Northeast Consortium Final Report

DOGGRATE: Development of a Spiny Dogfish Excluder in a Raised Footrope Whiting Trawl

Award Number: 09-047

Period of Performance: August 15, 2008 – June 30, 2011

Final Report Submitted: 30 September 2010

Contact: David Chosid
Marine Fisheries Biologist
And
Michael Pol (Principal Investigator)
Sr. Marine Fisheries Biologist

Division of Marine Fisheries
1213 Purchase St - 3rd Floor
New Bedford, MA 02740
+1.508.9902860 x116
mike.pol@state.ma.us
www.mass.gov/marinefisheries

Abstract

A spiny dogfish *Squalus acanthias* excluder grate (grid) within the extension of a silver hake (whiting) *Merluccius bilinearis* trawl net was designed and tested in Massachusetts Bay. We collected evidence between October 2008 and August 2009 using live-fed underwater video footage around the grate to support the proof of concept. Grates with 50 mm (2 in) spacing were investigated for effects from color (white or black), angles of placement, and direction (leading to a top or bottom escape vent). Spiny dogfish numbers were greatly reduced for all gear configurations based on video observations and data collected from the codend. Catches of target species were sizeable. Four tows (of various gear configurations) resulted in spiny dogfish blockages in front of the grate. The reduction of spiny dogfish led to apparent increases in the quality of marketable catches, reductions in non-target species mortality, and decreases in the codend catch handling times.

Participants

Michael Pol
Principal Investigator
1213 Purchase St., 3rd Floor
New Bedford, MA 02740
508-990-2860 x116
mike.pol@state.ma.us

David Chosid
Massachusetts Division of Marine Fisheries
508-990-2860 x140
david.chosid@state.ma.us

Mark Szymanski
Massachusetts Division of Marine Fisheries
508-990-2860 x137
mark.szymanski@state.ma.us

Frank Mirarchi
F/V Barbara L. Peters
67 Creelman Dr.
Scituate, MA 02066
(781) 545-3231
kaminc@comcast.net

Andrew Mirarchi
F/V Barbara L. Peters
67 Creelman Dr.
Scituate, MA 02066
(781) 545-3231

Introduction

Spiny dogfish *Squalus acanthias* are the most abundant shark species in the western North Atlantic Ocean, including the Gulf of Maine; their abundance has increased markedly in recent years (Sosebee and Rago, 2006). They are considered a nuisance by most fishermen and scientists (La Valley, 2007) and by some a hindrance to rebuilding of groundfish stocks and to fishing in general (pers. comm.). Spiny dogfish school by size and sex (Colette and Klein-MacPhee, 2002; Sosebee and Rago, 2006), sometimes in quantities large enough to fill commercial and survey trawl nets to overflowing (pers. obs.; Massachusetts Division of Marine Fisheries (MA DMF), unpubl. data). Specifically, spiny dogfish are a primary obstacle to exploiting the healthy northern silver hake (whiting) *Merluccius bilinearis* stock (pers. obs.; pers.

comm.).

The northern silver hake stock in the Gulf of Maine has generally exceeded its biomass targets in recent years and landings are at a historic low (Col and Traver, 2006). This fishery has traditionally been a source of income for small trawlers in ports from Maine to Massachusetts, USA and has potential to increase in importance as landings of other fish have declined in recent years (New England Fishery Management Council, 2003).

Currently, silver hake are targeted in some areas using a small mesh (≤76 mm (≤3 in)) mandatory raised footrope trawl. This gear avoids certain sensitive stocks by allowing those non-target species to pass under the net's footrope (Carr and Caruso, 1993; McKiernan et al., 1998). However, spiny dogfish, generally unwanted, are still susceptible to this gear and are easily retained in the small mesh codend.

Excluding spiny dogfish from trawl nets has multiple benefits, primarily the reduction of unwanted dogfish mortality (Harrington et al., 2005). High discards of dogfish could potentially close fisheries if catch allowances are exceeded (based on Amendment 16 sector regulations or the Days-At-Sea system). Additionally, the abrasive skin and spines of dogfish can damage other catch, reducing quality and market value. Very large catches of spiny dogfish can also clog and damage trawl nets, and may be hazardous to bring on board due to their bulk. Finally, the discarding of spiny dogfish consumes fishing time, which can result in lost income and higher expenses.

Preferably, mixed stocks of silver hake and spiny dogfish are avoided in the silver hake fishery. As dogfish populations increase, avoidance becomes more difficult. Fortunately, dogfish are generally larger than silver hake, and therefore can be mechanically removed from or herded out of a net using an excluder grate (grid) (Amaru, 1996; Broadhurst, 2000; Eigaard and Holst, 2004). Excluder grates in trawl nets act like a sieve; the spacing between the bars of the grate directly influences the size of excluded, unwanted fish and the target fish that can pass through the grate (Fonseca et al., 2005). Finding the optimal bar spacing is the primary challenge in designing an effective grate: if the bar spacing is too narrow, larger target fish will be lost (He and Balzano, 2007); if the bars are too far apart, more unwanted fish will be captured (Kvalsvik et al., 2006) or become wedged between the bars (pers. obs.).

The grate sorting process is not entirely mechanical; some fish avoid direct, physical contact with grates. Fish respond to visual cues during the fish capture process and much work has investigated specific visual stimuli for fish within fishing gear to enhance escape (Glass et al., 1995; He, 2010). Visual characteristics, and other factors beyond the bar spacing, may influence the effectiveness of the grate. Further, different species may have different reactions to visual stimuli or abilities to perceive these stimuli which can then be used to encourage a unique behavioral response (Chosid et al., 2008). It is known that visibilities and contrast of different color twines vary with water depth and the viewed angle (Wardle, 1989). For instance, in the water column, white twines are more easily seen from above while black twines are more easily viewed from below. We theorized that the color of the experimental grate might enhance escape by dogfish without an additional impact on silver hake loss; black and white grates were easily attainable and provided a broad comparison of dissimilar colors and contrasts.

Grates are typically angled into or away from the tow direction to help direct the escape of unwanted fish out of the net, with an escape opening (vent) either on top or bottom, at the aft extreme of the grate. Some species of fish are known to vertically separate in the trawl mouth and extension (Main and Sangster, 1981) and prior experience suggests that vent orientation might alter the ease of escape of some species. Therefore, various grate angles, top and bottom openings, in combination with black and white-colored grates, were investigated during this study.

We conducted research to design a prototype excluder grate to eliminate spiny dogfish in a raised footrope trawl net. In order to accomplish this goal, the following objectives were identified:

1. Observe the behaviors of spiny dogfish and silver hake around excluder grates using underwater video;
2. Investigate and refine the effectiveness of excluder grate properties, gauged by target species catches and spiny dogfish exclusions;
3. Produce a prototype grate design to be used in follow-up commercial trials;
4. Make recommendations for an expanded silver hake fishery in Cape Cod Bay and Massachusetts Bay.

Methods and Data

An opportunity to expand testing beyond the scope funded by the Northeast Consortium (NEC) arose when an Exempted Fishing Permit (EFP) became available prior to NEC funding. Consequently, this investigation was conducted in two phases: Phase 1 was funded by contributions from participants Frank and Andrew Mirarchi and MA DMF. Phase 2 was funded by the NEC, and built upon the results from Phase 1, resulting in more robust testing than anticipated. Different nets and grates were used in each phase. Testing locations also differed between trials. In Phase 1, grate angles were investigated using an initial white prototype grate with a bottom escape opening. In Phase 2, we refined the grate design and explored grate color effects and leading fish towards a top or bottom escape vent. This report includes all information from both phases.

Net and Grate

Phase 1

The raised footrope whiting net acquired and fished in this phase was in poor condition. Full examination of this two-panel net at the end of this phase revealed multiple unusual modifications to repair prior damage and to adjust for warped meshes; these repairs are too complex to depict in a schematic and are therefore not provided. We measured headrope and footrope lengths of 27.4 m (90 ft) and 34.1 m (112 ft) respectively. The sweep and vertical chains (to the footrope) were 7.9 mm (5/16 in) galvanized chain; vertical drop chains were 1.1 m (42.0 in) long. Sixteen 20.3 cm (8.0 in) floats were on the headrope. Single, green polyethylene (PE) diamond-shaped meshes were used unless specified below; nominal sizes are provided. The lower extreme wingends were replaced with 76.2 cm (30 in) long, 1.3 cm (½ in) chains. The lower wings, lower belly, upper wingends, and square were constructed of 15.2 cm (6.0 in), 3.0 mm diameter mesh. One portion of each upper wing was 15.2 cm (6.0 in) (forward section) white nylon and 7.6 cm (3.0 in) (back section), 2.5 mm diameter mesh. The bellies were constructed of 7.6 cm (3.0 in), 2.5 mm diameter mesh except for a roughly-triangular center portion of the lower belly (15.2 cm (6.0 in), 3.0 mm diameter mesh), used to fill in after considerable warping. A 5.1 cm (2.0 in) diamond-shaped codend was used with a 15.2 cm (6.0 in) diamond-shaped double mesh strengthening bag. The extension was 200 meshes around with

5.1 cm (2.0 in) mesh. Mesh measurements were collected for the net before and after the field work was completed and included the codend, codend cover, extension, square, and port-side top wing. A modification to the gear was made during the research. On tow 4, the original 7.9 mm (5/16 in) drop chains were switched to 9.5 mm (3/8 in) chain to provide added weight (approximately 4.5 kg (10 lbs)) along the footrope.

The excluder grate was attached within the extension of this net. This initial white grate had 15 1.3 cm (0.5 in) bars with 50 mm (2.0 in) bar spacings and was constructed of high density polyethylene (HDPE) (Figure 1). The overall dimensions of this project's grate were 114.3 cm (45.0 in) wide x 125.7 cm (49.5 in) high x 2.5 cm (1.0 in) thick with one central horizontal cross bar for extra structural support. Four 20.3 cm (8.0 in) floats were placed along the top of the grate to keep it upright while towing (Isaksen et al., 1992). The grate was attached to the webbing by plastic fastening strips on each side of the grate outside the webbing, so that the grate would be at the desired angle when the extension was pulled tight. The grate was nearly neutrally buoyant. Bar spacings were measured along the center in the top and bottom half of the grate (between the horizontal cross bar) at the beginning, middle, and end of Phase 1.

Figure 1: The initial excluder grate, following usage in Phase 1 testing with visible warping in the bars. Image source: /Construction/IMGP0239.JPG

A 2.0 m (78.0 in) guiding panel (funnel) with 5.1 cm (2.0 in) meshes was attached inside the extension leading fish up to the top of the grate towards an approximate 38.1 cm (15.0 in) long x 114.3 cm (45.0 in) wide escape opening (vent). The end of the guiding panel (at the center) was set approximately 20.3 cm (8.0 in) away from the grate, and approximately 30.5 cm (12.0 in) from the nearest mesh of the extension. A loose flap of webbing was attached forward of the vent acting as a cover to deter silver hake and other target fish from escaping through the vent before passing through the bars. Larger, excluded fish could still be mechanically guided out or escape.

