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Tagging Mortality of Greenland Halibut *Reinhardtius hippoglossoides* (Walbaum)

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Abstract

Tagging mortality for Greenland halibut (*Reinhardtius hippoglossoides*) was studied under summer and winter conditions. The fish were caught using longlines and tagged with a T-bar tag. The winter experiment was conducted in Cumberland Sound, Canada in May 1997. Air temperatures were below 0°C and cold water-masses were present at 0–300 m. Fish were immediately placed in a tub of water after capture and transported by snowmobile to a heated tent for tagging and then placed in cages that were submerged to 300 m depth. The summer experiment was conducted in Upernavik, Greenland in August 1998. Air temperatures were above 0°C but intermediate cold water-masses were present at 60–200 m. In the summer experiment, fish were tagged and released in a observation tank to assess immediate tagging mortality (1 to 18 hr). They were then placed in specially designed cages and submerged to 300–500 m to assess short-term tagging mortality (up to 117 hr). A total of 155 Greenland halibut were included in the study. Overall tagging mortality was estimated to be 7%. Immediate handling and tagging mortality in both winter and summer experiments was low (< 5%). Several factors were shown to have significant effects on the outcome (level of condition). Fish held in the tanks for longer time periods were in better condition. Females had a tendency to be in poorer condition than males immediately following tagging. Overall short-term mortality was 4%. There was no significant difference in mortality rates between seasons. There was no effect on mortality of the covariates size, time held in the cage and several other factors examined, but overall mortality was so low that differences would be difficult to detect. However, there was a significant correlation between the fish condition and mortality. The study showed that tagging under harsh winter conditions is just as possible as under summer conditions as long as exposure to sub-zero air/water temperatures are minimized. Our study further suggests that holding the tagged fish in an observation tank for a period of 5 hr or more could reduce the tagging mortality on released fish.

Key words: Baffin Bay, Davis Strait, Greenland halibut, mortality, oxytetracycline otolith marking, *Reinhardtius hippoglossoides*, tagging, temperature

Introduction

The application of external tags is an important tool that has been used in fisheries biology for over 100 years to determine migration patterns, discriminate between stocks and estimate stock sizes. Tags have also been widely used to assess growth, mortality, age and behaviour. A variety of tag types have been used over time (for a review see McFarlane *et al.*, 1990). The prerequisites for a successful tagging program are: 1) the fish survive the tagging operation; 2) the tag is not lost; and 3) there is certainty that a portion of the tagged fish can be recaptured at a later date. In this paper we evaluate tagging of the deepwater species Greenland halibut, *Reinhardtius hippoglossoides,* with special attention to tagging mortality.

Greenland halibut are widely distributed over most of the northern circumpolar arctic and sub-arctic

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oceans in depths ranging from 200 to at least 2 200 m, and are associated with water temperatures of 1 to 6°C (Bowering, 1999; Jørgensen, 1997). Greenland halibut have, in the last decade, become an important commercial species (Bowering and Nedreaas, 2000). As a result, there has been an increased demand for studies at both stock and individual levels for management purposes. In many of these studies tagging is an important assessment tool.

To our knowledge, the first tagging experiment on Greenland halibut was conducted in West Greenland waters in the 1930s (Hansen, 1949, ref. *in* Smidt, 1969). Subsequently, several tagging experiments and programs have been carried out in West Greenland (Smidt, 1969; Boje, MS 1994; Simonsen and Boje, MS 2001; Boje, 2002), in Canadian waters (Bowering, 1984; Northlands Consulting, MS 1994; Stephenson *et al*., MS 1997), in the Svalbard area near Norway (Lahn-Johansen 1965 *in* Nedreaas *et al.*, MS 1999; Godø and Haug, 1987; Nedreaas *et al.*, MS 1999; Å. Høines, Marine Research Institute, Bergen, Norway, pers. com.), in the waters around Iceland (Sigurdsson, 1981; E. Hjorleifsson, Marine Research Institute, Reykjavik, Iceland, pers. com.), and in the Gulf of Alaska (J. Ianelli, Alaska Fish. Science Center, Seattle, WA USA, pers. com.). These different studies have used either trawl or longlines to catch the fish and tagging has been with Petersen-type discs, T-bar anchor tag, Lea tag and different kinds of spaghetti or wire tags. None of the above studies have evaluated tagging mortality and tag loss.

The fisheries for Greenland halibut in the Davis Strait and Baffin Bay are continuing to develop both in the inshore and the offshore areas (Jørgensen, MS 2001; Simonsen and Boje, MS 2001; Treble, MS 1999). Tagging programs have been used successfully in the past and are believed to be an important tool in furthering our understanding of Greenland halibut migration and stock boundaries in these areas. Summer tagging programs have been going on for many years in West Greenland waters but tagging mortality and tag loss have never been evaluated. Mathias and Chiperzak (MS 1996) suggested that the most cost-efficient method to tag several thousand fish in Canadian Arctic waters would be to tag during the winter long-line fishery. However, tagging in harsh winter conditions (air temperatures of -10 to -30°C) is a new approach that could result in severe handling/tagging mortality. In the present paper, we examine tagging mortality within both our summer and winter tagging programs and review mortality factors in the present and in previous studies.

