

Survival of Discarded Sublegal Atlantic Cod in the Northwest Atlantic Demersal Longline Fishery

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Abstract.—The survival of sublegal Atlantic cod *Gadus morhua* discarded in the U.S. Northwest Atlantic demersal longline fishery was examined for the effects that handling technique, sea surface temperature, and capture depth have on it. Longline-caught Atlantic cod were either removed from the hook by hand (unsnubbed) or by allowing the hydraulic hauler to pull the fish against the parallel steel cylinders placed vertically on the gunwale, causing the hook to pull through the jaw (snubbed). Jigged-caught fish served as an indicator of mortality occurring because of the experimental design in the survival experiments. Once caught, live fish were placed in underwater cages, and short-term survival was assessed after holding the fish for 3 d (approximately 72 h). Survival was analyzed with respect to three water depths and four sea surface temperature (SST) strata. Atlantic cod survival in these strata ranged from 31% to 100%. Depth and SST affected survival more than the dehooking technique; survival was higher in shallow depths and at lower temperatures. Unsnubbed fish had higher survival rates than snubbed fish.

Because selectivity can only be approximated in fishing gear, undersized or juvenile individuals are inadvertently taken as part of all commercially harvested marine catches. Federal regulations require that undersized individuals of commercially important species taken in the Northwest Atlantic multispecies groundfish fishery be returned to the sea as bycatch (NEFMC 1985; Magnuson–Stevens Fishery Conservation and Management Act 2007), and the National Marine Fisheries Service has made research on discard mortality rates a priority. Estimating the survival of discarded fish has been the focus of many investigations. The actual survival of bycatch depends on numerous factors, such as species (Robinson and Carr 1993; Carr et al. 1995; Poiner and Harris 1996; Smith 1996), fish age (i.e., length) (Neilson et al. 1989; Milliken et al. 1999; Davis 2005), gear type (Rutecki and Meyers 1992; Carr et al. 1995), fishing depth (Neilson et al. 1989), the duration of the set (Robinson and Carr 1993), handling time (Neilson et al. 1989; Robinson and Carr 1993), and individual injury levels (Main and Sangster 1990; Milliken et al. 1999).

The survival of bycatch in commercial fisheries is poorly understood. Developing quantitative methods to accurately assess discard mortality requires an understanding of the factors that contribute to this mortality, how mortality is defined within each context, and how to measure variables under commercial fishing conditions (Davis 2002). Estimating discard mortality accurately is critical to both biomass estimates from stock assessment models and the development of successful management measures (Mesnil 1996; Chopin et al. 1997; Davis 2002; Ryer 2004). Unless the survival of bycatch is specifically quantified for a species, assessing the status of that stock, setting appropriate fishing levels, and developing an optimum yield may be problematic (Mesnil 1996; Chopin et al. 1997; Ryer 2004).

Many discarded groundfish (including Atlantic cod *Gadus morhua*) in the bottom trawl and gill-net fisheries are assumed to suffer 100% mortality. However, in the demersal longline fishery, the assumption that 100% of the discarded cod and other species do not survive is not supported by previous research (Milliken et al. 1999) or the experience of other fisheries using longline gear (Neilson et al. 1989; Orsi et al. 1993). Bycatch in the longline gear have high survivability as compared with other fishing methods. Soldal and Huse (1997) found no mortality of

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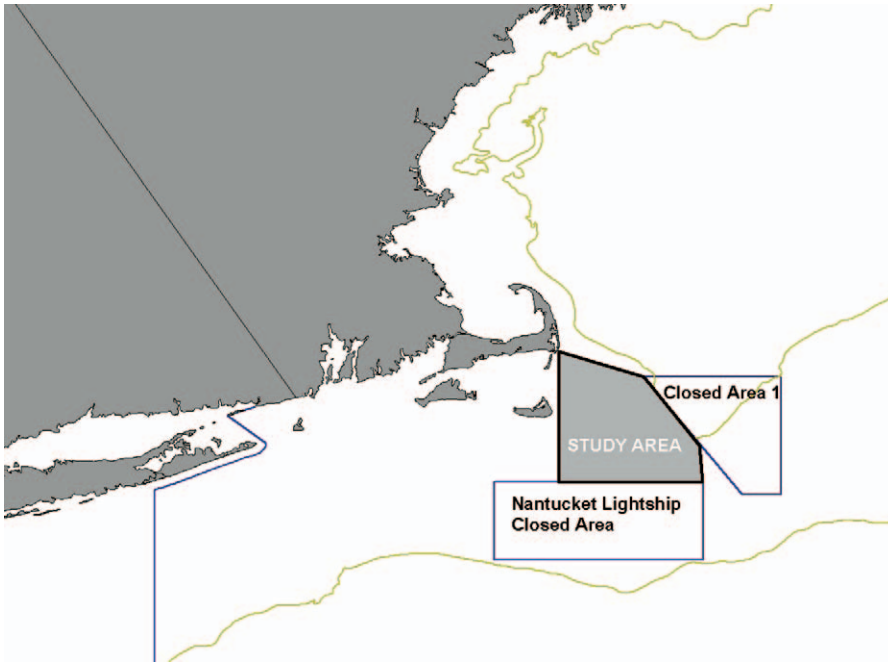


FIGURE 1.—Area in which Atlantic cod were captured and caged during the study of the survival of discards.

