Commonwealth of Massachusetts
Division of Marine Fisheries
251 Causeway Street, Suite 400
Boston, Massachusetts 02114
(617)626-1520
fax (617)626-1509

Paul J. Diodati
Director

Deval Patrick
Governor
Ian A. Bowles
Secretary
Mary B. Griffin
Commissioner

HadFleet2: Continued Testing of the Five-Point Trawl Net
Final Report

Report Submitted: February 20, 2013

Massachusetts Division of Marine Fisheries
1213 Purchase St., Floor 3
New Bedford, MA 02740
Phone: 508-990-2860
Fax: 508-990-0449

David Chosid
Project Coordinator
Phone: 508-990-2860 x140
Email: david.chosid@state.ma.us

Michael Pol
Conservation Engineering Project Leader
Phone: 508-990-2860 x116
Email: mike.pol@state.ma.us

Mark Szymanski
Project Support
Phone: 508-990-2860 x137
Email: mark.szymanski@state.ma.us

Abstract

The experimental Five-Point Haddock Trawl net was designed to harvest Georges Bank haddock *Melanogrammus aeglefinus* while avoiding a weaker stock of Atlantic cod *Gadus morhua*. This semi-pelagic, sweepless, raised footrope trawl net touches bottom with five drop-chains and exploits the rising behavior of haddock while passing over cod during the herding process. Phase 1 testing (June-July, 2006) by the Massachusetts Division of Marine Fisheries revealed highly significant reductions of cod and variable catches of haddock as compared to a standard bottom trawl net; in Phase 2 (February-March, 2007) the experimental net was tested initially against a separator panel net over various substrate types, on more vessels, and in different seasons. However, two trips resulted in either small catches (from low fish availability) or net stability problems (from incorrect door rigging). We then tested changes in geometry and height off-bottom of the Five-Point Haddock Trawl net during towing (April, 2008). Using cameras mounted on a towed underwater vehicle and net mensuration sensors, we demonstrated that when fished as designed, the experimental net held an overall stable shape and height off-bottom. Continued catch comparisons of the Five-Point Haddock Trawl net and a separator panel trawl were conducted in May, 2009. Conducted analyses included paired non-parametric randomizations and generalized linear mixed models. Haddock, cod, and most flatfish catch results indicate that the experimental net does not perform significantly different than a separator trawl net; yellowtail flounder catch was significantly lower in the experimental net. Based on the strong reductions in Atlantic cod and proven overall stability, this net may be ready for inclusion into regulations for use along with other selective haddock nets.

Purpose

Catch regulations on Georges Bank, based on each stock's status, heavily favor the harvest of haddock *Melanogrammus aeglefinus*, a healthy abundant stock, over weaker stocks such as Atlantic cod *Gadus morhua*. Unfortunately, selection for particular species in a multispecies trawl fishery is often difficult or not possible. Past research in species separation often focused on using separator panels, which are horizontal webbing panels in the forward belly of a trawl net, directing fish to two or more different codends which may have different selectivities to retain catch or allow it to escape. These panels exploit distinctive species behaviors (Atlantic Fisheries Adjustment Program, 1992; Wardle, 1993).

Haddock have been observed to rise in an approaching net while Atlantic cod tend to rise more slowly or remain near the bottom during the herding process (Main and Sangster, 1982; Harris and Carr, 1994; Krag et al. 2009); flatfish also often stay towards the bottom (He, 2003; Chosid et al., 2008). Based on these behaviors, the National Marine Fisheries Service (NMFS) has allowed the additional harvest of haddock within the Eastern U.S./Canada and Haddock Special Access Program (SAP) management areas of Georges Bank, using trawl nets equipped with separator panels or the Ruhle trawl (another specialized gear) to protect weak fish stocks (50 CFR § 648.85, 2006; Beutel et al., 2008). Further areas may become available to new specialized gears under sector management and through regulation exemptions.

Separator panels, however, are complex to specify in legislation and to construct. Also, these panels have been described as difficult to mend and to use at sea. Effective separator trawls may require optimization in a flume tank and adjustment at sea using a net mensuration system and underwater video to perform properly, and even with tuning, the separator panel may restrict necessary flexibility of the net. Further, fuel efficiency is reduced by, essentially, towing a second codend that must remain open and doesn't retain catch.

Interest in refining haddock separator trawl designs has led to several research projects in the region (Winger, 2006). For example, He et al. (2008) used a separator panel with combinations of high contrast areas within the codend extension and horizontal separator ropes within the belly to effectively separate haddock from non-target fish by exploiting different behavioral characteristics.

Semi-pelagic nets, including raised footrope and sweepless designs, have several advantages over separator trawls. Species-specific behaviors can be exploited by constraining the semi-pelagic net opening to a limited vertical range in the water column (Brewer et al., 1996; Pol, 2003). By definition, semi-pelagic trawls have reduced contact with the sea floor as compared to demersal otter trawls (Ramm et al., 1993), and therefore may reduce impacts on the bottom (and groundfish habitats) (Moran and Stephenson, 2000; Løkkeborg, 2005; Packer, 2006). An additional benefit of the semi-pelagic design is a reduction in stress that a standard or separator trawl would otherwise place upon a fish when encountered (Suuronen, 2005). Separator trawls may require fish to reach exhaustion, to negotiate grids, or to pass through escape panels or fisheyes before escaping the gear (Fridman and Milliken, 1996). A semi-pelagic trawl may decrease the likelihood of unobserved escape mortality because bottom-tending fish never actually enter the net but, rather, are passed over by the net with no contact from gear.

The Massachusetts Division of Marine Fisheries (MA DMF) sought to design, build, and test the Five-Point Haddock Trawl net that: used the sweepless design to limit bottom contact; eliminated the complexity of a separator panel; and exploited behavioral differences between haddock, cod, and flatfish. Our goal was to allow a feasible haddock fishery in a mixed groundfish fishery without interfering with the rebuilding of the weaker stock, Georges Bank Atlantic cod.

Prior Work

Trawl Designs and Flume Tank Testing

The experimental Five-Point Haddock Trawl (also referred to as "Five-Point") net is a modified three-bridle, four-panel box trawl designed by Reidar's Manufacturing Inc., New Bedford, USA (Figure 1). A 1/10th scale model of the experimental net was constructed and tested at Memorial University's Fisheries and Marine Institute's flume tank in St. John's, Newfoundland. Flume-tank model testing and tuning demonstrated the following characteristics: 1) Bottom contact is limited to five "drop-chains" that hang from the fishing line (hence the name "Five-Point Haddock Trawl"). These chains maintain net shape by the contact of the chains only; no other bottom contact is made by the net. 2) The mouth of the net fishes at about 1.5 meters off-bottom. 3) Height of the fishing line off the bottom is adjustable using the bottom and top legs, or bridle. 4) Height off-bottom remains stable over varying speeds.

The full size experimental and control nets were constructed by Reidar's Manufacturing, Inc. (Figure 1 and Figure 2). The Five-Point net body consisted of double braided 5 mm diameter polyethylene (PE) twine with 330 mm (13 in) nominal aperture; the codend and extensions consisted of double braided 3.6 mm diameter, PE twine with 165 mm (6.5 in) nominal aperture. The fishing circle was 280 meshes. Five separate 3 m (10 ft), 15.9 mm (5/8 in) Midlink "drop" chains were located along the footrope on the wing-ends, corners, and center of the experimental net. Drop-chains were equipped with quick links on Viking hooks, for fast removal. The headrope and footrope were constructed of Spectra; the length of the headrope was 43.2 m (142 ft, 2 in) with 55 27.9 cm (11 in) diameter floats along the length; the length of the footrope was 54.8 m (179 ft, 9 in). The top bridles had extension chains for adjusting height off bottom.

The control net design, based on a standard groundfish trawl net, was composed of double braided 3.6 mm diameter PE twine with 165 mm (6.5 in) nominal mesh aperture in the net body and codend (Figure 2). The fishing circle was 340 meshes. The headrope and footrope were constructed of Spectra; the length of the headrope was 29.3 m (96 ft) with 58 20.32 cm (8 in) diameter floats along the length; the length of the footrope was 34.1 m (112 ft) with 40.6 cm (16 in) maximum diameter rock-hoppers.

Phase 1 Research
The Phase 1 field research was conducted from the commercial fishing vessel *Mary Elena*, a 24 m (78 ft), 653 kW (875 hp) groundfish Western-rig commercial trawler with stern ramp, multiple net reels, and Thyborøn 4.2 m^2 type 4 doors. Testing took place in the Western and Eastern U.S/Canada areas, Georges Bank, USA over two voyages (June 19–25, 2006 and July 10-18, 2006) (Figure 3). Exemption to use our gear in the Haddock SAP under the "A" Days-at-Sea (DAS) program was granted to us by NMFS before the second voyage.

The fishing gear was tuned early in the field work to obtain more optimal and comparable catch rates for both the control and experimental gears. Adjustment chains on the upper bridle of the experimental net were positioned to a length of 0.9 m (3 ft). Although not in the original design plan, 73.2 m (40 fa) of cookie-wrapped ground cable were added to the existing 36.6 m (20 fa) of bottom legs on the experimental gear. Also, a total of 64.0 m (35 fa) cookie-wrapped ground cable was added to the existing 45.7 m (25 fa) of cookie-wrapped ground cable and 9.1 m (5 fa) chains on the control net to maintain comparable door spreads.

The Five-Point net exhibited shine along the drop-chains approximately half way to three quarters of the lengths, indicating that the footrope was approximately 1.5 m off-bottom (Chosid and Pol, 2007). Net mensuration sensor readings and underwater video also generally indicated correct fishing geometries of the experimental net.

No significant difference was found between haddock catches in the control and experimental nets (Chosid and Pol, 2007), although the overall total catch of haddock in the control net was approximately three times the experimental net's total haddock catch. Also, the largest haddock catch weights within the Five-Point net occurred over rougher (rocky) bottom; boulders within these areas damaged this net. The combination of the additional ground gear added and the lack of a sweep may have made the Five-Point net susceptible to damage by pushing boulders into the wings. Therefore, we only performed a limited number of tows over this type of bottom.

