A Draft Final Report Submitted to the Northeast Consortium

Title: Evaluation of closed areas: Cashes Ledge as juvenile cod habitat

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Abstract:

The effectiveness of fisheries management is limited by the paucity of information on how management tools, such as marine protected areas, impact key fisheries species. In the Gulf of Maine, more information is needed to determine how marine protected areas such as the Cashes Ledge Closure Area influence fish population dynamics and subsequently the status of fishery stocks. We utilized video surveys and multibeam sonar to quantify current habitats on Cashes Ledge. We also conducted seasonal surveys in 2006 and 2007 on the kelp, barren cobble, and mud habitats in the vicinity of Cashes Ledge using video, trap, and gill net sampling to quantify how habitat influences the abundance and distribution of Atlantic cod, *Gadus morhua*. Seasonal surveys identified that cod are still abundant on Cashes Ledge; however, their spatial and temporal distribution on Cashes Ledge is influenced by habitat and other species such as spiny dogfish, *Squalus acanthius*. These results are being compared with historic cod datasets that were collected prior to the inception of the closure, and predate extensive harvesting on Cashes Ledge in the early 1990’s, to determine if cod populations have recovered locally. Quantifying important ecosystem functions such as the provision of nursery habitat for commercially important fish species will assist managers in selecting the most appropriate areas for management action. This study also provides baseline information that will be of value to ongoing efforts to monitor the impact of the Cashes Ledge Closure Area on rebuilding cod populations.
Introduction:

The ecology of Atlantic cod

Atlantic cod (Gadus morhua) are thought to settle in shallow water and move to deeper depths as they age (Swain 1993, Lineham et al. 2001). Juvenile cod typically are found in structured habitats such as seagrass beds and kelp habitat, and utilize these structured habitats to avoid predators (Keats et al. 1987, Gotceitas and Brown 1993, Gotceitas et al. 1995, Fraser et al. 1996, Gotceitas et al. 1997, Gregory and Anderson 1997, Grant and Brown 1998, Lindholm et al. 1999). Anderson and Gregory (2000) suggested that adult cod regulate juvenile populations and implied that preferred seabed habitat by juveniles may be limiting cod populations. Scientists reviewing cod use of habitat in European waters have also concluded that cod population dynamics are limited by habitat availability because they provide food and refuge for juveniles (Bjornstad et al. 1999, Fromentin et al. 2001). In the offshore waters of the Gulf of Maine, cod live in deeper waters and recruit to structured habitats including boulder and cobble fields (Lough et al. 1989). However, post-settlement survival of cod that recruit to these habitats is unclear, in part because of the difficulty of studying cod in these environments.

Cashes Ledge as habitat for cod

In the 1980s, juvenile cod were frequently observed in studies of the kelp forests of Cashes Ledge (Vadas and Steneck 1988, Witman and Sebens 1992, Steneck 1997). Video methods determined that the distribution and abundance of Cashes Ledge cod was approximately an order of magnitude higher than the densities on several inshore ledges (Witman and Sebens 1992, Steneck 1997). Steneck (1997) determined that the average cod size recorded on Cashes Ledge in the 1980’s ranged between 30 and 40 cm (approximately 2 years old based on average growth
curves for the Gulf of Maine and Georges Bank [Bigelow and Schroeder 1953]). Much smaller fish have also been recorded on Cashes Ledge (Steneck 1997), suggesting that young of the year cod were occupying the kelp forests on Ammen Rock Pinnacle. Older cod are generally found in deeper water (Swain 1993), but Steneck (1997) recorded cod up to a meter in length within the kelp forest at 30 m on Cashes Ledge (i.e., Ammen Rock). Jigging while on station yielded a high catch rate of cod at and around the kelp forest, and cod up to 18 kg (40 lbs) were caught at that location. Cashes Ledge was historically a productive fishing ground for cod in the middle of the Gulf of Maine until it was closed to groundfishing gear. Yet cod essential fish habitat on Cashes Ledge has not been consistently monitored. In this study, we mapped benthic habitat types on Cashes Ledge and evaluated cod habitat preferences.

