Ecosystem Studies of Atlantic Cod Spawning Aggregations in Relation to Fisheries Interactions Using Novel Active and Passive Acoustic Approaches

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Title: Ecosystem Studies of Atlantic Cod Spawning Aggregations in Relation to Fisheries Interactions Using Novel Active and Passive Acoustic Approaches

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Project Summary

Reliably identifying the distribution of fish spawning activity is critical for understanding their life history and informing fishery management. Multiple measures have been implemented to protect spawning aggregations of Atlantic cod (*Gadus morhua*) within the Gulf of Maine management unit. However, persistent difficulties remain with respect to managing the rebuilding of this resource and many historical spawning components have been extirpated with little evidence for any recolonization of abandoned spawning sites. Therefore, an improved understanding of the spawning dynamics of remnant spawning components is required to support rebuilding efforts and inform fishery management measures. The objective of this project was to identify the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay to improve our understanding of cod spawning dynamics and inform fishery management.

Through effective collaboration among state, academic, federal, and NGO scientists, and commercial fishermen, this study successfully utilized multiple acoustic technologies to identify the spatial and temporal distribution of cod spawning activity during three consecutive winter spawning seasons from October 2013 through March 2016 in Massachusetts Bay. Based on a combined synthesis of the acoustic telemetry and passive acoustic monitoring data, from both fixed station and mobile autonomous glider deployments, the temporal distribution of cod spawning activity was shown to have some inter-annual variability, but based on the results from all three years, spawning activity primarily occurred during early November through January with a peak in mid-December. The spatial distribution of spawning activity was generally consistent among years and concentrated in areas deeper than 50 meters. Our scale of observation annually increased and permitted documentation of multiple hotspots of spawning activity, including just west of the northwest corner of Stellwagen Bank as the primary focal point of spawning activity, with other lesser focal points inside the WCCZ and just east of the Neptune LNG terminal.

Our findings have provided very valuable information for informing the development and potential modification of spawning protection measures for winter spawning cod in Massachusetts Bay. Our results are largely consistent with spatial and temporal extent of the current Framework 53 management measures. However, important areas have been identified for further consideration and evaluation by fishery scientists and managers in order to optimally balance protecting spawning cod and permitting access to other more abundant species.

1. Introduction

Since 1972, Atlantic cod (*Gadus morhua*) off the northeast coast of the United States have been managed and assessed as two units: the Georges Bank and Gulf of Maine stocks (Figure 1; Serchuk and Wigley, 1992). In recent decades, these stocks have declined in abundance due to interactions between overfishing (NEFSC, 2015), environmental variation (Rothschild, 2007; Halliday and Pinhorn, 2009), and species interactions (Frank et al., 2011; Ames and Lichter, 2013; Friedland et al., 2013). Persistent difficulties remain with respect to managing the rebuilding of the Gulf of Maine cod stock (Figure 2; NEFSC, 2015). Management actions designed to promote stock rebuilding have often taken the form of catch limits (i.e., annual quotas, possession limits) or effort controls (e.g., days-at-sea, seasonal and year round closures, limited entry permits). The goal of such actions has been to reduce fishing mortality, with the hope of allowing for expanded population growth. Scientific uncertainty is contributing to the continued difficulties with respect to managing the rebuilding of cod in the Gulf of Maine, including our incomplete understanding of cod population dynamics.

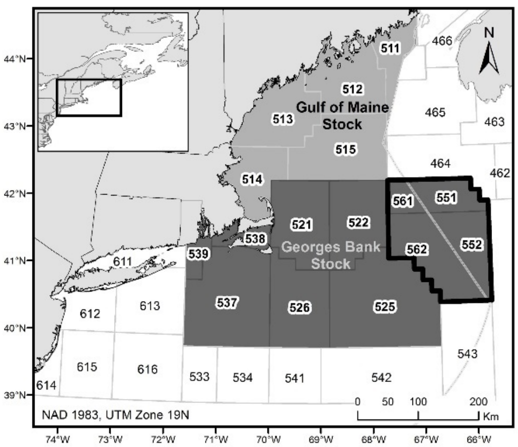


Figure 1:Atlantic cod stock management areas

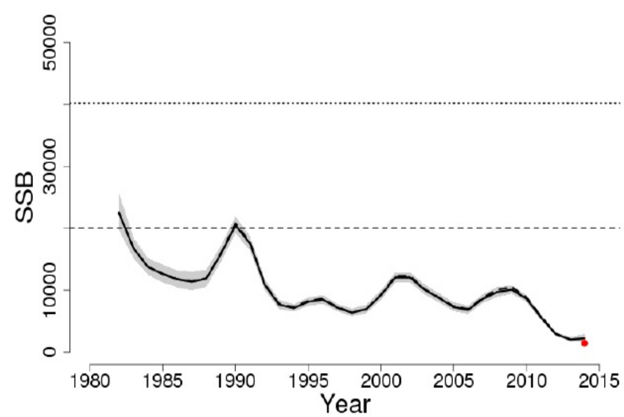


Figure 2: Gulf of Maine cod spawning stock biomass from 2015 stock assessment update (NEFSC 2015)

Multiple Atlantic cod stocks have been described as metapopulations (e.g., Smedbol and Wroblewski, 2002; Wright et al., 2006), including in U.S. waters (Ames, 2004; Zemeckis et al., 2014a), in that they are comprised of multiple genetically-distinct subpopulations and many finer-scale spawning components. Failure to recognize this population structure in stock assessment and fishery management has been identified as a primary mechanism for declines in abundance, the extirpation of historical spawning components, and unsuccessful stock rebuilding efforts (Ames, 2004; Reich and DeAlteris, 2009; Kerr et al., 2010, 2014). If a spawning component is exploited beyond its capacity to sustain itself, it may be extirpated and the evolutionary knowledge to spawn at a given time and location can be lost forever. Declines in spawning diversity limit the stock's capacity to generate future recruitment and decreases the probability that environmental conditions will be optimal for at least some portion of the spawning stock (Cushing, 1990). Therefore, maintaining a high level of spawning diversity is important for stock productivity and stability (Berkeley et al., 2004).

Concomitant with the declines in abundance of the Gulf of Maine cod stock have been the extirpation of historical spawning components (Ames, 2004) and contraction of biomass into the western portion of the stock area (Palmer, 2014; Richardson et al., 2014). Currently, the major active spawning grounds that are known in the Gulf of Maine are in Ipswich and Massachusetts Bays. Atlantic cod form large, dense spawning aggregations in locations and seasons that are often predictable every year within these regions (Zemeckis et al., 2014b). These dense, semi-discrete aggregations can be vulnerable to extirpation given their spatial and temporal predictability, proximity to shore, and the dense number of individuals within a relatively small area (Armstrong et al., 2013). Furthermore, the natural spawning behaviors of cod have been shown to be vulnerable to disruption by fishing activity (Morgan et al., 1997; Dean et al., 2012). As a result, cod are a prime candidate species for the application of spawning closures as part of a multidisciplinary approach to fishery management (Gruss et al., 2014; Zemeckis et al., 2014a; Sadovy de Mitcheson, 2016).

The Gulf of Maine cod stock is comprised of genetically-distinct spring- and winter-spawning subpopulations (Kovach et al., 2010; Zemeckis et al., 2014a). Previous studies have provided insights into the broad-scale (i.e., between bays) spawning dynamics of both subpopulations (Berrien and Sibunka, 1998; Hoffman et al., 2012). However, research on fine-scale (i.e., within bays) cod spawning dynamics has focused on the spring-spawning subpopulation, including observations in Massachusetts Bay of multi-year spawning site fidelity, connectivity among inshore spawning sites, and complex sex-specific spawning behaviors that are vulnerable to disruption (Dean et al., 2012, 2014; Zemeckis et al., 2014c; Zemeckis et al., *In press*). Similarly, acoustic telemetry and hydroacoustic surveys have been used to map the fine-scale distribution of cod spawning activity during the spring in the vicinity of the Whaleback spawning site in Ipswich Bay (Gurshin et al., 2013; Siceloff and Howell, 2013). The results from these studies have been considered in the design of multiple management measures to protect aggregations of spring spawning cod in Massachusetts Bay and Ipswich Bay (Armstrong et al., 2013).

In contrast, much less is known about the fine-scale spawning dynamics of the winter-spawning subpopulation in Massachusetts Bay, which has long been known as a major cod spawning ground. Massachusetts Bay has been the focus of multiple iterations of closures to protect spawning cod dating back to the 17th century when harvest was prohibited in December and January (Charters and General Laws of the Colony and Province of Massachusetts Bay, 1814). From the mid-1990's until 2010, groundfish "rolling closures" prohibited commercial fishing in locations and seasons of high cod abundance, and these closures simultaneously protected cod spawning aggregations, including during October and November in Massachusetts Bay (Figure 3; Murawski et al., 2005). In 2003, a spawning closure was implemented within Massachusetts state waters to prohibit commercial and recreational fishing, referred to as the Winter Cod Conservation Zone, from November 15 through January 31 (Figure 3, Armstrong et al., 2013). Spawning was evidently also occurring in federal waters and after the implementation of a catch share management system in 2010, most vessels were allowed into the October and November "Rolling Closures" and the daily trip limits were lifted. Therefore, winter spawning aggregations in federal waters were unprotected and this area was reportedly subjected to dramatically increased fishing pressure (Brewer, 2014). Concerned about the sustainability of this rapidly expanding fishery, a group of commercial fishermen approached our research team to initiate a study to investigate the spawning dynamics of this subpopulation.

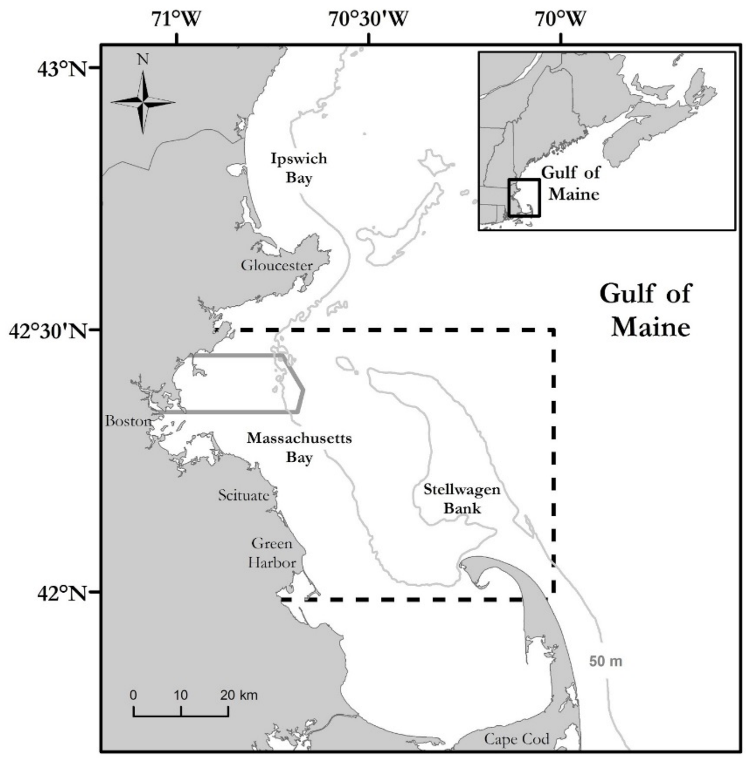


Figure 3: Map of historic western Gulf of Maine cod closures, including the groundfish "Rolling Closure" for October and November (dashed line) and the Winter Cod Conservation Zone closed November 15 through January 31 (gray).

The goal of this project was to provide a detailed description of the spatial and temporal extent of winter cod spawning activity in Massachusetts Bay. Our project was designed to yield results that would provide the scientific information needed to inform a seasonal fishery closure to protect the winter cod spawning components which remain active in Massachusetts Bay, with the aim of preventing their extirpation while balancing protecting cod and permitting access to other more abundant species. At the beginning of our project, these spawning components received no protection in Federal waters, with only partial protection from fishing activity in state waters by means of the WCCZ. However, since the present study began, fishery managers have implemented additional closures that have offered protection to winter spawning components in Massachusetts Bay.

As this grant was beginning an update of the Gulf of Maine cod stock assessment became available in August 2014 (Palmer, 2014). Results from this stock assessment indicated that the Gulf of Maine cod population was in a much more depleted state than suggested by previous stock assessments, which led to the adoption of strict fishing regulations, including large seasonal closures encompassing the study site, enacted by Interim Action (Department of Commerce, 2014) in November 2014 (Figure 4). These interim action measures closed broad areas and seasons with high cod catch rates, which concurrently protected winter cod spawning aggregations in Massachusetts Bay from November through February. In May 2015, the New England Fishery Management Council (NEFMC) approved Framework 53 (FW 53) to the groundfish fishery management plan (Department of Commerce, 2015), which refined the interim action spatial management measures to permit fishing for other more abundant species while still offering protection to spawning cod (see Figure 5). These management measures remain in place as of the time of this report.

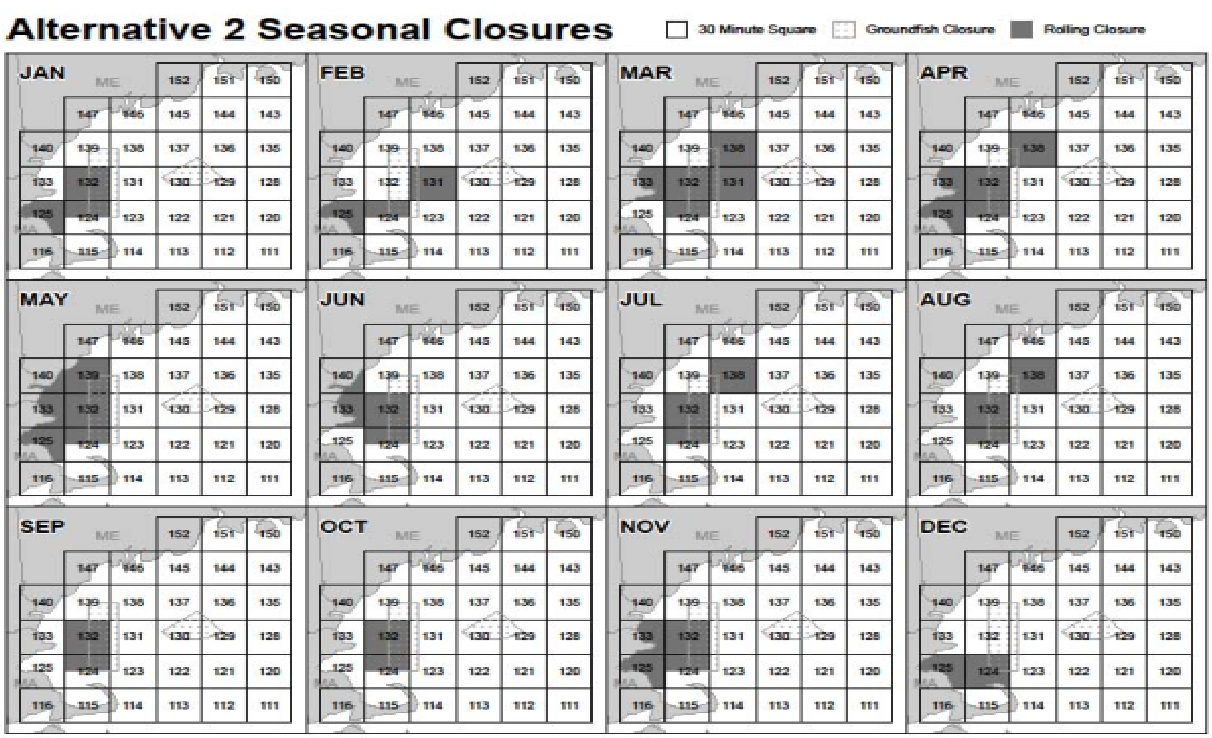


Figure 4: Interim Action cod protection measures in effect Nov 13, 2014 - April 30, 2015. (Department of Commerce, 2014)

The sequence of recent management actions highlights the continued concern over protecting spawning aggregations and preventing further erosion of reproductive capacity. The critically depleted status of the resource forced fishery managers to act on coarse spatial information and an incomplete seasonal description of cod spawning activity, leaving uncertainty as to the appropriateness of these broad-scale closures. Therefore, although fishery managers took action during our study, the results from this research remain very valuable and pertinent in order to evaluate recent conservation measures and to inform potential modifications.

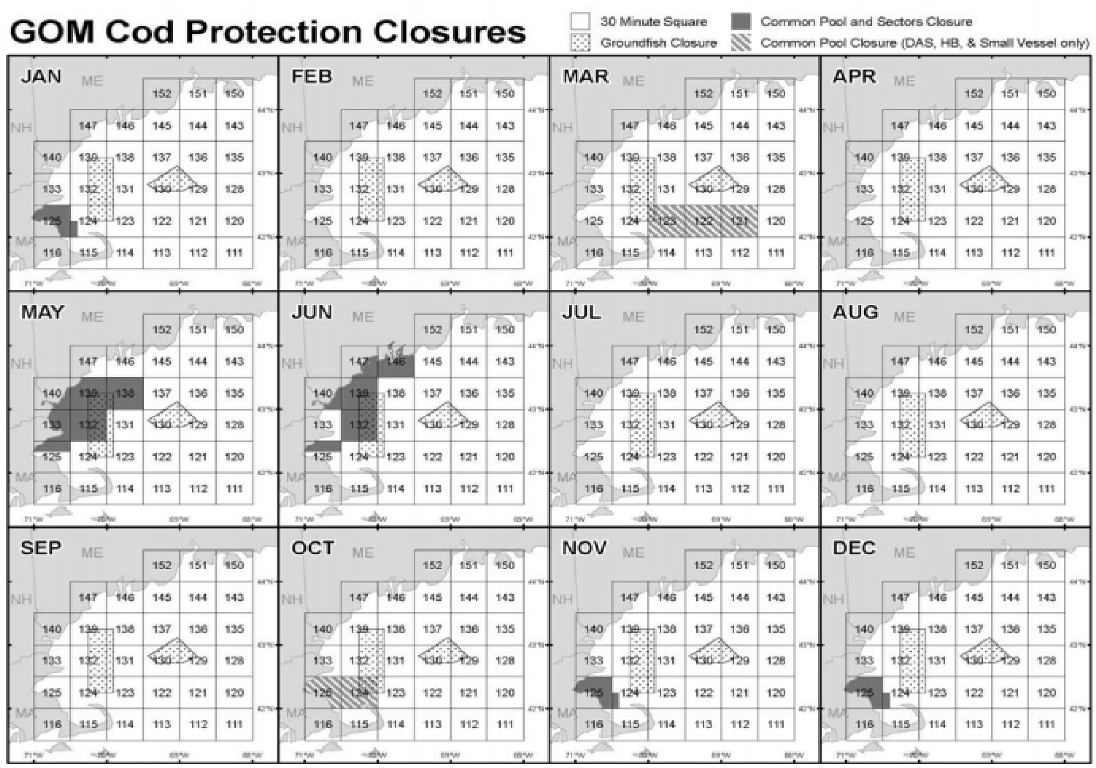


Figure 5: Framework 53 to the Northeast Multispecies fishery management plan refined cod spawning closures. These measures went into effect May 1, 2015 and remain in place today. (Department of Commerce, 2015)

2. Project Objectives

The primary goal of this project was to describe the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay in order to improve our understanding of cod spawning dynamics and inform fishery management decisions. We achieved this goal by addressing the following originally proposed research objectives:

Objective 1: Identify key winter spawning aggregations from pilot study data

Objective 2: Document the location and timing of winter cod spawning activity in Massachusetts Bay using acoustic telemetry and passive acoustic monitoring.

Objective 3: Analyze results and describe patterns in spawning activity in relation to habitat and fishing activity.

Objective 4: Communicate results to the New England Fisheries Management Council (NEFMC).

3. Methods

Research on winter spawning cod in Massachusetts Bay began in 2013, which was one year before NOAA funding was received through this award. This pilot work was completed with funding from The Nature Conservancy and the Commonwealth of Massachusetts so that the project could begin within a few months of the conception of our research plan and during the preparation of proposals for expansion into a multi-year study. Although other sources funded the fieldwork for this pilot work, NOAA funding supported the analysis of the data that was collected during our first year of sampling.

The distribution of cod spawning activity was investigated by tracking tagged cod via acoustic telemetry and using passive acoustic monitoring to record grunts produced by males as part of courtship rituals (Brawn, 1961; Fudge and Rose, 2009). Utilizing both complementary technologies helped to reliably monitor the distribution of spawning activity throughout the study site. In addition to the pilot work completed in Year 1, NOAA funding was used to monitor putative spawning sites for two additional winter spawning seasons from September 2014 through March 2016 with an array of monitoring equipment deployed at fixed locations and mobile gliders to survey a broader area. Preliminary results were considered to annually modify the monitoring of putative spawning sites by balancing trade-offs between expanding within the constraints of available equipment and maintaining consistent stations.

3.1 Study Site and Planning

This multi-disciplinary research required regular project team, in person, meetings to ensure alignment and efficiency. Each meeting included 3-5 commercial fishermen and all scientific collaborators. Thanks to the Stellwagen Bank National Marine Sanctuary for hosting each team meeting at their facility in Scituate, MA.

In June 2013, working closely with collaborating fishermen primarily from Northeast Fishery Sector X (Figure 6), the project team mapped existing information about the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay (Figure 7), including bottom trawl survey data from the Massachusetts Division of Marine Fisheries (MADMF: Hoffman et al., 2012) and NOAA Northeast Fisheries Science Center spring and fall Bottom Trawl Surveys, areas with high catch-per-unit-effort from commercial fishery observer data, ichthyoplankton survey data (Berrien and Sibunka, 1999), existing passive acoustic monitoring data (Van Parijs et al., 2015), and fishermen's ecological knowledge (Figure 8). This information was used to inform the deployment of monitoring equipment in Year 1.

Figure 6: Captains Frank Mirarchi (center right) with Phil Lynch (top right) and Kevin Norton (lower right) describe historic cod spawning areas. MA DMF's Dr. David Pierce (top left) and Micah Dean (bottom left) look on. © The Nature Conservancy (C. McGuire)

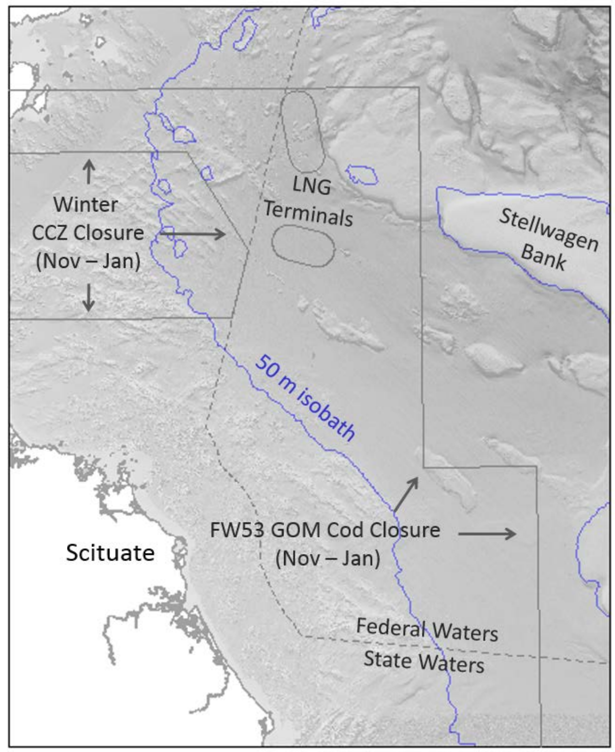


Figure 7: Map of Massachusetts Bay showing bathymetry, management areas, 50 meter isobath, and commercial LNG installations.

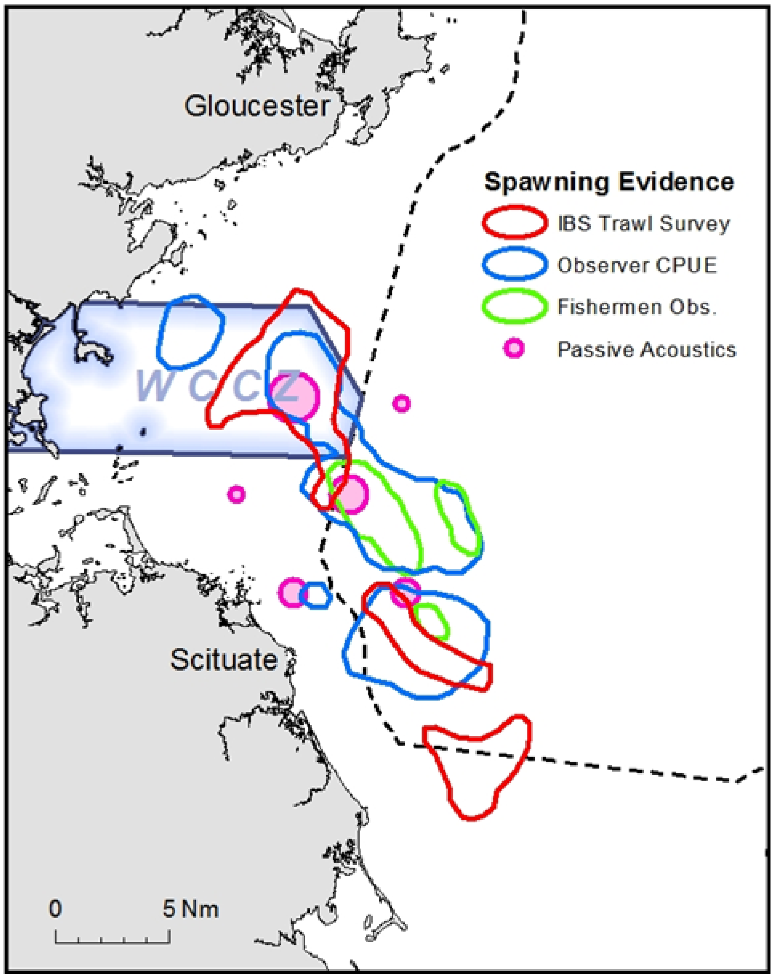


Figure 8: Composite map of baseline cod spawning information including: 2003-2007 MA DMF Industry Cased cod survey tows with skewed sex ratios (red); High cod CPUE from observer data (blue); Observations from Scituate fishermen (green); and recorded cod grunts from historic passive acoustic data (purple).

