Time and tide

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Marcella, Pol and Szymanski probe the viability of baited cod pots as an environmentally responsible alternative to current commercial fishing gears.

Who should read this paper?

Those who appreciate the challenge of trying to think like a fish and those who care about how the fish they eat are caught.

Why is it important?

Commercial fishing provides vital protein and productive employment, and can and should be practiced in the most sustainable manner possible. Profitable yet sustainable exploitation of ocean resources is not an oxymoron. The key is innovative application of technology (in this case baited pots) combined with a positive environmental attitude on the part of fishermen, and the diligence of the scientific community.

Baited pots are increasingly being seen as a viable replacement for other gear types, with the added benefit of having less collateral impacts in terms of by-catch (non-target species) and habitat degradation. Pots also appear to harm cod less than other gears, so that juveniles can be released and go on to reproduce, and landed cod are of the highest quality, producing the best flavour and commanding the highest price. Pots may also be used as survey tools to improve estimates of the abundance of cod in rockier habitat, and therefore sustainable exploitation of the biomass. The authors compared two successful designs for cod pots to see which was most efficient, effective and practical.

Cod pots are currently being investigated and implemented commercially across the North Atlantic, but improvements in catch efficiency are needed in order to further encourage commercial uptake. This paper represents two important steps along that path.

About the authors

The authors are a multidisciplinary team that includes two fisheries biologists who study fishing gear and fish behaviour during the capture process, and an experienced, forward-thinking lobsterman. Michael Pol and Mark Szymanski have carried out many research projects in collaboration with commercial fishermen to reduce impacts to non-targeted species, and have worked on cod pot development for several years. Robert Marcella fished commercially for over 35 years, captained the fishing vessel *Ann Marie*, and contributed to the design and testing of the pots. Captain Marcella passed away in 2010.

SEASONAL CATCHABILITY OF STATIC AND FLOATING ATLANTIC COD POTS

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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 to current commercial fishing gears 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.

Large, large-mesh static pots designed in Newfoundland were compared to smaller, small-mesh, off-bottom floating pots designed in Norway 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 behaviour in cod near pots is still vital and problematic.

KEYWORDS

Pot; Atlantic cod; *Gadus morhua*; Behaviour

INTRODUCTION

Fish pots display many characteristics of an idealized fishing gear: they can be highly selective for the target species, they produce catches with high vitality and high quality, and they individually have a low impact on the environment [Bjordal, 2002; ICES, 2006]. As with other static gears, pots are low energy and low impact to non-target species and habitats and represent a possible alternative to fishing gears with greater impacts [Thomsen et al., 2010; Suuronen et al., 2012]. Fish discarded from pots may have low or zero release mortalities [Pol and Walsh, 2005]. Pots also provide an alternative survey and harvest method for areas inaccessible to trawling, such as coral reefs and hard bottom [ICES, 2009]. On the negative side, use of pots may increase buoy lines in the water and risk injury to marine mammals and turtles [Pol et al., 2010; Rihan, 2010; Suuronen et al., 2012]. Most importantly, the current relatively low catch rates of most pot designs require improvement before achieving commercial viability [Pol et al., 2010; Thomsen et al., 2010].

Interest in Massachusetts in pots arose from occurrence of "overharvest" – catches of legal-sized fish that exceed regulatory limits – during seasonal mating aggregations of Atlantic cod *Gadus morhua* in Massachusetts Bay [Dean et al., 2012]. Where overharvest occurs, unnecessary damage and discard mortality of fish, or loss of quality if fish are left in the water captured in the gear for later harvest, is typically inevitable. In these cases, a gear that can catch and hold fish harmlessly, or that allows discard with low or no mortality, will improve stock rebuilding and economic return by allowing discarded fish to survive and reproduce. Pots appear to be a gear with these characteristics [Pol and Walsh, 2005; Suuronen et al., 2012].

Pol and Walsh [2005] reported the first catches in New England of Atlantic cod *Gadus morhua* in a cod pot. During experimental trials, as many as 13 cod were caught at one time, using pots designed at the Centre for Sustainable Aquatic Resources, Marine Institute of Memorial University of Newfoundland. However, captured cod tended to be below minimum landing size (MLS; 55.9 cm) and average catch rates and revenues were not adequate for commercial viability. Further investigation in the same area in December 2005-February 2006 compared catches in Newfoundland-designed pots to nearby multimesh gillnets and showed similar low catch rates, but cod caught in pots were smaller and hungrier than cod caught in gillnets (Pol, unpublished data). However, the sampling area for this small study was restricted and the number of samples and the number of pots used were very low. Underwater footage collected at that time showed cod attracted to, but not often entering, the pot and inspired the possibility of modifying the pot design to encourage entry.

