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Mortality of Walleye Pollock Escaping from the Codend and Intermediate (= Extension) Section of a Pelagic Trawl

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1.0 Abstract

Experiments were conducted on a pelagic trawler in the Gulf of Alaska to (a) test trawl gear modifications to improve escapement for undersized walleye pollock (*Theragra chalcogramma*), and (b) measure mortality of pollock that escape though trawl meshes. Although pollock managed to escape through square meshes of the codend, underwater video showed that these meshes became increasingly blocked as catch volume increased. Therefore, a square-mesh panel was sewn into the intermediate section of the trawl to compensate for this diminished escapement from the codend. Pollock actively escaped intermediate-square meshes as far as 18 m in front of the catch bulge. The survival of fishes escaping trawls should be estimated before gear regulations (e.g., minimum mesh size) are implemented, or when the fishing fleets voluntarily use devices, such as escape panels, to enhance escapement from their gear. Unless substantial amounts of fish escaping from trawls survive, conservation regulations implemented to permit escapement may be of little value. A caging method was used to capture escapees at trawling depth. These fish were held in sea-bed cages and checked once or twice per day for 14 days by SCUBA divers. Although many pollock that escape through trawl meshes survived, our results suggest potentially significant levels of size-dependent mortality. Management implications of these results are discussed.

2.0 Introduction

Numerous studies have estimated the size selectivity of trawls for walleye pollock, *Thereagra chalcograma* (e.g., Efanov and Istomin 1988; Bublitz 1993; Matsushita et al. 1993; Erickson et al. 1996; Guttormsen 1996; Matsushita and Inoue 1997). The studies by Erickson et al. (1996) and Guttormsen (1996) showed that escapement of undersized pollock diminished as codend-catch volume increased. Erickson et al. (1996) suggested that this reduction in escapement was caused by increased mesh blocking as catch-volume increased. Furthermore, these authors suggested that a size-sorting device (e.g., square mesh windows or longitudinal grids) placed in front of the codend may allow escapement independent of catch volume. Escapement from the intermediate section of trawls has been demonstrated for Atlantic cod (*Gadus morhua*) and herring (*Clupea harengus*) using longitudinal grids (e.g., Larsen and Isaksen 1993; Suuronen 1995). Hence, one objective of this research was to determine whether walleye pollock will escape through square-mesh windows installed into the intermediate (= extension) section of a pelagic-trawl.

Survival of fishes escaping trawls should be estimated before gear regulations (e.g., minimum mesh size) are implemented, or when the fishing fleets voluntarily use devices, such as escape panels, to enhance escapement from their gear. Unless substantial amounts of fish escaping from trawls survive, conservation regulations implemented to permit escapement may be of little value (Chopin and Arimoto 1995; Suuronen 1995; Kuikka et al., 1996). Mortality of pollock that passed through codend meshes was estimated at only 0 - 8% by Efanov and Istomin (1988); however, their estimates were made on the day of capture. These mortality estimates are likely low because mortality of fish escaping trawls is often delayed (e.g., Chopin and Arimoto 1995; Sangster et al. 1996; Suuronen et al, 1996a, 1996b). Hence, our second objective was to estimate mortality of pollock escaping through square meshes of the codend and extension using a caging method described by Lehtonen et al. (1998) and modified by this research team. This caging method is unique in that samples of escapees can be taken at any moment while trawling.

3.0 Methods

Field trials took place 18 May - 8 June 1998 off Kodiak Island, Alaska in an area that was well protected from storms. The *F/V Peggy Jo*, a 31-m trawler/crabber combination, towed a pelagic trawl (NETS 764) for this experiment. The top panels of the vessels codend and extension were replaced with experimental netting (= escape panel) for selectivity and escape-mortality trials. These escape-panels consisted of 93-mm square meshes (stretched diagonally) made of 280-ply braided-knotless polyethylene (Ultra Cross). The square-mesh panels measured approximately 9.3 m in length and 1.8 m in width.

Trawl escapees: Pollock that escaped through square-mesh panels were herded using a specially designed top-panel cover (Figure 1). This top-panel cover, originally designed by Roger Larsen (Norwegian College of Fishery Science, Tromsø) and modified by Victory Fishing Gear, was made so that only escapees passing through square-mesh panels were herded towards the terminal end of the cover. Fish that passed through any other meshes of the trawl (e.g., side or bottom panels of the codend) escaped into the open water. Schematic diagrams of this cover can be found in Erickson et al. (1999).

The performance of the top-panel cover and pollock activity was monitored using a low-light video camera (Silicon Intensified Target (SIT.)) at ambient light. Two or three self-contained SIT camera systems were attached to the codend, extension, or top-panel cover each tow. Observations indicated that the cover maintained adequate distance from the trawl meshes (i.e., did not block escapement), and fish maintained some distance from the cover. The cover did not appear to cause injuries to escaping fish.

Fish that escaped through treatment meshes were herded by the top-panel cover to a specially designed caging system (Figure 1). This system was comprised of two cages (a front section (release unit) and a rear section (collection unit)) that were attached to the terminal end of the top-panel cover. Each cage section measured 1.7 m x 1.7 m. Cage frames were made of hollow, 25-mm diameter stainless steel. The release unit was webbed with 42-mm square, knotted PE meshes, whereas the collection unit was webbed with 26-mm square, knotless polyethylene meshes.

Midwater trawling was conducted at depths of 28 to 79 m (headrope depth) for up to 8 hours with both front and rear gates of the collection unit held open (Figure 1). This allowed fish to accumulate in the codend while escapees swam freely through the top-panel cover and through the caging system into the open ocean. Activity within the caging system was monitored in real time from the wheel house using underwater video and a third wire system. The rear gate of the caging system was closed by activating a latch-release device through the third wire system (Figure 2a) after we were certain that some level of catch had accumulate in the codend. The collection period (duration that the rear gate was closed while the front gate was open) ranged from 1 to 8 minutes. The front gate was closed after sufficient numbers of fish were observed inside of the cage (Figure 2b). The collection unit (hereafter referred to as a cage) was detached from the trawl approximately 2 minutes after the front gate closed (Figure 2c). The cage then sank (or floated) to approximately 50 m (Figure 2d), where it remained until being recovered by an assistant vessel (*M/V Three Bears*).

Cages were raised from 50 m to 15 m by the assistant vessel at a rate of 10 m/minute, and transported at speeds of 1.9 to 2.6 km/h (Table 1) to a protected cove (57^o 56.69' N, 152^o 29.08' W). Cage transportation distance ranged from 3.3 to 10.6 km. Underwater video observations of pollock inside two cages were recorded during transit to the staging site. Pollock appeared to swim and maintain their position away from cage walls during this transportation process.

Once at the staging area, cages were lowered to the substrate and attached to groundlines by SCUBA divers. Holding depths ranged from 10 to 16 m. Surface waters within this cove remained calm throughout the study. The bottom was flat and consisted of a sand/silt mix.

Pollock escapees collected from eight tows were held in sea-bed cages (Table 1). These fish passed through square meshes of the codend (4 tows) or the intermediate (4 tows). Trawl catches (= catch accumulated in the codend) ranged from 61 to 1,086 kg. Trawling duration prior to collecting escapees ranged from 0.3 to 8.6 hours. Other potential explanatory variables are listed in Table 1.

