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

Final Report

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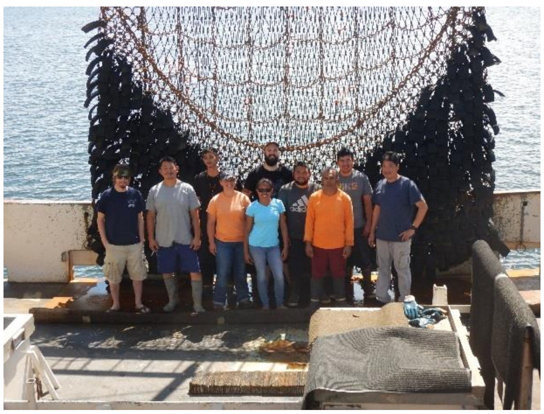


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3. Collect biological samples to examine conditions affecting scallop meat quality.
4. Assess scallop meat discards and measure scallop meat loss due to shucking.
5. Investigate the general biology of scallops and main bycatch species, specifically maturity, growth, and diseases.
6. Conduct biological sampling of bycatch crustacean and echinoderm species.

This report presents data and analysis from funding year 2015-2016 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. From 2010 until 2014, survey stations were located in the scallop access areas in Closed Area I (CAI) and Closed Area II (CAII). Beginning with the project highlighted in this report, 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.

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 funding year, the project tested a TDD with a 5-row apron against a TDD with a 7-row apron. The survey operates with a fixed grid design, and tow parameters have been standard since 2010.

The paired dredge catch data is processed on-board the vessels, with additional analysis done back on land. 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 2015-2016 project year, we examined flounder, monkfish, and lobster bycatch rates. Windowpane flounder and monkfish bycatch rates were highest (> 8 lbs. of fish/lb. of scallops), while yellowtail and winter flounder bycatch rates were low (< 2 lbs. of fish/lb. of scallops). Lobster bycatch was relatively high in the summer to fall months (> 4 lbs of lobster/lb. of scallops). Scallop meat weight peaked in summer, when monkfish and lobster catch was also high. 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 and yellowtail flounder diseases 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 the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) and Roger Williams University (RWU). Previous work suggested that gray meats are caused by an apicomplexan parasite, yet results from SMAST and 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 January, primarily in CAII, and in May, primarily in the open area. Monkfish catch was also high in May, while catches of yellowtail flounder and winter flounder were low overall.

Preliminary data was collected to assess meat loss during shucking and damage to lobsters by dredges, and we started a sampling program focused on crabs and sea stars.

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 $439,714,189 in 2015 (NOAA 2015). 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 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 had 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), but this information was and still is lacking for northern Georges Bank.

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 (NA10NMF4540473, NA11NMF4540027, NA12NMF4540034, and NA13NMF4540011) provided the data needed to shift scallop access 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).

There is a downside to this adjustment to the scallop management plan, highlighting 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). Due to a similar lack of seasonal distribution data for key bycatch species, management measures proposed for the northern portion of Georges Bank, encompassing Closed Area II north of 41°30'N (CAII N) and surrounding open areas, may result in high catches of non-target species. CAII N is currently closed to scallop fishing year round (Smolowitz *et al.* 2016). Yet the proposed Omnibus Habitat Amendment 2 (OHA2) currently under consideration could open this area to scallop fishing (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 they 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 (NA13NMF4540011; NEFMC 2014). Gear comparison and seasonal catch data collected during the CFF bycatch project continue to provide the detailed information needed to enact sensible, data-driven AMs that should mitigate economic losses compared to other AM alternatives.

Finally, another important factor that affects marine populations and harvestable biomass is disease. 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 some of the 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* (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 have 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
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.

GENERAL SAMPLING METHODS

Study area

Georges Bank, located off the New England coast, supports many valuable commercial fisheries due to the high levels of primary productivity in the area. Also in this area, the largest wild scallop fishery globally is found (Caddy 1989). Georges Bank has three closed areas for all mobile bottom-tendering gears since 1994 in order to protect declining groundfish stocks. To help answer questions about the northern part of Georges Bank, eight research trips were conducted for the 2015 seasonal bycatch survey (**Table 1**). The initial plan was to sample from the northern corner of CAI eastward to the CAII access area, then north into the groundfish closure and within the Georges Bank northern edge Habitat Area of Particular Concern (HAPC), then westward to the 100 meter depth contour, the final survey did not include stations in the HAPC due to permit restrictions. The finalized grid was sampled every other month with additional trips in June and October; this grid consisted of 61 stations, which were determined after the first trip (**Figure 1**). The starting point for each station was randomly selected prior to each trip using 4 points 0.25 miles away from the grid position.

Table 1. Trip dates and dredges used for the 2015 bycatch survey.

Month	Trip dates	Control dredge	Experimental dredge
August	5 Aug– 11 Aug2015	CFF TDD with 7-row apron	CFF TDD with 5-row apron
September	26 Aug – 1 Sep 2015	CFF TDD with 7-row apron	CFF TDD with 5-row apron
October	6 Oct – 12 Oct 2015	CFF TDD with 7-row apron	CFF TDD with 5-row apron
November	16 Nov – 22 Nov 2015	CFF TDD with 7-row apron	CFF TDD with 5-row apron
January	5 Jan – 10 Jan 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron
March	29 Feb – 3 Mar 2016	CFF/vessel TDD with 7-row apron*	CFF TDD with 5-row apron
May	10 May – 16 May 2016	CFF TDD with 7-row apron	CFF TDD with 7-row apron**
June	13 Jun – 19 Jun 2016	CFF TDD with 7-row apron	CFF TDD with 5-row apron

** CFF turtle deflector dredge (TDD, 7-row apron) broke during the trip. It was changed for vessel TDD (7-row apron) dredge.*
*** CFF turtle deflector dredge (TDD) with heavy headbale.*

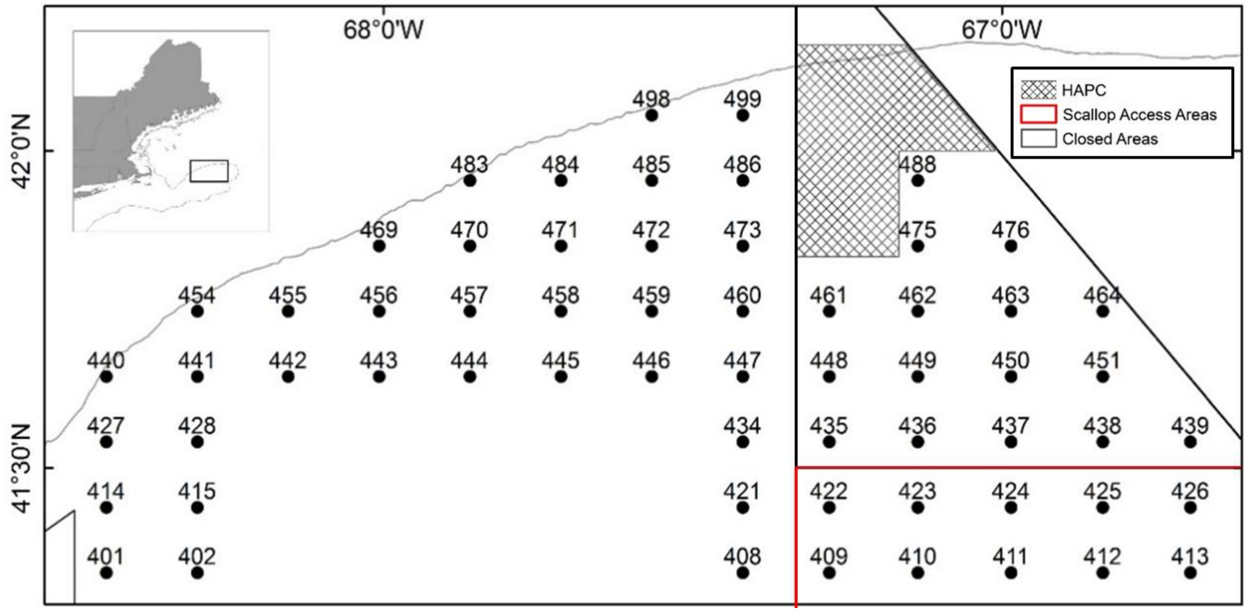


Figure 1. Location of the survey stations sampled for the 2015 seasonal bycatch survey on the northern portion of Georges Bank. The HAPC is shown as hashed lines and scallop access areas and the Hague line are shown in black. Stations are separated by 12 km.

Sampling design

At each fixed 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 the control dredge had a 7-row apron and the experimental dredge had a 5-row apron. This planned comparison was completed for seven out of eight trips. But because the control dredge broke during the March trip, the CFF TDDs were redesigned with heavier reinforced center bars, and during the May trip, the old versus new TDD frames were tested with 7-row aprons on both.

Target tow duration was 30 minutes, with a minimum tow time of 20 minutes in the case of technical difficulties. Stations were resampled if the tow parameters were not followed or in the case of a gear malfunction (e.g. dredges fishing upside down) until an acceptable tow was completed. Tow direction was at the discretion of the captain, who was instructed to pass through the station center coordinates at some point during the tow. Tow start and end were determined by the captain when the winches were locked or engaged for haul back. Tow parameters were recorded using a Getac F110 ruggedized tablet with a custom access database. Vessel position, speed, and heading was recorded every 15 seconds using the built-in GPS on the Getac tablet, and GPS information was also collected from the vessel system. A water temperature and depth logger (Star-Oddi milli-TD) was deployed in steel sheaths welded to the TDD to record depth and temperature every 30 seconds throughout the survey. All data was reviewed for errors upon returning to land.

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 (10) randomly selected windowpane, winter (*Pseudopleuronectes americanus*), and yellowtail flounders were sampled at each station to determine sex and reproductive stage. Additionally, the subsample of yellowtail flounder (10 or fewer if the total yellowtail catch equaled less than 10 fish) was examined macroscopically for *Ichthyophonus* infection. During the first four trips, all yellowtail hearts were collected, and during the last four trips, heart and liver tissues from fish with visibly high levels of infection were removed and preserved in 10% neutral buffered formalin for histological evaluation.

The entire scallop catch was quantified as bushels (bu=35.2 liters). A one-bushel subsample of scallops was selected at random from each dredge and measured in 5-mm shell height increments. At five stations during the first three trips (one station in August and two station each in September and October), one bushel was taken to estimate meat discards for scallops. During this assessment, the scallops were examined for damage from the dredge (crushed), meat lost during shucking (left on the shells), meat quality (gray meats), and meat lost during washing.

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 specific diseases. These scallops were measured to the nearest millimeter from the umbo to the shell margin then carefully shucked. Meat quality was assessed based on a qualitative color scale (**Figure 2**) and qualitative assessment of stringiness (if the meat appears to be stringy and tears easily or not). A subsample of scallop meats of different colors were sampled for further laboratory evaluation. Also, each animal was 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. A second scallop with no noticeable nodules was also collected following the same procedure with clean equipment as a negative control.

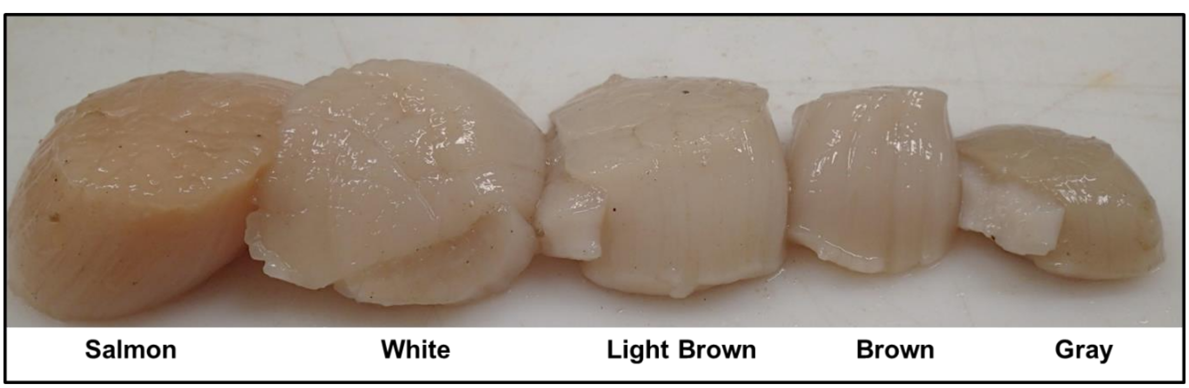


Figure 2. Scale used to classify scallops by meat color. Scallops with brown/gray meat show muscle degeneration.

All lobsters (*Homarus americanus*) caught in the dredges were examined (Smith and Howell 1987). Carapace length, sex, presence of eggs, shell hardness, incidence 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 (details in **Table 2**).

To address a concern about the scallop prey-predation relationship, we completed a preliminary assessment of crabs. All crabs caught in the control dredge were counted and weighed by species. Crabs were separated from the catch after each tow to evaluate presence of shell disease.

Sea stars were evaluated for sea star wasting disease. Indicators of sea star wasting disease included deformities and oozing limbs, making wasting disease difficult to distinguish from damage during the tow. The samples suspected of disease were sorted by species, photographed, and measured (center disc to point of longest arm in cm), with condition of the animal recorded as mild or severe infection.

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)	
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 further processed in the laboratory. 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 and occurrence of ascarid infections. Muscle thinning was determined and reported on a scale of 0 to 3 (0 = normal; 1 = mild thinning of fibers, 2 = moderate thinning of fibers; 3 = severely thinned fibers).

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.

Scallops with orange nodules: Samples with orange nodules were evaluated to identify the species of *Mycobacteria* infecting scallops. Samples with nodules were either allowed to further incubate at room temperature then cultured or were immediately cultured on Middlebrook 7H10 media in plates. Potential colonies were sub-cultured up to 7 times to purify each colony visually, and these colonies were tested using polymerase chain reaction (PCR) analysis with general *Mycobacterial* primers to identify if the organisms were *Mycobacterium* sp. Subcultures were held both at room temperature and at 4° C for 4 weeks or more.

Yellowtail with *Ichthyophonus* infection: these samples were examined grossly and sections of tissue were trimmed and processed in paraffin with production of one or more hematoxylin and eosin stained slides for each fish (depending on probable *Ichythyophonus* sp. infection level). Samples were evaluated for occurrence of *Ichythyophonus* sp. and other parasites.

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. In addition, random variation in the data can occur as a result of both temporal and fine scale spatial variability in the process. Incorporating a random effect in the model accounts for this variability by evaluating the data at the station level and allows the intercept and/or slope to be estimated for every station grouping. The station grouping variable consists of a unique identifier that relates to the trip (temporal identity) and spatial location of the sample. This approach tends to capture and account for this variability more effectively relative to a model with only fixed effects. Information criteria such as Akaike's information criterion (AIC) was used to select the best model configuration.

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. Not all predictors were included in the final modelling efforts as a correlation analysis demonstrated some variables to be collinear (i.e. month and bottom temperature). The collinear variables were evaluated and the decision to retain them in the modelling efforts was based upon the biological relevance and ease of interpretation and/or ability to be used in the future utilization of the estimated parameters.

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

Continuous Variables	**Minimum**	**Maximum**	**Mean**	**St. Deviation**
Shell Height	60	174	131	15

Continuous Variables	Minimum	Maximum	Mean	St. Deviation
Depth (m)	25.96	109.7	62.14	1.27
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			
Stringy Meat	Yes, No			
Orange Pustule	Yes, No			
Interaction Variable	Month*Area, Area*Depth, Shell Height*Area			

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. 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.

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.

Because one of the dredges used in the study broke during the March 2016 trip, not all trips tested the 5 vs. -7-row apron dredges. While seven of the trips did test these configurations, there was one trip that instead used the original light and new heavy headbales with a consistent 7-row apron bag (**Table 1**). During this trip, there were 62 tows, and catch was pooled over length to determine if overall catch of scallops or fish species were altered by the change in headbale construction (see **Appendix D)**.

Economic impact of gear modification: Potential changes to the value of the scallop catch, resulting from the tested gear modification, were calculated using the NMFS overall SHMW equation for Georges Bank (NEFSC 2014) and scallop auction prices available at the Buyer's and Seller Exchange (BASE) (www.baseseafood.com).

The observed length frequency data from the measured bushels for each gear type were expanded by the catch to obtain overall length frequency data for the seven trips using the 5-row and 7-row aprons **(Appendix E)**. Meat weights were calculated for each shell height using the NEFSC parameters estimates for Georges Bank (*a* = -8.79, *b* = 2.55), and meats were groups into commercial categories. Catch data was summarized by total meat weight per category, and the value of each category was estimated using recent prices reported on BASE.

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 apicomplexan parasite, meat color was plotted as a function of sporozoite number, muscle condition index, and cellularity index (**Appendix F**). We attempted to construct a model to predict meat color based on these predictors using a generalized additive mixed model with station as a random effect (function "gam" in the R package "mgcv" with family "ocat" for ordered categorical dependent variables) (R Core Team 2015, Wood 2011).

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 only 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) (**Table 2**). 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. The overall bycatch rates for winter and yellowtail flounder were low (< 2 lbs. fish/lb. of scallops). Bycatch rates peaked at 0.91 in September for yellowtail and at 1.61 in January for winter flounder (**Figure 3a**). Bycatch rates for windowpane flounder and monkfish were higher (reaching > 8 lbs. of fish/lb. of scallops). Windowpane bycatch rate was highest in January at 8.3 (**Figure 3a**), while monkfish bycatch rate was extremely high in June at 10.3 (**Figure 3b**). Lobster bycatch rates were high in September and October at 4.1 and 4.4, respectively (> 4 lbs. of lobsters/lb. of scallops; **Figure 3c**). Overall, spring 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 was also mapped for each survey trip (**Appendix G**). Each of the species manifested a differential spatial distribution. Scallops were distributed in the periphery of the sampling area (**Figure G1**), with a peak abundance in May (**Table 4**) in both CAII and non-CAII. For yellowtail flounder catch was low, but with a clear preference for the eastern part of the sampling area (CAII; **Figure G2**), with a peak of abundance in May (**Table 4**). In contrast, winter flounder, windowpane flounder, and monkfish were distributed across the study area (**Figures G3-G5**). Windowpane flounder was the most abundant species throughout the year of sampling, especially in January in CAII and in May in non-CAII (**Table 4**). Winter flounder catch peaked in May in both areas (**Table 4**), and monkfish were most abundant in May and June, in CAII and non-CAII, respectively (**Table 4**). Summer flounder catch was minimal, never exceeding 90 individuals in non-CAII (**Table 4**); the catch was greatest during the summer months, but was otherwise relatively low. Finally, lobsters were observed in most of the study area, with the highest catch numbers in the eastern part of CAII in August, September, and October (**Figure G6**; **Table 4**).

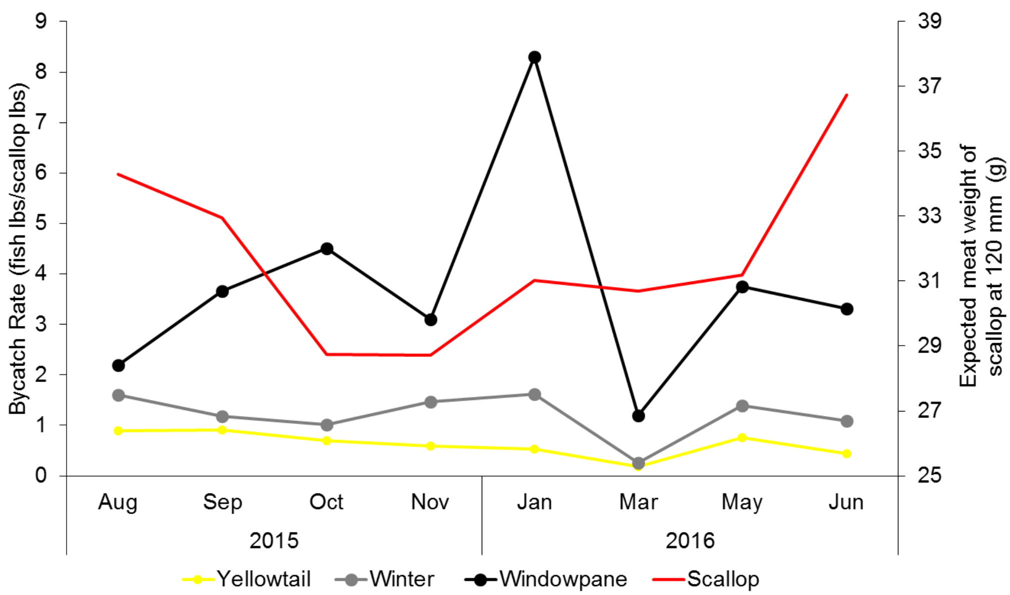
Table 4. Total catches by area by trip. Scallop catch is quantified in bushels and fish in number of fish.

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
2015	Aug	1389.56	1174.62	18	90	149	8	124	50	381	693	51	53	124	89
	Sep	1064.92	1341.32	14	90	191	31	56	79	681	1055	62	87	209	111
	Oct	838.2	1755.46	11	28	130	20	42	53	716	1268	110	129	201	104
	Nov	1108.45	1808.93	7	6	99	35	81	61	471	1042	199	203	29	45
2016	Jan	748.59	1325.6	2	0	80	11	81	52	1426	1388	139	81	2	7
	Mar	934.17	1780.95	0	0	38	2	14	14	358	197	13	9	5	5
	May	2070.66	1978.84	1	10	223	19	164	105	646	1723	647	232	3	6
	Jun	874.99	1375.21	35	62	78	8	78	39	298	1137	541	312	37	43

Shell height-meat weight (SHMW) relationship

During the eight trips that took place from August 2015 through June 2016, a total of 4,974 scallops were sampled at 239 stations. Scallop shell heights ranged from 60 mm to 174 mm and meat weights varied from 4.0 g to 87.0 g. The observed shell heights and meat weights collected by sub-area over the eight sampling cruises are shown in **Figure 4**. This information is the basis for subsequent spatio-temporal analyses of the SHMW relationship. There was relative consistency in the size distribution of the animals sampled during every cruise at each station, with a wide range of sizes measured in both areas. **Figure B1** shows log-transformed shell height and meat weight data with various groupings (month, meat color). This graph depicts the spread of the observed SHMW data and partition these data by some potentially important covariates (i.e. month, meat quality). Despite of it is a bit difficult to show the nuances of the observations, this graphs are trying to convey that the observations are fairly variable and that seasonality as well as meat quality (as designated by a proxy of meat color) appeared to be potentially promising predictors of meat weight in addition to shell height. The natural logarithm of shell height was used in the depiction of this data only to linearize the exponential form in order to more easily visualize the relationship. This transformed response variable enters into the GLMM model as a predictor.

a)



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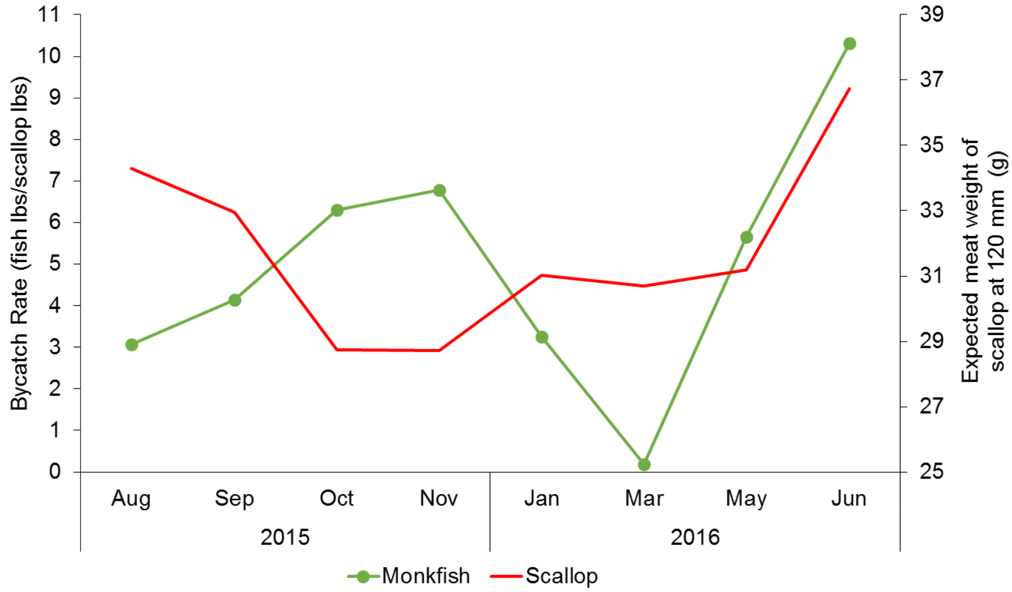

