NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N4258 **NAFO SCR Doc. 00/29**

SCIENTIFIC COUNCIL MEETING – JUNE 2000

A Review Using Longlining to Survey Fish Populations with Special Emphasis on an Inshore Longline Survey for Greenland Halibut (*Reinhardius hippoglossoides*) in West Greenland, NAFO Division 1A

by

C. S. Simonsen [1], J. Boje[2] & M.C.S. Kingsley [1]

Greenland Institute of Natural Resources
[1.] P.O.Box 570, 3900 Nuuk, GREENLAND
[2.] Pilestræde 52, P.O.Box 2151, 1016 Copenhagen K, DENMARK

Abstract

In this paper we present a review on the use of longline surveys for stock assessment of Greenland halibut in the fjords of Northwest Greenland We examined the different factors that could influence catch rate and analysed the variability in catch rates both with regard to time and space. Within station variance was analysed by examining repeated settings and settings with subdivided lines. Variability in catch rates was found just as high within stations as between adjacent stations. Of other factors that influenced the catch rate of Greenland halibut was subarea and year. By means of cluster analysis, we found that some areas showed consistent higher catch rate than others. The presence of other species did not influence catch rate, but big and small Greenland halibut seemed positively correlated. Analyses of the CPUE in relation to time of day point to that Greenland halibut is just as active feeding at night- as at day-time.

Introduction

Most surveys of marine fish stocks use trawl fishing or acoustic reflections to measure fish abundance. However, in many areas of the sea it is not possible to trawl because of bottom conditions, and some fishes—those without a swimbladder, e.g. flatfish and sablefish— reflect sound poorly and are hard to detect by acoustic means. In such cases longlines can be the only effective gear.

Scientific longline surveys for stock monitoring and stock assessment purposes are, however, not very common. In only few cases are longline surveys at present carried out regularly. From a literature review we were able to locate the following:

1) In the Gulf of Alaska, where the Alaska Fisheries Science Centre, National Marine Fisheries Service, NOAA conducts a longline survey with sablefish (Anoplopoma fimbria) and other groundfish as principal target species (Rutecki et al., 1997);
2) The Department of Oceanography and Fishes, University of the Azores executes a survey in the Macaronesian Archipelagos of the Azores and Madeira where such deep-water species scabbard-fish (Lepidopus caudatus), alfonsino (Beryx splendens), blackspot sea bream (Pagellus bogaravo) and bluemouth (Helicolenus dactylopterus) are the most abundant species (Silva & Menezes, 1996).
3) In the northern Pacific Ocean the International Pacific Halibut Commission surveys Pacific halibut (Hippoglossus stenolepis) (Trumble, 1998);
4) In the fjords in northern West Greenland a longline survey targets Greenland halibut (Reinhardtius hippoglossoides) carried out by the Greenland Institute of Natural Resources (Simonsen & Boje, 1999).

Longlining for assessment purposes

The perfect gear for monitoring and abundance estimation of fish stock does not exist. All known fishing gears introduce bias of some kind (Godø, 1994; Engås & Løkkeborg, 1994). One of the most serious limitations to longlines is difficulties in estimating area exploited by the gear and thus in providing an absolute estimate of abundance (Engås and Løkkeborg, 1994). Longline fishing also introduces biases, mainly concerned with the processes by which fish actively have to seek and find the baited hook, get hooked and stay hooked until they are on deck (Løkkeborg, 1994).

Finding the bait

In order for a fish to find the baited hook, it has to have visual or chemical contact. Studies have shown that pelagic fish and fish foraging in mid-water use vision as the primary sense (Gaw & Flanagan, 1997; Johannessen, 1984), while dermesal and deep-water species depend, solely or to a much higher degree, on the odour of the bait (Løkkeborg *et al*., 1989; Løkkeborg & Johannessen, 1992). The release of potential attractants from bait has been shown to be initially high, rapidly decreasing to a subsequently low level (Løkkeborg, 1992). Catch rates on longlines have also been shown to be highest just after setting, then declining (Sigler, 1997). Soaking time of the baited hooks thus seems to have a time minimum after which catch rate does not increase (Grimes *et al*., 1982). Optimum soaking time depends on type of bait and current velocities in the areas of fishing. Experiments have found that in practice optimum time is often around 2–6 h. depending on bait type (Løkkeborg, 1992). However, if the target species has a daily cycle of feeding activity, it is of course important that feeding period and soaking period coincide. The swimming activity of the fish may also influence its chance of finding the bait. Optimal foraging theory predicts that larger fish should have a larger feeding radius as a result of their higher optimal swimming speed (Hart, 1986), thus searching a larger volume of water for food and having higher probability of contact with the baited gear (Hamley & Skud, 1978).
Size and behaviour of other fish may also influence a fish's chance of finding and getting the bait, as both inter- and intra-specific competition are likely to exist. Most fish are predators on smaller fish and many fish are aggressive toward other fish in general. Therefore, bigger fish in an area could scare smaller fish away, introducing a selection process that exposes bigger and more aggressive fish species to the bait more than smaller ones. For example, larger cod (*Gadus morhua*) and tusk (*Brosme brosme*) have been observed to chase or frighten away smaller fish from baited hooks (Løkkeborg and Bjordal, 1992). In addition, wolffish (*Anarhichas* sp.) was found to have very aggressive bait-defence behaviour towards other fish (Godø *et al*. 1996).

Getting hooked and staying hooked

When a fish has found the baited hook the next process is to get hooked. Most fish caught on longlines are hooked in the mouth (Woll *et al*., 1998) (Løkkeborg, 1991)—especially in the outer parts of the jaw—or if they swallow the hook, in the alimentary tract (Huse & Fernö, 1990). The size and shape of the hook has an influence on the hooking process. Bigger hooks seem to catch bigger fish and vice versa. However, bait size may be just as important a factor (see discussion in Løkkeborg and Bjordal (1992)).

The shape of the hook has been in focus in recent years as it has a significant influence on catch rate. For example Woll *et al* (1998) found that circular hooks gave 55% higher catch rates than ordinary J-type hooks. Direct observations on longlines being retrieved showed that 17% of the fish were lost because the hook pulled out (Grimes et al., 1982). For species that are often hooked in the jaw, such as Atlantic halibut (*Hippoglossoides platessoides*), Greenland halibut (reffered to as G. halibut in the following text), hake (*Merluccius* spp.) and haddock *(Melanogrammus aiglefinus*), the shape of the hooks seems to have a conclusive effect (Løkkeborg and Bjordal, 1992; Woll, et al., 1998).

It should be evident that assessing fish populations using longline survey is not an easy task. The present paper reviews the longline survey for G. halibut in northern West Greenland. We will examine the different factors that could influence the catch rate, analysing the variability in catch rates and investigating the survey's ability to provide an abundance estimate, or at least an index, for G. halibut. Finally some suggestions are proposed on optimisation of the survey.

The Greenlandic longline survey

The survey is primarily intended to monitor the G. halibut stock components in the inshore part of northern West Greenland in NAFO Div. 1A. The survey has been carried out since 1993 and covers three fjord systems: in northern Disko Bay, Uummannaq and Upernavik (Fig. 1). More than 99% of the total Greenland inshore catch of G. halibut is in 1999 taken in these fjords (Simonsen and Boje, 1999). The G. halibut stock component in each of the surveyed fjord systems is considered a separate stock unit with little or no intermingling with other components (Boje, 1999). Only two fjord systems are surveyed every year. The survey is conducted in July and August, when the fjords are relatively free of ice and accessible to longline fishery.

The survey design uses fixed stations; approximately 25 stations have been chosen in each of the three areas. The stations are not systematically arranged. The geographical area covered by the survey was initially selected based on the landing statistics from the commercial fishery for G. halibut. It was assumed that the distribution of the fishery represents the exploitable G. halibut population. Therefore more stations were placed where the commercial fishery was most intense, fewer in areas with little fishing. The survey covers size and age structure in the G. halibut population from about 30 cm total length—about 5 years of age—and up. However, the fish are not fully recruited to the longline fishery until about 50-cm long and about 7–8 years old.

Each set (station) consists of about 1000-1500 hooks. The long-line is a Mustad 8 mm polypropylene line with 0.5 m. gangions spaced 1.2 m. and mounted with a Mustad No. 8, type 7255D hook. The hooks are baited with squid by a random baiter. The baited hooks are counted and their number is used as the measure of effort. Soaking time is minimum 6 hours.

The length of all fish is measured to the cm below (total length). Further, fish are sampled for biological features, using length as a stratification variable, i.e. otoliths for age determination, gonad examination for maturity and stomachs for food habits.

Methods and Materials

The following data was used for the evaluation of the survey:
1) Survey data from the period 1993-1999. This includes records of species caught, and contains additional information on position, fishing depth, soak time, water temperature (measured at a single point of the line) and number of baited hooks per set. All survey data are related to statistical squares measuring 7.5’ of latitude by 15’ of longitude with an area of about 138 sq. km. Due to the limited numbers of surveys conducted in Upernavik only data from Disko Bay and Uummannaq is used.
2) In 1998 and 1999 special sets were conducted. These were a) repeating the same station several times, b) repeating the same station with a different number of baited hooks.
3) Furthermore, in the survey in 1999 each set was subdivided for every 200 hooks and catch was recorded for each interval with information about average depth for the interval.

CPUE trends in different areas

In order to look for patterns in CPUE (N) within geographical areas we used a cluster analysis approach. Attempting to find patterns in the variations in CPUE within areas, we wanted to examine if special indicative areas could be identified: i.e. areas in which the observed CPUE behaved like the overall CPUE for the given study area. The cluster analysis is a passive analysis, in which the objective is to solicit the data to reveal patterns of similarity between observational units. Because the data were sparse and to reduce the problem of missing data, observational units were grouped. Field codes (statistical squares) were grouped into subareas (Figs. 2 and 3). Survey years were grouped into periods—1993–94, 1995–96 and 1997–99—to further reduce the problem of missing data (Table 1). Catches were averaged as number of fish per 1000 hooks over subareas and periods. There were therefore six variables for each subarea, viz. the catches in three periods and two sizes of fish. Subarea Torssukataq East was not fished in the survey in 1996 or 1997 and the missing data excluded it from the full cluster analysis. Cluster analysis was run on catches, which would group areas having similar sizes and time patterns of catches.

