Optimize the Georges Bank Scallop Fishery by Maximizing Meat Yield and Minimizing Bycatch

Final Report

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Sea Scallop Research Set-Aside
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EXECUTIVE SUMMARY

This report presents data and analysis from funding year 2016-2017 for the Coonamessett Farm Foundation (CFF) seasonal bycatch survey on Georges Bank. This bycatch survey has been conducted since October 2010 and has been modified and adapted to address current management concerns. The surveys operate with a fixed grid design, and tow parameters have been standard since 2010. From 2010 until 2014, survey stations were located in the scallop access areas in Closed Area I (CAI) and Closed Area II (CAII). Beginning in 2015, the survey stations were moved to the northern portion of Georges Bank, covering the northern half of CAII (not currently open for the scallop fishery) and open areas to the west.

This year, as in years past, the project goals and objectives included:

1. Quantify groundfish bycatch rates in comparison to scallop meat yield with the goal of optimizing scallop harvest while minimizing impacts to other stocks.
2. Compare a modified dredge bag (5-row apron) designed to reduce flatfish bycatch, with the standard dredge (7-row apron).
3. Collect biological samples to examine conditions affecting scallop meat quality.
4. Assess scallop meat discards and measure scallop meat loss due to shucking.
5. Investigate the general biology of scallops and main bycatch species, specifically maturity, growth, and diseases.
6. Conduct biological sampling of bycatch crustacean and echinoderm species.

The paired dredge catch data is processed on-board the vessels. Scallop and bycatch species catch is quantified (counts, weights, and lengths), with particular focus on important bycatch species including yellowtail flounder, windowpane flounder, winter flounder, and lobster. Samples are collected to assess scallop meat quality and disease presence in scallops and yellowtail flounder.

During the 2016-2017 project year, we examined flounder, monkfish, and lobster bycatch rates. Scallop meat weight peaked in summer, when monkfish and lobster catches were also high. Overall, yellowtail and winter flounder bycatch rates were low (< 1.5 lbs. of fish/lb. of scallops). Windowpane bycatch rate was highest in May (> 2 lbs. of fish/lb. of scallops). Monkfish bycatch rates were the highest observed since the northern Georges Bank survey began in 2015 (> 3 lbs. of fish/lb. of scallops), except during the months of January and March (< 1.5 lbs. of fish/lb. of scallops). Lobster bycatch rate was also high in the summer to fall months (≥ 1 lbs of lobster/lb. of scallops). The majority of the catch was female, and 46% of the lobsters (322/703 lobsters) were not damaged by the scallop dredges. A total of 292 lobsters with a high chance of survival were tagged, and to date, eight tagged lobsters have been recaptured.

Since 2010, at least one of the dredges used in the project has been a turtle deflector dredge (TDD) with a 7-row apron. A second dredge has been towed at all stations, allowing for additional testing of gear modifications during the bycatch survey trips. For the 2015-2016 and 2016-2017 funding years, the projects tested a TDD with a 5-row apron against a TDD with a 7-

row apron. Analysis of the paired catch data suggested that the 5-row apron may be an effective gear modification for reducing flatfish bycatch.

CFF collaborators continued to study scallop meat quality and health using samples collected during bycatch survey trips. Understanding the cause of gray meats in scallops was a focus for the project, and samples of scallops with gray meats were examined by researchers at Roger Williams University (RWU). Previous work suggested that gray meats are caused by an Apicomplexan parasite, yet results from RWU suggest the cause of gray meat may be more complicated than originally determined since the parasite was found in white and gray meat scallops and parasite presence was not correlated with meat color.

Significant work was done to analyze spatio-temporal patterns in catch data and temporal patterns in fish and scallop reproductive stages. We observed high numbers of windowpane flounder across the northern portion of Georges Bank, with catches peaking in May, primarily in CAII, and in October, primarily in the open area. Monkfish was the most abundant fish species with the highest catch in June, while catches of yellowtail flounder and winter flounder were low overall.

The CFF seasonal bycatch survey continues to provide a wealth of data that can be used to address a wide range of issues that impact the ecosystem on Georges Bank. The long-term seasonal data set is unique and, as such, has been used to evaluate populations of multiple commercial fish species, supplying fisheries managers with critical information required to adhere to ACLs and AMs to optimize the harvest of scallops while minimizing bycatch. As new issues arise, the bycatch survey has adapted. There has been increasing interest in using the bycatch survey data as a time series. If it could provide a long-term seasonal data set that could be more effectively used to track changes in scallop and fish abundance over time on Georges Bank, the value of the project would be increased. Therefore, we hope to begin incorporating a set of fixed stations that would remain constant each year as the seasonal bycatch project continues.

INTRODUCTION

One of the most successful and economically valuable fisheries in the world is the wild Atlantic sea scallop (*Placopecten magellanicus*) fishery along the eastern coast of the United States (US), which brought in $489,151,816 in 2016 (NOAA 2016). The stock has been rebuilt from its overfished status in 1997, and no overfishing is occurring (NEFMC 2014). However, this profitable fishery is impacted by fish bycatch issues resulting in the potential loss of millions of dollars in revenues. Yellowtail (*Limanda ferruginea*) and windowpane (*Scophthalmus aquosus*) flounder Annual Catch Limits (ACLs) and Accountability Measures (AMs) have created a complex regulatory environment for the scallop fishery. Triggering the yellowtail flounder AM on Georges Bank results in scallop fishing area restrictions across eastern Georges Bank (NEFMC 2016), and time/area closures and gear restrictions are currently being considered to minimize windowpane flounder bycatch (NEFMC 2016).

Seasonal information pertaining to groundfish bycatch and scallop meat yield on Georges Bank was limited before the RSA-funded seasonal bycatch surveys began in 2010. Spatial and temporal variation in scallop meat yield has been observed on Georges Bank in relation to depth, flow velocity, and water temperature (Sarro and Stokesbury 2009). Although variation in yellowtail flounder bycatch rates had been noted on Georges Bank through observer data (Bachman 2009), the lack of spatially and temporally specific data on seasonal factors that influence meat yield and bycatch rates needed to be addressed. The seasonal bycatch survey that Coonamessett Farm Foundation (CFF) conducted from 2010 to 2013 addressed this data gap for Closed Area I (CAI) and Closed Area II (CAII) south of 41°30'N (CAII S), and in 2015 CFF started to fill this gap for the northern portion of Georges Bank. For this project the important bycatch species have been windowpane, winter, and yellowtail flounders, lobster, and monkfish; despite of this last species is typically not considered a bycatch species in the sea scallop fishery since they are landed for sale.

Under Amendment 10 of the Sea Scallop Fishery Management Plan (FMP), the scallop resource is regulated and harvested through a rotational area-based management scheme designed to allow for the identification and protection of juvenile scallops. The increased scallop harvest allowed by this strategy sometimes may unintentionally result in increased fish bycatch, in part due to a lack of knowledge of the life history of each fish species. For example, scallop access areas and fishing times were initially established in the closed areas on Georges Bank with limited data on the seasonal variation in yellowtail flounder distributions. As a result, scallop vessels were allowed to fish when yellowtail flounder were present in high numbers and scallop meat weights were low (Smolowitz *et al*. 2016). Data collected during our 2011-2013 seasonal bycatch survey (Smolowitz *et al*. 2012a, Smolowitz *et al*. 2012b, Goetting *et al*. 2013, and Huntsberger *et al*. 2015) provided the data needed to shift scallop fishing times to months when scallop meat yields are high and yellowtail flounder abundance is low, thereby reducing bycatch. This strategy was incorporated into Scallop Framework 24 which came into effect during the 2013 fishing year (NEFMC 2013).

This type of adjustment highlights the difficulties inherent to designing management plans that maximize catch and minimize bycatch of multiple species. Windowpane and yellowtail flounder occupy Closed Area II south (CAII S) during different seasons, and windowpane flounder abundance and bycatch rate peak when scallop vessels currently have access to CAII S (Siemann *et al.* 2017). This adjustment therefore lowers bycatch of one species, but may increase catch of another. In addition, the northern portion of Georges Bank, encompassing Closed Area II north of 41°30'N (CAII N) and surrounding open areas, suffers from a similar lack of seasonal distribution data for these bycatch species. Therefore, management measures proposed for CAII N may result in high catches of non-target species. CAII N is currently closed to scallop fishing year round (Smolowitz *et al.* 2016).

Despite efforts to minimize bycatch, yellowtail and windowpane flounder quotas continue to impact the scallop fishery. The allocation of Georges Bank yellowtail flounder to the scallop fishery was substantially reduced in 2015 based on results from the 2016 Transboundary Resource Assessment Committee's Georges Bank yellowtail flounder assessment (Legault and Busawon 2016). Since limited data on seasonal abundance of yellowtail flounder in the proposed survey area was used in this assessment, it is possible that overly-restrictive yellowtail sub-ACLs will be placed on the scallop fleet.

Additionally, bycatch of northern windowpane flounder is of considerable concern to the scallop industry. The northern windowpane ACL has been exceeded in recent years, resulting in restrictions being imposed solely on the New England groundfish fleet (NEFMC 2017). Yet northern windowpane bycatch rates are also high in the scallop fishery, and have increased in recent years (NEFMC 2017). Consequently, a very restrictive northern windowpane flounder sub-ACL has been allocated to the scallop fleet (NEFMC 2017). Potential solutions for reducing northern windowpane flounder bycatch include new adjustments to seasonal closures and scallop gear modifications. For example, triggering of the scallop fishery AM for southern New England (SNE) windowpane flounder closes areas west of 71°W and imposes gear restrictions (5-row apron and 1.5:1 hanging ratio) based on results from gear research conducted by CFF with RSA funding (Huntsberger *et al*. 2015; NEFMC 2014). Gear comparison and seasonal catch data collected during the CFF bycatch project continue to provide detailed information needed to enact sensible, data-driven AMs that should mitigate economic losses compared to other AM alternatives.

Finally, disease is often overlooked or dismissed as a cause of decreased or decreasing populations in marine animals (Grimm *et al*. 2016). However, when diseases cause scallops with poor quality meat, fishermen have to discard those meats, which leads to low meat yield and generates economic losses for the fishery. Scallop meat is normally firm and creamy-white. However, gray meat and orange nodules in the adductor muscle have occasionally been detected in our surveys. These diseases have been associated with Apicomplexan parasite (Inglis *et al*. 2016) and *Mycobacterium* sp. infections (Grimm *et al*. 2016), respectively. The Apicomplexan parasite may be responsible for the total collapse of a now-extinct species of scallops in Iceland (Kristmundsson *et al*. 2015), and *Mycobacterium* spp. are considered pathogenic in humans (Grimm *et al*. 2016). In addition, yellowtail flounder has been observed with *Ichthyophonus* sp., a protozoan parasite which has been identified as a cause of disease in over a hundred species of marine, fresh, and brackish teleost fish, as well as marine copepods and crustaceans. This parasite is lethal or debilitating in many fish species (Huntsberger *et al*. 2017). There is currently not enough evidence about the real impact of these three different diseases on scallops and yellowtail flounder on Georges Bank. The regular seasonal collection of scallop and fish tissue samples during the bycatch project has been invaluable for studying all of these potentially devastating diseases.

OBJECTIVES

1) Quantify groundfish bycatch rates in comparison to scallop meat yield with the goal of optimizing scallop harvest while minimizing impacts to other stocks.
2) Compare a modified dredge bag (5-row apron), designed to reduce flatfish bycatch, with the standard dredge (7-row apron).
3) Collect biological samples to examine conditions affecting scallop meat quality.
4) Assess scallop meat discards and measure scallop meat loss due to shucking.
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GENERAL SAMPLING METHODS

Study area

Georges Bank, located off the New England coast, supports many valuable commercial fisheries, including the largest wild scallop fishery in the world (Caddy 1989). Georges Bank has three areas (CAI, CAII, and HAPC) closed to all mobile bottom-tending gears since 1994 in order to protect declining groundfish stocks. For the 2016 seasonal bycatch survey, eight research trips were conducted on Georges Bank (**Table 1**). The initial plan was to sample within the Georges Bank northern edge Habitat Area of Particular Concern (HAPC), but the final survey did not include stations in the HAPC due to permit restrictions. The finalized grid, consisting of 58 stations, was sampled every other month with additional trips in June and October. Stations were the same as those sampled in the 2015 seasonal bycatch project. The start position for each station was randomly selected prior to each trip using 4 points 0.25 miles away from the station position (**Figure 1**).

Table 1. Trip dates and dredges used for the 2016 bycatch survey.

Month	Trip dates	Control dredge	Experimental dredge
July	13 Jul– 19 Jul 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron
September	7 Sep – 13 Sep 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron
October	11 Oct – 17 Oct 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron
November	15 Nov – 21 Nov 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron
January	10 Jan – 16 Jan 2017	CFF TDD with 7-row apron	CFF TDD with 5-row apron
March	7 Mar – 13 Mar 2017	CFF TDD with 7-row apron	CFF TDD with 5-row apron
May	2 May – 8 May 2017	CFF TDD with 7-row apron	CFF TDD with 5-row apron
June	15 Jun – 21 Jun 2017	CFF TDD with 7-row apron	CFF TDD with 5-row apron

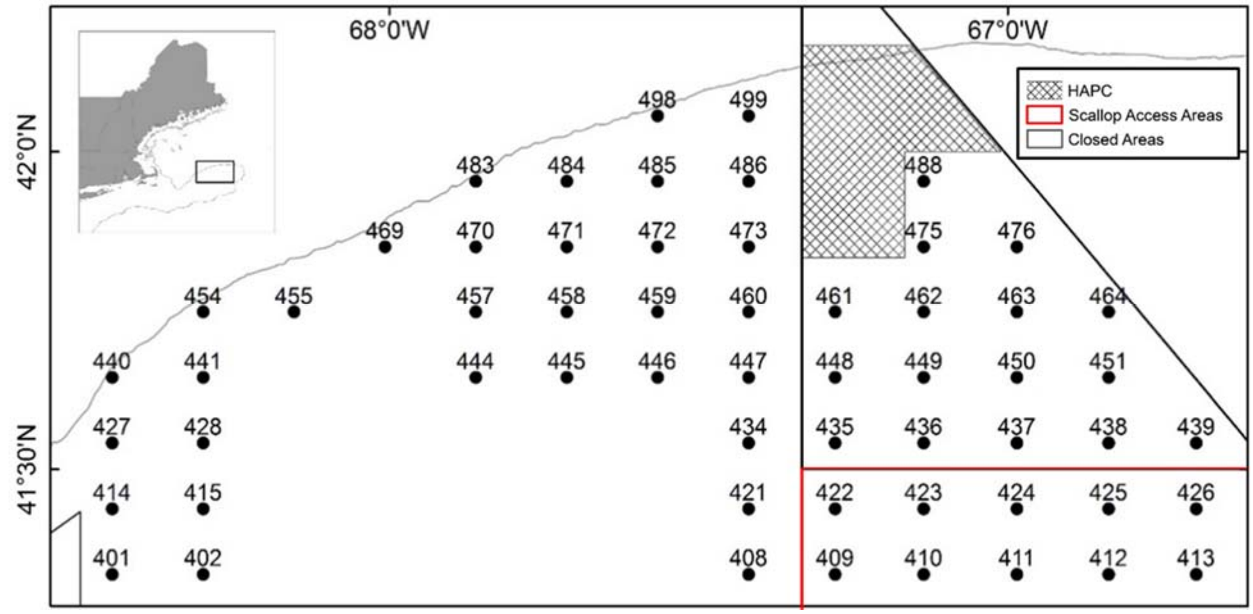


Figure 1. Location of the survey stations sampled for the 2016 seasonal bycatch survey on the northern portion of Georges Bank. The HAPC is shown as hashed lines and scallop access areas and the Hague line are shown in black. Stations are separated by 12 km.

Sampling design

At each station, a control and an experimental dredge (**Table 1**) were deployed simultaneously and towed at a target speed of 4.8 knots using a scope of 3:1 + 10 fathoms wire to depth ratio (gear details in **Table A1**). Both dredges were turtle-deflector dredges (TDDs), and for all trips, the control dredge had a 7-row apron and the experimental dredge had a 5-row apron. Target tow duration was 30 minutes, with a minimum tow time of 20 minutes due to technical difficulties. Stations were resampled if the tow parameters were not followed or if there was a gear malfunction (e.g. dredges fishing upside down). Tow direction was at the discretion of the captain, who was instructed to pass through the station's central coordinates at some point during the tow. Tow start and end, defined as when the winches were locked or engaged for haul back, were determined by the captain. Tow parameters were recorded using a Getac F110 ruggedized tablet with a custom access database. Vessel position, speed, and heading were recorded every 15 seconds using the built-in GPS on the Getac tablet. A Star-Oddi milli-TD data logger was deployed in a steel sheath welded to the TDD to record depth and temperature every 30 seconds throughout the survey.

For each paired tow, the catch from each dredge was processed identically. The catch was separated by species and weighed using Marel 1100 series motion compensated scales. Commercially important fish were measured to the nearest centimeter, and all other fish species were individually counted. Winter (*Leucoraja ocellata*) and little skates (*L. erinacea*), and occasionally other skate species, were counted together and categorized as "unclassified skates." Composition and estimated quantity of benthos (including rocks, sand dollars, crabs, sea stars, clams and shell debris) was also noted. **Table A2** lists all species that were caught by common and scientific name, number captured, and the sampling protocol.

Ten randomly selected windowpane, winter (*Pseudopleuronectes americanus*), and yellowtail flounders (10, or fewer if the total yellowtail catch equaled less than 10 fish) were sampled at each station to determine sex and reproductive stage. Additionally, the subsample of yellowtail flounder was examined macroscopically for *Ichthyophonus* infection.

The entire scallop catch was quantified in bushels (bu=35.2 liters). A one-bushel subsample of scallops was selected at random from each dredge and shell height was measured in 5-mm increments. At two stations during the last trip, one bushel was taken to estimate meat discards for scallops. During this assessment, the scallops were examined for marketable meats, unmarketable meats, and scrapings.

At each station, 30 scallops (or fewer if total catch < 30 scallops) were randomly selected to determine shell height, meat weight, gonad weight, sex, reproductive stage, quality of the meat, and presence of orange pustules. These scallops were measured to the nearest millimeter from the umbo to the shell margin then carefully shucked. Meat quality was assessed on a qualitative color scale (**Figure 2**). A subsample of scallop meats of different colors was collected for further laboratory evaluation. Each animal was also examined for the presence of orange nodules, and if nodules were present, two separate tissue samples were collected, one in formalin and the other in ethanol for laboratory processing. White meat scallops with no noticeable nodules were also collected following the same procedure with clean equipment as controls.

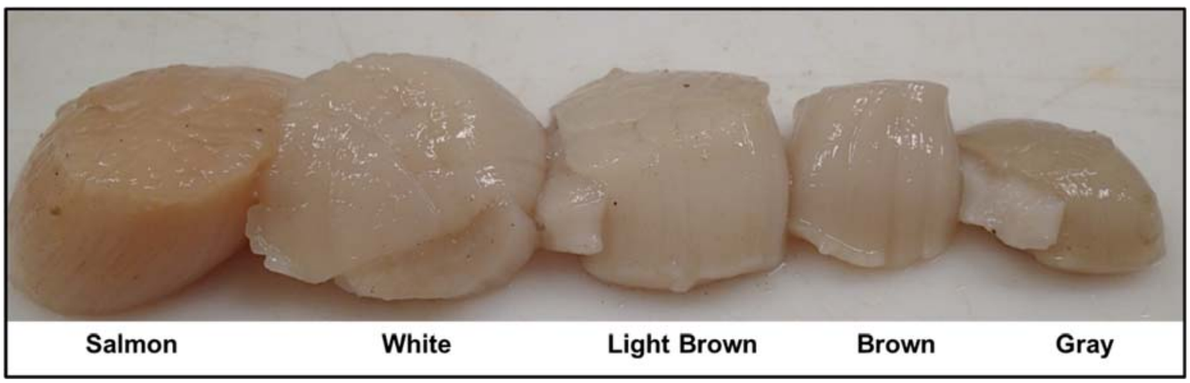


Figure 2. Image showing the qualitative scale used to classify scallops by meat color. Scallops with brown/gray meat show muscle degeneration. Scallops with salmon and white meats were combined.

All lobsters (*Homarus americanus*) caught in the dredges were examined (Smith and Howell 1987). Carapace length, sex, presence of eggs, shell hardness, incidence of shell disease, and damage due to the dredge were recorded. Dredge damage was assessed on a scale from 0 to 5, with 0 indicating no damage and 5 indicating a fatal/dismembering crush by the dredge (**Table 2**).

Table 2. Classification of types of damage to lobsters caused by scallop dredges.

Valid Damage	Damage Description	Category of damage
0	No damage	**No Damage**
1	Missing an appendage, chipped carapace, (90% chance of survival)	**Moderate Damage**
2	Moderate damage to shell, slow response after 10 minutes observation (70% chance of survival)	

Valid Damage	Damage Description	Category of damage
3	Lethal injury, still responding (less than 30% chance of survival)	**Lethal Damage**
4	Killed by dredge, still intact	
5	Killed by dredge, smashed, ripped to pieces	

Laboratory analysis

Scallops with gray meat: Muscle tissues preserved in formalin were processed in the Aquatic Diagnostic Laboratory at Roger Williams University laboratory (RWU ADL). One paraffin-embedded tissue section from each sample was stained with hematoxylin and eosin (Howard *et al*. 2004). These sections were evaluated for the occurrence and severity of Apicomplexan parasites and their effects on the adductor muscle using the following parameters: microscopic condition of the muscle fibers, occurrence of zoites (presumed sporozoites), macrogametes, and overall cellularity of the muscle (Levesque *et al*. 2016). Adductor muscles were also evaluated for the occurrence and severity of mycobacterial granulomas. Muscle condition was determined and reported on a scale of 0 to 3 (0 = normal, 1 = mild, 2 = moderate, 3 = severe).

Cellularity was evaluated and reported as the product of two measurements. First, cellularity based on the increase in visible nuclei was noted in the histological sections using a scale from 0 to 3 (0 = no increase; 1 = mild increase in cellularity; 2 = moderate increase; 3 = severe increase). Second, the histological location of the increase in muscle cellularity was also evaluated using a scale from 0 to 3 (0 = normal; 1 = focal increase in cellularity; 2 = multifocal increase in cellularity; 3 = diffuse increase in cellularity). Therefore, total cellularity values ranged from 0 to 9.

Finally, the RWU ADL developed a new PCR test method to detect the presence of the Apicomplexan parasite in the meats. The development of this PCR test can be found in Mastrostefano 2018.

Data analysis

Shell height-meat weight (SHMW) relationship: Sea scallop meat weight was predicted using a generalized linear mixed model (gamma distribution with log link using PROC GLIMMIX on the SAS system v. 9.2). This mixed modeling approach uses likelihood-based estimation that has multiple advantages to traditional approaches. The gamma distribution used in this analysis is generally considered a more appropriate distribution for data of this type. A random effect for station+trip was included in the model to account for random variation in the data due to both temporal and fine scale spatial variability. This grouping variable is a unique identifier that relates to the trip (temporal identity) and spatial location of the sample. **Table 3** shows the continuous and categorical variables used in the analysis. The samples were spatially segregated into two areas. The delineation of the areas was based upon the current boundaries of CAII, thereby dividing the samples between areas that are fished regularly (non-CAII) versus not fished for years or fished seasonally (CAII). Potentially biologically relevant interactions were also explored in the analysis. Akaike's information criterion (AIC) scores were used to select the best model configuration (**Appendix B**).

Table 3. Predictor variables used in the shell height/meat weight analysis.

Continuous Variables	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Shell Height	50	193	135.98	12.88
Depth (m)	26.7	97.3	60.63	14.3
Classification Variables	**Levels**			
Area	CAII, Non-CAII			
Month	August, September, October, November, January, March, May, June			
Sex	Male, Female			
Reproductive Stage	Resting, Spent, Ripe, Partially Spent, Developing			
Meat Color	Light Brown, Brown, Gray, White			
Interaction Variables	Month*Area, Area*Depth, Shell Height*Area			

An additional analysis of the seasonal SHMW relationship was done for the working group for the 2018 sea scallop benchmark assessment to assess the impact of changes in scallop survey timing and the SHMW relationship used in biomass estimations of Georges Bank scallops. This analysis excluded scallops with shell heights under 70mm and scallops with gray meats. Meat weight was modelled using log shell height (lnSH), time as days since April 30th (mday), mday^2, and an interaction term between lnSH and mday. Station was included as a random effect. Models were run using the function "pqlmer" in the R package "r2glmm" (Jaeger 2017). Akaike's information criterion (AIC) scores were used to select the best model configuration.

Groundfish bycatch rates vs scallop meat yield: the seasonal catch rates of important bycatch species (windowpane, winter, and yellowtail flounders; monkfish (*Lophius americanus*); and lobsters) were calculated in relation to the scallop catch. For this analysis, both dredges were combined. To calculate the total meat weight of scallops caught per trip, we calculated the expected meat weights using a generalized linear model with shell height, trip month, and depth as predictor variables (R base function "glm" with gamma distribution and log link) (R Core Team 2015). Results of the more extensive SHMW model testing indicated these variables were all important predictors of meat weight (described in SHMW results). The meat weight (in pounds) was calculated for the measured bushel, which was expanded for the entire catch. The measured weight of bycatch species (in pounds) was divided by the calculated scallop weight to get a bycatch rate (fish weight/ scallops weight).

Gear comparison: This analysis attempted to construct a model that would predict the relative efficiency of the 5-row apron dredge (experimental) relative to the 7-row apron dredge (control) for scallops and fish species based on a variety of covariates including animal length and trip. Because gear modifications can possibly alter the relative size composition of the catch, the unpooled catch data was examined to predict the changes that the 5-row dredge had on the relative catch at length for the two gears. For many species; however, length was not a significant predictor of relative efficiency. Therefore, overall changes in the relative total catch were also tested using the pooled catch data. See **Appendix C** for a detailed description of the analytical framework used in the study.

Scallop meat quality: The numbers of scallops with gray meats and orange nodules in the subsets sampled for SHMW analysis were mapped to look for areas with high infection rates. To determine if there is a relationship between gray meats and the Apicomplexan parasite, meat color was plotted as a function of sporozoite number, muscle condition index, and cellularity index.

General biology of the target and main bycatch species: The reproductive stages of the sea scallop and three flounder species (winter, windowpane and yellowtail flounders) were plotted to examine seasonal changes and estimate spawning periods for each species. Scallops were assessed using the gonadal mass index (GMI):

$$GMI = {}^{GM}/_{SH^b}$$

where *b* = slope of the regression line for gonadal mass (GM) against shell height (Bonardelli and Himmelman 1995). For the flounder species, reproductive cycle was described based solely on macroscopic observations.

Length-weight relationships for the main bycatch species by sex were estimated using the traditional linear regression model based on the standard allometric equation to predict fish weight

$$ln\mathrm{W} = ln\ a + b\ ln\mathrm{L}$$

where W = weight (kg), L = length (cm), a = y-intercept, and b = slope (Wigley *et al.* 2003).

Damage assessment was done for all lobsters caught in the dredges, with lobster damage scored on a scale from no damage to dismembered (0 – 5). These damage scores were grouped in three categories for further analysis (**Table 2**).

RESULTS BY OBJECTIVE

Objective 1: Quantify groundfish bycatch rates in comparison to scallop meat yield with the goal of optimizing scallop harvest while minimizing impacts to other stocks.

