Determining Groundfish Movement Patterns In and Around
the Western Gulf of Maine Area Closure

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Abstract

This objective of this research was to study the movement patterns of cod in and around the Western Gulf of Maine Area Closure (WGoMAC) using mark and recapture techniques. A total of 59 days, between July 2002 and June 2003, were spent collecting and tagging cod in the WGoMAC and adjacent areas. A total of 6,953 cod were tagged. Of these, 230 (3.3%) were recaptured prior to Dec. 31, 2003, and are included in this report. Days at large ranged from 0 (recaptured the same day) to 421. Most (76.8%) were recaptured within 120 days of being tagged and released. Virtually all fish were adults, and there was some variation in mean length among areas and times. Mean values ranged from 53.8cm (Area 124 in August 2002) to 84.4cm (Area 133 in June 2003). There were no clear seasonal trends in mean length in any of the areas, but in general, the mean length in all areas tended to be largest in the spring (April, May and June). Distances between release and recapture were relatively small. They ranged from 0.7 to 223km, but most of the fish (63.6%) moved less than 30 km from their point of release, and only 6.3% moved more than 100km. North-south and east-west velocities varied by tagging month, but both ranged from about 0.05 to 0.31 km/d. Dispersion coefficients also varied by month of tagging, ranging from a low of 16.45 km^2/d (July 2002), to a high of 77.17 km^2/d (April and May 2003). Mean catch-per-unit-effort (CPUE) values ranged from as low as 2, to more than 650kg/h. Values in the WGoMAC were generally similar to those of adjacent areas. The highest mean CPUE was seen in Area 133 in May, indicative of spawning aggregations. The lowest CPUE values tended to be from the northern sector of the WGoMAC and the adjacent Area 139. The number of recaptures from the western Gulf of Maine Area Closure was low, presumably because commercial fishing is prohibited in the area. This small sample size prevented us from drawing any definitive conclusions about the effectiveness of this area in fisheries conservation. Similarities in abundances (CPUE), and small numbers of spawning cod in the western Gulf of Maine Area Closure, indicate however, that this is not an area where adult cod are particularly abundant, and that the area is not an important spawning area.

Introduction

The Atlantic cod (*Gadus morhua*) is widely distributed on both sides of the North Atlantic, and supports important commercial and recreational fisheries throughout its range. The two stocks in the western north Atlantic, Gulf of Maine and Georges Bank, are both considered to be overfished, and a series of management measures have been established to rebuild the populations. Currently, these include gear restrictions, minimum size limits, days-at-sea restrictions, a moratorium on new permits, and trip limits (Mayo and O'Brien 2000). Another management measure has been the creation of areas that are closed to harvesting. These include time/area closures, in which commercial fishing is restricted during certain times of the year, and a permanently closed area, the western Gulf of Maine Area Closure (WGoMAC), where commercial groundfish harvesting is restricted year-round. Both time/area closures and the permanent closure have the goal of reducing overall fishing mortality rates by displacing fishing effort away from these highly populated areas. It is hoped that this reduction will contribute to the rebuilding of the Gulf of Maine cod stock.

The WGoMAC is located off the coasts of northern Massachusetts, New Hampshire and southern Maine (Fig. 1). It was established in 1997 as part of Amendment 7 to the Northeast Multi-species Fishery Management Plan (NMFMP). It is approximately 32km wide (east-west) and 97km long (north-south), and covers a large portion of Jeffreys Ledge. Depths range from about 45-230 meters, and substrate types vary from exposed bedrock to soft mud. Six adjacent time/area (rolling) closures (Areas 124, 125, 132, 133, 139 and 140), each about 48km on a side, with some (124, 133, 139) overlapping with the WGoMAC (Fig. 1), were also created as part of Amendment 7 (Framework 33). In these, fishing is restricted during certain times of the year, often at times when cod biomass is especially high (e.g. for spawning). The timings of the western Gulf of Maine rolling closures have been changed several times since their implementation, with the intent to make them more effective. During the course of this study, areas 124 and 125 were closed in April and May, and again in October and November. Areas 132 and 133 were closed from April through June, and areas 139 and 140 were closed in May and June.

