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Longlining haddock with manufactured bait to reduce catch of Atlantic cod in a conservation zone

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ABSTRACT

A manufactured bait, Norbait© 700E, and two natural baits, clams and herring, were tested to compare catch of haddock and Atlantic cod using longlines in a cod conservation zone. Trials on a commercial fishing vessel demonstrated that the manufactured bait had the lowest catches of cod and the lowest ratio of cod to legal-sized haddock compared to either natural bait. Interactions of bait type, area of set, and trip confounded the effects of bait on catch. Based on the haddock catch per unit effort (CPUE), estimates of economic viability using only the manufactured bait suggested that a fishery may be infeasible. Use of Norbait© to limit Atlantic cod bycatch in haddock longline fisheries may require fishery-by-fishery evaluation.

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1. Introduction

Increasing the species selectivity of commercial gear in a multi-species fishery can allow access to healthy fish stocks if the catch of over-exploited stocks can be minimized. Appropriate access to healthy fish stocks will have positive impacts to the fishing industry, seafood consumers, and coastal communities while protecting the sustainability of marine resources. Successful development of more selective gear is often related to the level of collaboration between members of the fishing industry (fishermen, net makers, and others) and scientists experienced in fishing gears and sampling techniques.

Species selectivity in longlines can be primarily influenced by bait type (Løkkeborg, 1990; Løkkeborg and Bjordal, 1992; Bjordal and Løkkeborg, 1996). Reductions in catch of Atlantic cod *Gadus morhua* and an increase in catch rates for haddock *Melanogrammus aeglefinus* was found by Løkkeborg (1991) using minced herring in nylon bags, compared to natural baits of mackerel and squid. This work led to the development of several types of commercial manufactured bait, Norbait© (Norbait DA, Norway) (S. Løkkeborg, Institute for Marine Research, pers. comm.). Norbait© consists of a gelling agent/binder added to fish and fish offal that is extruded into a casing, much like sausage; the type used for this experiment, Norbait© 700E, primarily consists of Atlantic mackerel *Scomber scombrus* (S. Løkkeborg, Institute for Marine Research, pers. comm.).

Three recent unpublished studies in the northwest Atlantic have estimated haddock and Atlantic cod catch rates by comparing different baits to Norbait© 700E. The Cape Cod Commercial Hook Fishermen's Association (CCCHFA) led two studies. The first study compared squid, herring, and three artificial baits: Norbait© 700E, Trident (Trident Seafoods, USA) which differs slightly from Norbait© in composition but generally follows similar guidelines, and a third undefined type, in an area closed to groundfishing—Georges Bank Closed Area I (CAI) (M. Leach and S. Goldhor, CCCHFA, unpubl. data). The second study compared those three baits in CAI and other areas in the Gulf of Maine and Georges Bank (M. Sanderson, CCCHFA, unpubl. data). The third study, by the Fisheries and Marine Institute (MI) of Memorial University, compared mackerel and Norbait© 700E on the northeastern edge of Georges Bank (P. Walsh, MI, unpubl. data). In general, all three studies showed lower catch rates of Atlantic cod, expressed as a percentage of the haddock caught, using Norbait© 700E compared to natural baits and other manufactured baits. The results from CAI were used in a management action to allow qualified longline fishermen to target haddock despite excessive levels of fishing

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effort and mortality in the overlying stock of Atlantic cod (Mayo and O'Brien, 2006).

In December 2003, the Massachusetts Division of Marine Fisheries (DMF) began restricting fishing for Atlantic cod in the Cod Conservation Zone (CCZ) off Boston Harbor to protect high densities of spawning cod. Most of this area is 30–76 m deep with dramatic localized relief (Butman et al., 2007). Depth generally increases with distance from shore. Current is theorized to be uniform in strength and direction throughout the water column, and is mainly influenced by tides, with some effect from wind. In each tidal cycle, the current rotates 360° (C. Chen, School for Marine Science and Technology, University of Massachusetts—Dartmouth pers. comm.).