A significant difference was found for the Atlantic cod catches in the control and experimental nets (Chosid and Pol, 2007), with a 98 % reduction in the experimental net. Catches in the Five-Point trawl were reduced by 94% or greater for other important species including winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Limanda ferruginea*), American plaice (*Hippoglossoides platessoides*), gray sole (*Glyptocephalus cynoglossus*), windowpane flounder (*Scophthalmus aquosus*), fluke (*Paralichthys dentatus*), monkfish (*Lophius americanus*), and American lobster (*Homarus americanus*) (Chosid and Pol, 2007).

Phase 2 Research
The successful avoidance of Atlantic cod and variable haddock catch by the Five-Point net in Phase 1 inspired continued testing, this time in comparison to the already approved haddock separator net, with the intent of achieving the Five-Point net's approval as a regulated gear-type within the Eastern U.S./Canada and Haddock SAP area. We compared the Five-Point trawl in its original configuration (without added ground gear) to the permitted separator panel groundfish net, and expanded the number of vessels, the range of seasons, and the range of bottom substrates tested. We sought to answer the following questions (objectives):

1. Does the Five-Point Haddock Trawl net perform as well as the currently-permitted haddock separator net?
2. Does the Five-Point Haddock Trawl net perform differently for various vessels?
3. Does the Five-Point Haddock Trawl net perform consistently over a broad range of habitats?

Research directions were expanded for low cost through additional industry partnerships. Stability testing of the net was investigated in this manner in response to concerns over the net's performance, beyond our original objectives. We also optimized available funding by fine-tuning the experimental net at minimal cost during a commercial trip on the final contracted vessel prior to that research testing.

This report describes Phase 2: the catch comparisons of the Five-Point trawl to the separator net and stability testing of the Five-Point trawl, as well as some improved analyses of the Phase 1 results.

Methods

Field work for Phase 2 research occurred on Georges Bank, USA, on-board the New Bedford-based commercial fishing vessels *Illusion* (February 9-14, 2007) and *Megan Marie* (March 21–28, 2007). The F/V *Illusion* is a 25.3 m (83 ft), 745.7 kW (1000 hp) groundfish Western-rig commercial trawler with stern ramp, two net reels, and Hi-Lift 4 m^2 trawl doors; the F/V *Megan Marie* is a 29.0 m (95 ft), 652.5 kW (875 hp) groundfish Western-rig commercial trawler with two stern ramps, two net reels, and Patriot 3.5 m^2 trawl doors.

A third trip, with the F/V *Fisherman,* was planned in 2007 but not conducted when funding became unavailable. Instead, stability testing of the net was conducted on the Five-Point net on the F/V *Barbara L. Peters* (see *Stability Testing* below)(April 10,11, and 13, 2008). This vessel is a 16.8 m (55 ft), 214.8 kW (288 hp) groundfish Western-rig commercial trawler with two stern ramps, two net reels, and Thyborøn 1.6 m^2 trawl doors.

Funding to complete work on the F/V *Fisherman* was reestablished in May 2009 and field work occurred May 20-27. Additionally, the F/V *Fisherman* conducted prior fine-tuning tows under MA DMF supervision in April, 2009. The F/V *Fisherman* is a 27.4 m (90 ft), 536.9 kW (720 hp) groundfish Western-rig commercial trawler with stern ramp, two net reels, and Thyborøn 4 m^2 (800 kg) trawl doors.

For all Phase 2 work, the Five-Point net was converted back to its original configuration without additional ground gear. The Phase 1 control net was modified by adding a separator panel from the front of the belly which led back to two codends; the lower codend remained open in accordance with regulations and to allow cod to escape. The separator panel was constructed of 16.5 cm (6.5

in) diamond mesh. Like the experimental net, extra ground gear on the control net from Phase 1 was removed for this work. The front of the separator panel was initially set approximately 102 cm (40 in) from the footrope with chains to constrain the opening. However, on the F/V *Fisherman* this height was later reduced to approximately 51 cm (20 in) to better mimic the height of the experimental net's footrope at that time. Various quantities of chain were added onto the footrope of the experimental net during trials to provide extra weight as the captains thought necessary. Since we continued monitoring the shine on the drop-chains (an indicator of the footrope height off bottom), the extra weights were not considered a vital factor for analysis.

Catch Comparison Testing
Exempted Fishing Permits (EFPs) were granted on Jan. 30 and Feb.5, 2007 allowing comparative testing of the experimental Five-Point Haddock Trawl net and the control separator panel net.

The study area encompassed the Haddock SAP, and the area between the northwestern side of Closed Area 2 to the west side of Closed Area 1 of Georges Bank, USA (Figure 3). Work was not permitted inside the Closed Areas themselves. The study area was based on the locations of January 2003 haddock tows collected from the University of Massachusetts, School for Marine Science and Technology (SMAST) Trawl Survey Project. The area was overlaid with a 10 minute coordinate grid, which was selected based on the area required to perform two-hour tows. To maximize the likelihood of finding the appropriate species mix for testing, captains of the participating vessels (F/Vs *Illusion*, *Megan Marie,* and *Fisherman*), other vessel captains/owners (F/Vs *São Paulo* and *Mary K*) and the MA DMF project coordinator (Chosid) each identified 30 10-minute squares as preferred fishing locations. Twenty of the selected squares were then randomly assigned (with replacement) to each participating vessel; squares were weighted by the number of times identified. An additional ten squares were randomly selected and retained as alternatives if assigned ones were found to be impractical. Each vessel was tasked with completing a tow with the Five-Point net and the separator net in succession within the squares assigned to that vessel. The actual start points within the square remained the choice of the captains in order to provide flexibility to find areas with target fish concentrations. The captains chose the order to fish the assigned squares. Deviation from the assigned areas was allowed based on observed catches and recommendations from other vessels concerning the current whereabouts of targeted fish stocks.

Scheduling of the first Phase 2 trip was initially left to the discretion of the captain of the F/V *Illusion*. The start of later trips was determined by haddock landings at the New Bedford Seafood Display Auction and input from participating captains.

The first net tested at the first square was chosen randomly (via coin toss). Each net was towed about two hours on the F/Vs *Illusion* and *Megan Marie* (approximately six nautical miles) to simulate procedures used by the fishing industry. Based on recommendation from the Northeast Fisheries Science Center (NEFSC), later tows completed on the F/V *Fisherman* were reduced to approximately one-hour in order to maximize sample size. Variations in the durations were expected to minimally affect the mean length composition of trawl catches (Godø et al., 1990). The compared tow then followed a similar path nearby but not directly over the same area. Fouled tows were discarded and restarted when logical for the paired comparison (i.e. not too much time had passed for a valid comparison). The first tow at subsequent squares usually began with the same net that completed the prior grid for operational ease and to minimize catch bias from the net order.

Tow duration, distance traveled, total codend catch weight, and the coordinates at the beginning and end of each trawl were recorded by the captain. All catch retained in the codend was sorted by species into baskets. Total weights for each species were taken (using a motion-compensated Marel M1100 floor scale) and recorded and the midline length measurements to the nearest cm were recorded for target fish. Data were later entered into a customized relational database using Microsoft Access.

For most analyses, we normalized catch and length frequency data for each tow by the tow duration (catch per unit effort, CPUE and length per unit effort, LPUE). Both weights and lengths were raised to the total amount of catch when sub-sampling occurred. Only paired tows with at least one fish present in either net were included in all analyses for that species. Analyses were conducted using Microsoft Excel and R statistical software (R Development Core Team, 2009; Sarkar, 2009).

Scatterplots were constructed for each selected species showing the CPUE for the paired experimental and control nets with an equal catch line.

Adjusted catches of selected species were tested for significance using paired non-parametric randomization testing with 1000 iterations ($\alpha = 0.05$). This method preserves the value of pairing that is lost using non-paired randomization testing as in some prior research (Rago, 2004; Pol, 2006). For each analysis, adjusted catch rates of each tow pair were randomly assigned (via Excel), without replacement, to one of the two net types, and mean differences were calculated. We compared the observed difference in actual paired treatments against a distribution of the randomly assigned paired values. The reported probability value is the proportion of the randomly determined differences that are greater than or equal to the actual observed value (Sprent, 1989). Probability values will vary with repeated runs; we report the more likely result (based on at least ten runs).

Generalized linear mixed models (GLMMs) were used to compare unmodified (by duration, etc.) species counts between the paired nets in Phase 1 and 2 (Holst and Revill, 2009). The proportion (experimental count at length / experimental and control total count at length) was then related to the observed lengths. Only Atlantic cod and haddock were analyzed based on their importance to the project and the amount of usable data. Four GLMM models were evaluated: constant, linear, 2^{nd} order, and 3^{rd} order polynomial fits. Model selection was based on parsimony, significance of model terms, residuals, similarity to proportions based on pooled lengths, and 95% confidence bands. Offsets were built into the GLMMs and included adjustments for catch subsamples, tow durations, and pairs in which catches summed from two experimental tows were compared against a single control tow (eight pairs in Phase 1 testing).

Acoustic net mensuration sensors (Notus Electronics, Inc., Newfoundland) were used to monitor trawl geometries and height off-bottom, which was additionally monitored by shine on the drop-chains. Acoustic sensors were usually mounted onto the top wings, headrope, and footrope of the Five-Point net for each tow; the separator control net was usually also equipped with sensors on the top wings. Some tows were performed without these sensors due to recharging times or maintenance and examination of the sensors. On the F/Vs *Illusion* and *Fisherman*, the hydrophone was hung off the starboard outrigger; on the F/V *Megan Marie*, the hydrophone was hung from the starboard outrigger at first and then mounted under the starboard outrigger's stabilizer later in the trip. This change was made to attempt improving the acoustic signal reception. Door spread was also recorded approximately once per tow from wheelhouse displays for vessel-owned Simrad ITI sensors (Kongsberg Maritime AS, Norway) with hull-mounted hydrophones on the F/Vs *Illusion* and *Megan Marie*; Notus Electronics Ltd. door sensors were used on the F/V *Fisherman*.