The effectiveness of permanent or rolling closures as a management tool depends on many things, including their size and location. Of particular importance is the degree of fish movement in and out of them (Appeldoorn 1997; Zeller and Russ 1998). It has been shown that for species that exhibit only small, localized movements, closed areas may lead to an increase in fish biomass (Ingram and Patterson 2001), but that protection may not be sufficient if distances moved are high relative to closed area size (Appeldoorn 1997). It is important to note that for a closed area to achieve its desired goal, fish must enter and remain in the area for some period of time. That is, the area must serve as a "sink". Indeed, Metcalfe et al. (1998) have stated that "marine protected areas only protect fish that remain within them"….and that….."understanding population movement is critical to a proper evaluation of the effectiveness of this method of management". It is equally obvious that fish, and/or their offspring, must also leave the area if they are to contribute to the harvestable population, i.e. the area must serve as a "source". Finally, the amount that the area contributes towards stock rebuilding will depend on the species and numbers of fish that utilize the closed area's many attributes. It is clear from this that in order to measure the effectiveness of the WGoMAC, or any other closed area, one must know

which species enter the area, where they come from, how many there are, and how they utilize the habitats associated with the closed area. One must also know when they leave, where they go, and if the area is serving as a source of new recruits. Mark and recapture techniques have proven effective in studying the temporal and spatial distribution patterns and movements of fish, and they are beginning to be used with great effectiveness in studying the movements of fish in and out of closed areas (Appeldoorn 1997).

Project Objectives

This objective of this research was to study the movement patterns of cod in and around the Western Gulf of Maine Area Closure using mark and recapture techniques.

Participants

Hunt Howell – UNH Professor of Zoology, Durham, NH
David Goethel – Commercial Fisherman, Hampton, NH
Carl Bouchard - Commercial Fisherman, Exeter, NH
Jim Ford - Commercial Fisherman, Newburyport, MA
Frank Mirachi - Commercial Fisherman, Scituate, MA
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Methods

The study area included the Western Gulf of Maine Area Closure (WGoMAC) and the adjacent time/area closure blocks 124, 125, 132, 133, 139 and 140 (Fig. 1). For the purposes of this study, the WGoMAC was divided into northern (N), central (C) and southern (S) sectors. The northern sector is defined as north of 43°00'N Latitude (adjacent to area 139). The central sector extends from 42°30' to 43°00' N Latitude (adjacent to area 132), and the southern sector is south of 42°30'N Latitude (adjacent to area 124). Note that as defined here, the central sector is slightly larger than the northern and southern sectors. Areas east of the WGoMAC were not selected because their distance from shore would have required multiple day fishing trips, and because catches of cod are relatively low in these areas. The study was conducted in cooperation with 5 members of the New England commercial fishing industry. They were selected because of their interest in the project, and because all had extensive fishing experience in the study areas. The National Marine Fisheries Service issued a scientific sampling permit to each vessel that enabled sampling in the closed areas. Fish were collected by otter trawl (15.2cm codend mesh) in short duration tows (15-30 minutes). Fish were collected as shallow as possible to minimize decompression of the swimbladder. Towing depths ranged from 30-270m, but more than 90% of the tows were less than 180m in depth. Upon completion of a tow, fish that were to be tagged were placed into onboard tanks supplied with flowing seawater. The primary species tagged was Atlantic cod (*Gadus morhua*), but haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius virens*), American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), witch flounder (*Glyptocephalus cynoglossus*), goosefish (*Lophius americanus*) and wolffish (*Anarhichas lupus*) were also tagged as time permitted. Fish were measured to the nearest centimeter, and a 7cm Floy^{TM} T-bar tag was inserted into the musculature at the base of the first dorsal fin. The tag was

bright orange in color and included an identification number and telephone number to call when the fish was recaptured. Gender and reproductive condition were noted when obvious, i.e. if the fish extruded milt or eggs as it was handled. Once tagged, the fish was placed headfirst back into the water. The time it took to tag a fish and return it to the ocean was less typically less than 30 seconds. The date, Loran C coordinates, start and stop time, and depth of the tow were recorded. Data on the length of the fish, tag number, and reproductive condition were also recorded.

A poster that contained a brief description of the project, and information on how to report a tag return, was distributed at fishermen's co-ops in Maine, New Hampshire, and Massachusetts. Fishermen involved in the project also encouraged other fishermen to return tag information. When a tag return was reported, the tag number, date, and position of capture were recorded. Only those recaptures with complete date and positional information were used. All release and recapture data were complied into Microsoft Excel™ worksheets for analyses.

Movement statistics:

We used POSAID2™ software to convert all Loran C positions into latitude and longitude coordinates. For each recapture, straight-line distance traveled (km) and vector angle, measured as degrees from true north, were obtained by plotting the release and recapture position into a Maptech® digital Chartkit 2001 software program. This information was then used to calculate North-South and East-West velocities, a mean-vector angle, and dispersion rates for groups of fish. N-S and E-W velocities, which measure the rate and direction of travel over time, were calculated using the equations from Saila and Flowers (1968) and Zar (1999). Mean angle of travel for each selected group was calculated by a series of equations that take into account all the individual vector angles of the group (Zar 1999).

