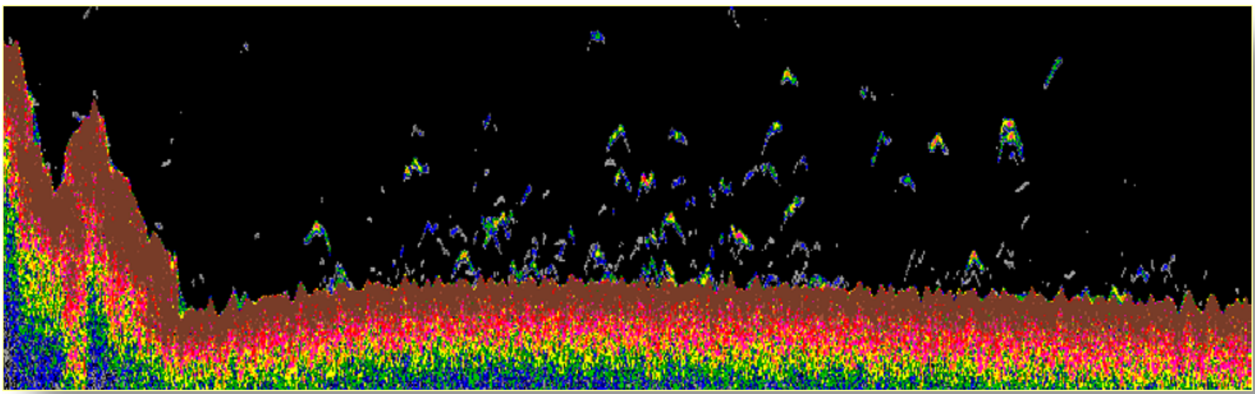
Synoptic acoustic and trawl surveys to characterize biomass and distribution of the spring spawning aggregations of Atlantic cod in Ipswich Bay

Northeast Consortium Collaborative Research Award



Award No.: 111675
Study Period: 2011- current
Annual Report Submitted: 1 July 2011

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Project Objectives & Scientific Hypotheses

The GOM cod spawning protection area (GOM-CSPA) is an example of an area management measure recently implemented in the northeast multispecies fishery management plan, which prohibits commercial and recreational fishing, from April through June, in a small area in the western Gulf of Maine. The spring spawning GOM Atlantic cod (*Gadus morhua*) caught in the GOM-CSPA, locally referred as the "Whaleback" area, have been shown to be genetically distinct (Kovach et al. 2010) and exhibit a high degree of inter-annual site fidelity and residency (Howell et al. 2008, Siceloff 2009). However, the relative importance of this area has not be quantified, and the appropriateness of its size has not be assessed. What proportion of the Gulf of Maine cod spawning stock biomass (estimated at 33,877 mt, Mayo et al. 2009) use this area for spawning during the closure? Should the size of the closed area be reduced, expanded, or redefined? These questions are quite fundamental, and this research was designed to provide partial answers. Specifically, the primary objectives of the proposed research were:

1. Estimate the biomass and areal density (number and biomass per area) of spring-spawning GOM cod within the GOM-CSPA.
2. Compare biomass estimates and spatial distribution of cod within the GOM-CSPA before spawning (early April), during spawning (May-June), and after spawning (July), when this area reopens to fishing.

3. Determine if cod biomass density (D) is higher inside the GOMCSPA than outside among adjacent acoustic survey transects (H_0: $D_{in} = D_{out}$)

In addition to these primary research objectives, data collected will allow the following secondary objectives to be addressed:

1. Estimate *in situ* target strength of Atlantic cod (i.e., acoustic signal of a single free-ranging cod at sampling depths).
2. Correlate acoustically derived density estimates with those derived from large and small mesh trawls.
3. Determine the co-occurrence, relative measure of abundance, and distribution of other species such as haddock, silver hake, Atlantic herring, Atlantic mackerel, and spiny dogfish.

Methods and Work Plan

Synoptic acoustic and trawl surveys were made to estimate the total biomass, and describe the spatial and temporal distribution of spring-spawning Atlantic cod in the GOMSPA. A 14-m fishing vessel ("*F/V Lady Victoria*") equipped with Simrad 38- and 120-kHz split-beam EK60 echo sounders surveyed ten 8-km parallel transects that covered an approximate 78-km^2 area, which overlapped the Gulf of Maine (GOM) cod spawning protection area (Figure 1). Location, orientation, length and spacing of transects were selected based on prior knowledge of cod movements and catches, tow path considerations, desired coverage, sufficient resolution, survey vessel speed (~5 knots), and the allowable ship time (~10 h/d). Surveys were performed largely during night (dusk to dawn) on 7-8 April 2011, 28-29 May 2011, and 18-19 June 2011, with one survey planned for early July.