Stability Testing
The Five-Point Haddock Trawl net was investigated for stability and correct net geometry on-board the F/V *Barbara L. Peters* in Cape Cod Bay off Scituate, MA. The net's codend remained open throughout this work since retaining catch was not necessary during this part of the project. A Letter of Authorization (LOA) was acquired from both MA DMF and NMFS.

Notus Electronics Ltd. acoustic sensors were positioned on the doors and net to collect measurements, including door distances, door spread, wing spread, headrope height from bottom, and net mouth vertical opening. A light/depth/temperature sensor was also placed on the headrope of the net for supplemental information but did not function. Underwater video was captured from MA DMF's MacArtney Focus-2 towed underwater vehicle (TUV) (MacArtney, Inc, Denmark). The TUV provides a mounting surface for survey equipment and was designed to allow operators to maintain consistent preset or manual heights off-bottom or from the surface with horizontal planar control. Underwater video cameras and optional lighting, mounted on a pan-and-tilt device, were deployed on the TUV and allowed live viewing of the net from monitors on the vessel's bridge. Underwater video was captured to a Sony Mini-DV recorder.

Following setting of the net, acoustic data were reviewed for correct net geometry readings and the net's height off-bottom. The TUV was then deployed, starting with the third tow, from a stern ramp of the vessel towards the headrope of the net. The distance to the headrope was estimated from the warp wire out, door spread measurements, known net bridle lengths, and the reported or assumed wingspread (from acoustic data). Operators attempted to image desired sections of the net in order to further confirm the net shape and stability. Live video was checked against the acoustic sensor data. Tow lengths were based on the net's performance, available work time, and tow space. Once the tow was completed, the TUV was retrieved followed by the net. The lengths of shine on the drop-chains were inspected to further confirm correct bottom contact. During final tows, changes in geometry were recorded during vessel turns, speed alterations, and changes to bottom sediment composition.

Video and acoustic sensor results were reviewed following the field work using Adobe Premiere and Notus Electronics Ltd. Trawlmaster software. Only data acquired after at least five minutes at the start of the tow were used for these analyses to allow for the doors and net to settle. Likewise, five minutes of mensuration data were removed from the end of each tow (when the door retrieval began). Acoustic sensor data were further examined using box and whisker plots (McGill et al., 1978). Box-plots were drawn using the 25th and 75th quantiles as lower and upper limits, with a bar representing the median. The distance between the quantiles is called the interquartile range (IQR); approximately 50% of observed values are within this range. Whiskers extend to at most 1.5 times the IQR and end at an observed value. Points beyond the whiskers are greater than 1.5 times the IQR and can be considered outliers (Sokal and Rohlf, 2000). Box widths are proportional to the square roots of the sample sizes within each grouping.

Results

In summary, the following research was conducted and the results of the Phase 2 work are presented below and some Phase 1 data are reanalyzed:

- Trawl design and flume tank testing of model Five-Point Haddock Trawl net

- Phase 1 research: Catch comparisons of the Five-Point Haddock Trawl net and standard control net (F/V *Mary Elena* (two trips)).
- Phase 2 research
  - Catch comparison of the Five-Point Haddock Trawl net and separator panel control net (F/V *Illusion*, F/V *Megan Marie,* F/V *Fisherman*).
  - Stability testing of the Five-Point Haddock Trawl net (F/V *Barbara L. Peters*).

Catch Comparison Testing

Overall, 28 alternate tows (12 valid pairs) were completed on the F/V *Illusion*, 35 alternate tows (10 valid pairs not including those with uncertain door positions (see below)) on the F/V *Megan Marie*, and 52 alternate tows (20 valid pairs) on the F/V *Fisherman* (Figure 3). Valid pairs are experimental and control tows matched by proximal location and time, without any major gear damage to the nets and in appropriate gear configurations.

Total species' catch weights (including valid and foul tows) for both nets were lower than expected: 332.5 kg (733 lbs) from 16 taxa on the F/V *Illusion*; 1336.3 kg (2,946 lbs) from 29 taxa on the F/V *Megan Marie*; 3319.4 (7,318 lbs) from 29 taxa on the F/V *Fisherman* (Table 1). Adjusted catch results for paired tows from the F/V *Illusion* for all species, weights, and numbers were extremely low in both nets (Figure 4) although catches for all taxa were generally lower in the Five-Point net. No Atlantic cod were caught in the experimental net; a few haddock were caught in both nets on this trip. Due to the uncertainty in the F/V *Megan Marie*'s door rigging (see below), no further results or analyses are provided from this vessel. Larger catches for both nets were obtained on the F/V *Fisherman* trip (Figure 5).

Paired randomization tests were conducted for haddock and Atlantic cod catch weights (CPUE) from the F/Vs *Illusion* and *Fisherman*. The trips' data were combined for these analyses due to the small catches from the F/V *Illusion* (Table 2). Catches of haddock ($n=23$; $p=0.34$) and Atlantic cod ($n=15$; $p=0.67$) were not significantly different between the Five-Point net and the separator trawl net. Other species analyzed included winter flounder ($n=9$, $p=0.21$), yellowtail flounder ($n=19$, $p=0.048$), and American plaice ($n=16$, $p=0.44$); only yellowtail flounder showed a significant difference between the control and experimental nets.

Reanalysis of Phase 1 data from the F/V *Mary Elena* also using paired randomization testing (Table 2) showed highly significant differences ($p<0.001$) between the experimental net and a standard groundfish net for Atlantic cod, winter and yellowtail flounder, and American plaice, but not for haddock ($n=17$, $p=0.09$, $\alpha = 0.05$). These results are similar to previously-reported haddock and cod analyses which used unpaired randomization testing.

Differences in haddock catch by length were determined using a GLMM for Phase 1; a second order polynomial GLMM model (Figure 6) showed the best fit. It found significantly higher catch in the standard net ($p<0.05$) for large-sized (>49 cm) and small-sized (<37 cm) haddock; no significant difference ($p\geq0.05$) was found for haddock in between those sizes. For all tow pairs with at least one haddock in Phase 2, a constant GLMM model provided the best fit to the data; no significant differences were found for haddock over all size ranges. For Atlantic cod captured in Phase 1, the linear GLMM model showed that significantly less cod were caught in the experimental net for most sizes during comparison with a standard groundfish trawl (Figure 7); some indication was found that there may be no difference in catches at the smallest lengths (<36 cm). Phase 2 results determined that no significant difference between the Phase 2 separator and experimental net were found for cod catches over all sizes, based on a constant GLMM model.

Problematic sensor readings and inconsistent shine on the drop-chains obtained on the F/V *Megan Marie* initially led us to believe that the experimental net was having stability problems. Throughout this trip, we attempted modification of the experimental gear to achieve correct geometries, including adding chain to the footrope for increased weight and removing floats to reduce buoyancy. Later, we learned that incorrect rigging on the doors probably greatly contributed to poor net and door sensor readings, unstable net performance, and weak, inconsistent catches in both nets during this trip. Based on input from the net designer, we found that the inside chains at the bail of the doors were attached too high which could cause the top of the doors to pull inward (towards the net). Due to this uncertainty, we did not place great importance on any analyzed variations in door spreads between nets for this trip.

Net mensuration data were acquired from the F/Vs *Illusion* and *Fisherman*. For both trips, the control nets showed median door spreads slightly greater than the experimental nets' interquartile ranges (Table 3). Also, the median door spreads were generally smaller on the F/V *Illusion* trip. We attempted to maintain similar wing spreads (within nets) for both trips. The experimental net's wing spreads from the two trips were similar. Wing spreads on the control net were not obtained from the F/V *Fisherman*. Also, the wing spread data from the F/V *Illusion* for both nets were similar. The experimental net's headline heights were smaller on the F/V *Fisherman* trip. Insufficient data were obtained from the vertical openings of the experimental net and are therefore not provided. Net sensor readings obtained from both trips were generally stable.

Stability Testing

Ten tows were completed on-board the F/V *Barbara L. Peters*. During the first tow, only the Five-Point net was deployed (without the TUV) to verify that net geometry and height off-bottom were appropriate and sensors were functioning. Using this net, the vessel speed was maximized at approximately 3.0 knots, which was kept fairly consistent throughout the study. The warp wire to depth (scope) was initially set at approximately a 5:1 ratio and was increased during the first tow in order to attain the desired door spread. Depths over the entire trip ranged from about 22-37 m. On the second tow, the TUV was deployed without setting the experimental net to practice the TUV setting, controlling, and retrieving protocol and to confirm the camera was functioning.

Approximately 3.5 hours (six tows) of underwater video of the net were collected using the TUV on subsequent tows. Video was recorded of the headrope, square section, upper belly, upper wings, and side panels of the experimental net. Acoustic net measurements, successfully collected on seven tows, included the distances from the hydrophone to each door (Door (Port) and Door (Starboard)), door spreads, wing spreads, headrope height, and vertical opening of the net (Figure 8). During tow one, large ranges of door distances were observed which likely resulted from changes in warp to depth ratio during that tow. Hydrophone cable damage prevented us from collecting mensuration data on tows six and seven. Generally, net characteristics showed low variability within and between tows, confirming net stability.

The net's shape during a vessel turn, towing at different speeds, and towing over rocky bottom were examined using acoustic sensors during the last parts of tows nine and ten. These results were filtered out of the net geometry plots so that this data would not interfere with the tow-by-tow comparisons (Figure 8). During the turn, the trawl doors were not aligned. That is, during a turn, the doors had a skewed alignment (as expected) resulting from different velocities. Changes in vessel speeds (ranging from approximately 2.5 – 2.9 knots) caused net geometry initially to change rapidly. After a few minutes, the geometry of the net and doors stabilized to typical ranges. Net geometry also appeared to be minimally affected by harder bottom. As the substrate shifted to larger boulders (as indicated on the depth sounder (exact substrate sizes unknown)), the net was retrieved to prevent net and sensor damage.