During research activity in the CCZ, unusual numbers of haddock were observed in multimesh gillnets (DMF, unpubl. data). While exceptional numbers of haddock are currently observed on Georges Bank, the stock of haddock that encompasses the CCZ was considered to be below biomass targets with fishing exploitation rates at appropriate levels at the time of testing (Brodziak and Traver, 2006). This study was designed to compare haddock and Atlantic cod catch rates using Norbait© 700E, clams *Mercenaria mercenaria*, and herring *Clupea harengus* to establish whether a special access program (SAP) could be developed targeting haddock while continuing the protection of Atlantic cod spawning concentrations.

2. Methods

The CCZ is bounded to the south by latitude 42°20′N and to the north by latitude 42°30′N and extends from the shore to the limit of jurisdictional waters of the Commonwealth of Massachusetts, 10–16 nm from shore in the area (Fig. 1). The study area was restricted to the eastern, deeper part of the CCZ based on fishermen's and scientists' knowledge of haddock distribution and further divided into three separate approximately equal areas along Loran-C lines running approximately N–S (∼330°). This division was intended to encompass reported seasonal migration of haddock (based on traditional ecological knowledge) that could affect catch rates as well as to distribute samples across the range of a possible fishery. The total area was approximately 58.25 nm^2.

All fieldwork was conducted from the F/V Sandra Jean (LOA 13.7 m; 300 kW) a western-style fiberglass commercial fishing vessel equipped with a gillnet/longline hauler. The captain and crew were experienced longline fishermen.

Three bait types were used: "food-grade" herring, clams, and the manufactured product Norbait© 700E. Hooks were baited for the first four trips by hand by the crew; for the last four, a different bait shop was contracted. Baits were requested to be similar in size. Examples of baits ($n > 7$ per bait type), coinciding with the second and seventh trips of the experiment, were collected from each baiter to assess differences between physical characteristics of baits among trips. Following the end of field trials, bait samples were defrosted, soaked in sea water for 2 h, and weighed. Dimensions along primary axes were measured, and a volumetric estimate was obtained by displacement in water.

Longline gear was standardized for all variables except bait type and was constructed of white braided polyester negatively buoyant mainline (#7 Osprey, Rocky Mount Cord Co., Rocky Mount, NC), 5.5 mm in diameter with a nominal breaking strength of 438 kg. Hooks were attached every 1.8 m by gangions to the mainline. Gangions were 35.6 cm in length and made from braided nylon twine (#550), 2.2 mm diameter with greater than 113 kg breaking force.

Hooks were 11/0 circle hooks (O. Mustad and Sons AS, Norway), and measured 41 mm in total length, 2 mm in diameter, with a point-to-shank gape of 10 mm. They were coated with a silver-colored, corrosion resistant surface, and had a large ringed eye and a kirbed point. The hooks were attached to the gangion with overhand loops.

Each longline "string" was composed of six sections. Each section was approximately 457 m long and consisted of 250 hooks baited with a single bait type. Sections were clipped together with an approximately 1.4 kg sash weight inbetween. At each end of a string was a weight made of steel, buoy line, and highflier.

One string (approximately 2740 m long) was set in each of the three areas of the study area during each experimental trip (Fig. 1). The fisherman was allowed to select the set location within the area. Direction of set was restricted by local practice to avoid gear conflicts. Two sections in each string were baited with each bait type. At projected sample sizes, randomization of bait order risked imbalance in treatments. Therefore, order of baits within strings was strictly controlled, so that (1) adjoining sections could not have the same bait, (2) the bait pattern for the first three sections could not be repeated in the next three sections, and (3) a bait pattern could be used for only one trip. As an adjunct investigation, three sections of hooks using only Norbait© were set at distance from the mixed bait experiments on three trips. As the raw catch data were not noticeably different from the mixed bait strings and because this effort was not part of the original design of the experiment, those results were not included nor discussed here. Each section was considered as a treatment unit.

Temperature plays a vital role in the willingness of fish to take bait (Stoner et al., 2006). Calibrated TidBit temperature recorders (Onset Comp. Corp., USA) were attached to one end of each string. Species catch weights were obtained to the closest tenth of a pound and converted to kilograms. Fish lengths were recorded to the nearest whole centimeter as the greatest distance from the snout to the end of the caudal fin along the fish's centerline (the mid-line length).

