Fisheries Research xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope silver hake *Merluccius bilinearis* trawl

David M. Chosid[a,*], Michael Pol[a], Mark Szymanski[a], Frank Mirarchi[b], Andrew Mirarchi[b]

[a] *Massachusetts Division of Marine Fisheries, 1213 Purchase St. – 3rd Floor, New Bedford, MA 02740, USA*
[b] *Fishing Vessel Barbara L. Peters, 67 Creelman Dr., Scituate, MA 02066, USA*

ARTICLE INFO

Article history:
Received 30 November 2010
Received in revised form 9 March 2011
Accepted 16 March 2011

Keywords:
Excluder grate
Grid
Trawl
Squalus acanthias
Merluccius bilinearis
Behavior

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, USA between October 2008 and August 2009 using a live-fed underwater video camera. Grates with 50 mm spacing were investigated for effects from color (white or black), angle, 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, while target species were caught in commercial quantities. Four tows (of various gear configurations) resulted in spiny dogfish blockages in front of the grate. The reduction of spiny dogfish led to increases in the quality of marketable catches, likely reductions in non-target species mortality, and decreases in the codend catch handling times.

Published by Elsevier B.V.

1. 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 often a hindrance to rebuilding of groundfish stocks and to fishing in general (Bowman et al., 1984; Rago et al., 1998; Hilborn, 2011). 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 obs.; Massachusetts Division of Marine Fisheries, unpublished data). Specifically, spiny dogfish are a primary impediment to exploiting the healthy silver hake (whiting) *Merluccius bilinearis* stock (pers. obs.).

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 mainly using a small mesh (≤76 mm), mandatory raised footrope trawl. A raised footrope trawl is a trawl with its fishing line (footrope) raised above the groundgear using a number of connecting toggle (drop) chains (He, 2007). For this study, this rigging raises the footrope approximately 0.5 m off-bottom and allows some non-target species to pass under the net (Carr and Caruso, 1993; McKiernan et al., 1998; He and Winger, 2010). However, spiny dogfish, generally unwanted, are still susceptible to this trawl net and are easily retained in the small mesh codend.

Excluding spiny dogfish from trawl nets has multiple benefits, primarily the reduction of dogfish mortality (Harrington et al., 2005). High discards of dogfish could potentially close fisheries if catch allowances are exceeded. 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 spatially or temporally in the silver hake fishery. As dogfish populations increase, avoidance becomes more difficult. Fortunately, dogfish are generally larger than silver hake, and therefore could potentially be mechanically removed from or herded out of a net using an excluder grate (grid) (Amaru, 1996; Broadhurst, 2000;

Abbreviations: RFT, raised footrope trawl; pers. obs., personal observation; PE, polyethylene; HDPE, high density polyethylene; RFEA, Raised Footrope Exemption Area; nk, not known; Atl., Atlantic; TYP, typical; SMAST, School for Marine Science and Technology.

* Corresponding author. Tel.: +1 508 990 2860x140; fax: +1 508 990 0449.
E-mail addresses: david.chosid@state.ma.us (D.M. Chosid), mike.pol@state.ma.us (M. Pol), mark.szymanski@state.ma.us (M. Szymanski), kaminc@comcast.net (F. Mirarchi), amirarchi5@gmail.com (A. Mirarchi).

0165-7836/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.fishres.2011.03.007

Eigaard and Holst, 2004). Excluder grates in trawl nets act somewhat 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 larger, 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. Specific visual stimuli can enhance fish escape within fishing gear during the capture process (Glass et al., 1995; He, 2010). Different species may have different reactions to visual stimuli, such as color and contrast, which can then be used to encourage unique behavioral responses (Chosid et al., 2008). Therefore, the color of an excluder grate might enhance the escape of certain species without affecting the capture of others. Black and white grates were easily attainable and provided a broad comparison of dissimilar colors and contrasts for this study.

Grates are typically angled into or away from the tow direction to help direct the escape of unwanted fish out of the net, with the net's escape opening (vent) on top or on 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 location might alter the ease of escape of some species. Therefore, two grate angles, top and bottom openings, in combination with black and white-colored grates, were investigated during this study.

Four objectives were identified in developing an excluder grate to eliminate spiny dogfish from a raised footrope trawl net: observe the behavior of spiny dogfish and silver hake around excluder grates using underwater video; investigate and refine the effectiveness of excluder grate properties, gauged by target species catches and spiny dogfish exclusions; produce a prototype grate design to be used in follow-up commercial trials; make recommendations for an expanded silver hake fishery in Cape Cod Bay and Massachusetts Bay.

2. Materials and methods

This project was conducted in two phases. Different nets and grates were used in each phase and testing locations also differed between trials. In Phase 1, grate angles were investigated using a white prototype grate with a bottom escape opening in a used raised footrope trawl (RFT). In Phase 2, we refined the grate design and explored the effects from different colored grates (black or white) and escape vent position (top or bottom) in a new RFT.

2.1. Net and grate

2.1.1. Phase 1

Careful examination of this phase's two-panel RFT at the end of the fieldwork revealed multiple irregular modifications to repair prior damage and to adjust for warped meshes that occurred before our acquisition of the net. Headrope and footrope lengths were 27.4 m and 34.1 m respectively. The sweep and drop chains were 7.9 mm galvanized chain; vertical drop chains were 1.1 m long. Sixteen 20.3 cm diameter floats were on the headrope. Single-twine, green polyethylene (PE) diamond-shaped meshes were used unless specified below; nominal sizes are provided. The lower extreme wingends had been replaced with 76.2 cm long, 1.3 cm chains. The lower wings, lower belly, upper wingends, and square were constructed of 152 mm, 3.0 mm diameter mesh. One portion of each upper wing was 152 mm (forward section) white nylon and 76 mm (back section), 2.5 mm diameter mesh. The bellies were constructed of 76 mm, 2.5 mm diameter mesh except for a roughly triangular center portion of the lower belly (152 mm, 3.0 mm diameter mesh), used to fill in after considerable warping. A 51 mm diamond-shaped codend was used with a 152 mm diamond-shaped double mesh strengthening bag. The extension was 200 meshes around with 51 mm mesh.