During each survey, two bottom trawl vessels (one with a small mesh and one with a large mesh net) each made ten parallel tows at approximately 2-2.5 knots behind the acoustic survey vessel for a duration of 10 minutes (time between winch engagements). A shrimp net with a stretch mesh of 1.75 inches (4.4 cm) throughout the body and codend was towed by "*F/V Julie Ann II*". A commercial multispecies bottom trawl with a 6-inch (15.2-cm) stretch mesh body and 6.5-inch (16.5-cm) codend was towed by the "*F/V Ellen Diane*". Each tow had an approximate 30-m spread between doors and an average swept area of 23,100 m^2 area.

The split-beam transducers, with nominal 3-dB beam widths of 12° for the 38 kHz and 7° for the 120 kHz, were mounted from a pole attached mid ship and 2.5 m below the water line. Sound transmission was based on 0.512-ms pulse duration, 2-Hz ping rate, and a power of 1000 W at 38 kHz and 500 W at 120 kHz. Raw acoustic backscatter, georeferenced with a GARMIN GPSMAP78sc (< 3 m accuracy), were collected using the Simrad ER60 data acquisition software and later imported into Echoview software for processing echograms. Prior to each survey, the echo sounder systems were calibrated with target strength (*TS*) measurements of a reference target (38.1-mm tungsten carbide sphere) suspended 10-12 m from each transducer by a monofilament line (Foote et al. 1987).