Water temperature and depth were recorded throughout the trawling, detachment, transportation, and holding process for all cages (Figure 3). Temperatures ranged from 6 ^oC (at trawling depth) to 8 ^oC near the surface throughout the study period. Note that these cages were held at 10 m depth or more throughout the experiment (i.e., live pollock were never raised to the surface until the end of the study).

***Seine-caught pollock (= controls)*:** The *F/V Mythos* (13.5 m commercial seiner) caught the "control" group using a herring-purse that fished to a depth of 26 m . Meshes were 3.5 cm (stretched diagonally) and made of tarred nylon. Pollock were enclosed by the seine, and webbing was pulled onboard until fish began to concentrate near the surface. A collection unit (hereafter referred to as a cage), with one gate tied open, was lowered into the water using the vessels boom. Pollock were herded into the cage while drying up the bunt end, and the gate was manually closed. The cage was lowered to approximately 15 m, and a weight was attached to the towing line approximately 2 m from the cage. Control cages were transported to the cage-staging site in the same manner as cages containing trawl escapees. Average transportation speeds for the "control" group were 2.2 to 3.0 km/h, and transport distance ranged from 4.6 to 5.6 km.

Fourteen sets were made by seine, three of which successfully encircled pollock (Table 1). In two cases (i.e., cage 10 and in particular cage 11), too much seine was retrieved and pollock became momentarily crowded. In these cases, pollock thrashed near the surface, scraping against meshes and each other until some of the seine was returned into the water.

Diving, underwater photography, and biological data: Divers collected dead pollock twice per day throughout the 14-day caging period. Fifty-seven dives (SCUBA) were conducted during the field season. Video and still photographs were taken of live pollock inside of each cage at 1, 4, 8, and 12 days post-escapement. All dead pollock that were collected by divers were counted and measured (rounded fl, cm). Injuries were quantitatively assessed; however, only qualitative descriptions are provided in this paper. The project was terminated after 14-caging days, when all live and dead pollock were counted and measured.

4.0 Results

Observations of escapement: Underwater video showed pollock actively escaping through the square mesh top panels, often in large numbers. Escapement began immediately after pollock entered the area of the trawl containing the escape panels, up to 18 m ahead of the catch bulge. Fish falling back through the trawl, while swimming into the towing direction, oriented upward and quickly passed through the meshes (vertically) using rapid tail beats. Smaller individuals struck their flank and caudal fin area against the square-mesh bars during this escape process. Larger individuals sometimes became stuck (gilled) in the meshes. These fish either worked their way through or remained impinged between the bars. Fish too large to pass through the meshes repeatedly attempted escape by striking the upper layer of meshes (snout first) as they fell back toward the puckered end of the codend. Fish within the catch bulge were extremely crowded, pressing against each other and becoming impinged against the codend wall. Some of these individuals eventually escaped.

Length Frequency Distributions**:** In six of eight cases, the majority of trawl escapees were 31 to 36 cm in length (Figure 4a). Few escapees were smaller than 30 cm. A bimodal length frequency distribution was observed for two collection units (cages 3 and 4), where most fish were between 24 - 28 cm and 31 – 36 cm (Figure 4b). Few pollock larger than 40 cm were able to escape the 93-mm square meshes (Figure 5).

The size distribution of seine-caught pollock was similar to that of trawl escapees. Most pollock caught by seine measured 32 to 37 cm (Figure 6). Almost no seine-caught pollock were smaller than 30 cm, and few were larger than 40 cm.

Mortality**:** Mortality of pollock caused by trawling, escapement, and the sampling procedure after 14 days ranged from 46 to 84% (Table 1). Maximum levels were higher for fish escaping through codend meshes (84%) than for fish escaping through extension meshes (64%). Much of the observed mortality occurred within one week post escapement (Figure 7). Fourteen-day mortality for seine caught fish (i.e., the “control” group) showed more variability than that for trawl escapees - values were 2, 15, and 59% (Figure 8). Seine-caught fish were handled extremely rough during the set showing highest mortality (cage 11). In this case, fish became crowded and stressed when too much seine was pulled into the boat.

None of the potential explanatory variables associated with methodological procedures (excluding the capture process) significantly affected mortality of pollock during this experiment ($p > 0.05$; Table 2). Fish density per cage, cage transportation duration, cage transportation distance, wind speed during the transportation process, and trawling duration with the rear gate closed and the front gate open showed no relation to mortality. Because sample sizes are small, however, conclusive interpretation of these results is difficult, especially for cases that indicate a potential trend (e.g., cage-transportation speed).

Two fishing practices that may have an impact on escape mortality (trawling duration and catch volume) were measured during this experiment. Neither trawling duration or catch volume were significantly related to mortality ($n = 8$; Table 2). Catch volumes were small, ranging only from 61 to 1,086 kg. Trawling duration ranged from less than 30 minutes to over 8 hours.

***14-day mortality related to body size*:** The relation between body size and 14-day mortality was analyzed using General Linear Modeling (SAS 1989). Data were pooled by treatment (codend escapees, extension escapees, or seine-caught fish). The response variable (square root of the proportion dead after 14 days, or $M^{-1/2}$) was arcsin transformed and regressed against fork length. The analysis was weighted by N and produced the following predictive equations (Figure 9):

(1) Codend: $\arcsin(M^{-1/2}) = 1.509 - 0.016(L)$, $R^2 = 0.19$,
(2) Extension: $\arcsin(M^{-1/2}) = 1.476 - 0.019(L)$, $R^2 = 0.39$,

where M = proportion dead by cm length group, and L = fork length (cm). In both cases, mortality was inversely correlate with body size.

General linear modeling was performed to determine whether mortality-length relations were significantly different between the two trawl-treatment groups (i.e., equations 1 and 2). Independent variables included in the model were length, treatment, and their interaction. This weighted analysis showed no significant difference in mortality-length relations between codend and extension escapees ($p = 0.918$; Figure 9). Mortality was significantly correlated with length ($p < 0.001$). The interaction between length and treatment was not statistically significant ($p = 0.793$). Hence, codend and extension data were combined to produce the following equation:

(3) Codend + Extension: $\arcsin(M^{-1/2}) = 1.4656 – 0.0162(L)$, $R^2 = 0.18$.

Mortality of seine-caught fish (“control”group) also showed an inverse relation with length (Figure 10). Cage 11, which exhibited high mortality due to unintentional crowding while pulling in the seine (Figure 8), was not included in this analysis. Mortality of seine-caught fish, while excluding cage 11, was described as:

(4) Seine: $\arcsin(M^{-1/2}) = 2.220 - 0.0556(L)$, $R^2 = 0.54$.

Mortality caused by trawling and escapement: Escape mortality was predicted by size using models 3 and 4 (Table 3). Even though predictions are shown for all sizes of fish captured, we emphasize mortality estimates for length categories containing more than 10 fish. Regressions were weighted by sample size; hence, cells containing low numbers of fish had little influence on the final outcome.