An international workshop on gadoid harvest with pots (GACAPOT) in Gloucester in 2006 examined progress on catching haddock, cod and related fish in pots [Pol et al., 2010]. One conclusion drawn from that meeting was the benefit of lining up the entrance of the pot with the bait or odour plume caused by the movement of water over the bait. Pots designed by Furevik et al. [2008] are anchored to the sea floor, but float and rotate in response to current, thus orienting the pot's single entrance down current. Underwater observation of those pots showed >95% of fish approaching from the down current direction, where the bait scent is carried by the current and detected by fish. Rotation of the pot with the current allows a cod to swim up the detected bait scent and immediately into an entrance, without the need for further searching.

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 [Pol et al., 2010]. This vulnerability is seen in all fishing gears, and may be due to behaviour, hunger levels, presence of prey or predators, migration, spawning status, temperature, or a combination of these and other factors [Laevastu and Favorite, 1988]. Testing of improvements or refinements of pots is optimal when cod are maximally vulnerable to pots. If pot modifications are tested when cod are not available to the gear, results can be spurious or misleading. Describing temporal availability maxima can therefore help determine when a possible fishery could be developed, and when further experiments on the details of pot design and deployment are best timed.

We compared the static (Newfoundland (NF)) pots to the floating (Norwegian (NO)) pots described by Furevik et al. [2008]. We conducted paired overnight sets for four days per month in Massachusetts state waters of both designs, across eight months of 2008-2009 (November-June). We planned to conduct filming of fish behaviour, primarily reaction to bait, using underwater cameras. The objectives of this research were to quantify catch rates in pots across eight months, to compare effectiveness of two pot designs, and to determine the best time to catch cod with pots.

METHODS

Tests were conducted on board three similar vessels, each approximately 13 m and 260 kW, equipped with a hydraulic line hauler and a boom extending outboard with a block (or pulley) to support lifting of the pots. Open transoms, where the aft end of the vessel is widely notched to the deck level, allowed pots to slide across the deck and into the water, simplifying setting of pots.

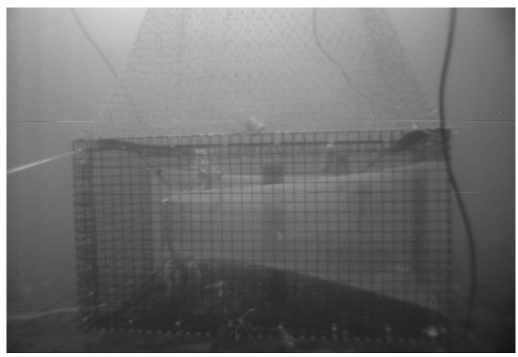

Figure 1: Underwater view of Newfoundland-style pot.

Ten pots each of the static Newfoundland and floating Norwegian design were set singly in pairs for periods within each of eight months: December 2008-June 2009 and November 2009. The Newfoundland design (NF) cod pots were all pyramidal when fishing and were constructed in three ways: two are approximately 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 (Table 1). The third type is 1.8 m x 1.8 m x 1 m and made from polyvinyl-coated wire 50 mm square mesh (Figure 1). All three have netting

Design	Norwegian floating	Newfoundland static
Overall dimensions (m) and volume (m^3)	1.12 x 0.51 x 1.35; 0.77	2 x 2 x 1 or 1.8 x 1.8 x 1; 5.3
Chambers	2	1
Entrances	one entry 25 x 15 cm and one 90 cm between chambers	two 40 cm dia circular rings with netting funnels of 63.5 mm mesh with one-way triggers
Construction	three 2 cm dia PVC frames with added internal steel in the bottom frame and flotation (11 gillnet floats) in the top frame	13-19 mm mild steel frame with netting or PVC coated wire (50 mm squares), both with 30 meshes of 100 mm mesh plus float
Body mesh size (mm)	black 50 mm (body) white 50 mm (entrances)	green 100 mm plus pyramid of 30 M of 100 mm diamond mesh

Table 1: Construction characteristics of cod pots.

attached at the top: 30 meshes of 100 mm diamond mesh with a float that creates the pyramid of netting on top. (All mesh measurements are nominal knot-to-knot mesh openings.) Each pot has two entrances on opposite sides with 40 cm diameter circular rings and netting funnels. The pots sit on the sea floor and are intended to be static. Previous research 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; Table 1) pots are collapsible two-chamber rectangular pots made of netting, with a single bridle attached to an anchor (>5 kg links of chain) 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 diameter PVC electrical conduit, with 13 cm radius corners, glued with cement. The frame sizes were 1.12 m x 0.51 m x 1.35 m. After several months, observations of cracking and catches of lobsters suggested that pots were not floating. A tank investigation confirmed this problem. The upper frames were then deliberately perforated and 11 deep-water gillnet floats were added to each pot. Measurements from the tank investigation were 3 m to the top of the pot; the bottom of the pot was 1.5 m off-bottom.