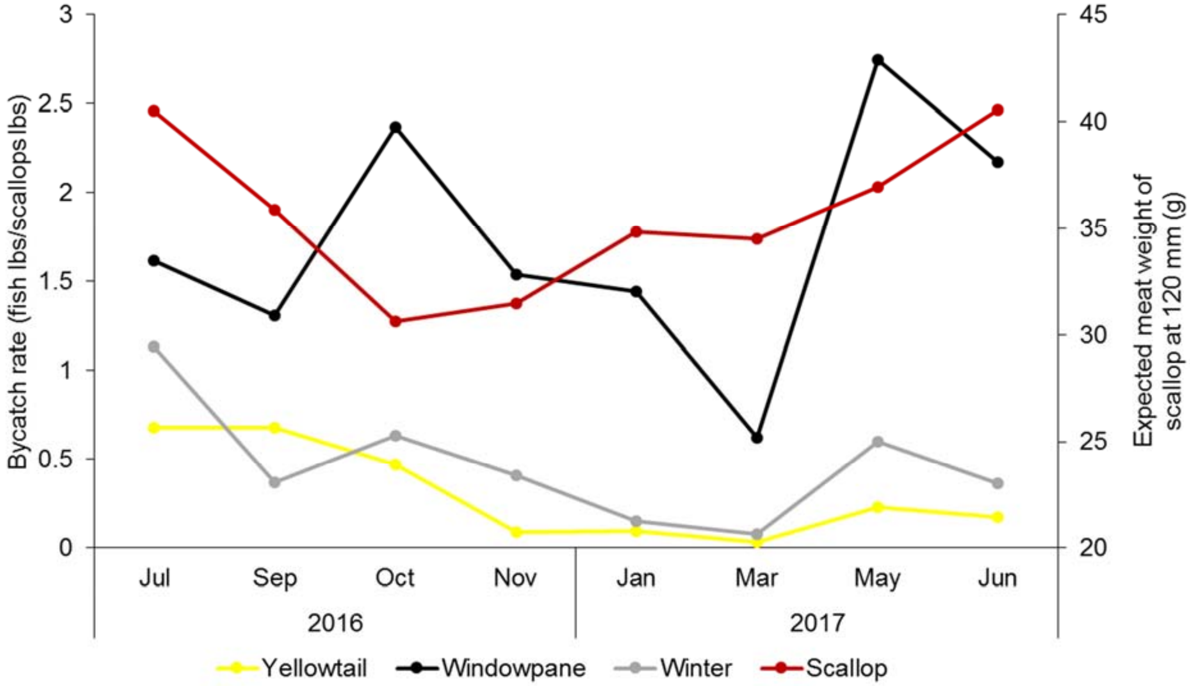
The seasonal catch rates of important bycatch species were calculated in relation to the scallop catch (i.e., lbs. of fish/lbs of scallops). The overall bycatch rates for winter and yellowtail flounder were low (< 2 lbs. of fish/lbs of scallops). Bycatch rates peaked at 0.68 lbs. of fish/lbs of scallops in July and September for yellowtail and at 1.13 lbs. of fish/lbs of scallops in July for winter flounder (**Figure 3a**). Windowpane bycatch rate was highest in May at 2.75 lbs. of fish/lbs of scallops (**Figure 3a**). Bycatch rates for monkfish were higher in general (> 8 lbs. of fish/lbs of scallops) and peaked in June at 12.8 lbs. of fish/lbs of scallops (**Figure 3b**). During this project lobster bycatch rates were low, with October being the month with the highest rate (1.7 lbs. of fish/lbs of scallops; **Figure 3c**). Overall, winter months had the lowest bycatch rates for the bycatch species that were examined.

Total catch by species by area is displayed for each survey month in **Table 4**, and distribution of total catch is also mapped for each survey trip. Each of the species manifested a differential spatial distribution. Scallops were distributed mostly in the periphery of the sampling area during the sampling period (**Figure E1**), with peak abundance in September (**Table 4**) in both CAII and non-CAII areas. Yellowtail flounder catch was low with a clear habitat preference towards the eastern part of the sampling area (CAII; **Figure E2**) and peak abundance in September (**Table 4**). In contrast, winter flounder, windowpane flounder and monkfish had fairly uniform distributions in the study area (**Figure E3**, **E4**, **E5**), with windowpane flounder as the most abundant species throughout the sampling period, especially in May in CAII and in October in non-CAII (**Table 4**). Winter flounder catch peaked in July in CAII and in May in non-CAII (**Table 4**), and monkfish were most abundant in July and September in CAII and non-CAII, respectively (**Table 4**). Summer flounder catch was minimal, never exceeding 120 individuals per trip (**Table 4**); the catch was greatest during the summer-fall months, but was otherwise relatively low. Finally, lobsters were caught in most of the study area, but in higher numbers in the eastern part of the survey area during the months of July, September, and October (**Figure E6**; **Table 4**).

Table 4. Total catches by area by trip. Scallop catch is quantified in bushels and fish in number of fish.

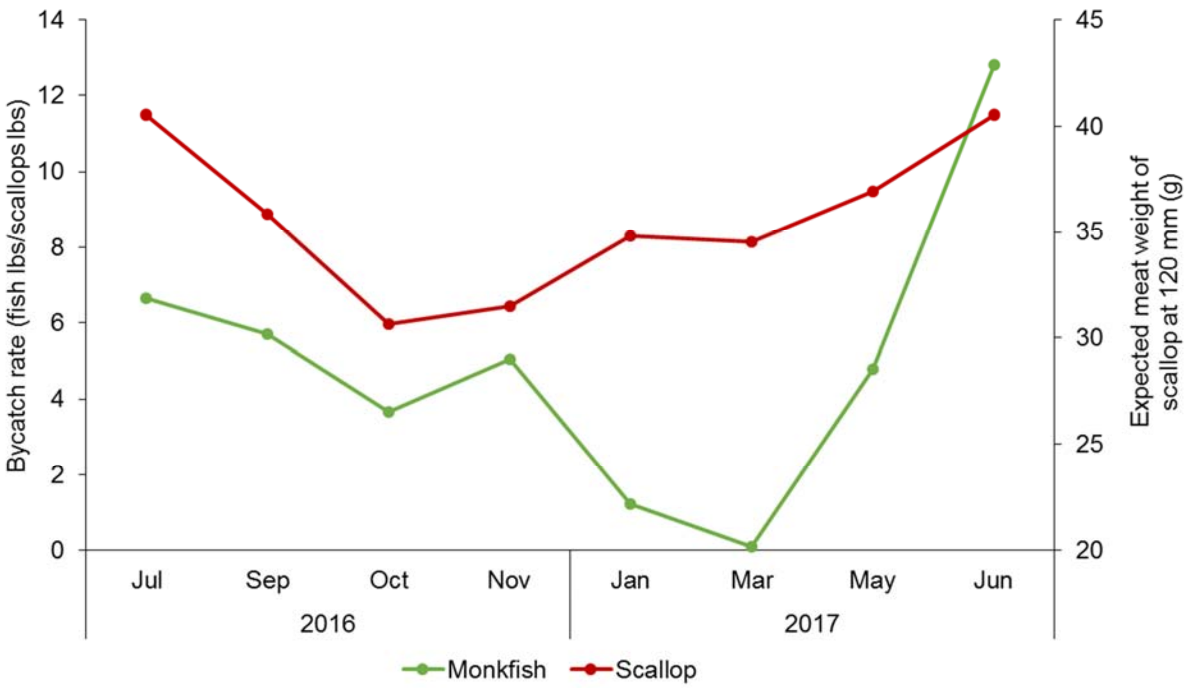
Year	Month	Scallop		Summer Flounder		Yellowtail Flounder		Winter Flounder		Windowpane Flounder		Monkfish		Lobster	
		CAII	Non-CAII	CAII	Non-CAII	CAII	Non-CAII	CAII	Non-CAII	CAII	Non-CAII	CAII	Non-CAII	CAII	Non-CAII
2016	Jul	33.46	41.47	24	76	151	13	97	61	471	791	450	515	72	86
	Sep	50.69	53.14	30	88	304	2	55	32	509	832	178	715	116	81
	Oct	22.96	36.82	23	50	154	8	80	30	614	1006	79	228	45	134
	Nov	30.99	43.46	16	1	23	11	42	24	439	565	127	322	9	37
2017	Jan	28.96	23.67	0	0	24	1	13	7	554	245	32	32	0	1
	Mar	31	37.19	0	0	13	0	16	0	408	78	3	3	3	1
	May	26.4	43.23	1	2	54	27	52	68	1003	958	215	105	5	3
	Jun	26.11	35.07	8	40	39	22	28	28	193	965	284	670	53	58

a)



3
2.5
2
1.5
1
0.5
0
45
40
35
30
25
20
Bycatch rate (fish lbs/scallops lbs)
Expected meat weight of scallop at 120 mm (g)
Jul
Sep
Oct
Nov
Jan
Mar
May
Jun
2016
2017
Yellowtail
Windowpane
Winter
Scallop

b)



14
12
10
8
6
4
2
0
45
40
35
30
25
20
Bycatch rate (fish lbs/scallops lbs)
Expected meat weight of scallop at 120 mm (g)
Jul
Sep
Oct
Nov
Jan
Mar
May
Jun
2016
2017
Monkfish
Scallop

c)

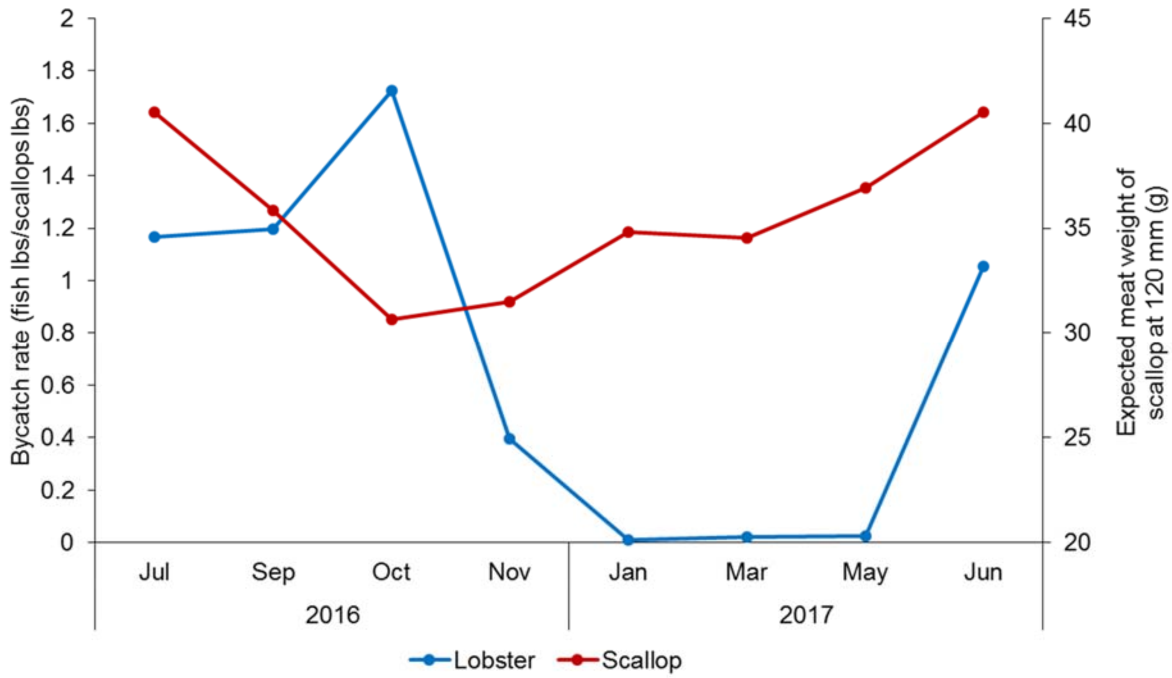
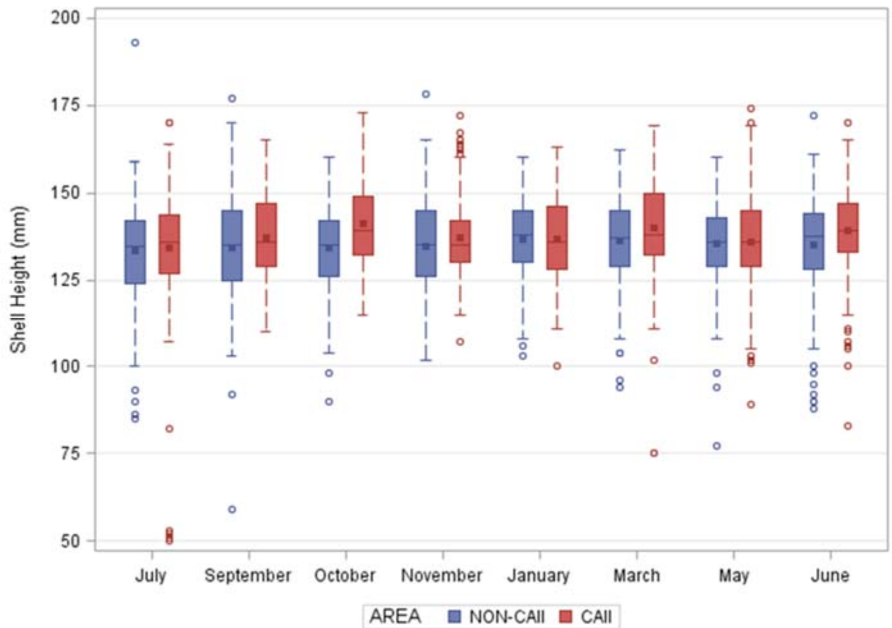


Figure 3. Bycatch rates for commercially important species **a)** flatfish, **b)** monkfish and **c)** lobsters, in relation to scallop catch during this survey. The seasonal change in meat weight for a 120-mm scallop is expressed as expected weight in grams (g) using the results from the SHMW model (red solid line with secondary axis).

Shell height-meat weight (SHMW) relationship

During the eight trips that took place from July 2016 through June 2017, a total of 4,339 scallops were sampled at 225 stations. Scallop shell heights ranged from 50 mm to 193 mm and meat weights varied from 7.0 g to 110.0 g. Spatial and temporal distributions of the collected shell heights and meat weights are shown in **Figure 4**. Log transformed shell height and meat weight data with various groupings (month, meat color) are shown in **Figure B1**.

a)



b)

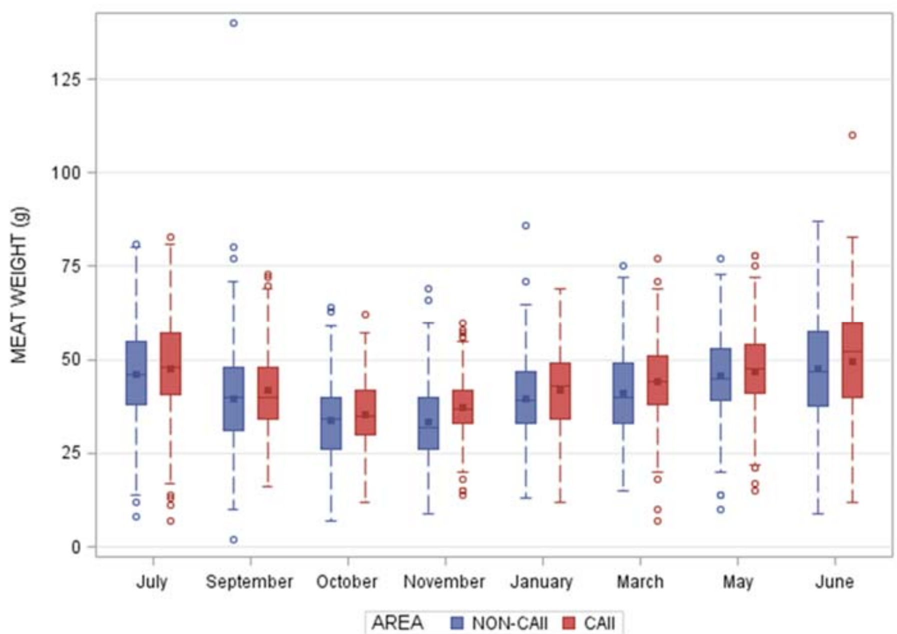


Figure 4. Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples in CAII and non-CAII. The marker and line inside the box represents the mean and median values, respectively. The bottom and top edges of the box represent the interquartile range (25th and 75th percentiles). The whiskers that extend from each box indicate the range of values outside the interquartile range and the markers outside of the whiskers represent the observations outside of 1.5 times the interquartile range.

Candidate models were evaluated and the model that produced the lowest AIC value was chosen as the model that best fit the data. Combinations of explanatory variables that were evaluated and resulting AIC values are shown in **Table B1**. The selected model is shown below:

$$MW = e^{(\beta_0+\delta+\beta_1 *\ln(SH)+\beta_2*(M)+\beta_3*(A)+\beta_4*(S)+\beta_5*(C)+(\beta_6*ln(SH)*A)+\epsilon)}$$

where δ is the random effect term (intercept), MW is scallop meat weight in grams, SH is shell height in millimeters, M is trip month when the sample was taken, A is subarea (non-CAII, CAII), C is meat color and an interaction term between SH and location. Based on an examination of residuals, model fit appears to be reasonable.

Parameter estimates shown in **Table B2** predicted increasing meat weight as a function of increased shell height. Meat weights were slightly higher in Closed Area II relative to stations outside of the area. The temporal trend indicated that meat weights were elevated through their peak from June-July and decreased to a trough from October – November. Meat color was a significant predictor of meat weight. As meats deviated from white and transitioned through brown to gray, there was a decreasing predicted value of meat weight relative to shell height. The interaction between shell height and area returned a negative coefficient for CAII, indicating that that meat weight increased more rapidly with shell height in the open area. Temporal trends of a modeled 120 mm scallop for the two areas are shown in **Figure 5**. Estimated curves by month for the two areas are shown in **Figures 6**. Finally, **Figure 7** shows the predicted effect of meat color on meat weight. Gray meats typically are associated with lower meat weights relative to shell size.

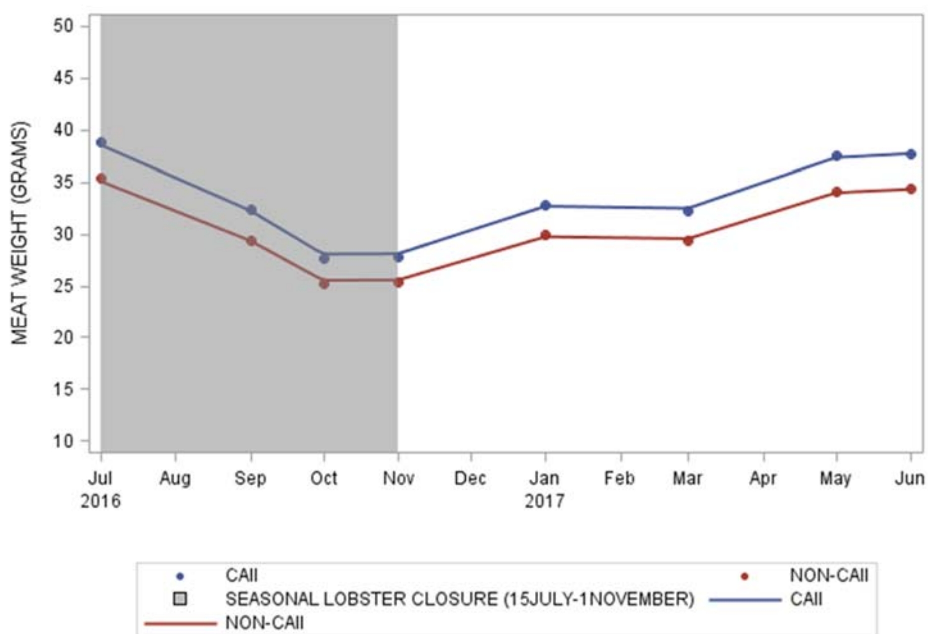
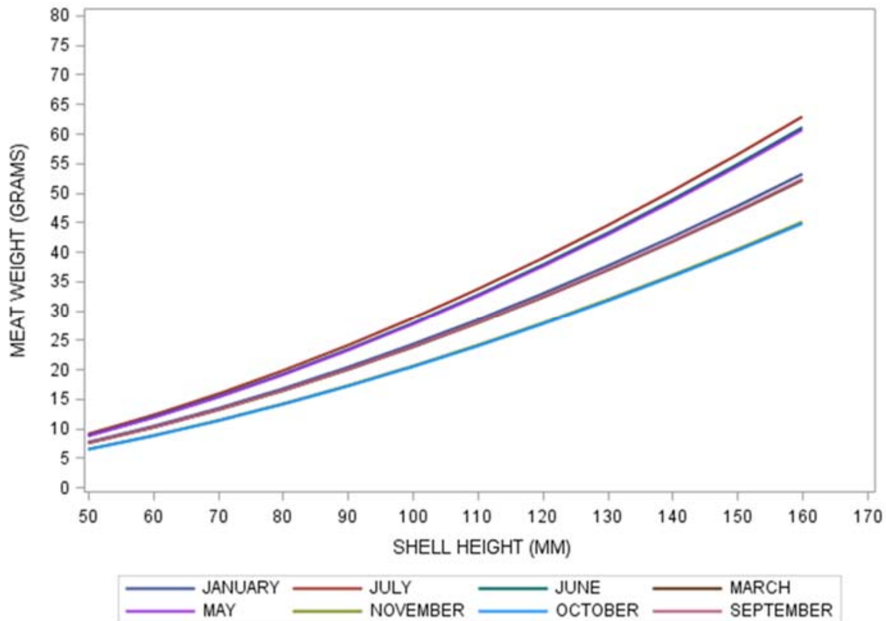


Figure 5. Temporal trends for the predicted meat weight of a white-meat 120-mm shell height scallop from the two areas on the northern edge of Georges Bank. Estimated meat weights were calculated from parameter estimates from the lowest AIC value model (red and blue circles). A smoothed curve is used to show the seasonal trend in meat weight (red and blue lines).

a)



b)

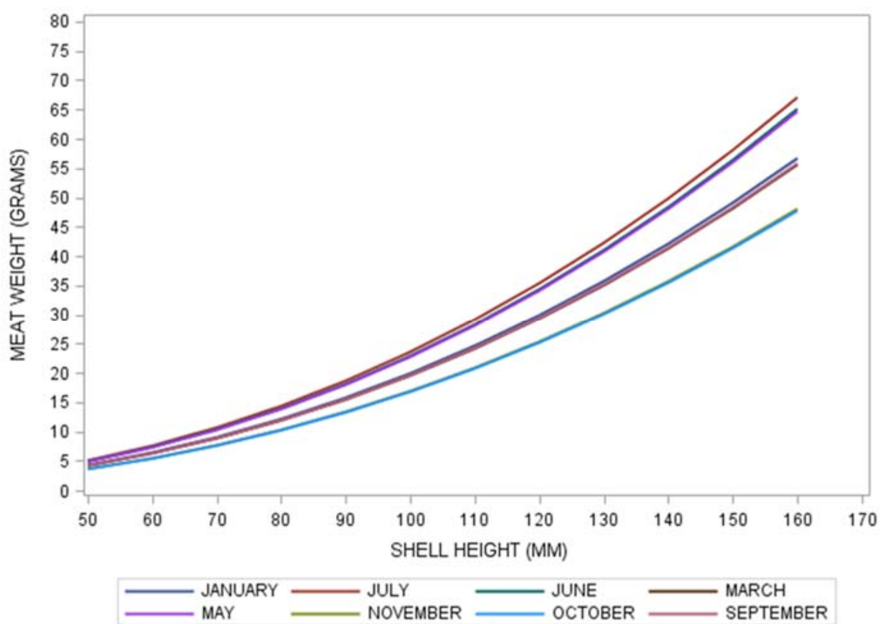


Figure 6. Comparison of estimated SHMW curves for white meat scallops for each month in **a)** CAII and **b)** non-CAII.

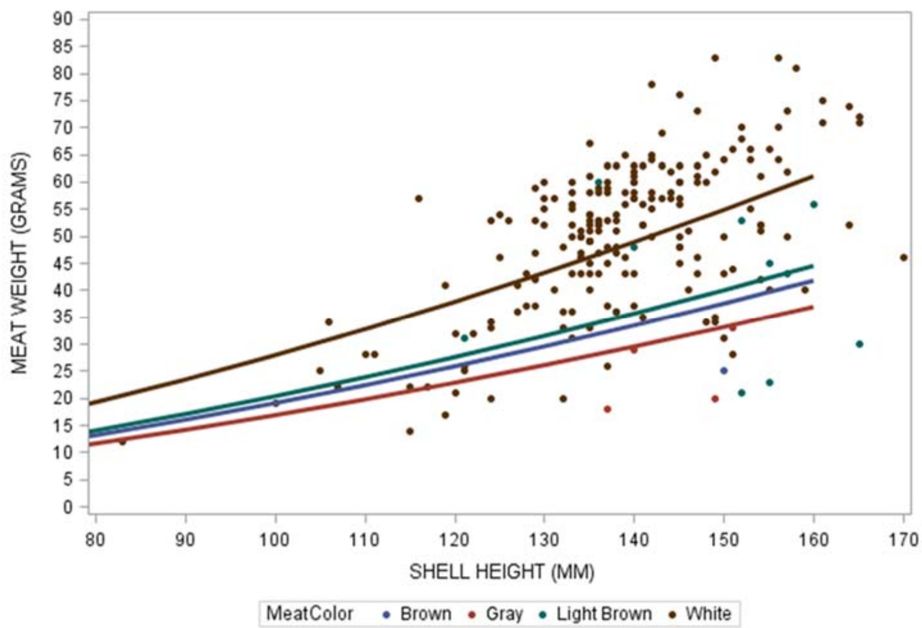


Figure 7. Scale of the effect of meat color on the predicted meat weight of scallops from CAII during June of 2017.

Seasonal shell height-meat weight (SHMW) relationship: The model with all effects included was selected using AIC scores (**Table 5**). Meat weight estimates increased with increasing shell height (**Table 6**) and meat weights at each shell height were highest in May and lowest in winter months (**Figure 8**). The analysis indicated that seasonal effects should be included when estimating the biomass of Georges Bank scallops.

Table 5. AIC values used to select the best seasonal GLMM model for Georges Bank.

Fixed effects	df	AIC
lnSH, mday, mday^2, lnSH:mday	7	-3135.558
lnSH, mday, mday^2	6	-3123.278
lnSH, mday	5	-2883.184
lnSH, mday, lnSH:mday	6	-2881.667
lnSH	4	-2379.824

Table 6. Parameter estimates for the best model selected by minimum AIC value.

Fixed effects			
	Estimate	SE	t value
(Intercept)	-5.64E+00	1.94E-01	-29.07
lSH	1.92E+00	3.95E-02	48.67
mday	-6.91E-03	9.97E-04	-6.92
mday^2	4.47E-06	2.32E-07	19.29
lSH:mday	1.02E-03	2.02E-04	5.02

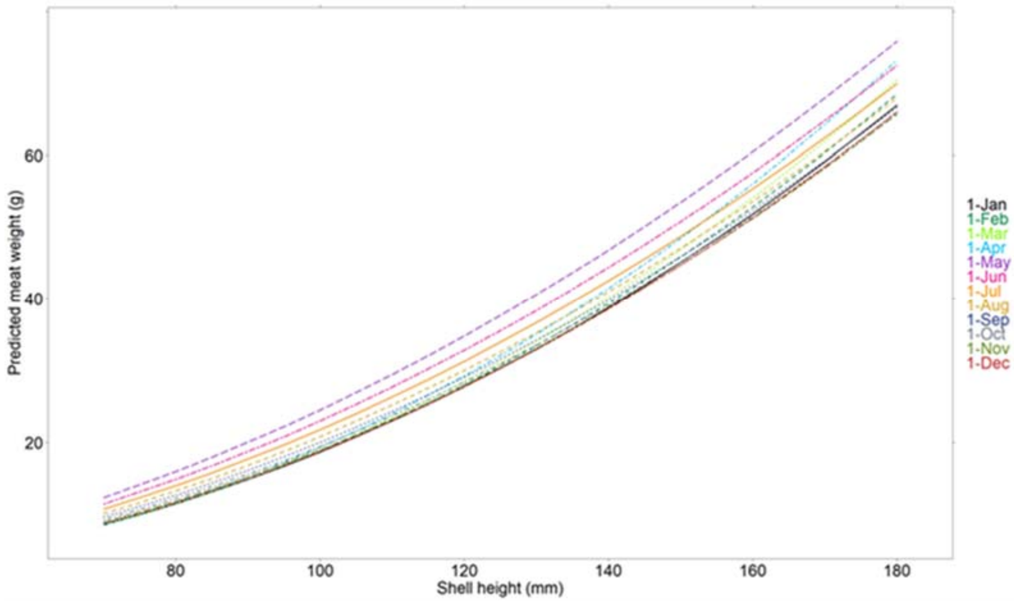


Figure 8. Predicted meat weights by shell height and month.

<u>Objective 2: Compare a modified dredge bag (5-row apron), designed to reduce flatfish bycatch, with the standard dredge (7-row apron).</u>

Gear comparison (5-row vs. 7-row apron)

During the 2016 survey year, there was consistency in the tested dredge gear. All trips used standard dredges that differed only with respect to the configuration of the apron. It was this attribute of the experimental design that allowed for the examination of the resulting catch data as a single data set. Overall, this data set consisted of 454 valid tow pairs that were examined in the analysis. Not all species were present in all tow pairs and for the species examined, individual tows with zero total catch for a given species were uninformative and excluded from the analysis. While a broad cross section of bycatch species were encountered, we focused our analysis on a subset of species encountered that consisted of commercially important species or species of special management concern. The species examined were unclassified skates, barndoor skate (*Dipturus laevis*), summer flounder (*Paralicthyes dentatus*), fourspot flounder (*Hippoglossina oblonga*), yellowtail flounder, winter flounder, windowpane flounder, monkfish and sea scallops.

