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Cod bycatch in otter trawls and in longlines with different bait types in the Georges Bank haddock fishery

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ABSTRACT

In the Northwest Atlantic, bycatch of depleted groundfish stocks in the haddock fishery on Georges Bank is an ongoing concern. In recent years, this fishery on the American side of Georges Bank has been limited by high bycatch rates of cod. Considerable conservation engineering work has been done to address the problem, including experiments with different longline baits and modifications to otter trawl gear. Fabricated baits have shown promise for increased selectivity when longlining, but it has sometimes been difficult to establish whether low cod catch rates with fabricated baits have resulted from bait selectivity or from a low abundance of cod in the area. In this study, we compare catch rates of cod and haddock between otter trawls and longline gear in experimental and commercial fishing on Georges Bank in the summer of 2005. We also compare cod bycatch rates among longlines baited with squid, herring, or fabricated baits (mainly Norbait 700E) in Georges Bank Closed Area 1, from October 2003 to June 2005. Records from the Northeast Fisheries Observer Program were combined with data collected by the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), and compared using generalized linear models. In the Eastern US-Canada Resource Sharing Area (EUSCA) in the summer of 2005 catch of cod per haddock by weight was significantly lower when fishing with longline gear (0.008–0.045 kg cod per kg haddock) than with otter trawl gear (0.059–0.826 kg cod per kg haddock), in all months and areas. Cod bycatch rates were also significantly lower for longlines fishing for haddock than for otter trawls fishing for groundfish species other than haddock. In Closed Area 1, statistically significant differences in cod to haddock ratios were found between baits, with squid catching the highest amount of cod, fabricated baits catching the lowest amount, and herring at an intermediate level. The development of fishing methods that minimize cod bycatch is a high priority in many regions of the North Atlantic. These results indicate that longlines with fabricated bait have the potential to maintain a very low catch of cod while fishing for haddock.
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1. Introduction

Following the widespread collapse of Atlantic cod stocks in the Northwest Atlantic in the early 1990s, cod catch restrictions have impacted fisheries targeting other groundfish species off Atlantic Canada and the Northeastern US. One of these fisheries, the haddock fishery on the US side of Georges Bank, was closed in 2005 at 8% of the total allowable catch and in 2007 at 12% of the total allowable catch due to high bycatch of cod (US Federal Register, 2007). Efforts have been made to reduce cod catches in this fishery, including gear substitution, gear modification for otter trawl gear (e.g. Beutel et al., 2006), and alternative baits for longlines (e.g. Walsh et al., 2006). This study compares cod and haddock catch ratios between longlines using fabricated baits and traditional baits, and between longlines and otter trawls to assess the ability of longlines with fabricated baits to catch haddock while avoiding cod.

Several large areas in the Gulf of Maine and Georges Bank have been closed to groundfish fishing since 1994, and access to these areas is granted by the National Oceanic and Atmospheric Administration (NOAA) through Special Access Programs (SAPs) or Exempted Fishing Permits (EFPs) (NEFMC, 2004). This study includes fishing done with longlines under SAPs or EFPs inside Closed Area 1 (CA1) and Closed Area 2 (CA2), and with longlines and otter trawls outside CA2 in the Eastern US-Canada Resource Sharing Area (EUSCA) (Fig. 1). Due to regulatory, logistic, and budget constraints, it has not been possible to perform comprehensive side-by-side field comparisons of gear and bait performance experimentally in this area. There have been field trials using different baits in side-by-side experiments, but they have been limited in scope and size (Leach and Goldhor, 2005; Sanderson et al., 2005).