Locally caught clams, shelled and frozen, shown to be preferred by cod in a prior study [Pol et al., 2008], were used for bait during the entire experiment. Bait was purchased in one lot, and maintained in a commercial bait freezer for the duration of the experiment. Quantities were defrosted prior to setting of the pots. Bait was presented in perforated cups

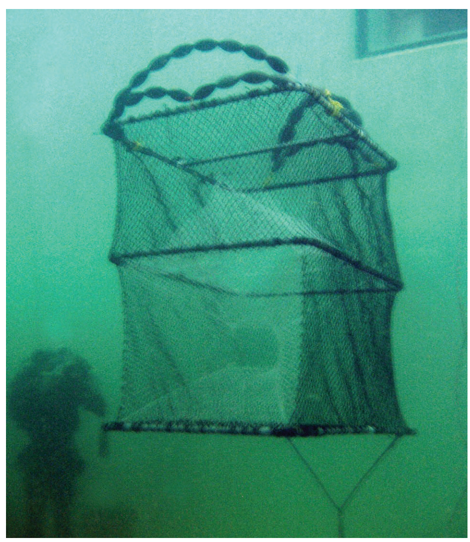

Figure 2: Underwater view of a Norwegian-style pot.

and unprotected on skewers and in 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, bottom topography, 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 deep with dramatic localized relief [Butman et al., 2007]. Depth generally increases with distance from shore. Current is theorized to be uniform throughout the water column, and is mainly influenced by tides, with some effect from wind. In each tidal cycle, the current rotates 360° (C. Chen, School for Marine Science and Technology, University of Massachusetts, personal communication).

Catch was identified, weighed, and measured. Operational and biological data were collected, including catch composition and weights for all species, lengths for Atlantic cod, set and haul times and locations, pot type, 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], especially the package lattice [Sarkar, 2009].

Holst and Revill [2009] described an implementation of generalized 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, 2nd order, and 3rd order relationships of length) were tested, each using pair as a random effect. The penalized 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 test, was used [Holst and Revill, 2009].

Additionally, we attempted to conduct at least one filming session each month to observe fish behaviour in the vicinity of the 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, with 377 pot-hauls considered valid for analysis. Pairs where no cod were caught in either pot were removed for cod catch analysis, resulting in 114 pairs where at least one cod was caught. Pots were set in an area of approximately 16 sq. km. (Figure 3), inside waters of the Commonwealth of Massachusetts.

Monthly median soak durations (h) typically ranged from 22.5-24.8, with longer durations in December 2008 (median = 43.8) due to weather (Figure 4). Median monthly bottom temperatures (°C) ranged from 3.1 (February 2009) to 10.0 (November 2009); within month temperatures did not vary more than one

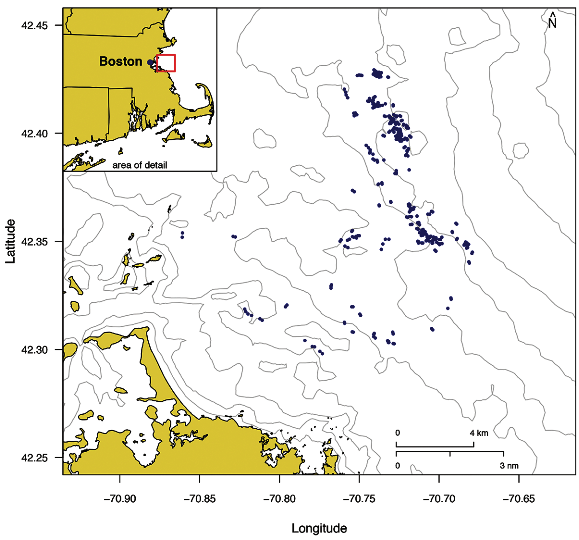

Figure 3: Study area showing all pot-haul locations for the entire study (blue dots) with bathymetry at 5 m intervals.