To search for common features in the data, a stepwise dummy-variable linear regression was carried out. Binary dummy variables were constructed for each year in the 7-year study, for the major divisions of the study area—i.e. Uummannaq, Disko Bay -and for the sub-areas into which the divisions were subdivided. A stepwise regression with a 15% criterion for both entering and leaving the model was run on total fish per 1 000 hooks, and also for small fish and for large fish per 1000 hooks. In order to have a check on whether regression models were being thrown up as significant because of large skewness in the data we also ran the stepwise regression models using the fourth roots of the dependent variables.

CPUE variance within a setting and between settings.

In order to examine whether the catch variation between repeated sets in the same place differs significantly from the variation between adjacent settings, i.e. at different locations within the same statistical square, we used analysis of variance. To evaluate within-set variance in CPUE, we used data from the special settings carried out during the routine survey: i) line settings where catch was recorded per 200-hook subdivision and ii) line settings which were repeated at same position (alternating settings). To evaluate between-set variance we used linesettings within statistical squares selected as those most commonly covered by the survey (Fig. 2 and 3). These linesettings within a square were chosen within the entire time span of the survey (1993-99) (Table 5). Within-line-setting variance was evaluated by the following model:

CPUE = LINESETTING + VARIATION

where LINESETTING is the mean catch in numbers per 1 000 hooks for the set or the interval, and 'variation' is that between the sets or the line intervals.

The between-line-setting variance was evaluated by the model:

CPUE = YEAR + STATISTICAL SQUARE(YEAR) + VARIATION

where YEAR is the mean catch in numbers each year and STATISTICAL SQUARE(YEAR) is the nested effect of a statistical square given a year. For the line setting subdivided in 200 hooks intervals, each interval was regarded as an individual setting.

Loss of fish during line hauling

To estimate the fish lost during the hauling process it was assumed that loss was proportional to time on the line. Therefore 24 linesettings with more than 1000 hooks were subdivided in 200-hook subdivisions and labelled in the order the line was hauled, *A* being the first, *E* the last. This was done for the total catch (in numbers) of all species and for G. halibut alone.

Statistics

The following software packages was used for statistical analyses; SAS (SAS, 1990-96), EXCEL97 (Microsoft-Corporation, 1985-97) and STATISTICA for Windows (StatSoft, 2000). Correlation analysis was done by the product moment correlation coefficient (Sokal & Rohlf, 1981). Cluster analyses used average linkage.

We used the following definitions:
Subareas= each area was divided into a number of subareas (Fig. 2 and 3).
Night = the period 00 – 06 o'clock
Small / big fish (for G. halibut only) = below / above 50 cm
CPUE (N)= catch per unit effort, expressed in number of fish per 1000 hook.
CPUE (W)= catch per unit effort, expressed as total weight in kg per 100 hook.

Results

Variation in CPUE in time and space

The overall trend in CPUE (W) for the two areas (i.e. Disko Bay and Uummannaq) have been stable within the 6-year period investigated, but with high uncertainties (variation) on the estimates (Fig. 4). To examine at each area we looked at the development in time for the different subareas (Fig. 5 A & B).

Disko Bay showed considerable variation in CPUE (W) both from year to year and from area to area (Fig. 5 A). The subareas in the southern part of Disko Bay generally had low catch rates and did not follow the trend observed in Torssukattaq. Kangia South had moderate catch rates in the first year (1993) but subsequently had very low catches. In Kangia, CPUE (W) fell throughout the period except for 1997, when the CPUE nearly doubled. In the northern part of Disko Bay, in Torssukattaq Fjord, the areas East and Central generally had high catch rates. The center area showed a positive trend in CPUE (W) except for a smaller decrease in 1996, while a stable to weak decrease was observed for area East. The western parts of the fjord had lower catch rates but any uniform trend in time was not evident. 1997 was different from the other years as CPUE this year almost doubled. In Uummannaq CPUE (W) generally increased in the period (Fig. 5 B), except that it decreased in three out of the four subareas in 1996. Uummannaq West had lower catch rates than the other areas in most years.

The variation from year to year in catches in different areas was analysed by means of cluster analysis on catch in numbers (CPUE (N)) of large and small G. halibut in order to look for pattern in the variation[1]. Clustering on catches formed 4 pairs of subareas (Fig. 6). Torssukattaq Central and Uummannaq North had fairly good catches of small fish in the first 2 periods, increasing to good catches in the last period, and good catches of large fish in the first 2 periods increasing to very good catches in the last period (Table 1). Uummannaq Central and South had moderate catches of small fish in all periods, and moderate catches of large fish, increasing slightly in the last period. A third pair of subareas was Kangia and Kangia South, with few large fish at any time and not many small fish. The fourth pair was Torssukattaq West with Uummannaq West, both of which had rather high catches of small fish, especially in 93–94, and rather small catches of large fish. The first 2 pairs formed a cluster of four—Uummannaq Central, North, and South, with Torssukattaq Central—all having moderate to good catches of both large and small fish, with general increases in the last period. They then added another pair, Torssukattaq West and Uummannaq West, which had not such good catches. The pair of southern areas in Disko Bay off Ilulissat, with their low catches, remained distant from the other 6 and were last to be added to the cluster.

The catch data were standardised by dividing by the subarea mean so that trend in catches could be analysed. Clustering on trends formed a pair Torssukattaq Centre–Uummannaq North which as described above shared not only catch levels but also time trends: increasing catch of small fish and a strong last-period increase in large fish (Fig. 7). Uummannaq South, however, combined with Torssukattaq West to form a pair characterised by stable catch of small fish and a less marked increase in large fish. No other pairs formed. These 2 pairs then combined and added Uummannaq Centre giving a group of 5 with stable catches of small fish and increasing catches of large fish. 4 of these 5 subareas were members of the central cluster in the earlier analysis. Torssukattaq West grouped with them rather than with Uummannaq West on the basis of its relatively flat trend, especially of small fish.

Other subareas, different in various ways, then joined this group one at a time. Kangia, which had a flat trend in large fish, was next to be added, followed by Uummannaq West with strong increasing trends for both sizes. The resulting combination of all the subareas except one was characterised by more or less increasing catches of both size classes. The hold-out was Kangia South which was the only subarea to have a large decreasing trend in both size classes, and therefore had a large distance from the group formed by all the other subareas.

Torssukattaq East was not included in these cluster analysis because it had missing data in 1995–96. However, it was conspicuously different from the other sub areas in having large catches of both large and small fish in the first period, but the catch of small fish moderated in the third period while the catch of large fish remained high. A separate cluster analysis was run omitting all the data for the second period 1995–96, so that this subarea

1 Note that Torssukkattaq East was omitted because of missing data (see above).

could be included, and it was found that it was the last to enter the cluster and was distant from the others. Therefore its omission did not affect the clustering of the other subareas in the analysis including all periods.

A similar clustering omitting the second period (1995–96) was run on the trends in catch. The same first group of 5 formed as in the 3-period analysis, comprising Uummannaq South, Centre and North, and Torssukattaq Centre and West, and characterised by increase in catches of large fish and less marked increase in catches of small fish. As in the three-period analysis, single subareas then added on, differing from this initial group in different ways and therefore not forming other separate clusters beforehand. Kangia had a slight increasing trend in catches of both large and small fish; next to join was Torssukattaq East with small decreases in both sizes; then Uummannaq West with large increases in catches especially of large fish; and finally Kangia South, with large decreases, especially of large fish.

In the stepwise dummy-variable linear regression few variables was observed in most models (Table 4). This is interpreted as indicating that overall, the variability was rather high and consistent patterns—for good or bad areas or subareas, or for good or bad years—were few. However, the coefficient of determination of the models for large fish were about 50%, even with only about 7–9 coefficients in the model, indicating that the effects that did enter were quite large.[2]

General deductions agreed with other data summaries. The years 1997–99 appeared to have been good for catching large fish, whereas for small fish, 1995 was good and 1996 was poor. Among the divisions of the study area, Kangia in general had poor catches, its southern part being very low. Furthermore, these sub-areas were especially poor in large fish. The inner parts, i.e. central and eastern parts, of Torssukattaq fjord were rich in large fish, but the western area was not. Torssukattaq overall registered as being good for small fish. The Uummannaq Central and West subareas registered negative coefficients for large fish, but Uummannaq overall appeared to be average for small fish.

Variation in CPUE within settings and between settings

Analyse of the variation at both within and between linesettings showed in general high variance. Both models on within setting variance exhibited the extreme values of variances of the three tested. The second model (repetition of a setting) shows the highest variance in CPUE estimate, while the first model (subdivision in 200 hook intervals) showed the lowest variance. Testing the difference between the variances by means of an F-test, revealed that all three obtained variances were significantly different from each other (a two tailed 5% rejection region (Table 7). The high variation in CPUE within a longlinesetting means that changes in CPUE from one year or area to another is just as likely to happen as when conducting a new trial at the same position or comparing catches along a linesetting.

Inter- and intraspecific competition

In order to analyse the effect of hook saturation and intraspecific competition with special emphasis on size effects, G. halibut were divided into small fish below 50 cm and large fish above 50 cm The CPUE of small fish was less when that of large fish was greater (Fig. 8), but a linear regression had a negative slope of only -0.02, so there appears to be no strong relationship between the two variables.

