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Trawl hangs, baby fish, and closed areas: a win–win scenario

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The frequency and geographic distribution of trawlnet hangs from a fishery-independent survey are evaluated. The hangs data were plotted on a substratum map to confirm that many, but not all, were naturally occurring, high relief substrata. The data were also coupled with the occurrence of juvenile cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) to assess the degree of association between juvenile gadoids and high relief substrata. The average minimal distance from a fish occurrence to a hang ranged from 8.1 to 12.0 km (4.4–6.5 nautical miles), well within the reported daily range of movement for these fish. A similar pattern was detected for the sea raven (*Hemitripterus americanus*), a predator of juvenile gadoids, confirming the location of these microhabitat foodwebs. On average, closing an area 3.7 km (2 nautical miles) around a hang will enclose 17–30% of the populations of these juvenile fish; a wider buffer (18–28 km; 10–15 nautical miles) will close a linearly increasing portion of the populations. Additionally, closing areas surrounding the hangs, particularly regions of high hang density, will help to minimize losses of or damage to fishing gear. We propose a win–win scenario by establishing or evaluating closed areas in regions with high concentrations of known hangs. This approach is widely applicable for many marine ecosystems and may help to achieve simultaneous conservation and resource management goals, whereby one can both protect pre-recruit fish and enhance the effectiveness of a fishery.

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Introduction

The effects of fishing activities on the seafloor off New England have been receiving increased attention from fishery managers, conservationists, fishery scientists, and fishers (Auster *et al.*, 1996; Dorsey and Pederson, 1998; Auster and Shackell, 2000). Specifically, Georges Bank (Figure 1) is a productive ecosystem that is an important nursery ground for several economically valuable species (Smith and Morse, 1985; Lough *et al.*, 1989). Large areas of the bank have been closed to fishing to protect recovering stocks (Murawski *et al.*, 1997; Fogarty and Murawski, 1998). As groundfish populations continue to decline in areas open to fishing, there is increasing pressure to allow access to resources in closed areas, or at least to re-evaluate the duration, size, and location of the closures. Additionally, fishery managers and other resource stakeholders are increasingly requiring information about the relationship between habitat type and fish population survivability, growth, feeding, etc. However, establishing these relationships and the rationale for maintaining indefinite area closures remains difficult.

Year-round, no-take marine reserves have been identified as conservation tools that can enhance both populations of exploited species in particular and biodiversity in general (McManus, 1998; Auster and Shackell, 2000; Mosquera *et al.*, 2000; Cote *et al.*, 2001; NRC, 2001; Roberts *et al.*, 2001; Fisher and Frank, 2002). However, delineating, agreeing upon, implementing, and enforcing such area closures can be a contentious process. We propose a method that identifies high relief, potentially untrawlable bottom and explores the relationship between such locations and the presence of juvenile fish. From this information and the simple relationships, we hypothesize that win–win scenarios, regarding how future area closures might be established or evaluated, are feasible.

Material and methods

To evaluate the frequency of occurrence and distribution of high relief, complex substrata, we plotted the incidence of hangs from the NEFSC bottom trawl survey (1963 through 2002; see Azarovitz, 1981; NEFC, 1988; Figure 1). All

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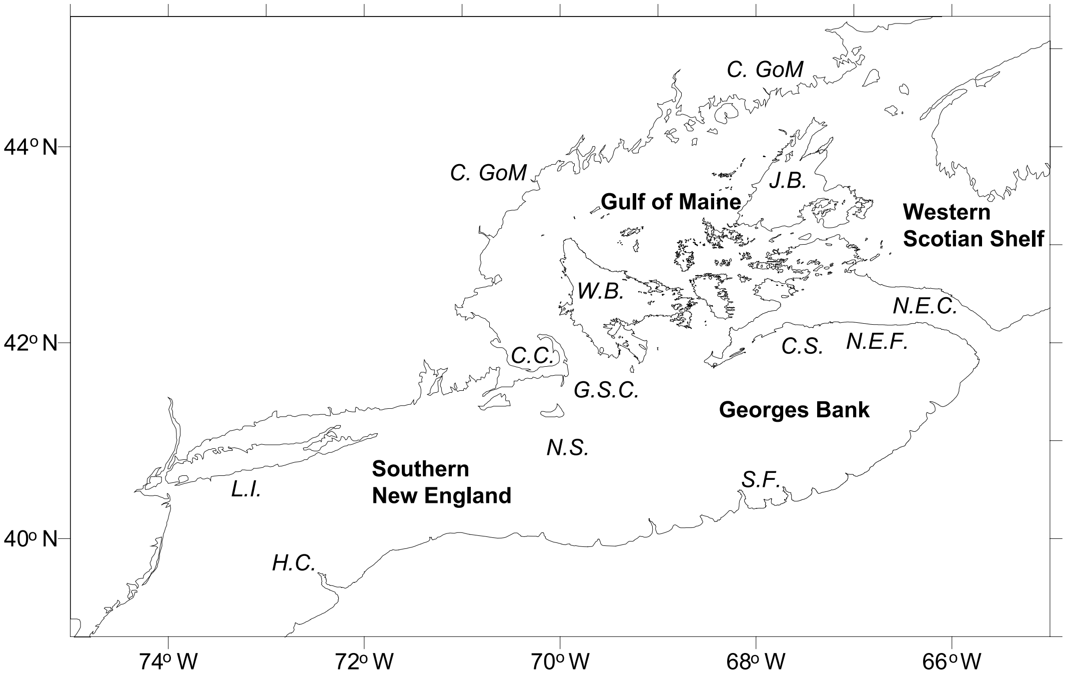

