Catches of Greenland halibut (*Reinhardtius hippoglossoides)* in ghost fishing gillnets on the Norwegian continental slope

by

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Abstract

Catches in deliberately "lost" gillnets were studied during a ten-day cruise conducted at Storegga 70 nm off the coast of mid-Norway in July 2000. Gillnet fleets were deployed at depths of between 537 and 677 m, and soak time varied from one to seven days. Four fleets set 45 days earlier were also retrieved during the cruise. Most of the catch (94 %) consisted of the target species Greenland halibut *(Reinhardtius hippoglossoides).* All individuals were categorized according to seven condition stages ranging from "alive with no injuries" to "only bones remaining". Results revealed that fish could be fully decomposed/consumed within a 24-hour period, probably due to amphipod and isopod scavenger activity. A decline in total catches was first observed after five days whereas catch composition remained stable during the first seven days. After 45 days a relatively high total catch was obtained but only 25 % were still at stages 1-4 (consumable). The cumulative catch after 45 days was estimated at 2.7 and 3.0 tons on the basis of two different methods. Gillnets retrieved after 45 days were evaluated as being highly effective, with gear saturation being the only factor leading to decreased efficiency.

Keywords: ghostfishing, cumulative catch, Greenland halibut

Introduction

Several studies and retrieval projects have demonstrated that gillnets may continue to fish after they are lost, a process also known as 'ghostfishing' (Breen, 1990). The level of ghostfishing mortality may be considerable (Laist, 1995; Goni, 1998), but the lack of standardized methodologies means that confidence in much of the data collected must be low (Chopin et al., 1996).

Gillnets are lost from time to time for various reasons. Strong currents can drag the buoy below the surface to depths at which it will gradually collapse. The gear might catch on objects on the bottom, leading to rupture of the buoy line. Gear conflicts can lead to displacement of fleets or destroyed nets (e.g. by trawlers, Millner, 1985). Seismic vessels and merchant ships can cause loss of gillnets by cutting end markers.

Since 1983 annual retrieval cruises have been conducted in Norwegian waters (Anon, 1983-1999). Between 1983 and 1997 the numbers of retrieved gillnets have ranged from 106 to 1180 a year (Kolle et al., 1997). Gillnets are lost in fisheries for ling *(Molva molva)*, saithe *(Pollachius virens)*, cod *(Gadus morhua),* monkfish *(Lophius piscatorious)* and Greenland halibut *(Reinhardtius hippoglossoides)*. Live and fresh fish have been found in various types of gillnet, with the most conspicuous catches occurring in Greenland halibut nets. However, no calculations of ghostfishing mortality have been made, due to lack of suitable methods.

Assuming that the cumulative catch can be calculated from catch condition and catch rates at retrieval, registrations of fresh and decayed fish from the retrieval cruises are valuable. In order to investigate this aspect, an experimental fleet of gillnets (simulating ghost fishing nets) was set out and retrieved after various soak times. As well as taking into account the general characteristics and dynamics of lost nets, experiments were designed to provide information about the condition of the catch. This information was then used to calculate catch rates and the long-term total catch in ghost-fishing gillnets.

Methods

The experiment was conducted between July 17 -24 2000. The experimental site was at Storegga on the continental slope 70 nm miles off the coast of mid-Norway, where commercial gillnetting for Greenland halibut is carried out. Gillnets were deployed in depths of 537 to 677 m, over a seabed of sand and mud.

A commercial gillnetter was chartered for the experiment. Monofilament (0.6 mm) gillnets of 27.5 m length and 5.1 m height, were combined in fleets of 27-30 nets. The mesh size (stretched) was 180 mm with a hanging ratio of 0.5. Due to the range of different fleet lengths all results are standardized to 30 gillnets per fleet. Seventeen fleets with soak times that ranged from one to seven days were set during the trials (Table 1). A further four fleets that had already soaked for 45 days were also retrieved.

Table 1. Experimental schedule. Note that a commercial fishing vessel deployed four fleets one and a half months before the main period from 17-24. July.