An analysis of variance with big-fish numbers as dependent variable and small-fish numbers as well as subarea, depth, day/night period and soak time as independent variables, reveals only significance for small numbers and subareas. A subsequent ANOVA with only small numbers and subarea as effects, reveals significance of both effects, meaning that CPUE of small fish will affect CPUE of big fish. Plotting small fish versus big fish for each subarea (Fig. 9), expose that for all of the subareas surveyed, a positive correlation exists apart from a few where no

---

[2] There is need for caution in interpreting these results, as correlation between the dummy variables induces non-independence in the selected coefficients. E.g. the inclusion of a good fishing area in the survey area in one year, and its omission in another may appear in the results as a positive effect for the year in which the good area was included. This problem is not unique to the technique of dummy-variable regression but is general for the analysis of unbalanced designs.

correlation seem to exist. Regression analyses carried out separately by subarea, shows positive correlation but not significant. Conclusively can be condensed that the presence of smaller fish do not seem to inhibit the presence of bigger fish, but contrary the two groups seem to be positively correlated when treating them by subarea.

Longlines have a saturation point, i.e. if other species than G. halibut are hooked first, the hook will not be available for G. halibut. Other species hooked might also affect the attraction of G. halibut to the hooks Therefore we examined whether numbers of fish caught other than G. halibut (by-catch) seemed to influence the catch of G. halibut. An ANOVA analysing CPUE of G. halibut for the effects of subarea and by-catch CPUE, was not significant regarding by-catch CPUE. There is no strong general trend between by-catch and catch of G. halibut, although the overall trend is slightly negative (Fig. 10, Fig. 11).

Time of day

In order to investigate if G. halibut have a daily rhythm in feeding activity the different line-settings throughout the day were analysed for any time-related pattern (Fig. 12). No clear pattern was evident, but very high CPUEs seemed to be clustered at certain times of the day, namely around 0800, 1400 and 2200 hrs. This was especially true for the Disko area. However, these periods were at the same time identical to periods of high line-setting activity, and rare high values would be more likely at such times, when there were many. When we examined catches at night versus those in the day-time, no difference was found (Fig. 13).

Soaking time

Most sets had soak times between 6 and 12 hours. We did not observe an increasing catch rate with time (Fig. 14).

Depth

We found a somewhat positive correlation between fish size and fishing depth ($P<0.001$, $R=0.36$, $N=158$), Fig. 15. At line settings carried out at shallower depth (above 400 meters) mean fish size was more variable (between 38 and 65 cm) than in settings at greater depths (between 51-62 cm). Small fish were only caught in shallower water and big fish were caught at all depths. Catch in numbers generally increased with increasing depth ($P<0.001$, $R=0.36$. $N=240$) Fig. 16.

Loss of fish during line hauling

The loss of fish during the hauling process was assumed proportional to the time hooked. Loss of fish were examined by evaluating the special settings where a longline was subdivided in sections (A to E) consisting of 200 hooks. If fish were lost we expected a catch decline from the first line section A hauled to the last section E—which we did not observe (Fig. 17). There was a tendency—not significant—for catches to be higher in the middle sections of the line all species including G. halibut.

Discussion

Biotic factors

Studies on cod and tusk have demonstrated that larger fish scare away smaller ones of the same species (Løkkeborg and Bjordal, 1992), so we hypothesised that younger G. halibut also might not share habitat with older and bigger specimens. However, with the data available we did not find such an inverse relationship between distributions of big and small fish. However, our definition of smaller and bigger fish was arbitrarily set above and below of 50 cm, and any other values are not analysed for in this context. Neither did the presence of any other fish have an effect on the catch rate. This implies that non-target fish did not saturate the gear. In theory gear saturation is a problem for abundance estimates from longline catches (Murphy, 1960). In areas with many non-target fish this theory is realised and becomes a problem in practice (see e.g. Silva and Menezes, 1996). In Greenland waters however, the catch on the longlines of species other than G. halibut is low and did not influence catch rate of halibut. Although we did not find that other fish significantly influenced catch rate of G. halibut local gear saturation might appear. Observations on the longline surveys tell us that G. halibut show evidence of aggregation on the line, often occurring on several consecutive hooks. The order of the aggregation is approximately 3 to 10 fish within a limited number of hooks (~10-20). A possible explanation for this could be that G. halibut forage in small schools. However, we are not aware that foraging strategy have ever been studied in adult G. halibut and thus could confirm our observations. Feeding activity of juvenile G. halibut (1 year old) is higher at night than during day (Jørgensen, 1997), while such diurnal pattern was not detective for the adult G. halibut (present study and Jørgensen, 1997).

In conclusion, with the data available we did not find biotic or biotic related factors that significant influence CPUE of G. halibut.

The gear factor

The gear used is heavier than that used by the commercial fishermen. They use mainlines of around 3-5 mm with and 2-mm gangions. When fishing in the same places as the commercial fishery we experienced catch rates approx. 2-4 times lower. Catch-rate difference was believed to be due to the different gear as bait and fishing areas were the same. Even though, the low catch rate obtained with the survey gear should result in lower parallel CPUE, very low CPUE are more sensible to "noise". The low CPUE values could thus have a negative effect on the precision of the CPUE.

We use a J-type hook in the survey. For this hook type loss during hauling have been reported to be considerable in rough weather and high wave amplitude (due to the ships movement pull hooks free) (Woll, et al., 1998). From regular observations on the survey we know that loss of fish happen in the upper (visual parts) of the water column (and probably also deeper). Even so, losses were not found to be related to hauling process, as we could not detect any difference from the first to the last part of the line being hauled. The longline surveys was conducted in protected fjords were wave height generally is small (0-0.5 m) which point to that loss during hauling in the wind and wave protected fjords probably can be considered low. Loss of fish was thus considered to happen at random and not in a way that biased the CPUE.

The surveys ability to provide an abundance estimate or index

In order to use catch rates from longlinefishing the exploit area has to been known. As pointed out earlier this is it difficult to estimate as it requires knowledge of the active distribution of the fish (search and feeding range) and the effective areas the line is fishing, (e.g. from what Range fish are attracted towards the bait). The latter is probably very variable as local currents and bottom topography probably have a conclusive effect on dispersal of the odour plume (McQuinn *et al*., 1988). Thus, as neither of these variables could be estimated it is believed that the longline survey could not be used for providing absolute abundance estimate.

Could the CPUE from the longline survey then be used as an abundance index? A precondition is the existence of correlation between fish abundance and catch rate. A number of studies have demonstrated that such a correlation seems to exists (Engås *et al*., 1996). Some authors (e.g., Murphy (1960), (Engås and Løkkeborg, 1994)) has drawn to attention that factors such as gear saturation, competition among fish for a unit of gear; the "attraction-" or "frighten effect" of one hooked fish towards another fish; and fluctuations from year to year in prey abundance could screw the correlation between CPUE and fish abundance. However, we did not find that either gear saturation or presence of other fish significant influenced survey CPUE. Therefore, in that respect the CPUE fulfil the needs for a CPUE index. . On the other hand we found that variance of CPUE in both repetitions of a linesettings and within smaller geographical areas were high. Highest variance of CPUE was found when repeating a setting and lowest when comparing sections within a line. The in year variation within an area was in the same order of magnitude as the year to year variation. This could question whether difference in CPUE between years is to be used an indicator of stock abundance development. However, looking at geographical areas we did find that some areas have consistent high / low CPUE and that CPUE between adjacent subareas showed the same trends in time. This points to the fact that CPUE could be used as an abundance indicator. The lack of other sources of "stock abundance indicators" such as effort from the commercial fishery impedes the conclusion of the surveys CPUE to be used at a stock abundance index. At present it is believed that caution should be taken when analysing trends in CPUE from the longline survey and that studies should be continued to investigate if the observed variation in CPUE is caused by natural behaviour of the G. halibut or if it is due to survey design.

The survey design

A correct survey design is important as it reduces survey variability, improves coverage and thereby increases the reliability of the survey estimates. The review of the survey points to the fact that fixed station design has disadvantages:

1) Ice condition in the fjords often makes it impossible to do several of the fixed stations in some parts of or entire subareas. Alternative stations are, if possible, placed close too and in the same depth interval. This practice of choosing alternative stations increases the risk of introducing subjective sources of bias.
2) The shift in survey coverage from year to year and often in areas of higher fish density impedes the assessment.
3) The survey does not cover the entire area of distribution of the exploitable population. Fishery now takes place in areas that was not exploited in 1993 when the survey area was selected. This is especially the case in the northern area, Upernavik, where the fishery have continued further north as new fishing grounds are discovered (Simonsen and Boje, 1999). The present survey design with a fixed area and stations is not dynamic in relation to a shifting fishery.
4) A fixed station design in general have some statistical problems in providing bias and precision to the estimate compared to a random design (Aksland, 1998).

Improvement of the survey design

It seems conclusive to undertake studies to investigate whether the high variance at a linesettings is due to natural causes (e.g. foraging behaviour of G. halibut) or the surveys design (e.g. the relatively heavy gear). Comparative fishing using present and different longlines and hook types gear could throw light on this topic. Furthermore, a better resolution of the catch along the longline would provide better data for studying inter- and intraspecific competition; local gear saturation and their influence on CPUE.

The present practice with surveying two out of three areas pr year and shifting alternate introduce problems when analysing time-series data. It is therefore recommended that areas be surveyed at regular time intervals.

A random design with stratification in the plane would reduce the problem with stations or areas that are not completed due to ice conditions. Furthermore, our analyses suggest that some subareas should be considered left out of the survey because of very different CPUE and trends in CPUE.

In order to provide a better forecast of recruitment to the fishery it might be considered that the survey also targets the age groups 4-7 year.

References

Aksland, M. (1998). Elements from probability sampling theory with application on sampling in the plane. *Lecture notes on the survey design for trawl surveys and egg and larva surveys under BFM334* .

Boje, J. (1999). Intermingling and seasonal migrations of Greenland halibut stock components in the Northeast Atlantic based on tagging studies. *NAFO Scr.Doc.* **99/25**.