Figure 1. Map of the major regions (emboldened) of the northeastern US continental shelf (the western Scotian Shelf and portions of the Georges Bank are in Canadian waters). Italicized labels denote major features of the region and are provided for reference purposes. H.C., Hudson Canyon; N.S., Nantucket Shoals; G.S.C., Great South Channel; W.B., Wilkinson Bank; C.GoM, Coastal Gulf of Maine, both in Massachusetts/New Hampshire and Maine; J.B., Jordan Basin; N.E.C., Northeast Channel; N.E.F., Northeast Flank of Georges Bank; C.S., Cultivator Shoals; S.F., Southern Flank of Georges Bank; C.C., Cape Cod; L.I., Long Island. The contour line represents the 200 m isobath.

cases where the trawl gear was significantly torn, ripped, hung up, or lost were plotted to the appropriate georeferenced points (taken as the start latitude and longitude of each tow). The gear used in the surveys was a No. 36 Yankee otter trawl, with 40.6 cm (16 inches) roller gear and 450 kg polyvalent doors. There are three levels of gear condition for which a tow could be noted as potentially hung. Level 3 is a mild hang that may or may not be indicative of a high-relief obstruction (termed mild), level 5 is a case of definite trawlnet destruction (termed severe), and level 9 is a complete wreckage of the trawl (termed very severe). For this study, we used level 5 and above to indicate a significant trawl hang. The assumption is that, regardless of actual material, a hang incident indicates an area unsuitable for trawling and therefore a more complex substratum. Such areas could be boulders, cobble, shipwrecks, etc., but the particular type of hang was not differentiated.

We overlaid the hangs with the Poppe *et al.* (1989) dataset to evaluate the occurrence of hangs in different substratum types. We did this primarily to determine if the hangs could augment the bedrock, cobble, and gravel components of the Poppe *et al.* (1989) data, given the broad resolution of the information at some localities. Poppe *et al.* (1989) present sediment data at relatively coarse spatial scales, interpolated into a map, which is often and mistakenly used beyond the original sampling resolution. We condensed the nine original sediment categories into six. Large sediment features (e.g. boulders, cliffs, underwater canyons) were not sampled by the Poppe *et al.* (1989) gear, but they have been noted from several submersible dives (Cooper *et al.*, 1987). Known instances of these features are also compared with the occurrence of hangs.

To evaluate the association of these hangs with fish, we plotted occurrences of juvenile haddock (*Melanogrammus aeglefinus*) and cod (*Gadus morhua*) – we define juvenile as <30 cm – taken in the bottom trawl survey during the years 1995–2002. The start latitude and longitude of each tow that caught one of these juvenile gadoids were plotted. The occurrences indicate how common the presence of a particular fish species was in proximity to a hang, irrespective of absolute density or abundance. We also plotted the occurrence of sea raven (*Hemitripterus americanus*) with the hangs data, because this species is a known ambush predator of juvenile gadoids in high relief habitat (Tupper and Boutilier, 1997; Hermsen, 2002).

The Pythagorean distance from each fish occurrence to each hang of level 5 and above was calculated, and the distances from the hangs to the different fish species were evaluated using the start latitude and longitude of each tow.

Because the vessel was under way at 6.5 km h^{-1} (1.8 m s^{-1} or 3.5 knots) and towed for 30 min, the actual location of a hang could be anywhere along the tow track from the start to almost 3.7 km (2 nautical miles) away. Generally, a severe or very severe hang produced a stoppage in the tow, so there is no way of evaluating the exact locality of a hang. Therefore, we chose to use the start coordinates. Although we present results that are less than 3.7 km, we recognize that some of these could be slightly below the resolution of our sampling. After calculating all these distances, the distance to the closest hang for each fish occurrence was ascertained by taking the minima of all possible distances calculated, then averaging these minimal distances across all fish occurrences to come up with an index of fish proximity to the hangs. This was done for all three species. Additionally, we counted the number of fish occurrences at the same location and within 0.9, 1.9, 2.8, 3.7, 4.6, 5.6, 7.4, 9.3, 18.5, and 27.8 km (0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 10, and 15 nautical miles) of the nearest hang.