Discussion

Phase 1 testing demonstrated that the Five-Point Haddock Trawl net met its objective to catch haddock while avoiding Atlantic cod, although not robustly because haddock catches were highly variable. Catch comparison to a haddock separator trawl on Phase 2 trips revealed that all analyzed species (with the exception of yellowtail flounder) showed no significant differences between the experimental and separator panel groundfish net. Therefore, the current project succeeded in meeting the performance of a haddock separator net, although we had strived for a significant improvement over the separator design in either catching more haddock or further reducing the cod catch.

In order for new gear types to be accepted into federal regulations, the catch results must demonstrate a reasonably small bycatch. Based on our findings from both Phase 1 and Phase 2, the Five-Point net can be considered for commercial usage in the groundfish fishery. Additionally, the experimental net's significant reduction in yellowtail flounder, a weak Georges Bank stock, even when compared against a separator net which avoids most flatfish, suggests that this new net design could further assist in their rebuilding.

Avoidance of flatfish and other non-target species by the Five-Point net is likely caused by its height off-bottom. This design generally avoids direct contact with fish that pass under the net rather than excluding those fish using grids, separators, or other devices requiring greater physical contact. Any contact with gear would most likely add an additional stressor to fish, increasing their escape mortality (He, 2010). In this respect, the Five-Point net offers a superior alternative to separator and other haddock trawls.

Greater certainty of the effectiveness of the experimental net may have been achieved if larger quantities of fish were encountered. Despite our efforts to incorporate historical knowledge by multiple experienced fishermen and by monitoring actual landings, target fish catch quantities were highly variable over all trips. This variation may simply be due to the availability of the target species, which we believe was particularly low during the F/V *Illusion* trip (Table 1). Additionally, when comparing against a separator net, another selective catch design, as in Phase 2, catches of all non-target species are expected to be low. Therefore, fewer total fish were expected to be collected than caught when using a standard groundfish net, as in Phase 1, and therefore robust results are more difficult to achieve.

The use of the general linear mixed models provides deeper insight into the catch performances of the experimental and control nets by exposing size-related differences. For Atlantic cod and haddock, the GLMM results reinforce and expand the results for both Phase 1 and 2 from non-parametric paired randomization testing of differences in catch weight. The randomization test for haddock in Phase 1 showed near-significance at 0.09 (Table 2). Significant differences within the GLMM results for haddock were only found at small and large sizes in the Phase 1 research which, we believe, confirms the near-significance of the randomization results (Figure 6). Small quantities of Atlantic cod acquired in Phase 2, partially due to the cod-avoidance designs of the nets, yielded large confidence bands in the GLMM models (Figure 7), an unavoidable consequence of limited tows.

Some industry members have questioned the stability and sensitivity of semi-pelagic trawls, especially sweepless designs such as the Five-Point Haddock Trawl net. These concerns concentrate on determining appropriate rigging, maintenance of geometry during turns, and vulnerability to damage in hard bottom. (In practice, these latter two concerns are linked, as vessels may turn sharply in hard bottom areas to avoid boulders and other bottom features.) Initially, these concerns seemed to be supported by variable catches and weak sensor results from the F/V *Megan Marie* that pointed toward either wide variation in the nets' performances between vessels or a gear rigging problem. Later examination suggested that improper door rigging was a primary contributor to disappointing results, a factor unrelated to the Five-Point Haddock Trawl net design. Further, overall stable net performances were witnessed (based on net mensuration data, drop-chain shines, and video) for the F/Vs *Illusion*, *Barbara L. Peters*, and *Fisherman*. This stability provided further confirmation that gear problems unrelated to the net occurred on the F/V *Megan Marie*. We did observe differences in catches that may be due to minor gear modifications, such as changes to the adjustments chains or the scope of warp wire deployed. Variations in gear usage most likely explain the difference in door spreads, headrope heights, and the drop-chain shine between the F/Vs *Illusion* and the *Fisherman*. However, differences in the vessels' gear types themselves, such as different doors, can also affect net performance.

Some of our results did confirm sensitivity in the Five-Point net's stability. During the F/Vs *Fisherman* and *Barbara L. Peters* trips, the experimental net's geometry (based on net mensuration and video data) seemed heavily influenced by current direction; strong cross currents (or tides) seemed to distort the net's structure. Attempts were generally made to either tow into or with the currents.

Proper net geometries (based on flume tank modeling, height off-bottom, a stable net shape, and acoustic sensors) were observed during stability testing on the F/V *Barbara L. Peters*. Predominately, measurements were stable and did not vary greatly. Acquired video visually confirmed the net's stability. While towing the net over flat areas (as confirmed by the depth sounder and headrope height sensor), the net was seen remaining level on the video and meshes were taut. These observations further indicate that the Five-Point net retained its shape and height off-bottom while towing. Also, confirmation of stable height was provided by the visual inspection of the drop-chains once the tow was completed. We therefore conclude that the net is fundamentally stable when properly rigged and operated. We further observed that the net remained stable overall despite some change in door spread.

Our ability to confirm the full behavior of the net (especially the lower portions including the footrope and drop-chains) was hampered by high turbidity in the water, which limited visibility, and our inability to adequately maneuver the TUV into desired positions between the net's wings due to strong currents and relatively low tow speeds. Consequently, the TUV was not able to image the footrope and lower net sections without risk of hitting and catching in the large mesh wing sections of the net. These problems may be unavoidable limitations of this technology.

The height of the net mouth off-bottom is a critical value; results from testing of separator trawls and semi-pelagic trawls indicates that small changes in height can alter the ratio of Atlantic cod to haddock (Martins et al., 2006). Higher net mouths appear to exclude more cod, while also losing some haddock. Acoustic measurements of this height during catch comparison testing were unreliable, unavailable, or nonsensical. Recent discussion with other researchers and sensor manufacturers' representatives (ICES, 2010) has led us to understand that accurate acoustic measurement of height off-bottom may be difficult to obtain or not possible, as the short amount of time between the sensor signal and its reception means the impulse returns too quickly to the receiver sensor, which experiences a period of latency after signal where it cannot record the returning impulse. Our use of shine on the net chains is necessarily a crude measure, as we do not know the angle of the chain behind the footrope, nor would we be able to reliably distinguish between a constant height off-bottom and an oscillating or temporary height – only the approximate maximum height is observable. We theorize that areas of moderate shine may be indicative of partial bottom contact where the chains or part of the chains may be touching bottom for periods of time. We are currently investigating alternate measurement methods; nevertheless, this shine provided the best measure available.

Overall, both the Phase 1 and 2 captains and crews developed similar opinions of the Five-Point net. While they felt the design had good potential to target haddock while avoiding Atlantic cod and flatfish, design modifications could facilitate the stability and structural reliability of the net. In all modification suggestions, the net was still elevated off the sea bed by vertical drop-chains. However, most felt that the five drop-chains created an operational difficulty or injury risk to the gear and crew. We received suggestions on modifications that were beyond the scope of the projects' experimental designs. We believe that some of those suggestions (such as replacing a portion of the drop-chains with a weighted sphere to keep the chains from entangling in the large meshes) would have negligible affect on the gear's fishing performance, bottom impact, and may not require additional testing.

The expense of a new net is another possible criticism of the Five-Point net, as is the case with nearly all new equipment. Some of this concern may be reduced by the lower drag and lesser fuel consumption since the experimental net is considerably lighter than standard nets with heavy ground gear. The expense must also be evaluated in light of regulatory factors, such as the costs of the bycatch of nets associated with strict catch limits.

The Five-Point Haddock Trawl net seems to work as well as the separator net with the additional benefits of decreased bottom contact, increased yellowtail flounder avoidance, and a lighter net design. Based on the strong reductions in Atlantic cod when compared against a standard net design and proven overall stability, the Five-Point net should be considered for inclusion into regulations for use within the Haddock SAP area in Georges Bank or as an exempted gear under sector management, providing an additional choice for the fishing industry to harvest the strong Georges Bank haddock stock.

Acknowledgements

This work was largely funded by the National Marine Fisheries Service via the Massachusetts Marine Fisheries Institute. We acknowledge the significant contribution of Frank and Andrew Mirarchi, who made the stability testing possible. We are grateful also to the captains and crews of the F/Vs *Illusion*, *Megan Marie*, and *Fisherman* whose experience and willingness to participate are invaluable. Additionally, the captain and crew of the F/V *Fisherman* donated time for this work. We also thank the vessel captains/owners of the F/Vs *São Paulo* (Tony Borges) and *Mary K* (Henri Franco and Pat Kavanagh) for participating in the selection of sampling areas. From MA DMF, Dr. Kathryn Ford and Steven Voss managed and operated the TUV and their support is gratefully recognized. We thank Crista Bank and Sally Roman from the SMAST, Richard Raynes and Tyler Staple from NMFS, R.J.A. Macfarlan, Jim Rossignol, and Steven Voss from MA DMF, and John Nadeau from Net Systems, Inc. for assisting in the field work. Also thanks to Dave Martins from SMAST for finding vessels and crews to conduct this research. Hans and Tor Bendiksen from Reidar's Manufacturing, Inc. have been instrumental in designing and using the fishing gear. Finally, data analyses and R scripts were completed with the assistance of Antonello Sala (Italian National Research Council's Institute of Marine Sciences), Tim Miller (NMFS), and Steve Correia (MA DMF).

Supplemental Material Provided

Additional supplements to this final report include the project database, images, and a video produced by MA DMF titled: "The Five-Point Haddock Trawl Net, Stability Testing". R code, net mensuration data, and video from all trips are also available upon request to the Massachusetts Division of Marine Fisheries.

References

50 CFR § 648.85, August 25, 2006: Special management programs.

Atlantic Fisheries Adjustment Program. 1992. Cod and Haddock Separator Trawl. Project summary. Fisheries and Oceans. 4 pp.

