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Selectivity and retention of pollock *Pollachius virens* in a Gulf of Maine trawl fishery

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Measuring the size selectivity of pollock, or saithe, *Pollachius virens*, has been challenging due to the patchy, elusive nature of the species. By using data collected opportunistically during a redfish *Sebastes fasciatus* selectivity study, selectivity of three sizes of mesh opening (114, 140 and 165 mm double 5 mm twine diamond) for pollock was determined using a commercial fishing vessel fishing off Provincetown, Massachusetts, USA. Fifty-six tows were completed in March and April 2013; 21 included sufficient catches of pollock to estimate size selectivity. Robust, simple models for the mean L50s (50% selection length) and SR (selection ranges), and confidence intervals, were developed for all three tested codends, incorporating both within and between haul variability. Selection parameters and selection ranges were determined for codends with nominal mesh sizes of 114 mm (L50: 34.8 cm; SR: 2.4 cm), 139 mm (L50: 45.6 cm; SR: 3.1 cm), and 165 mm (L50: 52.4 cm; SR: 3.6 cm). All measures of model validity were positive, indicating robust and reliable findings that can be used to provide guidance to fishery managers, stock assessment scientists, and fishermen on size-dependent retention of pollock by codend mesh size.

1. Introduction

Pollock, or saithe, *Pollachius virens*, is an important commercial and sport fish along continental margins throughout the North Atlantic (Robins and Ray 1986; Collette and Klein-MacPhee 2002; Mayo et al., 1989). It is a fast and efficient swimmer, capable of sustained swimming speeds of 0.89 m per second (He and Wardle, 1988; Collette and Klein-MacPhee 2002). They are patchily distributed, and notably active and elusive, often using the entire water column (Collette and Klein-MacPhee 2002). The elusiveness of this species is belied by the occurrence of directed fisheries — typically, pollock is a welcome bycatch during multispecies fisheries, and not a target (Mayo et al., 1989). But, targeted fisheries for this species do occur in the North Sea (Holley and Marchal 2004). A targeted fishery also briefly existed in the Gulf of Maine, USA during the 1980's (Mayo et al., 1989).

The elusiveness, activity and patchy distribution of the species has apparently hindered the conduct of mesh selectivity studies — our search of the literature revealed only a handful of attempts to quantify size selectivity for pollock, and most of these studies were "gray" literature and/or suffered from inadequate numbers of fish. In one particular example, a gillnet mesh selectivity analysis for pollock was completed opportunistically during a haddock gillnet mesh study (Marciano et al., 2006).

No pollock trawl selectivity results were found for the range of sizes most relevant to current fisheries in the Gulf of Maine and Georges Bank. DeAlteris and Chosid (2008) tested trawl codend mesh sizes of 165 mm square and diamond, and even larger diamond and square meshes of 178 and 203 mm in the region. Smolowitz (1983) used both a covered codend and alternate hauls to test a 138 mm diamond mesh codend, among other sizes, on nearby Georges Bank. Dahm (1998) (reported in Halliday et al., 1999) tested 121 mm diamond using a covered codend in European waters.

Pollock is one of three groundfish species in the Northeast United States with Annual Catch Limits (ACL) in excess of 10,000 metric tons (Greater Atlantic Regional Fisheries Office, 2014). In 2014, only 38.1 % of the commercial allowable catch limit was caught (Greater Atlantic Regional Fisheries Office, 2014). The biomass of the population exceeds target levels and the exploitation rate is at a sustainable level (Mayo and Terceiro 2005).

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Therefore, this stock offers an opportunity for continued and increased exploitation.

Our goal was to develop length retention curves for pollock to advise and to inform fishing industry members, fishery managers, and assessment biologists of appropriate mesh sizes to harvest and manage this species while maintaining and sustaining the health of this stock. Working in collaboration with the fishing industry and other interested parties, three candidate mesh sizes were tested: 114, 140, and 165 mm. This size range was chosen for relevance in the Acadian redfish fishery in which pollock is taken as a welcome bycatch. The tested sizes include the mandated minimum and two sizes at equal increments below that size that represent candidate mesh sizes for a regulatory exemption. The mesh selectivity data and analysis of this paper is a result of opportunistic capture of pollock during a redfish mesh selectivity study (see Pol et al., 2015; this volume). For this paper, we summarize only those tows where pollock was captured in sufficient numbers for size selectivity analysis.

2. Materials and methods

The fishing gear, codends, fishing operation and sampling are the same as described in Pol et al. (2015; this volume) in which detailed descriptions are provided. Some key elements are summarized for completeness.

2.1. Fishing vessel and gear

Sea trials were carried out on board F/V Guardian (25 m LOA; 425HP), a commercial groundfish trawler based in Boston, MA, USA. The trouser trawl method was used for the experiment; a small mesh control codend was attached to one leg of the trouser, and an experimental codend to the other leg. The trouser trawl method is considered one of the accepted methods for conducting selectivity studies for towed gears by the International Council for the Exploration of Sea (Wileman et al., 1996). The vessel provided a balloon trawl front end (ground gear, wings, and net mouth) to be attached to a "trouser trawl" section. The headline of the trawl was 33.4 m in length with 100 floats 20.3 cm in diameter. The footrope was 42.5 m in length and attached to 30 cm diameter rockhopper groundgear. The front end of the net had 152 mm diamond mesh constructed of 4.0 mm diameter braided PE twine. The fishing circle was 190 meshes across the bottom panel and 240 meshes across the top.