Engås, A. & Løkkeborg, S. (1994). Abundance estimation using bottom gillnett and longline -The role of fish behaviour. In *Marine Fish behaviour in capture and abundance estimation*, pp. 134-165. Edited by A. Fernö & S. Olsen: Fishing News Books.

Engås, A., Løkkeborg, S., Soldal, A. V. & Ona, E. (1996). Comparative fishing trials for cod and haddock using commercial trawl and longline at two different stock levels. *J.Northw.Atl.Sci.* **19**, 83-90.

Gaw, E. R. & Flanagan, W. (1997). The 'magic' of lightsticks in tuna fisheries. *Fishing News International* **36**.

Godø, O. R. (1994). Factors affecting the reliability of groundfish abundance estimates from bottom trawl surveys. In *Marine Fish behaviour in capture and abundance estimation*, pp. 166-195. Edited by A. Fernö & S. Olsen: Fishing News Books.

Godø, O. R., Huse, I. & Michalsen, K. (1996). Bait defence behavior of wolffish and its impact on long-line catch rates. *ICES J.Marine Science* , 273-275.

Grimes, C. B., Able, K. W. & Turner, S. C. (1982). Direct observation from a submersible vessel of commercial longlines for tilefish. *Trans. Am. Fish. Soc* **111**, 94-98.

Hamley, J. M. & Skud, B. E. (1978). Factors affecting longline catch and effort: II Hook-spacing. *Int. Pac.Halib.Comm. Sci. Rep.* **65**, 15-24.

Hart, P. J. B. (1986). Foraging in teleost fishes. In *The behavior of teleost fishes*, pp. 211-235. Edited by T. J. Pitcher: Croom Helm Ltd.

Huse, I. & Fernö, A. (1990). Fish behaviour studies as an aid to improve longline hook design. *Fisheries Research* **9**, 287-97.

Johannessen, T. (1984). Fishing experiments with different longline baits for cod. In *ICES ad how Working Group on Artificial bait and bait attraction*. Hirtshals, February 1984

Jørgensen, O. A. (1997). Pelagic occurrence of Greenland halibut, Reinhardtius hippoglossoidesm, in West Greenland waters. *J.Northw.Atl.Sci.* **21**, 39-50.

Løkkeborg, S. (1991). Fishing experiments with an alternative longline bait using surplus fish products. *Fisheries Research* **12**, 43-56.

Løkkeborg, S. (1992). Rate of release of potential feeding attractants from natural and artificial bait. *Fisheries Research* **8**, 253-61.

Løkkeborg, S. (1994). Fish behaviour and longlining. In *Marine Fish behaviour in capture and abundance estimation*, pp. 134-165. Edited by A. Fernö & S. Olsen: Fishing News Books.

Løkkeborg, S., Bjordal, A. & Ferno, A. (1989). Responses of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) to baited hooks in the natural environment. *Can. J. Fish. Aquat. Sci.* **46**, 1478-1483.

Løkkeborg, S. & Bjordal, Å. (1992). Species and size selectivity in longline fishing: A review. *Fisheries Research* **13**, 311-322.

Løkkeborg, S. & Johannessen, T. (1992). The importance of chemical stimuli in bait fishing -fishing trials with presoaked bait. *Fisheries Research* **14**, 21-29.

McQuinn, I. H., Gendron, L. & Himmelman, J. H. (1988). Area of attraction and effective area fished by a whelk (*Buccinum undatum*) trap under variable conditions. *Can. J. Fish. Aquat. Sci.* **45**, 2054-2060.

Microsoft-Corporation (1985-97). EXCEL97. : Microsoft-Corporation,.

Murphy, G. I. (1960). Estimating abundance from longline catches. *J. Fish. Res, Board. Can.* **17**, 33-40.

Rutecki, T. L., Sigler, M. F. & Zenger, H. H. (1997). Data Report: National Marine Fisheries Service Longline Surveys, 1991-96. .

SAS (1990-96). The SAS system for Windows, release 6.12. : SAS Institute Inc, Cary, NC, USA.

Sigler, M. F. (1997). Sabelfish (Anoplopoma fimbria) behavior in relation to longline. *ICES CM* **1997 / W:03**.

Silva, H. M. & Menezes, G. (1996). An intensive fishing experiment in the Azores. , pp. 57. Horta: University of the Azores.

Simonsen, C. S. & Boje, J. (1999). An assessment of the inshore Greenland halibut stock component in NAFO Division 1A inshore. *NAFO Scr.Doc.* **N4107**, 24.

Sokal, R. R. & Rohlf, F. J. (1981). *Biometry,* Second edn. New York: W.H. Freman and Company.

StatSoft, I. (2000). STATISTICA for Windows. : StatSoft, Inc, Tulsa, OK: StatSoft, Inc., 2300 East 14th Street, Tulsa, OK 74104, US.

Trumble, R. J. (1998). Northeast Pacific flatfish management. *Journal of Sea Research* **39**, 167-181.

Woll, A. K., Boje, J., Holst, R. & Gundersen, A. C. (1998). Catch rates and hook and bait selectivity in longline fishery for Greenland halibut at East Greenland. *ICES CM* **1998 /O:28**, 13 pp.

Table 1. Catches for cluster analysis

Subarea	Catch of small fish per '000 hooks			Catch of large fish per '000 hooks		
	93–94	94–95	96–97	93–94	94–95	96–97
Kangia	9.38	5.09	12.66	1.21	1.32	1.32
Kangia South	5.42	0.72	1.10	0.20	0	0
Tors. East	24.09	.	12.66	27.25	.	20.31
Tors. Central	16.81	13.64	21.47	8.21	7.35	27.38
Tors. West	23.73	18.85	20.25	3.02	3.14	6.06
Ummannaq Central	9.27	17.16	11.97	4.94	9.82	13.61
Ummannaq North	10.9	17.20	20.77	8.56	9.86	25.51
Ummannaq South	10.61	10.36	10.84	7.70	10.30	20.90
Ummannaq West	8.75	19.35	27.81	0.53	2.99	11.26

Table 2. Standardised catches, i.e. relative to subarea mean, for cluster analysis

Subarea	Catch of small fish per '000 hooks			Catch of large fish per '000 hooks		
	93–94	94–95	96–97	93–94	94–95	96–97
Kangia	1.04	0.56	1.40	0.94	1.03	1.03
Kangia South	2.25	0.30	0.46	3.00	0.00	0.00
Tors. East	.	.	.	.	.	.
Tors. Central	0.97	0.79	1.24	0.57	0.51	1.91
Tors. West	1.13	0.90	0.97	0.74	0.77	1.49
Ummannaq Central	0.72	1.34	0.94	0.52	1.04	1.44
Ummannaq North	0.67	1.06	1.27	0.58	0.67	1.74
Ummannaq South	1.00	0.98	1.02	0.59	0.79	1.61
Ummannaq West	0.47	1.04	1.49	0.11	0.61	2.29

Table 3. Signed significance (%) of variables entering a stepwise dummy-variable regression for fish catches in a long line survey in northern West Greenland.

	Fish/hook	Fish/hook 4th root	Small fish/hook1	Small fish/hook4th root	Large fish/hook	Large fish/hook 4th root
1993	-2	-6				
1994						
1995			+7			
1996	-0.6	-1	-12	-7		
1997					+5	
1998					+.01	+0.4
1999					+14	
Ummannaq overall						-5
Ummannaq Central					-5	-10
Ummannaq North						
Ummannaq South				-8		
Ummannaq West					-0.2	-0.01
Torssukataq overall			+0.1			
Torssukataq East	+0.01	+4			+.01	
Torssukataq Central	+0.7	+8			+6	
Torssukataq West					-0.3	-0.01
Kangia overall	-0.01	-0.01	-2	-0.01	-0.01	-0.01
Kangia		+0.3		+0.8		+0.8
Kangia South						
Overall coefficient of determination of model (%)	34.8	38.9	17.1	21.4	52.2	54.9

significance limit for being in the model is 15%.

1 Kangia was forced into this model, to facilitate comparison with others.

Table 4.: Effects of dummy variables entering a stepwise regression of catches in a longline survey in northern West Greenland as a percentage of the intercept.

	fish/hook	fish/hook 4th root	Small fish/hook	Small fish/hook 4th root	Large fish/hook	Large fish/hook 4th root
1993	-24.00	-7.04				
1994						
1995			40.45			
1996	-27.36	-9.00	-21.28	-6.66		
1997					34.70	
1998					86.95	19.84
1999					27.57	
Ummannaq overall						-12.62
Ummannaq Central					-33.53	-10.72
Ummannaq North						
Ummannaq South				-8.82		
Ummannaq West					-80.40	-38.31
Torsakattak overall			51.31			
Torsakattak A (east)	67.17	11.03			123.84	
Torsakattak B (central)	35.13	8.09			37.98	
Torsakattak C (western)					-73.22	-44.46
Kangia overall	-54.68	-46.38	-33.35	-42.10	-99.54	-94.44
Kangia		21.82		22.16		27.16
Kangia South						

limiting significance to enter or leave the model was 0.15.

Table 5. Data on linesettings used in analyses of CPUE variance within and between linesettings.

model design	**mean depth (m)**	**nos of settings (N)**	**nos of fish (N)**	**mean cpue (nos/1000 hooks)**	**mean length (cm)**
Subdivision of line in 200 hooks intervals	466	24	641	31.1	56.2
Repetition of settings – alternation	626	9	329	23.1	61.8
Between settings within a statistical square	507	26	1272	37.9	59.9

Table 6. Outcome of ANOVA's on within and between variation in CPUE's (in numbers) from linesettings.

Source of variation	*df*	SS	MS	F
1. model: cpue=setting ;(200 hooks intervals)	24	1677.647	69.902	4.73***
error	103	1523.345	14.790	
total	127	3200.992		
2. model: cpue=setting ;(repetition of setting)	3	2766.722	822.241	0.57
error	6	7163.500	1435.700	
total	9	9630.222		
3. model: cpue=year+stat square(year); (between settings within a stat. sq.)	16	6657.958	416.122	1.49
error	22	6154.870	279.767	
total	38	13812.829		

Table 7. Matrix of F-tests for difference between variances in models given in Table 2.