18 sublegal haddock *Melanogrammus aeglefinus* that had the hooks ripped from their mouths. The survival of Atlantic halibut *Hippoglossus hippoglossus* caught by longline was 77%, compared with 35% for those caught by trawls (Neilson et al. 1989). The survival of juvenile sablefish *Anoplopoma fimbria* was much higher when captured by hand jigging (81%) than in traps (25%), presumably because of the decreased incidence of secondary bacterial infection resulting from skin abrasions caused by the traps (Rutecki and Meyers 1992). An increase in the survival of hook-caught Chinook salmon *Oncorhynchus tshawytscha* occurred when circle hooks were used instead of lures. This decreased the incidence of gut hooking and thus mortality because of the less traumatic nature of the injuries (Orsi et al. 1993).

The only previous evaluation of the survival of sublegal Atlantic cod in the Northwest Atlantic demersal longline fishery (Milliken et al. 1999) assessed fish that had been placed in cages at the depths at capture and assessed after 72 h. Survival rates ranged from 22% to 47% for fish that were snubbed and from 38% to 63% for fish that were carefully removed from the hooks (Milliken et al. 1999). However, “control” fish that were individually captured by jigging (i.e., handgear, comprising handlines, manual rod and reel, and electric rod and reel) and carefully removed from the hooks also experienced

significant mortality. Because the caging process and experimental techniques may have influenced survival, the results of this study may not have been accurate (Milliken et al. 1999). The need for better data and the concerns of fishermen and managers alike about the previous study combined to necessitate additional work. An ambitious and rigorous research protocol that included input from the fishing community and that addressed factors such as seasonality and depth of capture was deemed essential.

The objective of this study was to document the short-term survival of sublegal Atlantic cod captured in the bottom-set (demersal) longline fishery in New England. This study focused on the effects of season (sea surface temperature), depth of capture, and unhooking technique and used commercial vessels that fished commercial longline gear in waters where the fleet has historically fished for cod.

Methods

Summary.—The field research used one to two commercial longline vessels that were accompanied to the fishing grounds by one to two jig vessels that caught the control fish. All fish were placed in holding tanks, caged, and sunk using the same techniques. Each longliner and jig vessel had onboard a captain, crew, and technician–scientific data collector (tech–SDC). The tech–SDC was either a scientist or a technician

TABLE 1.—Number of sublegal-size Atlantic cod dead and alive upon retrieval from cages by date, sea surface temperature, depth of capture, and capture or dehooking treatment.

| Date caught | Date retrieved | Temperature category (°C) | Depth (m) | Jigged | | Snubbed | | Unsnubbed | |
|-------------|----------------|---------------------------|-----------|--------|------|---------|------|-----------|------|
| | | | | Alive | Dead | Alive | Dead | Alive | Dead |
| 28 Dec 2005 | 31 Dec 2005 | <6.7 | 37 | 147 | 11 | 32 | 10 | 87 | 15 |
| 6 Jan 2006 | 9 Jan 2006 | <6.7 | 55 | 129 | 29 | 69 | 37 | 35 | 19 |
| 24 Jan 2006 | 29 Jan 2006 | <6.7 | 73 | 152 | 14 | 87 | 35 | 50 | 10 |
| 9 Jun 2004 | 12 Jun 2004 | 6.7–9.0 | 37 | 49 | 5 | 42 | 17 | 73 | 8 |
| 26 Nov 2005 | 29 Nov 2005 | 6.7–9.0 | 37 | 37 | 8 | 14 | 7 | 61 | 23 |
| 17 May 2005 | 20 May 2005 | 6.7–9.0 | 55 | 65 | 0 | 66 | 30 | 67 | 8 |
| 11 Jan 2006 | 17 Jan 2006 | 6.7–9.0 | 73 | 146 | 14 | 45 | 10 | 94 | 26 |
| 5 Dec 2005 | 9 Dec 2005 | 6.7–9.0 | 73 | 35 | 8 | 25 | 11 | 50 | 18 |
| 21 Jun 2004 | 24 Jun 2004 | 9.1–14.4 | 55 | 38 | 38 | 13 | 3 | 22 | 3 |
| 9 Jun 2005 | 12 Jun 2005 | 9.1–14.4 | 73 | 48 | 25 | 24 | 32 | 63 | 31 |
| 30 Jun 2004 | 3 Jul 2004 | 9.1–14.4 | 73 | 13 | 15 | 85 | 54 | 98 | 27 |
| 10 Aug 2005 | 13 Aug 2005 | >14.4 | 37 | 111 | 16 | 34 | 19 | 84 | 22 |
| 6 Aug 2005 | 9 Aug 2005 | >14.4 | 55 | 67 | 38 | 73 | 83 | 105 | 41 |
| 2 Aug 2005 | 5 Aug 2005 | >14.4 | 73 | 61 | 47 | 45 | 101 | 51 | 104 |

recruited from the local fishing industry and trained by an experienced scientist. No sooner than 72 h, a vessel returned to haul all the cages. Survival of the fish in the cages was assessed and recorded. This protocol was based on work by Sangster et al. (1996), which showed that the majority of the mortality attributable to the capture process occurs in the first 72 h. After retrieval, the cages were brought back to port until the next sampling event.

