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Survey strategy for monitoring Norwegian deep-sea fish species

Alf Harbitz, Benjamin Planque, Elvar Hallfredsson and Ole Thomas Albert

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PROSJEKTRAPPORT

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Tittel (norsk/engelsk):
Survey strategy for monitoring Norwegian deep-sea fish species

Toktstrategi for overvåkning av norske dyphavsarter

Forfatter(e):
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Sammendrag (norsk):

Rapporten dokumenterer resultatene fra prosjekt 13327 med formål å etablere metoder for overvåking av dypvannsarter. Etter presentasjon av prosjektets mandat og bakgrunnsinformasjon om tidligere tokt og deres rolle for råd og forskning, er en generell metode for toktevaluering presentert. Videre er spesifikke aspekter ved survey design evaluert med kvantitative metoder. Basert på resultatene av disse analysene, er en multiårlig surveystrategi foreslått. Den bygger på tre kjernetokt: To tokt langs Eggakanten ca. 62°N – 75°N (Egga Sør) og 62°N – 80°N (Egga Nor), og et tokt i Norskehavet ("dyp-pelagisk" Norskehavstokt). Egga Nor og Egga Sør bør bli gjennomført annenhvert år, alternerende, mens timeplanen for det dyp-pelagiske norskehavstoktet bør defineres i henhold til anbefalinger fra ICES-WGRS. I tillegg bør dypvannsstasjoner opprettholdes på økosystemtoktet i Barentshavet og på reketoktet i Nordsjøen (Norskerenna). Denne nye strategien innebærer en betydelig reduksjon i årlig seiletid sammenlignet med tidligere år, også for 2011 der alle toktene er planlagt gjennomført.

Summary (English):

This document reports on the results of the project 13327 on establishing methods for the surveillance of deepwater resources. After a presentation of the project mandate and background information on past surveys and their role for advice and research, a general method for survey evaluation is presented and specific aspects of survey design are evaluated with quantitative methodologies. Based on the results of these analyses, a multiannual survey strategy is proposed. It is build on three core surveys: two surveys along the continental slope approximately 62°N-75°N (Egga Sør) and 62°N-80°N (Egga Nor), and a survey in the Norwegian Sea ("open sea deepwater"). Egga Nor and Egga Sør should be conducted every two year, alternating, while the schedule of the "open sea deepwater" survey should be defined in accordance with recommendations from ICES-WGRS. Additionally deepwater stations should be maintained on ecosystem survey in the Barents Sea and on shrimp survey in the North Sea (Norwegian Trench). This new survey strategy offers a

substantial reduction in requested annual ship-time in comparison with recent years, even for 2011 when all three surveys should be conducted.

Emneord (norsk):	Subject heading (English):
1. Flerårlig toktdesign	1. Multi-annual survey design
2. Saktevoksende bestander	2. Slow-growing species
3. Toktevaluering	3. Suvrey evaluation

Prosjektleder

Faggruppeleder

Content

1   Abstract and Recommendations

1.1   Abstract

A multiannual survey strategy is proposed, based on three core surveys: "Egga Nor", "Egga Sør" and "open sea deepwater". Egga Nor and Egga Sør should be conducted every two years, alternating, while the schedule of the "open sea deep water" should be defined in accordance with ICES-WGRS recommendations. All three surveys should be conducted in 2011.

1.2   Recommendations

Based on analyses of available deep-water surveys, the following recommendations are made:

1. **Egga Nor is the key Greenland halibut survey**. The adult Greenland halibut survey along the continental slope in August using Alfredo trawl (the Egga Nor-survey) is the key survey for this species and provides consistent and reliable indices of as well abundance as of stock composition. This survey is necessary for stock assessment and management advice on Greenland halibut and provides important additional data for advice on other parts of the deep-sea eco-region.

2. **Restricted annual Greenland halibut sampling is sufficient for stock monitoring**. The Egga Nor survey provides information on Greenland halibut age-groups from the late juveniles and upwards. For the mature part of the stock, the inter-annual variation is low, and it is considered sufficient to cover this part of the stock every two year. For information on recruitment to the fishable stock, it is necessary to have annually repeated measures of stock composition. This requires less effort than a full coverage to estimate abundance. Thus, adult Greenland halibut should be given full coverage every other year, while a restricted sampling will be sufficient for the years in between.

3. **Bear island trench should be included in Greenland halibut surveys**. The Egga Nor survey has traditionally left out the deeper part of the Bear Island trench. This is unfortunate, as a substantial part of the adult and late juvenile stock is found there, and since it only requires a few extra days to cover it. At the same time, there is room for reducing the total number of stations within the area traditionally covered by the survey. It is recommended that area coverage of the new biennial Egga Nor survey be extended into the Bear Island trench, without increase in the number of stations.

4. **Alfredo 5 trawl is needed for Greenland halibut**. Extensive trawl comparisons have shown that the Campellen trawl (standard bottom trawl at IMR) is not suitable to catch adult Greenland halibut, due to severe length and density dependence in catchability. The Alfredo 5 trawl is also similar to the trawls used for Greenland halibut in neighboring areas to the south (British, Fareoes, Icelandic, Greenlandic areas), which are included in the ICES WGNEACS Nordic deep-water surveys coordination. It is therefore imperative to use Alfredo 5 trawl on the Egga Nor surveys. This limits the potential vessels to G.O. Sars, Johan Hjort and Helmer Hanssen, or a suitable rented commercial vessel.

5. **Biennial Egga Sør spring surveys should be run for greater silver smelt and redfishes**. The continental slope and adjacent deeper shelf areas from approximately 62°N to 75°N are important areas for greater silver smelt and redfishes during their spawning periods in late spring. This is where and when these species are most concentrated, and recent surveys suggest that reliable abundance estimates of both

species may be achieved with a trawl-acoustic survey using both demersal trawl and large pelagic trawls. It is recommended to establish Egga Sør survey on a regular biennial basis.

6. **Egga Sør provides needed Greenland halibut recruitment data and requires Alfredo 5 trawl**. The area coverage of the Egga Sør survey will overlap with Egga Nor, but will be run in other years and in spring instead of autumn. Analyses show little seasonal variation in Greenland halibut abundance and structure, and it is considered that the biennial Egga Sør survey may provide the necessary length compositions of Greenland halibut from the years when Egga Nor is not run. This requires that Alfredo 5 trawl be used as the demersal trawl on Egga Sør.

7. **Data on *Sebastes mentella* from IMR-surveys in cooperation with international surveys**. The international survey on pelagic beaked redfish in the open Norwegian Sea is coordinated by ICES WGRS and is expected to run every two or three years. It is recommended to run this survey in cooperation with the international partners and with the frequency that will be adopted by the working group. The survey provides necessary data for management of the pelagic fishery by NEAFC in international waters and for the assessment of *S. mentella* in ICES areas I and II.

8. **No lower frequency than every two years is recommended for the Egga Nor and Egga Sør surveys.** Based on the data analyses it is not recommended to reduce the frequency of Egga Nor or Egga Sør surveys to less than once every two years. Since no deep-sea surveys were conducted in 2010, it is therefore suggested to run all three in 2011 and start alternating between surveys from 2012 onwards.

9. **Dedicated sampling required from other surveys**. In addition to the surveys above mentioned, assessment of deepwater fish stocks and ecosystem requires dedicated sampling to be carried out during other IMR-surveys. The current level of sampling of deepwater species during regular surveys (e.g. winter and ecosystem) must be maintained, except for a possible reduced sampling of juvenile Greenland halibut in the ecosystem survey. In addition, it is suggested that extra days of sampling should be allocated to the coastal and fjord survey and the Skagerrak shrimp survey to specifically cover the deeper parts of these regions.

2 Mandate

The commercially important deep-sea fish species greater silver smelt, beaked redfish and Greenland halibut are distributed in a continuous belt-like manner along the continental slope and deeper continental shelf areas, greater silver smelt mainly in the southern part, the redfish species further north while Greenland halibut is the northern most species. For these species management advice is required and thus IMR must keep on having secure good estimates on stock dynamics (abundance and stock structure). New research shows that all these species are slow growing with long live span. The need for yearly surveys might thus be reduced, and to save survey time, one may wish to establish a multi annual survey strategy with rotating centre of attention (one year a good coverage of greater silver smelt, but still a small part of the Greenland halibut distribution is covered, next year best coverage of redfish etc.). The project will incorporate simulations of different multiannual coverage, based on established

surveys, to find the optimal combination and periodicity, for each species or each subarea. It will also include statistical problems regarding the establishing of time series based on varying coverage. The project has relevance for other slow growing species as well, including Roughhead grenadier, Roundnose grenadier and many species of elasmobranchs.