During the summer of 2014, three research team meetings were held to plan for the Year 2 field season including: identifying key spawning areas from Year 1 data, designing the fixed station array and an approach for glider deployments, and agreeing upon research timing. Tradeoffs were confronted with respect to the scale of area that could be monitored using acoustic telemetry receivers versus gliders, as well as resolving issues in areas where maintaining acoustic receivers was a challenge (i.e. receivers lost in shipping lanes) during pilot work.

Meetings were again held in June and September 2015 with discussion focusing on reviewing the preliminary results, identifying future analytical approaches for available data, and outlining plans for publishing project results in scientific journals. Planning for the final field season (Year 3), included again refining the fixed station array and glider tracks, and coordinating timing of equipment deployments.

A final results meeting was held in May 2016 to discuss analytical approaches, results, and publications.

3.2 Tagging

Co-PIs from the MADMF were issued a Scientific Research Letter of Acknowledgement (LOA) in November 2013 (Appendix B) from the NMFS in order to conduct cod tagging trips in Massachusetts Bay. As part of the pilot work in Year 1, two trips were made with commercial fishermen and researchers to jig for cod during November of 2013 (Figure 9; *F/V Endeavor, F/V Michael Brandon*, Scituate, MA). However, no spawning cod suitable for the surgical implantation of acoustic transmitters were caught during these trips.

Figure 9: Researchers D. Zemeckis (left) and W. Hoffman (right) jigging for cod aboard Scituate based F/V Michael Brandon on December 3, 2013 ©John Clarke Russ (for The Nature Conservancy)

Therefore, we shifted to commercial bottom trawl fishing vessels that were more successfully capturing spawning cod (*F/V Yankee Rose*, Scituate, MA; *F/V Mystique Lady*, Gloucester, MA). Four research tagging charters were completed aboard bottom trawl fishing vessels between December 14, 2013 and January 10, 2014.

Figure 10: Capt. Kevin Norton, center, aboard the Scituate-based F/V Yankee Rose tosses a freshly-caught Atlantic cod into a holding tank as MA DMF biologist J. Kneebone (far left), deckhand Greg Cook, C. McGuire and D. Zemeckis (far right) look on. December 14, 2013. ©John Clarke Russ (for The Nature Conservancy)

Cod were captured for tagging during 10-30 minute tows (Figure 10). Total length (nearest cm) was measured for all fish, and their sex and maturity stage were determined via visual inspection or cannulation. Each fish was assigned a maturity stage based on guidelines from Burnett *et al.* (1989). Cod in excellent physical condition that were >/= 55 cm total length and either Developing, Ripe, Ripe and Running, or Spent maturity stages were considered for tagging with acoustic transmitters. Following the procedures outlined in Dean et al. (2012, 2014), coded 69 kHz acoustic transmitters (model V16-6H; Figure 11) with a battery life > 1300 d and a 60s mean transmission rate (Vemco Division, AMIRIX Systems, Inc., Nova Scotia, Canada) were surgically-implanted (Figure 12) into spawning cod. Floy internal anchor tags were inserted inside each incision to increase the likelihood of recovering the tag in the event of a fishery recapture. All other captured cod were externally-tagged beneath the first dorsal fin with two conventional t-bar anchor tags (Type TBA, Hallprint, Australia).

Figure 11: VR16 acoustic tag and Floy tag ready to surgically implant in cod ©John Clarke Russ (for The Nature Conservancy)

Figure 12: D. Zemeckis performs surgery to insert acoustic tag in cod. C. McGuire records data as J. Kneebone assists. ©John Clarke Russ (for The Nature Conservancy)

Using NOAA funding, four tagging trips were conducted aboard commercial bottom trawl fishing vessels from Scituate and Gloucester, MA during Year 2. These trips were completed aboard the *F/V Mystique Lady* from Gloucester, MA with Captain Joe Jurek (November 22, 2014, December 12, 2014) and the *F/V Barbara L. Peters* from Scituate, MA with Captain Kevin Norton (November 23, 2014 and December 5, 2014). The same tagging protocols were followed as in Year 1 with acoustic transmitters being surgically implanted into spawning cod (figures 11 & 12) and all other fish being opportunistically tagged with conventional t-bar anchor tags.

3.3 Spawning Site Monitoring (Fixed Stations)

3.3.1 Acoustic Telemetry

During the pilot work in Year 1, the available information on the distribution of cod spawning activity (Figure 7) was used to design an acoustic receiver array consisting of 34 Vemco VR2W acoustic telemetry receivers moored with a surface float (Figure 13). These receivers were deployed to monitor the study site from November 6, 2013 through February 12, 2014 (Figure 14; see Appendix A1). Note that the deployment duration (i.e., number of receiver days) varied among stations due to lost receivers from which data was recovered for either a part of the spawning season, or in some instances no data at all was successfully recovered. All acoustic telemetry receiver deployments, maintenance, and retrievals for this project were completed aboard commercial fishing vessels (*F/V Destiny*, *F/V Sarah Ann*: Green Harbor, MA) or aboard MA DMF research vessels (*R/V Alosa*, *R/V Michael Craven*: Gloucester, MA). In Year 1, the acoustic receivers were spaced ~3 km apart on average, achieving ~25% coverage efficiency over a 240 km^2 area, assuming 750 m detection radius for each acoustic receiver based on the results from a range test experiment completed as part of a previous project. The receivers were downloaded every 1-1.5 months and then redeployed in place to continue monitoring the study site for the duration of the spawning season. A total of eleven acoustic receivers were lost during Year 1, but some

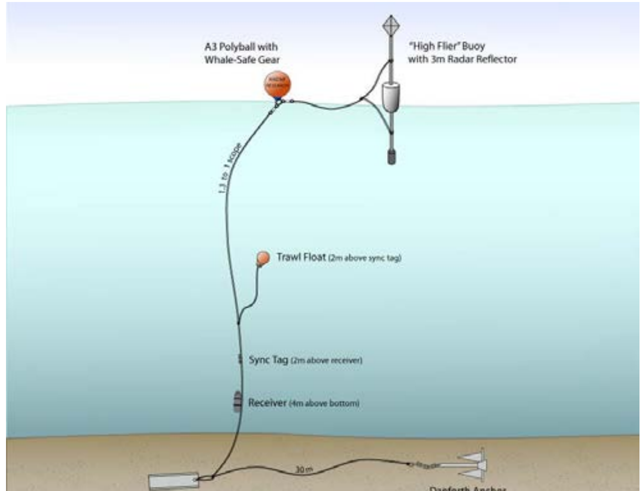


Figure 13: Acoustic telemetry mooring setup.

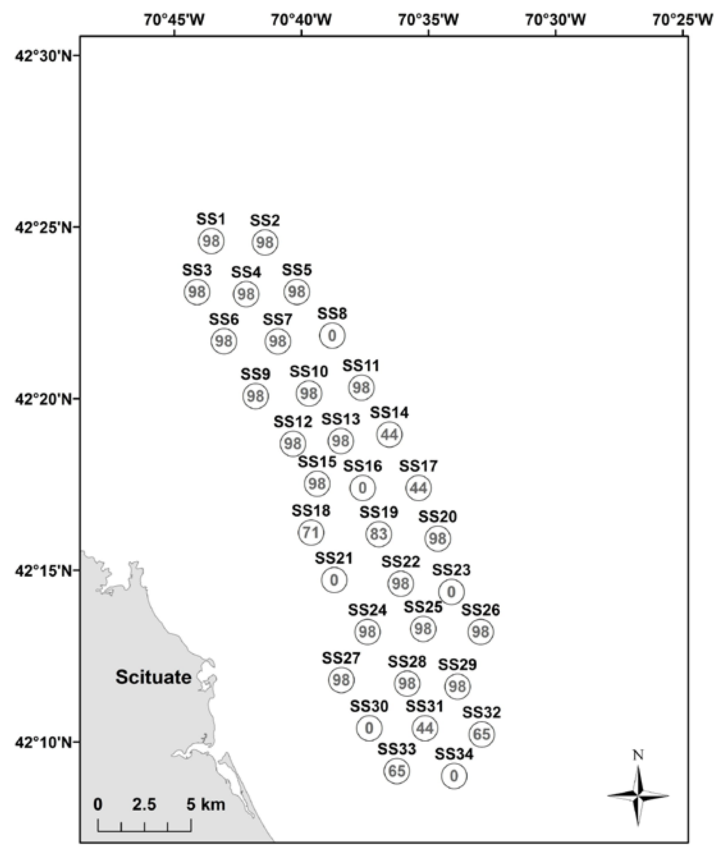


Figure 14: Location and numbers of acoustic telemetry receiver array in year 1. Numbers in circle indicate number of days of data recovered.

data were recovered from five of these during mid-season downloads. Receiver losses were heaviest in the Boston shipping lanes.

Based upon preliminary Year 1 results, and with NOAA funding to purchase additional receivers, the acoustic receiver array was expanded to a total of 42 acoustic receivers for Year 2 in order to monitor a larger area (~300 km^2), particularly to the northeast beyond the detection range of the Year 1 acoustic receiver array (Figure 15; Appendix A2). Data collected during pilot work conducted in Year 1 indicated that the area around the Northeast Gateway and Neptune Liquefied Natural Gas (LNG) terminals in Massachusetts Bay appeared to be habitat for spawning cod. Therefore, attempts were made to deploy acoustic equipment inside of these restricted areas via communications with the United States Coast Guard (USCG) and associated gas companies. Deploying the equipment in these prohibited areas would have had the benefit of preventing interactions with the gear of other fishermen, thus minimizing the likelihood of losing research equipment.

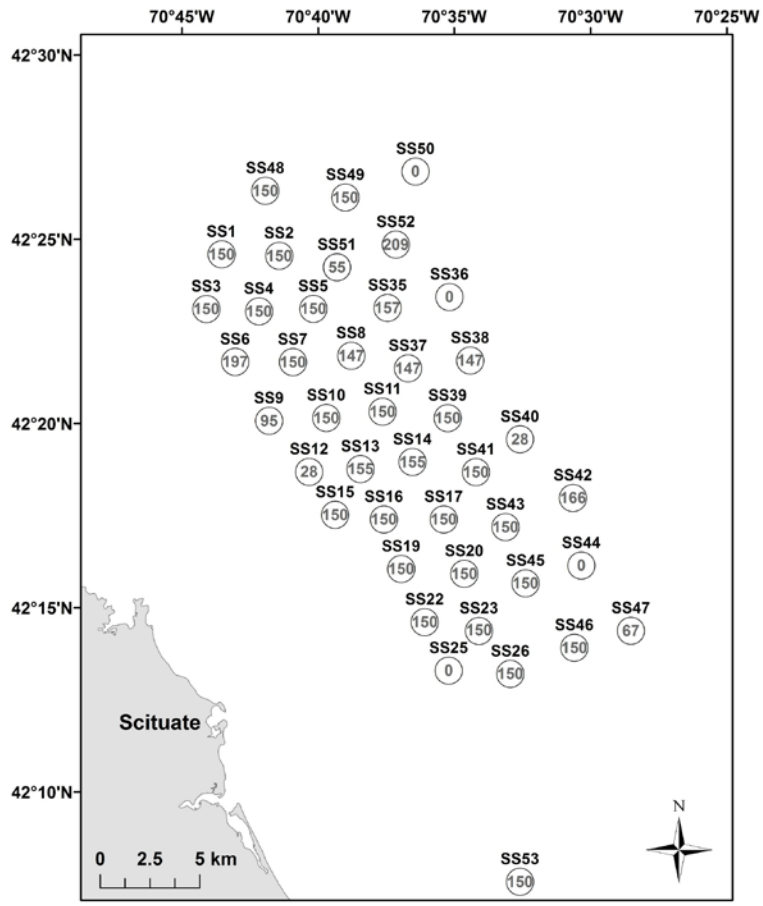


Figure 15: Location and numbers of acoustic telemetry receiver array in year 2. Numbers in circle indicate number of days of data recovered.

These planned deployments were abandoned in response to legal and insurance concerns by the gas companies, despite receiving approval from the USCG. As a result, the acoustic receivers were instead deployed as close to the boundaries of the restricted areas as possible, which was intended to minimize conflict with other user groups (i.e., gas companies and fishermen).

In Year 2, the acoustic telemetry receivers were deployed at-sea aboard commercial fishing vessels from Scituate, MA in early or late October 2014 (Appendix A2). The acoustic receiver stations within the Boston shipping lanes were deployed on the bottom using acoustic releases to avoid vertical lines and the risk of losing receivers due to passing ships. The project team worked diligently to download the receivers monthly, but the harsh February weather forced a wider spacing between downloads late in the season. The array was hauled-out for the season during a research charter aboard a commercial fishing vessel on March 8, 2015. Some acoustic receivers could not be retrieved because their surface buoys were cut off, the acoustic releases were malfunctioning, or they were missing entirely. Three grappling trips were made by fishermen and staff from the MA DMF, and together they recovered six receivers, which helped to recover a great deal of data and equipment. Nonetheless, eight acoustic receivers and the associated data and mooring gear were lost during this season, which was still considered successful given the harsh winter weather with multiple blizzards. Following the final download during all field seasons, all acoustic telemetry data was organized and uploaded to the Acoustic Telemetry database at the MA DMF and the Atlantic Cooperative Telemetry (ACT) database, and all tagging data was uploaded to the SMAST Cod Tagging database.

For Year 3, the acoustic receiver array design was further modified in an attempt to achieve a more complete description of cod spawning activity. Specifically, an additional 14 acoustic receivers were added to increase the array to 56 total acoustic receivers and to expand to the northeast to increase the total coverage area of the array to ~400 km^2 (Figure 16). The acoustic receiver array in Year 3 maximized the area which could be covered with the available equipment and included more receivers and increased spatial coverage in comparison to previous years. Similar to the Year 2 field season, VEMCO acoustic receivers in the shipping lanes were deployed on acoustic releases to reduce the likelihood of losing receivers at these stations. Also, as done in previous years, the acoustic receivers were downloaded every 1-1.5 months and then redeployed in place to continue monitoring the study site. In Year 3, the acoustic receivers were deployed on separate trips due to the availability of gear, weather conditions, and vessel limitations with such a large array. The receivers were deployed between September 14, 2015 and October 16, 2015 (Appendix A3). The acoustic receiver array

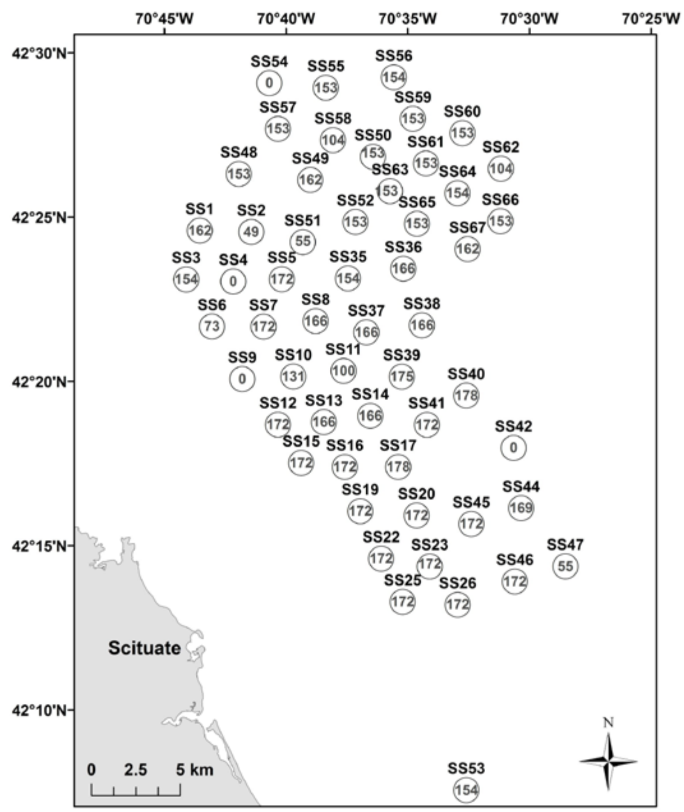


Figure 16: Location and numbers of acoustic telemetry receiver array in year 3. Numbers in circle indicate number of days of data recovered.

was hauled-out for the season over the course of two trips aboard commercial fishing vessels in mid to late March. Some acoustic receivers could not be retrieved because their surface buoys were cut off. Two grappling trips were made by commercial fishermen on April 2 and April 19 in 2016 to attempt to recover lost receivers with mixed success. A total of nine receivers were lost during Year 3. The composite three year acoustic receiver array is shown in Figure 17.

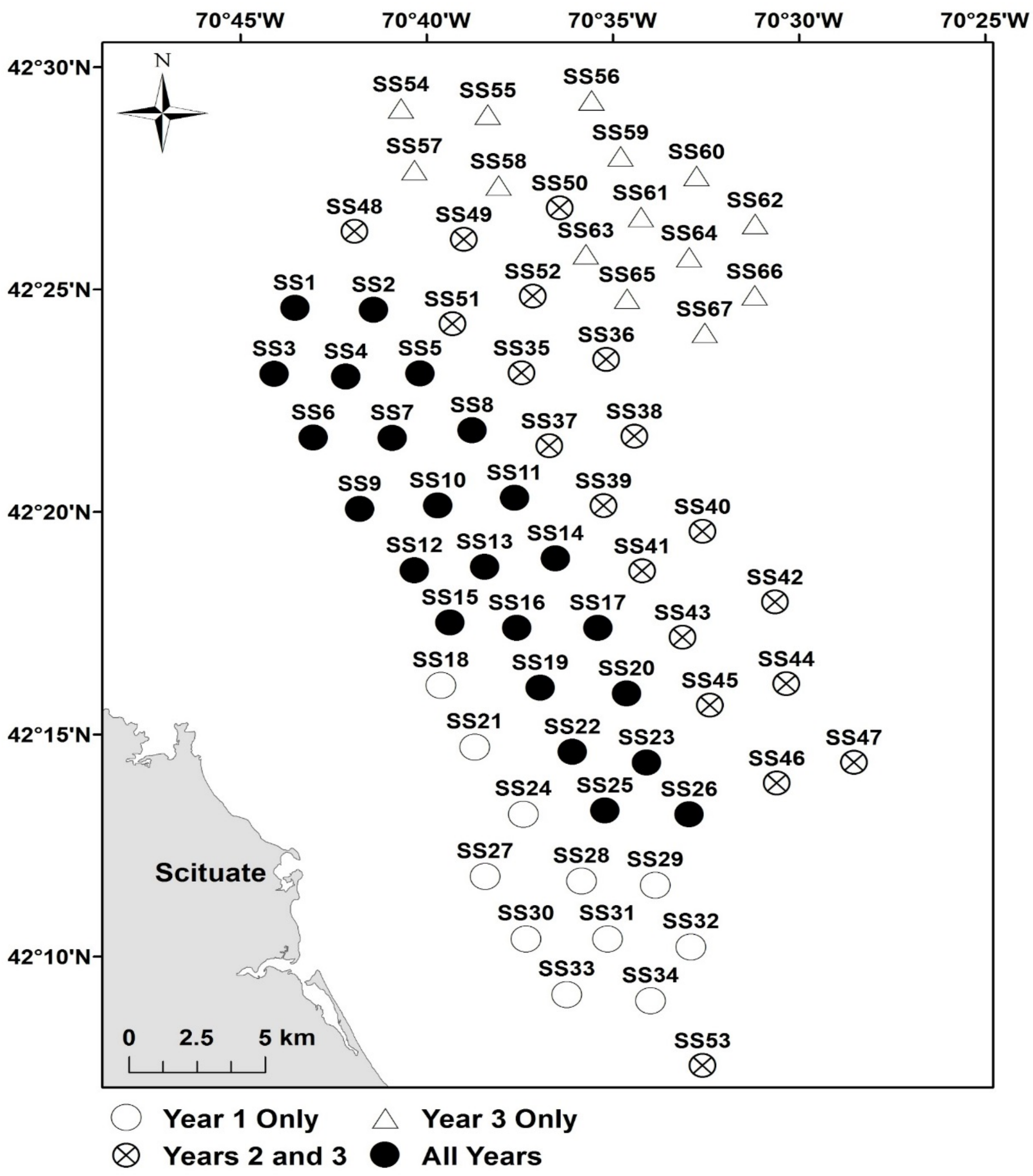


Figure 17: Composite year 1, 2, 3 Acoustic telemetry array.

3.3.2 Passive Acoustic Monitoring

Previous research identified the utility of passive acoustic monitoring for investigating the occurrence and spatial extent of cod spawning activity in the Gulf of Maine (Hernandez et al., 2013). Passive acoustic recorders were deployed at putative spawning sites from commercial fishing vessels to collect information on the long-term spatial and temporal presence of cod grunts (Figure 18). There were a total of 17 Marine Autonomous Recording Units (MARUs, Calupca et al., 2000) deployed during the three years of the study, all of which were programmed to record continuously at a sampling rate of 2000 Hz. There were five MARUs deployed in Year 1 and six MARUs deployed in each Year 2 and Year 3 (Figure 19; Table A4). All MARU's deployed in Year 2 and Year 3 were collocated with an acoustic receiver and a temperature logger (Star-ODDI milli-L in Year 2, Onset TidBit v2 in Year 3).

Figure 18: Fishermen Paul Unangst (left) and Phil Brazao (right) work with NOAA NEFSC researcher Genevieve Davis to deploy a MARU In October 2013 from F/V Destiny. © The Nature Conservancy (C. McGuire)

In Year 1, the MARU deployed at SS3m failed two days after deployment and no data was collected after the failure. The MARU deployed at SS53m in Year 1 went adrift on January 2, 2014 and was recovered January 7, 2014 on a beach in Duxbury, MA; data were not analyzed after it became untethered on January 2. All other MARUs were recovered in the beginning of April.

In Year 2, MARUs deployed at SS35 and SS51 malfunctioned <3 d after deployment; resulting in no data collected for the majority of their deployments. The MARU at SS35 did not surface after receiving the burn command, but it did surface on its burn date (March 15, 2015) and was recovered by the *M/V Gateway Endeavor*. SS51 released on its own after mixing up damaged hydrophone electrical impulses for a burn command on December 3, 2015 and was adrift in Massachusetts Bay, transmitting its position via ARGOS satellite relay. It was recovered by MA DMF co-PI Bill Hoffman on December 5, 2015 aboard the *R/V Michael Brandon*. The MARU was not redeployed and was returned to Cornell for data recovery. The remaining MARUs were recovered in mid-March.

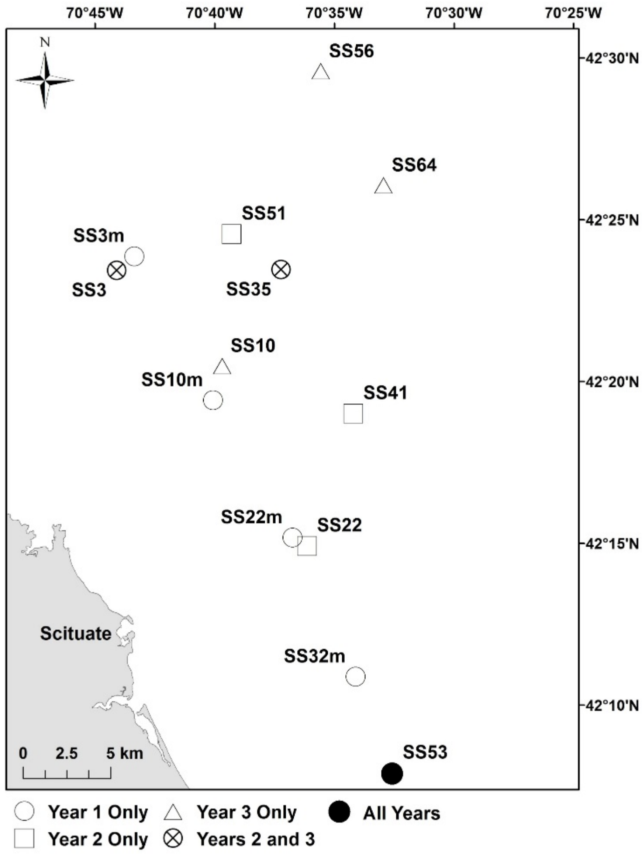


Figure 19: Composite years 1,2,3 MARU locations

MARUs were deployed each year in locations where cod grunts were recorded in previous years to ensure recording of these events, if they repeat as well as areas that the gliders had found cod. Five of six available MARUs were deployed by MADMF and NOAA staff on September 14, 2015. One MARU had issues with the power line and was returned to Cornell for a replacement. The replacement was deployed from the *F/V Sarah Ann* on October 7, 2015. All six MARUs were recovered in mid-February 2016. The MARU at SS56 experienced a power failure during deployment and did not record for the entirety of the survey period. It did however burn on its burn timer and was retrieved by Bill Hoffman on the *R/V Michael Brandon* on February 19, 2016.

3.4 Spawning Site Monitoring (Gliders)

Mobile autonomous gliders were deployed in Years 2 and 3 in order to survey Massachusetts Bay and expand upon the coverage of the fixed station deployments. Webb Slocum gliders (some funded outside this grant) were used through a contract with the Woods Hole Oceanographic Institution (WHOI: PI - Mark Baumgartner). All gliders (Figure 20) were equipped with a Vemco VR2W acoustic receiver, internal and external hydrophones (continuous 2000 Hz sampling rate), data storage drives, and oceanographic sensors (salinity, pressure, temperature, and chlorophyll) (see Baumgartner and Fratantoni 2008 for further details on sensors).

