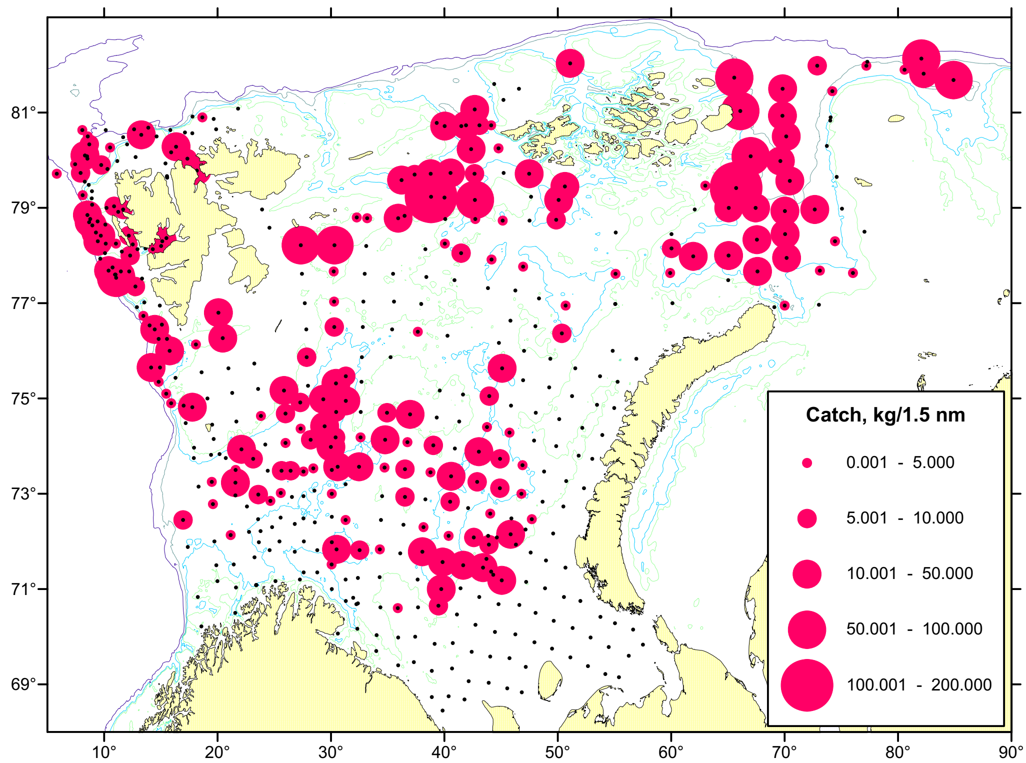


Figure 4. Greenland halibut catches (in weights) in August-October 2008, kg./1.5 nm. Data from Barents Sea Ecosystem Survey using Campelen trawl.

A long series of trawl experiments and behavior studies were made in both the previous and the present tree-year program in order to find the best suited trawl equipment, and with the ultimate goal of developing more realistic absolute abundance estimates from trawl surveys. The Alfredo 5 is three times larger than Campelen and equipped with a much heavier rockhopper ground gear and larger otter boards. The differences influence both gear performance (e.g. bottom contact at great depth) and the behavior of Greenland halibut in relation to the trawl (e.g. avoidance and escapement). Video recording in front of a Campelen trawl showed that large Greenland halibut were only encountered during the first 150 m of the trawl path, and both mean length and rate of encounter were significantly larger in the very start of the hauls than during any other part of the haul duration. The Alfredo 5 on the other side caught large Greenland halibut throughout the haul duration (Albert *et al.*, 2006).

How trawls are selective in catching fish is an important and difficult parameter regarding use of trawls as sampling gear. One part of an otter trawl that has to be addressed separately regarding selection is the gear between the trawl wings and the doors, consisting of bridles, sweepline and tailropes. From the area covered by this part of the gear only fish that are herded into the path directly in front of the trawl will be caught. The selection will thus be different for fish directly in front of the trawl compared to fish that are herded into the trawl path by bridles and sweeps. Flatfish tend to lay still or even burrow themselves into sediments to hide from danger (Ryer, 2008). Thus flatfish usually do not react to oncoming sweeps until the sweeps are close up to them or even touches the fish (Main and Sangster, 1981, Ryer and Barnett, 2006). They may then swim a short distance before settling on the bottom again. Consequently flatfish will be herded into the trawl path in a typical zigzag manner by the repeatedly approaching sweeps (Main and Sangster, 1981).

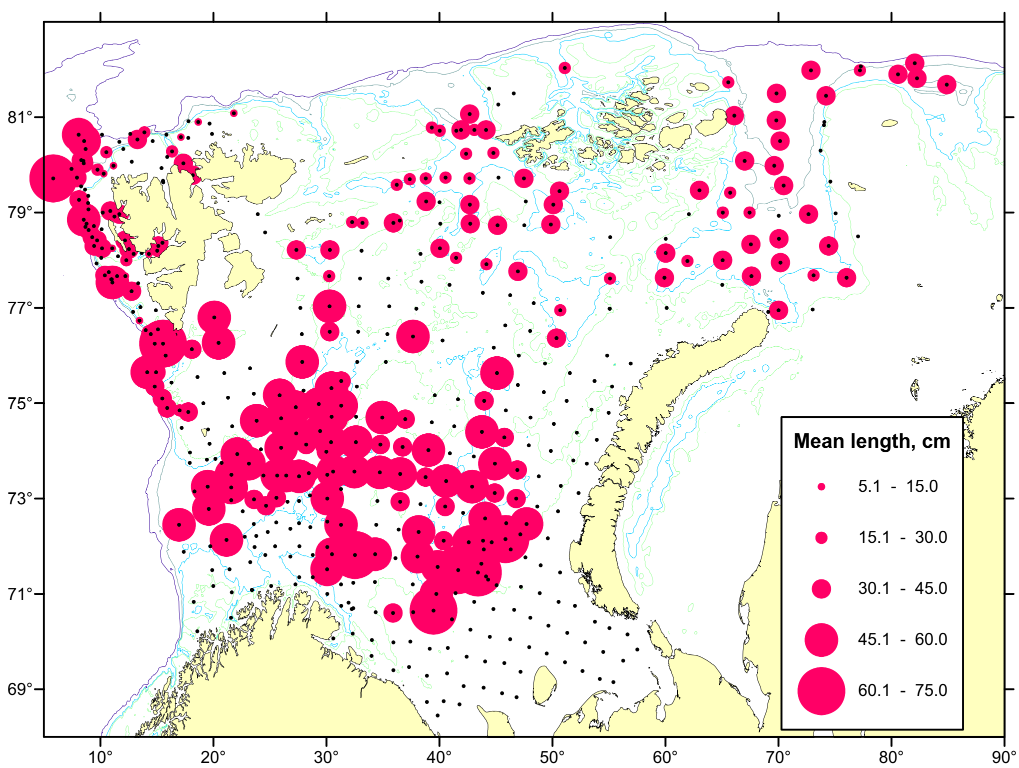


Figure 5. Greenland halibut mean length in trawl catches in August-October, cm. Data from Barents Sea Ecosystem Survey using Campelen trawl.

To examine herding of Greenland halibut by sweeps in Alfredo trawl a field experiment was conducted with three different sweepline lengths; 99 m, 133 m (standard) and 180 m (Hallfredsson *et al.*, in prep.). The results show that trawling with different sweepline lengths did not affect fishlength selection (Figure 7a). Catch rate was lower with 99 m sweeps compared to 133 m and 180 m sweeplines. Catch rate did not differ between 133 m and 180 m sweeps. This shows that there is a functional increase in catch rate with increased sweeplength up to a point where longer sweeps do not result in further increase in catch rate. In another trawl experiment, three auxiliary bags were mounted below the ground rope of the Alfredo 5, catching fish that were overrun or tried to escape below the ground gear. About 90 % of the Greenland halibut passing the ground gear were retained in the main cod-end, and also this part of the catchability coefficient was independent of fish size (Figure 7b).

Based on results from the sweepline length and bag experiments Hallfredsson *et al.* (in prep.) derive a model that describes selection of Greenland halibut in Alfredo 5 trawls. It is believed that the model can improve estimate of absolute biomass based on data from Greenland halibut surveys.