Project leader: Alf Harbitz. *Duration:* 1 year. *Budget*: 0.5 mill. NOK. *Program connection*: Norskehavet.

Comment: Due to rather extensive workload on the preparation of the data, the extent of the intended stochastic simulations was reduced.

3.   Background
3.1   General context
This report deals with fishery independent surveys of deep-water fish in Norwegian waters. This includes the continental slope from British sector to Svalbard, and further eastwards along the shelf break of the Arctic Ocean, as well as several deeper trenches and channels extending into the North Sea, Barents Sea, and coastal areas. The species of interest include several commercially exploited ones, such as Greenland halibut, Atlantic halibut, beaked redfish, golden redfish, greater silver smelt, roughhead grenadier, roundnose grenadier, ling, tusk, with combined commercial value close to one billion NOK annually. It also includes several species of low or no commercial interest, like velvet belly, spiny dogfish, rattail, thorny skate, arctic skate, spinetail skate, round skate, and several others.

Apart from Greenland halibut and greater silver smelt, all these species are either listed on the national Norwegian red-list as vulnerable or worse (www.artsdatabanken.no), or the status is considered uncertain or is not evaluated due to lack of data. Based on general biological features, like growth rate, longevity, age at maturity and fecundity, more than half of the 82 fish species occurring in IMR deep-water trawl surveys (below 400m) have high or very high intrinsic vulnerability[1] The rest are mostly species with their main distribution in shallower areas, which to a large degree are covered by IMR's regular bottom fish surveys and pelagic surveys.

Unlike species associated with shelf seas and coastal banks, there exist few distribution boundaries for the deep-water species. They are generally distributed more or less continuously along the slopes on either side of the Norwegian Sea. It is therefore highly relevant for future Norwegian deep-water surveys that the Nordic countries have recently initiated cooperation with respect to standardisation and analyses of data from comparable

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[1] E.H. Hallfredsson, T. Vollen, L. Heggebakken, B. Planque and O.T. Albert 2009. Fishes below 400m depth in Norwegian waters: Vulnerability and Management. Poster presentation E55 at the ICES Symposium "Issues Confronting the Deep Ocean", Horta, Portugal, 2009. ; William W.L. Cheung, Tony J. Pitcher and Daniel Pauly, 2005. Biological Conservation, 124: 97-111

deep-water surveys. This work is coordinated within ICES working group for NE-Atlantic Continental Slope surveys, WGNEACS[2].

This report is based on the premise that it is necessary and important to regularly evaluate the status of commercially exploited stocks, as well as of other species influenced by fisheries and other anthropogenic activities, in all eco-regions, including the Deep Sea eco-region. This is considered self evident in the context of present national and international laws, agreements, conventions and protocols signed by Norway (*New Norwegian ocean resources act, Convention on Biological Diversity, Rio agreement on straddling and highly migratory fish stocks, Johannesburg declaration on sustainable development, Kyoto agreement on Sustainable Contribution of Fisheries to Food Security, FAO code of conduct for responsible fisheries).*

The report also assumes that part of the information must be sampled by fishery independent methods. Only species that can be sampled by trawls or observed acoustically are considered, since these are the observation methods that are most developed to provide quantitative estimates. This leaves out some important deep-water species, like ling and tusk, which are distributed in areas not suitable for bottom trawling, and which are mostly caught with long-lines. It is recognized a potential for a stratified long-line survey series covering the wide-spread hard-bottom areas of the deeper shelf, but data from such surveys would not be comparable with those from the trawl surveys.

The previous deep-water surveys were initially designed for single stock purposes, but our purpose is to establish a new survey series that balances the requirements for data-rich stock assessments of all the commercially most important species, as well as providing sufficient data on changes in other biological components of the Deep Sea eco-region.

3.2   Role of surveys for DW fisheries science and advice.

Direct observations of fish stocks and other components of marine systems do not restrict to vessel-based surveys, but also include market sampling, fisheries observers, buoys & other automated in situ instruments, or remote observations (planes, satellite). These are now more and more combined with numerical models to help interpreting the data collected or to provide hind-, now-, or forecasts of marine system states and more generally to provide robust quantitative estimates. Data collection from each of these observation platforms needs to be considered in the context of the ensemble of available observation methods. Observation collection must also be designed, so that collected data can be useful for the numerical models in use or numerical models that can reasonably be anticipated.

Monitoring fish stocks can be achieved using fishery data, but surveys provide essential data. There is a long history of collection of fishery dependent data to monitor both fisheries and

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[2] ICES CM 2009/LRC:03, Report of the Planning Group on the North-east Atlantic Continental Slope Survey, 9–11 June 2009, Tromsø, Norway, ICES. 2010. Report of the Working Group for North-east Atlantic Continental Slope
Survey (WGNEACS), 8–10 June 2010, ICES HQ, Copenhagen, Denmark. ICES CM 2010/SSGESST:16. 81 pp.

fish stocks. These include for example: market sampling, observers at sea, log books or more recently VMS[3]. Although relatively inexpensive in comparison with research surveys, fishery data suffer from severe limitations such as the near-total lack of data collection for species other than commercial fish, cases of misreporting and irregular area coverage. This can (and has) lead to discrepancies between what fishery data can tell and what a given fish stock is actually undergoing. It is, for example, well known that CPUE series can remain stable whilst a fish stock is being depleted due to unaccounted progresses in fishery technology (not reflected in the effort) or to aggregative behaviour of fish, which allows for high catch rates until the near collapse of a stock. Fishery independent survey data are thus essential to adequately monitor the state of marine populations.

Scientific surveys-at-sea are essential platforms for scientific investigations and ecosystem monitoring. Aside from abundance estimates and demographic parameters (e.g. age, length, sex, maturity), field surveys can also provide information that cannot usually be derived from fishery data. These include data on populations (e.g. geographical distribution and aggregative patterns, or vertical distribution) and at ecosystem level (e.g. species composition, biodiversity, physical and chemical ocean environment). This is of primary importance when investigating key issues such as effects of climate change on population's geographical ranges, changes in trophic interactions, or ecosystem scale dynamics (regime shifts and resilience).

In summary, dedicated scientific field surveys can provide the necessary data to assess the state of commercially exploited fish and shellfish wild populations, as well as the state of marine ecosystem. Such data can be complemented - but not replaced - by other data sources and numerical model simulations.

3.3   Expectations for DW ecosystems and species at IMR.

Deepwater eco-region is not a well-defined concept. For the purpose of this report deepwater eco-region within the Norwegian EEZ is defined as shelf and slope areas where bottom depth exceeds three to four hundred meters. The Norwegian deepwater eco-region thus includes deeper continental shelf and slope areas, as well as deep areas within fjords. This definition corresponds with distribution of fish that are considered deep-sea species within IMR. The main focus of surveys covered here are fish communities rather than invertebrates, and current surveys are aimed at shelf and slope areas rather than fjords. This report covers to little extent expectations of Norwegian participation in surveys in international waters.

Species defined as deepwater fish at IMR are of different commercial importance. In the past there have been aimed surveys on primarily Greenland halibut, redfish and greater silver smelt. Data are scarcer on other species such as ling, tusk, Atlantic halibut, elasmobranches. However, Norwegian laws on resources in the sea advocate broader view concerning the effects of human activity, including effects on fish stocks other than mortality caused by

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[3] Vessel Monitoring System

targeted fisheries. At the same time funding is a limiting factor. International survey coordination to be kept in mind relates to the ICES groups PGRF, WGNAPES, WGNEACS, and PGDNSS.

Expectations on delivery from Norwegian deep-sea surveys relates to data collection for research on methodological improvements and basic research (aimed for publishing in international journals) as well as routine data collection. There is a need to develop and adapt scientific methods to improve quality of advice on consequences of human activity as fisheries in the deep-sea eco-region. Related issues are non-target deep sea species and biodiversity. This basic research is primarily depending on fisheries independent data while both fisheries data and survey data are utilized in assessment of commercial species. The main objectives of the routine survey data collection for assessment purposes are at present:

NEA Greenland halibut: Maintain time series to monitor distribution and abundance for adult stock and juveniles (trawl indices). Survey data are also used as tuning series for analytical assessment with age structured single species models. Currently XSA is used but only accepted as indicative for trends due to problems in age reading. This situation puts increased importance on survey indices at present. Delivery to ICES expert group AFWG.