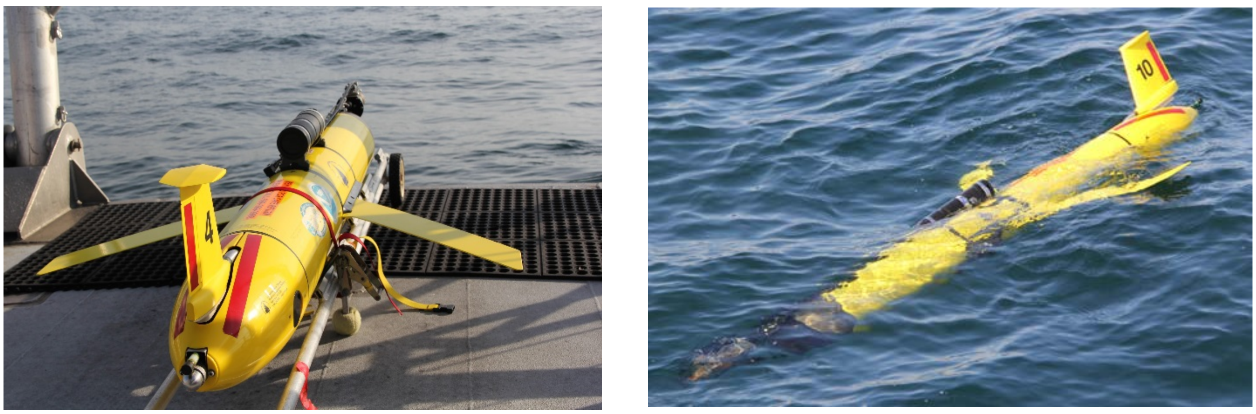


Figure 20. Images of Slocum glider deployments in Massachusetts Bay with an internal hydrophone for passive acoustic recordings and externally mounted VR2W Vemco acoustic telemetry receiver. © The Nature Conservancy (C. McGuire)

In Year 2, two autonomous gliders (model numbers: we04, we10; http://dcs.whoi.edu/sbnms1214/sbnms1214.shtml) were deployed from the *R/V Auk* (Stellwagen Bank National Marine Sanctuary research vessel) in December 2014 at the same start location, but with a 6 hr offset (Table 1). These gliders were programmed to follow the same tracks, which were designed based on the peak spawning season and locations observed in preliminary Year 1 results (Figure 21). These gliders were offset by 6 hr in an attempt to survey the same areas during day and night. One glider (we10) was retrieved mid-survey by a well-intentioned lobsterman on December 13, 2014 and redeployed from the *R/V Auk* December 15, 2015. Both gliders were recovered on December 22, 2014.

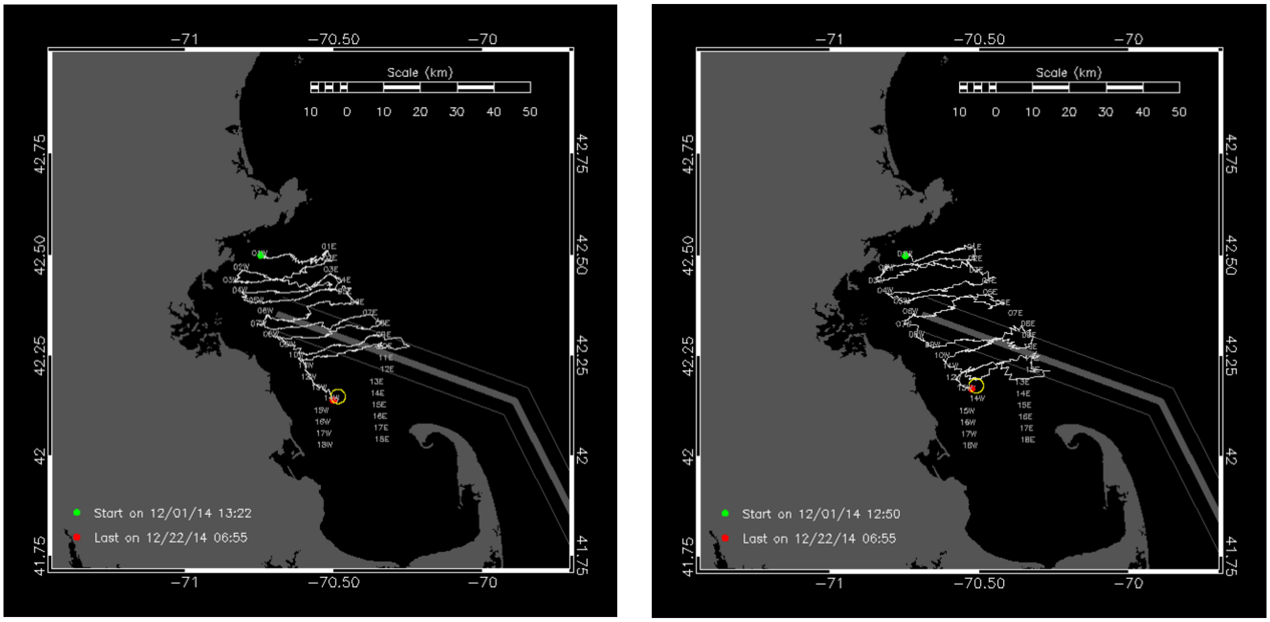


Figure 21: Year 2 glider tracks, we 04 (left) and we10 (right)

In Year 3, three autonomous gliders (model numbers: we04, we10, we03; http://dcs.whoi.edu/sbnms1115/sbnms1115.shtml, http://dcs.whoi.edu/sbnms1215/sbnms1215.shtml, http://dcs.whoi.edu/sbnms0216/sbnms0216.shtml) were deployed with the *R/V Auk* to survey Massachusetts Bay near-continuously from November 2, 2015 through March 1, 2016 (Table 1). The three glider deployments in Year3 were also completed with our collaborators at the WHOI (Figure 22).

These gliders were programmed to follow the same tracks, but were modified to cover a broader area than the gliders in Year 2 and the fixed station deployments based upon preliminary results from the first two project years. Collectively, these gliders in Year 3 completed five full North to South surveys of the study area.

Figure 22: Year 3 glider tracks. we04 (top left), we10 (top right) and we03 (bottom)

	Glider	Deployment	Retrieval	Duration(days)	Distance Travelled (km)
Year 2	we04	12/1/2014	12/22/2014	21	403
	we10	12/1/2014	12/22/2014	21	399
Year 3	we04	11/2/2015	12/7/2015	35	588
	we10	12/7/2015	1/25/2016	49	855
	we03	2/2/2016	3/1/2016	28	522

Table 1:Glider deployment dates, duration, and distance travelled.:

3.5 Data Analysis

3.5.1 Acoustic Telemetry

The acoustic telemetry dataset was first reviewed to remove fish considered to have died as a result of the capture and tagging procedure. Failure to account for these individuals can significantly bias results, as their lack of movement could be falsely interpreted as an area of high spawning activity. Fortunately, the large extent and long duration of the receiver array made it relatively simple to identify mortalities. Any fish that was consistently detected at a single acoustic receiver over its last month or more of detection was considered to be dead. In most cases, dead fish were detected at a single location for multiple years because all tagging occurred only in the first two of three field seasons. Some fish likely died soon after tagging, but were not detected until the array was expanded in the third year; however, due to a lack of detection in the tagging year it is not possible to say when or how the fish died (i.e., tagging-induced, natural, or fishery mortality). Regardless, these data were omitted and the description of spawning activity was restricted to live fish that displayed some amount of movement.

The spatial distribution of tagged fish was described using a Brownian bridge movement model (BBMM). This technique was originally developed for datasets where individual animal trajectories are comprised of a sequence of unique positions with known or estimable precision, such as GPS transmitters (e.g., Horne et al., 2007) or acoustic telemetry positioning systems (e.g., Dean et al., 2014). In contrast, the individual trajectories in our dataset are made up of a sequence of observations at fixed receiver locations, with the detection range representing the location precision. Given that our receivers were spaced far enough apart ($\underline{x}$ = 2.8 km) to prevent simultaneous detection at multiple receivers, any sequence of observations at different receivers represents movement (i.e., a transit from the detection radius of one receiver to the next). As such, the BBMM approach is also relevant to these data. This model requires two parameters: mean location error (δ), and Brownian motion variance (σ_m^2), which is related to animal mobility. The location error parameter was estimated from a previously published dataset that used identical tags and receivers to record the movements of spring spawning cod in a nearby portion of Massachusetts Bay (Dean et al., 2014). In that study, an acoustic telemetry positioning system allowed for estimating tag positions with high precision (3 m position error) via hyperbolic positioning. The δ parameter was calculated to be 740 m using the mean distance between estimated tag positions and a known receiver position (i.e., when within range of that receiver). The Brownian motion parameter was then estimated via maximum likelihood from the raw tag trajectory data. This was done separately for males (σ_m^2= 1.90) and females (σ_m^2= 1.01), as previous work revealed that the movement and space use of spawning cod is strongly influenced by sex and diel period (Dean et al., 2014). Separate estimates for day and night were not pursued because the spatial resolution of the array was too coarse to reliably resolve sub-daily patterns in movement.

Once estimates for the two parameters were obtained, the BBMM was used to predict utilization distributions (UDs), which are two-dimensional probability distributions for locating a tagged individual over a given period of time. To describe the patterns in individual space use, the area encompassed by the 95% probability contour (i.e., UD_{95} or "home range") was extracted from each UD. To describe the spatial distribution of the spawning aggregation as whole, a composite UD was created by averaging individual fish UDs, weighted by the number of days detected.

The acoustic telemetry detection data generated by these glider surveys were treated in an identical way to the fixed station data: detections from dead fish were first removed, and the BBMM was used to predict individual fish UDs, which were then assembled to create composite UDs for each year.

3.5.2 Passive Acoustic Monitoring

Through a contract with JASCO Applied Sciences, an automated detection algorithm for Atlantic cod grunts was developed and delivered in early 2015 and has made a dramatic difference in the research team's ability to process the passive acoustic data for cod grunts. It is difficult to quantify the exact performance (in terms of accuracy) of the detector since there is no precise count of cod grunts for comparison with the detector output. The detector appears very successful at indicating times of no grunts, which can dramatically reduce review time by analysts down to 1-3 minutes per day per recorder (depending on the number of detections) as the analyst is pointed to times in the data with cod-like sounds. Without the detector, the data had been subsampled to eight 1-hour periods in which the first 10 minutes of these 8 hours were browsed in order for the data to be processed in 8 analyst hours. With the detector, the dataset does not need to be subsampled, and depending on the number of detections, in 8 hours an analyst can review on average 5 days of data containing 5 recorders (total= 25 recorders). As a result of this effort a publication describing the software and its performance was published as Urazghildiiev and Van Parijs (2016). This detector is being used beyond this project and is being run through long term existing records of passive acoustic data to examine sites in Massachusetts Bay, as well as in data collected throughout the entire Gulf of Maine and south of Nantucket between 2006 to current dates in order to look for evidence of spawning activity of Atlantic cod in all of these records.

Detections classified as cod grunts were manually verified using Raven Pro 1.5 (Bioacoustics Research Program, 2014). Detections were viewed in a 5x5 spectrogram grid adjacent to a context spectrogram (Figure 23). Detections in the grid were viewed from 10-400 Hz using a fast Fourier transform (FFT) of 256 points and 75% overlap, a one second time pad, and brightness of 55 and contrast of 74. The context spectrogram was viewed at a 10 s time window with a FFT of 1024 points and 75% overlap from 0-500 Hz. Brightness was set at 61 and contrast at 60.

A maximum of 2,000 detections per day were verified by an analyst to limit the time spent per

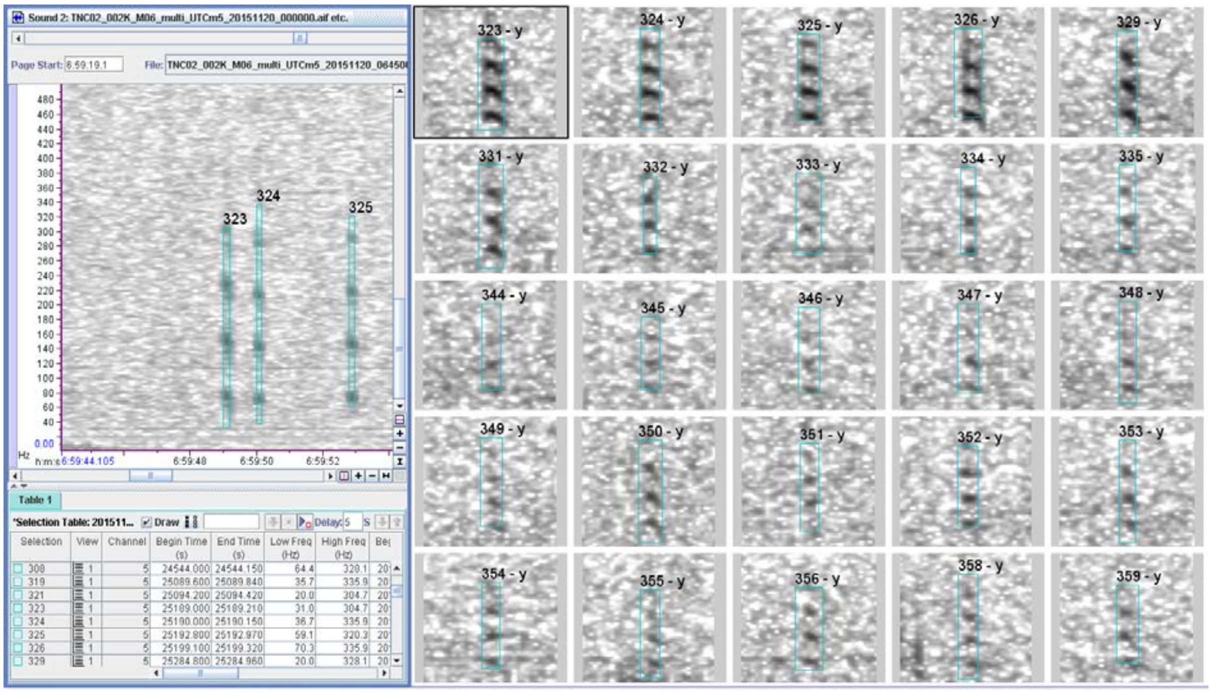


Figure 23: Cod grunts as viewed in Raven Pro 1.5 where the context spectrogram containing detections viewed in a 10 s page window is shown on the left, and the linked 5x5 spectrogram grid each containing one detection in a ~1 s window is shown on the right. True positive detections have been labeled in the grid with a "y". Note the presence of 2-3 harmonics in most of the grid cells.

day of data. If a day exceeded that maximum number of detections, 2,000 detections were randomly extracted for verification by an analyst. The number of true positives as identified by the analyst (TP_V) was then used in the ratio in Equation 1 to extrapolate how many cod grunts (TP_E) would be in the total sample (TS).

$$TP_E = (TP_V * TS)/2000. \qquad \text{Equation 1}$$

Atlantic cod grunts in the Gulf of Maine have a fundamental frequency of ~47.5 Hz, and can have 2-8 harmonics depending on the proximity of the fish to a receiver (Hernandez et al., 2013). All detections with two or more harmonics in the correct frequency bands were visually accepted as cod grunts, but detections with one or no harmonics (just fundamental) were further assessed aurally. If the detection was audible and sounded like a cod grunt, then it was accepted, otherwise it was marked as a false positive. Data from MARU deployments were examined for possible lunar trends in the frequency of cod calls from periods when subsampling occurred. Subsampled true positive detections from these deployments were grouped according to lunar phase (i.e., new, first quarter, full, third quarter) based on data from: https://www.timeanddate.com/moon/phases.

Passive acoustics data from glider surveys were also passed through the custom built cod grunt detector in Matlab and reviewed in Raven Pro 1.5. Glider data review deviated from MARU data review only in brightness and contrast values to compensate for the difference in data acquisition. Two gliders from Year 3 (we04 and we10) contained enough detections to observe the depths of the glider at which Atlantic cod were detected. The depth of the glider that was closest to the time of the positively identified cod grunt was extracted. In the case that two times were equidistant from the grunt, the time following the grunt was used. It should be noted that the depth at which the glider detected the grunt does not equate to the depth where the grunting cod was.

4. Results

4.1 Tagging

As part of the pilot work in Year 1, a total of 155 cod were tagged with acoustic transmitters within or along the eastern edge of the acoustic receiver array (n=46 on 12/14/13, n=39 on 12/17/13, n=34 on 12/19/13, n=35 on 1/10/14). There were 83 males (n=32 Ripe, n=51 Ripe & Running) and 72 females (n=20 Developing, n=43 Ripe, n=7 Ripe & Running, n=2 Spent) tagged in Year 1 (Figure 24), with an average length of 67.3 cm +/- 7.8 cm (Figure 25).

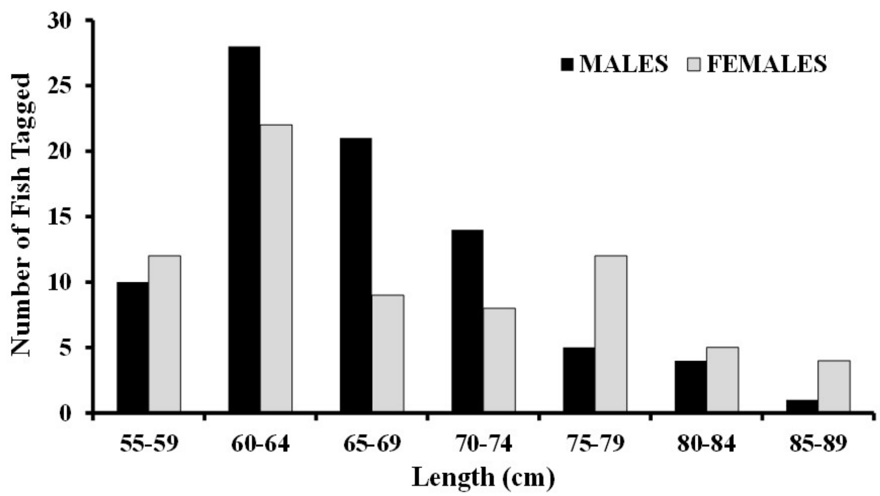


Figure 24: Length distribution of cod tagged with acoustic transmitters in year 1.

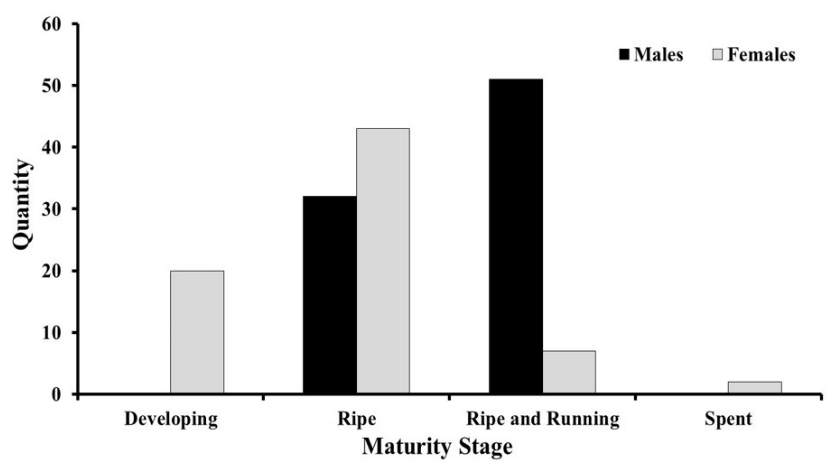


Figure 25: Maturity distribution of cod tagged with acoustic transmitters in year 1.

Using NOAA funding, a total of 162 cod were tagged during Year 2, including 85 males (n=20 Ripe, n=65 Ripe and Running) and 77 females (n=31 Developing, n=36 Ripe, n=10 Ripe & Running) (Figure 26). The mean length of fish tagged with acoustic transmitters in Year 2 was 67 cm +/- 8 cm (Figure 27).

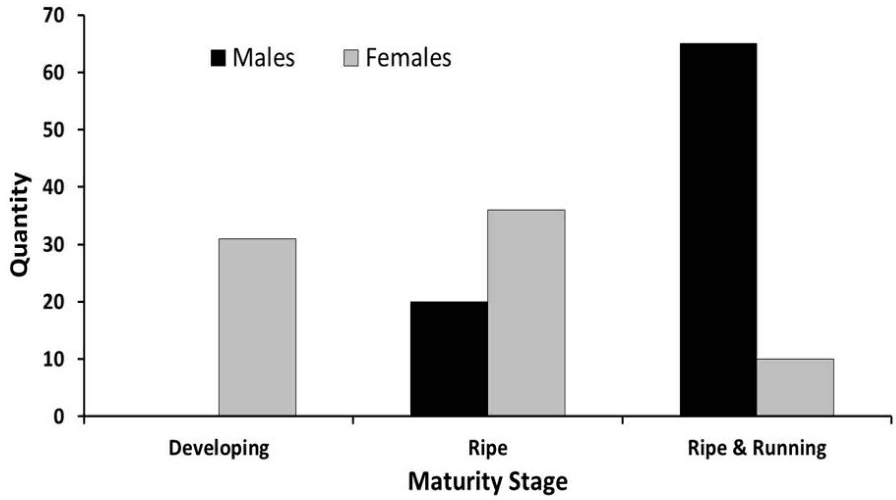


Figure 26: Maturity distribution of cod tagged with acoustic transmitters in year 2.

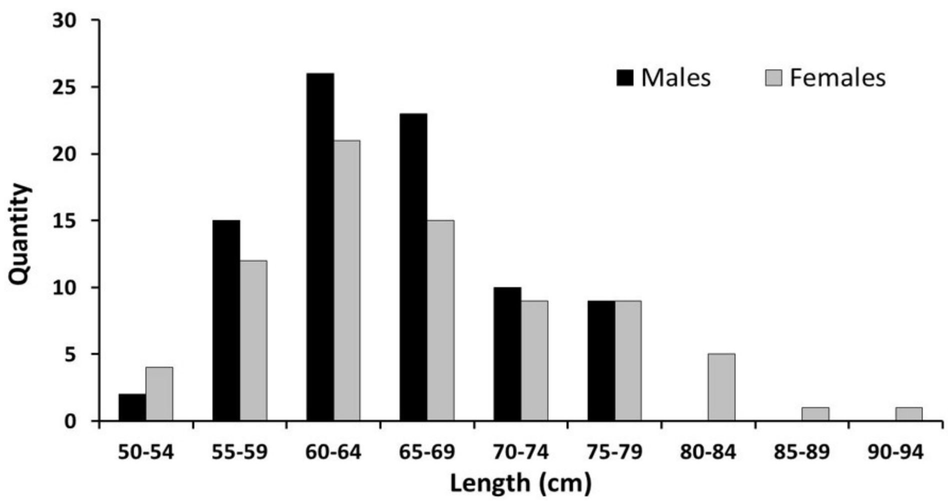


Figure 27: Length distribution of cod tagged with acoustic transmitters in year 2.

4.2 Acoustic Telemetry (Fixed Stations)

Temporal:

Of the 317 cod tagged with acoustic transmitters during this project, 17 (5%) were presumed to have died based on a consistent lack of movement over the last month or more of detection (Table 2; Figures 28,29). Six of these fish appeared to die soon after release and were consistently detected at a single station for multiple years. Four fish that were presumed dead went undetected in their release year, but were later detected continuously at a single station when the array was expanded in subsequent years. The remaining seven presumed dead fish were apparently alive in the year of their release (detected at multiple stations), but were detected continuously at a single station in subsequent years. In total, 53% of the total recorded detections came from fish that were presumed dead.

			# Fish Detected (alive fish)			# Detections (alive fish)		
Tag Year	# Tagged	# Died	Y1	Y2	Y3	Y1	Y2	Y3
Y1	155	8	68	26	15	69717	52433	67966
Y2	162	9		126	60		113046	406408
Total	317	17	68	152	75	69717	165479	474374

Table 2. Summary of tagged fish detections by the fixed acoustic telemetry array.

A total of 51% of the tagged fish released in Year 1 were never detected by the array in Year 1. Most of these fish were released just outside of the array, near the end of the spawning season (January 10, 2014). The modifications and expansion of the array in Year 2 improved its detection efficiency, with only 17% of the fish tagged in that year going undetected.

Of the tagged fish released in Year 1 that were not presumed dead, 20% were detected returning to the spawning area in subsequent years (18% Y1-Y2; 50% Y2-Y3). For the tags released in Year 2, 39% were detected returning in Year 3. Collectively, the increasing rate of returning fish is likely the result of the increase in array detection probability and/or a decrease in mortality over the course of the project. Both explanations are likely given the array improvements, quota reductions, and fishery closures enacted between Year 1 and Year 3.

	Median Arrival Date	Peak Date	Median Departure Date	Median Residence Time	Median Days Detected
Year 1			Jan 04		
Year 2	Nov 21	Nov 27 - Dec 11	Dec 13	15	11
Year 3	Nov 11	Dec 12	Jan 15	59	30
All Years	Nov 12	Dec 11 - 12	Dec 23	42	21

Table 3. Summary of the seasonality of presence of tagged fish in the telemetry array. All values are calculated from returning fish only, except for departure date, which includes the release year as well.

The median arrival date (date of first detection) of returning fish was similar (Table 3) between Years 2 and 3 (t-test: p=0.069; df=99). However, it should be noted that some fish were already present in the area when the receiver array was deployed in each year (3 fish in Year 2; 1 fish in Year 3). If data from the release years are included, the median departure date (date of last detection) from the array was several weeks earlier in Year 2 than in Years 1 or 3 (Y1-Y2 *t*-test: p<0.001; df=218; Y2-Y3 *t*-test: p<0.001; df=225). The date when the largest number of returning tagged fish were present in the array was similar between years, although there were two "peak dates" in Year 2, separated by two weeks (Table 3, Figures 30, 31). The median residence time (departure date minus arrival date) in Year 3 was four times greater than in Year 2 (*t*-test: p<0.001; df = 99), which is likely related to the increase in array size and detection efficiency in Year 3. Tagged fish periodically went undetected during their time in the spawning area, with the typical fish having no detections on half of the days during its residency period. This is likely related to the incomplete coverage of the spawning area in Years 1 and 2, and the ~25% detection efficiency of the array in all years.