Phase 2

Phase 2 used a new whiting net and an improved grate design. The new, typical, 4-panel box raised footrope whiting net was constructed by Levin Marine Supply Co. with single, diamond-shaped meshes throughout (Figure 2). Nominal sizes are provided below. The headrope was 28.7 m (94 ft, 1 in); the footrope was 29.5 m (96 ft, 9 in). A section of the lower bridle to adjust the footrope height (flychain) was composed of 3.0 m (10.0 ft) 9.5 mm (3/8 in) diameter stainless steel wire and 0.3 m (1.0 ft) of 7.9 mm (5/16 in) diameter galvanized chain which allowed adjustment by links. Twenty-five 20.3 cm (8.0 in) floats were on the headrope spaced approximately 1.2 m (4.0 ft) apart. The square, top bellies, lower bellies, and all but the first section of the side panel were constructed of 7.6 cm (3.0 in), 2.5 mm diameter green poly mesh; all other sections were approximately 16 cm, 3 mm diameter green euroline mesh; the codend was made from 6.4 cm (2.5 in) mesh; the same extension and guiding panel were used as in Phase 1. Nine galvanized vertical chains (7.9 mm (5/16 in) diameter, 1.1 m (42.0 in) long) from the footrope to the 7.9 mm (5/16 in) diameter galvanized chain sweep were set approximately equally spaced. Mesh measurements were collected at the start and end of this phase and included the codend, extension, square, side panel, top belly, and lower belly.

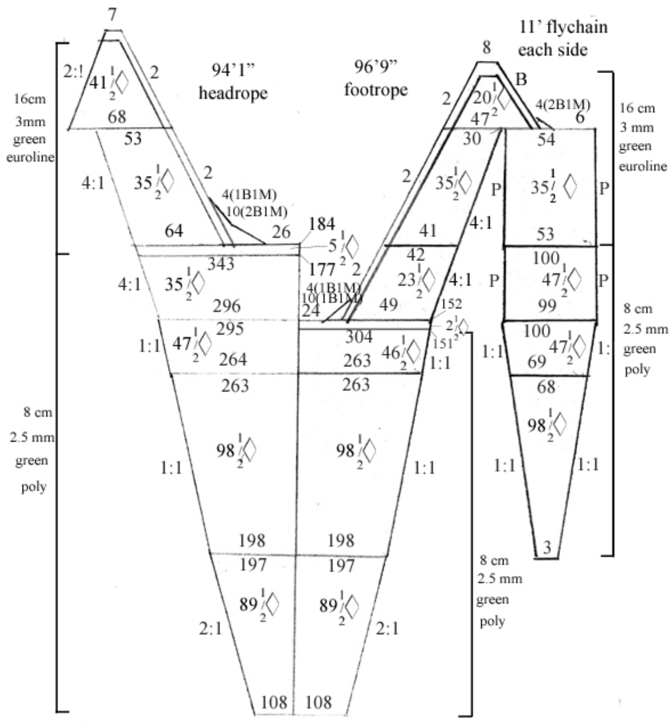


Figure 2: Net plan for the Phase 2 whiting net.

Two 121.9 cm (4.0 ft) square grates were designed (Brooke Ocean Technology USA, Inc.) and constructed (Palco Plastics Inc.), both with 50 mm (2.0 in) bar spacings (Figure 3). The grates were constructed of 25 mm (1.0 in) thick HDPE, one black and one white. Two horizontal cross bars were used to add additional support to the vertical bars, based on warping observed during Phase 1. Two 20.3 cm (8.0 in) floats were initially placed on the sides (near the top) of the grate to keep it upright while towing. The grates were inserted into the net's extension as in the Phase 1 testing. We concluded from Phase 1 that the grate angle of 45° was preferable for the continued research (see Discussion). Therefore, the grates angles' were set at 45° from the top and bottom extension walls for all of Phase 2.

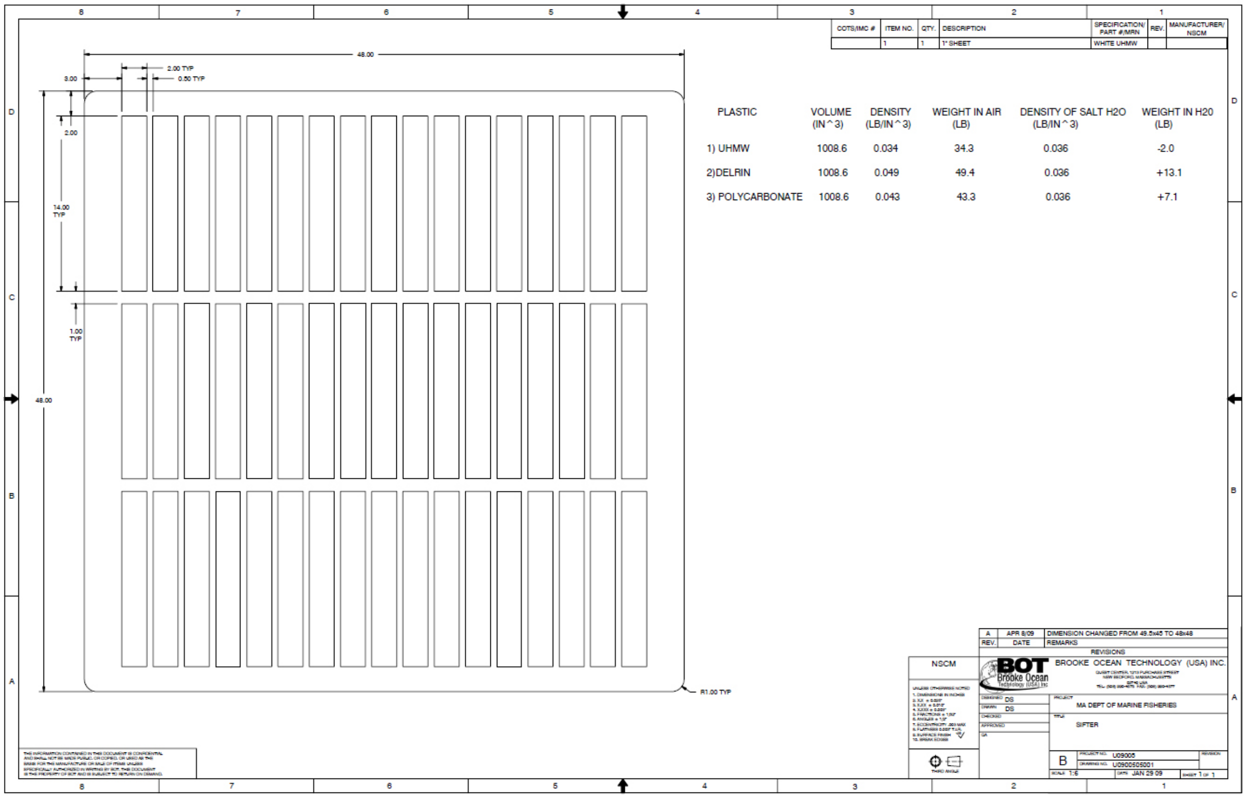


Figure 3: Schematic of the excluder grates used during Phase 2.
Image source: /Schematics/GrateSpecs2.jpg

The guiding panel dimensions were the same as that used during Phase 1 research.

Minor modifications to the gear were made during this phase consistent with normal fishing operations and as recommended by the industry partners. On tow 11, two floats were removed from each wingend. A 63.5 cm (25.0 in) setback was added to the lower bridle chain to bring the net mouth down more. Following tow 15, the bottom bridle was changed from 9.5 mm (3/8 in) to 1/2 inch wire. After tow 17, two 20.3 cm (8.0 in) floats were added onto the upper sides of the grates (four floats total) to improve the grates' upright stability and maintain its correct orientation. After tow 18, two additional 7.9 mm (5/16 in) vertical chains were added to the sweep. Each chain was 1.1 m (42.0 in) long and spacings between vertical chains were approximately equally spaced.

Field Work

Field work for both phases was conducted on-board the F/V *Barbara L. Peters* (Coast Guard #149951), 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. The net was set by the vessel's crew and tow timing began once the doors were on bottom and the warp winches were locked; the end of the tow was marked by the start of the winches to retrieve the net. Tow location was based on personal experience and observed depth sounder fish marks - the captain attempted to set near species of interest to this project. All tows were conducted during daylight hours following typical fishing practices for silver hake. Adherence to experimental design, sampling protocols, and EFP reporting requirements were overseen by MA DMF personnel.

Target tow times were less than one hour but were also influenced by real time video observations of fish, depth sounder fish marks, and unexpected occurrences. Vessel speed-overground was kept at around 1.5 m/s (~3.0 kt) when possible but was affected by water current directions. Operational data (location, weather, time, duration, etc.) were recorded for each haul. Catch composition and weights (using a motion-compensated Marel M1100 floor scale) were determined for all species retained. Mid-line lengths were recorded for spiny dogfish, silver hake, red hake *Urophycis chuss*, managed species (Atlantic cod *Gadus morhua*, yellowtail flounder *Limanda ferruginea,* winter flounder *Pseudopleuronectes americanus*, etc), and other selected catch. Sub-samples were taken as time required. Data were recorded and entered into a customized Microsoft Access database.

The first tow in both phases was used to familiarize the researchers and vessel crew with the net and no video or sonar equipment was used. On subsequent tows, video images were live-fed into the vessel wheelhouse when possible. The first goal of the filming was to ensure proper net and grate rigging and orientation. Once proper rigging had been established, reactions of spiny dogfish and silver hake were observed and recorded to mini-DV tapes. The camera or cameras were tethered (via the cable) to an independent winch mounted on the deck; the length of cable deployed was coordinated with the warp wire released during the tow. Video was collected under natural light to avoid fish behavioral effects from artificial light sources (He, 2010). A Notus Electronics Ltd. net mensuration system was used to observe and record gear characteristics and to also ensure proper gear rigging. The hydrophone for the mensuration system was deployed, when possible, from the starboard side of the vessel off the outrigger; a paravane was used to stabilize and direct the hydrophone in the water. Video and net data were recorded, post-processed, and later reviewed using Adobe Premiere and Notus Trawlmaster software respectively.

As a gear development project, decisions on gear configurations were made *ad hoc*. While we developed general plans to test specific characteristics such as grate colors, the number of tows conducted with each gear variation was performed as time allowed.

Phase 1

Originally, field work was planned to begin outside the Massachusetts Special Access Program (SAP) Raised Footrope Area in June-August, 2008; an EFP request was submitted to the National Marine Fisheries Service (NMFS) in May 2008 and granted in August 2008 (EFP# 9058). However, funding was not yet available and investigators contributed their own time (October-November, 2008) and equipment to perform this work during the normal silver hake season in the exemption area near Provincetown (Figure 4). Marketable fish were landed and sold and retained by the vessel crew as a source of project funding.

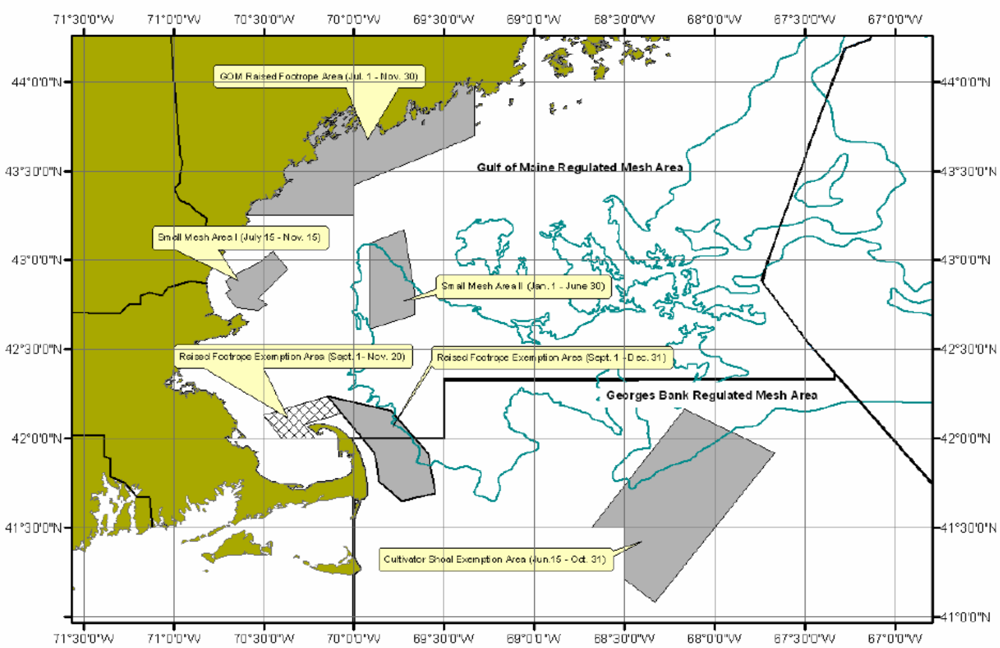


Figure 4: NMFS listed Northeast (NE) Multispecies Small Mesh Fishery Exemptions (2010) areas.

