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

## Final Report

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## EXECUTIVE SUMMARY

This report presents data and analysis from funding year 2017-2018 for the Coonamessett Farm Foundation (CFF) seasonal bycatch survey on Georges Bank. This bycatch survey has been conducted since October 2010 and has been modified and adapted to address current management concerns. The surveys operate with a fixed grid design, and tow parameters have been standard since 2010. From 2010 until 2014, survey stations were located in the scallop access areas in Closed Area I (CAI) and Closed Area II (CAII). Beginning in 2015, the survey stations were moved to the northern portion of Georges Bank, covering the northern half of CAII (not currently open for the scallop fishery) and open areas to the west. The current sampled area is located in the eastern part of Georges Bank covering CAII and open areas to the west and south.

This year the project goals and objectives were:

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 industrial dredge with an extended link bag configuration, designed to reduce flatfish bycatch and small individuals, with the standard CFF dredge.
3. Collect biological samples to examine conditions affecting scallop meat quality.
4. Collect biological samples to identify seasonal changes in reproductive cycles and spawning aggregations of scallops and key fish species.
5. Conduct biological sampling of American lobster caught in the dredge to assess shell hardness, presence of eggs, shell disease symptoms, and damage due to the dredge.

During each dredge survey trip, the paired dredge catch data was processed on board the vessels. Scallop and bycatch species catch was quantified (i.e., counts, weights, and lengths), with particular focus on important bycatch species including yellowtail flounder, windowpane flounder, winter flounder, and lobster. Samples were collected to assess scallop meat quality and disease presence in scallops and yellowtail flounder.

During the 2017-2018 project year, scallop meat weight peaked in October and February. The bycatch rates for the three flounders listed above, monkfish, and lobster were low, primarily because scallop catch was high. Yellowtail and winter flounder bycatch rates were less than 0.1 lbs. of fish/lb. of scallops. Windowpane and lobster bycatch rates were less than 0.4 lbs. of fish/lb. of scallops. Monkfish bycatch rates were the highest in this year's project (> 1 lbs. of fish/lb. of scallops), except during the month of February (< 0.2 lbs. of fish/lb. of scallops).

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 this year's project, we tested extended link aprons on non-standard industry dredges supplied by participating vessels against a CFF TDD with a 7-row apron. Analysis of the paired catch data suggested that the extended link apron may be an effective gear modification for reducing flatfish bycatch, but with a reduction in scallop catch as well. Continued testing of this dredge modification will be done during other CFF projects focused on gear design to provide more substantial results about the utility of the extended link apron.

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

Significant work was also done to analyze spatiotemporal patterns in catch data and temporal patterns in fish and scallop reproductive stages. We observed high numbers of windowpane flounder across the entire sampling area, with catches peaking in January, primarily in CAII. Monkfish was the most abundant fish species with the highest catch in September, while catches of yellowtail flounder and winter flounder were low overall.

The CFF seasonal bycatch survey continues to provide a wealth of data that can be used to address a wide range of issues that impact the ecosystem on Georges Bank. The long-term seasonal data set is unique. As such, it has been used to evaluate populations of multiple commercial fish species, supplying fisheries managers with critical information required to adhere to Annual Catch Limits (ACLs) and devise Accountability Measures (AMs) to optimize the harvest of scallops while minimizing bycatch. As new issues arise, the bycatch survey has adapted. Recently, the scallop industry has become concerned about the observed distribution and magnitude of poor-quality scallops, and there has been increasing interest in using the bycatch survey data as a time series. The value of the project would be increased if it could provide a long-term seasonal data set that could be more effectively used to continue the seasonal monitoring of important bycatch species and better understand the dynamic of the diseases in scallops over time on Georges Bank,. Therefore, we hope to begin incorporating a set of fixed stations that would remain constant each year as the seasonal bycatch project continues.

## INTRODUCTION

One of the most successful and economically valuable fisheries in the world is the wild Atlantic sea scallop (*Placopecten magellanicus*) fishery along the eastern coast of the United States (US), which brought in $486,202,680 in 2016 (NOAA 2016). The stock has been rebuilt from its overfished status in 1997, and no overfishing is occurring (NEFMC 2014). However, this profitable fishery is impacted by fish bycatch issues resulting in the potential loss of millions of dollars in revenues. Yellowtail (*Limanda ferruginea*) and windowpane (*Scophthalmus aquosus*) flounder ACLs and AMs have created a complex regulatory environment for the scallop fishery. Triggering the yellowtail flounder AM on Georges Bank results in scallop fishing area restrictions across eastern Georges Bank (NEFMC 2016), and time/area closures and gear restrictions are currently being considered to minimize windowpane flounder bycatch (NEFMC 2016).

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

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

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

Despite efforts to minimize bycatch, yellowtail and windowpane flounder quotas continue to impact the scallop fishery. The allocation of Georges Bank yellowtail flounder to the scallop fishery was substantially reduced in 2015 based on results from the 2016 Georges Bank yellowtail flounder assessment by the Transboundary Resource Assessment Committee (TRAC) (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. During the most recent TRAC meeting, allocation of yellowtail flounder to US fisheries was reduced overall, further increasing concerns (Barrett and Brooks 2018).

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

Finally, disease is often overlooked or dismissed as a cause of decreased or decreasing populations in marine animals (Grimm *et al*. 2016). CFF's seasonal survey collects data on two scallop and one yellowtail flounder diseases. Scallop meat is normally firm and creamy-white. However, when scallop diseases cause poor quality meat, fishermen have to discard them, which leads to low meat yield and subsequent economic losses for the fishery. Gray meat and orange nodules in the adductor muscle have occasionally been detected in our surveys. These diseases have been associated with an apicomplexan parasite (Inglis *et al*. 2016) and *Mycobacterium* sp. infections (Grimm *et al*. 2016), respectively. An apicomplexan parasite may be responsible for the total collapse of the Iceland scallop (*Chlamys islandica*) stock around Iceland (Kristmundsson *et al*. 2015), and *Mycobacterium* spp. are considered pathogenic in humans (Grimm *et al*. 2016). Until recently, it was believed that an apicomplexan parasite was highly pathogenic, and once scallops showed clinical signs of gray meat disease (e.g., gray color, stringy adductor muscle), they would eventually die (Levesque *et al*. 2016).

Yellowtail flounder have 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 a significant lack of evidence about the real impact of these three different diseases on scallops and yellowtail flounder on Georges Bank, and the regular seasonal collection of scallop and fish tissue samples during the bycatch project has been invaluable for studying all three 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 industrial dredge with an extended link bag configuration, designed to reduce flatfish bycatch and small individuals, with the standard CFF dredge.
3) Collect biological samples to examine conditions affecting scallop meat quality.
4) Collect biological samples to identify seasonal changes in reproductive cycles and spawning aggregations of scallops and key fish species.
5) Conduct biological sampling of American lobster caught in the dredge to assess shell hardness, presence of eggs, shell disease symptoms, and damage due to the dredge.

## GENERAL SAMPLING METHODS

### Study area

Georges Bank, located off the New England coast, supports many valuable commercial fisheries, including the largest wild scallop fishery in the world (Caddy 1989). Georges Bank has two areas (CAI and CAII) that were closed to all mobile bottom-tending gears in 1994 in order to protect declining groundfish stocks. Scallop vessels were granted seasonal access to portions of these closed areas in 1999. The northern part of CAII includes a Habitat Area of Particular Concern (HAPC) to protect juvenile cod. For the 2017 seasonal bycatch survey, eight research trips were conducted on Georges Bank (**Table 1**). The initial plan was to sample across CAII, including within the Georges Bank northern edge HAPC, but the final survey did not include stations in the HAPC due to permit restrictions. The finalized grid, consisting of 49 stations across the rest of CAII and just outside its boundaries, was sampled every other month with additional trips in September and January. The last two years of seasonal bycatch projects were on the northern portion of Georges Bank, but starting in August 2017, stations were shifted to the eastern portion of Georges Bank. The start position for each station was randomly selected prior to each trip using four points 0.25 miles away from the station position (**Figure 1**).

**Table 1.** Trip dates and vessels used for the 2017 bycatch survey.

| Month | Trip dates | Vessel Name |
|---|---|---|
| August | 16 Aug – 22 Aug 2017 | F/V Endeavor |
| September | 06 Sep – 12 Sep 2017 | F/V Atlantic |
| October | 11 Oct – 17 Oct 2017 | F/V Polaris |
| December | 14 Dec – 20 Dec 2017 | F/V Vanquish |
| January | 10 Jan – 16 Jan 2018 | F/V Blue North |
| February | 21 Feb – 28 Feb 2018 | F/V Liberty |
| April | 11 Apr – 17 Apr 2018 | F/V Regulus |
| June | 05 Jun – 11 Jun 2018 | F/V Blue North |

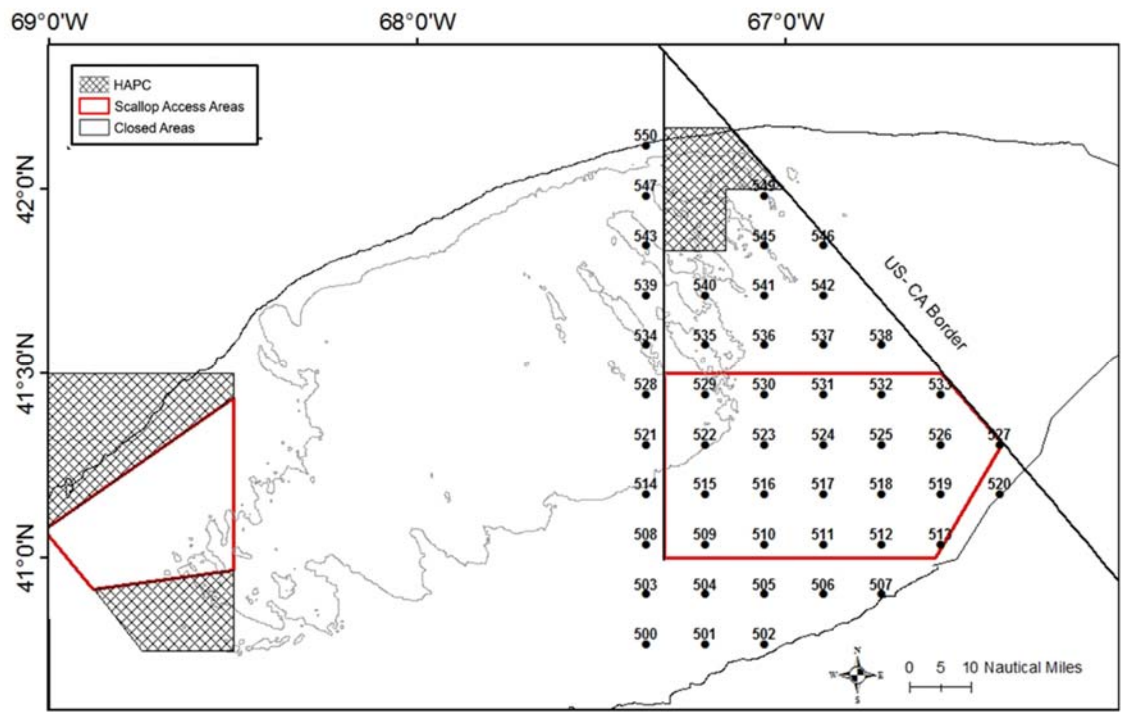



**Figure 1.** Location of the survey stations sampled for the 2017 seasonal bycatch survey on the eastern portion of Georges Bank. The HAPC is shown as hashed lines and scallop access areas and the Hague line are shown in black. Stations are separated by ~13 km.

## Sampling design

At each station, a control and an experimental dredge 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. The control dredge was, in every case, a turtle-deflector dredge (TDD) with a 7-row apron, while the experimental dredge was supplied by the vessel. Therefore, during every trip the experimental dredge had different specifications (**Table A1; Appendix A**). The original project proposed testing an experimental dredge with a 5-row apron and a 1.5:1 twine top hanging ratio against a standard CFF TDD. However, CFF has tested the 5-row apron for over five years, and its success has already been demonstrated by its incorporation into regulation. Therefore, the decision was made to deviate from the proposed plan and gather more data on another promising modification, the extended link apron that has been previously tested during dedicated CFF gear projects (Davis et al. 2018; Davis and Siemann 2017). This modification consists of joining the steel rings together with two interconnected links (**Figure 2**), increasing the inter-ring spacing of the apron and thereby increasing mechanical sorting, which in theory could facilitate the escape of fish and small scallops.

Target tow duration was 30 minutes, with a minimum tow time of 20 minutes if there were technical difficulties. Stations were resampled if the tow parameters were not followed or if there was a gear malfunction (e.g. dredges fishing upside down). Tow direction was at the discretion of the captain, who was instructed to pass through the station's central coordinates at some point during the tow. Tow start and end, defined as when the winches were locked or engaged for haul back, were determined by the captain. Tow parameters were recorded using a Getac F110 ruggedized tablet with a custom access database. Vessel position, speed, and heading were recorded every 15 seconds using the built-in GPS on the Getac tablet. Two Lotek data loggers were deployed in steel sheaths welded to the control dredge to record depth and temperature throughout the survey, with one logger set to record every 30 seconds and the other set to record every second.

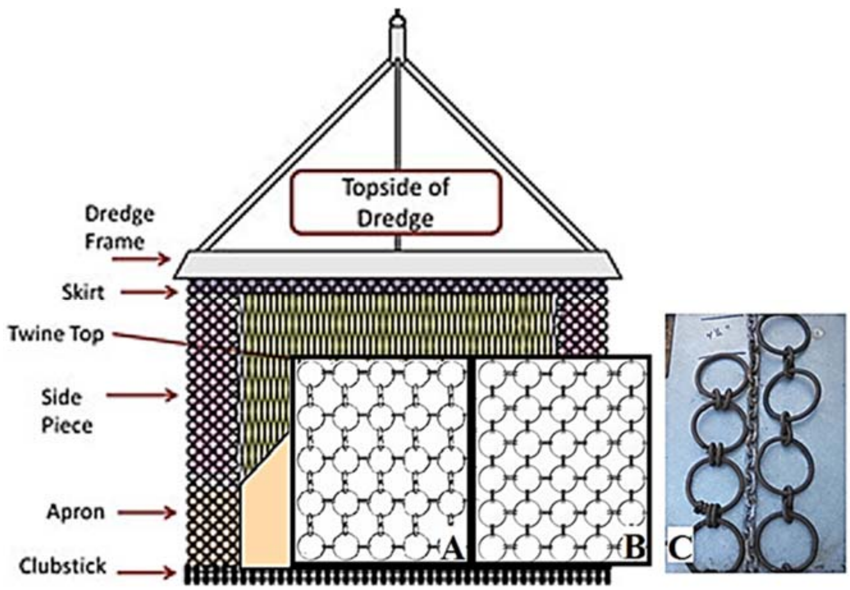



**Figure 2.** Diagram of the topside of a dredge illustrating the difference between **A)** an extended link apron and **B)** a standard linked apron. **C)** Chain or shackles are used to connect standard linked portions of the bag to the extended link.

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." **Table A2** lists all species that were caught by common and scientific name, number captured, and the sampling protocol used.

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

The entire scallop catch was quantified in bushels (bu=35.2 liters). A one-bushel subsample of scallops was selected at random from each dredge, and shell height was measured in 5-mm increments. At each station, 30 scallops (or fewer if the total catch < 30 scallops) were randomly selected to determine shell height, meat weight, gonad weight, sex, reproductive stage, quality of the meat, and presence of orange pustules. These scallops were measured to the nearest millimeter from the umbo to the shell margin then carefully shucked. Meat quality was assessed on a qualitative color scale (**Figure 3**). A subsample of scallop meats of different colors was collected for further laboratory evaluation (half in 10 % formalin and the other half in 95% ethanol). Each animal was also examined for the presence of orange nodules, and if nodules were present, two separate tissue samples were collected, one in 10 % formalin and the other in 95% ethanol, for laboratory processing. White meat scallops with no noticeable nodules were also collected following the same procedure with clean equipment as controls.

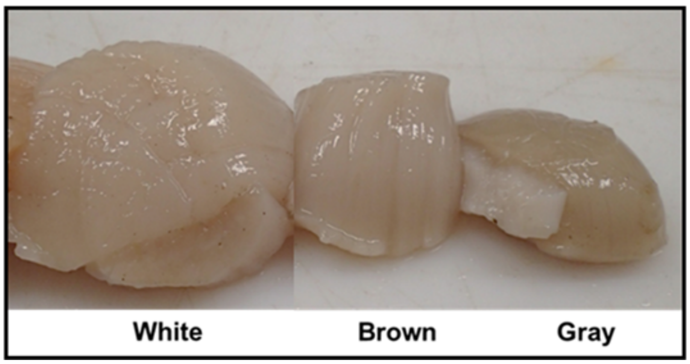



**Figure 3.** Image showing the qualitative scale used to classify scallops by meat color. Scallops with brown/gray meat show muscle degeneration. Scallops with salmon and white meats were combined.

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

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

| Valid Damage | Damage Description | Category of damage |
|---|---|---|
| 0 | No damage | **No Damage** |
| 1 | Missing an appendage, chipped carapace, (90% chance of survival) | **Moderate Damage** |
| 2 | Moderate damage to shell, slow response after 10 minutes observation (70% chance of survival) | |
| 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 and ethanol were processed in the Aquatic Diagnostic Laboratory at Roger Williams University laboratory (RWU ADL). Animals were selected for this analysis based on the color of the muscle tissue (white to gray) and the occurrence of any visible orange nodules in the muscle or brownish linear discolorations. 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) and macrogametes, and overall cellularity of the muscle (Levesque *et al*. 2016). Muscle condition was determined and reported on a scale of 0 to 3 (0 = normal, 1 = mild, 2 = moderate, and 3 = severe), with scores reflecting the degree of muscle thinning. 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, and 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. Second, adductor muscles were evaluated for the occurrence and severity of mycobacterial granulomas. Third, linear tracts were examined and described along with the occurrence of larval worms (if noted histologically).

