Determining the Seasonal Catchability of Atlantic Cod *Gadus morhua* Pots

Robert Marcella[1], Michael Pol[2], Mark Szymanski[2]

[1]F/V Ann Marie, 28 Western Ave, Hull, MA 02045 USA (deceased)
[2]Massachusetts Division of Marine Fisheries, 1213 Purchase St – 3rd Floor, New Bedford, MA 02740 USA +1.508.990.2860 (mike.pol@state.ma.us; mark.szymanski@state.ma.us)

Abstract

A worldwide interest in investigating and improving the capture of Atlantic cod *Gadus morhua* using fish pots currently exists. This interest is fueled by the potential for cod pots to be an environmentally responsible alternative gear due to species selectivity, low energy, and low impact. To further development of pots, paired comparisons of two different designs were conducted over an eight month period in Massachusetts Bay, USA.

Newfoundland-style, large, large-mesh static pots were compared to Norwegian-style smaller, small-mesh, off-bottom, dynamic pots in a controlled study from a commercial fishing vessel from November 2008-November 2009. Results from analysis indicate that cod were most vulnerable to pots during a limited season, and that the smaller mesh pot caught more small cod. Otherwise, the pots performed similarly. We conclude that either pot style may be effective for further development, that seasonality plays an important role and should be exploited for further testing, and observation of near-field behavior in cod near pots is still vital and problematic.

Keywords: pot, Atlantic cod, *Gadus morhua*, behaviour

Introduction

Fish pots possess many characteristics of an idealized fishing gear: they can be highly selective for the target species, and they yield apparently undamaged, high quality, healthy fish for sale, tagging and other scientific studies (Bjordal, 2002; ICES, 2006). Releases of undersized and unmarketable fish from pots have low or zero release mortalities in our previous research (Pol and Walsh, 2005). Pots also provide an alternative survey and harvest method for areas inaccessible to otter-trawling, such as coral reefs and hard bottom (ICES, 2009). As static gears, pots are low energy and low impact to non-target species and habitats and high fuel efficiency may result from their use (Thomsen et al., 2010). On the negative side, wider use of pots would increase buoy lines in the water, a safety concern for marine mammals and sea turtles. Current research suggests that, primarily, pots require improvements in catch per unit effort before commercial viability (Pol et al., 2010, Thomsen et al., 2010).

Interest in Massachusetts in pots arose from occurrence of “overharvest”, otherwise landable fish that are discarded due to catch limits. Where overharvest occurs, unnecessary damage and discard mortality of fish may result. Or, fish may be left in the water for harvest the next day, with loss of quality. In these cases, a gear, such as pots, that can catch and hold fish harmlessly, or that allows discard with low or no mortality will improve stock rebuilding and economic return.

Pol and Walsh (2005) reported the first catches of Atlantic cod *Gadus morhua* in a cod pot during scientific trials in New England, up to 13 in one pot haul, using pots designed at the Centre for Sustainable Aquatic Resources, Marine Institute of Memorial University of Newfoundland (CSAR). However, pot-captured cod tended to be below minimum landing size and average catch rates were not economical. Further investigation in the same area in December 2005 - February 2006 comparing catches in CSAR pots to nearby multimesh gillnets showed similar low catch rates, and suggested that cod in pots were smaller and more empty stomachs than cod caught in nearby gillnets (Pol, unpublished data). However, the sampling area was limited in size and the number of samples and the number of pots used were very low. Underwater filming showed cod attracted to, but not often entering, the pot.

An international workshop on gadoid harvest (GACAPOT) in Gloucester, USA (2006) examined progress on catching cod, haddock *Melanogrammus aeglefinus*, and related fish in pots (Pol et al. 2010). The meeting concluded that it was necessary to align the bait’s scent plume (caused by the movement of water over the bait) with the direction of entry to the pot’s entrance. Furevik et al. (2008) designed pots to float and rotate in response to current. Underwater observation of their pots showed >95% of fish approached the pot from the down-current direction.

A second important conclusion from GACAPOT was that fish in general and Atlantic cod specifically are only vulnerable to pots during certain times of year. This vulnerability may be due to seasonal behavior, hunger levels, presence of prey or predators, migration, spawning status, or temperature, or a combination of these and other factors. Therefore, in development of pots, it is of primary importance to establish when cod will be maximally vulnerable. This knowledge can then lead to refinement of the pot design by testing during those time periods.