Deployed	Retrieved	Soak time (days)	N (fleets)	N (gillnets)	Water depth (m)
3. June	18. July	45	4	127	630-652
12. July	19. July	7	2	60	583-657
12. July	17. July	5	2	57	639-648
17-20.July	20-23. July	3	7	217	593-667
17-22.July	19-24.July	2	3	90	611-639
20. July	22. July	1	3	97	537-667

The objective of the experiment was to find a way of calculating daily catch rates from retrieved nets on the basis of catch condition. The total cumulative catch can then be calculated by the following formula (assuming constant daily catch rates):

$$C = c_r n = \left(\frac{\sum_1^k c_k}{t_{max}} \right) n \qquad (1)$$

where; C = cumulative catch

      n = days since set

      c_r = mean catch rate (number of fish per day)

      c_k = catch at stage k at retrieval

      k = decomposition stage (k= 1-7, as seven stages were identified)

      t_{max} = time taken to reach the highest stage

By taking advantage of relative fishing efficiency measures, catch rates when retrieved can also be calculated as the proportion of normal (commercial) catch rates, giving:

$$C = c_r n = \left(\frac{c_k}{c_{kc}} c_{rc} \right) n \qquad (2)$$

where; c_{kc} = catch at stage k after c days (c=commercial~normal soak time)

      c_{rc} = total catch rate after c days

In order to find the time from which individual fish got tangled until hauled, each individual was classified on the basis of its condition. Seven stages were identified on the basis of knowledge gained from earlier retrieval cruises and observations made during the first hauls.

1. Alive, fresh: the fish is alive and shows no sign of morphological injury, is uniformly dark in colour and has no faded gills.
2. Alive, some damage: the fish is alive; disrupted colorization with brighter patches unevenly distributed over the body. Physical damage such as cuts, scratches and skin lacking between fin rays due to gillnet twine.
3. Dead fresh: the fish has faded gills and glossy eyes. (Contraction/cramps might occur).
4. Dead, some damage: similar in appearance to to stage 2, but dead.
5. Dead, extensive damage: the above damage indicators plus small holes in the flesh caused by scavengers (amphipods and isopods), but with most parts of the body still intact. Other criteria included white skin or some parts of the fish with exposed flesh.
6. Dead, severely damaged: bones partially exposed (sticking/protruding out from flesh), intestines lacking, larger parts of fish possibly missing. Body penetrated by small holes. Both fish clearly partially eaten and fish in the process of bacterial decay were included in this stage.
7. Bone relics: Only skeleton or parts of it remaining.

This classification can be compared with that used in the annual retrieval cruises mentioned in the introduction, in which two stages were used; fresh or with commercial value, equivalent to stages 1 - 4, and valueless or decayed, which is equivalent to stages 5 - 7.

Samples of the catches were selected for length, weight and sex determination. Only stage 1 was used to estimate weight at length relationships, since post mortem weight varies with degree of decay.

Results

Greenland halibut compromised about 94 % of the total catch in terms of numbers. The bycatch consisted mostly of roughhead grenadier (*Macrourus berglax*), but other species were also caught although in very small numbers (see Appendix). Hereafter, the term "catch" refers only to Greenland halibut. A total of 6478 halibut were caught and classified into the condition stages described above. The catch was dominated by females with a female sex ratio (females/(females + males)) of 0.9. The mean length and weight of females were 64.9 cm and 2.73 kg, and 61.7 cm and 2.37 kg in males.

Splitting the catch into condition stages showed that fish could go through all seven stages of deterioration within a 24-hour period. The classification of fish into condition stages was unproblematic although a more refined scale may be required. During the first seven days the presence of scavengers (amphipods and isopods, fish lice) was evident and these are believed to be major contributors to the decaying process. After 45 days soak time fewer fish lice were registered but all stages of deterioration were observed. The time between the 7th and 45th day at which the transition from a mixture of bacteria and fish lice to bacteria-dominated decay occurs is not known.

The frequency distribution of the catch at different stages and soak times resembled a shift from the first stage, which dominated during the first seven days to a catch dominated by stage 6 after 45 days (Fig. 1).
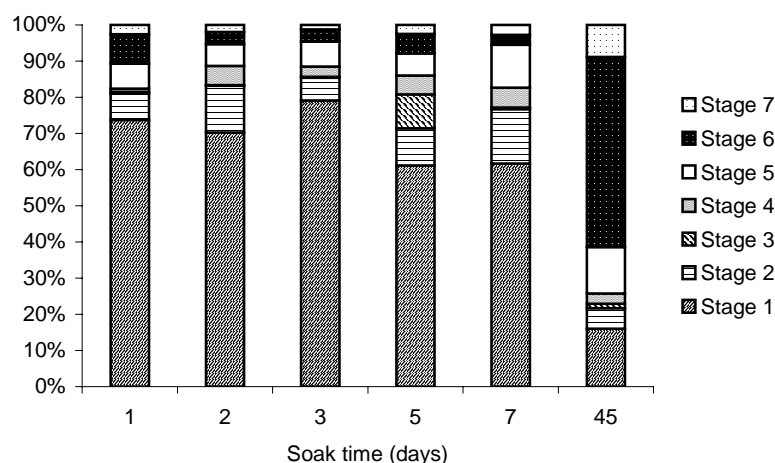

Figure 1. Frequency distribution of catch at different stages of deterioration. Note that the fifth day had a high proportion of fish in stage 3, see text for explanation.