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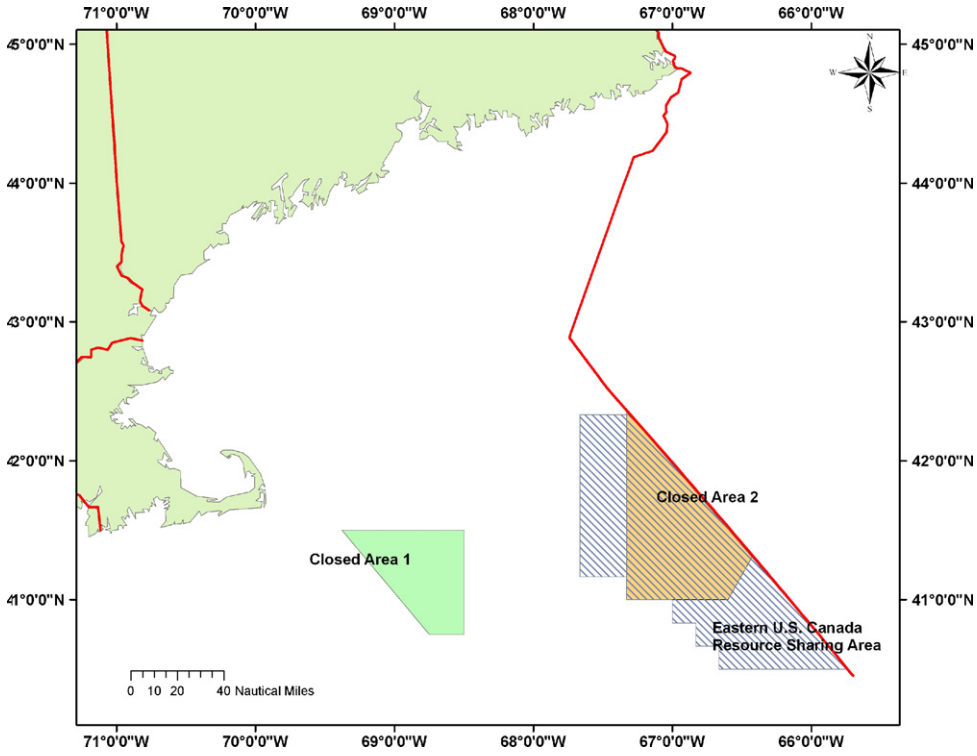

Fig. 1. The study area in the Gulf of Maine, USA. Gear comparisons are based on fishing by otter trawls and longlines in the Eastern US-Canada Resource Sharing Area (EUSCA), the area indicated by diagonal lines. Bait comparisons are based on trips to Closed Area 1 (CA1). The red line forming the border of the EUSCA is the US-Canada border.

However, this study shows that there are sufficient records of catches with different gears and baits operating in the same areas of Georges Bank during the same time period to be able to determine whether there are differences in their cod and haddock catch ratios.

Previous studies have experimentally compared catch composition among different fishing gears in the same time and place. Huse et al. (2000) found lower cod to haddock ratios in catches from an otter trawler than from a longliner fished simultaneously over 6 days in the Barents Sea, but the difference was not statistically significant. Engås et al. (1996) found the opposite, with longlines catching relatively more haddock and less cod than otter trawls fished simultaneously in the Barents Sea.

Several studies have investigated the use of alternative longline baits to target particular species or size ranges. Sizes of bait can be used to select for different sizes of target species (Halliday, 2002; Huse and Soldal, 2000). Some groundfish have documented preferences for particular baits; Thorsteinsson and Björnsson (1996) found that both haddock and cod preferred squid to mackerel and mackerel to herring. Woll et al. (2001) showed an increase in Greenland halibut catch with grenadier bait (over squid) and a reduction in bycatch. Løkkeborg (1991) found that a fabricated bait based on herring gave a better catch rate for haddock, cusk, and lingcod than unprocessed herring, whereas it reduced catch of cod.