The trouser section of the trawl was constructed of 152 mm diamond mesh, 3.6 mm diameter braided PE twine. It was designed with a 47.5 meshes deep common "mixing area" that was then separated uniformly into two lateral equal circumference legs (130 meshes across the bottom; 161 meshes across the top). One leg of the trouser trawl was longer by 25 meshes of double 4 mm 165 mm mesh to avoid contact or inhibition of escape by one codend by the other.

Mesh openings in the codends were measured prior to and after the experiment using an ICES OMEGA mesh gauge and associated protocols (Fonteyne, 2005). The number of meshes for each test codend and the control codend were adjusted so that the same diameter and overall length were maintained for all codends. The control codend was constructed of double 4 mm diamond shaped twine with a nominal mesh size of 64 mm, and was 125 meshes long and 125.5 meshes around. The test codends (114, 140, and 165 mm nominal) were all constructed of diamond double 5 mm, and were 70, 60, and 50 meshes long and 70.5, 60.5, and 50.5 meshes around, respectively. The actual mean mesh sizes taken before and after the experiments were 65.6 mm, 108.4 mm, 141.9 mm and 163.2 mm for the codends of nominal mesh sizes of 64 mm, 114 mm, 140 mm, and 165 mm, respectively. A test codend was attached to one leg of the trouser trawl and the control codend was attached to the other side. The side of the test and control codends was switched regularly to avoid possible side-based effects, including the effect of the longer leg of the trouser trawl, described above. The same test codend was used for approximately three days before switching to another codend with a new mesh size.

Tow locations were based on the captain's knowledge of locations of Acadian redfish, echo sounder signals (including bottom topography), and a mix of redfish sizes. Tows were only made in daylight hours following the practice of the redfish fishery. Control of tow durations was not necessary for valid comparisons, and varied based on the captain's assessment of the volume of fish in the net and fishing ground conditions, as consistent with commercial practice. Very large catches were avoided if possible to reduce catch handling time and maximize the number of tows.

The length of warp used was set by the captain based on the water depth and the bottom topography of the tow track. The range of tow speed was restricted to within normal operational conditions for Acadian redfish.

2.2. Gear monitoring

A GoPro Hero2 high-definition camera (San Mateo, CA) with a deepwater underwater housing and lights (Sartek Industries, Port Jefferson, NY) was mounted to view fish behavior in the mixing area during some tows. Lights were pointed aft to minimize effects on fish behavior. Net geometry was measured using a trawl monitoring system (Notus Electronics, St. John's, Newfoundland) with sensors on both doors, the trawl's wing ends, just behind the headrope, and on the control codend. The sensors were set to provide bottom temperature, door spread, door heel (angle of the door to the right or left of the direction of travel), wing spread and to indicate when the control codend was full. In addition, these sensors provided distance from the sensor to a towed hydrophone. Bottom temperature was also recorded with calibrated TidBit temperature recorders (Onset Computers Inc., Pocasset, Massachusetts).

2.3. Catch sampling

Codends were hauled on deck one at a time, with the codend attached to the shorter "leg" hauled and emptied first. Catches from the experimental and control codends were deposited in separate areas on deck, and processed separately.

Catch by species was weighed to 0.1 kg with subsampling when there was a large amount of catch. Lengths (measured as midline length, MLL) of a random subsample of more than 100 pollock (if possible) from each codend from each tow were measured to the nearest cm. For length-frequency (LF) analysis, counts at each length were multiplied by the subsample weight divided into the total weight.

Other organisms were also identified, and weighed to the nearest 0.1 kg. Weights were directly measured or quantitatively determined; for example, by basket counts.

2.4. Analysis

All catch data (along with trip and gear data) were entered and uploaded into a customized relational database in Microsoft Access 2007 and were analyzed using Microsoft Excel and R statistical software (R Development Core Team, 2009), primarily using the lattice package (Sarkar, 2009) and SELNET. SELNET was developed to acquire and analyze size selectivity and catch data for towed fishing gears, both at the haul level and for a group of hauls (Frandsen et al., 2010; Herrmann et al., 2012; Herrmann et al., 2013). The methods implemented in SELNET comply with accepted recommendations for the analysis of size selectivity data of towed fishing gears (Fryer, 1991; Wileman et al., 1996).