In addition to catch information, operational and environmental data were collected, including set locations using GPS and durations. For analysis, Atlantic cod were separated into legal (≥ 55.9 cm total length (TL)) and sublegal (< 55.9 cm TL) categories. Haddock were similarly separated into legal and sublegal categories using 46.4 cm fork length (FL).[1]

Trips were conducted on approximately weekly intervals during April and May 2007, and were numbered 1–8. Boxplots (McGill et al., 1978) and interaction plots were used during exploratory analyses to illustrate trends in catch numbers due to the factors of bait, area, and trip, and to examine interactions between factors. Exploratory ANOVAs using normalized data for legal haddock and all sizes of Atlantic cod using bait, area, and trip as factors with all possible interactions were conducted. Data were transformed using $\log_2(\text{count} + 1)$. Diagnostic plots (normal quantile–quantile, residuals vs. fitted, scale location, and constant leverage) were examined. A linear model was applied to bait, area, and trip effects, using a step-wise procedure and Akaike's information criterion (AIC) to select parameters. Different models generally agreed with each other, and the results from the general linear model are presented in this paper.

The ratio of the count of all sized cod to legal haddock was estimated by bait type, area and trips pooled. Bootstrapping was used to estimate the uncertainty in the catch ratio by bait type instead of calculating the variance of these ratios because of the large coefficient of variation; sample sizes were not adequate to generate parametric confidence limits. The ratio of the mean count of all-sized Atlantic cod to legal haddock was calculated by the

[1] A relationship of $FL = 0.9532TL + 0.3761$ ($R^2 = 0.99$) was used to convert the minimum landing size from TL to FL (DMF, unpubl. data).