Finally, an improved PCR test method using a new DNA extraction kit was developed for this project to detect the presence of the apicomplexan parasite in the meats. As reported last year, the biggest hurdles in developing a PCR method were 1) incorrect PCR methods published by Kristmundsson et al. (2011) that had to be identified and then adjusted, and 2) an incorrect positive control provided by collaborators for development of the test (the wrong parasite was sent as a positive control). However, the RWU ADL was able to develop an appropriate PCR method with a modification in the protocol and by using heavily infected adductor muscles collected by CFF as a positive control (Mastrostefano 2018). The RWU ADL laboratory continues to develop a sensitive and specific test for the protozoan parasite now identified as *Merocystis kathae* (Kristmundsson and Freeman 2018). The test method is working, but it still needs refinements to eliminate false negatives. The use of a new method of DNA extraction this year has proven to be more sensitive than the method reported on previous years (i.e. we are better able to detect the parasite in the muscle). Further development of methods for dissolving the muscle are underway. The new method uses a bead homogenizer, so that more adductor muscle can be homogenized and used as a basis for extraction. This is important since the location of the parasite in mildly infected animals is spotty and using more tissue in the method will increase detection accuracy.

Yellowtail *Ichthyophonus* examination: Tissues were sampled from animals depending on the gross lesions observed in the liver of the fish. *Ichthyophonus* (Huntsberger *et al*. 2016) usually presents macroscopic lesions different from those resulting from parasite infection by ascarid or cestode larvae. Selection of tissues for examination this year were based on gross observations. Few animals with lesions characteristic for *Ichthyophonus* were noted, so few tissues were collected. All tissues collected were preserved in neutral buffered formalin and processed making sure to include the grossly observed lesions in the selected tissue section. Tissue sections were processed in paraffin and stained with hematoxylin and eosin (Howard *et al*. 2004). Histological sections were examined for the occurrence of *Ichthyophonus* as well as any other lesions noted.

**Data analysis**

<u>Shell height-meat weight (SHMW) relationship</u>: A generalized linear mixed model (GLMM) with a gamma distribution (log link using PROC GLIMMIX on the SAS system v. 9.2) was developed to estimate scallop meat weights using shell height and a suite of additional variables (**Appendix D**). This mixed modeling approach uses likelihood-based estimation that has multiple advantages to traditional approaches using least squares regression of the linearized data (i.e. lnMW*lnSH). Some advantages of the mixed modeling approach are the ability to define the underlying distribution of the data. The gamma distribution used in this analysis is generally considered a more appropriate distribution for data of this type. This modeling approach also avoids the bias involved with back-transformations from log-linear models. In addition, incorporating a random effect in the model accounts for random variation in the data that can occur as a result of both temporal and fine scale spatial variability. The station grouping variable consists of a unique identifier that relates to the cruise (temporal identity) and spatial location of the sample. Akaike information criterion (AIC) values were used to select the best model configuration.

**Table 3** shows the suite of possible predictor variables used in the analysis as well as applicable descriptive statistics. The samples were spatially segregated into two areas. The delineation of the areas was based upon the current scallop and habitat relevant boundaries of Closed Area II (i.e. CAII, NON-CAII). Potential biologically relevant interactions were also explored in the analysis. Candidate interactions are shown in **Table 3**. 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 in the modelling efforts was based upon the biological relevance and ease of interpretation and/or ability to be used in the future management 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 | 62 | 175 | 122 | 18 |
| Depth (m) | 45.72 | 104.25 | 77.83 | 12.18 |
| Latitude | 40° 44.79’ | 42° 06.77’ | | |
| **Classification Variables** | **Levels** | | | |
| Area | CAII, Non-CAII | | | |
| Month | August, September, October, December, January, February, April, June | | | |
| Sex | Male, Female | | | |
| Meat Color | White, Brown, Gray | | | |
| Stringy Meat | Yes/No (not included due to lack of positive observations) | | | |
| Orange Pustule | Yes/No (not included due to lack of positive observations) | | | |

| Continuous Variables | Minimum | Maximum | Mean | St. Deviation |
|---|---|---|---|---|
| Nematodes | Yes/No (not included due to lack of positive observations) | | | |
| **Interaction Variables** | Shell Height*Depth, Shell Height*Month, Area*Month | | | |

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 the GLMM selected during SHMW model testing. The meat weight (in pounds) was calculated for the measured bushel, which was expanded for the entire catch. The measured weight of bycatch species (in pounds) was divided by the calculated scallop weight to get a bycatch rate (fish weight/scallop weight).

Changes in the relative abundance of important bycatch species: This year's survey included stations that are in CAII S and stations in waters just to the south of CAII S that were previously part of an extended closure (EXT). These areas were also surveyed during the 2011-2014 seasonal bycatch trips. We plotted the average catch per tow (ACPT) at stations in these two areas for yellowtail and windowpane flounder, and monkfish to investigate changes in the seasonality and relative abundance of these fish in CAII S and EXT. Trend lines for annual changes in catch data for each species were estimated by 1) calculating the 12-month two-sided moving average of the ACPT from 2011 to 2014 to smooth the data and remove strong seasonal fluctuations and 2) determining the best fit line for that smoothed data. These trend lines were extended into the 2017-2018 survey using the months since April 2011 as the x-value for the line equation ($y=m\mathbf{x}+b$) estimated from the smoothed data. Catch during 2017-2018 was compared to the values that were predicted (y in the line equation) if the trends observed in 2011-2014 had continued to the present day.

Gear comparison: This analysis attempted to construct a model that would predict the efficiency of the control dredge relative to the industry provided experimental dredge based on a suite of covariates. In many instances, especially with gear modifications that can possibly alter the relative size composition of the catch, using the unpooled catch data and exploring the length-based relative efficiency becomes informative. This analysis utilizing the unpooled catch data predicts the changes that the experimental 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. In these cases, an overall change in the relative total catch was possible and was tested via a model specification using the pooled catch data. See **Appendix C** for a detailed description of the analytical framework used in the study.

Scallop meat quality: The numbers of scallops with gray meats and orange nodules in the subsets sampled for SHMW analysis were mapped to look for areas with high infection rates. Additional analysis of gray meats investigated the relationships between qualitative meat colors and results from histological analysis from samples collected during bycatch trips from 2015-2018 and PCR tests on a subset of these samples.

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

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

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

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

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

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

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

## RESULTS BY OBJECTIVE

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

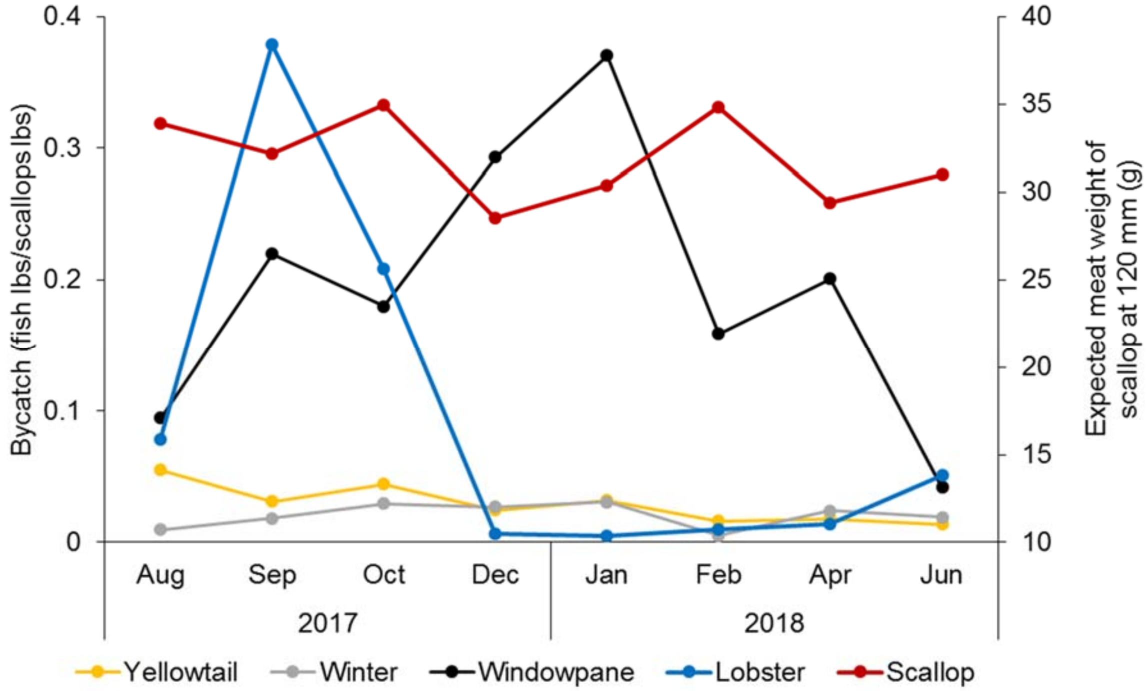
The seasonal catch rates of important bycatch species were calculated in relation to the scallop catch (i.e., lbs. of fish/lbs. of scallops). For this year's project, the overall bycatch rates for all the species analyzed were low (< 1.5 lbs. of fish/lb. of scallops). Bycatch rates for yellowtail and winter flounder were less than 0.1 lbs. of fish/lb. of scallops, and for windowpane flounder and lobster, bycatch rates were less than 0.4 lbs. of fish/lb. of scallops (**Figure 4a**). Bycatch rates for monkfish were higher than the other species (> 1 lbs. of fish/lb. of scallops), but still were low compared with other year projects (**Figure 4b**).

Total catch by species is displayed for each survey month in **Table 4**, and distribution of total catch is also mapped for each survey trip (**Appendix F**). Each of the species manifested a differential spatial distribution. Scallops were distributed mostly in the south portion of the sampling area during the sampling period (**Figure F1**), with peak abundance in June (**Table 4**). Yellowtail flounder catch was low, and they were widely distributed throughout the sampling area (**Figure F2**); peak yellowtail abundance was in August (**Table 4**). Winter flounder were observed mostly in the northern portion of the sampling area (**Figure F3**), and the peak of abundance was in June (**Table 4**). In contrast, windowpane flounder and monkfish had fairly uniform distributions in the study area (**Figures F4 - F5**) Windowpane flounder were the most abundant species throughout the sampling period, especially in January (**Table 4**). Monkfish were most abundant in September and June (**Table 4**). Summer flounder (*Paralicthyes dentatus*) catch was minimal, never exceeding 42 individuals per trip (**Table 4**); the catch was greatest during December trip, but was otherwise relatively low. Finally, lobsters were caught across the study area, with peaks in September and October (**Figure F6**; **Table 4**).

**Table 4.** Total catches 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 |
|---|---|---|---|---|---|---|---|---|
| 2017 | August | 350 | 31 | 83 | 5 | 317 | 408 | 25 |
| | September | 232 | 22 | 46 | 13 | 286 | 430 | 154 |
| | October | 405 | 20 | 57 | 19 | 457 | 321 | 76 |
| | December | 310 | 42 | 56 | 22 | 977 | 230 | 8 |
| 2018 | January | 301 | 30 | 54 | 27 | 1376 | 262 | 6 |
| | February | 375 | 3 | 32 | 6 | 706 | 76 | 2 |
| | April | 347 | 9 | 41 | 27 | 859 | 186 | 13 |
| | June | 756 | 31 | 45 | 34 | 303 | 429 | 49 |

**a)**




**b)**

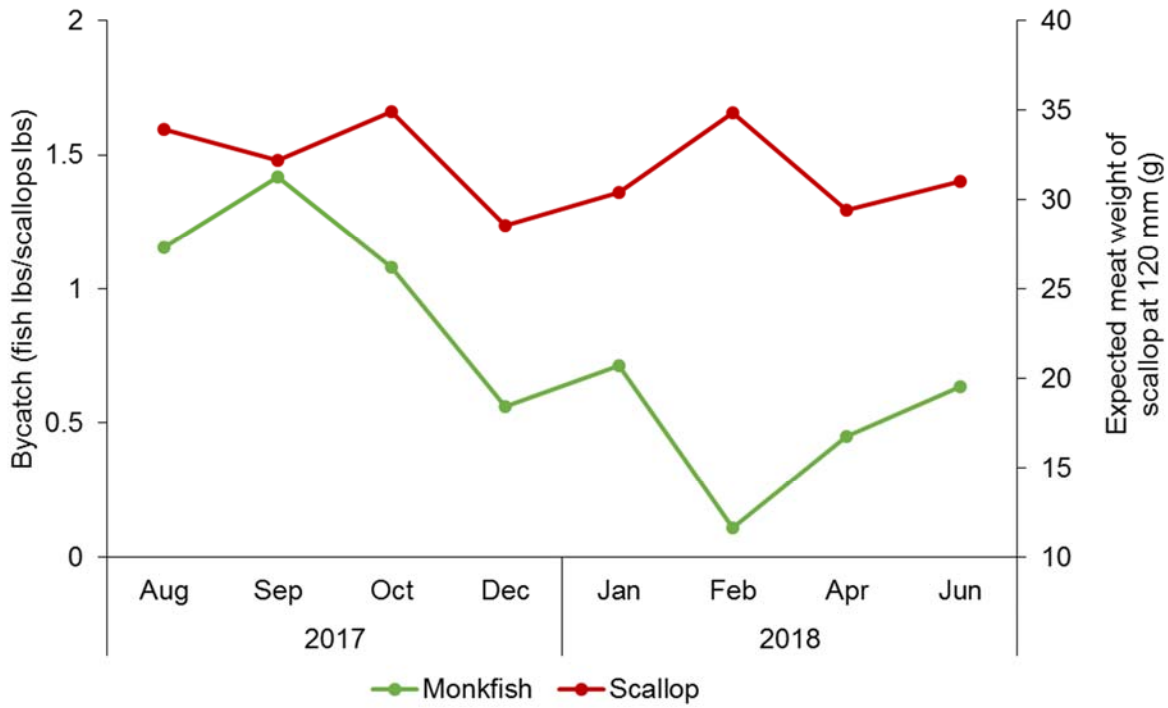



**Figure 4.** Bycatch rates for commercially important species, including **a)** flatfish, lobster and **b)** monkfish, in relation to scallop catch during this survey. The seasonal change in meat weight for a 120-mm scallop is expressed as expected weight in grams (g) using the results from the SHMW model (red solid line with secondary axis).

ACPT plots for yellowtail flounder show decreased catch rates in CAII S and in EXT south of the closed area (**Figure 5a**). Peak yellowtail flounder catch in CAII S and EXT during the 2017-2018 bycatch survey was reduced by over 90% from catch during the 2011-2014 surveys (CAII S – 93% reduction, EXT – 95% reduction). Reductions in average catch for each region between the 2017-2018 survey and the 2011-2014 surveys were similar (CAII S – 83% reduction, EXT – 97% reduction). Yet examination of the trend lines for yellowtail flounder indicates that the predicted reductions were even greater. In both areas, yellowtail flounder catch was predicted to be zero by 2017.

Peak windowpane flounder ACPT was reduced by almost 50% in the same areas (CAII S – 46% reduction, EXT – 49% reduction), while reductions in average catch followed similar trends (CAII S – 23% reduction, EXT – 45% reduction). The trend lines for windowpane flounder showed decreasing catch between 2011 and 2014, although the rate of decrease was minimal in EXT (**Figure 5b)**. Observed ACPT for windowpane flounder in CAII S was higher than what was predicted based on trends observed in 2011-2014, similar to what was seen with yellowtail flounder. However, windowpane flounder catch in EXT was lower than predicted.

Monkfish catch overall was similar 2011-2014 and 2017-2018, but there was evidence of a shift in monkfish distribution, with more monkfish caught in the shallower waters on Georges Bank in the late summer/early fall of 2017 than during previous surveys (CAII S – 36% increase in peak catch, EXT – 38% decrease in peak catch). Examination of the trend lines for both areas show increasing catch rates in CAII S and decreasing catch rates in EXT (**Figure 5c**). The observed increased catch in CAII S was similar to predicted values, while the catch in EXT was higher than predicted using the trend line from 2011-2014.