Although juvenile cod abundances were quantified at Cashes Ledge in the 1980’s (Witman and Sebens 1992, Steneck 1997), few field studies of juvenile habitat usage have been initiated recently in the central and eastern portions of the Gulf of Maine even though these waters historically were important fishing grounds. Therefore, assessment of juvenile groundfish usage of and population dynamics on Cashes Ledge is necessary to determine the degree to which kelp beds function as juvenile groundfish habitat and contribute disproportionately to the production of adult fish such as cod in central areas of the Gulf of Maine.

*The Cashes Ledge Closure Area*

The New England Fisheries Management Council recommended several changes to existing closed areas in order to protect essential fish habitat under Amendment 13 to the Northeast Multispecies Fishery Management Plan. Among these management measures is the closure of a
portion of Cashes Ledge on a year round basis to all bottom-tending mobile gear (a Level III closure). This Level III closure went into effect on May 1, 2004 and creates the opportunity to establish baseline information about this historically important area for groundfish and to begin documenting its contribution to the distribution and abundance of cod throughout the Gulf of Maine.

Area closures on Georges Bank have been very successful for rebuilding scallops, haddock and yellowtail flounder, but have had disappointing results for cod. Fundamental questions of what is necessary to sustain cod stocks remain unanswered. This project identifies Cashes Ledge as an area uniquely suited for studies to answer these important questions. Cashes Ledge has been recognized as a critical area where groundfish are extremely abundant due to the presence of essential habitat supporting multiple groundfish life stages. It was identified by Collins and Rathbun (1887) and by Rich (1929) as an isolated but productive fishing ground in the middle of the Gulf of Maine.

More recent Cashes Ledge studies have recorded the highest population density of cod in the Gulf of Maine (Witman and Sebens 1992, Steneck 1997, Steneck and Carlton 2001). Because of its ecological importance, Cashes Ledge has been and will continue to be an area subject to intensive management attention. Yet cod ecology on Cashes Ledge has not been thoroughly studied and essential habitat has not been consistently monitored. This study will contribute to our understanding of the extent of essential cod habitat and the importance of this habitat to various life stages.
Both the New England Fisheries Management Council and the Northeast Consortium have specified that evaluating the contribution of closed areas to rebuilding fish stocks is a current research priority. Specifically, greater historical and biological information is needed to determine how these areas influence fish population dynamics and subsequently the status of fishery stocks. Research initiatives that quantify the extent to which Cashes Ledge supports spawning, juvenile and adult cod habitat will help managers assess the effectiveness of current management schemes and refine the scope and timing of future management actions. In particular, establishing habitat maps and quantifying important ecosystem functions such as the provision of nursery habitat for commercially important fish species will assist managers in determining whether the closure is effective. This study will also provide baseline information that would be of value to monitor the impact of the Cashes Ledge closure.

Project Objectives and Hypotheses:

OBJECTIVES

1) Review existing habitat maps and cod sampling from previous investigations at Cashes Ledge.

2) Produce current benthic habitat maps (video and multibeam) on Cashes Ledge closed area for comparison with historical information.

3) Quantify juvenile cod use of Cashes Ledge.

HYPOTHESES

1) Cashes Ledge promotes high densities of juvenile cod.

2) Kelp forests on the pinnacle of Cashes Ledge (Ammen Rock) enhance juvenile cod survivorship.
3) Juvenile cod grow more rapidly on Cashes Ledge than on surrounding unstructured bottom.

Participants:

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Methods:

Developing habitat maps of Cashes Ledge

We utilized video surveys and multibeam sonar to quantify current habitats on Cashes Ledge. In 2005, multibeam sonar acoustic surveys were conducted in the western Gulf of Maine, including Cashes Ledge. We used seafloor maps resulting from the 2005 surveys to design higher-
resolution multibeam mapping in June of 2006 on a ten square-mile area of the seafloor on
Cashes Ledge (Figure 1). A Reson SeaBat 7125 multibeam echosounder was utilized to collect
water column backscatter data. Quester Tangent Corporation’s (QTC) Multiview software was
used to analyze the backscatter data in order to create habitat classifications. Multiview permits
statistical parameterization of backscatter amplitudes from multibeam sonographs (Preston et al.
2004, Robidoux et al. 2008). QTC Multiview allows an objective segmentation based on the
extraction of 132 variables from rectangular patches of the compensated backscatter imagery
(Robidoux et al., 2008). Each rectangular patch has a user-defined geospatial footprint
determined by the number of pixels in X and Y orientation, which in turn is a product of vessel
speed, ping rate and angular sector of the sonar system. Each rectangle centroid is thereafter
represented by a point containing each of these attributes, called FFVs (Full Feature Vectors).