In the Gulf of Maine and Georges Bank, catch rates of cod and haddock have been compared experimentally between traditional baits such as squid, herring, and mackerel, and fabricated baits similar to that developed by Løkkeborg (1991), including the commercially available Norbait 700E. The fabricated baits tested generally consist of ground herring, mackerel, or both mixed with a binding agent, and extruded into a sausage-like shape held by netting. Over 141 trips between 2003 and 2005, the kg of cod caught per kg of haddock caught was highest for squid bait at 0.091, intermediate for herring bait at 0.033, and lowest for Norbait 700E at 0.003 (Leach and Goldhor, 2005). Estimates of average kg cod per kg haddock caught with Norbait 700E on Georges Bank and in the Gulf of Maine ranged from 0.029 to 0.118 (Sanderson et al., 2005). Experimental side-by-side longline bait trials with mackerel and Norbait 700E were conducted by the Fisheries and Marine Institute at Memorial University of Newfoundland in 2005 (Walsh et al., 2006). The number of cod was reduced from 0.6 cod per hundred hooks with mackerel as bait to 0.2 cod per hundred hooks with Norbait 700E. No test of statistical significance was given in Walsh et al., but they cautioned that test fishing should also be done at locations and times with higher relative cod abundances.

In this study, we compare the catch of cod per haddock by weight between otter trawls and longline gear, and among longlines operating with squid, herring, or Norbait 700E as bait. In the absence of a comprehensive framework of side-by-side experiments, we use differences in the catch ratios of gears and baits being fished in the same areas at the same times to determine how catch ratios of cod to haddock vary between gears and bait types.

2. Materials and methods

2.1. Gear comparison

Data from groundfish trips with otter trawls and bottom longlines in the EUSCA (Fig. 1) were obtained from the Northeast Fisheries Observer Program from June 2005 to January 2006. This was combined with data collected by the CCCHFA from longline trips in the same area from June 2005 to February 2006. Data provided by the CCCHFA were collected by trained, independent scientific data collectors, under a protocol designed to generate data comparable to that collected by the NOAA Northeast Fisheries Observer Program (CCCHFA, 2005). Data are held by the NOAA Northeast Fisheries Science Center and the CCCHFA. All the longline data included in this study are based on fishing with 12/0 circle

Table 1
Cod per haddock, by weight, in hauls with temporal and spatial overlap targeting haddock in summer 2005 in the EUSCA

Square	Month	Longline		Otter trawl			
		<50 m	*n*	<50 m	*n*	≥50 m	*n*
41,673	June	0.045 (0.022–0.092)	23	0.726 (0.644–0.795)	114		
42,671	June	0.019 (0.011–0.033)	39			0.130 (0.052–0.288)	2
42,671	July	0.008 (0.005–0.012)	72	0.310 (0.163–0.507)	11	0.059 (0.026–0.127)	19
42,671	August	0.019 (0.007–0.051)	12			0.134 (0.055–0.293)	13

The bracketed numbers are the 95% confidence intervals and *n* is the number of observations for that combination of gear, month, area, and depth strata.

hooks. All fabricated baits were cut into pieces roughly 25 mm long, with a consistent diameter. Almost all longline records from the EUSCA were listed as having "fish with binders/casings" as bait, which at that time would be Norbait 700E (T. Rudolph, personal observation), but a small number were listed as baited with clams or "other" and were removed.

Catch data was obtained from the Observer Program for June to December 2005 with locations given by quarter degree-square rather than with coordinates for business confidentiality reasons. In this region, a quarter degree-square (as used by NMFS) covers an area of about 40 km × 55 km. Overlap between otter trawl sets and longline sets occurred in four quarter degree-squares in June, July, and August 2005 on the northern edge of Georges' Bank, along the western boundary of CA2, inside the EUSCA (Fig. 1). All fishing included in this study is in American waters (Fig. 1).

For both gears, records of haddock "kept" were converted from dressed to round weights by multiplying by 1.14 (the National Marine Fisheries Service standard), and all records of haddock caught in the same haul (i.e., kept or discarded for any reason) were added together to get one record for "haddock" for each haul. For any haul with no record of haddock caught, a record with a catch of zero was created. The same procedure was applied to cod records, except with a dressed to round conversion ratio of 1.17. For the CCCHFA records, "observed" and "estimated" weights were added together and treated the same way. Data from both sources was combined into a single data set and analysed together.