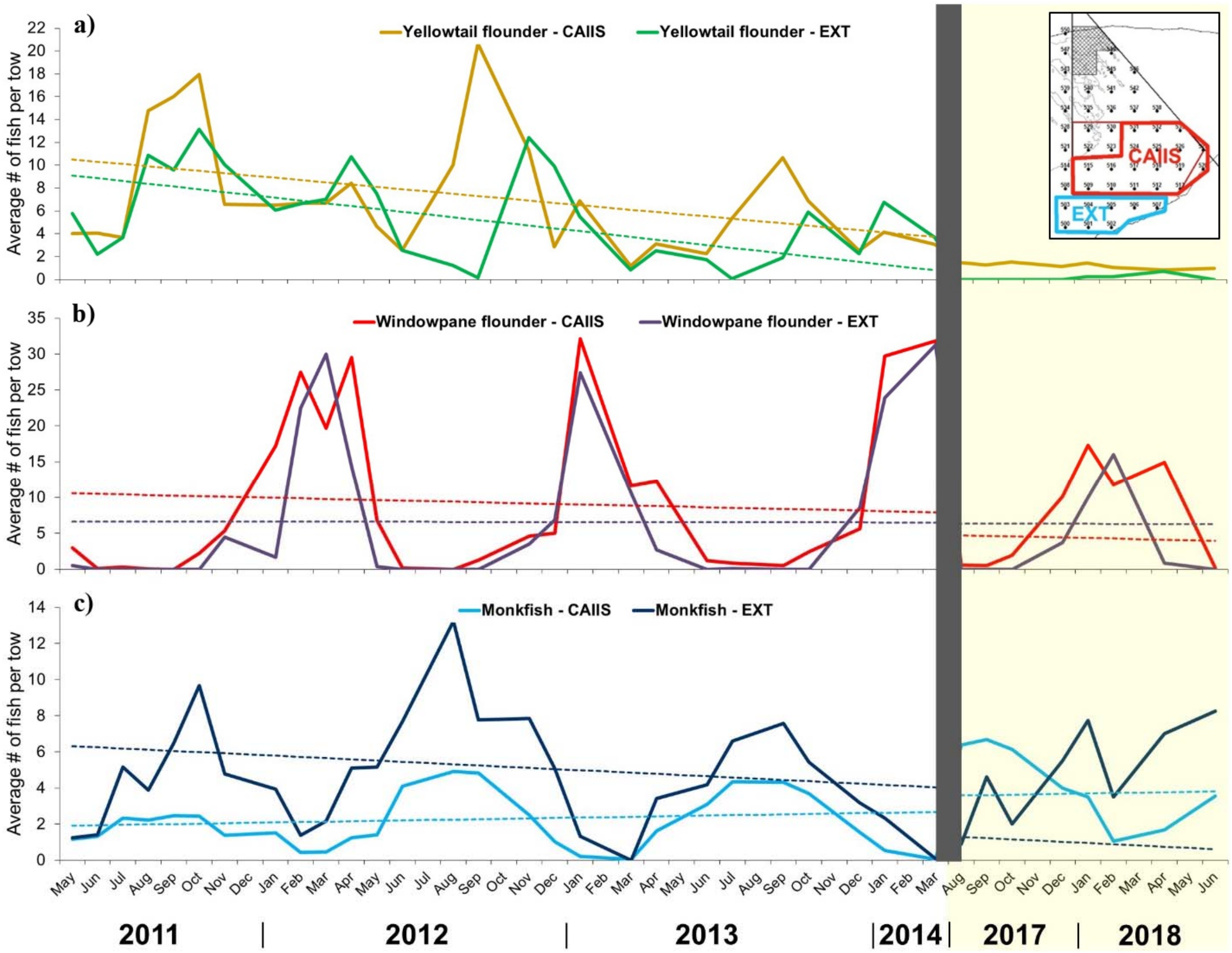
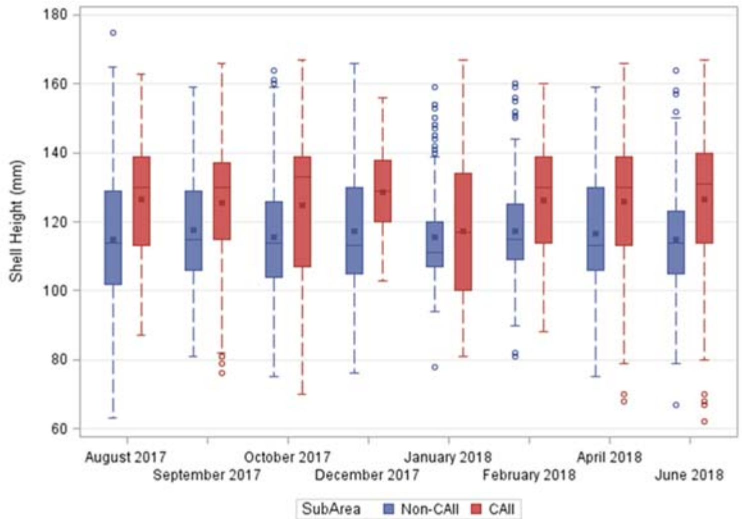



**Figure 5.** Average catch per tow (ACPT) at stations in CAII S and EXT during the 2011-2014 vs 2017-2018 seasonal bycatch surveys for **a)** yellowtail flounder, **b)** windowpane flounder, and **c)** monkfish. Trend lines for each time series of catch data are shown with same-colored dashed lines. The trend lines from 2011-2014 were extended into 2017-2018, and the shift in values across the time gap between March 2014 and August 2017 can be seen for windowpane flounder and monkfish. The trend lines for yellowtail flounder are not visible for 2017-2018 because the lines crossed zero before 2017.

## Shell height-meat weight (SHMW) relationship

During the eight trips that took place from August 2017 through June 2018, a total of 6,391 scallops were sampled at 182 stations. Scallop shell heights ranged from 62 mm to 175 mm and meat weights varied from 4.5 g to 90.0 g. Spatial and temporal distributions of the collected shell heights and meat weights are shown in **Figure 6**. Log-transformed shell height and meat weight data with various groupings (month, meat color) are shown in **Figure B1** of Appendix B.

**a)**

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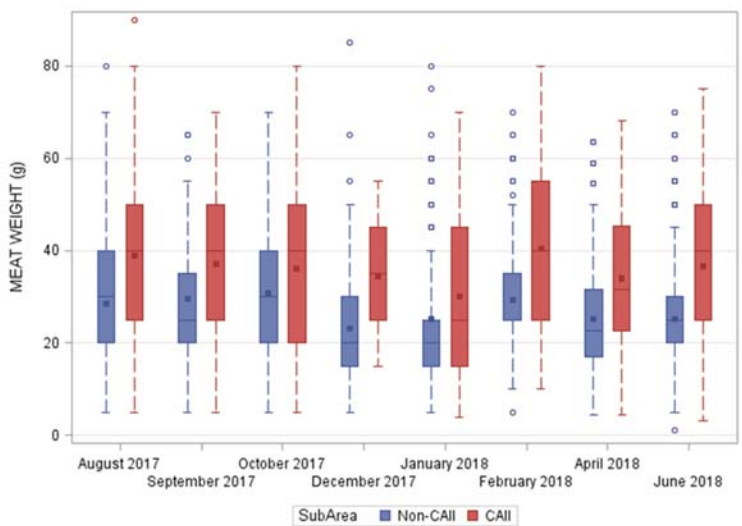



**Figure 6.** Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples in CAII and non-CAII. The marker and line inside the box represents the mean and median values, respectively. The bottom and top edges of the box represent the interquartile range (25$^{th}$ and 75$^{th}$ 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 factors were evaluated by fitting models with individual predictor variables to a common data set that included all observations with no missing values. These variables were ranked by increasing AIC value. A forward selection procedure was then used to evaluate the candidate models by sequentially adding factors in the order of increasing AIC. All final 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:

$$MW = e^{(\beta_0+\delta+\beta_1*\ln(SH)+\beta_2*(M)+\beta_3*(A)+\beta_4*(C)+\beta_5*(lnD)+\beta_6*ln(Lat)+(\beta_7*ln(SH)*M)+(\beta_8*\ln(SH)*lnD)+\epsilon)}$$

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, Lat is the latitude, D is depth (in meters), A is subarea (non-CAII, CAII), and C is meat color. Interaction terms between SH and depth and SH and month were also included.

Parameter estimates, shown in **Table B2**, were reasonably precise and predicted increasing meat weight as a function of increased shell height. Meat weights were slightly higher in CAII relative to stations outside of the area. The temporal trend indicated that meat weights were elevated through their peak during the spring and summer/early fall and decreased to a trough in December, before increasing again in January and February. Meat color was a significant predictor of meat weight; as meats transitioned from white to gray, there was a decreasing predicted value of meat weight relative to shell height. Temporal trends of a modeled 120-mm scallop for the two areas are shown in **Figure 7**. Estimated curves by month for white meats in the two areas are shown in **Figure 8**. The peak in scallop meat weights in February (**Figures 6 - 7**) is unusual for this time of year. Further analysis is required to explain this observation, which may be the result of, but not limited to, a specific size-class biasing the meat weight or increased production in a particular sampling area.

Spatially and temporally explicit fishery-independent length-to-weight information tends to be difficult to obtain on the scale that was collected by this study. These results document trends between the two 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.

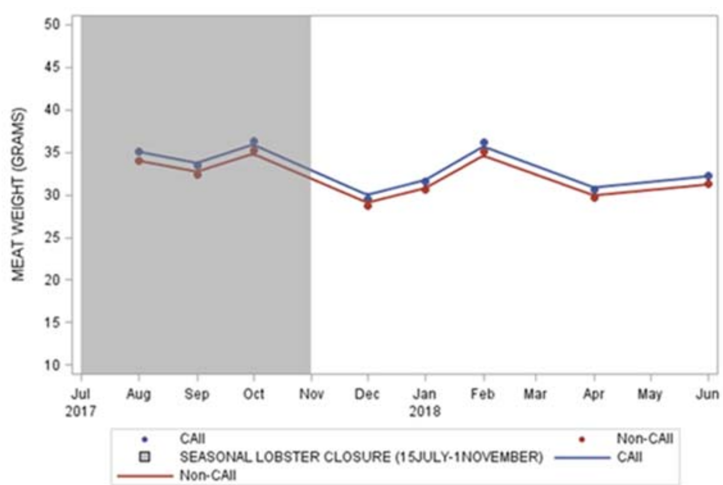
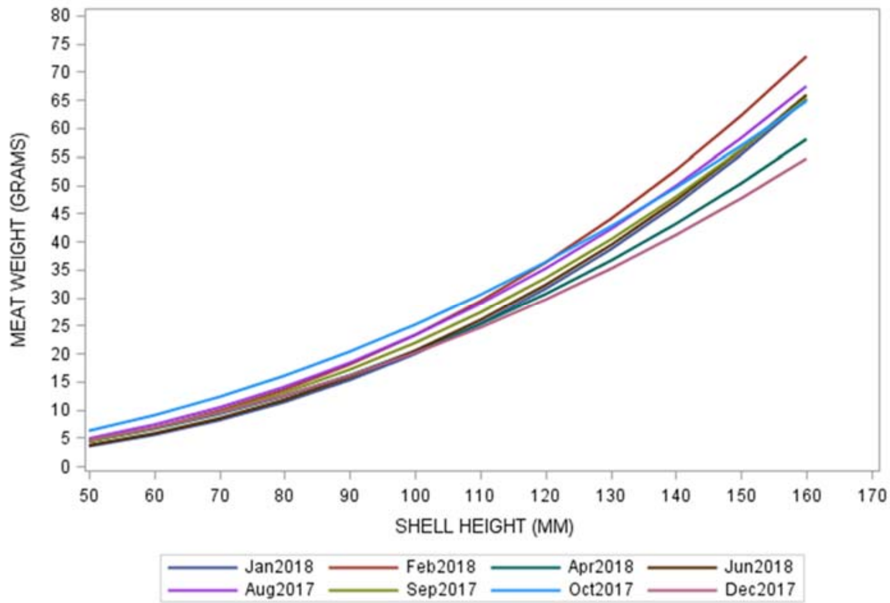



**Figure 7.** Temporal trends for the predicted meat weight of a white-meat 120-mm shell height scallop from the two areas on the northern edge of Georges Bank. Estimated meat weights were calculated from parameter estimates from the lowest AIC value model (red and blue circles). A smoothed curve is used to show the seasonal trend in meat weight (red and blue lines).

**a)**

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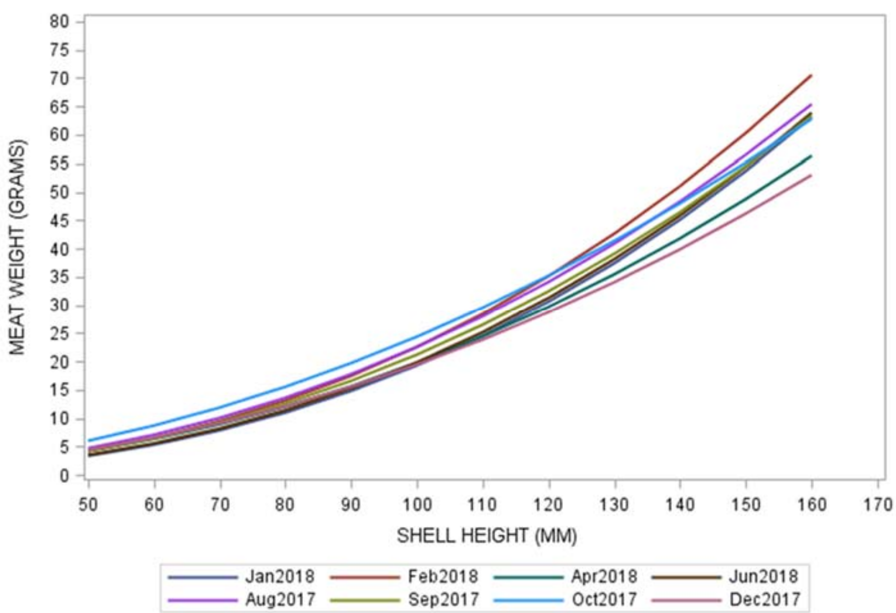


**Figure 8.** Comparison of estimated SHMW curves for white meat scallops for each month in **a)** CAII and **b)** non-CAII.

**Objective 2: Compare the standard CFF dredge with an industry dredge fitted with an extended link apron**

During the 2017 survey year, there was consistency in the control dredge gear, but the experimental dredge was different during every trip because every vessel supplied their own dredge with a modified extended link apron (**Appendix A**). Overall, this data set consisted of 385 valid tow pairs that were examined in the analysis. Not all species were present in all tow pairs, and for the species examined, individual tows with zero total catch for a given species were uninformative and excluded from the analysis. While a broad cross section of bycatch species were encountered, we focused our analysis on a subset of species that consisted of commercially important species or species of special management concern. The species examined were unclassified skates, barndoor skate (*Dipturus laevis*), American plaice (*Hippoglossoides platessoide*), summer flounder, fourspot flounder (*Hippoglossina oblonga*), yellowtail flounder, winter flounder, windowpane flounder, monkfish and sea scallops.

Length-based models: For the analysis that tested for a difference in relative efficiency as a function of fish/scallop size, we used the catch data not pooled over length. The covariates tested in this analysis were length, the second order polynomial of length, the third order polynomial of length (Holst and Revill 2009), Beaufort number (a qualitative measure of sea state), scope (length of towing warp deployed/depth), depth, and the interaction between depth and Beaufort number. 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 or produced parameter estimates that were unrealistic. **Table D1** shows the model building/selection results to find the most parsimonious model of catch by length for each species. Parameter estimates associated with the selected model specification for each species using the unpooled data is shown in **Tables D2-D3**.

For the length-based model, sea scallops and fourspot flounder were the only species where length represented a significant or marginally significant predictor of relative efficiency. **Figures D1-D2** show the graphical results for these species as a function of length, and **Figure D3** shows the scallop model results by month. For both species, there was a general trend for the experimental gear to become less efficient as length increased, suggesting that the control dredge captured a greater number of larger animals. It should be noted that the sample size of fourspot flounder was somewhat low and this is reflected in the uncertainty around the estimated proportion at length.

Pooled-over-length estimates: Animal length was not a significant predictor of relative dredge efficiency for most of the species analyzed. Since this was the case, catch was pooled over length to examine the relative efficiency of the two dredge configurations with respect to total catch. **Figure D4** shows the catches by tow for the control vs experimental dredge for all species. **Table D4** shows the model building/selection results to find the most parsimonious model of total catch for each species. Parameter estimates associated with the selected model specification for each species is shown in **Tables D5-D6**. Graphical representations of the observed catches by tow and predicted relative efficiencies derived from the model output are shown in **Figures D5-D6.** For all species except windowpane flounder, the intercept only model was the most appropriate. For the aforementioned species, Beaufort number was a significant factor predicting the relative efficiency between the two dredge configurations. The observed total reduction in catch (pooled over all tows and trips) and the model estimated reduction in catch using tow-by-tow data are shown in **Table 5**.

For the species where the intercept only model was most appropriate, the relative catch based upon the pooled catch data was only significant for unclassified skates. The other species were typically characterized by low sample sizes even though in some cases the percent differences and the relative efficiency estimated by the model was large (~20%). This could suggest a mechanism for relative differences between the two gears, but low sample sizes did not provide sufficient statistical power to detect a difference. For example, 232 yellowtail flounder were captured by the control dredge with 186 captured by the experimental dredge. This returned a 19% difference in the catch, but the statistical model returned a non-significant result. Monkfish represents a species that catch is fairly invariant to gear modifications. Typical of prior studies where monkfish catch remained robust to gear modifications, this study was no different, returning a non-significant result closely centered around 0% change.

**Table 5.** The observed total reduction in catch (pooled over all tows and trips) and the model estimated reduction in catch using tow-by-tow data. Statistical significance (alpha=0.05 level) is specific to that model and may not be the most parsimonious model from the analysis because other variables (e.g. length and Beaufort number) were significant predictors for some species.

| Species | Experimental Dredge | Control Dredge | Percent Difference | Model Estimate | Significance |
|---|---|---|---|---|---|
| **Uncl. Skates** | **12,237** | **14,918** | **-17.97** | **-18.80** | **YES** |
| Barndoor Skate | 485 | 512 | -5.27 | -4.10 | NO |
| American Plaice | 44 | 56 | -21.43 | -19.80 | NO |
| Summer Flounder | 97 | 91 | 6.59 | 10.71 | NO |
| Fourspot Flounder | 325 | 311 | 4.50 | 6.61 | NO |
| Yellowtail Flounder | 186 | 232 | -19.83 | -18.19 | NO |
| Winter Flounder | 69 | 88 | -21.59 | -19.88 | NO |
| **Windowpane Flounder** | **2,256** | **3,021** | **-25.32** | **-26.02** | **YES** |
| Monkfish | 1158 | 1175 | -1.45 | 1.33 | NO |
| **Sea Scallops** | **169,577** | **212,245** | **-20.10** | **-24.06** | **YES** |

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

Orange nodules: No hot spot was indicated for this disease during the 2017-2018 project. In total, six scallops were observed to have orange nodules (**Table 6**). Only one case was evidenced at stations 500, 518, 538, and 547; and two cases were observed at station 502 (**Figure 9**). As described in previous final reports, *Mycobacteria* sp. have been identified as a causative agent of the orange nodules in Georges Bank scallops (Grimm *et al*. 2016). The inflammation and lesions generated by the mycobacterial infection give the meats this particular orange coloration.