Materials and Methods

Tagging mortality for Greenland halibut was studied under summer and winter conditions. The winter experiment was conducted in Cumberland Sound, Canada in May 1997 and the summer experiment was conducted in Upernavik, Greenland in August 1998 (Fig. 1). For both summer and winter tagging programs, Greenland halibut were caught using longlines. The longlines were set in 400–850 m and soaked for 5–12 hr. Fish were gently landed to minimize damage. If the hook was placed in the outer mouthparts and the fish was undamaged it was used in the tagging experiment. We were interested in the effects of tagging on fish mortality, therefore, fish that died at capture or were considered too damaged to tag were not included in the analysis. Individual fish were measured (total length) and tagged using a Dennison tagging gun. The tag was placed slightly posterior to the line of maximum body depth and approximately 1–2 cm (depending on the size of the fish) below the insertion of the dorsal fin. The external portion of the tag was aligned to protrude from the right (dorsal) side of the fish and angled posteriorly. Greenland halibut are known to be relatively passive and easy to handle so no anesthetic was used. The fish were initially released into an observation tank in order to determine immediate mortality. In the summer experiment, fish were briefly assessed and assigned a condition factor (Table 1) after being held for a predetermined time in the observation tank. All live fish were placed in a cage for the study on short-term mortality. In order to make the experimental conditions as comparable as possible to a normal tagging operation, the cages were submerged and held at 300–500 m (approximately the depth of capture). At the predetermined time, the cages were retrieved and fish mortality and tag loss were recorded.

Summer Tagging Experiment

This experiment was carried out in two fjords in Upernavik District along the West Coast of Greenland (Fig. 1). Greenland halibut were captured at 14 stations (longline sets, referred to as stations *a* to *n* in Table 2) as part of a longline survey in August 1998. The longline was equipped with a J-type hook, Mustad no. 8, 7255D, baited with squid (for details about the longline survey see Simonsen *et al*., MS 2000). Hooked fish were gently netted as the line was retrieved and brought on board. They were

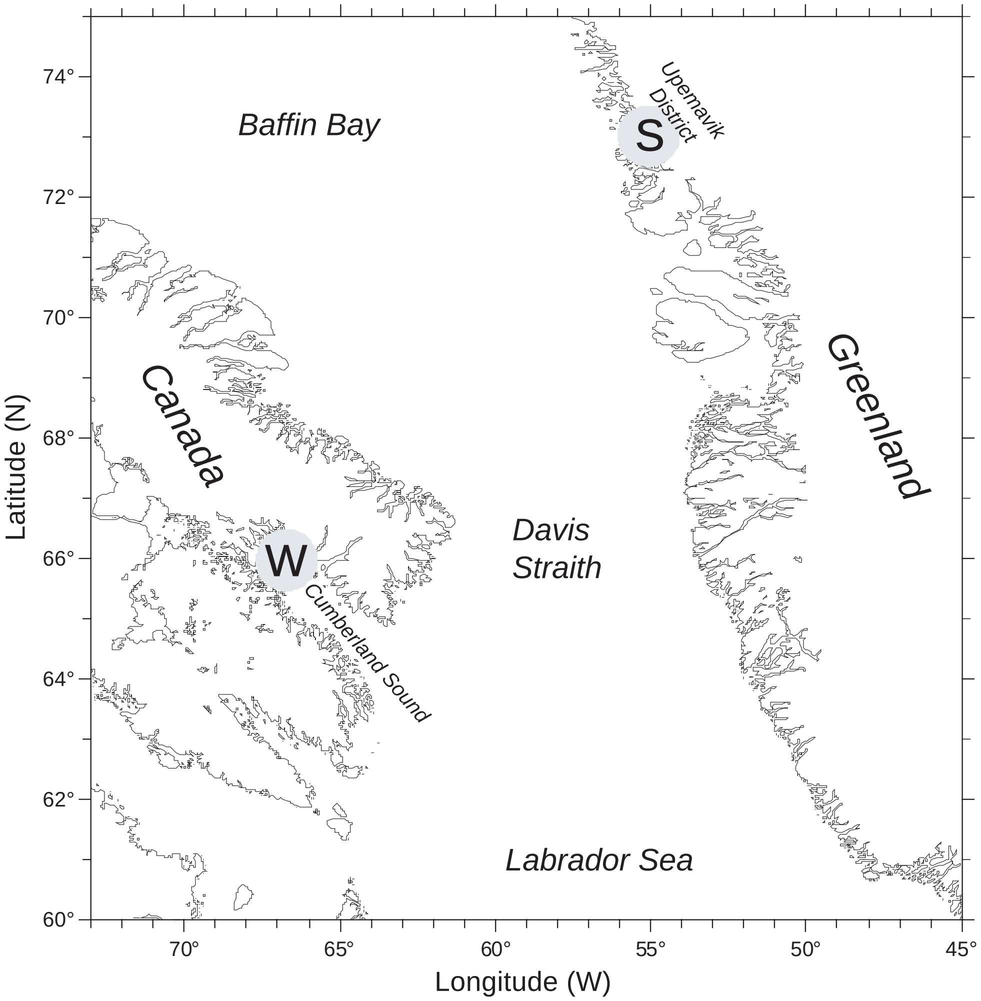

Fig. 1. The winter (W) and summer (S) experiment sites in Canada and Greenland. The winter experiment was conducted in Cumberland Sound in May 1997 while the summer experiment was conducted in two fjords in the Upernavik district in August 1998. Greenland halibut were caught close to the experiment sites using longlines and later released in cages, Fig. 2 and Table 3.