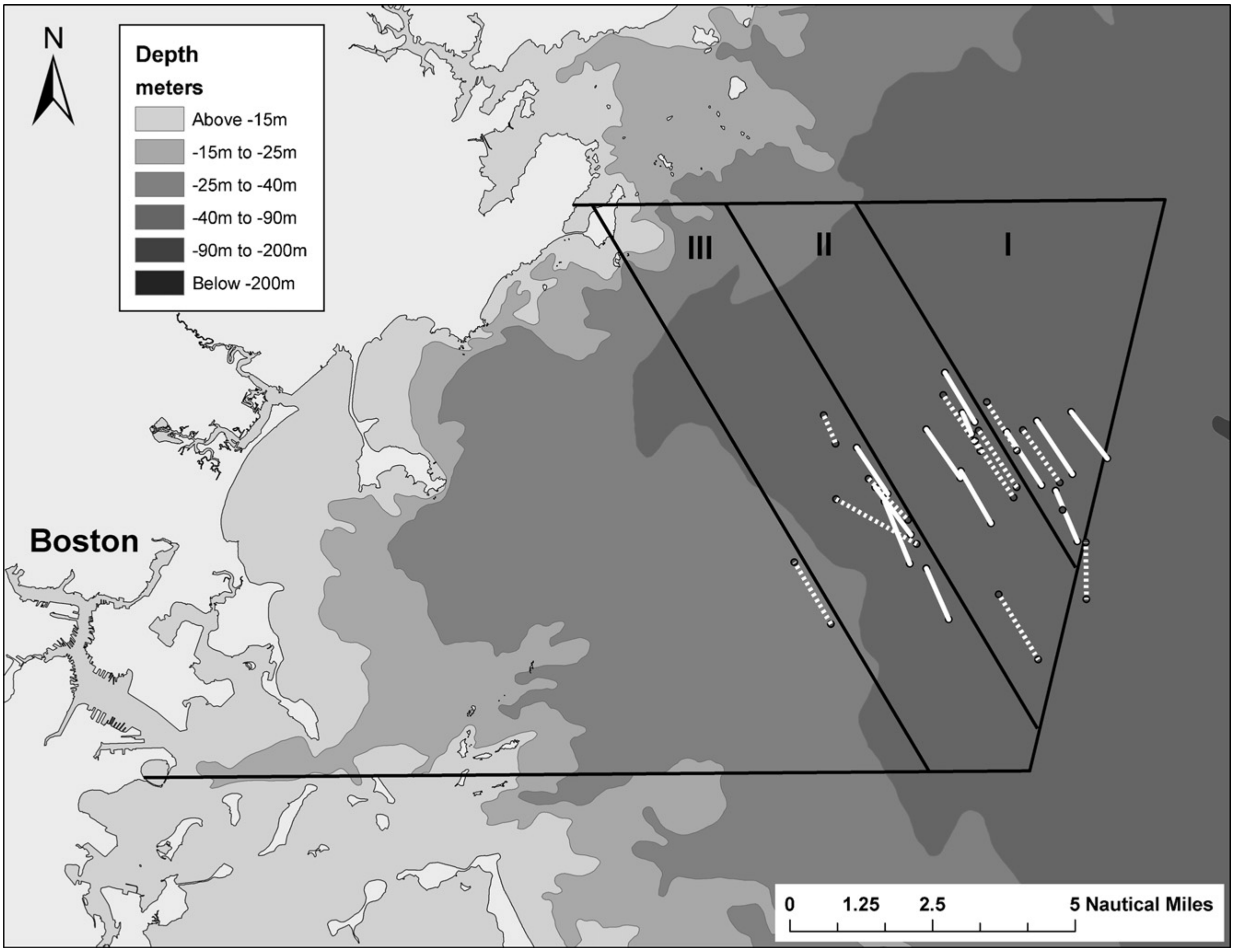

Fig. 1. Chart of the study area, showing the Cod Conservation Zone with a dark line and study areas denoted with Roman numerals (I, II and III). Dots show vessel location at beginning and ends of hauls. Strings (lines) are separated into trips 1–4 (April; dotted) and 5–8 (May; solid). Strings outside of lines and solitary dots are due to reporting omissions and these sets were considered approximate.

selection of 24 observed values for each bait type with replacement. This process was repeated 1000 times for each bait type. The 95% confidence limits were calculated using Efron's percentile method (0.025–0.975th quantiles) of the bootstrap distribution without bias correction. A randomization test was applied to the new pseudo-values obtained from the bootstrapping and differences in ratios were calculated for each bait type, using 1000 replications. The observed differences were compared with cumulative distribution of differences from randomization to obtain the probabilities.

The viability of a Norbait©-only fishery was investigated based on an industry-provided estimate of 136–227 kg of dressed haddock landed per trip to achieve economic viability. Catch data were used to project which trips from this study would have been economically viable using only one bait type, using the fitted values from the linear model. Fitted values for haddock were scaled to 4500 hooks (an estimate of a practical amount of hooks that could be hauled in 1 day), and then compared graphically on a trip-by-trip basis to the industry thresholds. To convert our fitted data from counts to landed, dressed weight, the total reported landed poundage of haddock from auction receipts was divided by the total count of all legal-sized haddock caught. Damaged haddock, unsold legal haddock, and haddock from Norbait©-only sets were included in the count; the Norbait©-only-set-caught fish could not be separated from the rest of the fish and the catch of shared or damaged fish was considered to be a byproduct of catching the landed fish.

3. Results

Eight overnight sets were conducted between 9 April and 28 May 2007 at approximately weekly intervals (median time between sets: 8 days (interquartile range (IQR[2]): 6.5–8.0), resulting in 48 sections of each bait type fished. String locations are presented in Fig. 1. Median soak times, defined as the duration between beginning of setting of gear and retrieval of the last piece of gear, was 17.6 h (IQR: 17.0–18.3). Median bottom temperatures within each area ranged between 3.5 and 4.5 °C, except for trip 7 in area 3. For that trip, the median temperature was measured at 5.3 °C. Median depth of each string was 60 m (IQR: 50.7–68.1 m).

Catch composition was limited to nine species (Table 1) and varied between bait types. Norbait© 700E caught less haddock overall than clams but more than herring; the median values, however, were not significantly different (Fig. 2). Norbait caught the least amount of Atlantic cod; clam baits caught the most. The median values for Atlantic cod catches, pooled by bait, varied significantly

[2] Range provided indicates the 25th and 75th percentiles; 50% of observed values are between these two values.