The two pot designs have both been effective at capturing cod in their areas of development, although their characteristics differ greatly: floating v. static; large v. small; two large entrances v. one small entrance. In a paired, controlled study, we compared the CSAR (Newfoundland) pots to the floating (Norwegian) pots described by Furevik et al. (2008) to further development of cod pots in this region. Paired overnight sets were conducted for four days per month in Massachusetts state waters of both Newfoundland and Norwegian designed cod pots, across eight months of a year (November-June). We planned to film fish behaviors, primarily reaction to bait, using underwater cameras. The results of this work were intended to quantify catch rates in pots across eight months, compare the effectiveness of two pot designs, and determine the best time to catch cod with pots.

Methods

Tests were conducted onboard three similar vessels, primarily used for lobster pot fishing, each approx. 13 m, 260kW, equipped with a pot hauler and a boom. Open transoms simplified setting of pots.

Ten pots each of the Newfoundland and Norwegian design were set singly in pairs approx. 0.25 nm apart for periods within each of eight months: December 2008-June 2009, and November 2009. The Newfoundland design (NF) cod pots are all pyramid-shaped when fishing and are constructed in three different ways: two are approx. 2 m x 2 m x 1 m and consist of a steel frame with netting panels; one of these designs is collapsible, saving deck space (Figure 1). The third construction type is 1.8 m x 1.8 m x 1 m and made from polyvinyl-coated wire 50 mm square mesh. All three have netting attached at the top: 30 meshes of 50 mm diamond mesh with a float whose buoyancy creates the pyramid of netting on top. Each pot has two entrances on opposite sides with 40 cm diameter circular rings. Attached to the rings are "triggers": stainless steel 5 mm diam. rods about 50 mm apart that swing in to allow entrance, but do not swing out. The pots are designed to be static on the sea floor. Previous research (Pol and Walsh 2005) showed these three designs did not fish differently from one another, and for the purposes of this study were treated as identical.

The Norwegian design (NO) (Figure 2) pots are collapsible two-chamber rectangular pots made of netting, with a single bridle with anchor along the short end of the pot, allowing it to float and to turn with the current, adapted from Furevik et al. (2008). They have one entrance at the opposite end as the bridle, and are made of 50 mm black poly mesh for the trap body and 50 mm white poly for the entrances (into the pot and between chambers). The frame was constructed of 2 cm diam. PVC electrical conduit, with 13 cm radius corners, glued with cement. The frame sizes were approx. 44 in x 20 in x 53 in. The bridles were anchored with >5 kg links of chain. After several months, observations of cracking in the PVC and catches of lobsters suggested that pots were not floating as expected. A pot was set in a large-scale, laboratory sea water tank, and did not float off bottom. The PVC pipes were then perforated and 11 deep-water gillnet floats were added along the upper frame to achieve proper orientation. All NO pots were subsequently modified in this manner. During the tank investigation, the height of the NO pot was measured to be 3 m off bottom; the bottom of the pot was 1.5 m off-bottom.

Locally caught clams, shelled and frozen, were used for bait during the field research. This bait was shown to be preferential for cod in a prior study (Pol et al. 2007). Bait was purchased in one lot for the entire experiment, and maintained in a commercial bait freezer. Quantities were defrosted prior to setting of the pots as needed. Bait was presented in perforated cups, unprotected on skewers, and in mesh bait bags. The amount of bait per pot was approximately equal, although not strictly controlled.

Pots were set and hauled on three or four consecutive days in each month. Set locations were determined using fishing experience, an echo-sounder, and jigging. Bottom structure in the study area is glacially-influenced, and is composed of cobble/gravel mounds in shallower areas interspersed with deeper areas of a sand/silt matrix (Butman et al., 2007). Depths in the northwestern corner of the area are quite shallow but most of the area is 30-76 m (100-250 ft) deep with dramatic localized relief. Depth generally increases with distance from shore. Bottom current is mainly influenced by tides, with some effect from wind. In each tidal cycle, the current rotates 360 degrees (pers. comm., C. Chen, School for Marine Science and Technology, University of Massachusetts)

Catch was identified, weighed, and measured. Operational and biological data were collected by DMF biologists, including: catch composition and weights for all species, midline lengths for Atlantic cod (and other species as practical) to the nearest cm, set and haul times, locations, weather conditions, depth, and bottom seawater temperature. Data were entered into a customized Access database and analyzed using the open-source statistical program R (R Development Core Team, 2009; Sarkar 2009).