Angular deviations, which measure of variation in the calculated mean angle of travel, were calculated using the methods given by Zar (1999). A high angular deviation suggests the population is dispersed around the mean angle of travel, while a low angular deviation suggests that the population is concentrated around the mean angle. We also calculated a dispersion coefficient for each group, which measures the area and rate (km^2/d), over which the tagged fish disperse from the release location (Saila and Flowers 1968).

Rayleigh's test (Zar 1999) was used to examine the distribution of recapture locations of groups of interest (e.g. fish released in a particular place and time), relative to their release location. If the z-statistic is insignificant, the recapture locations are uniformly distributed around the release location, and movement is considered random. Alternatively, if the z-statistic is significant, the distribution of recapture locations is not uniform around the release location, and movement away from the release location is considered to be directed.

Abundance statistics:

To determine changes in the abundance of Atlantic cod in the western Gulf of Maine over time, catch-per-unit-effort (CPUE, kg/h) was calculated for each tow. Since fish were not weighed, weight was estimated from the following length-weight relationship (SAW 33):

$$\ln\ wgt(kg) = -11.7231 + 3.0521 \times \ln\ \lg t(cm)$$

CPUE estimates were calculated for each area and month. Because catch-per-unit-effort data are ratios, and are asymmetric around the arithmetic mean, geometric means, that are more suitable for calculating confidence intervals for log-normal data (McConnaughey and Conquest 1993), were calculated for each data set.

Length Statistics:

In order to examine changes in fish length over time within an area, and between areas in the same time period, mean lengths were calculated. Since in most cases the gender of the fish was not determined, mean lengths represent a combination of males and females. Differences in mean length between areas within month, and within month between areas, were analyzed using analysis of variance tests, followed by a Tukey's test if significant differences ($p < 0.05$) were found.

Data

A total of 59 days, between July 2002 and June 2003, were spent collecting and tagging. The distribution of days among areas, the number of tows, and the number of fish tagged and recaptured are given in Table 1. Months when tagging occurred included July through October 2002, and April through June 2003. A total of 6,953 cod were tagged. Of these, 230 (3.3%) were recaptured prior to Dec. 31, 2003, and are included in this report. Days at large ranged from 0 (recaptured the same day) to 421. Most (76.8%) were recaptured within 120 days of being tagged and released (Fig 2).

Results

Mean total lengths of tagged cod, for all combinations of sampling month and area, are given in Table 2. Virtually all fish were adults, and there was some variation among areas and times. Mean values ranged from 53.8cm (Area 124 in August 2002) to 84.4cm (Area 133 in June 2003). There were no clear seasonal trends in mean length in any of the areas, but in general, the mean length in all areas tended to be largest in the spring (April, May and June). Notably large mean sizes were seen in April in Area 132, and in Area 133 the following month. This represents, in all likelihood, a pre-spawning aggregation of large fish in area 132 in April, and their subsequent movement westward into Area 133 where the fish spawn (Morin, In Review).

In general, distances between release and recapture were relatively small (Table 3). They ranged from 0.7 to 223km, but most of the fish (63.6%) moved less than 30 km from their point of release, and only 6.3% moved more than 100km. Mean distances traveled by fish tagged in the different areas are given in Table 3. The highest mean distances (>50km) were for fish tagged in areas 124, 139, and the southern sector of the WGoMAC. Fish tagged in area 133 moved intermediate distances (about 30 km), while those in areas 132 and the central portion of the WGoMAC moved the shortest distances (<20km). There were too few recaptures from the northern portion of the WGoMAC to obtain a meaningful mean distance traveled. Mean

distances traveled by fish tagged in some areas were significantly different (ANOVA on natural log transformed data, P=0.001) than other areas. Those released in the southern sector of the WGoMAC moved, on average, significantly longer distances than those released in areas 124 and 132 (P<0.001). There were no other significant differences. Mean distances traveled by fish tagged in different months (Table) ranged from 10.0 (Oct) to 138.7km (Aug), but there were no significant differences between months (ANOVA, P=0.64).

There was no relationship (p=0.20) between fish length and distances traveled (Figure 3), or between days-at-large and distance traveled (p>0.05).