Results

zFigure 2 shows the frequency of occurrence for all levels of hangs on the northeastern continental shelf. There were 875 instances of mild hangs (Figure 2A), 660 of severe hangs (Figure 2B), and 140 of very severe hangs (Figure 2C). Most hangs were widespread across the continental shelf, except in areas known to have a low relief substratum (e.g. central Georges Bank or mid Southern New England). As the level of hang damage increased, a concentration of high relief and potentially untrawlable regions became more apparent in coastal Maine, the Great South Channel (southeast of Cape Cod), and the northeast flank of Georges Bank.

Overlaying the hangs and substratum data confirms that hangs are widespread across a wide range of substratum type (Figure 3). However, the three main regions described above, which contain most of the significant hangs, are generally associated with gravel or coarser substratum. We interpret this to mean:

1. There are likely high relief, potentially untrawlable areas in sandy or muddy substrata that are not natural occurrences (e.g. shipwrecks, artificial reefs, fixed fishing gear, dumpsites);
2. Some hangs may be gravel, bedrock, or other naturally occurring high relief substrata that were missed by the coarseness of the Poppe *et al.* (1989) data;
3. Most hangs coincide with known areas of high relief substratum or steep depth profiles (i.e. underwater cliffs), suggestive of cobble or boulder piles or gravel heaps being the most important cause of fishing net hangs.

Visual inspection reveals that juvenile cod are strongly associated with instances of trawl hangs (Figure 4). Areas

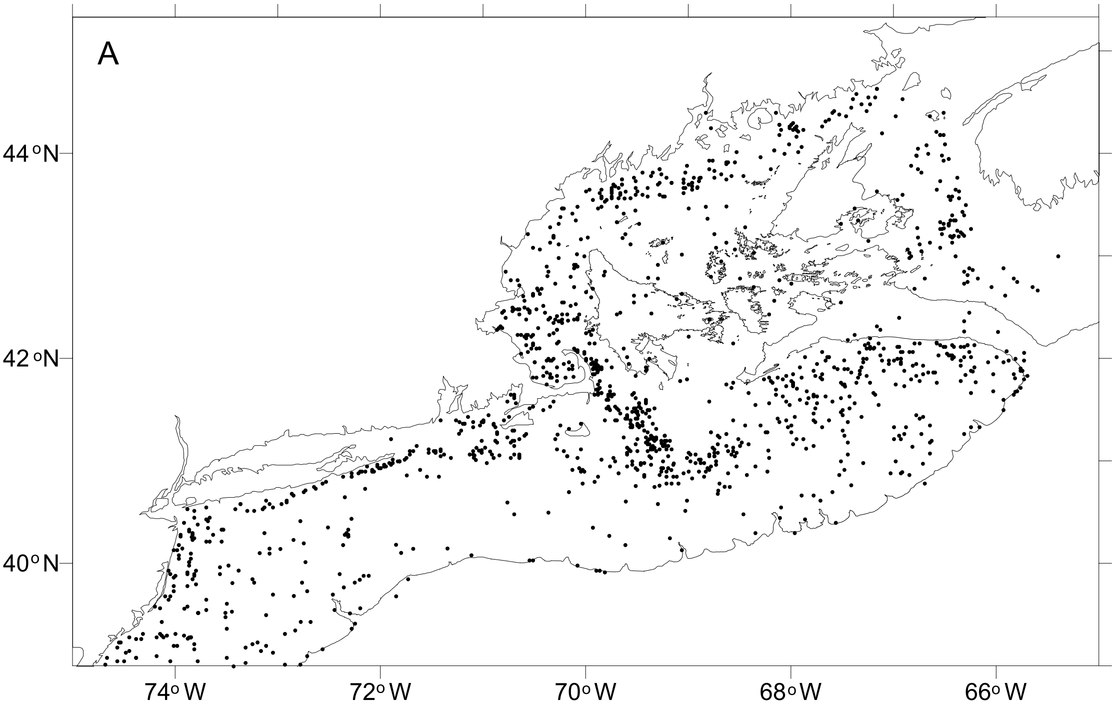

Figure 2. Location of three levels of hangs, with (A) 3 being the mildest (all levels shown), (B) 5 being severe (levels 5 and above shown), and (C) 9 being the most severe (shown).