Redfish (*S. mentella, S. marinus*): Data to monitor stock abundance and distribution requiring participation in an internationally coordinated pelagic survey in the Norwegian Sea, in addition to data on the distribution on the continental slope within the Norwegian EEZ (acoustic data, trawl indices). Data to support a single species model (SCAA, GADGET). Delivery to ICES expert group AFWG.

Greater silver smelt: Data on biological parameters such as maturity, length/age distribution, spatial and temporal distribution to support fisheries data. The aim is monitoring based on fisheries data along with acoustic survey indices. Main attention is on the area north of 62°N where direct fisheries takes place, but additionally distribution of concern is found south of 62°N (North see/Skagerrak). Delivery to ICES expert group WGDEEP.

Ling and tusk: At present the assessment is based on fisheries data and evaluation of CPUE trends. Fisheries independent data are called for to monitor recruitment and abundance. Longline survey is considered most suitable due to hard bottom habitat choice. Delivery to ICES expert group WGDEEP.

Roundnose grenadier: No analytical assessment, landing trends and length compositions from survey. Identification of strong year classes between years, and abundance indices. At present data are provided from deep stations from a North Sea shrimp survey. Delivery to ICES expert group WGDEEP.

Roughhead grenadier: No analytical assessment, landing trends only. Identification of strong year classes between years, and abundance indices (survey dependent).

Atlantic halibut: Information on distribution and indices on density from surveys. Data on length distribution and age distribution if possible. Data on other biological reference parameters (which parameters yet to be decided). Access to better data from other sources such as tourist fisheries would strengthen monitoring.

Sharks, skates and other non-commercial species: Presently regular evaluation of the state of these species is limited or absent in Norwegian waters. Information on distribution and indices on density could be derived from surveys that cover the whole deepwater eco-region on a regular basis.

4.   Overview of past and current surveys

At IMR, surveys targeting deep-water species have largely been species-specific, providing the basis for stock evaluations and advice to fishery management. Most notably, two Greenland halibut bottom-trawl surveys have been run annually since the early/mid nineties, one targeting the adult stock and another on the juvenile distribution. Both surveys have recently been modified to target a broader set of species. These two surveys cover a depth gradient along the shelf break towards the Norwegian Sea (from Lofoten to Spitsbergen), and the Arctic Ocean, respectively.

Another survey targeting greater silver smelt and redfish by means of acoustics, as well as pelagic, semi-pelagic and demersal trawls, were run annually in 1980-1994 and in 2007 and 2009. Provisional trials were done in 2007 and 2008, based on historic survey series in the eighties, before a successful methodology and coverage was established in 2009. It is believed that this survey captures the main part of the spawning stock of both greater silver smelt and beaked redfish. This survey covers the slope and the deeper part of the shelf from 62°N to Tromsøflaket.

An international survey covering the deeper part of the pelagic Norwegian Sea was carried out during summer 2008 and 2009. This survey was mostly dedicated to the evaluation of the redfish (*S. mantella*) stock in this area, as a response to the developing pelagic fishery in international waters.

In the Skagerrak deep, some deep trawl stations have been included in the annual shrimp survey, and a few deeper stations are also taken during the coastal ecosystem survey.

Table 4.1 lists key features of the abovementioned deep-sea surveys.

Figure 4.1 shows approximate survey coverage of the three main Norwegian deepwater surveys in 2009.
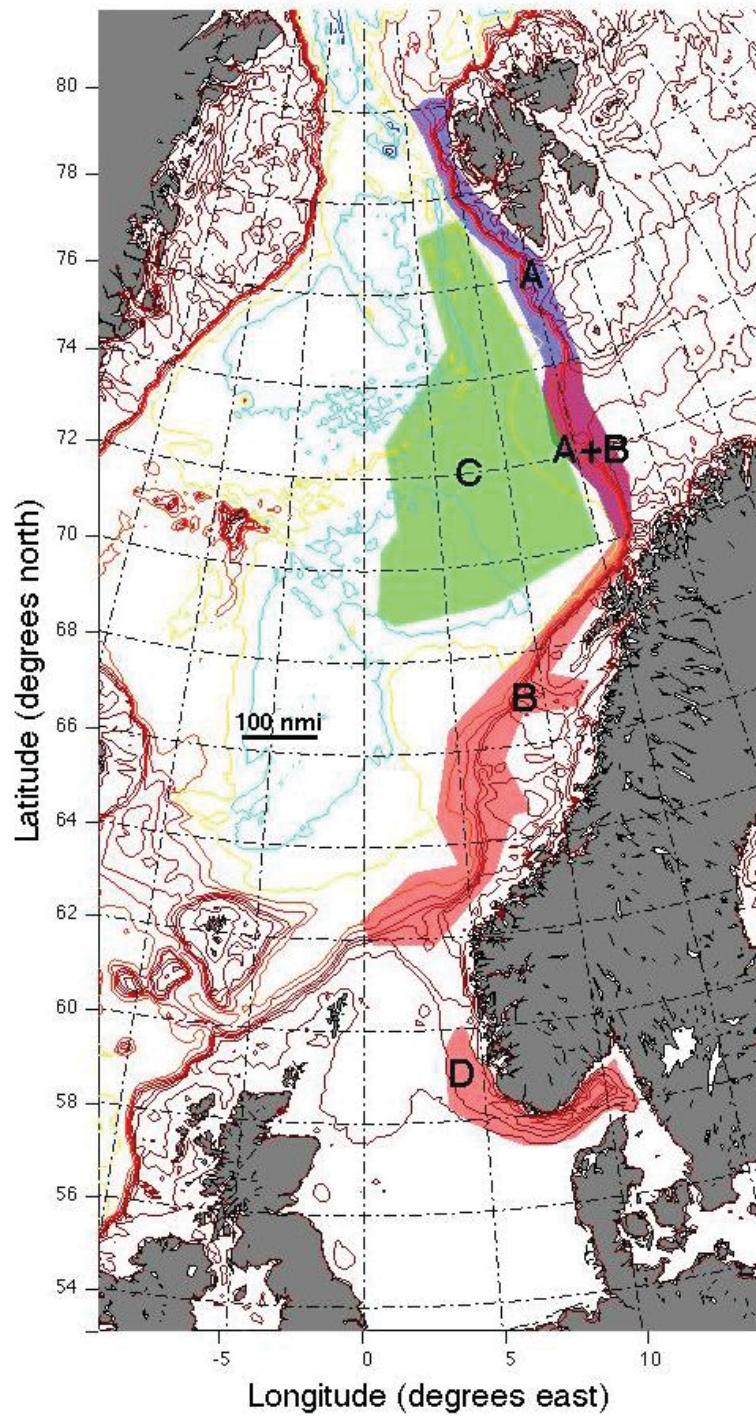
Figure 4.1. Approximate survey coverage of main Norwegian deepwater surveys:
A: Egga Nor, B: Egga Sør, C: Open Sea deepwater, D: Norwegian shrimp survey in Skagerrak and the
Norwegian Deep

Table 4.1. Key features of current deep-sea surveys and other surveys contributing to deep-sea species investigations.

Survey name and type of vessel	Area coverage and main sampling gear	Season and freq.	Approximate number of trawl hauls			Other relevant sampling
			Pelagic trawls >300m	bottom trawls >500m	bottom trawls 400-500m	
Greenland halibut survey (Eggatoktet) Rented vessel	Slope and deeper shelf, 68-80°N Alfredo	Aug-Sep Annual	0	170	20	
Greater Silver smelt and redfish survey Rented vessel	Slope and deeper shelf, 62-72°N Argentine trawl	Mar-Apr Occasional	30	21	13	Acoustic, CTD
Shrimp survey in Skagerrak HI-vessel	Skagerrak and the Norwegian Deep Campelen	Jan-Feb Annual	0	0	7	CTD
Coastal ecosystem survey HI-vessel	Coast-near areas from Kirkenes to Ålesund Campellen	Oct-Nov Annual	0	0	5	Acoustic, CTD
Juvenile Greenland halibut survey HI-vessel and Russian vessels	Deeper shelf towards the Arctic Ocean Campelen	September Annual		5	5	Acoustic, CTD
Barents Sea Ecosystem Survey[4] HI-vessel	Barents Sea down to 4-500m Campelen	Aug-Sep Annual	0	21	25	Acoustic CTD
WGNAPES[5] HI-vessel / Rented vessel + other nations	Norwegian Sea, pelagic down to 400m Pelagic trawl	June Annual	78	0	0	Acoustic CTD
Pelagic redfish in Norwegian Sea Hired vessel[6]	Norwegian Sea, pelagic below 500m Gloria trawl	September Occasional	24	0	0	Acoustic, CTD
WGNEACS[7] Combination of hired vessels and vessels run by different national laboratories	Deeper demersal areas of East Greenland, Iceland, Faro Islands and Norway	Annual, coordination in progress	0	195	117	

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[4] reported numbers are from the 2009 survey
[5] reported numbers are from the 2009 ICES-PGNAPES report
[6] reported numbers are from the 2009 survey
[7] 2009 data for Iceland, Faroe Islands and Greenland (Norwegian surveys in former table rows)

5. Evaluation of DW surveys with multiple goals – expectations and evaluation criteria

Based on the information presented in sections 1-2, we summarise below the main expectations from DeepWater surveys and the key elements of context in which these surveys are conducted. On this basis it is possible to define a set of evaluation criteria against which survey strategies can be evaluated (sections 5,7).