Principal components analysis is subsequently applied, reducing the dataset to the three values
most responsible for the variance, which then become the axes X (Q1), Y (Q2) and Z (Q3) in 3-D
vector space (Q-space). These reduced FFVs are then clustered into groups based on common
attributes in an objective manner using the software’s Automatic Clustering Engine (ACE), until
an optimum split is defined. Post-clustering, the classified values and their associated confidence
and probability measures are appended to each FFV, and exported in a format suitable for
assimilation into conventional 3rd party GIS applications. Using this software in the manner
described facilitates the objective selection of a relatively low number of ground truthing stations
(Figure 2b), which can in turn be used to extrapolate the classification in each segmented region
in a statistically robust manner.
Independent of *Multiview*, the results of the MBES survey were initially processed in CARIS HIPS and SIPS v.5.3 (Universal Systems Ltd.) software environments. The bathymetric data were logged in the native format for the Reson 7125 (.s7k), converted to generic sensor format (.GSF), and gridded at 5- and 10-m resolution using a weighted moving average in Fledermaus v6.5.1. The backscatter imagery presented (Figure 5b) was processed using a Beta version of IVS3D’s FM Habitat. The output grid formats were defined as generic Ascii to facilitate inclusion in a GIS environment for standard spatial analysis (ESRI’s ArcMap v.9.2).

At present, QTC *Multiview* only accepts Reson 7125 data in PDS2000 format, and not the native .s7k format. In order to satisfy this requirement, the data were converted using Reson’s PDS software. The remainder of data conditioning for *Multiview* was performed with the minimum deviation from the processing flow suggested by Quester Tangent in the product literature (QTC 2005). The data were cleaned for use in *Multiview* using the internal threshold tool set to 500 for all survey lines. For the generation of rectangles, the sample size of the backscatter patches determined to be most appropriate was 513 x 9 pixels (corresponding to 11.1 x 32.4 metres over ground). The Automatic Clustering Engine was employed because it is the most objective method for separating the FFV ordination (Q-space) into discreet units of similar characteristics. Thereafter, the results of the QTC *Multiview* analysis produced a series of derivative products associated with each FFV at each geographic location, namely values describing Q1, Q2, Q3, Confidence, Probability, and Class. Each of these point data were used to derive continuous interpolated surfaces for each of these values. With the exception of Class (categorical data), all data were interpolated using inverse distance weighted technique in ArcMap v.9.2. The categorical data (Class) were interpolated using QTC *Clams v2.0 (Classification Mapping Suite)* Quester Tangent’s independent categorical interpolation software. This interpolation process is
based on the most frequently occurring class value to the spatial centre of each grid node. Further details of a similar process of data conditioning, processing, and analyses to create classification schemes are provided in McGonigle et al. (2009).

Video work was conducted at Cashes Ledge during seasonal (spring, summer, and fall of 2007) research cruises on the F/V Robert Michael. Sony Handycam® Camcorders (DCR-SR100) were deployed individually in PREVCO™ clear Polycarbonate rectangular (9.2 x 11.9 x 19.7 cm) housings. Each camera was equipped with a 30 gigabyte hard drive and a 7.5 hr battery. Cameras were also outfitted with a 0.5X lens in order to ~double the camera’s field of view.

Each camera-housing unit was attached to a blank lobster trap (92 x 58 x 42 cm, l x w x h). The unit was mounted just inside the trap 22 cm’s from the bottom and along the longer trap axis (Figure 2). The camera was oriented slightly downward to capture the bottom habitat immediately adjacent to the trap. A one-inch PVC pipe was mounted to the lobster trap so that the pipe extended 1 m from the trap directly into the field of view of the camera. At the end of the pipe, an additional 1 m PVC pipe was attached to it forming a T. Holes were drilled in both pipes at 10 cm intervals and black cable ties attached. A buoy line with sinking pot warp was attached to each trap so that each unit was able to be deployed and recovered from a small vessel. During each sampling period, 10-12 separate video samples were collected at each of the following depths (5-10, 20-40, and 40-60 m) to quantify and compare habitats on the pinnacles (e.g., North Ammen Rock Pinnacle and Ammen Rock Pinnacle) and sides of Cashes Ledge with adjacent mud bottom (Figure 1, 2).
Quantifying cod populations on Cashes Ledge