	1. model: within settings - 200 hooks intervals	2. model: within settings - repetition of setting
2. model: within settings – repetition of setting	F_s=96.76**>$F_{0.25[4,64]}$	
3. model: between settings within a statistical square	F_s=18.91**>$F_{0.25[21,64]}$	F_s=5.12**>$F_{0.25[4,21]}$

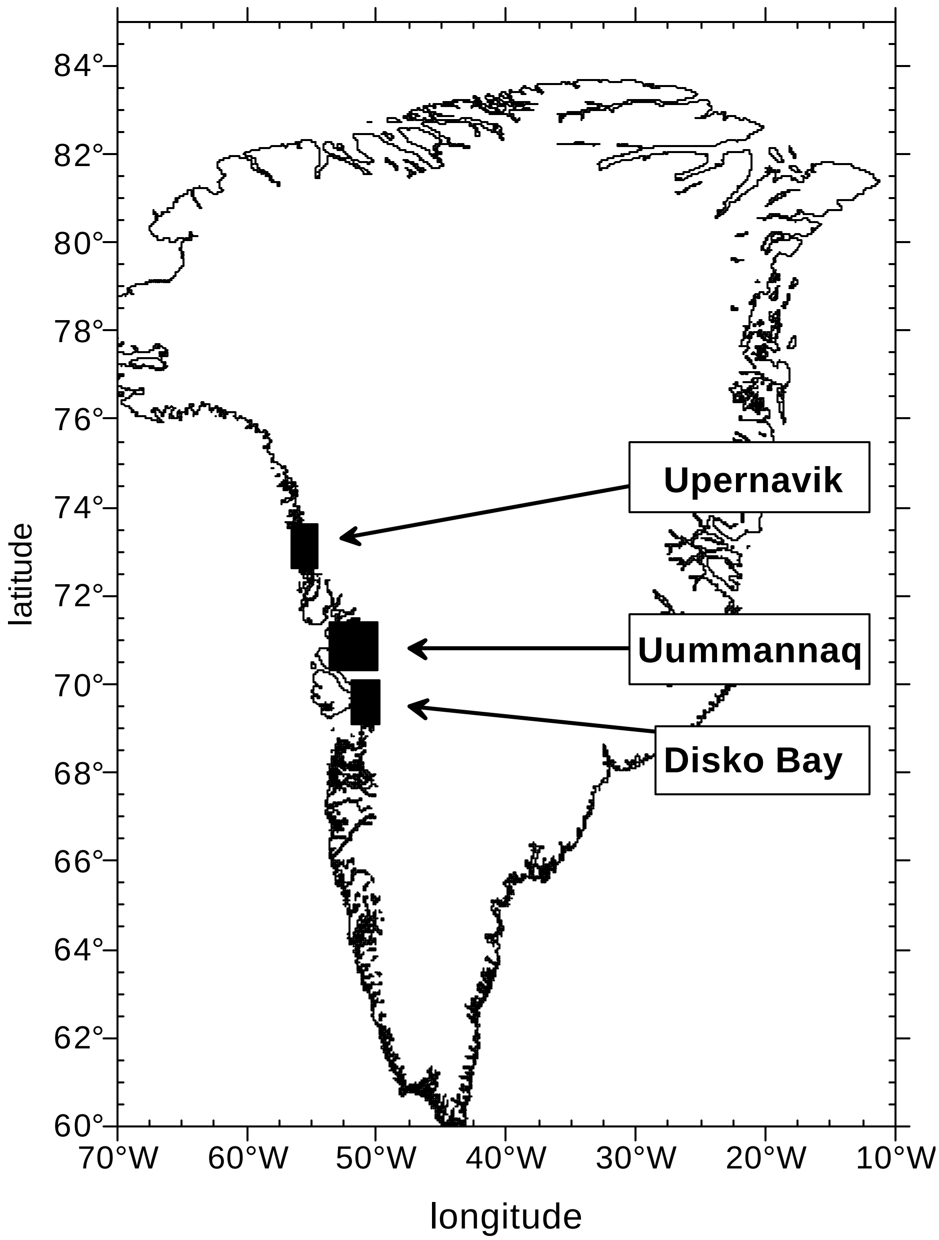


Figure 1. Map of Greenland with indication of the three longline survey areas.

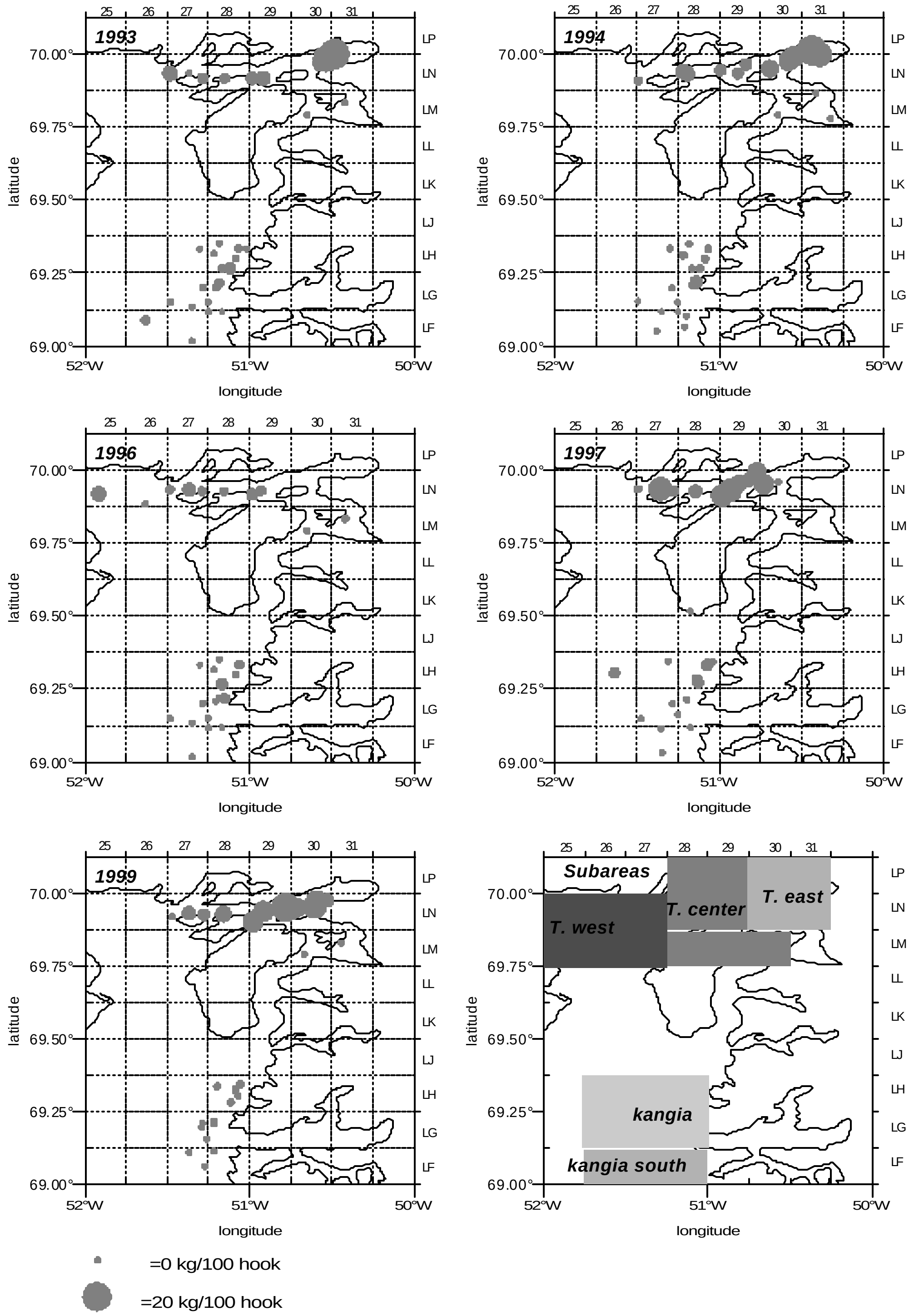


Figure 2. Greenland halibut CPUE (w) distribution in Disko Bay in 1993, 1994, 1996, 1997 & 1999. Statistical square-net and subareas shown on maps.