Holst and Revill (2009) described an implementation of Generalised Linear Mixed Models (GLMM) to paired catch experiments. This implementation allows fitting of curves of limited complexity to expected proportions-at-length (in our case, count of cod in NO pots/total count in both pots for each pair). GLMMs in the Holst and Revill (2009) method incorporate between-pair variance (Fryer, 1991). Four fixed-effect models (constant, linear, 2^{nd} order, and 3^{rd} order polynomial relationships of length) were tested, each using pair as a random effect. We used the penalised quasi likelihood function (glmm-PQL function in MASS package of the *R* statistical software (R Development Core Team, 2009)), where insignificant terms are removed based on the Wald's test (Holst and Revill, 2009).

Additionally, we attempted to conduct at least one filming session each month to observe fish behavior in the vicinity of a pot. An underwater camera was attached to a pot and a live-fed to the vessel and recorded.

Results

We completed 383 pot-hauls on 24 trips; 377 pot-hauls were considered valid for analyses. Pairs where no cod were caught in either pot were removed for cod catch analyses, resulting in 114 pairs where at least one cod was present. Overall, pots were set in an area of approx. 16 sq. km (Figure 3), inside of Massachusetts state waters.

Median soak durations generally ranged from 22.5-24.8 hours, with longer durations in December 2008 (median = 43.8 hours) due to weather (Figure 4). Median monthly bottom temperatures ranged from 3.1(Feb 2009) to 10.0°C (Nov 2009). Median depth fished ranged from 27.5 to 50.6 m.

Catches consisted of 16 species (Table 1) with Atlantic cod, cunner *Tautoglabrus adspersus,* pollock *Pollachius virens,* and lobster *Homarus americanus* the primary catches. Catches of lobster in NO pots were dramatically reduced after modification of flotation was made.

A total of 397 cod were caught in pots; counts of cod varied noticeably between months (Figure 5). Over 50% (n=217) were caught combined in the months of April and May. The highest pot catches (above nine) occurred in these months; the highest median catches (1.5-3 cod per pot-haul) also occurred during these months. December, March, June and November's catches were intermediate. Only five cod were caught in January and February combined.

Few cod above legal size were caught in any month (Figure 6); only 28 fish above the minimum landing size of 55.9 cm were caught in total.

Equal catch plots of pot pairs (Figure 5) demonstrated that the Norwegian pots frequently caught more cod than the Newfoundland designs; in some months, performance seemed similar between the two designs. Histograms of catch by pot (Figure 6) indicated that smaller cod were caught more frequently in the NO pots.

GLMM analysis confirmed that Norwegian pots caught more small fish (Figure 7). The best fit model resulted in a significant ($p<0.05$ for all terms) third order polynomial fitting the proportion of cod caught in the NO pots. The model indicates that the NO pots caught significantly more cod <38 cm ($p<0.05$) than the NF pots. For cod >38 cm, catches were not significantly different ($p>0.05$). Above MLS (56 cm), variability increased a great deal (as seen in the width of the error bands), likely due to low numbers of cod above this size.

Filming of cod behavior was not effective. Dangerous weather and poor visibility limited observations. The ability to film was established, but no useable video was collected, despite many attempts.

Discussion

We sought to measure seasonal variation in cod catches in pots. Catch results changed dramatically over the course of the study, suggested that vulnerability or presence of cod varied with season. Very low catches occurred during January and February in mid-winter. Low water temperature can change the effective area of a pot by reducing the swimming and searching ability of a fish (He and Pol, 2010). However, low catches were not directly related to bottom temperature, as temperatures were similar in these months and months with higher catches. The seasonality of these catches reinforced traditional knowledge and observation of fish on the grounds, but do not coincide exactly with times of higher longline or gillnet catches (some traditional knowledge of fish presence in the area is hindered by long-standing seasonal closures). Traditional knowledge also suggested that larger cod might be caught in November and December. While some evidence was found to support this observation, too few fish were caught to conclusively demonstrate it. We can conclude that further research to improve efficiency of pot designs in this region should concentrate on the months of April and May, and avoid the months of January and February.

The efficiency of the two pot designs differed, based on the length of the fish (Figure 7). The smaller size cod (<38 cm) caught by the NO design may be due to the smaller mesh size of the pot construction. However, underwater video collected in other studies (Pol et al., 2010) suggests that mesh penetration of the sides of a pot is rare during fishing. It is possible that the hauling method for the NF pots, with the pyramid top trailing, may cause a codend effect, with cod escaping if they can fit through the meshes. If smaller sized fish are desired, the pyramid mesh can be replaced fairly easily. Additionally, the triggers on the entrances to the NF pots may also be selective, as smaller fish have been observed to exit between trigger fingers (Pol and Walsh 2005).