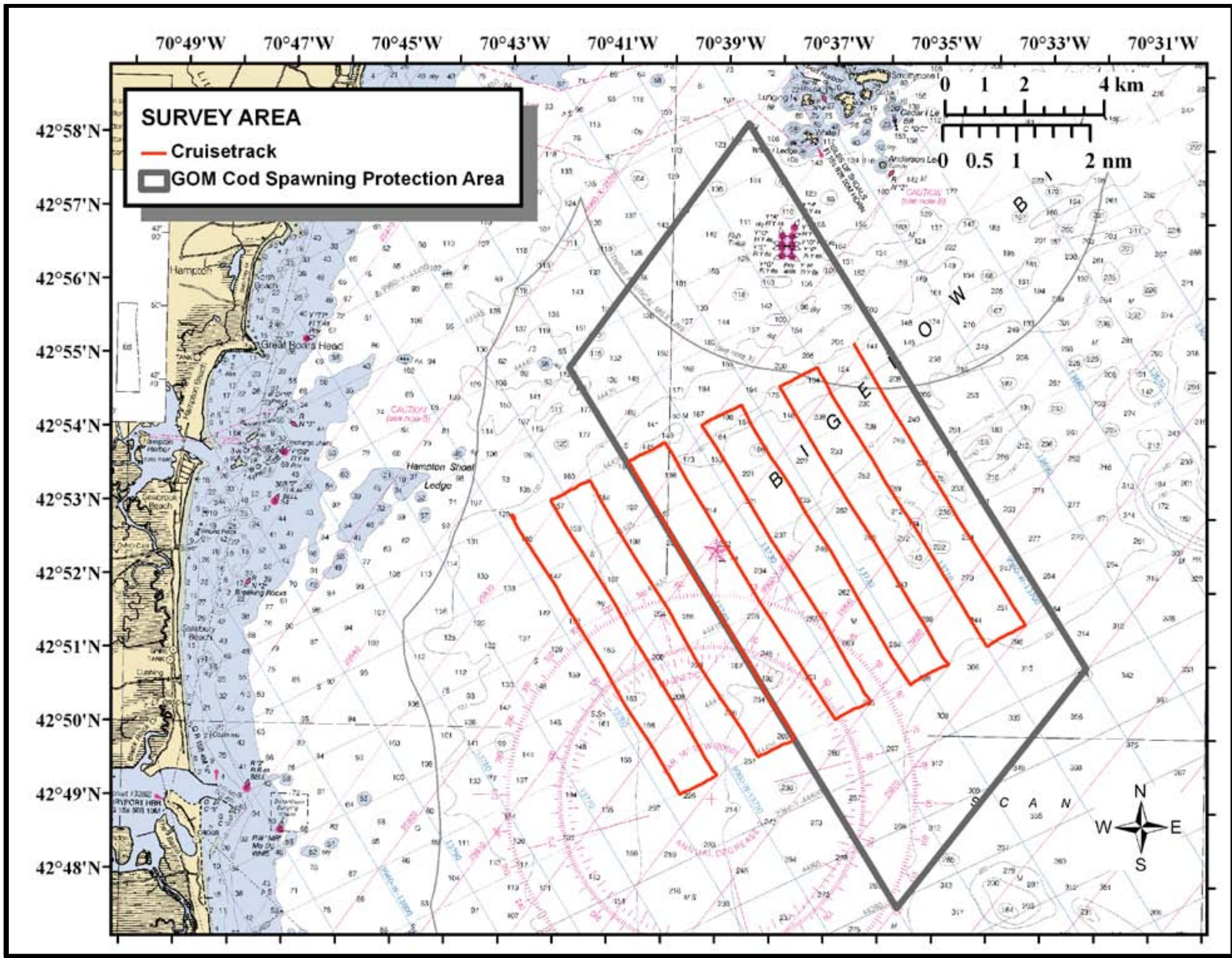

Figure 1. Study area and cruisetrack of the acoustic vessel *F/V Lady Victoria* during 28-29 May 2011. Transects are numbered 1-10 (west –east).

At the start and end of each survey, salinity and temperature depth profile measurements were taken at 2-3 locations using a Sea-Bird Electronics SBE-25 CTD. Sound speed profiles will be derived from these data and applied to echogram processing. In an effort to detect spawning sounds produced by male cod, underwater sound was recorded by a calibrated omni-directional hydrophone (Cetacean Research Technology, C-55) for 1-5 minute durations at the start, end, and areas of high cod abundances. Mean sensitivity of the hydrophone was -163.3 dB re 1 V/µPa. These sound recordings were acquired and processed using SpectraPRO332 professional sound analysis software.

Preliminary analyses of acoustic data were based on standard terminology defined by MacLennan et al. (1992) and Simmonds and MacLennan (2005). Mean area backscattering coefficient (s_a) was based on echo integration above a -70 dB minimum S_v threshold and below a fixed of water depth of 30 m, every 500 m for classical statistics and 200 m for geostatistical estimation of biomass and mapping. For this preliminary analysis, acoustic backscatter within approximately 0.5 m from the detected bottom was excluded without acoustic dead zone corrections, and as a result may have underestimated results. Fish weights (W, kg) were derived from total length (L, cm) using known L-W relations (e.g., W=7.751x10$^{-6}L^{3.053}$ for cod; Wigley et al. 2003). The mean s_a attributed to cod ($s_{a,cod} = W_{cod}\sigma_{bs,cod} / \Sigma_i(W_i\sigma_{bs,i})$ was defined by apportioning s_a based on the biomass proportion (W) weighted by the mean backscattering coefficient (σ_{bs} in units of kg) of each species (i) in the small mesh catch for each transect separately (McQuinn et al. 2005), excluding flounders, skates, sculpins, sea ravens, and goosefish which were assumed to have negligible acoustic detectabilities. Catch and size distribution of cod in the small mesh trawl was assumed to be unbiased by size selectivity, but will be formally examined in future analysis. The mean or expected σ_{bs} (m^2 /1 kg of fish) was derived by $10^{(TSw/10)}$ for each species. Target strength in units of dB re 1 m^2/kg (TS_w) for each species was derived from known parameters (Table 1) for TS-L and L-W relations defined by:

TS (dB re 1 m^2/fish) $=20\text{Log}_{10}(L)-b_{20}$ Equation 1,

$W = aL^b$ Equation 2,

and TS_w (dB re 1 m^2/kg) = $m_w\text{Log10(L)}+b_w$ Equation 3,

where b_{20} is the y-intercept parameter, m_w=20-(10b), and $b_w=b_{20}-10\text{Log}_{10}(a)$.

Cod biomass density (D, kg/m^2) was estimated as $s_{a,cod} / \sigma_{bs,cod}$ and total cod biomass (B, kg) was estimated as $B = \langle D\rangle_{unstr}$ x A where $\langle D\rangle_{unstr}$ is the unstratified average cod biomass density and A is the area. The total biomass for the entire survey area was based on the $\langle D\rangle_{unstr}$ of transects 1-10. The total biomass for the GOM-CSPA was estimated by extrapolating the $\langle D\rangle_{unstr}$ of transects 4-10 (mean of transects within the closed area) to the entire closed area (116 km^2). The cod biomass densities inside and outside of the GOM-CSPA by testing whether $\langle D\rangle_{unstr}$ of transects 1-3 (outside or unprotected) and transects 5-7 (inside or protected) were equal using a non-parametric two-sample Wilcoxon test (α=0.05).