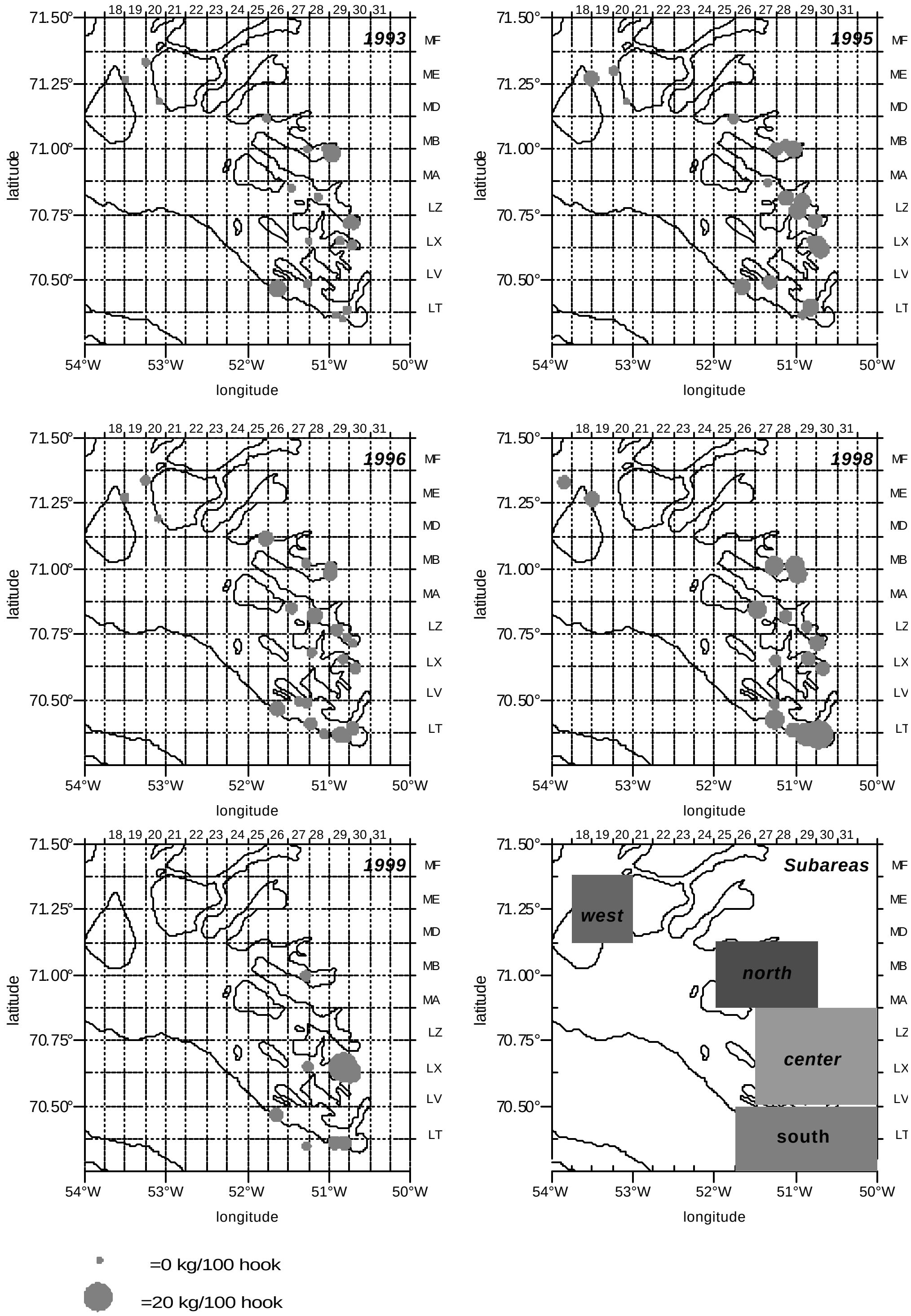


Figure 3. Greenland halibut CPUE (W) distribution in Umanak in 1993, 1995, 1996, 1998 & 1999. Statistical square-net and subareas shown on maps.

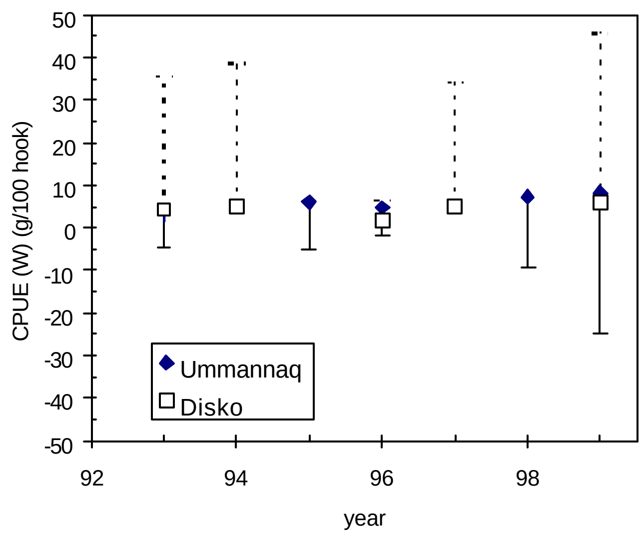
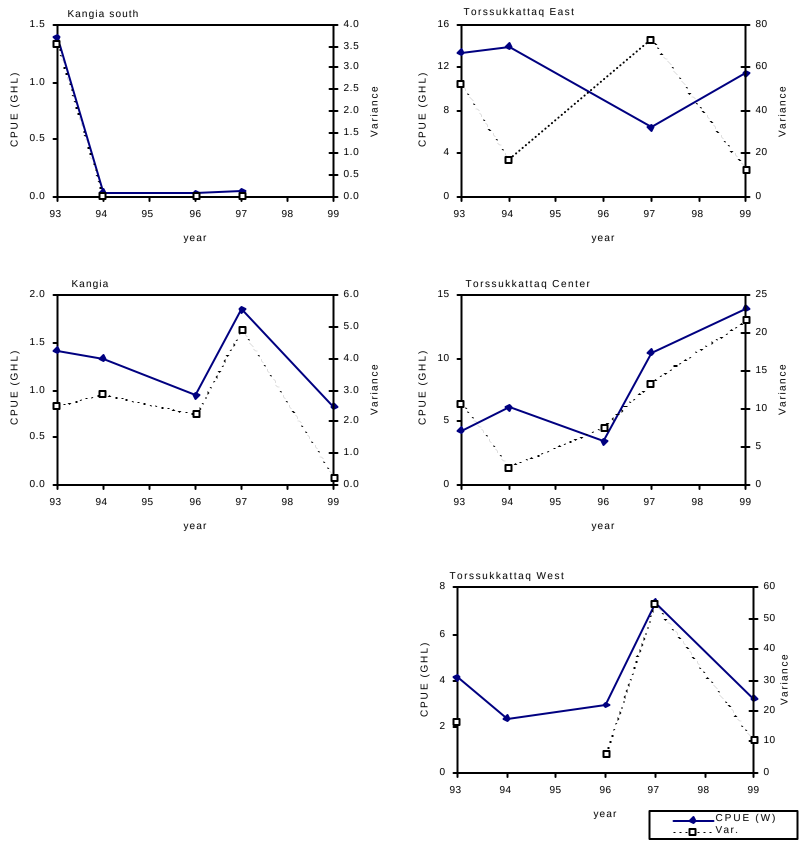


Figure 4. CPUE (W) for Greenland halibut. Errorbars indicate variance of the mean.

A)



B)

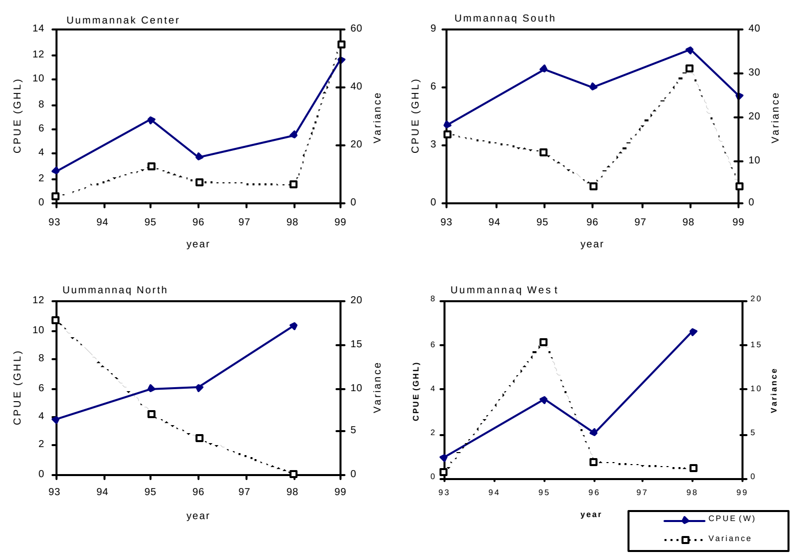


Figure 5. A) CPUE (W) Greenland halibut in subareas in Disko **B)**. CPUE (W) Greenland halibut in subareas in Uummannaq.

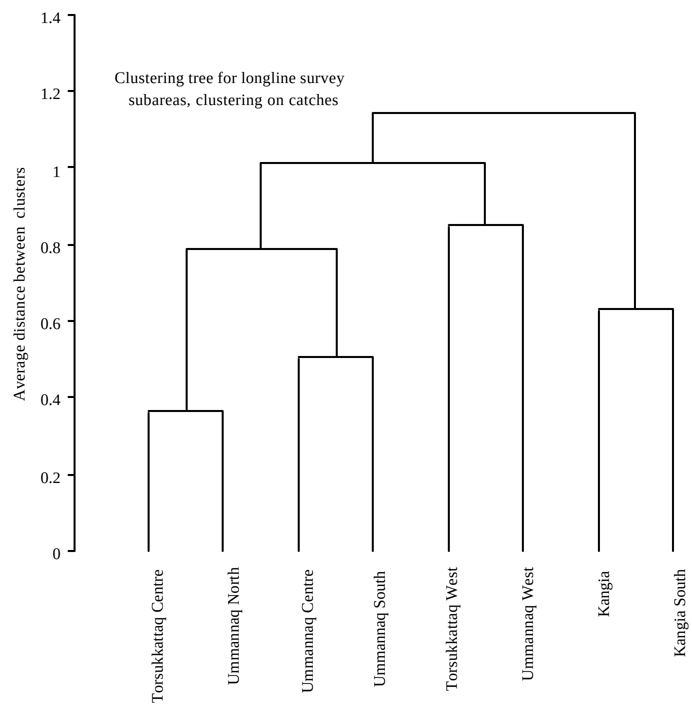


Figure 6. Clustering tree for longline survey subareas, clustering on catches.