Velocities and dispersion coefficients, calculated for groups of fish, are given in Table 4. North-south and east-west velocities varied by tagging month, but both ranged from about 0.05 to 0.31 km/d. Dispersion coefficients also varied by month of tagging, ranging from a low of 16.45 km^2/d (July 2002), to a high of 77.17 km^2/d (April and May 2003).

To interpret movement patterns, all tag returns from specific months and areas of tag and release were grouped. There were only 6 tagging area/month combinations from which we had enough recaptures (>5 fish) to do quantitative analyses (Table 4). In addition to these, in which all recaptures were aggregated independent of recapture month, we were able to examine the movement of fish tagged in area 124 in April, and in area 133 in May, in more detail. In these analyses, we grouped the recaptures by month (Table 4).

There were differences in movements between areas during the same periods of time, and also differences over time within given areas.

Three of the six aggregated recapture data sets (Table 4) indicated that the fish moved in a random, non-directional manner from their point of release (Rayleigh test, P>0.1). These included 2 groups of fish tagged in area 124 in the spring (April and May 2003), and a group of fish tagged in area 132 in July 2002.

Only 3 of the data sets indicated that the fish had moved in a non-random fashion from their point of release (Rayleigh test, P<0.01). This included one group of 11 fish tagged in April 2003 in the southern portion of the WGoMAC. This group traveled to the northwest (332°), and had a relatively high velocity (0.30 km/d). A second group of 39 fish, tagged in May 2003 in area 133 (inshore area), moved to the east-southeast (109°), and had a relatively high velocity (0.24 km/d). A third group, tagged in the same inshore area (133) in June 2003, showed a similar pattern. They moved to the east-southeast (119°), and had a relatively high velocity (0.31km/d).

In the data sets in which we were able to examine recaptures by month (Table 4), cod tagged in area 124 in April 2003, and recaptured in May and June of the same year, showed no significant directional movement. In contrast, those tagged in area 133 in May, and recaptured in the following months, with the exception of those recaptured in June, displayed significant directional movement. Fish of this group recaptured in the ensuing months of July, August and September all moved in non-random directions (Rayleigh test, P<0.05), generally towards the east (Table 4).

Catch-per-unit-effort (kg/h) values were calculated for the various month/area combinations to determine if changes in abundance coincided with fish movement patterns. Because of the small number of tows, and the inherent patchy distribution of schooling species such as cod, geometric mean CPUE values (Table 5) were quite variable. Differences between vessels engaged in the study undoubtedly added to this variation. Nevertheless, they provide crude estimates of abundance that are useful in interpreting tag and recapture data. Mean values ranged from as low as 2, to more than 650kg/h. Values in the WGoMAC were generally similar to those of adjacent areas. The exception to this was seen in the southern sector, where mean CPUE (299 kg/h) in April was higher than in surrounding areas, although values were also relatively high in the adjacent Area 124 in the same time period (April and May). The highest mean CPUE (>650 kg/h) was seen in Area 133 in May, indicative of spawning aggregations described in this area and time by Morin (In Review). The lowest CPUE values tended to be from the northern sector of the WGoMAC and the adjacent Area 139.

Western Gulf of Maine Area Closure

A total of 1,215 cod were tagged in the WGoMAC. Because the area is closed to commercial fishing, only 39 of these (3.2%) were recaptured, and only 24 had complete recapture information. Of these 24, none were tagged in the northern sector, 8 were tagged in the central sector, and 16 were tagged in the southern sector. Of the 8 fish tagged in the central sector, 4 were recaptured inside the closed area (3 in the central sector and 1 in the northern sector), and 4 were recaptured outside the closed area (3 in area132 and 1 in area 133). Thus with one exception, all fish recaptured from the central sector, either stayed in the same sector, or moved westward. The single exception was a 53cm fish tagged in mid-July 2002. The mean distance traveled by fish tagged in the northern sector was 14.4km. The mean number of days at large was 176, and the mean direction of travel was 191°.

Of the 16 fish tagged in the southern sector, 3 were recaptured inside the WGoMAC, and 13 were recaptured outside the WGoMAC. Of those recaptured inside, 2 were from the southern sector and 1 was from the northern sector. Of the13 that were recaptured outside the closed area, 4 moved into area 125 (southwest), 3 moved into area 132 (northwest), 3 moved into area 133 (northwest), 2 were caught off Cape Cod to the south, and 1 was caught off Cape Porpoise well to the north. The mean distance traveled by fish tagged in the southern sector was 50.5km. The mean number of days at large was 135, and the mean direction of travel was 195°.