Two major changes from the survey design originally proposed were the survey times and the transect design. After an initial planning meeting among project participants, it was decided to shift the transect direction and spacing such that transects were bounded to the north and south by Loran-C TD lines 44430 and 44405, respectively. The transects were then shifted to be parallel to the Loran-C TD lines 13758 to 13704 by 6 microseconds from west to east. This orientation allowed for better tow paths. The other modification was the timing of each survey. The times of the surveys completed to date were a result of coordinating the schedules of three vessels during adequate weather conditions.

Table 1. Parameters for length-weight (L-W) relation and target strength-length (TS-L) relations in units of weight ($TS_w = m_w Log_{10}(L) + b_w$) for acoustically-detectable species caught by small mesh trawl.

Species	$W=aL^b$ (Wigley et al. 2003) a ($x10^{-6}$)	b	b_{20}	TS-L relation Source for $TS=20Log_{10}+b_{20}$	b_w	m_w
Acadian redfish	8.2897	3.2036	-68.7	Gauthier & Rose 2002	-17.885	-12.036
Atlantic cod	7.7509	3.0527	-66	Rose & Porter 1996	-14.894	-10.527
Atlantic herring	9.3887	2.9794	-71.2	Sascha et al 2009	-20.926	-9.794
Fourbeard rockling	4.2258	3.0979	-66	based on cod	-12.259	-10.979
Haddock	7.4582	3.0766	-66	based on cod	-14.726	-10.766
Pollock	6.7877	3.1024	-66	based on cod	-14.317	-11.024
Red hake	4.2258	3.0979	-66	based on cod	-12.259	-10.979
Silver hake	3.7513	3.1512	-68.5	Simmons & MacLennan 2005	-14.242	-11.512
Spiny dogfish	1.7955	3.0596	-88	Clay & Castonguay 1996 (mackerel)	-30.542	-10.596

Work Completed to Date

As of 1 July 2011, three nighttime synoptic acoustic and trawl surveys have been conducted and data analysis is well underway. At least one additional survey is scheduled for early to mid July 2011.

Results to Date

The results presented herein are provisional based on partially audited data and preliminary analysis. No cod were caught by either trawl during the 7-8 April 2011 survey and few cod echoes were detected. The remainder of the results reported here are for the 28-29 May 2011 survey. By biomass, the trawl catches were dominated by cod among all transects sampled in May, followed by haddock, silver hake, and red hake (Figure 2). The trawl catch statistics for cod are reported in Table 2. Length distributions of cod in each catch are spatially presented in Figure 3. Mean acoustic density of cod among transects 1-10 was 0.00447 kg/m^2 (CV=105%, n=165), which was about 47% higher than the small mesh trawl density of cod. The total cod biomass estimated over the entire survey area was 347 metric tons (mt). Based on the mean acoustic density of cod from transects 4-10 (0.00493 kg/m^2, CV=102%, n=116), the acoustic biomass estimate of cod within the GOM-CSPA during 28-29 May was 572 mt. The majority of the cod were distributed south of the “Whaleback” ledge (Figure 4). Based on this survey, large concentrations of cod were also present west of the boundary of the area closure, exposing these cod to fishing. The mean acoustic density of cod inside the GOM-CSPA (transects 5-7) was significantly higher than that outside the closed area (transects 1-3, Wilcoxon test, $p<0.05$, Figure 5). During the 28-29 May survey, many male cod individuals were observed in ripe condition with presence of milt, but no indication of gravid females or observed eggs during fish handling. Three potential cod sounds matching cod grunts described by Fudge and Rose (2009), with peak frequency around 140 Hz and 120 dB SPL, were detected during 28-29 May at one of the locations where substantial cod were observed acoustically and caught by trawl (Figure 6). Acoustic and trawl data were not analyzed from the 18-19 June Survey at this time, but observations of cod in the catch indicated presence of ripe males and females.

Table 2. Trawl catch statistics for Atlantic cod during 28-29 May 2011.