We sampled cod in 4 distinct habitats that exist in specific depth zones (Table 1). Multibeam data analyses coupled with our video surveys established that depths shallower than 20 m consistently contain dense coverage of Laminaria kelp. Our video surveys also established that a loose canopy of shotgun kelp is common between depths of 20 to 40 m. To avoid these vegetated habitats completely, we sampled bare rock ledge/ boulder bottom at depths ranging from 40 to 70 m. Finally, we found abundant stretches of mud/sand bottom at depths as shallow as 70 to 100 m. These habitats were actively selected using both the bottom topography maps generated from the 2005 multibeam survey and using the depth finders/echo sounders on the vessels to verify that we were in fact sampling mud/sand sediment habitats.

Table 1. Habitats sampled on Cashes Ledge for Atlantic cod.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Depth</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow (S)</td>
<td>&lt;20 m</td>
<td>Laminaria kelp</td>
</tr>
<tr>
<td>Mid (M)</td>
<td>20-40 m</td>
<td>shotgun kelp</td>
</tr>
<tr>
<td>Deep (D)</td>
<td>40-70 m</td>
<td>Bare rock</td>
</tr>
<tr>
<td>Extra Deep (XD)</td>
<td>70-100 m</td>
<td>mud/sand</td>
</tr>
</tbody>
</table>

To avoid damaging critical habitat via trawling, we quantified the abundance of groundfish at Cashes Ledge using three less invasive methods during each seasonal survey: video, hook-and-line, and gill net sampling. We quantified fish using a deployable video recorder (DVR) system that we developed in 2006 (3 mm resolution; Grabowski et al. 2009). Sampling was conducted in the spring (May/June), summer (August), and fall (September/October) of 2007. A drop camera was released for 30 minutes at 10-12 replicate sites in each of the three most shallow
habitat zones delineated above to quantify cod visitation rates in habitats on Cashes Ledge. Video surveys were not conducted in the deepest habitat zone because of poor visibility (video).

Hook-and-line surveys were also conducted at 4-6 replicate sites in the shallowest 3 habitat zones during the spring, summer, and fall of 2007. During each sampling interval, 1-3 rods were utilized to sample juvenile cod in each habitat. Each sampling duration ranged from 30 to 60 minutes, and the total fishing time (number of minutes fished * number of rods) ranged from 85-210 minutes. Each rod was outfitted with a #14 Sabiki mix-flasher leader hook, and frozen soft-shell clam bait and mackerel (~5 grams per hook) were used to attract cod. Captured fish were identified, measured, and weighed. The deepest zone was not sampled by hook and line because strong tides at Cashes Ledge reduced our ability to keep the gear on the bottom.

Gill netting was conducted off the F/V Alice Rose in the spring, summer, and fall of 2007 to compare the relative abundance of juvenile groundfish on the ledge to the adjacent mud bottom. Gill nets with three consecutive 20 m x 2 m panels targeting juvenile cod (3” stretch net; 1-3 yrs old; 15 – 35 cm), young adults (4.5’ stretch; > 3 – 4 yrs old; 36 – 50 cm) and old adults (6” stretch; > 4 years old, > 75 cm) were deployed. One gill net was deployed at 4-8 replicate sites in each of the three deepest habitat-depth zones for 12 hours during each research cruise. Captured fish were identified, measured, and weighed. Gillnets were not deployed in the shallowest habitat to avoid damaging the kelp habitat, which likely also would have reduced the efficacy of gillnets.
Results and Conclusions:

**Developing habitat maps of Cashes Ledge**

QTC *Multiview* identified nine classes as the optimum number of splits in the 3-D ordination as determined by the ACE procedure. Analysis of the FFVs in 3-D vector space shows that whilst Q1 is the axis of the greatest variance, the majority of the differences are occurring in another dimension of the classified space (Q2; Figure 3 a and b). The proximity of individual units in the ordination is indicative of their relatedness. Q3 does not appear to have contributed as much in terms of individual class identities, although Class 8 has a high degree of spatial variability in this plain.