To compare catch composition of Campelen and Alfredo 5 trawls a comprehensive trawl experiment was conducted during the slope survey in 2006, with both trawl types used on 84 of the standard survey stations. The results showed that catch rate estimates based on Campelen were severely biased compared with those based on Alfredo 5. And even more importantly, the bias was highly influenced by both the fish length and by the density of

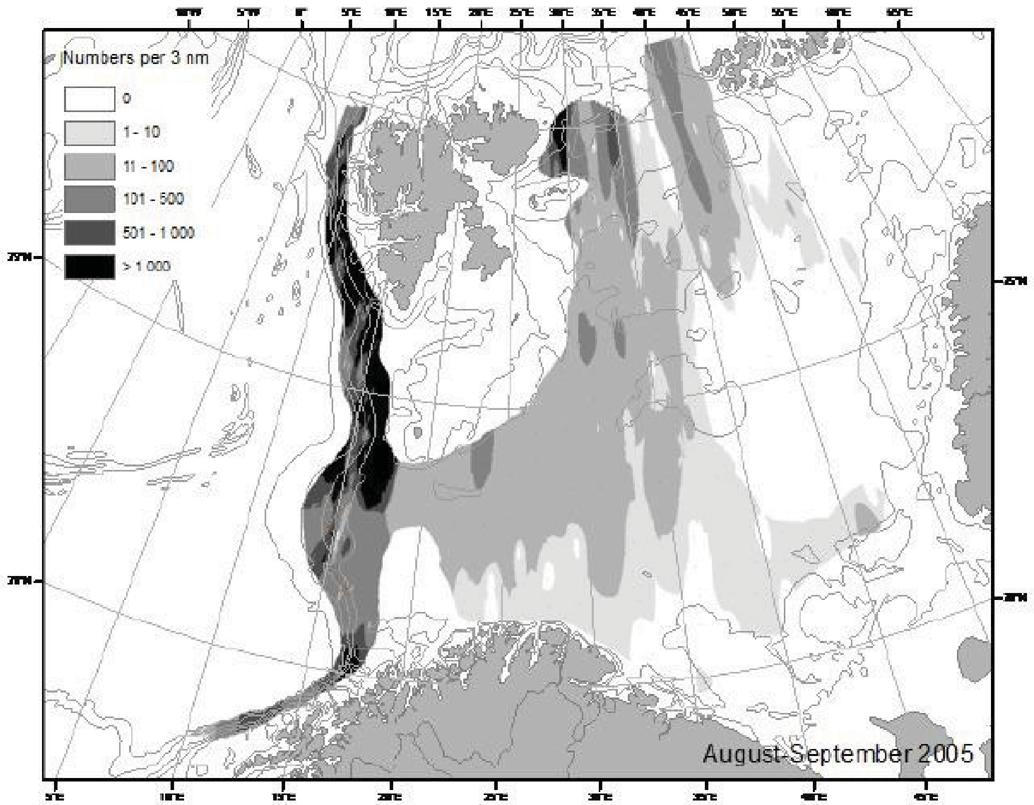


Figure 6. Total density distribution of Greenland halibut from bottom trawl survey on the northern slope and in the Barents Sea, August-September 2005 using Alfredo 5 trawl. Dots indicate sampling stations.

Greenland halibut (Figure 7c) (Albert, in prep.). While length dependent catchability may be accounted for in abundance estimation, there is no way to compensate for large density effects, especially not when the effect vary between size groups. It is therefore concluded that Alfredo 5 gives much more representative samples than Campelen of Greenland halibut in the main adult distribution area along the continental slope.

As part of an effort to estimate zonal attachment of Greenland halibut, catch rates from both the shelf and the slope areas were combined to give a total distribution map. The combination was based on a simplified procedure, not taking into account the experimental results, as these are not yet fully refereed.

There is inconclusive information on seasonal variations in distribution and the variation observed seems to be of minor importance even if there are observed some tendency for mature fish to concentrate in the slope area in the spawning time, i.e. Nov-Dec (Kovtsova *et al.*, 1987; Harbitz, 2010). Due to ice conditions, the young fish areas may only be surveyed during late summer. The snapshot done every year in August-September each year is therefore assumed to give a relatively good picture of the distribution of the stock.

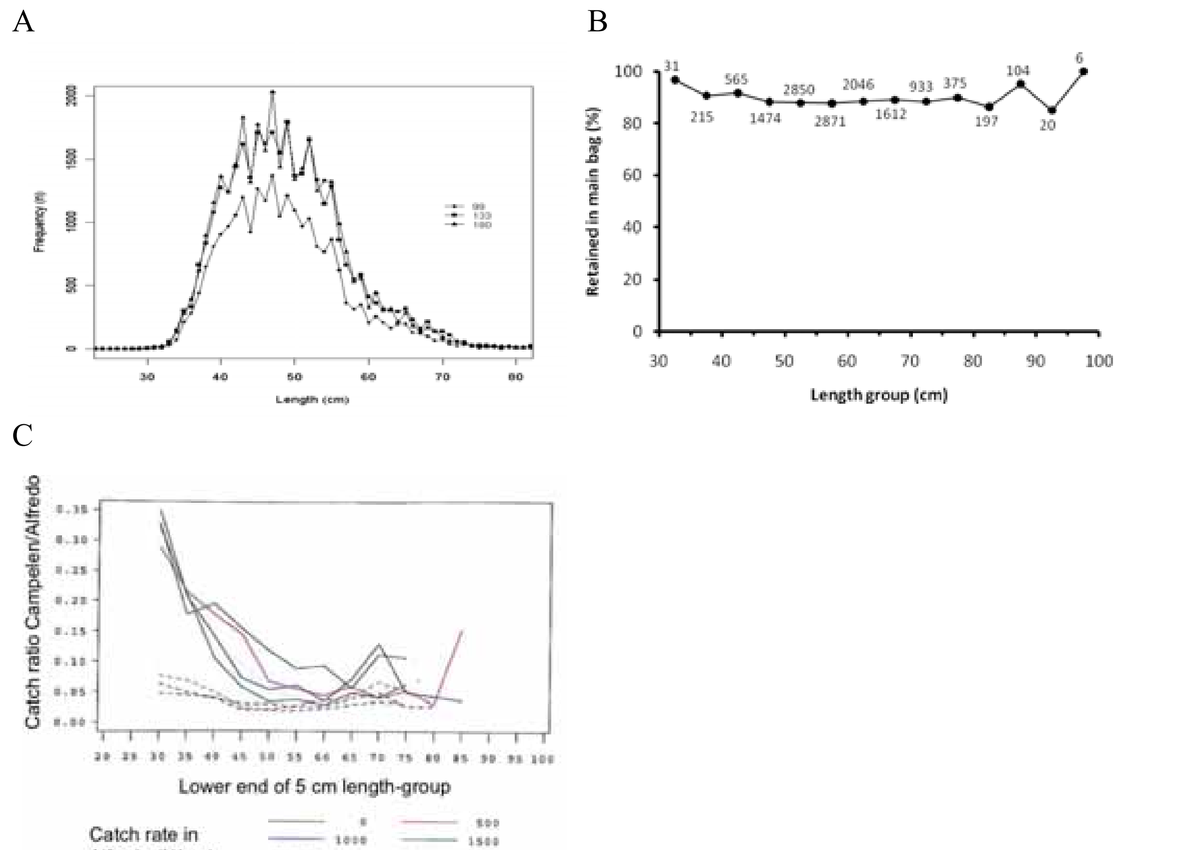


Figure 7. A) Length distribution for the total catch of Greenland halibut per nautical mile at all stations in sweeplength experiment, when trawling was with sweepline lengths 99 m, 133 m and 180 m. B) Proportion by numbers of Greenland halibut retained in the main bag, as found in the experiments for selection in the trawl path. Also shown are total numbers in catch of each length group summed for main bag and auixiliary bags. C) Catch rate by length in Campelen trawl as proportion of catch rate in Alfredo trawl in the pair trawling experiment, separate for low to high catch rate in Alfredo trawl.