Two approaches were taken to illustrate minimum and maximum mortality predictions (Table 3). The first approach (= maximum mortality predictions) assumes that mortality was only caused by the trawling and escape process (M_t). These estimates were not reduced by seine-mortality values. The second approach ($M_t – M_s$) assumes that caging and cage transportation caused some mortality. Hence, M_t was reduced by M_s for each length interval to compensate for mortality caused by the caging process. Maximum escape mortality predictions (M_t) ranged from 56% to 67% for 31- to 38-cm fish, whereas minimum predictions ($M_t – M_s$) were 45% to 55% for the same size classes.

Discussion

Escapement: Underwater video observations showed that pollock actively escaped through square meshes installed into the top panel of the codend and extension. Although the rate of escapement was never formally quantified, Table 2 provides some idea of potential escape rates. In one case, as many as 493 escapees were caged in a period of only one minute. Most pollock that escaped through the 93-mm square meshes were smaller than 38 cm; very few fish larger than 40 cm were able to pass through these meshes (Figure 5).

Erickson et al. (1996), Pikitch et al. (1996) and Suuronen et al. (1997) suggested that installing escape panels in front of the codend may enhance escapement of undersized fish. Our results confirm this hypothesis. Video observations showed escapement taking place along the entire length of the escape panel to 18 m in front of the catch bulge. Hence, for this species and trawl design, an escape panel installed ahead of the codend will (a) presort the catch (by size) before fish reach the codend meshes and (b) allow escapement of undersized fish even after the codend meshes become blocked with fish. It should be pointed out that not all undersized fish encountered or passed through the extension meshes (see Figure 5). Hence, escape panels should be installed throughout the length of the codend and extension to maximize the size selectivity properties of this pelagic gear. Furthermore, escape panels made of different materials (e.g., sorting grids) could improve selectivity even more than shown herein (Larsen and Isaksen 1993; Suuronen et al. 1993; Van Marlen et al. 1994;).

The rate of escapement and size of fish escaping trawl meshes depends on numerous factors. Pollock escapement may vary with catch size (Erickson et al. 1996; Guttormsen 1996), geographic location or time of year (Matsushita and Inoue 1997), amount of available light (Olla et al. 1997, 2000), water temperature (Inoue et al. 1993) and other factors. Although it is likely that this study was conducted under conditions that maximized the potential for escapement, other studies demonstrated that undersized pollock escape through trawl meshes at much deeper depths (i.e., darker and colder environment) and higher catch rates (Erickson et al. 1996; Guttormsen 1996). Hence, it is likely that use of selective gear will decrease the catch of undersized pollock in commercial fisheries under most conditions. Some commercial-pollock fishermen have installed square-mesh escape panels in the codend and/or extension of their pelagic trawls to enhance escapement of undersized fish (Erickson, personal observation).

Mortality and injuries: Even though we showed that pollock actively escape through trawl meshes, we also demonstrated that some of these escaping fish do not survive. Predicted mortality ranged from 45% to 67% depending on pollock size and other assumptions (Table 3). This range in mortality is moderate to high relative to that shown for other species (see Chopin and Arimoto 1995). Much higher mortality levels were described for herring (Suuronen et al. 1996a, 1996b), whereas similar levels were shown for vendace (*Coregonus albula*, Suuronen et al. 1995). Mortality for escaping haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) may be considered low to moderate, ranging from 11 to 52 % (Sangster et al. 1996). Atlantic cod are most resistant to stress and injuries caused by trawling; Soldal et al (1993) and Suuronen et al. (1996c) demonstrated nearly 0% escape mortality for this species.

Most of the mortality in this study took place during the initial 4-days after escapement. Thereafter, mortality was low but somewhat constant until the end of the experiment. This pattern of mortality is common for fish encountering fishing gears (e.g., Wassenberg and Hill 1993; Chopin et al. 1996; Suuronen et al. 1995; Suuronen et al. 1996c). Bublitz et al. (1999) demonstrated that many pollock escaping trawl meshes were bruised to some extent, and that bruising was correlated with mortality (more bruised = higher liklihood of death). We observed trawl escapees with significant scrapes and scale loss one day following escapement (Erickson et al., 1999). These results suggest that some individuals incur substantial skin damage and injury during the trawling and escape process. Skin damage, bruising (= deep muscle damage), and potential exhaustion can lead to somewhat rapid mortality due to osmotic imbalance and other associated problems (see discussions by Soldal et al. (1993) and Suuronen et al. (1996c)).

Even though most mortality was seen during the initial four days, approximately 22% additional mortality (on average) took place during the remaining period (Erickson et al., 1999). These delayed deaths were correlated with the onset of various skin problems (e.g., deteriorated caudal fins, lesions, and sores; Erickson et al., 1999). Similar secondary infections have been described for individuals of other species that escaped trawl meshes and subsequently died (Main and Sangster 1990; Soldal et al. 1993; Suuronen et al. 1996c).

Mortality decreased with increasing fish size for trawl escapees and seine-caught pollock (Figures 8 and 9). Others have demonstrated inverse relations between size and escape mortality (Soldal and Isaksen 1993; Soldal et al. 1993; Sangster et al. 1996; Suuronen et al 1996a, 1996b). This size-mortality relation is probably due to differential effects of exhaustion and injury (e.g., skin damage) among sizes, and suggests that factors other than (or in addition to) squeezing through trawl meshes damaged pollock. For example, Xu et al. (1993) showed that pollock became fatigued during the trawl-capture process, and Beamish (1966) demonstrated that muscle fatigue alone can cause mortality. In addition, Suuronen (1995) showed that herring bumped and scraped against trawl meshes and other fish during the capture process (prior to escapement), resulting in scale loss and skin injuries. Smaller, weaker swimming fish are more susceptible to these types of injuries than larger individuals. Hence, it is not surprising to find an inverse relation between body size and mortality since larger fish exhibit longer sustained swimming speeds than smaller fish.

Although two ranges of mortality predictions are shown in Table 3, we suggest that most “control” mortalities were caused by the capture process (i.e., seining) rather than our experimental procedures (i.e., caging and cage transportation). Hence, “control” mortality (M_s) should not be subtracted from trawling mortality (M_t) to derive predicted escape mortality. No significant relationships were found between experimental procedures (e.g., caging and cage transportation) and mortality (Table 2). Differences were noted among seining procedures, however, which likely caused the extreme variability of “control” mortality (Figure 8). Pollock held in cage 11 (which showed highest mortality) were crowded to such an extent during the seining process that they thrashed and boiled on seine webbing that was unintentionally pulled tight near the surface. Although the webbing was immediately released to provide space for swimming, this action likely caused extensive skin damage (see Erickson et al. 1999) and stress. Seine-caught pollock held in cage 9, on the other hand, were not crowded during the capture process. Mortality of pollock in this cage was only 2%, and almost no fish showed skin damage

(Erickson et al. 1999). Lockwood et al. (1983) also found that excessive crowding during final stages of purse-seine retrieval resulted in high mortality for mackerel (*Scomber scombrus*).