Beutel, D., L. Skrobe, K. Castro, P. Ruhle Sr., P. Ruhle, Jr., J. O'Grady, and J. Knight. 2008. Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery. Fisheries Research 94: 190-198.

Brewer, D., S. Eayrs, R. Mounsey, and Y. Wang. 1996. Assessment of an environmentally friendly, semi-pelagic fish trawl. Fisheries Research, 26:225-237.

Chosid, D.M. and M.V. Pol. "Five-Point Haddock Trawl' slashes cod catch". Commercial Fisheries News. Jan. 2007:14B.

Chosid, D.M., M. Pol, M. Szymanski, L. Ribas, and T. Moth Poulsen. 2008. Diel variation within the species selective "topless" trawl net. Journal of Ocean Technology, 3(2):31-58.

Fridman, A.L. and H.O. Milliken III. 1996. Substantiation of the use of a trawl escape panel and determination of its optimal parameters. A report submitted to ICES FTFB meeting. Department of Fisheries, Animal, and Veterinary Science, Fisheries Center, East Farm, University of Rhode Island, Kingston, RI 02881. 9 pp.

Godø, O.R., M. Pennington, and J.H. Vølstad. 1990. Effect of tow duration on length composition of trawl catches. Fisheries Research. 9:165-179.

Harris, J. and H.A. Carr. Separation of cod and haddock through gear modifications: a review prepared for the New England Fisheries Management Council. 1994. 8 pp.

He, P. 2010. Behavior of Marine Fishes: Capture Processes and Conservation Challenges. Blackwell Publishing Ltd.

He, P., T. Smith and C. Bouchard. 2008. Fish behavior and Species Separation for the Gulf of Maine Multispecies Trawls. Journal of Ocean Technology, 3(2):59-77.

He, P. 2003. Swimming behaviour of winter flounder (Pleuronectes americanus) in natural fishing grounds as observed by an underwater video camera. Fisheries Research, 60:507-514.

Holst, R. and A. Revill. 2009. A simple statistical method for catch comparison studies. Fisheries Research, 95, 2-3, 254-259.

ICES. 2010. Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB), 31 May – 4 June 2010, ICES Headquarters, Copenhagen. ICES C.M. 2010/SSGESST:14. 252 pp.

Krag, L. A., R. Holst, and N. Madsen. 2009. The vertical separation of fish in the aft end of a demersal trawl. ICES Journal of Marine Science, 66: 772–777.

Løkkeborg, S. 2005. Impacts of trawling and scallop dredging on benthic habitats and communities. *FAO Fisheries Technical Paper.* No. 472. Rome, FAO. 2005. 58 pp.

Main, J. and G. I. Sangster. 1982. A study of multi-level bottom trawl for species separation using direct observation techniques. Scottish Fisheries Research Report No. 26. 17 pp.

Martins, D., S. Cadrin, B. Rothschild, and B. Lane. 2006. Cooperative industry-based at-sea experiment to test the performance of a haddock-separator trawl in Closed Area I – Georges Bank. National Marine Fisheries Service Completion Report No.EA133F-04-CN-0039. 32 pp.

McGill, R., J.W. Tukey, and W.A. Larsen. 1978. Variations of Box Plots. The American Statistician 32:12-16.

Moran, M.J. and P.C. Stephenson. 2000. Effects of otter trawling on macrobenthos and management of demersal scalefish fisheries on the continental shelf of north-western Australia. ICES Journal of Marine Science, 57: 510-516.

Packer, D.B. (ed.). 2006. Essential Fish Habitat Source Documents for all listed EFH species, NOAA Technical Memorandum. http://www.nefsc.noaa.gov/nefsc/habitat/efh/.

Pol, M. 2006. Testing of Low-Profile, Low Cod-Bycatch Gillnets: Phases I and II. Report. Northeast Consortium, 142 Morse Hall, 39 College Road, Durham NH 03824.

Pol, M. 2003. Turning Gear Research in to Effective Management: A Case History. *In* D. Witherell (ed). Managing Our Nation's Fisheries: Past, Present, and Future. Proceedings of a conference on fisheries management in the United States, Washington DC, November 2003.

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.

Rago, P. 2004. Parametric and non-parametric tests. Catch Comparison Workshop, University of Rhode Island, Dec 8-9, 2004.

Ramm, D.C., R.P. Mounsey, Y. Xiao, and S.E. Poole. 1993. Use of a semi-pelagic trawl in a tropical demersal trawl fishery. Fisheries Research, 15:301-313.

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

Sokal, R.R. and F.J. Rohlf. 2000. Biometry. 3rd ed., W.H. Freeman and Co., New York.

Sprent, P. 1989. Applied Nonparametric Statistical Methods. Chapman and Hall, New York. 259 pp.

Suuronen, P. 2005. Mortality of fish escaping trawl gears. FAO Fisheries Technical Paper. No. 478. 72 pp.

Wardle, C.S. 1993. Fish behavior and fishing gears. *In* Behavior of Teleost Fishes. 2nd ed., pp. 609 -643. Ed. By T.J. Pitcher. Chapman & Hall, New York. 715 pp.

Winger, P. 2006. Mobile case study. Effectiveness of trawl modifications to reduce Atlantic cod by-catch in U.S. haddock fishery on Georges Bank. http://www.ccfi.ca/pdf/Mobile%20Gear.pdf.

Table 1: Total catch weights (lbs.) by trip, including both kept and discarded individuals. "nk" = unknown classification. Commercially important species are listed first.

		F/V *Illusion*		F/V *Megan Marie*		F/V *Fisherman*	
Species Name	**Scientific Name**	separator net	5-Point net	separator net	5-Point net	separator net	5-Point net
Haddock	*Melanogrammus aeglefinus*	22.9	2.4	328.6	201.8	2209.8	1905.3
Cod, Atlantic	*Gadus morhua*	57	0	545.8	307.7	197.2	358
Pollock	*Pollachius virens*	47.4	0	25	61.4	29.8	9.1
Flounder, American plaice (dab)	*Hippoglossoides platessoides*	2.05	0	17.4	5	71.2	29.7
Flounder, winter (blackback)	*Pseudopleuronectes americanus*	11.6	0	19.2	5.4	38.5	15.7
Flounder, yellowtail	*Limanda ferruginea*	10.9	0	19	3.4	91.6	37.1
Flounder, witch (grey sole)	*Glyptocephalus cynoglossus*	0	0	0.8	1	6.7	2.3
Flounder, sand dab (windowpane)	*Scophthalmus aquosus*	15.2	0.5	31.6	25.2	15.3	9.9
Flounder, fourspot	*Hippoglossina oblonga*	0	0	0	0	0.8	0
Flounder, summer (fluke)	*Paralichthys dentatus*	0	0	0	0	15.7	0
Monkfish (angler, goosefish)	*Lophius americanus*	53.4	0	4.6	0	2.5	19.2
Dogfish, spiny	*Squalus acanthias*	4.2	0	43	15.6	426	112.9
Hake, red (ling)	*Urophycis chuss*	0	0	0	0	3.2	0.02
Hake, silver (whiting)	*Merluccius bilinearis*	1.2	0	0.4	0	3.2	0.5
Hake, white	*Urophycis tenuis*	0	0	0.6	0	0	0
Cusk	*Brosme brosme*	0	0	4.6	0	0	0
Mackerel, nk	*Scomber scombrus*	0	0	1	0	0	0
Mackerel, Atlantic	*Scomber scombrus*	19.5	17.6	0.2	21.8	0	0
Herring, nk (shad)	*Clupeidae*	0	0	0.4	0	0	0
Shad, hickory	*Alosa mediocris*	0.6	0	0	0	0	0
Scallop, sea	*Placopecten magellanicus*	0	0	0.2	0	0	0
Sculpin, longhorn	*Myoxocephalus octodecemspinosus*	19.8	10	0	6.1	2.1	3.6
Sculpin, nk	*Cottidae*	0.6	0	0.4	5.4	0.8	0
Sea raven	*Hemitripterus americanus*	0	0	1.1	15.8	5.5	6.6
Shark, porbeagle (mackerel shark)	*Lamna nasus*	0	0	0	0	0	540
Skate, nk	*Rajidae*	309	89.9	0	467.6	79	67.8
Skate, barndoor	*Raja laevis*	0	0	0	0	58.5	1.9
Skate, little	*Raja erinacea*	35.8	1	204.8	148.2	68.6	52.8
Skate, smooth	*Raja senta*	0	0	2	3.4	0	0
Skate, thorny	*Raja radiata*	0	0	2.2	0	5.1	44.1
Skate, winter (big)	*Raja ocellata*	0	0	244.4	119.8	348.6	379.3
Lumpfish	*Cyclopterus lumpus*	0	0	0	9.8	0	0
Wolffish, Atlantic	*Anarhichas lupus*	0	0	0	0	0	17.4
Lobster, American	*Homarus americanus*	0	0	16.9	5.8	12.9	8.2
Clam, nk	*Bivalvia*	0	0	0	0.8	0	0
Crab, hermit, nk	*Paguroidea sp*	0	0	0	0.5	0	0
Crab, rock	*Cancer irroratus*	0	0	0	0	0.7	0
Squid, Atlantic long-fin	*Loligo pealeii*	0	0	0	0	0.2	0
Squid, nk	Order *Teuthida*	0	0	0	0	0.2	0
Squid, short-fin	*Illex illecebrosus*	0	0	0	0	0	2.7

Table 2: Results for select species of non-parametric paired randomization tests comparing catch weights (CPUE) in the Five-Point net to the control groundfish net (Phase 1, F/V Mary Elena) and to a haddock separator net (Phase 2, F/Vs Fisherman and Illusion). The average percent rank (p) is derived from 10 repetitions of the test. "n" is the actual number of paired data. Significant values are in bold.