The highest catch rate was observed after five days (Fig. 2) (although this was not significant due to high variance). As the plot shows, the increase in the catch rate of fresh fish does not result in an increased rate of old fish, which is constant at around 17 fish per day.
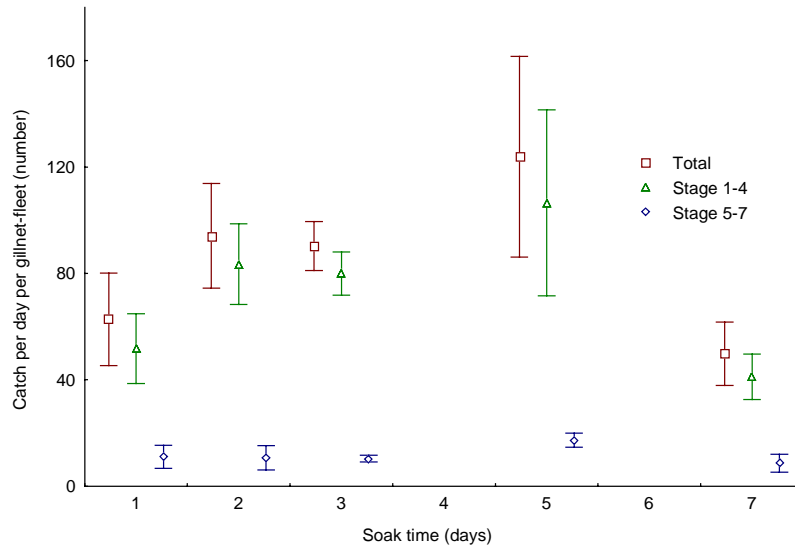
Figure 2. Catch divided by soak time. Bars indicate standard deviation.

A rise in catch rates for stages 1-4 with a maximum after five days and a decrease on the seventh day was observed, with the exception of stage 3 which suddenly rose (Fig. 3). By using the increase in stage 3 after five days to find t_{max} for $k=3$, gillnet fleets after 45 days soak time would have caught 990 fish (2.7 tons) using equation (1) ($k=3$, $t_{max}=5$, the sum of c_k after 45 days=110 and $n=45$).

The frequency distribution of stages 1-4 at 5 and 45 days soak time did not differ significantly (2 x 2 contingency table, $p=0.065$, stage 1 against 2-4$_{pooled}$). The catch of stage 1 after 45 days was reduced to 20.4 % compared to that of five days. By using these figures ($c_k=77$, $c_{kc}=378$, $c_{rc}=123$, $k=1$, $n=45$) in equation (2) an estimate of the cumulative catch after 45 days would be 1130 fish or 3.0 tons.
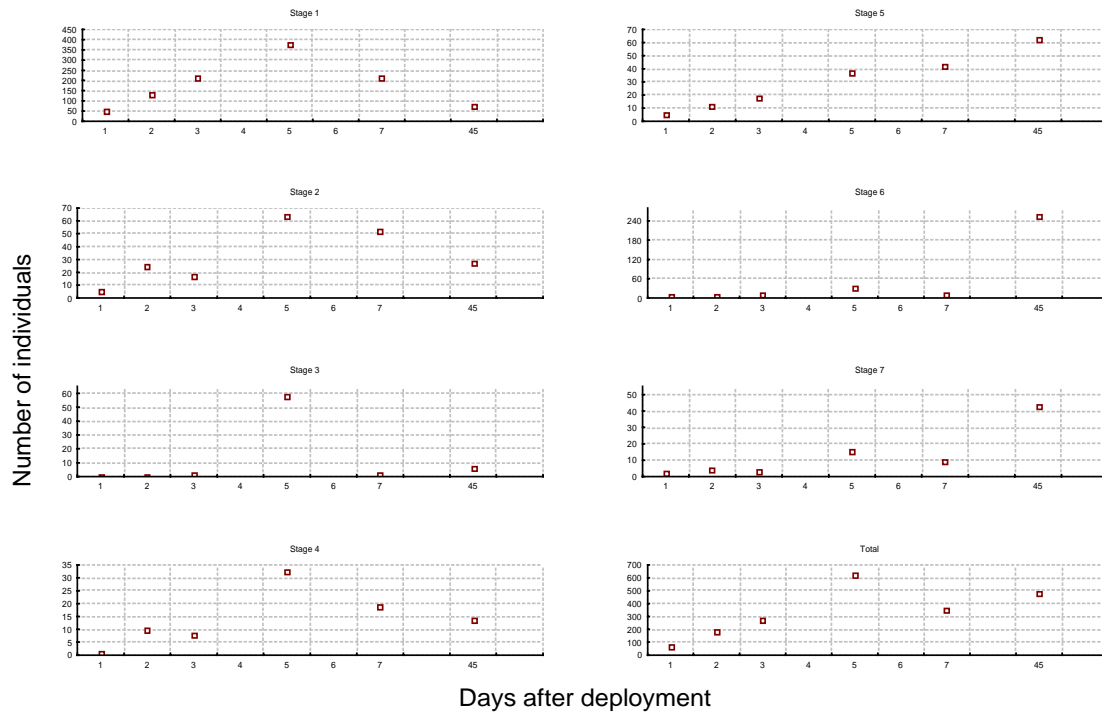
Figure 3. Catch in numbers at different soak times for each stage. Note different y scales, and a scale break at x=7.