A total of 16 cod were recaptured in the WGoMAC. Nine of these were tagged outside the closed area. Of these, seven were caught in the central sector and 2 were caught in the south sector. Of the 9, 3 came from 124 (from south) and 6 came from area 133 (from west). All were caught between mid-May and the end of August 2003, and all were tagged between late April and mid-June. The 2 fish caught in the southern sector came from area133, and therefore had moved in a southwesterly direction. The 3 fish tagged in 124 were all caught in the central sector, and therefore had moved in a northerly or northeasterly direction.

Seven of the cod recaptured in the WGoMAC were tagged inside the closed area. Five of the seven were recaptured in the same sector of the WGoMAC as they were tagged. Two of the

seven were recaptured away from their tagging location. One had moved from the central to the northern sector, and one had moved from the southern to the northern sector.

Preliminary Conclusions

1. Results of this, and the previous NEC supported tagging study, indicate that cod movements in the southwestern Gulf of Maine are associated with spawning. Fish move into area 132 in April and May, and then continue to move inshore into area 133 where they spawn from late May through July. After spawning they disperse offshore in all directions. Thus there is a general contraction of the population for spawning, followed by a post-spawning expansion.
2. The time/area closures, as currently configured, are appropriate for protecting spawning aggregations of cod.
3. Distances moved by cod during their spawning movements are relatively short (most <30km), and velocities are generally slow (<1km/d). There is no relationship between cod size and distance traveled.
4. The number of recaptures from the western Gulf of Maine Area Closure was low, presumably because commercial fishing is prohibited in the area. This small sample size prevented us from drawing any definitive conclusions about the effectiveness of this area in fisheries conservation. Similarities in abundances (CPUE), and small numbers of spawning cod in the western Gulf of Maine Area Closure, indicate that this is not an area where adult cod are particularly abundant, and that the area is not an important spawning area.

Partnerships

The interaction between fishermen and scientists was extensive. It began with project planning, included joint efforts in all the fieldwork, and extended all the way through manuscript preparation. The partnership was excellent in all respects because there was interest in the research by all participants

Impacts and Applications

It is hoped that results will provide fisheries scientists and managers with information about the small-scale temporal and spatial distribution of cod, which will thus contribute towards an understanding of this closed area's effectiveness.

Related Projects

This study was a logical extension of an earlier, and larger, NEC funded cod-tagging project, which studied cod movements and spawning in the western Gulf of Maine <u>except</u> for the western Gulf of Maine Area Closure. The research also led to a current NEC proposal to study the spawning behavior and habitat of cod in Ipswich Bay.

Student participation

Several undergraduate and graduate students participated in the research. They included Mike Ball, Nate Rennels, Suzanne Biron, Scott Elzey, Jeff Kneebone, and Mike Morin. The first cod tagging study served as the basis for M. Morin's MS thesis.

Published reports and papers

One paper has been submitted for publication to Transactions of the American Fisheries Society. Reference is: Morin, M. D., D. Goethel and W.H. Howell. Movement of Atlantic cod (*Gadus morhua*) in the western Gulf of Maine as determined through mark and recapture. It is currently in revision based on the reviewer's comments.

A second paper will be submitted to Canadian Journal of Fisheries and Aquatic Science this autumn. Reference is: Howell, W.H., M. Morin, N. Rennels and D. Goethel. Movement of Cod (*Gadus morhua*) In and Around Closed Areas in the Western Gulf of Maine.

Figure 1 – Areas where cod tagging occurred in the western Gulf of Maine.