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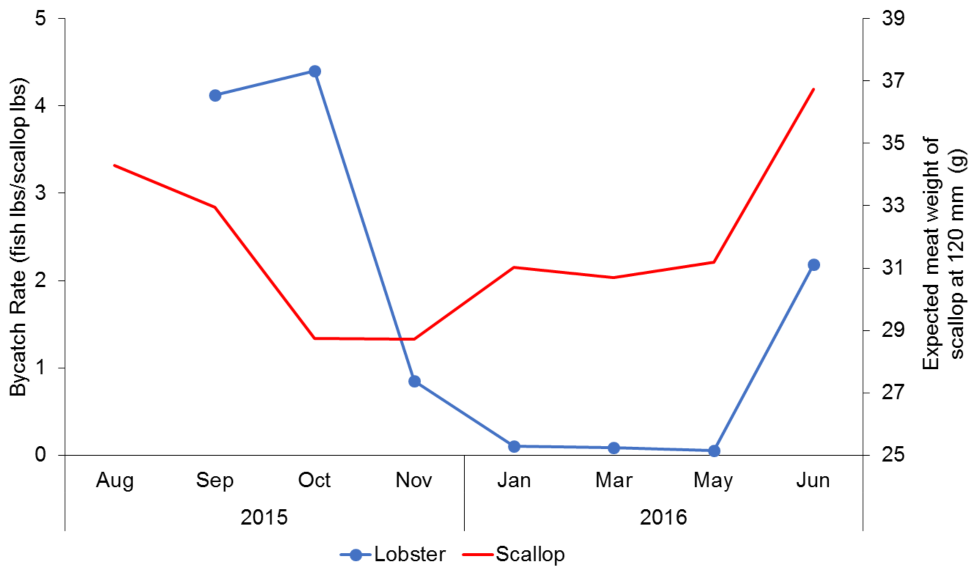
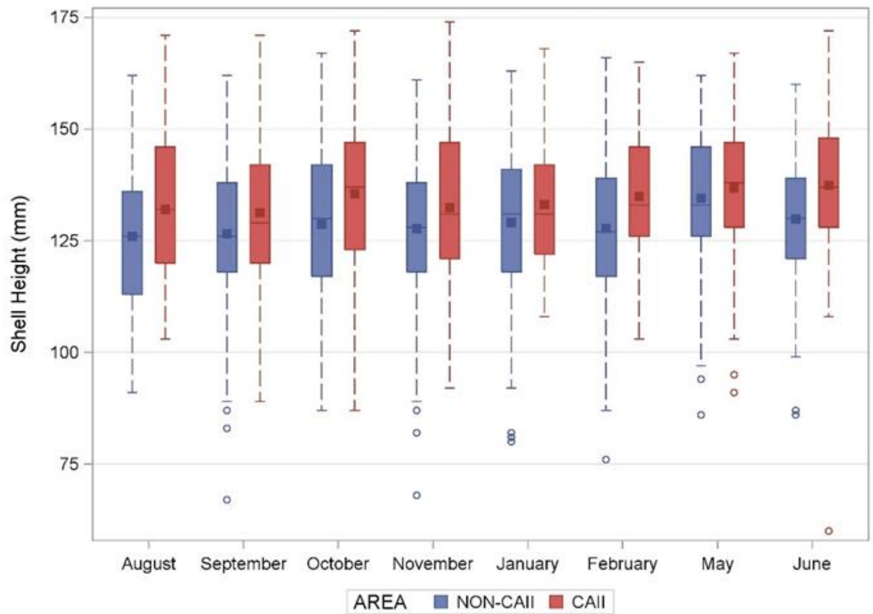


Figure 3. Bycatch rates for commercially important species **a)** flatfish, **b)** monkfish and **c)** lobster in relation to scallop catch during this survey. The seasonal change in meat weight for a 120mm is expressed as expected weight (g) using the results from the SHMW model (red solid line with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

a)



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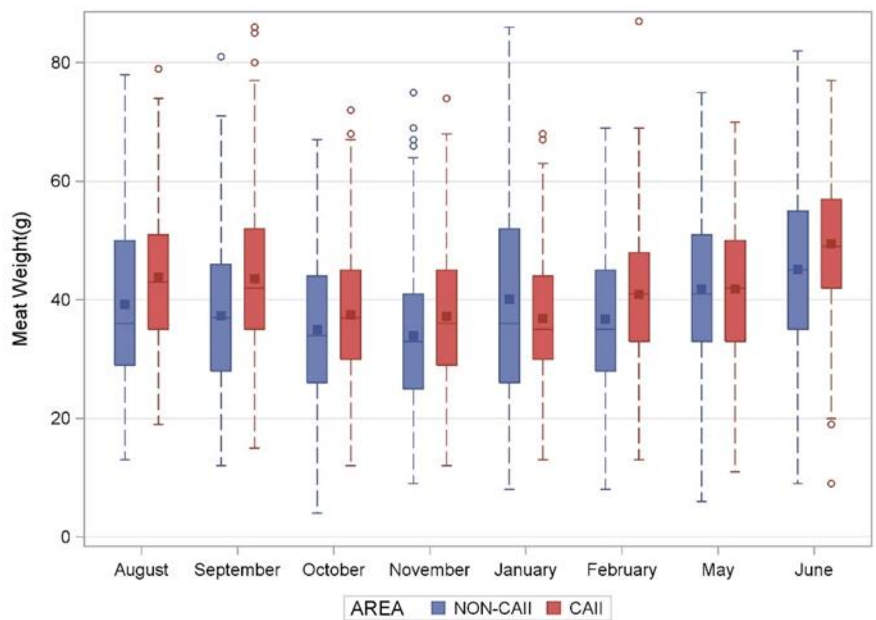


Figure 4. Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples in CAII and non-CAII. The marker and line inside the box represents the mean and median values, respectively. The bottom and top edges of the box represent the interquartile range (25th and 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), S is an identifier variable for stringy meat, and C is meat color. Based on an examination of residuals (**Figure B2**), model fit appears to be reasonable. There do appear to be a few outliers that consist of mostly heavier expected meats especially at smaller shell heights. These observations could represent natural anomalies such an extraordinarily robust animal or measurement error. Regardless, the outliers were few and had minimal impact on parameter estimates.

Parameter estimates shown in **Table B2** predicted that meat weight increased with shell height (positive coefficient estimate). 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 from June-August and low from October–November. March and September were transition months. Two attributes associated with product quality were shown to be significant predictors of meat weight. Meat color on a qualitative scale showed that as meats deviated from the typical white and transitioned through browns to gray, there was a decreasing predicted value of meat weight relative to shell height. The presence of observable stringiness of the meat (associated with poor meat quality) also showed a similar effect. The interaction between shell height and area returned a negative coefficient for the CAII area (non-CAII was modeled as a reference category). This indicates that for the CAII area as shell height increases, the slope of that line decreased relative to the slope in the non-CAII area. Temporal trends of a modeled 120 mm scallop for the two areas are shown in **Figure 5**. To show the effect of month on meat weight, estimated SHMW curves for a white meat scallop by month for the two areas are shown in **Figure 6**. To show the effect of meat color on meat weight, estimated SHMW curves for non-CAII scallops in November are shown in **Figure 7**.

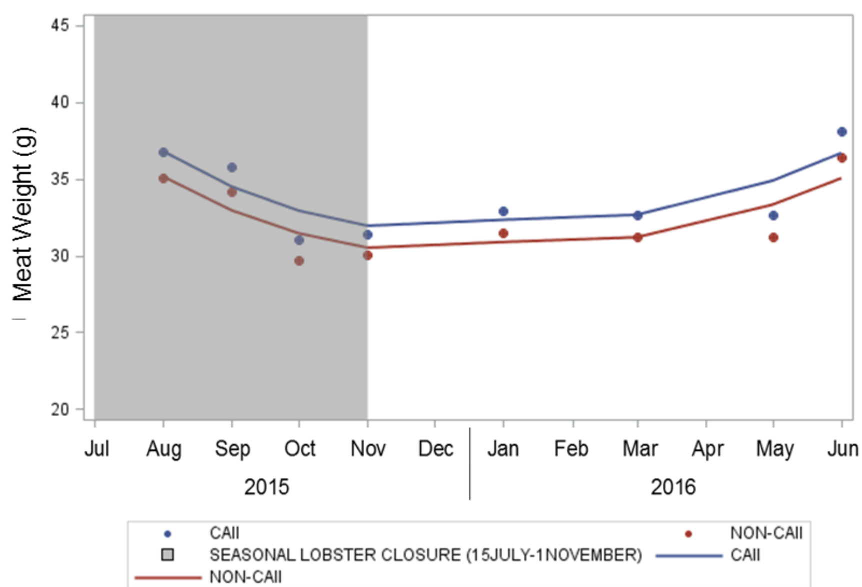
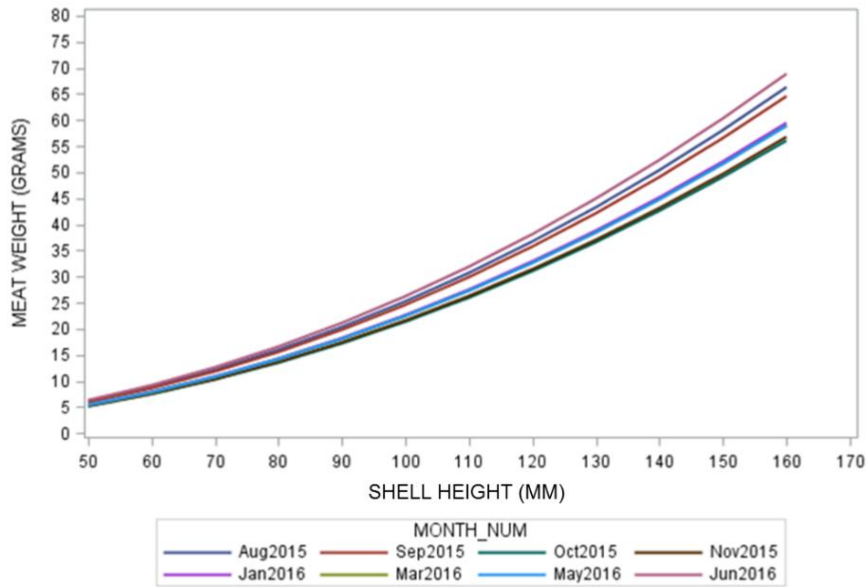


Figure 5. Temporal trends for the predicted meat weight of a white-meat 120-mm shell height scallop

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)



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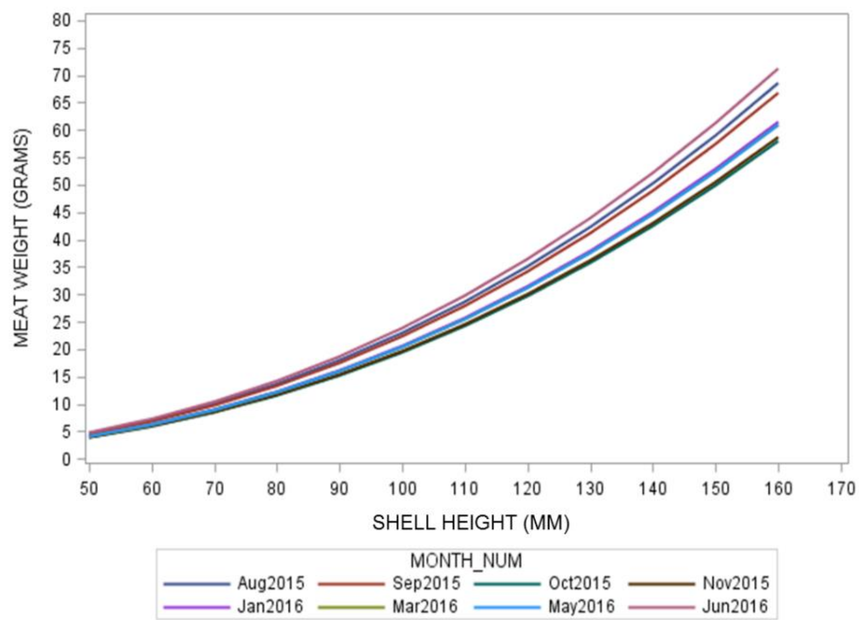

Figure 6. Comparison of estimated SHMW curves for white meat scallops for each month in **a)** CAII and **b)** non-CAII.

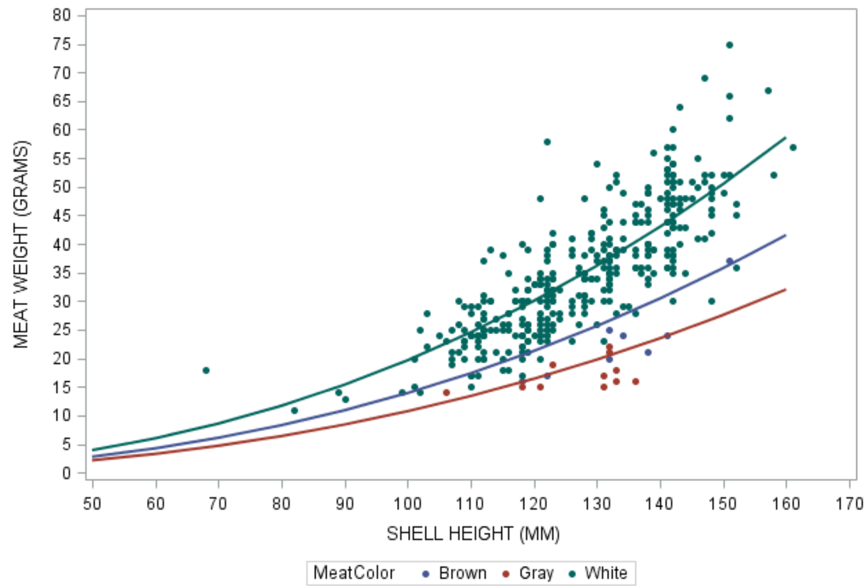

Figure 7. Scale of the effect of meat color on the predicted meat weight of scallops from non-Closed Area II during November of 2015.

Spatially and temporally explicit fishery-independent length-weight information tends to be difficult to obtain on the scale that was collected by this study. These results document trends between the three areas on quasi-monthly basis and demonstrate that the differences between the areas that can be used in combination with the bycatch data included in this study to formulate a strategy to optimize the harvest of sea scallops in the Georges Bank Closed Areas.

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

Gear comparison (light vs. heavy headbale)

This comparison was done to determine if the new reinforced TDD fished similar to the original lighter TDD. Scallop catch was similar in both dredges (0.08% decrease with the heavy headbale, combined catch = 138 bushels, $p < 0.001$) (**Figure 8**). However, changes in fish catch varied by species. Monkfish and windowpane flounder catch increased with the heavier headbale (monkfish: 2.9% increase, combined catch = 866 fish, $p < 0.001$; windowpane: 4.6% increase, combined catch = 2,364 fish, $p < 0.001$). However, yellowtail and winter flounder catch decreased with the heavier headbale (yellowtail: 35.5% decrease, combined catch = 242 fish, $p < 0.001$; winter: 9.7% decrease, combined catch = 266 fish, $p < 0.001$).

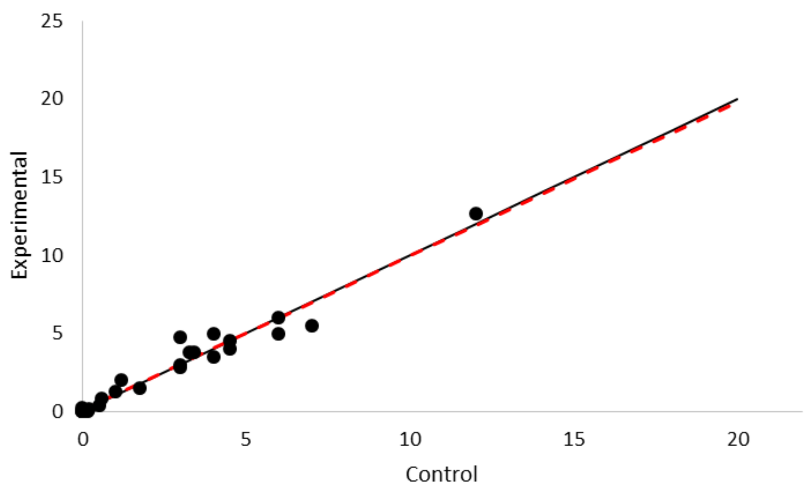

Figure 8. Total pooled scallop catches for the heavy vs. light headbale with 7 row apron bag. The estimated relative efficiency is show as the red dashed line. The black line is the equal catch line with a slope of one.

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

Results from the May trip (above) were not included in the analysis because that trip did not use the control and experimental dredges used for the rest of the study. Catch data from the remaining seven survey trips were treated as a single data set since the experimental treatment was consistent across trips and the heavier dredge (June 2016) did not appear to fish differently than the original dredge (August 2015 – March 2016). Overall, 488 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. We focused our analysis on a subset of species, including those that are commercially important or 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.

Length-based estimates: 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 seven months, 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, 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-D4**.

For the length-based model, winter flounder, windowpane flounder, and sea scallops were the only species where length represented a significant or marginally significant predictor of relative efficiency. In addition, these three species also exhibited differences in the slope of the length-based relationship as a function of trip. **Figure D2-D4** show the graphical results for these species as a function of length. In the majority of cases, the 5-row apron dredge captured fewer smaller scallops, and as size increased, this dredge became more efficient (**Figure D4**). For windowpane flounder, the estimated slope was negative. An examination of the trip specific curves demonstrates that the 5-row apron dredge was less efficient relative to the 7-row apron dredge as windowpane flounder size increased (**Figure D3**).

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 relative efficiency of the two dredge configurations with respect to total catch was modeled without length included. **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 D5-D8**. For unclassified skates, barndoor skates and windowpane flounder, trip was a significant factor predicting the relative efficiency between the two dredge configurations.

For the other species where the intercept-only model had the best fit, differences in the catch between the dredges were statistically significant for summer flounder, yellowtail flounder and winter flounder. Across the flatfish species, there was a consistent reduction of catch by the 5-row apron versus the 7-row apron. In most cases, this reduction was 10-20%. Barndoor skate, monkfish and sea scallops showed slight but statistically insignificant increases in catch by the 5-row apron. A comparison of model generated estimates and the percent changes from the raw catch data using an intercept only model are shown in **Table 5**.

Table 5. A comparison of the observed percent differences from the catch data and the relative efficiencies estimated from the intercept only model for the analyzed species. Statistical significance (alpha=0.05 level) is specific to the intercept-only model and may not be the most parsimonious model from the analysis.

Species	5-row Apron	7-row Apron	Percent Difference	Model Estimate (RE)	Statistical Significance
Sea Scallops	27712	28772	-3.68	2.67	No
Yellowtail Flounder	399	474	-15.82	-16.21	Yes
Windowpane Flounder	5456	6361	-14.23	-13.17	Yes
Winter Flounder	358	429	-16.55	-19.54	Yes
Monkfish	1018	957	6.37	7.03	No
Summer Flounder	154	193	-20.21	-19.53	No
Fourspot Flounder	155	172	-9.88	-8.81	No
Barndoor Skates	249	219	13.70	14.70	No
Uncl. Skates	26178	27313	-4.16	-2.61	No

One of the most significant results 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, yellowtail, 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.

Gear comparison (economic analysis)

Scallop catch in the 5-row apron dredges was shifted toward larger scallops, with the 7-row apron dredge catching more 10-20 and smaller scallops and the 5-row apron dredge catching more U12 and larger scallops (**Table E1**). Summed over all of the stations and trips, catch in the 5-row apron was 2,409 lbs., while catch in the 7-row apron was 2,177 lbs. As a result, the estimated value of the catch from the experimental 5-row apron dredge ($31,421) was ~12% higher than the estimated value of the catch from the control 7-row apron dredge ($28,029).

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

Orange nodules: Stations 473 and 488, near the HAPC, routinely had high percentages of poor quality scallops and high occurrences of scallops with orange nodules (**Figure 9**). During the 2015 research project, 25 scallops (0.5%) were observed to have orange nodules during the shell height meat weight analysis (**Table 6**). Previous work from the 2013 bycatch survey identified *Mycobacteria* sp. as a causative agent of the orange nodules in the Georges Bank sea scallops (Grimm *et al*. 2016). This was the first time *Mycobacteria* sp. infections were identified in scallops. The orange coloration is a result of the inflammatory response, and lesions caused by mycobacterial infection have a different macroscopic appearance than lesions observed from nematode infections in the mid-Atlantic. We currently have a suspect colony, yellow in color and slow growing, that has tested positive using PCR as *Mycobacteria*. It will be sent for sequencing to verify it is *Mycobacteria* before further speciation testing is accomplished.

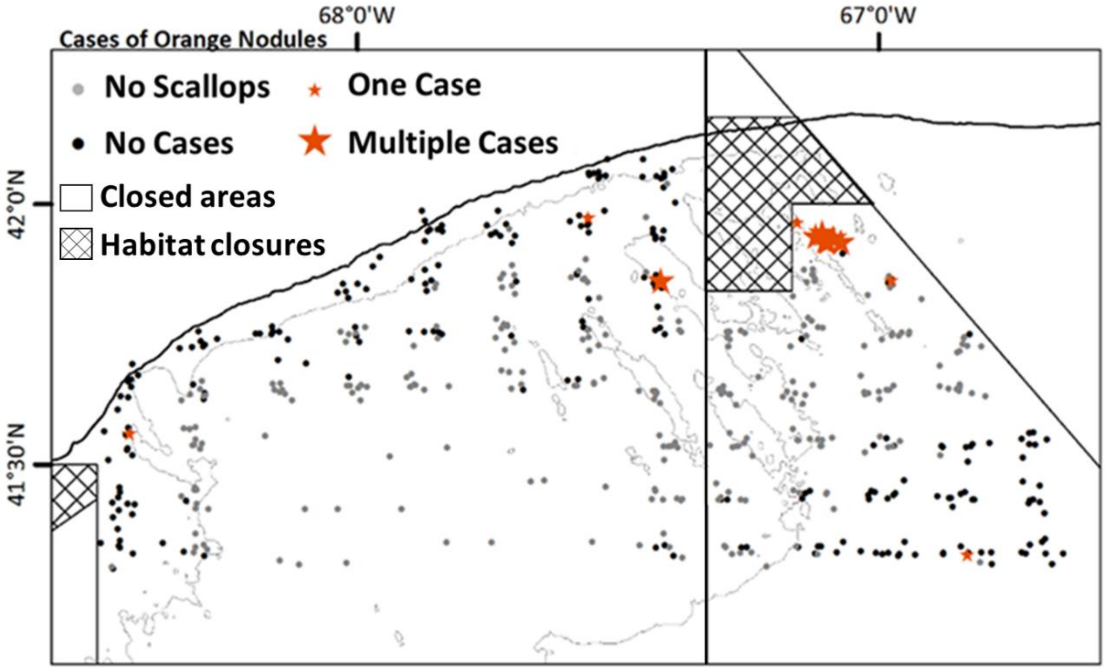

Figure 9. Locations where orange nodules (stars) have been identified during the 2015 seasonal bycatch survey on the northern portion of Georges Bank. Orange nodules have been identified during every trip at station 488 just south of the CAII HAPC (hatched area).

Table 6. Number of scallops by color and with orange nodules

Trip Month	White	Salmon	Light Brown	Brown	Gray	Orange Nodules	
						Number	Percent
Aug	456	0	38	13	8	2	0.39%
Sep	524	1	39	26	11	2	0.33%
Oct	509	3	72	32	18	4	0.63%
Nov	569	2	57	25	17	5	0.75%
Jan	535	2	49	21	12	3	0.48%
Mar	646	4	24	6	6	5	0.73%
May	656	6	19	9	5	3	0.43%
Jun	523	1	25	5	0	1	0.18%
Total	4418	19	323	137	77	25	0.50%

Gray Meat: Until now, it is believed that apicomplexan parasite is highly pathogenic and once scallops show clinical signs of gray meat disease (e.g., gray color, stringy adductor muscle) they will eventually die (Levesque *et al*. 2016). Historically, gray meat outbreaks in Atlantic sea scallops have been described as episodic. Currently, however, these outbreaks appear less episodic and more persistent on Georges Bank and now include smaller size classes of scallops (Stokesbury *et al*. 2016). Gray meat scallops were frequently and widely observed in the survey areas throughout the sample period (March 2015 - June 2016), although we did observe an overall decrease in the number of gray meat scallops. The locations of gray meat scallops during the present project are presented in **Figure 10**. The percentages of gray meat (gray and brown meats) scallops observed at each station, as presumed proxies for infection intensity, are presented in **Table F1**. The highest percentages of gray meat scallops by station were found at stations 473 (27%, 17 of 63 samples), 472 (26%, 5 of 19 samples), 488 (25%, 49 of 200 samples), and 485 (22%, 52 of 240 samples). These four stations were clustered around the HAPC. Station 409 also had a high percentage of gray meat (25%), but only four scallops were caught at this station, and only one had gray meat. At all other stations, less than 10% of all scallops caught had gray meats. CFF is planning further evaluation of this dataset in the near future.