The majority of the survey area appears to be composed of hard substrates with the exception of classes 4 and 9, which are tentatively inferred to be 2 grades of unconsolidated sediment. Classes 1 and 7 are characterized by a high acoustic reflectivity in the areas immediately surrounding the pinnacles of the ledge feature. Examination of the geo-spatial analysis shows that there appears to be a degree of depth dependency in the segmentation as delineated by the software (Figure 4 a and b). The vast majority of the FFVs (11, 365 [53.95%]) belong to class 3, which occupies the central extent of the point cloud and extends along the full axis of greatest variability (Q1; Figure 4 a and b). This is likely a mixed substrate of predominantly coarse grained sediments (i.e., gravel, boulders, and bedrock). Class 8 appears to be noise inferred from its loose identity in the 3-D ordination, coupled with its geographic occurrence in areas of high topographic complexity. The remaining classes (2, 5, and 6) are assumed to be intermediary grades of sediment, or potentially similar grades of sediment with more subtle variations in epifaunal assemblages.
However, these are speculative inferences, and further interpretation will only become possible subsequent to the acquisition of adequate ground truth data.

Confidence values associated with the QTC *Multiview* classification do not appear to have any strong geographic distribution or relatedness to any single classified result (Figure 5a). The Geocoder mosaic of the entire 7125 survey area produced in IVS3D’s FM Habitat is similarly presented in figure 5b, showing the corrected mosaic of the backscatter imagery. This represents an additional means of conditioning and presenting the raw backscatter data, which is then input to the classification process.

A targeted groundtruthing cruise is scheduled for May/June 2009, which will be utilized to finalize classification of habitats on Cashes Ledge. During this cruise, we will collect additional video footage and grab samples (if necessary) in habitat class transition zones to determine if and how these habitats differ. These data will be used to qualify the acoustic segmentation performed by *Multiview*, and enable us to groundtruth the Cashes Ledge habitat maps.

A separate analysis of the 2006 multibeam data was conducted to determine the spatial extent of *Laminaria* spp. on Cashes Ledge. Because Laminaria is buoyant and contains air cavities, water column backscatter data were effective at identifying where kelp is located on the ledge. This analysis determined that kelp habitat exists as deep as 30 m, but is predominately isolated to shallower than 20 m (Figure 6). Laminaria kelp habitat is also confined almost predominately to North Ammen Rock and Ammen Rock Pinnacles in the central portion of Cashes Ledge.
Quantifying cod populations on Cashes Ledge

Gillnet surveys in 2007 determined that cod abundances were mostly consistent across habitat zones and seasons except in the summer (Figure 7). In the spring of 2007, cod abundances ranged from 1.1 ± 0.6 (mean ± 1 SE) cod/gillnet in the mud/sand zone to 1.9 ± 0.5 cod/gillnet in the shotgun kelp zone and 2.3 ± 0.5 cod/gillnet in the bare rock zone. Cod abundances increased in the summer by a factor of 3 to 6.3 ± 1.5 cod/gillnet in the shotgun kelp, and more than doubled in the mud/sand zone (1.5 ± 0.5 cod/gillnet). However, abundances in the bare rock zone were lower than in the spring (1.5 ± 0.5 cod/gillnet). Abundances were lowest in general in the fall, and were more consistent with those in the spring than in the summer (shotgun kelp: 1.1 ± 0.3; bare rock: 0.8 ± 0.5; and mud/sand: 1.3 ± 0.7 cod/gillnet). The size of fish caught in gillnets did not differ among habitats, in part because the gillnets that we used caught predominately large fish: shotgun kelp 649 ± 13 mm total length [TL], 3378 ± 236 g total weight; bare rock 645 ± 23 mm TL, 3288 ± 377 g total weight; mud/sand = 664 ± 20 mm TL, 3345 ± 297 g total weight.