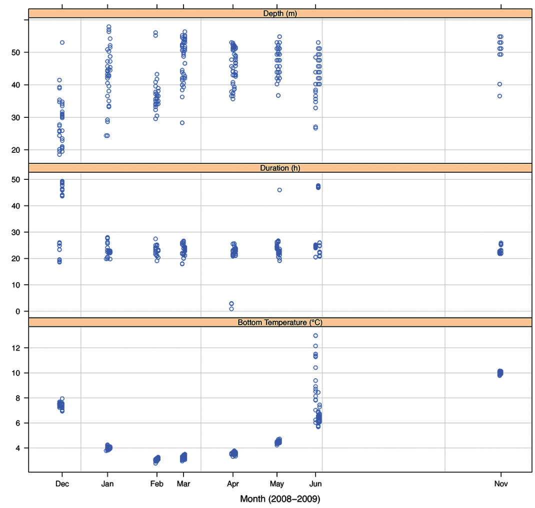

Figure 4: Boxplots of depth (m), soak duration (h), and bottom temperature (°C) for all pot-hauls.

Species		Pot Type	
		Norwegian	Newfoundland
Atlantic cod	*Gadus morhua*	231	184
Cunner (Yellow perch)	*Tautogolabrus adspersus*	79	3
Pollock	*Pollachius virens*	69	2
American lobster	*Homarus americanus*	45	10
Spiny dogfish	*Squalus acanthias*	16	
Jonah crab	*Cancer borealis*	13	4
Red hake (Ling)	*Urophycis chuss*	7	1
Rock crab	*Cancer irroratus*	4	
Sea raven	*Hemitripterus americanus*	2	5
Ocean pout	*Macrozoarces americanus*	2	2
Atlantic herring	*Clupea harengus*	2	
Redfish (Ocean perch)	*Sebastes sp*	1	1
Cusk	*Brosme brosme*	1	
Lumpfish	*Cyclopterus lumpus*	1	
Northern stone crab	*Lithodes maja*		5
Winter flounder (Blackback)	*Pseudopleuronectes americanus*		1

Table 2: Counts of all species caught in pots, separated by design.

degree, except in June, when seasonal turnover occurred (Figure 4). Median depth fished (m) ranged from 27.5 to 50.6.

Catches consisted of 16 species (Table 2) with Atlantic cod, cunner *Tautoglabrus adspersus*, pollock *Pollachius virens*, and lobster *Homarus americanus* the primary catches, predominately in the NO pots. Catches of lobster in NO pots were dramatically reduced after modification of flotation.

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

Norwegian pots frequently caught more cod than the Newfoundland designs in the paired comparisons, as evidenced by equal catch plots (Figure 5); however, in some months,

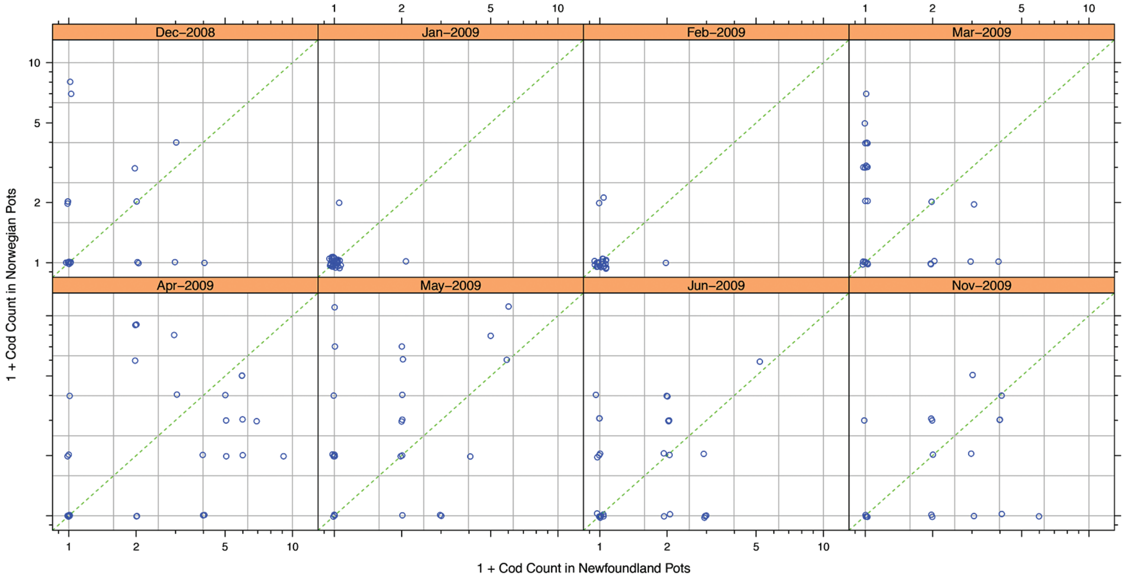

Figure 5: Equal catch plots of counts of Atlantic cod in paired pot-hauls of Newfoundland and Norwegian-style pots, by month. The green diagonal line is the line of equal catch.