A white grate with 15, 13 mm wide vertical bars with 50.8 mm bar spacings constructed of high density polyethylene (HDPE) was attached within the net's extension. The overall dimensions of this phase's grate were 1143.0 mm wide × 1257.3 mm high × 25.4 mm thick with one central horizontal cross bar for extra structural support. Four 20.3 cm 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 (with the lower portion closer to the aft in Phase 1) when the extension was pulled tight. The grate was nearly neutrally buoyant.

A 2.0 m guiding panel (funnel) with 51 mm meshes was attached inside the extension leading fish up to the top of the grate. The mid-point of the trailing end of the guiding panel was set approximately 20.3 cm away from the grate, and approximately 30.5 cm from the nearest mesh of the extension. The escape opening (vent) was located at the bottom of the extension, just forward of the grate and was approximately 38.1 cm long × 114.3 cm wide. 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.

2.1.2. Phase 2

A new whiting net and a grate design were used in Phase 2. The new, typical 4-panel box RFT was constructed with single-twine, diamond-shaped meshes throughout (Fig. 1). Nominal sizes are provided below. The headrope was 28.7 m; the footrope was 29.5 m. A section of the lower bridle, used to adjust the footrope height (flychain), was composed of 3.4 m 9.5 mm diameter stainless steel wire and 0.3 m of 7.9 mm diameter galvanized chain which allowed adjustment by links. Twenty-five 20.3 cm diameter floats were on the headrope spaced approximately 1.2 m apart. The codend was made from 64 mm mesh. The same extension and guiding panel were used as in Phase 1. Nine galvanized drop-chains (7.9 mm diameter, 1.1 m long) from the footrope to the 7.9 mm diameter galvanized chain sweep were set approximately equally spaced.

Two 1219.2 mm square grates were designed and constructed, both with 50.8 mm bar spacings (Fig. 2). The grates were constructed of 25.4 mm 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 diameter 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 Phase 1 testing. The grates angles' were set at 45° from the top and bottom extension walls for all of Phase 2.

Minor modifications to the gear were made during both phases consistent with normal fishing operations and as recommended by the industry partners. These modifications included changes to buoyancy and weights of the grate and net, and setback to bridle chains.

2.2. Field work

Field work for both phases was conducted on-board the F/V *Barbara L. Peters*, a 16.8 m, 214.8 kW 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

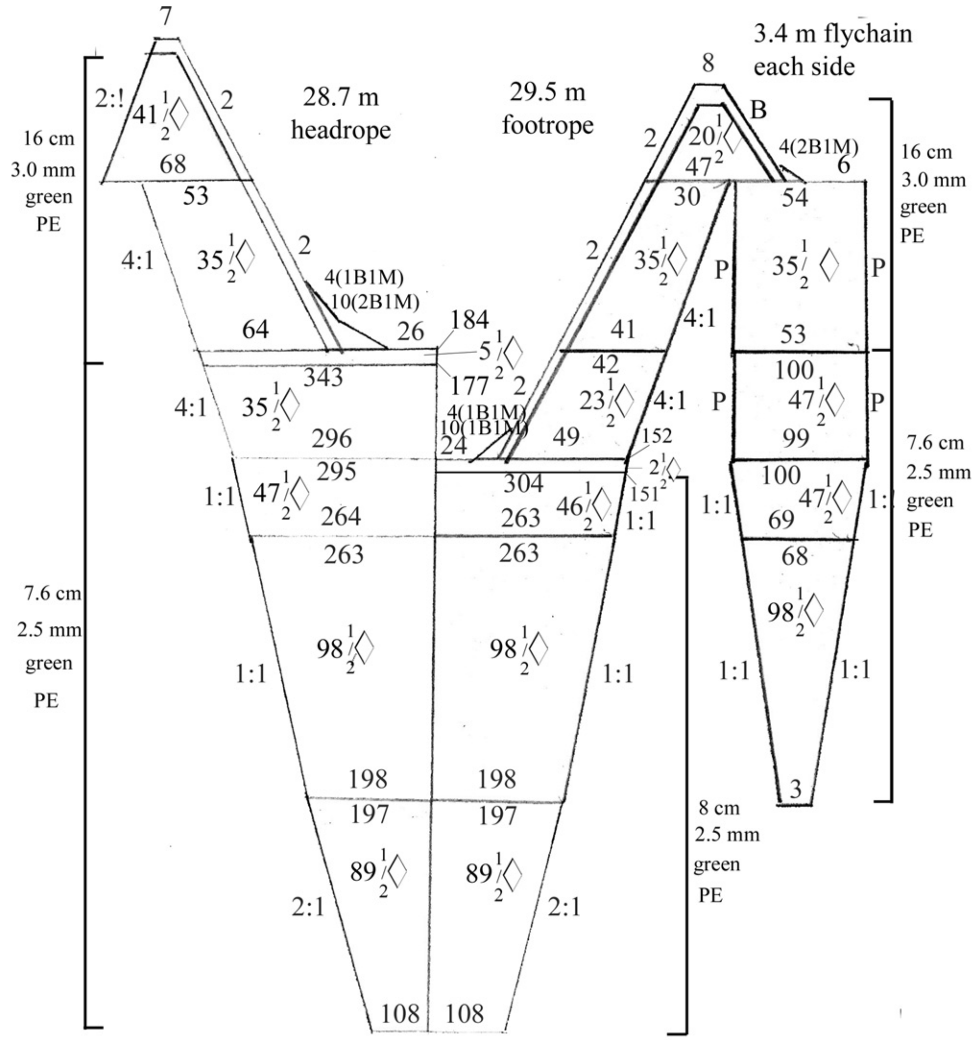
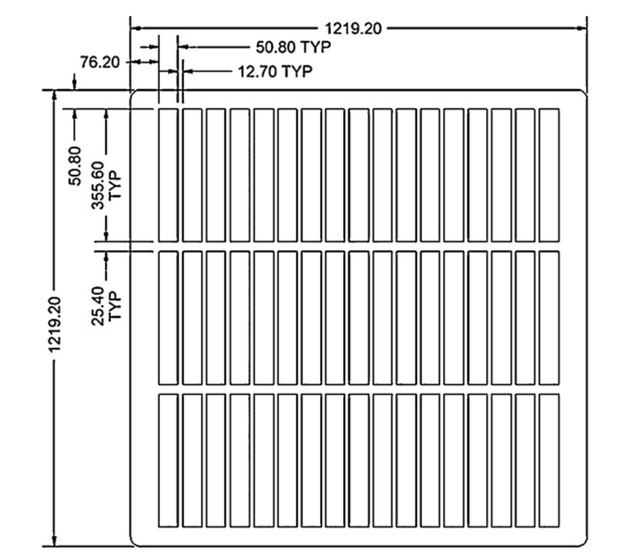