All CCCHFA trips were targeting haddock only, but trips in the Observer Program were targeting various species and could have up to 3 target species recorded. Winter flounder was the most common target, followed by haddock and then yellowtail flounder. Cod bycatch rates were compared among gears in trips only targeting haddock and again in trips with all targets. When considering all targets, hauls where the primary target was unspecified flounder or unspecified groundfish were removed.

Models were run on only the hauls in quarter degree-squares and months with both longline and otter trawl records. The variable modeled was the empirical logit of the cod per haddock, log((cod + 0.5)/(haddock + 0.5)), with the 0.5 added to prevent missing values when cod or haddock catches were zero. (Other values between 0.01 and 1 were tried, but did not change results significantly.) When neither haddock nor cod was caught, that observation was dropped (34 hauls out of 661 investigated).

Let C_h be the catch of cod in haul h and H_h be the catch of haddock in haul h. Then the dynamics are assumed to be given by:

$$\log \frac{(C_h + 0.5)}{(H_h + 0.5)} = \mu + \text{gear}_i + \text{month}_j + \text{area}_k + \text{deep}_l + e_h$$

where gear i is the gear used in haul h (otter trawl or longline), month j is the month of haul h, area k is the quarter degree-square for haul h, and deep is a categorical variable representing whether the depth of the haul is greater than 50 m or not. The model was fit with quasi-likelihood (using family = quasi in R), to allow for overdispersion (with constant variance).

A small number of hauls with both gears were done in CA2, inside the EUSCA (Fig. 1). The model was also run with a variable indicating whether or not the fishing was inside CA2, to see if the results were affected by the inclusion of these hauls.

2.2. Baits comparison

To compare between different baits, catch records were examined from longline trips conducted by CCCHFA in CA1, on western Georges Bank (Fig. 1). These records cover 147 trips from October 2003 to June 2005. The records are collected in the same manner described above, and held by the Northeast Fisheries Science Center and CCCHFA.

In this database, three fabricated baits based on herring, mackerel, or both were combined for analysis (Norbait 700E, a similar fabricated bait by Trident Seafoods, or an experimental "homemade" product by S. Goldhor of Center for Applied Regional Studies in Boston) (Leach and Goldhor, 2005). This seemed reasonable based on an earlier analysis of the data by Leach and Goldhor (2005), which showed that the Trident and Norbait 700E baits (which make up 96% of fabricated bait effort) had similar cod and haddock catch rates based on 148,511 hooks fished. Some records had more than one bait type. All hauls with two bait types were dropped from the dataset (19 out of 640 hauls in the dataset) because it was not possible to separate catch by bait in these cases. As in the previous analysis, weights for cod and haddock kept were converted from dressed to round weights using the standard National Marine Fisheries Service conversion factors. Any haul with no record for haddock catch was assigned a catch of zero, and catches of haddock kept or discarded were added together to obtain a single haddock catch record for each haul. The same was done for cod. We identified cases when at least two different baits (squid, herring, or fabricated) were fished on the same day in the same quarter degree-square, and used those in the analysis.

Because this dataset involved a small number of comparisons on each day for many days (instead of a large number of comparisons over only a few months), a mixed effects model was fit using the nlme (non-linear mixed effects) package in R, with "day" as a random effect:

$$\log \frac{(C_h + 0.5)}{(H_h + 0.5)} = \mu + \text{bait}_i + \text{day}_j + \text{area}_k + \text{depth} + e_h,$$

where C_h and H_h are the catch of cod and haddock (respectively) in pounds in haul h, bait i is the bait used in haul h, area k is the quarter degree-square for haul h, and depth is the depth at the end of haul h, in metres. Day j is the date of haul h, and its effect size is a normally distributed random variable with zero mean. Model errors were assumed to be normal, and were fit with restricted maximum likelihood.