Recommendations:

- In adult distribution area along the continental slope it is recommended to use a larger ground fish trawl (e.g. Alfredo 5) for representative sampling of a wider length range than what is possible with Campelen.
- Efforts to develop absolute abundance estimates of Greenland halibut from surveys should be continued. This includes finalization and implementation of results from the different studies in this program as well as designing new experiments to improve precision of parameters that influence results from trawl surveys (sweep-effects, pelagic occurrence, escapements in different phases of the process of trawl-fish encounter, and under different light conditions, density, etc.).

Activities:

- Trawl surveys between Franz Josef Land, Severnaya Zemlya and Novaya Zemlya in 2008 and 2009
- Sweep-length experiment survey, Apr-May 2007.
- Photo-survey for absolute abundance estimation, June 2008
- Trawl experiment survey with bags beneath the fishing line, 2006.
- Alfredo-Campelen trawl comparison survey, 2007
- Results of the investigations requested by the JRNFC were submitted as working papers to the Working Group of the Joint Russian-Norwegian Fisheries Commission on allocation keys for the Northeast Arctic Greenland halibut stock, which presented a report at 38th session.

4 Subproject on pelagic occurrence

Greenland halibut is generally considered a vigorous swimmer (Smidt, 1969; de Groot, 1970) and a voracious predator (Woll and Gundersen, 2004). Tagging experiments show migrations over thousands of kilometers (Boje, 2002), and fast-swimming pelagic fish and cephalopods are the most common prey items (Shvagzhdis, 1989; Dawe *et al.*, 1998; Michaelsen and Nedreaas, 1998; Hovde *et al.*, 2002). Based on experimental fishing with vertical pelagic long-lines and recordings from data storage tags (DST), Vollen and Albert (2008) showed that Greenland halibut make regular excursions several hundred meters through the water column. The distribution of long-line catches within the water column was confined to a well-defined depth layer overlapping with blue whiting, an important prey species, and depth recordings from the DST's overlapped with Atlantic herring, the other major fish prey. Interactions with pelagic prey species can thus potentially influence results from bottom trawl surveys.

The degree of pelagic use varied with fish size as well as seasons. Smaller individuals were found further off the bottom, and pelagic activity was greatest during early autumn. Appropriateness of bottom trawl indices as indicators of stock structure and trends in abundance for this species will depend on if the proportion of pelagic fish is relatively constant between years at the time when surveys are conducted.

It is a general challenge for abundance estimation and behavior studies of demersal fish to distinguish periods when the fish are distributed in close proximity to the bottom, from periods when they are more pelagic in their distribution. This distinction may be of great importance for understanding the behavioral ecology of the species (e.g. foraging times and areas, energy budgets, migrations), as well as the availability of the fish to sampling and fishing gears. For many species, a general understanding of the vertical distribution may be gathered acoustically, but Greenland halibut, as other flatfishes, has very low acoustic target strength due to the lack of swim bladder, and acoustic measurements are presently not feasible.

For place in the North Sea, it has been possible to distinguish pelagic from demersal sequences based on DST trajectories of depth and temperature (Metcalfe & Arnold, 1997). This was not possible for Greenland halibut, since there is no way to distinguish ambient depth from bottom depth in the steep slope area where this species is found.

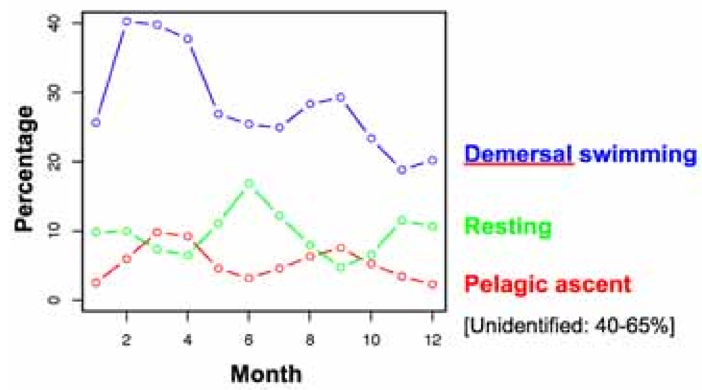


Figure 8. Mean activity budget for adult Greenland halibut througout the year, deduced from archival tag recordings. Assuming pelagic descents take as much time as the pelagic ascents, Greenland halibut may use up to 20% of the time in the pelagic zone.

In order to separate demersal from pelagic time periods in DST recordings, experiments were done with a new tag type that records body angles (pitch and roll) together with depth and temperature. Based on previous investigations of flatfish swimming performance, three hypotheses regarding frequency distribution of body angles during periods of pelagic excursions and periods when the fish swims along the bottom were formulated and evaluated. A total of 19 tags were recovered, representing 80,000 hours of recording. Albert *et al.* (in press) show that for periods when pelagic or demersal swimming behavior can be deduced from the depth trajectories alone, the angular spectra were consistent with the hypothesized patterns for pelagic and demersal phases, respectively. Based on this, a rough estimation was done of the percentage of the time each calendar month that the recaptured fishes had used in the pelagic environment. The results indicated that in spring (March-April) and autumn (August-September), Greenland halibut used about 20% of their time in the pelagic environment (Figure 8). These were also the period when demersal swimming activity peaked, while resting or inactivity was most common in mid summer (June).

Further analyses are currently being made in order to describe the time budget of individual fish throughout the year and how it varies with fish sex and size. Preliminary results (Planque *et al.*, in prep.) show that the activity level of Greenland halibut may vary with light level, with daily active periods gradually decreasing in length around spring equinox and increasing around autumn equinox. During the polar night and polar day periods, there was no apparent diurnal pattern in activity periods.

There has for long been a common perception based on both anecdotic information from fishermen and some scientific information (de Groot, 1970) that Greenland halibut adopt a vertical swimming position during pelagic excursions or during long distance migrations, behaving to some extent similar to a round fish. However, with almost no occurrences of vertical swimming positions during all recording sequences, and no instance of continued swimming in this position, we conclude that such behavior is rare or even absent in Greenland halibut.

Recommendations:

1. Greenland halibut perform frequent excursions into the pelagic, both with cyclic (dial or seasonal) and erratic periodicities, and this might seriously reduce the accuracy of traditional survey indices. This should be taken into account in future benchmark assessments, and may lead to more emphasis on analytical approaches as opposed to survey trends.
2. A method was developed to estimate the pelagic component from analyses of electronic tag trajectories. This method is at present very expensive, but future development of tagging and tracking technology may make it more applicable. Future research could focus on finding practical ways of estimating abundance of this species throughout the water column.

Activities of the subproject:

- Tank experiments on swimming behavior, Mont-Jolly, May 2007 (Vollen *et al.*, in prep.).
- Pelagic trawl survey, Aug-Sep 2006 and 2007.
- Paper-writing workshops, Sommarøy, May 2008 and 2009.
- Paper on vertical occurrence (Vollen and Albert, 2008)
- Oral presentation at Tagging and Tracking symposium, New Zealand, 2008.
- Paper on DST pitch and roll methodology (Albert *et al.,* in press)
- Oral presentation at Ocean Science Meeting, Portland, Feb 2010

5 Subproject on sexual dimorphism and effects of fisheries on population structure

Greenland halibut as other fish species of the order *Pleuronectiformes* has significant distinctions between males and females in rates of sexual maturation (Figure 9), growth dynamics and life span. Females live longer than males and reach bigger sizes (Figure 10). Mechanism of sexual distinctions is considered to be many-sided. Differentiation of males and females by periods of sexual maturation is programmed genetically, and is a ground for a rise and development of other observed displays of sexual dimorphism. Distinctions in life span and growth rates are explained by difference in males and females' rates of maturation. Available data suggests that length of reproductive period in ontogeny for both sexes is the same, but males mature earlier than females. Males' accelerated maturation compared to females requires increased energy inputs to maintain reproductive functions and leads to its growth rate reduction in earlier age.

Table 1. Mean length of Greenland halibut males and females in different areas in 2007-2009 based on the Russian trawl surveys data.

ICES area	Mean length (cm)	
	Males	Females
I	46.6	51.6
IIa	50.3	56.5
IIb	47.3	51.6
Average	48.8	53.7

The basic adaptive significance of males' earlier maturation may be to maintain its maximum possible abundance in spawning grounds. This leads to high concentration of spermatozoa in the flowing water and is essential for successful fertilization of laid eggs. Additionally, distinctions in maturation and growth rates are known to regulate food provision of population's specimen (Nikolsky, 1974).