Table 1
Catches of all species during the experiment, grouped by bait type

Common name		Bait type		
		Clams	Herring	Norbait©
Haddock	kg	1087.2	486.5	522.1
	Count	615	271	327
Legal-sized haddock	Count	585	257	309
Atlantic cod	kg	640.1	461.0	172.3
	Count	442	264	111
Spiny dogfish	kg	345.7	1028.2	910.2
Red hake	kg	39.3	51.9	41.7
Thorny skate	kg		62.0	45.0
Winter skate	kg		19.8	
Cusk	kg		17.7	
Ocean pout	kg	11.9		
Little skate	kg		10.1	

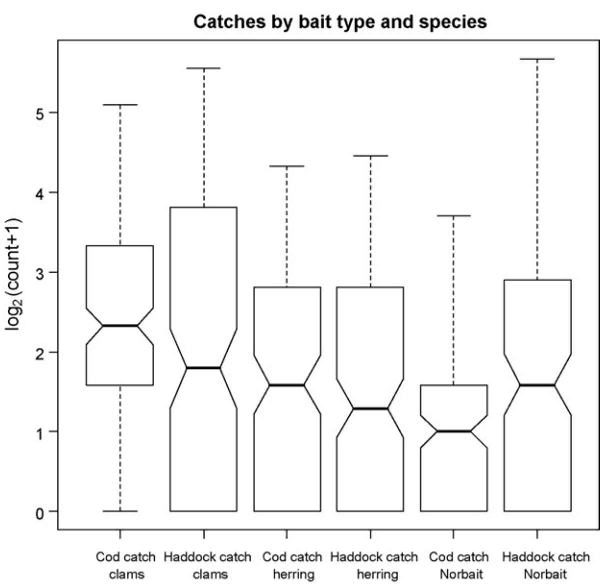

Fig. 2. Boxplots of overall counts for each bait type and for Atlantic cod and haddock, converted to $\log_2(\text{count}+1)$ to simplify comparisons. Notches approximate 95% confidence intervals.

among the three bait types, with overall catches with Norbait© significantly lower than both herring and clam baits (Fig. 2); median catch of Atlantic cod on herring was lower than on clams. Norbait© was the only bait that showed a significant difference between catches of Atlantic cod and haddock (Fig. 2). Herring caught the widest diversity of organisms, and caught the most spiny dogfish *Squalus acanthias*. Small amounts (<136 kg total) were caught of (in descending amounts) red hake *Urophycis chuss*, thorny *Raja radiata* and winter skates *R. ocellata*, cusk *Brosme brosme*, ocean pout *Macrozoarces americanus* and little skates *R. erinacea*.

Non-target species appeared to prefer certain baits over others, and their composition changed during the experiment. Only 15% of spiny dogfish were caught on hooks baited with clams, and 78–85% of spiny dogfish were caught during the last three experimental sets. No skates of any species were caught using clam bait; only thorny skates were caught using Norbait©. Herring caught thorny, winter, and little skates. Cusk were only caught on herring-baited hooks. Ocean pout were only caught on clams.

Ratios of cod:haddock were lower for Norbait© (0.38) than either herring (1.06) or clams (0.80) (Table 2). The boot-strapped 95% limits of the pseudo-values resulted in a much wider distribution of catch ratios for herring than either Norbait© or clams (Table 2). Randomization testing of the boot-strapped ratios resulted in probabilities of 0.004 (one tail test) for differences in herring–Norbait© ratio and 0.079 for clams-Norbait©. The probability for clams-herring was 0.44, suggesting little difference in the ratio of cod:haddock for these two bait types.

Although based on limited amounts of data, fitted haddock (Fig. 3) and Atlantic cod (Fig. 4) catch rates from the model showed several prominent features: catch rates for both species generally declined over the period of the experiment for all three bait types, but declines were greatest for clams. Differences between baits also declined over trips. Atlantic cod catches were lowest in area 1 and highest in area 3. Haddock catches showed less consistency, but were lowest in area 3, the westernmost and shallowest area. Differences in catch rates among areas were greatest in April (trips 1–4), and became more homogenous in May (trips 5–8) as overall catches declined.