5.1 Information/data expectations and constrains

Data collection should support:
- advisory capacity for commercially important species, for non-commercial iconic species and for deepwater ecosystems,
- development of high quality publishable science
- technological development (and benefit from them)

Survey data should include:
- demographic data of sufficient quality to support the assessment of key commercial deepwater fish populations, i.e.: Greenland halibut, Atlantic halibut, redfishes, greater silver smelt, grenadiers, ling and tusk
- data on spatial distribution of key populations
- data on biodiversity, ecosystem structure and trophic interactions
- data in support for investigation of climate change effects on deepwater ecosystems

In addition, the following data aspects should be considered:
- seasonal variations in geographical distributions and migrations
- coverage of fjords, continental shelf, slope and open ocean systems
- environmental observations (meteorology, ocean physics, chemistry and biochemistry)
- maintenance of existing time series (which form the backbone of any climate change related study)

Collection of data and information should also account for:
- existing knowledge
- political and institutional priorities
- national and international scientific collaborations
- available technology
- available competence
- available vessels and ship-time
- available funding

5.2 The following evaluation criteria are recommended to evaluate different survey strategies:

Advisory capacity on single stocks:
Greenland halibut
Beaked redfish
Golden redfish
Greater silver smelt

Ling and tusk
Atlantic halibut
Grenadiers
Elasmobranches

Advisory capacity on other stocks:
Non target deep sea fish species
Biodiversity

Geographical coverage:
Fjords
Shelf
Slope
Open Ocean

National and international collaboration:
(Iinter)national projects (e.g. EU projects)
(Inter)national survey coordination (e.g. through ICES)

Research:
Process studies and methodological developments
Potential for publication

Other matters:
Maintenance of time series
Coverage of difference bottom types (including rocky bottom)
Collection of environmental information
Seasonal coverage
High seas

The advisory capacity on individual stocks remains a primary objective of the fisheries surveys conducted by IMR. For this reason, specific numerical analyses have been undertaken to assess the impact of different survey strategies on the quantitative assessment of key stocks. To assess the effect of running regular surveys with a lower frequency than once per year, a time series is needed. The report therefore has focused on the Greenland halibut data, which is the only deepwater species for which an available time series was available. The analyses are presented in section 6.

6.   Quantitative Analysis of present DW surveys

6.1   Introduction

The main purpose of the quantitative analysis is to examine how fast important biological parameters, such as length frequency distributions and abundance, appear to change over time (years). The slower the change is, the lower frequency of repeated surveys is needed. And in general the change is expected to be rather slow for long-lived deep water fish species. To do this exercise a survey time series is needed, which only exists for Greenland halibut (1994-2009) for the scope of this study[8].

Another purpose of the quantitative analysis is to estimate the precision of the parameter estimators, to have an idea of how large real changes must be in order to be discovered from one survey to the next.

6.2   The annual Egga survey, Aug-Sep 1994-2009

These annual surveys have the duration of about 3 weeks providing close to 200 bottom trawl samples along the continental shelf slope between 68 and 80 degrees north and at bottom depths between 400 and 1350 meters.

Visualization of the spatial distribution of biomass density

The extension of the study area is very small across the slope (approximately east-west direction) compared to the extension along the slope (approximately south-north direction). To illustrate the spatial distribution of e.g. biomass density over the horizontal plane, it is therefore convenient to visualize this in a (depth, latitude) coordinate system rather than in the traditional geographical coordinate system. An example is shown in Figure 6.1 for 2006, which also shows the 16 stratified areas that are used in the abundance calculations.

Figure 6.1 clearly indicates that the density is much lower in the shallowest and in the deepest strata compared to depths in between (500-1000m). No very clear density trends are seen in the north-south direction (in contrary to some other years), and within each stratum the densities (circle areas) appear to be rather independent in general. Some depth gradients are indicated within some of the strata, along with some spatial correlation in the north-south direction. Still, in the estimates of abundance precision (cv = standard deviation divided by mean value)-it is assumed that no big error is done by treating the observations within each stratum as being independent of each other. Neglecting a positive correlation will give too small cv-values, while neglecting monotonic trends goes in the opposite direction.

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[8] Høines, Å.S. and Gundersen, A.C. 2008. Rebuilding the Stock of Northeast Arctic Greenland Halibut (*Reinhardtius hippogglossoides*). J. Northw. Atl. Fish. Sci., Vol. 41: 107-117.
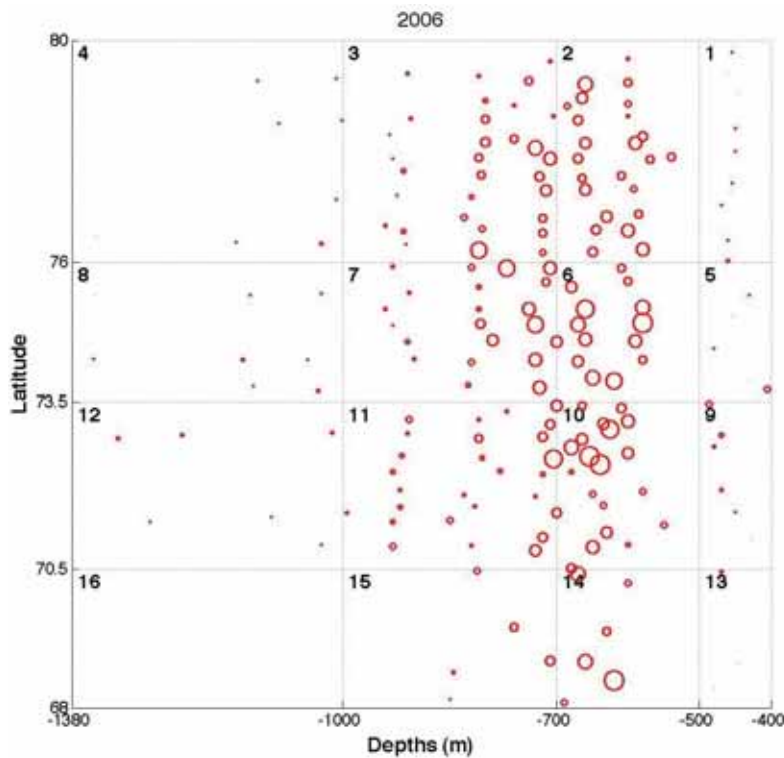
Figure 6.1. Biomass densities for Greenland halibut as observed during the Egga Survey Aug-Sep 2006. Circle areas are proportional to density (kg/nmi^2) at each station. Strata numbers are shown in the upper left corner of each stratum.