Due to its proximity to the HAPC, 29 live scallops from station 488 were collected and dissected for confirmation of the apicomplexan infection. These scallops were analyzed at the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) laboratory, where the meat quality observed was as follows: white (n=5), light brown (n= 7), brown (n=6), and gray (n=11). The sizes of scallops with gray meats ranged from 99 mm to 161 mm SH, and the histological analysis, conducted on five gray and five white meat scallops, confirmed the presence of the apicomplexan in scallops exhibiting both gray (**Figure 11a**) and white meat conditions.

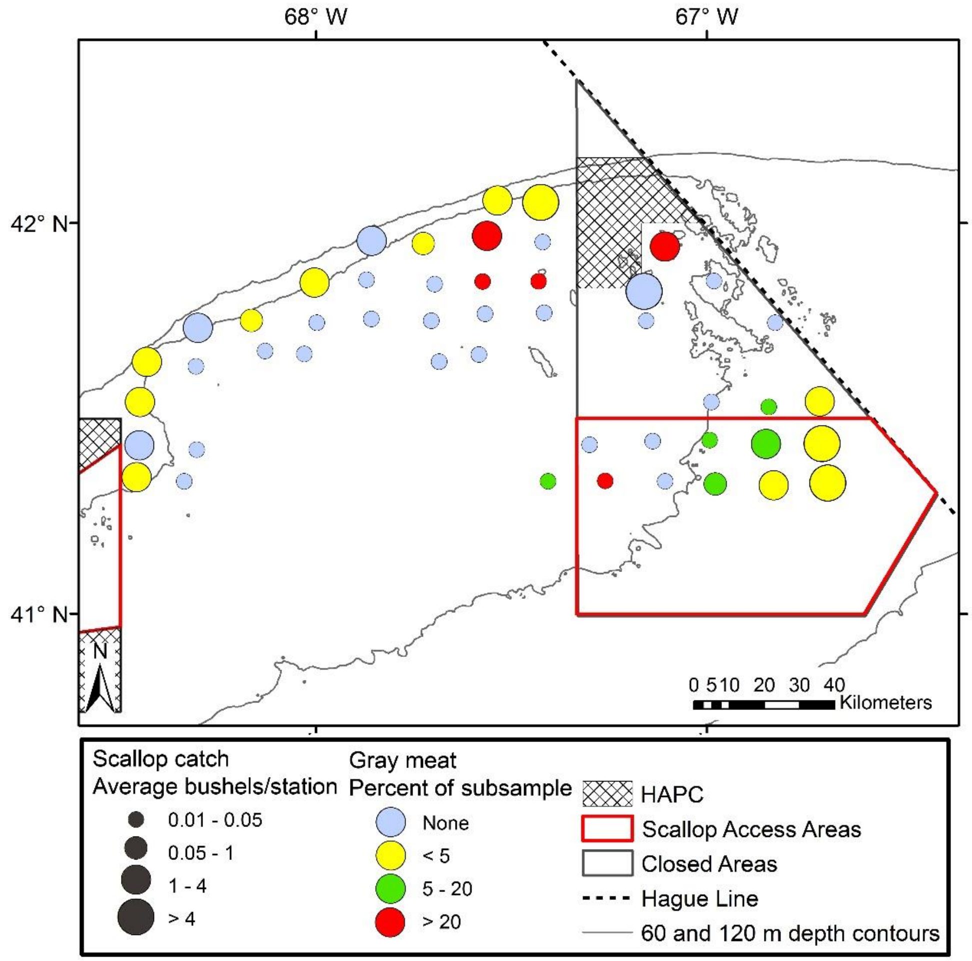

Figure 10. Scallop catch and location of gray meat aggregations during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

Samples from each trip were also sent to the Aquatic Diagnostic Laboratory at Roger Williams University (RWU). These included all gray, brown, and light brown meats collected, as well as a subsample of at least five control individuals per trip with white meat. Evaluation of the apicomplexan in the adductor muscles showed small groupings of zoites (**Figure 11b**). These presumed sporozoites were the most commonly identified form of the parasite in the tissue sections in the adductor muscles and were easy to identify when in observed in the muscles. Macrogametes were very rarely noted. Cysts containing microgametes were not identified in the tissues examined; however, in some severely infected animals, we observed increased numbers of cells, some of which appeared to be small cells (4-µm diameter) that may represent tachyzoites, or another forms of the parasite.

a) b)

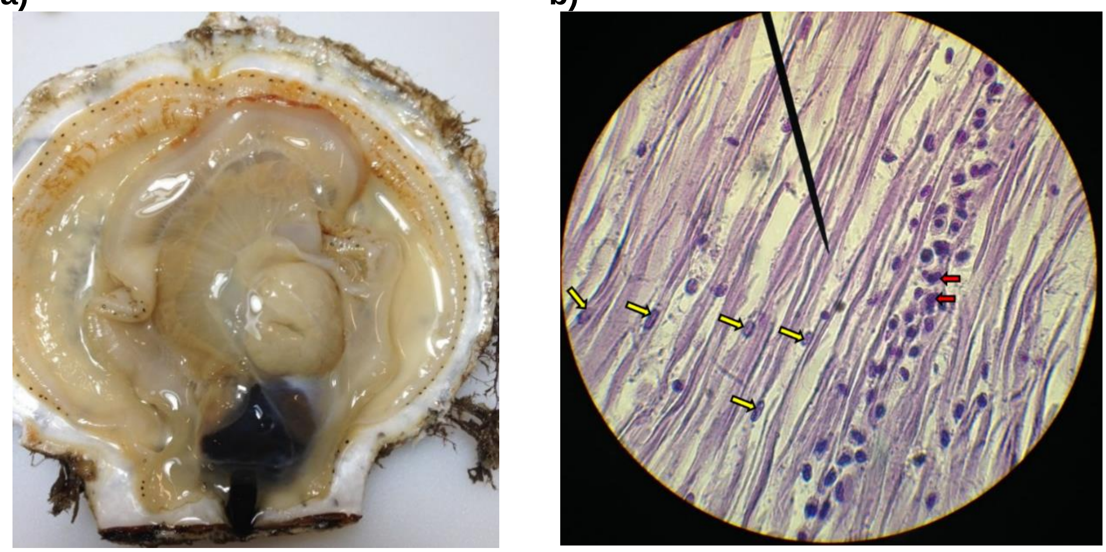

Figure 11. a) An example of a gray meat scallop (shell height 115 mm) from Station 488 during the November 2015 Survey. **b)** Apicomplexan infection in a scallop exhibiting gray meat, collected from Station 488 during November 2015. The yellow arrows point to muscle nuclei and the red arrows identify the zoites of the apicomplexan.

Plots of meat color versus microgamete number, cellularity score, and muscle thinning scores showed no clear relationship between meat color and severity of infection (**Figure 12**). Attempts to model meat color as a function of microgamete count, cellularity, and muscle thinning were unsuccessful. 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).

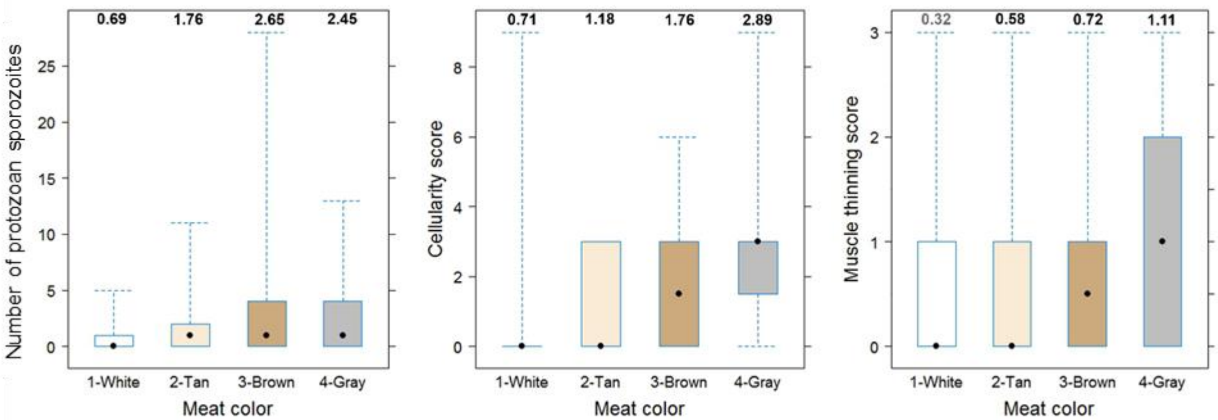

Figure 12. Box and whisker plots of meat color against protozoan sporozoites, cellularity scores, and muscle thinning scores for samples collected during the 2015 seasonal bycatch survey on the northern portion of Georges Bank. The dots are the median values. Boxes end at the first and third quartiles 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.

These findings support the development of quantitative molecular analyses for evaluation of tissues, in situ hybridization techniques to positively identify the parasites in section, and also indicate the cause of gray meat may be more complicated than originally determined.

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

During August, September and October, meat loss was estimated in subsampled bushels by quantifying the percentages of kept meat, bad quality meat, crushed meats, meat lost during washing, and meat lost during shucking. The average total meat loss was 10.7% (range 9.0-14.3%), with the majority being due to shucking loss (6.5-10.9%) (**Table 7**).

Table 7. Scallop adductor muscle retained vs meat loss during processing by weight.

Trip Month	Station	Kept	Bad quality	Crushed	Washing	Shucking
August	412	85.75%	2.88%	0	0.44%	10.93%
September	412	89.08%	0	0.78%	0	10.14%
September	439	90.76%	1.19%	0	0	8.04%
October	412	89.76%	0.00%	0	0.69%	9.55%
October	442	91.03%	2.34%	0	0.16%	6.48%

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 January. High catches of juvenile and adult monkfish occurred at the deeper stations, 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 G1- G6 of Appendix G**.

Scallops: A total of 5,009 scallops in 448 bushels were collected during the project (**Table 8**). The highest monthly percentages of mature females occurred in August and September. The spawning occurred in October and November, with gonads recovering in November through January (**Figures 13 and 14**). 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 this discrepancy.

Table 8. Catch of scallop for each trip by gear type.

Date		Number of bushels		Weight (lbs)	
		Control	Experiment	Control	Experiment
2015	August	49	49	1317.2	1331.1
	September	44	45	1172.7	1233.5
	October	47	47	1241.4	1352.2
	November	52	51	1461.5	1455.9
2016	January	38	38	1031.0	1043.2
	March	42	55	1168.1	1547.0
	May	71	70	2037.8	2011.7
	June	36	40	1067.3	1182.9
Total		379	395	10497	11157.5

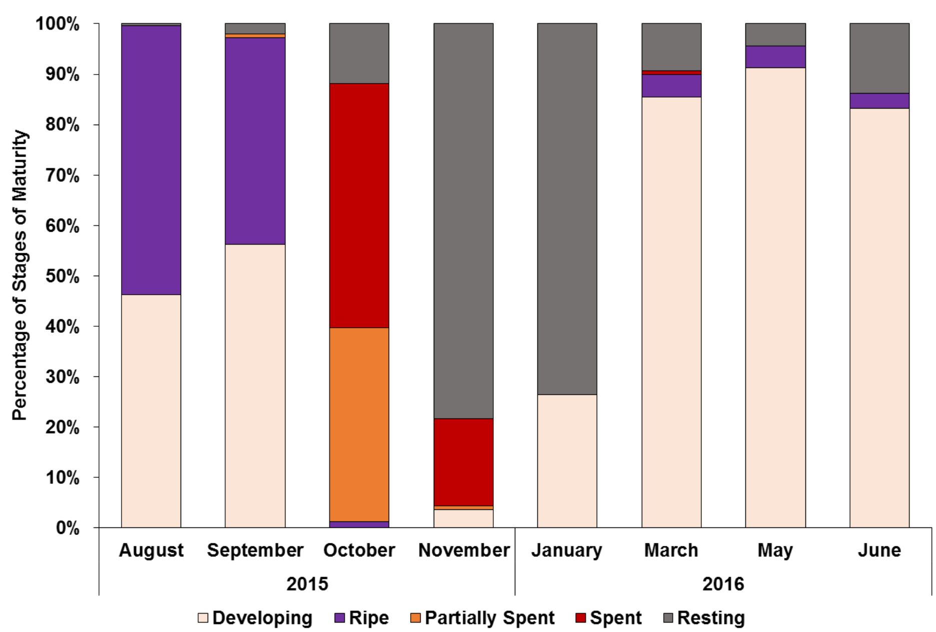

Figure 13. Seasonal maturity results for female scallops for each month during the 2015 seasonal bycatch

survey on the northern portion of Georges Bank determined through macroscopic observations.

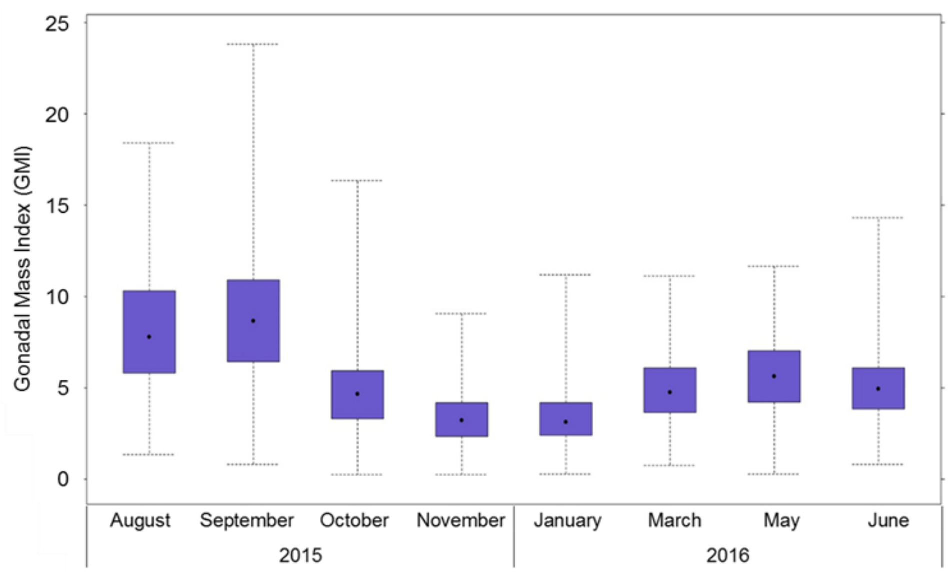

Figure 14. Seasonal changes in the gonadal mass index (GMI) for scallops during the 2015 seasonal bycatch survey on the northern portion of Georges Bank. The dots are the median values. Boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

Winter flounder were typically caught in the eastern stations in CAII, and 1,094 flounder were caught overall (**Table 9**). Overall, captured winter flounder were 52% female. All fish caught per station, or a subsample of ten if more than ten were caught, were evaluated to assess reproductive stages. The March trip had the fewest winter flounder overall (12 females and 17 males), while catch peaked in May (91 females and 98 males). Developing gonads were observed between September and March, while spent females were seen between May and June (**Figure 15**). No female winter flounder were observed in the ripe and running condition (**Figure 15**). These results match previous findings (Burton and Idler 1984, Harmin *et al*. 1995).

Table 9. Catch of winter flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	**Experiment**	**Control**	**Experiment**
2015	**August**	99	75	245	155
	September	69	66	146	125
	October	53	42	120	106
	November	80	62	206	158
2016	**January**	67	66	130	176
	March	14	15	37	23
	May	135	134	265	268
	June	65	52	134	123
	Total	582	512	1283	1134

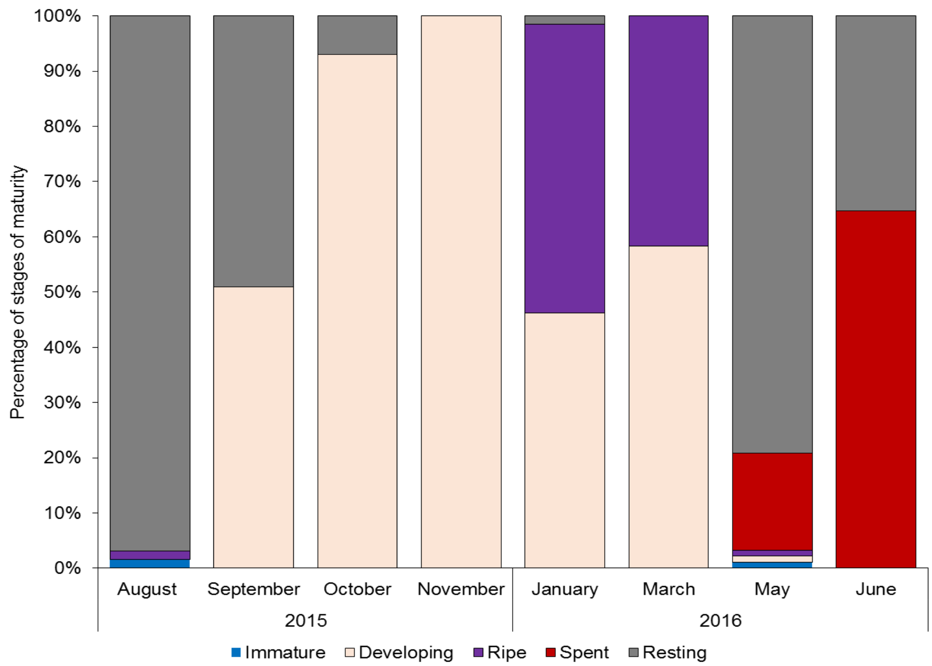

Figure 15. Seasonal maturity results of female winter flounder for each month during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

Windowpane flounder were by far the most abundant flounder caught as bycatch during this project (13,480 fish), with catch peaking in January (2,814 fish), when the majority of the fish were developing their gonads for spawning (**Table 10 and Figure 16**). They were caught at nearly every station, with catches often exceeding 50 fish for each dredge. Ripe female windowpane flounder were observed in May and June (**Figure 16**). Ripe and running flounder were also observed in June (**Figure 16**). Most males were resting by June.

Table 10. Catch of windowpane flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experiment	Control	Experiment
2015	August	611	463	318	232
	September	922	814	451	397
	October	1057	927	545	457
	November	753	760	385	384
2016	January	1387	1427	767	797
	March	234	321	169	102
	May	1199	1170	716	734
	June	794	641	445	330
	Total	6957	6523	3796	3433

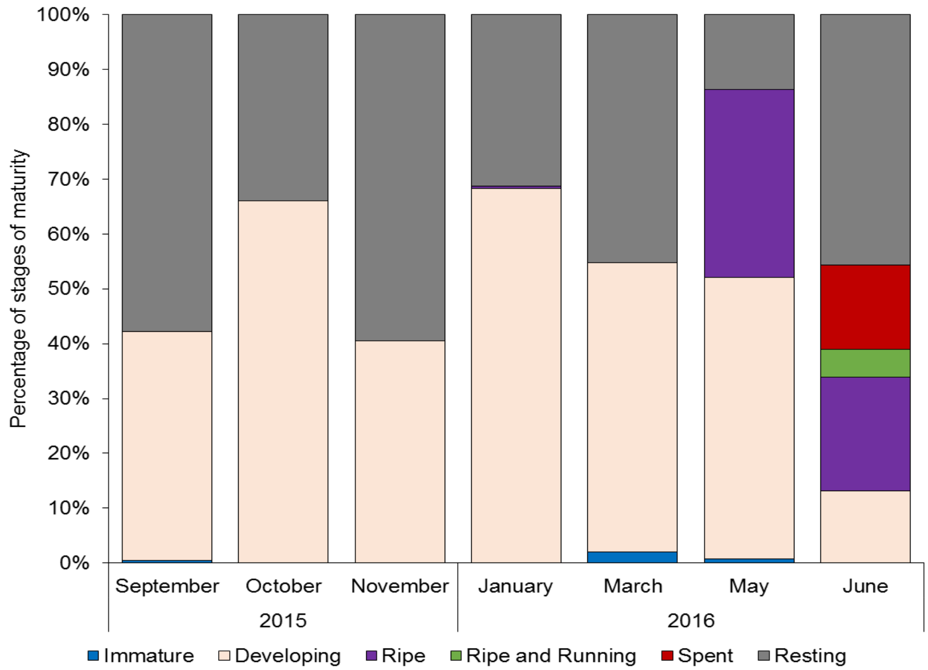

Figure 16. Seasonal maturity results of female windowpane flounder for each month during the 2015 seasonal bycatch survey on the northern portion of Georges Bank. No data was collected in August for this species.

<u>Yellowtail flounder</u>: A total of 1,122 yellowtail flounder were captured for this project (**Table 11**), of which 81% were females. The peak catch of yellowtail flounder occurred in May in CAII (**Figure G2**). They were not observed in ripe and running condition during this project. Males were observed to be ripe between January and June, and females were observed to be ripe beginning in May. By June, 41% of the female yellowtail had completed spawning (**Figure 17**).

Table 11. Catch of yellowtail flounder for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experiment	Control	Experiment
2015	August	87	70	134	92
	September	120	102	108	103
	October	77	73	80	76
	November	64	70	74	72
2016	January	46	45	52	48
	March	12	28	31	14
	May	127	115	155	138
	June	36	50	68	33
	Total	569	553	702	576

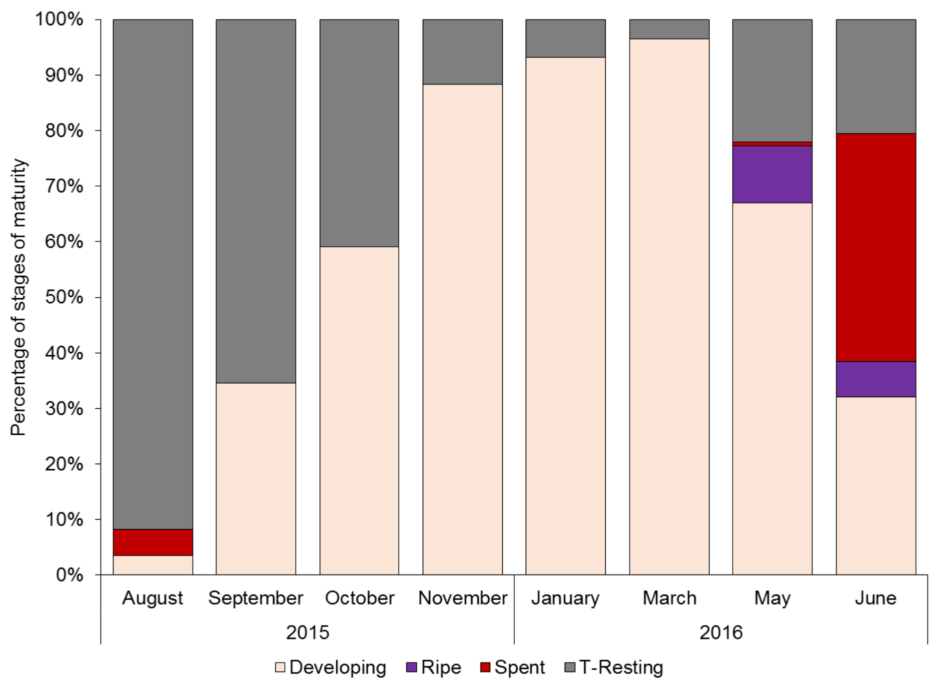

Figure 17. Seasonal maturity results of female yellowtail flounder for each month during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

From the flounder that were captured, 481 samples were collected for further analysis at the RWU laboratory. Macroscopically, seven individuals were observed with *Ichthyophonus* infection. From these samples, six were confirmed histologically to have *Ichythyophonus* sp. present in their tissues, while the seventh had no observable parasites in the histology slides (**Table 12**). In one additional individual, with no macroscopic disease characteristics, *Ichythyophonus* sp. were identified at the laboratory (**Table 12**).

Table 12. Macroscopic vs microscopic observations of *Ichthyophonus* infection in yellowtail flounder during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

Month	Macroscopic Observation (No. Individuals)		Histologically confirmed (No. Individuals)
	Not infected	Infected	
August	107	0	1
September	134	0	0
October	83	2	2
March	40	1	1
May	97	1	1
June	78	3	2

<u>Length-weight relationships:</u> In addition to conducting catch and reproductive stage analysis, we examined length-weight data collected in this project for winter, windowpane, and yellowtail flounders to estimate the length-weight relationships for these species. For each species, the parameters used to describe this relationship were determined for females, males, and the two sexes combined, and the values we obtained for fish on northern Georges Bank were

compared to those obtained from a published study using fish collected along the northeast coast of the United States (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 13**. Comparing the data of this project with the study conducted along the northeast coast of the United States using bottom trawl surveys from 1992 to 1999, there were differences for all three species (**Table 13**). 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 area, it is important to provide insights about length-weight relationship for these species.