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

| Year | Month | White | Brown | Gray | Orange Nodules |
|---|---|---|---|---|---|
| 2017 | August | 866 | 5 | 2 | 1 |
| | September | 778 | 3 | 1 | 0 |
| | October | 762 | 13 | 2 | 2 |
| | December | 743 | 7 | 4 | 1 |
| 2018 | January | 746 | 8 | 1 | 0 |
| | February | 836 | 4 | 1 | 2 |
| | April | 729 | 15 | 1 | 0 |
| | June | 857 | 7 | 0 | 0 |
| **Total** | | **6317** | **62** | **12** | **6** |

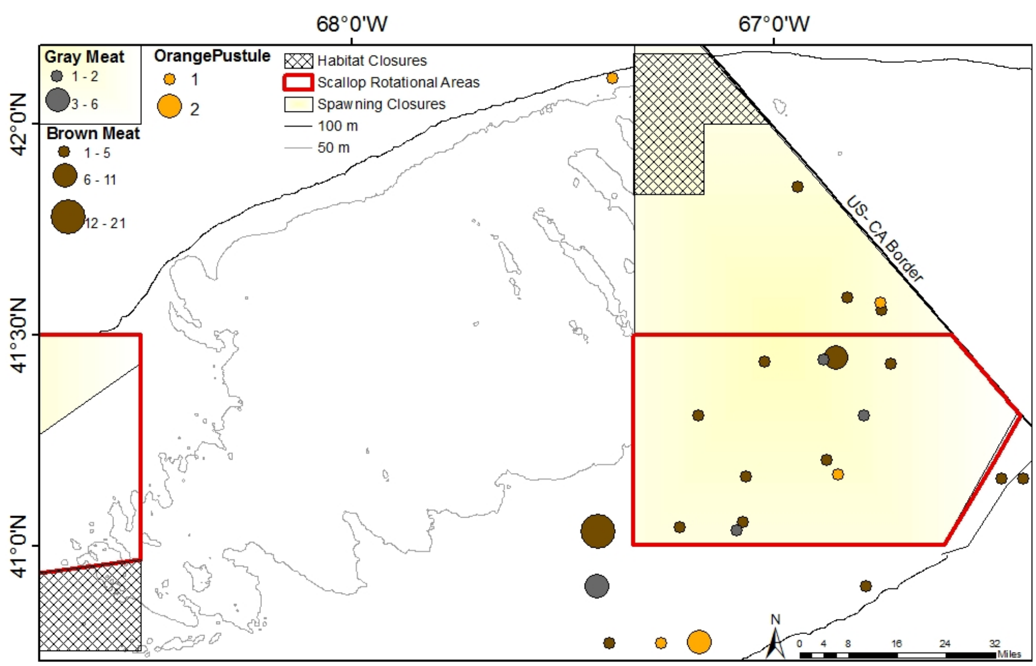


**Figure 9.** Locations where orange nodules, brown and gray meats have been identified during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

Gray Meat: Historically, gray meat outbreaks in Atlantic sea scallops have been described as episodic. However, in 2016 these outbreaks started to appear less episodic and more persistent on Georges Bank, and they included smaller size classes of scallops (Stokesbury *et al*. 2016). During 2017-2018, only one to six gray meats were observed at only five stations which were widely distributed in the survey area (**Figure 9**). Where gray meat scallops were observed, the percentages by station were: 3.9% for station 532 (2 of 51 samples), 2.9% for station 524 (1 of 35 samples), 2.5% for station 508 (6 of 240 samples), 0.9% for station 509 (2 of 207 samples), and 0.5% for station 503 (1 of 195 samples). No scallops with gray meats were caught at any other station.

All gray and brown meats collected, along with white meat controls, were sent to the RWU ADL to confirm apicomplexan infection using histological methods and PCR. Parasite forms identified in this report followed previous descriptions of similar parasites (Dubey *et al*. 1998; Kristmundson *et al*. 2015). Histological evaluation of presumed infected and uninfected meats showed a range of results, including normal adductor muscle in gray and white meats, as well as moderate to severe changes in discolored meats (**Figure 10**). In general, based on histological evaluation of presumed infected and uninfected meats the appearance of grey or brown meats is not always different than white meats. However, when muscle necrosis is noted histologically it is almost always in brown or grey meats (**Figure 10a-c**). To date, the only forms of the parasite identified in the adductor muscles are the aggregations of zoites (**Figure 10d**) and very rarely a possible oocyst (**Figure 10e**).

There is general correlation between gross muscle color and cellularity, muscle condition, and the number of zoite foci, with white, and sometimes tan, meats having lower values for these scores used for histological rating of samples (**Table 7** and **Figure 11**). Differences in each of these scores by color were analyzed using one-way ANOVAs, with pairwise comparisons using Tukey honest significant difference (HSD) post-hoc tests. There were statistically significant differences in the means of all three scores by color (muscle condition: $F(3,326) = 20.86$, $p < 0.001$; cellularity score: $F(3,326) = 7.23$, $p < 0.001$; and zoite number: $F(3,326) = 8.82$, $p < 0.001$) (see **Appendix E** for ANOVA tables). Cellularity scores and zoite numbers were significantly different between white meats and the three categories of discolored meats, while muscle condition scores were significantly different between white meats and gray/brown meats and tan meats and gray meats (see **Appendix E** for Tukey HSD pairwise comparisons of means).

**Table 7.** Average values for muscle condition score, cellularity score, and zoite number by meat color for samples collected from 2015 to 2018. The number of samples analyzed per meat color category are shown in parentheses.

| Meat color | Cellularity score | Muscle condition score | Zoite number |
|---|---|---|---|
| White (N = 152) | 0.87 | 0.59 | 1.06 |
| Tan (N = 29) | 2.29 | 0.55 | 4.24 |
| Brown (N = 36) | 2.35 | 1.07 | 3.50 |
| Gray (N = 113) | 2.75 | 1.01 | 2.69 |

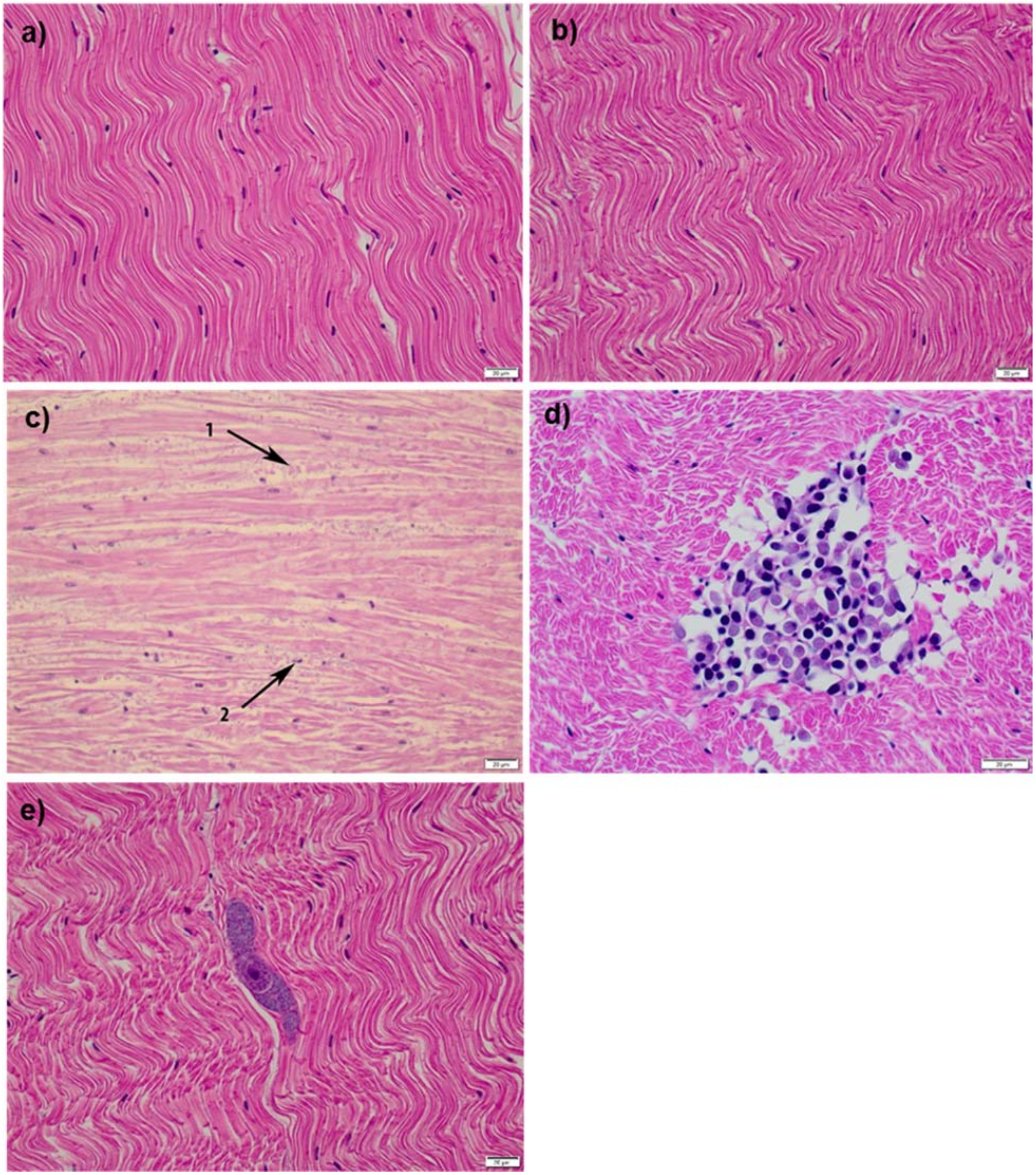


**Figure 10.** Histological appearance of adductor muscle from 3 sea scallops: **a)** Gray muscle with no significant abnormalities. **b)** White muscle with no significant lesions. **c)** Brown muscle with significant changes characterized by coagulation [(1) necrosis and (2) inflammation]. **d)** Tissue from an infected animal with zoite aggregation. **e)** Probable oocyst in the adductor muscle of a sea scallop. All tissues were paraffin embedded, and stained with hematoxylin and eosin.

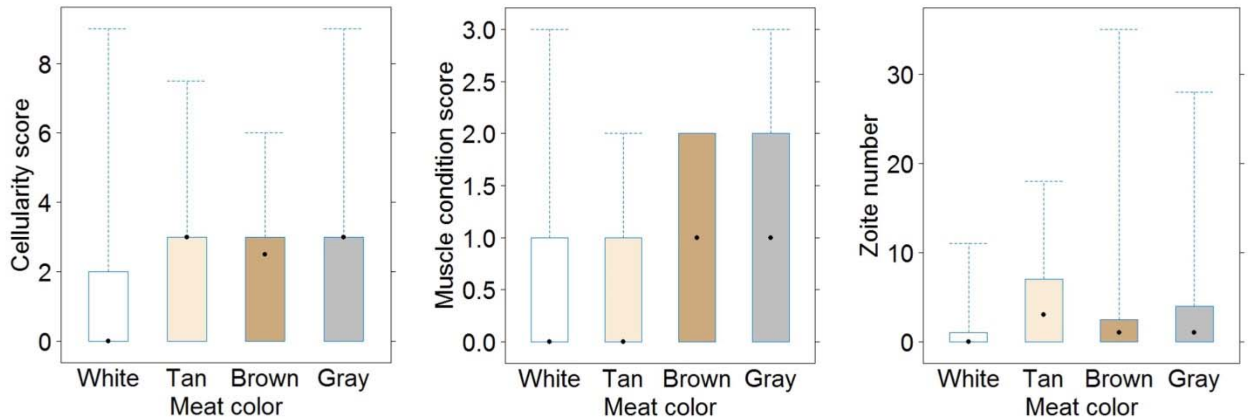


**Figure 11.** Box and whisker plots of meat color against a) cellularity scores, b) muscle thinning scores and c) protozoan sporozoites for samples collected during the 2015-2018 seasonal bycatch surveys. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers extending to the minimum and maximum values.

Polymerase Chain Reaction (PCR) Detection Method Development: The RWU ADL has developed an appropriate PCR method by using heavily infected adductor muscles collected by CFF as a positive control (Mastrostefano 2018). Gels showing PCR products from nine samples, with eight strong signals and one faint band, are shown in **Figure 12**. The results from the PCR test, specifically the percentages of meats that tested positive for the presence of apicomplexan parasite, were compared to qualitative meat color classifications (**Table 8**). Positive signals were detected in samples of white and discolored meats, further supporting the hypothesis that a mechanism other than the accumulation of apicomplexan zoites is responsible for gray meat disease.

**Table 8.** Results of PCR analysis of meat samples using a primer set specific for the apicomplexan parasite. The percentage of PCR results with a strong positive signal for the parasite is shown by meat color.

| Meat color | Number of samples analyzed | Percentage of samples with the parasite present |
|---|---|---|
| White | 10 | 80% |
| Tan | 6 | 67% |
| Brown | 10 | 100% |
| Gray | 8 | 100% |

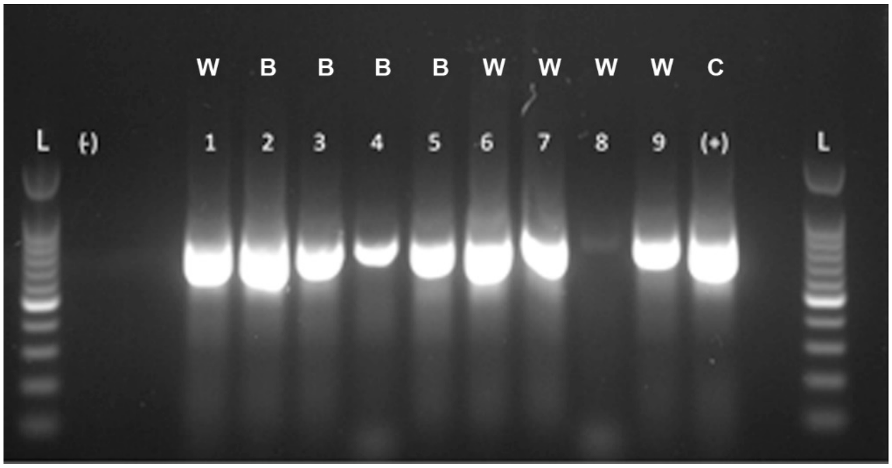

**Figure 12.** PCR gel showing the presence of apicomplexan DNA in nine samples, with eight strong signals and one faint band. Meat colors are shown above each band (W = white and B = brown). Control DNA (C) is also shown.

**Objective 4: 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 flounder were relatively scarce and spread out across the survey area. Winter flounder were also caught in relatively low numbers, but they were concentrated in the northern portion of the survey area. Windowpane flounder catches were high across the survey area, with catches peaking in January. High catches of monkfish occurred in August and September, with the lowest catches in February. 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 and are shown in **Figures F1- F6 of Appendix F**.

Scallops: A total of 2,794 bushels (137,505 lbs) were collected during the 2017 project (**Table 9**). The highest monthly percentages of mature females occurred from August through October, which coincide in part with the spawning seasons reported by Thompson *et al*. 2014; they also reported a spring spawning period that was not observed during this year's project by macroscopic examination (**Figure 13**). However, using the gonadal mass index (GMI), it is evident there are two spawning periods, a strong one in the spring and a less clear one in the fall (**Figure 14**).

**Table 9.** Catch of scallop for each trip by gear type.

| Year | Month | Number of bushels | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 207 | 115 | 11454.9 | 6691.9 |
| | September | 113 | 124 | 6573.1 | 7204.3 |
| | October | 140 | 119 | 8161.3 | 6921.1 |
| | December | 161 | 163 | 9378.4 | 9514.1 |
| 2018 | January | 193 | 141 | 11213.2 | 8211.4 |
| | February | 230 | 166 | 13391.8 | 9692.0 |
| | April | 195 | 153 | 8073.1 | 6100.7 |
| | June | 328 | 248 | 8416.7 | 6507.2 |

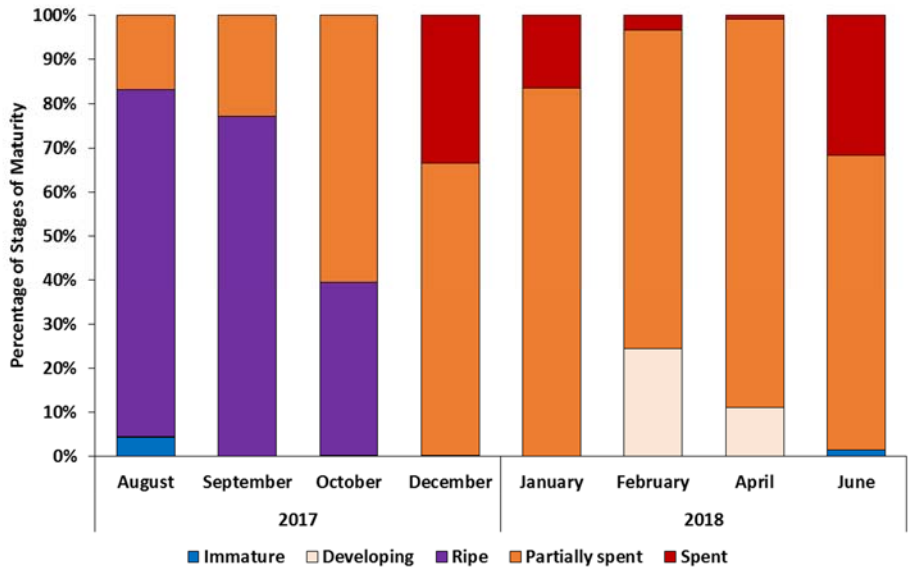


**Figure 13.** Seasonal maturity results for female scallops for each month during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank determined through macroscopic observations.