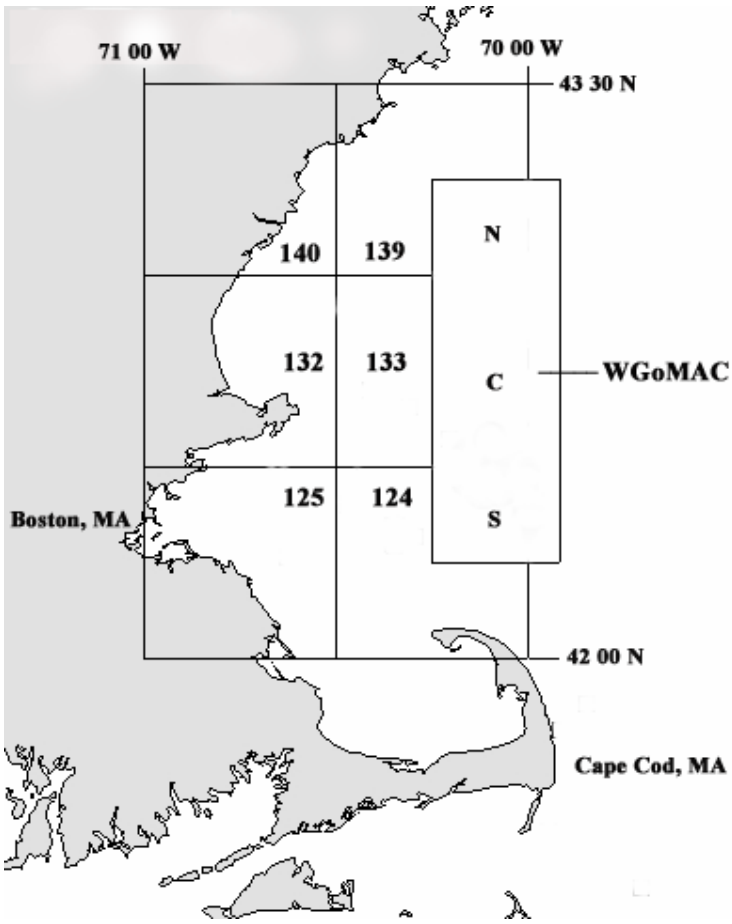

Figure 2. Frequency distribution of days at large following tagging.

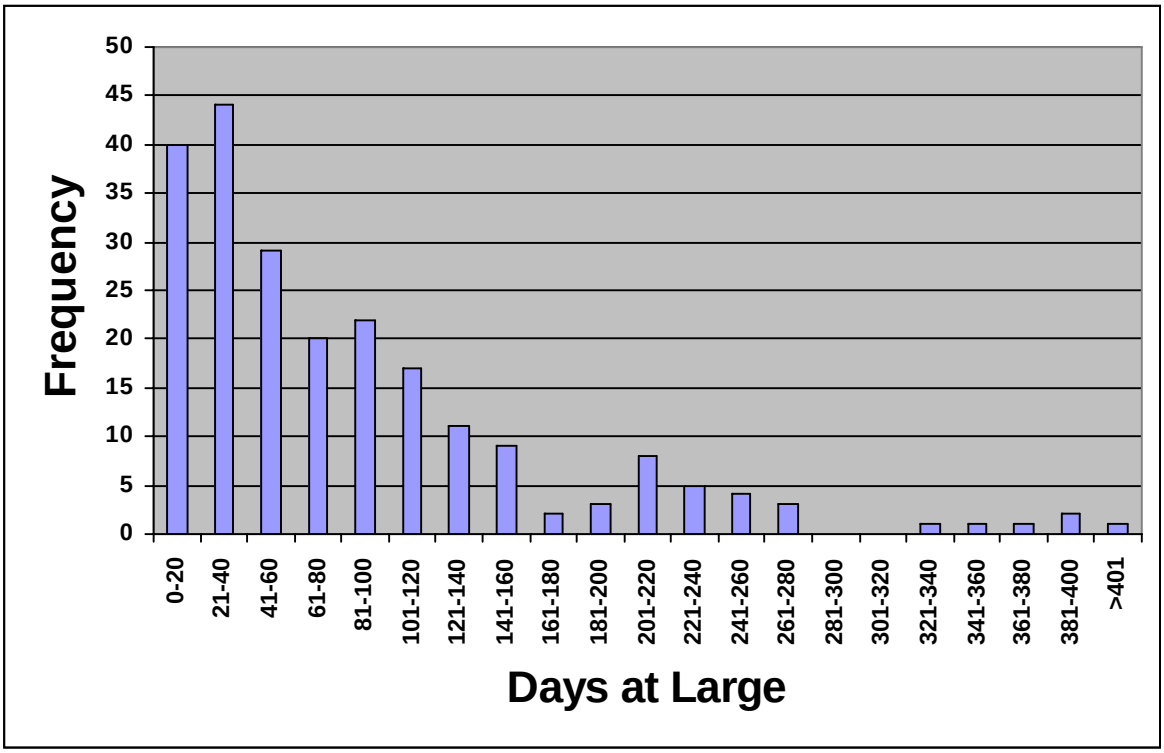

Fig. 3. Distance traveled by cod of different lengths. There was no relationship between size and distance traveled.