<u>Length-based estimates</u>: For the analysis that tested for a difference in relative efficiency as a function of fish/scallop size, length was included in the model as a predictor. Since the trips were conducted over eight individual trips, it was informative to examine whether the relationship between the length-based relative efficiency varied between trips. The covariates tested in this analysis were length, second order polynomial of length (to capture potential non-linearity in the length term, trip, and interaction between trip and length (this effect tested for different slopes between trips). For some species, there was not enough data to provide meaningful results from the more complex models. In most of these cases this failure resulted from a small number of tow pairs where there were non-zero observations and the model failed to converge. **Table D1** shows the model building/selection results to find the most parsimonious model for each species. Parameter estimates associated with the selected model specification for each species is shown in **Tables D2-D4**. Graphical representations of the observed, length based catches and predicted relative efficiencies derived from the model output are shown in **Figures D1-D3**.

For the length-based model, windowpane flounder, sea scallops, and fourspot flounder were the only species where length represented a significant or marginally significant predictor of relative efficiency. In addition, two species (sea scallops and windowpane flounder) also exhibited differences in the slope of the length-based relationship as a function of trip. **Figure D1-D2** show the graphical results for these species as a function of length. Looking across the landscape of length based estimates, there was no consistent directionality across species and trips suggest a wide variation between within species and between trips with respect to the predicted function. This is demonstrated in the trip-specific curves generated for sea scallops, where in some of the trips the 5-row dredge captured fewer smaller scallops and as size increased, this dredge became more efficient. For other trips, this pattern was reversed. For windowpane flounder, the estimated slope was typically flat to slightly negative. This result suggested that the 5-row apron dredge was slightly more efficient at smaller lengths and the relative efficiency decreased as length increased. Trip was not a significant predictor of fourspot flounder catch and the slope of the relationship was significantly negative as a function of increasing length. It should be noted that the sample size for this species was somewhat low and this is reflected in the uncertainty around the estimated proportion at length.

Pooled-over-length estimates: Animal length was not a significant predictor of relative efficiency for many of the species analyzed. Since this was the case, the length data was pooled over length to examine the relative efficiency of the two dredge configurations with respect to total catch. **Table D5** shows the model building/selection results to find the most parsimonious model for each species. Parameter estimates associated with the selected model specification for each species is shown in **Tables D6-D7**. Graphical representations of the observed pooled catches and predicted relative efficiencies derived from the model output are shown in **Figures D4-D6**. For all species except unclassified skates and yellowtail flounder, the intercept only model was the most appropriate. For the aforementioned species, trip was a significant factor predicting the relative efficiency between the two dredge configurations.

For the other species where the intercept-only model was most appropriate, total catches for barndoor skate, summer flounder and monkfish were not statistically significant. For the species where trip was a significant factor, unclassified skate catch was reduced in the 5-row apron relative to the 7-row apron dredge. Yellowtail flounder catch was not reduced in the 5-row apron relative to the 7-row apron, and this was reflected in the variability observed between trips. When relative efficiencies were examined by grouping the data for all species across lengths and trips (intercept only models), there was a consistent reduction of flatfish and skate catch by the 5-row apron, with statistically significant reductions for fourspot, winter, and windowpane flounders and unclassified skates (**Table 7**). Monkfish catch increased overall, while scallop catch decreased slightly, but both changes were not significant.

Table 7. A comparison of the relative efficiencies estimated from the intercept-only models for the analyzed species and the observed percent differences from the catch data. Statistical significance (alpha=0.05 level) is specific to that model and may not be the most parsimonious model from the analysis.

Species	5-row Apron Dredge	7-row Apron Dredge	Percent Difference	Model Estimate	Statistical Significance
Uncl.Skates	**25,434**	**27,871**	**-8.74**	**-11.74**	**YES**
Barndoor Skates	265	315	-15.87	-13.63	NO
Summer Flounder	175	184	-4.89	-4.89	NO
Fourspot Flounder	**75**	**108**	**-30.56**	**-36.38**	**YES**
Yellowtail Flounder	400	446	-10.31	-16.88	NO
Winter Flounder	**249**	**381**	**-34.65**	**-41.95**	**YES**
Windowpane Flounder	**4,461**	**4,869**	**-8.38**	**-11.33**	**YES**
Monkfish	2,019	1,939	4.13	5.11	NO
Sea Scallops	21,297	20,836	2.21	-2.18	NO

The modifications to the apron of the dredge bag resulted in differences in the catch of both the target species as well as the common bycatch species encountered during the survey. One of the most significant conclusions of this work is the overall reduction of catch by the 5-row apron dredge relative to the 7-row apron dredge for flatfish species of concern (winter and windowpane flounders). One of the principles for any gear modification is the maintenance of target catch, and our results indicated that the overall scallop catch was not reduced significantly.

Moreover, there was a reduction in the catch of small scallops by the 5-row apron dredge with a concomitant increase in relative efficiency for larger sized scallops during some trips. These results are informative in that they provide insight into how apron modifications with its implied shift in twine top position relative to the sweep chain can affect individual species or similar groups of fish. With this insight, further modifications can be made in an attempt to facilitate additional reductions in bycatch.

Objective 3: Collect biological samples to examine conditions affecting scallop meat quality

Orange nodules: Stations 488 and 473, near the HAPC, had poor quality scallops and station 488 had the only occurrence of scallops with orange nodules (**Figure 9**). During the 2016 research project, one scallop was observed to have orange nodules during the shell height meat weight analysis (**Table 8**). Previous work from the 2013 bycatch survey identified *Mycobacteria* sp. as a causative agent of the orange nodules in the Georges Bank sea scallop (Grimm *et al.* 2016). This was the first time *Mycobacteria* sp. infections were identified in scallops. The orange coloration is a result of inflammation, and lesions caused by mycobacterial infection have a different macroscopic appearance than lesions observed from nematode infections in the mid-Atlantic.

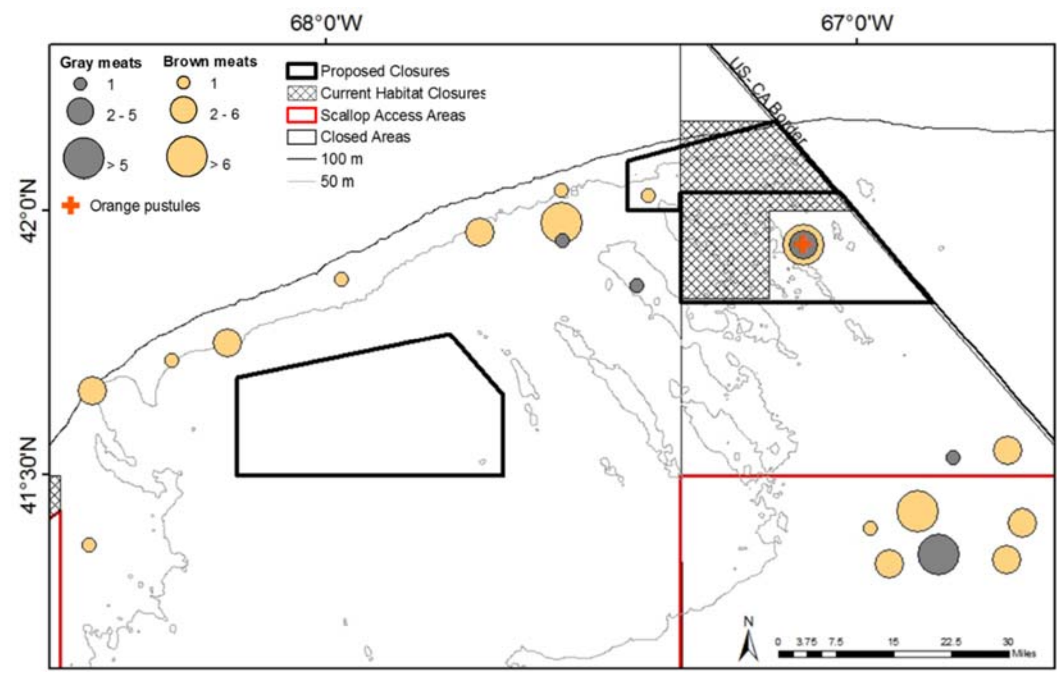


Figure 9. Locations where orange nodules, brown and gray meats have been identified during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Table 8. Number of scallops by color and with orange nodules

Year	Month	White	Light Brown	Brown	Gray	Orange Nodules
2016	Jul	529	12	11	0	0
	Sep	509	7	1	0	0
	Oct	515	5	2	1	0
	Nov	566	13	1	1	0
2017	Jan	484	11	1	6	0
	Mar	521	3	1	2	0
	May	631	0	2	0	0
	Jun	501	11	2	4	1
Total		**4256**	**62**	**21**	**14**	**1**

Gray Meat: Until recently, it was believed that Apicomplexan parasite was highly pathogenic and once scallops showed clinical signs of gray meat disease (e.g., gray color, stringy adductor muscle) they would eventually die (Levesque *et al*. 2016). Historically, gray meat outbreaks in Atlantic sea scallops have been described as episodic. However, in 2016 these outbreaks appear less episodic and more persistent on Georges Bank and included smaller size classes of scallops (Stokesbury *et al*. 2016). In this year's project, gray meat scallops were widely observed in the survey areas throughout the sample period (July 2016 - June 2017; **Figure 9**), although we did observe an overall decrease in the number of gray meat scallops compared with last year project. The percentages of gray meat scallops by station were: 4.5% for station 488 (5 of 112 samples), 2.5% for station 412 (6 of 242 samples), 1.3% for station 438 (1 of 78 samples), and 0.9% for station 485 (1 of 112 samples). Station 473 also had a high percentage of gray meat (5%), but only twenty scallops were caught at this station, and only one had gray meat. At all other stations, no scallops with gray meats were caught. CFF is planning further evaluation of this dataset in the near future.

All gray, brown, and light brown meats collected, along with white meat controls, were sent to the RWU ADL to confirm Apicomplexan infection. Identification used in this report followed previous descriptions of similar parasites (Dubey *et al*. 1998; Kristmundson *et al*. 2011). In general, based on histological evaluation of presumed infected and uninfected meats, white and light brown meats showed normal adductor muscle (**Figure 10a**), while brown and gray meats often showed moderate to severe degeneration (**Figure 10b**). These characteristics varied amongst the scallops rated as these colors. One foci, which is the primary center from which a disease develops or in which it localizes, contained probable developing bradyzoites, the dividing stage present in tissue cysts during infection, that appeared to be associated with smaller cells identified as likely scallop hemocytes (**Figure 10c**), which is of interest because bradyzoites are reported to form in hemocytes (Kristmundson *et al*. 2011). Rarely, other forms of presumed parasites were noted in the tissues, although some foci were observed containing cells with granular blue cytoplasm as shown in **Figure 10e**. Finally, Gram staining of a presumed blue foci showed potential small, triangular shaped organisms in the cytoplasm of the cells (**Figure 10f**). The stage of the life cycle for this potential parasite is unknown.

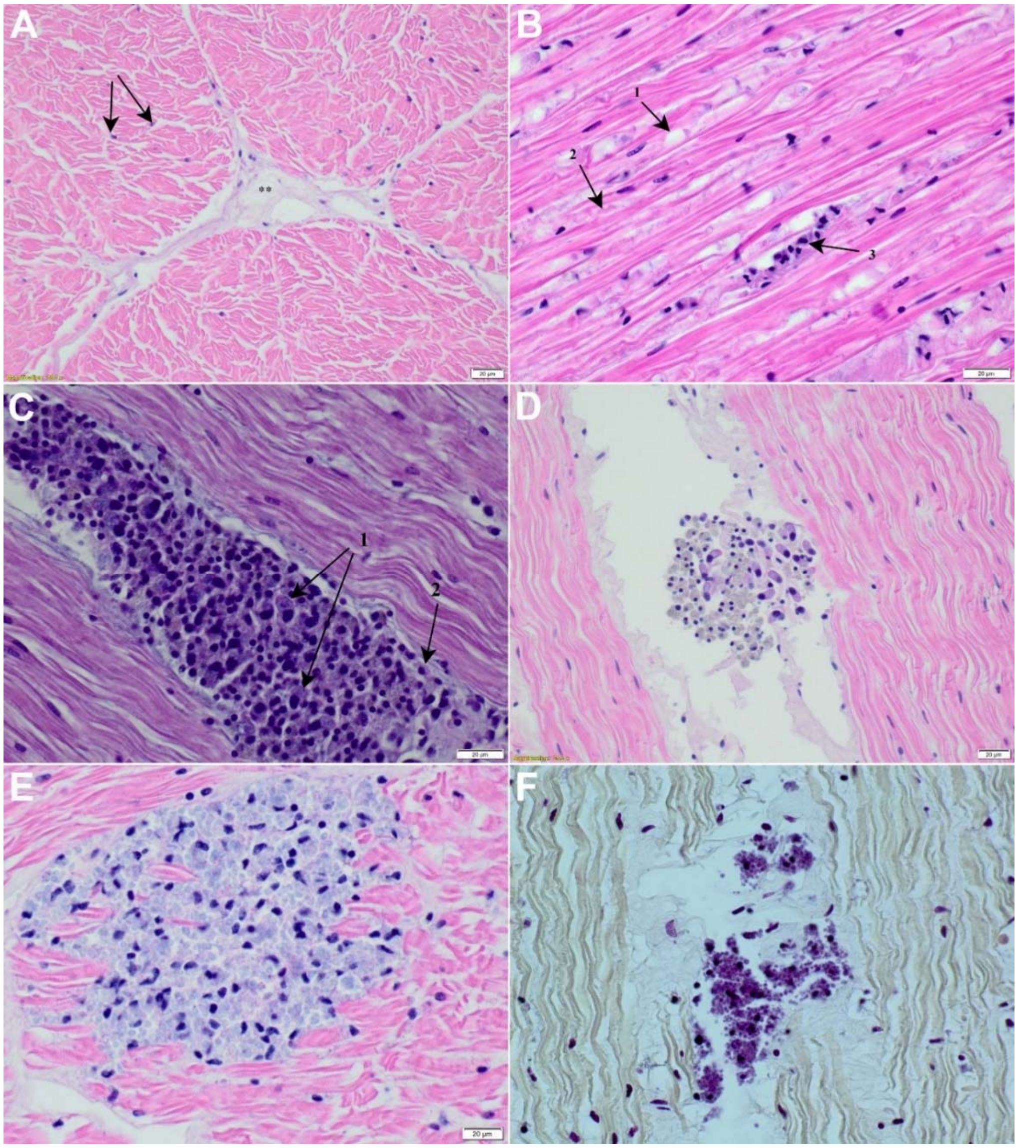


Figure 10. Photomicrographs of histological sections showing: **a)** Normal adductor muscle. Arrows indicate normal muscle nuclei, and asterisks indicated a normal connective tissue septum between muscle bundles. **b)** Adductor muscle from an animal rated as grey when shucked. Notable details include intra- and inter-fiber edema (1); loss of striation, fragmentation and coagulation of fibers (2); and hemocytes within necrotic fibers (3). **c)** Adductor muscle from an animal rated as grey when shucked with a focus containing an admixture of developing bradyzoites (1) and hemocytes (2). The surrounding muscle is only mildly affected by the infection. **d)** Tissue from an infected animal with sporozoites surrounded by small cells with granular brown/grey cytoplasm that are presumed to be hemoctyes in the process of phagocytosis of necrotic tissue. **e)** A focus of cells with granular blue cytoplasm presumed to be a developing oocyst. These foci were very rarely noted in affected adductor muscles, and the surrounding adductor muscle does not look abnormal. **f)** Severely affected adductor muscle with a focus of cells containing abundant blue-purple granules, each with probable centrally located nuclei. All tissue was paraffin embedded. **a)-e)** were hematoxylin and eosin stained. **f)** was treated with Gram stain.

In the majority of white to brown meats, bradyzoites were noted in defined foci in the muscle and surrounding muscle tissues were not apparently affected. However, in several gray meats, significant damage was noted throughout the muscle. In some of these meats, sporozoites (potentially tachyzoities) were noted singly or in small, poorly defined groups in the degenerating muscle in many locations. No sporozoites of either type were intermixed with the degenerating tissues. These findings suggest another mechanism, besides the accumulation of sporozoites in the muscle, may cause degradation of the muscle tissues. These include: 1) generalized toxin production by the parasite, 2) infections at other sites in the body causing poor nutrition and subsequent muscle degeneration, and 3) potential microzoites (**Figure 10e**), which could be responsible for muscle degeneration, if they are released and spread through the tissues. In order to better understand the correlation of infection by the parasite and degeneration of muscle tissue, further work should be completed, including: 1) in situ hybridization to identify parasites in the unusual foci and potential microzoites/spores in the degenerating tissues, 2) correlation of PCR identification of the parasite in meats with histological evaluation, and 3) development of a quantitative PCR method that can quantify the abundance of parasites in the meats.

To corroborate histologic analysis, plots were made of meat color versus microgamete number, muscle thinning scores, and cellularity scores. There was no simple relationship between meat color and severity of infection, but cellularity scores increased between white and gray meat (**Figure 11**). Attempts to predict meat color using generalized additive mixed models (R package "mgcv") with fixed effects for cellularity scores, muscle thinning scores, and protozoan numbers were unsuccessful. The deviance explained by the models was always under 40%, although the models confirmed that cellularity scores were better predictors of meat color than muscle thinning scores or protozoan numbers. However, in moderate to sometimes severe cases of infection, it is hard to microscopically differentiate forms of the parasite from hemocytes (circulating blood cells of the scallop).

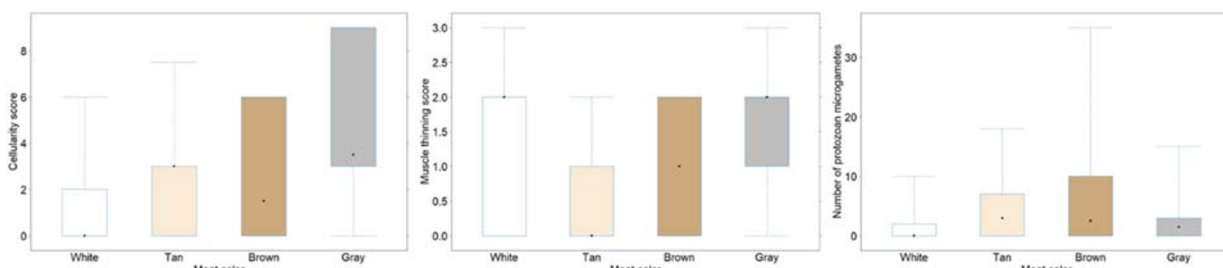


Figure 11. Box and whisker plots of meat color against **a)** cellularity scores, **b)** muscle thinning scores and **c)** protozoan sporozoites for samples collected during the 2016 seasonal bycatch survey on the northern portion of Georges Bank. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers extending to the minimum and maximum values. Average values for each meat color are shown above the whiskers in each plot.

<u>Polymerase Chain Reaction Detection Method Development</u>: Methods of preparing and extracting preserved muscle collected on the vessels to detect the presence of Apicomplexan parasite had to be developed. Extraction kits were compared to find the best kits to use. The biggest hurdles were 1) incorrect PCR methods published by Kristmundsson *et al*. (2011) that had to be changed, and 2) an incorrect positive control provided by U.MASS for development of the test (the wrong parasite was sent as a positive control). However, the RWU ADL was able to

develop an appropriate PCR method with a modification in the protocol and by using heavily infected adductor muscles collected by CFF as a positive control (Mastrostefano 2018; **Appendix E**). Results from selected samples are listed in **Table 9**. The main goals of the laboratory at this point are to identify the best primers to use for PCR detection and use these in a PCR test on previous and future samples. Further, the primers will be used to develop an in situ hybridization method to identify forms of the parasite in the tissues. Eventually, the laboratory expects to develop a quantitative PCR test method that can directly quantify the number of parasites in the tissue without the use of histology. This test can then be used as a fast accurate monitoring tool.

Table 9. Meat color PCR results (positive or negative for the parasite) is compared to the color of the muscle at the time of shucking (gross color), the number of bradyzoite foci noted in the tissue histologically (plate 2, figure unknown) and the histological condition of the muscle.

Gross Color	Number of Bradyzoite Foci	PCR +/-
Light Brown	0	Positive
Gray	13	Positive
Gray	0	Positive
Brown	28	Positive
Gray	13	Positive
Brown	35	Positive
Gray	15	Positive
Brown	22	Positive
White	0	Negative
Light Brown	6	Negative
Light Brown	9	Negative
Gray	3	Negative

Objective 4: Assess scallop meat discards and measure scallop meat loss due to shucking

During June, meat loss was estimated in subsampled bushels at two stations by quantifying the percentages of marketable meat, unmarketable meat, and scrapings. The total meat loss averaged 10.5% at two stations (12.52% at station 449 and 8.68% at station 401) (**Table 10**). These values are comparable to those observed last year (10.7%; range 9.0-14.3%).

Table 10. Scallop adductor muscle retained vs meat loss during processing by weight.

Trip Month	Station	Kept	Bad quality	Scraping	Shucking
June	449	87.48%	0%	7.64%	4.88%
June	401	91.32%	0%	5.00%	3.68%

Objective 5: Investigate the general biology of scallops and main bycatch species, specifically maturity, growth, and diseases.

Data collected for this one-year project indicate that yellowtail and winter flounders were concentrated in relatively low numbers in the eastern portion of this survey area, inside the groundfish closure. Windowpane flounder catches were high across the sample area, with catches peaking in May. High catches of monkfish occurred in May, with the lowest catches in March. Catches at each station, highlighting the relative abundance and distribution of scallops, yellowtail flounder, winter flounder, windowpane flounder, monkfish, and lobsters, were mapped for each survey trip for these species and are shown in **Figures F1- F6 of Appendix F**.

Scallops: A total of 566 bushels (33,103 lbs) were collected during the 2016 project (**Table 11**). The highest monthly percentages of mature females occurred in July and September. Just one spawning occurred from October to January (**Figures 12 and 13**). Similar spawning periods have been described for scallops in CAI and CAII S (Thompson *et al*. 2014). Based on macroscopic examinations and histology, they reported one spawning period in September through October and a second spawning period in April through May. Histological analysis to assess scallop spawning on northern Georges Bank is needed and could explain better this cycle.

Table 11. Catch of scallop for each trip by gear type.

Date		Number of bushels		Weight (lbs)	
		Control	Experimental	Control	Experimental
2016	July	38	37	2370.9	2280.8
	September	40	64	2372.2	3871.6
	October	32	28	1775.4	1590.6
	November	35	39	1970	2328.9
2017	January	29	24	1553.8	1249
	March	36	33	1988.4	1994.6
	May	36	34	2268.8	1996.5
	June	30	31	1784.9	1706.2

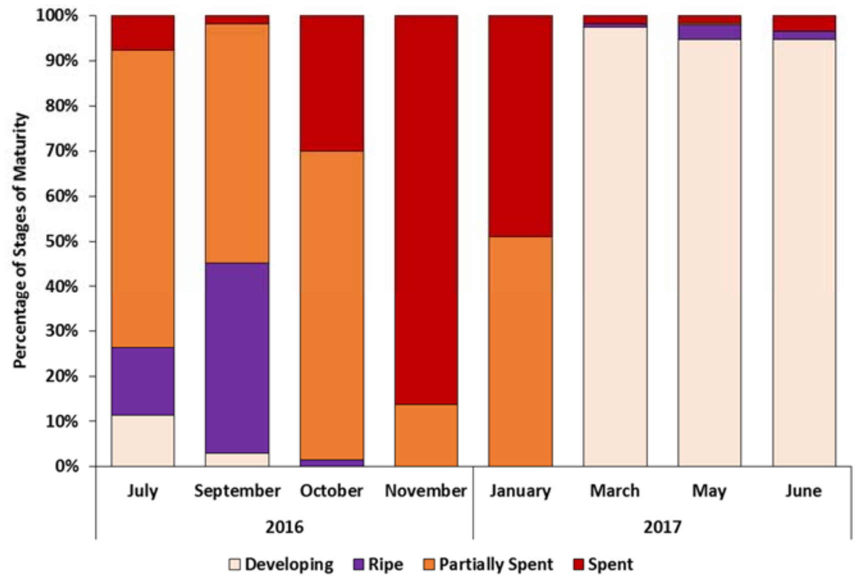


Figure 12. Seasonal maturity results for female scallops for each month during the 2016 seasonal bycatch survey on the northern portion of Georges Bank determined through macroscopic observations.

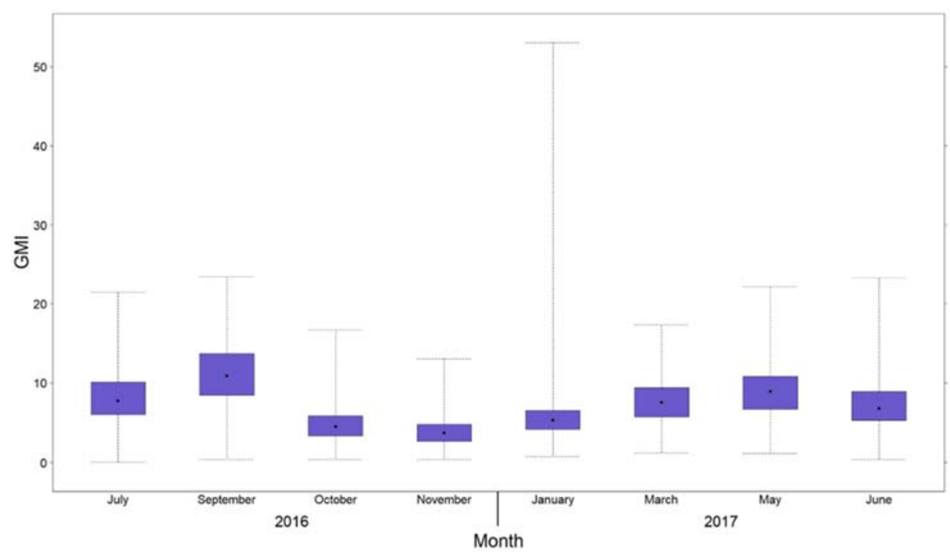


Figure 13. Seasonal changes in the gonadal mass index (GMI) for scallops during the 2016 seasonal bycatch survey on the northern portion of Georges Bank. Boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

Winter flounder: Overall, 663 winter flounder were captured in the entire sampled area and concentrated mainly in the eastern stations of CAII (**Table 12**). All fish caught per station, or a subsample of ten if more than ten were caught, were evaluated to assess sex and reproductive stages. From this subsample, it was observed that 48% of winter flounder were female. The March trip had the fewest winter flounder overall (subsampled catch: 5 females and 10 males), while catch peaked in July (subsampled catch: 53 females and 57 males). Developing gonads were observed between September and March, while spent females were seen between March and July (**Figure 14**). No female winter flounder were observed in the ripe and running condition (**Figure 14**). These results match previous published findings (Burton and Idler 1984, Harmin *et al*. 1995) and those from the 2015 project.

Table 12. Catch of winter flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experimental	Control	Experimental
2016	July	103	55	318.8	216.0
	September	46	41	102.8	90.0
	October	74	36	163.2	79.9
	November	37	29	94.0	79.7
2017	January	16	4	36.3	10.6
	March	12	4	23.1	9.1
	May	66	54	125.6	120.6
	June	30	26	80.2	55.5
	Total	384	249	943.9	661.5

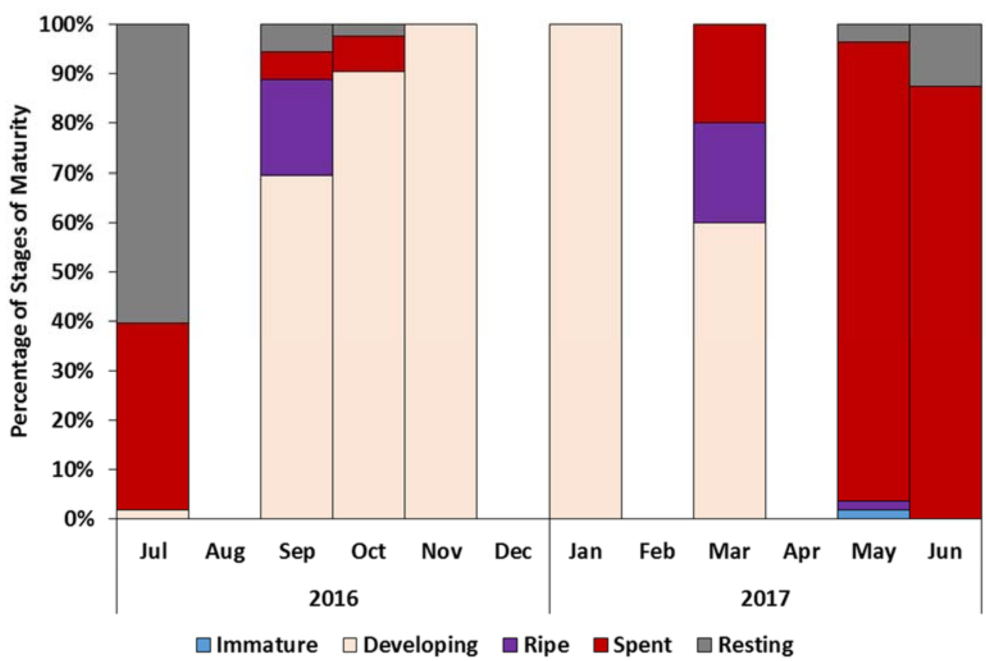


Figure 14. Seasonal maturity results of female winter flounder for each month during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Windowpane flounder: Windowpane flounder was the most abundant flounder caught (9,631 fish), with catch peaking in May (1,961 fish; **Table 13**). They were caught at nearly every station, with catches often exceeding 50 fish for each dredge. Ripe female windowpane flounder were observed throughout the entire year (**Figure 15**). Ripe and running females were observed from July to September (**Figure 15**).