Table 13. 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				Northeast coast of the US 1992-1999			
		N	Length (cm)	a	b	N	Length (cm)	a	b
Winter Flounder	Female	466	29 - 59	0.047	2.66	5322	9-60	8.56E-06	3.12
	Male	427	28 - 56	0.113	2.4	3796	5-54	1.13E-05	3.02
	Combined	893	28 - 59	0.042	2.68	9325	4-60	9.22E-06	3.09
Windowpane Flounder	Female	1514	16 - 42	0.032	2.69	2754	7-40	1.366E-05	2.98
	Male	1588	16 - 38	0.079	2.4	2153	4-36	1.465E05	2.92
	Combined	3102	16 - 42	0.034	2.67	8009	2-44	1.275E-05	2.97
Yellowtail Flounder	Female	639	30-49	0.028	2.68	4356	6-55	3.93E-06	3.27
	Male	148	28-43	0.053	2.47	4290	11-49	7.41E-06	3.05
	Combined	787	28-49	0.013	2.9	8775	4-55	5.18E-06	3.17

Monkfish are typically not considered a bycatch species in the sea scallop fishery since they are landed for sale. Monkfish were the most abundant fish species captured by weight during this project (**Table 14**). The majority of the monkfish caught during this survey were juveniles, using the 50% maturity cut off at 43cm (NEFMC 2014) indicating that they would be discarded at sea during commercial trips (**Table 14**). 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 13**).

Table 14. Catch of monkfish for each trip by gear type.

Date		Number		Weight (lbs)	
		Control	Experiment	Control	Experiment
2015	**August**	48	56	367	396
	September	73	76	452	506
	October	112	127	709	702
	November	190	212	746	932
2016	**January**	93	127	278	335
	March	12	8	19	27
	May	436	443	1003	1181
	June	341	412	1261	1146
	Total	1305	1463	4835	5225

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 until October (**Table 15** and **Figure 18**), mostly concentrated in the eastern portion of the survey area. Catch started to drop off for the November trip and few lobsters were present from January through June when catch began to increase slightly (**Figure G6**).

Table 15. Catch of lobster for each trip by gear type. Lobsters were not weighed during the first trip.

Date		Number		Weight (lbs)	
		Control	Experiment	Control	Experiment
2015	**August**	113	100	-	-
	September	157	163	206.353	227.14
	October	142	163	200.71	245.48
	November	39	35	54.18	41.169
2016	**January**	6	3	6.72	1.881
	March	3	7	1.318	7.828
	May	4	5	5.02	3.718
	June	34	46	56.945	175.05
	Total	498	522	531.246	702.266

The majority of the catch was females. Numbers of male lobsters caught remained consistently low over the course of the survey, with the highest catches occurring the first two trips (18 males each trip). A total of six incidences of shell disease were observed. Overall, 303 lobsters had no damage, 215 were moderately damaged (missing claws, walking leg), and 265 were classified as lethally damaged **(Figure 19**). A total of 445 females and 8 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, one lobster tagged by CFF has been returned.

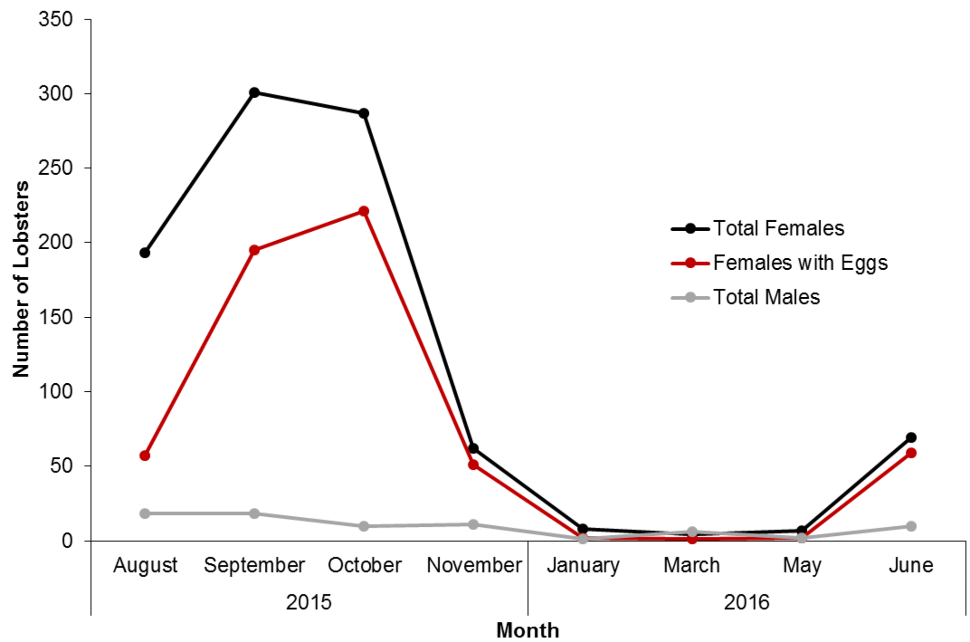

Figure 18. Catch of lobsters by trip separated by sex during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

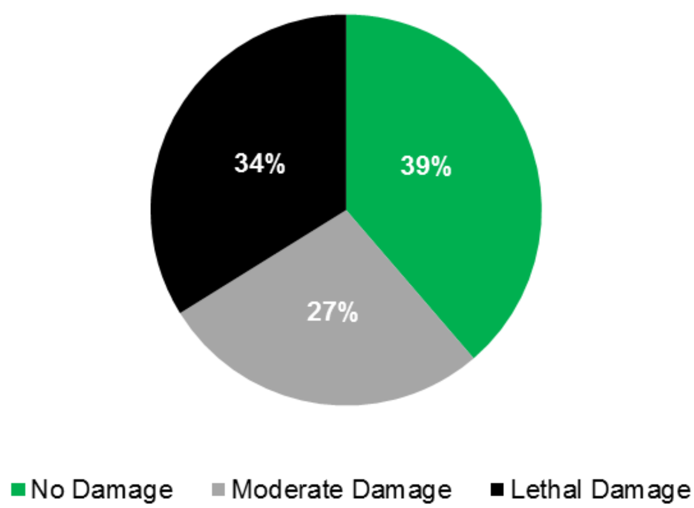

Figure 19. Summary of dredge-induced damage to lobsters during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

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 16**). Skates were present in high numbers at nearly every station sampled. Barndoor skate (*Dipturus laevis*) was also relatively abundant. Atlantic cod (*Gadus morhua*) were seen in higher numbers than expected and typically caught inside CAII. Haddock (*Melanogrammus aeglefinus*), American plaice (*Hippoglossoides platessoides*), and witch flounder (*Glyptocephalus cynoglossus*) were also caught regularly (**Table 16**).

Table 16. Catch (number of fish) of additional species for each trip by gear type during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.

Date		Unclassified skate		Barndoor skate		Atlantic Cod		Haddock		American plaice		Witch flounder	
		Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp
2015	August	4752	4333	43	77	0	1	6	3	2	1	6	13
	September	5656	5765	66	65	6	1	16	19	0	0	6	1
	October	4485	4072	35	43	5	3	14	7	0	2	0	0
	November	3681	3476	43	27	3	1	13	9	0	1	0	0
2016	January	3837	4076	19	24	6	6	26	20	9	7	0	0
	March	1575	1341	0	0	4	2	5	3	30	12	1	1
	May	5566	5141	47	46	14	15	15	13	25	13	3	10
	June	4107	3722	18	19	4	1	13	3	5	1	12	8
	Total	33659	31926	271	301	42	30	108	77	71	37	28	33

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

Crabs were counted and weighed by species for the control dredge during this project. No data was collected during the first trip. Starting in October, all Jonah crabs (*Cancer borealis*) were separated into sublegal (<120mm) and legal size to collect counts and weights (**Table 17**). 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.

Table 17. 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		
2015	September	487		71.72		469	27.78
	October	34	55	16.21	12.11	605	13.12
	November	57	44	22.04	6.81	100	8.62
2016	January	6	58	2.73	11.7	325	24.96
	March	7	21	3.13	4.16	210	14
	May	17	40	6.96	6.08	683	37.98
	June	13	42	3.2	12.16	210	15.9
	Total (Oct-Jun)	134	260	54.27	53.02	2133	114.58

During the first four research trips, counts of crabs (*Cancer* sp.) infected with shell disease were collected. Infections averaged 7% of the catch. Infections typically presented as minor discoloration and pitting to the carapace. No severe lesions were noted.

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.

CONCLUSIONS AND RECOMMENDATIONS

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. Most recently, data has been collected on meat loss during shucking and crustaceans and sea star biology.

To date, CFF has completed 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 will shift 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.

We recommend additional investigation of the economic impact of the different dredge modifications. We consider it very important to continue to analyze the selectivity of the dredges, as we have been doing successfully in this project. But it is also imperative to add a more in-depth economic analysis (taking into account costs, landed value of fish, scallop price, etc.) that allows decision makers and fishermen to recognize that different modifications of the dredges can not only diminish the environmental impact, but also result in economic gains. Finally, it is well known that one of the causes for the weakening of a stock can be natural mortality, and over years of sampling a range of species, CFF has identified several diseases affecting both scallop and bycatch species. Therefore, we recommend more extensive monitoring of the diseases found on scallop fishing grounds.

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APPENDICES

Appendix A: General

Table A1. Specifications of CFF dredges used during the 2015 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 2015 seasonal bycatch survey on the northern portion of Georges Bank. It was measured for fish: total lengths, for squid: mantle length and for scallop: shell height.

Common Name	Scientific Name	Number Caught	Sample Procedure
Cusk	*Brosme brosme*	1	Count/Weigh
Jonah crab	*Cancer borealis*	1241	Count/Weigh
Jonah crab (sub-legal)	*Cancer borealis*	298	Count/Weigh
Rock crab	*Cancer irroratus*	2936	Count/Weigh
Black sea bass	*Centropristis striata*	3	Weigh/Measure
Herring uncl.	*Clupidae*	2	Weigh/Measure
Conger eel	*Conger oceanicus*	4	Weigh/Measure
Barndoor skate	*Dipturus laevis*	572	Weigh/Measure
Loligo squid	*Doryteuthis pealeii*	37	Weigh/Measure
Crabs uncl.	*Eubrachyura*	356	Count/Weigh
Atlantic cod	*Gadus morhua*	72	Weigh/Measure
Grey sole	*Glyptocephalus cynoglossus*	61	Weigh/Measure
Sea raven	*Hemitripterus americanus*	130	Count/Weigh
American plaice	*Hippoglossoides platessoides*	109	Weigh/Measure
Illex squid	*Illex illecebrosus*	2	Weigh/Measure
Yellowtail flounder	*Limanda ferruginea*	1122	Weigh/Measure/ Reproductive/Disease
Monkfish	*Lophius americanus*	2868	Weigh/Measure
Haddock	*Melanogrammus aeglefinus*	185	Weigh/Measure
Silver hake	*Merluccius bilinearis*	446	Weigh/Measure
Smooth dogfish	*Mustelus canis canis*	3	Weigh/Measure
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	107	Count/Weigh
Summer flounder	*Paralichthys dentatus*	374	Weigh/Measure
Fourspot flounder	*Paralichthys oblongus*	366	Weigh/Measure
Butterfish	*Peprilus triacanthus*	1	Weigh/Measure
Sea scallop (bushels)	*Placopecten magellanicus*	772.46	Weigh/Measure/ Reproductive/Disease
Northern searobin	*Prionotus carolimus*	1047	Count/Weigh
Blackback flounder	*Pseudopleuronectes americanus*	1093	Weigh/Measure/ Reproductive
Skates uncl.	*Rajidae*	65575	Count/Weigh
Windowpane flounder	*Scopthalmus aquosus*	13480	Weigh/Measure/ Reproductive
Spiny dogfish	*Squalus acanthias*	126	Weigh/Measure
Cunner	*Tautogolabrus adspersus*	14	Weigh/Measure
Squid uncl.	*Teuthida*	2	Weigh/Measure
Torpedo ray	*Torpedo nobiliana*	2	Weigh/Measure
Red hake	*Urophycis chuss*	396	Count/Weigh
Ocean pout	*Zoarces americanus*	5	Weigh/Measure

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

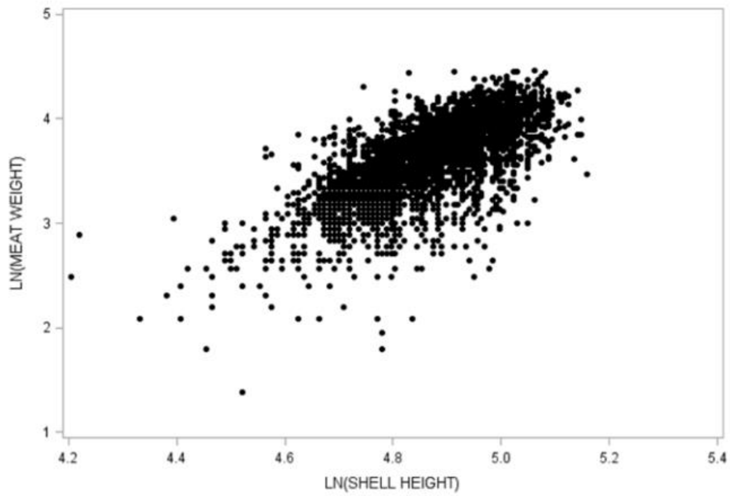
Table B1. Results from iterative model building. The model with the minimum AIC value is shown in bold. Fixed effects are shown to the right of the ~ symbol. This symbol separates the response (Meat Weight) from the predictor variables used in the analysis. Interaction terms are denoted with the factor1*factor2 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	Δ AIC
MW ~ INT, SHELLHT, MONTH, AREA, COLOR, STRINGY, SHELLHT*AREA	**INTERCEPT**	**33,727.32**	-
MW ~ INT, SHELLHT, MONTH, AREA, COLOR, STRINGY, MONTH*AREA, SHELLHT *AREA	INTERCEPT	33,731.72	-4.40
MW ~ INT, SHELLHT, DEPTH, COLOR, DEPTH, MONTH*AREA, SHELLHT *AREA,	INTERCEPT	33,733.41	-6.09
MW ~ INT, SHELLHT, MONTH, AREA, COLOR, STRINGY, MONTH*AREA, SHELLHT *AREA, AREA*DEPTH	INTERCEPT	33,733.69	-6.37
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR, STRINGY, ORANGEPUSTULE, MONTH*AREA, DEPTH*AREA, SHELLHT *AREA	INTERCEPT	33,736.58	-9.25
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR, STRINGY	INTERCEPT	33,750.83	-23.51
MW ~ INT, SHELLHT, MONTH, AREA, MEATCOLOR, STRINGY, DEPTH*AREA	INTERCEPT	33,751.25	-23.93
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR, STRINGY, ORANGEPUSTULE	INTERCEPT	33,751.84	-24.52
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR, STRINGY, ORANGEPUSTULE, MONTH*AREA	INTERCEPT	33,754.50	-27.17
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR, STRINGY, ORANGEPUSTULE, MONTH*AREA, DEPTH*AREA	INTERCEPT	33,756.44	-29.12
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX, COLOR	INTERCEPT	33,762.43	-35.11
MW ~ INT, SHELLHT, MONTH, AREA, COLOR, STRINGY, SHELLHT *AREA	NONE	34,298.10	-570.78
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH	INTERCEPT	34,592.56	-865.24
MW ~ INT, SHELLHT, MONTH, AREA, DEPTH, SEX	INTERCEPT	34,593.61	-866.29
MW ~ INT, SHELLHT, MONTH	INTERCEPT	34,597.97	-870.64
MW ~ INT, SHELLHT, MONTH, AREA	INTERCEPT	34,598.84	-871.52
MW ~ INT, SHELLHT	INTERCEPT	34,644.38	-917.06
MW ~ INTERCEPT ONLY	INTERCEPT	37,900.51	-4173.19

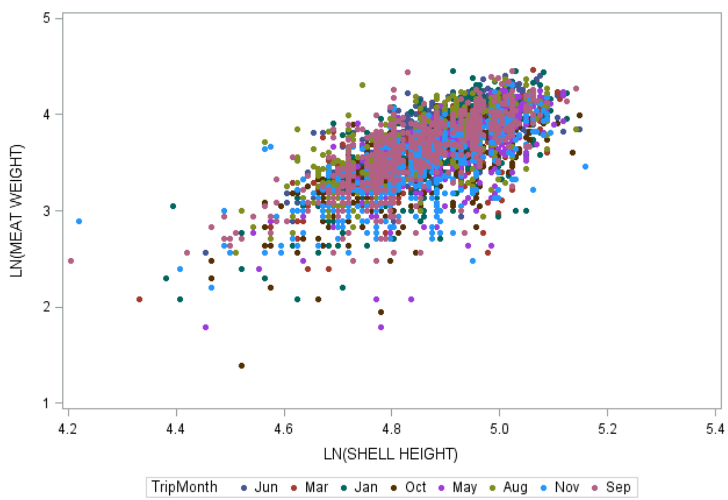
Table B2. Parameter estimates for the best model as described by minimum AIC value. For the categorical variables (trip month, location, meat color, and stringiness), differences within that category are relative to the value with a 0 parameter estimate (i.e. non-CAII, June 2016, white meat, and stringy). 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	Stringy	Color	Area	Estimate	SE	DF	t-value	p-value
Intercept					-7.654	0.176	4957	-43.580	0.000
Shell height					2.328	0.035	4957	66.191	0.000
Month	Aug				-0.038	0.030	4957	-1.270	0.204
Month	Sep				-0.064	0.028	4957	-2.293	0.022
Month	Oct				-0.206	0.028	4957	-7.296	0.000
Month	Nov				-0.194	0.027	4957	-7.081	0.000
Month	Jan				-0.147	0.028	4957	-5.248	0.000
Month	Mar				-0.156	0.028	4957	-5.609	0.000
Month	May				-0.156	0.028	4957	-5.666	0.000
Month	Jun				0.000				
Area				CAII	1.363	0.271	4957	5.021	0.000
Area				Non-CAII	0.000				
Color			Brown		-0.345	0.018	4957	-19.604	0.000
Color			Gray		-0.605	0.023	4957	-26.051	0.000
Color			Lt. Brown		-0.156	0.012	4957	-13.179	0.000
Color			White		0.000				
Stringy		No			0.104	0.030	4957	3.489	0.000
Stringy		Yes			0.000				
Shell height*Area				CAII	-0.275	0.056	4957	-4.942	0.000
Shell height*Area				Non-CAII	0.000				

a)



b)



c)

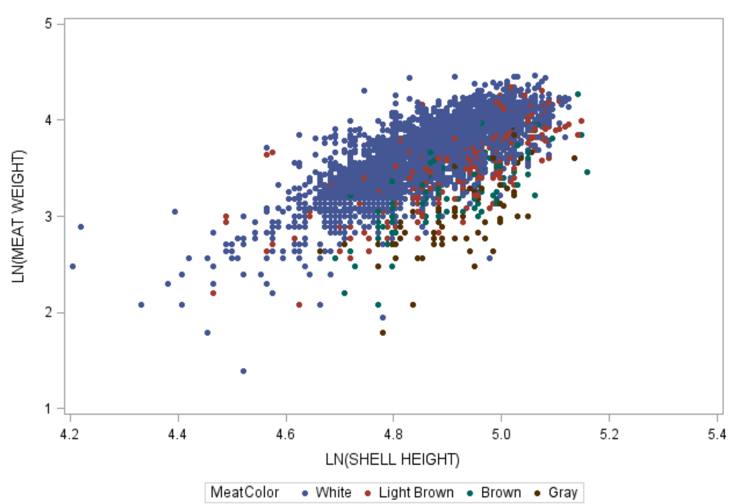


Figure B1. Shell Height:Meat Weight data for: **a)** all trips combined, **b)** all trips combined separated by month of sampling, and **c)** all trips combined separated by meat color.

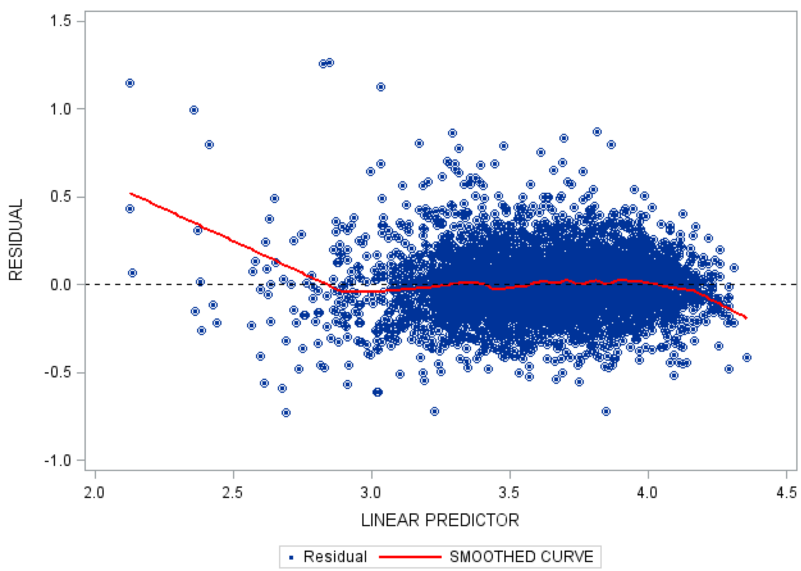


Figure B2. Residuals for the best model fit as determined by minimum AIC value. Residuals show slight evidence of patterning at the smallest levels of the linear predictor suggesting a number of larger than expected meats from relatively small shell heights. This results in a small number of large, positively valued residuals.

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 (λ_{ir}/ λ_{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. λ_{ir}= λ_{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:

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

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:

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

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.

Species	Fixed Effects	Random Effects	AIC	Delta AIC
Barndoor Skate	Length, Trip	None	594.67	0.00
	Intercept only	Intercept	596.10	1.43
	Length, Trip	Intercept	596.18	1.51
	Length	Intercept	597.52	2.85
	Length, Trip	Intercept, Slope	597.83	3.16
	Intercept only	None	597.91	3.24
	Length	None	598.93	4.26
	Length, Trip, Length*Trip	None	602.14	7.47
	Length, Trip, Length*Trip	Intercept	603.56	8.89
Summer Flounder	Intercept only	None	462.36	0.00
	Length	None	462.58	0.23
	Intercept only	Intercept	463.98	1.63
	Length, Trip	None	464.44	2.09
	Length	Intercept	464.45	2.09
	Length, Trip	Intercept	466.37	4.02
	Length, Trip	None	467.20	4.84
	Length, Trip	Intercept, Slope	468.37	6.02
Fourspot Flounder	Intercept only	None	417.34	0.00
	Intercept only	Intercept	418.47	1.13
	Length	None	419.32	1.98
	Length	Intercept	420.47	3.12
	Length, Trip	None	426.73	9.39
	Length, Trip	Intercept	428.06	10.72
	Length, Trip, Length*Trip	None	433.19	15.84
	Length, Trip, Length*Trip	Intercept	434.60	17.26
Yellowtail Flounder	Length	Intercept	942.65	0.00
	Intercept only	Intercept	943.64	0.99
	Length	None	943.97	1.32
	Intercept only	None	944.98	2.32
	Length, Trip	Intercept	945.12	2.47
	Length, Trip	None	945.66	3.01
	Length, Trip, Length*Trip	Intercept	950.86	8.21
	Length, Trip, Length*Trip	None	952.16	9.50
Winter Flounder	Length, Trip, Length*Trip	Intercept	937.68	0.00
	Length, Trip, Length*Trip	None	939.73	2.05
	Intercept only	Intercept	939.85	2.17
	Length	Intercept	941.82	4.14
	Intercept only	None	950.23	12.55
	Length, Trip	Intercept	951.38	13.70
	Length	None	952.06	14.38
	Length, Trip	None	961.16	23.48
Windowpane Flounder	Length, Trip	Intercept	5956.83	0.00
	Length, Trip	Intercept, Slope	5958.21	1.39
	Length, Trip, Length*Trip	Intercept	5965.49	8.66
	Length, Trip, Length*Trip	Intercept, Slope	5966.91	10.08
	Length	Intercept	5968.24	11.42

Species	Fixed Effects	Random Effects	AIC	Delta AIC
	Length	Intercept, Slope	5970.08	13.25
	Intercept only	Intercept	5970.20	13.37
	Intercept only	Intercept, Slope	5972.19	15.36
	Length, Trip	None	6021.87	65.04
	Length, Trip, Length*Trip	None	6031.16	74.33
	Length	None	6054.84	98.01
	Intercept only	None	6055.34	98.51
Monkfish	Intercept only	None	2170.08	0.00
	Intercept only	Intercept	2171.30	1.21
	Length	None	2172.08	2.00
	Intercept only	Intercept, Slope	2173.10	3.02
	Length	Intercept	2173.30	3.21
	Length, Trip	None	2173.82	3.74
	Length	Intercept, Slope	2175.10	5.02
	Intercept	Intercept	2175.81	5.72
	Length, Trip	Intercept, Slope	2177.70	7.62
	Length, Trip, Length*Trip	None	2181.19	11.10
	Length, Trip, Length*Trip	Intercept	2183.06	12.98
	Length, Trip, Length*Trip	Intercept, Slope	2185.02	14.94
Sea Scallops	Length, Trip, Length*Trip	Intercept, Slope	6696.19	0.00
	Length, Trip, Length*Trip	Intercept	6697.09	0.90
	Length	Intercept, Slope	7005.20	309.01
	Length, Trip	Intercept, Slope	7009.64	313.45
	Length	Intercept	7013.63	317.44
	Length, Trip	Intercept	7022.31	326.12
	Intercept only	Intercept, Slope	7040.12	343.93
	Length, Trip, Length*Trip	None	7043.09	346.90
	Intercept only	Intercept	7048.28	352.09
	Length, Trip	None	7307.32	611.13
	Length	None	7340.39	644.20
	Intercept only	None	7383.69	687.49