Abundance estimation

The abundance estimates in terms of biomass and number of individuals for the whole study area are shown in Figure 6.2. The 95% confidence intervals are calculated based on the assumption of independent observations. Their widths are proportional to the inverse of the square root of sample size. In general the cv-value is about 10%. If the effort was reduced by 50% the cv would increase to about 14%, corresponding to a reduced survey time of about a week, mostly due to less needed trawl sampling. A substantial reduction in sailing time cannot be obtained, because the sailing time is dominated by the long cruise route along the slope, which is rather independent of the number of trawl stations.
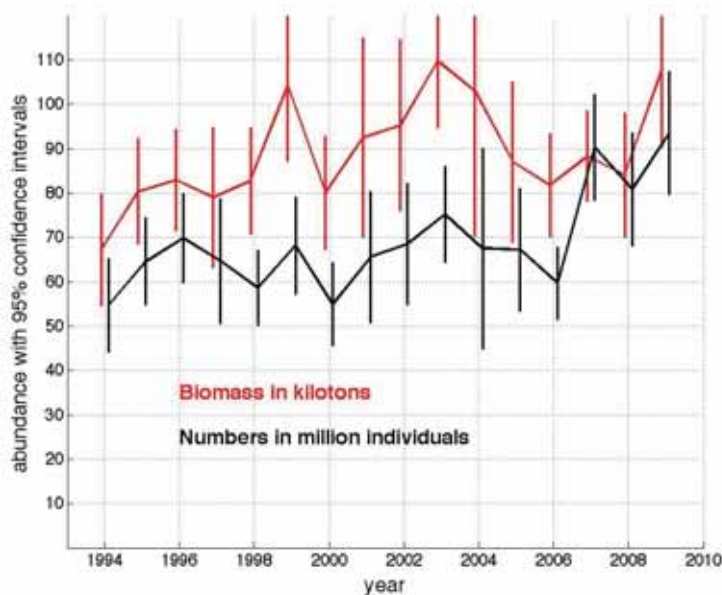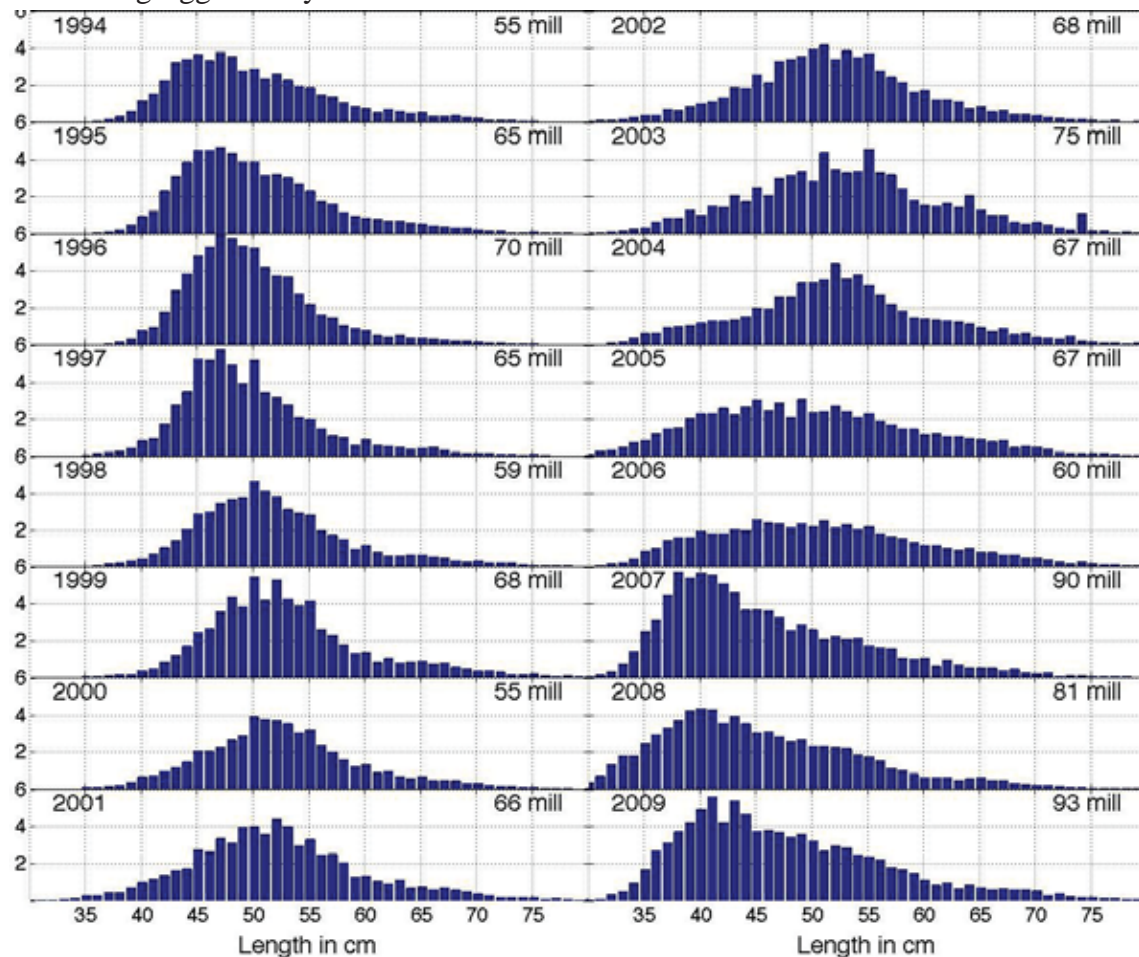

Figure 6.2. Estimated Greenland halibut abundance in biomass and by number of individuals from the Egga surveys 1994-2009. The vertical bars show 95% confidence intervals.

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Length frequency distributions

The length frequency distribution for a survey is found by weighting the standardized length frequency distribution from each trawl station with the abundance density estimate at the station in terms of number of individuals per square nautical miles as well as with the area (in square nautical miles) of the actual stratum. The accumulated result is scaled so that the number at each length in cm is the estimate of the total number of individuals of this length in the entire study area. The result for 1994-2009 is shown in Figure 6.3 below.

The gradual shift towards larger modal lengths for the first half of the series indicates an annual growth of about 2 cm per year. Note the dramatic shift in 2007 towards smaller lengths, where the new modal length appears to increase with about the same amount as the modal length in the first part of the time series. To discover such rapid changes it is paramount not to have a too large survey periodicity, and a maximum of 2 years between succeeding Egga surveys is recommended.

Figure 6.3. Length frequency distributions for Greenland halibut from the Egga surveys 1994-2009. Note the abrupt shift in 2007. Vertical axis in millions.

Conclusions

For abundance estimation purposes the rather slow variation from year to year indicates that there is no big risk of running the Egga Nor survey biennially. On the other hand, to follow rather abrupt changes in the stock composition, as revealed in 2007, that may give important

information about recruitment to the fishable stock, no lower frequency than biennial surveys is recommended at the present stage. The precise abundance estimates (cv = 10%) also indicate that the effort could be substantially reduced. For example a 50% reduction of the number of stations would only result in an increase of cv to about 15%.

6.3   The seasonal Greenland halibut project surveys 2003-2005

In 2003-2005 altogether 12 Greenland halibut surveys were run along the continental shelf. Half of the surveys were conducted in the same area as the annual Egga survey, and the other half further south (62-70.5 deg north) and including the Bear Island trench. The north and south surveys overlapped at the slope at 68-70.5 deg north for vessel comparison. The following surveys were run:

North, Aug/Sep 2003 (egga survey)

North, Aug/Sep 2004 (egga survey)

North March 2004

North March 2005

North Nov 2003

North Nov 2004

South Aug/Sep 2003

South Aug/Sep 2004

South March 2004

South March 2005

South Nov 2003

South Nov 2004

The biomass estimates from these surveys are given in Table 6.1 below. As is seen from the total estimates at the bottom line, the total abundance estimate appears to be rather constant independent of year and season except for a low biomass estimate in the November 2004 survey.

Table 6.1. Estimated biomass abundance in kton for Greenland halibut. Fields to be added vertically to obtain total are highlighted

Area[1]:	Aug 2003	Aug 2004	Mar 2004	Mar 2005	Nov 2003	Nov 2004
N	89	77	69	71	88	53
S	18	23	21	14	9	7
NS	21	28	81	46	52	17
SN	26	24	18	26	27	7
(NS+BS)/2	24	26	49	36	39	12
B300a	5	6	5	11	6	4
B300b	1	1	1	1	0	0
B400	15	15	7	11	6	8
B	21	22	13	23	12	13
Total	151	148	151	144	149	85

[1]N: north (strata 1:12, for stratified areas see figure 6.1), S: south (strata 17:24), NS: strata in south survey overlapping with north survey (strata 13:16), SN: strata in north survey overlapping with south survey, B: Bear Island trench, B300a: large 3-400 m domain (Figure 6.5, red area), B300b: minor 3-400 m depth domain (Figure 6.5, green area), B400: 4-500 m domain (Figure 6.5, blue area), total: entire study area.