		Mean		
Mesh	Catch (n)	TL (cm)	Density (kg/m^2)	% Catch (by kg)
Small	269	63	0.0033	94
Large	332	69	0.0050	98

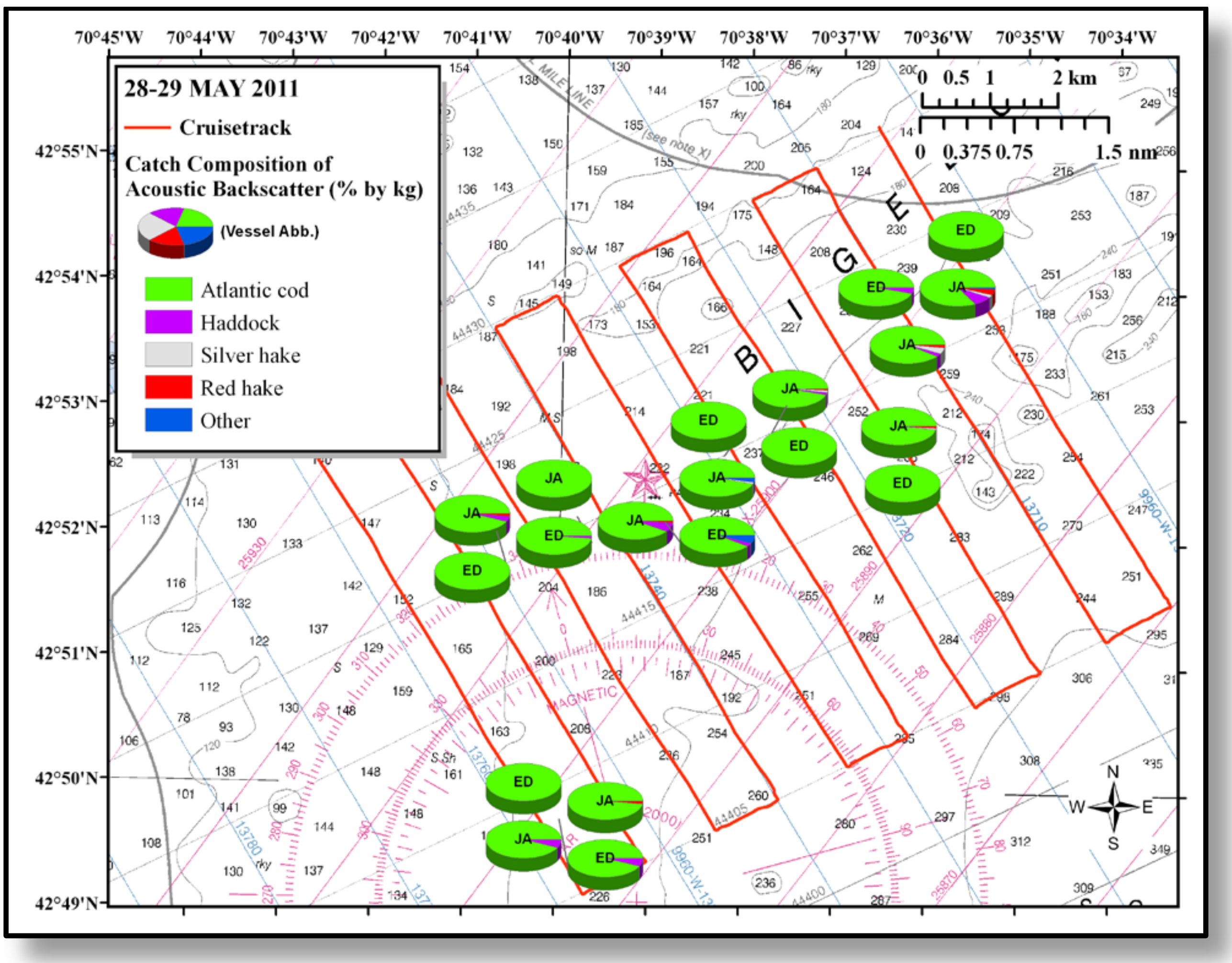

Figure 2. Species composition (% by weight) of trawl catches, excluding flounders, skates, sculpins, and goosefish (negligible acoustic detectability). Other species include pollock, redfish, Atlantic herring, and fourbeard rockling.