First, a logistic curve described by the parameters L50 (50% selection length) and the SR (selection range) was used to model the size selection (Wileman et al., 1996). For each haul, the number of fish counted at each length l in the experimental codend was described as nt_l, and in the control codend as nc_l. The proportion of the total catch measured for lengths is described by the subsampling rates qt (experimental) and qc (control). The size selection in each haul can then be obtained by minimizing the following function with respect to the parameters L50, SR and SP:

$$-\sum_{l}\left\{nt_l \times \ln\left(\frac{qt \times \varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP})}{qt \times \varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}) + qc \times (1-\varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}))}\right)\right.$$
$$\left.+ nc_l \times \ln\left(\frac{qc \times (1-\varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}))}{qt \times \varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}) + qc \times (1-\varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}))}\right)\right\}$$

With:

$$\varphi(l, \mathrm{L50}, \mathrm{SR}, \mathrm{SP}) = \frac{\mathrm{SP} \times r_{\mathrm{logit}(l, L50, \mathrm{SR})}}{1 - \mathrm{SP} \times (1 - r_{\mathrm{logit}}(l, \mathrm{L50}, \mathrm{SR}))}$$

SP is defined as the split parameter and expresses the assumed length independent relative entry of fish to the test or control side of the trouser trawl during the fishing process. SP needs to be estimated to assess the values of the selection parameters L50 and SR.

Fit statistics (i.e., the p-value and model deviance versus degrees of freedom (DOF)) were inspected for individual hauls (Wileman et al., 1996). Where the p-value < 0.05 or the deviance » DOF, the residuals were examined for patterns or structural problems. Where no pattern was seen, the poor fit was considered overdispersion in the data and the data were included.

Second, between-haul variation was considered (Fryer, 1991) using the results from all the individual hauls simultaneously for the L50, SR and SP, together with their covariance matrix and information on the values of the mesh size, m. In addition, the effect of w (total test codend catch weight, in kg) and S (the side of the trouser trawl the test codend was attached to). Since one codend necessarily stayed in the water longer during haulback, and could potentially lose more fish, we wanted to test whether this longer hauling time might impact size selectivity.

A model considering the potential effect of the parameters m, w and S was constructed with the following form and applied in SELNET.

$$L50 = f_0 + f_1 \times \mathrm{m} + f_2 \times \mathrm{w} + f_3 \times \mathrm{S}$$

$$SR = g_0 + g_1 \times \mathrm{m} + g_2 \times \mathrm{w} + g_3 \times \mathrm{S}$$
$$SP = h_0 + h_1 \times \mathrm{m} + h_2 \times \mathrm{w} + h_3 \times \mathrm{S}$$

The parameters $f_0 \ldots f_3$, $g_0 \ldots g_3$ and $h_0 \ldots h_3$ were estimated while fitting the model to the data with values for L50, SR and SP based on the selectivity results from the individual hauls. Models were selected based on the lowest AIC value (Akaike, 1974), while considering every possible simpler sub-model following the procedure described in Wienbeck et al. (2011) and Herrmann et al. (2013).

Individual haul results were plotted for the L50 and SR with 95% CI versus the mean model estimated values and the predicted 95% CI for the total variation (between-haul variation + uncertainty around the mean). The lower and upper 95% CI for the estimated between-haul variation in the selection parameters (lim L50, lim SR) were calculated by:

$$\mathrm{limL50} = \mathrm{L50_{mean}} \pm 1.96 \times \sqrt{(\mathrm{VarL50_{mean}} + \mathrm{D_{11}})}$$

$$\mathrm{limSR} = \mathrm{SR_{mean}} \pm 1.96 \times \sqrt{(\mathrm{VarSR_{mean}} + \mathrm{D_{22}})}$$
$$\mathrm{limSP} = \mathrm{SP_{mean}} \pm 1.96 \times \sqrt{(\mathrm{VarSP_{mean}} + \mathrm{D_{33}})}$$

where $\mathrm{L50_{mean}}$, $\mathrm{SR_{mean}}$ and $\mathrm{SP_{mean}}$ are the predictions based on the selected submodel and $\mathrm{D_{11}}$, $\mathrm{D_{22}}$ and $\mathrm{D_{33}}$ are the diagonal elements in the estimated between-haulvariation matrix for the selected model (Fryer, 1991).

These plots were inspected to see if the model predictions appeared to reflect the main trends for the effects of catch size on the results for each codend and to see if it was necessary to consider the estimates of the between-haul variation and uncertainty on the means in the selection process in addition to the uncertainty of the haul results. After successful model validation based on the above procedure, the models were applied to predict size selection for codend mesh sizes between 80 and 170 mm.

3. Results

Tows were conducted generally east and northeast of Provincetown, Massachusetts, USA over an area of approximately 3800 nm^2. Fifty-six tows were completed in two trips between 27 March and 1 April, and between 3 April and 8 April, 2013. Twenty-one tows included sufficient numbers of pollock for analysis. Overall, 6 tows were included pairing the 114 mm mesh, with 2 on the starboard side; 8 tows with the 140 mm with 6 on the starboard side; 7 tows with the 165 mm codend with 4 on the starboard side. Only four tows were subsampled for pollock; subsampling fractions ranged from 0.29 to 0.52. Catches of pollock in individual hauls ranged from 0.6 to 437 kg in a codend.

Durations for tows with pollock catches ranged from 0.3 to 1.1 h with a median tow duration of 0.5 h. Median depth fished was 99 fm, ranging from 50 to 117 fm; median towing speed was 3.0 knots (range: 2.9–3.3 kts); median warp length was 225 fm (range: 225–250 fm). Median wave height experienced was 1.2 m with a maximum of 2.4 m; these heights are unlikely to substantially affect net performance as they are within typical commercial operational conditions.