Due to later maturation females stay longer than males in juvenile feeding grounds and join the adult populations on the spawning grounds at quite large sizes. This is reflected in larger mean size of females in areas where adult Greenland halibut is found (Table 1). Bigger sizes compared to males' may allow females to take the lead in a competitive fighting for food. Results of stomach content observations made in the distribution areas of dense halibut

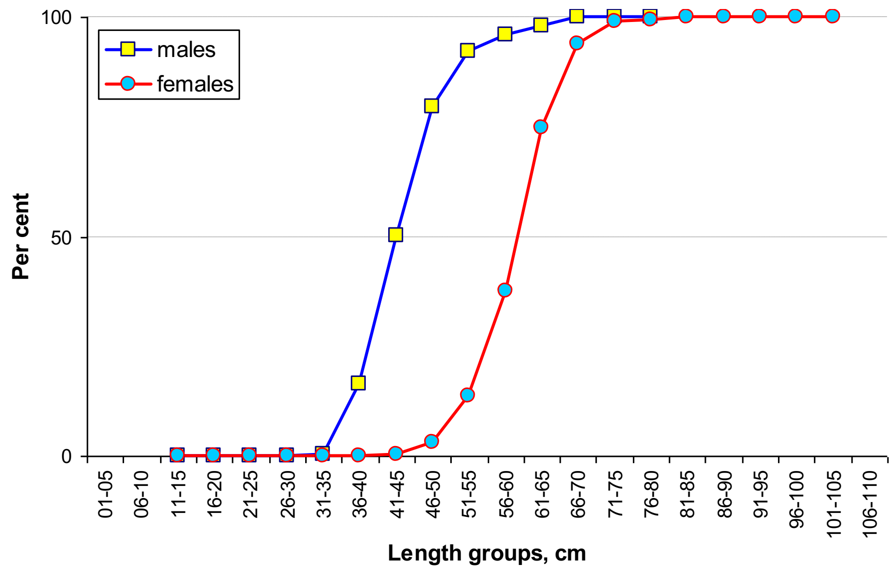


Figure 9. Portion of mature specimens among males and females by length groups in 2007-2009.

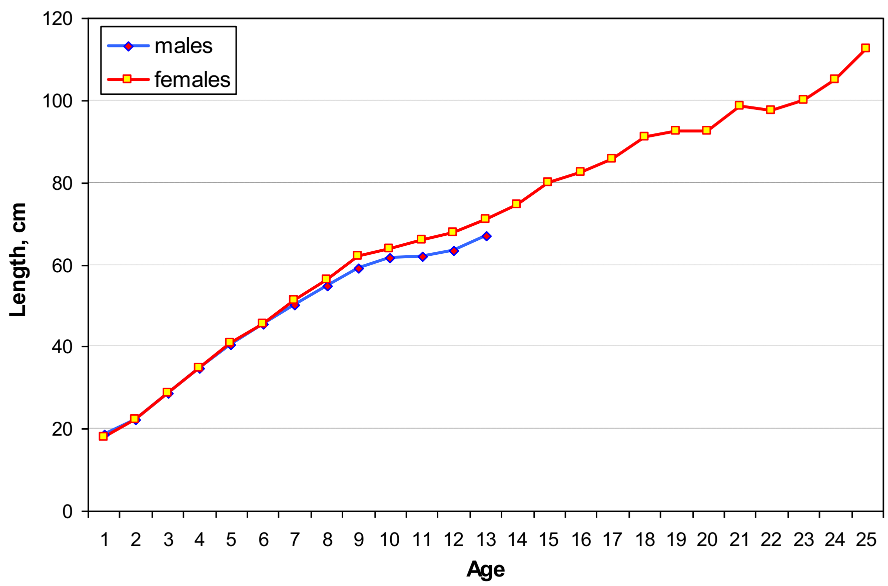


Figure 10. Mean length of males and females at different age in 2007-2009 (based on traditional Russian age reading methods).

concentrations showed that females were almost constantly full-fed (Figure 11).

Feeding success of females compared to males might also be explained by females' distinctive features such as longer feeding period (due to spawning period reduction), higher activity in search for food as reflected in food composition (fish objects' predominance) (Figure 12) and by liability to lengthy feeding migrations. Thus biological consequence of Greenland halibut sexual dimorphism lies in that under other vice equal living conditions females predominate over males in feeding, growth and survival. This promotes population fecundity to a maximal level. The longer females live, the bigger is their accumulation in a spawning stock and the older they become, the more eggs each of them could produce. It is especially vital for Greenland halibut as an accumulation of larger mature females can compensate for relatively

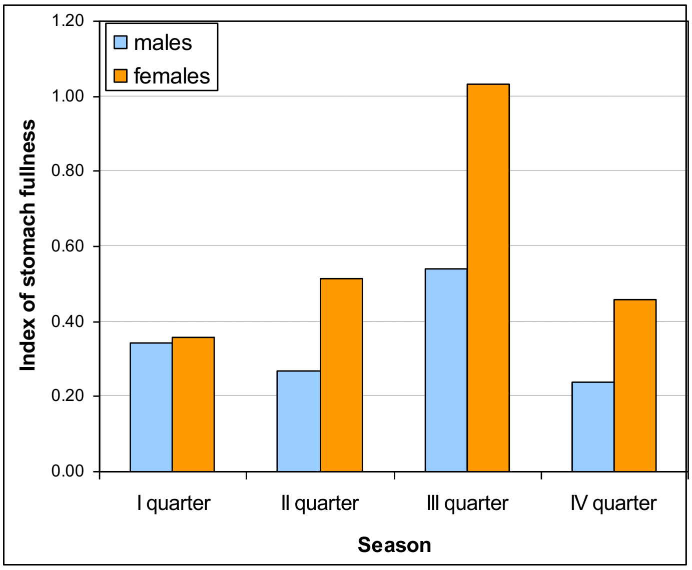


Figure 11. Fullness of males’ and females’ stomachs in the Bear Island area during 2007.

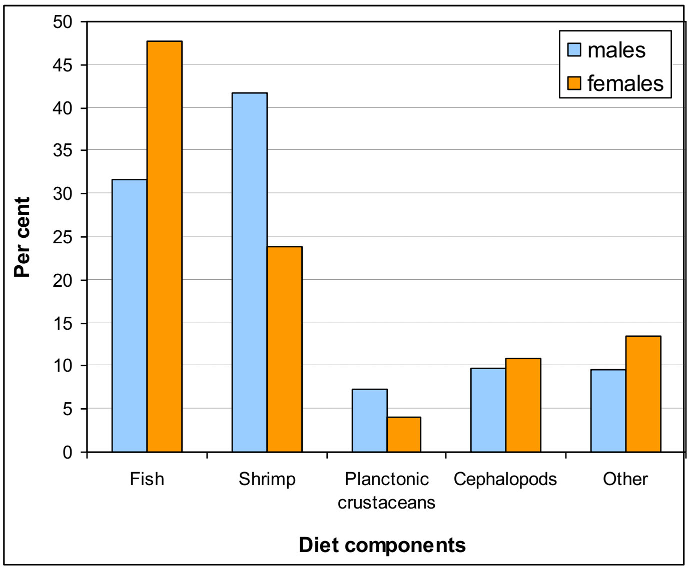


Figure 12. Fullness of males’ and females’ stomachs in the Bear Island area during 2007.

low individual fecundity. Older females have proportionally higher fecundity compared to younger mature females (Smirnov, 1998; Gundersen *et al.*, 2000).