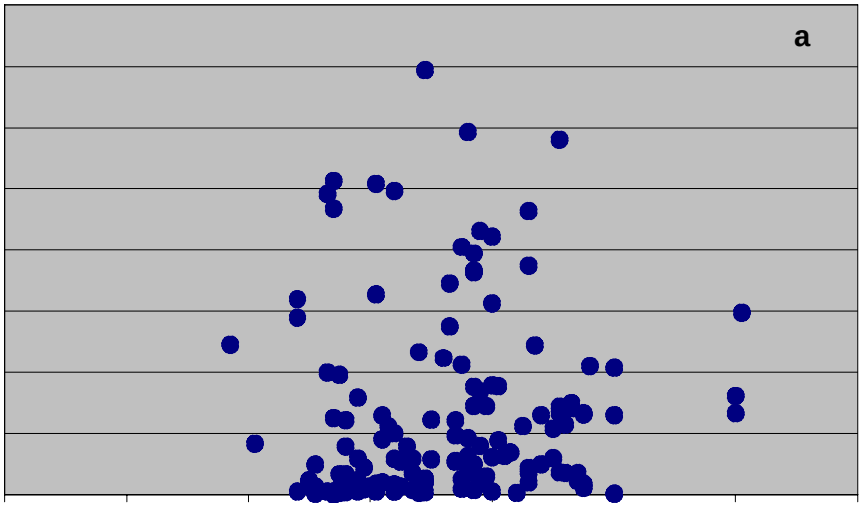

Table 1. Summary of tagging effort and recaptures by area.

	Area							
	124	132	133	139	WGoMAC-S	WGoMAC-C	WGoMAC-N	Totals
No. days	8	10	12	8	6	10	5	59
No. tows	41	53	71	53	28	60	19	325
No. fish tagged	1529	2107	3466	826	883	879	220	9910
No. fish recaptured	82	39	94	8	36	19	2	280
Percent recaptured	5.36	1.85	2.71	0.97	4.08	2.16	0.91	2.83
No. cod tagged	1207	1149	2924	458	773	319	123	6953
No. cod recaptured*	73	30	85	3	25	13	1	230
Percent cod recaptured	6.04	2.61	2.90	0.65	3.23	4.07	0.81	3.30

Table 2. Mean (+/- SD) length of cod tagged in the various areas and months. If number less than 5, no means are given.

Month-Year	**Area**						
	124	132	133	139	WGoMAC North	WGoMAC Central	WGoMAC South
Jul-02	59.1 (13.5)	67.8 (10.0)	78.7 (14.3)	77.9 (14.3)	74.7 (12.2)	69.2 (17.5)	
Aug-02	53.8 (10.0)	64.1 (9.0)	83.5 (21.3)			74.1 (12.0)	60.4 (8.7)
Sep-02	65.1 (9.6)		73.0 (9.2)			70.4 (14.2)	63.6 (6.9)
Oct-02		73.0 (11.2)			72.7 (6.1)		
Apr-03	61.6 (9.4)	80.0 (16.2)	71.4 (13.8)			75.2 (10.8)	75.9 (9.4)
May-03	59.5 (10.5)	69.7 (16.0)	81.3 (15.4)	70.6 (11.5)	78.0 (15.4)	71.5 (14.3)	75.5 (11.5)
Jun-03	55.6 (6.8)	66.5 (15.7)	84.4 (14.5)	83.6 (12.1)	77.8 (13.4)	73.0 (12.0)	

Table 3. Mean (+/- SD) distances traveled by cod tagged in the various areas and months. If number of recaptures is less than 5, no means are given.

Tag month	Mean distance (km)	SD
July '02	16.5	22.0
August '02	138.7	300.9
September '02	15.4	18.6
October '02	10.0	-
April '03	35.5	38.6
May '03	46.7	32.0
June '03	17.7	18.7

Tag location	Mean distance (km)	SD
124	53.9	114
132	14.4	17.9
133	29.2	30
139	51.2	36
North	-	-
Central	14.3	15.3
South	50.6	34.3

Table 4. Velocities, dispersion coefficients, mean angle, and angular variation of recaptured cod tagged in the indicated months and areas. Significant Raleigh tests (*) indicate direction of travel was directed.