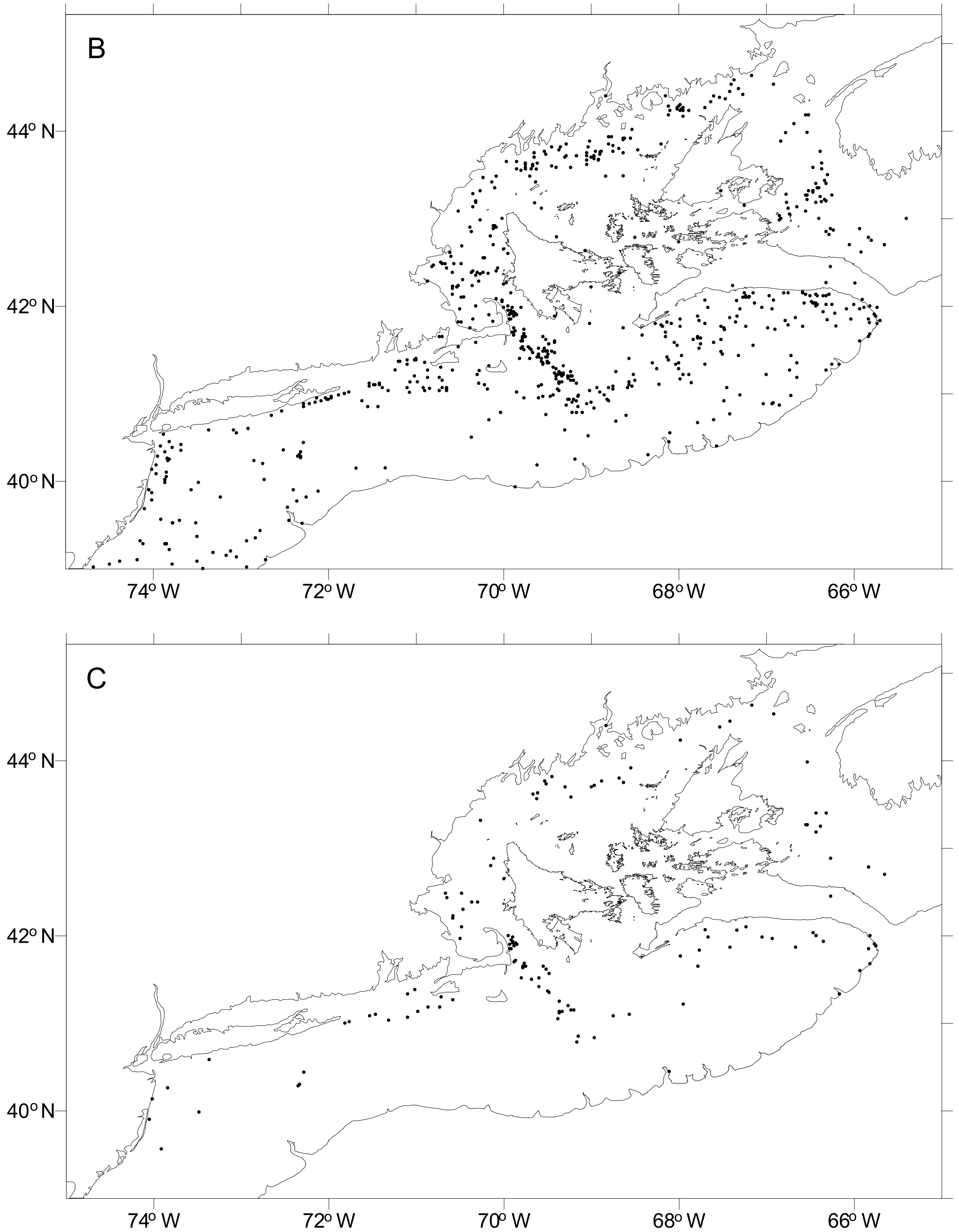

Figure 2 (*continued*)

along the Great South Channel, coastal Maine, the northeast flank of Georges Bank, and the western Scotian shelf show a high co-occurrence of juvenile cod and hangs. There are a few areas, principally on the south-central Georges Bank and off southern New England, where juvenile cod were not proximal to a hang, but for the most part the pattern is striking in its similarity. The average distance from an occurrence of juvenile cod to the nearest hang was 8.1 km