A median headrope height of 4.1 m (Interquartile range (IQR): 3.8–5.1 m, $n = 17$ tows), door spread of 79 m ((IQR): 71–87 m, $n = 15$), and door heel medians of 3.4 degrees (IQR: 0.8–5.5 degrees, $n = 15$) (port) and 5.1 degrees (IQR: 0.9–6.3 degrees, $n = 13$) (starboard) inward were recorded. Median distance to doors was 423 m (IQR: 420–468 m, $n = 15$); to the headrope 556 m (IQR: 554–567 m, $n = 16$); to the codend 603 m (IQR: 598–608 m, $n = 9$) — these distances increased with depth and longer warp length. Based on net geometry, no anomalous tows were identified. Median temperature was 6.9 degrees (IQR: 6.4–7.1 degrees) and did not differ between mesh sizes.

The total catch of all species was just over 47,900 kg, with redfish comprising 42,482.9 kg or 89.7% of all catch. Pollock was the main bycatch species (3390.5 kg), with 21 other species with catches greater than 10 kg total (See Table 2 in Pol et al., 2015, this volume). Over 1800 pollock were measured. Lengths ranged from 18 to 86 cm with distributions differing between codends (Fig. 1).

Twenty-one hauls were included in the pollock size selectivity analyses. Testing of the full model and all simpler models – a total of 4096 models in all – resulted in selection of a sub-model where the L50 and the SR depend only on mesh size, m:

$$\mathrm{L}_{50} = 0.3212 \times m(\mathrm{CI}: 0.3011, 0.3413)$$

$$\mathrm{SR} = 0.0221 \times m(\mathrm{CI}: 0.0120, 0.0322)$$

The model estimate of SP = 0.5359 (CI: 0.4389, 0.6328) was near the ideal value of 0.5 with the 95% confidence interval (CI) overlapping 0.5. Video recordings collected from this area indicated no unusual fish behavior. The side the codend was on (S) and the total weight of the catch (w) were not present in the final model.

Full logistic curves with 95% confidence intervals illustrating the catch curves for the codends as measured were constructed from model results (Fig. 2). L50 (in MLL) and selection ranges

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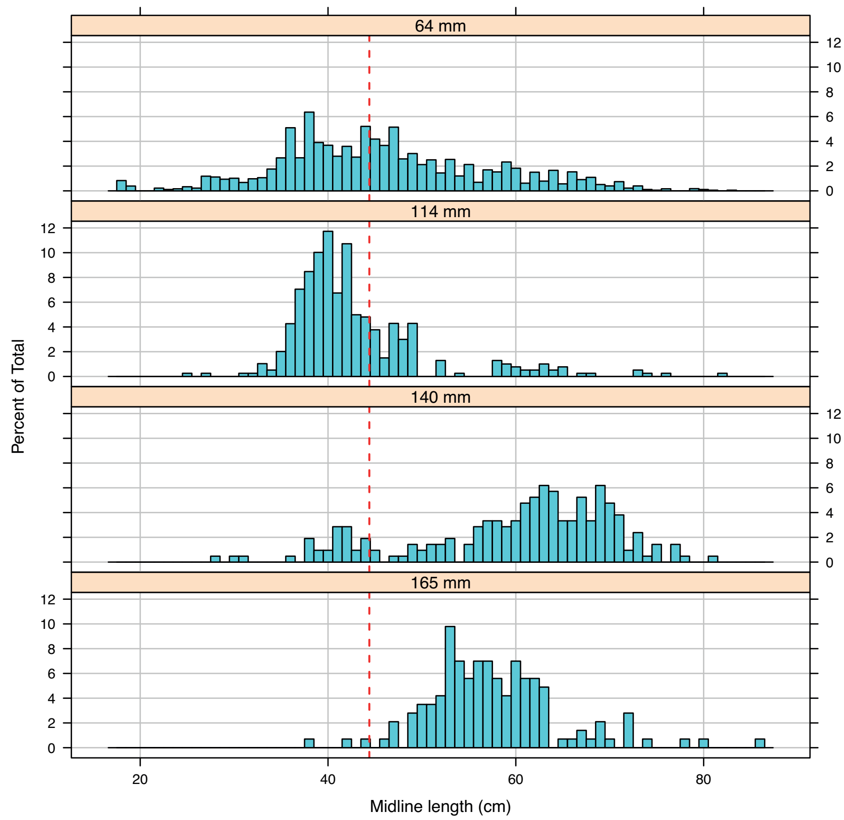

Fig. 1. Pollock length frequencies (cm) by mesh size (mm). Vertical dashed lines mark the minimum landing size, converted to FL using Pol et al. (2011).