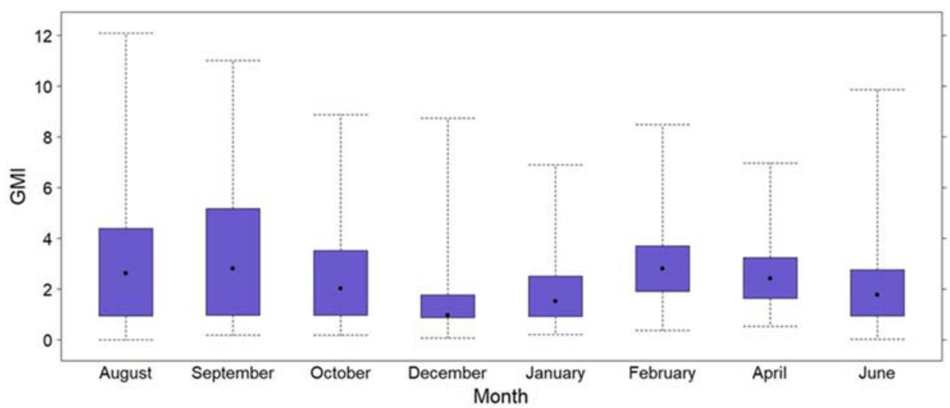


**Figure 14.** Seasonal changes in the gonadal mass index (GMI) for scallops during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank. Boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

Winter flounder: Overall, just 158 winter flounder were captured during the year, mostly in the northern portion of the sampled area (**Figure F3**). Since less than 10 individuals were caught at every station, all winter flounder were evaluated to assess sex and reproductive stages. Approximately 51% of winter flounder caught were female. The June trip had the highest winter flounder catch overall (14 females and 22 males), while August and February were the trips with the lowest catch (August: 5 females and 2 males; February: 2 females and 4 males; **Table 10**). Developing gonads were observed between September and February, while mature females were seen between August and December (**Figure 15**). Four female winter flounder were observed in the ripe and running condition during the June trip (**Figure 15**).

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

| Year | Month | Number | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 3 | 4 | 8.2 | 10.6 |
| | September | 7 | 6 | 11.5 | 15.2 |
| | October | 10 | 9 | 21.9 | 22.7 |
| | December | 14 | 9 | 39.3 | 21.1 |
| 2018 | January | 13 | 15 | 25.4 | 39.5 |
| | February | 6 | 0 | 13.9 | 0.0 |
| | April | 18 | 10 | 42.9 | 17.1 |
| | June | 20 | 16 | 43.7 | 32.3 |
| Total | | 91 | 69 | 206.8 | 158.6 |

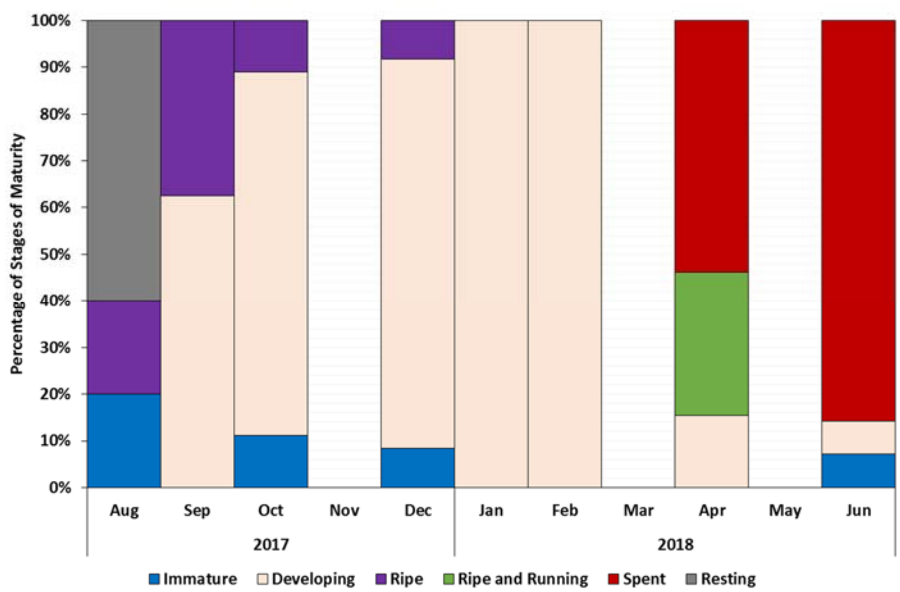


**Figure 15.** Seasonal maturity results of female winter flounder for each month during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

Windowpane flounder: Windowpane flounder was the most abundant flounder caught (5,295 fish), with catch peaking in January (1,380 fish; **Table 11**). They were caught at nearly every station, with catches often exceeding 20 fish per dredge. Ripe female windowpane flounder were observed from August throughout October and from March to June (**Figure 16**). Ripe and running females were observed from August to October and from April and June (**Figure 16**).

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

| Year | Month | Number | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 164 | 153 | 42.9 | 40.87 |
| | September | 167 | 121 | 49.9 | 29.94 |
| | October | 286 | 173 | 75.45 | 48.34 |
| | December | 597 | 384 | 171.28 | 128.33 |
| 2018 | January | 719 | 661 | 180.84 | 173 |
| | February | 487 | 221 | 132.21 | 60.59 |
| | April | 481 | 378 | 130.34 | 98.47 |
| | June | 131 | 172 | 30.13 | 44.69 |
| Total | | 3032 | 2263 | 813.05 | 624.23 |

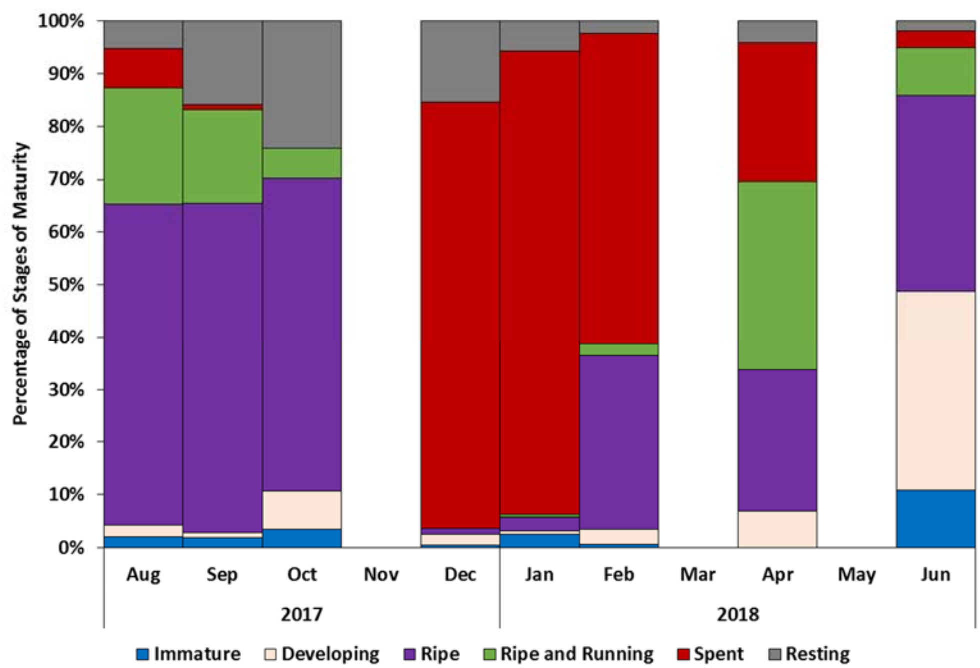


**Figure 16.** Seasonal maturity results of female windowpane flounder for each month during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

<u>Yellowtail flounder</u>: A total of 426 yellowtail flounder were captured during the 2017 project (**Table 12**), of which 84.9% were females. The peak catch of yellowtail flounder occurred in August (**Figure F2**), and the lowest catch occurred in February. They were observed in ripe and running condition in August 2017 and June 2018. Females were ripe beginning in

August, and completed spawning by December (**Figure 17**). This result was surprising because stage data collected during previous bycatch surveys indicate that the historical yellowtail flounder spawning season on Georges Bank has been during the late spring and early summer, with most spawning completed during the summer months (Huntsberger *et al.* 2015, Garcia *et al.* 2017, Garcia *et al.* 2018). Results from this project seems to indicate spawning is occurring through the late fall.

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

| Year | Month | Number | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 42 | 41 | 27.52 | 21.04 |
| | September | 29 | 18 | 14.13 | 6.59 |
| | October | 28 | 30 | 14.65 | 15.86 |
| | December | 28 | 29 | 12.15 | 13.06 |
| 2018 | January | 38 | 20 | 20.12 | 10.52 |
| | February | 22 | 12 | 15.48 | 4.52 |
| | April | 23 | 19 | 11.56 | 8.95 |
| | June | 29 | 18 | 15.01 | 9.29 |
| Total | | 239 | 187 | 130.62 | 89.83 |

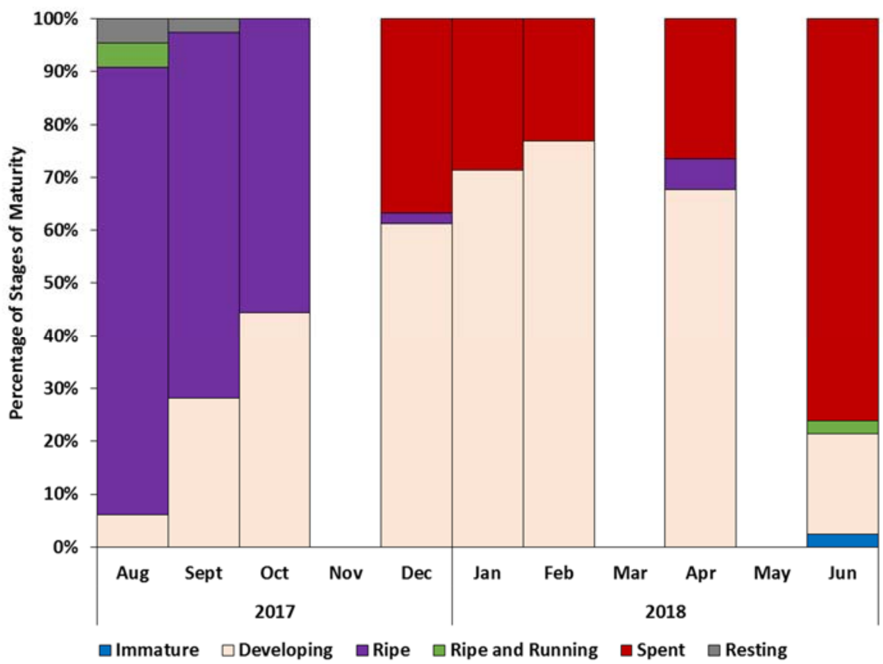


**Figure 17.** Seasonal maturity results of female yellowtail flounder for each month during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

Samples of twenty seemingly healthy livers were sampled and analyzed for *Ichthyophonus* infection. Histological examination indicated that two of them were infected with *Ichthyophonus* even though macroscopic inspection of the fish found no evidence of the disease. *Ichthyophonus* infections were identified in the liver of one animal and in the liver and spleen of a second animal (**Figure 18**). Infections were not severe, but instead were localized to the liver and spleen. It is probable that the occurrence of this infection is underestimated by basing the selection of tissue for histological evaluation solely on the presence of *Ichthyphonus* lesions. Our previous work has shown that Ichthyophonus most likely enters the animal through the gut epithelium (Huntsberger *et al.* 2016).


**Figure 18.** *Ichthyophonus* organisms in the liver parenchyma of a yellowtail flounder (paraffin embedded, 6 micron sections stained with hematoxylin and eosin).

Length-weight relationships for flounder species: In addition to conducting catch and reproductive stage analysis, we examined length-weight data collected in the eastern portion of Georges Bank from August 2017 to June 2018 for winter, windowpane, and yellowtail flounders. For each species, the parameters used to describe the length-weight relationship were determined for females, males, and the two sexes combined. The values we obtained were compared to those from a study using fish collected along the northeast coast of the United States using bottom trawl surveys from 1992 to 1999 (Wigley *et al.* 2003) and from our previous seasonal bycatch surveys in the northern portion of Georges Bank. Sample sizes, length ranges, and the a and b parameters that characterize the length-weight relationship for our project and previously published estimates are shown in **Table 13**. Both studies predicted that females are heavier at length than males, but Wigley *et al*. (2003) 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), the restricted geographical and time range of this project, or changes in the length-weight relationships of these fish over time.

**Table 13.** Length-weight relationship for the three flounder species, estimated from data collected during the 2017, 2016 and 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 | Eastern portion of Georges Bank August 2017- June 2018 | | | | Northern portion of Georges Bank August 2015- June 2017 | | | | Northeast coast of the US 1992-1999 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Length (cm) | a | b | N | Length (cm) | a | b | N | Length (cm) | a | b |
| Winter Flounder | Female | 65 | 26-55 | 0.021 | 2.88 | 722 | 29 - 64 | 0.076 | 2.53 | 5322 | 9-60 | 8.56E-06 | 3.12 |
| | Male | 59 | 28-52 | 0.037 | 2.71 | 705 | 26 - 56 | 0.137 | 2.35 | 3796 | 5-54 | 1.13E-05 | 3.02 |
| | Combined | 124 | 26-55 | 0.019 | 2.9 | 1427 | 26 - 64 | 0.058 | 2.59 | 9325 | 4-60 | 9.22E-06 | 3.09 |
| Windowpane Flounder | Female | 1057 | 15-45 | 0.038 | 2.66 | 2949 | 16 - 39 | 0.061 | 2.5 | 2754 | 7-40 | 1.37E-05 | 2.98 |
| | Male | 755 | 21-37 | 0.059 | 2.52 | 3212 | 16 - 38 | 0.108 | 2.31 | 2153 | 4-36 | 1.47E+05 | 2.92 |
| | Combined | 1812 | 15-45 | 0.035 | 2.68 | 6161 | 16 - 39 | 0.042 | 2.6 | 8009 | 2-44 | 1.28E-05 | 2.97 |
| Yellowtail Flounder | Female | 307 | 30-47 | 0.287 | 2.04 | 1055 | 21-49 | 0.096 | 2.35 | 4356 | 6-55 | 3.93E-06 | 3.27 |
| | Male | 53 | 25-43 | 0.407 | 1.91 | 221 | 25-45 | 0.045 | 2.52 | 4290 | 11-49 | 7.41E-06 | 3.05 |
| | Combined | 364 | 25-47 | 0.243 | 2.08 | 1276 | 21-49 | 0.031 | 2.64 | 8775 | 4-55 | 5.18E-06 | 3.17 |

Monkfish: The most abundant fish species captured by weight during this year's project was monkfish (**Table 14**). More than half of the monkfish caught during this survey were adults (80.6%) using the 50% maturity cut off at 43 cm (NEFMC 2014), indicating that more than half of the monkfish caught would be kept during commercial trips. The data collected during this project showed the monkfish catch was high in August and peaked in September (**Table 14**). This is consistent with results collected during the bycatch surveys in 2011-2014 showing that monkfish catches were highest in July through October in CAII (publication in review).

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

| Year | Month | Number | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 255 | 326 | 933.3 | 1318.8 |
| | September | 267 | 325 | 1030.4 | 1056.5 |
| | October | 221 | 150 | 941.4 | 693.9 |
| | December | 143 | 115 | 716 | 545.4 |
| 2018 | January | 140 | 122 | 822.1 | 679.5 |
| | February | 47 | 29 | 182.8 | 108.2 |
| | April | 102 | 104 | 559.9 | 565.6 |
| | June | 242 | 227 | 1363.7 | 1130.4 |
| Total | | 1417 | 1398 | 6549.6 | 6098.4 |

## Objective 5: Conduct biological sampling of American lobster caught in the dredge

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 in September and relatively high in October (**Table 15** and **Figure 19**), and lobsters were caught across the entire survey area. Catch started to drop off during the December trip, and few lobsters were present from January through April; in June, the catch began to increase slightly (**Figure F6**).

**Table 15.** Catch of lobster for each trip by gear type.

| Year | Month | Number | | Weight (lbs.) | |
|---|---|---|---|---|---|
| | | Control | Experimental | Control | Experimental |
| 2017 | August | 15 | 10 | 99.64 | 53.24 |
| | September | 78 | 76 | 325.8 | 232.1 |
| | October | 43 | 33 | 168.96 | 146.08 |
| | December | 4 | 4 | 11.53 | 15.97 |
| 2018 | January | 2 | 4 | 4.58 | 10.3 |
| | February | 1 | 1 | 10.52 | 0.07 |
| | April | 11 | 2 | 31.39 | 4.42 |
| | June | 29 | 20 | 115.68 | 86.2 |
| Total | | 183 | 150 | 768.09 | 548.37 |

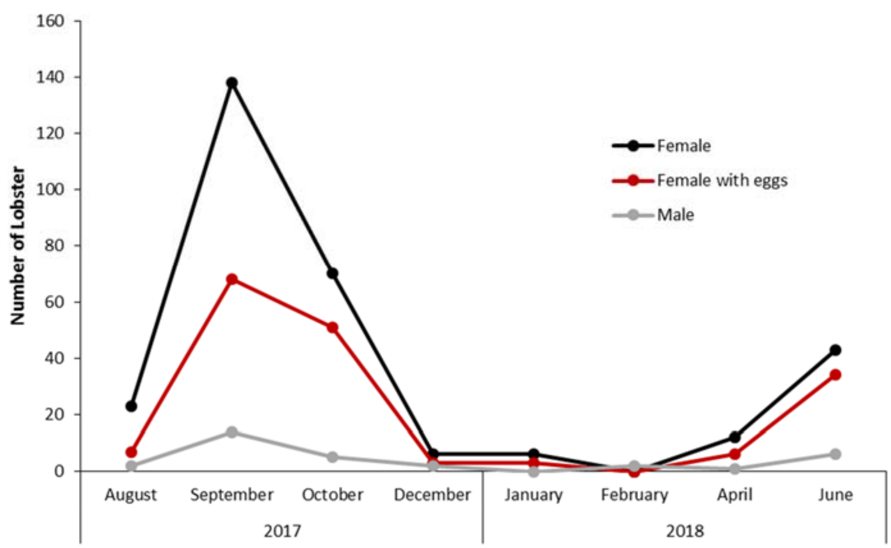


**Figure 19.** Catch of lobsters by trip separated by sex during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

The majority of the catch was female. Numbers of male lobsters caught remained consistently low over the course of the survey, with the highest catch during the September trip (14 males). A total of twelve incidences of shell disease were observed. Overall, 150 lobsters had no damage, 60 were moderately damaged (missing claws or a walking leg), and 123 were classified as lethally damaged **(Figure 20**). A total of 46 females and 5 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.