Structure of population is a species characteristic and under natural conditions is rather stable as it reflects formed relation with environment (Severtsov, 1941). In general *Pleuronectiformes* unlike other species (*Gadidae, Clupeidae* etc) has low natural fluctuations of abundance (Nikolsky, 1974; Nizovtsev, 1989). There might be reason to assume that observed changes in population dynamics of the Norwegian-Barents Sea halibut population are caused by human activities. In order to assess level and nature of exploitation impact on a state of fished stock it is essential in each case to take into account particular impact of an amount of catch, gear selectivity, areas and periods of fishery on any population. All existent fish species are phylogenetically adapted to a certain mortality rate. Populations of long-lived species such as Greenland halibut, with long maturation period, multi-aged stock structure and insignificant natural abundance fluctuations are especially vulnerable. According to Ricker's (Ricker, 1963) estimates even relatively low (5% of stock) level of annual catch may change the age structure of a population, whereas catch level of 15-20% may lead to a stock decrease by 2-5 times. According to other estimates (Malkin, 1995) these populations could maintain appropriate regenerative reaction under annual catch level of 16-17%. Based on data from Nizovtsev (1989) it could be indicated that up to the end of 1960s halibut catch didn't exceed 6-8% of commercial stock. According to ICES AFWG calculations in this period annual catch as percent of XSA biomass estimates was averagely 16%, in 1970-1977s – 25%, in 1978-1991s – 24% of landing sized individuals (Figure 13). During the period of trawl fishery ban (1992-2009) this level declined to 15%. It should be noted in this context that biomass estimates for NEA Greenland halibut based on XSA are only accepted as indicative for trends and not as absolute values by ICES AFWG.

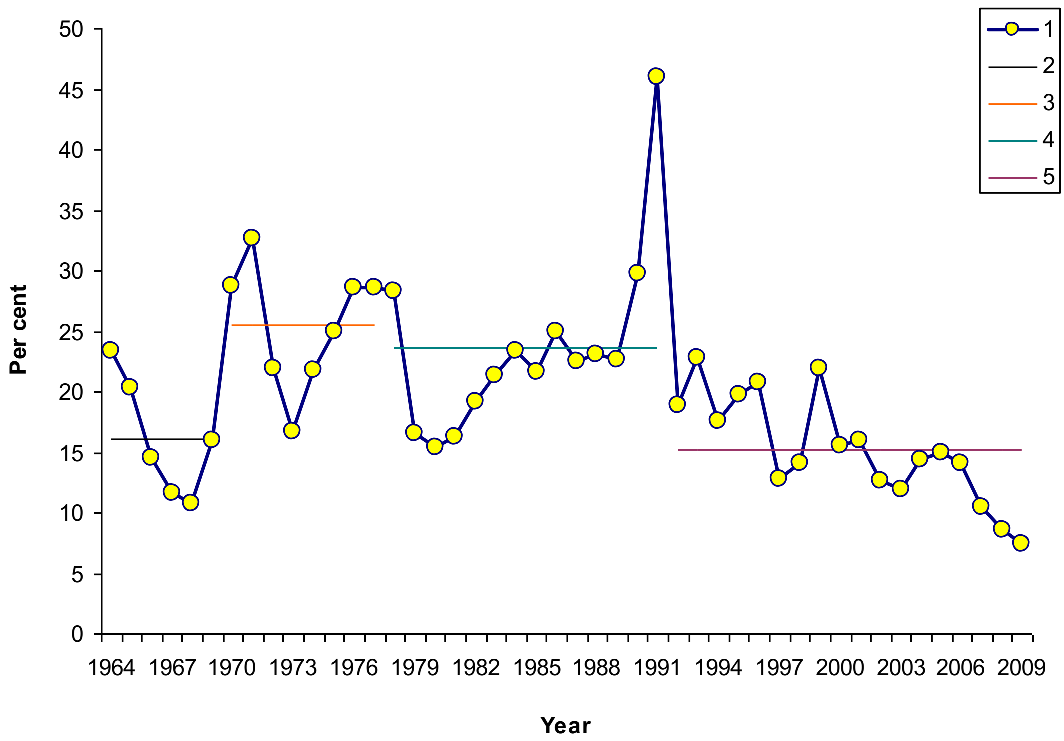


Figure 13. Ratio of total catch to stock biomass as estimated by XSA (ICES AFWG) (%) in 1964-2009 (1) and its average levels for time periods 1964-1969 (2), 1970-1977 (3), 1978-1991 гг. (4), 1992-2009 гг. (4) (ICES, 2010).

Any fishery is more or less selective i.e. intended to uptake particular specimen out of aggregations. Greenland halibut is being caught with a use of both active (trawls) and passive (long line, gill nets) gear. Catches obtained by different gear vary significantly in its composition. Results of earlier investigations in the adult distribution area showed that while bottom trawls mainly catch Greenland halibut less than 60 cm, gill-nets mainly catch fish larger than this and long-line catch intermediate size groups, mainly 60 +/- 10 cm (Huse *et al.*, 1999). Due to halibut's sexual dimorphism different types of fishery therefore affect not only size-age composition but also the sex structure and the ratio of mature and immature individuals in the population. Thus, compared to trawls, catch composition from long lines and gill nets is more dominated by mature females.

Calculations' results based on data of the ICES AFWG (ICES, 2010) and data on females and males ratio amid individuals of various age and on sexual maturity ogives, show that in 1964-1991 due to rejuvenation of the commercial stock, trend towards an increase of immature fish in a catch was observed (Figure 14). In 1992-2009 during the trawl fishery ban, significant catch decline off the Bear island-Spitsbergen area and specific weight decrease of trawl catches favored juveniles' catch stabilizing at the middle level of 2.6 million individuals per year, which affected stock state in a positive way.

In 1992-2009 about 2.3 million mature females had been caught annually (Figure 14) which was significantly contributed by long line and gill nets fishery. During the period trawl fishery decreased by almost 2.4 times in comparison with previous decades, whereas catch by passive

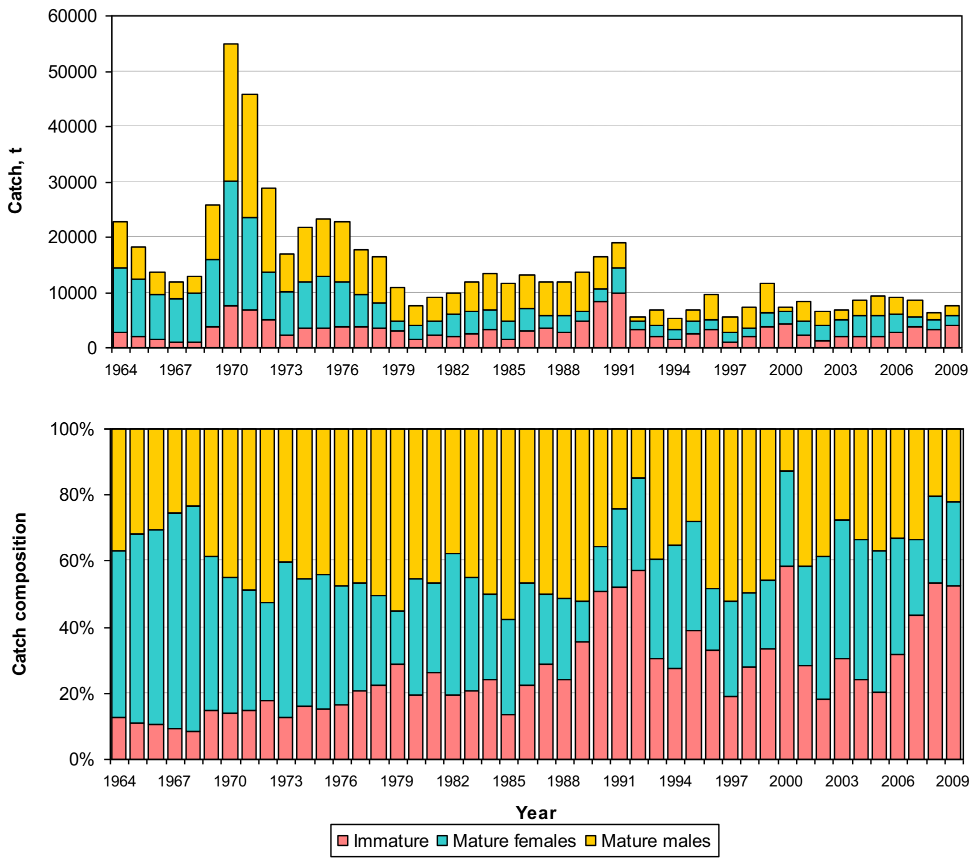


Figure 14. Greenland halibut catch by sex in 1964-2009.

gear increased 2.4 times (Figure 15). In order to achieve an early recovery of stocks, best efforts to protect not only juveniles but also the mature part of the population is important.