Table 13. Catch of windowpane flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experimental	Control	Experimental
2016	July	602	660	352.3	412.6
	September	624	717	307.9	377.6
	October	805	815	447.6	457.8
	November	483	521	266.1	388.9
2017	January	568	231	326.0	122.0
	March	290	196	155.7	108.5
	May	977	984	563.2	561.3
	June	622	536	482.7	325.8
	Total	4971	4660	2901.5	2754.7

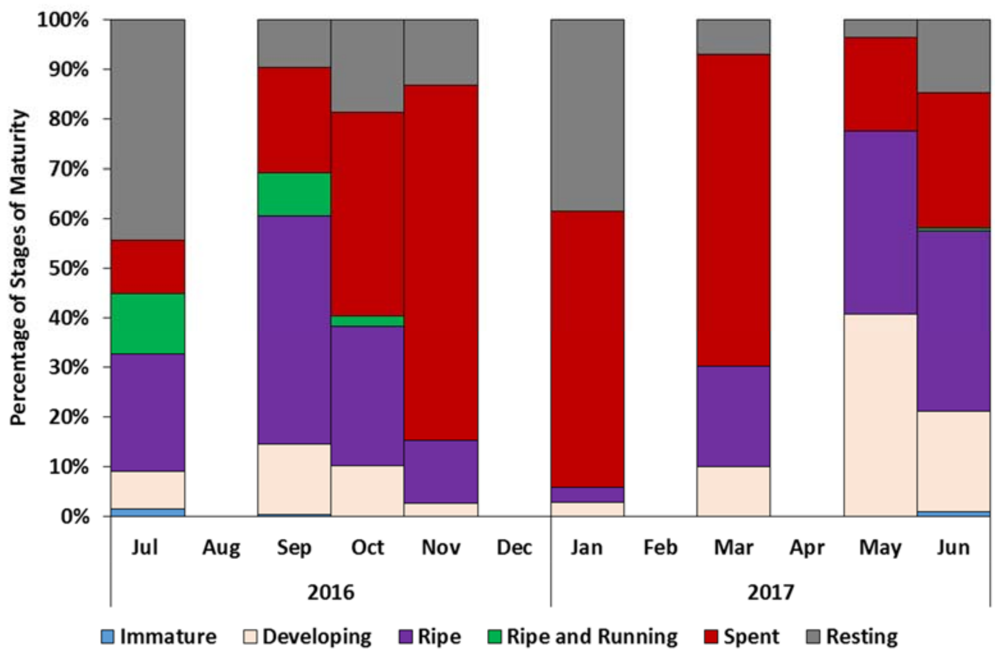


Figure 15. Seasonal maturity results of female windowpane flounder for each month during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Yellowtail flounder: A total of 846 yellowtail flounder were captured during the 2016 project (**Table 14**), of which 85% were females. The peak catch of yellowtail flounder occurred in September (**Figure F2**), and the lowest catch in March. They were observed in ripe and running condition in January and May. Females were observed to be ripe beginning in May, and completed spawning by July (**Figure 16**). Finally, in contrast to last year's project, *Ichthyophonus* infection was not observed for this species.

Table 14. Catch of yellowtail flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experiment	Control	Experiment
2016	July	77	87	57.8	88.2
	September	147	159	76.9	85.1
	October	103	59	50.38	31.7
	November	16	18	7.5	9.9
2017	January	20	5	10.7	2.5
	March	6	7	3.1	3.1
	May	46	35	24	18.4
	June	31	30	15.2	14.3
	Total	446	400	245.6	253.2

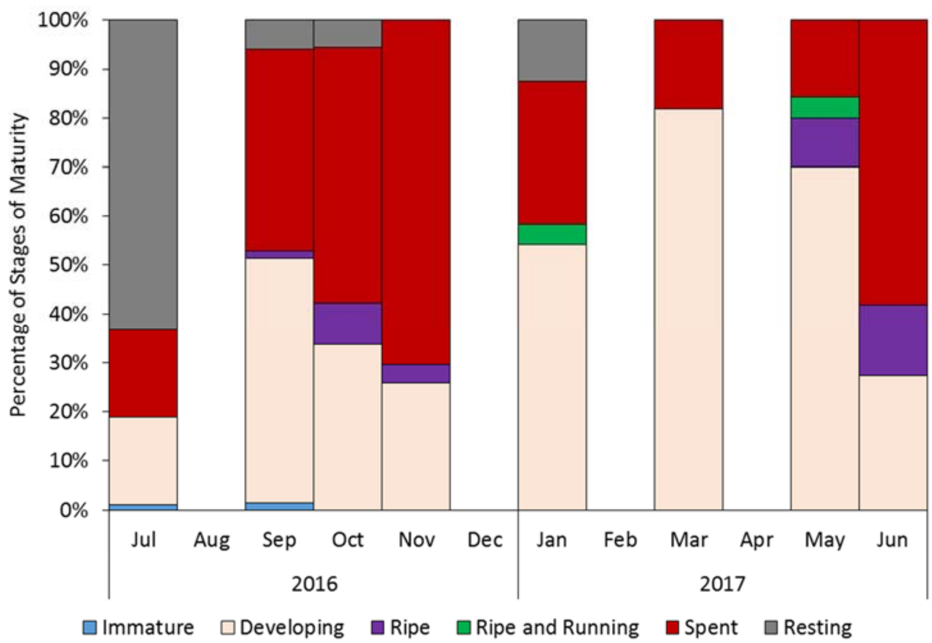


Figure 16. Seasonal maturity results of female yellowtail flounder for each month during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

<u>Length-weight relationships</u>: In addition to conducting catch and reproductive stage analysis, we examined length-weight data collected in the northern portion of Georges Bank from August 2015 to June 2016 for winter, windowpane, and yellowtail flounders. For each species, the parameters used to describe the length-weight relationship were determined for females, males, and the two sexes combined, and the values we obtained were compared to those from a study using fish collected along the northeast coast of the United States using bottom trawl surveys from 1992 to 1999 (Wigley *et al.* 2003). Sample sizes, length ranges, and the a and b parameters that characterize the length-weight relationship for our project and the previously published equation parameters are shown in **Table 15**. Both studies predicted that females are

heavier at length than males, but the Wigley *et al*. (2003) study predicted that all three species are heavier at length than our estimates suggest. These differences may be due to the different gear used in the projects, resulting in a larger range of fish lengths in Wigley *et al*. (2003), or the restricted geographical and time range of this project. However, since there is no data exclusively for Georges Bank, it is important to provide insights about length-weight relationship for these species.

Table 15. Length-weight relationship for the three flounder species, estimated from data collected during the 2015 seasonal bycatch survey and the 1992-1999 seasonal bottom trawl surveys conducted by the Northeast Fisheries Science Center (Wigley *et al.* 2003).

Species	Gender	Northern portion of Georges Bank 2015-2016				Northeast coast of the US 1992-1999			
		N	Length (cm)	a	b	N	Length (cm)	a	b
Winter Flounder	Female	722	29 - 64	0.076	2.53	5322	9-60	8.56E-06	3.12
	Male	705	26 - 56	0.137	2.35	3796	5-54	1.13E-05	3.02
	Combined	1427	26 - 64	0.058	2.59	9325	4-60	9.22E-06	3.09
Windowpane Flounder	Female	2949	16 - 39	0.061	2.5	2754	7-40	1.366E-05	2.98
	Male	3212	16 - 38	0.108	2.31	2153	4-36	1.465E05	2.92
	Combined	6161	16 - 39	0.042	2.6	8009	2-44	1.275E-05	2.97
Yellowtail Flounder	Female	1055	21-49	0.096	2.35	4356	6-55	3.93E-06	3.27
	Male	221	25-45	0.045	2.52	4290	11-49	7.41E-06	3.05
	Combined	1276	21-49	0.031	2.64	8775	4-55	5.18E-06	3.17

Monkfish: The most abundant fish species captured by weight during this year's project was monkfish (**Table 16**). Just over half of the monkfish caught during this survey were adults (52%), using the 50% maturity cut off at 43cm (NEFMC 2014), indicating that around half of the monkfish caught would be kept during commercial trips (**Table 16**). In the previous bycatch survey, sampling stations were in the scallop access areas in CAI and CAII, and monkfish catches started increasing in June and remained high until early fall (publication in review). The data collected during this project showed the monkfish catch increased starting in May and peaked in June (**Table 16**) coinciding with what was reported in last year report.

Table 16. Catch of monkfish for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experimental	Control	Experimental
2016	**July**	488	477	1575.7	1567.3
	September	440	453	1421.6	1564.9
	October	156	151	697.3	706.1
	November	205	244	1006.8	1150.4
2017	**January**	36	28	218.7	162.4
	March	3	3	34.2	8.7
	May	153	167	952.9	1007.7
	June	458	496	2238.0	2525.8
	Total	1939	2019	8145.1	8693.3

Lobsters: All lobsters caught during the project were sexed, measured for carapace length, and evaluated for shell disease, egg status, and dredge-induced damage. Lobster catch was high from the beginning of the survey (July) until October (**Table 17** and **Figure 17**) and mostly concentrated in the eastern portion of the survey area. Catch started to drop off during the November trip, and few lobsters were present from January through May; in June, the catch began to increase slightly (**Figure F6**).

Table 17. Catch of lobster for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experimental	Control	Experimental
2016	July	84	74	290.0	260.7
	September	98	99	304.6	323.0
	October	88	91	320.9	338.4
	November	22	24	85.1	84.2
2017	January	0	1	0	2.6
	March	1	3	1.5	7.3
	May	5	3	6.1	3.5
	June	63	48	213.6	179.5
	Total	361	343	1221.8	1199.2

The majority of the catch was female. Numbers of male lobsters caught remained consistently low over the course of the survey, with the highest catch during the July trip (20 males). A total of nine incidences of shell disease were observed. Overall, 322 lobsters had no damage, 149 were moderately damaged (missing claws, walking leg), and 232 were classified as lethally damaged **(Figure 18**). A total of 263 females and 29 males with a high chance of survival (i.e., lobsters with no or moderate damage) were tagged in collaboration with the Atlantic Offshore Lobstermen's Association. To date, eight lobsters tagged by CFF have been recaptured (**Table 18**).

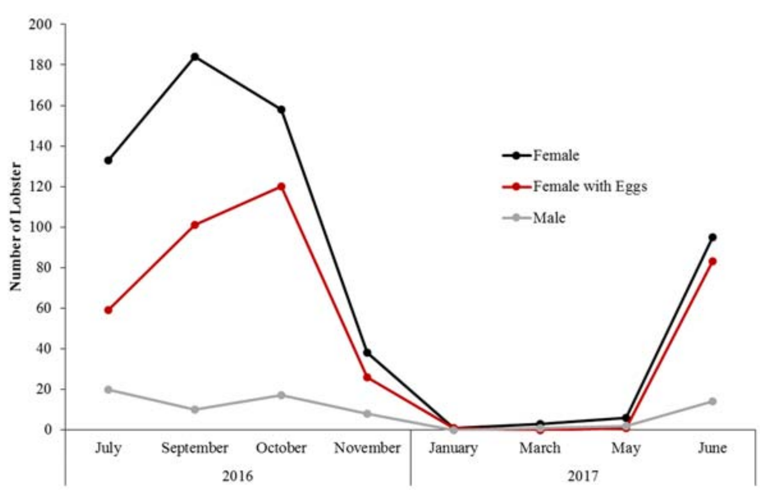


Figure 17. Catch of lobsters by trip separated by sex during the 2016 seasonal bycatch survey on the

northern portion of Georges Bank.

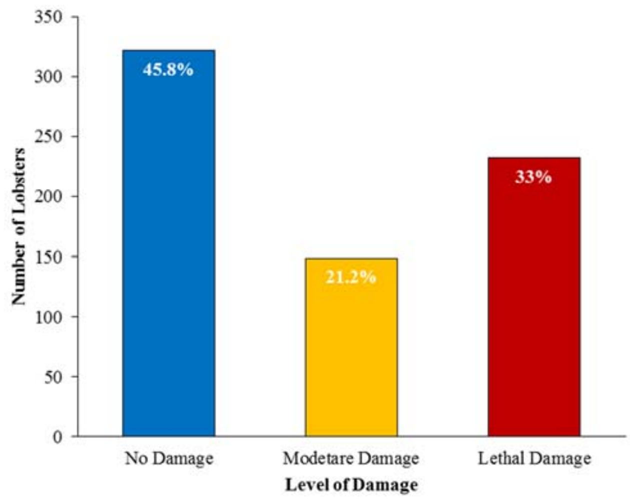


Figure 18. Summary of dredge-induced damage to lobsters during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Table 18. Lobster tagged by CFF and recaptured by fishermen.

Lobster	Sex	Carapace length (mm)	Eggs Tagged	Eggs Recaptured	Date Tagged	Date Recaptured
1	Female	119	Yes	Yes	10/8/2015	3/7/2016
2	Female	113	No	No	7/15/2016	9/12/2016
3	Male	81	-	-	7/18/2016	7/15/2017
4	Male	81	-	-	7/18/2016	7/26/2017
5	Male	149	-	-	9/11/2016	7/26/2017
6	Female	134	Yes	Yes	10/9/2015	8/28/2017
7	Female	113	No	Yes	6/16/2017	8/29/2017
8	Female	103	No	No	11/17/2016	11/21/2017

Other fish species: Unclassified skate catch was typically comprised of little and winter skates, but may have included thorny skate (*Amblyraja radiate*), clearnose skate (*Raja eglanteria*), or other species (**Table 19**). Skates were present in high numbers at nearly every station sampled. Barndoor skate (*Dipturus laevis*) was relatively abundant, except for March (0 bandoor skate caught). Atlantic cod (*Gadus morhua*) were seen in higher numbers than expected and typically caught inside CAII. Haddock (*Melanogrammus aeglefinus*) and American plaice (*Hippoglossoides platessoides*) were caught regularly, and witch flounder (*Glyptocephalus cynoglossus*) was caught in low numbers during three trips (**Table 19**).

Table 19. Catch of additional species for each trip by gear type during the 2016 seasonal bycatch survey

Date		Unclassified skate		Barndoor skate		Atlantic Cod		Haddock		American Plaice		Witch Flounder	
		Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp
	July	5312	4753	58	54	3	2	16	9	1	0	3	6
2016	September	3964	4016	53	63	0	0	0	0	0	0	0	0
	October	4289	3263	103	62	0	0	1	0	0	0	0	0

	November	2781	2879	20	29	3	1	2	3	0	0	0	0
2017	**January**	1589	921	12	5	5	4	3	1	7	2	0	0
	March	1227	1087	0	0	0	1	2	4	24	20	0	0
	May	3719	3966	24	21	10	4	12	9	28	64	1	0
	June	5115	4761	45	31	10	4	5	9	8	10	6	10
	Total	27996	25646	315	265	31	16	41	35	68	96	10	16

Objective 6: Conduct biological sampling of bycatch crustacean and echinoderm species.

Crabs were counted and weighed by species for the control dredge during some months during this project. All Jonah crabs (*Cancer borealis*) were separated into sublegal (<120mm) and legal size to collect counts and weights (**Table 20**). For these trips, Jonah crabs were most commonly seen at the western stations along the 100-m bathymetry contour. Atlantic rock crabs (*Cancer irroratus*) were collected and counted without size sorting. Note that lobsters were discussed in the previous section.

Table 20. Catch of crabs for each trip by gear type during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

Year	Month	Jonah crab				Atlantic rock crab	
		Number		Weight (kg)		Number	Weight (kg)
		Legal	Sub-Legal	Legal	Sub-Legal		
2016	July	19	67	21.2	26.8	801	105.6
	September	7	8	7.7	5.2	21	3.3
	November	7	0	7.1	0	-	-
2017	January	4	10	3.5	5.5	-	-

Sea stars were evaluated for sea star wasting disease. Sampling did not follow an established protocol and was opportunistic. Sea star wasting disease was not identified.

DISCUSSION

Seasonal bycatch survey data for CAII and open areas, collected from 2011 to 2017, indicate that bycatch spatiotemporal patterns have changed over the past six years. This can be attributed to natural changes in fish populations, changes in fishing pressure, or slight shifts in the areas sampled by CFF. Current data and data from 2011 to 2013 show yellowtail flounder catch in CAII was consistently higher in September (Huntsberger *et al*. 2015), while in 2015 catch peaked in May (Garcia *et al*. 2017; **Figure G2a-G3a**). This species was more abundant in the eastern part of Georges Bank/CAII (**Figure F2**) than in open areas for all the years sampled. For winter flounder in CAII, the catch peaked in September from 2011 to 2013, in May 2015, and in July 2016, indicating a shift in the peak of abundance from fall to summer (**Figure G2a-G3a**). In this and previous years, windowpane flounder was the most abundant flatfish species. Although catch of this species has been consistently higher during the winter months (especially January) in all previous years, the highest catch was observed in May during this project (**Figure G2b-G3b**). Windowpane flounder appears to make migrations from shallow to deep water in search of optimal temperatures. This is evident by a shift in the abundance towards deeper warmer waters in the winter, and shallow warmer waters in the summer (**Table G1** and **Figures G5**). Therefore, the seasonal shift in peak windowpane abundance could be related to changing temperature regimes across Georges Bank, although more data would be required to investigate this hypothesis.

The analysis of spawning periods for winter, yellowtail, and windowpane flounders during the 2016 project yielded surprising results. Previous studies found ripe gonads in winter flounder between January and March (Burton and Idler 1984, Harmin *et al*. 1995, Collette and Klein-MacPhee 2002), and previous CFF research indicated that winter flounder spawn on Georges Bank around May, with most fish visibly spent or resting beginning in June (Garcia *et al*. 2017). This year, ripe gonads were observed in winter flounder in March and September, indicating a possible fall spawning event. Similarly, results from previous years indicated that the spawning peak of yellowtail flounder on Georges Bank occurs during April/May (Huntsberger *et al*. 2015, Garcia *et al*. 2017), a result that agrees with published spawning data (NOAA 1990). However, results from 2016 analyses showed two spawning periods - one in spring and another in fall. Finally, windowpane flounder were observed in ripe and spent condition ubiquitously throughout the sampling period, which is in contrast to the previous years when mature females were only found in May and June, coinciding with published breeding habits (Collette and Klein-MacPhee 2002). Due to these discrepancies, CFF will begin verifying macroscopic maturity staging results with histological analysis for a subsample of ovaries collected during the 2017 bycatch project (for all three species described above).

One CFF's major contributions to marine research is its constant exploration of gear modifications designed to reduce bycatch. Since 2012, CFF has executed several projects investigating the impact of shortening the scallop dredge apron to 5 rows (current regulations require a minimum of 7 rows). In 2012 and 2013, CFF concluded that this configuration significantly reduces the bycatch of winter, yellowtail, and windowpane flounder while maintaining a scallop catch efficiency similar to a traditional dredge apron (Davis *et al*. 2012, Davis *et al*. 2013). Sea scallop shell height was found to be a significant predictor for relative efficiency, and 5-row apron dredge efficiency appears to increase with shell height relative to the standard 7-row apron (Davis *et al*. 2012). However, the significance of this effect varies when the 5-row apron was tested against industry-supplied dredges (Davis *et al*. 2013). Results from these projects were used in the creation and implementation of Framework Amendment 25 to the Scallop Fishery Management Plan (NEFMC 2014). Results from 2015 bycatch survey demonstrated similar significant reductions in flatfish bycatch (summer, yellowtail, and winter flounder) with the 5-row apron dredge relative to the control, with a small but not significant reductions in scallop catch (Garcia *et al*. 2017). This year, we also observed significant reductions in flatfish bycatch (fourspot, winter, and windowpane flounders) with the 5-row apron, while maintaining the same scallop catch. Both the 2015 and 2016 bycatch surveys confirmed that the bycatch reduction capabilities of the 5-row apron are not significantly impacted by seasonal and spatial variation in the distribution of bycatch species. Overall, these results suggest the 5-row apron dredge is more selective than the 7-row apron dredge, while maintaining, and in some cases improving, scallop catch.

CONCLUSIONS AND FUTURE RESEARCH

The CFF seasonal bycatch survey continues to provide a wealth of data that can be used to address a wide range of issues that impact the ecosystem on Georges Bank. The long-term seasonal data set is unique and, as such, has been used to evaluate populations of multiple commercial fish species, supplying fisheries managers with critical information required to adhere to ACLs and AMs to optimize the harvest of scallops while minimizing bycatch. The project has provided information on spatio-temporal patterns in bycatch rates in the scallop fishery and has been used to identify mechanisms to mitigate bycatch. As new issues arise, the bycatch survey has adapted.

To date, CFF has completed over three years (October 2010 – March 2014) of bycatch surveys on Georges Bank in the scallop access areas in CAI and CAII and two years (August 2015 – June 2017) of surveys on the northern portion of Georges Bank. Beginning in August 2017, we shifted the survey efforts to include all of CAII. It has become clear that the abundance of important bycatch species varies significantly, both spatially and temporally, across the eastern portion of Georges Bank, and the study area was selected to provide needed data about the seasonal patterns of habitat used by yellowtail and windowpane flounder. Because fishery access and habitat protection in this area may be adjusted in the near future, continued collection of scallop, fish, and lobster data from this region is critical.

Although the survey footprint has shifted in response to management requests, there has been increasing interest in using the bycatch survey data as a time series. If it could provide a long-term seasonal data set that could be more effectively used to track changes in scallop and fish abundance over time on Georges Bank, the value of the project would be increased. Therefore, we hope to begin incorporating "Golden Stations", a set of fixed stations that would remain constant each year (Cox *et al.* 2018). Additional stations would be added to meet current management needs.

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APPENDICES

Appendix A: General

Table A1. Specifications of CFF dredges used during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Head Bail Design	Normal	Experimental
Type of Chain for Turtle Mat	3/8" Grade 70	3/8" Grade 70
Up and Downs	13	13
Tickler Chain	9	9
Type of Chain for Sweep	Long Link Grade 80	Long Link Grade 80
Number of Links in Sweep	121 long links	121 long links
Chain Sweep Hanging	(6,4,4,2,4...every two links in the bag), 5/8 shackles	(6,4,4,2,4...every two links in the bag), 5/8 shackles
Twine Top	2:1 with two in the sides 60X9	1.5:1 with two in the sides 45X11
Diamonds	14	14
Skirt	2 X 28 or 2 X 40	2 X 28 or 2 X 40
Sides	6 X 18 or 6 X 20	6 X 20 or 6 X 22
Apron	7 X 40	5 X 40
Bag	10 X 40	10 X 40
Chafing Gear	Sewn in three rows down from the sweep for the bag and on the diamonds	Sewn in three rows down from the sweep for the bag and on the diamonds
Club Stick	20 link dog chains	20 link dog chains

Table A2. Species captured during the 2016 seasonal bycatch survey on the northern portion of Georges Bank. It was measured for some fish: total lengths, for squid: mantle length and for scallop: shell height.

Common Name	Scientific Name	Number Caught	Sample Procedure
American Plaice	*Hippoglossoides platessoides*	164	Weigh/Measure
Atlantic Cod	*Gadus morhua*	47	Weigh/Measure
Atlantic Herring	*Clupea harengus*	1	Weigh/Measure
Bandoor Skate	*Dipturus laevis*	580	Weigh/Measure
Butterfish	*Peprilus triacanthus*	1	Count/Weigh
Cunner	*Tautogolabrus adspersus*	1	Count/Weigh
Fourspot Flounder	*Paralichthys oblongus*	183	Weigh/Measure
Grey Sole	*Glyptocephalus cynoglossus*	26	Weigh/Measure
Haddock	*Melanogrammus aeglefinus*	76	Weigh/Measure
Jonah Crab	*Cancer borealis*	37	Count/Weigh
Jonah Crab (sub-legal)	*Cancer borealis*	85	Count/Weigh
Loligo Squid	*Doryteuthis pealeii*	16	Weigh/Measure
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	84	Count/Weigh
Monkfish	*Lophius americanus*	3958	Weigh/Measure
Northern Sand Lance	*Ammodytes dubius*	1	Count/Weigh
Northern Searobin	*Prionotus carolimus*	843	Count/Weigh
Ocean put	*Zoarces americanus*	8	Count/Weigh
Red Hake	*Urophycis chuss*	129	Count/Weigh
Rock Crab	*Cancer irroratus*	822	Count/Weigh
Sea Raven	*Hemitripterus americanus*	66	Count/Weigh
Sea Scallop (bushels)	*Placopecten magellanicus*	564.62	Weigh/Measure/ Reproductive/Disease
Silver Hake	*Merluccius bilinearis*	250	Count/Weigh
Skates uncl.	Rajidae	53642	Count/Weigh
Spiny dogfish	*Squalus acanthias*	71	Weigh/Measure
Summer Flounder	*Paralichthys dentatus*	359	Weigh/Measure
White Hake	*Urophycis tenuis*	2	Count/Weigh
Windowpane Flounder	*Scopthalmus aquosus*	9631	Weigh/Measure/ Reproductive
Winter Flounder	*Pseudopleuronectes americanus*	633	Weigh/Measure/ Reproductive
Yellowtail Flounder	*Limanda ferruginea*	846	Weigh/Measure/ Reproductive/Disease

Appendix B: Shell height-meat weight (SHMW) relationship

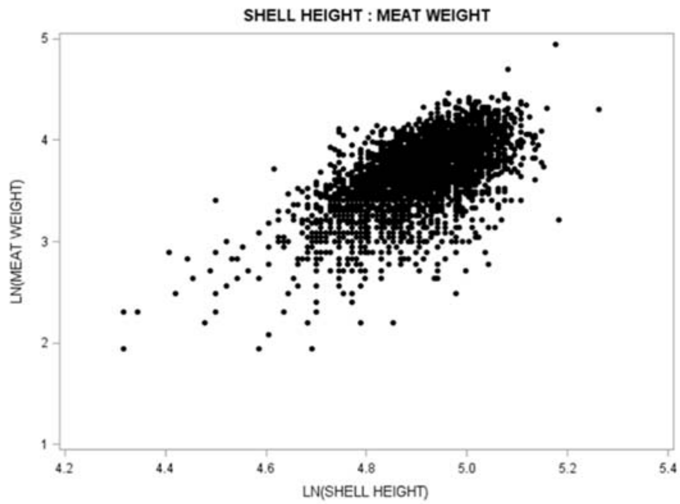
Table B1. Results from iterative model building. The model with the minimum AIC value is shown in bold. Fixed effects are shown to the right of the ~ symbol. This symbol separates the response (Meat Weight) from the predictor variables used in the analysis. Interaction terms are denoted with the factor1*factor2 nomenclature. For the models that included a random effect, this effect was always evaluated at the station level. The difference between AIC for the best fitting model and other models is also shown (Δ AIC). The best fitting model was also evaluated without a random effect to assess the impact of including a random effect in the model.