The total reported landed poundage of haddock (1501 kg) divided by the total count of legal-sized haddock (1135) equaled 1.3 kg landed for every legal haddock caught. This conversion yielded a range of 103–172 haddock necessary for a successful trip. Profitability is projected for only three trip-area combinations if Norbait© was the only bait: trips 2 and 3, area 2; trip 3, area 3. Trips 2 and 3 were hauled on 14 and 21 April (Fig. 3). The estimated Atlantic cod bycatch-predicted for these trips was approximated at 0, 10, and 55 individual Atlantic cod (Fig. 4).

Boxplot analysis of bait samples indicated that the median density of Norbait© varied significantly ($p < 0.05$, two-tailed) between the two baiters (trip 2: 1.09 g/ml (IQR: 1.04–1.07); trip 7: 0.93 g/ml (IQR: 0.9–1.0)). The median densities of the other two baits did not differ (clams: 1.06 g/ml (IQR: 1.03–1.10; herring: 1.06 g/ml (IQR: 0.92–1.25)). Weights of individual bait pieces were significantly different ($p < 0.05$, two-tailed) between baiters for all three baits; volumes were significantly different for herring and clams ($p < 0.05$, two-tailed) but not for Norbait©.

4. Discussion

The ability of bait type to influence species selectivity is demonstrated by our results, both in the catches of Atlantic cod and haddock, and in the catches of non-target, discarded organisms. Both overall catches and the ratio of Atlantic cod:haddock were lower using Norbait© 700E than with the natural baits, indicating that the manufactured bait succeeds in inhibiting Atlantic cod. Norbait© had lower overall CPUE than clams for haddock, demonstrating that the lower ratios were not the result of improved haddock catches using Norbait©. This lower efficiency also implies that gear saturation was not a factor, although we did not record

Table 2
Observed ratio of count (all cod:legal haddock) and mean and 95% confidence limits from bootstrap distributions for three bait types (back transformed from log scale).

Bait type	Observed ratio	Mean of bootstrap distribution	95% limits of bootstrap distribution
Norbait© 700E	0.38	0.38	0.23–0.63
Herring	1.06	1.07	0.63–1.68
Clams	0.80	0.80	0.55–1.22

Confidence limits generated using Efron's percentile method without bias correction.

