Video Observation and Testing of a Grate to Reduce Bycatch of Spiny Dogfish 
*Squalus acanthias* in a Silver Hake *Merluccius bilinearis* Trawl Fishery

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**Abstract**

The northern silver hake *Merluccius bilinearis* (whiting) stock in the Gulf of Maine generally exceeds its biomass targets and landings have been at a historic low. This fishery has traditionally been an important source of income for small trawlers in ports from Maine to Massachusetts, USA. Spiny dogfish *Squalus acanthias*, an abundant bycatch, can prevent or hinder exploitation of this healthy stock. This species needs to be kept out of silver hake trawl nets to reduce bycatch mortality and to prevent damage to the catch due to the abrasive skin of dogfish. Also, bycatch levels of spiny dogfish had become a concern when output control measures were implemented in May, 2010; high discards of critical species are capable of closing groundfish fisheries if bycatch allowances are exceeded. Furthermore, discarding of spiny dogfish is a time-consuming process.

Our collaboration of fishermen and biologists tested excluder grates with 50 mm (2.0 inches) spacing to eliminate spiny dogfish in a raised-footrope silver hake trawl net. Designs were varied by color (black or white), and upward or downward exclusion (through a top or bottom escape vent). Video showing the behaviours of silver hake, dogfish, and other species’ interacting with and around the grate were reviewed. Results based on observations and catch quantities indicate an overall excellent reduction of dogfish while allowing for commercial harvests of silver hake and Atlantic herring *Clupea harengus*. Industry acceptance of a grate can provide cost benefits for fisherman and protection for managed bycatch.

**Keywords:** grate; grid; bycatch; trawl; dogfish; *Squalus acanthias*; silver hake; *Merluccius bilinearis*; behaviour

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 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 hindrance to exploiting the healthy silver hake *Merluccius bilinearis* (whiting) 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 the 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) 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. To date, limited attention has been placed on elasmobranch bycatch reduction.

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. 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.).

Many fish respond to visual cues during the 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 a particular color of 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 the net’s 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, top and bottom openings, in combination with black and white-colored grates, were investigated during this study.

Preliminary research was conducted in Oct.-Nov. 2008 inside the Massachusetts, USA Special Access Program (SAP) Raised Footrope Area prior to this study. The optimal grate angles were investigated using an initial white prototype grate with a bottom escape opening (Figure 1). We then refined the grate design and explored grate color effects and leading fish towards a top or bottom escape vent. We concluded from this initial work that the grate angle of
45° was preferable for the continued research.

We refined and tested the 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.

2. Materials and Methods

2.1. Net and Grate

A typical 4-panel box raised footrope silver hake net was constructed with single, diamond-shaped meshes throughout (Figure 2). Nominal sizes are provided below. A cable in 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 2.5 mm diameter green poly mesh; all other sections were approximately 3.0 mm diameter green euroline mesh; the codend was made from 6.4 cm (2.5 in) mesh. 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 equally spaced.
Two 121.9 cm (4.0 ft) square grates were designed and constructed, both with 50 mm (2.0 in) bar spacings (Figure 3). The grates were constructed of 25 mm (1.0 in) thick high density polyethylene (HDPE), one black and one white. Two horizontal cross bars were used to add additional support to the vertical bars. 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 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 grates were nearly neutrally buoyant.
Figure 3: Schematic of the excluder grates.

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.

Minor modifications to the gear were made 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 was conducted on-board the F/V Barbara L. Peters, a 16.8 m (55 ft), 214.8 kW (288 hp) groundfish Western-rig commercial trawler with two stern ramps, two net reels, and Thyboron 1.6 m 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 reporting requirements were overseen by MA DMF personnel.

The field work was performed in Massachusetts Bay, USA, outside the Special Access Program (SAP) Whiting Area between 42°12’W lat. and 42°30’W lat. although some tows were started just inside the SAP.

The following tows and gear configurations were completed in sequence:
• Arrangement 1 (6 tows): Black grate, top of grate forward-leaning 45° angle, upward guiding panel, and bottom escape vent.
• Arrangement 2 (6 tows): Black grate, top of grate aft-leaning 45° angle, downward guiding panel, and top escape vent.
• Arrangement 3 (7 tows): White grate, top of grate aft-leaning 45° angle, downward guiding panel, and top escape vent.
• Arrangement 4 (5 tows): White grate, top of grate forward-leaning 45° angle, upward guiding panel, and bottom escape vent.

Target tow times were less than one hour 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 (~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 were determined for all species retained. Mid-line lengths were recorded for spiny dogfish, silver hake, red hake *Urophycis chuss*, and other selected catch. Sub-samples were taken as time required. Data were recorded and entered into a customized database.

The first tow 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. Video was collected under natural light to avoid fish behavioral effects from artificial light sources (He, 2010). A Notus Electronics Ltd. 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.

An 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.

2.3. 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). 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.

Performances of the grates were judged by their ability to exclude spiny dogfish even at high rates of encounter 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 (or whatever the remainder time was at the end of each tow under 10 minutes), and then randomly choosing one minute segments within each ten minute block. 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 passed through the grates.

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 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

Once spiny dogfish became impinged or twisted on the grate, 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.

3. Results

Researchers and the vessel crew completed twenty-four tows (23 valid tows) over nine days in and west to northwest of the raised footrope SAP area near Provincetown, Massachusetts (July-Aug. 2009) (Figure 4).
Figure 4: 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 polygon area is the raised footrope exemption area.

Video data were reviewed for all tows in which it was collected (23 tows).