Recommendations

Due to some evident differences in distribution and biology between males and females it is important to collect all scientific data on Greenland halibut including length measurements split by sex for its further utilizing in any analytical assessments.

Activities

- Russian and Norwegian scientific trawl surveys in the Barents Sea and adjacent waters in 2007-2009
- Monitoring fisheries in the slope area for observation on length distribution, feeding and maturation dynamics.

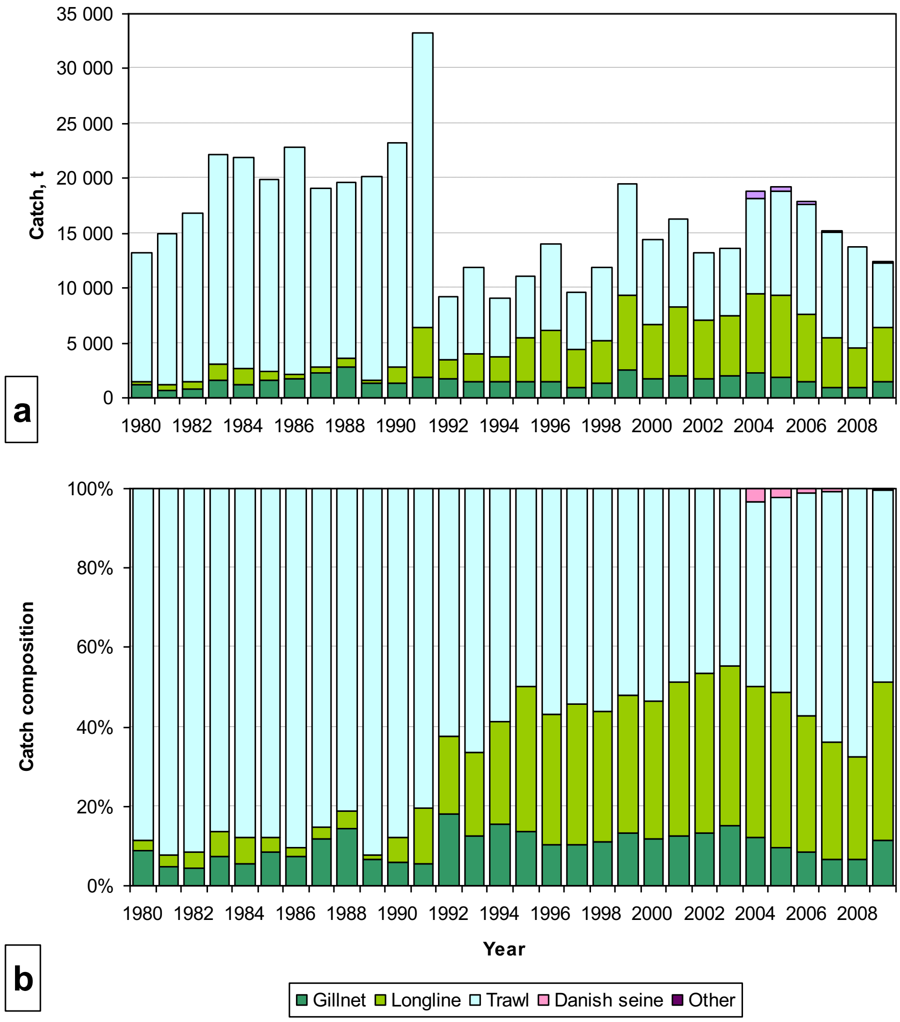
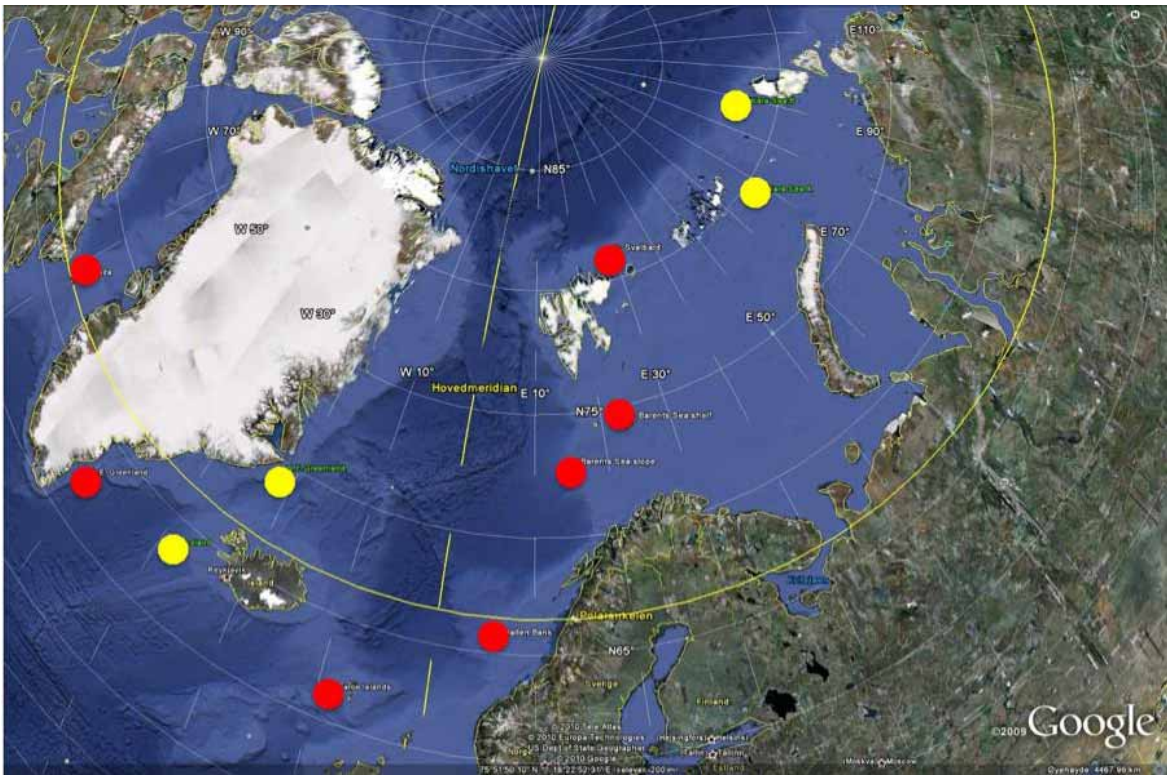


Figure 15. Greenland halibut catch by gears in 1980-2009 (ICES, 2010).

6 Subproject on improving methods of stock assessment

Population structure

In the period 2003-2007 a study of genetic structure of Greenland halibut was initiated. Samples were collected from six localities throughout the North Atlantic. About 100 individuals from each location were collected (Table 1 in Knutsen *et al.*, 2007). The samples were mostly composed of mature individuals except for the Svalbard sample which consist of



	5	6	7	8	9	10	11	4	3	2	1
5		0,275	0,940	0,476	0,901	0,411	0,619	0,175	0,027	0,032	0,051
6	0,001		0,996	0,497	0,988	0,261	0,848	0,241	0,152	0,374	0,078
7	-0,002	-0,003		0,984	0,629	0,727	0,943	0,380	0,931	0,944	0,003
8	0,000	0,000	-0,003		0,548	0,132	0,242	0,008	0,112	0,049	0,002
9	-0,002	-0,002	-0,001	0,000		0,319	0,642	0,214	0,531	0,869	0,277
10	0,000	0,001	-0,001	0,002	0,001		0,266	0,151	0,067	0,078	0,026
11	-0,001	-0,001	-0,002	0,001	-0,001	0,001		0,441	0,020	0,699	0,021
4	0,001	0,001	0,000	0,005	0,001	0,002	0,000		0,002	0,004	0,007
3	0,003	0,001	-0,002	0,002	0,000	0,002	0,003	0,006		0,112	0,045
2	0,003	0,000	-0,002	0,002	-0,001	0,002	0,002	0,005	0,002		0,101
1	0,003	0,002	0,007	0,007	0,001	0,005	0,004	0,006	0,003	0,002	

Figure 16. Genetic sample locations (Red dots: Previously analysed samples; Yellow dots: New samples) and pairwise comparisons of genetic distance. Fst values below diogonal and corresponding p-values above. Significance levels above 0.90 and 0.95 are marked with yellow and red respectively.

juveniles (Knutsen *et al.*, 2007). The samples were analyzed by six microsatellites (McGowan and Reith, 1999, Coughlan *et al.*, 2000). The results indicated a genetic structure where the subpopulations were partly isolated, with some evidence of isolation by distance. The next step was to include more samples from Island, Greenland and Kara Sea (Figure 16). These results support the initial findings by suggesting an east-west genetic structure of Greenland halibut. The results found no significant difference between the samples within the Northeast Atlantic and the "Kara Sea" samples.