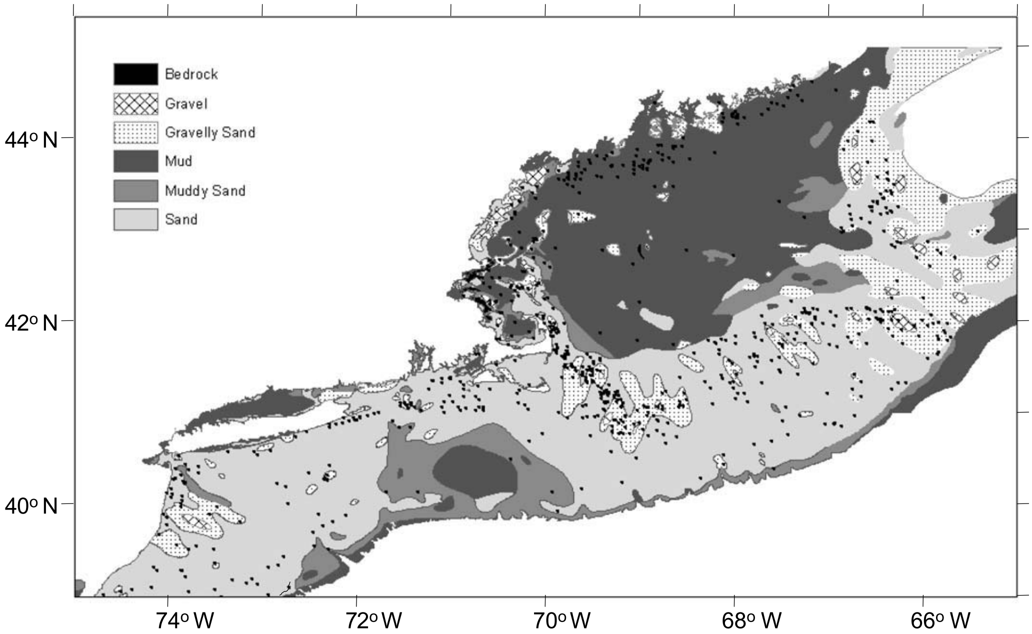

Figure 3. Significant hangs plotted over the Poppe *et al.* (1989) substratum data.

(4.4 nautical miles; Table 1). Of the 207 juvenile cod caught, nearly 40% were 4.6 km (2.5 nautical miles) or closer and 30% were 3.7 km (2 nautical miles) or closer to the nearest hang (Table 1). Interestingly, 17 juvenile cod were caught in the same locality as a hang, but just three more were caught within half a mile of a hang. This may be an artifact of the selection of the start latitude and longitude for each occurrence of a hang and fish presence.

Juvenile haddock exhibit a similar but less pronounced pattern with the hangs as juvenile cod (Figure 5). The major areas described above are also areas with high instances of co-occurrence of juvenile haddock and hangs, particularly

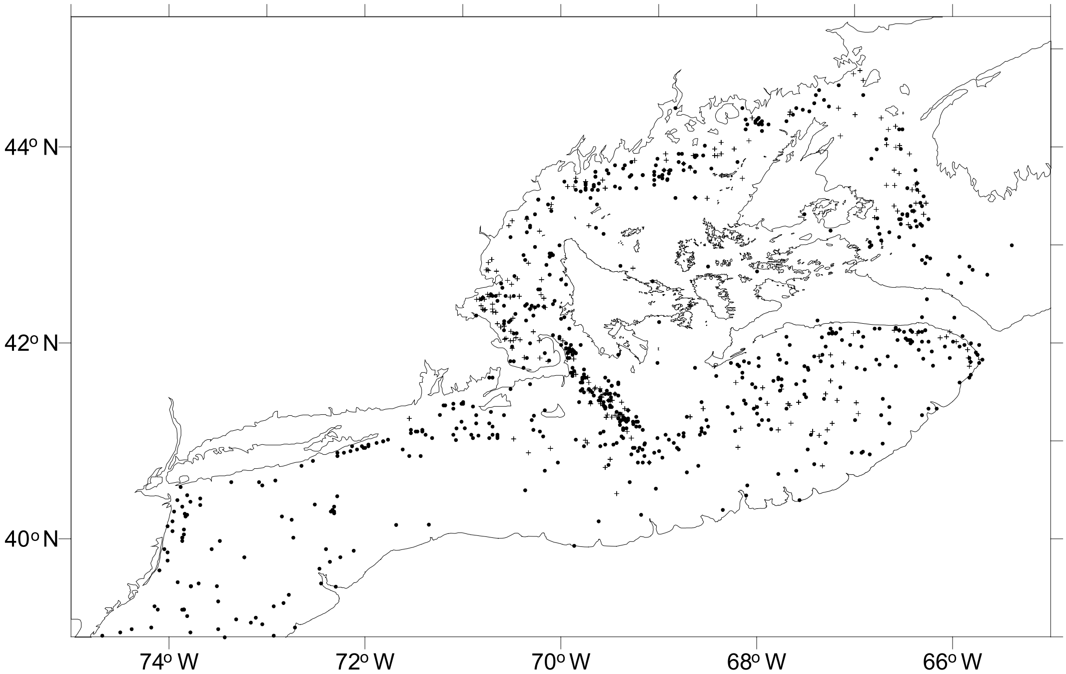

Figure 4. Occurrence of juvenile Atlantic cod (crosses) and the significant hangs (black dots).

Table 1. Average distance (km, with nautical miles – nm – in parenthesis) of each species to the nearest hang, the number of instances for each species (count), and the number of instances where the occurrence of a fish was exactly at (0) and within 0.9, 1.9, etc. up to 27.8 km of the nearest hang. The values in parenthesis are the percentages of all fish occurrences observed within each distance.