Fishing.—The study was designed to assess survival at different capture depths and to investigate the influences of sea surface temperature and depth on survival. Atlantic cod were collected between 9 June 2004 and 17 January 2006 by commercial vessels fishing southeast of Cape Cod (Figure 1). For each sampling event, defined as a day on which actual fishing took place, two to four vessels fished commercial bottom-set longline gear and rod-and-reel gear to capture cod. The longline gear consisted of “bundles” of 366 m of main line with 300 12/0 circle hooks spaced every 1.2 m. Three to four bundles were strung together to constitute a “string,” and three to four strings were set per fishing day, for a total effort of approximately 3,600 hooks per day. Strings of hooks were placed in close proximity to minimize any bias that might result from collecting fish from different areas (i.e., depths and temperatures). Bait type was kept consistent across a given fishing event. The fishery studied does not utilize long soak times, as fishing events are strictly timed to the tidal cycle. The gear was set just before slack tide and hauled as quickly as possible. Thus, the soak time was always less than 4 h. Set time, set location, set depth, and soak time were all recorded.

Another group of Atlantic cod were caught by electric rod and reel almost exclusively, a practice that

is referred to as “jigging.” The fish in this group were caught in the same area as the longline sets and placed in cages in close proximity to those with the longline fish. The study took advantage of the handling techniques developed by jig vessels contracted by the Cape Cod Commercial Hook Fisherman’s Association for the Northeast Regional Cod Tagging Program.

Atlantic cod were sampled (caught) in depths of 37 m (range, 27–46 m), 55 (range, 47–67 m), and 73 m (range, 68–79 m) (20, 30, and 40 fathoms, respectively). These depths are where most regional demersal longline fishing occurs (J. Pappalardo, Cape Cod Commercial Hook Fishermen’s Association, personal communication) The depth at which the gear was set was typically close to the targeted depth but, because there was a range of depths along the length of the strings, it was decided to keep these depths as categorical data as opposed to continuous data.

In addition to the depth categories, the project sampled Atlantic cod in four sea surface temperature

TABLE 2.—Percent survival of sublegal-size Atlantic cod in three treatments by depth and sea surface temperature.

| Temperature (°C) | Depth (m) | Treatment | | |
|------------------|-----------|-----------|-----------|---------|
| | | Jigged | Unsnubbed | Snubbed |
| Cold (<6.7) | 37 | 93 | 85 | 76 |
| | 55 | 82 | 65 | 65 |
| | 73 | 92 | 83 | 71 |
| Cool (6.7–9.0) | 37 | 87 | 81 | 70 |
| | 55 | 100 | 89 | 69 |
| | 73 | 89 | 77 | 77 |
| Warm (9.1–14.4) | 37 | | | |
| | 55 | 50 | 88 | 81 |
| | 73 | 60 | 74 | 56 |
| Hot (>14.4) | 37 | 87 | 79 | 64 |
| | 55 | 64 | 72 | 47 |
| | 73 | 56 | 33 | 31 |

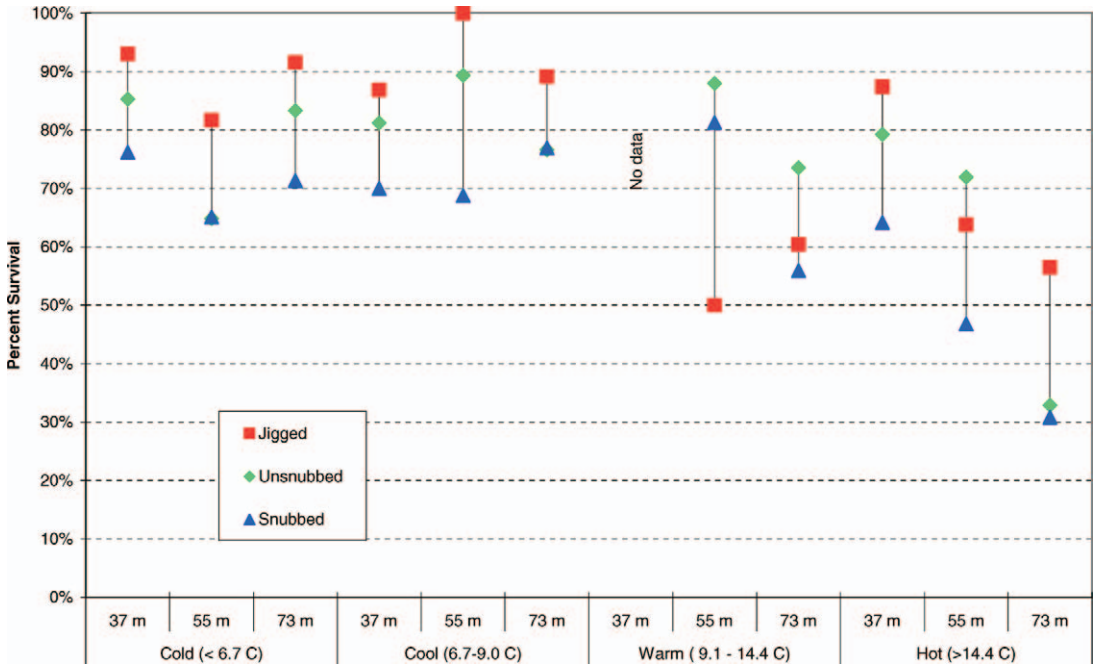


FIGURE 2.—Survival of sublegal-size Atlantic cod by depth of capture, sea surface temperature, and capture or dehooking technique.