Fig. 1. Net plan for the Phase 2 whiting net.



PLASTIC	VOLUME (mm^3)	DENSITY (kg/mm^3)	WEIGHT IN AIR (kg)	DENSITY OF SALT H2O (kg/mm^3)	WEIGHT IN H2O (kg)
HDPE	1.65x10^7	9.69	16.0	9.96	0.45

Fig. 2. Schematic of the excluder grates used during Phase 2. All dimensions are provided in mm. TYP, typical.

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 locations were 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.

Target tow times were less than 1 h but were also influenced by real time video observations of the fish, depth sounder fish marks, and unexpected occurrences. Vessel speed-over-ground was kept at around 1.5 m/s 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 (from the anterior extremity of the fish to the tip of the median rays of the tail) were recorded for silver hake, red hake *Urophycis chuss*, and other selected catch. Total lengths (from the anterior extremity to the posterior extremity) were recorded for spiny dogfish. 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

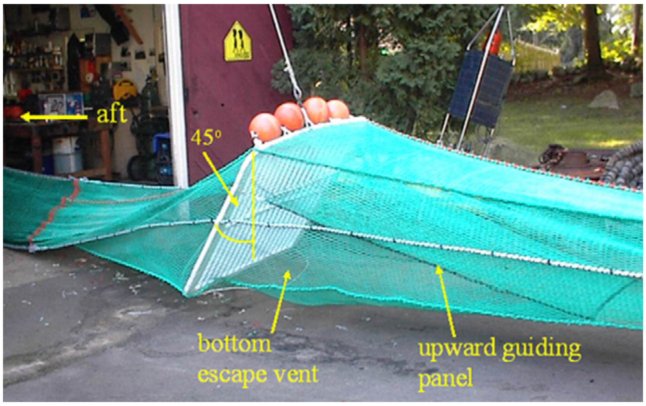


Fig. 3. Phase 1 excluder grate in the extension of the whiting net showing the gear components and initial orientations.

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. Video was collected under natural light to avoid behavioral effects from artificial light sources (He, 2010). A Notus Electronics Ltd. (St. John's, Newfoundland) net mensuration system with a portable hydrophone was used to observe and record gear characteristics and to also ensure proper gear rigging. Video and net data were recorded, post-processed, and later reviewed using Adobe Premiere and Notus Trawlmaster software respectively.

2.2.1. Phase 1

Phase 1 field work was completed October–November, 2008 during the normal silver hake season in the Raised Footrope Exemption Area (RFEA) north and west of Provincetown, Massachusetts, USA.

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 approximately at 45° and 35° on land) (Fig. 3).

Tows were conducted with the following grate configurations:

- Arrangement 1, tows 1–6: grate set at 45°.
- Arrangement 2, tows 7–9: grate set at 35°.

Both arrangements 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 model or a custom built system) was attached either on the guiding panel pointing aft or on the grate itself viewing towards the escape vent.

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

2.2.2. Phase 2

The field work for Phase 2 was performed in Massachusetts Bay, USA, primarily outside the RFEA between 42°12′W lat. and 42°30′W lat.; some tows were conducted just inside the RFEA.

The following tows and gear configurations (with numbering continued from Phase 1) were completed, all with a 45° angle:

- Arrangement 3, tows 10–15: black grate, top of grate forward-leaning, upward guiding panel, and bottom escape vent.
- Arrangement 4, tows 16–21: black grate, top of grate aft-leaning, downward guiding panel, and top escape vent.
- Arrangement 5, tows 22–28: white grate, top of grate aft-leaning, downward guiding panel, and top escape vent.
- Arrangement 6, tows 29–33: white grate, top of grate forward-leaning, upward guiding panel, and bottom escape vent.