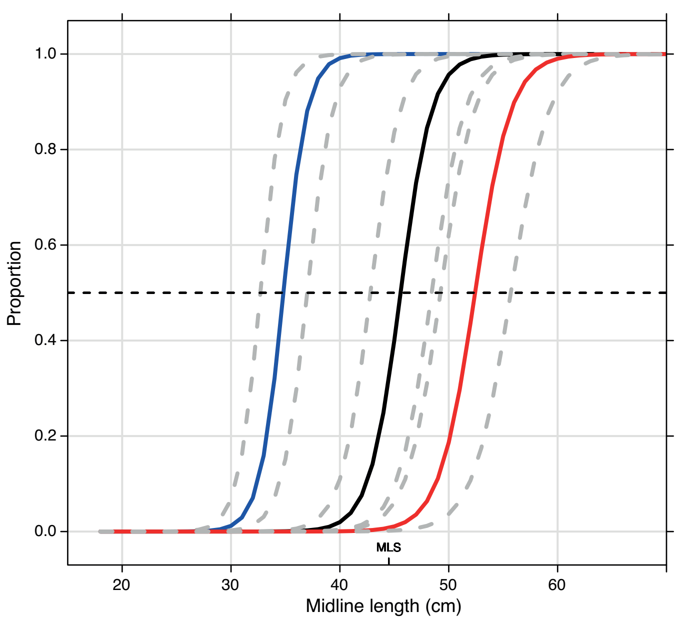

Fig. 2. Selection curves (solid lines) for 114 (left), 140 (center), and 165 (right) mm codends, with 95% confidence bands in dashed lines. MLS converted from TL using Pol et al. (2011).

were determined for codends with nominal mesh sizes of 114 mm (L50: 34.8 cm; SR: 2.4 cm), 139 mm (L50: 45.6 cm; SR: 3.1 cm), and 165 mm (L50: 52.4 cm; SR: 3.6 cm). Further validation of the selectivity model was demonstrated by plotting L50 (Fig. 3) and SR values (not shown)) for each individual haul, with 95% confidence intervals as error bars, along with overall mean values predicted by the final model, against the catch weight of the codend (Fig. 3). Only six hauls were found to have values of L50 outside the 95% CIs; all of these hauls overlapped their error bars with the confidence band indicating that the model is an appropriate fit to the data.

A similar comparison was made for the selection range (not pictured); six individual hauls had SR values outside the overall CI for the mean SR. All of these also had error bars overlapping the CI band. These combined results indicated that the fit of the individual hauls to the overall results were excellent.

Model results were used to produce estimates of mean L50 and SR (Fig. 4) across a broad range of mesh sizes to support the choice of appropriate mesh sizes. Model results can be used to estimate these values for both larger and smaller meshes, but expansion outside the tested range is less reliable and likely unnecessary.

4. Discussion

Testing and analysis of the selectivity of the codends provided robust results with good measures of validation and a simple selection model. These results can be used to identify appropriate codend mesh sizes for sustainable harvesting of the species and for incorporating into stock assessment models and other management measures. While it is not frequently targeted, pollock is a primary bycatch species when targeting Acadian redfish and other groundfish species such as haddock; our results can be incorporated with selectivity results for redfish to anticipate the effects of different choices of codends in the current and any future redfish directed fishery and other groundfish fisheries.

Testing of codends was sequential; that is, for operational reasons, codends were used in blocks, and not randomized or rotated per haul. Geometry, geographical area, weather conditions, depth, and temperature did not vary substantially, limiting uncontrolled sources of variability, and supporting comparability of the codends. Aft-pointing lights in the mixing area did not appear to affect behav-