Tows were conducted during Phase 1 to investigate the general performance (catching and exclusion properties) of the grate at two different angles (set with the lower portion of the grate tilted to the aft of the net at approximately 45° and 35° on land) (Figure 5).

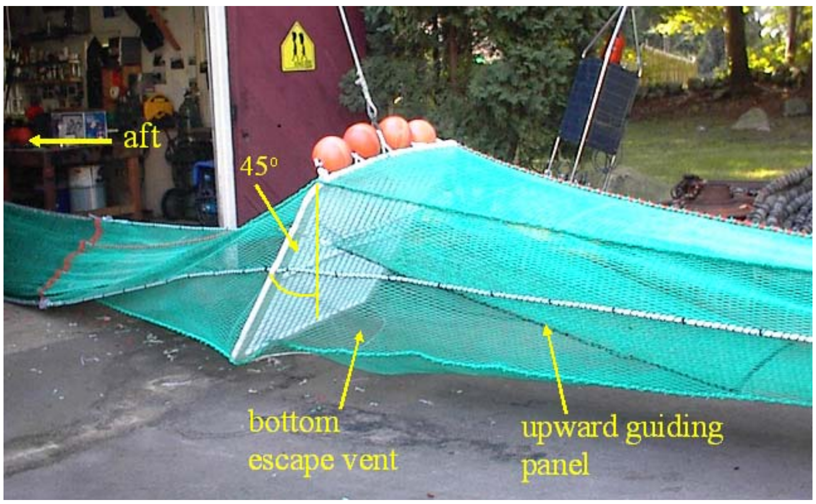


Figure 5: Phase 1 excluder grate in the extension of the whiting net showing the gear components and initial orientations. Image source: /Construction/Whiting Grate 003.jpg

Tows one through six were conducted with the grate set at approximately 45° (arrangement 1); tows seven through nine had the grate set at approximately 35° (arrangement 2). All used an upward guiding panel, a white grate with a forward-leaning top portion, and a bottom escape vent.

An underwater camera (Remote Ocean Systems Navigator) was attached either on the guiding panel pointing aft or on the grate itself viewing towards the escape vent. During the retrieval of tow 4, the main underwater camera slipped out of the net and was lost. Backup camera units (custom built systems) were then used.

Net mensuration sensors were used to obtain door spreads, wing spreads, headrope heights, and net openings. Additionally, an angle sensor was borrowed from Notus Electronics Ltd. to record the grate's angle while towing; this sensor was attached to the grate.

Phase 2

The field work for Phase 2 was performed in Massachusetts Bay, outside the SAP Whiting Area (between 42°12'W lat. and 42°30'W lat.) although some tows were conducted just inside the SAP (Figure 4). The prior EFP was reissued in July 2009 and allowed retention and sale of marketable catches; income was allocated per NEC guidelines and the vessel was paid a day rate. Catches were reported to NMFS after each day trip under the conditions of the EFP.

The following tows and gear configurations (continuing sequentially from Phase 1) were completed:

- Arrangement 3, Tows 10-15: Black grate, top of grate forward-leaning 45° angle, upward guiding panel, and bottom escape vent.
- Arrangement 4, Tows 16-21: Black grate, top of grate aft-leaning 45° angle, downward guiding panel, and top escape vent.
- Arrangement 5, Tows 22-28: White grate, top of grate aft-leaning 45° angle, downward guiding panel, and top escape vent.
- Arrangement 6, Tows 29-33: White grate, top of grate forward-leaning 45° angle, upward guiding panel, and bottom escape vent.

The underwater camera was attached forward of the grate looking aft; camera distances from the grate and angle of views were not standardized. The same camera winch system was used for the live feed of the video. For most tows, a second camera was situated in various locations and used to observe fish and their behaviors around the escape vent; these other camera placements and observations included: on the grate looking at the escape vent, outside the net looking aft at the escape vent, and outside the net looking forward at the escape vent. Secondary video footages are supplemental and were used to verify some of the behaviors of the primary video and to make other general observations. Additionally, as in Phase 1, net mensuration data were collected for exploratory analyses (without an angle sensor); some data were also collected on the square height and footrope height while towing. Temperature data were collected using an Onset Tidbit logger also for exploratory purposes.

A tradeoff occurred between the cameras' fields of views and the optimal distance back that the cameras were mounted. If the cameras were mounted too far from the area of interest in order to view a larger area, clarity and detail would be lost. We attempted mounting our cameras at various positions, assessed daily, to optimize the video. The sensor and cameras mounted on the grate would most likely affect catch results as this equipment blocks bar spaces; this effect was also a tradeoff in order to capture video and angle information.

Data Analyses

Data were analyzed using Microsoft Excel and R statistical software (R Development Core Team 2009), primarily using the lattice package (Sarkar, 2009). Unless specified, default R conventions were followed. Some data are presented in box and whisker plots (McGill et al., 1978). Boxes in boxplots 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 outside this range are individually plotted (Sokal and Rohlf, 2000). Box widths are proportional to the square roots of the sample sizes within each grouping unless otherwise noted.

Catch weights were adjusted by tow lengths (catch per unit effort (CPUE)). Variations in the durations were expected to minimally affect the mean length composition of trawl catches (Godø et al., 1990). Sub-samples were scaled to the entire catch weight for analysis. Length frequency distributions were analyzed within the gear configurations using box and whisker plots. Catch comparisons were considered a secondary priority, and the study was not designed to allow rigorous comparisons using statistical methods. Complete catch comparisons were planned for follow-on study once an effective prototype grate was developed.

Performance of the grate during Phase 2 was judged by its ability to exclude spiny dogfish while allowing target species to pass through the bars. To estimate performance, we attempted to measure the rate at which species of interest entered the field of view of the camera. Additionally, effectiveness of the different grate configurations was estimated by the proportion of spiny dogfish counted in the codend to the estimated number that entered the extension. We presumed that the dogfish passing the grates were not capable of escaping through the small codend meshes (Colette and Klein-MacPhee, 2002). The number of dogfish entering the extension was estimated by first dividing tow video into ten minute blocks (and whatever the remainder time was at the end of each tow under 10 minutes), and then randomly choosing one minute segments (via Excel) within as many randomly selected blocks as time allowed. If video quality was adequate and spiny dogfish were present in the clip, the clip was recorded from mini-DV tapes to AVI files using Adobe Premiere.

Dogfish viewed in the video clip were counted and their behaviors were categorized once they entered the field of view of the camera. Dogfish that appeared and then swam forward past the camera were not counted and the behaviors were not categorized (to avoid double-counting if they reappeared). The dogfish counts were expanded to account for the blocks not sampled and the total time within each tow. Tows where the grate became blocked were too concentrated with dogfish to provide a count estimate. The count estimates per tow were compared against the numbers of spiny dogfish that were caught in the codend. Spiny dogfish analyses were completed for each grate configuration using dot-plots.

Dogfish behaviors from the video clips were individually categorized until they were lost off the camera, lost from view, escaped, or were captured (through the grate). Within sampled clips, clear and perceived behaviors of dogfish, judged to be intentional and not passive, were recorded and included the following ten categories:

- Swim to side
- Swim up
- Swim down
- Swim forwards (towards front of net)
- Swim backwards (aft)
- Bump net with nose
- Bump grate with nose
- Wedge head into grate
- Body impinged on grate
- Body twists on grate

Once spiny dogfish became impinged or twisted on the grate, or escaped through the vent, we then recorded the area of the body where the dogfish contacted the grate and the head orientation (when possible). The final body position and facing were recorded only after the dogfish settled into those movements. Unintentional movements, such as rolling on the grate or drifting, were not recorded.

General behavioral notes for other selected species were made from the video collected and with respect to the different gear configurations when possible.

Video, acoustic sensor data, and other measurements were reviewed following the field work to determine if the nets performed appropriately. Only acoustic data acquired after at least five minutes at the start of the tow were used for sensor analyses to allow for the net and doors to settle. Also, five minutes of data were clipped at the end of the tow to assure that the doors were actually on bottom. Net geometry data were examined using box and whisker plots to identify anomalous net geometry or problems; trends in grid angle were examined with a loess smoother (span=1, family=symmetric). Changes in mesh measurements and grates' bar spacings were analyzed using 95% confidence intervals around the means (± 2 standard errors). Measurements were taken at the start and end of each phase.

Results

Researchers and the vessel crew completed nine Phase 1 tows over four days in the raised footrope SAP area near Provincetown, MA (Oct.-Nov. 2008) (Figure 6); twenty-four Phase 2 tows (23 valid tows) were completed over nine days inside and west and northwest of the SAP (July-Aug. 2009).

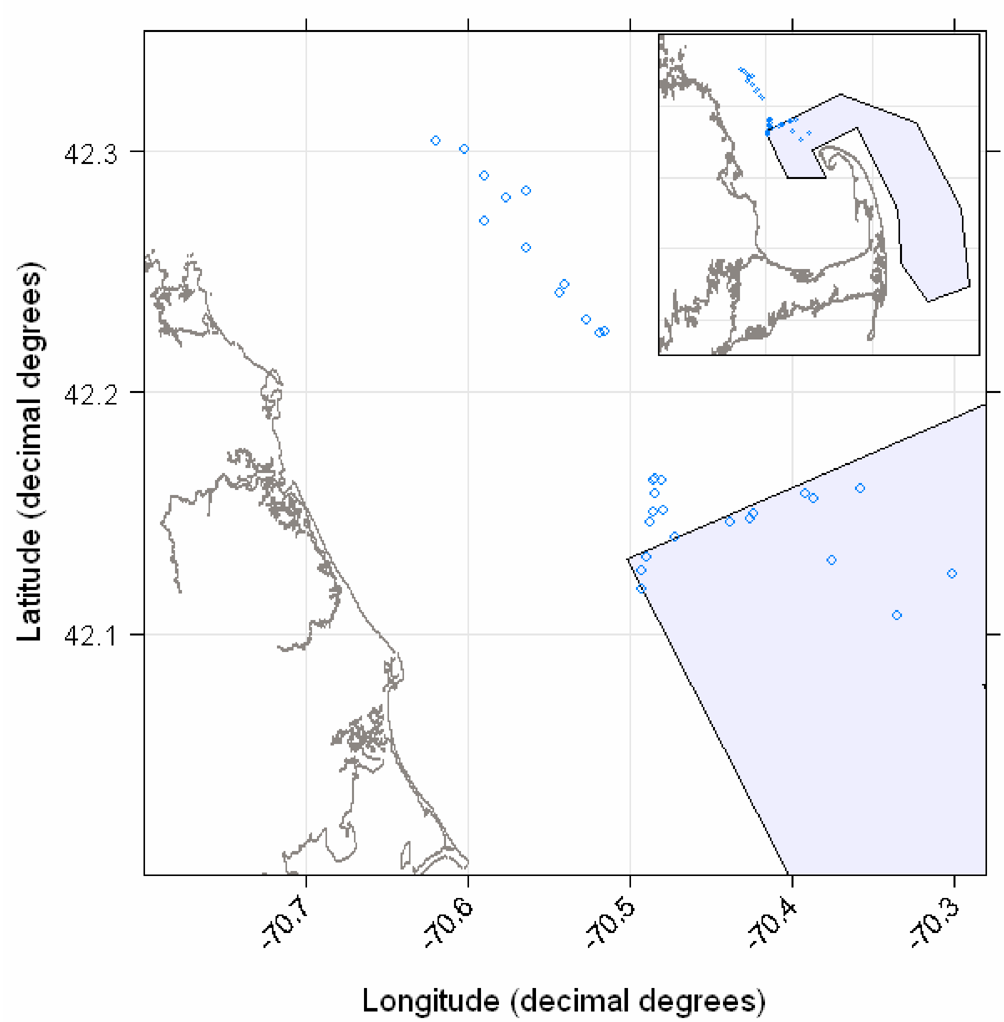


Figure 6: Start of research tow locations in Massachusetts Bay. The inset shows the greater area of Cape Cod; Boston is just northwest of the inset. The blue shaded polygon is the raised footrope exemption area.