The coverage of the spawning area, the number of returning tagged fish, and the amount of data per fish were all at a maximum in Year 3. Therefore, data from this year should be considered the most accurate and complete representation of spawning activity in this area. Considering this, it appears that while a typical fish might spend 2 months on the spawning ground, there were fish present over the entire 6 month period with 77% of the 75 returning tagged fish in Year 3 present outside of the current November to January closure period. However, only 12% of year 3 detections occurred outside the closure months, indicating that most of the spawning activity was encompassed by the closure window.

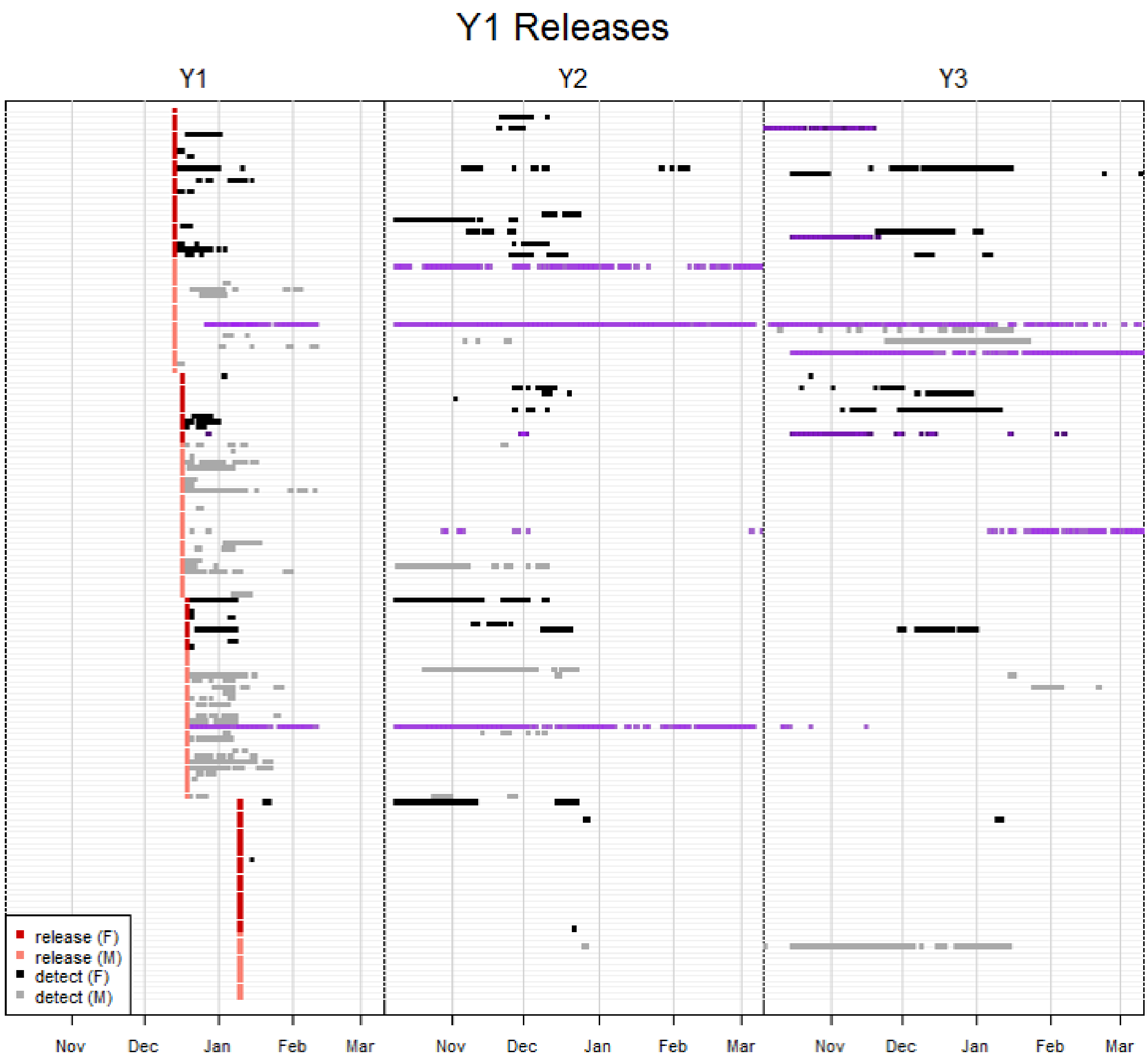


Figure 28. Detection history plot for tags released in Year 1 (each row represents an individual fish). Red marks identify the date of release; Male and female detections are identified by black and gray marks, respectively. Purple marks identify fish that were presumed dead.

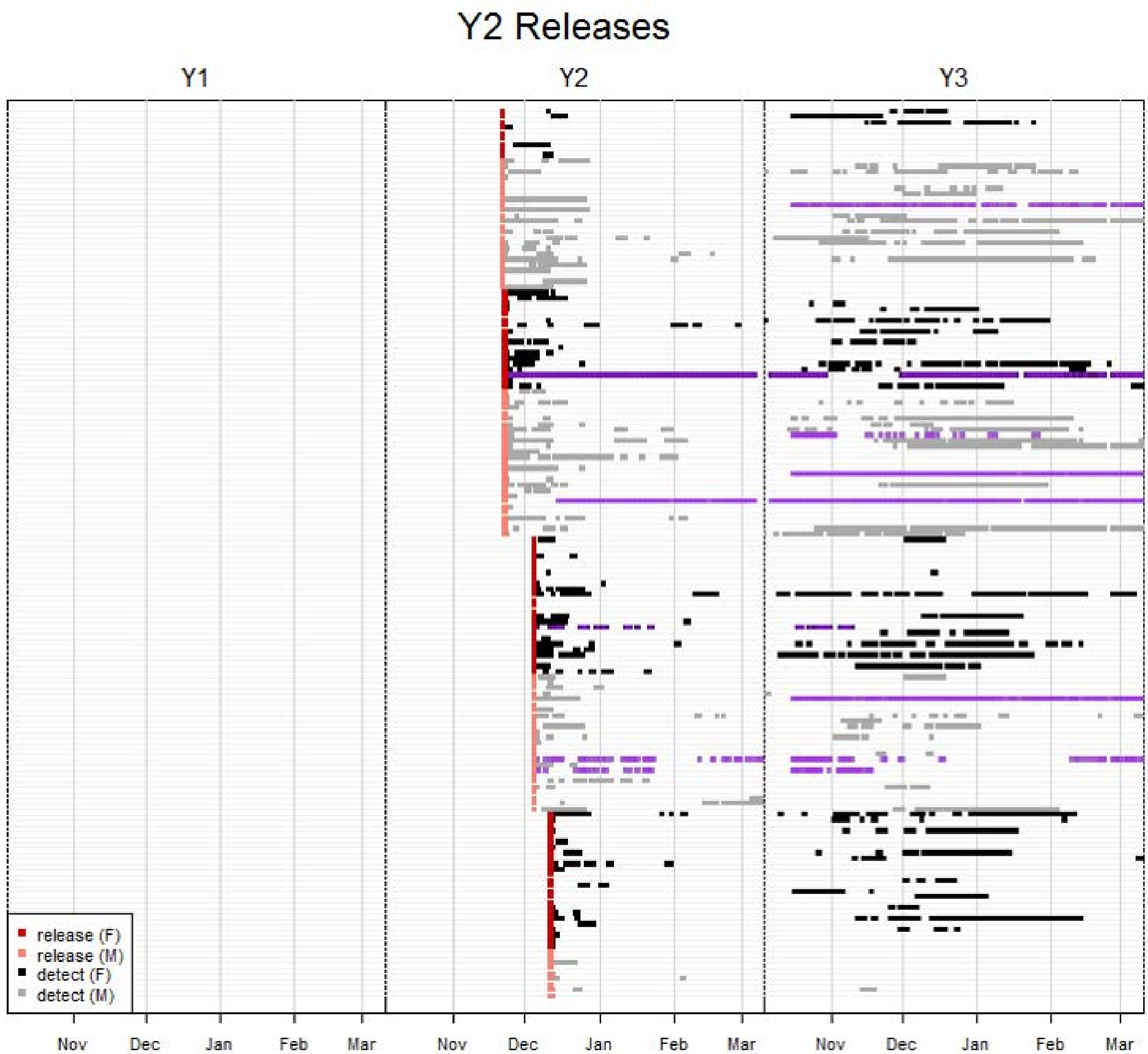


Figure 29. Detection history plot for tags released in Year 2 (each row represents an individual fish). Red marks identify the date of release; Male and female detections are identified by black and gray marks, respectively. Purple marks identify fish that were presumed dead.

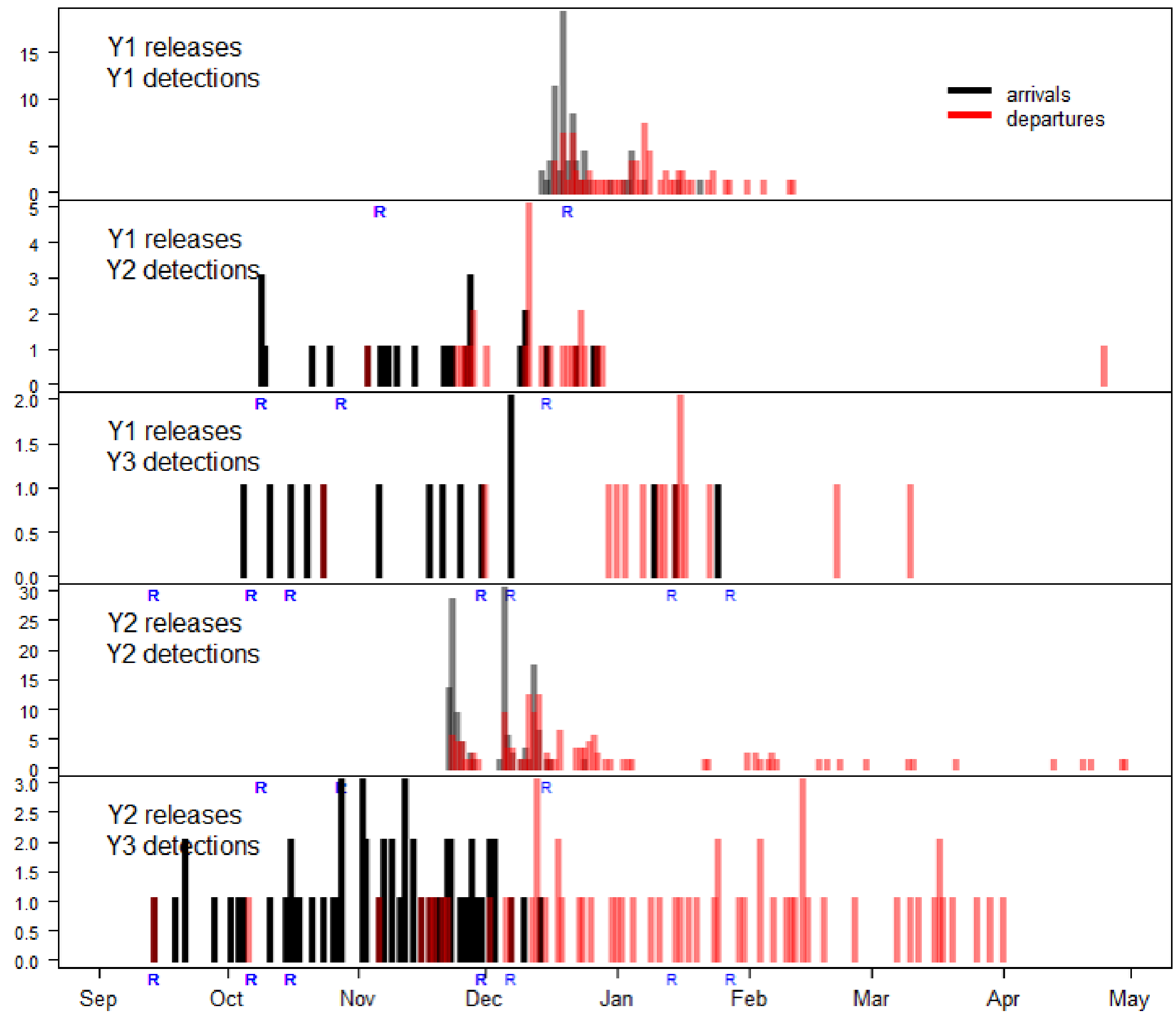


Figure 30. Arrival and departure dates for tagged fish, grouped by tag release year and detection year. Gray bars indicate the date of first detection in the year of release, whereas black bars indicate the date of first detection in following years. Red bars indicate the last date of detection.

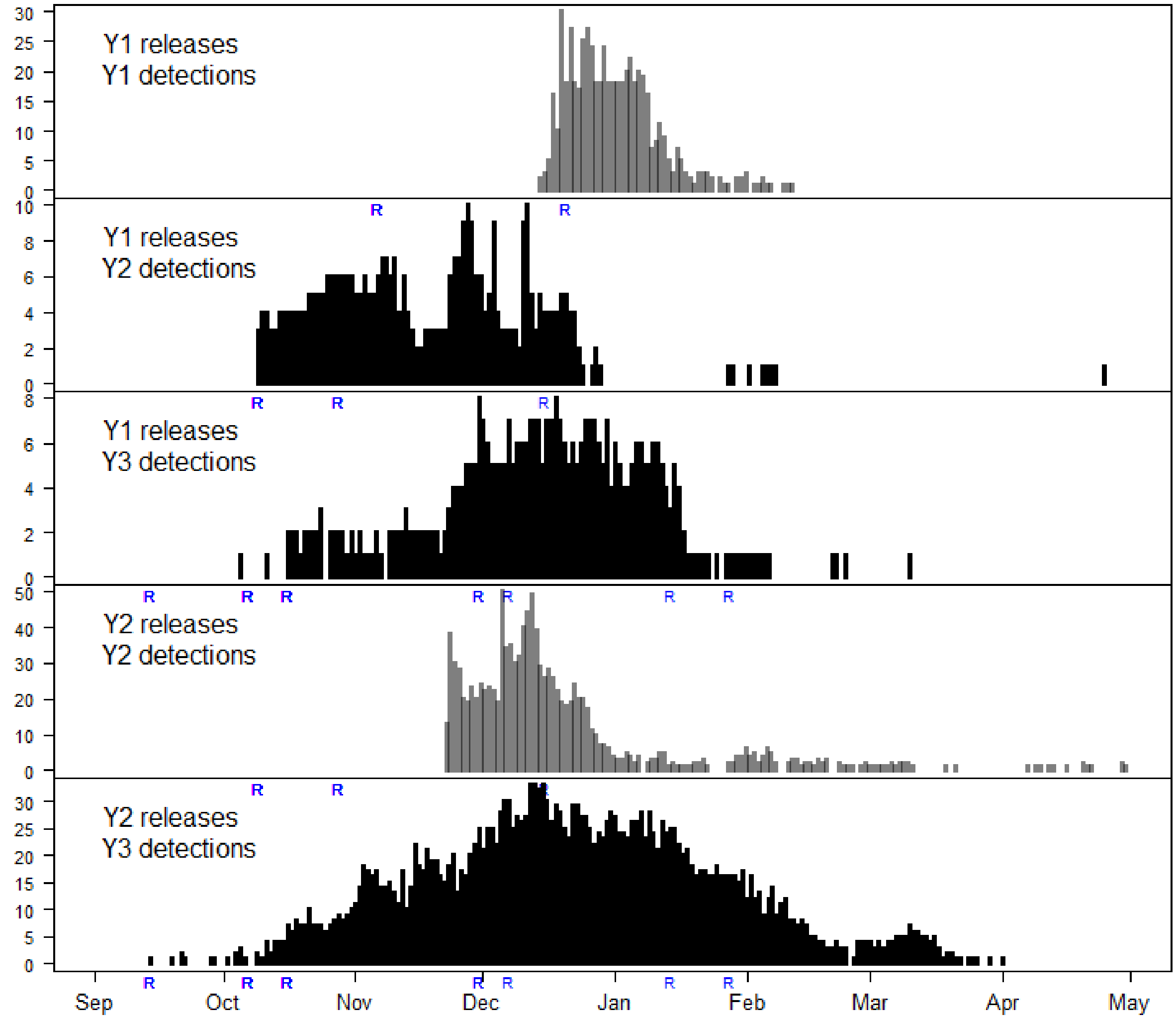


Figure 31. Total number of tagged fish present in the telemetry array by date, grouped by tag release year and detection year. Gray bars represent detections in the release year, whereas black bars represent detections of tagged fish from returning to the array from previous year. Receiver deployment dates are indicated by a blue "R".

Spatial:

In the first and second years, the stations with the greatest number of detections were located near the center of the array, just south of the LNG terminals. However, the stations that detected the greatest number of unique fish were located at the northeastern edge of the array in both of these years. Due to a concern that our telemetry array was missing a key portion of the spawning area, the array was expanded each year in that direction, maintaining an approximate 3 km receiver spacing. The array in Year 3 appeared to provide the most complete coverage of the spawning activity, as evidenced by a six-fold increase in the detections per fish (Table 4). While the station that detected the greatest number of unique fish in Year 3 was better contained within the array (i.e. not at the edge) than in previous years, the greatest number of detections was at the northeast edge, just off the northwest corner of Stellwagen Bank. In all years, only a small percentage of tagged fish were detected shallower than the 50 meter isobath (Figure 32), and this area yielded an even smaller percentage of total detections (Figure 33). Seasonal change can be seen in the number of individual fish detected at station by month (Figure 34).

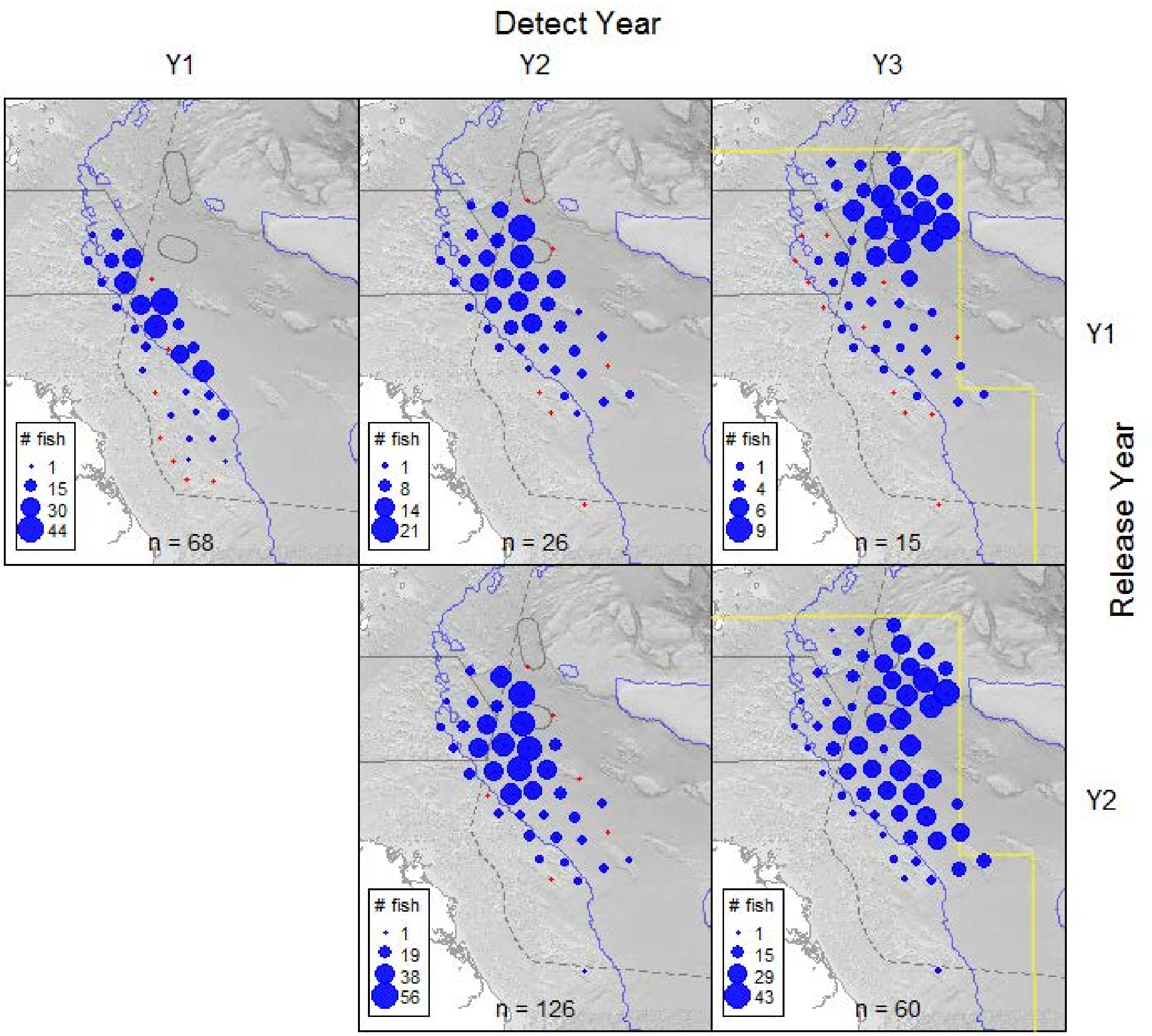


Figure 32: Total number of unique tagged fish detected at each station, grouped by tag release year and detection year. The yellow line indicates the boundaries of the seasonal fishery closure enacted during the course of the project ("seasonal cod protection measures" under Framework 53

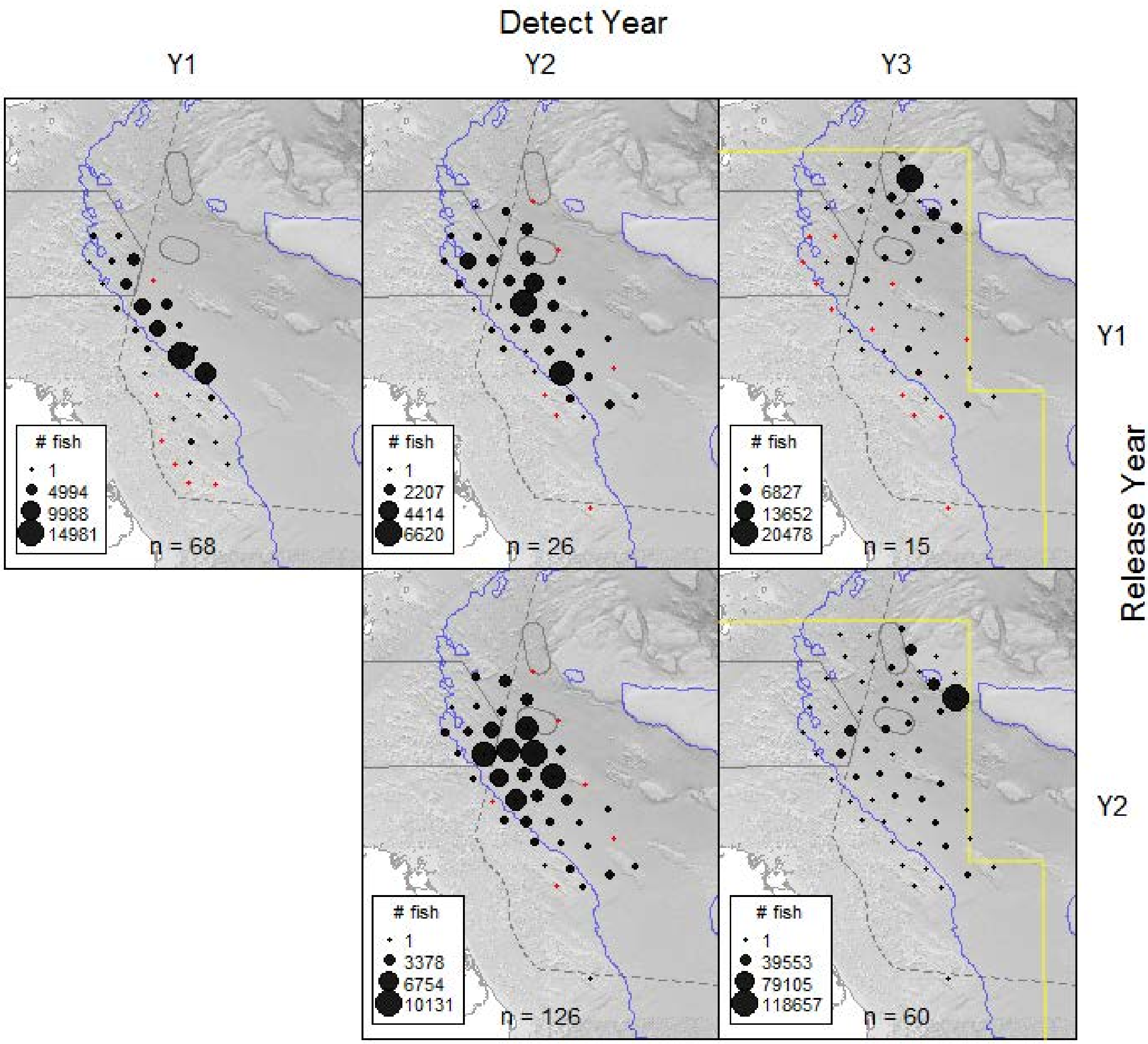


Figure 33: Total number of detections recorded at each station, group by tag release year and detection year. The yellow line indicates the boundaries of the seasonal fishery closure enacted during the course of the project ("seasonal cod protection measures" under Framework 53.