It was thought that the alignment of plume and entrance by the NO-style pots would lead to much greater catches than in the NF pots, based on previous work by others and our own prior underwater observations of Atlantic cod milling around a pot and not actively seeking entrances (Pol et al., 2010). Larger catches were mostly seen for smaller fish only, which suggests a difference in size-selectivity of pot structures. It may be possible that the greater catches of small fish were caused by the plume-entrance alignment, if a behavioral difference related to plume following or entrance can be related to Atlantic cod of that size. Atlantic cod of 38 cm in this stock are approximately 3 years old (Collette and Klein-MacPhee, 2002). Perhaps those fish and smaller sizes more actively search for or react to bait plumes (i.e., have a greater feeding motivation), and thus are more vulnerable to the gear. Alternatively, the circulation patterns in the study area may cancel out the effect of the plume-entrance alignment by rotating 360° approximately every 24 hours.

The pots were equally efficient for a mid-size range of fish. For fish above MLS (56 cm), they were also equally efficient, but the uncertainty in the results is much higher. It has previously been suggested that large pot volumes are necessary for effective cod capture; further, concern over the apparent size of the pot mouths (entrance)in the NO design led to the thought that the smaller NO design would catch fewer large fish. Our results suggest that volume is not a barrier to large catches, and are inconclusive on any size limitation for either design.

Why were so few large cod captured in either design? Several explanations are possible: cod that size were absent (as evidenced by jigging and the echo-sounder); they were not vulnerable to the pot, perhaps due to inadequate motivation to feed, seek shelter, or to move; entry was difficult due to entrance size or design, or other factors; escape was easy. Further investigation of these possibilities is not equally possible, as the in-situ population structure and behavioral motivations are difficult to assess. Testing of modifications to entrances and other aspects of design is possible, especially as times of high vulnerability can now be recommended.

The NO design pot has many practical advantages, mostly related to their compact nature. Many more of them can be transported on a vessel and no specialized handling equipment is necessary. Some improvement to the basic design is suggested, including separating the functions of frame structure and flotation so that damage to the structure does not affect flotation.

Both designs are now demonstrated to be effective at catching Atlantic cod in the region. Each design has advantage; the NO design appears especially practical for scientists and others wishing to sample sublegal sized cod for tagging, broodstock, or other purposes. Commercial practicality still appears elusive; while few legal sized fish were caught, the number of pots used was very low. For comparison, ratio of kept lobsters per pot in the local lobster pot fishery is less than 0.5 (DMF, unpubl. data). If a cod pot fishery were scaled to the 600 pots or so allowed in the lobster pot fishery, commercial viability might be achieved. It is also possible that under new stricter cod stock management, the number of fish of legal size will increase, and catches would increase. Additional development of entrances should continue as a primary means of improving efficiency.

Observation of wild Atlantic cod as part of a gear experiment proved to be difficult, in part because a choice was made to emphasize the gear comparisons. Safe weather conditions were often the limiting factor, allowing only completion of pot sets. When weather was acceptable, visibility was limiting. Further observation of Atlantic cod reaction to cod pots is vital. Future attempts to record cod behavior in situ should be as the central focus of a study, so that adequate time and resources can be available to collect useful observations.

Acknowledgments

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Table 1: Counts of all species caught in pots, separated by design

Species		Pot Type	
		Norwegian	Newfoundland
Cod, Atlantic	*Gadus morhua*	231	184
Cunner (Yellow Perch)	*Tautogolabrus adspersus*	79	3
Pollock	*Pollachius virens*	69	2
Lobster, American	*Homarus americanus*	45	10
Dogfish, Spiny	*Squalus acanthias*	16	
Crab, Jonah	*Cancer borealis*	13	4
Hake, Red (Ling)	*Urophycis chuss*	7	1
Crab, Rock	*Cancer irroratus*	4	
Sea Raven	*Hemitripterus americanus*	2	5
Ocean Pout	*Macrozoarces americanus*	2	2
Herring, Atlantic	*Clupea harengus*	2	
Redfish, Nk (Ocean Perch)	*Sebastes sp*	1	1
Cusk	*Brosme brosme*	1	
Lumpfish	*Cyclopterus lumpus*	1	
Crab, Northern Stone	*Lithodes maja*		5
Flounder, Winter (Blackback)	*Pseudopleuronectes americanus*		1