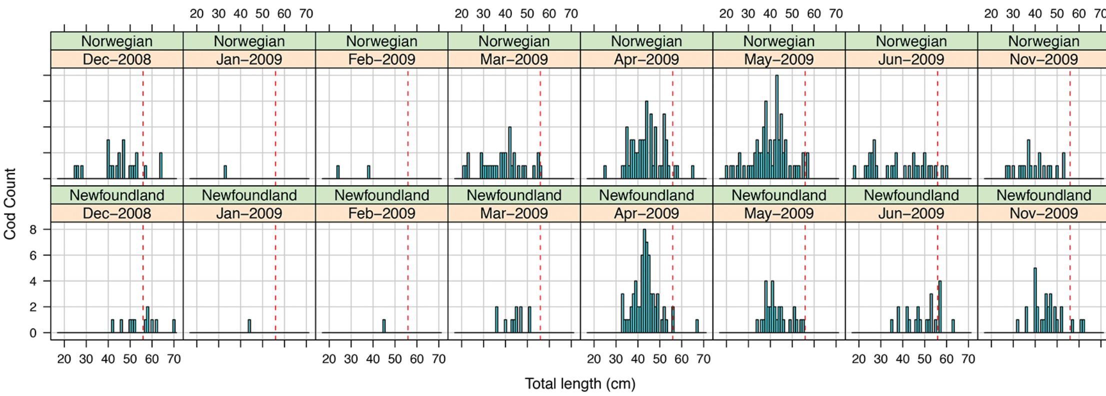

Figure 6: Length frequencies of counts of Atlantic cod lengths captured in two pot designs (Norwegian: top row; Newfoundland: bottom row) and by month (columns). The red dashed line indicated minimum landing size in the region at the time of the study (55.9 cm).

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. Few cod above legal size were caught in any month (Figure 6). Only 28 fish above the MLS at that time of 55.9 cm were caught in total.

GLMM analysis confirmed that Norwegian pots caught more small fish. 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 (Figure 7). The model was a good fit to the observed proportions and indicated 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 (55.9 cm), variability increased due to small amounts of cod above this size.

Filming of cod behaviour 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.

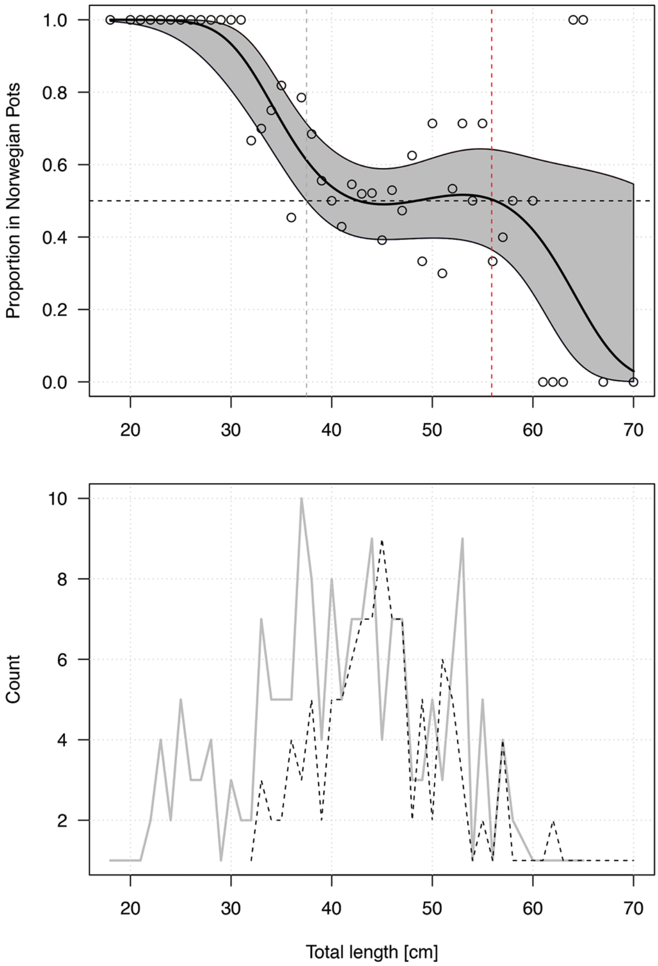

Figure 7: (top panel) Observations, GLMM and associated confidence regions (shaded in grey) for proportion of cod in Norwegian pots for each length caught in both designs. The horizontal dashed line at 0.5 defines equal performance of both designs. The red dashed line indicates minimum landing size in the region at the time of the study (55.9 cm). The proportion is significantly different where the confidence region does not intersect the 0.5 line, marked by the vertical grey dashed line. (bottom panel) Observed length frequencies of cod caught in Norwegian floating pots (solid grey line) and Newfoundland static pots (dashed line).