(SST) categories: cold (<6.7°C), cool (6.7–9.0°C), warm (9.1–14.4°C), and hot (>14.4°C). The categories were determined by the industry partners and are representative of the sea surface temperatures in the study area during each season.

Within each temperature and depth combination, three different treatments were conducted: snubbed, unsnubbed, and jigged. The snubbed and unsnubbed fish were caught by the longline vessel, while the jigged fish were caught on a separate vessel in close proximity to the longline vessel. Prior to fishing, a coin was tossed to determine which treatment (snubbed or unsnubbed) would be used for the first string, and then treatments were alternated on subsequent strings. Once assigned, a given treatment was used until 50 fish were caught or the end of the string was reached.

Handling.—The unsnubbed treatment group was unhooked by hand, without allowing the fish to contact the fair lead roller (a set of steel cylinders that guide the line and restrain the fish) and without allowing the force of the hydraulics to pull the hook out. The snubbed treatment group was dehooked by allowing the fish to contact the fair lead roller, and the force of the hydraulics was used to pull the hook through the jaw. The result is that the hook often tears flesh, breaks the jaw, or causes other injuries. These two treatments included the first 50 fish caught off a given string

regardless of condition. While dead fish were not tanked or caged to avoid attracting scavengers, they were still counted as mortalities and treated as part of the sample.

The jigged fish were intended to act as indicators of handling and cage-induced mortality. Only healthy-looking sublegal fish exhibiting no major injuries or behavioral anomalies were selected for the 50-fish sample; dead, weak or injured fish were not used or counted.

For each of the twelve sampling strata (four sea surface temperatures × three depth strata), a minimum of 150 sublegal fish were obtained in each of the three treatments. The sublegal fish were measured, assessed for condition, and placed in live tanks, with an emphasis on limiting handling time. The information recorded for each fish included handling technique; depth of capture; air, surface and bottom temperatures; size; time of capture; and behavior upon placement in the live well. The Atlantic cod were kept in the live wells until 50 fish were collected or haul-back was completed. To minimize tanking time in cases when the sample was achieved early in the haul, participating fishermen would tie off the longline gear midhaul to sink the cage.

Each vessel was equipped with live tanks sufficient to hold 50 fish. Live wells were aerated with circulated

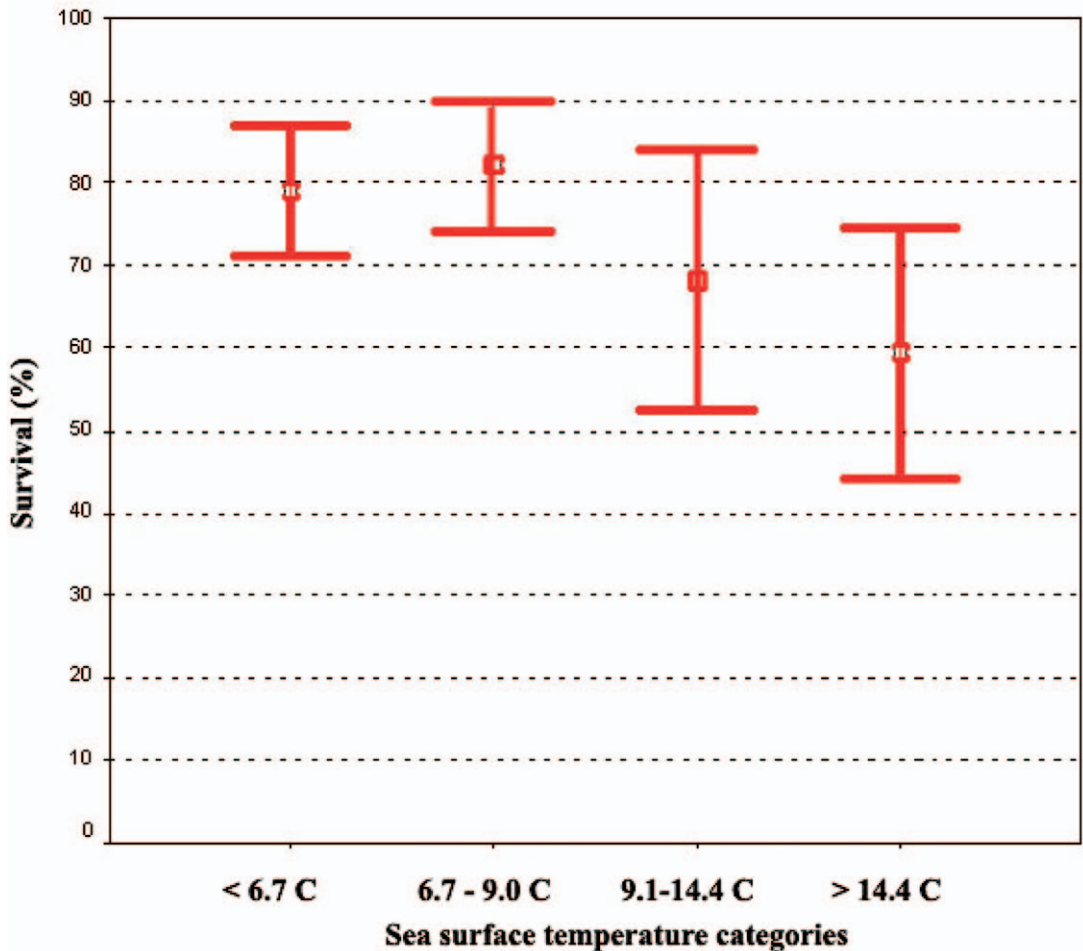


FIGURE 3.—Survival of sublegal-size Atlantic cod by sea surface temperature. The data are shown as 95% confidence intervals around the means.