TABLE 1. Criteria used to determine the condition of the fish after the predetermined time in the summer tank experiment.

Condition level	Description
I	Very good condition. Fish swimming lively, deep-red gills
II	Good condition. Fish swimming, deep-red gills
III	Reasonable condition. Fish swimming slowly, red gills
IV	Poor condition. Fish hardly swimming, pink gills
V	Dead

TABLE 2. Immediate mortality and condition in the summer experiment. The influence of: fish length, time in tank, station (longline set) and sex on fish condition (Levels I–V) in the tank experiment before release in cages. Eighteen fish from Location 1 (see Table 3) did not have condition evaluated and are thus not included in this table or the analysis of immediate mortality and condition. Both number of fish and corresponding % are given for each category and condition level.

		Condition					
		I N/%	II N/%	III N/%	IV N/%	V N/%	Total N
Length (cm)							
	30–40	1/50	0/-	1/50	0/-	0/-	2
	41–50	10/56	6/33	0/-	1/6	1/6	18
	51–60	31/72	8/19	0/-	0/-	4/9	43
	61–70	27/69	10/26	1/3	1/3	0/-	39
	71–80	2/67	1/33	0/-	0/-	0/-	3
	Total	71/68	25/24	2/2	2/2	5/5	105
Time in tank (hr)							
	1–5	38/60	18/29	2/3	2/3	3/5	63
	6–10	16/73	4/18	0/-	0/-	2/9	22
	11–20	17/85	3/15	0/-	0/-	0/-	20
	Total	71/68	25/24	2/2	2/2	5/5	105
Station							
	a	3/75	1/25	0/-	0/-	0/-	4
	b	0/-	2/100	0/-	0/-	0/-	2
	c	3/100	0/-	0/-	0/-	0/-	3
	d	3/50	1/17	0/-	0/-	2/33	6
	e	3/100	0/-	0/-	0/-	0/-	3
	f	10/91	1/9	0/-	0/-	0/-	11
	g	4/80	1/20	0/-	0/-	0/-	5
	h	3/60	1/20	1/20	0/-	0/-	5
	i	1/13	4/50	0/-	0/-	3/38	8
	j	5/100	0/-	0/-	0/-	0/-	5
	k	6/46	6/46	1/8	0/-	0/-	13
	l	4/36	5/45	0/-	2/18	0/-	11
	m	10/83	2/17	0/-	0/-	0/-	12
	n	16/94	1/6	0/-	0/-	0/-	17
	Total	71/68	25/24	2/2	2/2	5/5	105
Sex							
	Male	14/78	4/22	0/-	0/-	0/-	18
	Female	16/53	7/23	2/7	2/7	3/10	30
	Total	30/63	11/23	2/4	2/4	3/6	48

immediately measured and tagged with Floy tags (FD-68B) and released into an observation tank. Every second fish was given a dose of 50-mg/kg oxytetracycline (OTC) injected into the body cavity. The OTC is known to mark otoliths and was being tested for use in age validation of Greenland halibut. The observation tank was equipped with continuous water flow at an average temperature of 3.02°C (min. 0.9, max. 5.5°C). After 1 to 18 hr, condition was evaluated using a 5-point scale (Table 1) and fish were released into cages. Fish that died while in the observation tank were sampled for sex.

The temperature profile at cage release locations was determined using a temperature probe lowered through the water column. The cage was a modified box-type snowcrab pot consisting of a fine mesh net (black, mesh size 10 mm, knot free) stretched inside a metal frame (approximate volume 0.9 m^3; Fig. 2). An opening device at the top of the cage allowed the fish to be added and removed and a metal pipe (diameter 10 cm) situated in the middle of the cage provided an attachment site for the anchor rope. The lower part of the cage was equipped with buoys to suspend it in the water column. Each cage was held in the sea beside the ship while fish were transferred from the observation tank. A total of eight to 18 fish were placed in each cage (density 8.9 to 20.0 fish m^{-3}), then lowered (sinking rate was ~30 m per min) to the desired depth. The cages were retrieved after a predetermined study time and a portion of fish that were held in the cages was sampled for sex. Water temperature at each cage setting was monitored with an attached temperature probe and found to average 1.26°C (min. 0.6, max. 1.45°C). A total of 10 cage settings were carried out in two fjords at several locations (Table 3).