Discussion

It is impossible to control for all factors that may affect a ghost-fishing gillnet in a realistic experiment (Kaiser et al., 1996). Nets may be lost in a number of ways but in simulation studies it is necessary to single out one (e.g. Erzini et al. (1996) cut one end loose). Cutting off end markers and the displacement of fleets by strong currents are the main causes of net loss when gillnets are set on the continental slope (B. Finnøy, skipper of M/S *Synsrand*, personal communication). This type of loss will probably not affect the physical configuration of the net, and normal setting of experimental fleets was therefore adopted.

Several other studies have reported on fish at different stages, with typical classes such as "alive, fresh", "dead, recently dead" and "decomposed, old, decayed, unidentifiable" (Way, 1975; 1976; Brothers, 1992; Erzini et al, 1997), but none have utilized this information further in their analysis. The presence of fish at all stages of deterioration after only one day was somewhat unexpected. This rapid decay was related to the presence of fish lice. Earlier retrieval cruises have not reported fish lice attacks and it was therefore anticipated that the most important cause of decomposition would be bacterial. This was also the case for fish caught after 45 days soak time, which are most comparable to those caught in real lost nets. This pattern observed may be the same as fishermen term *saturation of fishing grounds* (Furevik, 1990). When fishermen arrive at new grounds, gillnets are set to catch fish that primarily feed fish lice and thus make for poor quality catches. After feeding these go into a dormant state (Johanesen, 1980) and catches of high quality fish are obtained. If it were possible to split catches in terms of the decomposition process it might be possible to trace the development of the two sub-processes and thereby model them, but since both bacteria and crustacean scavengers may lead to the same state it was impossible to distinguish

between the origin of decay for individual fish. In order to do so, each individual fish would have to be dissected and checked for scavengers.

The relative catching efficiency and catch rates applied were based on mean values, all of which have associated deviations. For this reason the estimates should only be regarded as indicative. The large variation in the material also demonstrates the unpredictable nature of ghostfishing nets, since a serious attempt was made to conduct the experiments under similar conditions. The similarity between the two estimates of cumulative catch of 2.7 and 3.0 tons, however, suggests that they may reflect the true value. It must be noted, however, that the t_{max} value for k=3 in equation (1) was not confirmed by similar observations of this stage on the following day. One explanation might be that this is a short transition stage and that gillnets were retrieved at a time when it could not be observed, the other possibility is that the observations on the fifth day were just a coincidence.

A characteristic of the development of stages 1-4 is that the process leading to the succession of stages is physical strain from gillnet (e.g. damage from thread and suffocations due to limited operculum movement; see description of stages). If it acts alone this process will lead to the same frequency distribution, independent of the magnitude of the catch, while the actual frequencies (counts of fish) will be proportional to the catch rate. In this way it is easy to determine the catch rate and total catch after 45 days by using equation (2). The reason why stages 5 - 7 do not fit this pattern is twofold. First, one of the processes leading to them (fish lice) is not constant over time, and we were unable to distinguish between this process and bacterial decay. Second, the frequencies of these stages is unreliable since some fish at these stages are lost during hauling. Furevik et al (2000) found that only 15 % of the catch registered by ROV was retained after hauling.