Parameter	Juvenile cod	Juvenile haddock	Sea raven
Average distance	8.1 (4.4 nm)	12.0 (6.5 nm)	11.3 (6.1 nm)
Count	207	460	1421
Occurrence			
0	17 (8.2%)	23 (5.0%)	55 (3.9%)
0.9 km (0.5 nm)	20 (9.7%)	26 (5.7%)	64 (4.5%)
1.9 km (1 nm)	32 (15.4%)	35 (7.6%)	113 (7.9%)
2.8 km (1.5 nm)	55 (26.6%)	60 (13.0%)	209 (14.7%)
3.7 km (2 nm)	63 (30.4%)	80 (17.4%)	256 (18.0%)
4.6 km (2.5 nm)	82 (39.6%)	115 (25.0%)	366 (25.8%)
5.6 km (3 nm)	95 (45.9%)	135 (29.3%)	430 (30.2%)
7.4 km (4 nm)	116 (56.0%)	182 (39.6%)	558 (39.3%)
9.3 km (5 nm)	133 (64.3%)	232 (50.4%)	688 (48.4%)
18.5 km (10 nm)	185 (89.4%)	365 (79.3%)	1153 (81.1%)
27.8 km (15 nm)	202 (97.6%)	419 (91.1%)	1342 (94.4%)

in the Great South Channel and the northeast flank areas. The difference is that haddock tended to encircle Georges Bank, whereas cod are more common across the bank. The average distance from an occurrence of a juvenile haddock to the nearest hang is 12.0 km (6.5 nautical miles; Table 1), two miles more than juvenile cod. Of the 460 juvenile haddock caught, 25% were 4.6 km (2.5 nautical miles) or closer and 17.4% were 3.7 km (2 nautical miles) or closer to the nearest hang. In all, 23 juvenile haddock were caught in the same locality as a hang.

Sea raven exhibit a similar pattern as juvenile cod and haddock, but are more common throughout the regions of the study (Figure 6). The same major areas of high co-occurrence as for the juvenile gadoids were the areas with a high co-occurrence of sea raven and hangs, particularly in the Great South Channel, and in the northeast and southern flank areas. The average distance of sea raven occurrence to the nearest hang is 11.3 km (6.1 nautical miles; Table 1). Of the 1421 sea raven caught, 25.7% were within 4.6 km and 18.0% within 3.7 km of the nearest hang.

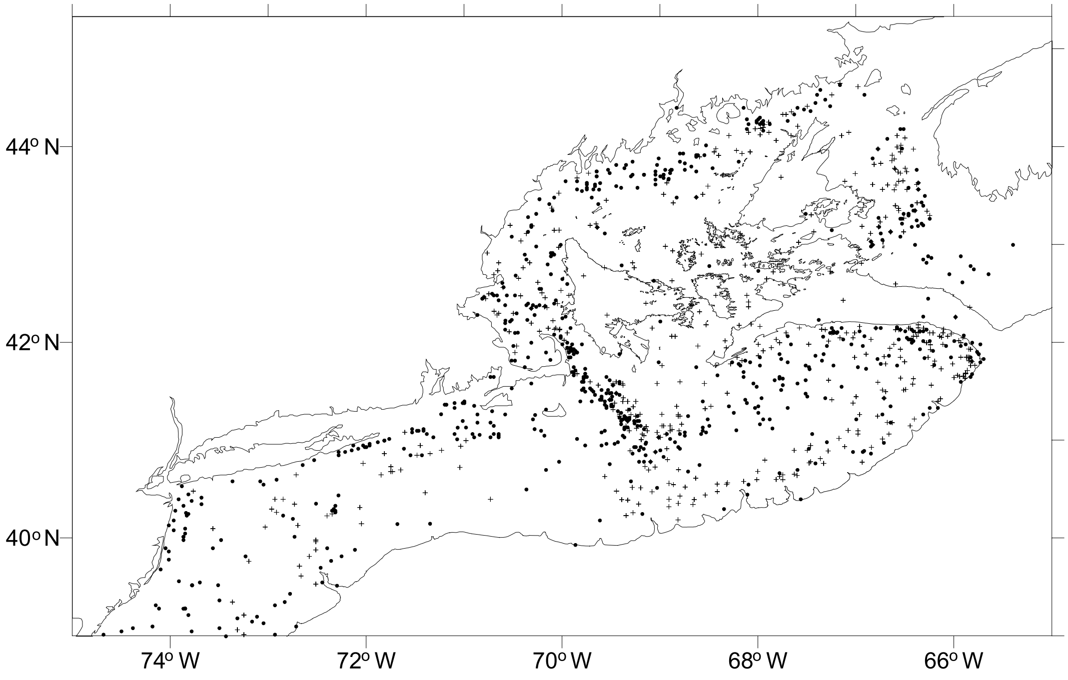

Figure 5. Occurrence of juvenile haddock (crosses) and the significant hangs (black dots).