Winter Tagging Experiment

This experiment was carried out in Cumberland Sound, Southeast Baffin Island (Fig. 1). Greenland halibut were captured using longlines set from the land fast sea ice and equipped with Milward circle (Kirbed) No. 2 hooks baited with arctic char (*Salvelinus alpinus*). Fish were removed from the hooks as quickly as possible and placed in 0 to 4°C water in a 70 liter fish tub. The fish tub was covered with plywood to limit exposure to sunlight and heat loss and transported to a tent on a sledge drawn by a snowmobile. The outside air temperature varied from -12.0°C to +2.0°C during the day. Wind-chill was a factor, particularly when removing fish from the unprotected fishing holes. We were able to limit the fishes' exposure to sub-zero air temperatures by tagging inside a tent. Heated water was added to the water in the tagging tank in order to keep it above 0°C. However, this made it difficult to maintain a constant temperature over the experiments (range 1 to 5°C). The water in the tagging tank was partially or completely changed at least two to three times a day to maintain clean, well-oxygenated water conditions. Once in the tent, fish were placed in an

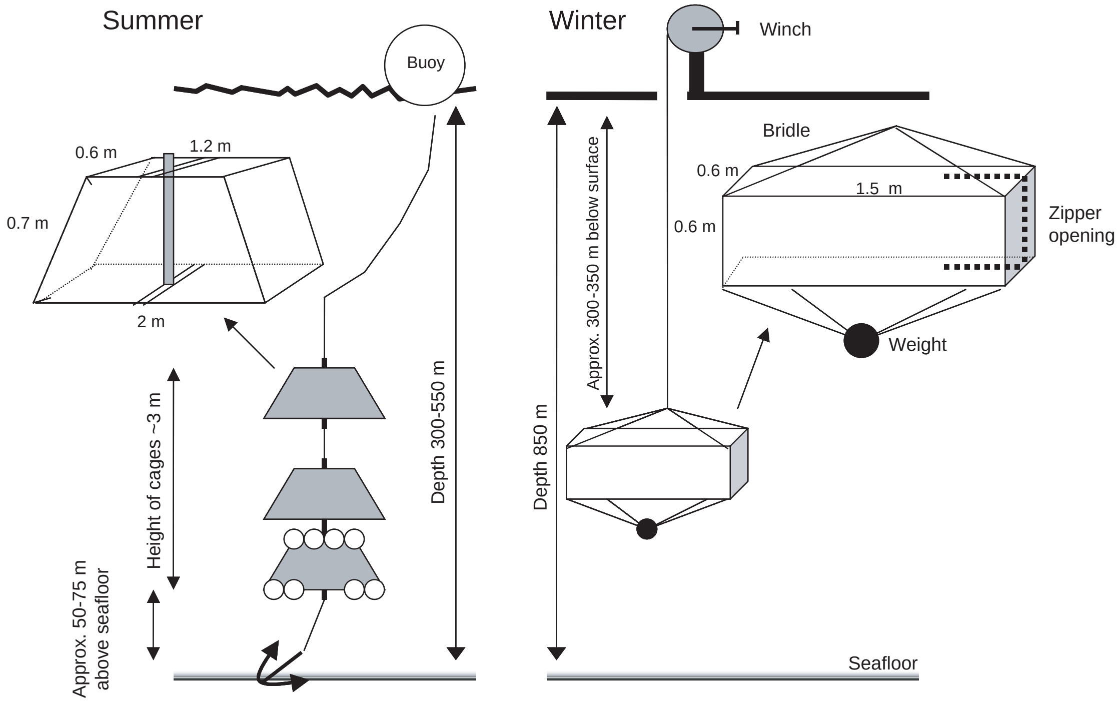

Fig. 2. Schematic presentation of the design and set-up in the summer and winter experiment.

TABLE 3. Summary of the cage settings (depth, time, number of fish, etc.) for the summer and winter tagging experiments carried out in August 1998 in Upernavik district, Greenland and May 1997 in Cumberland Sound, Canada.

	Location	Position	Depth of cage (m)	Time in tank (hr)	Time in cage (hr)	Fish in cage (n)
Summer	Fjords in Upernavik District	73°20'N 55°20'W	310	2½	32	9 [ab]
			310	2½	27	9 [b]
		73°12'N 55°31'W	450	2½	39	9
			450	2½	39	9
			450	3	29	11
			260	18	101	10
			260	3	86	8
			310	13½	62	14
			310	5	36	14
			310	10	36	14
	Total summer					**123** [c]
Winter	Cumberland Sound	65°59'N 66°43'W	300	<½	4½	1
			300	<½	5	11
			350	<½	10½	10
			350	<½	56½	10
	Total winter					**32**
Combined						**155**

[a] Fish were not tagged
[b] condition was not evaluated
[c] includes 5 fish that died in the tank

observation tank where they were measured, tagged (Floy tag, model FD-94) and held for 10–20 min prior to placing them in a holding cage. A hole was cut in the ice just inside the open end of the tent to allow deployment and retrieval of the cage.

The cage was held at depth, below the cold-water layer, where temperature was similar to that found on the bottom (Fig. 3). A conductivity, temperature and depth (CTD) sound was taken in order to determine the exact conditions for our tagging site. The cage was made from 2 cm diameter PVC pipe covered with fine mesh (6 mm) seine netting and measured 0.54 m^3 (Fig. 2). A zipper was sewn into one end of the netting to provide an opening for adding and removing the fish. Ten to 11 fish were placed in the cage (density 18.5–20.4 fish m^{-3}) on three different occasions and held for 5, 10.5 and 56.5 hr. A 20 kg weight was attached to lower the cage into the water (sinking rate ~9 m per min) and to keep it suspended in the water column on a line secured to the ice above. The temperature of the tagging and transport tanks was recorded and notes made on the condition of the fish before and after being held in the cage.