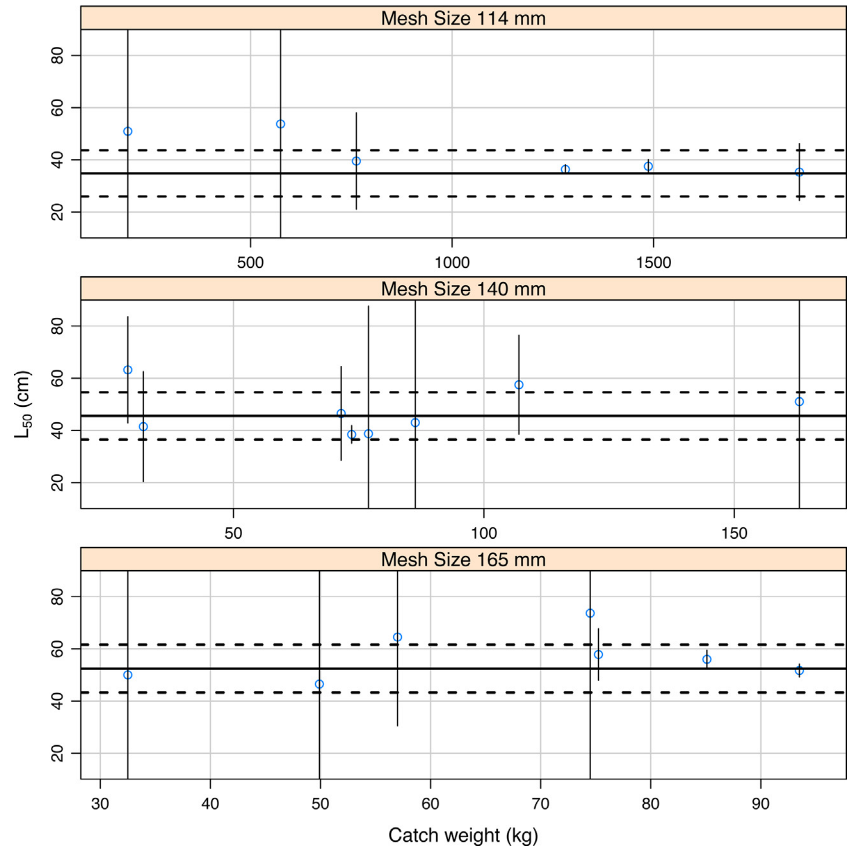

Fig. 3. L50 estimates by mesh size (mm) from individual hauls (circles) with 95% confidence intervals (error bars) compared to modeled mean L50 (solid horizontal line) and 95% confidence intervals (dashed lines), depicted by catch weight (kg).

ior and likely had little or no impact on codend selection. The employment of a trouser trawl, which simultaneously tows a selective test codend and a non-selective codend, helps obtain results that are consistent and accurate within each tow, as the same school of fish is exposed to both codends. And, while the trouser trawl is not used commercially in the fishery studied, the results are likely applicable to commercial gear.

The total catch weight in the codend or which side the codends were attached to were not significant terms in the model. This lack of effect helps demonstrate good functioning of the trouser trawl and randomization of the distribution of fish between the test and control codends. Also, this result suggests that selectivity may not vary greatly across tows. While Wileman et al. (1996) recommended the use of a trouser trawl with a full vertical split, our design avoided a vertical panel (similar to He and Balzano, 2011) to reduce possible deformation or distracting motion in the net and panel. A trouser trawl can avoid deck-handling problems associated with covers, reduces risk of masking of codend meshes, and risk of over-filling the cover. Few difficulties were encountered using the trouser trawl, as the crew was adaptable to the hauling of two codends. Operationally it was not difficult to retrieve and empty two codends in a controlled and safe manner.

The absence of any intercept terms in the L50 and SR provided the logical result that as the mesh size is reduced to zero, the fish length would similarly be reduced to zero. The selection ranges were narrow compared to those found for redfish during the same study (Pol et al., 2015, this volume). The SR coefficient for pollock we determined (0.0221 × mesh size) is notably lower than that found for redfish during the same experiment (0.310 × mesh size) (Pol et al., 2015; this volume). It is reasonably safe to presume, since these results come from the same tows, that mechanical factors such as the opening angles of the meshes or the stiffness of twines were identical during the selection process for both species, and therefore permit comparisons between the results for the two species. Under these conditions, the SR depends only on morphological variation (Herrmann et al., 2009). Thus, the lower SR coefficient (by more than a factor of 10) implies that the escape ability of pollock changes quickly with size. While behavior undoubtedly plays a role in escape ability, girth is more likely the dominating factor. Therefore, the narrow SR illustrates greater uniformity in the length-girth relationship for pollock than for redfish.

Our results were compatible with earlier studies. Using an alternate tow method, DeAlteris and Chosid (2008) found an identical L50 for 165 mm diamond mesh (52.4 cm), but with a SR of 12.33 cm, compared to our SR of 3.6 cm using similar analytical methods. This difference may be explained by the smaller sample size in the earlier study (11 pairs vs. 21 in our study). DeAlteris and Chosid (2008) also tested square mesh of the same dimension, which resulted, as expected, in a much larger L50 (67.6 cm, SR: 7.6 cm). The L50 reported by Smolowitz (1983) for 138 mm diamond mesh using a covered codend on Georges Bank was 45 cm, with a selection factor of 3.26. Our results for the L50 of 140 mm mesh were similar to that study: 45.6 cm and a SR of 3.1 cm. Dahm (1998) reported a L50 of 51.8 for 121 diamond; this size is intermediate to our tested codends, and does not match well with our results, which predict a L50 of 38.9 cm for this mesh size.

The similarity of the L50 across studies further implies that the fish length to girth relationship for pollock is steady. Fish girth can vary due to condition and breeding status, changing the retention probabilities (Wileman et al., 1996; Özbilgin et al., 2006). Additionally, twine type and thickness and other gear parameters may also influence retention probabilities (Wileman et al., 1996). Variation