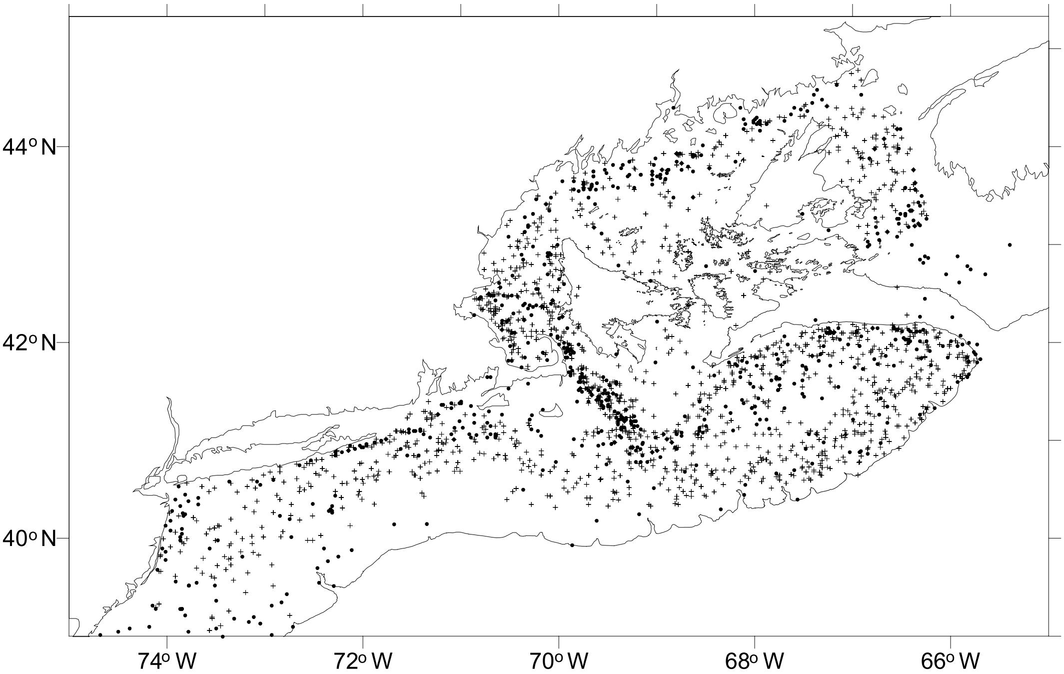

Figure 6. Occurrence of sea raven (crosses) and the significant hangs (black dots).

Discussion

This work broadly confirms the association of juvenile gadoids and high relief substrata (Lough *et al.*, 1989; Tupper and Boutilier, 1995, 1997; Gregory *et al.*, 1997; Auster *et al.*, 2001). Previously published distribution plots of adult cod and haddock show a similar pattern, but the distribution and abundance are not as strongly associated (compared with the juveniles) with areas that have a high density of hangs (cf. Grosslein and Azarovitz, 1982). Demersal species such as flatfish or skates are clearly not associated with hangs. Therefore, the goals for any area closure will need to be species-, guild-, or assemblage-specific, and by extension, habitat-specific.

The association of sea raven with the hangs in similar locations as the juvenile gadoids is not surprising given the known predator–prey relationship (Tupper and Boutilier, 1997; Hermsen, 2002). The presence of all three species in close association with the hangs confirms the Poppe *et al.* (1989) dataset of high relief substratum locations. The degree of predation on juvenile gadoids by sea raven and other species in these microhabitat foodwebs is unknown in the field, but it has been documented in laboratory experiments (Lindholm *et al.*, 1999; Hermsen, 2002). Whether the dynamics in these high relief microhabitats have population level effects is also unclear, but the predation rate on juvenile gadoids is much higher in areas without complex habitats, such as the hangs.

The ambit of cod ranges from 8 to 284 km (4–153 nautical miles; Clark and Green, 1990; Svasand and Ksristiansen, 1990; Pihl and Ulmestrand, 1993; Perkins *et al.*, 1997), with cod documented to move on the order of 0.5–15 km per day (0.3–8.5 nautical miles per day; Pihl and Ulmestrand, 1993; Lindholm and Auster, 2003). These ranges of individual fish movement are certainly within the distances 8.1–12.0 km (4.4–6.5 nautical miles) between the nearest hang and fish recorded in this study. Coupling the ambit with distance to the nearest hang implies that, if a certain concentration of hangs were closed to fishing or related impacts on the ocean floor, then a large portion of juvenile cod populations, and probably juvenile haddock as well, would be inside the protected area. If a buffer zone of 3.7 km (2 nautical miles) was created around each hang, then, on average, 30% of juvenile cod would be within the buffered area. This assumes that some of the juvenile cod do not move to the fullest extent of their ambit, and that for those that do, the immigration and emigration rates are similar. Making the buffer zone larger, say to the maximum distance of known daily movement of cod (10–15 km), would on average enclose a vast majority of juvenile cod within the buffered area. The same general pattern would also be true for juvenile haddock. The buffer zones could be grouped to identify a collection of areas (oddly shaped polygons) that have a high concentration of hangs (e.g. Figure 7). Certainly, better geostatistics (e.g. optimization of variograms, maximizing the number or concentration of hangs buffered, minimizing the total buffered area or volume or surface, kriging for a particular objective function, all using higher levels of precision in GIS estimation capabilities) are required to derive the optimal