Video surveys also suggested a seasonal increase in cod abundance in the summer especially in the shotgun kelp zone (Figure 8). In the spring of 2007, visitation rates ranged from 1.9 ± 1.0 cod/hr in the bare rock zone to 6.1 ± 2.8 cod/hr in the shotgun kelp zone and 6.7 ± 2.5 cod/hr in the Laminaria kelp zone. In the summer, cod visitation rates increased to 24.1 ± 9.5 cod/hr in the shotgun kelp zone and to 5.4 ± 4.0 cod/hr in the bare rock zone, but remained relatively constant in the Laminaria zone: 5.8 ± 4.5 cod/hr. Visitation rates in the fall once again more closely resembled those in the spring than in the summer (shotgun kelp: 3.3 ± 1.3; bare rock: 7.3 ± 1.7; and mud/sand: 3.5 ± 1.3 cod/hr).
In contrast to the results from the gillnet and video surveys, hook-and-line surveys found a consistent effect of habitat on cod abundance that was independent of the season sampled in 2007 (Figure 9). Cod abundances were highest in the shotgun kelp (2.4 ± 0.5 cod/hr) and Laminaria kelp (1.9 ± 0.2 cod/hr) habitats. Cod abundances in the bare rock totaled only 0.9 ± 0.2 cod/hr. Cod abundances in the hook-and-line surveys were extremely consistent among seasons: spring: 1.6 ± 0.3; summer 1.7 ± 0.4; and fall 1.7 ± 0.3 cod/hr. While it is possible that catch rates were slightly lower in the bare rock zone because this habitat is deeper, it is unlikely that this depth difference can completely explain the difference in catch rates.

Hook-and-line surveys were much more effective than gillnet surveys at catching juvenile cod. Hook-and-line surveys revealed that juvenile cod live primarily in the vegetated habitats (Figure 10). The mean size of cod captured was smallest in the Laminaria kelp zone (416 ± 7 mm TL, 783 ± 44 g total weight), slightly larger in the shotgun kelp zone (473 ± 11 mm TL, 1281 ± 111 g), and largest in the bare rock zone (538 ± 17 mm TL, 1793 ± 191 g). A larger proportion of the cod that inhabit the Laminaria kelp zone were juveniles than those in the other two habitat zones (% cod < 450 mm: Laminaria kelp = 75%; shotgun kelp = 45%; and bare rock = 23%).

Both the video and gillnet surveys revealed that cod were most abundant in the summer, especially in the shotgun kelp habitat. However, the hook-and-line results suggested that cod were always more abundant in the shotgun kelp habitat, although only slightly higher than abundances found in the Laminaria habitat zone. Although this pattern could be a result of spurious gillnet and video results, we have chosen to focus on why the hook-and line results
differed because this method is the least quantitative and results from the other two were consistent.

Hook-and-line sampling as a method to quantify relative abundance may be limited. Several other species were caught during hook-and-line sampling such as cusk (269), pollock (130), cunner (94), dogfish (36), and haddock (14). Catch of these species may reduce cod catch rates because they require time and effort to reel in and remove from the hook. In general, there was a negative relationship between the catch rate of all species other than cod and cod catch rates ($R^2 = 0.3553$). However, catch rates of other species were relatively low during the summer of 2008 in the shotgun kelp habitat. Thus it is unlikely that catch of other species can explain why hook-and-line surveys failed to detect an increase in cod abundance in the summer in the shotgun kelp zone. Another possible explanation is that cod feeding behavior could be influencing catch rates. For instance, if cod forage more effectively in the shotgun kelp zone in the summer, they may be more difficult to catch by hook-and-line. If this is the case, catch rates would not accurately reflect relative abundances.

The relationship between catch rates of cod and other species may reflect biological phenomena rather than an artifact of the sampling method. For instance, interactions among species may greatly influence the patterns of cod habitat utilization observed on Cashes Ledge. Specifically, when other species are abundant in a habitat, they could induce cod to emigrate from a particular area. In particular, cod could be competing for bottom habitat with other species such as dogfish and other gadids. Moreover, the ability of closed areas such as the Cashes Ledge Closure Area to perform key ecosystem functions such as providing EFH for cod and other groundfish species
may be influenced by interactions with other species that compete for these critical habitats. Investigating these species interactions is in concordance with an ecosystem approach to fisheries management, which stresses a more holistic approach by focusing on important ecological interactions rather than assessing individual fish stocks (Christensen et al. 1996, Botsford et al. 1997, Link 2002, FAO 2003, Rice 2005). Therefore, further investigation into interactions among species is merited on Cashes Ledge.