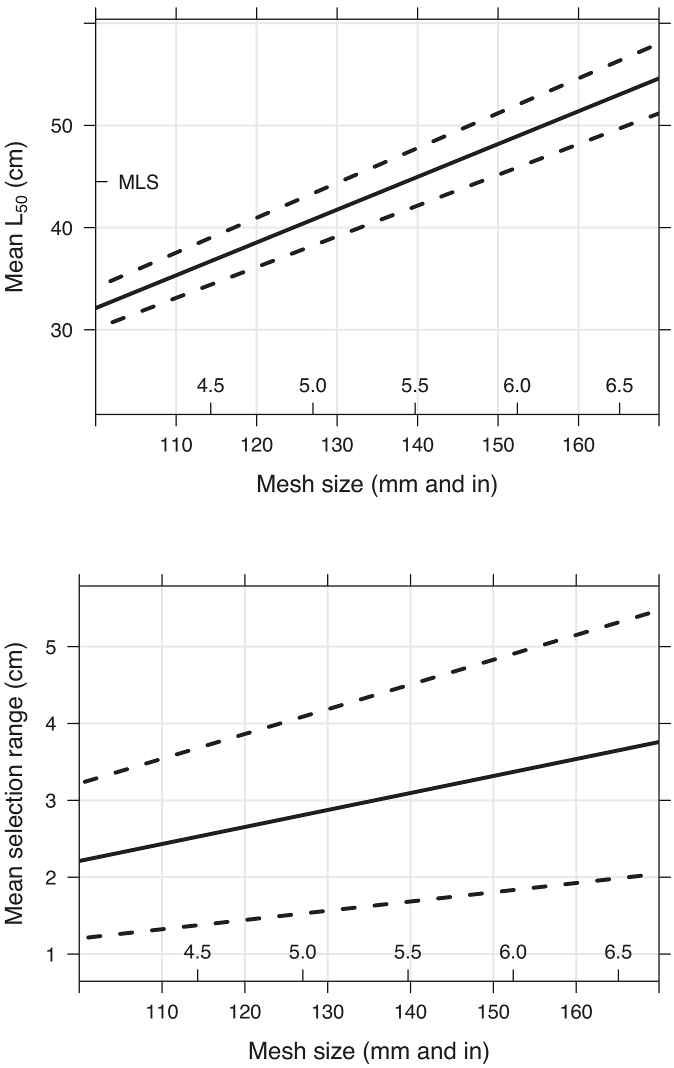

Fig. 4. Predicted mean L50 (top) and SR (bottom) v mesh size for pollock (solid line) with 95% confidence intervals (dashed lines). MLS converted using Pol et al. (2011).

in selection between seasons, gears, weather and other factors is also expected (Pope et al., 1975; DeAlteris and Grogan 1997). However, pollock seems less susceptible to change in the mesh size to length relationship. This stability may also be due to the location on the fish of the maximum girth – for example, rigid structures at this point would lead to less variability in the length-girth relationship. Further studies with pollock could determine the important cross-sections for pollock using the FISHSELECT method (Sistiaga et al., 2011).

The pollock and redfish selectivity models (Pol et al., 2015; this volume) for L50 and SR both rely only on mesh size. This simple relationship can assist in choosing an appropriate mesh size in the Gulf of Maine redfish fishery, where pollock is a primary bycatch species (although below 5% of total catch (Kanwit et al., 2013)). Using the relationship for redfish of L50 = 0.206 × mesh size (Pol et al., 2015; this volume) and for pollock of L50 = 0.3212 × mesh size, we find the L50 for pollock = 1.56 × L50 for redfish. This relationship assists in judging an appropriate mesh size when targeting redfish. (It also indirectly quantifies differences between these two species in body shape: a pollock of 50% retention probability is 1.56 times longer than a redfish of the same retention probability.) For example if a 22.9 cm (9 inch) MLL L50 is desired for redfish, our results allow quick calculation of an L50 of 35.7 cm MLL for pollock. This result highlights an inconsistency in the minimum landing sizes of these two species, as a 22.9 cm redfish is above the MLS of 17.8 TL; however, the predicted L50 for pollock is below the MLS of 48.3 cm TL for pollock. This incongruity highlights one challenge of managing a mixed species fishery. Our results provide valuable information for managing that fishery.

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References

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Auto Control 19, 716–722.

Collette, B., Klein-MacPhee, G., 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, third ed. Smithsonian Institution Press, Washington.

Dahm, E., 1998. Measurements of codend selectivity for North Sea saithe by the covered codend and divided trawl methods. Arch. Fish. Marine Res. 46, 43–59.

DeAlteris, J.T., Chosid, D.M., 2008. Effects of codend mesh size on the multispecies yield and spawning stock biomass in the western Georges Bank trawl fisheries. In: Completion Report. University of Rhode Island.

DeAlteris, J., Grogan, C., 1997. An Analysis of Harvesting Gear Size Selectivity for Eight Demersal Groundfish Species in the Northwest Atlantic Ocean. Fisheries Technical Report #1. University of Rhode Island Fisheries Center, Kingston, RI.

Fonteyne, R., 2005. Protocol for the use of an objective mesh gauge for scientific purposes. ICES Coop. Res. Rep. No. 279.

Frandsen, R.P., Herrmann, B., Madsen, N., 2010. A simulation-based attempt to quantify the morphological component of size selection of Nephrops norvegicus in trawl codends. Fish. Res. 101, 156–167.

Fryer, R., 1991. A model of the between-haul variation in selectivity. ICES J. Mar. Sci. 48, 281–290.

Greater Atlantic Regional Fisheries Office, 2014. Northeast multispecies fishery final year-end results for fishing year 2013. http://www.greateratlantic.fisheries.noaa.gov/aps/monitoring/nemultispecies.html Accessed 12 November 2014.

Halliday, R.G., Cooper, C.G., Fanning, P., Hickey, W.M., Gagnon, P., 1999. Size selection of Atlantic cod, haddock and pollock (saithe) by otter trawls with square and diamond mesh codends of 130–155 mm mesh size. Fish. Res. 41, 255–271.