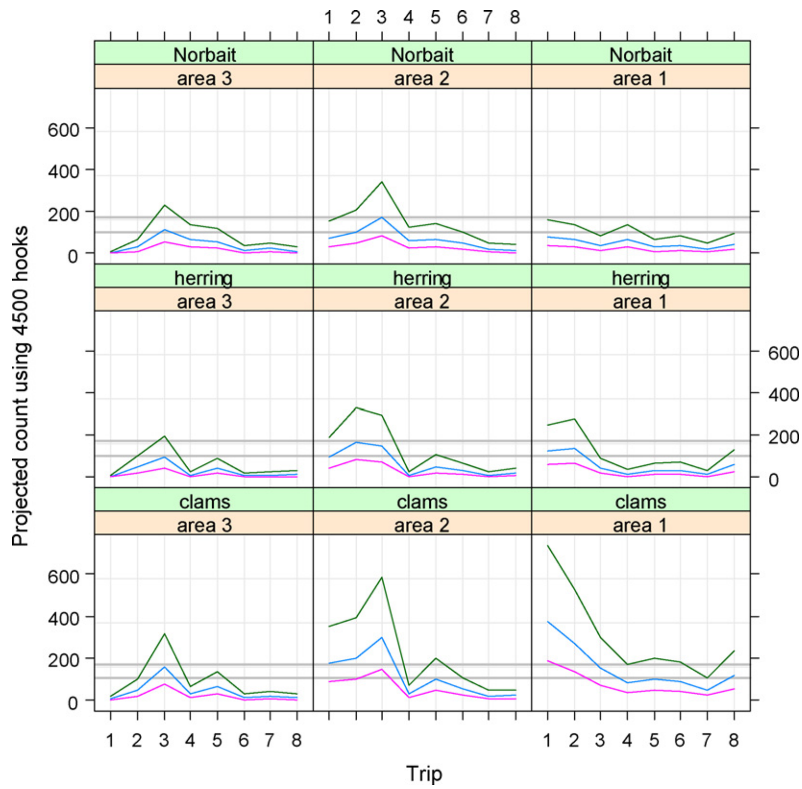

Fig. 3. Projected counts and upper and lower 95% confidence intervals of legal-sized haddock using 4500 hooks of a single bait type, in each of the study areas. Grey lines indicate estimated range of profitability. Estimates are based on fitted values.

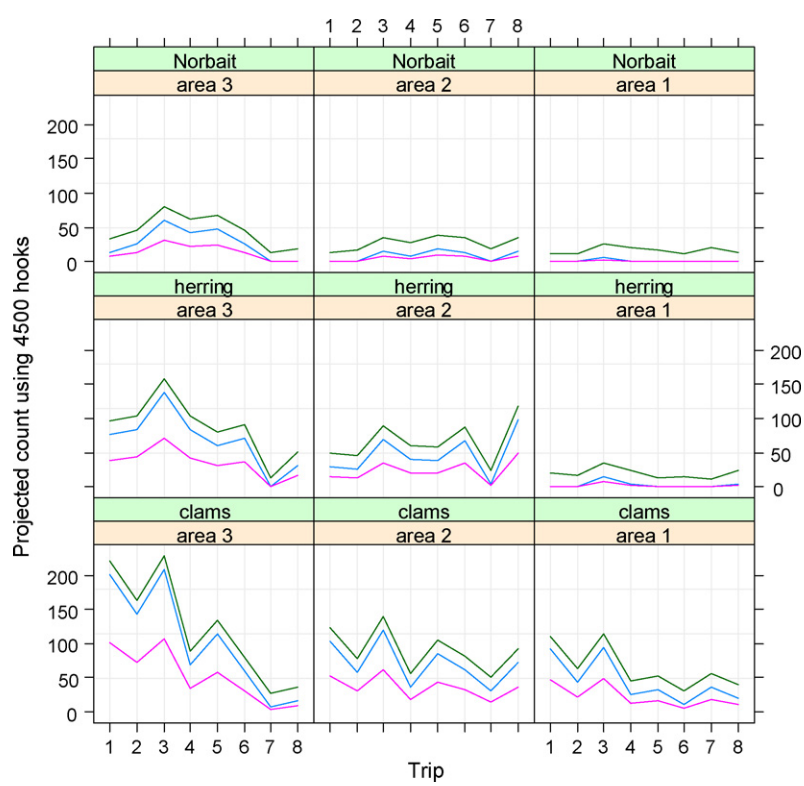

Fig. 4. Projected counts and upper and lower 95% confidence intervals of Atlantic cod using 4500 hooks of a single bait type, in each of the study areas. Estimates are based on fitted values.

frequencies or periodicities of empty hooks. Traditional observations that clams are the preferable bait when targeting Atlantic cod were confirmed in this study—the equal efficiency for haddock when using clams is less known. Herring was found to be generally equally attractive to haddock and Atlantic cod.

The results support other research using Norbait© 700E, although differences in study design and analysis and available information inhibit direct comparisons. Walsh (unpubl. data) and Goldhor and Leach (unpubl. data) found similar but higher reductions in cod:haddock ratios using Norbait© 700E compared to standard baits. The consistency across studies demonstrates that Norbait© can reduce but not eliminate Atlantic cod bycatch in haddock hook fisheries; the differences in magnitude of the reduction for the different regional tests suggests that other factors besides the bait type influence this ratio. In this study, the detection of interactions between bait, area, and trip also suggest that bait type is not the single controlling variable for these ratios. The size of reduction of Atlantic cod:haddock is likely dependent on spatial and temporal factors, especially the proportional mixture of those two species when the fishery is conducted. Additional investigation into baits that separate Atlantic cod from haddock is warranted based on current discrepancies in stock status in the Northwest Atlantic.