	Phase 1: F/V *Mary Elena*		**Phase 2: F/Vs *Fisherman* and *Illusion***	
species	**n**	**p**	**n**	**p**
haddock	17	0.09	23	0.34
Atlantic cod	14	**<0.001**	15	0.67
winter flounder	11	**<0.001**	9	0.21
yellowtail flounder	16	**<0.001**	19	**0.048**
American plaice	9	**<0.001**	16	0.44

Table 3: Net mensuration results (m) for the Five-Point net (experimental) and the haddock separator (control) from the F/V Illusion and F/V Fisherman. "na" = data not available.

	F/V *Illusion*							
	Control				Experimental			
	n	median	1st quartile	3rd quartile	n	median	1st quartile	3rd quartile
door spread	12	53.0	47.5	58.5	13	47.5	43.9	51.2
wing spread	1362	19.3	17.0	20.4	1538	20.1	19.2	22.9
headline height	na	na	na	na	1076	9.8	8.6	11.9

	F/V *Fisherman*							
	Control				Experimental			
	n	median	1st quartile	3rd quartile	n	median	1st quartile	3rd quartile
door spread	749	60.4	48.6	63.7	675	56.4	48.9	58.6
wing spread	na	na	na	na	42	21.8	21.0	23.3
headline height	70	2.9	2.6	3.4	212	7.0	6.0	8.3

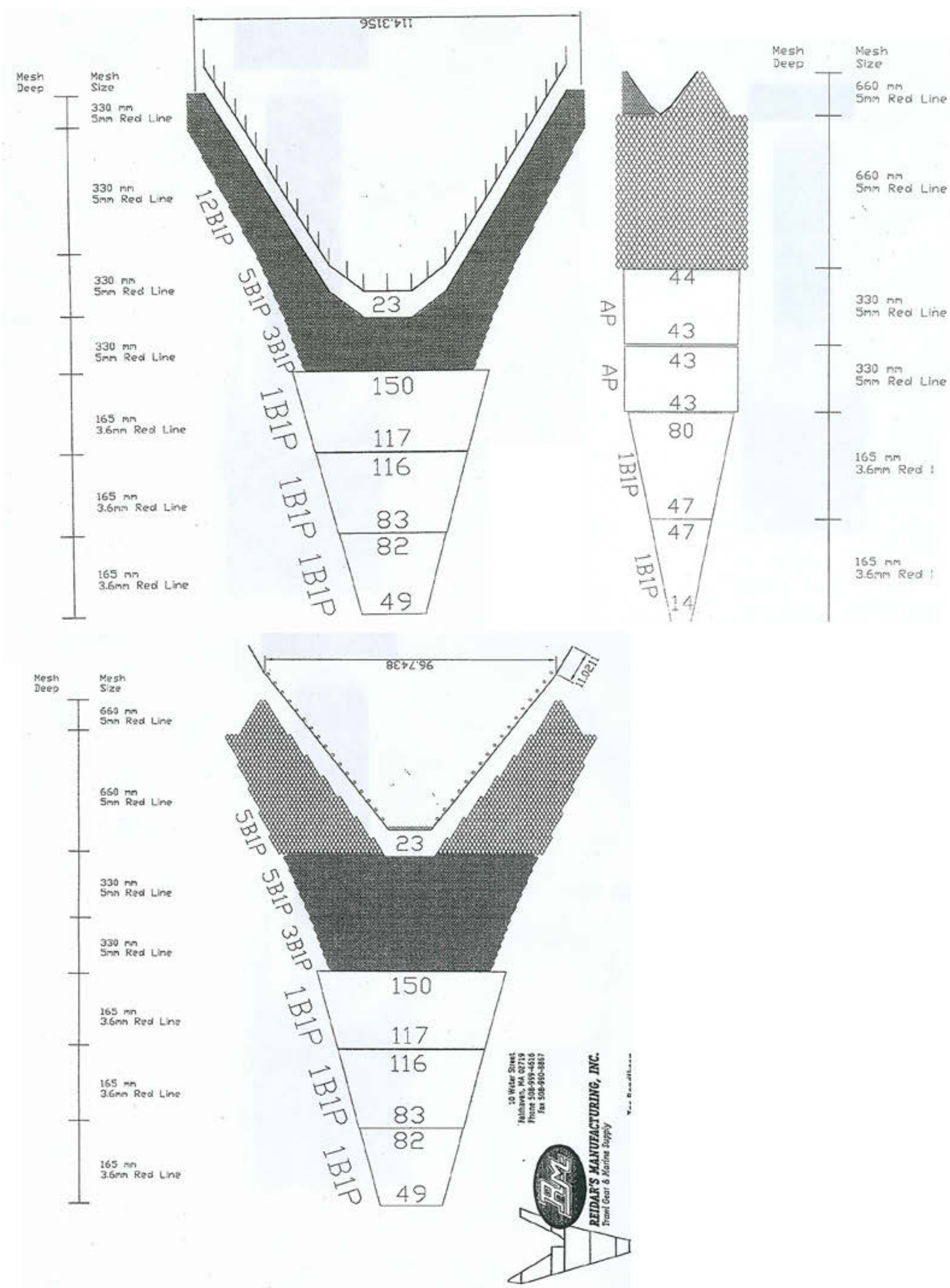

Figure 1: Schematic of the Five-Point Haddock Trawl net.

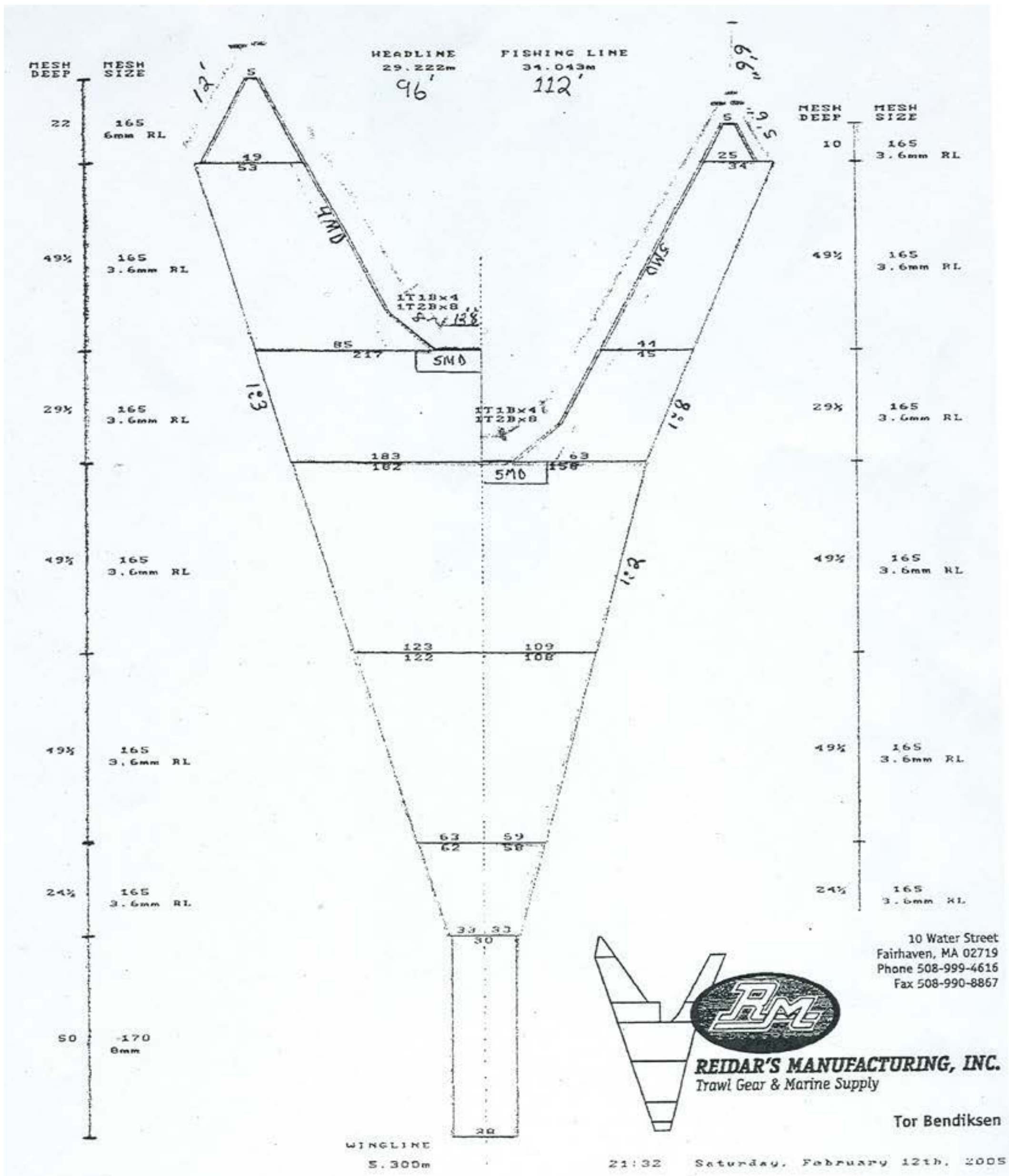

Figure 2: Schematic of the control groundfish trawl net, modified in Phase 2 with the addition of a separator panel (not shown).