FIXED_EFFECTS	RANDOM EFFECTS	AIC	DELTA AIC
SHELLHEIGHT, DEPTH, TRIPMONTH, AREA, MEATCOLOR, SHELLHEIGHT*AREA	INTERCEPT	30362.45	0.00
SHELLHEIGHT, DEPTH, MEATCOLOR, TRIPMONTH*AREA, SHELLHEIGHT*AREA,	INTERCEPT	30369.08	-6.64
SHELLHEIGHT, TRIPMONTH, AREA, MEATCOLOR, STRINGY, SHELLHEIGHT*AREA	INTERCEPT	30370.33	-7.88
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX, MEATCOLOR, TRIPMONTH*AREA, DEPTH*AREA, SHELLHEIGHT*AREA	INTERCEPT	30370.90	-8.46
SHELLHEIGHT, TRIPMONTH, AREA, MEATCOLOR, STRINGY, TRIPMONTH*AREA, SHELLHEIGHT*AREA, AREA*DEPTH	INTERCEPT	30371.16	-8.72
SHELLHEIGHT, TRIPMONTH, AREA, MEATCOLOR, STRINGY, TRIPMONTH*AREA, SHELLHEIGHT*AREA	INTERCEPT	30378.12	-15.67
SHELLHEIGHT, TRIPMONTH, AREA, MEATCOLOR, STRINGY, DEPTH*AREA	INTERCEPT	30400.74	-38.30
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX, MEATCOLOR	INTERCEPT	30401.04	-38.60
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX, MEATCOLOR	INTERCEPT	30401.05	-38.60
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX, MEATCOLOR, TRIPMONTH*AREA	INTERCEPT	30409.16	-46.72
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX, MEATCOLOR, TRIPMONTH*AREA, DEPTH*AREA	INTERCEPT	30410.03	-47.59
INTERCEPT, SHELL HEIGHT, TRIPMONTH, AREA, DEPTH	INTERCEPT	30662.30	-299.85
SHELLHEIGHT, TRIPMONTH, AREA, DEPTH, SEX	INTERCEPT	30663.36	-300.92
INTERCEPT, SHELL HEIGHT, TRIPMONTH, AREA	INTERCEPT	30674.11	-311.66
INTERCEPT, SHELL HEIGHT, TRIPMONTH	INTERCEPT	30679.27	-316.82
INTERCEPT, SHELL HEIGHT	INTERCEPT	30808.17	-445.72
INTERCEPT	INTERCEPT	32712.86	-2350.41

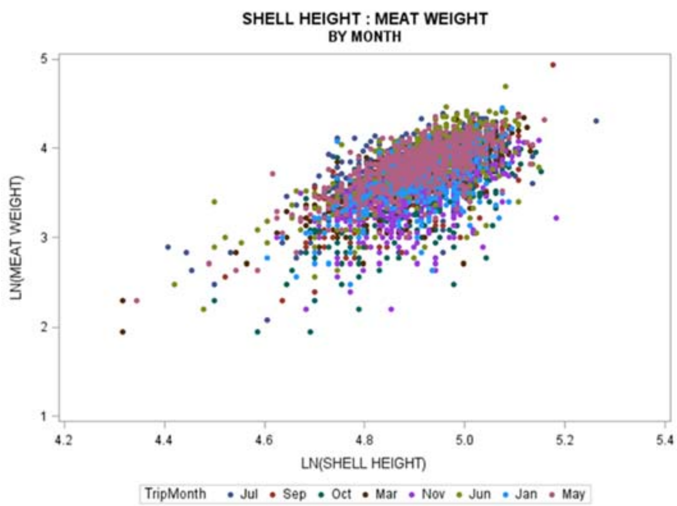
Table B2. Parameter estimates for the best model as described by minimum AIC value. For the categorical variables (trip month, location, meat color, and stringiness), differences within that category are relative to the value with a 0 parameter estimate (i.e. non-CAII, June 2016, white meat, and stringy). Similarly, p-values within a category are relative to that standard and not for the whole model. All included fixed effects were significant overall.

Effect	Month	Color	Area	Estimate	SE	DF	t-value	p-value
Intercept				-7.5414	0.259	206.0	-29.087	<0.001
Shell Height*Area				2.2245	0.047	4111.0	46.944	<0.001
Depth				0.1068	0.034	4111.0	3.109	0.0019
Color		Brown		-0.3809	0.045	4111.0	-8.419	<0.001
Color		Gray		-0.5053	0.054	4111.0	-9.301	<0.001
Color		Light Brown		-0.3170	0.026	4111.0	-11.979	<0.001
Color		White		0.0000				
Month	July			0.0298	0.030	4111.0	0.984	0.3250
Month	Sept.			-0.1544	0.031	4111.0	-4.917	<0.001
Month	Oct.			-0.3103	0.031	4111.0	-10.057	<0.001
Month	Nov			-0.3040	0.030	4111.0	-10.044	<0.001
Month	Jan			-0.1384	0.032	4111.0	-4.382	<0.001
Month	Mar			-0.1576	0.030	4111.0	-5.198	<0.001
Month	May			-0.0066	0.030	4111.0	-0.221	0.8250
Month	June			0.0000				
Area			CAII	2.7461	0.371	4111.0	7.396	<0.001
Area			NON-CAII	0.0000				
Shell Height*Area			CAII	-0.5539	0.076	4111.0	-7.327	<0.001
Shell Height*Area			NON-CAII	0.0000				

a)



b)



c)

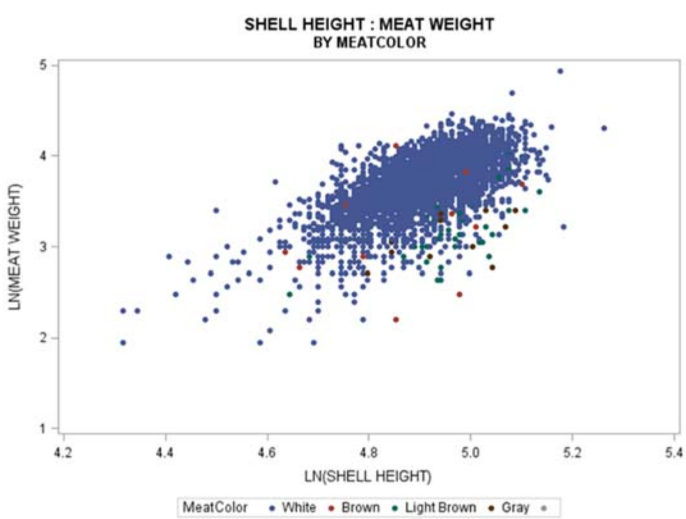


Figure B1. Shell Height:Meat Weight data for: **a)** all trips combined, **b)** all trips combined separated by month of sampling, and **c)** all trips combined separated by meat color.

Appendix C: GLMM Model Details

Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. This analysis is based on the analytical approach in Cadigan *et al*. 2006.

Assume that each gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the 5 row apron dredge and q_f equals the catchability of the 7 row apron dredge used in the study. The efficiency of the 5 row dredge relative to the row dredge will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \qquad (1)$$

The catchabilities of each gear are not measured directly. However, within the context of the paired design, assuming that spatial heterogeneity in scallop/fish density is minimized, observed differences in scallop/fish catch for each vessel will reflect differences in the catchabilities of the gear combinations tested.

Let C_{iv} represent the scallop/fish catch at station *i* by dredge *v*, where *v*=*r* denotes the 5 row dredge and *v*=*f* denotes the 7 row dredge. Let λ_{ir} represent the scallop/fish density for the i^{th} station by the 5 row dredge and λ_{if} the scallop/fish density encountered by the 7 row dredge. We assume that due to random, small scale variability in animal density as well as the vagaries of gear performance at tow *i*, the densities encountered by the two gears may vary as a result of small-scale spatial heterogeneity as reflected by the relationship between scallop/fish patch size and coverage by a paired tow. The probability that a scallop/fish is captured during a standardized tow is given as q_r and q_f. These probabilities can be different for each vessel, but are expected to be constant across stations. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the 7 row dredge is given by:

$$E(C_{if}) = q_f \lambda_{if} = \mu_i \qquad (2)$$

The catch by the 5 row dredge is also a Poisson random variable with:

$$E(C_{ir}) = q_r \lambda_{ir} = \rho \mu_i \exp(\delta_i) \qquad (3)$$

where δ_i =log ($\lambda_{ir}/\lambda_{if}$). For each station, if the standardized density of scallops /fish encountered by both dredges is the same, then δ_i=0.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir}= \lambda_{if}$), then ρ can be estimated via a Poisson generalized linear model (GLM). This approach, however, can be complicated especially if there are large numbers of stations and scallop/fish lengths (Cadigan *et al*. 2006). The preferred approach is to use the conditional distribution of the catch by the 5 row at station *i*, given the total non-zero catch of both vessels at that station. Let c_i represent the observed value of the total catch. The conditional distribution of C_{ir} given C_i=c_i is binomial with:

$$\Pr\left(C_{ic}=x \middle| C_i=c_i\right)=\binom{c_i}{x}p^x(1-p)^{r_i-x} \tag{4}$$

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the 5 row dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each station is eliminated as would be required in the direct GLM approach (equations 2 & 3). For the binomial distribution $E(C_{ir})=c_i p$ and $Var(C_i r)=c_i p/(1-p)$. Therefore:

$$\log\left(\frac{p}{1-p}\right)=\log(\rho)=\beta \tag{5}$$

The model in equation 5, however, does not account for spatial heterogeneity in the densities encountered by the two gears for a given tow. If such heterogeneity does exist then the model becomes:

$$\log\left(\frac{p}{1-p}\right)=\beta+\delta_i \tag{6}$$

where δ_i is a random effect assumed to be normally distributed with a mean=0 and variance=σ^2. This model is the formulation used to estimate the gear effect $exp(\beta_0)$ when catch per tow is pooled over lengths.

Often, gear modifications can result in changes to the length-based relative efficiency of the two gears. In those instances, the potential exists for the catchability at length (l) to vary. Models to describe length effects are extensions of the models in the previous section to describe the total scallop catch per tow. Again, assuming that between-pair differences in standardized animal density exist, a binomial logistic regression GLMM for a range of length groups would be:

$$\log\left(\frac{p_i}{1-p_i}\right)=\beta_0+\delta_i+\beta_1 l,\delta_i \sim N(0,\sigma^2), i=1,\ldots,n. \tag{7}$$

In this model, the intercept (β_0) is allowed to vary randomly with respect to station.
The potential exists, however, that there will be variability in both the number as well as the length distributions of scallops/fish encountered within a tow pair. In this situation, a random effects model that again allows the intercept to vary randomly between tows is appropriate (Cadigan and Dowden, 2009). This model is given below:

$$\log\left(\frac{p_i}{1-p_i}\right)=\beta_0+\delta_{i0}+\beta_1 * l,\delta_{ij} \sim N(0,\sigma_j^2), i=1,\ldots,n, j=0,1. \tag{8}$$

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch. In most instances, due to high scallop catch volume, particular tows were sub-sampled. This is accomplished by randomly selecting a one bushel sample for length frequency analysis. Most finfish were sampled completely without subsampling but there were some tows with large catches of windowpane flounder and the catch was subsampled. In these cases the model caught the tows that were subsampled and treated them accordingly. One approach to accounting for this practice is to use the expanded catches. For example, if half of the total catch was measured for length frequency, multiplying the observed catch by two would result in an estimate of the total catch at length for the tow. This approach would overinflate the sample size resulting in an underestimate of the variance, increasing the chances of spurious statistical inference (Millar *et al.* 2004, Holst and Revill 2009). In our experiment, the proportion sub-sampled was not consistent between tows as only a one bushel sub-sample was taken regardless of catch size. This difference must be accounted for in the analysis to ensure that common units of effort are compared. The subsampling offset adjusts the linear predictor of the model to account for differential scaling in the data (i.e. tow length, subsampling), in the case of windowpane flounder the subsampling rate was 1 on both sides. Since the offset is the log of the quotient of the sampling rate of both sides and the log(1/1) = 0, nothing is added to the linear predictor for windowpane flounder.

Let q_{ir} equal the sub-sampling fraction at station i for the vessel r. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1, \ldots, n. \quad (9)$$

The last term in the model represents an offset in the logistic regression (Littell *et al*. 2006).

Our analysis of the efficiency of the 5 row dredge relative to the 7 row dredge consisted of multiple levels of examination. For all species, the full model consisted of unpooled (by length) catch data:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1..n, j = 0,1\ldots. (10)$$

The symbol f_{ij} equals the categorical variable denoting dredge frame configuration. Model fit was assessed by AIC. If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length. The random intercept model was evaluated to assess relative differences in total catch (see equation 6).

We used SAS/STAT® PROC GLIMMIX v. 9.2 to fit the generalized linear mixed effects models.

Appendix D: Gear Comparison

Table D1. Model building for length-based models. Hierarchical models ranked based upon minimum AIC values. Some species have fewer candidate models as a function of non-convergence of individual models. In cases where random effects were included and insufficient variation wither in the slope or intercept existed, the models converged; however, the inclusion of the random effects were not warranted and those model specifications were not included in the table. In cases where the delta AIC value was less than 3 units, the simpler model was chosen. The selected model is shown in bold. Given the large amount of length data associated with sea scallops. The addition of a low order polynomial term for length was explored.

Species	Fixed Effects	Random Effects	AIC Value	Delta AIC
Barndoor Skate	**Intercept Only**	**Intercept**	**733.11**	**0.000**
	Size	Intercept	734.40	1.287
	Size, Trip	None	734.62	1.507
	Intercept Only	None	734.99	1.875
	Size, Trip	Intercept	735.44	2.328
	Size	None	736.69	3.573
	Size, Trip, Size*Trip	None	741.30	8.186
	Size, Trip, Size*Trip	Intercept	742.37	9.253
Summer Flounder	**Intercept Only**	**None**	**485.36**	**0.000**
	Intercept Only	Intercept	486.45	1.099
	Size	None	487.05	1.692
	Size	Intercept	488.07	2.716
	Size, Trip, Size*Trip	None	491.11	5.754
	Size, Trip	None	491.25	5.891
	Size, Trip	Intercept	492.99	7.635
	Size, Trip, Size*Trip	Intercept	493.04	7.687
Fourspot Flounder	Size, Trip, Size*Trip	None	208.34	0.000
	Size, Trip	None	213.09	4.750
	Size	**Intercept**	**216.93**	**8.589**
	Size	None	217.61	9.267
	Intercept Only	Intercept	229.40	21.057
	Intercept Only	None	229.83	21.491
Yellowtail Flounder	Size, Trip	None	811.56	0.000
	Intercept Only	**Intercept**	**813.72**	**2.161**
	Size	Intercept	815.72	4.159
	Intercept Only	None	817.62	6.054
	Size, Trip, Size*Trip	None	817.71	6.144
	Size	None	819.57	8.012
Winter Flounder	Size	Intercept	710.69	0.000
	Intercept Only	**Intercept**	**711.89**	**1.209**
	Size, Trip	Intercept	716.40	5.716
	Size, Trip, Size*Trip	Intercept	723.25	12.562
	Size	None	733.15	22.468
	Intercept Only	None	735.05	24.365

Species	Fixed Effects	Random Effects	AIC Value	Delta AIC
	Size, Trip	None	736.79	26.103
	Size, Trip, Size*Trip	None	743.77	33.085
Windowpane Flounder	**Size, Trip**	**None**	**5792.14**	**0.000**
	Size, Trip	Intercept	5796.27	4.132
	Size, Trip, Size*Trip	None	5797.11	4.972
	Size, Trip, Size*Trip	Intercept	5802.88	10.741
	Size	Intercept	5851.06	58.924
	Intercept Only	Intercept	5853.83	61.690
	Size	None	5951.10	158.968
	Intercept Only	None	5955.57	163.437
Monkfish	Size	None	3755.94	0.000
	Intercept Only	**None**	**3756.11**	**0.170**
	Intercept Only	Intercept	3757.58	1.638
	Size	Intercept	3757.73	1.787
	Intercept Only	Intercept, Slope	3759.58	3.639
	Size, Trip	None	3765.68	9.740
	Size, Trip	Intercept	3767.65	11.712
	Size, Trip, Size*Trip	None	3774.06	18.113
Sea Scallop	**Size, Size^2, Trip, Size*Trip, Size^2*Trip**	**Intercept, Slope**	**6191.78**	**0.00**
	Size, Trip, Size*Trip	Intercept, Slope	6249.35	57.57
	Size, Trip, Size*Trip	Intercept	6255.43	63.65
	Size, Trip	Intercept, Slope	6326.24	134.46
	Size	Intercept, Slope	6343.78	152.00
	Intercept Only	Intercept, Slope	6351.06	159.28
	Size, Trip	Intercept	6354.91	163.13
	Size	Intercept	6362.47	170.69
	Intercept Only	Intercept	6372.17	180.39
	Size, Trip, Size*Trip	None	6773.37	581.59
	Size, Trip	None	6942.3	750.52
	Size	None	7065.87	874.09
	Intercept Only	None	7068.23	876.45

Table D2. Models examining the unpooled catch data. Results are presented from the model that provided the best fit (intercept and length) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	Effect	Estimate	SE	DF	t-value	p-value	Alpha	LCI	UCI
Fourspot Flounder	Intercept	-32.64	9.121	150	-3.58	0.0005	0.05	-50.66	-14.62
	Size	-2.99	0.846	150	-3.54	0.0005	0.05	-4.67	-1.32

Table D3. Models examining the unpooled catch data. Results are presented from the model that provided the best fit (intercept, length and trip) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	Effect	Trip	Estimate	SE	DF	t-value	p-value	LCI	UCI
Windowpane Flounder	Intercept		-3.186	2.186	388	-1.458	0.146	-7.484	1.111
	Size		-0.313	0.228	2072	-1.372	0.170	-0.761	0.134
	Trip	July	0.263	0.155	2072	1.699	0.090	-0.041	0.566
	Trip	September	0.311	0.150	2072	2.070	0.039	0.016	0.605
	Trip	October	0.177	0.148	2072	1.193	0.233	-0.114	0.467
	Trip	November	0.293	0.160	2072	1.832	0.067	-0.021	0.606
	Trip	January	-0.781	0.168	2072	-4.655	0.000	-1.111	-0.452
	Trip	March	-0.245	0.176	2072	-1.392	0.164	-0.590	0.100
	Trip	May	0.175	0.145	2072	1.203	0.229	-0.110	0.460
	Trip	June	0						

Table D4. Models examining the unpooled catch data. Results are presented from the model that provided the best fit (intercept, size, size^2, trip, length*trip and size^2*trip) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	Effect	Trip	Estimate	SE	DF	t value	p value	LCL	UCL
Sea Scallops	Intercept		-5.071	1.993	190	-2.5445	0.0117	-9.0016	-1.1398
	Size		-2.031	0.780	182	-2.6046	0.0100	-3.5698	-0.4924
	Size^2		-0.196	0.076	1347	-2.5793	0.0100	-0.3446	-0.0469
	Trip	July	14.194	3.029	1347	4.6862	0.0000	8.2518	20.1352
	Trip	September	6.352	2.527	1347	2.5138	0.0121	1.3951	11.3091
	Trip	October	-4.141	2.946	1347	-1.4057	0.1601	-9.9199	1.6381
	Trip	November	6.702	2.965	1347	2.2606	0.0239	0.8860	12.5179
	Trip	January	13.135	3.266	1347	4.0220	0.0001	6.7282	19.5409
	Trip	March	6.390	2.597	1347	2.4604	0.0140	1.2951	11.4847
	Trip	May	1.741	2.980	1347	0.5843	0.5591	-4.1050	7.5877
	Trip	June	0.000						
	Size*Trip	July	5.252	1.185	1347	4.4304	0.0000	2.9262	7.5768
	Size*Trip	September	2.817	0.974	1347	2.8929	0.0039	0.9068	4.7279
	Size*Trip	October	-1.485	1.168	1347	-1.2717	0.2037	-3.7753	0.8057
	Size*Trip	November	2.802	1.173	1347	2.3892	0.0170	0.5013	5.1018
	Size*Trip	January	5.087	1.304	1347	3.9017	0.0001	2.5293	7.6446
	Size*Trip	March	2.703	1.023	1347	2.6420	0.0083	0.6960	4.7102
	Size*Trip	May	1.107	1.163	1347	0.9517	0.3414	-1.1748	3.3887
	Size*Trip	June	0.000						
	Size^2*Trip	July	0.457	0.115	1347	3.9607	0.0001	0.2307	0.6835
	Size^2*Trip	September	0.319	0.094	1347	3.4018	0.0007	0.1349	0.5023
	Size^2*Trip	October	-0.146	0.115	1347	-1.2646	0.2062	-0.3718	0.0803
	Size^2*Trip	November	0.281	0.116	1347	2.4242	0.0155	0.0535	0.5075
	Size^2*Trip	January	0.470	0.130	1347	3.6214	0.0003	0.2153	0.7242
	Size^2*Trip	March	0.268	0.100	1347	2.6709	0.0077	0.0712	0.4654
	Size^2*Trip	May	0.154	0.113	1347	1.3621	0.1734	-0.0678	0.3760
	Size^2*Trip	June	0.000						

Table D5. Model building for pooled-over-length models. Hierarchical models ranked based upon minimum AIC values.

Species	Fixed Effects	Random Effects	Value	Delta AIC
Uncl. Skates	**Intercept, Trip**	**Intercept**	**3467.32**	**0.00**
	Intercept	Intercept	3534.99	67.67
	Intercept, Trip	None	4490.93	1023.62
	Intercept	None	4740.70	1273.39
Barndoor Skates	Intercept, Trip	None	314.92	0.00
	Intercept	**Intercept**	**315.81**	**0.90**
	Intercept, Trip	Intercept	316.14	1.22
	Intercept	None	317.33	2.41
Summer Flounder	**Intercept**	**None**	**277.92**	**0.00**
	Intercept	Intercept	279.02	1.10
	Intercept, Trip	None	282.49	4.57
	Intercept, Trip	Intercept	284.21	6.29
Yellowtail Flounder	**Intercept, Trip**	**Intercept**	**380.10**	**0.00**
	Intercept, Trip	None	380.10	0.00
	Intercept	Intercept	384.24	4.13
	Intercept	None	388.13	8.03
	Intercept	**Intercept**	**419.82**	**0.00**
Winter Flounder	Intercept, Trip	Intercept	426.53	6.71
	Intercept	None	462.15	42.33
	Intercept, Trip	None	463.85	44.03
Monkfish	**Intercept**	**None**	**982.47**	**0.00**
	Intercept	Intercept	983.94	1.47
	Intercept, Trip	None	991.17	8.70
	Intercept, Trip	Intercept	993.09	10.61

Table D6. Models examining the pooled-over-length catch data. Results are presented from the model that provided the best fit (intercept only) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	Effect	Estimate	SE	DF	t value	p value	LCL	UCL
Barndoor Skate	Intercept	-0.147	0.102	127	-1.436	0.153	-0.348	0.055
Summer Flounder	Intercept	-0.050	0.106	124	-0.475	0.636	-0.259	0.159
Winter Flounder	Intercept	-0.544	0.143	166	-3.813	0.000	-0.825	-0.262
Monkfish	Intercept	0.040	0.032	302	1.272	0.205	-0.022	0.103

Table D7. Models examining the pooled-over-length catch data. Results are presented from the model that provided the best fit (intercept, trip) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

Species	Effect	Trip	Estimate	SE	DF	t value	p value	LCL	UCL
Uncl. Skates	Intercept		-0.066	0.062	442	-1.069	0.286	-0.188	0.056
	Trip	July	-0.053	0.088	442	-0.604	0.546	-0.226	0.120
	Trip	September	0.148	0.088	442	1.676	0.095	-0.026	0.322
	Trip	October	-0.267	0.089	442	-3.005	0.003	-0.441	-0.092

Species	Effect	Trip	Estimate	SE	DF	t value	p value	LCL	UCL
	Trip	November	0.137	0.091	442	1.505	0.133	-0.042	0.316
	Trip	January	-0.590	0.099	442	-5.968	0.000	-0.784	-0.395
	Trip	March	-0.116	0.100	442	-1.153	0.250	-0.313	0.081
	Trip	May	0.118	0.088	442	1.344	0.180	-0.055	0.291
	Trip	June	0.000						
Yellowtail Flounder	Intercept		-0.033	0.256	150	-0.128	0.898	-0.539	0.473
	Trip	July	0.155	0.300	150	0.516	0.606	-0.438	0.748
	Trip	September	0.111	0.281	150	0.397	0.692	-0.443	0.666
	Trip	October	-0.524	0.304	150	-1.727	0.086	-1.125	0.076
	Trip	November	0.151	0.429	150	0.351	0.726	-0.696	0.997
	Trip	January	-1.353	0.562	150	-2.409	0.017	-2.464	-0.243
	Trip	March	0.187	0.612	150	0.305	0.761	-1.023	1.397
	Trip	May	-0.241	0.340	150	-0.706	0.481	-0.913	0.432
	Trip	June	0.000						

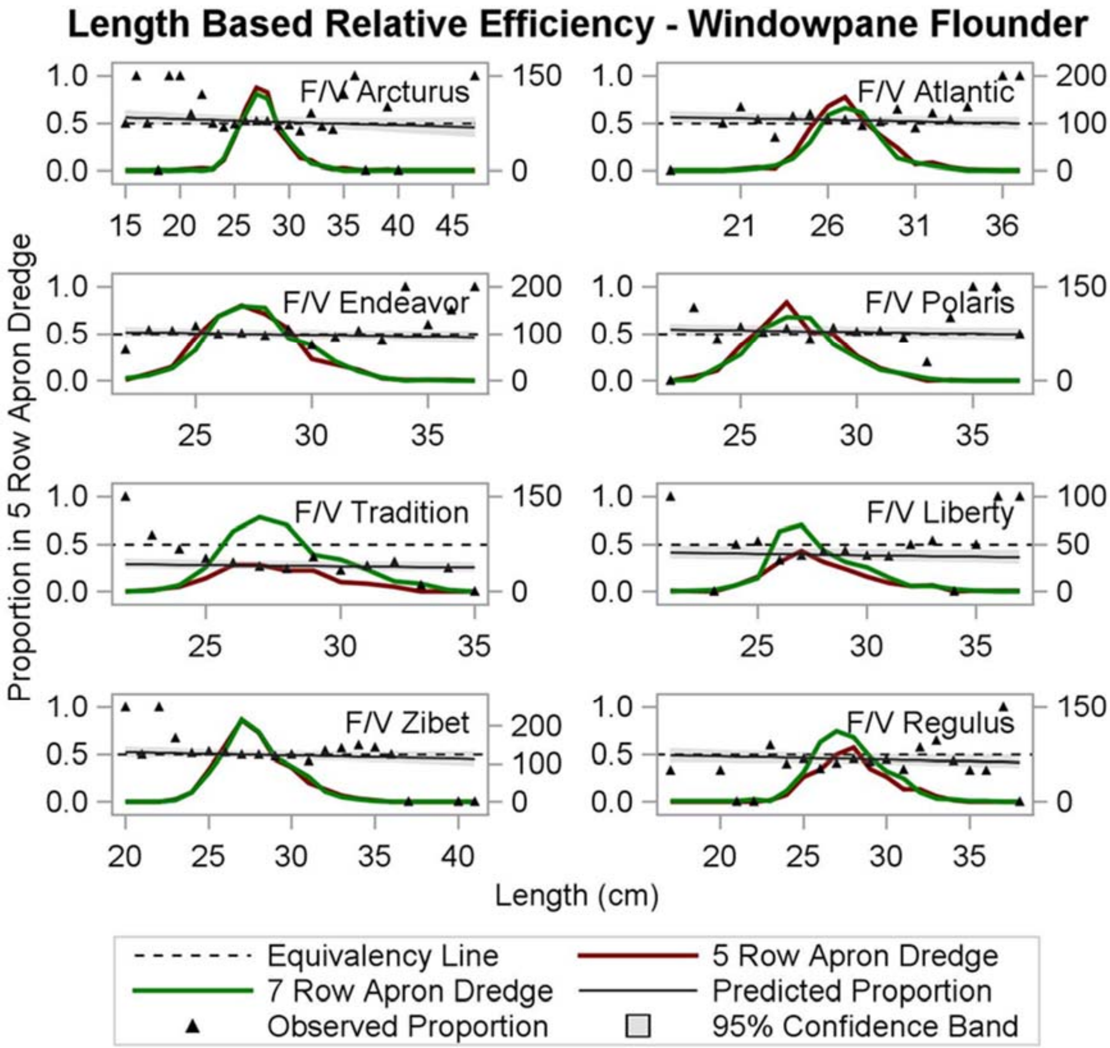


Figure D1. Relative windowpane flounder catch by the two dredge configurations. The triangles represent the observed proportion at length (Catch5row/(Catch5row + Catch7row), with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line). The model that provided the best fit to the data included a factor that accounted for individual intercepts with a common slope for each trip.