The underwater camera was attached forward of the grate looking aft; distances from the grate and angle of views were not standardized. 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 footage was supplemental and was used to verify some of the behaviors of the primary video and to make other general observations.

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.

2.3. Data analyses

Data consisted primarily of counts of dogfish obtained from video (see below) and in codend catches. Catch comparisons of the various gear configurations using statistical methods were considered a secondary priority, and were not rigorous by design. Collected 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). Box widths are proportional to the square root of the sample sizes within each grouping unless otherwise noted.

Catch weights were adjusted by tow lengths (kg/h). 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.

Performance of the grate during Phase 2 was judged by its ability to exclude spiny dogfish even at high rates of encounter while allowing target species to pass through the bars. To assess performance, we estimated 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 10 min blocks (and whatever the remainder time was at the end of each tow under 10 min), 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.

Spiny 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. Dot-plots were used to analyze and depict exclusion rates for each grate configuration.

Spiny dogfish behaviors from the video clips were individually categorized until they were lost off the camera, lost from view (due to poor video or visual blockages), 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 categories:

- Swim to side
- Swim up
- Swim down
- Swim forwards (towards front of net)
- Swim backwards (aft)
- Body impinged on grate
- Body twists on grate (heading or position adjustment after impingement occurs)

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. Passive 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, 5 min 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 (not shown) to identify anomalous net geometry or problems; trends in grid angle were examined using a dot-plot with a loess smoother (span = 1, family = symmetric).

3. Results

Researchers and the vessel crew completed nine Phase 1 tows over four days in the RFEA near Provincetown, Massachusetts (October–November 2008) (Fig. 4); twenty-four Phase 2 tows (23 valid tows) were completed over nine days inside and west and northwest of the RFEA (July–August 2009).

Video data were collected and reviewed in seven tows from Phase 1 and 23 tows from Phase 2.

3.1. Catch

Results for all species captured in both phases are presented in Table 1. Thirty-seven species or species groups were caught during this study. Species compositions retained in the codend seemed similar for tows conducted in the RFEA (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 normally of high quality.

Four tows from Phase 2 became blocked with spiny dogfish in front of the grate. All of these tows were stopped early except one which became clogged close to the planned end of the tow. One clogged tow used gear arrangement 3; two used arrangement 5; and one 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 that were caught in valid tows included: spiny dogfish, haddock *Melanogrammus aeglefinus*, red hake, silver hake, Atlantic herring, Atlantic mackerel *Scomber scombrus*, and butterfish *Peprilus triacanthus* (Fig. 5). 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 (Fig. 5).

Comparisons, limited by the design of the study, suggested that catches were not strongly affected by different grate arrangements (Fig. 5).

Length frequency distributions for each arrangement showed some differences in sizes for spiny dogfish (Fig. 6). The hake length results were very similar over all arrangements; some variations in sizes were seen during Phase 1 research with smaller sizes of red hake captured in the grate angled at 35°, although this difference may also be an effect of the smaller codend mesh size used in Phase 1.

Twenty-seven video blocks were analyzed for spiny dogfish counts and behaviors from tows with gear arrangement 3, 15 blocks from arrangement 4, and 17 blocks from arrangements 5 and 6 each. The proportion of the total tow time sampled using video ranged from five to eleven percent. Not including clogged tows (which could not be analyzed on video), the estimated numbers of spiny dogfish that entered the net per tow ranged from 0 to 1751.1 individuals (median = 61.8); the number of dogfish retained in the codend (also excluding clogged tows), adjusted for effort, ranged from 0 to 47 individuals (median = 3). More than 88% of the spiny dogfish that entered the extension were excluded by the grate regardless of color or gear configurations (Fig. 7). Other species were more difficult to track and count in video and therefore, not further analyzed for grate efficiencies. The black grate with a bottom escape vent showed the highest ratio of dogfish reduction (0.95–1.0) although the least number of dogfish was observed and caught in these tows overall (Fig. 5).

The grates showed high levels of performance. In the tow with the maximum estimated rate of spiny dogfish entry (1751 individuals), only six dogfish were retained in the codend and no blockage of the excluder grate occurred.

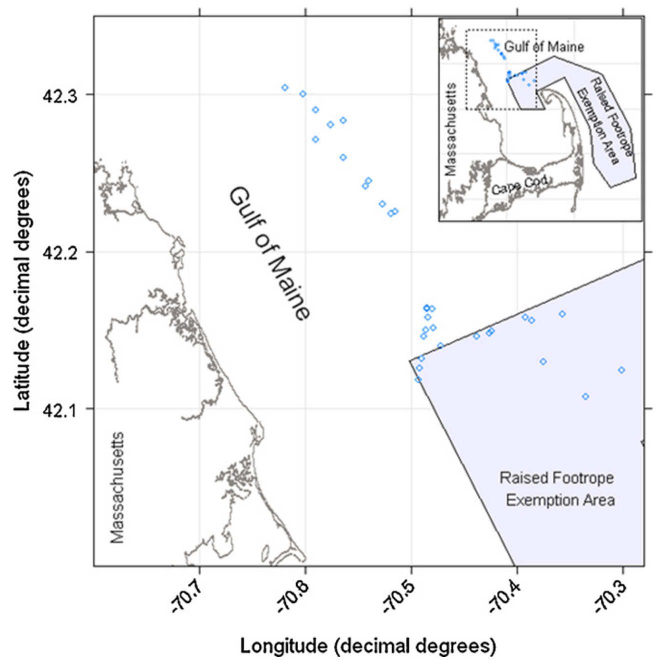


Fig. 4. Start of tow locations during Phase 1 and Phase 2 research in Massachusetts Bay. The area outlined is the Raised Footrope Exemption Area.