seawater or aeration pumps with air stones. Live-well water temperatures were maintained at approximately those of the various fishing depths to prevent prolonged on-deck temperature shock. Chillers or ice were used to lower the water temperature in the live tanks, and thermometers were used to ensure adequate cooling.

Caging.—Before the start of the survival work, a density test was performed in which eight cages were filled and sunk, two each with 15, 30, 45, and 60 Atlantic cod, respectively. No differences in mortality were observed after 72 h, and it was decided that 50 fish was a practical density.

Live fish were transferred by dip net from the live well to cages tethered alongside the vessel; no more than 50 fish of a single treatment were placed in each cage. Any dead fish found in the live wells were

recorded but not transferred to the cages. Each cage was closed, secured, and lowered to the bottom at a controlled rate (typically 1–2 min, depending on depth).

Because of concerns about the high center of gravity of the cages used in the previous Atlantic cod mortality study (Milliken et al. 1999), rigid low-rise cages with cylindrical shapes and integrated bottom weights were designed and tested in local waters; these cages showed great promise. The overall volume of the round cages was approximately 1.4 m³ (0.6 m high with a 1.2-m diameter), less than those used in Milliken et al. (1999).

Cages were set as singles, with one anchor, one buoy line, one buoy, and one high flyer per cage. Anchors were 36.3-kg sections of steel railroad track with bridles constructed of a steel shackle, 30.5 cm of chain, and 1.2 m of polypropylene rope. Buoy lines were 0.8

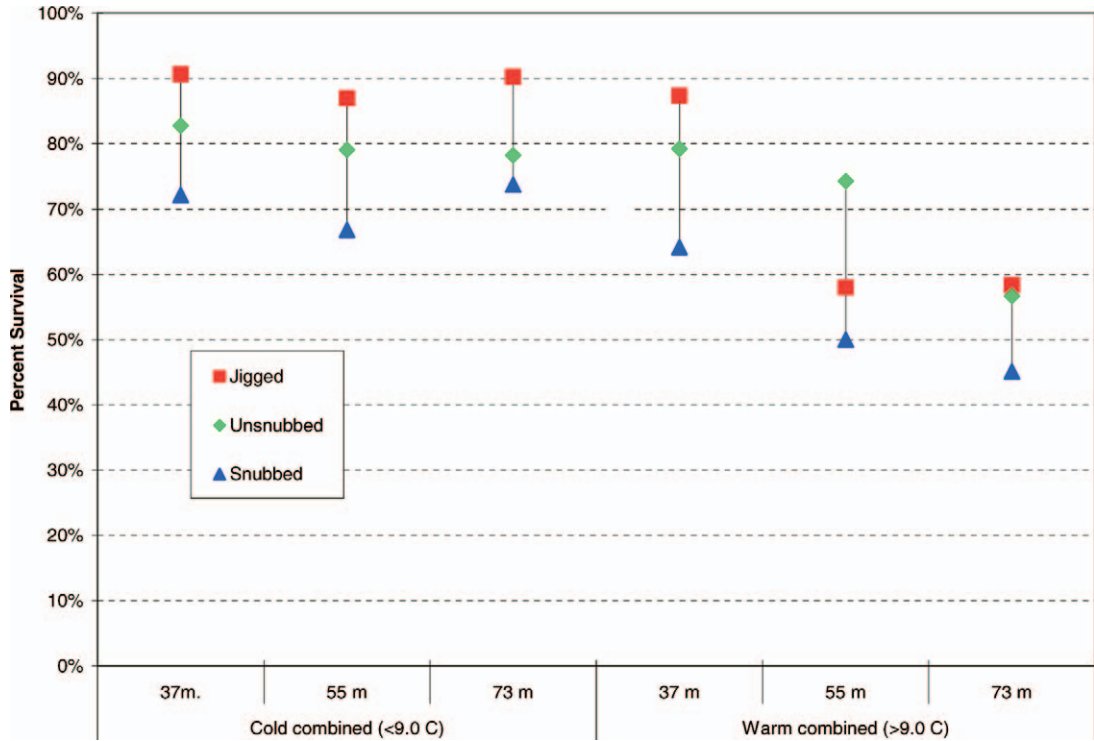


FIGURE 4.—Survival of sublegal-size Atlantic cod by depth of capture, broad sea surface temperature category, and capture or dehooking technique. The low survival of jigged fish at 55 m in warm water is probably due to the high temperature of the live well on the vessel in question.

or 0.86 cm lines that varied in length depending on the depth. Buoys were large, low-drag, polyballs. High flyers were 3.6 m long and equipped with radar reflectors. All gear was fully compliant with the requirements of the Atlantic large-whale take reduction plan, commercially purchased swivel-style weak links being incorporated into the buoy lines.