DISCUSSION

We sought to measure seasonal variation in cod catches in pots. Availability, vulnerability, or presence of cod varied dramatically over the course of the study with the lowest catches in the mid-winter period of January and February. While cold temperatures can change the effective area of a pot by reducing the swimming and searching ability of a fish [He and Pol, 2010], low catches did not appear to be directly related to bottom temperature, as temperatures were similar in these months and months with higher catches. The largest catches were in April and May. The observed seasonality of these catches reinforced traditional knowledge and observation of cod on the grounds, but do not coincide exactly with times of higher longline or gillnet catches. 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. One year's evidence is not sufficient to be conclusive, but based on our results, future testing 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. However, the current poor condition of the local cod populations is likely to hinder further development. In 2013, the spawning stock biomass of cod had declined to 4% of the target for maximum sustainable yield [NOAA, 2014], a record low in the fishery, and the commercial quota of cod was reduced to 207 mt [NOAA, 2015].

The efficiency of the two pot designs showed length-related differences in cod. It is likely the smaller mesh size of the NO pot hindered escape of smaller cod (<38 cm) from the NO design. In other studies of cod pots, larger meshes in floating pots led to retention of fewer small cod [Ovegård et al., 2011; Königson et al., 2015]. It is not exactly clear, however, when cod might escape through pot meshes. 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 size selection in pots occurs during the hauling process. In NF pots, the pyramid top trails behind the rest of gear during hauling thus potentially creating a "codend effect" as in a trawl net where cod escape if they can swim or squeeze through the meshes. Adjustment of mesh size in the pyramid top may be used to select for a desired fish size as the mesh top 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 in video footage exiting between trigger fingers [Pol and Walsh, 2005]. Further investigation of fish behaviour and escape from pots is needed to understand the timing and location of entry and escape and will lead to modifications of the pots for optimal retention.

The alignment of plume and entrance by rotation with the current by the floating NO-style pots was anticipated to lead to much greater catches of all sizes of cod. The observed greater catches of small cod between designs may have been caused by the plume-entrance alignment, if ontogenetic differences affect hunger status, search ability, or risk-taking. The age of fish with a length around 38 cm for this stock area is approximately three years old [Collette and Klein-MacPhee, 2002]. Those fish and smaller sizes may more actively search for or react to bait plumes (i.e., have a greater feeding motivation), and thus are more vulnerable to the gear. On the other hand, it is also possible that the circulation patterns in the study area negate any effect of the plume-entrance alignment by rotating 360° every 24 hours, and thus plume-entrance orientation is of minor importance. More information on high resolution circulation patterns is needed to further evaluate this possibility.

The pots were equally efficient for a mid-size range of fish. For fish above the MLS at the time (55.9 cm), they were also apparently equally efficient, but the uncertainty in the results is much higher due to small sample size. The equal efficiency occurred in spite of a large difference in volumes between pot designs (nearly 700%). Larger pot volumes are linked to higher catch rates [Pol et al., 2010], possibly due to higher retention rates. Further, concern over the apparent size of the pot entrances in the NO design led to the thought that the smaller NO design would catch fewer large fish. While our results suggest that volume is not a barrier to large catches, volume is confounded with too many other factors in this study to determine its individual effect; results are also 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 jigging and the echo sounder suggested); 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 – perhaps escape was easier for larger fish. Further investigation of these possibilities is not equally possible, as the in-situ population structure and behavioural motivations are difficult to assess, and populations in the region are currently low. Potentially, testing of modifications to entrances and other aspects of design will be possible when populations recover, as times of high vulnerability can now be suggested. A recent reduction in minimum landing size to 48.3 cm could theoretically improve the profitability of the current designs, but low densities of cod counteract this effect.

The species-selectivity of pots was somewhat confirmed by our results. Species other than cod were rare in the static design, perhaps aided by the larger mesh size in the body of the pot. Higher levels of by-catch in floating pots were likely due to both smaller mesh size and to ineffective flotation, which was resolved during the testing; by-catch was reduced following the modification. It was fortunate that non-targeted species caught and discarded were from populations in good condition. Escape by passage through meshes, with possible injury, or from barotrauma if escape occurs during hauling, may negate some of the positive aspects of pots. Further investigation of escape timing is warranted.