Video data were reviewed for all tows in which it was collected (seven tows from Phase 1 and 23 tows from Phase 2). No video was collected from tow 2 because the camera's cable disconnected. Tow 33 was ended prematurely due to a cable malfunction.

Catch

Tow-by-tow results for all species captured are presented in Appendix 1. Thirty-seven species or species groups were caught during this study in approximately normal commercial quantities. Species compositions retained in the codend seemed similar for tows conducted in the small mesh SAP (Phase 1) and largely outside (Phase 2) although more silver hake and Atlantic herring *Clupea harengus* were caught on average in Phase 1. Target species retained were generally of very high quality.

Four tows from Phase 2 became blocked with spiny dogfish in front of the grate: tows 21, 23, 26, and 31. All of these tows except 21 were stopped early; tow 21 became clogged close to the planned end of the tow. Tow 21 used gear arrangement 3; tows 23 and 26 used arrangement 5; tow 31 used arrangement 6. In each case, extension meshes were cut and dogfish had to be discarded before the extension and codend were brought on board.

Selected important species included: spiny dogfish, silver hake, red hake, haddock *Melanogrammus aeglefinus*, Atlantic herring, Atlantic mackerel *Scomber scombrus*, and butterfish *Peprilus triacanthus* (Figure 7). Tow 28 was excluded because it was considered a foul tow from a foreign gear interaction. Tows in which the grate became blocked by spiny dogfish are included in these catch data sets; visual estimates of discarded dogfish from these tows were made by the captain. These tows resulted in the three largest dogfish catches (Figure 7). Large amounts of Atlantic herring were caught in tow 2 and approximately two-thirds of the catch was released in the water. The remainder was brought on board and sorted, weighed, and measured. The measured catch weights for tow 2 were then used as a subsample to estimate the amount of released catch.

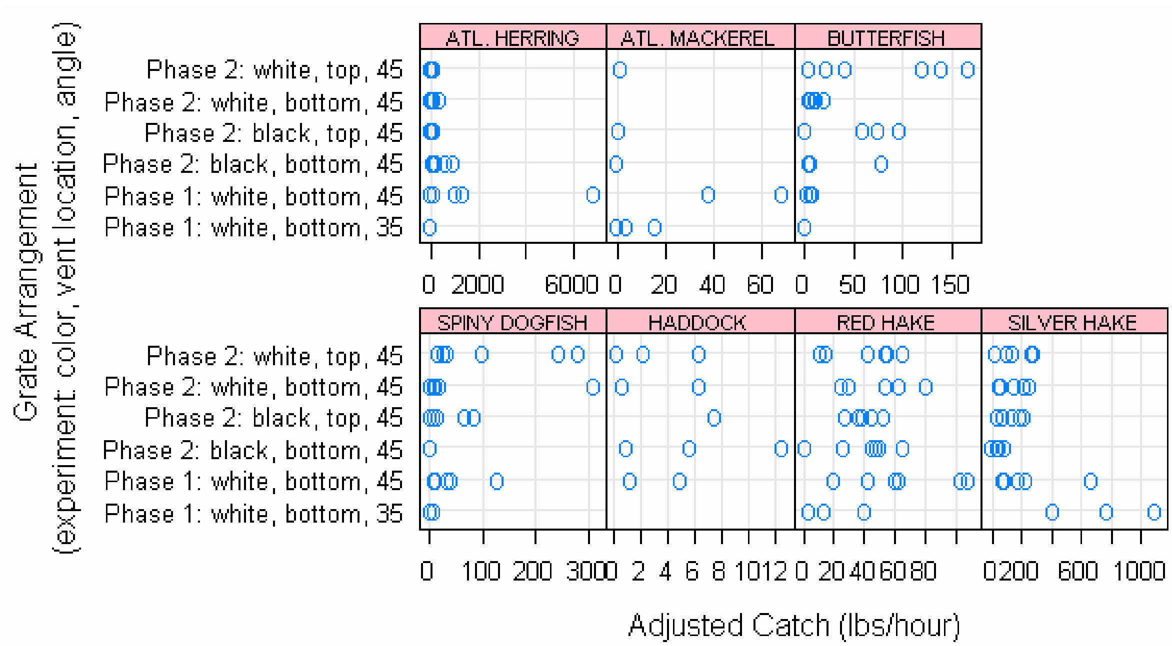


Figure 7: Adjusted catch (lbs/hour) of selected species per grate configuration. ATL=Atlantic.

Comparisons, limited by the design of the study, suggested that catches were not strongly affected by different grate arrangements. One case of a sensitive fish stock was captured in the codend in Phase1; approximately 109 kg (240 lbs) of river herring *Alosa sp.* were captured while less than 1 kg (2.2 lbs) were captured in Phase 2 (Appendix 1).

Length frequency distributions (Figure 8) for each arrangement showed some differences in sizes for spiny dogfish. The hake length results were very similar for all arrangements; some variations in sizes were seen during Phase 1 research with smaller sizes captured in the grate angled at 35°.

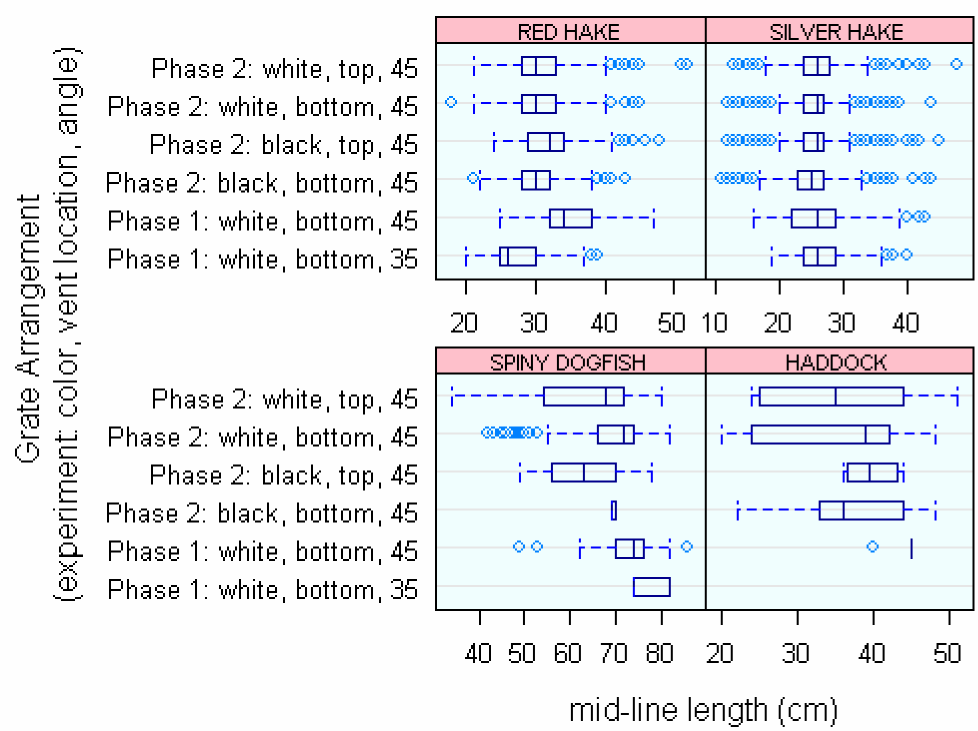


Figure 8: Box and whisker length frequency plot for selected species per grate configuration. Box widths do not represent sample sizes.

More than 90% of the spiny dogfish that entered the extension were excluded by the grate (except in one instance just under 90%), regardless of color or gear configurations (Figure 9). Other species were more difficult to track in video and therefore, these catches were not further analyzed for grate efficiencies.

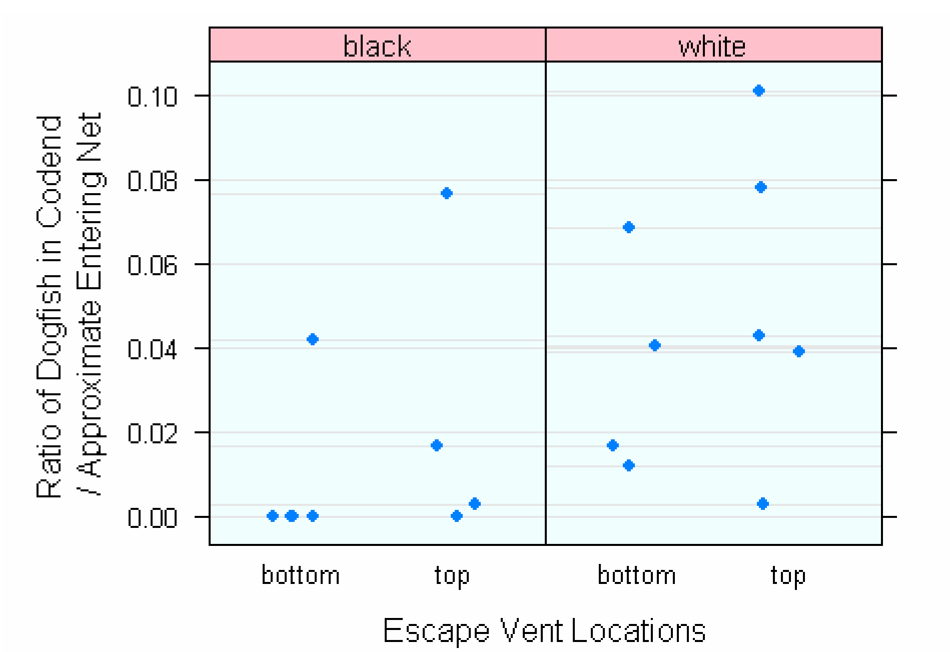


Figure 9: Tow-by-tow ratios of spiny dogfish retained in the codend to the estimated numbers that entered the net for each gear configuration (top opening/aft leaning; bottom opening/forward leaning) and grate color (black or white). Values along the x-axis are jittered (x=-1) to display overlapping points.

The black grate with a bottom escape vent showed the highest ratio of dogfish reduction (0.96-1.0) (Figure 9) although the fewest dogfish were caught in these tows overall (Figure 7).

The grates showed high levels of performance. In one tow, rates of entry of spiny dogfish to the primary camera's field of view were estimated at 1,751 individuals per hour. However, only 4.9 dogfish per hour were retained in the codend with no blockage to the excluder grate.

Behavior

Generalizations of behaviors were made for selected species in front of the excluder grates. However, based on the limited field of view and the small area within the extension of the net, true behavioral patterns for most species are difficult to confirm. Species appeared to react differently within the extension when schooling, near a school, and when concentrations and species compositions of fish changed.