He, P., Balzano, V., 2011. Rope grid: a new grid design to further reduce finfish bycatch in the Gulf of Maine pink shrimp fishery. Fish. Res. 111, 100–107, http://dx.doi.org/10.1016/j.fishres.2011.07.001

He, P., Wardle, C.S., 1988. Endurance at intermediate swimming speeds of Atlantic mackerel, *Scomber scombrus* L., herring, *Clupea harengus* L., and saithe, *Pollachius virens* L. J. Fish Biol. 33, 255–266.

Herrmann, B., Krag, L.A., Frandsen, R.P., Madsen, N., Lundgren, B., Staehr, K.-J., 2009. Prediction of selectivity from morphological conditions: Methodology and a case study on cod (*Gadus morhua*). Fish. Res. 97, 59–71.

Herrmann, B., Sistiaga, M., Nielsen, K.N., Larsen, R.B., 2012. Understanding the size selectivity of redfish (Sebastes spp.) in North Atlantic trawl codends. J. Northw. Atl. Fish. Sci. 44, 1–13.

Herrmann, B., Wienbeck, H., Moderhak, W., Stepputtis, D., Krag, L., 2013. The influence of twine thickness, twine number and netting orientation on codend selectivity. Fish. Res. 145, 22–36.

Holley, J., Marchal, P., 2004. Fishing strategy development under changing conditions: examples from the French offshore fleet fishing in the North Atlantic. ICES J. Mar. Sci. 61, 1410–1431, http://dx.doi.org/10.1016/j.icesjms.2004.08.010

Kanwit, K., Pol, M., He, P., 2013. REDNET — A network to redevelop a sustainable redfish (*Sebastes fasciatus*) trawl fishery in the Gulf of Maine. In: Component 2 — baseline catch and bycatch evaluation. Report to the Northeast Cooperative Research Partners Program, National Marine Fisheries Service.

Marciano, D., Rosen, S., Pol, M.V., Szymanski, M., 2006. Testing the selectivity of gillnets to target haddock in the Gulf of Maine. Final Report to the NMFS Cooperative Research Partners Initiative.

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Mayo, R.K., McGlade, J.M., Clark, S.H., 1989. Patterns of exploitation and biological status of pollock (*Pollachius virens* L.) in the Scotian Shelf, Georges Bank, and Gulf of Maine Area. J. Northwest Atl. Fish. Sci. 9, 13–36.

Mayo R.K., Terceiro M., Editors, 2005. Assessment of 19 Northeast groundfish stocks through 2004. 2005 Groundfish Assessment Review Meeting (2005 GARM). Northeast Fisheries Science Center, Woods Hole, Massachusetts, 15–19 August 2005. U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc. 05-13; 499 p.

Özbilgin, H., Ferro, R.S.T., Robertson, J.H.B., Holtrop, G., Kynoch, R.J., 2006. Seasonal variation in trawl codend selection of northern North Sea haddock. ICES J. Mar. Sci. 63, 737–748, http://dx.doi.org/10.1016/j.icesjms.2005.01.025

M.V. Pol, B. Herrmann, C. Rillahan, P. He, (submitted). Impact of codend mesh sizes on selectivity and retention of Acadian redfish Sebastes fasciatus in the Gulf of Maine trawl fishery Fish. Res. 2015;.

Pol, M.V., Szymanski, M., Chosid, D.M., Salerno, D.J., 2011. Fork length — total length conversions for haddock and pollock, North Am. J. Fish. Manag 31, 427–430, http://dx.doi.org/10.1080/02755947.2011.590115

Pope, J.A., Margetts, A.R., Hamely, J.M., Akyüz, E.F., 1975. Manual of methods for fish stock assessment, Part III - Selectivity of fishing gear. Rome.

R Development Core Team, 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org

Robins, C.R., Ray, G.C., 1986. A field guide to Atlantic coast fishes. Houghton Mifflin, Boston.

Sarkar, D., 2009. Lattice: Lattice Graphics. R package version 0. 17-26, http://CRAN Rproject.org/package=lattice.

Sistiaga, M., Herrmann, B., Nielsen, K.N., Larsen, R.B., 2011. Understanding limits to cod and haddock separation using size selectivity in a multispecies trawl fishery: an application of FISHSELECT. Can. J. Fish. Aquat. Sci. 68, 927–940, http://dx.doi.org/10.1139/F2011-017

Smolowitz, R.N. 1983. Mesh size and the New England groundfishery — applications and implications. NOAA Tech. Rpt. NMFS SSRF-776. pp. 121.

Wienbeck, H., Herrmann, B., Moderhak, W., Stepputtis, D., 2011. Effect of netting direction and number of meshes around on size selection in the codend for Baltic cod (Gadus morhua). Fish. Res. 109, 80–88.

Wileman, D., Ferro, R.S.T., Fonteyne, R., Millar, R.B., 1996. Manual of methods of measuring the selectivity of towed fishing gears. In: ICES Coop. Res. Rep., pp. No 215.