The data in Table 6.1 is illustrated in Figure 6.4 with the biomass in the upper panel and the biomass density per square nautical mile in the lower panel. Note that despite a negligible density in the Bear Island trench (lower panel, right strata 25-27), these areas contribute substantially to the biomass abundance (upper panel) due to the large area. Figure 6.5 shows the actual Bear Island trench area with the 300-400 m bottom depth domains (red and green) and 400-500 m depth interval domain (blue). The circle areas are proportional to estimated biomass densities at the actual stations, and we clearly see a larger density in the 400-500 m depth domain than in the more shallow waters.
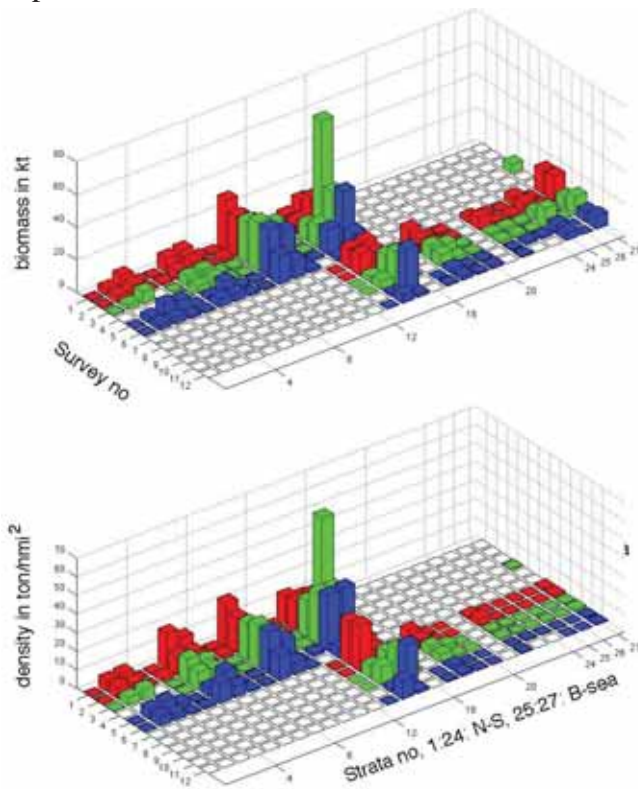
Figure 6.4. Biomass (upper panel) and biomass density (lower panel) of Greenland halibut from the surveys along the continental shelf slope (strata 1-24) and the Bear Island trench (strata 25-27) 2003-2005. Strata 1-24 goes in the north-south direction, and corresponds to depth intervals (in meters) 400-500, 500-700, 700-1000, 1000-15000, 400-500,... in cyclic order. For example strata 1-4 in this figure are the same as the four depth strata between 76°N and 80°N in figure 6.1, strata 5-8 are the four depth strata between 73.5°N and 76°N etc.. Strata 25-27 have depth intervals 300-400, 300-400, and 400-500, respectively. The other horizontal axis lists the 12 surveys defined in the text. Red: August 2003 (1,7) and 2004 (2,8), green: March 2004 (3,9) and 2005 (4,10), blue: November 2003 (5,11) and 2004 (6,12).
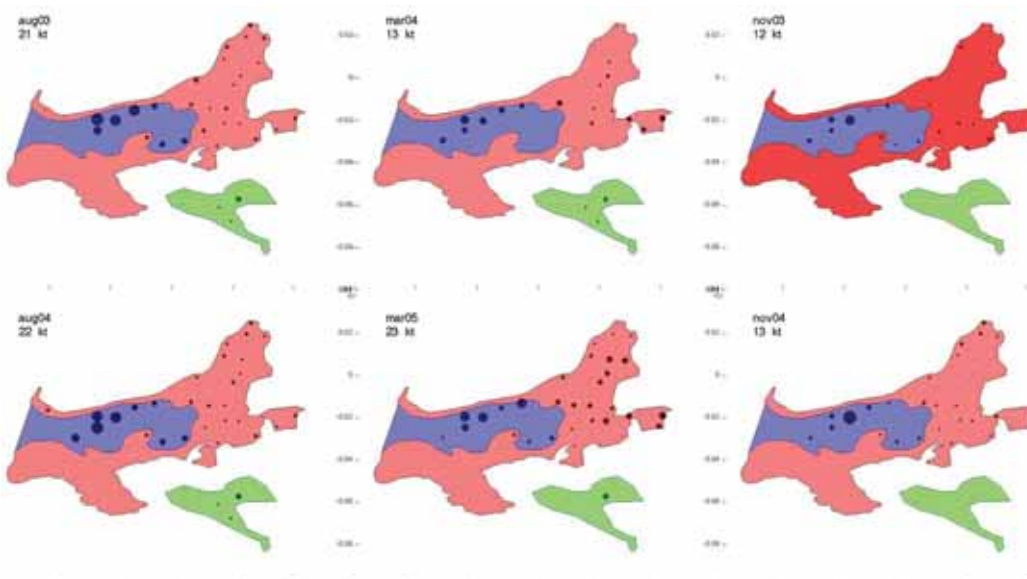
Figure 6.5. Observed biomass densities for Greenland halibut in the Bear Island trench from the surveys in 2003-2005. Red and green: 300-400 m depths. Blue: 400-500 m depths. Circle areas are proportional to biomass densities in kg/nmi^2.

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Conclusions

The March survey provide rather similar abundance estimates as the Egga Nor survey in Aug/Sep. Egga slope surveys in March is therefore assumed to provide comparable assessment on the adult Greenland halibut stock as the Egga Nor survey, except that the northernmost area is likely to be missed due to ice coverage. The southern survey data also reveal that this part contributes with about one third to the total abundance of Greenland halibut, so a two-year periodicity for an Egga Sør survey alternating with the Egga Nor survey would supply important information to the dynamics of spatial distribution. In addition, the contribution from the Bear island trench, in particular at depths between 400m and 500m, is substantial. This survey is in addition essential for the assessment of beaked redfish and greater silver smelt.

## 6.4   The annual Juvenile Greenland halibut survey 1996-2009

These surveys extend north and east of Svalbard that is an important recruitment area for Greenland halibut. A challenge with these surveys is the ice and limited access eastwards. The recruitment index based on these surveys is therefore considered quite uncertain. In addition the survey provides information on the age and length structures and on the spatial distribution of juvenile Greenland halibut.

An illustration of the length frequency distributions from these surveys is shown in Figure 6.6 from the 2001 survey, upper panel. The contribution from each station is standardized by dividing by the number of length-measured individuals, and weighted by the biomass density at each station. The resulting histograms are then fitted with a kernel density with Gaussian kernels and kernel width equal to one centimetre to more easily identify modal values corresponding to age than from the less smooth histograms. About half of the stations in 2006 contained no halibut. To examine the uncertainty of the abundance of the two first ages, two new length frequency distributions were calculated (lower two panels in Figure 6.6). These were based on every two station with Greenland halibut in the catch. The first length frequency distribution included stations 1, 3, 5 etc. while the latter included stations 2, 4, 6 etc. The stations are seen in Figure 6.7 and illustrate that the two distributions are both based on stations evenly distributed over the surveyed area. From Figure 6.6 it is clearly seen that the abundance of the first age relative to the abundance of the second age is rather uncertain, though the estimates of modal length at age seems to be rather stable.

The abundance data in general has a large variance. In the 2001 example the cv of the 82 biomass density estimates was about 2.5. In addition, the five stations with the largest sample sizes of length-measured individuals contributed with more than 50% of the accumulated sample sizes from all the 42 stations. 24 stations had less than 10 length-measured individuals.