Retrieval.—The cages were retrieved after at least 72 h and the condition and health of the Atlantic cod examined and recorded. For the analysis, fish were classified either as dead or alive. On three of the trips, the fish were caged longer than 72 h owing to adverse weather conditions (Table 1). An analysis of the survival of fish that experienced longer set times did not show discernable differences among the predicted survival rates, so these fish were included in the results.

Statistical analysis.—To evaluate discard survival, a logistic binomial model was developed using survival as the dependent variable and three sea surface temperatures, two depths, and three treatments as categorical predictors. Models with various combinations of the main effects, two-way interactions, and one three-way interaction were compared on the basis of the Akaike information criterion (AIC). When the AIC

values differed by more than 6.0 the models were assumed not to be supported by the data (Burnham and Anderson 2002). Odds ratios were generated from the model to compare the influence of the different effects on the model. Models were analyzed in Systat 10.

In addition to the binomial logistic comparison, the data were also tabulated and graphed to show the percent survival associated with various treatments and variables. The mean and 95% confidence intervals were graphed and, to evaluate the data further, the temperature data were grouped by cold ($SST \leq 9.0^{\circ}C$) and warm ($SST > 9.0^{\circ}C$) and analyzed by adding the mortality of the jigged fish to the rate of survival. A middle point was added to the data between these two points to show the possible range of mortality for the different treatments. Additionally, survival in the different treatments was compared by plotting the means and 95% confidence intervals for the different variables (e.g., depth, sea surface temperature, and catch and dehooking method) in Systat 10.

Results

Two to three vessels fished on each of fourteen different days and caught a total of 3,764 sublegal

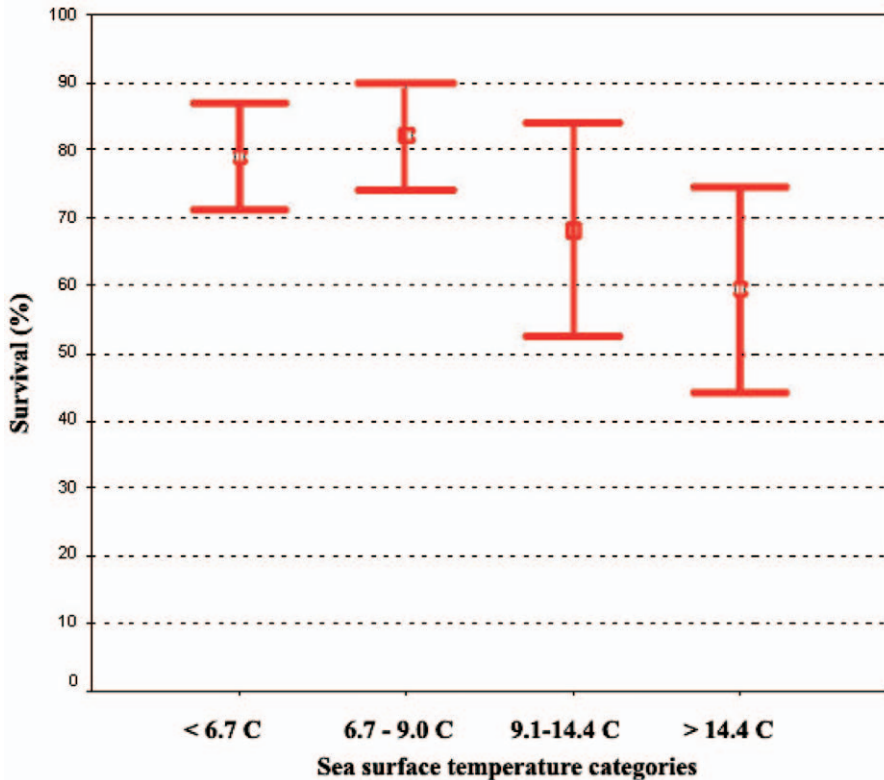


FIGURE 5.—Survival of sublegal-size Atlantic cod by depth of capture. The data are shown as 95% confidence intervals around the means.

Atlantic cod. These fish were assessed for survival after caging or marked as dead if they were dead when retrieved from the longline gear. They were captured at three different depths and four temperature ranges (Table 1). For all treatments, survival after caging ranged from 31% to 100% (Table 2), not counting for any mortality associated with the handling and caging process. On average, survival rates were higher at lower sea surface temperatures (<9°C; Figures 2, 3) and in shallower depths (Figures 4, 5). Temperature and depth had a greater influence on survival than treatment (Figures 2–7). When the data were grouped into two truncated temperature categories, cold (≤9°C) and warm (>9°C) (Table 3; Figures 4, 6) it became evident that warmer sea surface temperatures reduced survival at the two deeper depth zones (55 and 73 m). At the shallower depth (37 m), the effect of the warmer sea surface temperature on mortality is not apparent.