Catch results other than Atlantic cod and haddock showed patterns that suggest ways to decrease non-target catches. Herring bait was the least selective, appealing to the broadest range of species, particularly skates. Clams were preferred by the narrowest range of species, and seemed least attractive to spiny dogfish, whose localized abundances have reportedly inhibited hook fishing. The marked increase in catch of spiny dogfish later in the study suggests that they may best be avoided temporally, by fishing when dogfish are not present. Nevertheless, the narrow range of species caught using clams and the differences in catches of skates suggest that species selectivity of baits for non-target species bears further exploration.

Chemoreception in fishes is a complex process, with many species showing up-current swimming (rheotaxis) in response to chemical cues emitted by bait (Atema, 1996). Experimental evidence suggests that overlapping bait plumes may result in different CPUEs than individual baits. Bait combinations in work by Johnstone and Hawkins (1981) had higher CPUEs that individual baits. This experiment was designed to limit the overlapping of scent plumes emitted by baits by using long sequences of one bait type at a time; however, plume dispersion is also a complex process (Atema, 1996) and our understanding of the actual nature of plumes produced in this study is limited. In other areas where currents are less uniform, using separate baits on separate strings (as used in the unpublished work by Sanderson and others) may be more appropriate. The risk of this approach, however, is that separate populations or groups of fish are sampled by the separate strings and therefore the results from different strings in Sanderson's research and similar studies may reflect densities of localized fish assemblages and may not be directly comparable between strings. It is also possible that, in our study, the fish were distributed in patches that were smaller than our bait sections, but that seems unlikely given our understanding of local fish densities and the size of the sections.

Differences in bait size and quality may have affected catch. We attempted to standardize bait size between baiters and across trips but were unable to confirm consistency. The sizes of the baits supplied for analysis in the second set were substantially larger and therefore the samples may not have reflected actual bait size. The difference in densities of Norbait© is more critical; baits were handled identically for analysis, and both samples, indeed reportedly all Norbait© 700E recently used in the Northwest Atlantic, are from the same batch shipped together. Maintaining consistent bait quality is problematic when using natural baits; our results indicate that quality, as measured by density, also varies within manufactured baits.

The difference in density could affect fish perception of bait, or perhaps the buoyancy of the bait. Hooks baited with Norbait© were observed on the first trip to float to the surface of a seawater-filled fish tote. The depth of the tote was not adequate to see if the entire gangion or any of the mainline could be lifted; however, lifting of the mainline seems unlikely. Floating of hooks could strongly influence haddock catch; in other regions, haddock are targeted using semi-pelagic or pelagic longline gear to exploit haddock presence in these oceanic zones (Bjordal and Løkkeborg, 1996; Huse and Soldal, 2000). An investigation of the in situ behavior and buoyancy of hooks baited with Norbait©, and the effectiveness of semi-pelagic or pelagic hook gear for haddock in New England, represent possible future directions for research.

The potential for a haddock targeted fishery in this area, based on the results of economic analysis and Atlantic cod catch rates, appears limited. Very few trips were projected to meet profitability, and while areal and temporal trends were evident, the time periods of profitability are predicted to be too brief to support a fishery. The lack of profitability is dependent on the underlying population densities and the accuracy of the estimate of landings needed, although loss of efficiency of Norbait©, compared to clams, reduced profitability. Further, Atlantic cod catches were successfully but perhaps not sufficiently decreased by Norbait© 700E. In one trip only, haddock catches reached profitable levels with zero cod catch. Because the area is intended to protect Atlantic cod, permitting a fishery likely to take cod as part of a routine non-target catch appears inadvisable.

In this study, significant bait, area, and trip effects on all sized cod catch along with significant interactions with bait and area, bait and trip, and trip and area contraindicated the comparisons within the main effects and complicated the interpretation of the model. Also, the impact of important factors such as season, stock status, temperature, and year cannot be predicted from our results. Our results suggest that case-by-case assessments must be made to determine if the reduction of Atlantic cod catch in haddock longline fisheries demonstrated by Norbait© 700E is adequate for management purposes in mixed fisheries.

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