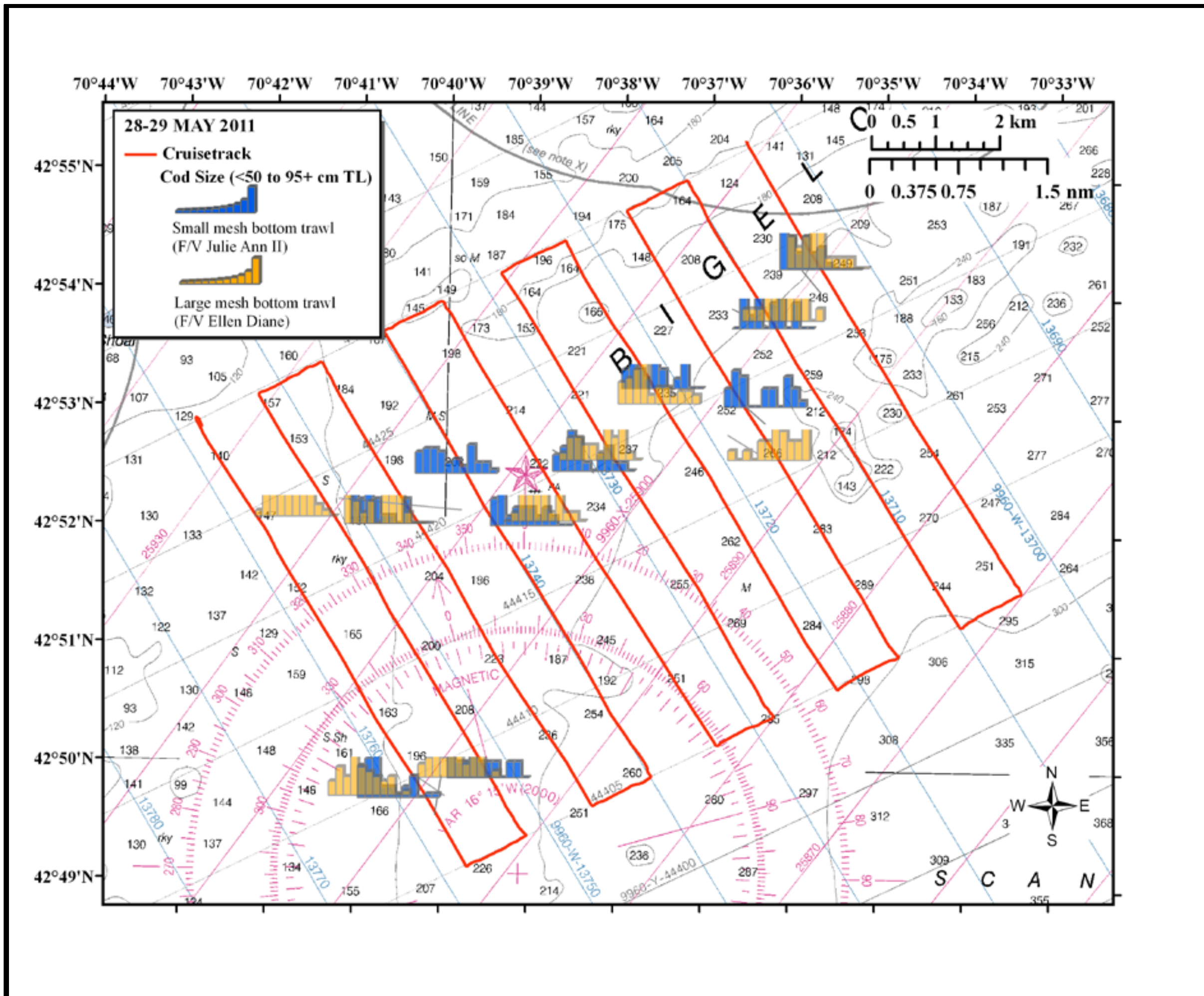

Figure 3. Length distributions of cod caught by bottom trawls during May 2011.