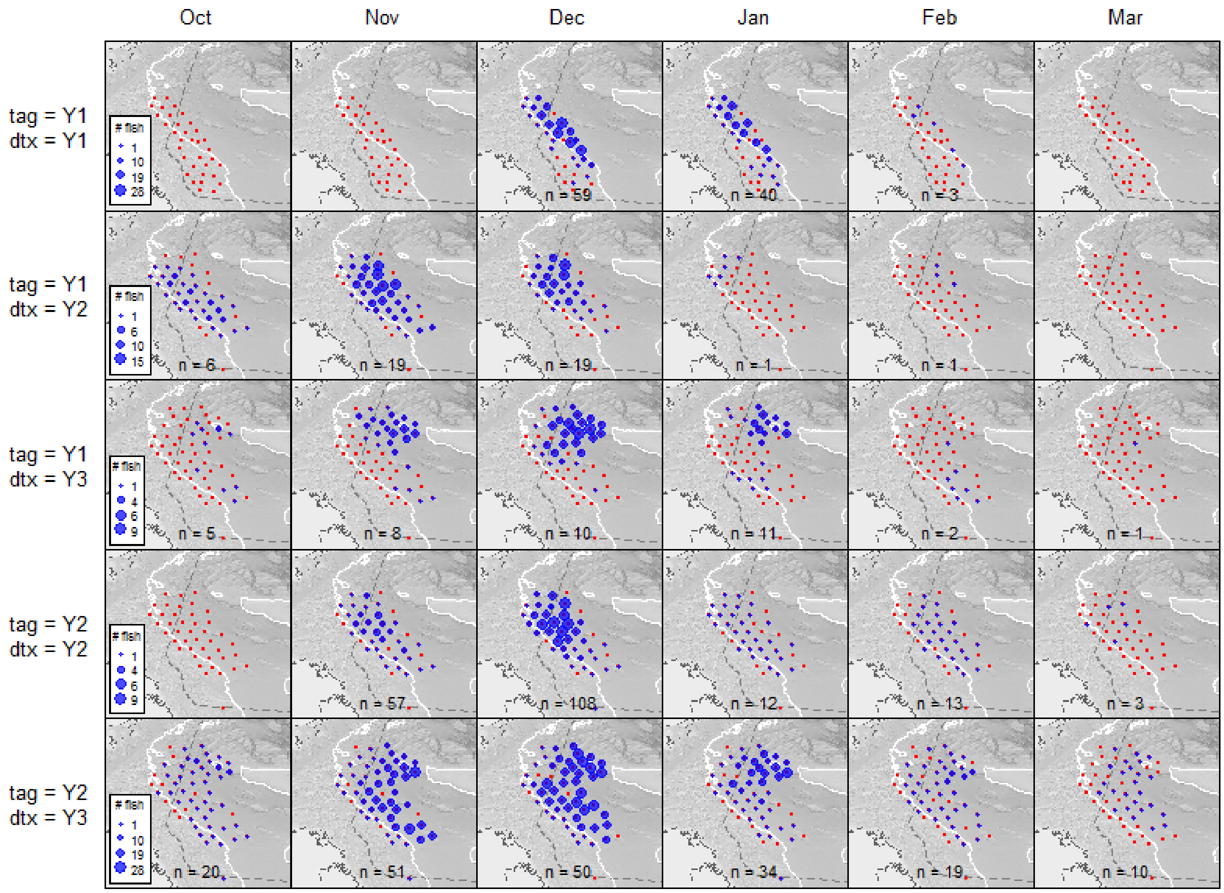


Figure 34. Total number of unique tagged fish detected at each station, group by tag release year, detection year and month. Red points indicate stations where no tags were detected.

It can be somewhat difficult to discern the general pattern of the spawning aggregation from "bubble plots" of either the number of fish detected (Figure 32) or the total number of detections (Figure 33), as the former does not account for the amount of time spent per station and the latter can be skewed by a single fish with limited movement. Furthermore, both metrics are vulnerable to differences in the number of days receivers were deployed. The composite UDs generated by the BBMM addresses each of these issues by using the information contained in the trajectories of individual fish (i.e., the sequence of stations they were observed at) to construct a continuous surface representing the intensity of space use. When the full dataset in each year is used to construct a composite UD, there is the appearance of substantial interannual variability in space use (Figure 35). However, this is likely a function of the differences in array design across years. When data from only those stations that remained consistent across years are used, there is little difference between the composite UDs (Figure 36). The composite

UD for the full array in Year 3 provides the most comprehensive view of the spatial pattern of spawning activity in this area. This view of the telemetry dataset suggests that the area just west of the northwest corner of Stellwagen bank was the primary focal point of spawning activity, with other lesser focal points inside the WCCZ and just east of the Neptune LNG terminal.

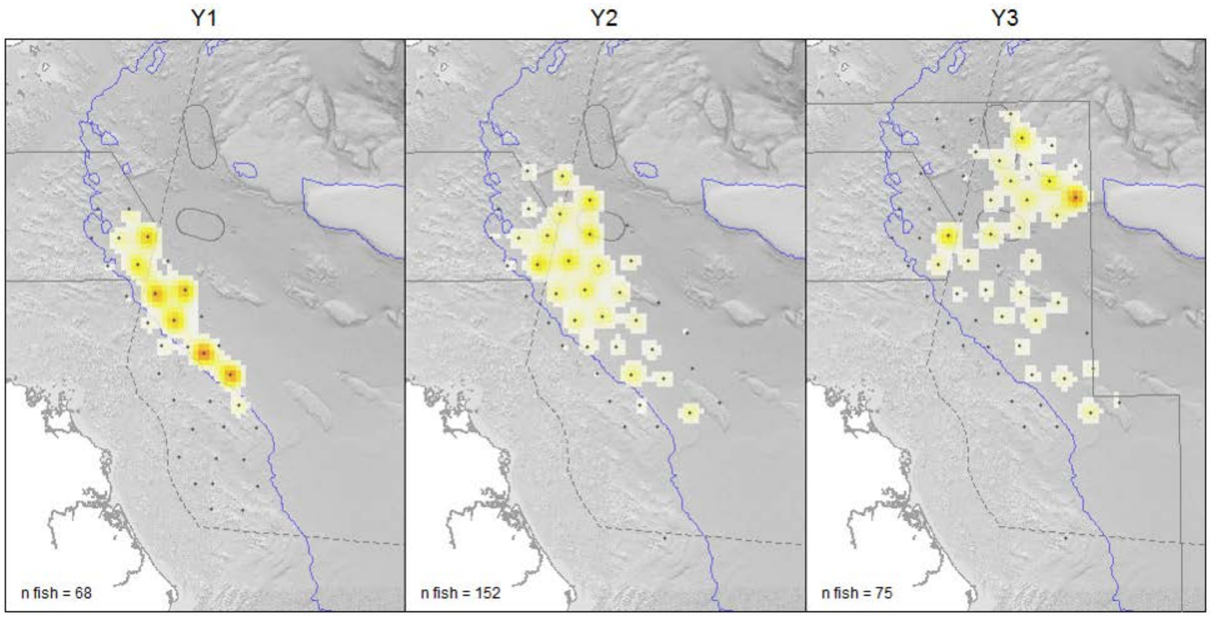


Figure 35: Aggregate utilization distributions (UDs) for each year, using all available data. Each UD represents the intensity of space use by tagged spawning cod. Darker colors indicate higher spawning activity.

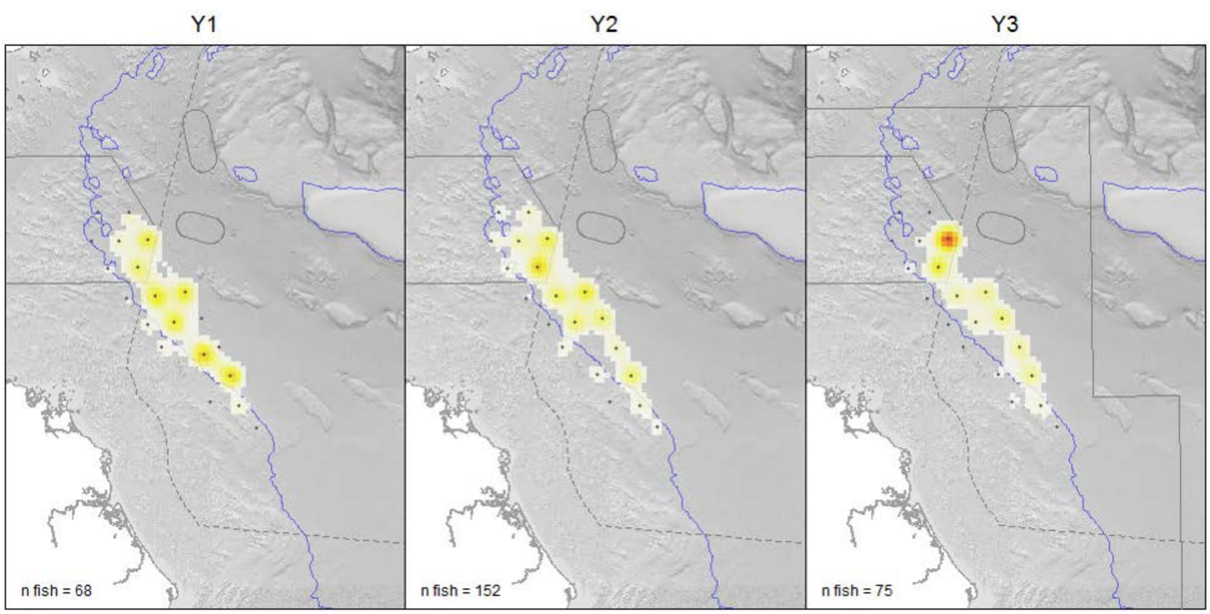


Figure 36: Aggregate utilization distributions (UDs) for each year, using only data from stations that remained consistent across all three years. Each UD represents the intensity of space use by tagged spawning cod. Darker colors indicate higher spawning activity.

4.3 Gliders

The gliders surveyed an approximate 1000 km^2 area, which is three to four times larger than the fixed telemetry array. On average, a glider covered a distance of 400 km in a single survey, which resulted in a detection area of approximately 600 km^2 (60% efficiency, assuming a detection range of 750 meters). Despite the gliders not monitoring any one particular location for very long, their broad-scale coverage proved to be effective at detecting whether or not a tagged fish was present within the spawning area. In most cases, more tagged cod believed to be alive were detected by the gliders than the fixed array, despite the gliders yielding only 1-2% of the detections per fish recorded by the fixed array (Table 4). The gliders also detected 13 of the 17 cod that were presumed to be dead, based on the analysis of fixed array data. These fish were detected at similar locations to their last fixed array detections, confirming their presumed mortality. In total, 34 fish were detected by the gliders that were never recorded by the fixed array (21 from Year 1 releases; 13 from Year 2 releases). While it is possible some of these fish could be mortalities, the roving nature of the glider surveys does not provide the continuous time series of observations at any given location necessary to infer mortality from a lack of movement.

	# Fish Detected				# Detections			
	Dead		Alive		Dead		Alive	
Tag Year	Y2	Y3	Y2	Y3	Y2	Y3	Y2	Y3
Y1	5	6	30	37	169	147	872	2201
Y2	4	7	57	70	147	297	1255	3490
Total	9	13	87	107	316	444	2127	5691

Table 4. Summary of detections of tagged cod by gliders, grouped by tag release year, detection year and whether the fish were presumed dead based on telemetry data from the fixed array.

Where and when they overlapped, the gliders and fixed telemetry array detected tagged cod in similar areas (Figures 37, 38, 39, 40). In Year 2, the majority of glider telemetry detections occurred outside the fixed array, particularly to the northeast. When the Year 3 fixed array was expanded in this direction, the spatial similarity between the glider and fixed array detections increased. However, Year 3 glider surveys still detected significant numbers of cod just to the north and east of the fixed array.

Most of the cod grunts recorded by the gliders were in areas frequented by tagged cod, with the exception of an area just west of central Stellwagen Bank. By examining each Year 3 glider survey in sequence, it appears the intensity of cod grunts correlates with the activity of tagged fish both seasonally and spatially (Figures 39, 40).

The composite UDs generated from glider telemetry data show a similar pattern in space use to that of the fixed array, only with a broader view; three areas of intensive space use stand out: along the northwest corner of Stellwagen bank, just outside the WCCZ and the Neptune LNG terminal (Figure 41). The southeastern and northwestern portions of the glider survey area saw little activity from tagged spawning cod. The spatial patterns evident in the glider composite UDs appear remarkably consistent between Years 2 and 3.

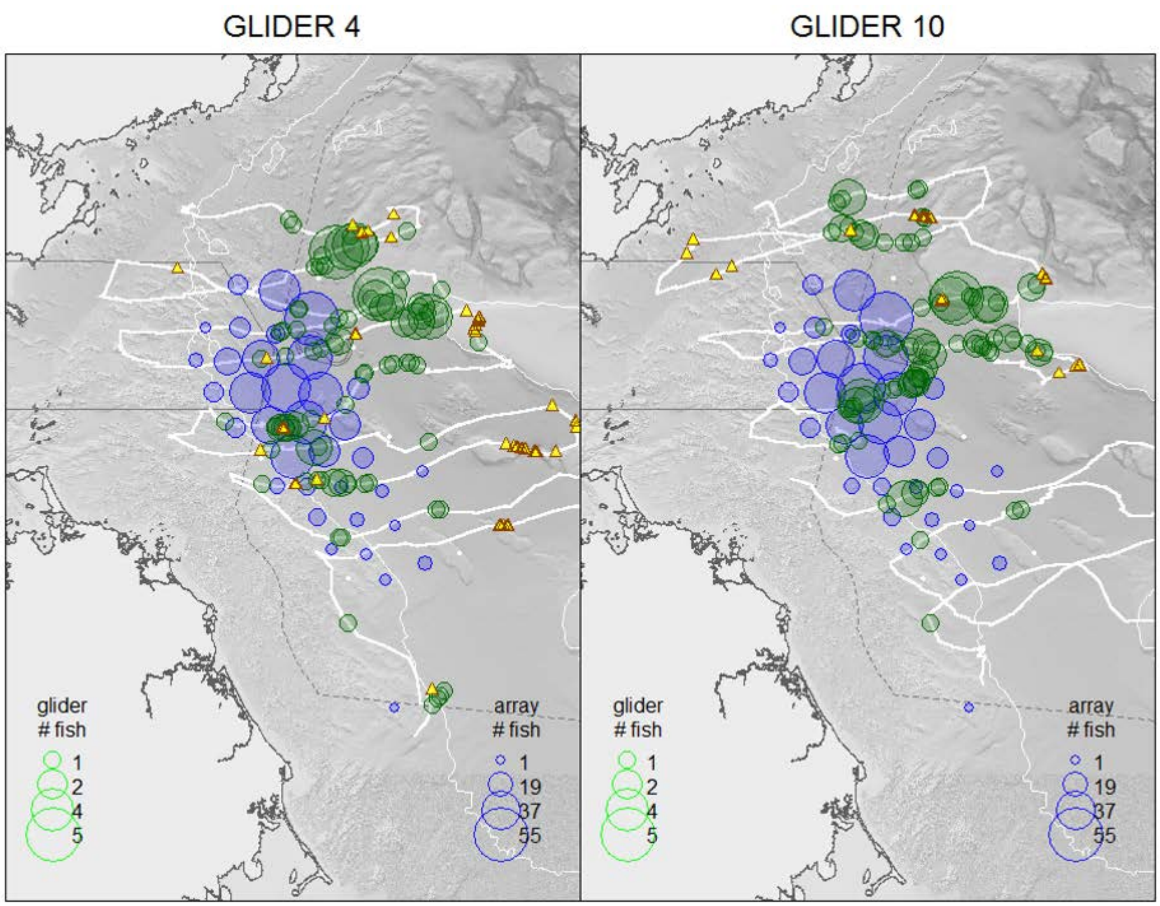
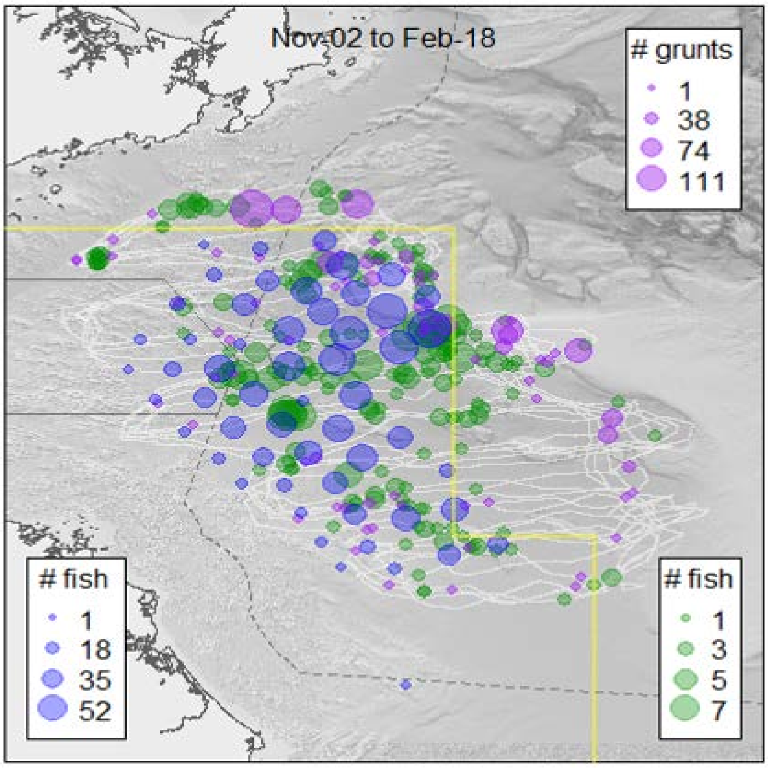


Figure 37: The number of unique fish detected in year 2 by the fixed station array (blue bubbles) and by each glider survey (green bubbles), as compared to the number of cod grunts recorded by each glider survey (yellow triangles). Both gliders operated concurrently from December 1, 2014 through December 22, 2014. Fixed telemetry array data were also restricted to these dates.



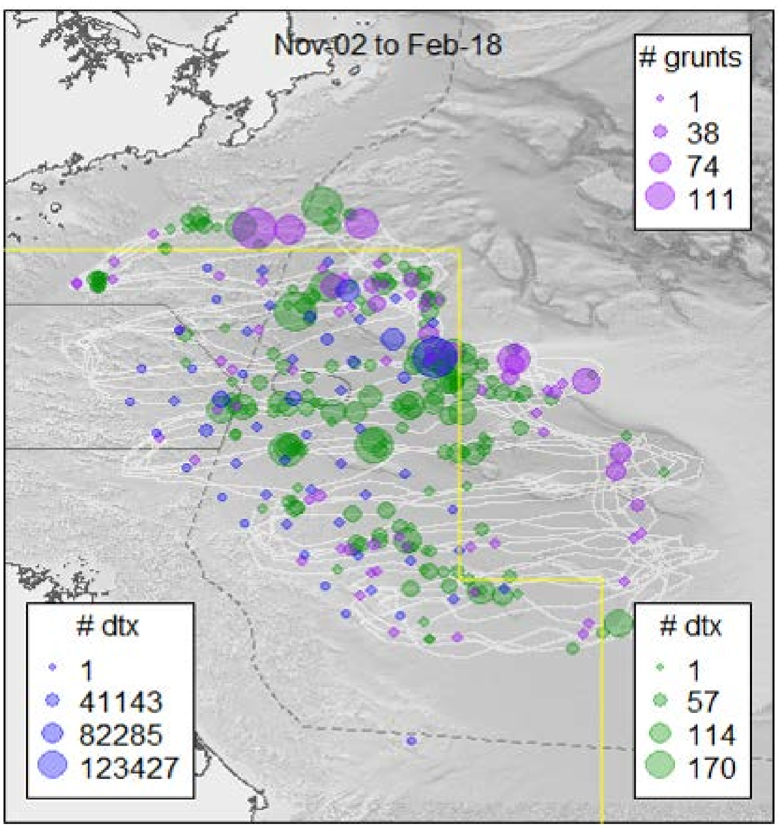


Figure 38: At left is the number of unique fish detected in year 3 by the fixed station array (blue bubbles) and all glider surveys combined (green bubbles). Below is an equivalent figure showing the total number of detections. In both panels, the purple bubbles represent the number of cod grunts recorded by the gliders. Data from gliders were summarized into six hour segments. Data from the fixed station array were subset to dates for which the gliders were deployed.

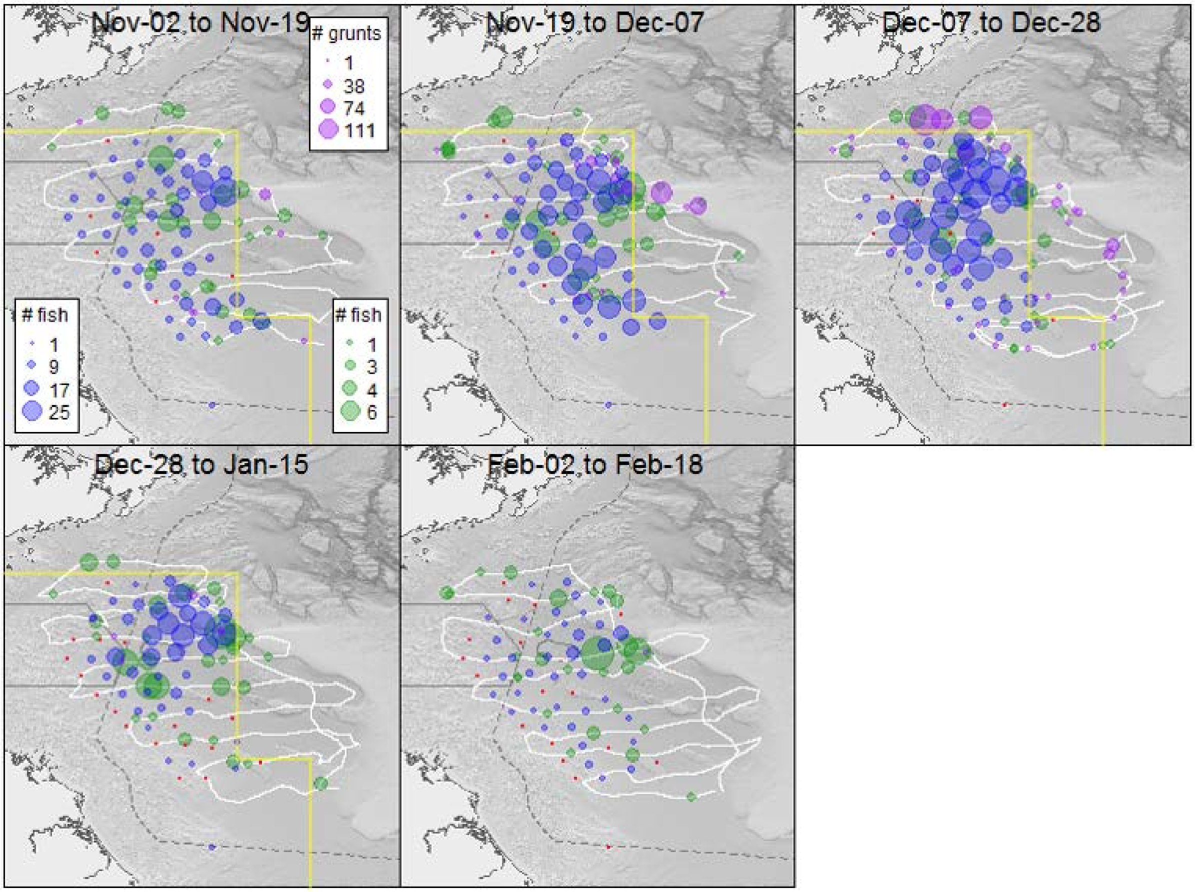


Figure 39: The number of unique fish detected in year 3 by the fixed station array (blue bubbles) and by each glider survey (green bubbles), as compared to the number of cod grunts recorded by each glider survey (purple bubbles). Data from the gliders were summarized into six-segments. In each panel, all datasets were restricted to the dates of that glider survey.

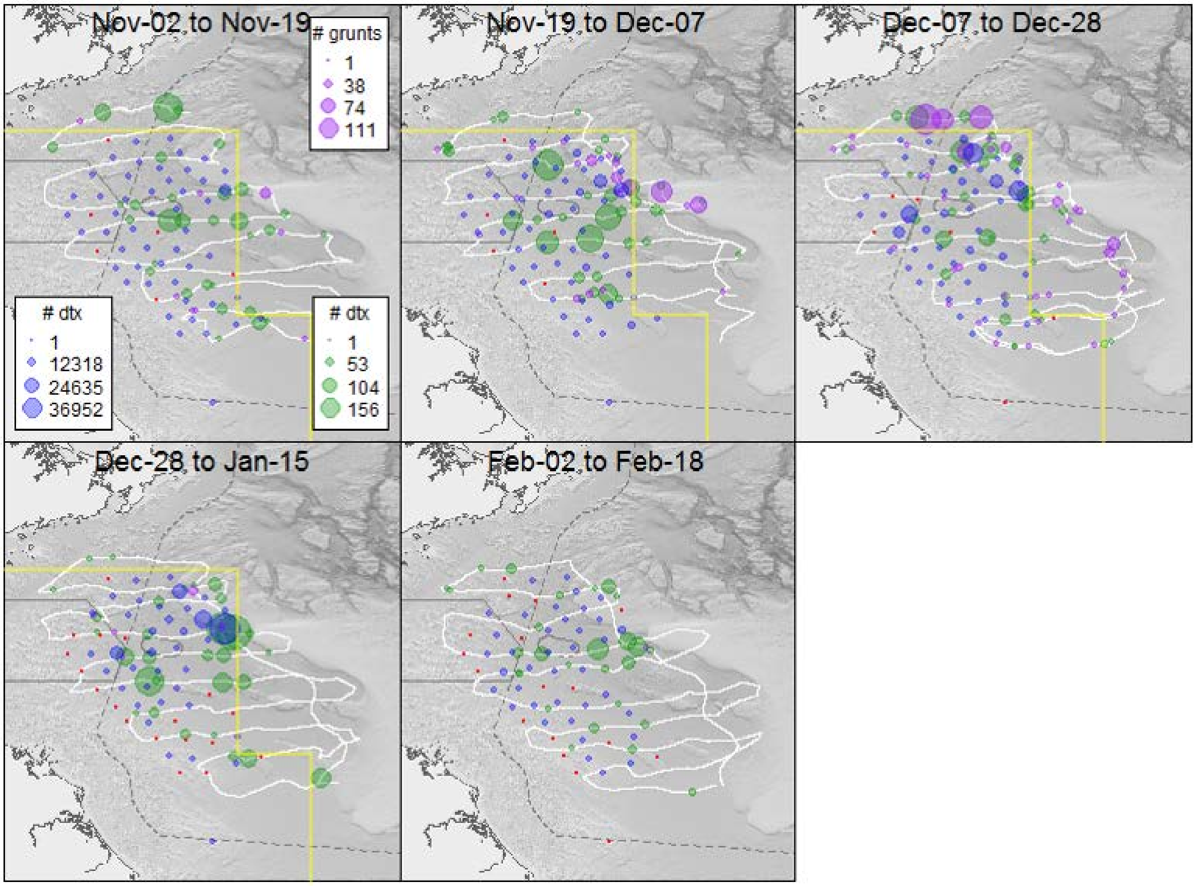


Figure 40: The total number of acoustic telemetry detections recorded in year 3 by the fixed station array (blue bubbles) and by each glider survey (green bubbles), as compared to the number of cod grunts recorded by each glider survey (purple bubbles). In each panel, all datasets were restricted to the dates of that glider survey.