There are systematic differences in densities (number of fish individuals per unit area) between some strata (totally 24 strata, 8 horizontal areas and 3 different depth intervals for

each area). In particular stratum 17 (300m – 500m depth, 25-35 deg E, 78-80 deg N) appears to rather consistently be the stratum with largest (or among the largest) densities over years.
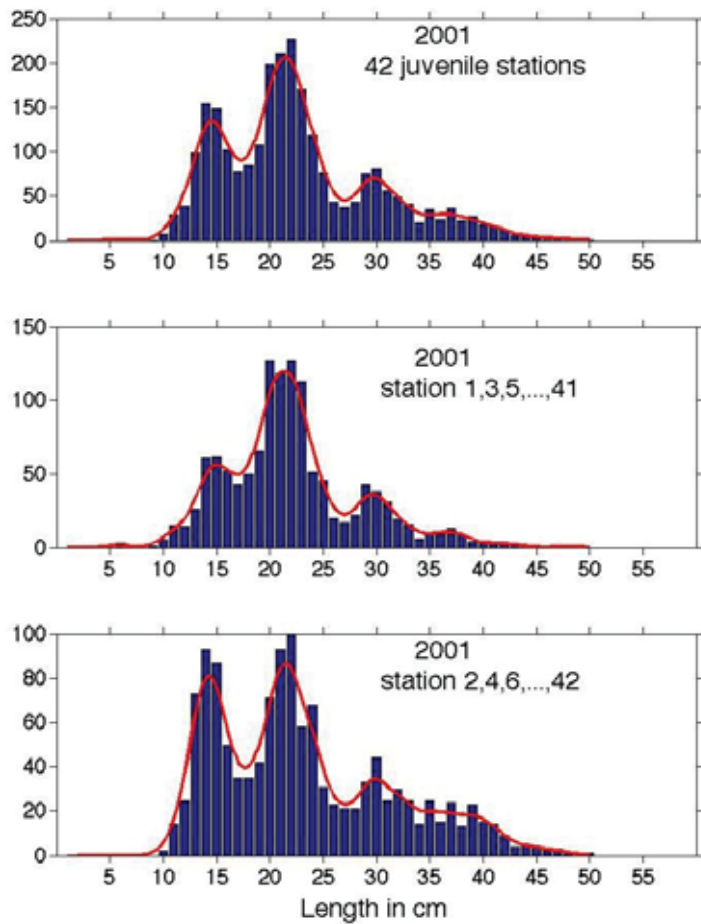
Figure 6.6. Length frequency distributions of juvenile Greenland halibut. Upper panel: Based on 42 stations. Mid and lower panels: Based on stations 1,3,5,... and 2,4,6,..., respectively, to show the uncertainty of the relative magnitude between the two first ages. See Figure 6.7 to see the actual station locations.
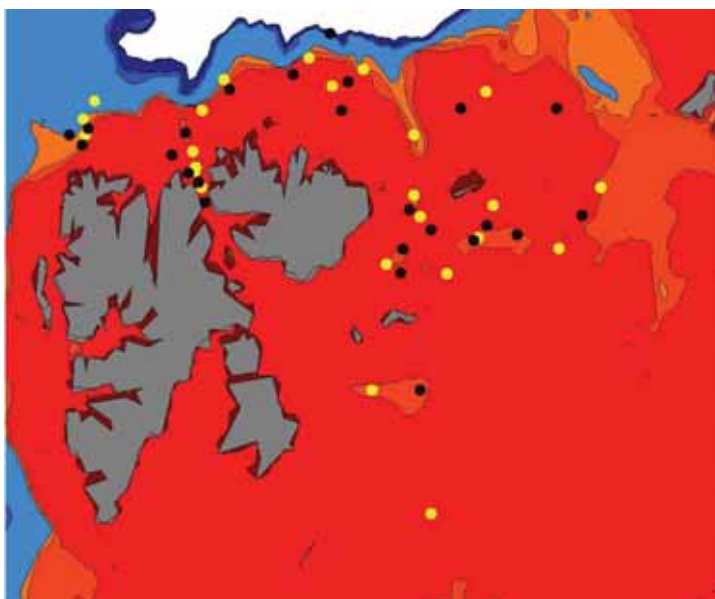
Figure 6.7. Juvenile Greenland halibut stations 2001. Yellow and black: Stations behind mid and lower panel in Figure 6.6, respectively. Upper panel in Figure 6.6 is based on all the yellow and black stations.

Conclusions

The Juvenile Greenland halibut give valuable information of Greenland halibut recruitment, but it is very difficult to get a reliable recruitment index from the data. This is partly due to a very skewed sampling distribution of density, and partly to the fact that the extension of the recruitment area is unknown. Thus a continuation of this limited directed biological sampling of Greenland halibut is not advised. Improvements would require such a substantial increase in effort that it is not considered justifiable for the sole purpose of providing a recruitment index for Greenland halibut.

However, monitoring of length composition and distribution of juveniles is still relevant and provides precise information of modal length at age for 1 and 2 year old fish. When such samples are taken it is recommended to take at least 10 random stations in stratum 17 (300m – 500m depth, 25-35 deg E, 78-80 deg N), and a minimum of 2 random stations from each of the other strata. Additionally if the Barents Sea ecosystem survey is extended into the north off Svalbard, Franz Josef Land and Kara Sea area for other purposes, some degree of sampling of Greenland halibut juveniles should be included.

Further analyses are required to confirm these conclusions.

6.5 Demersal trawl gears

The standard demersal sampling trawl at IMR is the Campellen, which is a relatively small modified shrimp trawl equipped with a rockhopper ground gear. For the Greenland halibut surveys (Egga-surveys) the Alfredo 5 groundfish trawl has been used as standard. The Alfredo 5 is three times larger than Campellen and equipped with a much heavier rockhopper gear and larger otter boards. The differences influence bottom contact and other parameters of the trawl performance, and video recordings showed differences in the behavior of Greenland halibut in front of the trawl. While large Greenland halibut were only caught during the first 100m of a Campellen trawl haul, no such surprise effects were seen for Alfredo 5, which caught large fish throughout the haul duration.

A comprehensive trawl comparison experiment was conducted during the Egga-survey in 2006, with both trawl types used on 84 of the standard survey stations. The results showed that catch rate estimates based on Campellen 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 Greenland halibut. In areas with high and low densities the catch rates of 50-65 cm fish in Campellen was 2 and 15% respectively of that in Alfredo 5. For 35 cm fish the figures were 15% and 35% respectively.

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 varies between size groups. It is therefore concluded that Campellen is not suitable to make representative samples of Greenland halibut in the main adult distribution area along the continental slope and in the deeper part of the shelf.

Conclusions

From the Egga survey Greenland halibut data it seems sufficient to run this survey every two years in August/September, but not more rarely. In addition, it is recommended to include the Bear island trench in this survey at depth 400m-500m. Additionally, an abundance precision of about 15% appears to be obtained even with a 50% reduction in the number of stations, so the extra effort in the Bear island trench will not require a longer survey than the former Egga surveys.

The 2003-2005 Greenland halibut surveys indicate that there is little difference between the abundance estimates in August and March, and the spring is a more appropriate season for species like greater silver smelt and *Sebastes mantella*. So by running a biennial Egga Sør survey, this is expected to give an acceptable periodicity for these species, in addition the survey provides supplementary information to the Greenland halibut assessment for examination of recruitment features and annual propagation of stock composition.

Extensive trawl comparisons have shown that the Campellen trawl (standard bottom trawl at IMR) is not suitable to catch adult Greenland halibut, due to severe length and density dependence on catchability. The Alfredo 5 trawl is also similar to the trawls used for Greenland halibut in neighbouring areas to the south (British, Fareoes, Icelandic, Greenlandic areas), which are included in the ICES WGNEACS Nordic deep-water surveys coordination. It is therefore imperative to use Alfredo 5 trawl on the Egga Nor surveys. This limits the potential vessels to G.O. Sars, Johan Hjort, Helmer Hanssen, or a suitable rented commercial vessel.

7.   A new survey strategy, with evaluation of performance

Based on the evaluation criteria (section 5) and the quantitative analysis (section 6) a new survey strategy is proposed. This strategy is built on 3 core deepwater surveys and data flow from 4 other surveys. The core surveys are primarily dedicated to the collection of data on deepwater fish stocks and deepwater ecosystems, while the other surveys have other primary goals, but can contribute additional sampling of importance for deepwater resources. Characteristics of each survey are given below:

7.1   Core deepwater surveys

Egga Nord

- time: August-September
- location: shelf and slope 68-80N
- frequency: every 2 year
- duration: 24d
- vessel: G.O. Sars, Helmer Hanssen, Johan Hjort, hired commercial stern trawler
- obs. method: bottom trawl (Alfredo 5)
- Additional obs: CTD, O_2, pH, hydro-acoustics
- tagging (?)

Egga Sør

- time: March-April
- location: shelf and slope 62-Ice fringe
- frequency: every 2 year
- duration: 24d
- vessel: G.O. Sars, Johan Hjort, Helmer Hanssen, hired commercial stern trawler
- obs. method: bottom trawl (Alfredo 5), Large pelagic trawl
- Hydroacoustics
- Additional obs: CTD, O_2, pH

Open Sea Deep water

- time: August
- location: open Norwegian Sea, 63-80N (International coverage)
- frequency: every 2 or 3 year
- duration: 19d
- vessel: G.O.Sars, Helmer Hanssen, Johan Hjort, hired commercial stern trawler
  obs. method: Pelagic trawl (Gloria), Hydro-acoustics
- Additional obs: CTD, O_2, pH

All core deepwater surveys build up from previously ongoing surveys in order to maintain existing or interrupted time-series. They include measurements of a minimum set of physical-chemical environmental information. Total weight, numbers and length are registered for all species caught with the sampling gears.