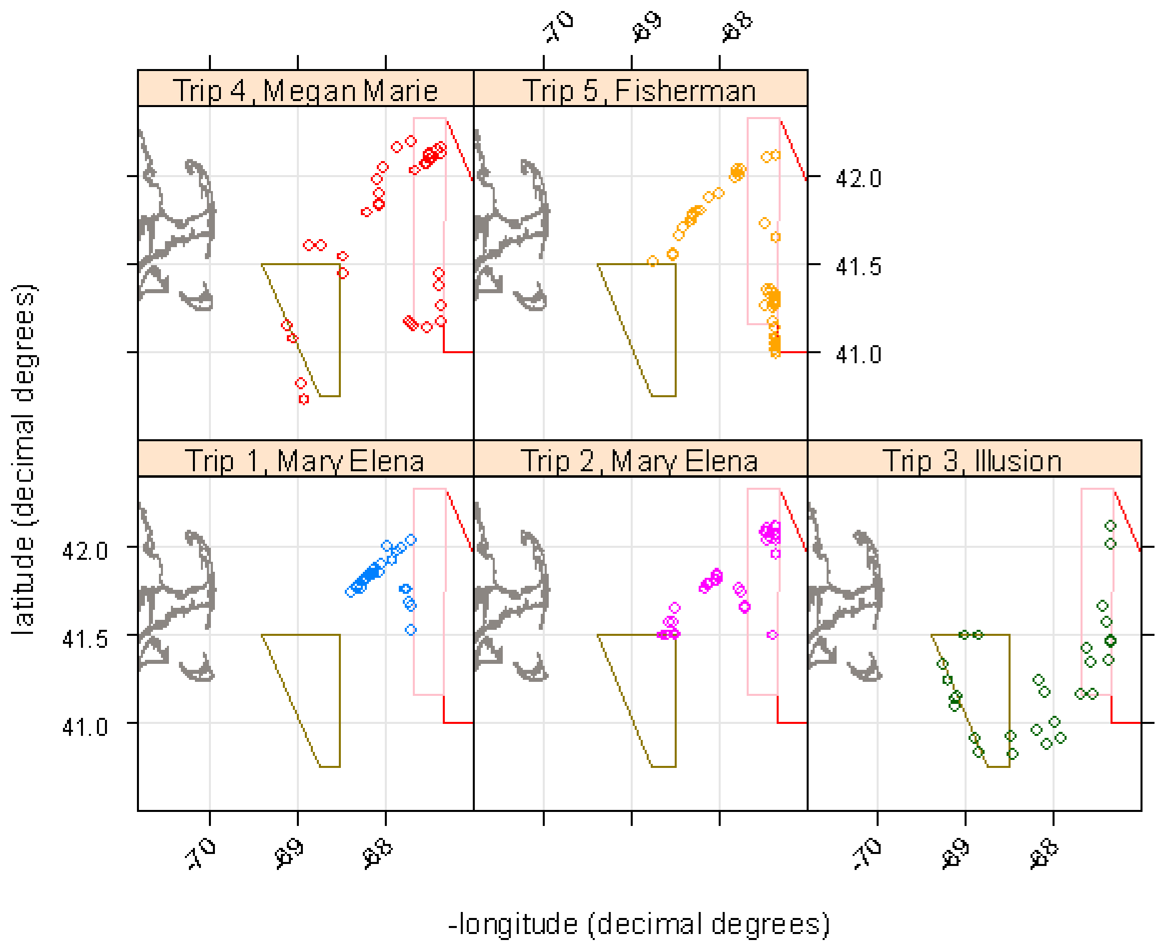

Figure 3: Start points by trip of each tow during Phase 1 (F/V Mary Elena) and Phase 2 (F/Vs Illusion, Megan Marie, and Fisherman) catch comparison testing. Closed Areas I (olive) and II (red) are shown. The Haddock SAP (pink) is on the western edge of Closed Area II. Cape Cod, Martha's Vineyard, and Nantucket are to the left.

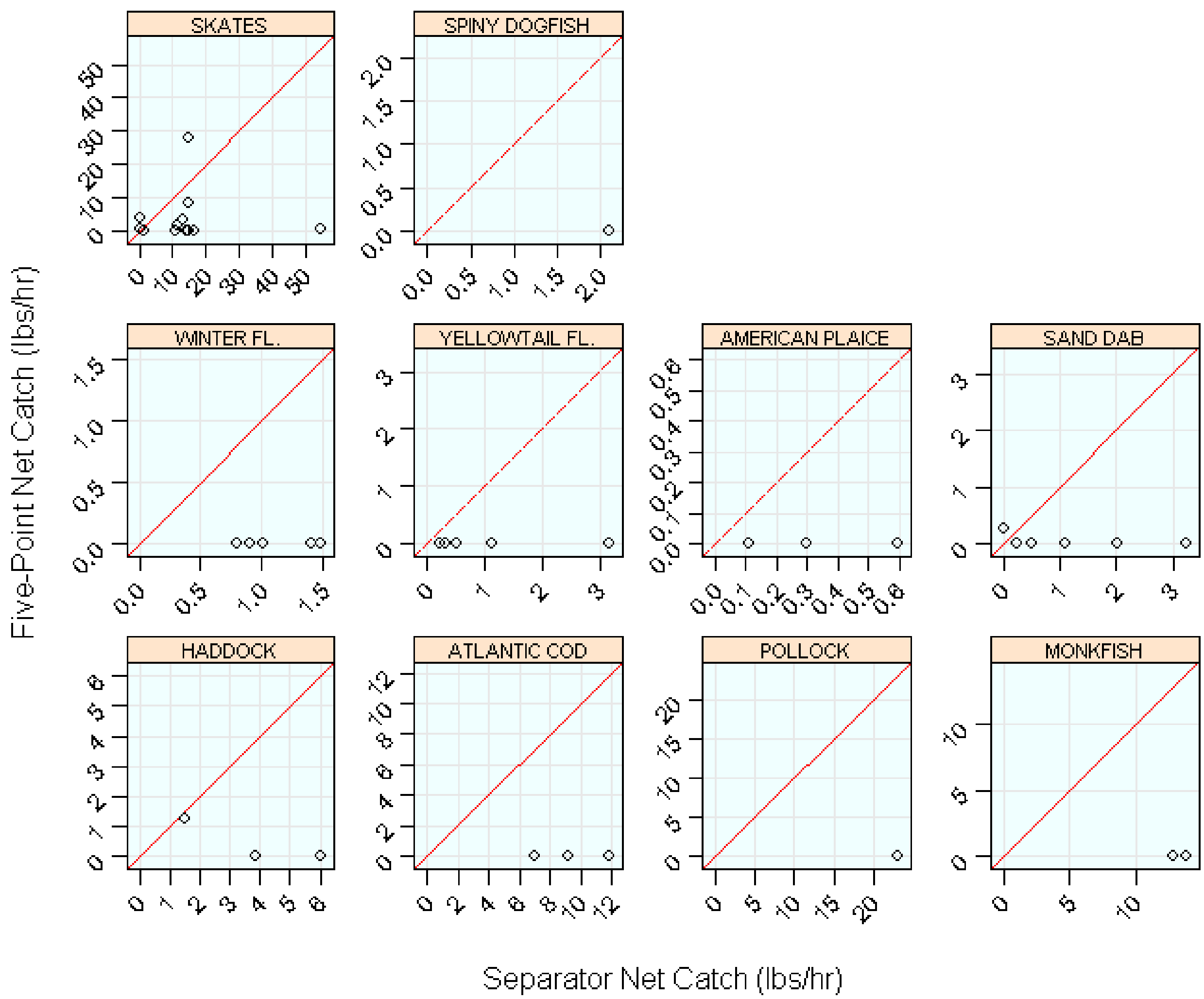

Figure 4: Paired CPUE (lbs/hr) for comparison of the Five-Point net and the separator net for selected species from the F/V Illusion (Phase 2). Only valid pairs are displayed. Skates were combined from multiple species (see Table 1). "FL."= flounder.

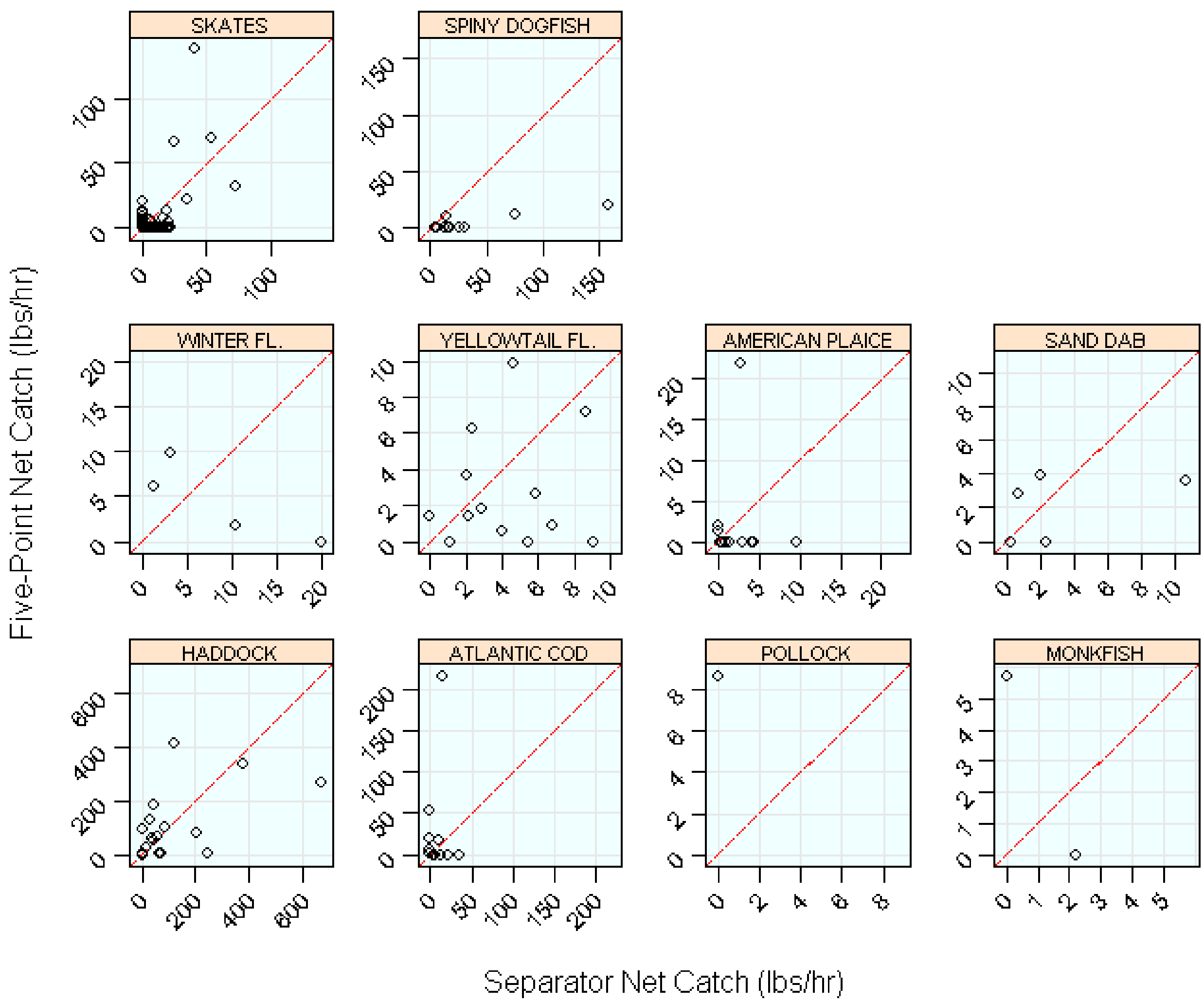

Figure 5: Paired CPUE (lbs/hr) for comparison of the Five-Point net and the separator net for selected species from the F/V Fisherman (Phase 2). Only valid pairs are displayed. Skates were combined from multiple species (see Table 1). "FL."= flounder.