Please cite this article in press as: Chosid, D.M., et al., Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope silver hake *Merluccius bilinearis* trawl. Fish. Res. (2011), doi:10.1016/j.fishres.2011.03.007

Table 1
Total catches (kg) for species captured in Phase 1 and Phase 2. Total catches 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 lampretaeformis*), little skate (*Leucoraja erinacea*), thorny skate (*Amblyraja radiata*), skate nk (*Rajidae*), cunner (*Tautogolabrus adspersus*), spotted hake (*Urophycis regia*), sculpin nk (*Cottidae*), fourspot flounder (*Hippoglossina oblonga*), and ocean pout (*Macrozoarces americanus*). Unknown species are listed as "nk" (not known).

Scientific names	Common names	Total weight (kg)	
		Phase 1	Phase 2
Alosa	Herring, river, nk (blueback or alewife)	108.9	0.7
Alosa pseudoharengus	Alewife	1.0	13.2
Alosa sapidissima	Shad, American	1.1	10.0
Clupea harengus	Herring, Atlantic	3978.9	1563.3
Clupeidae	Herring, nk (shad)	5.4	0.0
Gadus morhua	Cod, Atlantic	13.6	23.7
Glyptocephalus cynoglossus	Flounder, witch (grey sole)	0.1	10.8
Hippoglossoides platessoides	Flounder, American plaice (dab)	88.5	86.6
Homarus americanus	Lobster, American	0.0	5.0
Illex illecebrosus	Squid, short-fin (illex)	1.2	71.6
Limanda ferruginea	Flounder, yellowtail	8.3	14.6
Loligo pealeii	Squid, Atl. long-fin (loligo)	9.5	0.0
Melanogrammus aeglefinus	Haddock	1.8	18.4
Merluccius bilinearis	Hake, silver (whiting)	1344.9	974.4
Myoxocephalus octodecemspinosus	Sculpin, longhorn	4.9	3.8
Peprilus triacanthus	Butterfish	13.6	261.4
Pollachius virens	Pollock	0.0	54.9
Pseudopleuronectes americanus	Flounder, winter (blackback)	16.3	27.5
Scomber scombrus	Mackerel, Atlantic	85.1	1.4
Squalus acanthias	Dogfish, spiny	128.1	276.6
Coleoidea (subclass)	Squid, nk	16.8	0.0
Urophycis chuss	Hake, red (ling)	189.4	362.7
Urophycis tenuis	Hake, white	0.9	4.4

3.2. 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 *Alosa*, butterfish, and silver hake, were generally seen passing with ease through the grates' bars 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.

3.2.1. Spiny dogfish

We observed the behavior of 462 spiny dogfish in front of the grate and recorded 1686 total actions, divided into behavior categories and a non-action category. 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) (Fig. 8), impingement area on the body (either side, dorsal, belly, not known) (Fig. 9), and twisting on the grate (area on the body that the dogfish settles against the grate – either side, dorsal, belly, or not known) (Fig. 10).

In general, boxplots indicated that no differences were found within the behavior categories, or between gear configurations and grate colors (Figs. 8–10). Additionally, we observed that behavior could be altered by the presence of other species. For example, dogfish usually stayed lower in the extension when found

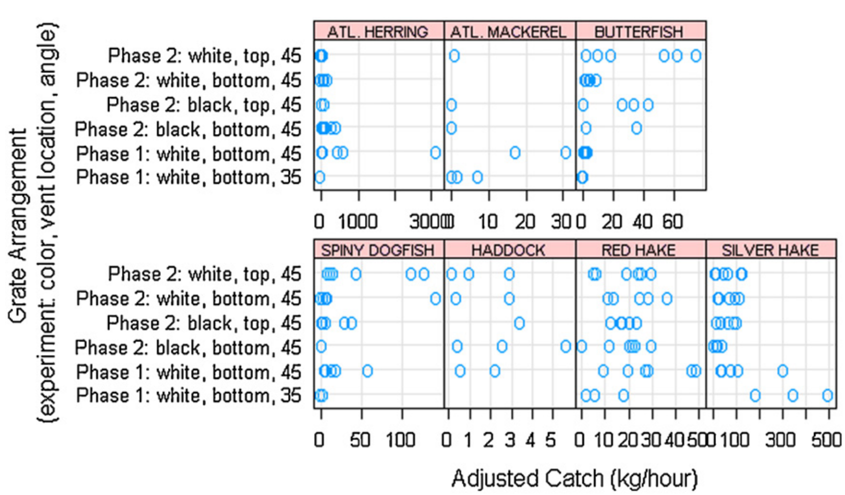


Fig. 5. Adjusted catch (kg/h) of selected species for each tow per grate configuration. ATL, Atlantic.

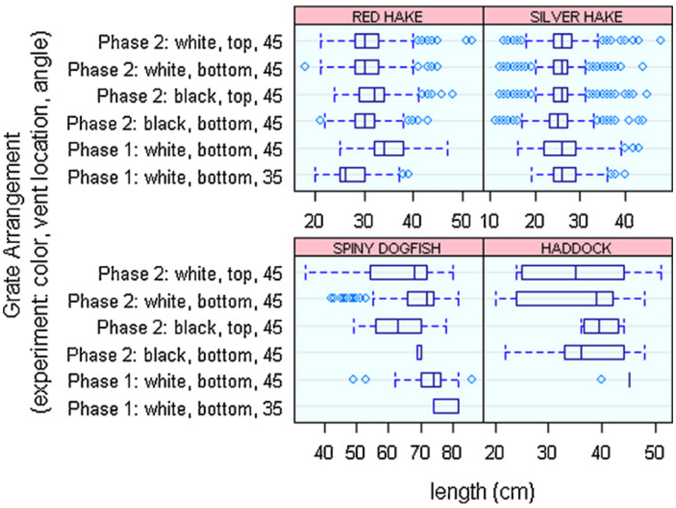


Fig. 6. Box and whisker length-frequency plot for selected species per grate configuration. Box widths do not represent sample sizes.