7.2   Deepwater sampling from other surveys

Ecosystem survey

- time: August-September
- location: Barents Sea and slope down to 500 m.
- frequency: every year
- obs. method: bottom trawl (Campellen), hydro-acoustics
- Additional obs: CTD, O_2, pH (+all from the ecosystem survey)
- specific requirements: sampling of DW species maintained at current level, some relaxation of juvenile Greenland halibut sampling possible
- additional sampling effort: none

Winter survey

- time: February-March
- location: Barents Sea and slope
- frequency: every year
- obs. method: bottom trawl (Campellen), hydro-acoustics
- Additional obs: CTD, O_2, pH (+all from the winter survey)
- specific requirements: sampling of DW species, maintained at current level
- additional sampling effort: none

Coastal and Fjord survey

- time: October-November
- location: Norwegian coast and fjords from Ålasund to Kirkenes

- frequency: every year
- obs. method: bottom trawl (Campellen), hydro-acoustics
- Additional obs: CTD, O_2, pH (+all from the coastal and fjord survey)
- specific requirements: sampling of DW species maintained at current level
- additional sampling effort: 3 days

Norwegian shrimp survey in the Skagerrak and the Norwegian Deep
- time: January-February
- location: Skagerrak
- frequency: every year
- obs. method: bottom trawl (Campellen), hydro-acoustics
- Additional obs: CTD, O_2, pH (+all from the winter survey)
- specific requirements: sampling of DW species maintained at current level
- additional sampling effort: 2 days

7.3   WGNAPES: North Atlantic Pelagic Ecosystem Survey

It has been suggested that the ICES coordinated survey WGNAPES survey could serve as a platform to monitor redfish in the open Norwegian Sea. This turns out to be impractical for several reasons: 1) the timing of the survey in spring when *S. mentella* is not yet distributed in the open ocean and far from the timing of the commercial fishery, 2) the depth of investigation on WGNAPES is typically in the first 400m whilst *S. mentella* distributes below, so the depth of trawling and hydro-acoustic registrations and scrutinizing of WGNAPES are incompatible with the observation of *S. mentella*, 3) the pelagic trawl used for WGNAPES is not suited to sample fish with low density at depth, this requires a Gloria type trawl.

ICES WGNEACS suggested use of WGNAPES surveys to collect acoustic data on greater silver smelt west off Ireland/Scotland. This is a part of the horizontal extent of the current greater silver smelt assessment unit where data are very scarce.

7.4   New survey strategy

The proposed new survey strategy is articulated as follows. Egga Nor and Egga Sør should run every second year, alternating. The frequency of the open sea deep water survey should not be less than every three year and this should be decided in accordance with the ICES working group on redfish surveys (WGRS). Additional days at sea are required from the coastal and fjord survey and the shrimp survey in the Skagerrak, to cover the deeper parts of these regions.

Effort (days at sea): Once up and running, the number of days-at-sea necessary to run this strategy will vary between 29 and 48 (Table 7.1). In 2011, a special survey effort is required to compensate for the total absence of deepwater survey in 2010 and to comply with ICES planning of the pelagic redfish survey in august 2011. This will amount to 72 days at sea, which remains lower than the effort in recent years (76, 81 and 77 days per year in 2007, 2008 and 2009).

Table 7.1. Number of days at sea dedicated to deepwater resources (future years are indicated in italics).

Year	Blåkveite	Vassild-uer-blkv	Pel uer	Juv. blkv	Andre	Skagerrak	Fjord	Totalt
2007	22	27	10	15	0	2		**76**
2008	22	14	16	15	12	2		**81**
2009	22	21	17	15	0	2		**77**
2010	0	0	0	0	0	2		**2**
2011	*24*	*24*	*19*	*0*	*0*	*2*	*3*	*72*
2012	*0*	*24*	*0*	*0*	*0*	*2*	*3*	*29*
2013	*24*	*0*	*0*	*0*	*0*	*2*	*3*	*29*
2014	*0*	*24*	*19*	*0*	*0*	*2*	*3*	*48*
2015	*24*	*0*	*0*	*0*	*0*	*2*	*3*	*29*
2016	*0*	*24*	*0*	*0*	*0*	*2*	*3*	*29*
2017	*24*	*0*	*19*	*0*	*0*	*2*	*3*	*48*
2018	*0*	*24*	*0*	*0*	*0*	*2*	*3*	*29*
2019	*24*	*0*	*0*	*0*	*0*	*2*	*3*	*29*
2020	*0*	*24*	*19*	*0*	*0*	*2*	*3*	*48*
2021	*24*	*0*	*0*	*0*	*0*	*2*	*3*	*29*
2022	*0*	*24*	*0*	*0*	*0*	*2*	*3*	*29*

Expected output from the surveys: the proposed survey strategy is a compromise between several objectives and limited resource availability. Therefore, it cannot perform best on all criteria defined in section 5. Table 7.2 below provides a rapid overview of what can be expected from such a survey design, its strengths and weaknesses. For each criterion, the survey strategy performance is divided in three categories: full performance (green), acceptable performance (orange), and not-acceptable performance (red). We anticipate that for most criteria, the performance will be acceptable, though sub-optimal. It is worth noticing that survey coordination, conduction of process studies or methodological developments, maintenance of time series and environmental observations rank to full performance score. Conversely, it is anticipated that this survey strategy will not be appropriate to deliver the necessary information on elasmobranches, will not provide the appropriate information on biodiversity, will not permit investigations of assessment in rocky bottom systems and will not cover high seas. These would need to be addressed in additional surveys, which have not been considered here.

Table 7.2. Survey performance in long term strategy for deep water surveys

#	Family	Criteria	Evaluation comment	Score
1	Advice – single stock	Greenland halibut	Biennial coverage of northern slopes (Egga) and Norteastern Svalbard, with appropriate biological sampling.	
2		Beaked redfish	Bi/triennial coverage of the slope, shelf and open ocean. Annual coverage of the Barents Sea in winter and summer.	
3		Golden redfish	Biennial coverage of the slope and shelf. Annual coverage of the Barents Sea in winter and summer.	
4		Greater silver smelt	Biennial acoustical index over the shelf and slope in spring.	

#	Family	Criteria	Evaluation comment	Score
5		Ling and tusk	Biennial recruitment index (?)	
6		Atlantic halibut	Annual recruitment index from the coastal and fjord survey (?)	
7		Roundnose grenadier	Extended sampling on the Skagerrak shrimp survey	
8		Demersal elasmobranches	Distribution of and biological data on skates and demersal sharks.	
		Pelagic elasmobranches	No fishery independent data	
9	Advice - other	Non-target deep sea fish species	Total weight, numbers and length registered for all species at all surveys. Additional aimed biological sampling.	
10		Biodiversity	Lack of dedicated sampling effort to monitor biodiversity in the deep other than what appears in the trawls.	
11		Habitats	Pelagic habitat partially measured. No information recorded on bottom habitat.	
12	Areas	Open ocean	Bi-/triennial international coordinated coverage of whole Norwegian Sea	
13		Slope/shelf	Biennial coverage from 60°N to 80°N Limited coverage south of 60°N, and north and east of Svalbard.	
14		Fjords	Annual extended sampling on the coastal and fjord survey	
15	Cooperation, coordination	Projects	Surveys support some project cooperation. No specific survey time available for dedicated (inter)national projects	
16		Survey coordination	Surveys can be fully coordinated at institutional, national and international levels	
17	Research	Process studies and methodological developments	Extra days of survey dedicated to process studies or methodological developments. Average of minimum 5 days per year. Substantial access to research vessels.	
18		Potential for publication	Project (15), survey coordination (16) and process studies (17) are green or orange.	
19	Other concerns	Bottom types (rocky bottom)	No coverage of rocky bottom	
20		Time series	Annual or biennial time series for main species and areas	
21		Environmental observations	Gear attached CTD (O_2, pH ?) on all surveys	
22		Seasonal coverage	Combination of surveys covers all seasons but not designed to resolve seasonal changes in one stock.	
23		High seas	No survey time devoted to high sea areas.	

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