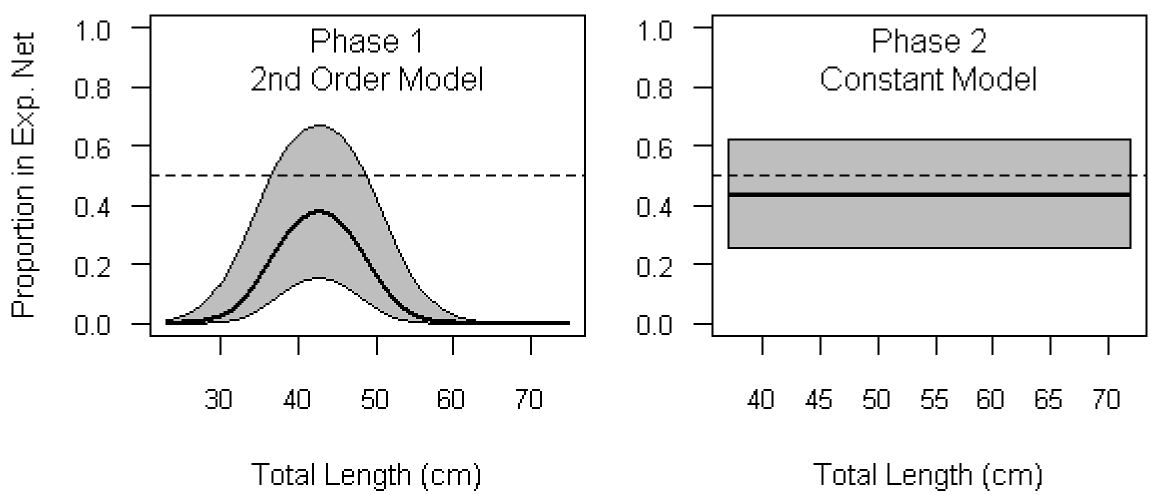

Figure 6: Phase 1 (left) and Phase 2 (right) best-fit generalized linear mixed model mean curves to the proportion of haddock at length in the Five-Point net over the total count in both compared nets. The horizontal dashed line at 0.5 defines equal performance of both designs. The shaded areas around the mean curve are 95% confidence regions. Non-overlap of the 0.5 line by the confidence regions indicated significant differences between designs.

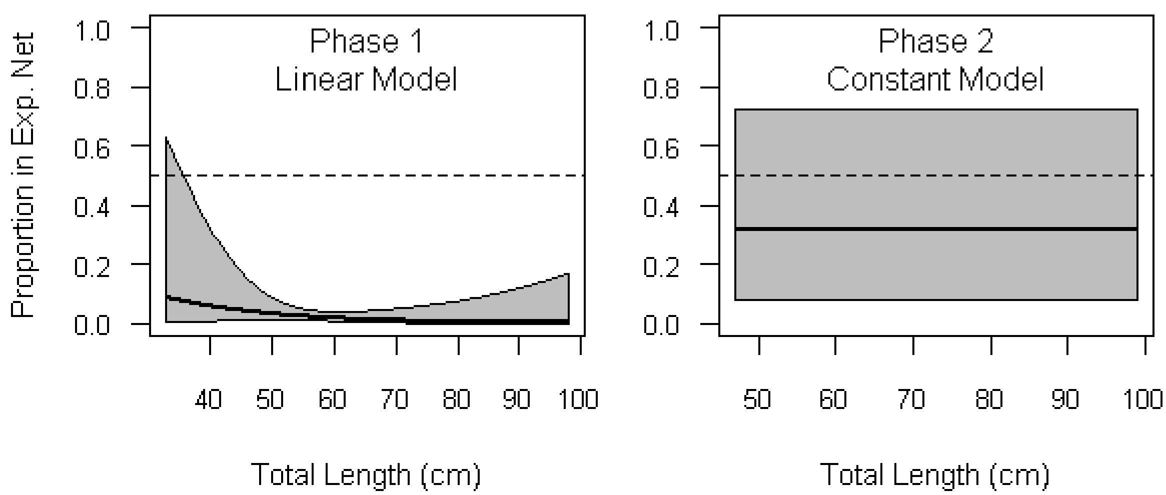

Figure 7: Phase 1 (left) and Phase 2 (right) best-fit generalized linear mixed model mean curves to the proportion of Atlantic cod at length in the Five-Point net over the total count in both compared nets. The horizontal dashed line at 0.5 defines equal performance of both designs. The shaded areas around the mean curve are 95% confidence regions. Non-overlap of the 0.5 line by the confidence regions indicated significant differences between designs.

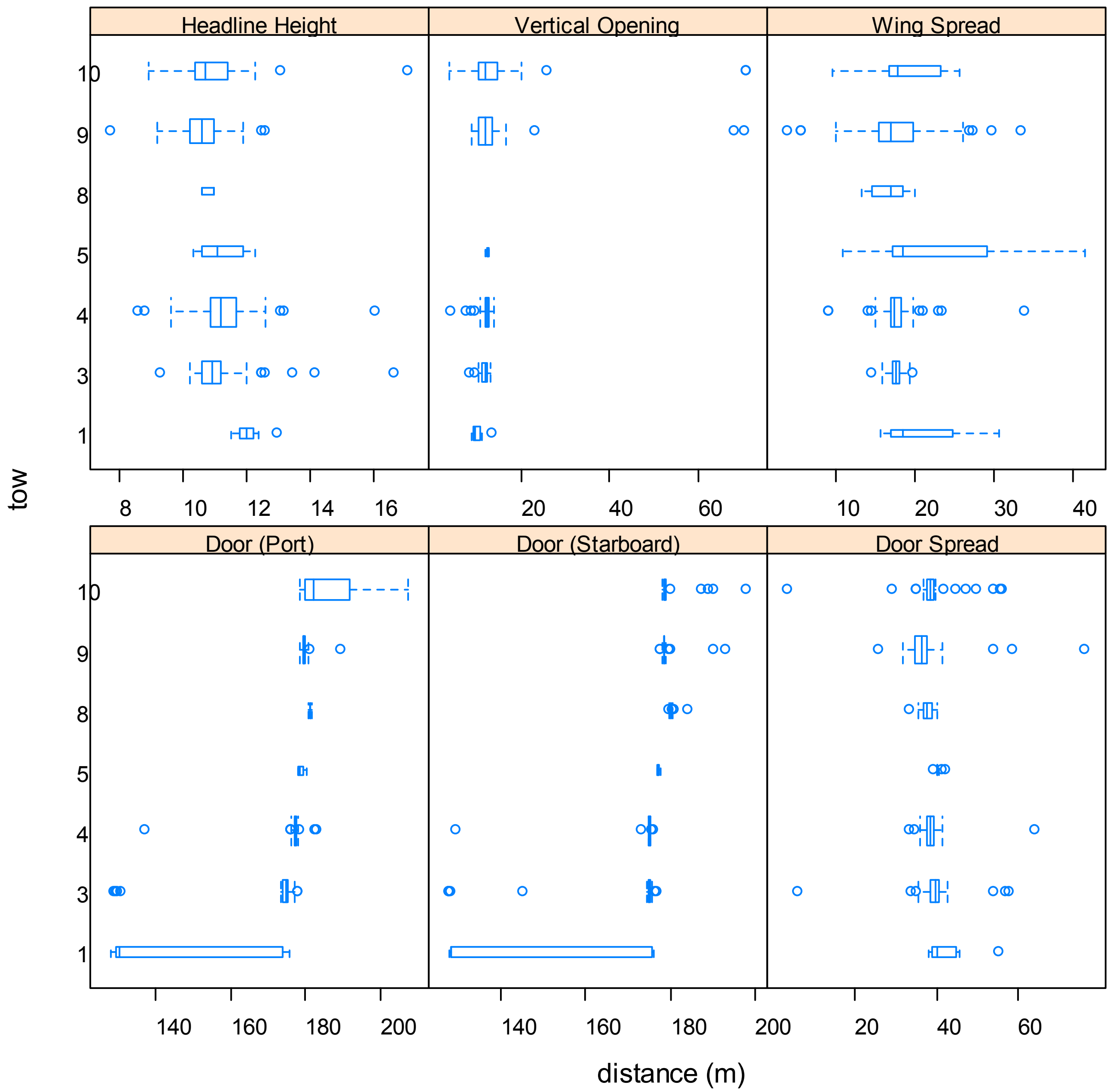

Figure 8: Tow-by-tow box and whisker plots of net mensuration data from acoustic sensors from stability testing on the F/V Barbara L. Peters; each panel depicts a different dimension. "Door (Port)" and "Door (Starboard) plots describe the distance from the doors to the hydrophone. The y-axis shows the tow identification numbers of the data collected.