The NO design pot has many practical advantages, mostly related to their smaller size. Many more of them can be transported on a vessel and no specialized handling equipment (such as additional booms or blocks) is necessary for many static gear fishermen. Some improvement to the adapted design tested in this study is suggested, including separating the functions of frame structure and flotation so that damage to the structure does not affect flotation. Addition of an escape panel of appropriate size to retain the current MLS could reduce discarding of cod. The NO design as is does appear to be practical for scientists and others wishing to sample sublegal sized cod for tagging, broodstock, or other purposes. Low efficiency for legal-sized fish may at first impede commercial uptake, as historically has been the case [Valdemarsen et al., 1977]. However, low efficiency need not be a barrier to commercial practicality. For comparison, the number of kept lobsters per pot-haul in the highly-successful local lobster pot fishery is less than 0.5 (DMF, unpublished data). If a cod pot fishery was scaled to the 600 pots or so allowed in the lobster pot fishery, commercial viability might be achieved. We would further anticipate fishermen would improve the design over time and use. The issue of large animal entanglement in buoy lines suggests the best pathway for commercial adoption may be as replacement for other, less desirable static gears, such as gillnets.

The information from this study may be used to improve catch per unit effort (CPUE) by concentrating effort in the appropriate season when cod appear vulnerable to pots. Königson et al. [2015] were able to exceed CPUE compared to standard commercial gears with the same design as the NO pots by determining the optimal seasons for potting. CPUE may also be improved through the use of lights or other visual stimuli. Bryhn et al. [2014] increased the CPUE of legal-sized cod by attaching green lights to NO-style pots.

Observation of 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. Future attempts to record cod behaviour in-situ should be the central focus of a study, so that adequate time and resources can be available to collect useful observations. Behavioural observations will lead to modifications that would improve pot design for optimal retention.

Interest in cod potting appears to remain high. Our comparison of the two pot designs indicates they are largely similar for catches above 38 cm for cod, while the NO pots are logistically easier to handle and more can be deployed from smaller vessels. In Massachusetts Bay, cod were most vulnerable to pots in April and May; further refinement of pot design to improve efficiency should be conducted at that time, once populations recover.

ACKNOWLEDGMENTS

We dedicate this manuscript to Capt. Robert Marcella, who passed away during the conduct of the research. His loss is still keenly felt. We are grateful to Capt. Chad Mahoney for filling in for Capt. Marcella, and to the hard-working crews of both vessels. We thank David Chosid of the Massachusetts Division of Marine Fisheries; University of Massachusetts School for Marine Science and Technology students and staff, especially David Martins, John Loehrke, and Lisa Kerr; and James Knott of Riverdale Mills, Inc. Capt. Kelo Pinkham modified the NO design and constructed the pots. Dr. Antonello Sala of the Italian National Research Council's Institute of Marine Sciences assisted with GLMM modelling. Funding for this work was provided by the Northeast Consortium. Support for Pol and Szymanski was partially provided by National Marine Fisheries Service Atlantic Coastal Act funds. Input from reviewers greatly improved the manuscript. Contribution No. 72 from the Massachusetts Division of Marine Fisheries.

REFERENCES

Bjordal, Å. [2002]. *The use of technical measures in responsible fisheries: regulation of fishing gear*. In K. Cochrane (Ed.), A Fishery Manager's Guidebook – Management Measures and their Application. FAO Fisheries Technical Paper 424, pp. 21-48. Rome, Italy.

Bryhn, A.C.; Königson, S.J.; Lunneryd, S.-G.; and Bergenius, M.A.J. [2014]. *Green lamps as visual stimuli affect the catch efficiency of floating cod* (*Gadus morhua*) *pots in the Baltic Sea*. Fisheries Research, Vol. 157, pp. 187-192.

Butman, B.; Valentine, P.C.; Middleton, T.J.; and Danforth, W.W. [2007]. *A GIS library of multibeam data for Massachusetts Bay and the Stellwagen Bank National Marine Sanctuary, Offshore of Boston, Massachusetts*. U.S. Geological Survey Data Series 99, DVD-ROM. Also available online at http://pubs.usgs.gov/ds/99/.

Collette, B.B. and Klein-MacPhee, G. (Eds.). [2002]. *Bigelow and Schroeder's fishes of the Gulf of Maine*, 3rd edition. Washington, DC: Smithsonian Institution Press.

Dean, M.J.; Hoffman, W.S.; and Armstrong, M.P. [2012]. *Disruption of an Atlantic cod spawning aggregation resulting from the opening of a directed gill-net fishery*. North American Journal of Fisheries Management, Vol. 32, pp. 124-134.