Data Analysis

We have divided the analysis of our results into two parts. First, we considered the tank experiment using data from the summer experiment only. The Greenland halibut were held in observation tanks immediately following tagging for 1½ to 18 hr. The outcome examined was the fish condition, assessed using a five-point scale (Table 1). The continuous variable *fish length* and categorical variables *time in the tank* (data grouped in 3 intervals 0–5 hr, 6–10 hr, and 11–20 hr), *station* and *sex* were examined for their influence on condition (Table 2). First we looked at each variable separately using univariate general linear regression (GLM) to determine the significance in the model of the variable or the variable levels (for categorical variables). Thereafter, we examined additive and interaction effects using multivariate models (for details see McCullagh and Nelder (1989), Chapter 2).

Secondly, we considered the cage experiment. After an assessment of immediate effects, the fish were placed in cages and held for relatively longer periods

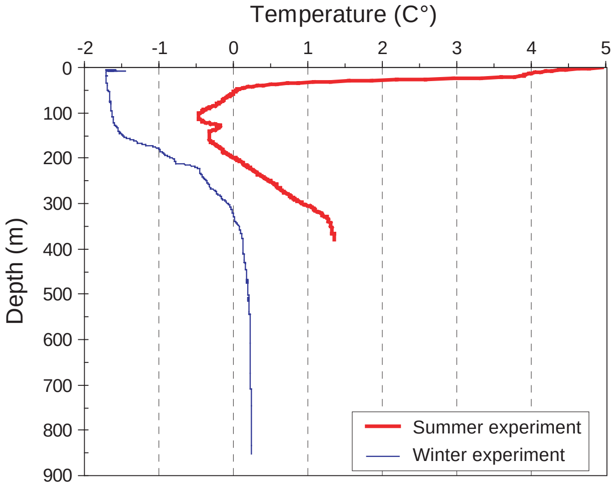

Fig. 3. Temperature profiles at the summer and winter locations. The summer experiment was conducted in August in Upernavik district, West Greenland and the winter experiment in May in Cumberland Sound, Canadian Eastern Arctic (see Table 3 and Fig. 1).

of time to assess short-term tagging effects. The total time the fish were held in captivity varied between 4½ and 119 hr (Table 4). Fish were pooled in 6 time intervals based on weighted mean values for each cage. Fish condition after the tank stay was used to evaluate the dependence of mortality on condition. The Floy tag itself or the additional handling due to attachment of the tag could introduce higher mortality. In the summer experiment, a total of nine fish in one cage setting were not tagged with a Floy tag, but were otherwise treated equally. In the cage experiment the outcome was the binary result dead or alive. Investigation of the relationship between the probability of dying and the explanatory variables *season, fish length, time held, condition, tag, cage, sex and OTC* was done using logistic regression (GLM). McCullagh and Nelder (1989), Chapter 4, provided an appropriate transformation (the link function1) of the probabilities. As was done in the tank experiment, we first took the univariate approach to determine the significance in the model of the variable or the variable levels (for categorical variables) and then examined additive and interaction effects using multivariate models.

Results

The weather conditions during the winter experiment in May (WINTER) were relatively warm for the season -12.0 to +2.0°C and thus excellent for tagging. The air-temperature was not monitored directly during the summer experiment (SUMMER), but was in the range +2 to +10°C (normal for the Upernavik area in August). The temperature conditions in the water column at each location are illustrated in Figure 3. Both WINTER and SUMMER locations had a cold, sub-zero, water layer present. In WINTER it extended from the surface down to ~300 m. However, between 100 to 300 m temperature gradually rose to 0°C. Below 350 m water temperature was homogeneous at approximately + 0.2°C. In SUMMER a cold intermediate water layer was present from 57 to 198 m. Below 200 m the temperature again rose and began to stabilize around +1.35°C at 300 m. As a consequence, the Greenland halibut were exposed to sub zero temperatures during both experiments when the longlines were retrieved and when the cages were lowered and raised.

A total of 155 fish were included in the study (Table 3). Nine fish died in the summer experiment and two died during the winter experiment for an overall mortality of 7.1%. Of the 11 dead fish, 5 died in the holding tank and 6 in the cages.

The low sample size and overall mortality in this study reduces the power of any statistical tests and therefore it is difficult to fully evaluate the extent to which certain factors contribute to the condition level in the tank experiment or the tagging mortality in the cage experiment. Furthermore, variables other than those we examined (e.g. physical or physiological factors that are difficult to measure) could have an effect on condition and probability of mortality. These points should be kept in mind when interpreting the outcome of the analyses presented below.

Immediate Mortality and Condition (Tank Experiment)

There was no immediate mortality in the winter experiment during the 10–20 min the fish were held prior to placement in the cages.

In the summer experiment, a total of 105 fish were included in the analysis of immediate mortality and fish condition (18 fish from the first location did not have their condition level evaluated) (Tables 2 and 3). Five fish were assigned to level V (dead), which corresponds to a mortality of 4.8%.