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 body movements (with tight turning rates) especially during these concentrations.

Spiny dogfish nearly always contacted the grates before escaping or becoming caught. They were rarely seen 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. Individuals 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 were often manifested as chaotic swimming. During blockages, dogfish

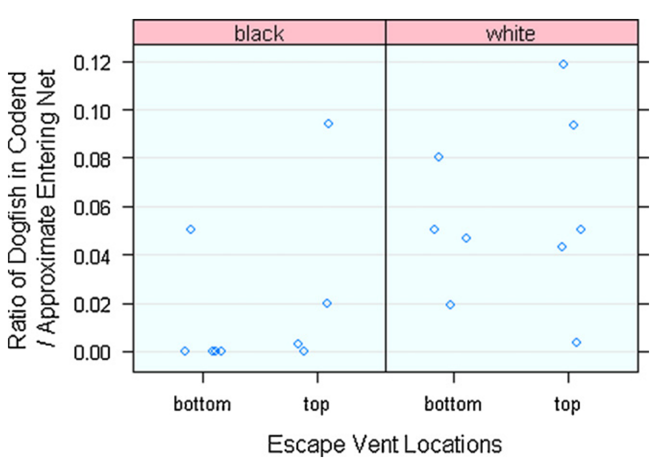


Fig. 7. Tow-by-tow ratios of spiny dogfish retained in the codend to the estimated numbers that entered the net for each gear configuration (top-opening/aft-leaning; bottom-opening/forward-leaning) and grate color (black or white). One tow was excluded as no dogfish were observed in the net and an estimation could not be obtained. Values along the *x*-axis are jittered ($x = -1$) to display overlapping points.

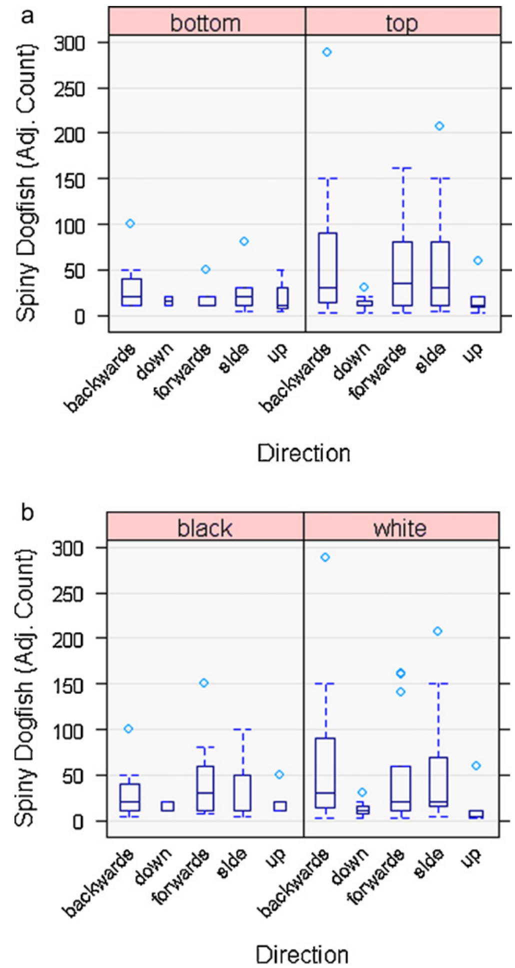


Fig. 8. Box and whisker plots showing the frequency of spiny dogfish swimming direction by escape vent configuration (a) and grate color (b).

might have been punctured from spines from other dogfish, based on small points observed in their dorsal surfaces.

3.2.2. Silver hake

Silver hake were usually 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.

Based on observations of video taken by the primary and secondary cameras, few silver hake were seen escaping through the vent relative to the quantities viewed inside the net.

3.2.3. Herring

Herring generally stayed high in the extension, especially when in large schools. They nearly always swam in the direction of the tow. Species identification could not always be confirmed with video; the catch consisted of mostly Atlantic herring although unidentified river herring, blueback herring *Alosa aestivalis*, alewife *Alosa pseudoharengus*, American shad *Alosa sapidissima*, and unidentified shad *Clupeidae* were also present. Other species, such as spiny dogfish and butterfish, seemed affected by large herring schools and usually stayed below them. In the absence of large herring concentrations, other species used the entire area of the extension more often.

Please cite this article in press as: Chosid, D.M., et al., Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope silver hake *Merluccius bilinearis* trawl. Fish. Res. (2011), doi:10.1016/j.fishres.2011.03.007