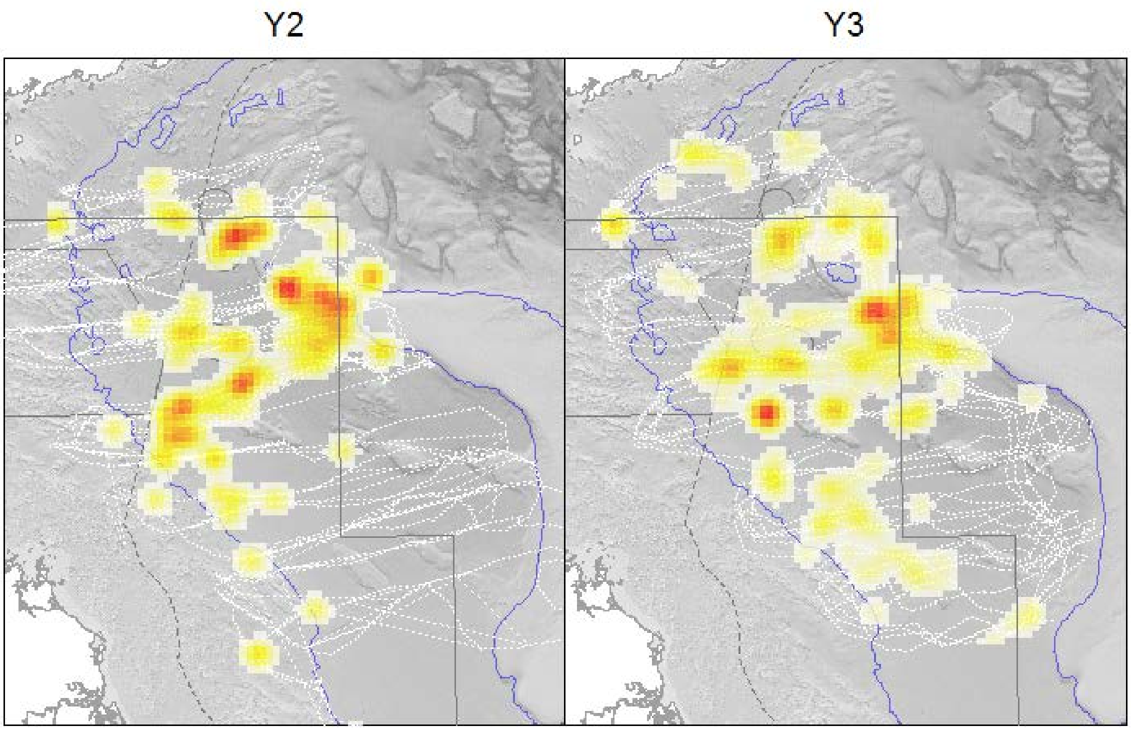


Figure 41: Composite utilization distributions (UDs) for each year, generated from glider telemetry data. Darker colors represent a higher intensity of space use. White dotted lines identify the glider track lines in each year.

Passive Acoustic glider analysis

A total of 126 of 19,331 passive acoustic detections were verified as cod grunts across both gliders in Year 2 (we04, n = 81; we10, n = 45). Most of the detections in Year 2 occurred within Stellwagen Basin and the Northwest Corner of Stellwagen Bank (Figure 37). No obvious temporal pattern was evident in Year 2 ($we04_{Day}$= 34 grunts, $we04_{Night}$= 47 grunts; $we10_{Day}$= 34 grunts, $we10_{Night}$= 11 grunts). In Year 3, 912 of 54,052 detections were verified as cod grunts across all three gliders (we04= 330, we10= 581, we03= 1). A peak of detections (n= 177 grunts) occurred on November 29th that was 1.8 km southeast from SS64 along Stellwagen Bank. A secondary peak occurred on December 12th (n= 140 grunts), with cod grunts normally distributed $\pm$ 2 days around the peak along Stellwagen Bank up into one of the northernmost tracklines near Gloucester (Figure 42). More grunts were detected at night than during the day on both we04 and we10 in Year 3 ($we04_{Day}$= 129 grunts, $we04_{Night}$= 201 grunts; $we10_{Day}$= 121, grunts $we10_{Night}$= 460 grunts).

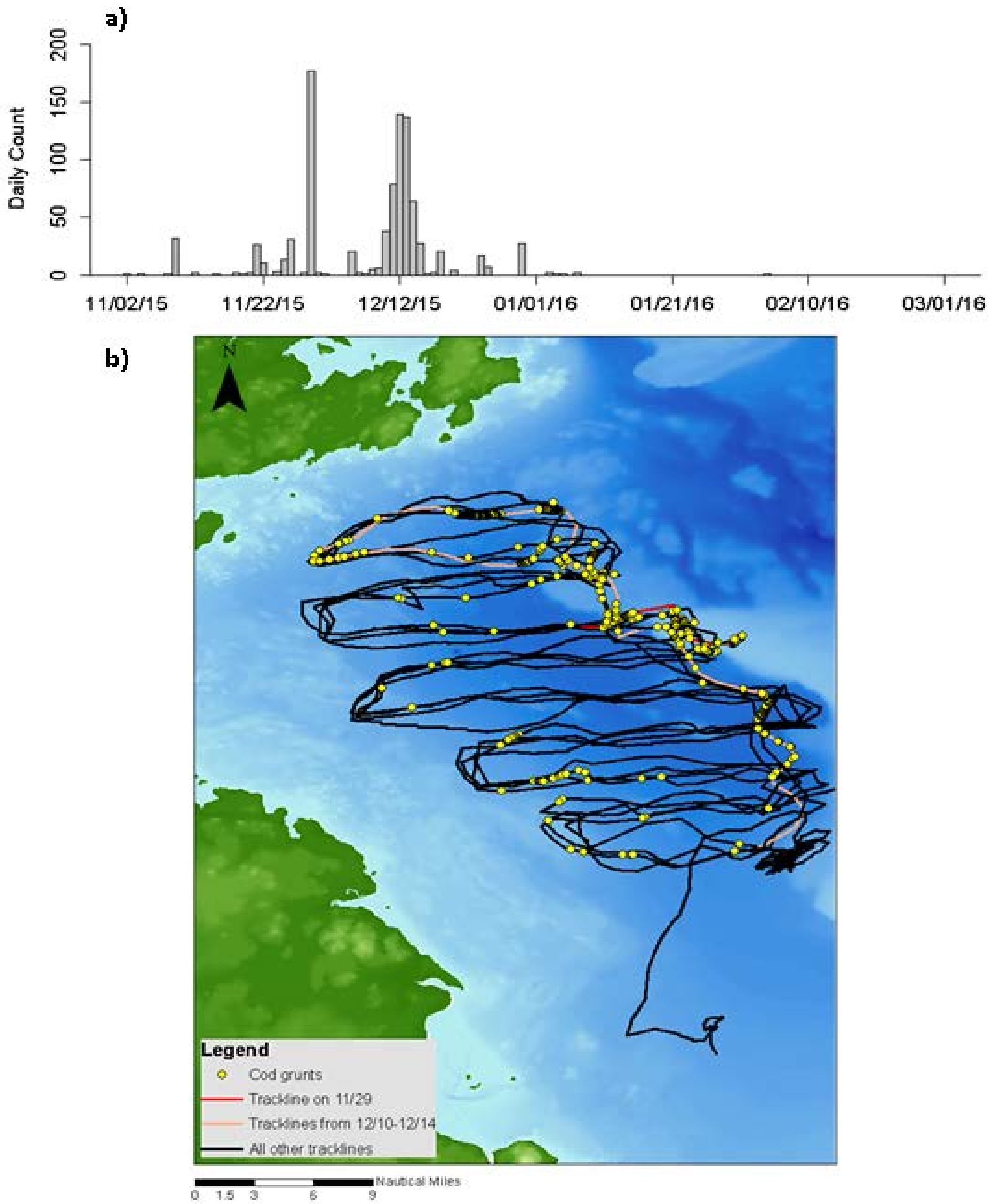


Figure 42 Daily presence of cod grunts detected on all three year 3 gliders in GMT-5 (a). Map showing the tracklines of we04 and we10 only (b) as we03 only had 1 grunt detected. Detected grunts are shown in yellow, and the periods of highest activity on the gliders are colored in red (11/29) and orange (12/10-12/14).

As cod grunts are thought to not travel far (~50 m), there was the concern that the glider would only pick up grunts at certain depths in the water column. However, Figure 43 shows that the detection of cod grunts is randomly distributed with respect to depth for we04 and we10 of Year 3.

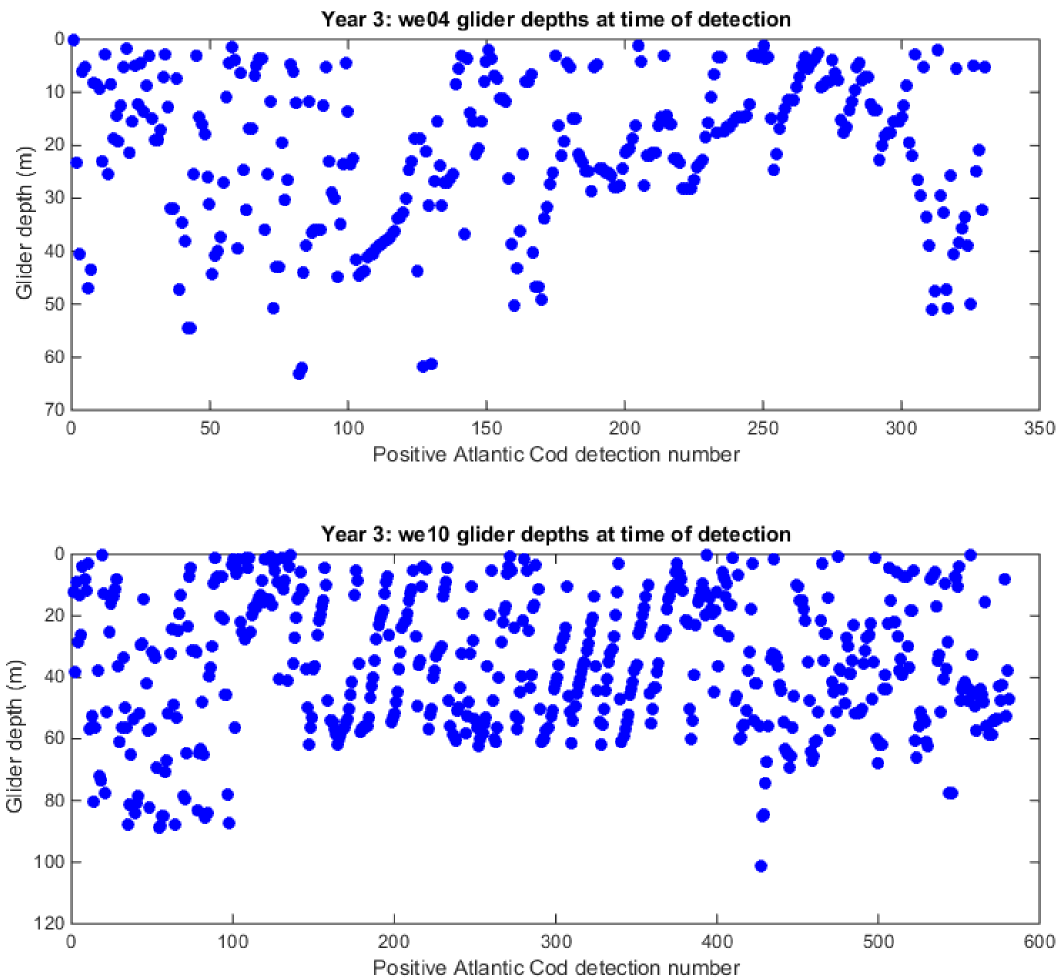


Figure 43: Glider depth at time of detected grunts in year 3.

4.4 Passive Acoustic Monitoring

Multiple MARUs failed to record due to hardware issues or becoming detached from their moorings. Therefore, the recording duration varied among MARUs and ranged from < 1 day to 166 days (Appendix A4). A total of 5,594 of 25,429 detections (22%) on the MARUs were positively identified as cod grunts in Year 1. In Year 2, a total of 3,142 of 45,541 detections (7%) were positively identified as cod grunts. Year 3 had approximately four times the number of detections as the previous two years. As a result, only 106,647 of 165,576 detections were manually reviewed. Of the 106,647 reviewed, 49,000 (46%) detections were positively identified as cod. As mentioned in the methods, all days with > 2,000 detections were subsampled such that only 2,000 detections per day were reviewed. Nine days on SS64 were evaluated using this method. Over the nine days, 55,957 detections were extrapolated to be positive detections of cod (TP_E); therefore the total number of positively identified cod grunts in Year 3 increased from 49,000 grunts manually verified to 104,957 grunts TP_E.

In Years 1 and 2, the majority of the grunts were detected at SS53, the maximum being 592 grunts in one day on October 23, 2013 (Figure 44). However, the maximum number of grunts recorded in these years was markedly lower than the maximum number of grunts recorded in one day at SS64 in Year 3 (Figure 44). A maximum of 1,957 grunts out of 2,000 detections were positively identified as cod on December 2, 2015, however, if incorporating TP_E, the day with the most grunts was November 28, 2015 with 16,519 grunts TP_E. Incorporating the extrapolated numbers for the nine days results in a grand total of 98,574 grunts TP_E for SS64. All other sites besides SS53 had few (< 300 grunts per day) to no detections of cod in all years. Cod grunts were detected earlier in the fall on SS53 (September - November) in comparison to SS64 (November - January). Sites such as SS10 and SS32 followed SS64's seasonality, just on a smaller scale. No other site had enough detections to assess seasonality.

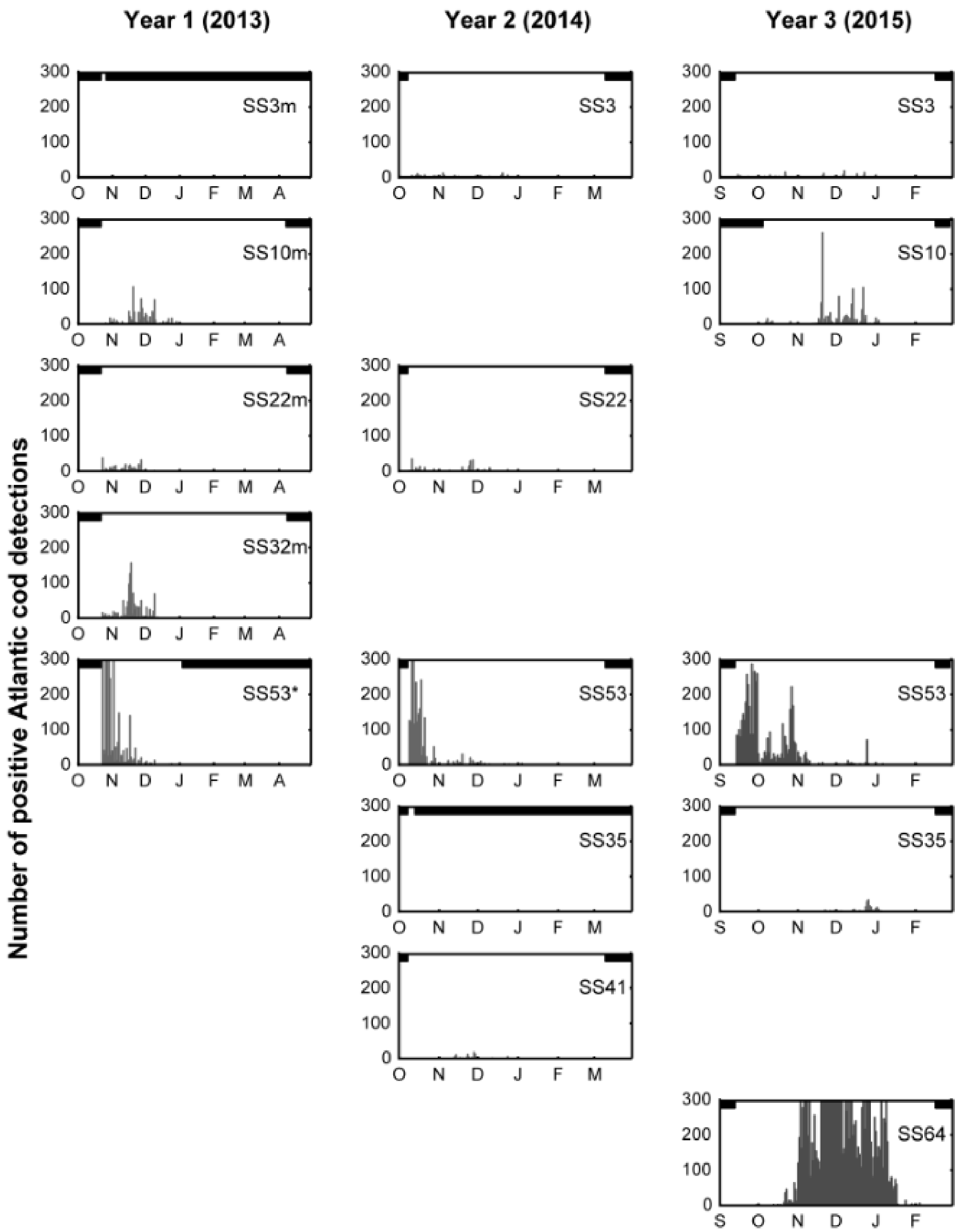


Figure 44: Daily presence of cod grunts detected on the MARUs over the three year study period. Black bars on the top of each subplot represent time when no data was collected. Blank areas denote years where no MARU was placed at that site. SS56 is not shown as the unit did not record, and SS51 is also removed as that unit recorded for less than one day and no cod grunts were detected during that short time period.

Only SS64 in Year 3 had detections > 2,000 per day, thus only this site was used to examine lunar trends using the subsampled detections. The peak grunting activity appeared to start at the transition between the first quarter and full moon phases, and continue through the full moon phase to end at the transition of the full and third quarter phases (Figure 45). This corresponded to November 24 - December 2, 2015. Most of the subsampled true positives occurred during the full moon phase (n_{full}= 17,569, 41%) and the least during the new moon (n_{new}= 4,296, 10%). First quarter and third quarter represented 23% and 26% of the number of true positives, respectively (n_{first}= 9,630, n_{third}= 11,122).

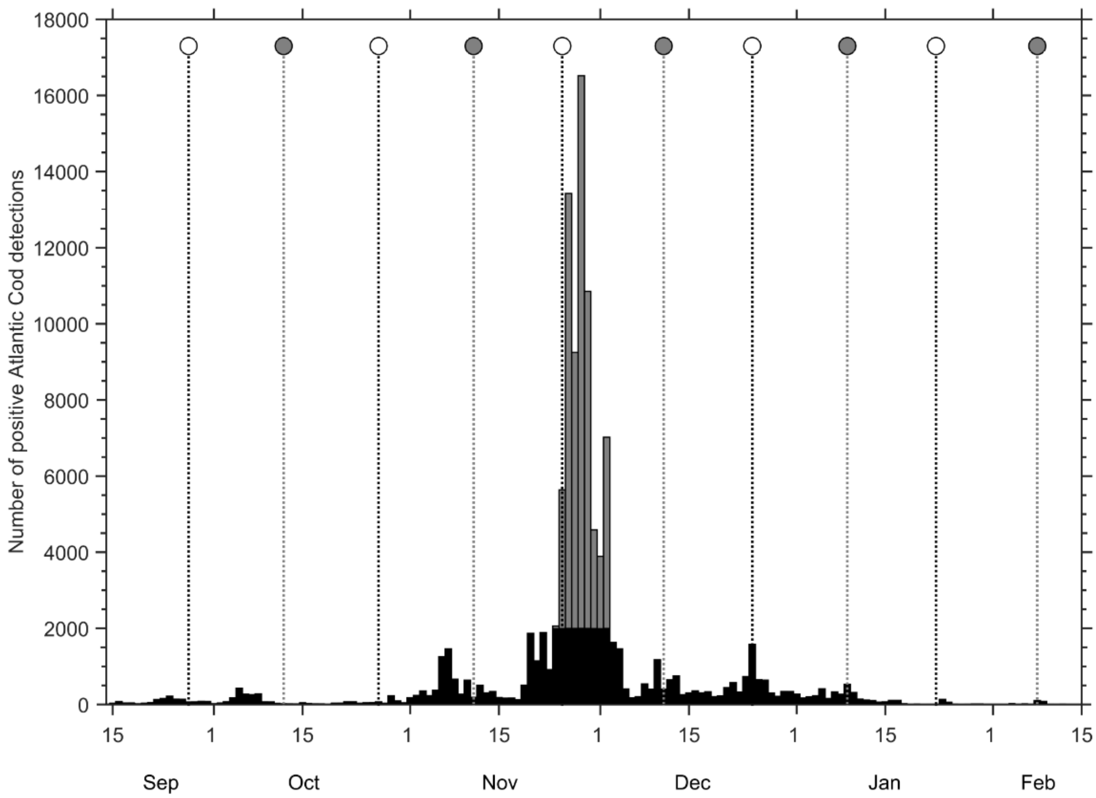


Figure 45: Daily cod grunts detected at SS64 during Year 3 with the number of positive detections that were verified (TP_V) in black and the extrapolated daily count (TP_E) in grey. Full moon (open circle) and new moon (grey circles) phases have been included.

4.5 Spawning patterns in relation to habitat and fishing activity

Seasonal variation in the number Atlantic cod grunt detections for November 2015 through to the end of January 2016 were contrasted with sea surface temperature measurements from the Slocum glider and the NDBC oceanography buoy in Massachusetts Bay. Our aim was to examine whether there was any relationship between temperature and the onset of the high cod grunting activity that was observed, in response to Objective 3 of the proposal. No clear relationship was observed either from data on the Slocum glider, which sampled the areas extensively and throughout the water column, or the NDBC buoy which is anchored at a given location (Figure 46). Sea temperatures dropped from early October through to late January but there was no change in sea surface temperature associated with the steep onset of cod grunting activity. It is difficult to draw any conclusions from this comparison other than that this approach has the capability to allow such comparisons to be made. We only detected this level of cod grunting activity in one site in the final year. Several more years covering the same time period and at the least the same area, or preferably an extended area, as in Year 3 are needed to be able to draw any conclusions as to relationships between grunting and environmental parameters.

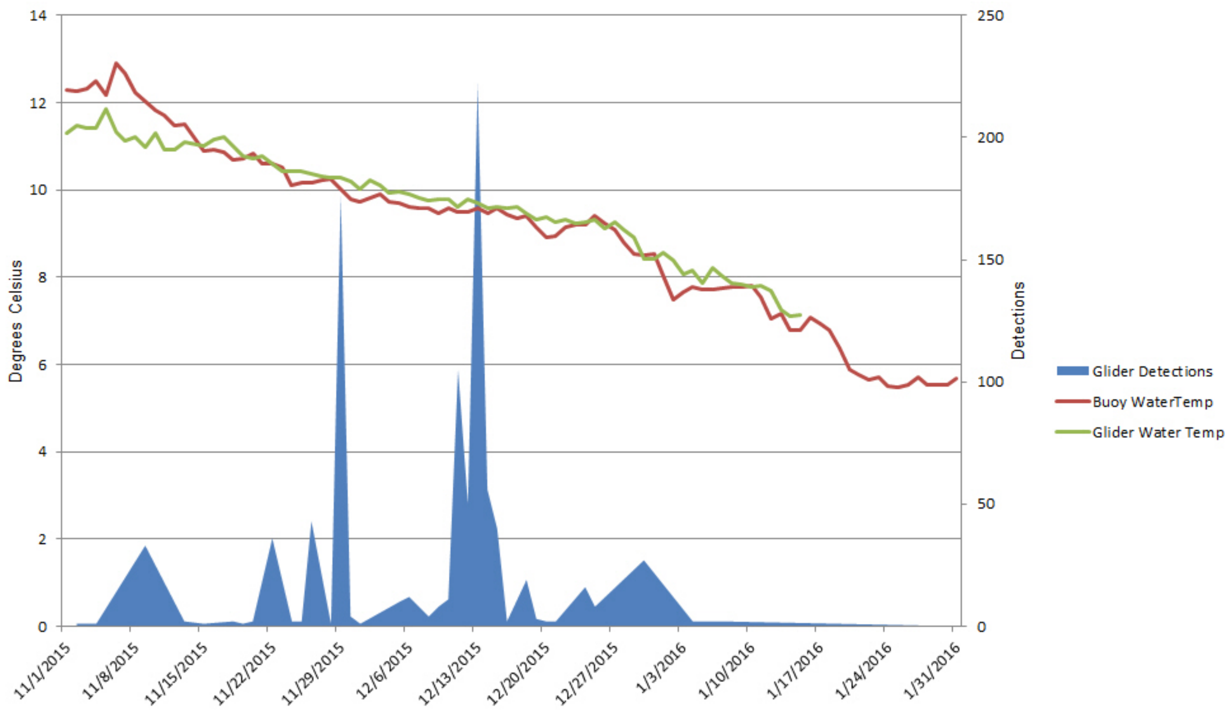


Figure 46: This figure plots the degrees in Celsius from November 1st 2015 to January 31st 2016 collected both using a Slocum glider and the National Data Base Center buoy at station 44029 in Massachusetts Bay. These data were plotted against the number of Atlantic cod grunt detections from gliders across that time period (in GMT).