A more refined calculation, would implement the dynamics of catch rate development (instead of using constant rate) in the equations (variation in fish abundance should also be considered). Matsuoka (in Chopin et al, 1996) suggested a time-dependent mortality, but such a calculation cannot be justified because we are not sure of the course between the experimental registrations. Nevertheless, by assuming constant catch rate the estimates may be regarded as conservative as they are based on the catch rate at the time when the gillnets are retrieved.

The drop in catch efficiency over time is likely to be the result of saturation. The mean total catch after 45 days was 480 fish per fleet (plus approximately 20 individuals belonging to other species). Using the figures provided by Meth (1970) gear saturation would appear at approximately 660 fish per fleet. The reason why saturation is still regarded as a likely explanation is that some fish are lost during hauling. Furevik et al (2000) found that the deviation in catches after hauling and catches registered by ROV increased with soak time. After 33 days only 15% of the catch registered by ROV was retained after hauling. The latter would also explain the decrease in total catch after seven days (Fig. 3), where an increase would have been expected had it not been for the losses.

Carr and Cooper (1987) found that groundfish gillnets at least four years old caught 15% as many fish as commercial nets would normally fish, on the basis of data on reduced vertical profile, fouling and integrity of the nets. Kaiser et al. (1996) found a significant relationship between headline height and fish catch. Headline height recordings were not available from our experiment but no signs of net collapse were noted (e.g. ground line over headline) when nets were hauled after 45 days. In a study by the Irish Sea Fisheries Board (BIM, 1995)

gillnets in deeper waters (80 m) suffered much less fouling than inshore gillnets (15 to 18 m) and were more effective in fishing terms. In our study neither signs of wear and tear, nor any fouling organisms were registered after 45 days. All in all, these factors suggest that the breakdown of gillnets is slow at these depths, and the only factor that contributes to reduced headline height appears to be the catch itself.

In fact, the targeted species may contribute to maintain the vertical extension of the net by swimming. Three different ways of capture are gilling, wedging and tangling (Olsen and Tjemsland, 1963; Hamley, 1975). The way in which fish were caught by the net was not monitored systematically but the impression was that most fish were wedged at their maximum girth rather than over the gills. Attachment in this way would mean that fish could remain alive for some time after they are caught and might prevent the gillnet from falling to the ground.

The catch composition showed that even after some time the targeted species was still the most abundant one. In a study of derelict gillnets investigated from a submersible, no fish belonging to the gadoid family were caught (Carr and Cooper, 1987), and later observations showed that gadoids successfully avoided the nets (cited from Breen, 1990). However, it is more likely that other species were not caught to a greater extent because they were not in the area at all as a result of their normal distribution, rather than because of avoidance. Other studies have revealed that the species composition changes when headline height drops as a result of the the weight of the fish and when large numbers of crustaceans are entangled as they come to feed on the decomposing fish (Kaiser et al., 1996). During the whole experiment only 5-10 crabs were caught. The lack of large crustaceans in the catch suggests that after the fish had decomposed, gillnets would rise again to an upright position and continue fishing. Way (1977) found that ghostfishing gillnets in areas of low crab concentrations in Newfoundland continued to fish efficiently for at least two years (fish are caught, die, decay and are replaced by live fish to continue the cycle).

Conclusions

Lost Greenland halibut nets continue to catch mainly the target species. When amphipod and isopod scavengers are present, the decomposition rate will decrease as the fish lice become saturated. The true catch is represented via the amount of fresh fish, as the old or decayed fish will show greater variation. It is possible to calculate catch rates and cumulative catches from the information provided by retrieval cruises. However, these methods need refinement, and they should be repeated and verified. Ghostfishing gillnets may be very effective because of the low degree of fouling at the depths studied, the slow degradation of gillnet material, lack of large crustaceans and the way in which nets are lost.

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Appendix

Table 1. Catch composition of fish.

Common name	Scientific name	% of catch
Greenland halibut	*Reinhardtius hippoglossoides*	93.54
Blue ling	*Molva dipterygia*	0.18
Greenland shark	*Somniosus microcephalus*	0.04
Ratfish	*Chimera monstrosa*	0.11
Roughhead grenadier	*Macrourus berglax*	5.67
Arctic skate	*Raja hyperborea*	0.11
Torny skate	*Raja radiata*	0.18
Ling	*Molva molva*	0.04
Skate indet.	*Raja spp.*	0.04
Redfish		
	Sebastes viviparus	
	Sebastes marinus	
	Sebastes mentella	
	Sebastes marinus,giant	0.04
Sole	*Soleidae spp*	0.07
Grand Total		100.00