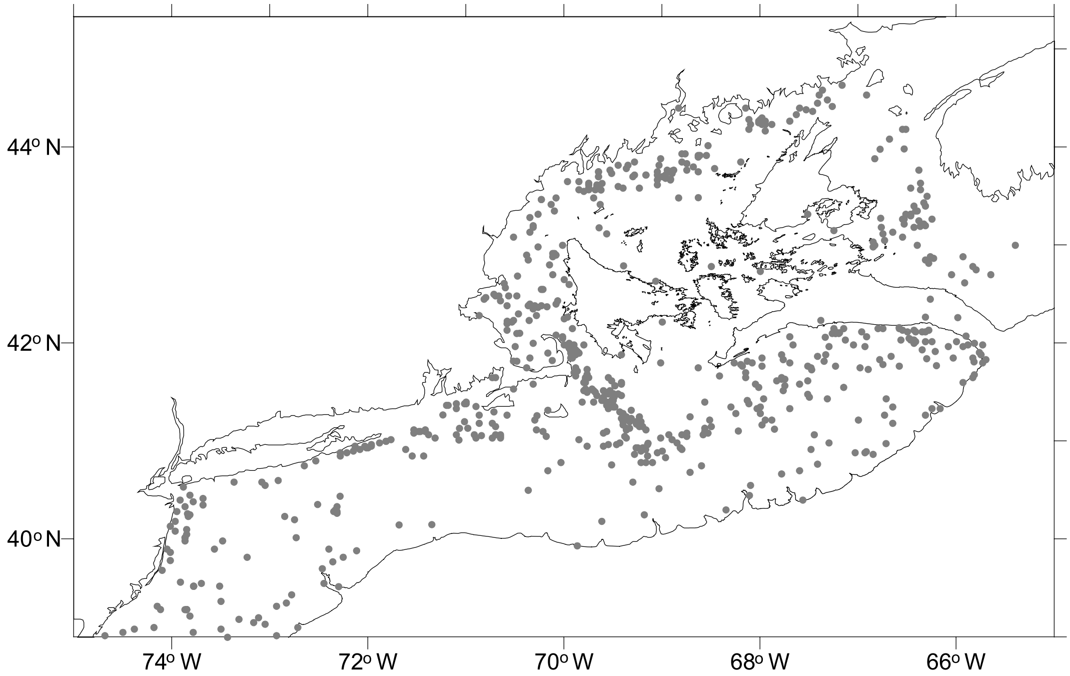

Figure 7. Significant hangs surrounded by 3.7 km (2 nautical miles) buffer zones for each group of significant hangs.

size of a proposed area closure and the optimal concentration of hangs to be enclosed. However, one can easily imagine a coupled grid (or buffer zone) and decision rule algorithm that would close a certain area of the grid if the concentration of hangs were above a particular threshold (e.g. >5 per 10 km^2). Including commercially available hangs data, after appropriate quality control, will only enhance this approach. The point is that, by selecting protected areas, closed areas, or marine reserves around known hangs, one is automatically going to provide some protection for a notable portion of the juveniles of commercially important fish. Also, the susceptibility to gear impacts and recovery times from such impacts for high relief habitats are well documented, and this approach would allow for further protection and recovery of these habitats (Auster *et al.*, 1996; Dorsey and Pederson, 1998; Benaka, 1999; Kaiser and de Groot, 2000).

Additionally, most fishers wish to avoid hangs. The cost of fishing gear is not trivial, and avoiding areas with a high probability of harming or destroying fishing gear minimizes both downtime and increased fishing costs. Certainly most fishers are skilled at dragging their gear and could pass a hang relatively close by with no detrimental effects. Another study showed that, with a buffer zone ranging from 0.1 to 10 ha surrounding untrawlable locations of the seabed, the actual total percentage of the ocean bottom closed to fishing was still only 1–4% (Link, 1997). As noted, many of the hangs are concentrated, so a buffer zone or a collection of buffer zones (such as those in Figure 7) would also serve to protect a trawl or dredge, or similar bottom-tending gear, from multiple possible hangs. It is also highly likely that fishers are aware of some of these hangs and are therefore already avoiding notable portions of the highly concentrated hang areas. How appropriate this approach is for fisheries other than those using mobile bottom-tending gear is debatable, and ultimately it depends on the management and conservation goals for a region. Closing areas that typically do not experience much effort, or areas that have a high probability of producing gear damage, should be more agreeable to implement.

We propose a win–win scenario for the evaluation of future closed areas in this and similar ecosystems. By establishing closed areas in regions with known concentrations of hangs, one can both protect pre-recruit fish and minimize gear damage. Closed areas centred around hangs may help to ensure the supply of fish for future fisheries and may also help to increase the effectiveness of a fishery. The details need to be fleshed out for a specific ecosystem with respect to particular terms of reference and management objectives. However, the concept should be applicable to this and a wide range of ecosystems with similar sets of data and similar concerns about the effects of fishing on the seabed.

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