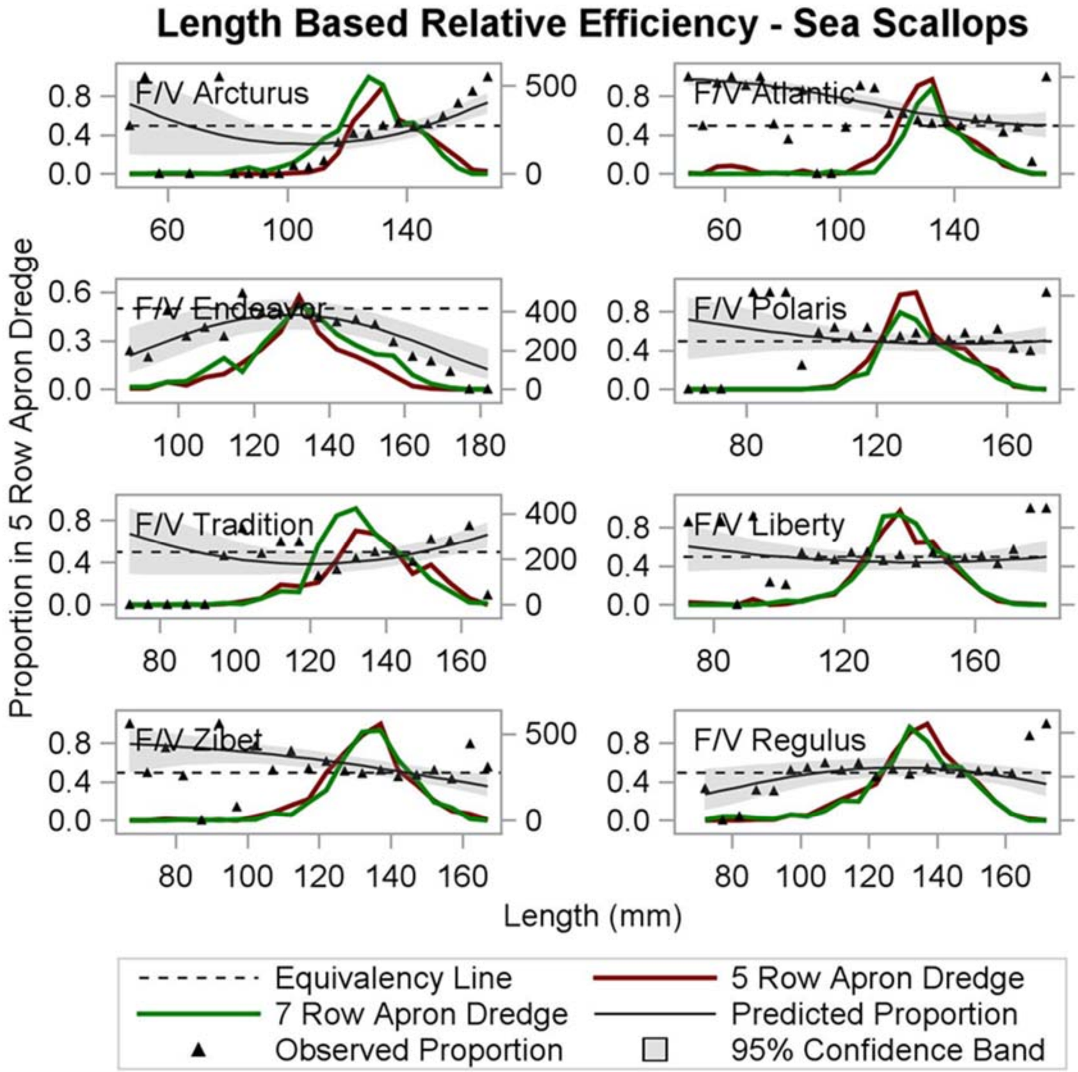


Figure D2. Relative sea scallop catch by the two dredge configurations. The triangles represent the observed proportion at length (Catch5row/(Catch5row + Catch7row), with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line). The model that provided the best fit to the data included a factor that accounted for individual slopes for each trip.

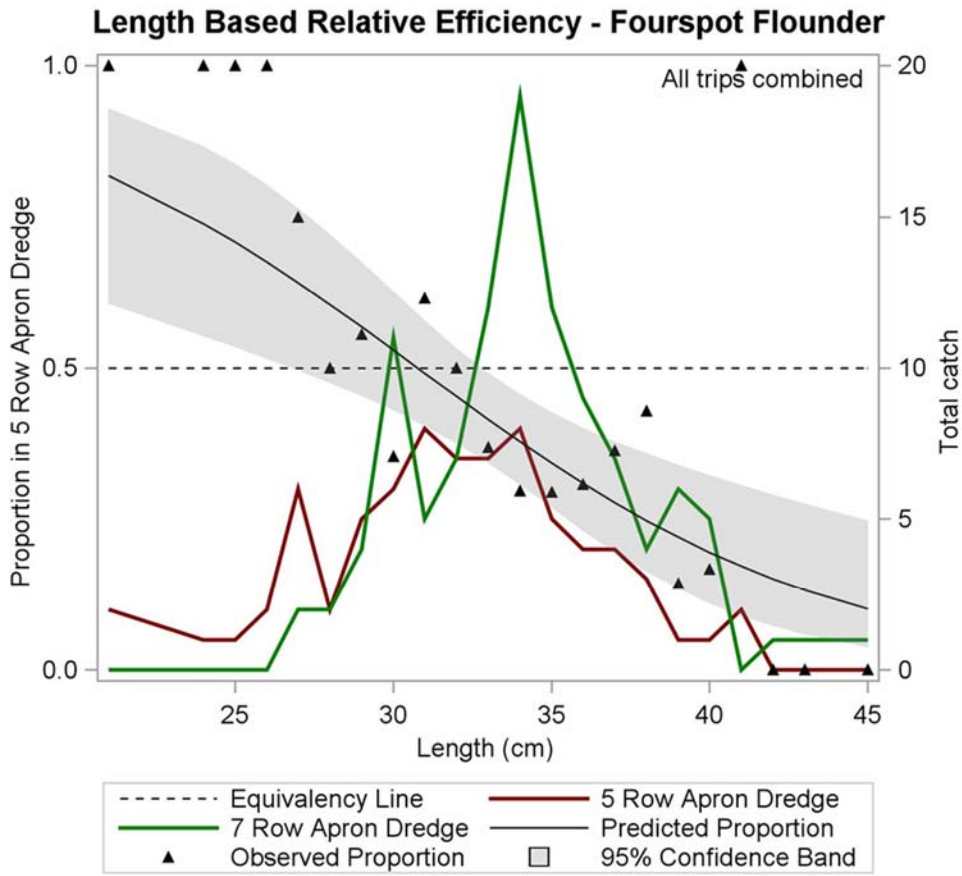


Figure D3. Relative fourspot flounder catch by the two dredge configurations. The triangles represent the observed proportion at length ($Catch_{5row}/(Catch_{5row} + Catch_{7row})$, with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line).

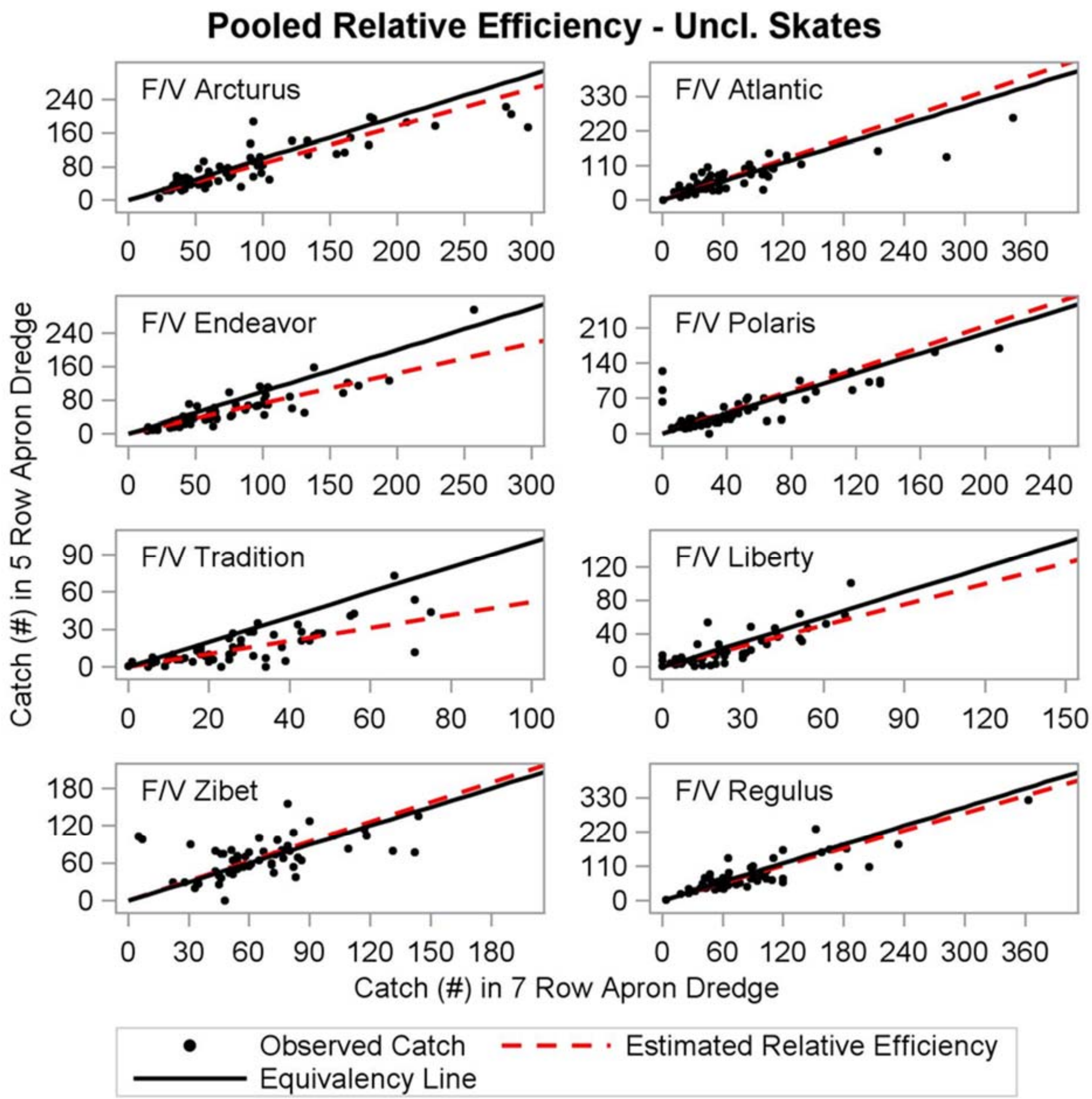


Figure D4. Total pooled catches for unclassified skates for the 5-row apron dredge vs. the 7 ring apron dredge. Model output from the analysis of the pooled data indicated that the model that included trip as a factor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

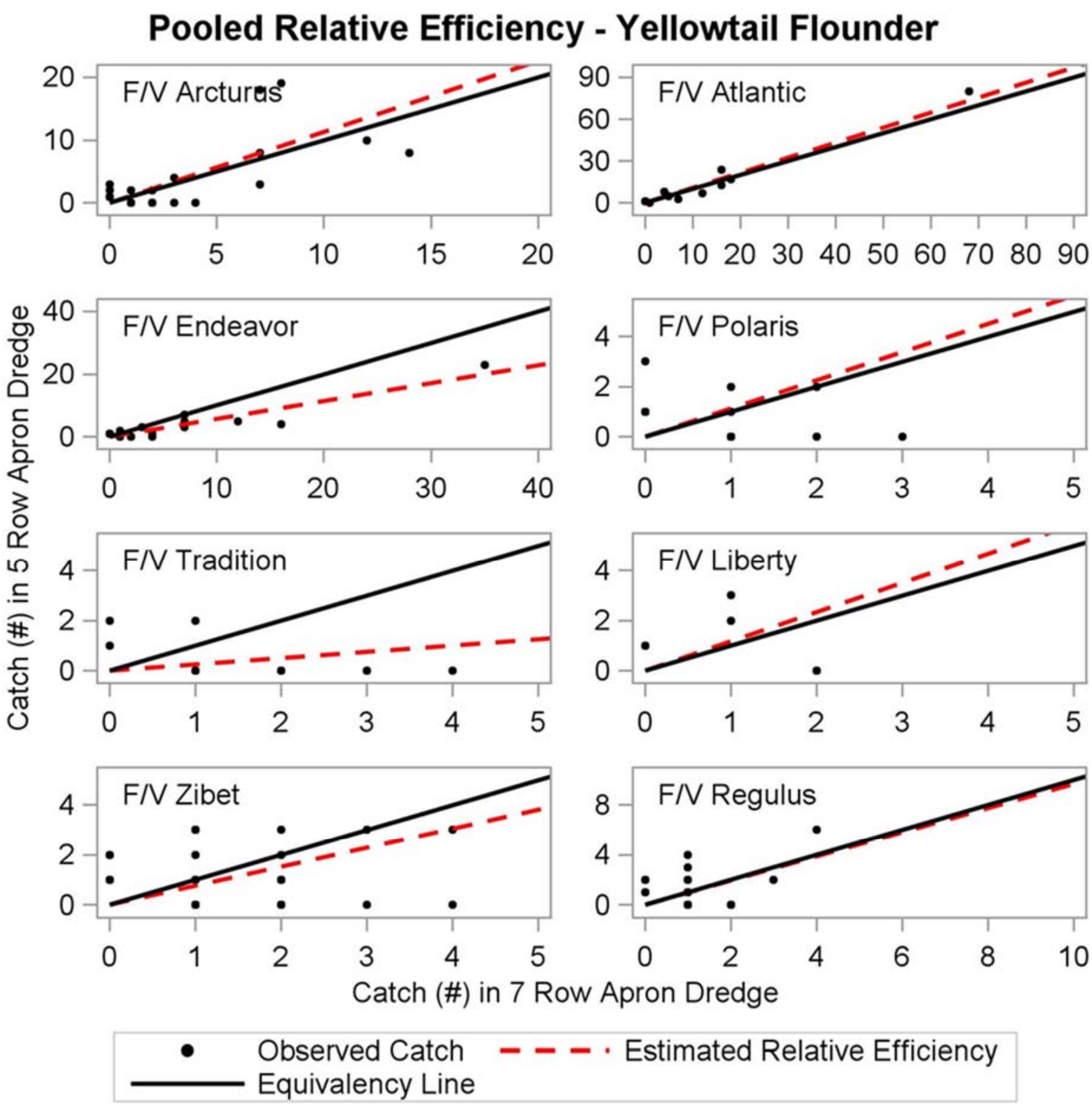


Figure D5. Total pooled catches for yellowtail flounder for the 5-row apron dredge vs. the 7 ring apron dredge. Model output from the analysis of the pooled data indicated that the model that included trip as a factor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

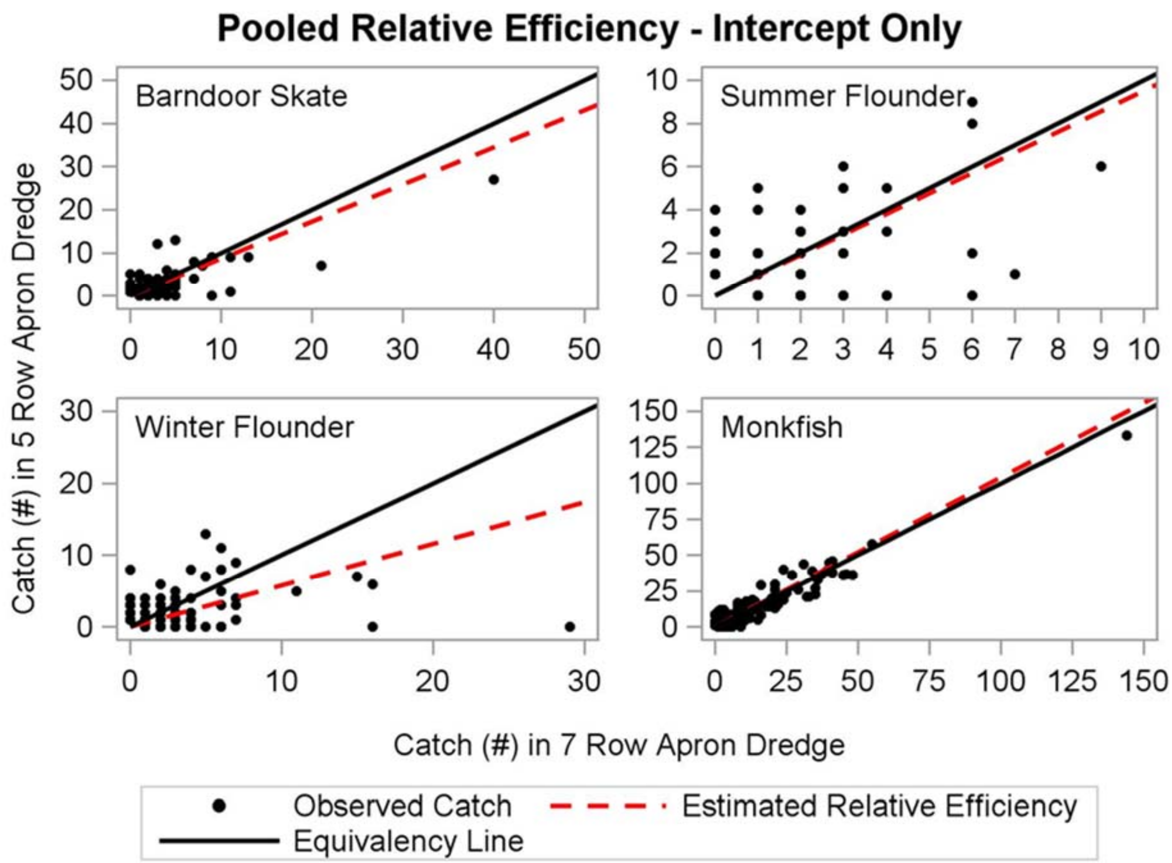


Figure D6. Total pooled catches for barndoor skate, summer flounder, winter flounder and monkfish for the 5-row apron dredge vs. the 7 ring apron dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

Appendix E:

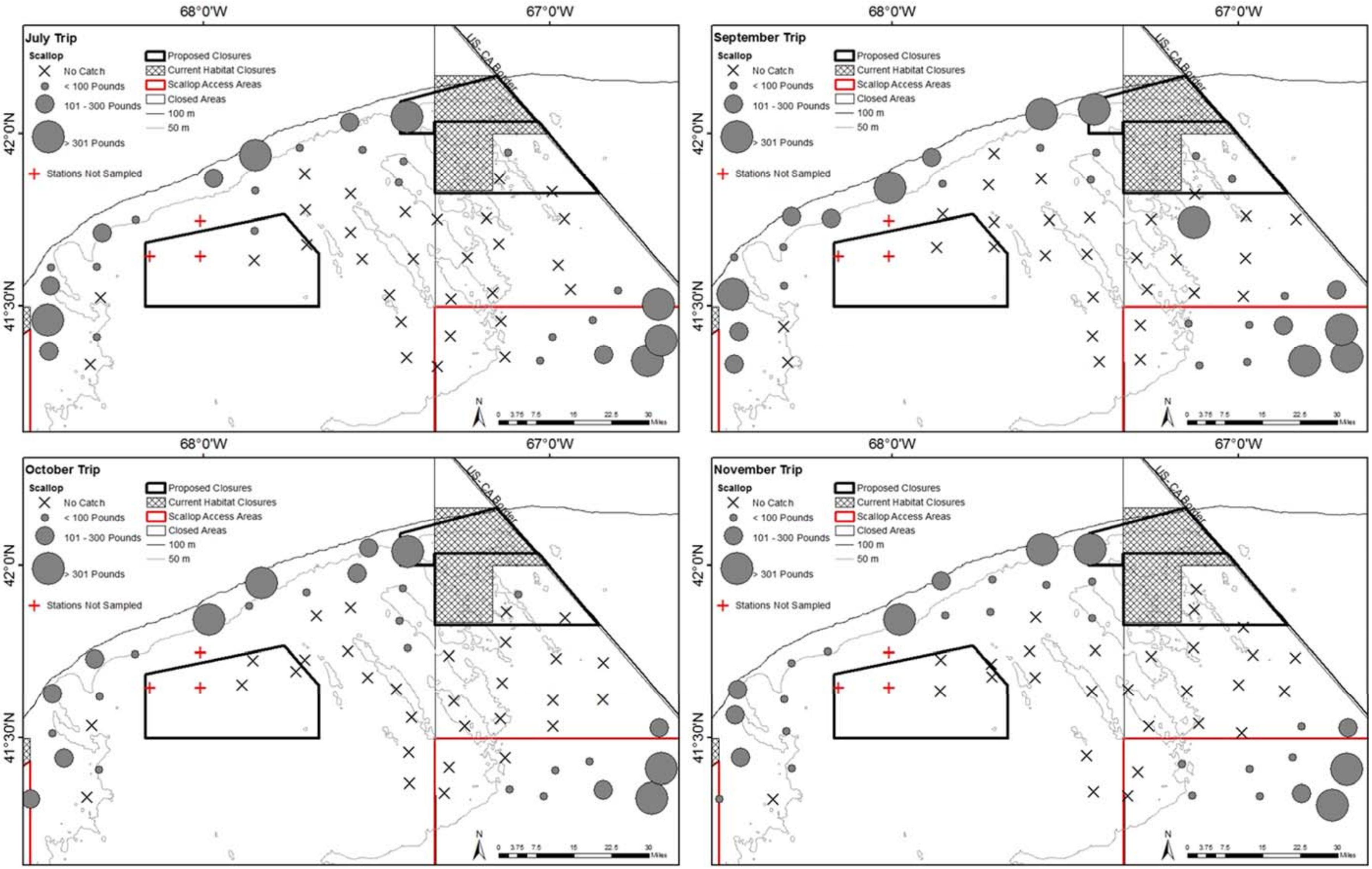
5

Abstract

In 2004, gray meat disease was found in Atlantic Sea Scallops (*Placopecten magellanicus*) in the Nantucket Lightship closed area, just south of Georges Bank. Previously seen in Nova Scotia and mid-Atlantic areas, the disease is characterized by weak, gray adductor muscles instead of the firm, white muscle found in healthy scallops. The adductor muscle is harvested and marketed as a high value, edible product. Adductor muscles with gray meat disease are of poor quality and cannot be sold, resulting in a biomass loss of nearly US$100 million ex–vessel in 2007 (Levesque et al, 2016). The cause of the disease is currently unknown, but previous research suggests that an apicomplexan parasite found in Icelandic Scallops (*Chlamys islandica*) exhibiting gray meat disease has a major role in the disease seen in *P. magellanicus*. In this study, scallop adductor muscle samples were collected from areas just south of Georges Bank from 2015 to 2018. These samples were used to develop a diagnostic method to detect the apicomplexan parasite in *P. magellanicus* using polymerase chain reaction (PCR). Sample collection, rehydration and homogenization methods were established to prepare the samples for DNA extraction. A PCR assay was developed using previously published primers to detect the apicomplexan parasite similar to *Aggregata*. The PCR data will be cross referenced with histological examination from all collected animals to understand the relationship between the presence and abundance of the parasite in the adductor muscle samples and the grossly observable gray appearance of the muscle.

Figure E1. Abstract of "Development of Diafnostic PCR Assay to Detect an Unknown Apicomplexan Parasite in Atlantic Sea Scallops (*Placopecten Magellanicus*) with Gray Meat Disease" senior thesis. Available upon request at the Roger Williams University (RWU).

Appendix F: Distribution of scallops and the main bycatch species



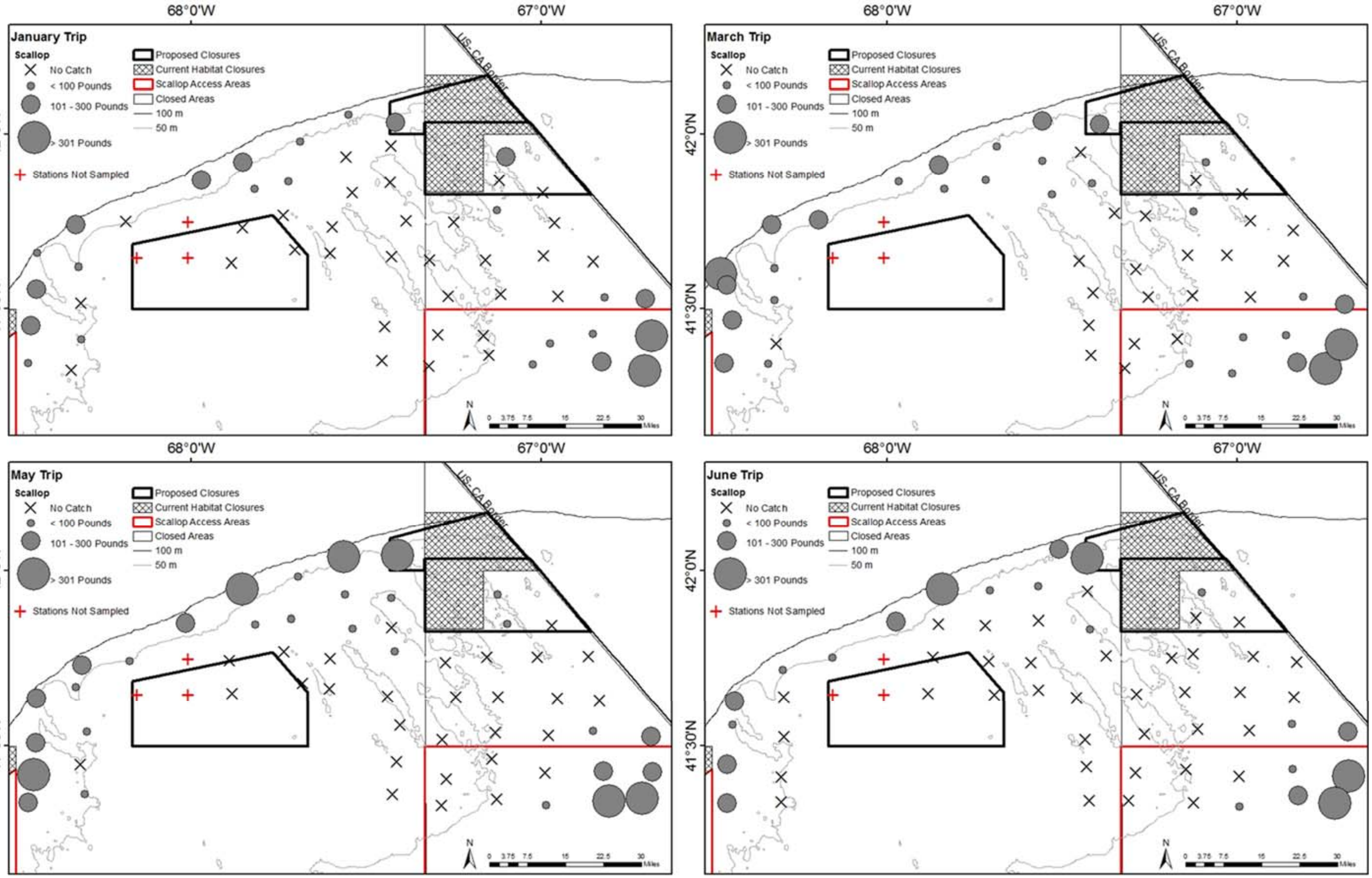
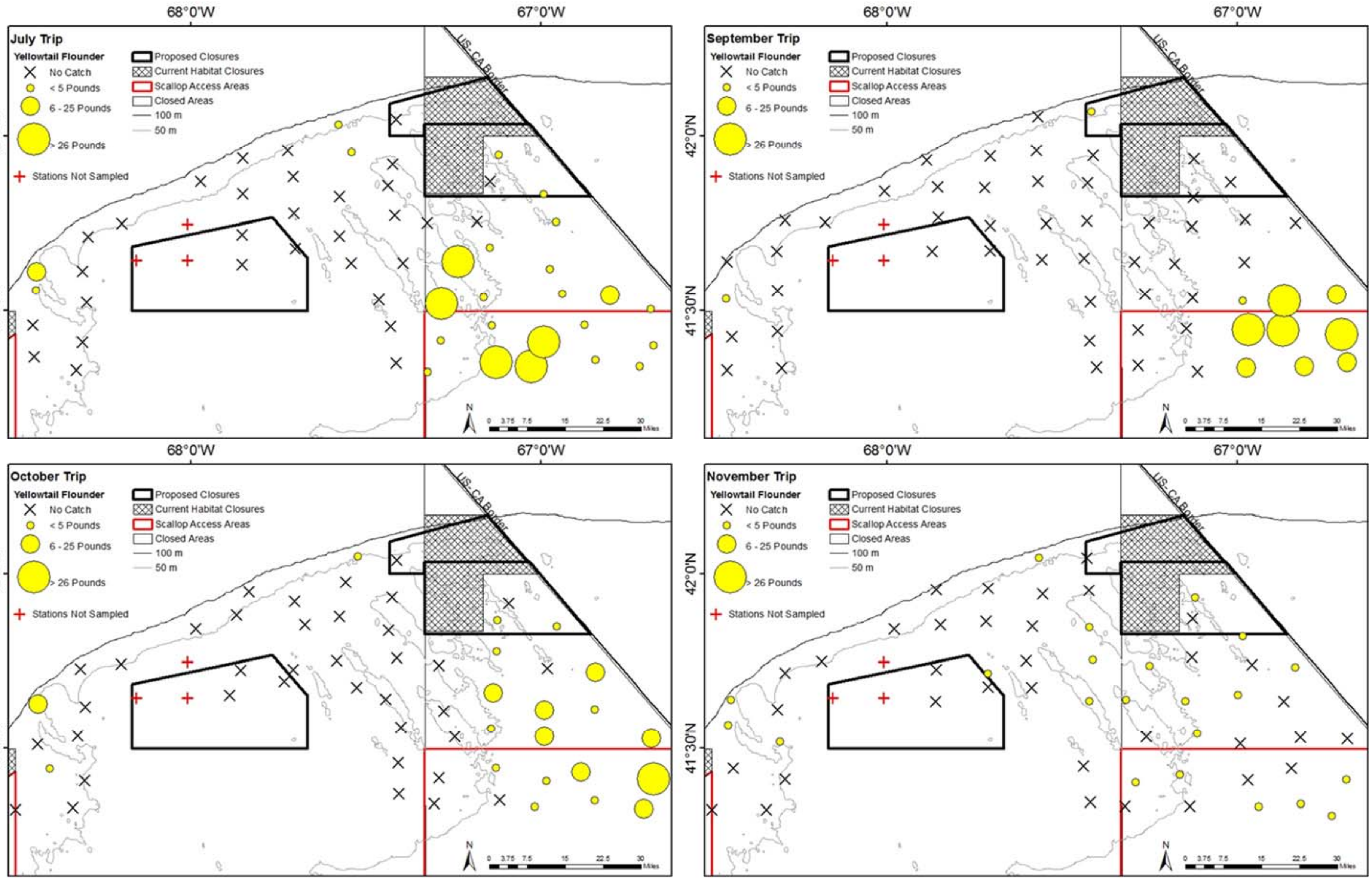


Figure F1. Distribution of sea scallops during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.