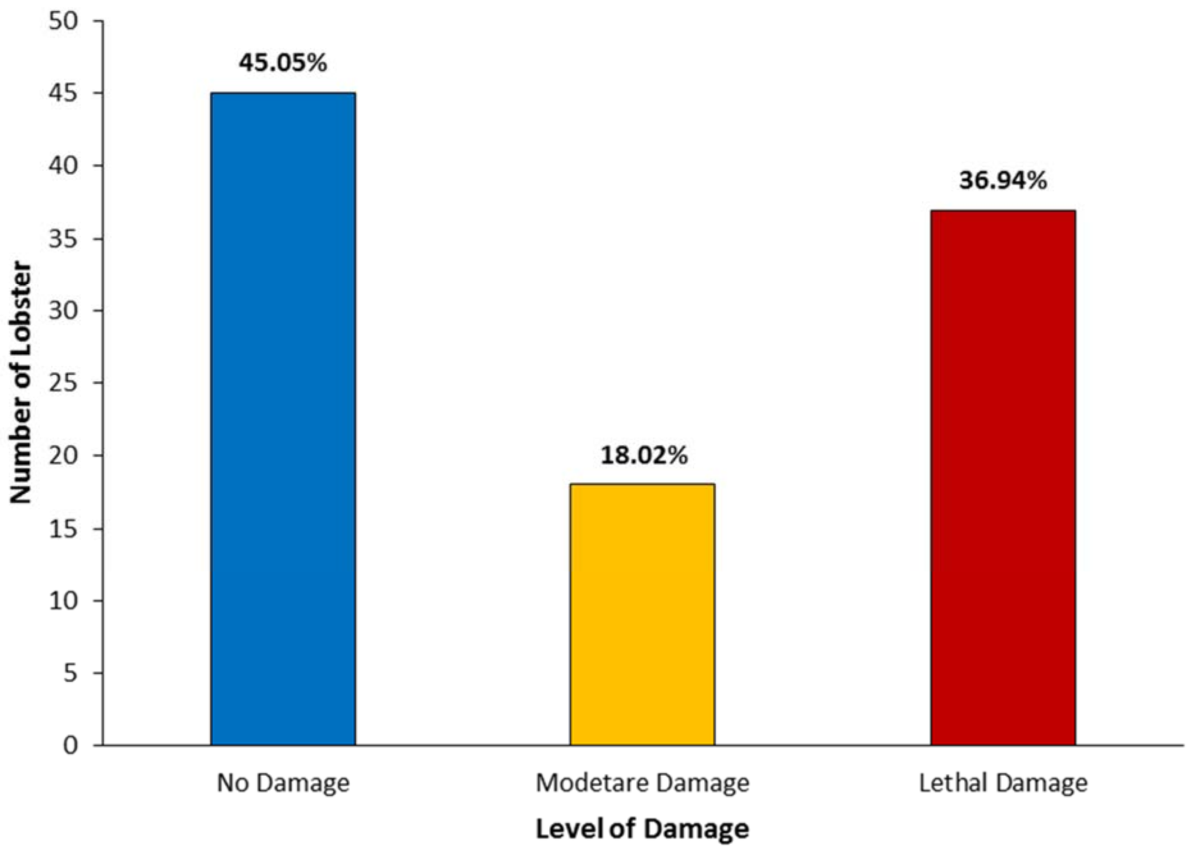


**Figure 20.** Summary of dredge-induced damage to lobsters during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.

<u>Other fish species</u>: 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*) were relatively abundant, with the lowest catch in February (39 barndoor skate caught) and the highest catch in October (210 barndoor skate caught). Atlantic cod (*Gadus morhua*) were seen in higher numbers than expected during the April trip. Haddock (*Melanogrammus aeglefinus*) catch was low for the entire project; American plaice (*Hippoglossoides platessoides*) were caught regularly after December trip, and witch flounder (*Glyptocephalus cynoglossus*) were caught primarily in the spring/early summer during the last two trips (**Table 16**).

**Table 16.** Catch of additional species for each trip by gear type during the 2017 seasonal bycatch survey

| Date | | Unclassified skate | | Barndoor skate | | Atlantic Cod | | Haddock | | American Plaice | | Witch Flounder | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Con | Exp | Con | Exp | Con | Exp | Con | Exp | Con | Exp | Con | Exp |
| 2017 | August | 1862 | 1381 | 55 | 48 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| | September | 1912 | 1469 | 47 | 77 | 0 | 0 | 2 | 4 | 1 | 0 | 0 | 1 |
| | October | 1676 | 1409 | 113 | 97 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | December | 1894 | 1506 | 39 | 44 | 2 | 3 | 3 | 1 | 3 | 2 | 0 | 0 |
| 2018 | January | 2023 | 2153 | 74 | 54 | 4 | 4 | 2 | 3 | 9 | 9 | 0 | 0 |
| | February | 1435 | 1023 | 25 | 14 | 1 | 1 | 0 | 0 | 22 | 17 | 1 | 0 |
| | April | 1666 | 1413 | 67 | 52 | 11 | 2 | 3 | 3 | 20 | 13 | 10 | 7 |
| | June | 2516 | 1922 | 92 | 99 | 2 | 3 | 1 | 2 | 0 | 3 | 15 | 7 |
| | Total | 14984 | 12276 | 512 | 485 | 20 | 13 | 11 | 15 | 56 | 44 | 26 | 15 |

## DISCUSSION

The CFF seasonal bycatch survey has continued to highlight the value of collecting fisheries data throughout the year. The primary survey used for groundfish stock assessments is the Northeast Fisheries Science Center (NEFSC) bottom trawl survey, conducted twice a year in the spring (March-May) and fall (September-November). Yet the CFF dredge survey has shown that the relative abundances of important commercial species, including windowpane flounder and monkfish, peak during winter and summer months, respectively, on Georges Bank (Winton *et al.* 2017, Siemann *et al.* in review). Consequently, current stock assessments may underestimate the abundance of these species on Georges Bank, an important commercial fishing ground.

Seasonal bycatch survey data for closed and open areas on Georges Bank have also captured important changes is the relative abundance and reproductive patterns of commercial species over the past seven years from 2011 to 2018. Reductions in the catch of yellowtail and windowpane flounder have been documented in this report, with yellowtail flounder catch numbers decreasing by over 90% on eastern Georges Bank in areas where they were once abundant relative to other parts of Georges Bank (Huntsberger *et al.* 2015, Smolowitz *et al.* 2016). In addition, the results of the reproductive staging may provide a clue to explain recent poor recruitment of yellowtail flounder on Georges Bank. Georges Bank spawning has been consistently documented to occur in the late spring to early summer in CFF projects (Huntsberger *et al.* 2015, Garcia *et al.* 2017, Garcia *et al.* 2018), with late spring to summer spawning described in life history documents by the National Marine Fisheries Service and the Canadian Department of Fisheries (DFO 1999, NMFS 1999). Yet beginning in 2016, CFF scientists documented ripe yellowtail flounder in September-November (Garcia *et al.* 2018) on northern Georges Bank. During this year's project, almost all ripe flounder were observed in August-October. Delayed spawning has been cited as a possible cause for poor recruitment in Atlantic cod because egg and larval stages may not experience the environmental conditions needed for survival (Wieland *et al.* 2000), and delayed spawning could have a similar impact on Georges Bank yellowtail flounder.

One of CFF's major contributions to marine research is its constant exploration of gear modifications designed to reduce bycatch. Because multi-year testing of the 5-row apron has consistently shown significant reductions in the bycatch of several flatfish species (Davis *et al.* 2012, Davis *et al*. 2013, Garcia *et al*. 2017), while maintaining no (or a small but insignificant) reduction in scallop catch (Garcia *et al*. 2017, Garcia *et al*. 2018), we chose to test the extended link apron, another promising gear modification, during this year's project. During dedicated gear trips, use of the extended link apron significantly reduced windowpane flounder bycatch while maintaining an equivalent or greater catch efficiency for larger scallops compared to a standard apron (Davis *et al.* 2018). However, the results from this study were quite different, with the experimental dredge catching fewer scallops overall while becoming less efficient as length increased for scallops and fourspot flounder.

During previous bycatch studies, the control and experimental gear was provided by CFF, minimizing the differences between the dredge frames. During the 2017-2018 project, this experimental design was altered, and the experimental dredge was supplied by the industry vessel. This design was intended to offer a full examination of the impact of the variability at the fleet level and an assessment of whether management objectives will be met in light of the resulting variability. However, we believe that by adding more variables that are difficult to control (e.g. dredge width, sweep), this design precludes the ability to assess trip by trip differences and the underlying process for those differences, making it difficult to interpret the results and compare them to previous gear studies. As such, differences in the results of the dedicated gear research and the gear comparisons conducted during this bycatch trip are not surprising, and they highlight the difficulties inherent in taking empirical results from controlled gear studies and drawing inferences at the fleet level.

Finally, the results from our ongoing gray meat research suggest another mechanism, besides the accumulation of apicomplexan sporozoites in the muscle, may cause degradation of the scallop muscle tissue. Positive signals for the presence of the apicomplexan parasite were detected in samples of both white and discolored meats. Zoites were noted in defined foci in the adductor muscle regardless of meat color in the majority of adductor muscles examined, and the surrounding muscle tissues did not appear to be impacted. In some gray to brown meats, the zoites foci were not associated with significant muscle damage. These findings indicate that other mechanisms, such as a generalized toxin produced by the parasite or infections at other sites in the body causing poor nutrition, may be contributing factors to muscle degeneration and gray meats. This hypothesis is further supported by ongoing modelling efforts that show gray meat prevalence is correlated with scallop reproductive stage and age (paper in preparation). In order to better understand the correlation of infection by the parasite and degeneration of muscle tissue, further work should be completed, including: 1) in-situ hybridization to identify parasites in the unusual foci and potential microzoites/spores or other parasitic forms in the degenerating tissues; 2) correlation of PCR identification of the parasite in meats with histological evaluation, and 3) development of a quantitative PCR method that can quantify the abundance of parasites in the meats. A quantitative PCR test method would directly quantify the number of parasites in the tissue without the use of histology, offering a fast and accurate monitoring tool.

## CONCLUSIONS AND FUTURE RESEARCH

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

To date, CFF has completed over three years (October 2010 – March 2014) of bycatch surveys on Georges Bank in the scallop access areas in CAI and CAII, two years (August 2015 – June 2017) of surveys on the northern portion of Georges Bank, and one year (August 2017 – June 2018) of surveys on the eastern portion of Georges Bank. The shift to include all of CAII was done to better understand the seasonal patterns of habitat used by the choke flatfish bycatch species, yellowtail and windowpane flounder, which are mainly distributed within this area. Because fishery access and habitat protection in this area may be adjusted, continued collection of scallop, fish, and lobster data from this region is critical.

The scallop industry has become increasingly concerned about the observed distribution and magnitude of poor-quality scallops, and there has been increasing interest in using the bycatch survey data as a time series. Therefore, we hope to begin incorporating a set of fixed stations that would remain constant each year, with these stations placed across important scallop fishing grounds. Our focus on disease research would continue, incorporating improved methods for disease detection and quantifying disease impacts.

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## APPENDICES

## Appendix A: General

**Table A1.** Specifications of CFF dredges used during the 2017 seasonal bycatch survey on the northern portion of Georges Bank.
Dredge characteristics for the control dredges used for each trip. Dredges varied by vessel preference. Month: August 2017 = AUG, Frame: New Bedford Dredge (NBD) and Turtle Deflector Dredge (TDD), Dredge width: Ft, Turtle Chains: Number used, Ticklers: Number used, Chain link size: In, Diamond: Number of rings/side, Sweep: Number of links, Bag/Apron/Side Piece Rings (Width/Length): Number of rings, Twine Top Mesh Size: In, Twine top (Width/Length): Number of meshes.

| Dredge | | Control | Experimental | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | | **All months** | **AUG** | **SEP** | **OCT** | **DEC** | **JAN** | **FEB** | **APR** | **JUN** |
| **New Sweep Chain** | | No | No | No | Yes | No | Yes | Yes | No | No |
| **New Shoes/Heels** | | No | No | No | No | Yes | Yes | Yes | No | No |
| **New Twine Top** | | No | Yes | No | Yes | No | Yes | No | No | No |
| **Frame** | | TDD | NBD | TDD | TDD | NBD | TDD | TDD | NBD | TDD |
| **Dredge Width** | | 15 | 15 | 15 | 15 | 14 | 14 | 15 | 15 | 14 |
| **Turtle Chains** | | 13 | | 13 | 3 | 3 | 11 | 13 | 3 | 5 |
| **Ticklers** | | 9 | 9 | 8 | 3 | 2 | 6 | 9 | 2 | 3 |
| **Chain Link Size** | | 5/8 | 5/8 | 3/8 | 3/8 | | | 5/8 | 1/2 | |
| **Diamond** | | 14 | 13 | 14 | 4 | 13 | 11 | 14 | 13 | 11 |
| **Sweep** | | 121 | 113 | 141 | 149 | 105 | 125 | 121 | | 117 |
| **Bag Rings** | **Width** | 40 | 40 | 40 | 42 | 38 | 40 | 40 | | |
| | **Length** | 10 | 8 | 10 | 9 | | 10 | 10 | | |
| **Apron Rings** | **Width** | 40 | 40 | 40 | 42 | 38 | 40 | 40 | | |
| | **Length** | 7 | 5 | 5 | 5 | 7 | 7 | 5 | | |
| **Side Piece** | **Width** | 6 | 6 | 6 | 5 | 6 | 4 | 6 | | |
| | **Length** | 20 | 19 | 20 | 26 | 18 | 13 | 20 | | |
| **Twine Top** | **Mesh size** | | 10 | 11 | 10 | | 10 | | 11 | 11 |
| | **Width** | 60 | 68 | 90 | 66 | | 82 | 45 | | 85 |
| | **Length** | 9 | 8.5 | 8.5 | 9.5 | | 6.5 | 11 | | 7 |

**Table A2.** Species captured during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank. It was measured for some fish: total lengths, for squid: mantle length and for scallop: shell height.

| Common Name | Scientific Name | Number Caught | Sample Procedure |
|---|---|---|---|
| American plaice | *Hippoglossoides platessoides* | 108 | Weigh/Measure |
| Atlantic cod | *Gadus morhua* | 33 | Weigh/Measure |
| Barndoor skate | *Dipturus laevis* | 1095 | Weigh/Measure |
| Butterfish | *Peprilus triacanthus* | 4 | Count/Weigh |
| Chain dogfish | *Scyliorhinus retifer* | 1 | Weigh/Measure |
| Conger eel | *Conger oceanicus* | 1 | Count/Weigh |
| Cusk | *Brosme brosme* | 1 | Count/Weigh |
| Fawn cusk eel | *Lepophidium profundorum* | 1 | Count/Weigh |
| Fourspot flounder | *Paralichthys oblongus* | 710 | Weigh/Measure |
| Gulfstream flounder | *Citharichthys arctifrons* | 34 | Count/Weigh |
| Haddock | *Melanogrammus aeglefinus* | 27 | Weigh/Measure |
| Jonah crab | *Cancer borealis* | 99 | Count/Weigh |
| Lady crab | *Ovalipes ocellatus* | 8 | Count/Weigh |
| Longhorn sculpin | *Myoxocephalus octodecemspinosus* | 31 | Count/Weigh |
| Monkfish | *Lophius americanus* | 2868 | Weigh/Measure |
| Northern searobin | *Prionotus carolimus* | 685 | Count/Weigh |
| Ocean pout | *Zoarces americanus* | 2 | Count/Weigh |
| Pollock | *Pollachius virens* | 2 | Weigh/Measure |
| Red hake | *Urophycis chuss* | 620 | Count/Weigh |
| Sea raven | *Hemitripterus americanus* | 66 | Count/Weigh |
| Sea Scallops (bushels) | *Placopecten magellanicus* | 33247 | Weigh/Measure/ Reproductive/Disease |
| Silver hake | *Merluccius bilinearis* | 111 | Count/Weigh |
| Spiny dogfish | *Squalus acanthias* | 17 | Weigh/Measure |
| Spotted hake | *Urophycis regia* | 2 | Count/Weigh |
| Summer flounder | *Paralichthys dentatus* | 215 | Weigh/Measure |
| Torpedo ray | *Torpedo nobiliana* | 1 | Count/Weigh |
| Unclassified skates | *Rajidae* | 72301 | Count/Weigh |
| White hake | *Urophycis tenuis* | 1 | Count/Weigh |
| White perch | *Morone americana* | 1 | Count/Weigh |
| Windowpane flounder | *Scopthalmus aquosus* | 5530 | Weigh/Measure/ Reproductive |
| Winter flounder | *Pseudopleuronectes americanus* | 171 | Weigh/Measure/ Reproductive |
| Witch flounder | *Glyptocephalus cynoglossus* | 46 | Weigh/Measure |
| Yellowtail flounder | *Limanda ferruginea* | 445 | Weigh/Measure/ Reproductive/Disease |