Pollock were held for 14 days in sea-bed cages to estimate mortality. It is clear that most trawl-caused deaths occurred within this time, and that only a small amount of additional mortality would have been observed beyond 14 days. Whether mortality would have been similar during this 14-day period for escapees left unrestricted by cages is debatable. Ryer (2002) showed that pollock subjected to capture and escape stresses were more likely to encounter predators (and be consumed by predators) than a control group under laboratory conditions. On the other hand, if escapees were not contained in the cages, then they would have been able to swim to more optimal sites for recovery (e.g., colder, darker waters).

Should selective gear be used in the pollock fishery given the levels of mortality shown in Table 3? Some argue that if escape mortality (= unaccounted mortality) is high, then nonselective gear should be used (see Chopin and Arimoto 1995; Kuikka et al. 1996). We suggest that escape-mortality predictions shown Table 3 are moderate relative to other species (see Chopin and Arimoto 1995). Modeling is needed to clearly evaluate the effects of these potential escape-mortality levels to the fishery before conclusions are made. For example, we showed that the smallest fish experienced the highest mortality. This size range (25 - 35 cm) also exhibits high natural mortality. Hence, additional mortality caused by the escapement process may be substantially lower than shown herein.

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Table 1. Potential sources of variation by sample (= cage) and cumulative mortality 14 days after caging. Variables are: treatment, trawling duration, catch volume in the codend (kg), density of pollock in the collection units, cage-transportation duration to the cage-staging site, average cage-transportation speed, and wind speed during cage transportation.

Cage number	Treatment	Date	Trawling duration (hrs)	Catch (kg)	Pollock density (n)	Duration of cage transport (hours)	Speed during cage transport (knots)	Wind speed (knots)	14-day mortality (%)
1	Codend	5/21	1.5	61	266	4.1	1.25	12	78
2	Codend	5/22	8.6	421	174	3.3	1.16	20	46
3	Codend	5/22	1.5	250	260	3.0	1.35	20	84
4	Extension	5/24	0.4	115	258	3.0	1.27	10	47
5	Extension	5/24	0.5	1,086	111	1.5	1.22	10	64
6	Extension	5/24	0.3	889	138	2.3	1.19	10	63
7	Extension	5/25	2.4	450	402	5.6	1.02	10	63
8	Codend	5/25	0.8	217	493	2.5	1.37	15	65
9	Seine	5/23	.	.	306	2.0	1.24	.	15
10	Seine	5/24	.	.	177	2.5	1.55	.	2
11	Seine	5/24	.	.	240	2.5	1.20	.	59

Table 2. Regression analyses. Response variable is arcsin(square root (p)), where p = proportion dead after 14-caging days). Model fit is arcsin($P^{-1/2}$) = $\alpha + \beta \bullet X$. Sample size (N) is either 8 cages (trawl escapees only) or 11 cages (trawl escapees and seine-caught fish combined). NA = not applicable, or data were not collected)

Independent variable (X)	P (N=8)	P (N=11)
Trawling duration	0.316	NA
Catch in codend (kg)	0.406	NA
Fish per cage	0.733	0.617
Cage transportation speed	0.386	0.156
Cage transportation duration	0.851	0.432
Cage transportation distance	0.636	0.603
Wind speed during cage transportation	0.688	NA
Trawling duration with rear gate closed	0.598	NA

Table 3. Difference in predicted mortality between treatment (trawl escapees calculated using equation 3) and control groups (seine-caught fish calculated using equation 4). N_t and N_s = sample size (number of pollock) by length class for trawl escapees and seine-caught fish, respectively. $M_t - M_s$ = difference in predicted mortality between treatment and "control" groups. Predicted mortality associated with sample sizes ≥ 10 for both treatment and control are highlighted in gray. Predictions outside of the shaded areas are suspect because of small sample sizes.

FL	N_t	M_t	Ns	$M_t - M_s$
23	4	0.79	0	0.13
24	18	0.78	1	0.17
25	38	0.76	0	0.22
26	66	0.75	0	0.26
27	66	0.73	1	0.30
28	28	0.72	0	0.34
29	22	0.70	1	0.38
30	39	0.69	3	0.41
31	143	0.67	14	0.45
32	300	0.66	36	0.48
33	433	0.64	95	0.50
34	413	0.63	106	0.52
35	283	0.61	105	0.54
36	120	0.60	61	0.55
37	43	0.58	20	0.55
38	29	0.56	19	0.55
39	21	0.55	4	0.55
40	5	0.53	6	0.53
41	7	0.52	2	0.51
42	4	0.50	2	0.49
43	0	0.48	0	0.46
44	1	0.47	2	0.42
45	0	0.45	2	0.37
46	0	0.44	1	0.33
47	0	0.42	0	0.27

Figure 1. Top-panel cover herding fish that passed through square meshes. Escapement took place throughout the square-mesh panel as far as 18 m in front of the catch bulge. Tows were conducted with the front and rear gates of the collection unit open until the end of the tow.

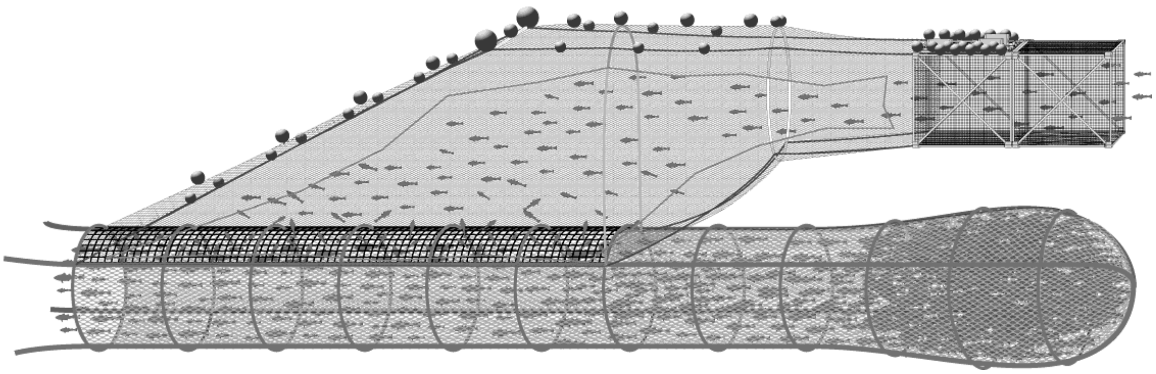


Figure 2. Caging procedure: (A) At any desired moment, the rear gate of the caging system was closed by activating the latch-release device through a third wire system from the wheelhouse. (B) The front gate was closed using the third wire system after sufficient numbers of fish were observed inside of the cage. (C) The collection unit containing escapees was detached from the release unit 1 - 2 minutes after the front gate closed. (D) The collection unit fell (or rose) to a depth of approximately 50 m.