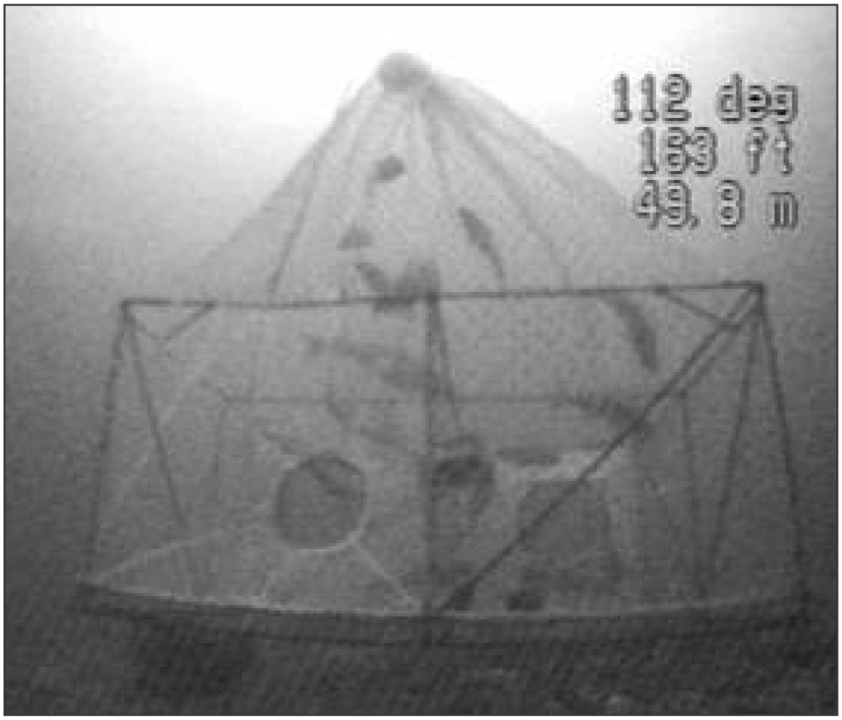

Figure 1: Underwater view of Newfoundland-style pot

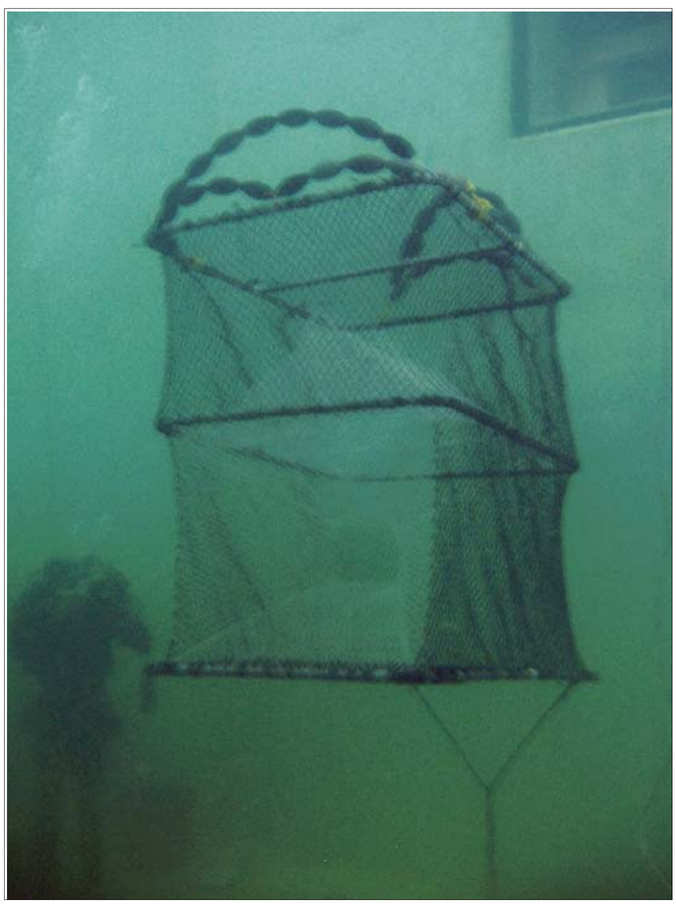

Figure 2: Underwater view of a Norwegian-style pot

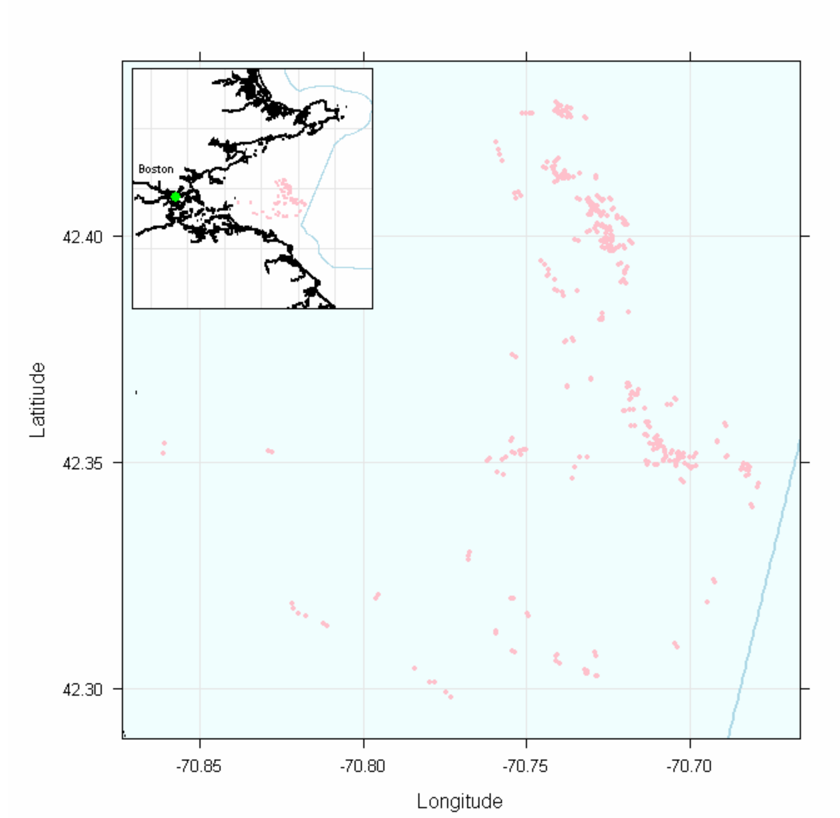

Figure 3: Study area showing all pot-haul locations for the