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

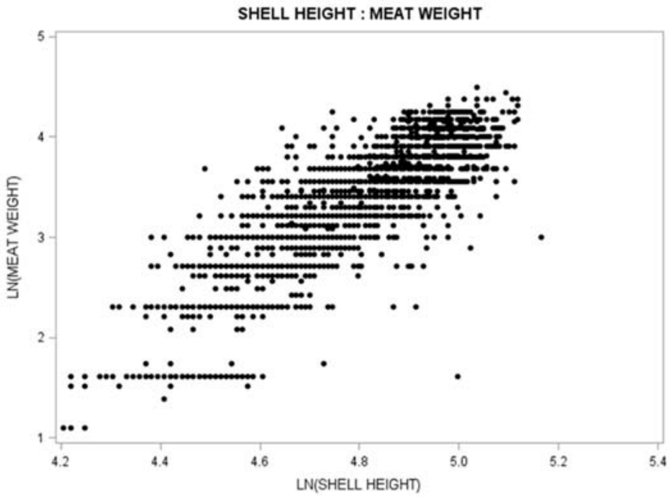
**Table B1.** Results from iterative model building. The model with the minimum AIC value is shown in bold. Fixed effects are shown to the right of the ~ symbol. This symbol separates the response (Meat Weight) from the predictor variables used in the analysis. Interaction terms are denoted with the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

| Fixed Effects | Random Effects | AIC | Delta AIC |
|---|---|---|---|
| **Shell Height, Depth, Month, Area, Latitude, Color, Shell Height*Depth, Shell Height*Month** | **Intercept** | **30,268.27** | **0** |
| Shell Height, Depth, Month, Area, Latitude, Shell Height*Depth, Shell Height*Month | Intercept | 30,350.94 | -82.67 |
| Shell Height, Depth, Month, Shell Height*Depth, Shell Height*Month | Intercept | 30,373.77 | -105.50 |
| Shell Height, Depth, Month, Area, Shell Height*Depth, Shell Height*Month | Intercept | 30,374.20 | -105.92 |
| Shell Height, Depth, Shell Height*Depth, | Intercept | 30,391.70 | -123.44 |
| Shell Height, Depth, Month, Area, Latitude, Color, Shell Height*Depth, Shell Height*Month | None | 30,975.75 | -707.48 |

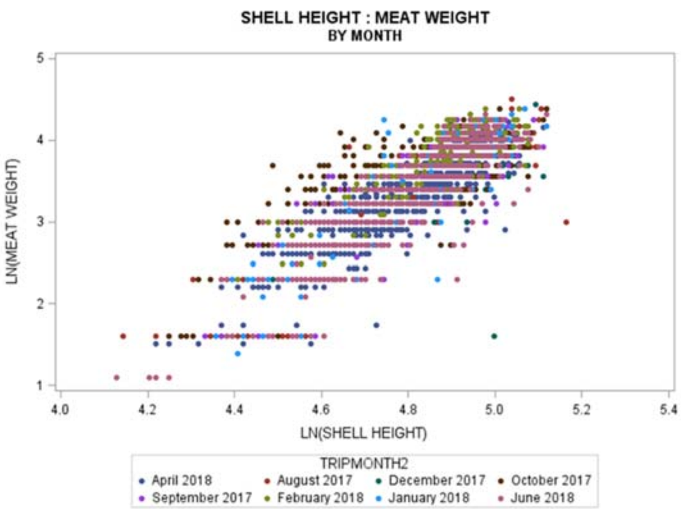
**Table B2.** Parameter estimates for the best model as described by minimum AIC value. For the categorical variables (Month, Color, Area), differences within that category are relative to the value with a 0 parameter estimate (i.e. Open Area and September 2017). Similarly, p-values within a category are relative to that standard and not for the whole model. All included fixed effects were significant overall.

| Effect | Month | Color | Area | Estimate | SE | DF | t-value | p-value |
|---|---|---|---|---|---|---|---|---|
| Intercept | | | | 25.527 | 7.933 | 4577 | 3.218 | 0.001 |
| Shell Height (SH) | | | | -2.141 | 0.847 | 4577 | -2.528 | 0.012 |
| Depth | | | | -5.723 | 0.932 | 4577 | -6.139 | 0.000 |
| SH * Depth | | | | 1.118 | 0.194 | 4577 | 5.760 | 0.000 |
| Month | August 2017 | | | 0.364 | 0.673 | 4577 | 0.540 | 0.589 |
| | September 2017 | | | 0.000 | | | | |
| | October 2017 | | | 1.590 | 0.616 | 4577 | 2.581 | 0.010 |
| | December 2017 | | | 0.837 | 0.937 | 4577 | 0.894 | 0.372 |
| | January 2018 | | | -0.981 | 0.808 | 4577 | -1.214 | 0.225 |
| | February 2018 | | | -0.380 | 0.638 | 4577 | -0.595 | 0.552 |
| | April 2018 | | | 0.403 | 0.658 | 4577 | 0.612 | 0.540 |
| | June 2018 | | | -0.784 | 0.601 | 4577 | -1.303 | 0.193 |
| SH * Month | August 2017 | | | -0.065 | 0.140 | 4577 | -0.467 | 0.641 |
| | September 2017 | | | 0.000 | | | | |
| | October 2017 | | | -0.315 | 0.128 | 4577 | -2.454 | 0.014 |
| | December 2017 | | | -0.200 | 0.196 | 4577 | -1.021 | 0.307 |
| | January 2018 | | | 0.193 | 0.169 | 4577 | 1.138 | 0.255 |
| | February 2018 | | | 0.096 | 0.133 | 4577 | 0.723 | 0.470 |
| | April 2018 | | | -0.103 | 0.137 | 4577 | -0.750 | 0.453 |
| | June 2018 | | | 0.156 | 0.125 | 4577 | 1.244 | 0.213 |
| Area | | | CAII | 0.031 | 0.023 | 4577 | 1.338 | 0.181 |
| | | | Non-CAII | 0.000 | | | | |
| Latitude | | | | -2.768 | 1.620 | 4577 | -1.709 | 0.088 |
| Color | | Brown | | -0.228 | 0.032 | 4577 | -7.016 | 0.000 |
| | | Gray | | -0.521 | 0.074 | 4577 | -7.033 | 0.000 |
| | | White | | 0 | | | | |

**a)**




**b)**




**c)**

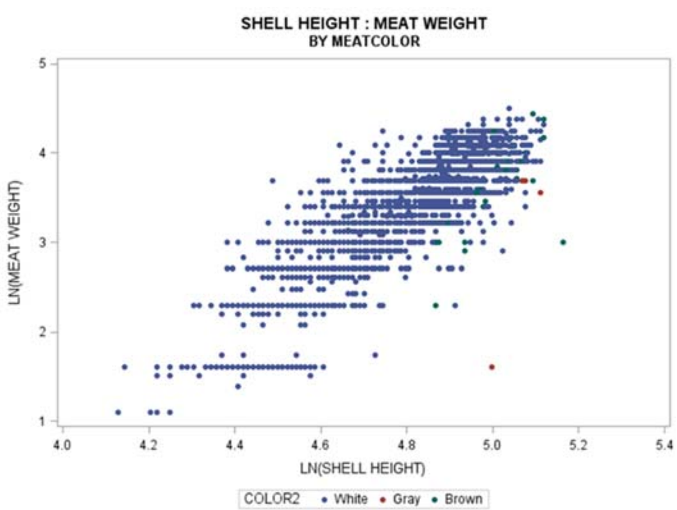



**Figure B1.** Shell Height:Meat Weight data for: **a)** all trips combined, **b)** all trips combined separated by month of sampling, and **c)** all trips combined separated by meat color.

**Appendix C: GLMM Model Details**

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

Assume that each gear combination tested in this experiment has a unique catchability. Let $q_r$ equal the catchability of the experimental dredge and $q_f$ equals the catchability of the control dredge used in the study. The efficiency of the experimental dredge relative to the control 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 experimental row dredge and *v*=*f* denotes the control dredge. Let $\lambda_{ir}$ represent the scallop/fish density for the $i^{th}$ station by the experimental dredge and $\lambda_{if}$ the scallop/fish density encountered by the control 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 control dredge is given by:

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

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

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

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

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir} = \lambda_{if}$), then $\rho$ 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 experimental 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:

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

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish captured by the experimental dredge. In this approach, the only unknown parameter is $\rho$ and the requirement to estimate $\mu$ 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 $\delta_i$ is a random effect assumed to be normally distributed with a mean=0 and variance=$\sigma^2$. 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 ($\beta_0$) 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:

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

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

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

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

The symbol $f_{ij}$ equals the categorical variable denoting dredge 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). In addition to evaluating the random effect as a function of tow, for this study we also evaluated cruise as relevant random effect and its inclusion in the final model was determined by a combination of AIC and a covariance test to assess the appropriateness of inclucion..

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

## Appendix D: Gear Comparison

**Table D1.** Model building for length-based models. Hierarchical models ranked based upon minimum AIC values. Some species have fewer candidate models as a function of non-convergence of individual models. In cases where random effects were included and insufficient variation intercept existed, the models converged; however, the inclusion of the random effects were not warranted and those model specifications were not included in the table. In cases where the delta AIC value was less than 2 units, the simpler model was chosen. The selected model is shown in bold. Given the large amount of length data associated with sea scallops, the addition of a low order polynomial term for length was explored.

| Species | Model | Fixed Effects | AIC Value | Delta AIC |
|---|---|---|---|---|
| American Plaice | M1 | INTERCEPT ONLY | 140.17 | 0.00 |
| | M2 | SLEN | 141.96 | 1.79 |
| | M5 | DEPTH | 142.14 | 1.97 |
| | M6 | SCOPE | 142.16 | 2.00 |
| | M3 | SLEN SLEN_SQ | 143.19 | 3.02 |
| | M7 | BEAUFORTSEASTATE | 143.33 | 3.16 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 144.92 | 4.75 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 149.23 | 9.06 |
| Barndoor Skate | M3 | SLEN SLEN_SQ | 1276.4 | 0.00 |
| | M6 | SCOPE | 1277.4 | 0.99 |
| | M1 | INTERCEPT ONLY | 1277.4 | 1.00 |
| | M2 | SLEN | 1277.7 | 1.33 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 1278.3 | 1.97 |
| | M5 | DEPTH | 1278.8 | 2.39 |
| | M7 | BEAUFORTSEASTATE | 1286.2 | 9.85 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 1291.2 | 14.85 |
| Fourspot Flounder | **M2** | **SLEN** | **749.98** | **0.00** |
| | M3 | SLEN SLEN_SQ | 751.96 | 2.50 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 752.84 | 2.86 |
| | M1 | INTERCEPT ONLY | 759.62 | 9.64 |
| | M6 | SCOPE | 760.05 | 10.07 |
| | M7 | BEAUFORTSEASTATE | 760.98 | 11.00 |
| | M5 | DEPTH | 761.35 | 11.37 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 763.51 | 13.53 |
| Monkfish | M3 | SLEN SLEN_SQ | 2774.1 | 0.00 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 2774.8 | 0.75 |
| | M1 | INTERCEPT ONLY | 2774.9 | 0.83 |
| | M2 | SLEN | 2775.5 | 1.37 |
| | M6 | SCOPE | 2776.1 | 2.04 |
| | M5 | DEPTH | 2776.3 | 2.23 |
| | M7 | BEAUFORTSEASTATE | 2781.4 | 7.28 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 2781.8 | 7.67 |
| Sea Scallops | **M3** | **SLEN SLEN_SQ** | **13347** | **0.00** |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 13349 | 2.00 |
| | M2 | SLEN | 13,384 | 36.57 |
| | M6 | SCOPE | 13,437 | 89.93 |
| | M1 | INTERCEPT ONLY | 13,442 | 94.73 |
| | M5 | DEPTH | 13,444 | 96.70 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 13,445 | 98.18 |
| | M7 | BEAUFORTSEASTATE | 13,451 | 103.61 |
| Summer Flounder | M2 | SLEN | 253.00 | 0.00 |
| | M3 | SLEN SLEN_SQ | 253.21 | 0.21 |
| | M1 | INTERCEPT ONLY | 253.64 | 0.64 |

| Species | Model | Fixed Effects | AIC Value | Delta AIC |
|---|---|---|---|---|
| | M6 | SCOPE | 255.18 | 2.18 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 255.20 | 2.20 |
| | M5 | DEPTH | 255.44 | 2.44 |
| | M7 | BEAUFORTSEASTATE | 259.66 | 6.66 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 263.13 | 10.13 |
| Windowpane Flounder | M7 | BEAUFORTSEASTATE | 3,788.9 | 0.00 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 3,793.0 | 4.07 |
| | M1 | INTERCEPT ONLY | 3,795.8 | 6.89 |
| | M2 | SLEN | 3,797.3 | 8.45 |
| | M6 | SCOPE | 3,797.4 | 8.46 |
| | M5 | DEPTH | 3,797.8 | 8.89 |
| | M3 | SLEN SLEN_SQ | 3,798.4 | 9.52 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 3,799.9 | 11.02 |
| Winter Flounder | M6 | SCOPE | 210.37 | 0.00 |
| | M1 | INTERCEPT ONLY | 211.44 | 1.06 |
| | M2 | SLEN | 213.42 | 3.05 |
| | M5 | DEPTH | 213.43 | * |
| | M3 | SLEN SLEN_SQ | 215.13 | 4.76 |
| | M7 | BEAUFORTSEASTATE | 216.02 | 5.65 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 217.06 | 6.69 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 218.87 | 8.50 |
| Yellowtail Flounder | M1 | INTERCEPT ONLY | 538.59 | 0.00 |
| | M3 | SLEN SLEN_SQ | 538.62 | 0.03 |
| | M2 | SLEN | 539.13 | 0.54 |
| | M5 | DEPTH | 540.31 | 1.72 |
| | M6 | SCOPE | 540.38 | 1.79 |
| | M4 | SLEN SLEN_SQ SLEN_CUBE | 540.44 | 1.85 |
| | M7 | BEAUFORTSEASTATE | 543.04 | 4.45 |
| | M8 | DEPTH \| BEAUFORTSEASTATE | 550.75 | 12.16 |

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

| Effect | Estimate | SE | DF | t value | p value | LCL | UCL |
|---|---|---|---|---|---|---|---|
| Intercept | 0.081 | 0.115 | 7 | 0.707 | 0.5027 | -0.191 | 0.353 |
| Size | -0.483 | 0.139 | 463 | -3.483 | 0.0005 | -0.756 | -0.211 |

**Table D3**. Models examining the unpooled catch data. Results are presented from the model that provided the best fit (intercept, length and length^2) to the sea scallop data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

| Effect | Estimate | SE | DF | t value | p value | LCL | UCL |
|---|---|---|---|---|---|---|---|
| Intercept | -0.309 | 0.053 | 184 | -5.832 | 0.0000 | -0.413 | -0.204 |
| Size | -0.170 | 0.032 | 2161 | -5.355 | 0.0000 | -0.232 | -0.108 |
| Size^2 | 0.179 | 0.029 | 2161 | 6.086 | 0.0000 | 0.121 | 0.237 |

**Table D4.** Model building for pooled-over-length models. Hierarchical models ranked based upon minimum AIC values.

| Species | Model | Fixed Effects | AIC Value | Delta AIC |
|---|---|---|---|---|
| Barndoor Skate | M3 | SCOPE | 522.70 | 0.00 |
| | **M1** | **INTERCEPT ONLY** | **522.71** | **0.01** |
| | M2 | DEPTH | 524.10 | 1.40 |
| | M4 | BEAUFORTSEASTATE (BSS) | 531.56 | 8.86 |
| | M5 | DEPTH *BSS | 532.80 | 10.10 |
| Monkfish | **M1** | **INTERCEPT ONLY** | **922.59** | **0.00** |
| | M3 | SCOPE | 923.80 | 1.21 |
| | M2 | DEPTH | 923.99 | 1.40 |
| | M4 | BEAUFORTSEASTATE | 929.04 | 6.45 |
| | M5 | DEPTH *BSS | 929.33 | 6.74 |
| Summer Flounder | **M1** | **INTERCEPT ONLY** | **172.01** | **0.00** |
| | M3 | SCOPE | 173.55 | 1.54 |
| | M2 | DEPTH | 173.82 | 1.81 |
| | M4 | BEAUFORTSEASTATE | 178.03 | 6.02 |
| | M5 | DEPTH *BSS | 178.58 | 6.57 |
| Uncl. Skates | M2 | DEPTH | 2713.3 | 0.00 |
| | **M1** | **INTERCEPT ONLY** | **2713.6** | **0.32** |
| | M3 | SCOPE | 2715.6 | 2.30 |
| | M5 | DEPTH *BSS | 2716.2 | 3.00 |
| | M4 | BEAUFORTSEASTATE | 2716.4 | 3.16 |
| Windowpane Flounder | **M4** | **BEAUFORTSEASTATE** | **1173.8** | **0.00** |
| | M5 | DEPTH *BSS | 1175.8 | 2.01 |
| | M1 | INTERCEPT ONLY | 1180.5 | 6.77 |
| | M3 | SCOPE | 1182.1 | 8.33 |
| | M2 | DEPTH | 1182.5 | 8.77 |
| Yellowtail Flounder | **M1** | **INTERCEPT ONLY** | **311.51** | **0.00** |
| | M2 | DEPTH | 313.23 | 1.72 |
| | M3 | SCOPE | 313.30 | 1.79 |
| | M4 | BEAUFORTSEASTATE | 315.96 | 4.45 |
| | M5 | DEPTH *BSS | 317.65 | 6.14 |