The lack of genetic structure between the Northeast Arctic stock and the samples from Faeroe Islands and from East Greenland waters north of Iceland may be due to migration of juveniles from Svalbard nursery area. Approximately 25 000 juvenile Greenland halibut were tagged (and OTC marked) in Svalbard waters during 2006-2008. Recaptures from Iceland and Faeroe Island appeared from 2009 onwards, and we expect more recaptures over the next few years. Of 44 recaptures from the tagging experiment in 2006, 14 were recaptured at Iceland or Faeroe Islands (Figure 17).

The six microsatellites selected for the present study was initially identified in halibut (*Hippoglossus hippoglossus*) by McGowan and Reith (1999) and Coughlan *et al.* (2000). They worked well for Greenland halibut, but experience shows that such microsatellites could be less variable in other related species and hence not be the perfect marker of choice to show the total history of population genetic structure of Greenland halibut. In a new project (funded by the Norwegian Research Council; "Use of Single Nucleotide Polymorphisms to improve

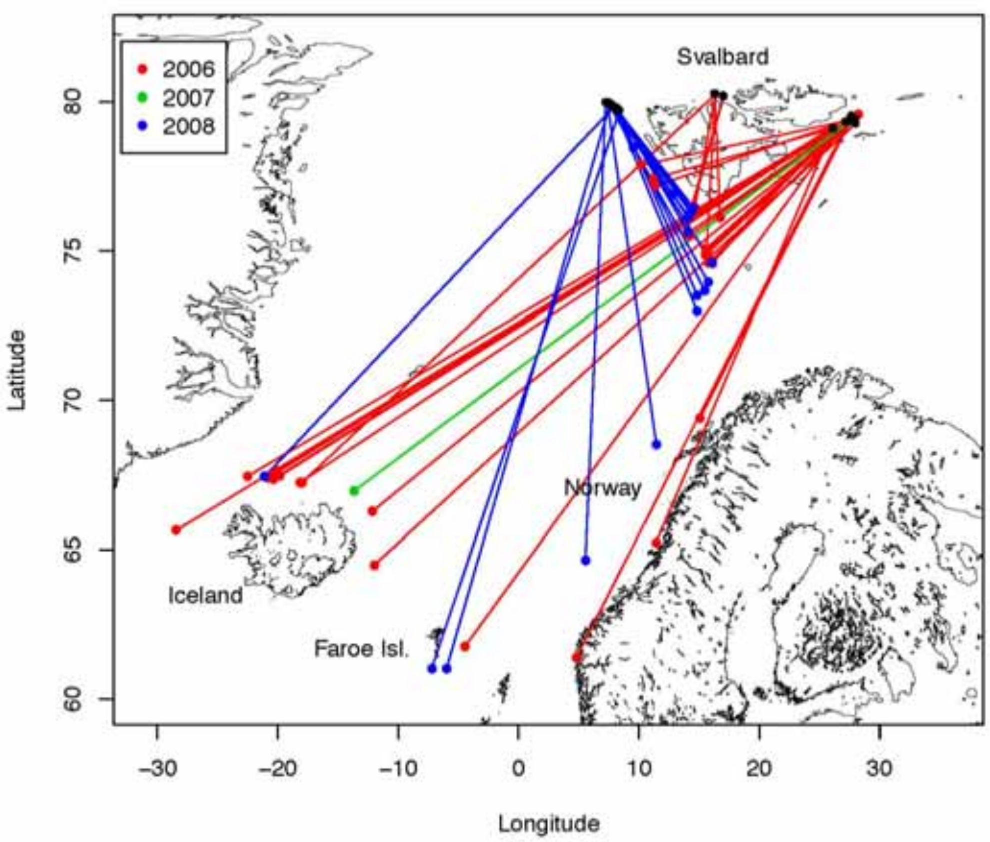


Figure 17. Recaptures of Greenland halibut tagged as juveniles in Spitsbergen waters 2006-2008. Tagged fish were injected with OTC for validation of age reading methodology.

fisheries management"; SNPFISK) we will the next years do additional analysis with genetic markers specially developed for Greenland halibut and hopefully give more power to the stock structure of the species.

Age structured models

Analytical assessment of NEA Greenland halibut has in recent years been focused on age structured models (XSA). Due to uncertainties in estimation on age reviled in course of the investigations this analysis is currently accepted only as indicative for trends within ICES (ICES AFWG 2010 report). Continued use of age structured models is considered the best way forward. This allows monitoring of recruitment and other age related attributes of the stock, as well as giving the best possible abundance estimates.

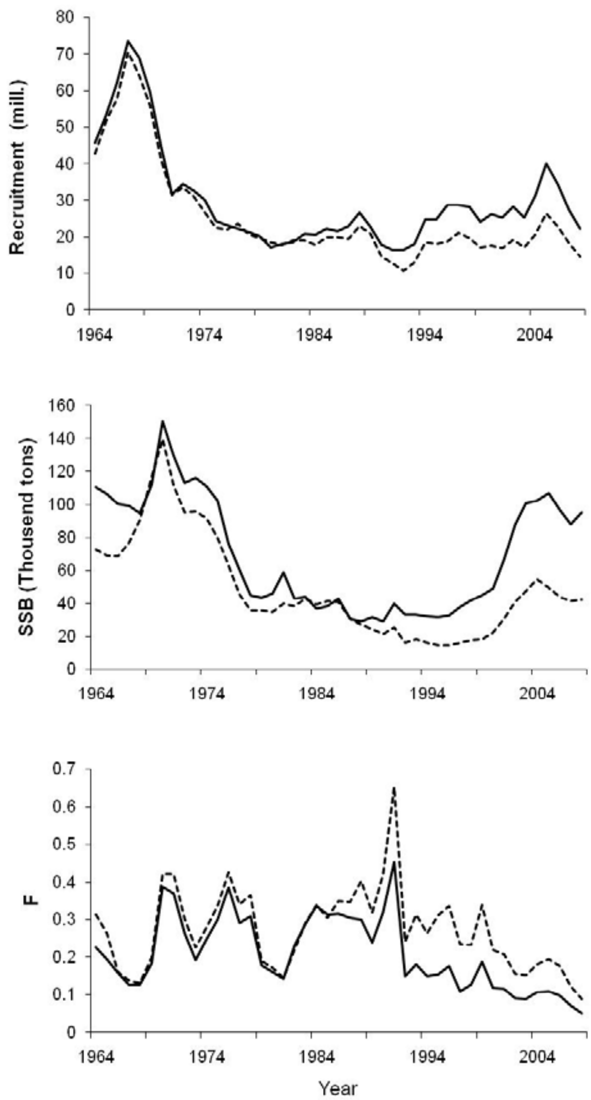


Figure 18. Estimated recruitment (R), spawning stock biomass (SSB) and fisheries mortality (F) by year for NEA-Greenland halibut; as found in the ICES assessment 2009 (stippled line) (ICES, 2009), and as found in Hallfredsson (2010) (black solid line) based on same data but with modification of age related model assumptions.