A logistic regression model including all main effects, all two-way interactions, and the three-way interactions provided a slightly better fit to the data (AIC = 2,151) than a model containing only treatment, depth, temperature, and temperature × depth (AIC =

2,154), which was the only other acceptable model. As the more complex model only improved the AIC value by 3, it was not used further. Plots of the predicted values from both models showed the same pattern of clear differences among treatments. The odds ratios generated from this model (Table 4) suggest that survival is affected more by sea surface temperature and depth than by treatment. The estimated probability of survival is approximately five times as great (5.245 [95% confidence interval, 3.242–8.486]) at the lowest sea surface temperatures (<6.7°C) as at the warmest sea surface temperatures (>14.4°C) (Table 4). Additionally, the probability of survival is almost six times as great (5.768) at a depth of 37 m as at a depth of 73 m. The survival odds for jigged fish are approximately twice as high (2.031) as those of unsnubbed fish, but the odds of snubbed fish are only about one-half (0.563) those of unsnubbed fish.

Discussion

Caution should be exercised in interpreting the survival of the jigged fish in this study. The intent was to use healthy jigged fish to provide an indicator of

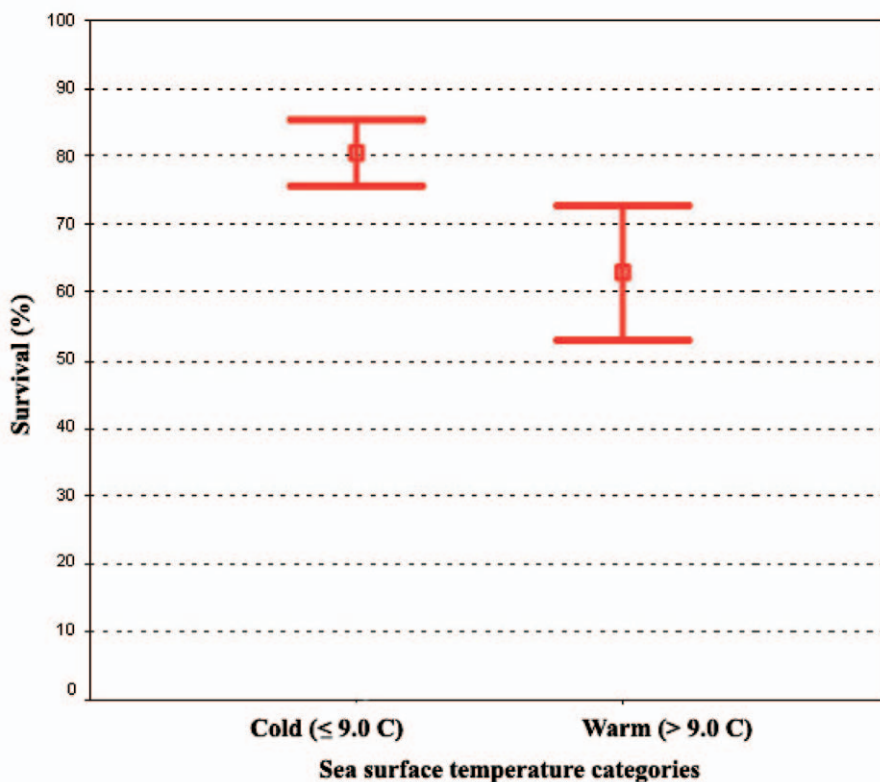


FIGURE 6.—Survival of sublegal-size Atlantic cod by broad sea surface temperature category. The data are shown as 95% confidence intervals around the means.

cage-induced mortality. Thus, if there were high mortality among both the treatment and the jigged fish, it would probably be the result of some separate event rather than being completely attributable to handling technique. Because only healthy jigged fish were selected, the calculated survival rate is for these fish only and does not take into account those that died and were discarded. That said, it was rare to discard jigged fish, as most of them were vigorous when captured and before caging. Regrettably, the number of jigged fish that were discarded was not recorded.

Fish were originally intended to be collected during all four seasons. However, the investigators recognized that the seasonal variable of concern was seawater temperature and therefore aimed to sample in each of four sea surface temperature categories. The categories were determined by the industry partners and were chosen as the temperatures that are prevalent during each season. On occasion, the research was delayed because the temperature changes had not occurred by the time of the scheduled sampling event.

Depth, sea surface temperature, and handling technique all affected discard survival. Although

handling technique had less effect on survival than depth and sea surface temperature, mortality may have been higher among snubbed fish assessed more than 72 h after caging because snubbing affected their subsequent feeding or promoted infection.

Survival was lowest when sea surface temperatures and depth were highest. High sea surface temperatures occur in the summer, when bottom temperatures are actually the lowest of the year (~ 6 – 10°C ; Mountain and Holzwarth 1989). In the winter, mixing warms the bottom waters, thus reducing the difference between bottom and surface temperatures. In our study area, at greater depths and during the summer, fish are hauled through water that is often 10°C warmer at the surface than on the bottom, where they reside. The resulting temperature change is a likely stressor that may have resulted in the greater observed mortality of the sublegal Atlantic cod.