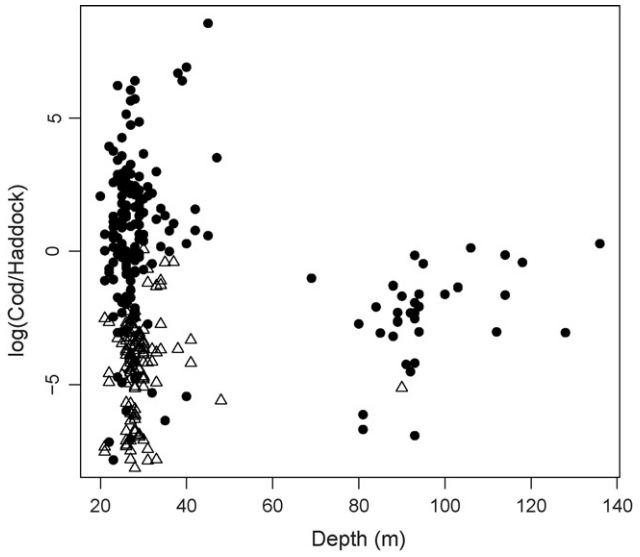

Fig. 2. Natural log of cod per haddock by depth for hauls targeting haddock in summer 2005 in the EUSCA. Otter trawl records are black circles and longline records are open triangles.

3. Results

3.1. Gear comparison

In the areas considered in the EUSCA in the summer of 2005, the proportion of cod to haddock caught was much lower when fishing with longline gear than with otter trawl gear (Table 1). Considering only hauls where haddock was the target species, longlines never caught more than an average of 0.045 kg cod per kg haddock. Otter trawl bycatch rates are more variable, from 0.059 kg cod per kg haddock in July to 0.726 kg cod per kg haddock in June. Cod per haddock by weight was significantly lower for longlines than for otter trawls in all months and areas.

The low cod catch rates attained by longliners in these areas do not appear to be a result of fishing at a time, area, or depth where cod abundances were particularly low. Longliners fished primarily in water shallower than 50 m. For otter trawls, cod catch rates were significantly higher in water shallower than 50 m than in water deeper than 50 m (Table 1, Fig. 2). There was enough overlap in time and space to compare the performance of the different gears—a total of 146 longline hauls and 159 otter trawl hauls in areas of overlap for trips targeting haddock (Table 1), and more when other target species are included.

While the analysis described above was limited to trips in which haddock was the species targeted, there were numerous otter trawl trips in the dataset in which groundfish species other than haddock were the targeted species. Both the ratio of cod to target species (i.e., kg cod per kg winter flounder when winter founder was the main target species) and the ratio of cod to haddock were modeled for all target species. Longline and otter trawl records from the same month and area were available in four quarter degree-squares over June, July, and August 2005 (the inclusion of other target species extended the spatial range over which comparisons could be made). The same result was seen, in which cod bycatch rates were consistently significantly smaller in longline hauls in the same area than in the otter trawl fishery (Table 2). Again, cod catch rates varied more in the otter trawl fishery, from 0.2 kg cod per kg target species to 0.461 kg cod per kg target species, than in the longline fishery (from 0.013 to 0.045 kg cod per kg target species). In only this comparison, depth and month were not significant predictors in the model (an *F*-test comparing the reduction in deviance for the model with and without these variables had a *P*-value of 0.23, using the anova procedure in R). Values in Table 2 are therefore produced from a reduced model with only gear and area included as predictors.

Table 2
Cod catch per catch of the target species, by weight, from hauls with temporal and spatial overlap in summer 2005 in the EUSCA

Square	Longline		Otter trawl	
		n		*n*
41,674	0.045 (0.017–0.112)	7	0.461 (0.261–0.674)	27
42,671	0.014 (0.009–0.021)	124	0.207 (0.141–0.294)	95
41,673	0.030 (0.017–0.053)	23	0.363 (0.301–0.429)	325
42,672	0.013 (0.005–0.035)	5	0.200 (0.096–0.371)	31

The bracketed numbers are the 95% confidence intervals and *n* is the number of observations for that combination of gear and area.