July Trip
September Trip
October Trip
November Trip
Yellowtail Flounder
No Catch
< 5 Pounds
6 - 25 Pounds
> 26 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
68°0'W
67°0'W
42°0'N
41°30'N
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles

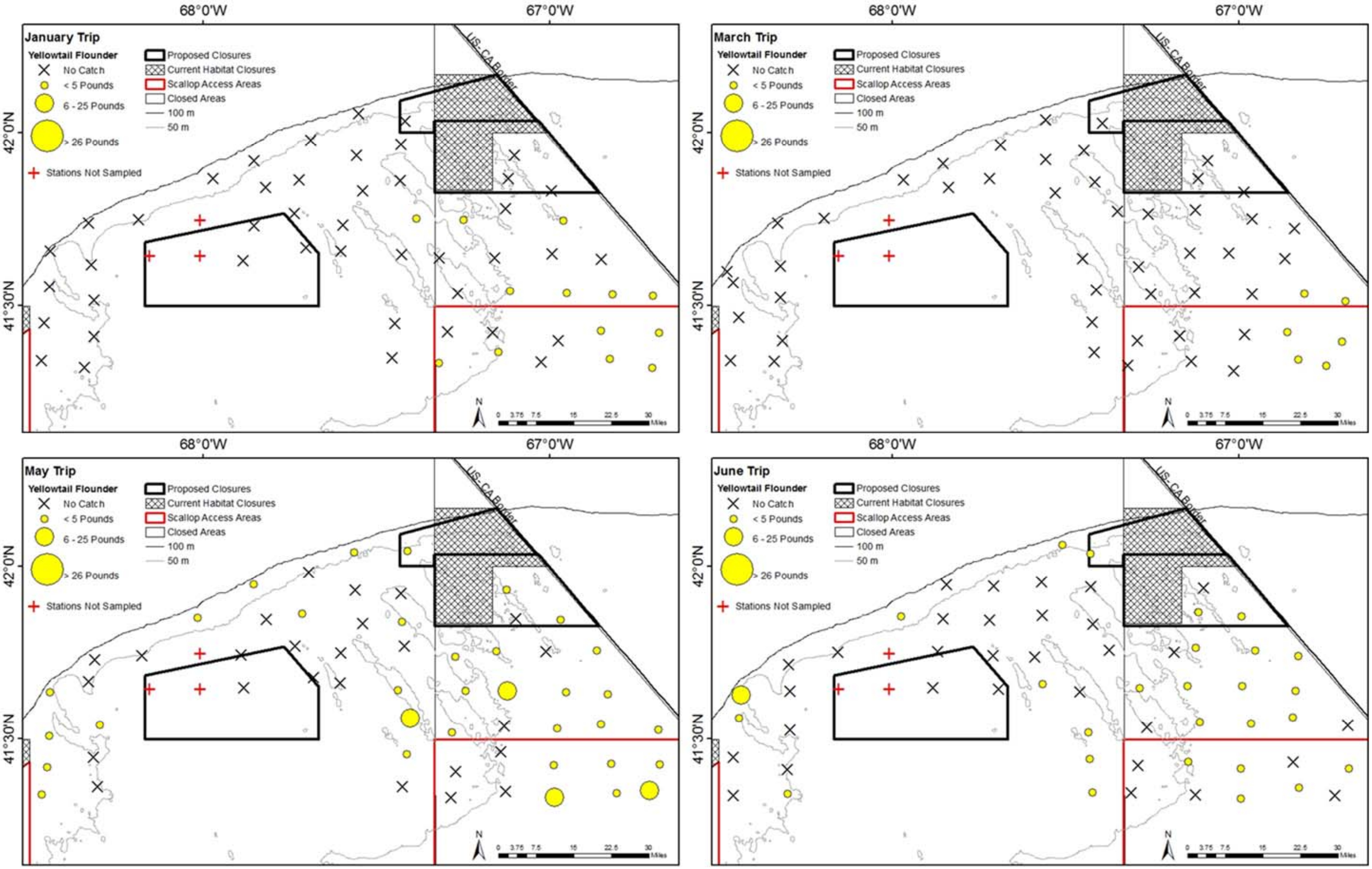
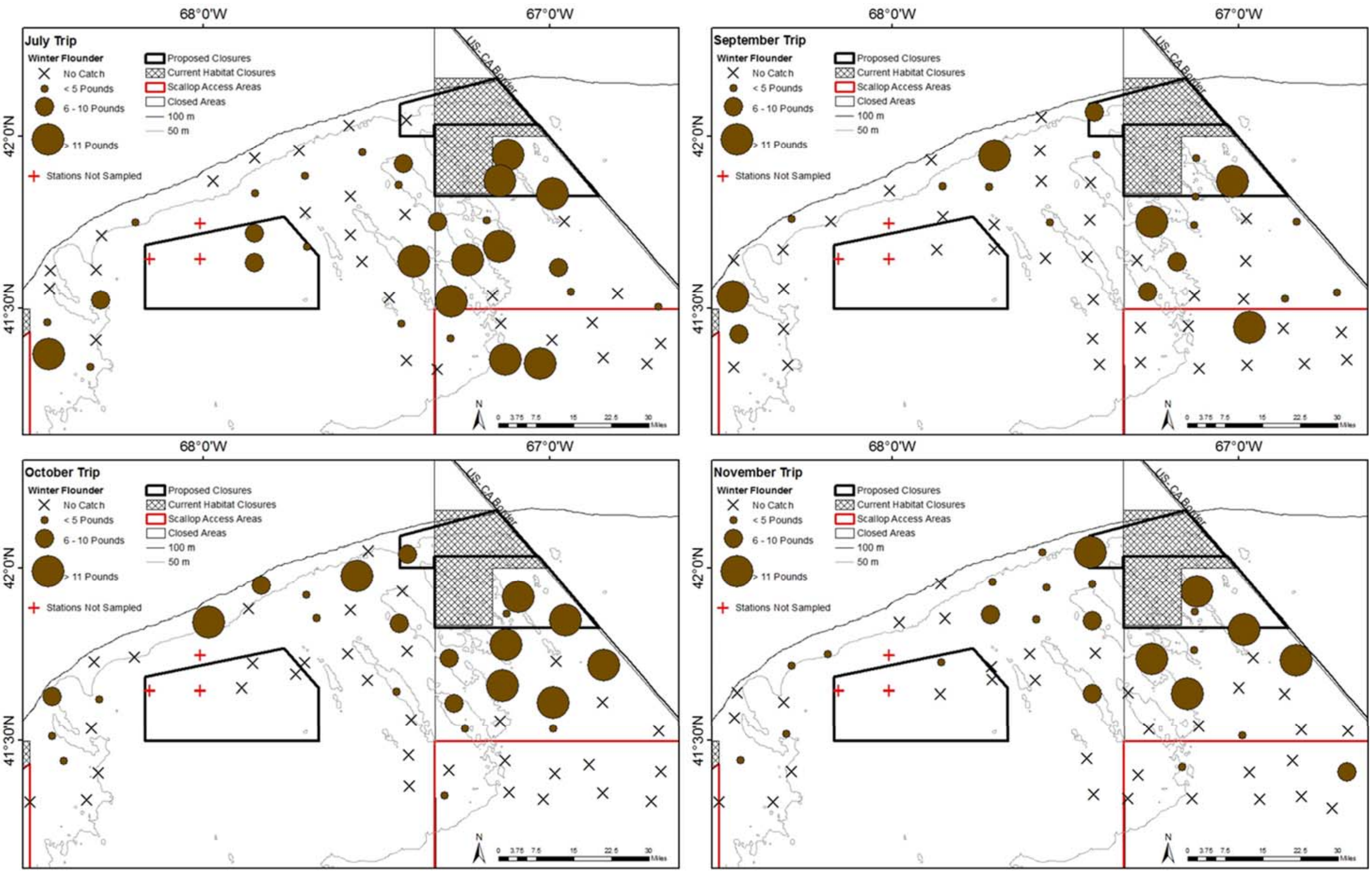


Figure F2. Distribution of yellowtail flounder during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.



68°0'W
67°0'W
42°0'N
41°30'N
July Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30
Miles
September Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
October Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
November Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m

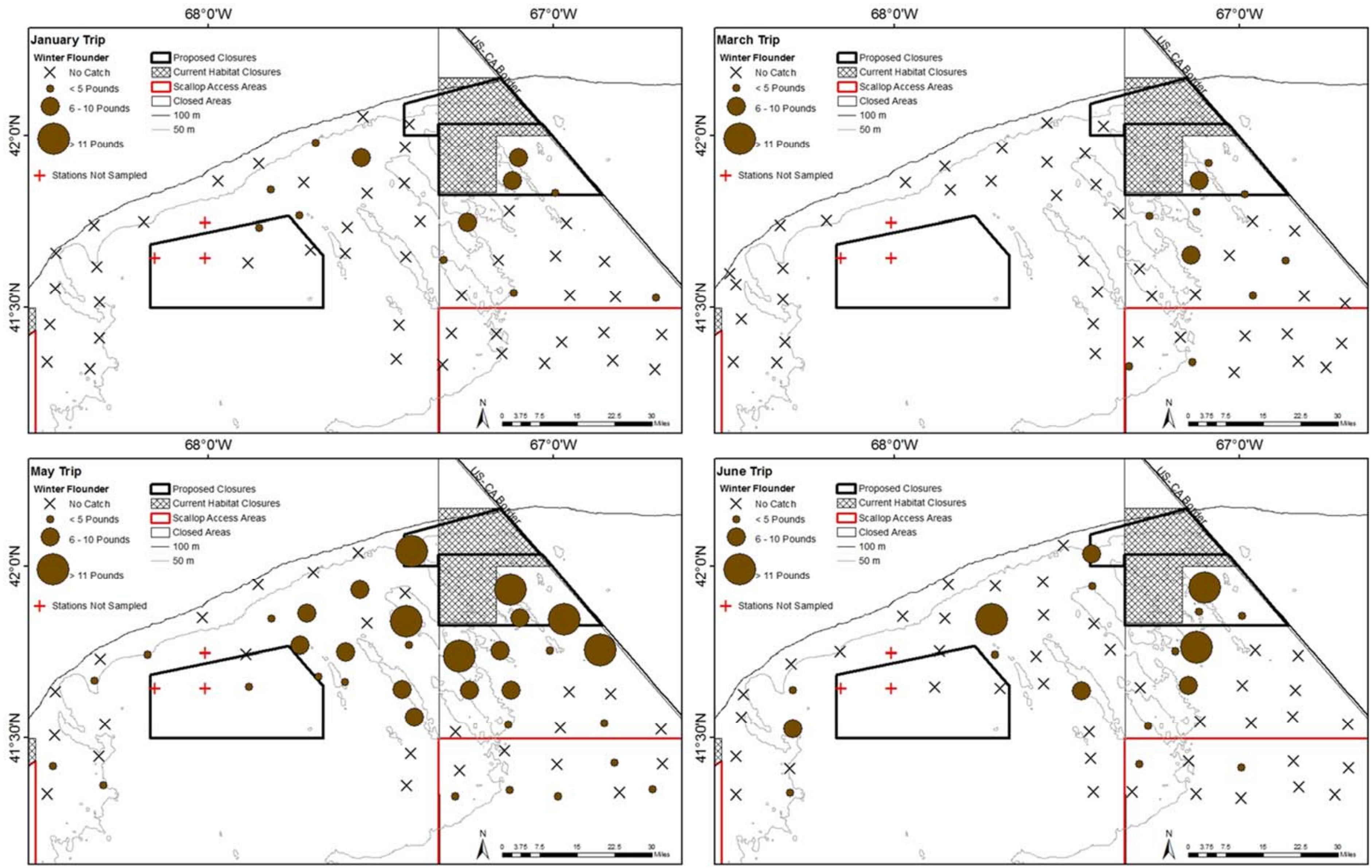
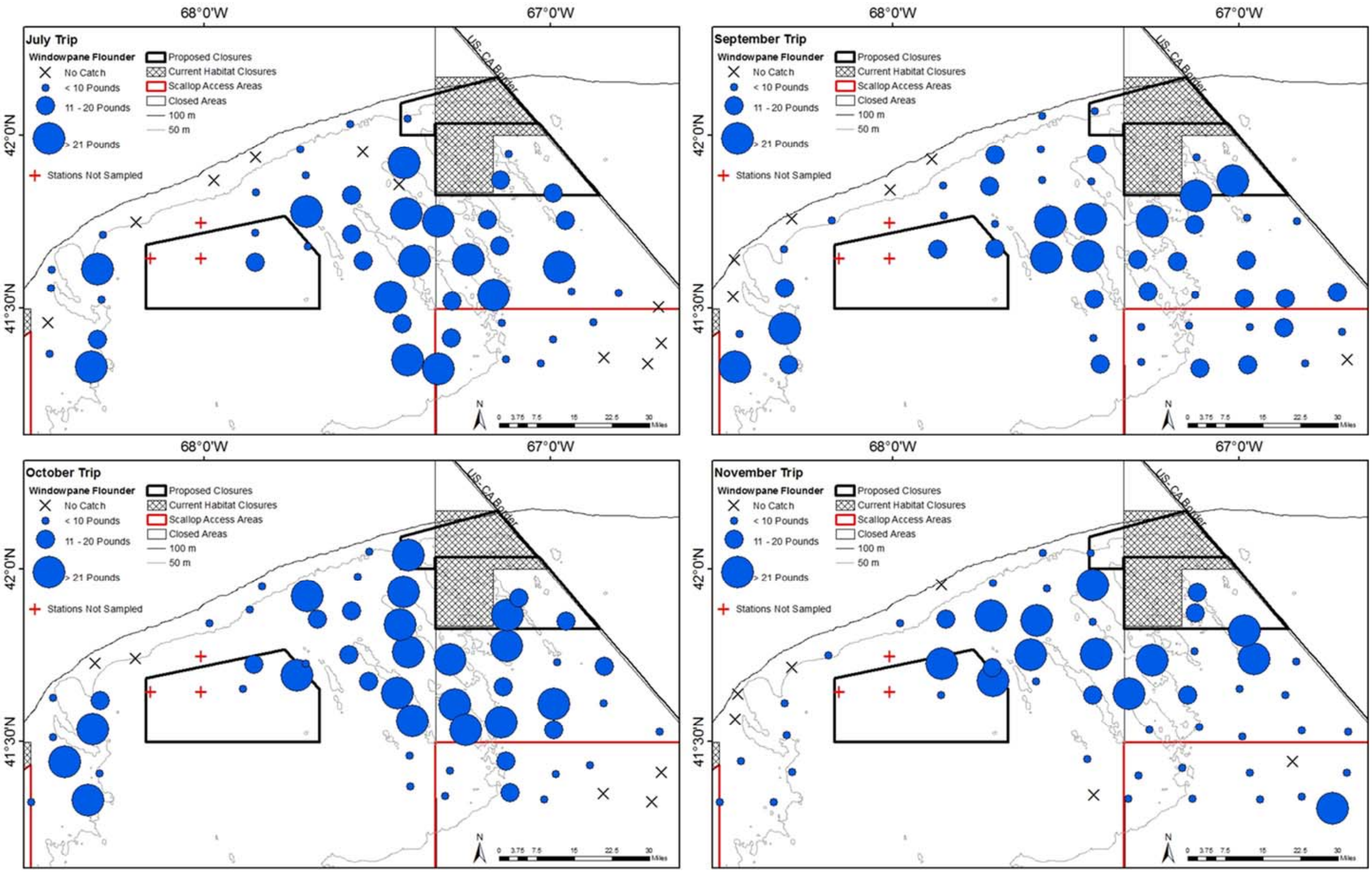


Figure F3. Distribution of winter flounder during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.



July Trip
68°0'W
67°0'W
42°0'N
41°30'N
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles
September Trip
68°0'W
67°0'W
42°0'N
41°30'N
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles
October Trip
68°0'W
67°0'W
42°0'N
41°30'N
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles
November Trip
68°0'W
67°0'W
42°0'N
41°30'N
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles

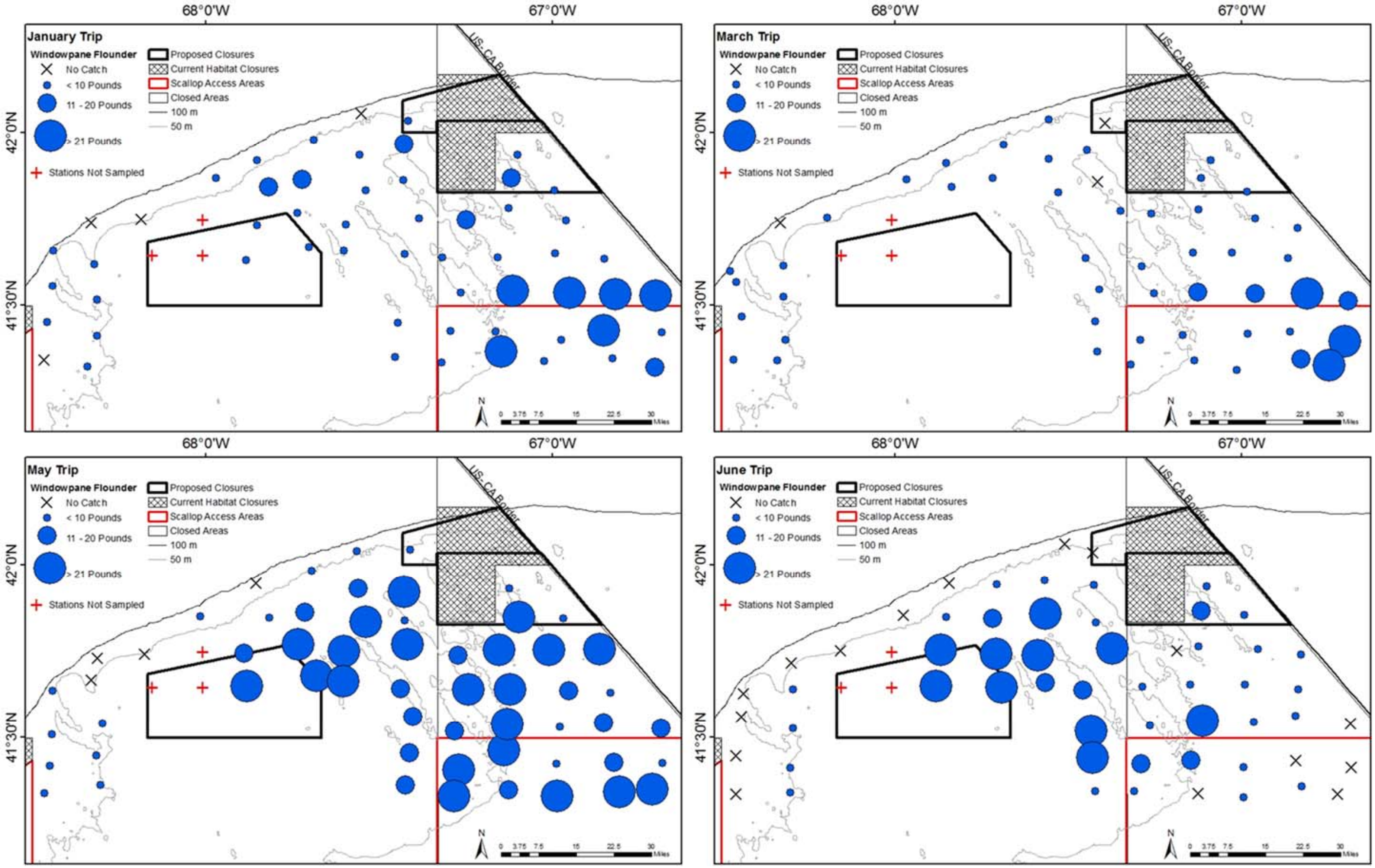
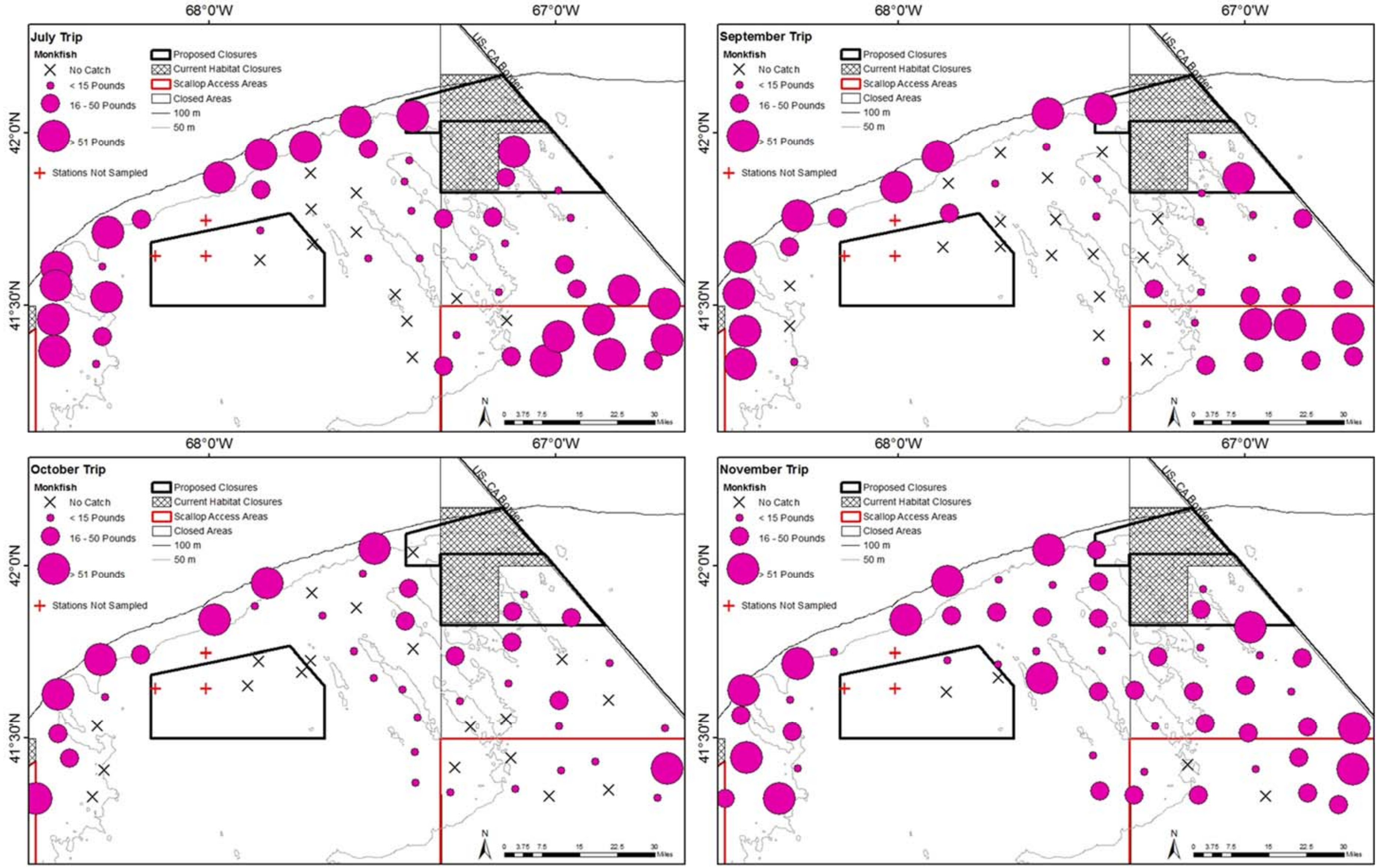


Figure F4. Distribution of windowpane flounder during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.