The discard survival rates obtained in this study are higher than those reported in a previous study in New England (Milliken et al. 1999). However, the larger sample size, reduced handling time, and improved caging techniques employed in this study suggest that

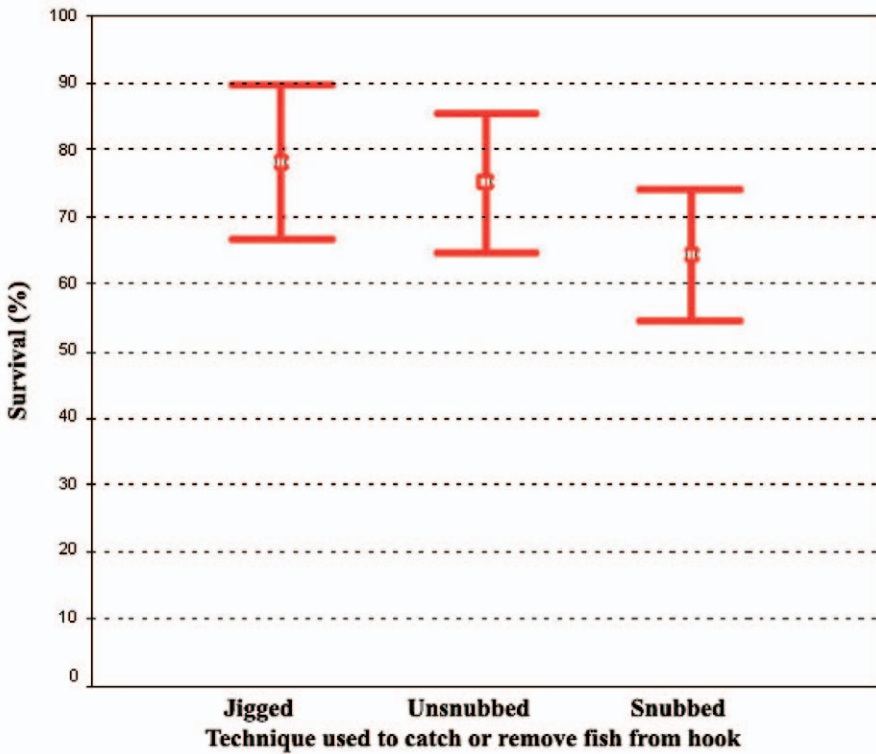


FIGURE 7.—Survival of sublegal-size Atlantic cod by capture or dehooking technique. The data are shown as 95% confidence intervals around the means.

the current survival rates are a closer representation of fishing mortality on sublegal Atlantic cod. Additionally, the current results should be more representative of the short-term discard survival rates in the fishery because the study was conducted under actual fishing conditions.

Although temperature and depth affected survival to a greater extent than treatment, removing the Atlantic cod by the unsnubbed technique (i.e., twisting the line

with the gaff, which causes the fish to be released with minimal injury) almost doubled survival, did not appreciably slow onboard operations, and was the method preferred by the fishermen involved in this study. Widespread adoption of the unsnubbed technique would be of great benefit. It is our understanding that this technique is widely used in the demersal longline fishery in the region where this study occurred. Encouraging fishermen in other regions to

TABLE 3.—Observed survival (%) of snubbed and unsnubbed sublegal-size Atlantic cod when data are grouped by broad cold ($\leq 9.0^{\circ}\text{C}$) and warm ($> 9.0^{\circ}\text{C}$) sea surface temperatures and observed survival plus the mortality experienced by jigged fish. Midpoints are also provided.

| Survival measure | Cold | | | Warm | | |
|----------------------------------|------|------|------|------|-------|------|
| | 37 m | 55 m | 73 m | 37 m | 55 m | 73 m |
| Unsnubbed | | | | | | |
| Survival + jigged cage mortality | 92.1 | 92.1 | 88.0 | 91.8 | 100.0 | 98.3 |
| Observed survival | 82.8 | 79.1 | 78.2 | 79.2 | 74.3 | 56.7 |
| Midpoint | 87.4 | 85.6 | 83.1 | 85.5 | 87.1 | 77.5 |
| Snubbed | | | | | | |
| Survival + jigged cage mortality | 81.5 | 79.8 | 83.5 | 76.7 | 92.0 | 86.8 |
| Observed survival | 72.1 | 66.8 | 73.7 | 64.2 | 50.0 | 45.2 |
| Midpoint | 76.8 | 73.3 | 78.6 | 70.5 | 71.0 | 66.0 |

TABLE 4.—Odds ratios and probability values for the different variables tested. Higher odds ratios imply more effect on the model and thus more influence on survival. Odds ratios were calculated relative to (1) the highest sea surface temperature (>14.4°C), (2) the greatest depth (73 m), or (3) the unsnubbed treatment, depending on the variable in question.

| Variable | Odds ratio | | P-value |
|-------------------------|------------|-------------------------|---------|
| | Mean | 95% confidence interval | |
| Constant | | | 0.004 |
| Sea surface temperature | | | |
| <6.7°C | 5.245 | 8.486–3.242 | 0.000 |
| 6.7–9.0°C | 4.785 | 6.305–3.631 | 0.000 |
| 9.1–14.4°C | 3.968 | 5.746–2.741 | 0.000 |
| Depth | | | |
| 37 m | 5.768 | 8.892–3.741 | 0.000 |
| 55 m | 2.34 | 3.015–1.817 | 0.000 |
| Treatment | | | |
| Jigged | 2.031 | 2.959–1.394 | 0.000 |
| Snubbed | 0.563 | 0.732–0.434 | 0.000 |

use it should lead to greater survival of sublegal cod in the longline fishery. Since it appears that the technique results in minimal costs, it has an economic advantage as well.

We recognize that this study was limited in that it only looked at the short-term survival of sublegal Atlantic cod in the demersal longline fishery. It would be beneficial to replicate this work with other fish species and to assess survival over a longer period.

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