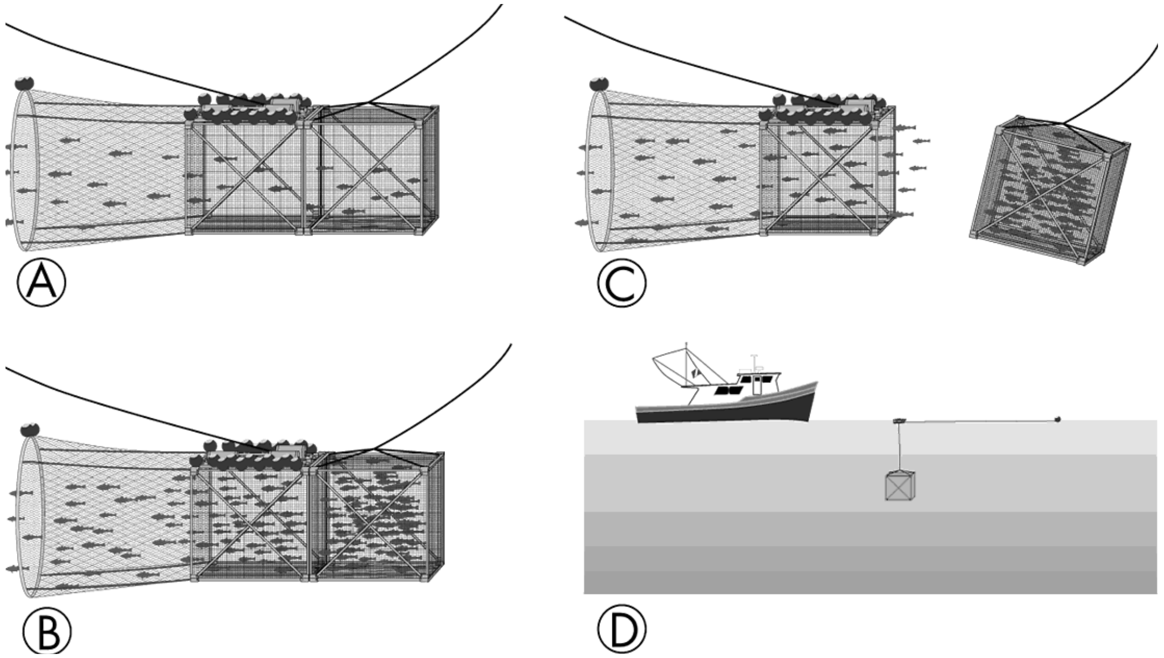


Figure 3. Temperature (^{o}C, gray) and depth (m, black) profiles recorded for cage 2 throughout the towing, caging, and transportation process. The time-depth recorder was attached to the cage. Rapid depth changes took place throughout the trawling process. The collection unit was released from the trawl at approximately 17:30, and floated to a depth of 50 m. The cage was recovered by the *M/V Three Bears* and transported to the cage-staging site at depths of 10 to 15 m.

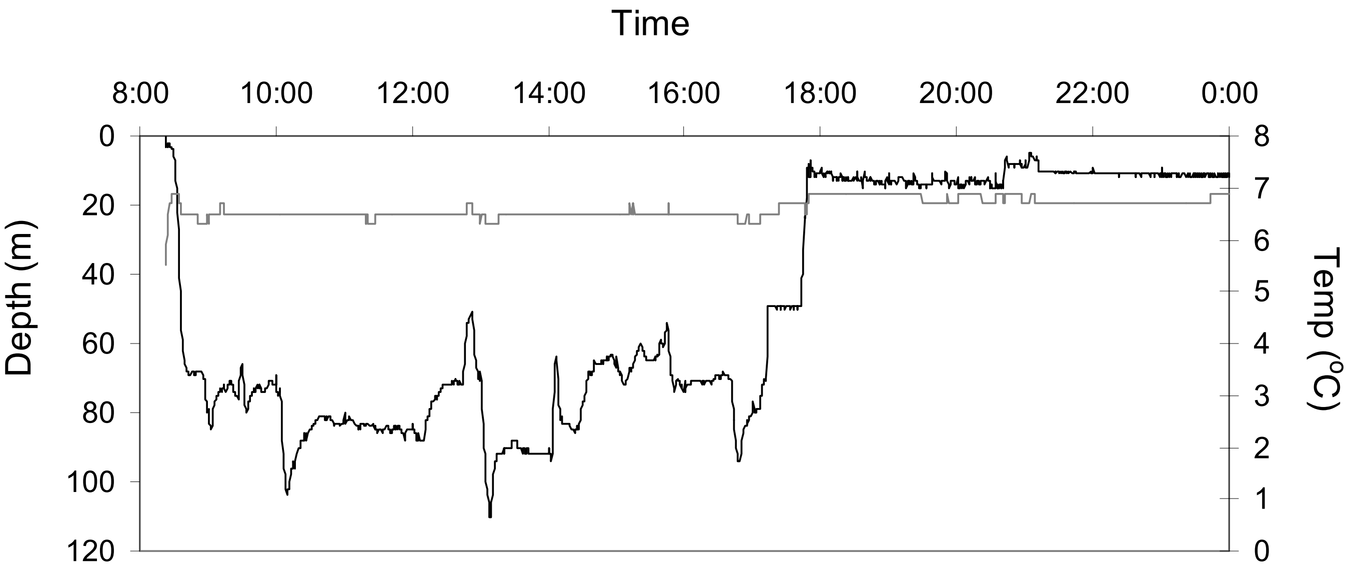
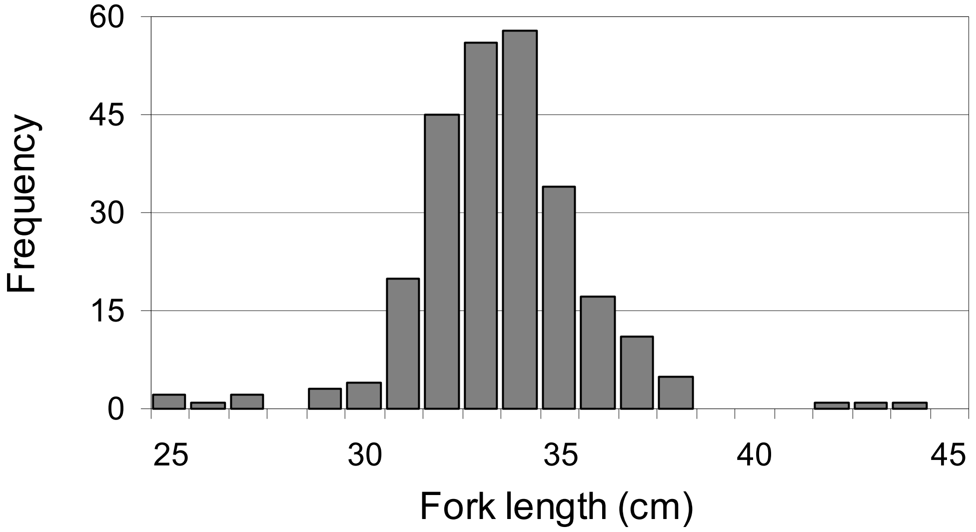


Figure 4. Examples of length-frequency distributions for pollock that escaped through 93-mm square meshes of the trawl. (A) Six cages contained pollock that were mostly 32 to 38 cm fork length. (B) The length-frequency distribution for two cages (cages 3 and 4) was bimodal - numerous fish were less than 30-cm.