entire study (pink dots). The blue line in the lower corner is the Massachusetts State waters boundary. The inset shows the City of Boston for reference.

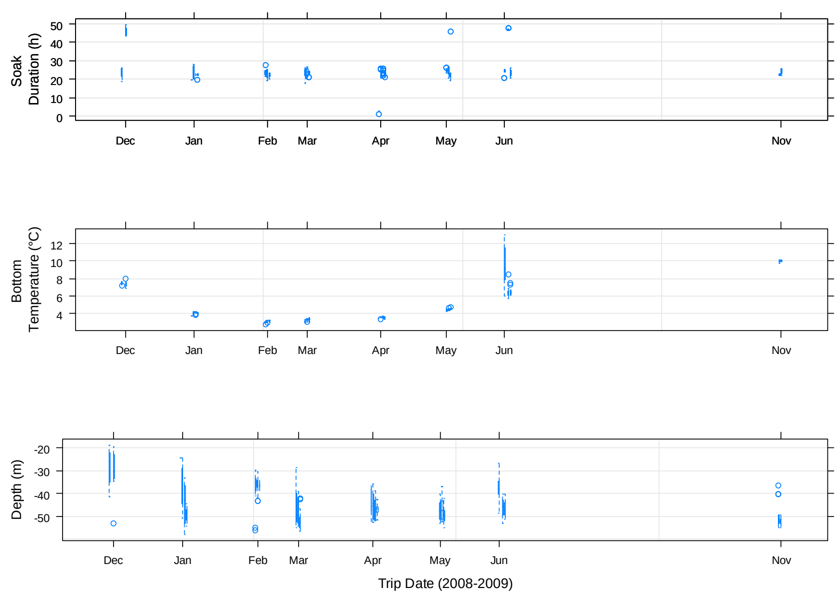

Figure 4: Boxplots of soak duration (h), bottom temperature (°C) and depth (m) for all pot-hauls.