3.1. Catch

Totals for all species captured are presented in Table 1. Twenty-eight species or species groups were caught during this study in approximately normal commercial quantities. Target species retained were generally of very high quality.
Table 1: Total catches (kg) for species captured. Total catches below 5.0 kg are not shown and include: river herring (Alose), ocean quahog (Artica islandica), rock crab (Cancer irroratus), sea raven (Hemitripterus americanus), fourspot flounder (Hippoglossina oblonga), American lobster (Homarus americanus), snake blenny (Lumpenus lumperetaformis), ocean pout (Macrozoarces americanus), longhorn sculpin (Myoxocephalus octodecemspinosus), thorny skate (Raja radiate), Atlantic mackerel (Scromber scombrus), cunner (Tautogolabrus adspersus), and white hake (Urophycis tenuis). Unknown species are listed as “nk”.

<table>
<thead>
<tr>
<th>Scientific Names</th>
<th>Common Names</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Alosa pseudoharengus</em></td>
<td>alewife</td>
<td>13.2</td>
</tr>
<tr>
<td><em>Alosa sapidissima</em></td>
<td>shad, American</td>
<td>10.0</td>
</tr>
<tr>
<td><em>Clupea harengus</em></td>
<td>herring, Atlantic</td>
<td>1563.3</td>
</tr>
<tr>
<td><em>Gadus morhua</em></td>
<td>cod, Atlantic</td>
<td>23.7</td>
</tr>
<tr>
<td><em>Glyptocephalus cynoglossus</em></td>
<td>flounder, witch (grey sole)</td>
<td>10.8</td>
</tr>
<tr>
<td><em>Hippoglossoides platessoides</em></td>
<td>flounder, American plaice (dab)</td>
<td>86.6</td>
</tr>
<tr>
<td><em>Illex illecebrosus</em></td>
<td>squid, short-fin (illex)</td>
<td>71.6</td>
</tr>
<tr>
<td><em>Limanda ferruginea</em></td>
<td>flounder, yellowtail</td>
<td>14.6</td>
</tr>
<tr>
<td><em>Melanogrammus aeglefinus</em></td>
<td>haddock</td>
<td>18.4</td>
</tr>
<tr>
<td><em>Merluccius bilinearis</em></td>
<td>hake, silver (whiting)</td>
<td>974.4</td>
</tr>
<tr>
<td><em>Peprilus triacanthus</em></td>
<td>butterfish</td>
<td>261.4</td>
</tr>
<tr>
<td><em>Pollachius virens</em></td>
<td>pollock</td>
<td>54.9</td>
</tr>
<tr>
<td><em>Pseudopleuronectes americanus</em></td>
<td>flounder, winter (blackback)</td>
<td>27.5</td>
</tr>
<tr>
<td><em>Squalus acantbias</em></td>
<td>dogfish, spiny</td>
<td>276.6</td>
</tr>
<tr>
<td><em>Urophycis chuss</em></td>
<td>hake, red (ling)</td>
<td>362.7</td>
</tr>
</tbody>
</table>

Four tows 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 1; two used arrangement 3; and one used arrangement 4. 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, red hake, silver hake, Atlantic herring, Atlantic mackerel, and butterfish (Figure 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 (Figure 5).
Comparisons, although limited by the design of the study, suggested that catches were not strongly affected by different grate arrangements.

Length frequency distributions (Figure 6) for each arrangement showed some differences in sizes for spiny dogfish. The hake length results were very similar over all arrangements.

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 7). Other species were more difficult to track in video and therefore, these catches were not further analyzed for grate efficiencies.
Figure 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). 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 7) although the fewest dogfish were caught in these tows overall (Figure 5). 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. Tows where the grate became blocked were too concentrated with dogfish to provide a performance estimate.

3.2. Behavior

Generalizations of behaviors were made for selected species in front of the excluder grates. 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, for all fish, were almost never witnessed in the videos, nor were seen at haul-back. Fish were rarely seen swimming forward beyond the grate after passing through it. Fine 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 1,686 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) (Figure 8), impingement area on the body (either side, dorsal, belly, unknown) (Figure 9), and twisting on the grate (area on the body
that the dogfish settles against the grate - either side, dorsal, belly, unknown) (Figure 10).

Figure 8: Box and whisker plots showing the frequency of spiny dogfish swimming direction by escape vent configuration (top plot) and grate color (lower plot).
Figure 9: Box and whisker plots showing the frequency of spiny dogfish impingement locations by escape vent configuration (top plot) and grate color (lower plot).
Figure 10: 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 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 backwards against the direction of the net.

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 dorsal surfaces.

3.2.2. Silver hake

Silver hake were generally observed at low concentrations, and were difficult to distinguish in large herring groups. However, silver hake were 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.

3.2.3. Herring

Herring (mostly Atlantic herring based on catch) 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. When large herring concentrations were not present, other species used the entire area of the extension more often.

Herring in large schools, which had passed through the grates, 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 during periods of slow down (such as haul backs). Schools were occasionally viewed swimming just aft of the grate after having passed through the bars.

As with silver hake, we infer that most herring passed through the grates (since relatively few were seen escaping in the secondary video). Those few 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 toward a 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. 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, and net, which were used to assess gear performances. No tows were excluded during analyses because of poor reported geometry.

4. Discussion

Independent of color 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% discard bycatch mortality (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 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.

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.

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 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). Shorter tows may also help avoid large dogfish blockages; physical stress from blockages greatly increases dogfish mortality (Mandelman and Farrington, 2007b)).

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 data. Some of the experimental tows (including the preliminary research) were conducted in areas and times outside the raised footrope SAP. The results from this work suggest an expanded fishery may be possible with aggressive non-target species avoidance.

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