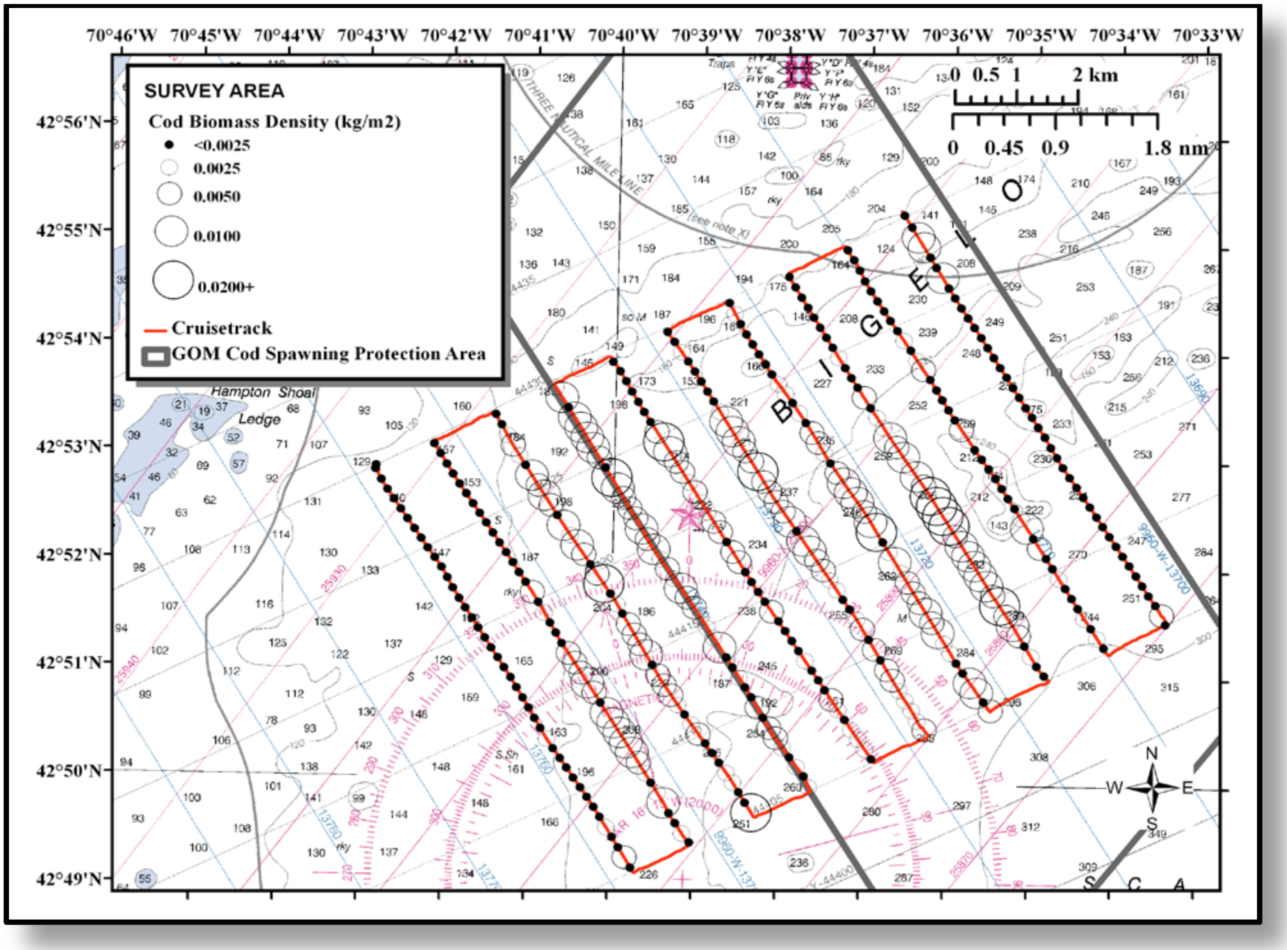

Figure 4. Cod distribution from an acoustic survey (38 kHz) during 28-29 May 2011.

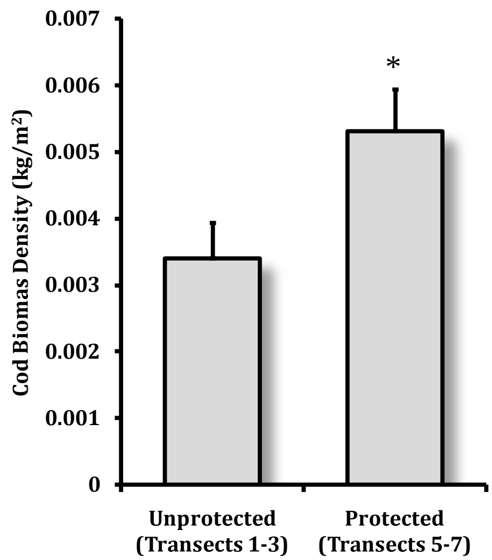

Figure 5. Mean (± SE) cod biomass density inside & outside the GOM cod spawning protection area during 28-29 May 2011 (* $p<0.05$).