68°0'W
67°0'W
42°0'N
41°30'N
July Trip
September Trip
October Trip
November Trip
Monkfish
No Catch
< 15 Pounds
16 - 50 Pounds
> 51 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30
Miles

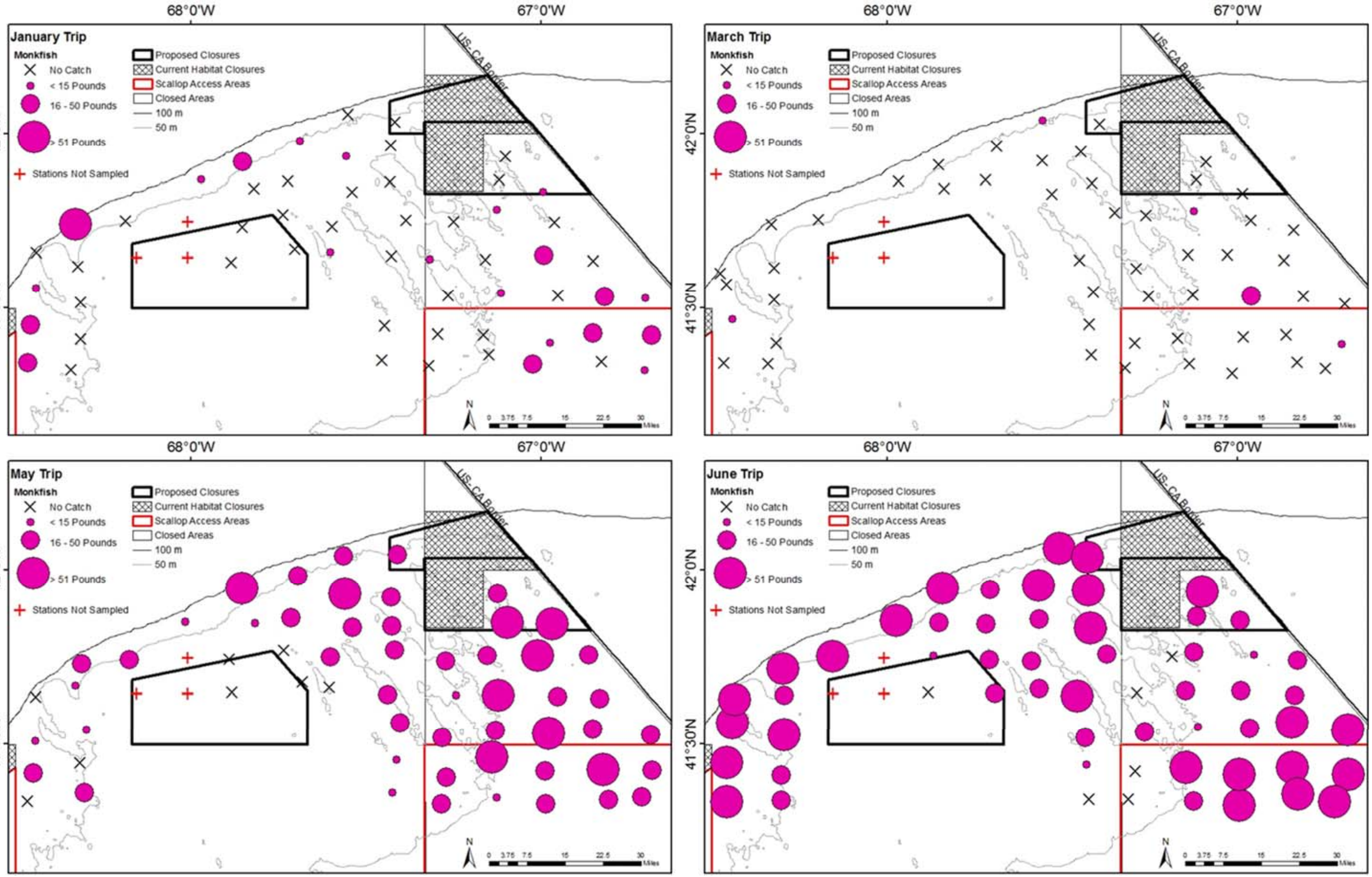
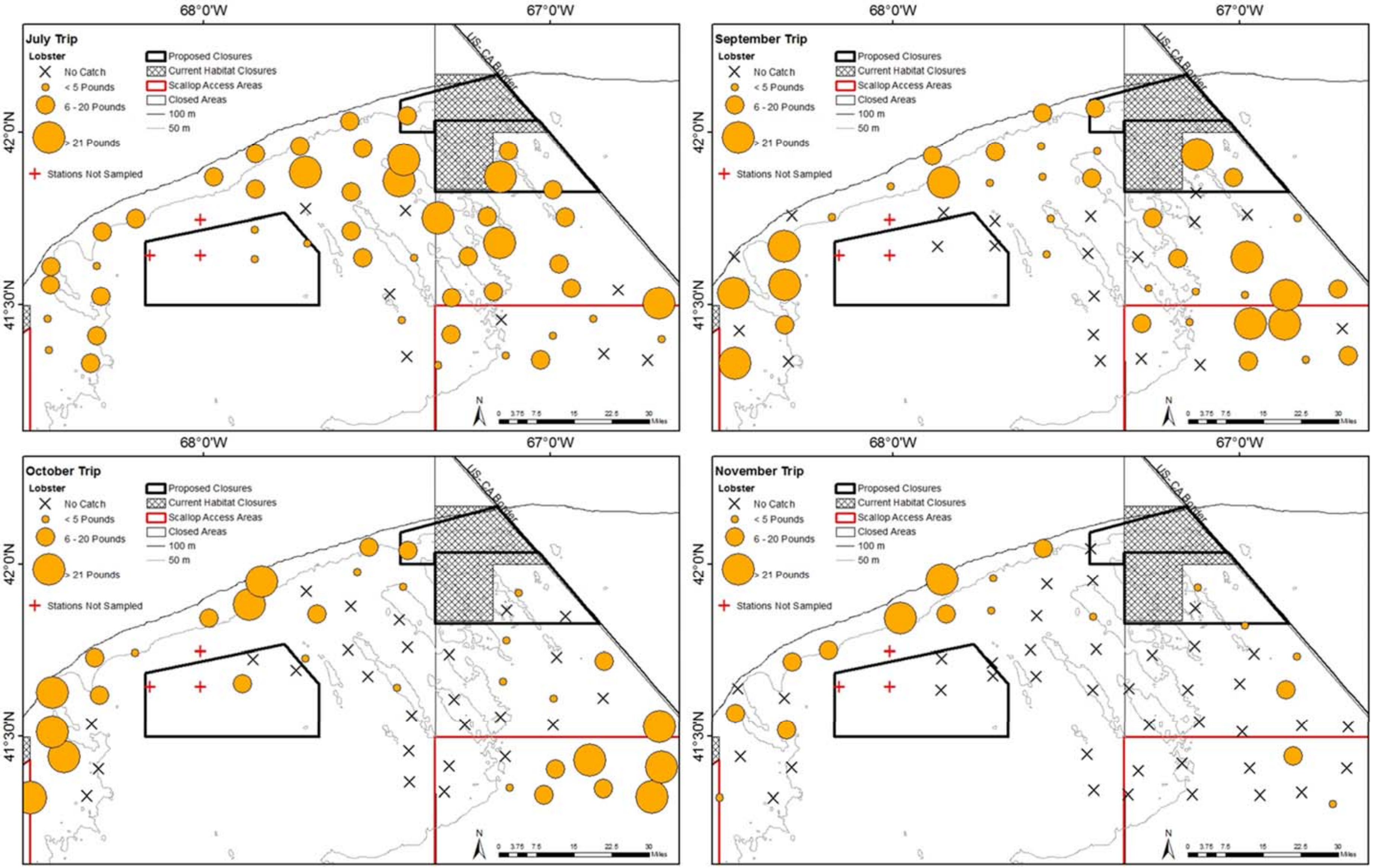


Figure F5. Distribution of monkfish during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.


68°0'W
67°0'W
42°0'N
41°30'N
July Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
N
0 3.75 7.5 15 22.5 30 Miles
September Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
October Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
November Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Stations Not Sampled
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border

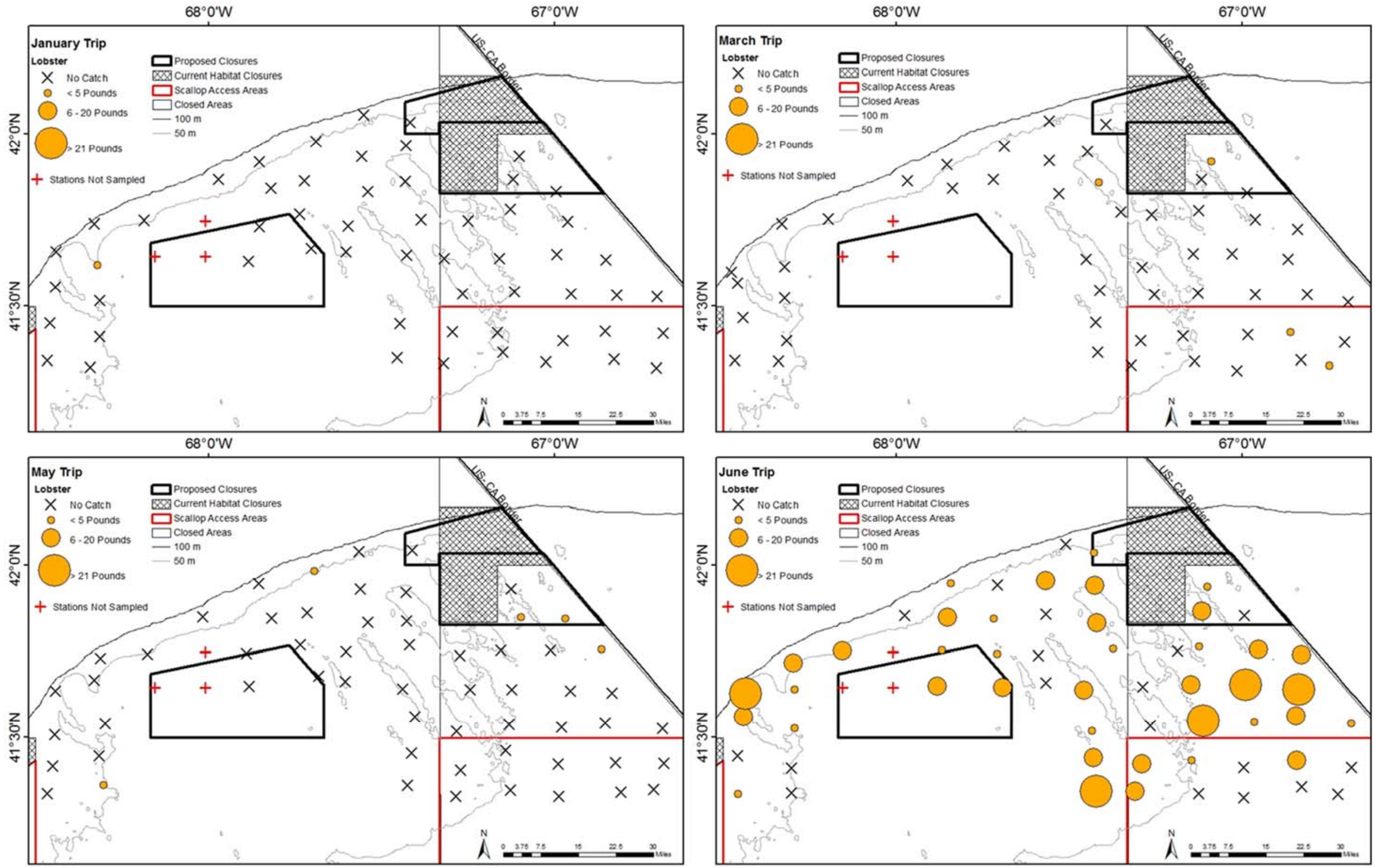


Figure F6. Distribution of lobster during the 2016 seasonal bycatch survey on the northern portion of Georges Bank.

Appendix G: 2015 – 2016 Bycatch Survey Results

Table G1. Average bottom temperature in the northern portion of Georges Bank during 2015 and 2016 seasonal bycatch project.

Year	Month	Average Bottom Temperature
2015	August	14.1
	September	14.8
	October	14.9
	November	12.8
2016	January	9.2
	March	6.2
	May	8.0
	June	11.0
	July	12.9
	September	-
	October	15.3
	November	12.7
2017	January	7.4
	March	6.2
	May	7.4
	June	9.8

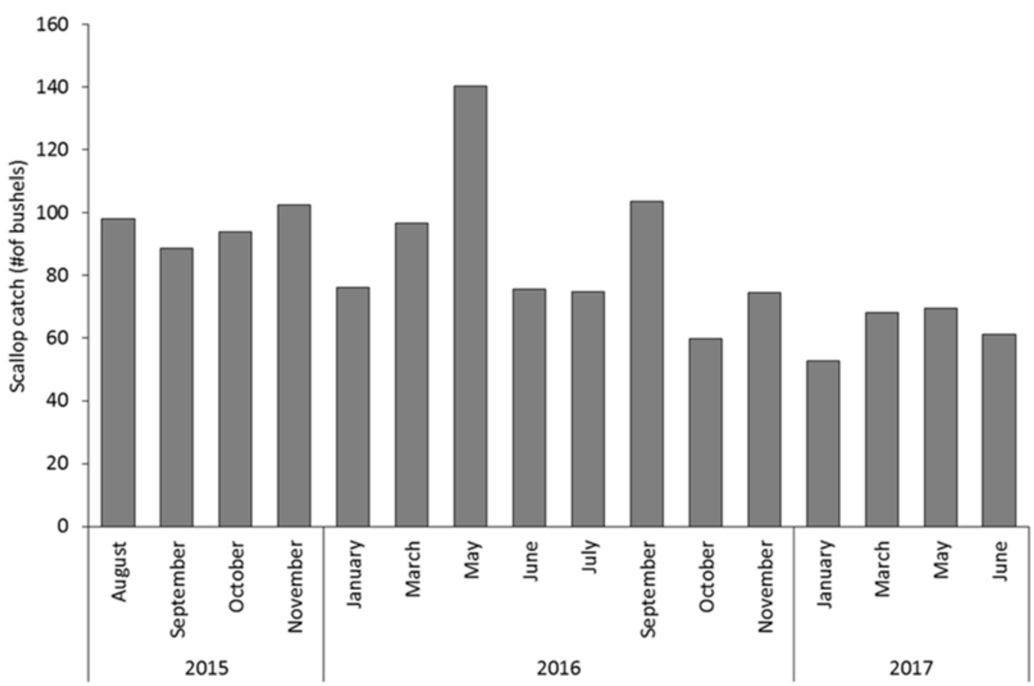
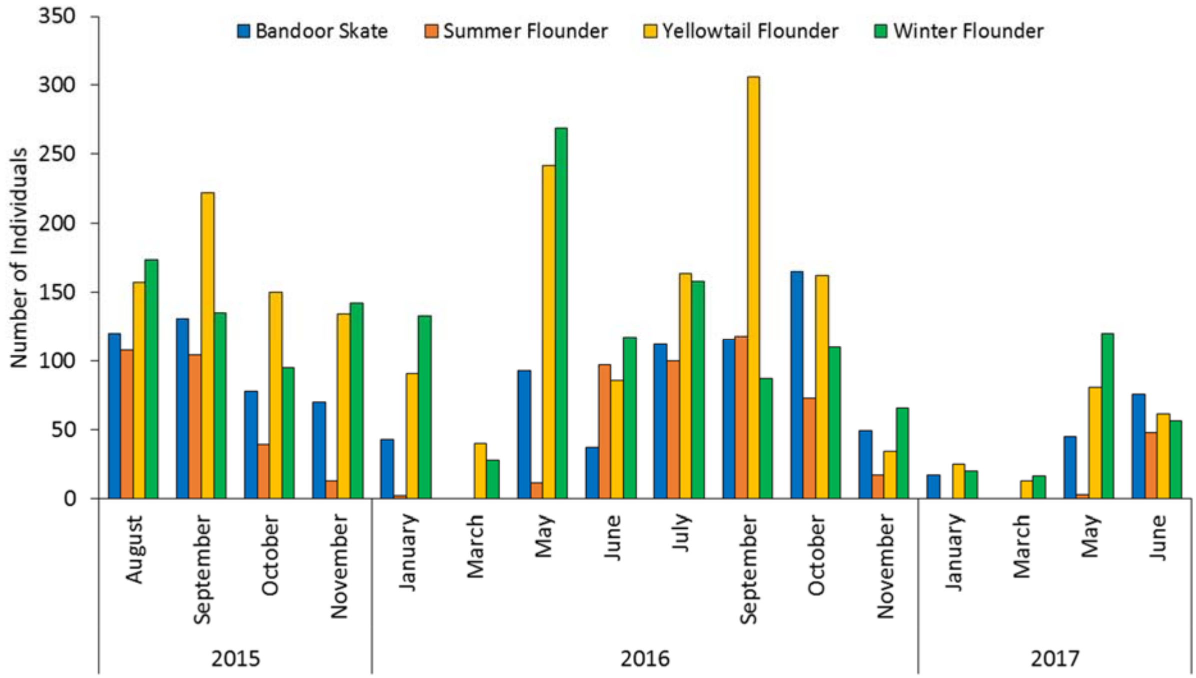


Figure G1. Number of bushels per month in the northern portion of Georges Bank during 2015 and 2016 seasonal bycatch project.

a)



b)

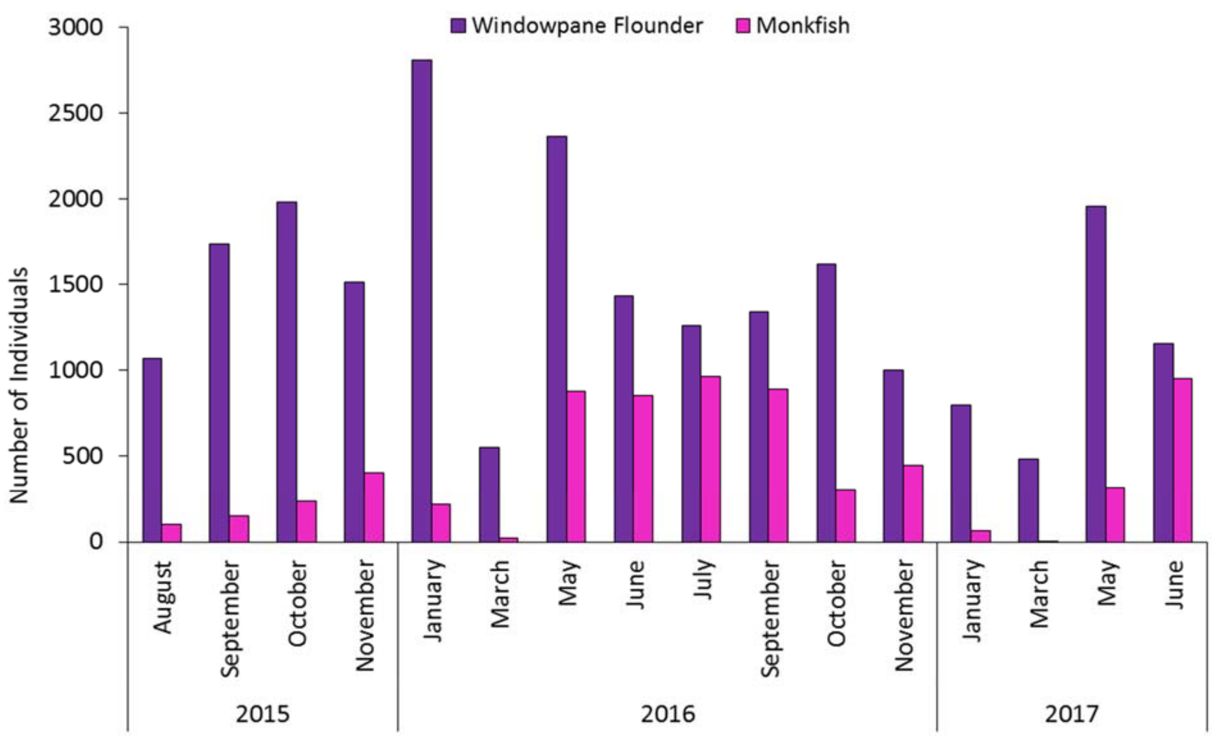
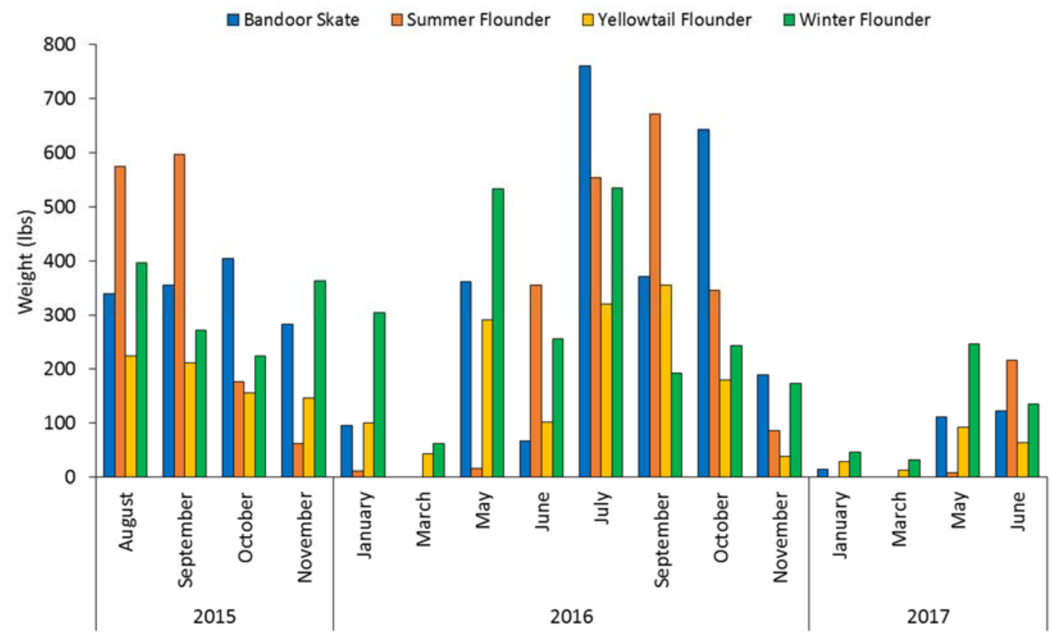


Figure G2. Number of individuals per month in the northern portion of Georges Bank during 2015 and **b)** 2016 seasonal bycatch project. **a)** Bandoor skate, summer, yellowtail, and winter flounders, and **b)** windowpane flounder and monkfish

a)



b)

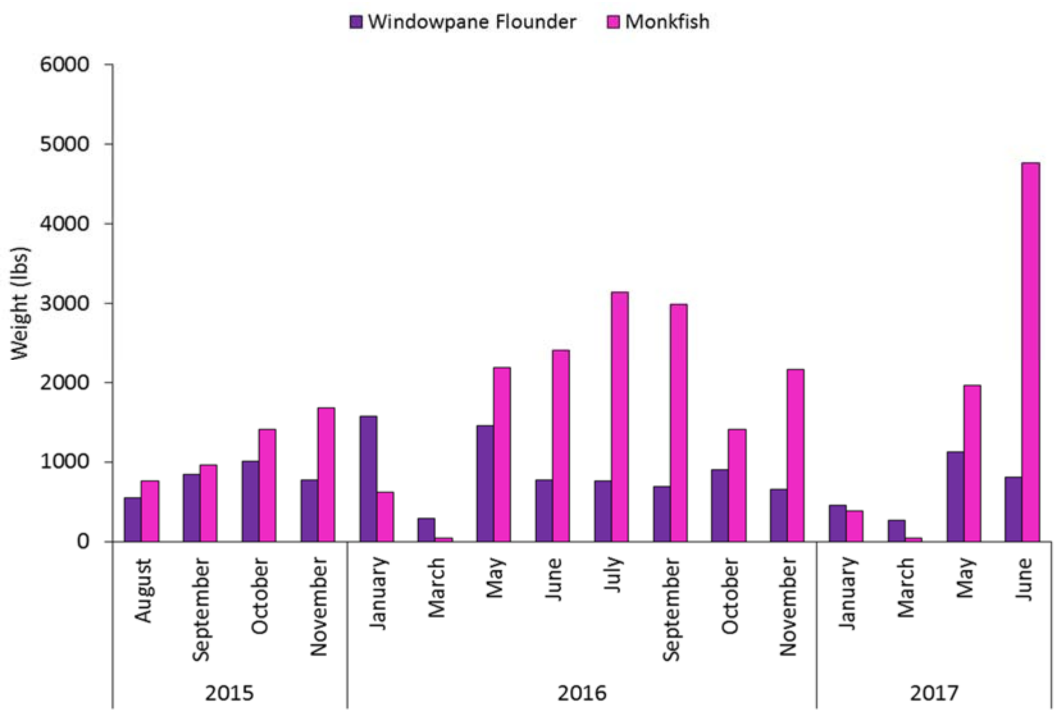


Figure G3. Weight per month in the northern portion of Georges Bank during 2015 and 2016 seasonal bycatch project. **a)** Bandoor skate, summer, yellowtail, and winter flounders, and **b)** windowpane flounder and monkfish

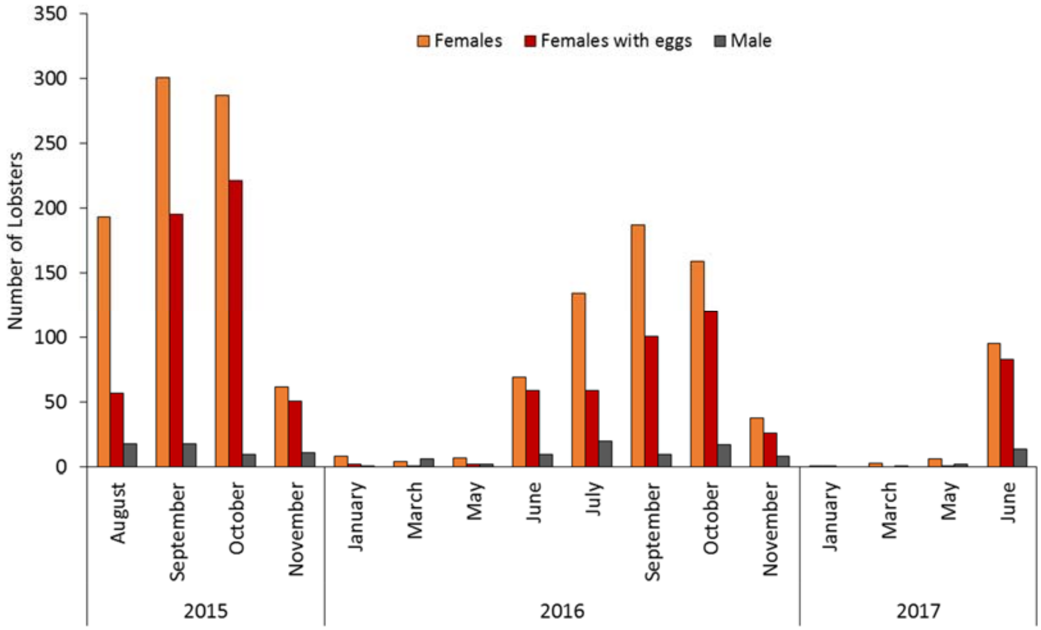


Figure G4. Number of lobsters per month in the northern portion of Georges Bank during 2015 and 2016 seasonal bycatch project.

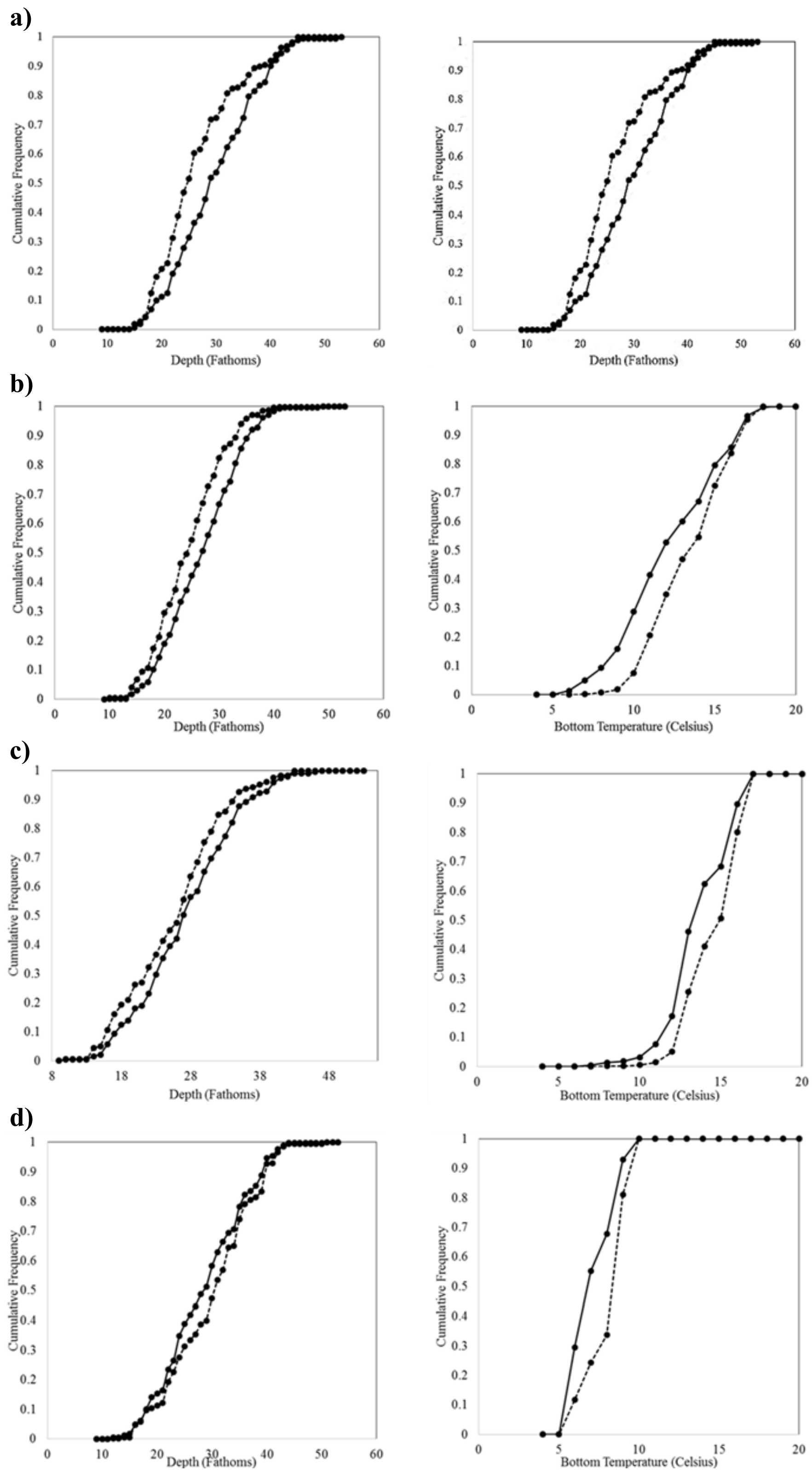


Figure G5. Weighted (dashed line) and unweighted (solid line) cumulative frequency distributions of station depths (fathoms) and bottom temperatures for windowpane flounder in **a)** spring, **b)** summer, **c)** fall, and **d)** winter.