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
Barndoor Skate	Intercept	-0.12070	0.266	393	-0.454	0.650	0.05	-0.644	0.402
	Size	0.00459	0.005	393	0.986	0.325	0.05	-0.005	0.014
Summer Flounder	Intercept	-1.06112	0.640	317	-1.659	0.098	0.05	-2.319	0.197
	Size	0.01528	0.012	317	1.327	0.185	0.05	-0.007	0.038
Fourspot Flounder	Intercept	0.01390	0.803	277	0.017	0.986	0.05	-1.567	1.595
	Size	-0.00365	0.025	277	-0.148	0.882	0.05	-0.052	0.045
Yellowtail Flounder	Intercept	1.09297	0.741	554	1.476	0.141	0.05	-0.362	2.548
	Size	-0.03366	0.020	554	-1.723	0.085	0.05	-0.072	0.005
Monkfish	Intercept	0.06007	0.166	1325	0.361	0.718	0.05	-0.266	0.386
	Size	0.00004	0.004	1325	0.011	0.991	0.05	-0.008	0.008

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		0.1771	0.2706	2438	0.654	0.513	-0.354	0.708
	Length		-0.0165	0.0091	2438	-1.817	0.069	-0.034	0.001
	Trip	172	0.0292	0.1280	2438	0.228	0.819	-0.222	0.280
	Trip	174	0.1422	0.1199	2438	1.186	0.236	-0.093	0.377
	Trip	184	0.1056	0.1177	2438	0.897	0.370	-0.125	0.336
	Trip	189	0.2425	0.1199	2438	2.023	0.043	0.007	0.478
	Trip	198	0.3229	0.1105	2438	2.922	0.004	0.106	0.539
	Trip	203	-0.1804	0.1385	2438	-1.302	0.193	-0.452	0.091
	Trip	221	0.0000						

Table D4. Models examining the unpooled catch data. Results are presented from the model that provided the best fit (intercept, length, trip and length*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
Winter Flounder	Intercept		-4.371	2.121	596	-2.061	0.040	-8.537	-0.205
	Length		0.093	0.048	596	1.943	0.052	-0.001	0.187
	Trip	172	7.986	2.675	596	2.985	0.003	2.732	13.240
	Trip	174	7.339	2.736	596	2.682	0.008	1.965	12.713
	Trip	184	1.922	2.674	596	0.719	0.473	-3.330	7.175
	Trip	189	6.093	2.742	596	2.222	0.027	0.707	11.479
	Trip	198	-0.268	2.681	596	-0.100	0.920	-5.533	4.997
	Trip	203	3.351	4.725	596	0.709	0.478	-5.929	12.631
	Trip	221	0.000						
	Length*Trip	172	-0.188	0.061	596	-3.060	0.002	-0.309	-0.067
	Length*Trip	174	-0.171	0.064	596	-2.653	0.008	-0.297	-0.044
	Length*Trip	184	-0.040	0.061	596	-0.653	0.514	-0.161	0.080
	Length*Trip	189	-0.140	0.062	596	-2.236	0.026	-0.262	-0.017
	Length*Trip	198	0.019	0.062	596	0.304	0.761	-0.102	0.140
	Length*Trip	203	-0.077	0.109	596	-0.705	0.481	-0.290	0.137
	Length*Trip	221	0.000						
Sea Scallops	Intercept		5.259	0.490	1844	10.743	<0.001	4.299	6.219
	Length		-0.040	0.004	1844	-10.915	<0.001	-0.047	-0.033
	Trip	172	-4.667	0.665	1844	-7.021	<0.001	-5.971	-3.364
	Trip	174	-5.953	0.603	1844	-9.878	<0.001	-7.135	-4.771
	Trip	184	-9.078	0.622	1844	-14.602	<0.001	-10.297	-7.859
	Trip	189	-9.122	0.620	1844	-14.719	<0.001	-10.337	-7.906
	Trip	198	-6.032	0.645	1844	-9.350	<0.001	-7.298	-4.767
	Trip	203	-5.271	0.640	1844	-8.242	<0.001	-6.526	-4.017
	Trip	221	0.000				<0.001		
	Length*Trip	172	0.036	0.005	1844	7.104	<0.001	0.026	0.046
	Length*Trip	174	0.046	0.005	1844	10.090	<0.001	0.037	0.055
	Length*Trip	184	0.069	0.005	1844	14.828	<0.001	0.060	0.078
	Length*Trip	189	0.071	0.005	1844	15.054	<0.001	0.061	0.080
	Length*Trip	198	0.046	0.005	1844	9.517	<0.001	0.037	0.056
	Length*Trip	203	0.039	0.005	1844	8.159	<0.001	0.030	0.049
	Length*Trip	221	0.000						

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

Species	Fixed Effects	Random Effects	AIC	Delta AIC
Uncl. Skates	Intercept, Trip	Intercept	2979.15	0.00
	Intercept Only	Intercept	2987.61	8.46
	Intercept, Trip	None	3526.32	547.17
	Intercept Only	None	3570.40	591.24
Barndoor Skates	Intercept, Trip	None	276.34	0.00
	Intercept, Trip	Intercept	277.82	1.48
	Intercept Only	Intercept	279.06	2.72
	Intercept Only	None	280.25	3.91
Summer Flounder	Intercept Only	None	255.24	0.00
	Intercept Only	Intercept	256.87	1.63
	Intercept, Trip	None	257.66	2.42
	Intercept, Trip	Intercept	259.38	4.14
Fourspot Flounder	Intercept Only	None	243.78	0.00
	Intercept Only	Intercept	244.91	1.13
	Intercept, Trip	None	251.17	7.39
	Intercept, Trip	Intercept	252.50	8.72
Yellowtail Flounder	Intercept Only	Intercept	409.78	0.00
	Intercept, Trip	Intercept	410.93	1.16
	Intercept Only	None	411.11	1.34
	Intercept, Trip	None	411.41	1.63
Monkfish	Intercept Only	None	738.93	0.00
	Intercept Only	Intercept	740.14	1.21
	Intercept, Trip	None	740.92	1.99
	Intercept, Trip	Intercept	742.91	3.98

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	LCI	UCI
Summer Flounder	**Intercept**	**-0.2257**	**0.1081**	**116**	**-2.089**	**0.039**	**-0.440**	**-0.012**
Fourspot Flounder	Intercept	-0.1041	0.1108	112	-0.940	0.349	-0.324	0.115
Yellowtail Flounder	**Intercept**	**-0.1768**	**0.0804**	**152**	**-2.200**	**0.029**	**-0.336**	**-0.018**
Winter Flounder	**Intercept**	**-0.2174**	**0.0941**	**197**	**-2.311**	**0.022**	**-0.403**	**-0.032**
Monkfish	Intercept	0.0618	0.0450	248	1.372	0.171	-0.027	0.150
Sea Scallops	Intercept	0.0263	0.0393	205	0.670	0.504	-0.051	0.104

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	LCI	UCI
Uncl. Skates	Intercept		-0.1094	0.0453	405	-2.416	0.016	-0.1984	-0.0204
	Trip	172	0.0958	0.0660	405	1.453	0.147	-0.0338	0.2255
	Trip	174	0.1681	0.0637	405	2.639	0.009	0.0429	0.2934
	Trip	184	0.0469	0.0638	405	0.736	0.462	-0.0784	0.1723
	Trip	189	0.0696	0.0650	405	1.071	0.285	-0.0581	0.1974
	Trip	198	0.2010	0.0638	405	3.152	0.002	0.0756	0.3263
	Trip	203	-0.0627	0.0741	405	-0.846	0.398	-0.2083	0.0830
	Trip	221	0.0000						
Barndoor Skates	Intercept		0.0541	0.3289	110	0.164	0.870	-0.5978	0.7059
	Trip	172	0.5850	0.3852	110	1.519	0.132	-0.1784	1.3484
	Trip	174	-0.0848	0.3728	110	-0.228	0.820	-0.8236	0.6539
	Trip	184	0.1518	0.4000	110	0.379	0.705	-0.6410	0.9445
	Trip	189	-0.5194	0.4105	110	-1.265	0.208	-1.3329	0.2940
	Trip	198	0.1795	0.4500	110	0.399	0.691	-0.7122	1.0713
	Trip	221	0.0000						
Windowpane Flounder	Intercept		-0.3106	0.0879	357	-3.534	<0.001	-0.4835	-0.1377
	Trip	172	0.0860	0.1244	357	0.691	0.490	-0.1588	0.3307
	Trip	174	0.1927	0.1161	357	1.660	0.098	-0.0356	0.4210
	Trip	184	0.1529	0.1139	357	1.342	0.180	-0.0711	0.3770
	Trip	189	0.2885	0.1164	357	2.478	0.014	0.0595	0.5174
	Trip	198	0.3356	0.1070	357	3.136	0.002	0.1251	0.5461
	Trip	203	-0.1431	0.1358	357	-1.054	0.293	-0.4101	0.1240
	Trip	221	0.0000						

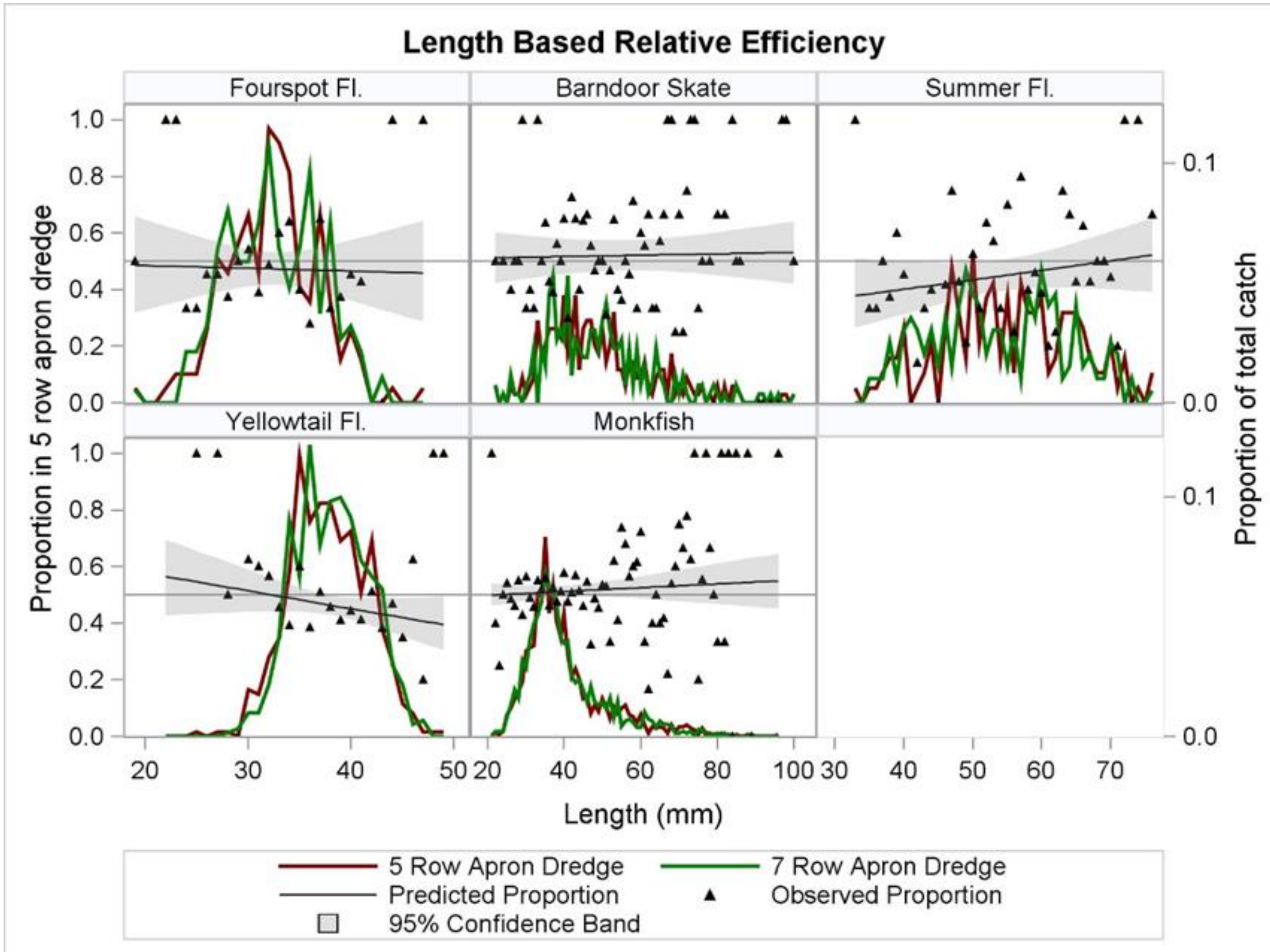


Figure D1. Relative catch by the two dredge configurations for **a)** barndoor skate, **b)** summer flounder, **c)** fourspot flounder, **d)** yellowtail flounder, and **e)** monkfish. The triangles represent the observed proportion at length ($Catch_{5row}/(Catch_{5row} + Catch_{7row})$), with a proportion >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).

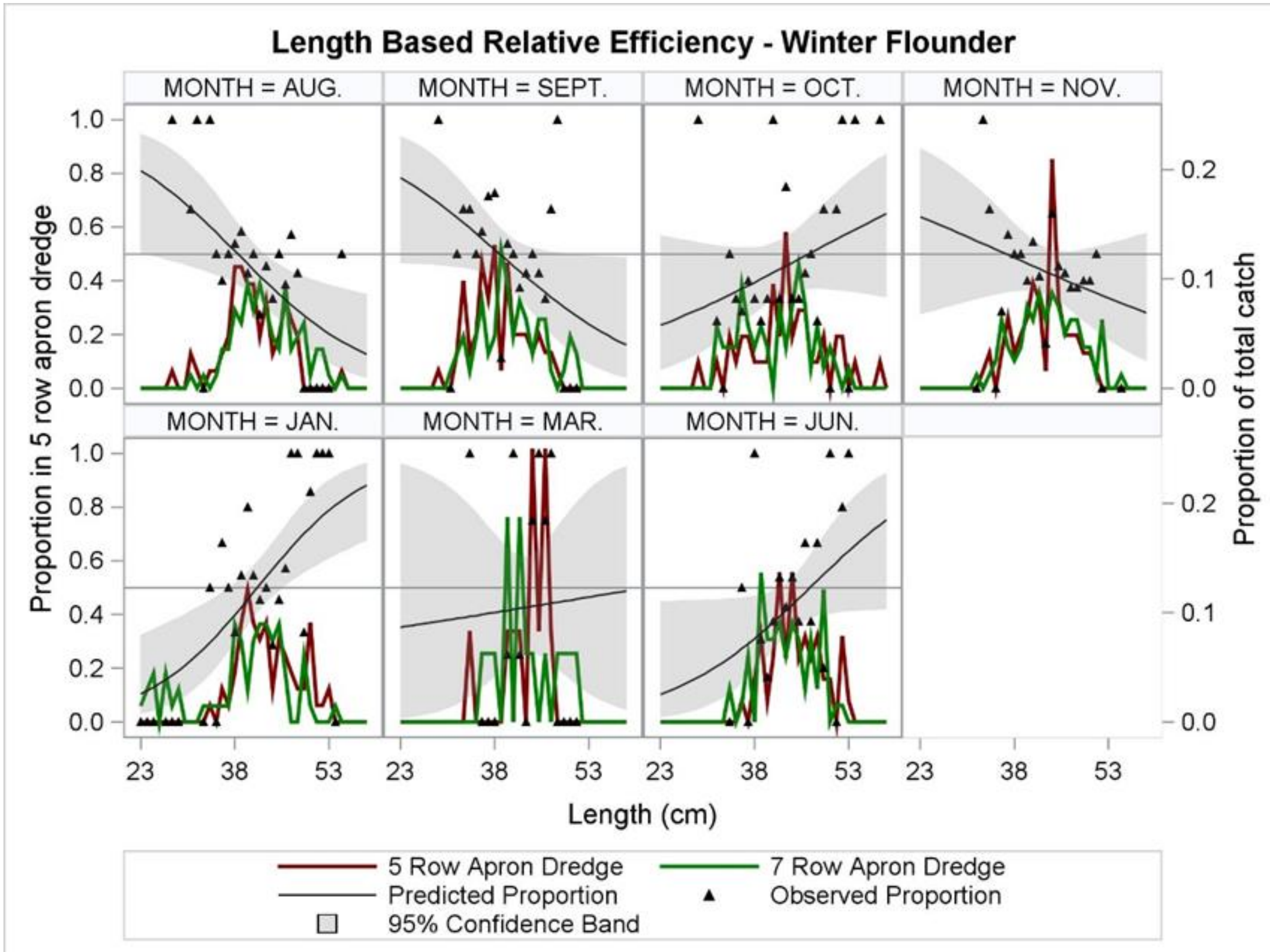


Figure D2. Relative winter flounder catch by the two dredge configurations by trip. The triangles represent the observed proportion at length ($Catch_{5row}/(Catch_{5row} + Catch_{7row})$), with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line). The model that provided the best fit to the data included a factor that accounted for individual slopes for each trip.

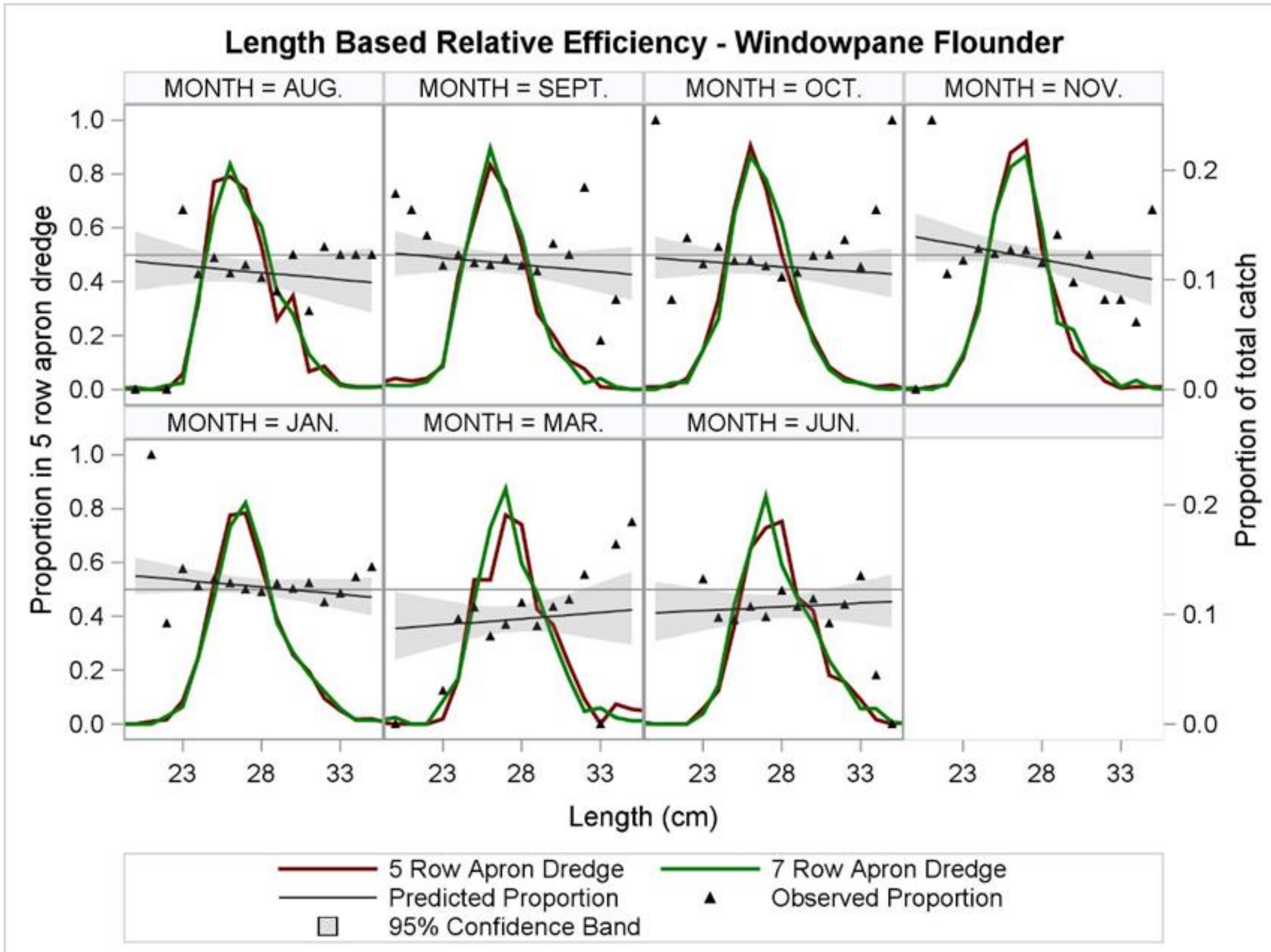


Figure D3. Relative windowpane flounder catch by the two dredge configurations by trip. The triangles represent the observed proportion at length ($Catch_{5row}/(Catch_{5row} + Catch_{7row})$), with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area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

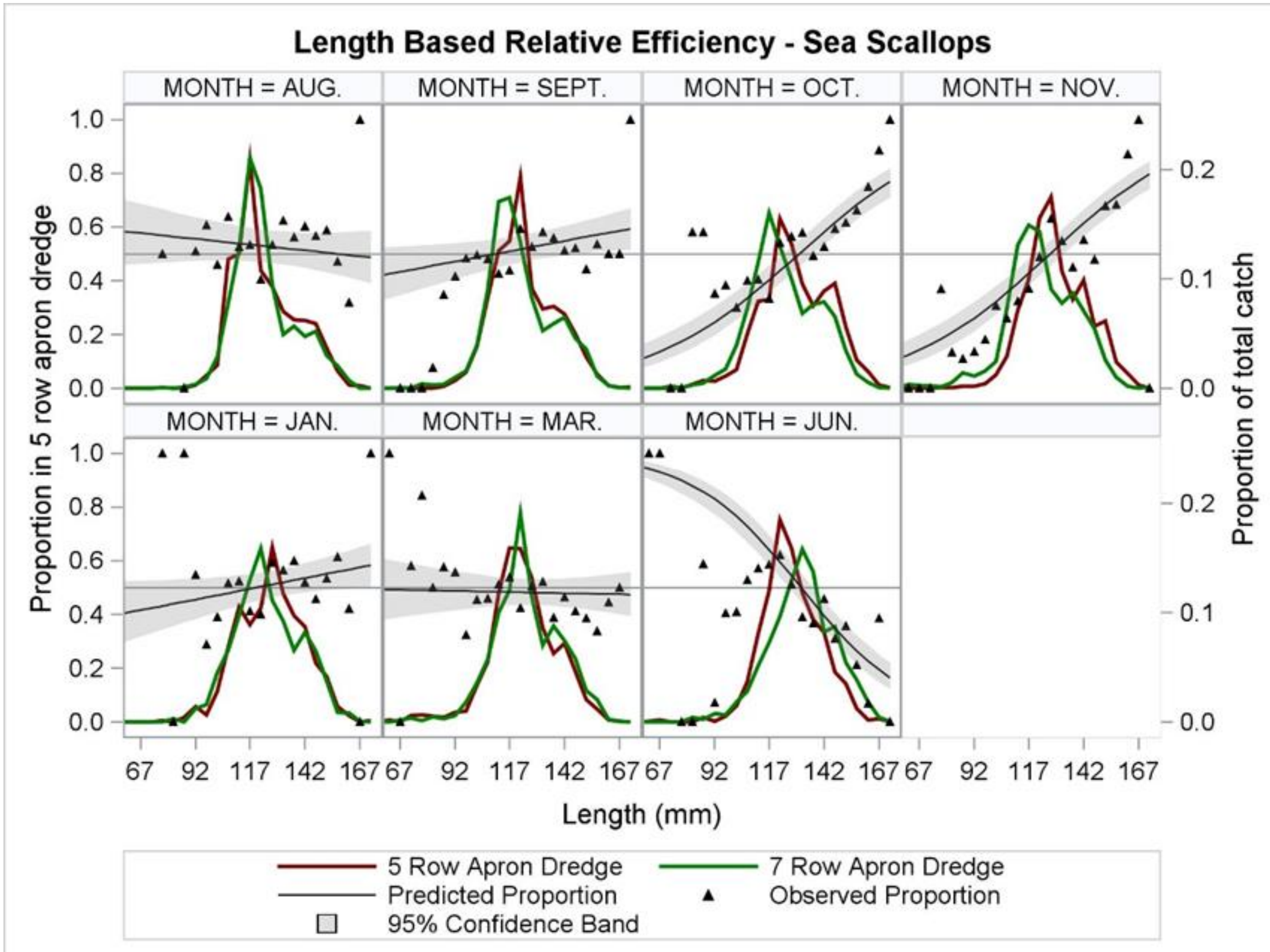


Figure D4. Relative sea scallop catch by the two dredge configurations by trip. The triangles represent the observed proportion at length ($Catch_{5row}/(Catch_{5row} + Catch_{7row})$), with a proportion >0.5 representing more animals at length captured by the 5-row apron dredge. The grey area represents the 95% confidence band for the modeled proportion (solid black line). The model that provided the best fit to the data included a factor that accounted for individual slopes for each trip.