The cod/haddock catch for longlines and otter trawls targeting all species were also compared. The results are similar again (Table 3), with consistently lower cod catches per kg of haddock with longlines than with otter trawls, in the same months and squares. Cod catches ranged from 0.013 to 0.071 kg per kg haddock caught by longlines. Cod catches by otter trawls were consistently higher in water shallower than 50 m (0.45–0.826 kg per kg haddock caught) than in water deeper than 50 m (0.169–0.541 kg per kg haddock caught) (Fig. 3). This decreasing cod to haddock ratio below 50 m was consistent across the comparisons we performed. A similar depth relationship did not appear between cod and other target species, as indicated by the lack of significance of the depth variable in the model comparing cod to other target species (Table 2).

In the dataset, there were 11 longline hauls and 17 otter trawl hauls inside CA2 (Fig. 1), so most fishing by both gear types is from areas of the EUSCA to the west of CA2. A variable indicating whether or not a haul was inside CA2 was tried in all three variations of the model (Tables 1–3), but was never statistically significant, indicating that cod to haddock ratios in the catch were not significantly different immediately inside or outside of the Closed Area.

3.2. Bait comparison

In order to account for changes in cod to haddock ratios over time and space, hauls using different baits in the same quarter degree-square on the same day were selected. There were 267 hauls

Table 3
Cod per haddock, by weight, in hauls with temporal and spatial overlap targeting all groundfish in summer 2005 in the EUSCA

Square	Longline		Otter trawl			
		n	<50 m	*n*	≥50 m	*n*
41,674	0.071 (0.030–0.154)	7	0.826 (0.689–0.910)	26	0.541 (0.312–0.754)	1
42,671	0.013 (0.009–0.018)	126	0.450 (0.320–0.587)	31	0.169 (0.112–0.246)	72
41,673	0.035 (0.020–0.060)	23	0.693 (0.640–0.741)	320	0.359 (0.221–0.525)	5
42,672	0.037 (0.016–0.083)	5	0.709 (0.504–0.853)	8	0.377 (0.220–0.564)	23

The bracketed numbers are the 95% confidence intervals and *n* is the number of observations for that combination of gear and area. Month was not a significant predictor in this model, so results are from the reduced model with 'month' removed.

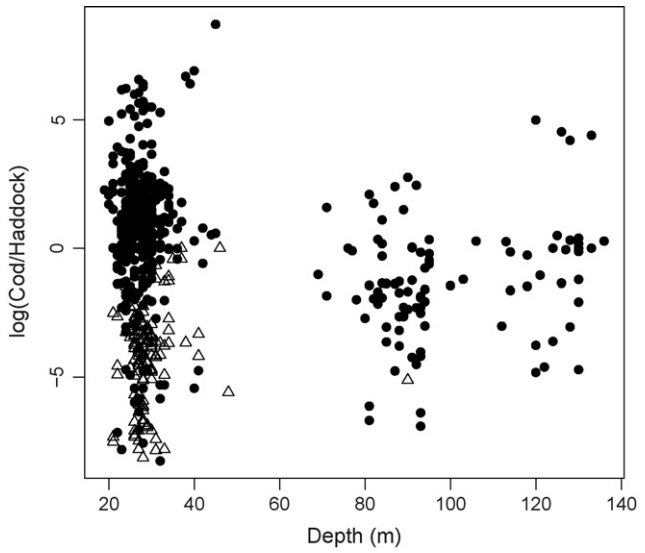

Fig. 3. Natural log of cod per haddock by depth for hauls targeting all groundfish in summer 2005 in the EUSCA. Otter trawl records are black circles and longline records are open triangles.