Depth and sediment type were also examined in comparison to both the spatial distribution of high cod grunt detections and acoustic telemetry detections. However, no clear conclusions could be drawn given that each year the area covered by the study was slightly different. As we learned more each year our study moved progressively to the East into deeper waters and away from previously known winter cod spawning areas since our data in each year showed that most activity appeared on the Eastern edge of our study area. Given that we did not find the areas of highest activity until year 3, it is difficult to derive any conclusions as to preferred spawning habitats. Unless further years covering the same area are examined it is not possible to draw any definite conclusions. In Year 3 the most cod activity was found on and around the north western part of Stellwagen Bank.

In year 1 there was a concentration of tagged cod near the Massachusetts Bay Gateway LNG terminals no-transit zone, an area protected from fishing. The group discussed the potential that spawning was occurring there because it was a refuge from fishing activity. Our attempts to deploy receivers inside the no-transit zone to test that hypothesis were unsuccessful. In November 2014 the entire study area was closed by interim action until March 1st, 2015, reducing fishing activity to zero.

The striking changes in fishing activity and cod landings (Figures 47 and 48) resulted from a combination of changing regulations (including area closures, introduction of a quota system in 2010, and reduction of quotas since 2010) and changing fish resource abundance and distribution. Between 2006 and 2015 these figures show a 12x reduction in the maximum number of groundfish trips taken per square kilometer and a 25x reduction in maximum cod landings per square kilometer.

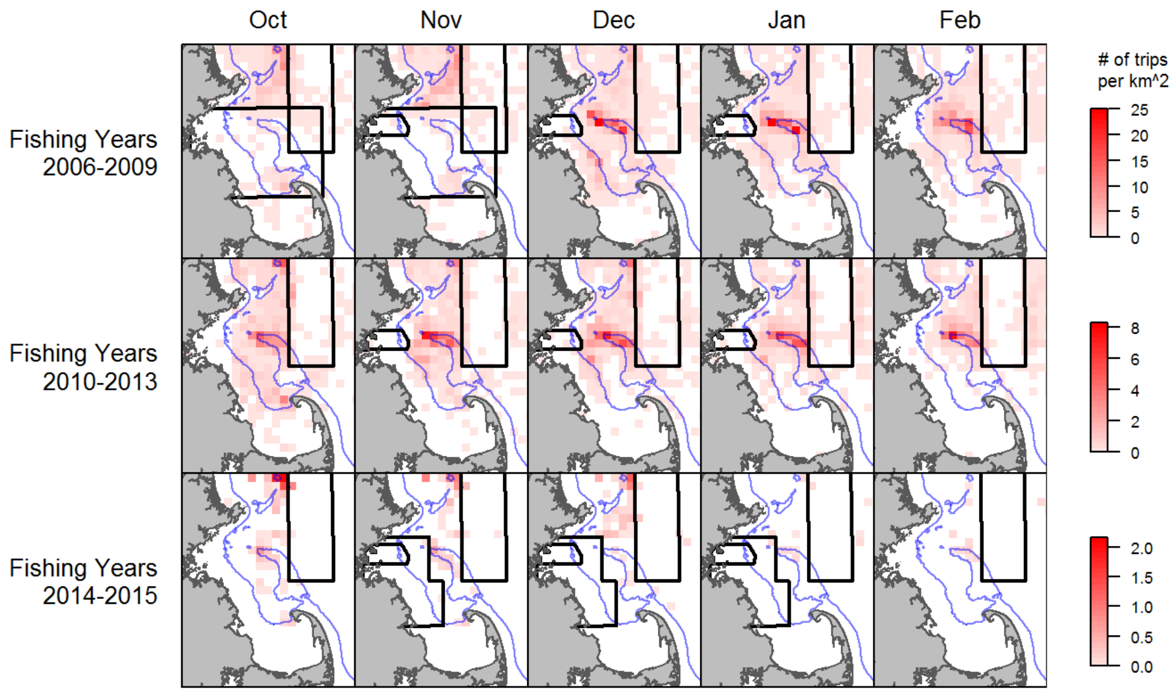


Figure 47: Spatial distribution of commercial groundfishing trips, based on the gear type reported to NMFS on vessel trip reports (VTRs). Any trip that reported using either bottom trawl, sink gillnets, or bottom longline gears (i.e., GEARCODE = OTF, GNS or LLB) were considered to be targeting groundfish. Darker red color indicates areas with a higher level of fishing effort. Thick black lines represent fishery closures. The thin blue line is the 50 meter isobath.

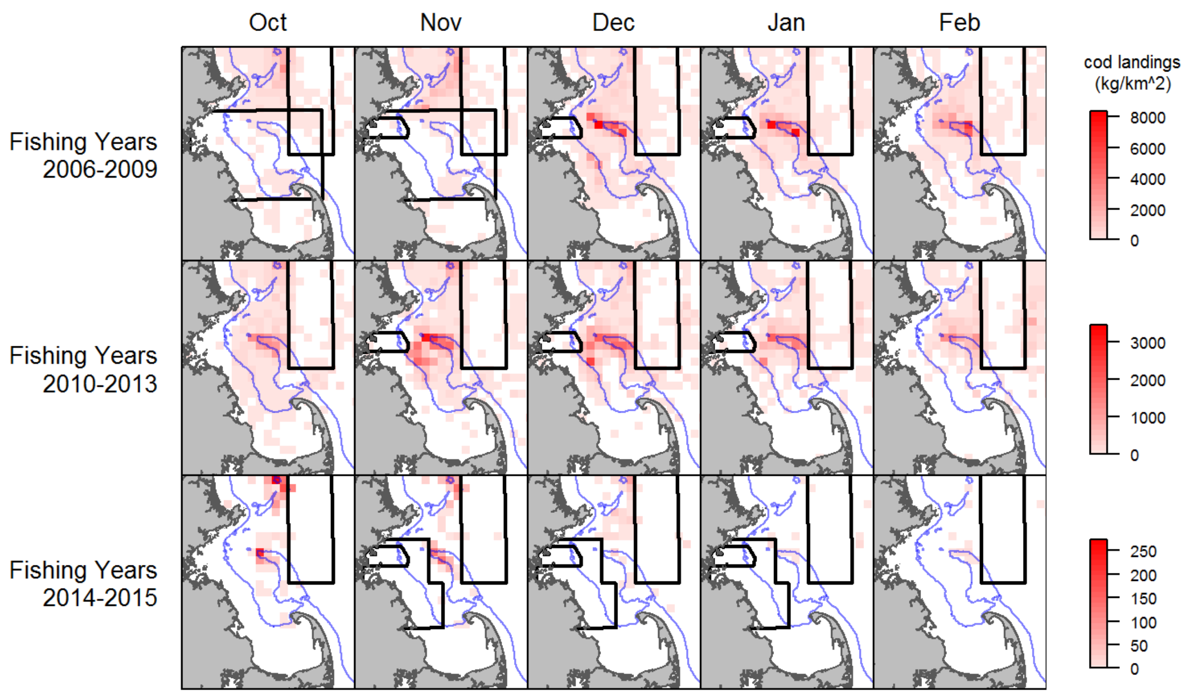


Figure 48: Spatial distribution of landed cod, based on the amount kept and fishing location reported to NMFS on vessel trip reports (VTRs). Darker red color indicates areas with higher reported cod landings. Thick black lines represent fishery closures. The thin blue line is the 50 meter isobath.

5. Project Outreach: Fishery Managers, Scientific Community, and General Public

Our research team and collaborating fishermen have regularly kept fishery managers and scientists updated on the methods and preliminary results of this study. During the pilot project, Captain Frank Mirarchi first presented the scope and goals of the project to the NEFMC during their September 2013 meeting. Preliminary year one project results were then discussed with fishery managers, including members of the NEFMC and the NEFMC Council Staff, during a presentation and meeting at the NEFMC headquarters in Newburyport, MA in June 2014 by many members of the research team. Preliminary project results were also presented to the Groundfish Committee and Plan Development Team of the NEFMC in September 2014 by M. Dean. Also, in October 2014, a presentation was made to the Stellwagen Bank National Marine Sanctuary Advisory Committee by C. McGuire, which is made up of scientists, resource users, regulators, and stakeholders.

A seminar presentation was prepared and delivered by D. Zemeckis in November 2014 as part of the SMAST Department of Fisheries Oceanography seminar series. This seminar included preliminary data from this project, including implications for fishery management, which was helpful for communicating project results to the scientific community and fishery managers. A recording can be viewed here: http://www.umassd.edu/smast/newsandevents/seminarseries/. D. Zemeckis also prepared and delivered a presentation to an audience comprised of fishery scientists and managers at the summer meeting of the Southern New England Chapter (SNEC) of the American Fisheries Society (AFS) on June 25, 2015. The presentation covered project results to date and plans for future work. A copy of this presentation was also emailed to Mark Grant, Sector Policy Analyst at NOAA's Greater Atlantic Regional Fishery Office, to keep regulators apprised of our progress.

In addition, the project was presented at an international scientific meeting. Principal Investigator C. McGuire delivered an oral presentation, 'Collaborative Cod Spawning Research in the Gulf of Maine' (ICES CM 2015/L:26) in the 'Science/Industry Partnerships' session at the International Council for the Exploration of the Seas (ICES) Annual Science Conference in Copenhagen in September 2015. The extended abstract associated with the presentation is available here: http://bit.ly/1YyWOqr . The audience was comprised of fishery scientists, managers, fishermen from the US, Canada, and Europe. The presentation focused on the collaborative genesis and implementation of this project.

Multiple presentations were also delivered at the 2016 Annual Meeting of the American Fisheries Society. D. Zemeckis presented scientific results in, "Using Acoustic Telemetry to Map Atlantic Cod Spawning Activity and Inform Fishery Management in the Gulf of Maine" during the 'Translating Essential Fish Habitat Science into Fishery Management Decisions' symposium. Abstract available here: http://bit.ly/2aFBOhn. C. McGuire presented lessons learned from the collaborative process in, “Collaborative is the new Cooperative: An Example from Cod Spawning Research in the Gulf of Maine” in the ‘Cooperative Research in Marine and Freshwater Systems’ symposium. Abstract available here: http://bit.ly/2a0Fz0j. Project results were also presented at the 2016 RARGOM annual science meeting in October 2016 by C. McGuire in an oral presentation titled “Identifying the distribution of Atlantic cod spawning activity to inform fishery management in the Gulf of Maine”. The full RARGOM program is available here: http://goo.gl/MyFYZU

Collaborator Sofie Van Parijs and developer Ildar Urazghildiiev published the first manuscript from this project in the May 2016 issue of the Journal of the Acoustical Society of America. The article, which was entitled “Automatic grunt detector and recognize for Atlantic cod (*Gadus morhua*)” , describes the successful development, testing, and use of the automated detector for cod grunts, which was funded through this grant. This paper helped to communicate our results to the scientific community.

Full Reference: Urazghildiiev, I.R., and Van Parijs, S.M. 2016. Automatic grunt detector and Recognized for Atlantic cod (Gadus morhua). Journal of the Acoustical Society of America, 139(5): 2532-2540.

Our research team has a second manuscript in preparation to publish our acoustic telemetry and passive acoustic monitoring findings with respect to the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay. This manuscript will help to communicate our findings to the scientific community and fishery managers, and it is planned to be submitted to the Fisheries Research journal during early 2017.

Full Reference (Article In Preparation): Zemeckis, D.R., Dean, M.J., DeAngelis, A.I., Van Parijs, S.M., Hoffman, W.S., Baumgartner, M., Buchan, N.C., Hatch, L., Cadrin, S.X., and McGuire, C.H. In Prep. Identifying the distribution of Atlantic cod spawning activity in the western Gulf of Maine. Planned Journal: Fisheries Research.

A third paper is planned to be prepared for publication in a peer-reviewed scientific journal that focuses on the finer-scale movements and behaviors at an individual level (e.g., Dean et al., 2014), which is beyond the scope of work proposed in the present grant but will provide significant additional value and exposure to the project. This planned paper will look closer into sex-related and diel behavior differences among cod tagged with acoustic transmitters. Potential outlets for publication include the ICES Journal of Marine Science or Marine Ecology Progress Series. This paper is planned to be produced and submitted during 2017.

Media:

Throughout the course of this project, this study also received a great deal of media attention, which was helpful for communicating to the general public the research that is ongoing to support rebuilding efforts of Atlantic cod off New England. For example, during the pilot year there was a joint press conference held in January 2014, and a number of news stories were published including:
http://www.capecodtoday.com/article/2014/01/13/23551-Researchers-track-cod-E-Z-Pass-Fish
https://www.bostonglobe.com/metro/regionals/south/2014/01/12/scituate-fishermen-pin-hopes-cod-tagging-project/FzH6GyPlFpRdy3PXPNmKmL/story.html
http://www.reel-time.com/articles/conservation/tag-youre/
http://www.gloucestertimes.com/news/local_news/project-aims-to-track-spawning-cod/article_f56362cb-e2aa-51cd-88cf-f122974fb7cf.html
Commercial Fisheries News: “Acoustic tags track spawning cod off MA”, March 2014, pg 44.

Furthermore, in order to communicate directly with fishermen (in an effort to reduce gear conflicts) the project ran ¼ page ads in the Massachusetts Lobstermen's Association newsletter in September and October of 2014, and in Commercial Fisheries News in December 2014 and January 2015. The ads discussed the project goals and identified the potential gear conflicts.

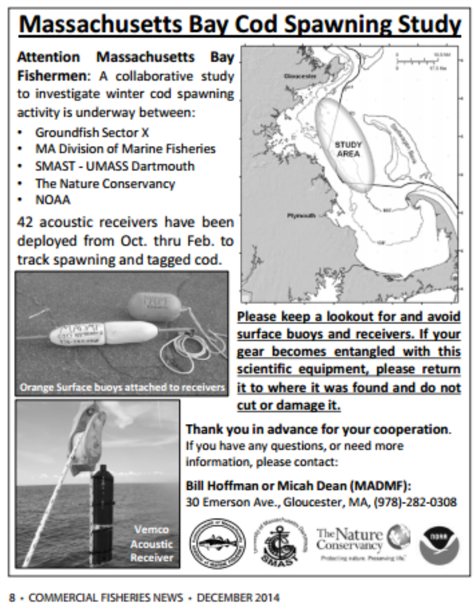


Figure 49: Informational ad in Commercial Fisheries News, December 2014.

In December 2014 a news story about the glider deployments appeared in the Cape Cod Times, along with a short video, accessible at this link:
http://www.capecodtimes.com/article/20141223/NEWS/141229792

In February 2015, the Cape and Islands NPR station, WCAI, hosted project partners from The Nature Conservancy, NOAA, and MADMF for an hour long discussion of the project. A recording can be heard at the following link: http://capeandislands.org/post/eavesdropping-private-lives-cod

In June 2015 a shorter piece was aired nationally on the NPR news program "All Things Considered" and can be heard here: http://www.nmfs.noaa.gov/podcasts/2015/03/listening_for_cod.html

Additional media coverage and recordings:
On the Line: A NOAA Fisheries Podcast: "Listening for Cod in the Gulf of Maine"
NEFSC Newsroom: "Listening for Whales and Fish in the Northwest Atlantic Ocean: Various platforms and technology offer vision for future network along U.S. East Coast"
NEFSC Newsroom: "Technology and Collaboration Critical to Monitoring Winter Spawning Activity of Atlantic Cod in Massachusetts Bay"

Stories about this project have appeared in three Nature Conservancy publications and a blog. This project was the cover story in the Massachusetts 'member update' which was sent out to the 35,000 members in Massachusetts in the fall of 2014, and again in the fall of 2016. Additionally a small story appeared in the Conservancy's Magazine in the October/November issue which mailed 640,000 paper copies to Nature Conservancy members across the United States in addition to the global tablet edition for electronic distribution.
http://blog.nature.org/science/2014/01/20/chasing-cod-tracking-a-fish-to-save-an-industry/

Travel funds for C. McGuire and D. Zemeckis to attend and present at AFS 2016 meetings and ICES annual science conference were provided by the Cabot Family Charitable Trust and other private donors.

6. Discussion

6.1 Distribution of Spawning Activity

Through effective collaboration among state, academic, federal, and NGO scientists, as well as members of the commercial fishing industry, this study successfully utilized multiple technologies to identify the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay. Based on the acoustic telemetry results, there was some interannual variability in the timing of spawning as identified by the median arrival and departure dates of tagged fish (Table 3; Figures 30, 31). For example, in Year 2, tagged fish often left the acoustic receiver array earlier than in Year 3. Nonetheless, based on the residency of tagged fish within the acoustic receiver array during all three years of monitoring it appears that the majority of tagged fish were present from early November through January with a peak in mid-December. However, this may not capture all of the activity on the spawning ground as 77% of tagged fish were present outside the FW53 closure period, just not in large numbers (Figures 37; 38). It is possible that some fish present for prolonged periods (i.e., >3 months) or outside of the peak spawning times were resident inshore pre- or post-spawning. The passive acoustic monitoring data corroborates this timing: in Year 3 grunts recorded at SS64 (Figure 45) began in early November, peaked in late November, and tapered off by mid-January, and sites SS10 and SS32 showed similar seasonality to SS64, just on a smaller scale. A similar temporal grunt pattern is also shown from the Year 3 glider results (Figure 37) The agreement between both technologies is reassuring, because acoustic telemetry data indicates when fish are aggregating and the passive acoustic monitoring data indicates when spawning events appear to actually be occurring within range of the MARU's, as based on our understanding of the cod mating system.

The acoustic telemetry data identified three hotspots of activity, particularly from Year 3 data which provided the most reliable picture of spawning activity, including just west of the northwest corner of Stellwagen Bank as the primary focal point of spawning activity, with other lesser focal points inside the WCCZ and just east of the Neptune LNG terminal. There was some interannual variability evident from the acoustic telemetry results, both spatially (Figure 34) and temporally (Figure 31), but this variability is within the typical temporal (i.e., by month) and spatial (i.e., by 30 minute squares) scales of fishery management. Furthermore, when looking at the acoustic receiver stations that were the same in all three years of monitoring, the spatial extent of spawning appears to be largely consistent among years (Figure 36). Therefore, the spatial variability observed is likely due to the different scales of observations as the acoustic receiver array was expanded and shifted each year. All of the fixed station acoustic receivers were within the current FW53 closure, so they were better positioned to evaluate activity inside of the closure, rather than outside. However, the gliders transected an area 3-4 times larger than the fixed station array and they helped to identify areas of apparent spawning activity beyond the range of the fixed station deployments in two areas, most notably just west of the northwest corner of Stellwagen Bank and also some tagged fish and grunts were detected along the glider transect just north of the current FW53 closure.

Both acoustic telemetry and passive acoustic monitoring results from Year 3 demonstrate that there is a hotspot of spawning activity along the northeastern portion of the FW53 closure, or the area just west of the northwest corner of Stellwagen Bank. It is possible that fishing activity along the boundary of this closure disrupted spawning activity and influenced the fish to aggregate inside of the closure where fishing activity was not occurring. However, with the very low allocations of Gulf of Maine cod, fishing effort has been severely reduced in this region (Figure 47) it is unlikely that the fishing activity was influencing the distribution of spawning activity during Year 3.

Many of the acoustically-tagged cod (18-50%) were documented exhibiting spawning site fidelity by returning back to the array over multiple consecutive winter spawning seasons. This is the first evidence of spawning site fidelity among winter spawning cod in Massachusetts Bay. This behavior has been previously documented by cod within other stocks (e.g., Robichaud and Rose, 2001; Skjaeraasen et al., 2012) and spring spawning cod in Massachusetts Bay, where it is believed to be an important mechanism contributing to the formation and maintenance of the observed metapopulation structure in the Gulf of Maine (Zemeckis et al., 2014c).

The MARU deployment at the southernmost site (SS53: Figure 44) reliably detected cod over the course of the three year study period from September through November. This was historically an important fishing ground known as “Fishing Ledge” and spawning cod were caught there during previous trawl surveys (Hoffman et al., 2012). However, the level of spawning activity documented during this study was substantially less than what was observed on SS64 in the eastern quadrant of the array in Year 3. While not at as high of levels observed at SS64, it appears that more than just a few cod were at SS53. It is unclear if that site is also used as a spawning ground, or whether what was detected were agonistic or other communicative calls. Very few cod tagged with acoustic transmitters were detected at SS53 (Figure 32), which suggests that the grunts recorded at this location were either agonistic or other communicative calls, or if spawning was occurring at this location then it represents a separate un-tagged spawning component. However, the seasonal and spatial correlation between peak levels of cod grunts and activity of tagged cod from other stations suggests that vocalizations are primarily associated with spawning aggregations in Massachusetts Bay, so additional follow-up investigations are warranted to determine whether historical spawning sites are active within the vicinity of Cape Cod Bay.

Contrary to historical accounts and some of the information available at the beginning of this study (Figure 8), we found little to no occupancy by tagged cod along the west side of the fixed station array and in waters shallower than 50 meters. There are multiple factors potentially contributing to these observations. For example, it is possible that the distribution of spawning activity has shifted to deeper waters. It is also possible that the spawning components that historically spawned in these shallower areas have been extirpated or cod that represent separate, untagged spawning components aggregate to spawn closer to shore. The gliders would have ideally been able to help resolve this by recording cod grunts in shallower depths and potentially detecting tagged fish, but the gliders had limited coverage shallower than 50 meters since at shallow depth the dive amplitude is very short which has a negative impact on battery life and deployment length.

The largest number of cod grunts recorded during this study was at station SS64 in Year 3. The number of grunts could loosely be termed a “chorus”. Chorusing was not assessed here as the energy of the fish calls would have needed to be compared to background ambient noise. As Massachusetts Bay is an area of high anthropogenic activity, ambient noise in this case is not pristine and is affected by passing vessels. Therefore, other metrics are needed to determine a cod chorus, which could not be assessed as part of this project. Work is being done to include this in a future manuscript.

Other MARU sites found little to no cod acoustic activity, indicating the importance of sites such as SS53 and SS64. One thing passive acoustic monitoring cannot do reliably is know the number of cod at a site. How many grunts can be considered a significant amount of cod? Based on presence over the three years, over 1000 grunts is rare in the study area and definitely constitutes an important location. But what about areas where 100-1000 grunts are detected? More work is required to determine what levels can be considered “significant”. Additional monitoring in the area west of the northwest corner of Stellwagen Bank may help to assess this. Furthermore, there is work currently being done to calculate the detection range of Atlantic cod grunts in Massachusetts Bay using MARU’s. Data from that study can be extrapolated to the glider in future applications to know what the possible detection range is; however, it would be most applicable to MARU data. A more reliable estimate of the detection range of cod grunts will be helpful to look further into cod spawning behavior (e.g., chorusing) and identifying active spawning sites from archived data.

6.2 Implications for Fishery Management

This project was designed to inform the creation of fishery management measures to protect spawning aggregations of cod during the winter in Massachusetts Bay. At the beginning of this project, no management measures were in place to protect winter spawning cod in Federal waters in Massachusetts Bay. However, during this project period two management actions (described in Section 1) were implemented which closed the majority of the study area to fishing for most of the spawning season, and simultaneously the Annual Catch Limit for GOM cod was drastically reduced shifting cod from a target species to a bycatch species to be avoided. Since the FW53 seasonal groundfish closures are the current management regime in our study area, including the months of November, December and January, our discussion of management implications will reference those boundaries and months.

Over the three years of monitoring there were only intermittent detections of cod south of 42d15'N (i.e., the North side of the FW53 bump out into block 124), using both the gliders (Figure 41) and fixed stations (Figures 35,36). This area does not appear to be utilized by many spawning cod during the winter in Massachusetts Bay and this region warrants further investigation by fishery managers. For example, given that this study has identified little to no evidence of spawning activity in the southern portion of our study site, combination with other existing datasets (e.g., Hoffman et al., 2012) is warranted to revisit the decision to close these areas to protect cod using the FW53 closures. However, it is acknowledged that the FW53 closures were designed to protect locations of high cod abundance and not just spawning fish. Therefore, it is possible that non-spawning cod utilize this area more than winter spawning cod, and these topics warrant further evaluation as modifying the current closures could provide additional fishing opportunities for the groundfish fleet with potentially little impact on cod conservation efforts.

Another important area warranting additional investigation by fishery managers is the area west of the northwest corner of Stellwagen Bank in the northeast portion of the FW53 closure, as well as just east of the current closure. This location was identified in the present study as an important region for winter spawning cod in Massachusetts Bay (Figures 37 and 38). For example, Year 3 glider data detected significant numbers of cod just to the north and east of the fixed array, and outside the FW53 closure (Figure 41) Most of the cod grunts recorded by the gliders were in areas frequented by tagged cod, with the exception of a small grouping just west of central Stellwagen Bank, near the 50 meter depth contour (Figures 37 and 38). Based on this two year finding, our data suggests that the area west of the northwest corner of Stellwagen Bank is an area frequently utilized by spawning cod during the winter. Further investigation of the data collected during this study, as well as other previous studies, is warranted to consider potential modifications to the current FW53 closures to potentially offer additional protection to spawning cod in this area. In addition, continued research from the present study would help to identify the eastern extent of spawning activity around the northwest corner of Stellwagen Bank as this project was limited in capacity for expanding any further east in our final year. It will be possible to detect acoustically-tagged cod as the battery life of the tags will still last for multiple years and passive acoustic monitoring using MARU's could help to identify the distribution of spawning activity in this area, which is still a location where fishing activity occurs (Figure 47 and 48).