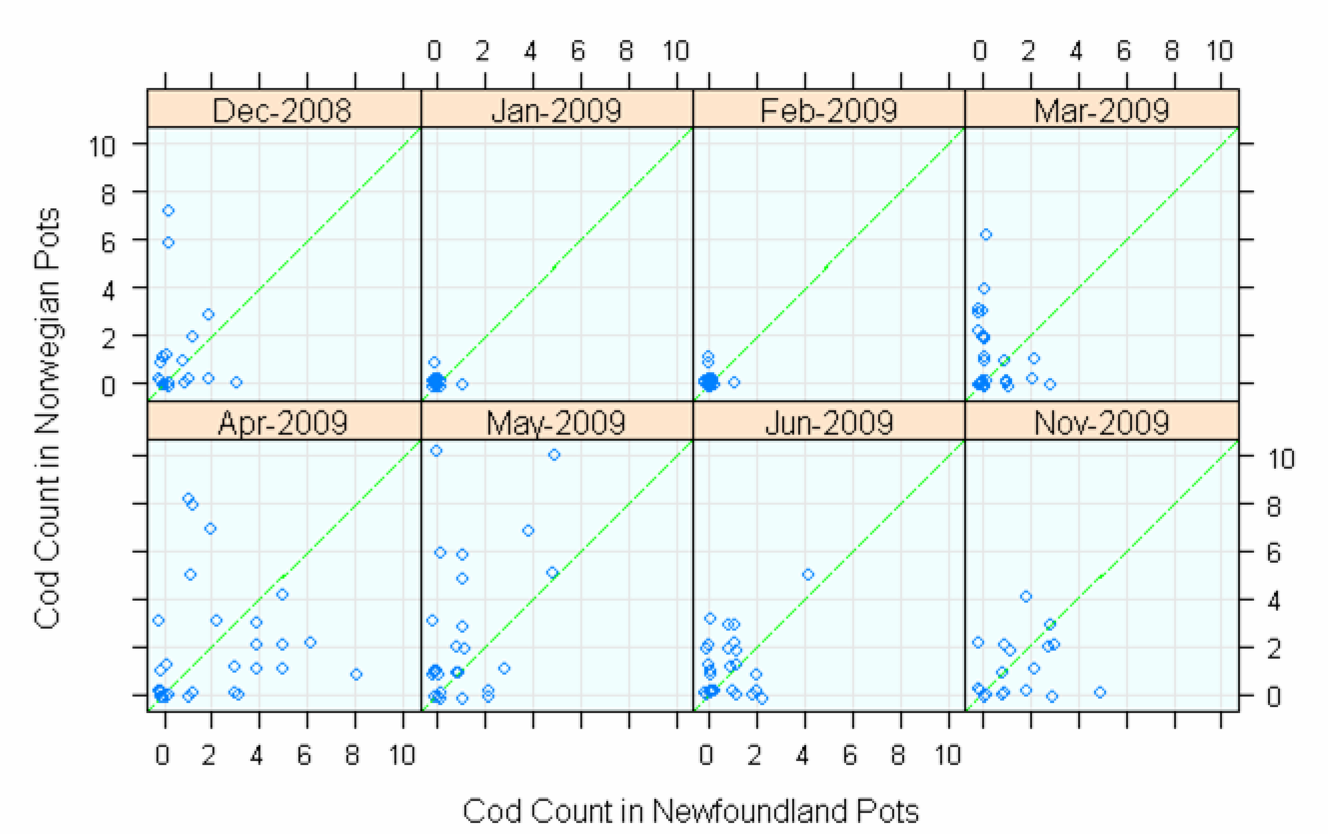

Figure 5: Equal catch plots of counts of Atlantic cod in paired pot-hauls of Newfoundland and Norwegian-style pots, by month. The green diagonal line is the line of equal catch.