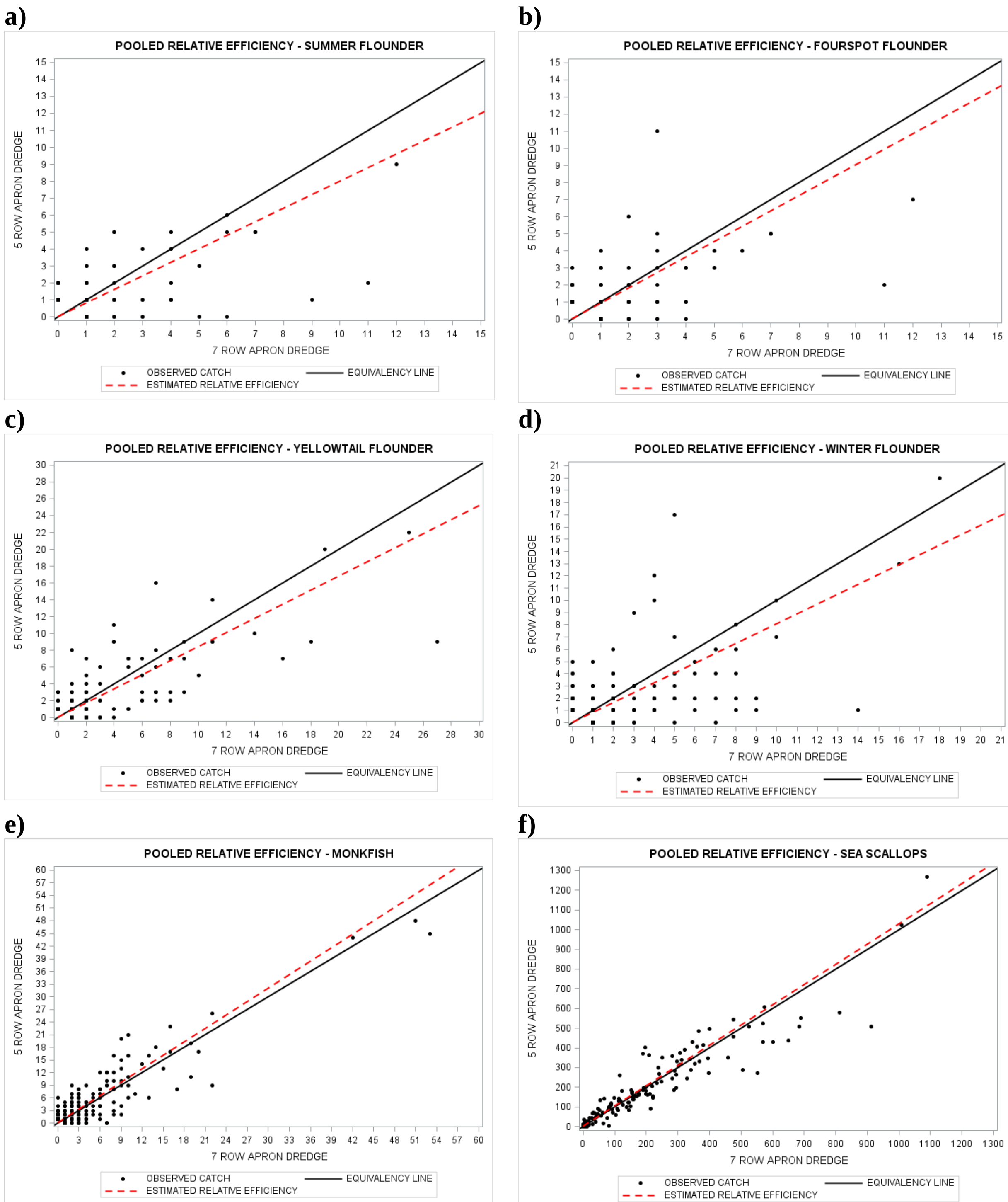


Figure D5. Total pooled catches (numbers) for the 5-row apron dredge vs. the 7-row apron dredge for **a)** summer flounder, **b)** fourspot flounder, **c)** yellowtail flounder, **d)** winter flounder, **e)** monkfish, and **f)** sea scallop. Model output from the analysis of the pooled data indicated 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.

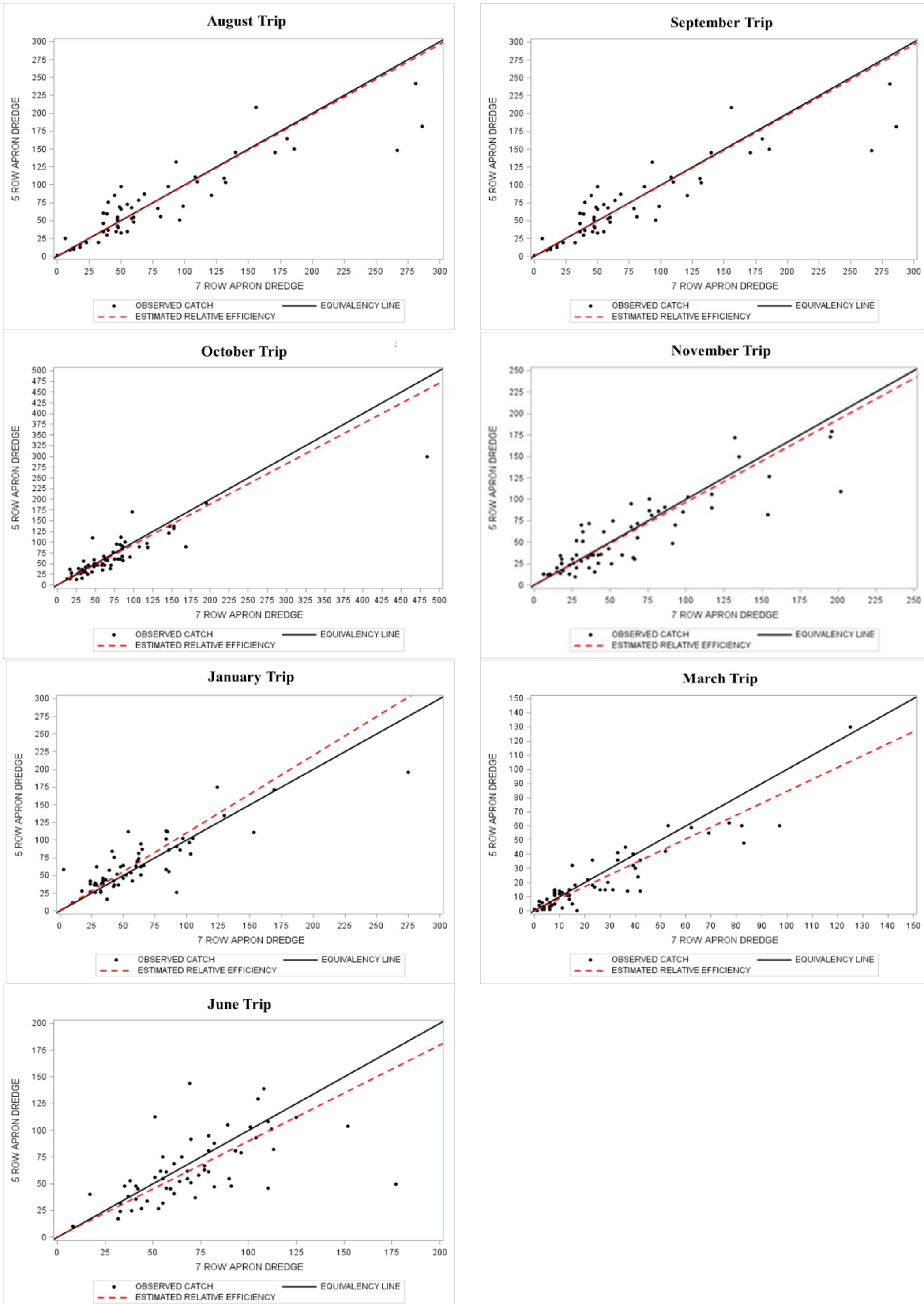


Figure D6. Total pooled catches for unclassified skates for the 5 row apron dredge vs. the 7 ring apron dredge by trip. Model output from the analysis of the pooled data indicated that the model that included trip as a factor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

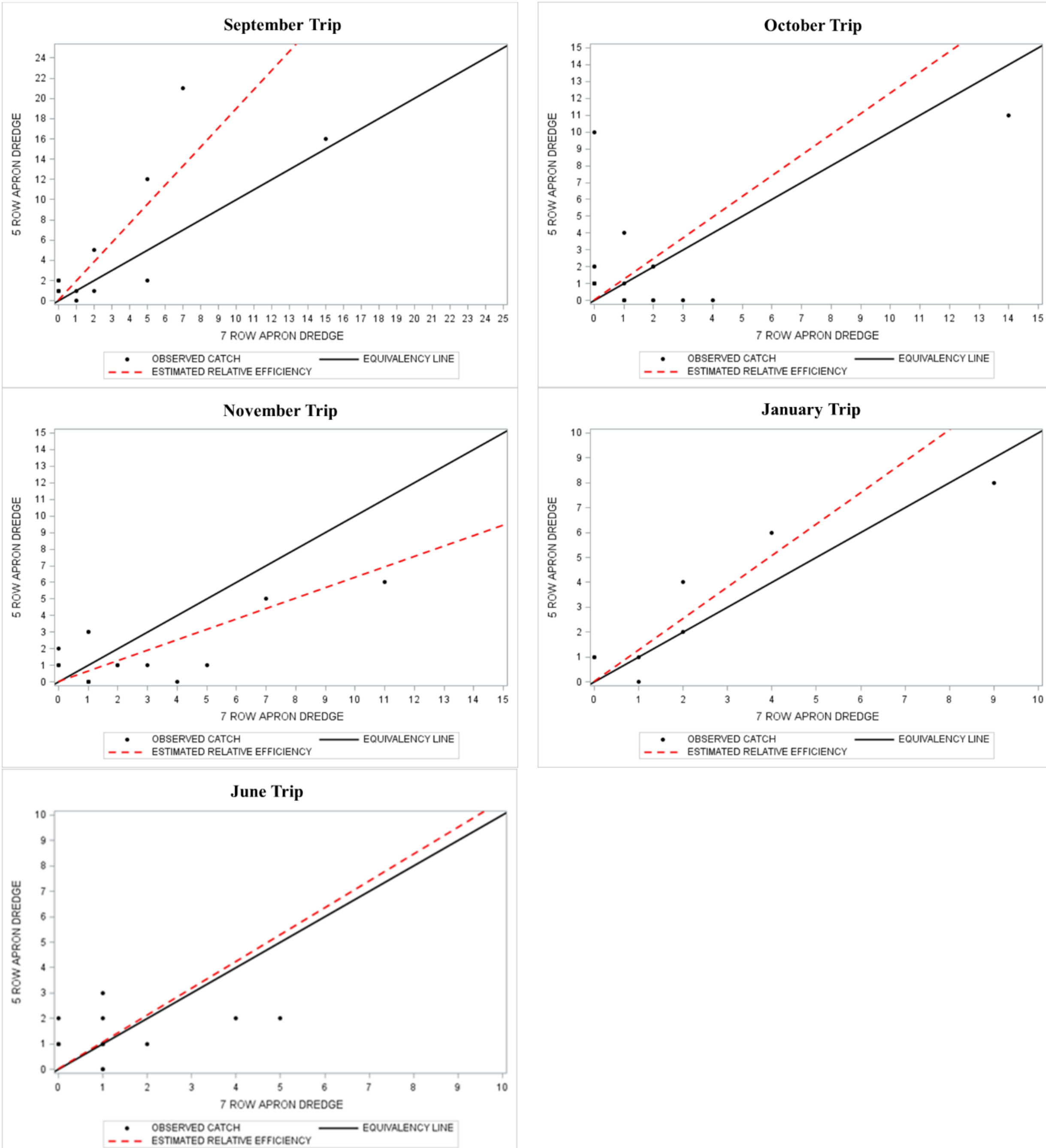


Figure D7. Total pooled catches for barndoor skate for the 5 row apron dredge vs. the 7 ring apron dredge. Model output from the analysis of the pooled data indicated that the model that included trip as a factor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

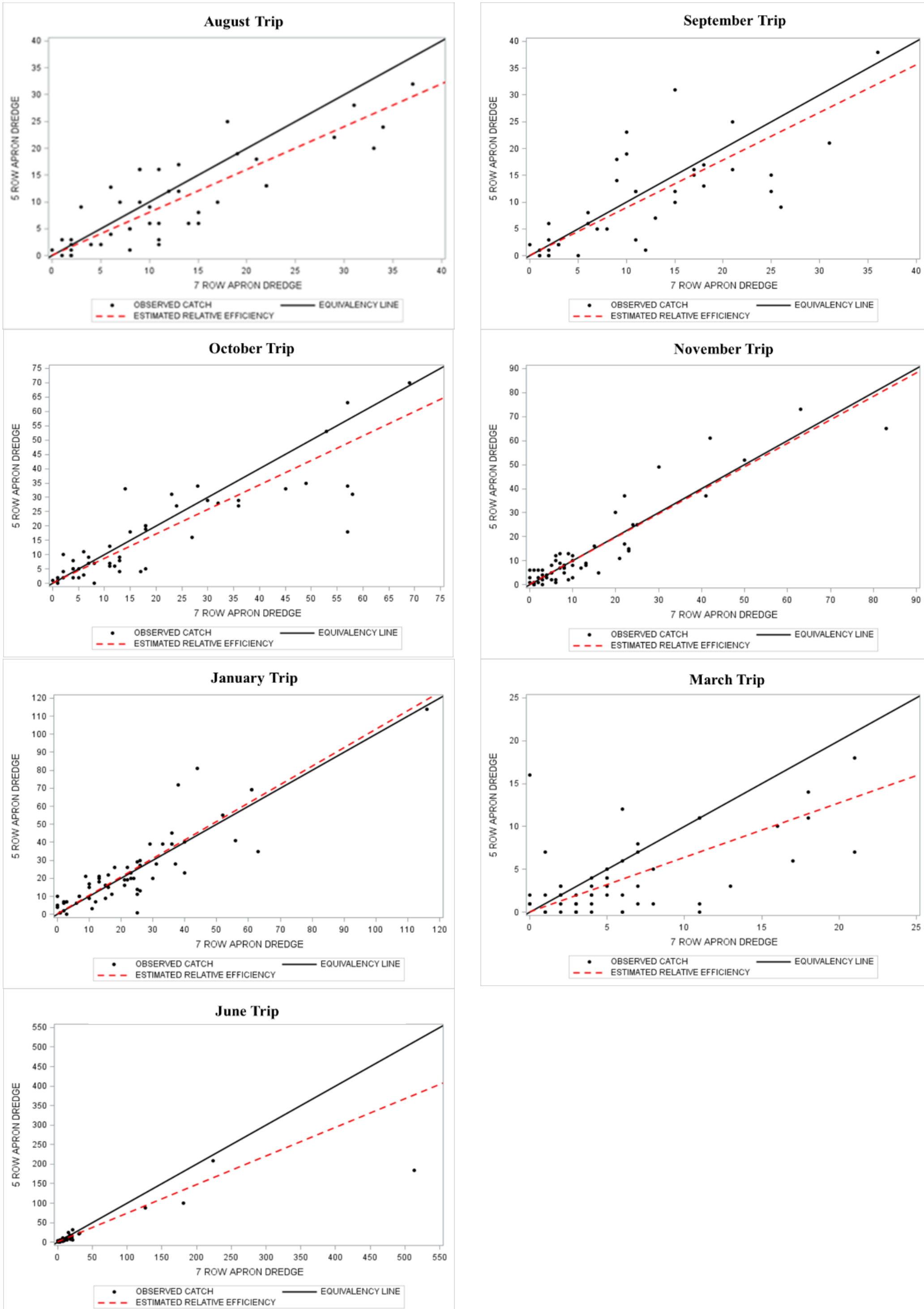


Figure D8. Total pooled catches for windowpane flounder for the 5 row apron dredge vs. the 7 ring apron dredge. Model output from the analysis of the pooled data indicated that the model that included trip as a factor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

Appendix E: Economic Analysis of Scallop Catch

Table E1. Comparison of scallop catch in the 7-row apron (control) and 5-row apron (experimental) dredges by commercial category, at estimated catch value.

Commercial Category	Size	Calculated Meat Count		Average weight (g) at size	Total Meat Weight (g)		Total Meat Weight (lbs) by Category		Price ($ US dollars)	
		Control	Experimental		Control	Experimental	Control	Experimental	Control	Experimental
	50-60	14	0	4.2	58.8	0	Discards	Discards	$0.00	$0.00
	61-70	40	15	6.54	261.6	98.1				
	71-80	108	38	9.39	1014.12	356.82				
20 - 30 $10.10/lb	81-90	257	143	12.88	3310.16	1841.84	186.15	152.99	$1,880.14	$1,545.17
	91-100	689	484	17.07	11761.23	8261.88				
	101-110	3153	2695	22	69366	59290				
10 - 20 $12.60/lb	111-120	8059	6346	27.71	223314.89	175847.66	1045.86	991.42	$13,177.90	$12,491.84
	121-130	7333	7998	34.24	251081.92	273851.52				
U12 $13.65/lb	131-140	4153	5388	41.63	172889.39	224302.44	765.28	967.53	$10,446.06	$13,206.81
	141-150	3491	4299	49.91	174235.81	214563.09				
U10 $14.05/lb	151-160	1218	1914	59.12	72008.16	113155.68	179.70	297.28	$2,524.80	$4,176.72
	161-170	129	299	69.3	8939.7	20720.7				
	171-180	7	12	80.48	563.36	965.76				
Prices from www.baseseafood.com for 23 June 2017						**Total**	**2,177.00**	**2,409.21**	**$28,028.90**	**$31,420.54**

Appendix F: Scallop Meat Quality

Table F1. The percent "gray" and "discolored" meat from the total number of scallops sampled per station from August 2015-June 2106.

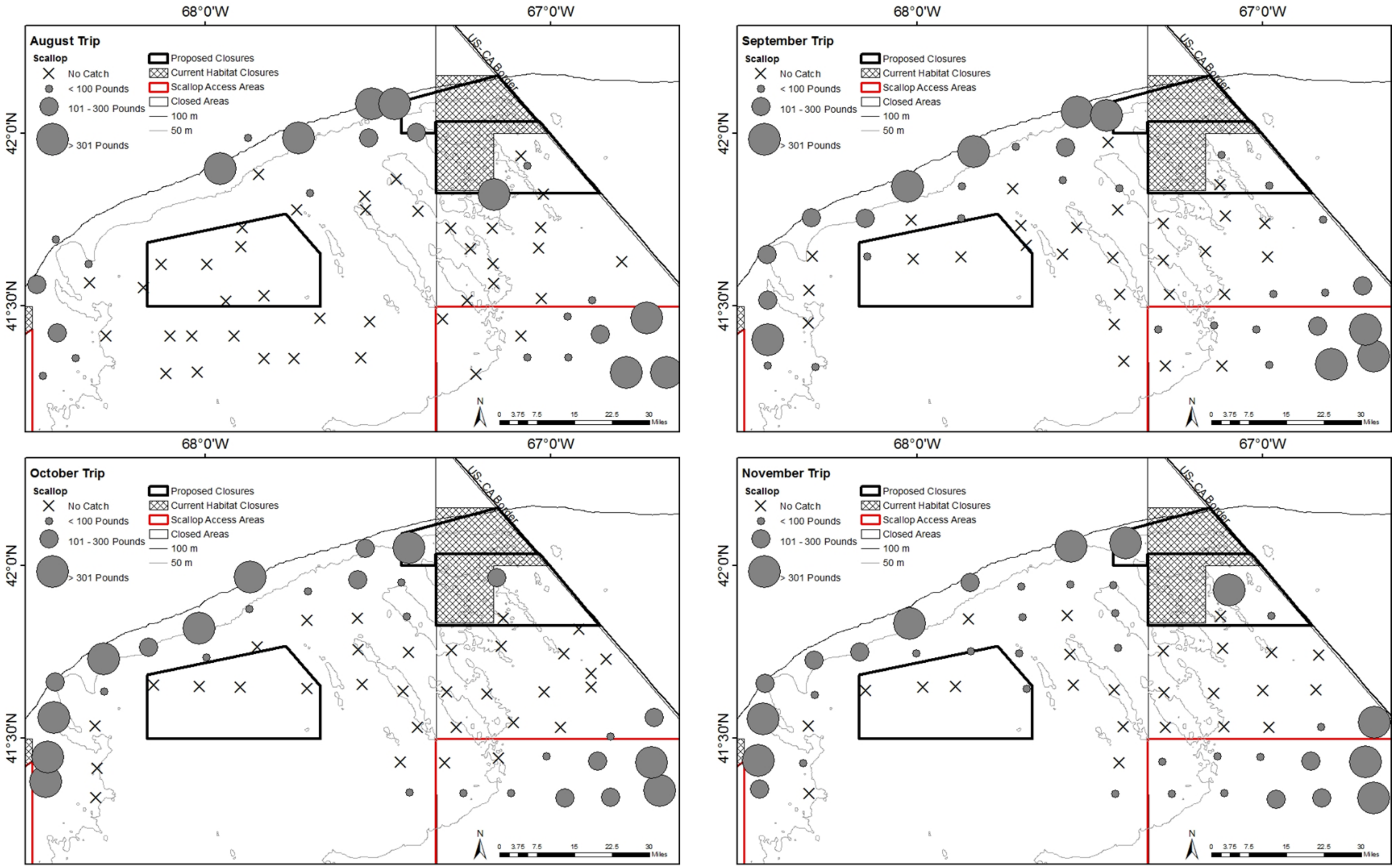
Month	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)
Aug	401	8	0.0	402	6	0.0							410	3	0.0
Sep	401	29	0.0	402	6	0.0									
Oct	401	30	0.0				408	12	8.3	409	1	0.0	410	1	0.0
Nov	401	30	0.0				408	11	9.1	409	3	33.3	410	1	0.0
Jan	401	30	0.0	402	2	0.0							410	5	0.0
Mar	401	30	0.0										410	1	0.0
May	401	30	6.7				408	11	0.0				410	3	0.0
Jun	401	30	0.0												
Aug	411	30	10.0	412	30	0.0	413	30	0.0	414	30	0.0			
Sep	411	29	17.2	412	30	0.0	413	30	0.0	414	30	0.0			
Oct	411	30	26.7	412	30	6.7	413	30	0.0	414	30	0.0			
Nov	411	30	13.3	412	30	10.0	413	30	6.7	414	29	0.0	415	1	0.0
Jan	411	30	6.7	412	30	3.3	413	30	0.0	414	17	0.0			
Mar	411	30	0.0	412	30	3.3	413	30	0.0	414	30	0.0			
May	411	30	0.0	412	30	0.0	413	30	0.0	414	30	0.0			
Jun	411	30	0.0	412	30	6.7	413	30	0.0	414	30	0.0			
Aug							424	8	0.0	425	30	6.7	426	30	0.0
Sep	422	1	0.0	423	3	0.0	424	11	9.1	425	30	3.3	426	28	3.6
Oct							424	15	0.0	425	30	20.0	426	30	0.0
Nov	422	2	0.0	423	5	0.0	424	23	17.4	425	30	3.3	426	30	0.0
Jan							424	5	0.0	425	30	3.3	426	30	0.0
Mar				423	6	0.0	424	28	0.0	425	30	0.0	426	30	0.0
May							424	11	9.1	425	30	3.3	426	30	0.0
Jun							424	3	0.0	425	31	0.0	426	30	0.0
Aug	427	30	0.0										440	5	0.0
Sep	427	30	0.0	437	1	0.0	438	4	0.0	439	30	6.7	440	30	0.0
Oct	427	30	0.0				438	30	10.0	439	30	3.3	440	30	3.3
Nov	427	30	0.0				438	6	0.0	439	30	13.3	440	30	0.0
Jan	427	29	3.4	437	3	0.0	438	16	6.3	439	30	6.7	440	30	3.3
Mar	427	30	0.0	437	1	0.0	438	9	0.0	439	30	3.3	440	30	0.0
May	427	30	0.0				438	29	6.9	439	30	0.0	440	30	0.0
Jun	427	30	0.0				438	4	0.0	439	30	0.0	440	30	0.0

Month	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)
Aug															
Sep															
Oct	441	1	0.0	441	1	0.0									
Nov	441	21	0.0	441	21	0.0							445	2	0.0
Jan															
Mar	441	1	0.0	441	1	0.0									
May							442	2	0.0	443	1	0.0			
Jun															
Aug															
Sep				454	30	0.0	455	30	0.0				457	2	0.0
Oct				454	30	0.0	455	30	0.0	456	6	0.0			
Nov				454	30	0.0	455	30	3.3	456	11	0.0	457	2	0.0
Jan				454	30	0.0	455	30	6.7	456	2	0.0	457	1	0.0
Mar	446	30	0.0	454	30	0.0	455	29	0.0				457	2	0.0
May	446	11	0.0	454	60	0.0	455	30	3.3				457	3	0.0
Jun				454	30	0.0	455	30	0.0						
Aug															
Sep													464	3	0.0
Oct							460	1	0.0						
Nov	458	1	0.0				460	1	0.0						
Jan															
Mar				459	4	0.0	460	1	0.0	462	3	0.0			
May				459	1	0.0	460	1	0.0						
Jun															
Aug	469	30	0.0	470	4	0.0									
Sep	469	30	0.0	470	8	0.0				472	9	44.4	473	17	47.1
Oct	469	30	3.3	470	4	0.0							473	7	42.9
Nov	469	30	0.0				471	4	0.0				473	15	13.3
Jan	469	30	0.0	470	17	0.0				472	6	16.7	473	8	25.0
Mar	469	30	0.0							472	4	0.0	473	2	0.0
May	469	30	0.0	470	29	0.0							473	13	15.4
Jun	469	30	0.0	470	25	0.0							473	1	0.0
Aug				483	30	0.0	484	30	3.3	485	30	6.7	486	30	0.0
Sep	476	1	0.0	483	30	0.0	484	11	0.0	485	30	40.0			
Oct				483	30	0.0	484	4	0.0	485	30	36.7	486	13	0.0
Nov	476	1	0.0	483	30	0.0	484	13	0.0	485	30	50.0	486	8	0.0
Jan				483	30	0.0	484	15	0.0	485	30	26.7	486	13	0.0
Mar				483	30	0.0	484	30	0.0	485	30	0.0	486	26	0.0
May				483	30	0.0	484	3	0.0	485	30	3.3	486	4	0.0
Jun	476	2	0.0	483	30	0.0	484	2	0.0	485	30	10.0	486	2	0.0

Month	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)	Station	Total Scallops Measured	Scallops With Gray Meat (%)
Aug	488	30	30.0	498	30	0.0	499	31	0.0
Sep	488	18	11.1	498	30	0.0	499	30	3.3
Oct	488	30	33.3	498	29	6.9	499	30	3.3
Nov	488	30	13.3	498	30	0.0	499	30	0.0
Jan	488	30	33.3	498	30	0.0	499	30	3.3
Mar	488	28	35.7	498	30	0.0	499	30	0.0
May	488	30	13.3	498	30	0.0	499	30	0.0
Jun	488	4	0.0	498	30	0.0	499	30	0.0

Note: "Gray" meat includes meat reported as gray or brown in color.
Empty cells denote months where no scallops were caught at that station.