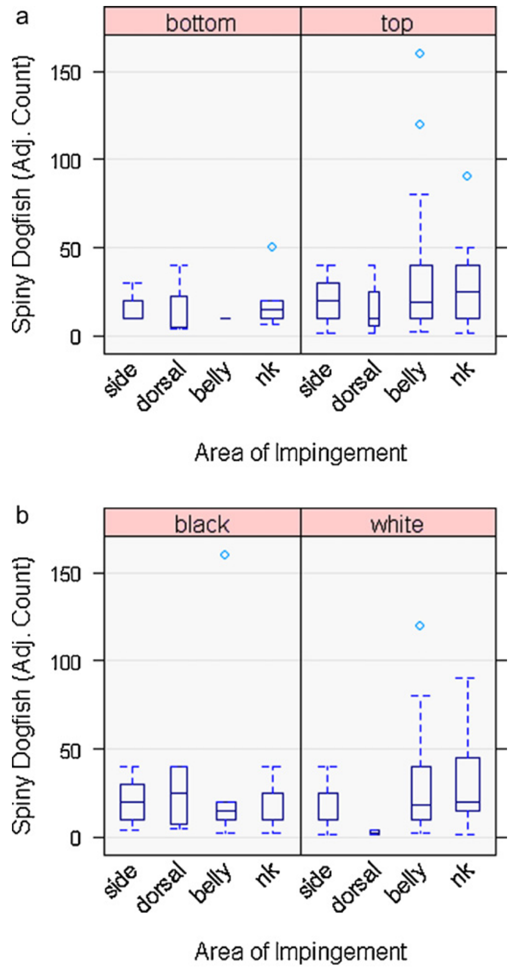


Fig. 9. Box and whisker plots showing the frequency of spiny dogfish impingement locations by escape vent configuration (a) and grate color (b).

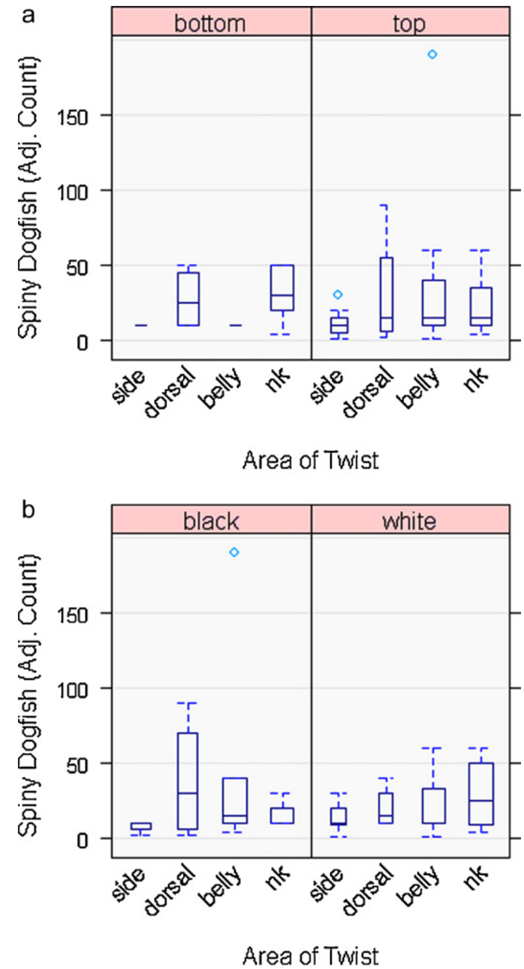


Fig. 10. Box and whisker plots showing the frequency of spiny dogfish twisting locations by escape vent configuration (a) and grate color (b).

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.

3.2.4. 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 towards one side or the codend.

3.2.5. 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.

3.2.6. Flatfish

Flatfish were not identifiable by species on video; species caught in the codend included grey sole *Glyptocephalus cynoglossus*, fourspot flounder *Hippoglossina oblonga*, American plaice *Hippoglossoides platessoides*, yellowtail flounder *Limanda ferruginea*, and winter flounder *Pseudopleuronectes americanus*. 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.

3.3. Gear

Net mensuration data were obtained for the doors, nets, and Phase 1 grate, and used to assess gear performance. No tows were excluded during analyses because of poor reported geometry.

Grid angles obtained during Phase 1 (tows 4–9) increased during the duration of the tow, although at varying rates (Fig. 11). Tow 4 revealed the most drastic change but was largely driven by a few observations; this tow was the only one to display an angle greater than the angle at which it was set on land (45°) while towing in water.

4. Discussion

Independent of color, angle, or gear orientation, the grates were successful at excluding spiny dogfish while retaining commercial-

Please cite this article in press as: Chosid, D.M., et al., Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope silver hake *Merluccius bilinearis* trawl. Fish. Res. (2011), doi:10.1016/j.fishres.2011.03.007