Outcomes/Conclusions:

- QTC-Multiview derived habitat maps of Cashes Ledge are currently a work in progress. The 9 classes that were derived indicate varying degrees of bottom hardness. A groundtruthing cruise will be conducted in the spring of 2009 to classify and consolidate these classes. Data collected in this cruise coupled with existing bottom habitat video data (Figure 2b) will be used to determine the biota and specific geological features associated with each class.

- Laminaria kelp is primarily located on the pinnacle of Cashes Ledge (i.e., Ammen Rock and North Ammen Rock) in water shallower than 30 m. Future work is needed on intra-and interannual variability in kelp habitat on Cashes Ledge.

- Cod sampling efforts suggest that cod are still abundant on Cashes Ledge. Two of the three sampling gears indicated that cod abundances are highest in the shotgun kelp during the summer. Further work is needed to identify what is driving seasonality in cod habitat usage patterns on Cashes Ledge.

- Juvenile cod are most prevalent in the Laminaria and shotgun kelp zones, and are almost non-existent in the deeper habitat zones. The Laminaria kelp zone had the highest
proportion of juvenile cod, but the absolute abundance caught in hook-and-line sampling was roughly equivalent.

- The Cashes Ledge Closure Area currently protects habitat that is important for Atlantic cod. In particular, both of the kelp habitats are providing EFH for juvenile cod, and adult cod are common throughout the habitats sampled on the ledge.

**Partnerships:**

Bob Tetrault, T/R Fish, Inc, originally approached scientists at GMRI urging us to explore whether the Cashes Ledge Closure Area is important habitat for cod fish. The project objectives were forged during those initial meetings between scientists and fishermen. The partnerships created in those early meetings have continued to develop throughout the course of the project. Mattie Thompson and Curt Rice were consulted throughout the planning stages and during the project to assist with the purchase and construction of different sampling gear. Although we eventually settled on video, hook-and-line, and gillnet sampling, we also attempted to utilize traps and long-line sampling to assess juvenile cod use of habitat on Cashes Ledge. Testing such a wide variety of sampling techniques was only possible because of the extensive fishing knowledge of our fishing partners. Furthermore, every aspect of the work was conducted by scientists and fishermen working together off of fishing vessels. Moreover, the success of this project hinged upon the local knowledge of Cashes Ledge that the fishermen involved in this project provided. In particular, their knowledge of the bottom was extremely useful when deciding where to deploy nets and gear, as well as being able to retrieve all of the gear, especially since Cashes Ledge is extremely complex bottom.
**Impacts and applications:**

The habitat maps developed by this project will be of value to fisheries managers attempting to examine the vulnerability of marine habitats to anthropogenic activities such as offshore energy development and commercial fishing. Currently the New England Fisheries Management Council’s Habitat Plan Development Team, of which Grabowski is a member, is assessing the vulnerability of geological and biological components of the seafloor throughout the Gulf of Maine, Georges Bank, Southern New England, and the Mid Atlantic bight to fishing gear impacts. This assessment integrates an understanding of how different gears contact the bottom with the susceptibility and recovery of the geological and biological substrate features to each gear type. Assessments such as these will be used increasingly by fisheries managers in an attempt to minimize the impacts of fishing activities, but their results are limited by the quality of the input data. Moreover, the Habitat PDT has identified that the paucity of seafloor information in the Gulf of Maine is limiting the efficacy of their analyses in this subregion, so that mapping efforts such as the work conducted in this study will be useful for future vulnerability assessments.

While better geophysical seabed information would improve our ability to manage fisheries and protect vulnerable habitat, these data need to be coupled with a better understanding of essential fish habitat. Information that establishes linkages between seafloor substrates and fish productivity (i.e., level 4 EFH) will be of greatest value to fisheries managers attempting to protect EFH. This next step requires examining the linkages between seabed substrates and life-history parameters such as survival, growth, and ultimately productivity. All of this information would be of great value to stock assessment models if they are going to begin including EFH
information in them. The models that are currently used to determine the Total Allowable Catch (TAC) limits for federally managed species in the Gulf of Maine such as cod and haddock currently are not spatially oriented, and thus limit the inclusion of habitat considerations in this important aspect of fisheries management. In our study on Cashes Ledge, we attempted to map existing habitat and link attributes of fish utilization to habitat components.