Multiple management measures have been implemented to protect spawning cod in the Gulf of Maine (Armstrong et al., 2013; Department of Commerce, 2014, 2015). However the stock has continued to decline in abundance (Palmer, 2014), with little evidence of any rebuilding from the most recent stock assessment update (NEFSC, 2015). Therefore, the series of spawning protection measures that have been implemented within the complex management scheme of New England groundfish have not yet been sufficient for achieving rebuilding. It is possible that these spawning protection measures have not been the key to initiate rebuilding because they were too little and too late (e.g., Clarke et al., 2015), as well as the overall inability to end overfishing in other locations and seasons (Rothschild et al., 2014; NEFSC, 2015), because multiple papers have suggested that spawning closures are most likely to be effective as an interdisciplinary approach that concurrently reduces overall fishing mortality (Gruss et al., 2014; Zemeckis et al., 2014a; Sadovy de Mitcheson, 2016). Nonetheless, the spawning protection measures are also designed to reduce the likelihood of extirpating semi-discrete spawning components and disrupting natural spawning behaviors (Dean et al, 2012) to promote successful reproduction. Therefore, although stock rebuilding has not yet been recognized, it is likely that these spawning closures have been successful at achieving these objectives of preventing the disruption of spawning behavior and reducing the likelihood of extirpating the remnant spawning components. These are important factors to consider with the implementation of spawning closures, particularly under a catch share management system based on ACL's.

6.3 Application of Complementary Technologies

The development and commercialization of acoustic technology in the last ~30 years has opened up new methods of studying fish behavior in their natural environment. This project combines three different technologies in a novel way: acoustic telemetry, passive acoustic monitoring, and autonomous gliders, to buttress the weaknesses of any one tool with the strengths of another.

Acoustic telemetry enables the monitoring of individually-tagged fish over a period of several years, and is particularly useful for fish that have regular site fidelity at particular times of the year, which is the case for spawning cod. Two limitations of acoustic telemetry are that information is only received from tagged fish (i.e., not the whole aggregation) and establishing and maintaining a large array of open ocean fixed receivers can be both challenging and costly, thus limiting the spatial extent of monitoring.

Over the three-year project, 23% of deployed receivers were lost by the end of the season, which resulted in loss of valuable data and equipment, which is another limitation of passive tracking using acoustic telemetry. One improvement demonstrated during this award was the use of acoustic releases to prevent the loss of receivers. Those releases are becoming less costly and more reliable, which should enable further use over time.

Passive acoustic monitoring of sound produced by animals/fish allows information to be received from any individual, not just those tagged. A limitation for cod grunt monitoring in particular is the low source level of the grunt in a noisy ocean means that moored receivers must be very close to the activity to record it. The passive acoustic receivers grunt data could be compared to previously collected data (when available) and were also critical in identifying the location of a single aggregation which was highly active over a period of two weeks in late November 2015. Moored MARU's were all recovered, but 25% (4 of 16) failed to capture data for a full season, which makes equipment reliability another limitation of passive acoustic monitoring. One challenge with passive acoustic monitoring on which substantial progress was made during this award is in the analysis time required. This award funded the creation of a purpose built cod grunt detector (Urazghildiiev and van Parijs 2016) which has increased the review efficiency of analysts by more than 20 times. This breakthrough has enabled our collaborators at the NEFSC to review archived data for evidence of cod grunts, work that is ongoing.

Autonomous gliders can carry both acoustic telemetry receivers and passive acoustic recorders which enables the monitoring of animals over a broader area than typically possible by maintaining arrays of equipment moored at fixed locations. Gliders performed well (i.e., were able to follow their predetermined tracks) in winter North Atlantic coastal conditions in this project, and are less susceptible to loss (although one glider was recovered by a well-meaning lobsterman, and redeployed the next day). One limitation is that the glider could be in the right place at the wrong time and miss important activity, but the transects could be modified accordingly if appropriate information (e.g., animal behavior, distribution) is available to inform the design of glider missions. So gliders provide good spatial resolution but not necessarily temporal, which is a strength of fixed station deployments. During this project changes in glider technology were evident, with year 2 first generation glider duration of 21 days, covering ~400km, and year 3 'G2' glider we10 lasting 49 days and transiting 855km, more than double the endurance.

Further development of this technology stacking could include: the use of advanced glider technology including longer lasting Slocum gliders and wave gliders; real-time transmission of grunt or telemetry data from gliders or moored array stations could be used to adaptively monitor aggregations of fish; and more reliable and cost effective MARUs could be deployed to enable greater spatial coverage.

6.4 Collaborative Research with Fishermen

Although often used interchangeably, there are important differences between 'cooperative' and 'collaborative' research conducted among scientists and fishermen. 'Cooperative' research is often interpreted as contracting fishing vessels to conduct a research project. Collaborative research on the other hand typically includes shared goals and incorporates fishermen in all phases of the research, from framing the questions to interpreting and disseminating results. That was the case in this project and will continue to be the case as we work to disseminate our findings to inform fishery management.

This project began as a conversation in a fisherman's kitchen where a small group of fishermen and the PI from The Nature Conservancy discussed the fishermen's concern about the overexploitation of cod while they were aggregated for spawning close to shore. The fishermen recognized that the only way to address this was to develop a seasonal closure based on high resolution information about where and when cod were spawning in the winter, information which was not available to managers who had imposed large seasonal spawning closures in the past. "We hope to provide these fish with protection while they're vulnerable," said Scituate Captain Frank Mirarchi. "The expectation is that we can provide discrete, small protected areas which will not be disruptive to fishing, while helping the cod stock to recover." Fishermen knew they could help, but that to inform future management actions they would need a team of scientists to partner with.

It was a big departure for the research team to be invited by fishermen to collaborate on a project with the specific goal of creating a seasonal fishing closure, and all the organizations were eager to get involved. In addition to framing the original question, fishermen conducted at-sea research tagging charters, deployed, maintained and recovered the acoustic array, participated in every research team meeting, and importantly were and remain spokesmen for the project. A leading fisherman first introduced the NEFMC to the project with a short presentation at the Council's September 2013 meeting. Since then fishermen have participated in press conferences, a number of media interviews, briefings for NEFMC staff, and visits with lawmakers. Fishermen's involvement has meant that the public perception of this work is 'fishermen embracing science' and 'fishermen as resource stewards', which is a welcome departure from many other New England fisheries stories mired in crisis and conspiracy.

Collaboration is not always easy, and depends on trust. When the pessimistic 2014 cod assessment was released, and NMFS subsequently instituted seasonal closures through interim action (described in section 1) there was a crisis of confidence. Some fishermen, including individuals collaborating on the project, thought that data from this project was being used to develop these management measures, that proved detrimental to their fishing businesses. Therefore, fishing partners were hesitant to continue collaborating on the project. The research team communicated with numerous members of the fishing industry to clarify that the results from the project were not considered in the recent fishery management decisions and to reinforce the importance of the project for collecting reliable scientific data that will be available for informing future fishery management decisions with respect to the cod spawning sites being studied in this project. These discussions helped to retain the support of our fishing industry collaborators and enabled completion of the required fieldwork for the study.

7. Conclusions

Through effective collaboration among state, academic, federal, and NGO scientists, as well as members of the commercial fishing industry, this study successfully utilized multiple technologies to identify the spatial and temporal distribution of cod spawning activity during the winter in Massachusetts Bay. Based on a combined synthesis of the acoustic telemetry and passive acoustic monitoring data, from both fixed station and glider deployments, the temporal distribution of cod spawning activity during the winter in Massachusetts Bay was shown to have some inter-annual variability, but based on the results from all three years, spawning activity primarily occurred during early November through January with a peak in mid-December. The spatial distribution of spawning activity was generally consistent among years and concentrated in areas deeper than 50 meters. However, our scale of observation annually increased and permitted documentation of multiple hotspots of spawning activity, including just west of the northwest corner of Stellwagen Bank as the primary focal point of spawning activity, with other lesser focal points inside the WCCZ and just east of the Neptune LNG terminal.

Our findings have provided very valuable information for informing the development and potential modification of spawning protection measures for winter spawning cod in Massachusetts Bay. Our results are largely consistent with spatial and temporal extent of the current FW53 management measures. However, important areas have been identified for further consideration and evaluation by fishery scientists and managers in order to optimally balance the protection of spawning cod and permit access to other more abundant species. For example, there was very little evidence of spawning activity in the southern portions of our study site, which is currently included in the FW53 closures. Therefore, these portions of the closures warrant further investigation and potential modifications to offer additional fishing opportunities for the New England groundfish fleet. Conversely, considerable spawning activity was documented along the northeastern edge of our study site, including areas not currently part of the FW53 closures. Therefore, further consideration is required to evaluate potential modifications for providing increased protection to spawning cod in this area, while balancing tradeoffs with respect to scientific uncertainty and access to other species. Upon the present completion of our project, a broad outreach effort will be launched to continue the dissemination of our findings to fishery managers and to work collaboratively to evaluate fishery management options for potential modifications to existing spawning protection measures in order to support rebuilding of cod in the Gulf of Maine and promote sustainable, profitable fisheries.

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11. Appendix A: Supplementary Tables

Appendix A1: Year 1 Acoustic Telemetry Stations

Station	Start Date	End Date	Missing Date	Receiver Days	Latitude	Longitude
SS1	11/6/2013	2/12/2014		98	42.411152	-70.72287
SS2	11/6/2013	2/12/2014		98	42.411001	-70.68766
SS3	11/6/2013	2/12/2014		98	42.386314	-70.73151
SS4	11/6/2013	2/12/2014		98	42.385724	-70.69935
SS5	11/6/2013	2/12/2014		98	42.387366	-70.66626
SS6	11/6/2013	2/12/2014		98	42.362697	-70.71326
SS7	11/6/2013	2/12/2014		98	42.363089	-70.67801
SS8	11/6/2013		11/6/2013	0	42.366437	-70.64249
SS8	12/20/2013		12/20/2013	0	42.366437	-70.64249
SS9	11/6/2013	2/12/2014		98	42.336267	-70.69191
SS10	11/6/2013	2/12/2014		98	42.338067	-70.65696
SS11	11/6/2013	2/12/2014		98	42.341415	-70.62277
SS12	11/6/2013	2/12/2014		98	42.313574	-70.66681
SS13	11/6/2013	2/12/2014		98	42.315294	-70.63559
SS14	11/6/2013		12/20/2013	44	42.318916	-70.60399
SS15	11/6/2013	2/12/2014		98	42.294338	-70.65049
SS16	11/6/2013		11/6/2013	0	42.292743	-70.62066
SS17	11/6/2013		12/20/2013	44	42.293252	-70.58429
SS18	11/6/2013	1/16/2014		71	42.270604	-70.65383
SS19	11/6/2013	1/28/2014		83	42.270454	-70.6096
SS20	11/6/2013	2/12/2014		98	42.268765	-70.57104
SS21	11/6/2013		11/6/2013	0	42.247719	-70.63816
SS22	11/6/2013	2/12/2014		98	42.246582	-70.59466
SS23	11/6/2013	11/6/2013		0	42.243016	-70.56143
SS23	12/20/2013	2/12/2014		54	42.243016	-70.56143
SS24	11/6/2013	2/12/2014		98	42.222906	-70.61585
SS25	11/6/2013	2/12/2014		98	42.224855	-70.57955
SS26	11/6/2013	2/12/2014		98	42.223922	-70.54201
SS27	11/6/2013	2/12/2014		98	42.199275	-70.63225
SS28	11/6/2013	2/12/2014		98	42.198147	-70.58928
SS29	11/6/2013	2/12/2014		98	42.19712	-70.55644
SS30	11/6/2013		11/6/2013	0	42.176142	-70.61349
SS31	11/6/2013		12/20/2013	44	42.176647	-70.57718
SS32	11/6/2013		1/10/2014	65	42.174148	-70.54007
SS33	11/6/2013		1/10/2014	65	42.155554	-70.5949
SS34	11/6/2013		11/6/2013	0	42.153704	-70.5575

Appendix A2: Year 2 Acoustic Telemetry Stations

Station	Start Date	End Date	Missing Date	Receiver Days	Latitude	Longitude
SS1	10/9/2014	3/8/2015		150	42.411152	-70.722874
SS2	10/9/2014	3/8/2015		150	42.411001	-70.687655
SS3	10/9/2014	3/8/2015		150	42.386314	-70.731508
SS4	10/9/2014	3/8/2015		150	42.385724	-70.699354
SS5	10/9/2014	3/8/2015		150	42.387366	-70.666259
SS6	10/9/2014	4/24/2015		197	42.362697	-70.713256
SS7	10/9/2014	3/8/2015		150	42.363089	-70.678009
SS8	10/28/2014	3/24/2015		147	42.366437	-70.642486
SS9	10/9/2014	1/12/2015		95	42.336267	-70.691906
SS10	10/9/2014	3/8/2015		150	42.338067	-70.656958
SS11	10/9/2014	3/8/2015		150	42.341415	-70.622769
SS12	10/9/2014		11/6/2014	28	42.313574	-70.666814
SS13	10/9/2014	3/13/2015		155	42.315294	-70.635592
SS14	10/9/2014	3/13/2015		155	42.318916	-70.603988
SS15	10/9/2014	3/8/2015		150	42.294338	-70.650485
SS16	10/9/2014	3/8/2015		150	42.292743	-70.620663
SS17	10/9/2014	3/8/2015		150	42.293252	-70.584286
SS19	10/9/2014	3/8/2015		150	42.270454	-70.609601
SS20	10/9/2014	3/8/2015		150	42.268765	-70.571043
SS22	10/9/2014	3/8/2015		150	42.246582	-70.594656
SS23	10/9/2014	3/8/2015		150	42.243016	-70.56143
SS25	10/9/2014		10/9/2014	0	42.224855	-70.579546
SS26	10/9/2014	3/8/2015		150	42.223922	-70.542007
SS35	10/9/2014	3/15/2015		157	42.3884	-70.621
SS36	10/28/2014		10/28/2014	0	42.3939102	-70.5832168
SS37	10/28/2014	3/24/2015		147	42.3612529	-70.6077098
SS38	10/28/2014	3/24/2015		147	42.365335	-70.569804
SS39	10/9/2014	3/8/2015		150	42.3390925	-70.5829252
SS40	10/9/2014		11/6/2014	28	42.3300535	-70.5386046
SS41	10/9/2014	3/8/2015		150	42.3148911	-70.5651386
SS42	10/9/2014	3/24/2015		166	42.3039667	-70.5056667
SS43	10/9/2014	3/8/2015		150	42.29025	-70.5464667
SS44	10/9/2014		10/9/2014	0	42.2734863	-70.499824
SS45	10/9/2014	3/8/2015		150	42.2650304	-70.5336477
SS46	10/9/2014	3/8/2015		150	42.2362167	-70.5032333
SS47	10/9/2014		12/15/2014	67	42.244328	-70.4689162
SS48	10/9/2014	3/8/2015		150	42.4402926	-70.6970315
SS49	10/9/2014	3/8/2015		150	42.4379779	-70.6479659
SS50	10/28/2014		10/28/2014	0	42.4503756	-70.6054556
SS51	10/9/2014	12/3/2014		55	42.4063167	-70.6522667
SS51	12/15/2014	4/24/2015		130	42.4063167	-70.6522667
SS52	10/9/2014	5/6/2015		209	42.4171033	-70.6165805
SS53	10/9/2014	3/8/2015		150	42.1299	-70.5338

Appendix A3: Year 3 Acoustic Telemetry Stations

Station	Station	Station	Station	Station	Station	Station
SS1	10/7/2015	3/17/2016		162	42.411152	-70.722874
SS2	10/7/2015		12/1/2015	55	42.411001	-70.687655
SS2	1/28/2016	3/17/2016		49	42.411001	-70.687655
SS3	9/14/2015	2/15/2016		154	42.386314	-70.731508
SS4	10/7/2015		10/7/2015	0	42.385724	-70.699354
SS4	11/30/2015	3/27/2016		118	42.385724	-70.699354
SS5	10/7/2015	3/27/2016		172	42.387366	-70.666259
SS6	10/7/2015	3/27/2016	11/1/2015	172	42.362697	-70.713256
SS6	1/14/2016	3/27/2016		73	42.362697	-70.713256
SS7	10/7/2015	3/27/2016		172	42.363089	-70.678009
SS8	10/16/2015	3/30/2016		166	42.366437	-70.642486
SS9	10/7/2015		10/7/2015	0	42.336267	-70.691906
SS9	11/30/2015	4/2/2016		124	42.336267	-70.691906
SS10	10/7/2015	2/15/2016		131	42.338067	-70.656958
SS11	10/7/2015		1/15/2016	100	42.341415	-70.622769
SS12	10/7/2015	3/27/2016		172	42.313574	-70.666814
SS13	10/16/2015	3/30/2016		166	42.315294	-70.635592
SS14	10/16/2015	3/30/2016		166	42.318916	-70.603988
SS15	10/7/2015	3/27/2016		172	42.294338	-70.650485
SS16	10/7/2015	3/27/2016		172	42.292743	-70.620663
SS17	10/7/2015	4/2/2016		178	42.293252	-70.584286
SS19	10/7/2015	3/27/2016		172	42.270454	-70.609601
SS20	10/7/2015	3/27/2016		172	42.268765	-70.571043
SS22	10/7/2015	3/27/2016		172	42.246582	-70.594656
SS23	10/7/2015	3/27/2016		172	42.243016	-70.56143
SS25	10/7/2015	3/27/2016		172	42.224855	-70.579546
SS26	10/7/2015	3/27/2016		172	42.223922	-70.542007
SS35	9/14/2015	2/15/2016		154	42.3884	-70.621
SS36	10/16/2015	3/30/2016		166	42.3939102	-70.583217
SS37	10/16/2015	3/30/2016		166	42.3612529	-70.60771
SS38	10/16/2015	3/30/2016		166	42.365335	-70.569804
SS39	10/7/2015		3/30/2016	175	42.3390925	-70.582925
SS40	10/7/2015	4/2/2016		178	42.3300535	-70.538605
SS41	10/7/2015	3/27/2016		172	42.3148911	-70.565139
SS42	10/7/2015		10/7/2015	0	42.3039667	-70.505667
SS42	11/30/2015	3/27/2016		118	42.3039667	-70.505667
SS44	10/16/2015	4/2/2016		169	42.2734863	-70.499824
SS45	10/7/2015	3/27/2016		172	42.2650304	-70.533648
SS46	10/7/2015	3/27/2016		172	42.2362167	-70.503233
SS47	10/7/2015		12/1/2015	55	42.244328	-70.468916
SS48	10/16/2015	3/17/2016		153	42.4402926	-70.697031
SS49	10/7/2015	3/17/2016		162	42.4379779	-70.647966

Station	Start Date	End Date	Missing Date	Receiver Days	Latitude	Longitude
SS50	10/16/2015	3/17/2016		153	42.4503756	-70.605456
SS51	10/7/2015		12/1/2015	55	42.4063167	-70.652267
SS52	10/16/2015	3/17/2016		153	42.4171033	-70.61658
SS53	9/14/2015	2/15/2016		154	42.1299	-70.5338
SS54	10/16/2015		10/16/2015	0	42.4867	-70.6774
SS54	12/7/2015	3/17/2016		101	42.4867	-70.6774
SS55	10/16/2015	3/17/2016		153	42.4849	-70.6386
SS56	9/14/2015	2/15/2016		154	42.4908333	-70.592183
SS57	10/16/2015	3/17/2016		153	42.4636	-70.6708
SS58	10/16/2015		1/28/2016	104	42.4584	-70.633
SS59	10/16/2015	3/17/2016		153	42.47	-70.5787
SS60	10/16/2015	3/17/2016		153	42.4632	-70.5446
SS61	10/16/2015	3/17/2016		153	42.4475	-70.5691
SS62	10/16/2015		1/28/2016	104	42.4455	-70.5178
SS63	10/16/2015	3/17/2016		153	42.4331	-70.5933
SS64	9/14/2015	2/15/2016		154	42.4327	-70.54715
SS65	10/16/2015	3/17/2016		153	42.4168	-70.5745
SS66	10/16/2015	3/17/2016		153	42.4188	-70.5175
SS67	10/7/2015	3/17/2016		162	42.4044	-70.5395

Appendix A4: MARU station location and data recovery times.

	Station	Latitude	Longitude	Analysis Start	Analysis End
Year 1	SS3m	42.3936	-70.71935	10/23/2013	10/25/2013
	SS10m	42.3203	-70.66278	10/23/2013	4/6/2014
	SS22m	42.25035	-70.60571	10/23/2013	4/7/2014
	SS32m	42.17938	-70.56026	10/23/2013	4/7/2014
	S53	42.12994	-70.5398	10/23/2013	1/2/2014
Year 2	SS3	42.38631	-70.73148	10/9/2014	3/8/2015
	SS51	42.40622	-70.65205	10/9/2014	10/10/2014
	SS35	42.38829	-70.61711	10/9/2014	10/12/2014
	SS41	42.31493	-70.56507	10/9/2014	3/8/2015
	SS22	42.24645	-70.59563	10/9/2014	3/8/2015
	SS53	42.12985	-70.53381	10/9/2014	3/8/2015
Year 3	SS3	42.386233	-70.73145	9/14/2015	2/15/2016
	SS10	42.338183	-70.65692	10/6/2015	2/15/2016
	SS35	42.3883	-70.61715	9/14/2015	2/15/2016
	SS56	42.490833	-70.59218	--	--
	SS64	42.4327	-70.54715	9/14/2015	2/15/2016
	SS53	42.1299	-70.53375	9/14/2015	2/15/2016

Appendix B: Letter of Acknowledgment

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
NORTHEAST REGION
55 Great Republic Drive
Gloucester, MA 01930-2276

SCIENTIFIC RESEARCH LETTER OF ACKNOWLEDGMENT

Principal Investigator: William Hoffman
Massachusetts Division of Marine Fisheries
30 Emerson Ave.
Gloucester, MA 01930
978-282-0308 ext. 106

Issuance Date: DEC 1 1 2013
Acknowledged Study Period: November 1, 2013, through January 31, 2014
November 1, 2014, through January 31, 2015

Vessel Owner or Operator	Vessel Name	Hull Number	Federal Permit Number
MA DMF	R/V ALOSA	MS301	N/A
Philip M Lynch	KATHY ELIZABETH	MS2582AM	150948
Thomas J Bell	MICHAEL BRANDON	626829	250541
Daniel J Shannon	SORRY CHARLIE	963285	222158
Kevin R Shea	ENDEAVOR	557094	230228
Joe Jurek	MYSTIC LADY	NH8883BB	146860
Ron Gustafson	CHERYL ANN	610571	250468
Kevin Norton	YANKEE ROSE	MS1568AZ	150849

In accordance with the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) provisions, 50 CFR 600.745, the activities conducted in accordance with this letter and the attached Scientific Research Plan are presumed to be scientific activities conducted by a scientific research vessel. Therefore, the above vessels are not subject to the Magnuson-Stevens Act or to fishery regulations published at 50 CFR part 648 while participating in the scientific research activities described herein and in the Scientific Research Plan, and while under the control of the Massachusetts Division of Marine Fisheries (MA DMF) during the above-specified study period.

The above-named vessels are conducting research activities associated with an experiment that will take place in the potential spawning area in Massachusetts Bay and adjacent waters, south of the MA DMF winter cod conservation zone, and off the south shore of Massachusetts. Work will be conducted over a 2-year period. Research will begin on November 1, 2013, end January 31, 2014, and then restart again in 2014 during the same monthly time period. Work will be conducted on seven commercial fishing vessels, listed above. Sampling and maintenance of scientific equipment will also be conducted on the MA DMF research vessel *Alosa* (MS 301).

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SCIENTIFIC RESEARCH LETTER OF ACKNOWLEDGMENT

Researchers will deploy approximately 30 acoustic receivers in the spawning area on a whale-safe mooring system. Fifty male and 50 female cod in spawning condition will be caught via hook and line, demersal longline, and/or trawl and tagged with acoustic transmitters and traditional anchor tags. The study will consist of five dedicated tagging trips each year. Researchers will collect DNA tissue samples from fish that have been fatally wounded or killed, and will release alive all other fish immediately. No fish will be retained for sale.

This letter does not acknowledge any other activity, including the landing of fish, conducted outside the scope of the Scientific Research Plan. Activities conducted outside the scope of the Scientific Research Plan may not be considered a scientific research activity and may require a separate permit. This letter is not intended to inhibit or prevent any scientific research activity conducted by a scientific research vessel. In addition, this letter does not exempt the above vessel from requirements imposed by any state.

This letter is separate and distinct from any permit or consultation required under the Marine Mammal Protection Act, the Endangered Species Act, or any other applicable law. If such a permit is required, or to determine if such a permit is required, please contact Lanni Hall at the Northeast Region's Protected Resources Division of NOAA's National Marine Fisheries Service at (978) 282-8492. Any necessary permits should be obtained prior to embarking on any research activity.

I request that a copy of any cruise report or other publication created as a result of the project, including the amount, composition, and disposition of the catch, be submitted to: Sustainable Fisheries Division, Northeast Regional Office, 55 Great Republic Drive, Northeast Regional Office, Gloucester, MA 01930.

Please carry copies of the scientific research plan and this Letter of Acknowledgment (LOA) on board the vessel while conducting this research. If the vessel is subject to vessel monitoring system reporting requirements, the vessel will need to declare out of fishery while operating as the research platform. In addition, it is recommended that for any scientific research activity, any fish, or parts thereof, retained pursuant to such activity be accompanied, during any ex-vessel activities, by a copy of the LOA.

Acknowledged by:

George H. Darcy

George H. Darcy
Assistant Regional Administrator
for Sustainable Fisheries