Appendix G: Distribution of scallops and the main bycatch species



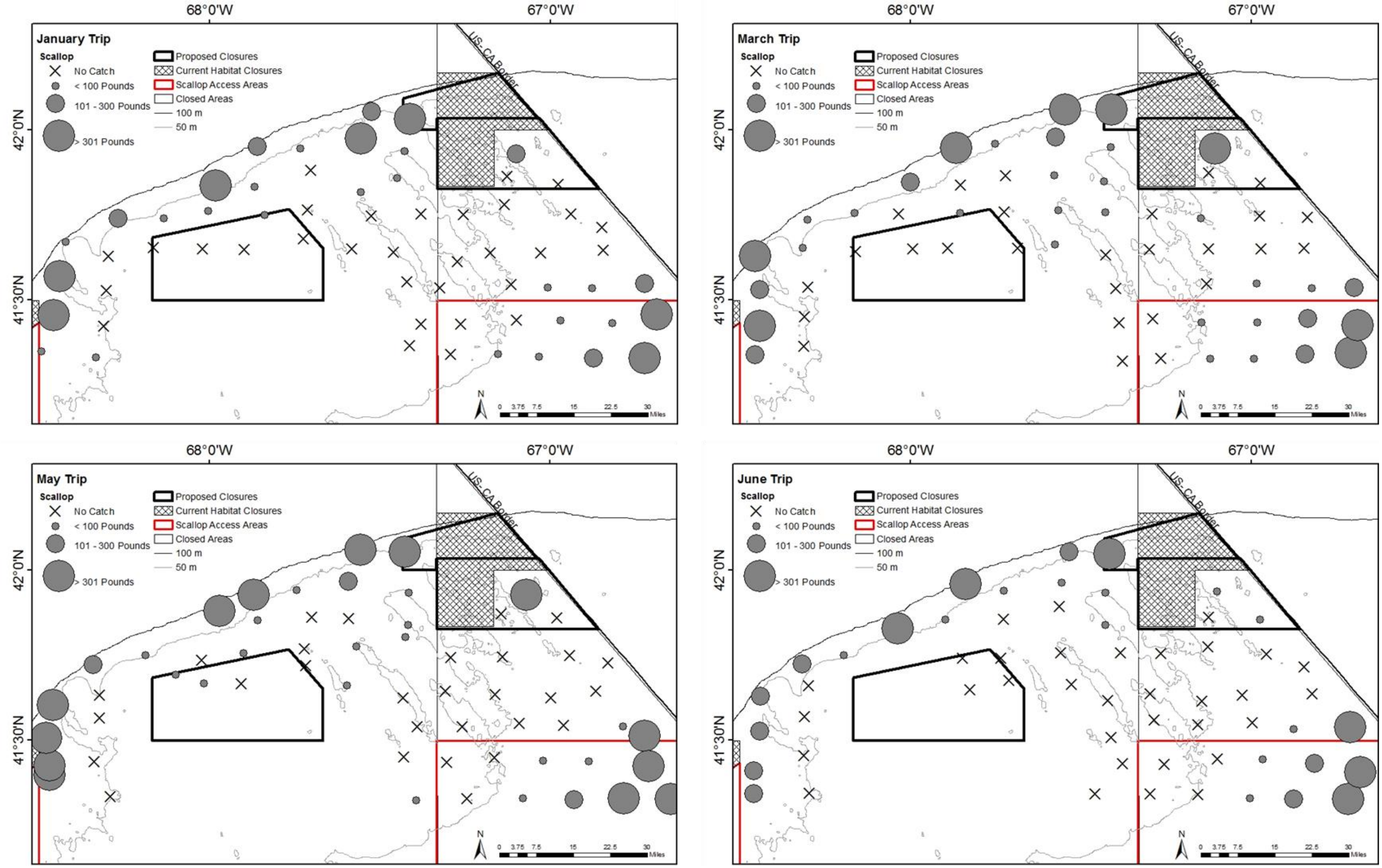
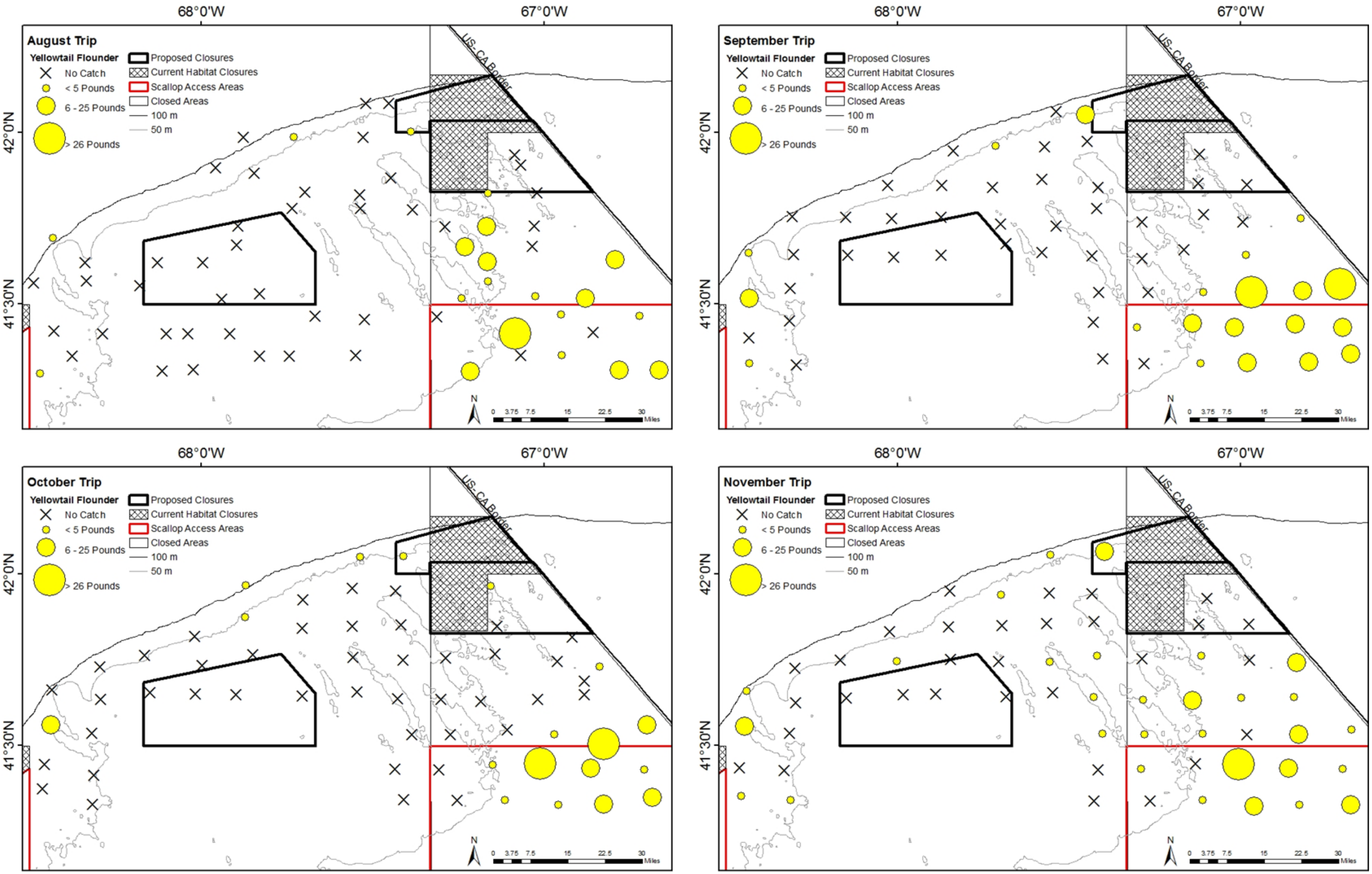


Figure G1. Distribution of scallops during the 2015 seasonal bycatch survey on the northern portion of Georges Bank. Red dots are reported Lobster Buoys.


68°0'W
67°0'W
42°0'N
41°30'N
August Trip
Yellowtail Flounder
No Catch
< 5 Pounds
6 - 25 Pounds
> 26 Pounds
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
October Trip
November Trip

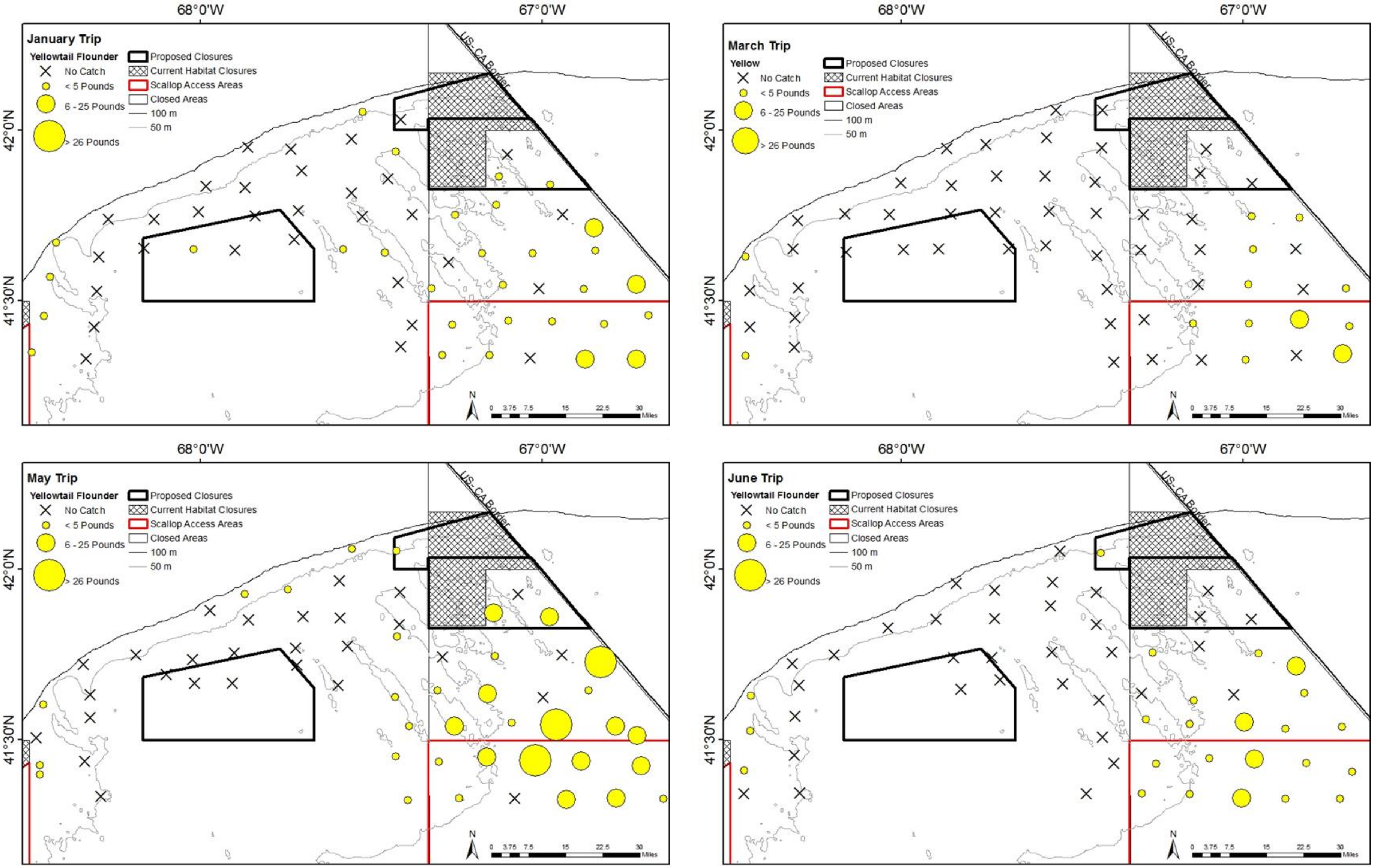
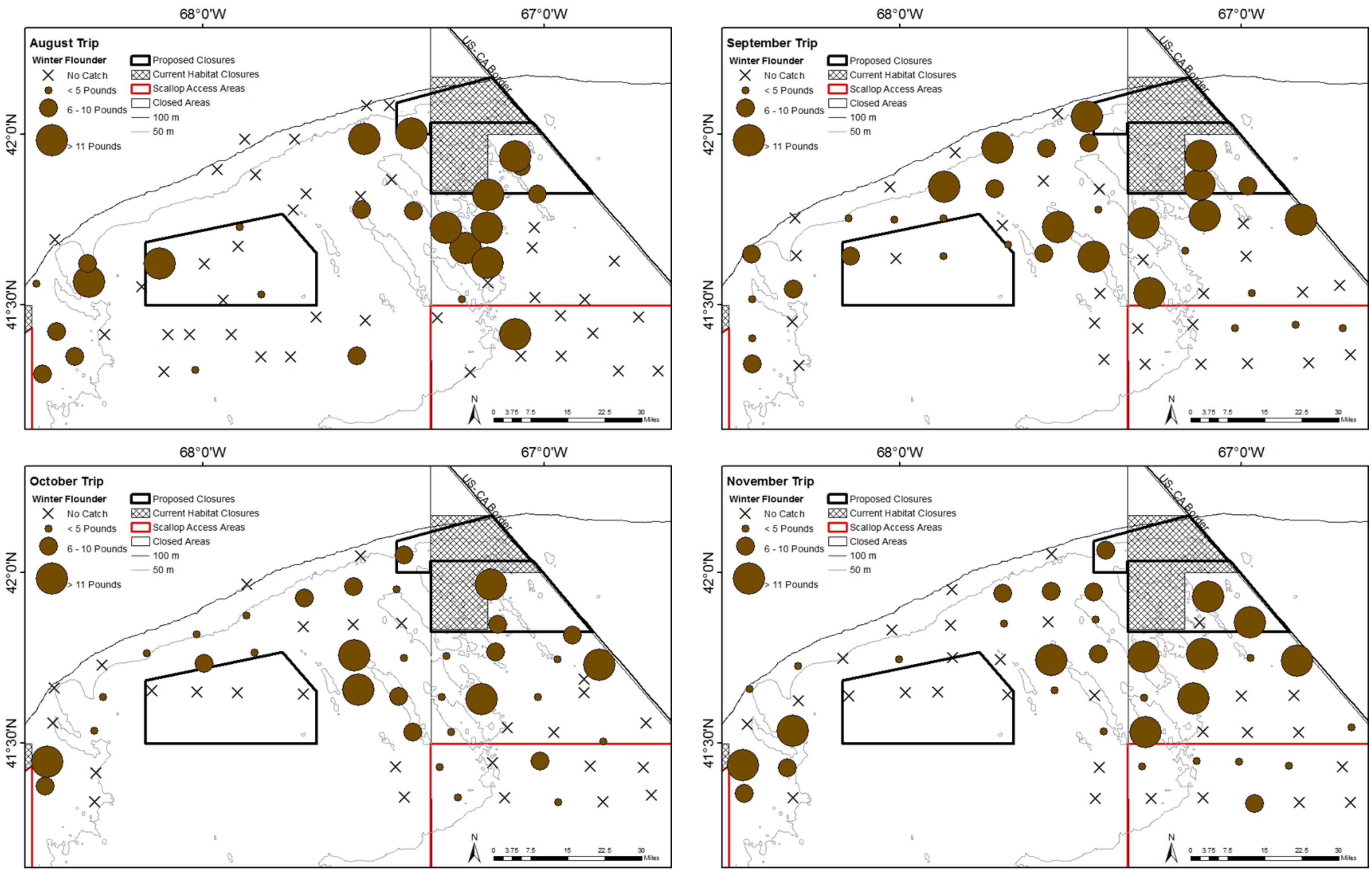


Figure G2. Distribution of yellowtail flounder during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.



August Trip
September Trip
October Trip
November Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
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

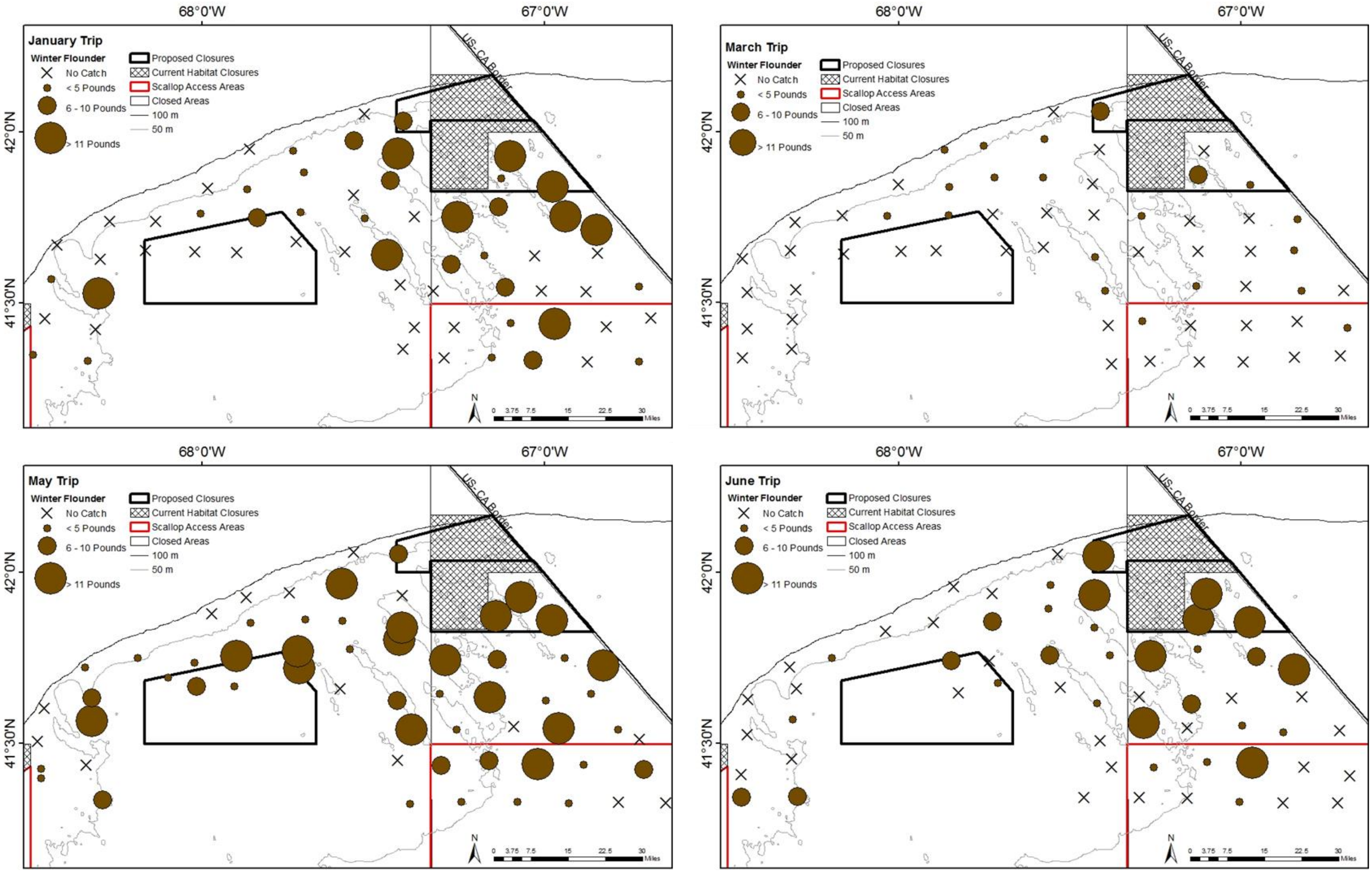
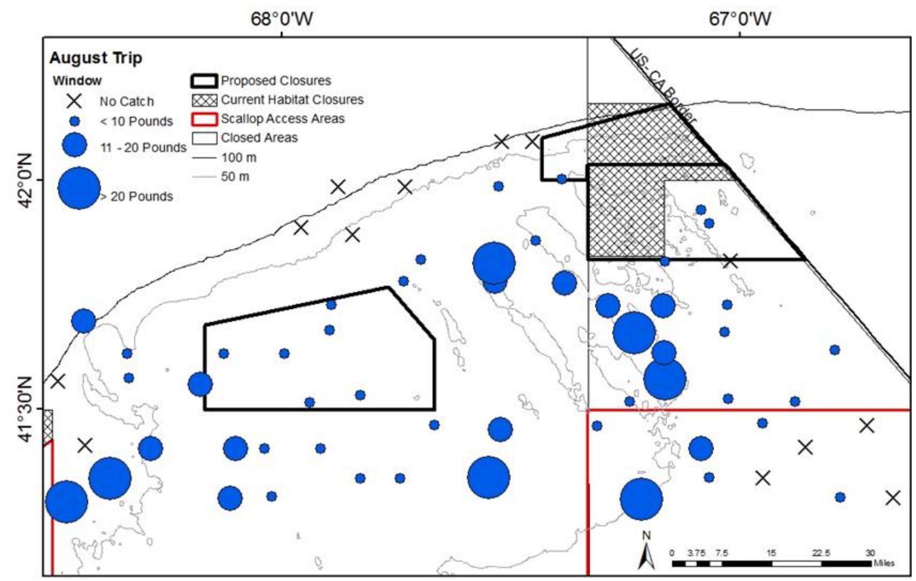
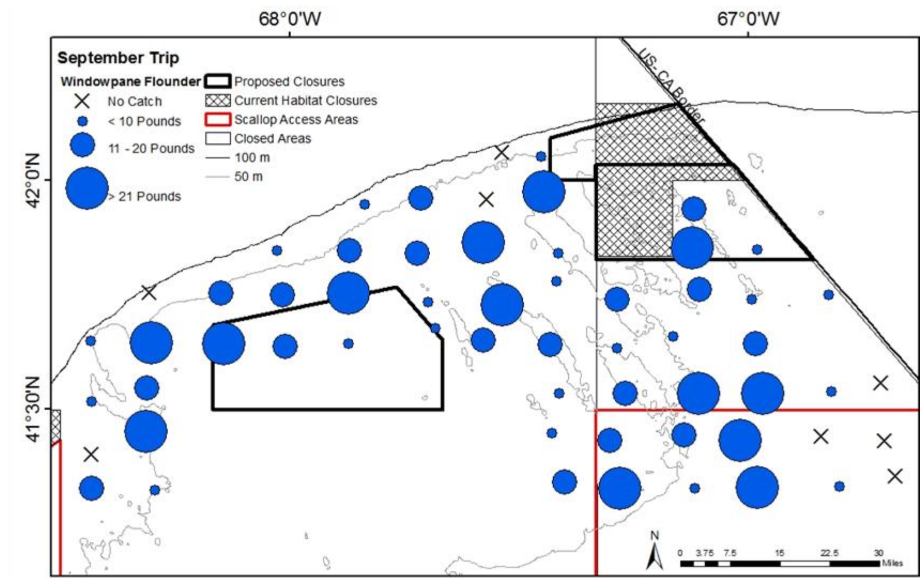
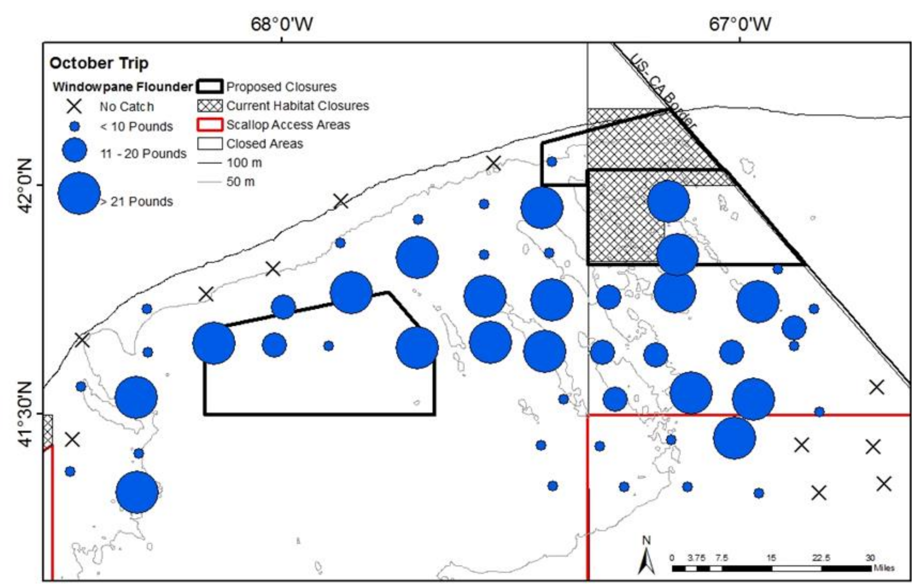
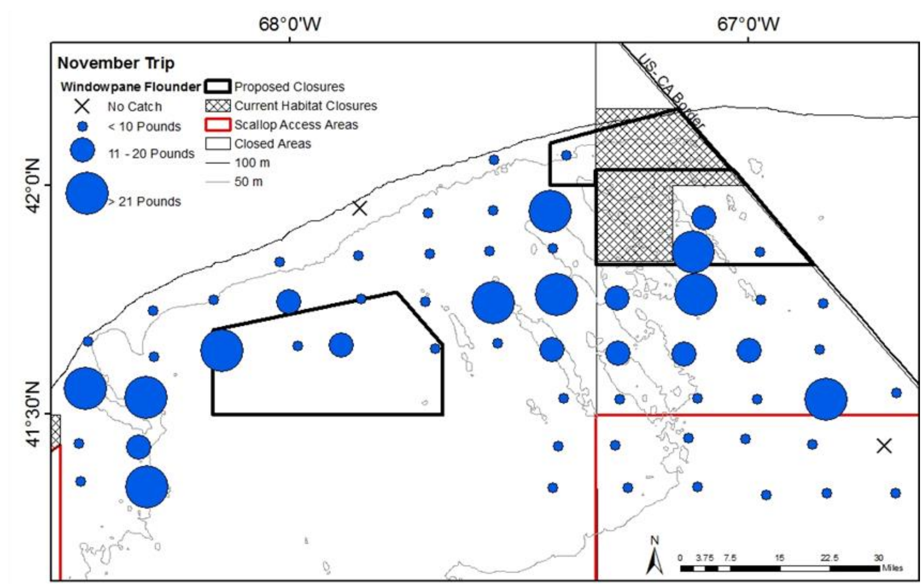