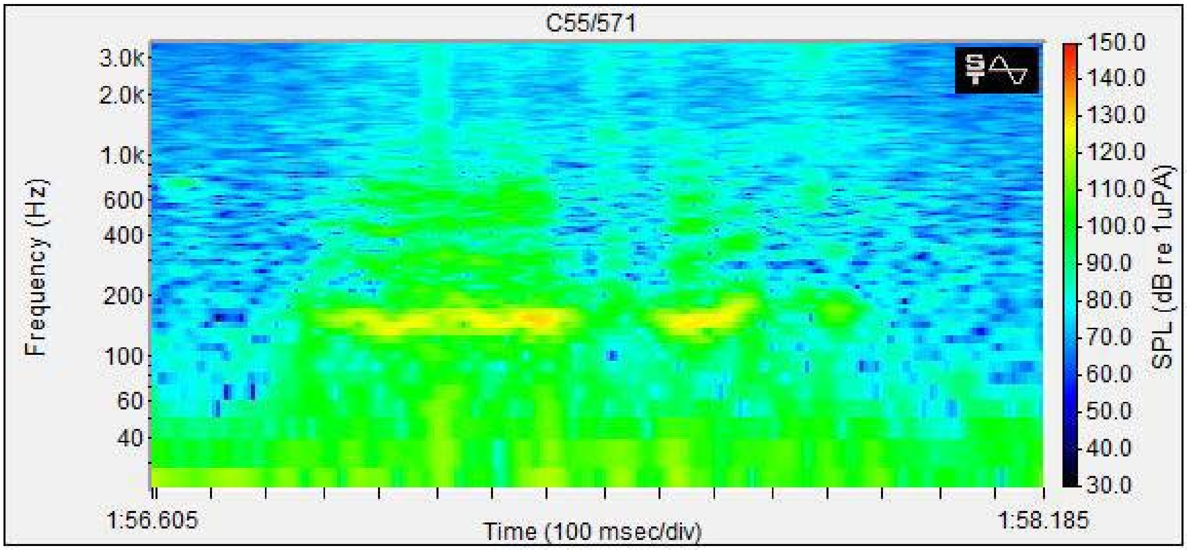

Figure 6. Spectrogram of an underwater sound (double grunt) potentially produced by Atlantic cod recorded during 28-29 May 2011. Peak frequency was around 140 Hz with duration of 100-400 ms.

Future Work

Future work remaining on this project includes at least one survey during early or mid July 2011 and continued analysis. Additional analyses will include acoustic dead zone corrections, acoustic classification methods, trawl and acoustic density comparisons, and geostatistics.

Impacts & Applications

Results to date verify the presence of spawning cod using the GOM-CSPA, and that spawning of cod in this area was not in progress during early April 2011. The preliminary acoustic biomass estimate of 572 mt within the GOM-CSPA represents 2% of the 2007 spawning stock biomass of 33,870 mt (Mayo et al 2009), but was likely an underestimate of 5-10% without acoustic dead zone corrections applied, and may not represent peak spawning. Peak spawning may have occurred 1-2 weeks earlier, or taken place in other neighboring areas not sampled. Alternatively, the 2007 SSB estimate may be overestimated, the relative low biomass reflects inter-annual variation in spawning activity (in space and time), or current SSB have decreased.

We anticipate that results of the research will both improve cod management and further the development of acoustic surveys for stock assessment. End-users will be those responsible for cod stock assessment and management, harvesters who rely on management decisions, and fishery scientists striving to develop acoustical surveying techniques.

Related Projects

Two tagging studies, funded by the NEC, showed that cod spawn in the area twice each year (winter and spring), and that the larger spring spawning group is resident to the area and displays spawning site fidelity (Howell et al. 2008; Siceloff 2009).

The use of multibeam and split-beam echosounders for studying mature Atlantic cod from Ipswich Bay has been studied in cooperative research at the University of New Hampshire. These studies were supported by a NEC Project Development award, and a two-year (2008-2010) New Hampshire Sea Grant award.

Partnerships

Three fishermen and 3 scientists have been involved with the project, and the partnership has worked well. All participants have been involved with most aspects of the study, including research design and data collection. One of the scientists (Chris Gurshin) will use the results as part of his doctoral dissertation, and he has done the bulk of the data analyses to date. All participants will be involved with final data interpretation. Preliminary results were recently reported at the "Reconciling Spatial Scales and Stock Structures for Fisheries Science and Management" workshop, and peer-reviewed publications will provide the end users with complete results.

Presentations

Gurshin, W.D., W.H. Howell, and J. M. Jech. 2011. Synoptic Acoustic and Trawl Surveys of Spring-Spawning Atlantic Cod in Ipswich Bay. Reconciling Spatial Scales and Stock Structures for Fisheries Science and Management. Portsmouth, NH, 27-28 June 2011.

Published Reports and Papers

A manuscript is in preparation for submission to a special issue of Fisheries Research.

Data

Data are stored, archived, and currently being proofed.

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