**Related Projects:**

The Gulf of Maine Council contributed funds (Award #: NA06OAR4600185 ) to support two months of Grabowski’s time to help develop juvenile fish habitat maps on Cashes Ledge. Support from a grant from the Davis Foundation was used to fund graduate student Chris McGonigle’s travel, housing and stipend in the summer of 2006 in Portland, Maine to develop substrate maps on Cashes Ledge.

**Presentations:**

Results from this study have been presented at the following conferences and meetings:


**Student Participation:**

*High School:*
Charlie Bolton
Andrew Swafford

*College/University:*
Jessica Leuders-Dumont, Colby College
Aaron Lyons, University of Southern Maine
Jane Johnson, University of New England
Zachary Whitener, Brown University

*Graduate Students:*
Christopher McGonigle, University of Ulster, Northern Ireland

**Published Reports and Papers:**


Future Research Recommendations:

We suggest the following research projects to build on the findings of this study:

- Future mapping efforts throughout the Gulf of Maine are needed as baseline information to enhance management activities associated with commercial fisheries bottom impacts, offshore energy development, and marine spatial planning.

- The work conducted on Cashes Ledge would be greatly enhanced by subsequent fish habitat studies in the other existing closures of the Gulf of Maine to determine if the patterns that we found on Cashes are general or specific to this particular closure.

- Studies that can establish level 4 EFH (i.e., links between habitat components and fish productivity) would greatly enhance efforts to protect the habitats that contribute most to fisheries productivity in the Gulf of Maine.

- Development of spatially oriented fisheries stock assessment models are needed so that empirical findings from studies such as ours on Cashes Ledge can be incorporated into future fisheries models.

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Literature Cited:


Conference and National Surveyors Conference; Session 8: Applications of surveying and mapping to other disciplines.


Figure 1. Bottom topography map of Cashes Ledge created with multibeam data collected for GOMMI in 2005, and processed by the Center for Coastal and Ocean Mapping/Joint Hydrographic Center. Shallow, mid and deep sites indicate locations of multibeam, video and fish survey work in 2006 and 2007.
Figure 2. a) Areas of Cashes Ledge mapped by MBES during 2005 (grayscale) and 2006 (colour). b) Hill-shaded bathymetry of area mapped in 2006 using a Reson SeaBat 7125 MBES. Existing seafloor habitat data collected on video during the study is indicated by symbols indicated in the key.
Figure 3. a) FFV ordination resulting from data processing in *QTC-Multiview* at rectangular dimensions of 513 x 9 pixels (11.1 x 32.4 m). Results displayed in 3-D vector space (Q-space) after clustering using ACE. An offset of +10 units has been applied to the Z axis (Q3) to allow the underside of the point cloud to be viewed in the inverted image presented below the horizontal plane. b) Detail of 4a.
Figure 4. Acoustic segmentation derived from processing Reson SeaBat 7125 MBES data collected in 2006 through QTC-Multiview. a) Classified surface is shown opaque over hillshaded bathymetry with 10 metre isobaths shallower than -50m. b) Image is displayed overlain on bathymetric slope (20% transparency) where darker colours indicate lower slope gradients. Area bounded by red shows detail inset.
Figure 5. a) Percentage confidence of the QTC Multiview classification interpolated from the original FFV records using inverse distance weighting in ArcMap v.9.2. b) Mosaiced backscatter imagery derived from Geocoder. This is the full extent of the 7125 coverage, overlain on the SAIC 8101 hill shaded bathymetry.
Figure 6. Map of kelp habitat on Cashes Ledge generated using water column backscatter data collected in 2006 with a Seabat Reson 7125 multibeam echosounder.
Figure 7. The abundance of cod caught in gillnet surveys conducted in shotgun kelp, bare rock, and mud/sand habitats on Cashes Ledge in the spring, summer and fall of 2007.
Figure 8. Visitation rates of cod captured in video surveys in Laminaria kelp, shotgun kelp and bare rock habitats on Cashes Ledge in the spring, summer and fall of 2007.
Figure 9. The abundance of cod caught in hook-and-line surveys in Laminaria kelp, shotgun kelp, and bare rock habitats on Cashes Ledge in the spring, summer, and fall of 2007.
Figure 10. Size-frequency distribution of cod captured in hook-and-line surveys in Laminaria kelp, shotgun kelp, and bare rock habitats on Cashes Ledge in the spring, summer,