(A) Cage 1

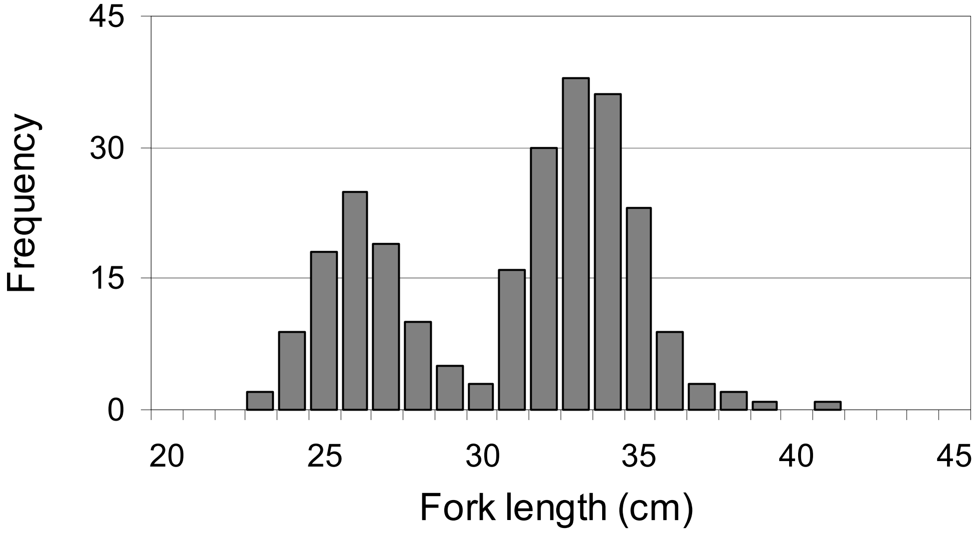

(B) Cage 4

Figure 5. Example of length-frequency distributions for pollock retained in the codend (gray) and pollock that escaped through square mesh top panels (black). All pollock recovered from cages were measured unless the caudal fin was severely deteriorated. Only a sample of the codend-retained specimens were measured.

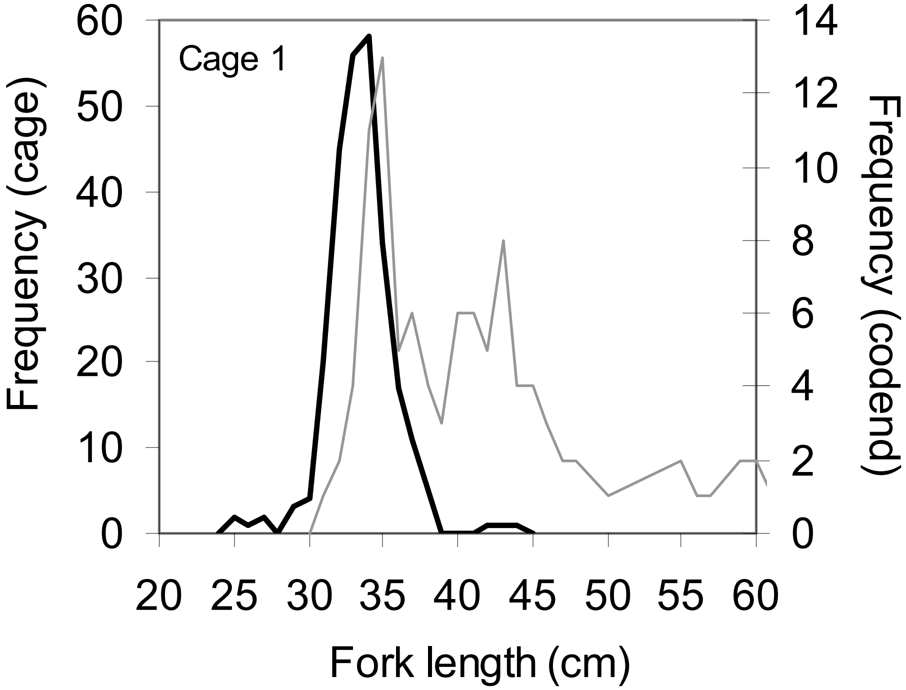


Figure 6. Length-frequency distribution of pollock caught by seine and caged (cage 9). Distributions were similar among all cages containing seine-caught pollock.

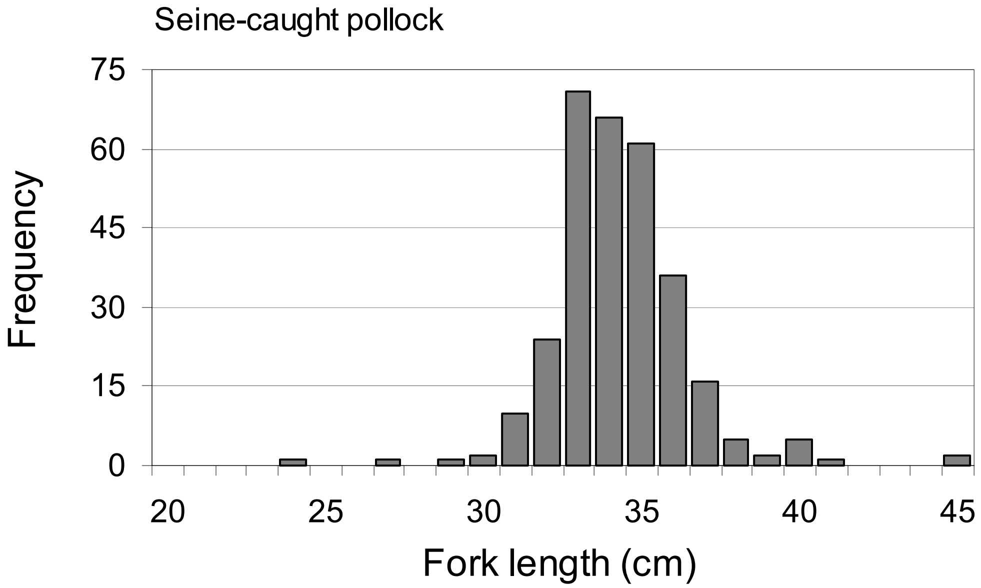
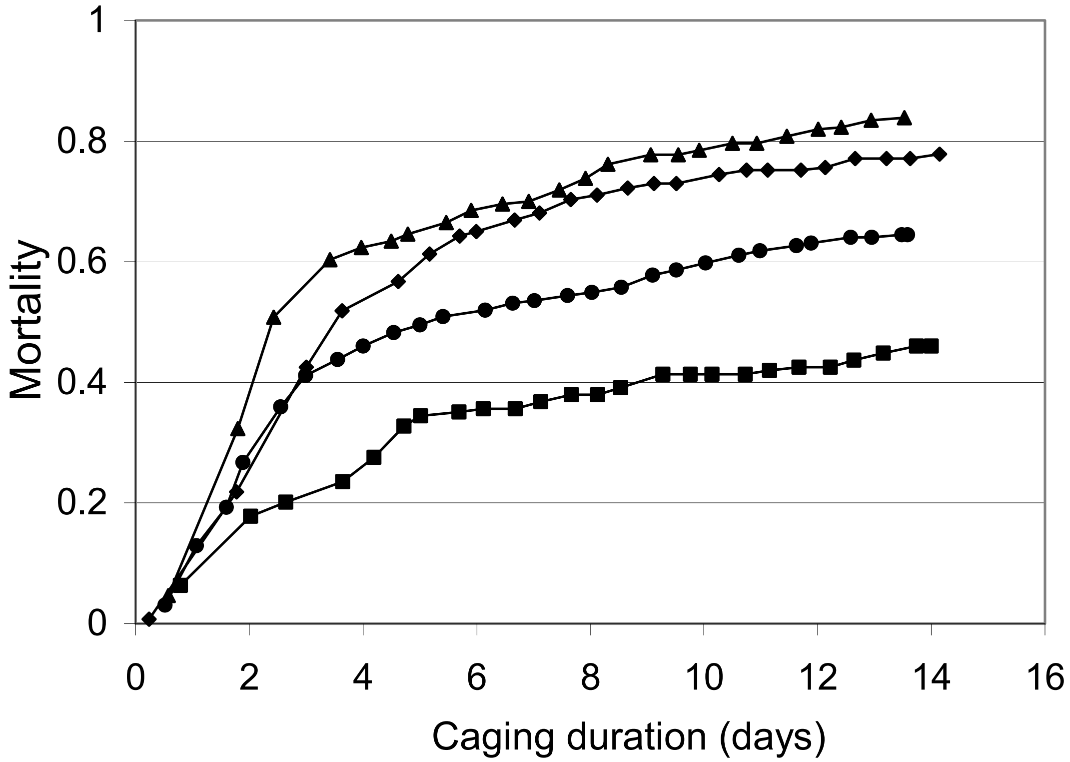