Fish lengths ranged from 35 to 73 cm but the majority were between 41 and 70 cm. Death only occurred in length interval 41–50 cm and 51-60 cm, whereas condition level I was observed for all length

TABLE 4. Short-time mortality (cage experiment). The mortality rate in % is also given for each category. The variable Condition has fewer observations because: 1) 18 fish from the summer experiment were not assessed for condition (see Tables 2 and 3), and 2) the winter experiment did not apply the five-point scale used in the summer experiment.

		Alive N	Dead N/%	Total N
Season				
	Summer	114	4/3	118
	Winter	30	2/6	32
	Total	144	6/4	150
Fish length (cm)				
	30–40	3	0/0	3
	41–50	26	2/7	28
	51–60	57	2/3	59
	61–70	52	2/4	54
	71–80	6	0/0	6
	Total	144	6/4	150
Time (hr)				
	8	21	1/5	22
	31	26	3/10	29
	42	45	1/2	46
	60	14	1/7	15
	80	17	0/0	17
	117	21	0/0	21
	Total	144	6/4	150
Condition				
	1	71	0/0	71
	2	23	2/8	25
	3	2	0/0	2
	4	0	2/100	2
	Total	96	4/4	100
Tag				
	No	9	0/0	9
	Yes	135	6/4	141
	Total	144	6/4	150
Cage				
	1	1	0/0	1
	2	10	1/9	11
	3	10	0/0	10
	4	9	1/10	10
	5	9	0/0	9
	6	9	0/0	9
	7	9	0/0	9
	8	8	3/27	11
	9	11	0/0	11
	10	10	0/0	10
	11	8	0/0	8
	12	14	0/0	14
	13	14	0/0	14
	14	13	1/7	14
	15	9	0/0	9
	Total	144	6/4	150
Sex				
	Male	18	1/5	19
	Female	32	2/6	34
	Total	50	3/6	53
OTC				
	No	84	5/6	89
	Yes	60	1/2	61
	Total	144	6/4	150

groups and was most abundant (Table 2). There was a small, but non-significant trend that the bigger fish were in better condition ($p = 0.16$). Condition did not appear to worsen with time spent in the tank. On the contrary, we observed the fish that were in the tank for the shortest period (0–5 hr) were the only ones that were classified as level III and IV. The category (0-5 hr) was significant ($p = 0.008$) to the overall effect of the variable time in tank on condition. The five fish that died originated from two of the 14 stations (*d* and *i*), however, the number of fish from these stations was limited and the small sample sizes could be influencing the significant result for these stations on the model ($p = 0.001$; $p = 0.03$). At the same time, station *n* almost exclusively produced fish of condition level I and thus, also had a significant effect on the model ($p = 0.03$). We found only female fish were classified as condition level III to IV and the effect of sex on condition was significant ($p = 0.03$).

Test models with additive as well as interactive effects were also carried out:

*time+length; time+sex; length+sex; length*time; sex*time; length*sex*

Even though many of the models also were statistically significant, the amount of variation explained was generally low (R^2 values 0.07 to 0.19) and not significantly better than the univariate approach. As our primary goal was to determine which covariates contributed the most to condition, we used the univariate models results to conclude that time in the tank and sex had the greatest influence on fish condition.

Short-time Mortality (Cage Experiment)

A total of 150 fish were included in the cage experiment to assess short-time mortality; 118 for the summer experiment and 32 for the winter. The proportions of fish that died are shown in Table 4. Overall, six fish died during the cage experiments (4.0%).

Mortality for the winter cage experiment was 6.3% and for the summer it was 3.4%. The difference was not significant ($p = 0.48$). Fish were in the size range 35 to 73 cm (total length). All deaths happened in the 41 to 70 cm length interval with the highest mortality in the 41–50 cm length group, however, there was no evidence of size-dependent mortality ($p = 0.43$). The highest mortality occurred in the 31 hr interval (10.3%) and lowest mortality occurred in intervals above 60 hr (0%), however, there was no correlation between time held and the proportion of fish that died ($p = 0.20$). None of the condition level I fish died (71 fish) while the mortality for level IV was 100% (2 fish). This difference in mortality among condition levels was significant ($p = 0.002$). None of the untagged fish died while 4.3% of the tagged fish died. However, the groups were very unbalanced (9 *vs* 141) and the difference was not significant ($p = 0.77$). Mortality was not significantly influenced by any of the cages. In one cage, 3 fish died (27%) but this cage did not contribute significantly ($p = 0.80$) to the overall effect of the variable cage on mortality. The mortality for both sexes were similar at around 5% ($p = 0.92$). Only one of the OTC-treated fish died compared to 5 in the untreated group. Therefore, there is no evidence that the OTC injection increased mortality ($p = 0.26$). In the summer experiment, we had 6 fish (5%) that lost their tag during the cage stay while the winter experiment had none.

Additive as well as interactive effects were then tested for the following combinations of variables:

*condition + otc; otc*condition; time*sex; length*sex; condition+otc+otc*condition*

In general, the explanatory variable *condition* had a strong influence and it seemed to drive most of the multivariate models when it was included (as additive or interactive effect). All the models where *condition* was included were thus significant, but none of them were significantly better than the univariate model (ANOVA, $p > 0.3$). An additive effect of OTC and fish condition was observed. Fish in poor condition that were treated with OTC had a significantly lower chance of dying ($p = 0.04$).