We also observed behaviors directly around the grate. Smaller fish, including Atlantic herring, river herring, butterfish, and silver hake, were generally seen passing through the grates' bars with ease on the primary camera's video. Little or no contact was observed with the grate for these small species. Wedging behaviors in the grate, for all fish, were almost never witnessed in the videos, nor were seen at haul-back. Fish were rarely seen swimming forward back out once beyond the grate. Small scale changes in behaviors for species (other than spiny dogfish) due to the gear orientations or color of the grates were not expressly observed as these fish were generally difficult to track on video.

Fish would sometimes swim in the area of the net below the guiding panel, when herded upward, or above the guiding panel, when herded downward (Figure 5). This area was blocked by netting and forced fish to swim either back to the grate or out the escape vent. This behavior was common with dogfish but also confirmed for flatfish; smaller species were more difficult to identify in this area.

Spiny Dogfish

We observed the behavior of 462 spiny dogfish in front of the grate and recorded 1,686 total actions, divided into the ten behavior categories and a non-action category. However, it was determined that the categories "Bump net with nose", "Bump grate with nose" and "Wedge head into grate" could not be assessed adequately from video.

We were able to analyze three groups of behaviors (seven behaviors in all) for spiny dogfish; direction of swimming in front of the grate (backwards, forwards, side, down, up) (Figure 10), impingement area on the body (either side, dorsal, belly, unknown) (Figure 11), and twisting on the grate (area on the body that the dogfish settles against the grate - either side, dorsal, belly, unknown) (Figure 12).

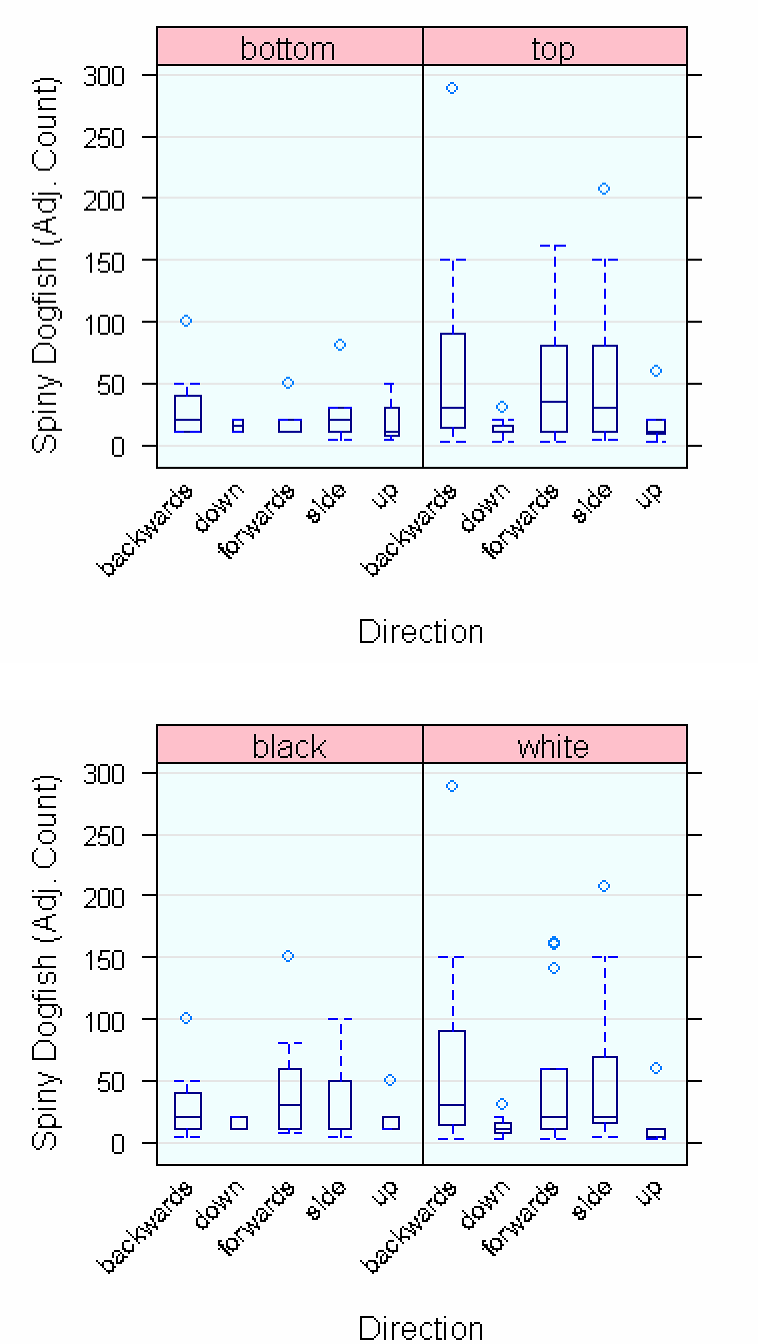
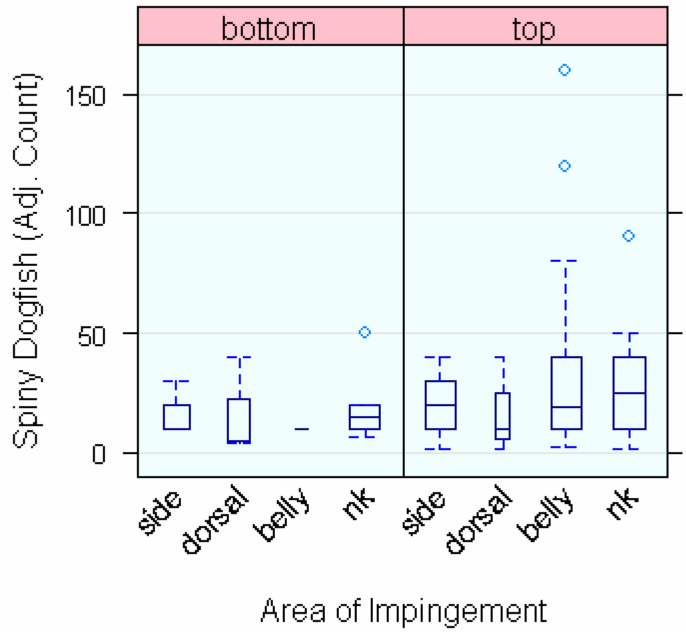


Figure10: Box and whisker plots showing the frequency of spiny dogfish swimming direction by escape vent configuration (top plot) and grate color (lower plot).



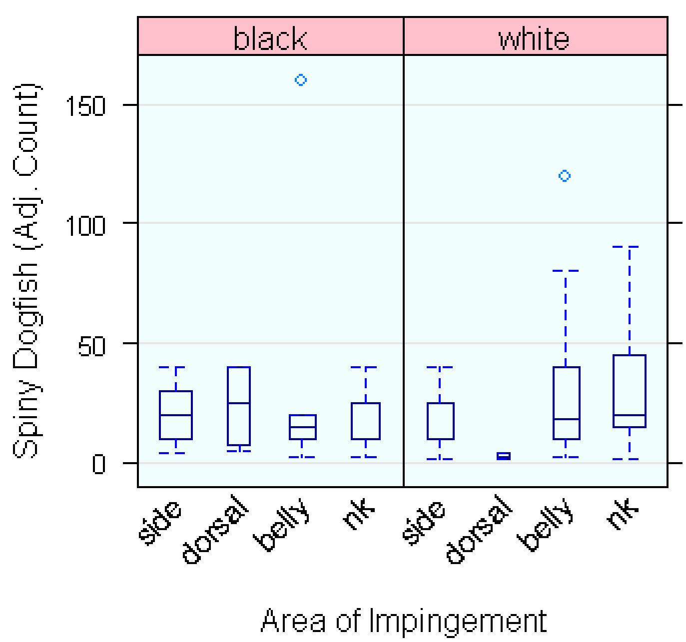


Figure 11: Box and whisker plots showing the frequency of spiny dogfish impingement locations by escape vent configuration (top plot) and grate color (lower plot).

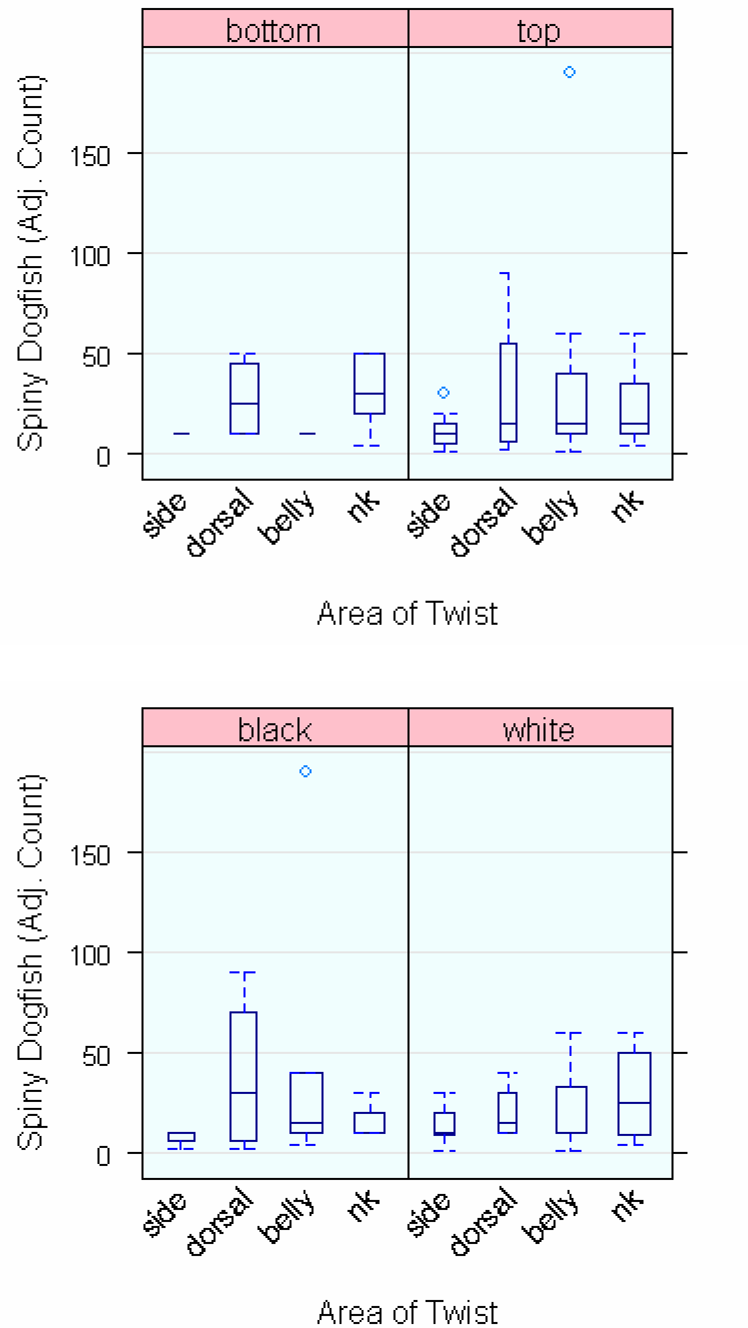


Figure 12: Box and whisker plots showing the frequency of spiny dogfish twisting locations by escape vent configuration (top plot) and grate color (lower plot).

In general, boxplots indicated that no differences were found within these categories, or between gear configurations and grate colors. Additionally, we observed that behavior could be altered by the presence of other species. For example, dogfish generally stayed lower in the extension when found in low concentrations, especially when large schools of herring were present although deviations from this behavior were also observed. In the highest dogfish concentrations, all fish behaviors appeared erratic; spiny dogfish displayed faster and highly flexible movements (with tight turning rates) especially during these concentrations (Domenici et al., 2004).

Spiny dogfish nearly always contacted the grates before escaping or becoming caught. They were rarely seen actually passing through the grates' bars.