Figure G3. Distribution of winter flounder during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.


68°0'W
67°0'W
August Trip
Window
No Catch
< 10 Pounds
11 - 20 Pounds
> 20 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
42°0'N
41°30'N
N
0 3.75 7.5 15 22.5 30
Miles


68°0'W
67°0'W
September Trip
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
42°0'N
41°30'N
N
0 3.75 7.5 15 22.5 30
Miles


68°0'W
67°0'W
October Trip
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
42°0'N
41°30'N
N
0 3.75 7.5 15 22.5 30
Miles


68°0'W
67°0'W
November Trip
Windowpane Flounder
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
US-CA Border
42°0'N
41°30'N
N
0 3.75 7.5 15 22.5 30
Miles

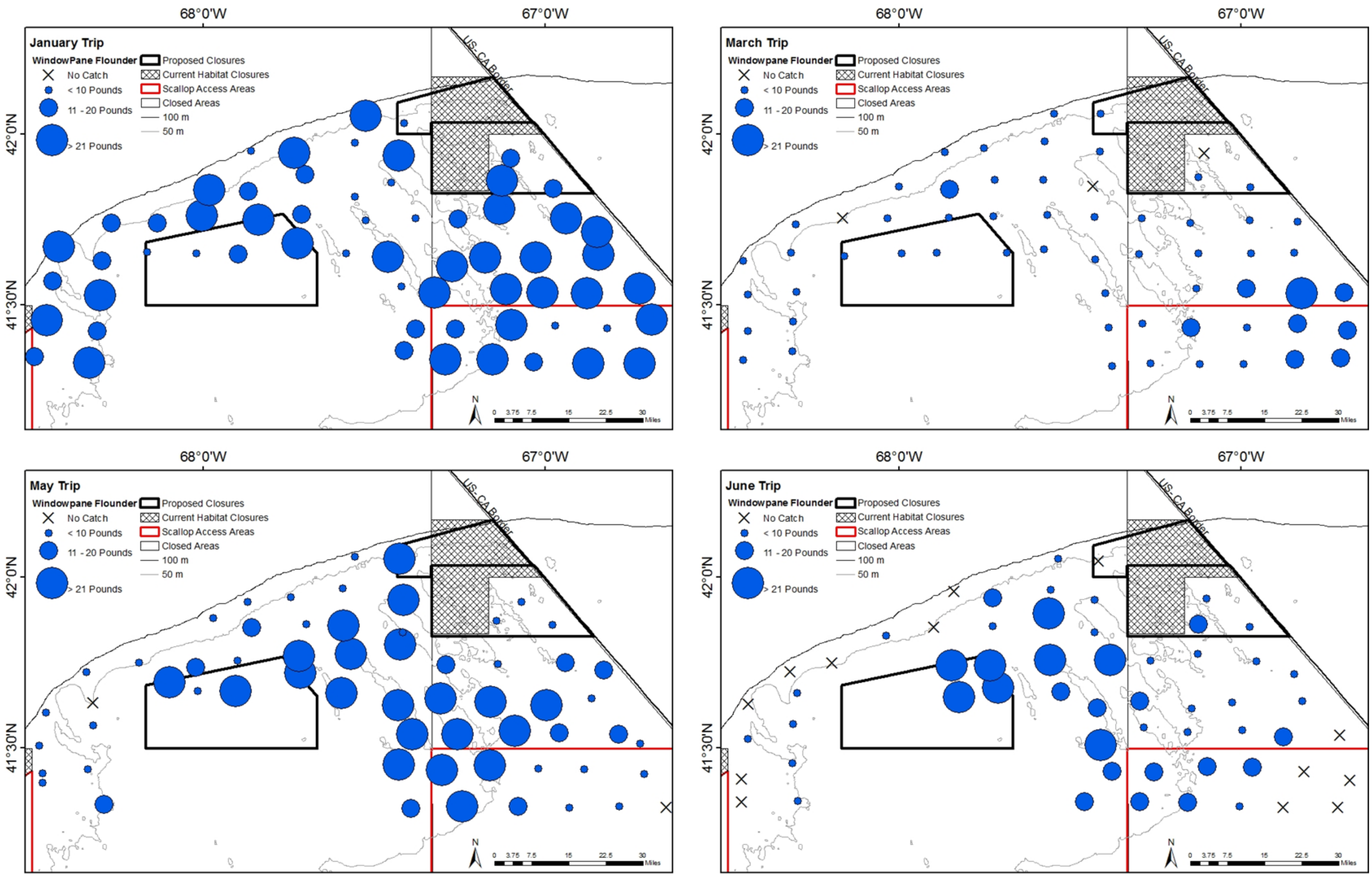
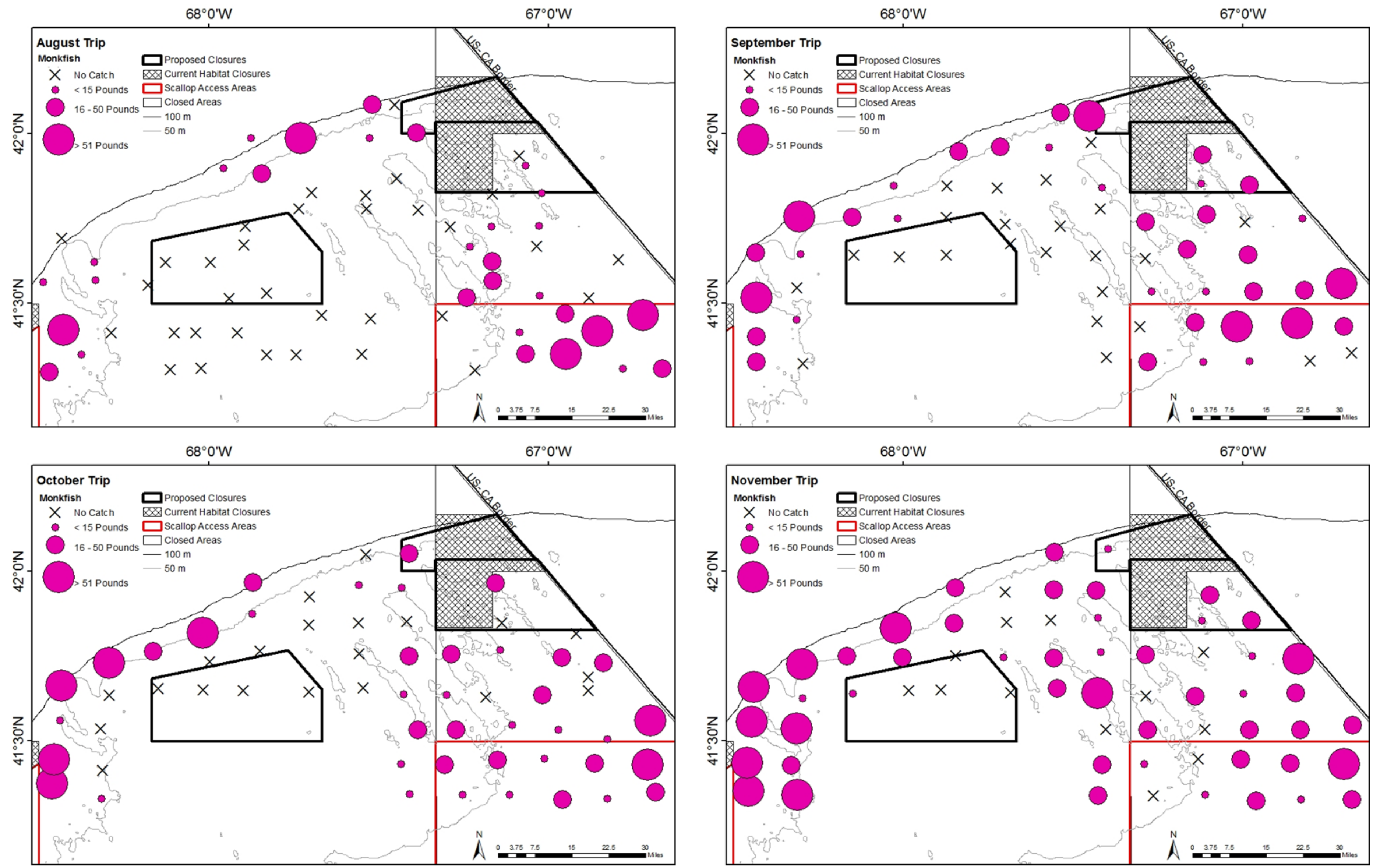


Figure G4. Distribution of windowpane flounder during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.



68°0'W
67°0'W
42°0'N
41°30'N
August Trip
September Trip
October Trip
November Trip
Monkfish
No Catch
< 15 Pounds
16 - 50 Pounds
> 51 Pounds
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

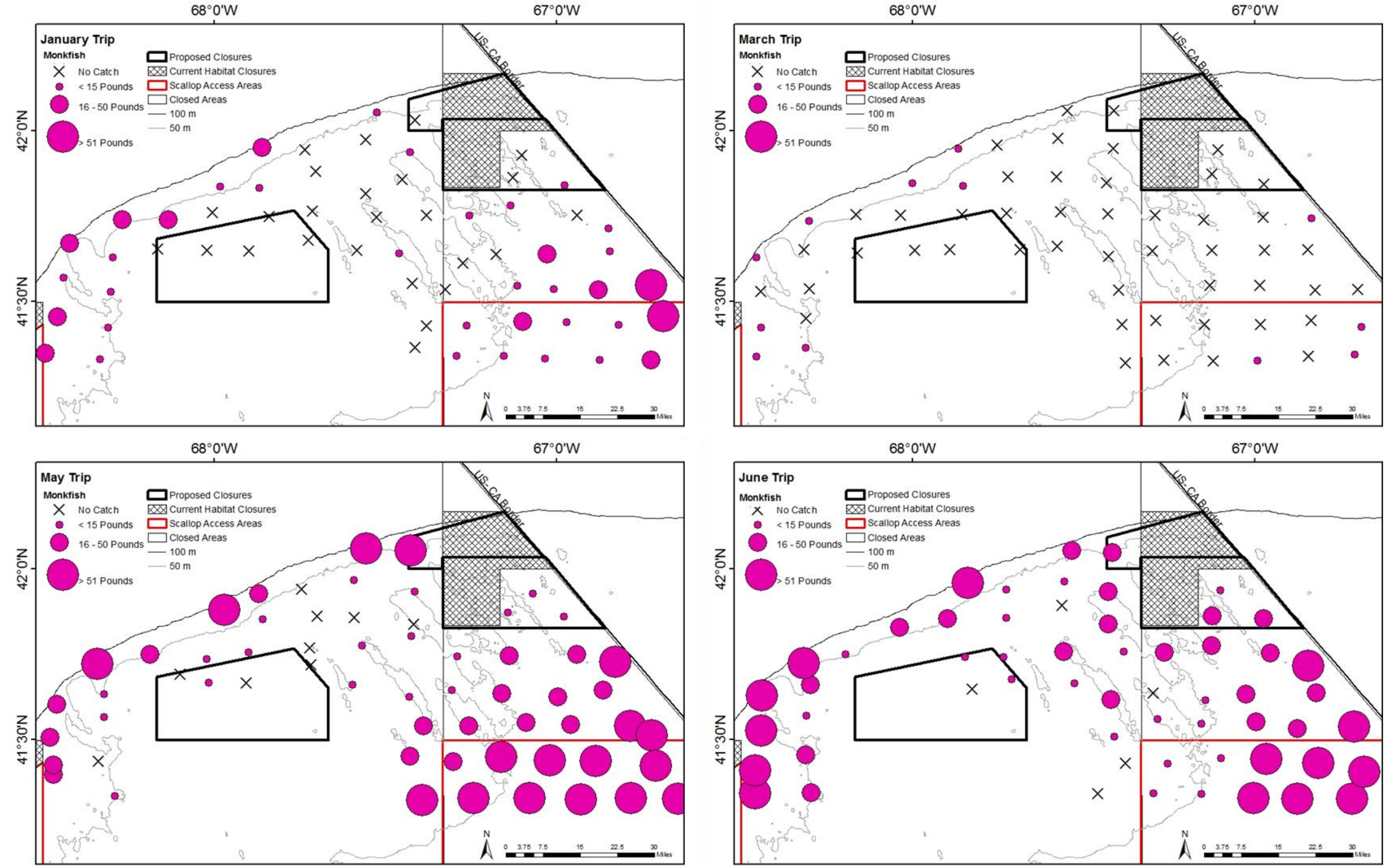
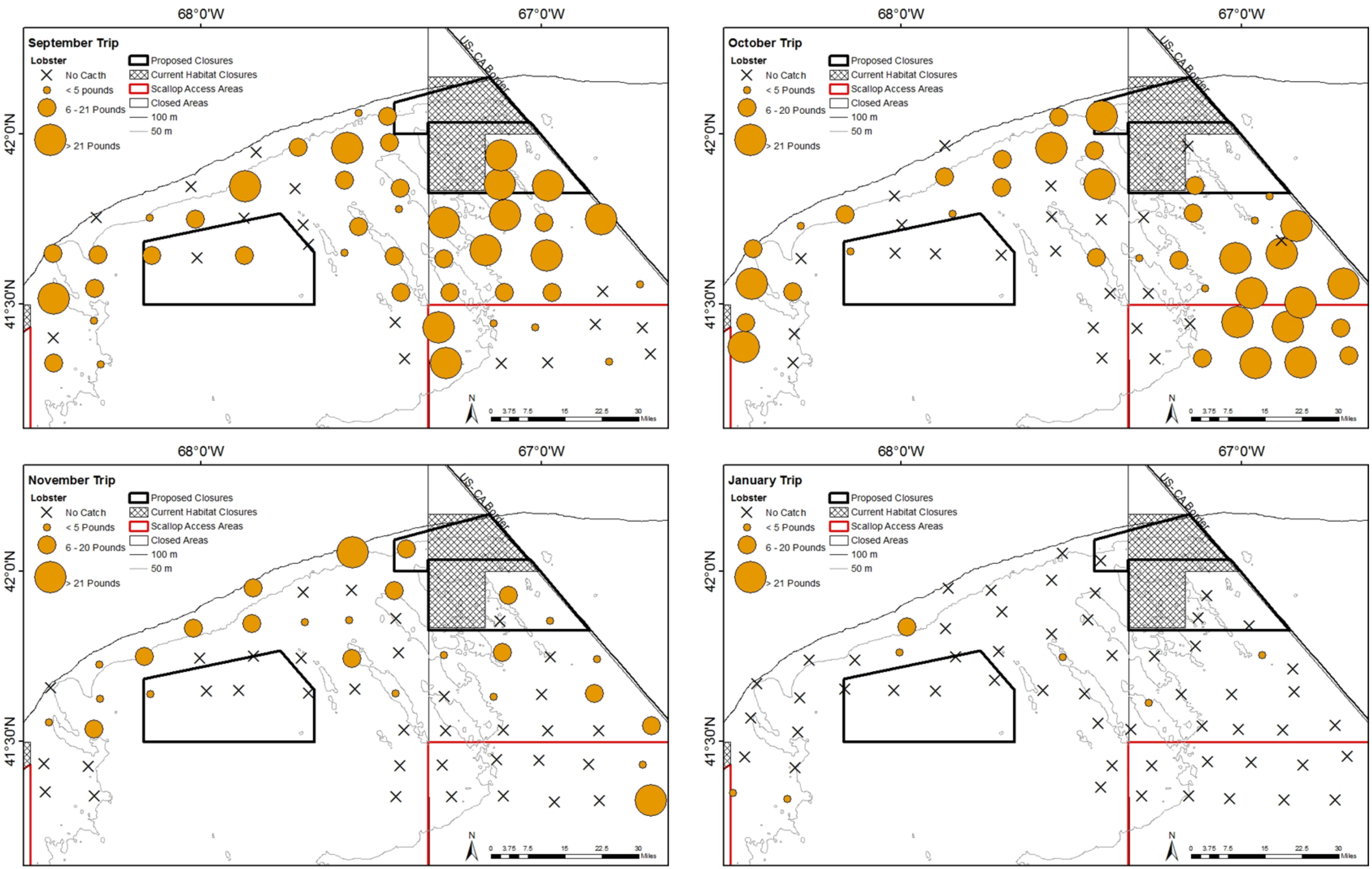


Figure G5. Distribution of monkfish during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.



68°0'W
67°0'W
42°0'N
41°30'N
US-CA Border
September Trip
Lobster
No Cacth
< 5 pounds
6 - 21 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
October Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
November Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
January Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Proposed Closures
Current Habitat Closures
Scallop Access Areas
Closed Areas
100 m
50 m
N
0 3.75 7.5 15 22.5 30 Miles

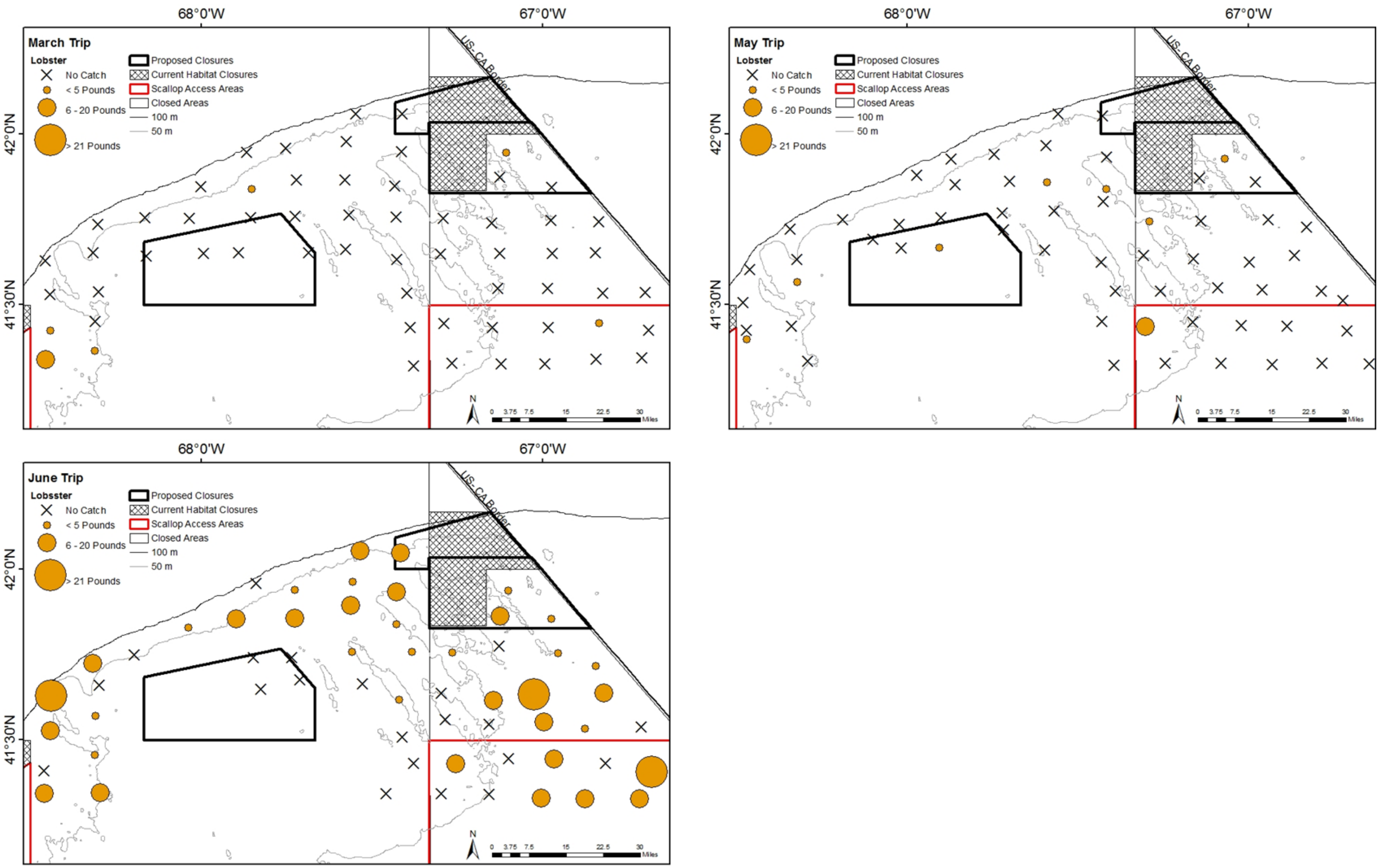


Figure G6. Distribution of lobster during the 2015 seasonal bycatch survey on the northern portion of Georges Bank.