Discussion

We believe tagging mortality may be caused by several factors: 1) capture method; 2) handling (capture, tagging, tag type); 3) increased risk of predation; and 4) environment (changes in temperature and pressure). In addition, variables such as size, fitness (condition) of the fish, and the type of tag used may also have an influence on mortality. Our experiments did not address predation or tag type, however, we have chosen to include observations and studies made by others in the following discussion on the factors that can influence tagging mortality.

The Capture Method

Greenland halibut in the present study were all caught on longlines. If we assume that our study design did not influence mortality rate, the overall mortality rate for Greenland halibut caught on longline and tagged with T-bar anchor tags is around 7%. To our knowledge, this is the first estimation of mortality rate for tagged Greenland halibut and possibly for any tagged flatfish.

The literature suggests tag return rates for tagging programs using longline (LL-fish) differ compared to otter trawl (OT-fish). In West Greenland, the return rate was 16% for LL-fish and only 3% for OT-fish (Riget and Boje, 1989). In a tagging program in the waters of Newfoundland, Bowering (1984) observed a return rate from LL-fish of 17.2 to 38.9% while it was as low as 0.1 to 1.7% for OT-fish. Data from Iceland showed that Greenland halibut caught using longline had consistently higher tag return rates (Sigurdsson, 1981). Even though some of the difference could be caused by variability in effort, the consistent results suggest that tagging mortality on OT-fish is several times higher than for LL-fish. A likely explanation seems to be that OT-fish often are damaged by the trawl (personal observation) and thus are in a weaker condition at release compared to LL-fish. Black (1958) argued that line caught deep-sea fish have a very high mortality, if released. He suggested the hooked fish are hyperactive and thus build up a deadly level of lactic acid (or other metabolic products) in the blood. This might be true for some deep-sea fishes but Greenland halibut are usually very passive on the line and have a bad reputation among sports fishermen for being a poor fighter. Therefore, we believe that for Greenland halibut, the optimal gear in a tagging operation is longline.

Handling and Tagging Methods

In the present study, we were not able to estimate the influence of handling or tag type directly. Many of the fish (5 out of the 9 deaths) in the summer experiment died in the holding tank within 10 hr of capture. One of the two fish that died in the winter experiment had obvious physical damage and died within 5 hr. This result is similar to an experiment examining the short-term (5 days) mortality of northern pike (*Esox lucius*) held in net pens, which found mortality was 2.4% (Pierce and Tomcko, 1993). All pike deaths occurred within two days of tagging and fish that were in poor condition (not able to swim upright prior to tagging) had a much higher mortality rate (73%). We did not observe higher (or worse) condition for the Greenland halibut that stayed longer in the tanks. Therefore, holding the fish in observation tanks for 5 hr or more could reveal fish with internal damage or high levels of lactic acid, thereby reducing mortality for released Greenland halibut. This is contrary to what Black (1958) found for sockeye salmon (*Oncorhynchus nerka*). He observed that salmon held in tanks had much higher lactic acid compared to fish that had just been caught using hook and line. He therefore concluded that holding fish in tanks for extended periods could increase lactic acid level and thus have a negative effect on survival. The level of lactic acid, however, is correlated with behavior and activity. Since Greenland halibut are observed to behave very calmly in the tanks, species behavior could explain the difference.

Schreck (1981) suggested that physical handling or psychological disturbance could lead to increased mortality. The longer the handling time and the longer it takes to apply the mark, the greater the chance of mortality (McFarlane *et al*., 1990). Different tag types require different handling times and may therefore have different mortality rates associated with their use. The effects of tag and tag type have primarily been examined for fish smaller (10–30 cm) than the Greenland halibut used in our experiments. Several studies have found a significant negative effect of external tags on survival of small fish (e.g. *Oncorhynchus mykiss,* 14–24 cm (Mourning *et al*., 1994); *Lutjanus carponotatus,* avg. 16 cm (Whitelaw and Sainsbury, 1986); *Clupea harengus,* juvenile fish, (Stobo *et al*., 1992)). Others found that mortality for larger fish was not significantly affected (e.g. *E. lucius* 38–73 cm (Pierce and Tomcko, 1993); *Oncorhynchus tshwytscka,* 2-year-old smolt (Eames and Hino, 1983)). We believe that the time it takes to apply the tag and the tag size in relation to fish size are important contributions to overall tagging mortality. For example, Godø and Haug (1987) noted that the recapture rate from Greenland halibut in the 20 to 30 cm size range tagged with Lea tags was nil compared to 2% for larger Greenland halibut. The same size-dependent recapture rate was also observed in a tagging experiment with 0-group cod (*Gadus morhua*) (Svaasand *et al*., MS 1987). Results from these studies as well as those presented in this paper have lead us to conclude that small and easy to apply tags like Floy tag and Lea tag can be used on Greenland halibut down to about 35 cm without introducing size-dependent handling or tagging mortality.