Fryer, R.J. [1991]. *A model of between-haul variation in selectivity*. Journal of Marine Science, Vol. 49, pp. 281-290.

Furevik, D.; Humborstad, O-B.; Jørgensen, T.; and Løkkeborg, S. [2008]. *Floated fish pot eliminates bycatch of red king crab and maintains target catch of cod*. Fisheries Research, Vol. 92, pp. 23-27.

He, P. and Pol, M. [2010]. *Fish behavior near gillnets: capture processes and influencing factors*. In P. He (Ed.), Behavior of Marine Fish: Capture Processes and Conservation Challenges, pp. 183-204. Ames, Iowa: Wiley-Blackwell.

Holst, R. and Revill, A. [2009]. *A simple statistical method for catch comparison studies*. Fisheries Research, Vol. 95, pp. 254-259.

ICES [2006]. *Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB)*, April 3-7, 2006, Izmir, Turkey. ICES CM 2006/FTC:06, Ref. ACFM. 180 pp.

ICES [2009]. *Report of the Study Group on the Development of Fish Pots for Commercial Fisheries and Survey Purposes (SGPOT)*, May 16-17, 2009, Ancona, Italy. ICES CM 2009/FTC:10. 13 pp.

Königson, S.J.; Fredriksson, R.E.; Lunneryd, S.-G.; Stromberg, P.; and Bergstrom, U.M. [2015]. *Cod pots in a Baltic fishery: are they efficient and what affects their efficiency?* ICES Journal of Marine Science, Vol. 72, pp. 1545-1554.

Laevastu, T. and Favorite, F. [1988]. *Fishing and stock fluctuations*. Fishing News Books, Ltd., Farnlaw, Surrey, England.

NOAA [2014]. *Gulf of Maine Atlantic Cod: 2014 Assessment Update Report*. Woods Hole, Massachusetts. Retrieved from: www.nefsc.noaa.gov/saw/cod/pdfs/GoM_cod_2014_update_20140822.pdf.

NOAA [2015]. *Northeast Multispecies (Groundfish) Fishing Year 2015 Regulations*. NOAA Fisheries, Greater Atlantic Regional Fisheries Office. Retrieved from: www.greateratlantic.fisheries.noaa.gov/nr/2015/April/15mulfw53phl.pdf.

Ovegård, M.; Königson, S.; Persson, A.; and Lunneryd, S.-G. [2011]. *Size selective capture of Atlantic cod* (*Gadus morhua*) *in floating pots*. Fisheries Research, Vol. 107, pp. 239-244.

Pol, M. and Walsh, P. [2005]. *Cod potting in Massachusetts*. In M. Pol (Ed.), Fishermen Assisting Gear Technologists and Scientists, pp. 15-18. Final report submitted to the Northeast Consortium. Retrieved from: www.northeastconsortium.org.

Pol, M.V.; Correia, S.J.; MacKinnon, R.; and Carver, J. [2008]. *Longlining haddock with manufactured bait to reduce catch of Atlantic cod in a conservation zone*. Fisheries Research, Vol. 94, pp. 199-205.

Pol, M.; He, P.; and Winger, P. [2010]. *Proceedings of the International Technical Workshop on Gadoid Capture by Pots (GACAPOT)*. Massachusetts Division of Marine Fisheries Technical Report Series TR-40. Gloucester, Massachusetts, USA.

R Development Core Team [2009]. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. Retrieved from: www.R-project.org.

Rihan, D. [2010]. *Measures to reduce interactions of marine megafauna with fishing operations*. In He, P. (Ed.), Behavior of Marine Fishes: Capture Processes and Conservation Challenges, pp. 315-341. Ames, Iowa: Wiley-Blackwell.

Sarkar, D. [2009]. *Lattice: Lattice Graphics*. R package version 0.17-26. Retrieved from: http://CRAN.R-project.org/package=lattice.

Suuronen, P.; Chopin, F.; Glass, C.; Løkkeborg, S.; Matsushita, Y.; Queirolo, D.; and Rihan, D. [2012]. *Low impact and fuel efficient fishing – looking beyond the horizon*. Fisheries Research, Vol. 119, pp. 135-146.

Thomsen, B.; Humborstad, O-B.; and Furevik, D. [2010]. *Fish pots: fish behavior, capture processes, and conservation issues*. In P. He (Ed.), Behavior of Marine Fishes: Capture Processes and Conservation Challenges, pp. 143-158. Ames, Iowa: Wiley-Blackwell.

Valdemarsen, J.W.; Fernö, A.; and Johannessen, A. [1977]. *Studies on the behaviour of some gadoid species in relation to traps*. ICES CM, B:42, 9.