Figure 7. Cumulative 14-day mortality for pollock that (A) escaped through codend square meshes and (B) escaped through extension square meshes. Dead fish were collected once or twice daily by divers.

Codend Escapees



Extension escapees

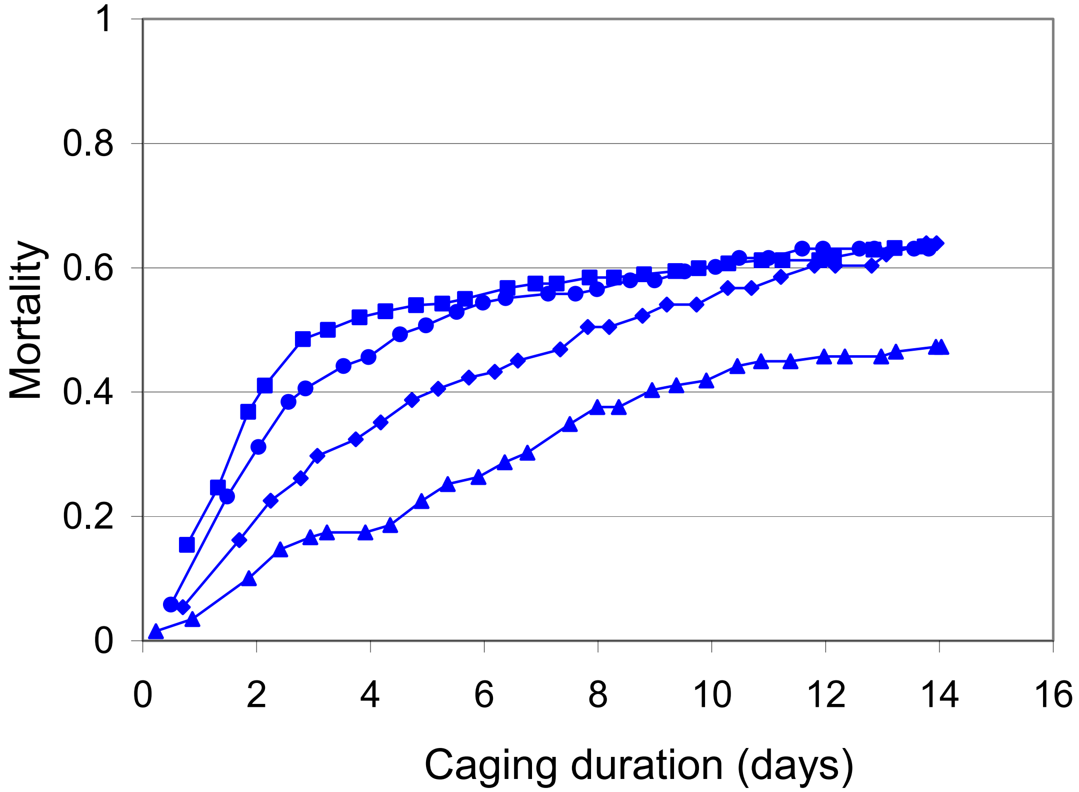


Figure 8. Cumulative 14-day mortality for pollock that were caught by seine. Dead fish were collected once or twice daily by divers.