Predation

There is the possibility that tagging could make the fish more vulnerable to predation as an external tag may act as an attractant to predators such as sea birds (Svaasand *et al*., MS 1987). Seagull attacks have been observed both in the Davis Strait and NE Atlantic when tagged Greenland halibut have been released from otter trawlers (J. Macpherson, Dartmouth, Nova Scotia, Canada, pers. comm.; Godø and Haug, 1987). However, seagull attacks have never been registered in the tagging program off West Greenland using longlines (J. Boje, Greenland Institute of Natural Resources, Nuuk, Greenland, pers. comm.). One reason for the difference could be that fish caught using otter trawl are smaller and weaker following tagging compared to fish caught using long-lines (see also The Capture Method paragraph above). These fish may remain at the surface longer during recovery from tagging and are therefore at greater risk of attack by sea birds. Otter trawlers may also attract seabirds more readily with the net streaming and a trail of small injured or dead fish behind the net, whereas longliners tend not to leave such a trail behind the ship and therefore do not attract as many seabirds. Several tags from Greenland halibut have been recovered from stomachs of seal (Godø and Haug, 1987), cod (Bowering, 1984) and shark (in Cumberland Sound, a tagged Greenland halibut was found in the stomach of a Greenland (boreal) shark (*Somniosus microcephalus*) 3 days after it had been released). Otterå *et al*. (1998) examined predation on tagged and untagged Atlantic cod (*G. morhua*) in the size range 20–41 cm and found that neither predation from other fish nor by birds were higher for the tagged fish. As illustrated from the seagull predation on tagged Greenland halibut, we find it likely that fish that have just been released, are easier prey for a predator than a normal fish and thus mortality due to predation could be higher immediately following tagging (especially for smaller fish). However, it does not seem likely that a relatively small tag on a fish like Greenland halibut should increase mortality rate after the first few days.

Environment

Changing environmental conditions (e.g. water temperature and pressure) may injure or increase stress in fish. Some fish species may be able to survive these stresses better than others. For example, most flatfish do not have swim bladders and are thus not as affected by pressure changes with depth compared to other species. Greenland halibut are probably one of the few deep-water species that can be tagged at the surface and released with success.

Temperature in air or water is another factor that is known to be crucial, probably because temperature differences of more than a few degrees can induce thermal shock (leading to death) in some species. For example, exposure to subzero temperatures has been reported to be lethal for some fish (e.g., Clay, 1990; Carline and Brynildson, 1972). In March 1993, a first attempt was made by Fisheries and Oceans Canada to tag Greenland halibut during the Cumberland Sound winter fishery. However, the fish were exposed to -20°C air temperatures, the tagging tank was placed on a sledge and a pump was used to circulate surface water (-1.9°C) through it. All the fish were dead or moribund as soon as they were transferred to the tagging tank. Two attempts were made with about 10 fish in each trial. No fish survived the capture and handling process (Dan Pike, North Atlantic Marine Mammal Commission, Tromsø, Norway, pers. comm.). Another concern with winter tagging conditions is the chance that some fish may be trapped in the cold water layer below the ice surface following their release if they are not strong enough to swim free of tidal currents running below the ice. These currents vary in strength throughout the day so fish released when these currents are weakest may have a better chance of survival. Godø and Haug (1987) also showed that temperature could affect tagging mortality on Greenland halibut. They found during a 3-year tagging program on Greenland halibut (1983–85), that recapture rate was much higher (16.5%) in 1984 when bottom temperature was the highest (2.2° to 3.2°C) compared to recapture rates below 1% in years with lower bottom temperatures (0.8° to 2.7°C).

Results from the winter tagging experiment show that tagging from the sea-ice is possible if steps are taken to limit exposure to subzero temperatures and does not result in tagging mortality that is higher than that found in the summer period. As of 1 May 2003, there have been 13 re-captures (0.8%, but low fishing effort) from the winter tagging (design as described in this study) in Cumberland Sound.

Tag loss

Tag loss or shedding is a common problem in many tagging programs (see e.g. Pierce and Tomcko, 1993; Waldman *et al*., 1990; Whitelaw and Sainsbury, 1986). The relatively high tag loss in the summer experiment could be due to the wider mesh-size in the net used in the summer (10 mm mesh in summer *vs* 6 mm mesh in winter) and thus the Floy tag was more easily caught in the meshes. Further studies with double tagging are needed to clarify the tag loss for Greenland halibut. However, the observed tag loss is within the range reported from other species tagged with anchor tags. For Atlantic cod (20–41 cm) double tagged with anchor tags, Otterå, *et al*. (1998) suggest that tag loss rate could be as high as 11%. For tropical fish (16 cm avg. length), tag loss was calculated at 6.1% after 55 days (Whitelaw and Sainsbury, 1986). Chinook salmon (20 cm avg. length), tagged using anchor tags, experienced tag loss of 2–5% (Eames and Hino, 1983).

Conclusion

Our cage experiments provide data on tagging mortality that was previously unavailable for Greenland halibut. The results suggest that if care is taken to minimize physical trauma and stress during the capture and tagging process, then mortality can be minimized, even under severe winter tagging conditions. It is important that the fish are in good condition prior to tagging them. Using longline is likely to produce fish of a better condition compared to other gear types. Our study further suggests that holding the tagged fish in an observation tank for a period of 5 hr or more could help to identify those fish that are in poor condition and thus reduce the mortality of released fish.

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