As correct ageing as possible is an essential input in age structured models and the current XSA analysis for Greenland halibut is shown to be sensitive to age related parameter choices. In a study of sensitivity of the current ICES analytical assessment of Greenland halibut XSA was run with the following modifications of model assumptions. Age 13 was defined as plus group in the model, instead of the oldest age in the data (15) as was done by the AFWG. This was done because the data available for the oldest fish were imperfect and gave high variance in the regression statistics. Catchability was defined independent of age for ages >= 11 instead of ages >=10, as catchability at age 11 was considered more in line with the trend in catchability (Hallfredsson, 2010). The results show that these modifications considerably change the estimates of recruitment (R), spawning stock biomass (SSB) and fisheries mortality (F) compared to the results of AFWG in 2009 running on the same data (Figure 18). Particularly the estimated 2008 SSB is considerably higher in the run with modifications. Even though both runs to some extend show similar trends, the difference is not a parallel displacement. E.g. in the run with modification, estimated SSB in 2008 is 86% of the 1964 SSB, while in the AFWG run 2008, SSB was 58% of 1964 SSB.

Thus the historical trends differ between these runs even though results in both cases show positive trends in SSB since 1995.

In the research program, substantial focus has been on improvement of age reading for Greenland halibut, as discussed in chapter 2 in this report. Solving the age reading problem is presently the one single effort that is most important for improvement of the analytical stock assessment. When age reading is in hand, considerable effort will be needed to implement new results and restore the analytical assessment.

Alternative models
Surplus biomass models are an alternative to age structured models. These models are not as data demanding, but the results are less informative than those from age structured models. A surplus model combined with Bayesian statistical approach is in use for Greenland halibut in northwest Atlantic (ICES NWWG). Hitherto signal in CPUE for NEA Greenland halibut stock has been considered insufficient for construction of reliable surplus biomass model fit.

During the last AFWG meeting (2010) a presentation was given on assessment for Greenland halibut in 1998-2009 based on satellite monitoring, daily reports and GIS methodology (Bulatov and Moiseenko, VNIRO, Moscow). The AFWG have found several points which does not allow for this method to be used for absolute abundance estimation and considered that it has probably potential for use only as an index of relative abundance that can be utilized as an additional tuning series for a VPA.

Recommendations:

- When age reading problems are solved data need to be revisited to get inputs to age structured models.
- Age structured models other than XSA might be applied to examine observation error in input data.
- Biomass models might be constructed to support the XSA run currently accepted as indicative for trends. An alternative here is the surplus model approach used for Greenland halibut in the northwest Atlantic.
- Continued genetic analysis of Greenland halibut with the newly developed molecular genetic markers

Activities:

- Working document to AFWG 2010 (Hallfredsson, 2010)
- Genetic analysis of stock structure, 2010

7 Subproject on developing optimal long-term harvesting strategy

In 2009 during traditional March meeting of PINRO's and IMR's scientists, Parties prepared and came to an agreement about proposals to the Greenland halibut Management Plan in the Barents Sea and adjacent waters, which included following statements:

"A ban on direct fishery for Greenland halibut in the Barents Sea and adjacent waters has been maintained since 1992. Catch limitations and stock conservation measures have been successful. ICES has for several years recommended that TAC be limited to 13 thousand tons, whereas actual catches in 1992-2008 varied between 8.6-19.5 thousands tones. In the same period measures of stock status have improved and show a positive dynamics.

In order to conserve and increase the Greenland halibut stock, to ensure its rational harvesting and long-term sustainable yield, the Parties agreed that a Management Plan (MP) with an appropriate harvest control rule (HCR) is needed. These should apply to all marine areas in the ICES Divisions IIa, IIb and I, and should specifically include measures to ensure precautionary sustainable development of the stock."

".... at present there is no agreement on the basic growth and mortality processes for this species. This uncertainty complicates the possibility to use biological target reference points, as biomass or fishing mortality, for stock management. Pending the development of such reference points, the Parties agreed that at the initial stage MP and HCR should be based on keeping the TAC within limits that has proved sustainable in the past.

Total allowable catch will be established by the Joint Russian-Norwegian Fisheries Commission on the basis of annual ICES advice and taking into account the recent scientific data. After adoption of an agreed MP, a HCR should be developed that specifies how new ICES advice on stock development should be transferred into management actions. As science develops, in the future MP and HCR should take into account an improved reliability of stock assessment.

TAC is allocated into national quotas in accordance with the developed allocation keys. The Parties should submit catch data in compliance with the reporting system that will allow for an effective quota control.

The Parties will continue to work at establishing and harmonization of technical regulations in the Greenland halibut fishery, including control and enforcement measures".

At 38th session of the JRNFC the Parties agreed that mutual effort of Russian and Norwegian scientists to research Greenland halibut has been successful and that knowledge on biology and distribution of this stock has been improved. The Parties agreed to lift the ban on direct fishery for Greenland halibut from 2010 onwards. They also agreed on division of the Greenland halibut stock and set a TAC of 15 thousand tones annually for 2010-2012 (Protocol, Chapter 8.1). Total quota for Greenland halibut (including scientific quotas allocated out of national quotas) is allocated as follows – 51% to Norway, 45% to Russia and 4% to third countries (Protocol, Annex 3).

The ICES Arctic Fisheries working group that is responsible for Greenland halibut stock assessment, stated in 2010: …"the assessment is considered to be still uncertain due to the age-reading and survey data quality problems. Nevertheless the assessment may be accepted as indicative for stock trends…The main result from the assessment is that the total stock has an increasing trend since 1992 and this is also seen in the SSB from 1995 to 2004. In 2004-2008 the SSB show a decreasing signal, whereas it has a significant increase in 2009".

Biomass index for adult Greenland halibut based on data from the Norwegian survey at the spawning grounds in August-September indicate much slower increase in biomass than does the XSA run from the AFWG, while biomass index from the Russian survey at the slope and in the Barents sea in October-December shows a pronounced increase after 2005 (Figure 19). The increase after 2005 might indicate increase in abundance in pre-adult Greenland halibut that are found inside the Barents Sea rather than at the slope, which is a positive signal regarding recruitment to the fishable stock. Length distributions from the Norwegian slope surveys support this and show increase in numbers of small fish (Harbitz *et al.*, 2010). The stock of Greenland halibut seems to be in a positive trend but the signals differ on how rapidly the stock is rebuilding, depending on data sources. This highlights the need for a solution on the aging problem to allow for age structured analytical assessment that is agreed upon within ICES.

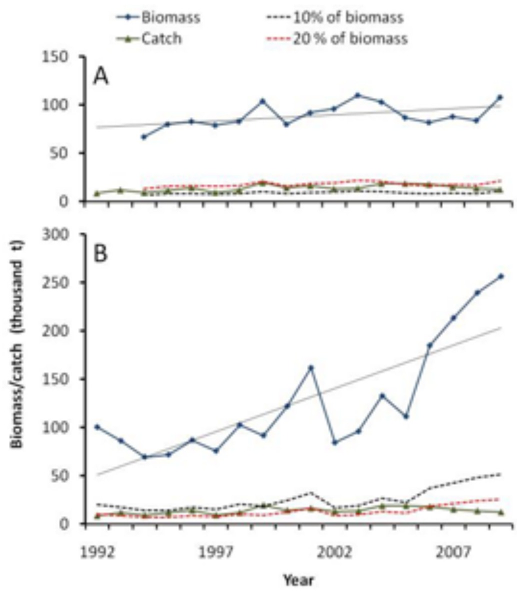


Figure 19. Total biomass index based on data from A) Norwegian slope surveys at the spawing grounds in august-september (Harbitz *et al.*, 2010) and B) Russian survey at the slope and in the Barents sea in October-December (Smirnov, 2010). Also shown is development in catches 1992-2009 (AFWG 2010).

As it was mentioned above development of scientific advice on further exploitation of Greenland halibut's stock based on specific biological target reference points would be possible only after overcoming divisions in age reading. Providing that management strategy is developed on the ground of catch volume that wouldn't prevent stock from growing, it should be mentioned that average catch during the period of fisheries ban (1992-2009) have consisted ca.14,000 t. Average catch during the period 1992-2003 have consisted ca. 13,000 t, and during last few years (2004-2009) – ca. 16,000 t (Figure 19).

Recommendations
To continue cooperation to develop the scientific basis for future fishery management of the stock.

Activities

- Working in special subgroups in frame of traditional March meetings of IMR and PINRO scientists.
- Participating in JRNFC working group on allocation keys for NEA Greenland halibut.
- Working documents for ICES AFWG.

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