Video from the secondary cameras in Phase 2 showed general behaviors around the vent opening. It was unclear whether spiny dogfish actually attempted to avoid the flap covering the escape vent or the escape vent itself. They would often become temporarily snagged or delayed in the flap. Once dogfish actually escaped through the vent, they demonstrated a variety of behaviors including swimming with the net, to the sides and then up, down, or off the camera to the side or aftwards.

Generally, the behaviors of all fish seemed to be disrupted by the presence of spiny dogfish, including other dogfish, and generally manifested as chaotic swimming. During blockages, dogfish might have been punctured from spines from other dogfish, based on small points observed in their surfaces.

Silver hake

Silver hake were generally observed at low concentrations, and were difficult to distinguish when mixed in large herring groups. However, silver hake were generally observed to be present lower down, below herring, and exhibited forward and side swimming with darting movements. Silver hake often swam with the net along the bottom or middle of the extension.

Few silver hake escaped through the vent, based on video taken by the secondary camera.

Herring

Herring (mostly Atlantic herring based on catch; species identification could not always be confirmed with video) generally stayed high in the extension, especially when in large schools. They nearly always swam in the direction of the tow. Other species, such as spiny dogfish and butterfish, seemed affected by large herring schools and generally stayed below them. In the absence of large herring concentrations, other species used the entire area of the extension more often.

Herring in large schools were occasionally viewed swimming just aft of the grate after having passed through the bars. They were rarely observed to swim back through the grates in large numbers even though they appeared to be physically capable of doing so. Exceptions to this behavior were witnessed when vessel and net speed slowed (such as during haul backs).

As with silver hake, we infer that most herring passed through the grates (since relatively few were seen escaping in the secondary video). Those seen escaping quickly darted out of the field of view.

Red hake

Red hake generally stayed low in the extension independent of fish concentrations. They demonstrated sustained swimming along the bottom of the extension or contact with the lower webbing near the camera, presumably an area protected from stronger water flow. Eventually, red hake drifted back or were displaced by other fish (commonly spiny dogfish), causing the red hake to turn toward a side or the codend.

Butterfish

Butterfish generally stayed below large schools of herring and used more of the extension when herring were not present. Infrequently, these fish were seen escaping through the vent and quickly out of view of the secondary camera.

Flatfish

Flatfish were not identifiable by species. They generally either remained against or near the lower meshes, swimming in the direction of the tow or resting on the webbing. Flatfish were rarely seen impinged on the grate; when passing through the grate, flatfish would maneuver on their sides to slip through the bars.

Gear

Damages to the net were repaired before setting the next tow. A portion of the chain sweep was detached from the footrope during tow 28 causing a foul tow. This damage was likely caused by contact with a ghost lobster trap (caught in the starboard wing) which we believe occurred in conjunction with a speed reduction and collapsed door spread during the tow.

Net mensuration data were obtained for the door spread, wing spread, headline height, footrope height, square height, and ranges from each of these related sensors to the hydrophone (Appendix 2) for both phases. The data were used to assess net performance. No tows were excluded during analyses because of poor reported geometry. Net parameters generally demonstrated very little variance within each dimension, although outlier values were common. Lower door spreads recorded on tow 26 possibly indicate a blockage due to spiny dogfish; increased drag of the dogfish could force the doors closer together. At the end of the project, the footrope sensor was found to be malfunctioning during the research; vertical openings are not reported.

Grid angles obtained during the Phase 1 research (tows 4-9) increased during the duration of the tow, although at varying rates (Figure 13). Tow 4 shows the most drastic change but is largely driven by a few observations. Also, tow 4 is the only one to display an angle while towing in water that is greater than the angle at which it was set on land (45°). Angle data were also collected for tow 3 but the sensor shifted during the tow providing poor data.

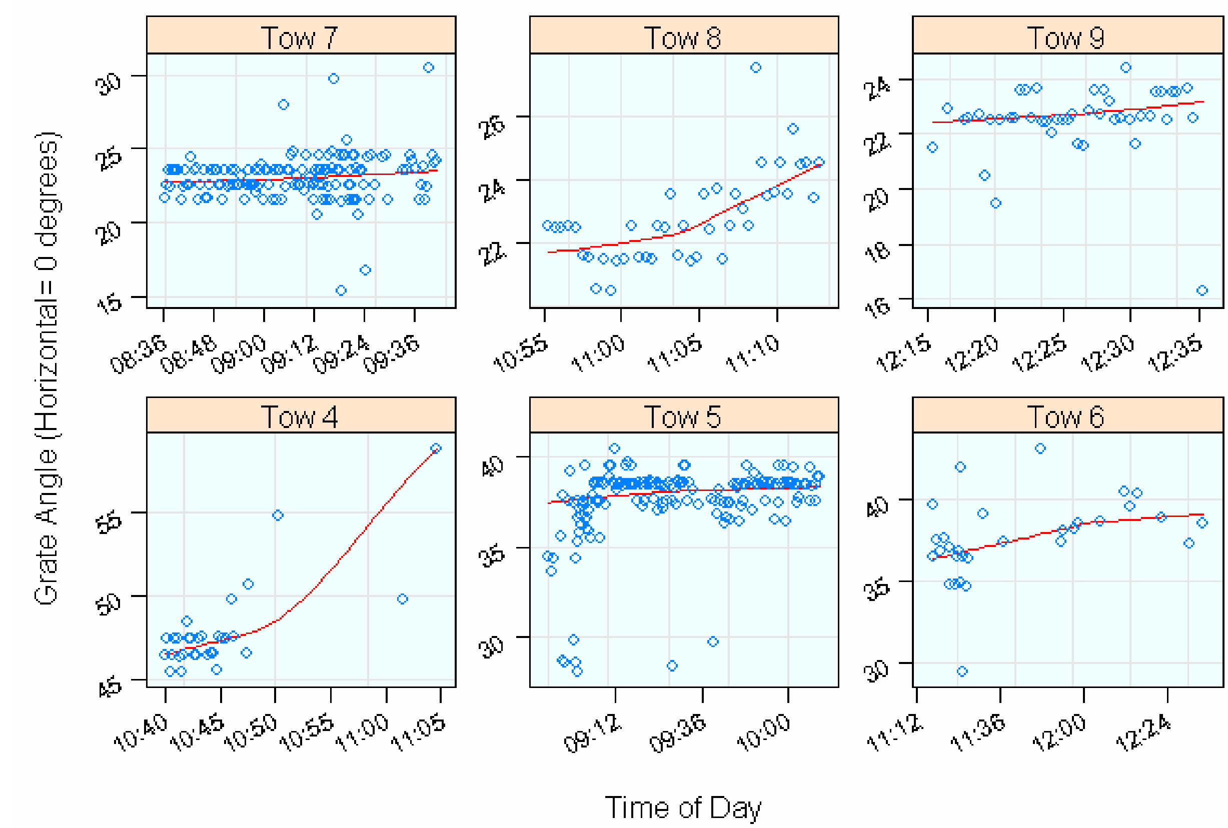


Figure 13: Grate angle measurement for various pre-trial tows. The grate angle was set at 45^{o} on land for tows 4, 5, and 6 and 35^{o} on land for tows 7, 8, and 9. The red line is a loess smoother (span=1, family=symmetric).

The vertical bars warped in the Phase 1 grate because the floats located along the top of the grate became trapped between the net drum (while reeling the net in) and the grate itself. Warping was measured following tow 6 (n=16, mean=1.98 in, standard error=0.09 in) and at the end of Phase 1 (n=16, mean=2.05 in, standard error=0.06 in). After tow 6, the floats were moved to the upper sides of this grate for the duration of Phase 1. Floats for the Phase 2 grates were consequently attached at the upper side, and no warping was seen for the Phase 2 grates. All grates became slightly concave along the vertical bars (from the front of the net) after continued usage although this did not affect the bar spacing.

The confidence intervals around the means (95%) showed no significant changes in measured mesh sizes for the Phase 1 net; in Phase 2, significant mesh reductions occurred in the top wing, side panel, and top belly sections over time; other measured sections had no significant differences. The extension (which was used for both phases) showed no significant difference over the course of the work.

The temperature logger that was attached to the net during Phase 2 was lost during field work. Therefore, no temperature data was analyzed.

Discussion

Independent of color, angle, or gear orientation, the grates were successful at excluding spiny dogfish while retaining adequate catches of silver hake and other smaller target species. The effectiveness of the grate was demonstrated by the dogfish seen escaping on the primary and secondary videos and by the low amounts of dogfish in the codend. Sharks are reported to have excellent spatial capabilities that may have assisted their ability to escape (Montgomery and Walker, 2001). Dogfish did not suffer any apparent injury from contact and escape, and any induced mortality from stress or injury by escaping from the grate is likely to be far less than the 5.9%-50% discard bycatch mortality estimated for trawl-caught individuals (Mandelman and Farrington, 2007a, 2007b). These results suggest that use of a dogfish excluder grate is preferable to discarding from on deck.

The catch of silver hake appeared to be of high quality, but the quantity lost, if any, by the grate is unknown. The industry partners on this project already judge that the exclusion of the dogfish has significantly reduced their total fish handling time, and improved the quality of their catch while obtaining commercial quantities of target species; they have adopted this design to use during their normal silver hake season and have also generated further interest in the fishing community.

The grates' 50 mm (2.0 in) bar spacings appeared to be appropriate to allow for commercial-sized catches with nearly no fish becoming wedged between the bars. Possible loss of larger target fish is a concern with any grate in a trawl fishery. The bar spacings were chosen based on our experience with a grid using 64 mm (2.5 in) spacing which caused spiny dogfish to become frequently wedged between the bars. He and Balzano (2007) also reported no significant loss in silver and red hake catches using a similar style grate with 25 mm (1.0 in) bar spacings in a Gulf of Maine shrimp net.

Based on observations made during Phase 1, grates set at 45° produced adequate exclusions of spiny dogfish while retaining satisfactory target catches compared to the 35° angle. Therefore, we subsequently set the grates at 45° (in both directions leading to either a top or bottom escape vent). The limited scope of the project did not permit a fuller examination of optimal grate angle. It is worth noting that Figure 7 displays the highest catch in silver hake using the 35° grate angle and the smallest dogfish catches, contrary to our expectations. This result may have been due to the concentrations of fish susceptible at the time. We are unsure as to why tow 4 showed larger angles overall (Figure 13). We conclude that the true angle of the grate may change based on multiple conditions that impact net geometry, such as substrate type, bottom contact, catch size, sea state, and currents.

Slight reductions in some mesh sizes occurred during Phase 2. The net used at this time was brand new and not yet fished. It is common that some initial reduction in mesh sizes occur with new nets (pers. comm.) but the difference was judged to be inconsequential for the conclusions.

The video captured was divided into blocks in order to reduce processing time, and to obtain representative fish concentrations throughout the course of the tow. Limitations to this approach occur during times of poor visibility, limited fields of view (due to twisting within the extension or camera blockages from fish or other objects), and spiny dogfish blockages in front of the grate. It was particularly difficult to estimate numbers and behaviors during high concentrations of dogfish that blocked the grates. For these reasons, some sections or tows could not be adequately analyzed for dogfish counts or behaviors.

The behavioral interactions between fish prevent simple statements on behavioral tendencies.

However, group behaviors may more appropriately represent the behaviors during actual fishing conditions.

Some video revealed that the grates displayed areas of different contrast (visible to the human eye) due to their squared edges. Penetrating sunlight most likely reflected off certain areas of the grates more readily depending on the angle of incidence and placement of the grates. This varying reflection may have improved the visibility of the grates to some species, especially for the white grates which offer better light reflection. The improved visibility may have helped or hindered species avoidance.