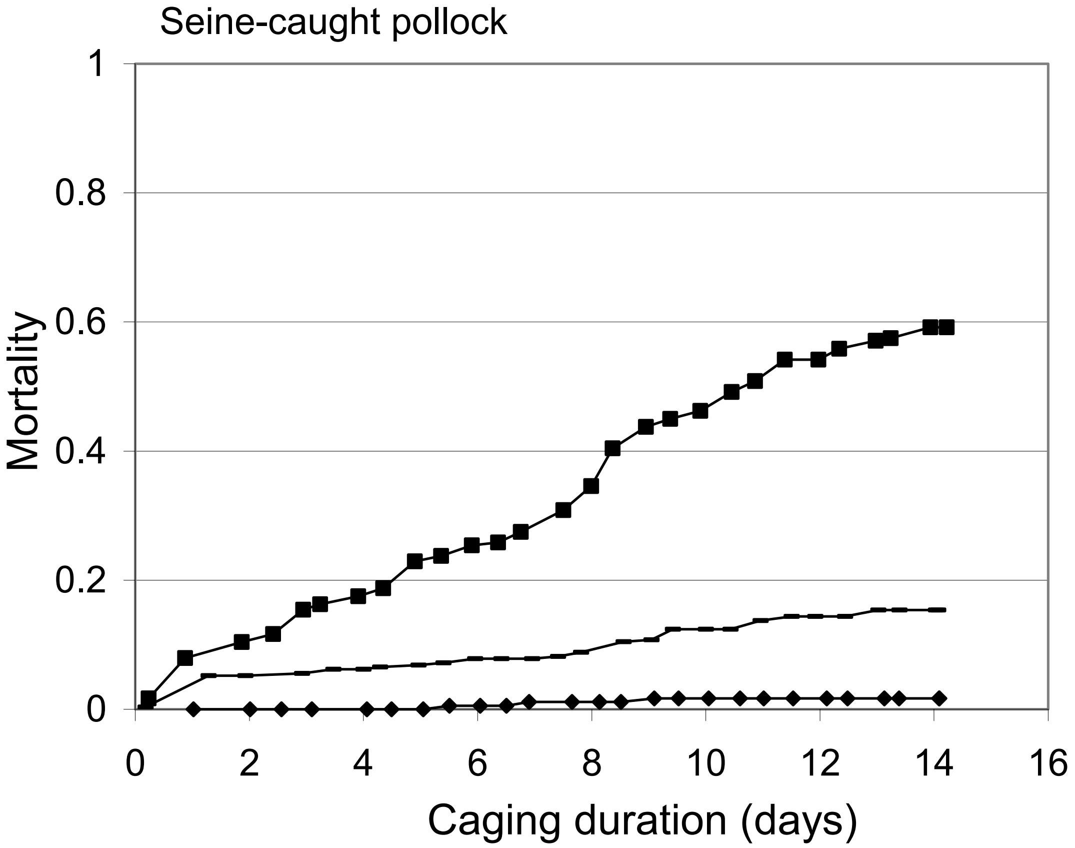
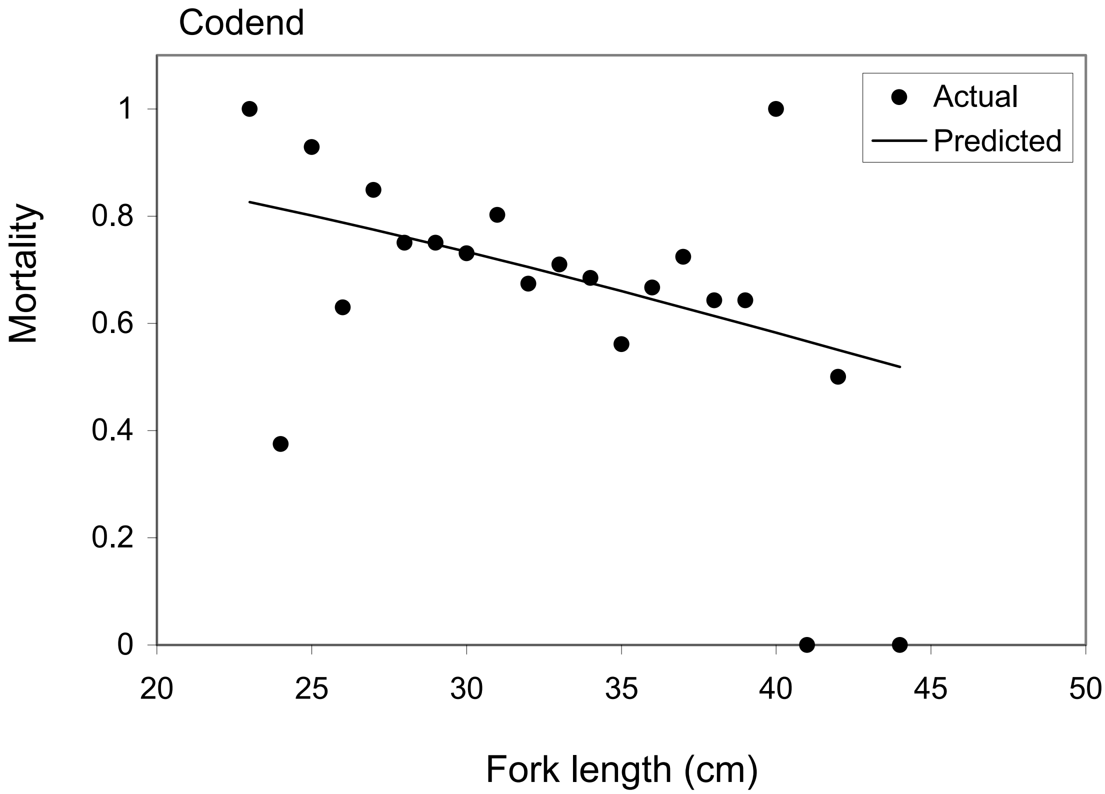


Figure 9. Actual and predicted fourteen-day mortality (proportion) for pollock that escaped through codend- or extension-square meshes, by centimeter-length category. A general linear model (weighted by N) was fit to angular-transformed data.


Codend

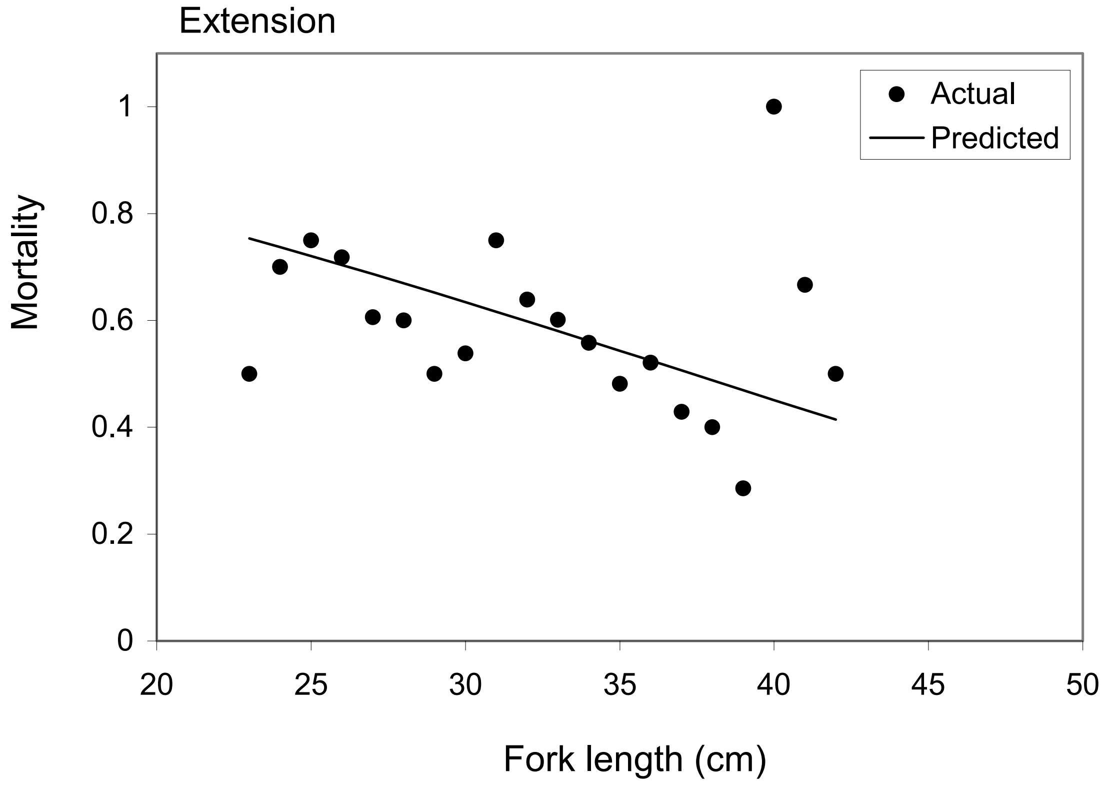

Extension

Figure 10. Actual and predicted fourteen-day mortality (proportion) for seine-caught pollock, by centimeter-length category. A general linear model (weighted by N) was fit to angular-transformed data. Data from cages 9 and 10 were included. Note that sample sizes for fish smaller than 31 cm were small (0 – 4 fish per cell) and had little influence on this weighted regression.