Table 4
Mean cod/haddock caught (by weight), in the degree-square indicated, on days when at least two of the three baits were used in that square on the same day, with depth set at 78 m (the overall average), and at 92 m (the maximum depth)

Square	Depth (m)	Squid		Herring		Fabricated	
			n		*n*		*n*
41, 691	78	0.0467	78	0.0121	165	0.0036	48
	92	0.0746		0.0251		0.0012	
41, 682	78	0.0214	15	0.0054	70	0.0016	64
	92	0.0347		0.0113		0.0005	

For each bait, area, and depth combination, *n* is the number of hauls included. Fishing was in Closed Area 1 between October 2003 and June 2005.

using either squid or herring on the same day in the same square, 198 hauls using either herring or fabricated bait on the same day in the same square, and 30 hauls using either squid or fabricated bait on the same day in the same square. Bait, square, and depth were all significant terms in the model. In Table 4, the average cod per haddock caught are given at the mean depth of 72 m and the maximum depth of 92 m. Cod catch (as a proportion of haddock catch) was higher when fishing deeper with herring but lower when fishing deeper with fabricated bait (depth × bait term is significant for herring and fabricated bait, but not squid) (Table 4). All baits are significantly different at the $P < 0.05$ level, and cod catches were lower with herring than squid, and lower with fabricated bait than herring. Average cod per haddock catch rates were below 0.1 kg cod per kg haddock for all bait types, including squid, and were well below 0.01 kg cod per kg haddock with fabricated baits (Table 4).

4. Discussion

Our results agree with previously reported findings that cod bycatch rates were lower when using fabricated baits than with traditional baits. The lower ratio of cod to haddock in longline catches than otter trawl catches in this study was similar to the findings of Engås et al. (1996). Huse et al. (2000) found the opposite, that cod catch rates were higher for longliners than otter trawls in the same region, but they were not attempting to avoid cod. From May to August 2005, the total US commercial catch in the EUSCA included 244,274 kg of cod and 561,588 kg of haddock, for an overall ratio of 0.43 kg cod per kg haddock (NMFS, 2008a; NMFS, 2008b). This overall cod catch probably represents a mixture of fishers targeting cod and fishing in which cod is accidentally caught, but it is clear that significant numbers of cod were present in the area over the time period included in this study. The cod/haddock ratio caught by longlines (mainly baited with Norbait 700E) in the summer of that year never exceeded 0.045 kg cod per kg haddock, about 10% of the cod per haddock catch ratio in the overall fishery.

Regulators have been encouraging the development of gear modifications to increase selectivity of otter trawls, such as the use of trawls with horizontal separator panels (US Federal Register 69 FR 67780, November 19 2004). In the dataset used in this analysis, only two trips were indicated to have a horizontal separator panel in use. Since there was not enough temporal or spatial overlap to test for an effect of the panel, these were removed from our comparison. The catch rates reported in this study are therefore believed to represent the catch rates without these gear modifications.

Following decades of overfishing, stocks of both haddock and cod on Georges Bank collapsed in the early 1990s (Brodziak et al., 2006). Since 1994, management measures have decreased fishing mortality such that haddock populations, while still depleted, are believed to be recovering well (Brodziak et al., 2006). Cod populations, however, are still being overfished. O'Brien et al. (2006) calculated that the fishing mortality on Georges Bank cod in 2004 was 0.24, while the sustainable fishing mortality (Fmsy) was 0.175. The spawning stock biomass in 2004 was 22,564 mt, an increase from the all-time low in 1995 but a decrease from the most recent previous stock assessment in 2001. The target spawning biomass for this stock is 217,000 mt, approximately ten times the current size (O'Brien et al., 2006). Cod recovery is a high priority for fisheries management in the region, and the ability to fish for haddock while avoiding cod is highly desirable for the fishing industry and fisheries management.

5. Conclusion

There is sufficient overlap and replication in the dataset examined to establish consistent differences in cod to haddock catch ratios between fishing gears and baits used in groundfish fishing on Georges Bank. Otter trawls fishing in the same months and areas showed consistently higher ratios of cod to haddock in catches than did longliners fishing with fabricated baits. Significant differences were also found in cod to haddock catch ratios with different baits when longlines were fished on the same days in the same areas. Fabricated bait caught significantly less cod per haddock than did herring or squid, but cod catches were less than 10% of haddock catches for all baits.

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