While all configurations effectively excluded dogfish, the optimal gear arrangement may depend on the species desired. Since herring appear to generally remain high in the extension, an arrangement with a bottom escape vent is suggested if herring are a primary or secondary target. Additionally, this arrangement would support the exclusion of moderate concentrations of spiny dogfish (which generally seem to stay lower based on video observations). We theorized that spiny dogfish would attempt to avoid a highly visible grate (within their visual capabilities). However, the grate colors seem to have had little impact on spiny dogfish behaviors based on the video observations. Conversely, a color that is not strongly visible to target species might have minimal exclusionary effects; other species' behaviors with respect to grate color are inconclusive at this time.

Not enough tows were conducted to predict which arrangements were likely to become blocked with spiny dogfish in extreme concentrations. Even though this work has demonstrated that dogfish can become blocked in front of the grates, the same problem can occur in the codend section if the grates are not used. Furthermore, even in heavy (but not extreme) dogfish concentrations, the grates were successful at excluding dogfish that would have otherwise ended up within the codend. We conclude that the excluder grate works well as a supplement to careful time and/or area planning while fishing (Fonseca et al., 2005; Gasper and Kruse, 2010). Shorter tows may also help avoid large dogfish blockages; physical stress from blockages greatly increases dogfish mortality (Mandelman and Farrington, 2007b). Also, short tows may avoid the effects of a changing grate angle while towing (presumably due to the codend becoming filled).

The excluder grate can expand fishing opportunities for the silver hake fishery when spiny dogfish are present. Geographic or temporal expansion of the SAP may require more knowledge of distribution of both spiny dogfish and other species of concern. Some of the experimental tows were conducted in areas and times outside the raised footrope SAP. The strongest commercial catches were still attained within the SAP area. However, river herring, which are preferably avoided due to poor stock condition, were caught in larger numbers inside the SAP (Appendix 1) and may be difficult to avoid even with the current gear modifications; the difficulty of adequately separating these hapless herring provides further reason to consider the usage of other fishing grounds.

References Cited

Amaru, W.H. 1996. A size selective, near-zero mortality trawl for silver hake. Saltonstall-Kennedy project # NA66FD0011, 88 pp.

Broadhurst, M.K. 2000. Modifications to reduce bycatch in prawn trawls: A review and framework for development. Rev. Fish Biol. Fish. 10: 27-60.

Carr H.A. and P. Caruso. 1993. Application of a horizontal separating panel to reduce by catch in the small mesh whiting fishery. Technical report. Massachusetts Division of Marine Fisheries. 7 pp.

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

Col, L. and M. Traver. 2006. Silver hake. In: Status of Fishery Resources off the Northeastern United States, National Marine Fisheries Service Northeast Fisheries Science Center. Edited by: R. Mayo, F. Serchuk and E. Holmes. http://www.nefsc.noaa.gov/sos/spsyn/op/dogfish/

Colette, B. and G. Klein-MacPhee. 2002. Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, DC.

Domenici, P., E.M. Standen, and R.P. Levine. 2004. Escape manoeuvres in the spiny dogfish (Squalus acanthias). J. Exp. Biol. 207: 2339-2349.

Eigaard, O. and R. Holst. 2004. The effective selectivity of a composite gear for industrial fishing: a sorting grid in combination with a square mesh window. Fish. Res. 68: 99-112.

Fonseca, P., A. Campos, B. Mendes, and R. Larsen. 2005. Potential use of a Nordmore grid for by-catch reduction in a Portuguese bottom-trawl multispecies fishery. Fish. Res. 73: 49-66.

Gasper, J.R. and H. Kruse. 2010. The spatial distribution of spiny dogfish (*Squalus acanthias*) in the Gulf of Alaska: the use of fishery-dependant data, fishery independent data, and generalized modeling for the spatial management of catch and bycatch. ICES C.M. 2010/E:07.

Glass, C.W., C.S. Wardle, S.J Gosden, and D.N. Racey. 1995. Studies on the use of visual stimuli to control fish escape from codend. I. Laboratory studies on the effect of a black tunnel on mesh penetration. Fish. Res. 23: 157-164.

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

Harrington, J.M., R.A. Myers, and A.A. Rosenberg. 2005. Wasted fishery resources: discarded by-catch in the USA. Fish Fish. 6: 350-361.

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

He, P. & V. Balzano. 2007. Reducing the catch of small shrimps in the Gulf of Maine pink shrimp fishery with a size-sorting grid device. ICES J. Mar. Sci. 64: 1551-1557.

Isaksen, B., J. Valdemarsen, R. Larsen, and L. Karlsen. 1992. Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. Fish. Res. 13: 335-352.

Kvalsvik, K., I. Huse, O.A. Misund and K. Gamst. 2006. Grid selection in the North Sea industrial trawl fishery for Norway pout: Efficient size selection reduces bycatch. Fish. Res. 77: 248-263.

La Valley, K. 2007. Can mischmetal stave off dogfish hordes? Commercial Fisheries News, September 2007. http://extension.unh.edu/Marine/Docs/SeaGrant9_07.pdf

Main, J. and G.I. Sangster. 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scottish Fisheries Research Report. Department of Agriculture and Fisheries for Scotland. 23: 23 pp.

Mandelman, J.W. and M.A. Farrington. 2007a. The physiological status and mortality associated with otter-trawl capture, transport, and captivity of an exploited elasmobranch, *Squalus acanthias*. ICES J. Mar. Sci. 64: 122-130.

Mandelman, J.W. and M.A. Farrington. 2007b. The estimated short-term discard mortality of a trawled elasmobranch, the spiny dogfish (*Squalus acanthias*). Fish. Res. 83: 238-245.

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

McKiernan, D.J., R. Johnston, W. Hoffman, H.A. Carr, H. Milliken and D. McCarron. Southern Gulf of Maine Raised Footrope Trawl 1997 Experimental Whiting Fishery. 1998. Technical report. Massachusetts Division of Marine Fisheries. 34 pp.

Montgomery, J. and M. Walker. 2001. Orientation and navigation in elasmobranchs: which way forward? Environ. Biol. Fishes. 60: 109-116.

New England Fishery Management Council. 2003. Whiting Plan Development Team (PDT) Report. Newburyport, MA. October 16, 2003. 2003 Small Mesh Multispecies Stock Assessment and Fishery Evaluation (SAFE) Report. http://www.nefmc.org/mesh/safe_reports/2003_whiting_safe.pdf.

Northeast (NE) Multispecies Small Mesh Fishery Exemptions. 2010. http://www.nero.noaa.gov/nero/regs/infodocs/Small_mesh_exemption.pdf.

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.

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.

Sosebee, K. and P. Rago. 2006. Spiny Dogfish. In: Status of Fishery Resources off the Northeastern United States, National Marine Fisheries Service Northeast Fisheries Science Center. Edited by: R. Mayo, F. Serchuk and E. Holmes.

http://www.nefsc.noaa.gov/sos/spsyn/op/dogfish/.

Wardle, C.S. 1989. Understanding fish behaviour can lead to more selective fishing gears. In "1988 World Symp. on Fishing Gear and Fishing Vessel Design, St. John's, NF (Canada), 20 Nov 1988". St John's, Newfoundland, Canada: The Newfoundland and Labrador Institute of Fisheries and Marine Technology.

Data and Other Supplemental Materials Provided

Additional supplements are included along with this final report and include the project database, images, selected Phase 1 underwater video, and selected sample one-minute clips of the Phase 2 video blocks analyzed. Only the video that was digitized from the original DV format is provided. Behavioral observations were either conducted from the DV tapes themselves or the digitized version which were chosen for space reasons and convenience.

Copies of presentations and MA DMF publications are also provided.

R code and additional video are available upon request to the Massachusetts Division of Marine Fisheries.

Partnerships

The goals provided in this paper represent interests of both science and the fishing community. The execution and completion of this work was dependant upon the cooperative input and resources between the research and industry participants. Additionally, both groups donated extra time and effort towards the project improving the results and forming a stronger partnership.

Tasks were divided into the following categories and assigned to the appropriate parties:

Task	Participant: research	Participant: industry
Acquisition of grid materials		x
Fabrication and modification of grid	x	x
Provide fishing net		x
Provide research equipment	x	
Operation of vessel and fishing gear		x
Project coordination	x	
Interpretation of behavior	x	x
Suggestions for grid changes	x	x
Camera supply acquisition	x	
Filming	x	
Report writing	x	
Data analysis	x	
Video analysis	x	
Camera deployment	x	
Sea sampling	x	
Administration/Invoicing	x	
Database development	x	
EFP issues	x	

Our industry partners, Frank and Andrew Mirarchi, were enthusiastically involved with this project from their design of the concept, to their superb field work, and their knowledgeable feedback while conducting research and after the field work was complete. The research benefited greatly from their participation. The Mirarchis and MA DMF have reestablished an excellent working relationship and we look forward to future shared projects.

Other participants from a number of science institutions and related industries assisted in the field work and further fostered the relationship with the research industry members. These people are listed in the Acknowledgements section below.

Impacts and applications

The results of this research have demonstrated that an excluder grate can substantially decrease spiny dogfish catch while retaining commercial levels of target species. Since the grate meets federal regulatory requirements, the industry partners have already employed this gear for their own commercial usage. Also, this work has stimulated interest among other fishermen.

This excluder grate provides multiple benefits for the industry including a decreased non-target species catch, improved quality of landed catch, reduced safety concerns (from over-loaded codends with spiny dogfish), time reduction for handling less dogfish, and a decreased chance of tripping a dogfish catch limit. Likewise, dogfish stocks also benefit in that the excluder grate most likely removes the discard mortality for individuals otherwise retained in a codend.

For these reasons, the dogfish excluder grate should have a high interest for the fishing industry and managers. The following individuals and institutions would benefit from knowing this research:

- Andrew Applegate. New England Fishery Management Council. 50 Water St., Mill 2,

Newburyport, MA 01950. Phone: 978-465-0492. Email: AApplegate@NEFMC.ORG
- Ken LaValley. New Hampshire Sea Grant. 219 Nesmith Hall, UNH, Durham, NH 03824. 603-862-4343. Email: ken.lavalley@unh.edu
- Tom Testaverde. Fisherman. Vessel: Midnight Sun. Gloucester. 978-375-0433.
- Laurel Col. Northeast Fishery Science Center. 166 Water St., Woods Hole, MA 02543. Phone: 508-495-2195. Email: laurel.col@noaa.gov
- Michele Traver. Northeast Fishery Science Center. 166 Water St., Woods Hole, MA 02543. Phone: 508-495-2195. Email: michele.traver@noaa.gov
- Local net makers

Presentations

Chosid, D.M. and Pol, M. 2009. [poster]. Let Slip the Dogs of War! Development of a Spiny Dogfish Excluder in a Raised Footrope Whiting Trawl. Northeast Consortium 8th Annual Project Participants' Meeting. Portsmouth, NH. March 25, 2009.

Chosid, D.M. 2010. Video observations of a whiting net bycatch reduction device. Presentation to Hake 2010: International Symposium on the Biology, Harvesting, Management and Conservation of Hakes, Portland, Maine. May 11-12, 2010.

Chosid, D.M., M. Pol., F. Mirarchi, M. Szymanski, and A. Mirarchi. 2010. DogGrate: Video Observation and Testing of a Grate to Reduce Bycatch of Spiny Dogfish in a Silver Hake Fishery. ICES ASC 2010: Theme Session E:23 – Elasmobranch Fisheries. Nantes, France. Sept. 20, 2010.

Mirarchi, F., M. Szymanski, D.M. Chosid, M. Pol., and A. Mirarchi. [scheduled]. DogGrate: Development of a spiny dogfish excluder in a raised footrope whiting trawl. Northeast Consortium 9th Annual Project Participants' Meeting. Portsmouth, NH. Oct. 21, 2010.