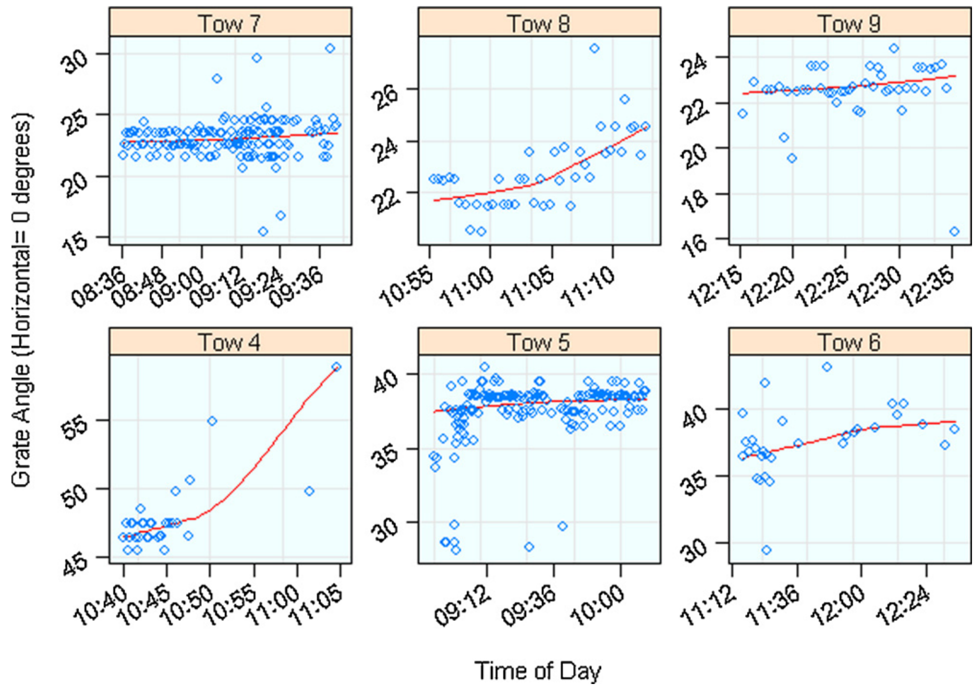


Fig. 11. Grate angle measurement for Phase 1 tows. The grate angle was set at 45° on land for tows 4, 5, and 6 and 35° on land for tows 7, 8, and 9. The line within plots is a loess smoother (span = 1, family = symmetric).

sized 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 small 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,b). 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.

The Phase 1 RFT had been used commercially and had undergone multiple repairs and mesh warping prior to this research. Any deviations from the intended design can affect a net's performance. However, based on video observations and net mensuration data, it did not appear that the orientation of the grate, and fish behavior in relation to the grate, was affected by the net's irregularities. Use of a new RFT in Phase 2 resolved any concerns.

The grates' 50 mm 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 using a grate with 64 mm spacing which caused spiny dogfish to become frequently wedged between the bars.

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). Tow 4 (set at 45° on land) showed larger angles overall (Fig. 11); we believe this change was due to a derelict fishing gear interaction, such as contact with a lost lobster pot that occurred during the tow, based on lower catch rates and an irregular shine on the chain sweep. The true angle of the grate may change based on additional conditions that impact net geometry, such as substrate type, bottom contact, catch size, sea state, and currents. The limited scope of the project did not permit a fuller examination of optimal grate angle.

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.

4.1. Conclusions

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, similar problems can occur in the codend 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 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 RFEA 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 RFEA. The strongest commercial catches were still attained within the RFEA area. However, river herring, which are preferably avoided due to poor stock condition, were caught in larger numbers inside the RFEA (Table 1) and may be difficult to avoid even with the current gear modifications; the difficulty of adequately separating herring provides further reason to consider the usage of other fishing grounds.

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 and equipment for the Phase 1 research which was beyond the original scope of this project. Rachel Feeney (Northeast Consortium), Doug Zemeckis (School for Marine Science and Technology (SMAST), University of Massachusetts), Andrew Applegate (New England Fisheries Management Council), Tyler Staple (National Marine Fisheries Service), and Steve Voss (Massachusetts Division of Marine Fisheries) provided sampling assistance. Dr. Pingguo He (SMAST) provided an underwater camera loan and advice on behavioral analyses. Massachusetts Division of Marine Fisheries Contribution No. 35.

References

Amaru, W.H., 1996. A Size Selective, Near-zero Mortality Trawl for Silver Hake. Report. Saltonstall-Kennedy Project # NA66FD0011, 88 pp.

Bowman, R., Eppi, R., Groslein, M., 1984. Diet and Consumption of Spiny Dogfish in the Northwest Atlantic. ICES C. M. 1984/G:27.

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., Caruso, P., 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., Moth Poulsen, T., 2008. Diel variation within the species selective "topless" trawl net. J. Ocean Technol. 3 (2), 31–58.

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

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

Eigaard, O., Holst, R., 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., Campos, A., Mendes, B., Larsen, R., 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., Kruse, H., 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., Wardle, C.S., Gosden, S.J., Racey, D.N., 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.

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

He, P., 2007. Technical measures to reduce seabed impact of mobile gears. In: Kennelly, S. (Ed.), Bycatch Reduction in World Fisheries. Springer, Netherlands, pp. 141–179.

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

He, P., Balzano, V., 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.

He, P., Winger, P., 2010. Effect of trawling on the seabed and mitigation measures to reduce impact. In: He, P. (Ed.), Behavior of Marine Fishes: Capture Processes and Conservation Challenges. Wiley-Blackwell, Ames, Iowa, pp. 295–310.

Hilborn, R., 2011. Future directions in ecosystem based fisheries management: a personal perspective. Fish. Res. 108, 235–239.

Isaksen, B., Valdemarsen, J., Larsen, R., Karlsen, L., 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., Huse, I., Misund, O.A., Gamst, K., 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., Sangster, G.I., 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. In: Scottish Fisheries Research Report. Department of Agriculture and Fisheries for Scotland, 23 pp.

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

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

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

Montgomery, J., Walker, M., 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.

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.J., Sosebee, K.A., Brodziak, J.K.T., Murawski, S.A., Anderson, E.D., 1998. Implications of recent increases in catches on the dynamics of Northwest Atlantic spiny dogfish (*Squalus acanthias*). Fish. Res. 39, 165–181.

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

Sosebee, K., Rago, P., 2006. Spiny dogfish. In: Mayo, R., Serchuk, F., Holmes, E. (Eds.), Status of Fishery Resources off the Northeastern United States, National Marine Fisheries Service Northeast Fisheries Science Center. , http://www.nefsc.noaa.gov/sos/spsyn/op/dogfish/.

Please cite this article in press as: Chosid, D.M., et al., Development and observations of a spiny dogfish *Squalus acanthias* reduction device in a raised footrope silver hake *Merluccius bilinearis* trawl. Fish. Res. (2011), doi:10.1016/j.fishres.2011.03.007