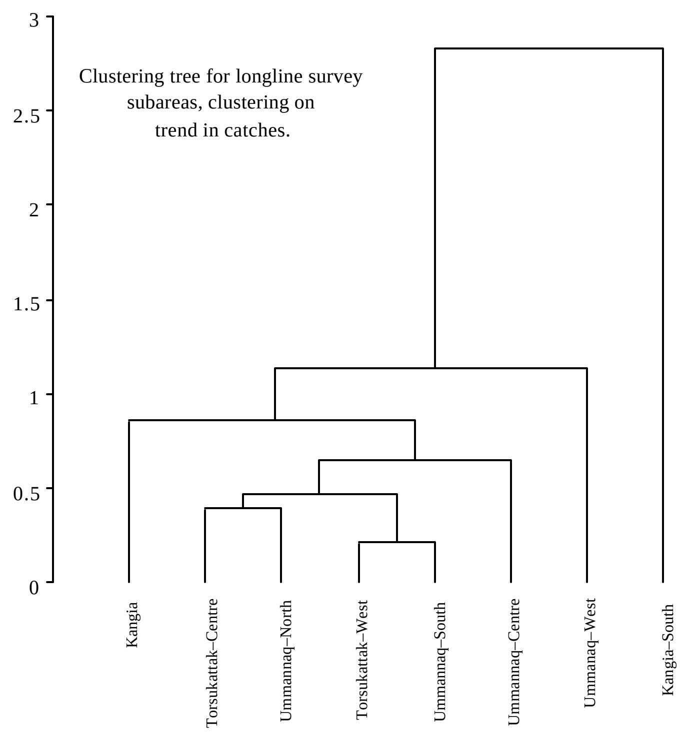


Figure 7. Clustering tree for longline survey subareas, clustering on subareas.

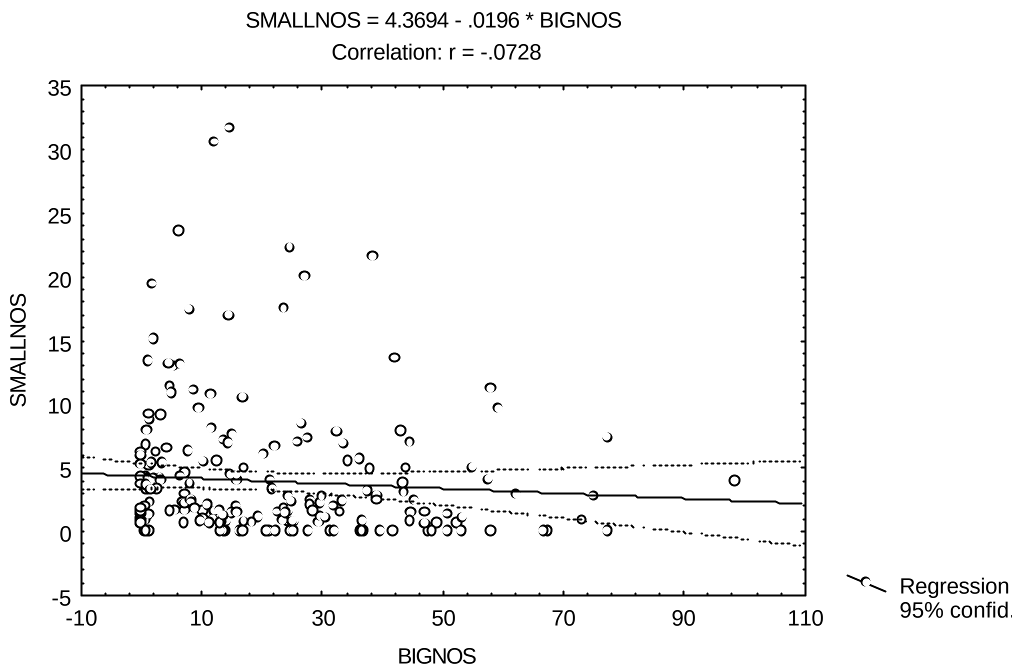


Figure 8. Scatterplot of numbers of big fish versus numbers of small fish and linear regression with confidence limits indicated.

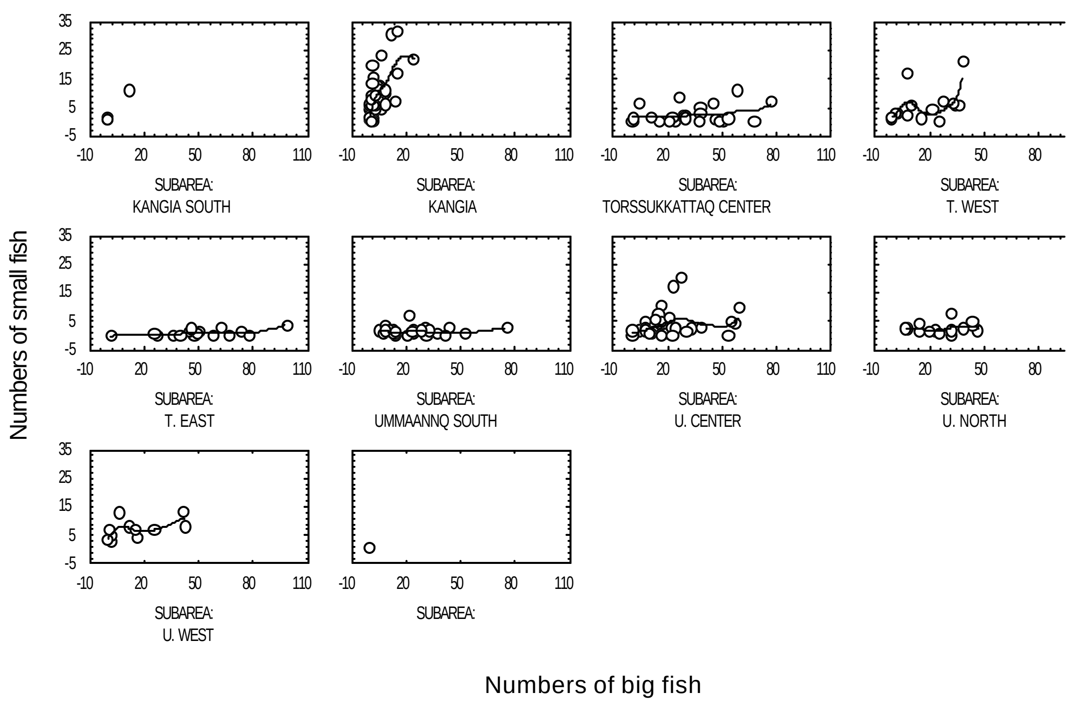


Figure 9. Scatterplot of small fish (G. halibut) versus big fish for each of the subareas with least squares fit.

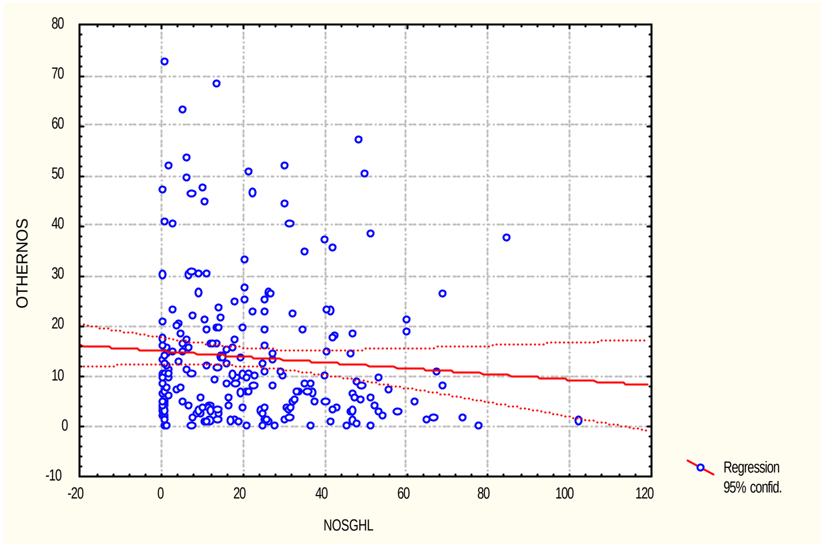


Figure 10. Scatterplot of numbers of G. halibut (GHL) versus numbers of other species and linear regresssion with 95% condidence intervals. r=0.083

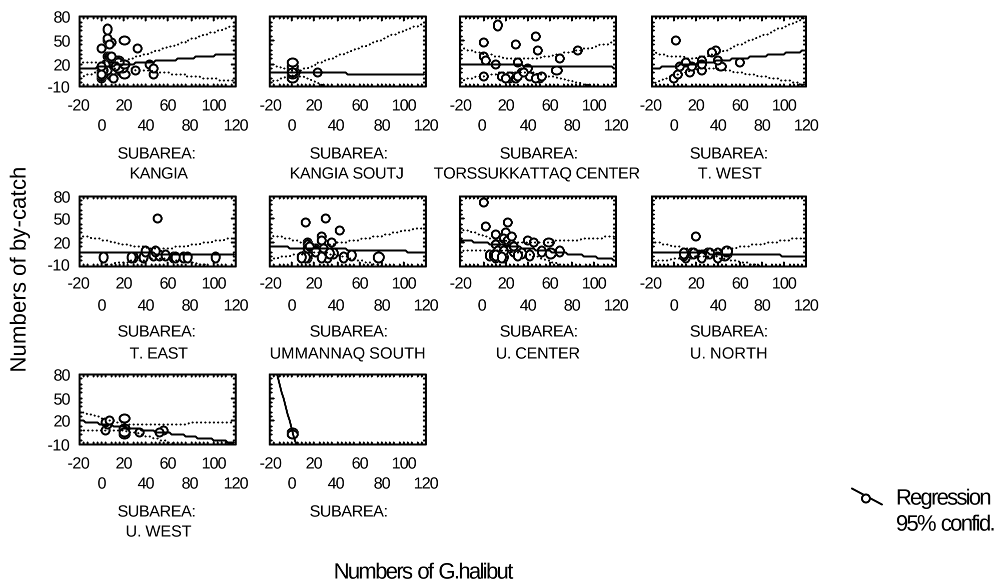


Figure 11. Scatterplot of nos G.halibut versus nos of other species. Linear regression with 95 % conf int indicated.