Published Reports and Papers

La Valley, K. 2009. Dog-grate aims to boost access to whiting. Commercial Fisheries News. June, 2009.

Chosid D.M., M. Pol, M. Szymanski, F. Mirarchi, and A. Mirarchi. [report submitted 2009]. Video Observation and testing of a grate to reduce bycatch of spiny dogfish *Squalus acanthias* in a silver hake *Merluccius bilinearis* trawl fishery. ICES C.M. 2010/E23.

Chosid D.M., M. Pol, M. Szymanski, F. Mirarchi, and A. Mirarchi. [report submitted 2009]. Development and observations of a spiny dogfish reduction device in a raised footrope whiting trawl. Submitted to the convenors for the Fisheries Research, Hake Symposium special edition.

Future Research

This project demonstrated that excellent spiny dogfish reductions can be achieved using an excluder grate while retaining commercial catches of target species. However, the actual quantity of species lost, both desirable and undesirable, is unknown. Continued research to investigate the catch lost requires a collection bag over the escape vent or catch comparison tows with a control net, neither of which this current project was permitted to use. This work would provide an excellent follow-up study to further prove that the experimental gear adequately retains target species.

Through a cooperative effort from New Hampshire Sea Grant, the Northeast Consortium, and the Massachusetts Division of Marine Fisheries, further outreach measures are planned to introduce the excluder grate design to interested fishermen. This grate design is legal to use and is a simple and cheap modification to existing fishing gear. Exposure to the grate may persuade fishermen that benefits can be gained, both for the health of the affected fish stocks and financially.

Acknowledgements

Funding for this research was primarily provided by the Northeast Consortium. We would like to thank various people for their contributions on this project. Frank and Andrew Mirarchi contributed their time, vessel, and equipment for the Phase 1 research beyond the original scope of this project. Rachel Feeney (NEC), Doug Zemeckis (School for Marine Science and Technology (SMAST), University of Massachusetts), Andrew Applegate (New England Fisheries Management Council), Tyler Staple (NMFS), and Steve Voss (MA DMF) provided sampling assistance. Dr. Pingguo He (SMAST) provided an underwater camera loan and advice on behavioral analyses.

9/30/10

Signature Date

Appendix 1 - Tables

Species captured by tow (kg). Species whose totals are below 5.0 kg are not shown and include: blueback herring (Alosa aestivalis),ocean quahog (Artica islandica), rock crab (Cancer irroratus), fourbeard rockling (Enchelyopus cimbrius), sea raven (Hemitripterus americanus), snake blenny (Lumpenus lumpretaeformis), little skate (Raja erinacea), thorny skate (Raja radiate), skate nk (Rajidae), cunner (Tautogolabrus adspersus), and spotted hake (Urophycis regia). Unknown species are listed as "nk".

		Tow											
Scientific Names	Common Names	1	2	3	4	5	6	7	8	9	10	11	12
Alosa	herring, river, nk (blueback or alewife))	0.0	0.0	0.0	0.0	20.9	46.7	15.0	21.3	5.0	0.0	0.0	0.0
Alosa pseudoharengus	alewife	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alosa sapidissima	shad, American	0.0	0.7	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Clupea harengus	herring, Atlantic	252.2	3129.8	339.1	7.0	117.4	130.4	2.0	0.5	0.5	53.4	94.9	30.5
Clupeidae	herring, nk (shad)	0.0	0.0	0.0	0.0	0.0	2.9	2.3	0.2	0.0	0.0	0.0	0.0
Cottidae	sculpin, nk	0.1	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gadus morhua	cod, Atlantic	1.1	0.0	2.7	0.9	4.5	1.8	1.1	1.1	0.2	0.0	0.5	4.9
Glyptocephalus cynoglossus	flounder, witch (grey sole)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	9.4
Hippoglossina oblonga	flounder, fourspot	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Hippoglossoides platessoides	flounder, American plaice (dab)	3.9	6.1	5.2	46.0	15.2	11.6	0.0	0.2	0.2	0.0	3.8	6.4
Homarus americanus	lobster, American	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Illex illecebrosus	squid, short-fin (illex)	0.8	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.0	1.8
Limanda ferruginea	flounder, yellowtail	0.0	0.0	0.0	0.0	1.6	0.1	1.8	1.1	3.6	0.0	1.7	1.8
Loligo pealeii	squid, Atl. long-fin (loligo)	0.0	1.4	2.9	1.4	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0
Macrozoarces americanus	ocean pout	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melanogrammus aeglefinus	haddock	0.9	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	5.7
Merluccius bilinearis	hake, silver (whiting)	32.7	39.5	24.5	306.6	160.6	60.3	229.3	157.9	333.6	0.4	11.6	16.9
Myoxocephalus octodecemspinosus	sculpin, longhorn	0.0	0.0	0.0	0.0	0.0	0.1	0.9	0.9	2.9	0.0	0.0	0.7
Peprilus triacanthus	butterfish	1.7	3.4	2.7	0.0	2.7	1.8	1.1	0.1	0.0	0.0	27.3	3.2
Pollachius virens	pollock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pseudopleuronectes americanus	flounder, winter (blackback)	0.0	0.0	0.0	0.9	6.8	2.0	2.0	0.0	4.5	0.0	0.6	0.0
Scomber scombrus	mackerel, Atlantic	0.0	0.0	0.0	0.0	25.9	48.8	9.1	0.1	1.4	0.0	0.0	0.0
Squalus acanthias	dogfish, spiny	2.5	6.8	3.4	59.6	22.5	29.7	1.1	0.0	2.5	1.4	0.0	0.0
Coleoidea (subclass)	squid, nk	0.0	0.0	0.0	0.0	4.3	5.0	0.0	4.5	2.9	0.0	0.0	0.0
Urophycis chuss	hake, red (ling)	19.1	9.5	19.7	49.7	42.6	31.3	7.7	8.4	1.4	0.4	16.4	23.4
Urophycis tenuis	hake, white	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0

Table cont.

Scientific Names	Common Names	Tow 13	14	15	16	17	18	19	20	21	22	23	24
Alosa	herring, river, nk (blueback or alewife))	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alosa pseudoharengus	alewife	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	5.0	1.1	6.5
Alosa sapidissima	shad, American	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	6.5	0.3	2.2
Clupea harengus	herring, Atlantic	105.2	246.9	376.3	83.9	28.3	17.4	26.9	21.0	29.7	8.0	0.5	6.5
Clupeidae	herring, nk (shad)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cottidae	sculpin, nk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gadus morhua	cod, Atlantic	0.4	0.0	0.8	0.2	3.6	0.0	0.1	3.0	0.0	0.0	1.1	5.1
Glyptocephalus cynoglossus	flounder, witch (grey sole)	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hippoglossina oblonga	flounder, fourspot	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hippoglossoides platessoides	flounder, American plaice (dab)	6.8	2.3	2.2	0.9	2.4	5.0	6.4	7.3	4.6	2.6	0.1	3.0
Homarus americanus	lobster, American	0.0	0.4	0.2	0.0	0.0	0.4	0.0	0.7	0.3	0.7	0.0	0.0
Illex illecebrosus	squid, short-fin (illex)	1.4	5.3	2.6	4.9	2.1	2.9	3.5	4.1	1.9	4.0	1.4	6.6
Limanda ferruginea	flounder, yellowtail	2.8	1.0	0.9	0.3	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.6
Loligo pealeii	squid, Atl. long-fin (loligo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macrozoarces americanus	ocean pout	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melanogrammus aeglefinus	haddock	2.4	0.0	0.4	0.0	0.0	0.0	0.0	2.9	0.0	0.9	0.0	2.5
Merluccius bilinearis	hake, silver (whiting)	37.0	17.9	19.1	31.0	14.5	55.2	83.1	77.5	58.8	54.1	2.4	11.4
Myoxocephalus octodecemspinosus	sculpin, longhorn	0.2	0.0	0.3	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.3
Peprilus triacanthus	butterfish	2.5	2.2	2.5	0.8	0.6	0.7	27.9	23.1	38.7	63.5	11.8	8.8
Pollachius virens	pollock	0.1	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0	52.5	1.2	0.0
Pseudopleuronectes americanus	flounder, winter (blackback)	3.2	2.9	1.2	0.4	0.7	1.6	0.3	2.5	0.5	1.8	0.2	0.0
Scomber scombrus	mackerel, Atlantic	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Squalus acanthias	dogfish, spiny	0.0	1.4	0.0	3.9	0.0	1.0	25.1	6.7	35.0	13.1	27.9	38.4
Coleoidea (subclass)	squid, nk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urophycis chuss	hake, red (ling)	20.0	10.3	26.2	19.1	14.6	14.2	19.7	15.3	11.1	20.5	1.2	5.8
Urophycis tenuis	hake, white	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0

Table cont.

Scientific Names	Common Names	Tow 25	26	27	28	29	30	31	32	33
Alosa	herring, river, nk (blueback or alewife))	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Alosa pseudoharengus	alewife	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alosa sapidissima	shad, American	0.0	0.0	0.1	0.0	0.7	0.0	0.0	0.0	0.0
Clupea harengus	herring, Atlantic	62.1	16.4	49.6	29.9	80.1	172.9	20.9	1.4	0.7
Clupeidae	herring, nk (shad)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cottidae	sculpin, nk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gadus morhua	cod, Atlantic	0.5	0.3	0.6	0.2	0.3	1.8	0.0	0.0	0.0
Glyptocephalus cynoglossus	flounder, witch (grey sole)	0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0
Hippoglossina oblonga	flounder, fourspot	0.0	0.0	0.1	0.2	0.2	0.6	0.1	0.0	0.0
Hippoglossoides platessoides	flounder, American plaice (dab)	5.1	1.2	5.7	7.0	7.8	4.6	0.7	0.5	0.1
Homarus americanus	lobster, American	0.7	0.0	1.0	0.0	0.0	0.2	0.0	0.0	0.0
Illex illecebrosus	squid, short-fin (illex)	4.7	1.4	2.8	2.0	1.2	2.3	3.7	4.5	1.5
Limanda ferruginea	flounder, yellowtail	1.1	0.2	0.8	0.0	1.5	0.7	0.3	0.0	0.5
Loligo pealeii	squid, Atl. long-fin (loligo)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macrozoarces americanus	ocean pout	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Melanogrammus aeglefinus	haddock	0.0	0.0	0.1	0.6	0.3	2.5	0.0	0.0	0.0
Merluccius bilinearis	hake, silver (whiting)	99.2	9.9	112.3	52.3	61.2	26.7	11.0	83.4	27.8
Myoxocephalus octodecemspinosus	sculpin, longhorn	0.0	0.2	0.1	1.0	0.0	0.0	0.0	0.0	0.0
Peprilus triacanthus	butterfish	15.7	12.7	2.2	2.5	4.1	4.9	1.4	2.0	2.3
Pollachius virens	pollock	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pseudopleuronectes americanus	flounder, winter (blackback)	2.2	0.0	1.3	3.5	1.6	1.4	0.7	0.8	0.0
Scomber scombrus	mackerel, Atlantic	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Squalus acanthias	dogfish, spiny	6.7	22.5	10.2	5.8	8.4	3.1	63.9	0.6	1.5
Coleoidea (subclass)	squid, nk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urophycis chuss	hake, red (ling)	20.9	3.9	25.7	12.6	32.1	21.6	13.1	12.0	2.8
Urophycis tenuis	hake, white	0.6	0.0	1.3	1.5	0.2	0.0	0.0	0.0	0.0

Appendix 2 – Figures

Box-and-whisker plots of net mensuration measurements (m) by tow.