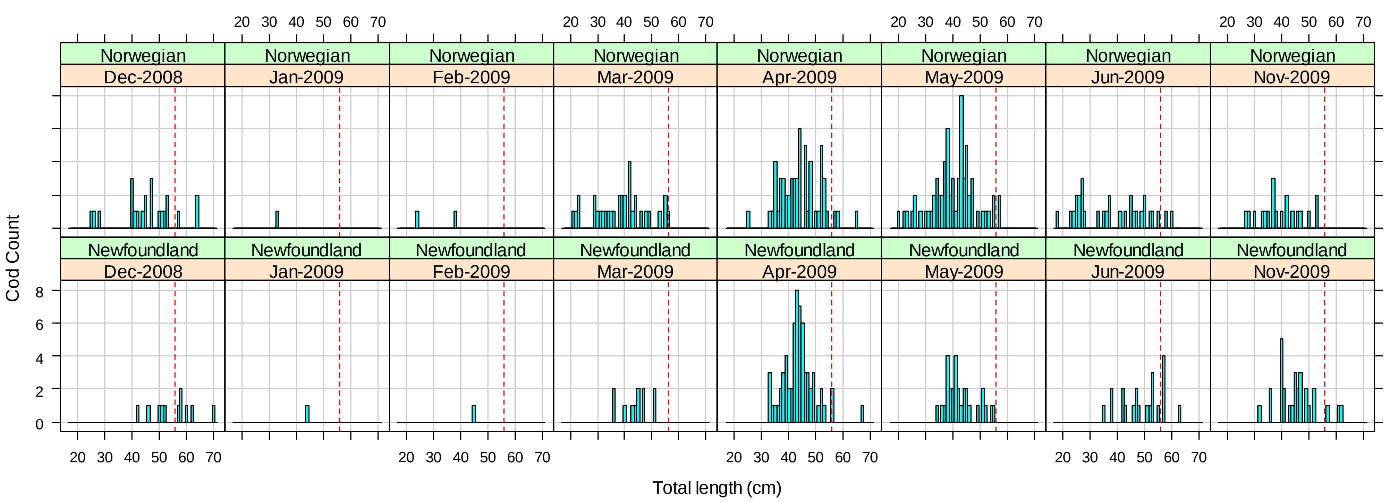

Figure 6: Length frequencies of counts of Atlantic cod lengths captured in two pot designs (Norwegian: top row; Newfoundland: bottom row), and by month (columns). The red dashed line indicated minimum landing size in the region (55.9 cm).

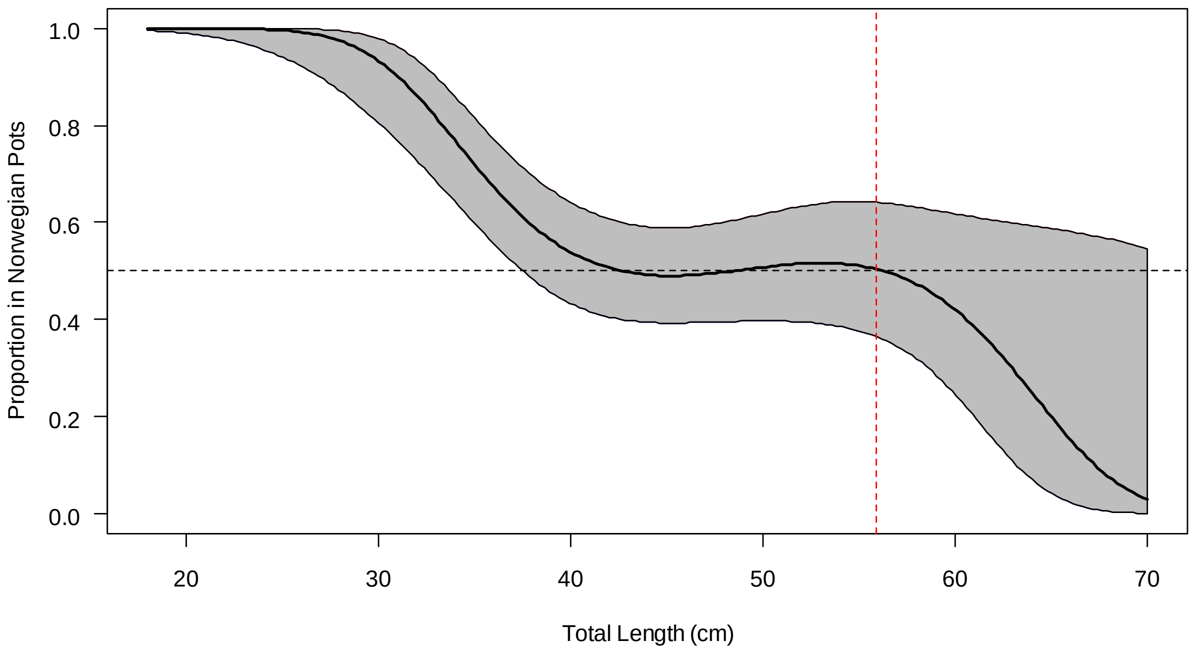

Figure 7: Generalized linear mixed model mean curve fit to the proportion of cod in Norwegian pots over the total count for each length caught in both designs. The horizontal dashed line at 0.5 defines equal performance of both designs. The shaded areas around the mean curve are 95% confidence regions. Non-overlap of the 0.5 line by the confidence regions indicated significant differences. The red dashed line indicated minimum landing size in the region (55.9 cm).