Month of Tagging	Area of Tagging	N/S Velocity km/d	E/W Velocity km/d	Dispersion km^2/d	Mean Angle	Angular Variation	Rayleigh	n
July(02)	132	0.08 S	0.10 E	16.45	151	71	0.71	14
Apr(03)	124	0.14 S	0.14 E	59.62	152	71	1.42	29
Apr(03)	WGoM AC-S	0.30 N	0.07 W	55.24	332	43	5.70*	11
May(03)	124	0.26 N	0.19 E	60.65	87	69	1.13	14
May(03)	133	0.10 S	0.24 E	30.54	109	59	8.42*	39
Jun(03)	133	0.18 S	0.31 E	25.00	119	42	6.65*	13

Month of Tagging	Area of Tagging	Month of Recapture	N/S Velocity km/d	E/W Velocity km/d	Dispersion km^2/d	Mean Angle	Angular Variation	Rayleigh	n
Apr (03)	124	May (03)	0.07 S	0.78 E	102.2	177	71	0.71	13
Apr (03)	124	Jun (03)	0.23 S	0.09 W	18.8	237	51	2.58	7
May (03)	133	Jun (03)	0.02 N	0.61 E	31.4	95	61	1.27	7
May (03)	133	Jul (03)	0.11 S	0.60 E	71.6	85	44	4.41*	9
May (03)	133	Aug (03)	0.16 S	0.26 E	16.9	129	48	2.90*	7
May (03)	133	Sep (03)	0.12 S	0.12 E	2.82	143	43	3.64*	6

Table 5. Mean (+/-SD) catch-per-unit-effort (kg/h) of cod in the indicated areas and times.

Date	**Area**						
	124	132	133	139	WGoMAC - N	WGoMAC - C	WGoMAC - S
Jul-01	28 +/-1	111 +/-6	74 +/-1	20 +/-7	44 +/-5	41 +/-3	
Aug-01	66 +/-2	25 +/-11	2 +/-5	2 +/-3		5 +/-5	22 +/-2
Sep-01	110 +/-3		9 +/-9			10 +/-7	15 +/-5
Oct-01		98 +/-3		2 +/-4	8 +/-5		
Apr-02	189 +/-3	6 +/-16	2 +/-3			4 +/-6	299 +/-3
May-02	146 +/-2	62 +/-6	654 +/-3	15 +/-5	54 +/-4	32 +/-4	197 +/-7
Jun-02	6 +/-7	25 +/-2	152 +/-6	137 +/-8	21 +/-14	80 +/-3	

Future research

The low of abundance of adult cod in the WGoMAC resulted in relatively few fish being tagged in the area. This, in combination with the lack of commercial fishing in the area, resulted in too few recaptures to draw any solid conclusions about cod movements in the area. We recommend that the study be repeated, with more fish be tagged in the area.

This study, and the former cod tagging project, confirmed that Ipswich Bay is a very important spawning ground for cod in the northwest Atlantic. It also led us to conclude that despite the economic importance of cod, little is known about their spawning habitat, their activities while on their spawning grounds, or their fine scale distribution as it relates to environmental attributes of the spawning areas. In response to this, we have prepared an NEC proposal with an overall goal to study the activity and fine scale distribution of cod in the Ipswich Bay spawning area. To accomplish this goal, 200 adult, pre-spawning cod will be equipped with data storage tags (DSTs), and 30 of these will also be equipped with an acoustic tag. Cod equipped with acoustic tags will be located approximately every other day by the fishing vessels engaged in the project. The position of each acoustic tag (fish) will be found using a towed, or handheld directional hydrophone. Location, depth, substrate type, and notable bathymetric features will be recorded at each fish's position each time it is located. To gather information about the daily activities of adult cod, we will locate multiple individuals every 30 minutes over the course of 24h. Each time an individual is located we will record time, depth, location, substrate type, and any notable bathymetric features. This fine scale daily sampling will occur 8 times, beginning in May and extending through June, at approximately weekly intervals, allowing us to sample over two lunar, and associated tidal cycles. The DSTs detect and archive data on pressure (depth), water temperature, and time, at a user-programmed time interval. Information from the DSTs will be used to supplement the information recorded each time the fish is located.

For thirty of the fish, the combination of a DST and an acoustic tag will allow us to construct a positional history of the fish (acoustic tag), and relate this positional history to habitat features (depth, proximity to bathymetric features, substrate type, and temperature) recorded synoptically during acoustic tracking, and archived on its DST. The associations will allow us to determine how horizontal movements, activity (vertical movements), and fine-scale distribution relate to important spawning habitat attributes such as depth, bathymetry, substrate type, and temperature. Integration of the data from all fish will allow us to broadly characterize the spawning habitat of cod in Ipswich Bay, and to determine how the spatial distribution of spawning fish relates to attributes of the spawning habitat. Time series analyses of depth variation over time will be used to determine if there are diel cycles in vertical movements. Swimming speed will be estimated as the distances between successive positional fixes divided by the elapsed time between fixes. Similar analyses will be used to determine if activity rhythms and swimming speeds are associated with lunar or tidal cycles.