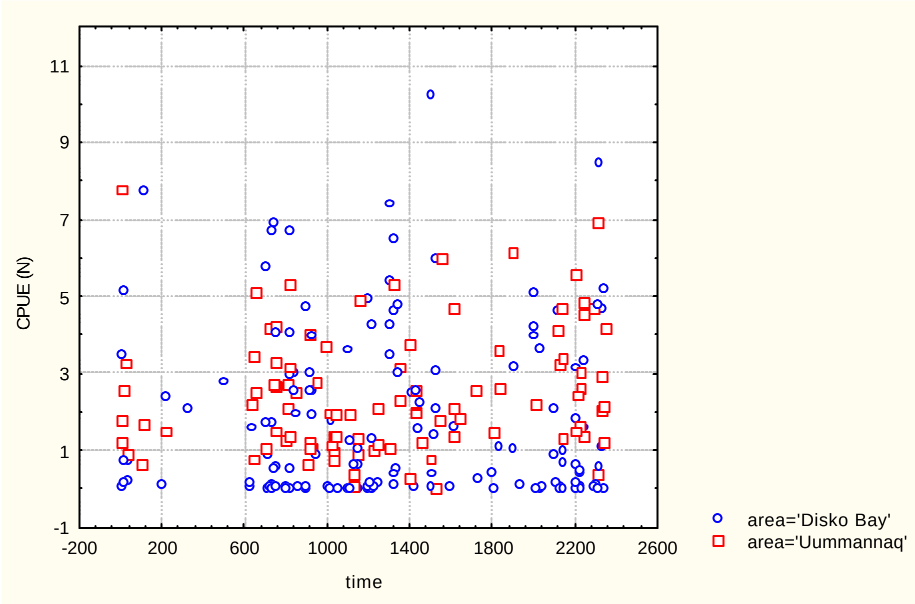


Figure 12. CPUE (N) from longline survey data in relation to time of day. Time recorded was the clock when the longline was set.

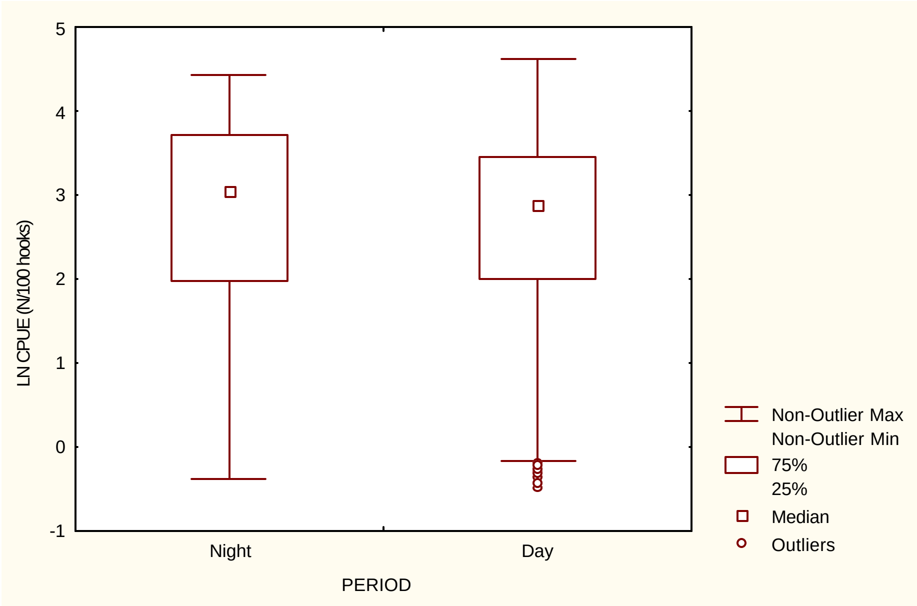


Figure 13. CPUE (N) at night and day. Note log. scale for CPUE

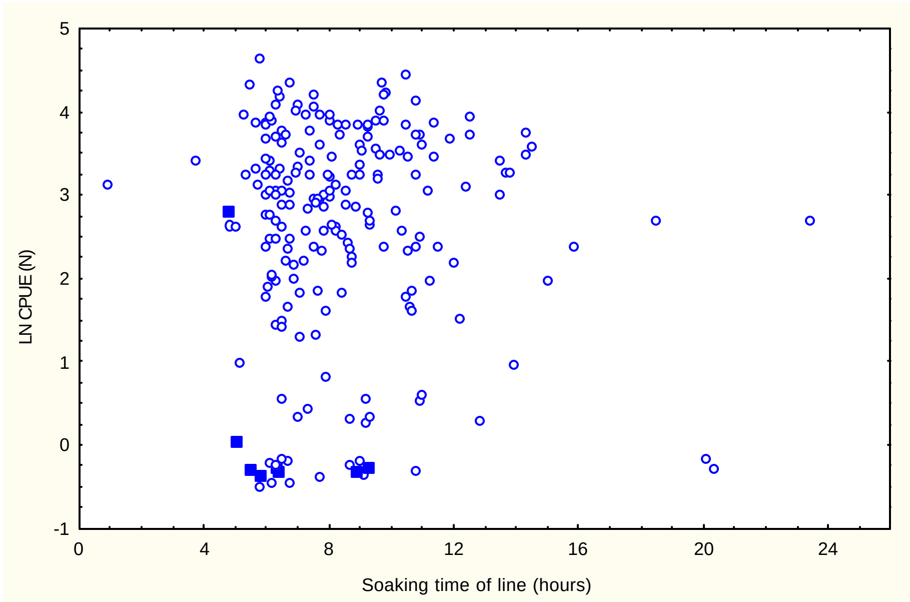


Figure 14. Catch from longline survey data in relation to soaking time (hours).

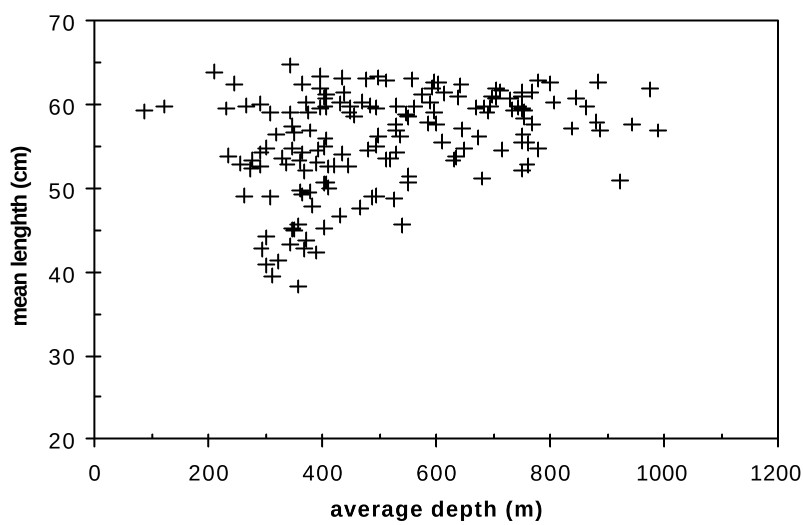


Figure 15. Correlation between size of Greenland halibut and fishing depth. Only linesettings with more than than 10 fish pr. linesetting was used. R=0.36, N=58

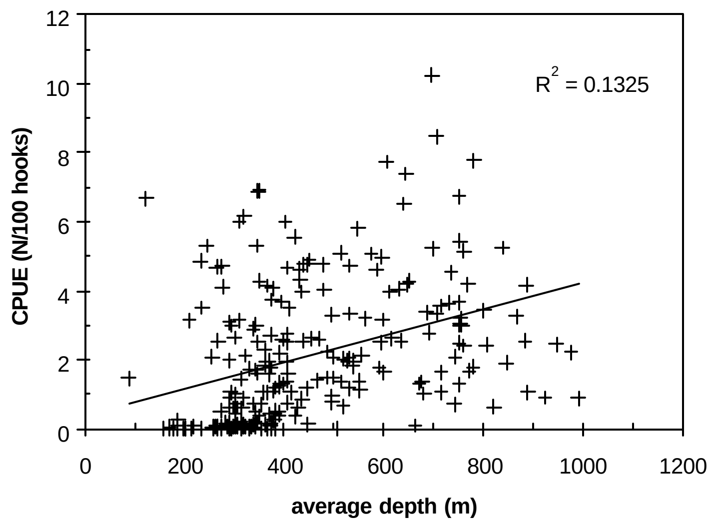


Figure 16. Catch rate at mean depth of lomgline. R=0.36. N=240.

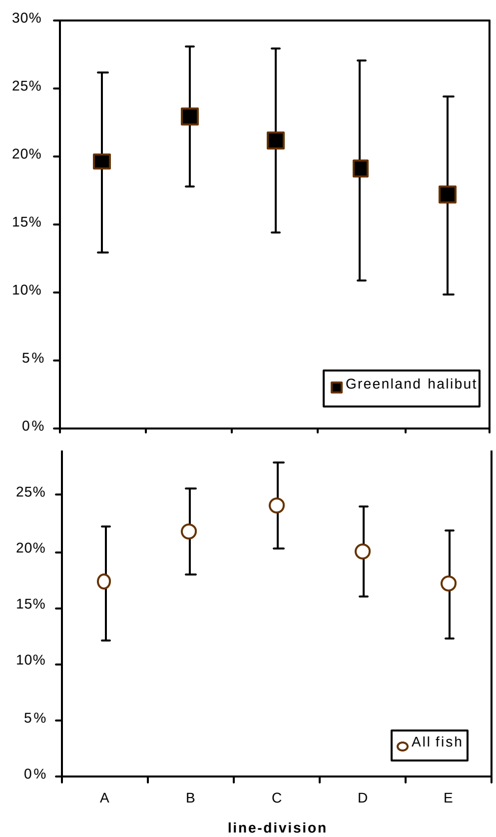


Figure 17. Releative catch of Greenland halibut in numbers on the first 4 sections on 24 longline settings. The line was hauled in the order from A to E. (errorbars show 95% conf. interval)