**Table D5.** Models examining the pooled-over-length catch data. Results are presented from the model that provided the best fit (intercept only) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

| Species | Effect | Estimate | SE | DF | t value | p value | LCL | UCL |
|---|---|---|---|---|---|---|---|---|
| American Plaice | Intercept | -0.223 | 0.201 | 56 | -1.108 | 0.2724 | -0.627 | 0.180 |
| Barndoor Skates | Intercept | -0.048 | 0.089 | 161 | -0.545 | 0.5865 | -0.223 | 0.127 |
| Monkfish | Intercept | 0.019 | 0.050 | 291 | 0.371 | 0.7108 | -0.080 | 0.117 |
| Summer Flounder | Intercept | 0.102 | 0.146 | 90 | 0.697 | 0.4879 | -0.188 | 0.392 |
| Uncl. Skates | Intercept | -0.208 | 0.041 | 367 | -5.118 | 0.0000 | -0.288 | -0.128 |
| Winter Flounder | Intercept | -0.220 | 0.161 | 71 | -1.362 | 0.1776 | -0.542 | 0.102 |
| Yellowtail Flounder | Intercept | -0.195 | 0.098 | 132 | -1.981 | 0.0497 | -0.390 | -0.000 |

**Table D6.** Models examining the pooled-over-length windowpane flounder catch data. Results are presented from the model that provided the best fit (intercept, cruise) 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.

| Effect | Beaufort Number | Estimate | SE | DF | t value | p value | LCL | UCL |
|---|---|---|---|---|---|---|---|---|
| Intercept | . | -0.114 | 0.161 | 266 | -0.708 | 0.4797 | -0.431 | 0.203 |
| Beaufort Number | 0 | 0.195 | 0.262 | 266 | 0.745 | 0.4569 | -0.321 | 0.712 |
| Beaufort Number | 1 | -0.183 | 0.229 | 266 | -0.799 | 0.4248 | -0.633 | 0.268 |
| Beaufort Number | 2 | -0.171 | 0.138 | 266 | -1.237 | 0.2170 | -0.444 | 0.101 |
| Beaufort Number | 3 | -0.176 | 0.135 | 266 | -1.305 | 0.1930 | -0.441 | 0.089 |
| Beaufort Number | 4 | -0.112 | 0.145 | 266 | -0.776 | 0.4387 | -0.397 | 0.172 |
| Beaufort Number | 5 | 0.000 | . | . | . | . | . | . |

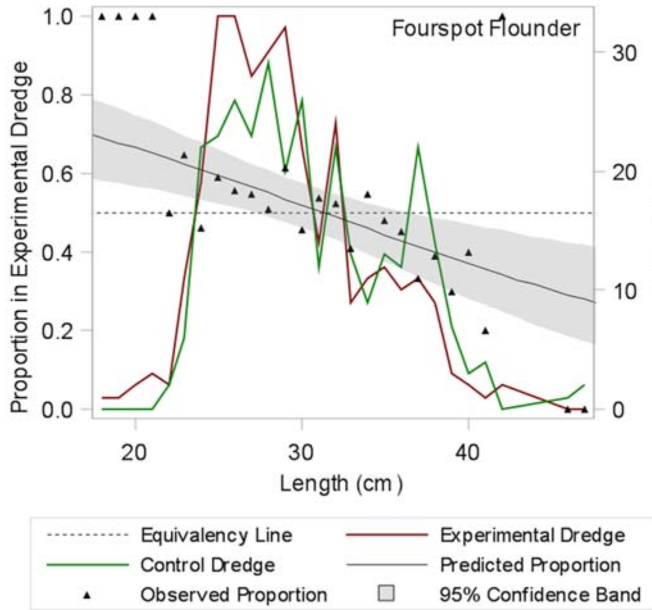



**Figure D1.** Relative fourspot flounder catch by the two dredge configurations. The triangles represent the observed proportion at length (Catchexp/(Catchexp + Catchcont), with a proportion >0.5 representing more animals at length captured by the experimental apron dredge. The grey area represents 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 at the station level.

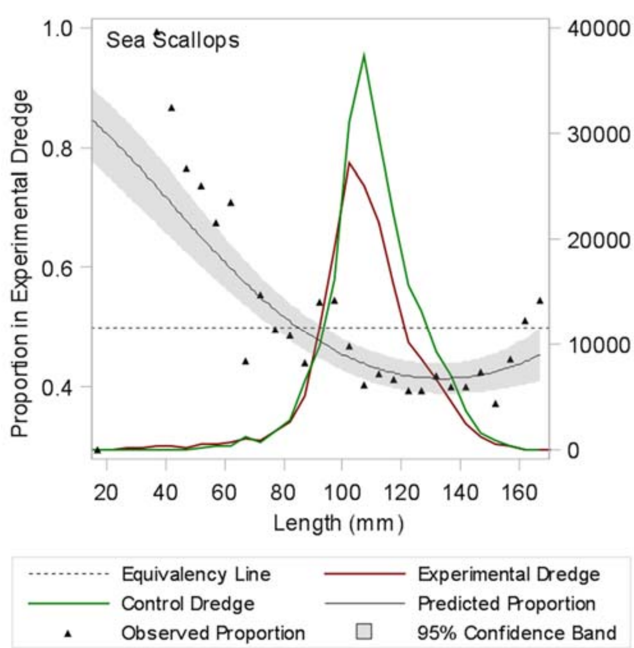



**Figure D2.** Relative sea scallop catch by the two dredge configurations. The triangles represent the observed proportion at length (Catchexp/(Catchexp + Catchcont), with a proportion >0.5 representing more animals at length captured by the experimental apron dredge. The grey area represents the 95% 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 at the station level.

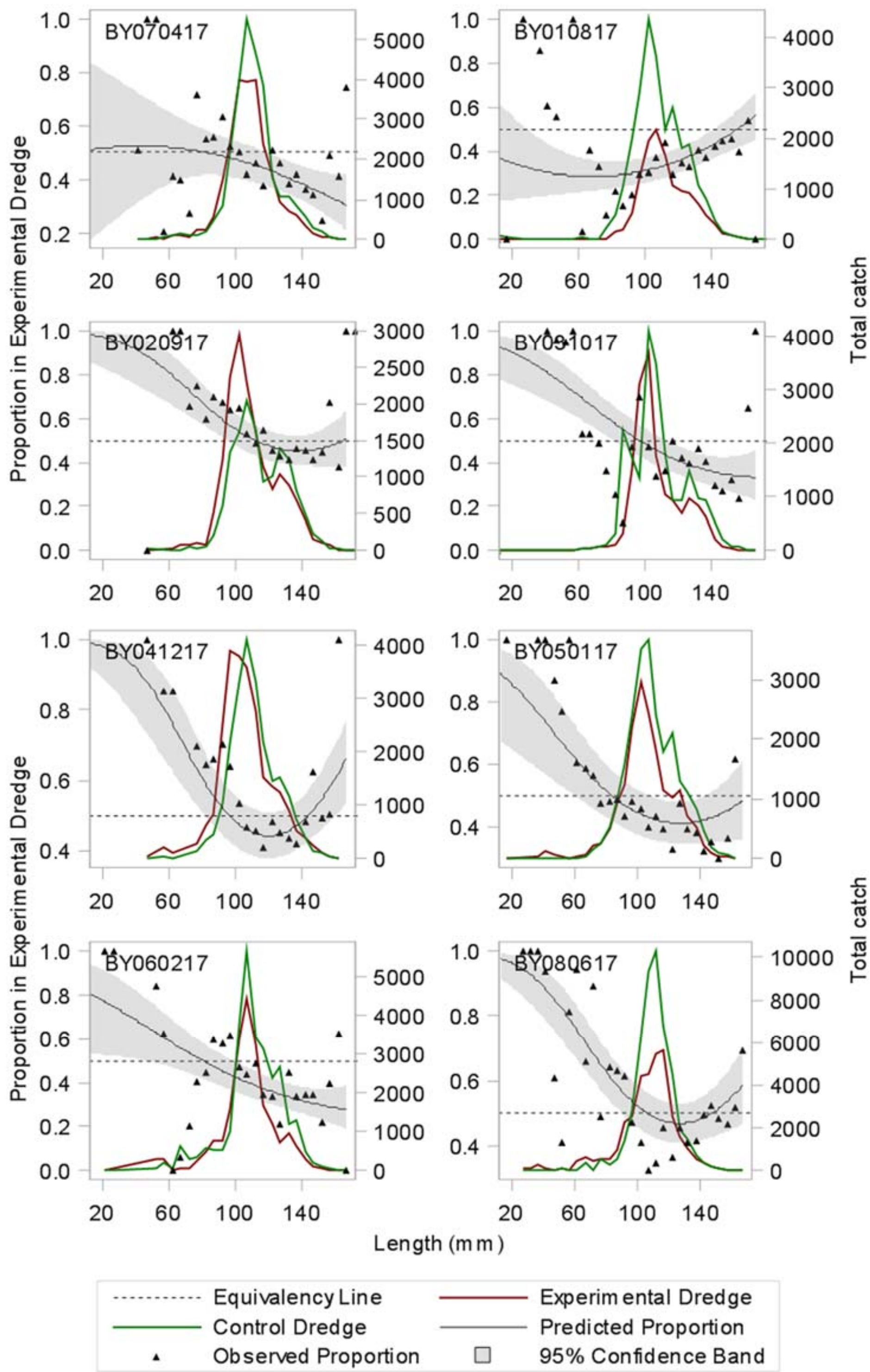



**Figure D3.** Relative catch by the two dredge configurations for sea scallops by cruise. The triangles represent the observed proportion at length (Catchexp/(Catchexp + Catchcont), with a proportion >0.5 representing more animals at length captured by the experimental apron dredge. The grey area represents 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 at the station level.

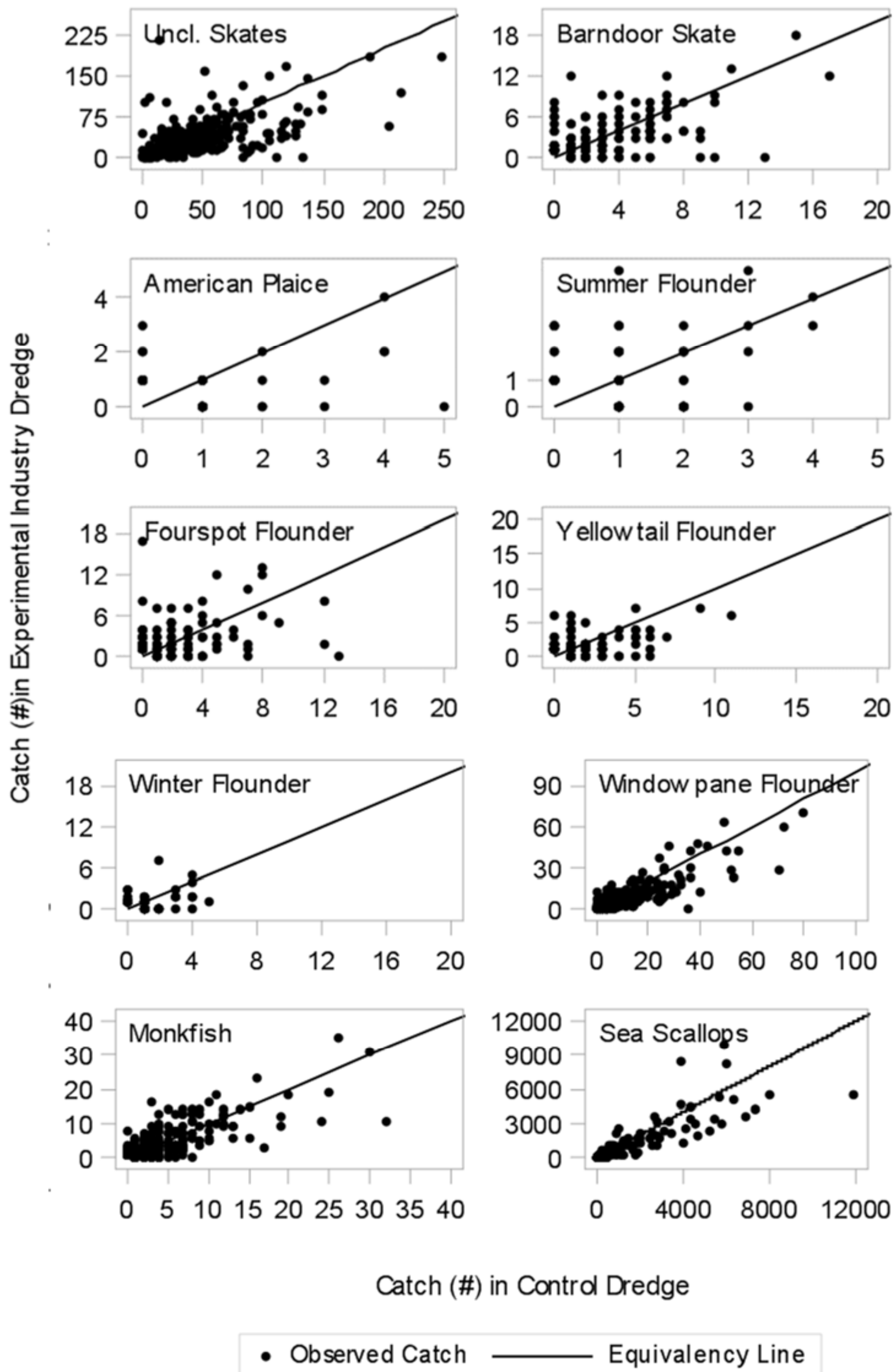



**Figure D4.** Scatterplots of the paired catch data for unclassified skates for uncl. skates, barndoor skates, american plaice, summer flounder, fourspot flounder, yellowtail flounder, winter flounder, windowpane flounder, monkfish and sea scallops

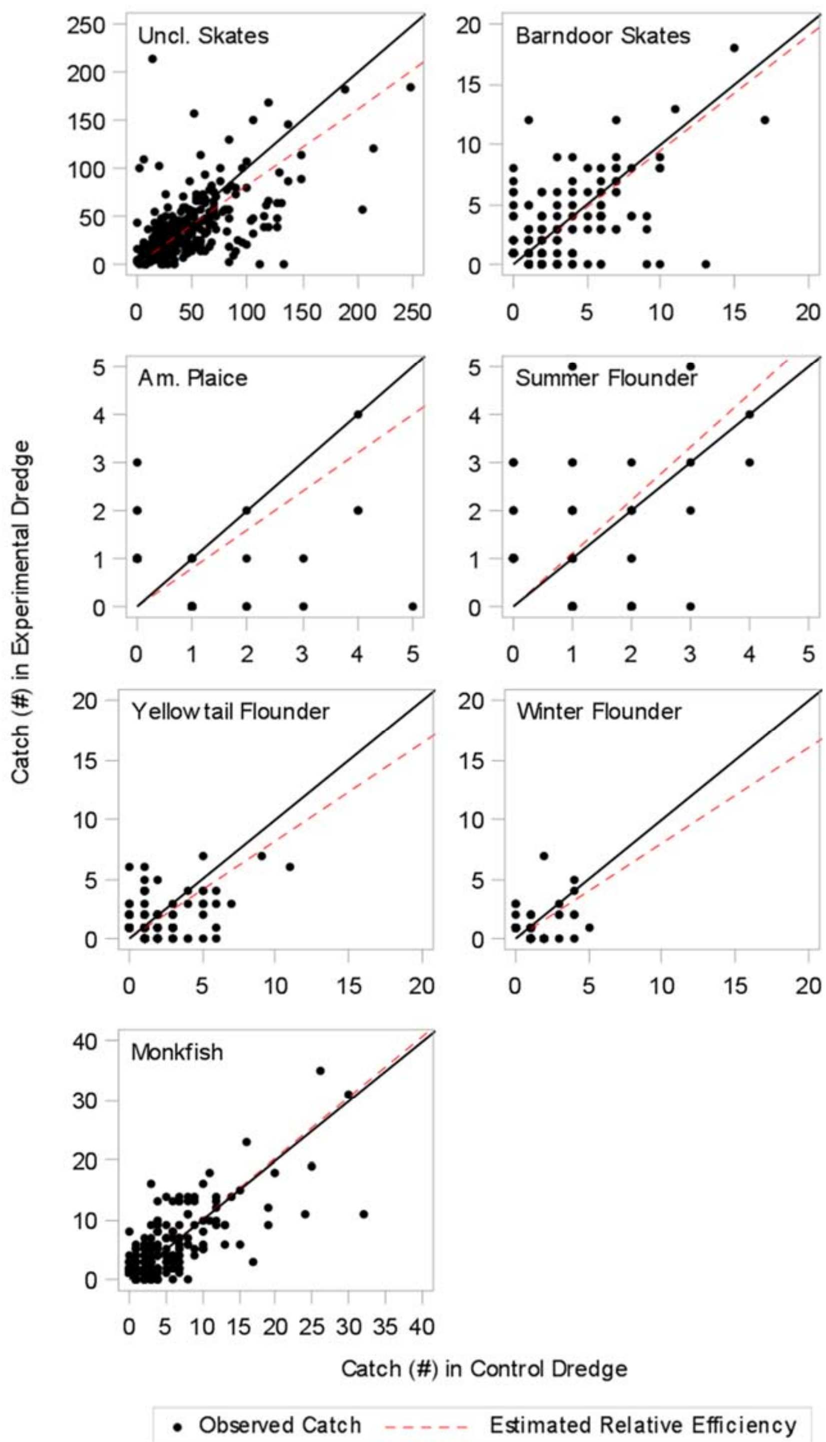



**Figure D5.** Total pooled catches for unclassified skates, barndoor skates, american plaice, summer flounder yellowtail flounder, winter flounder and monkfish for the experimental dredge vs. the control dredge. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

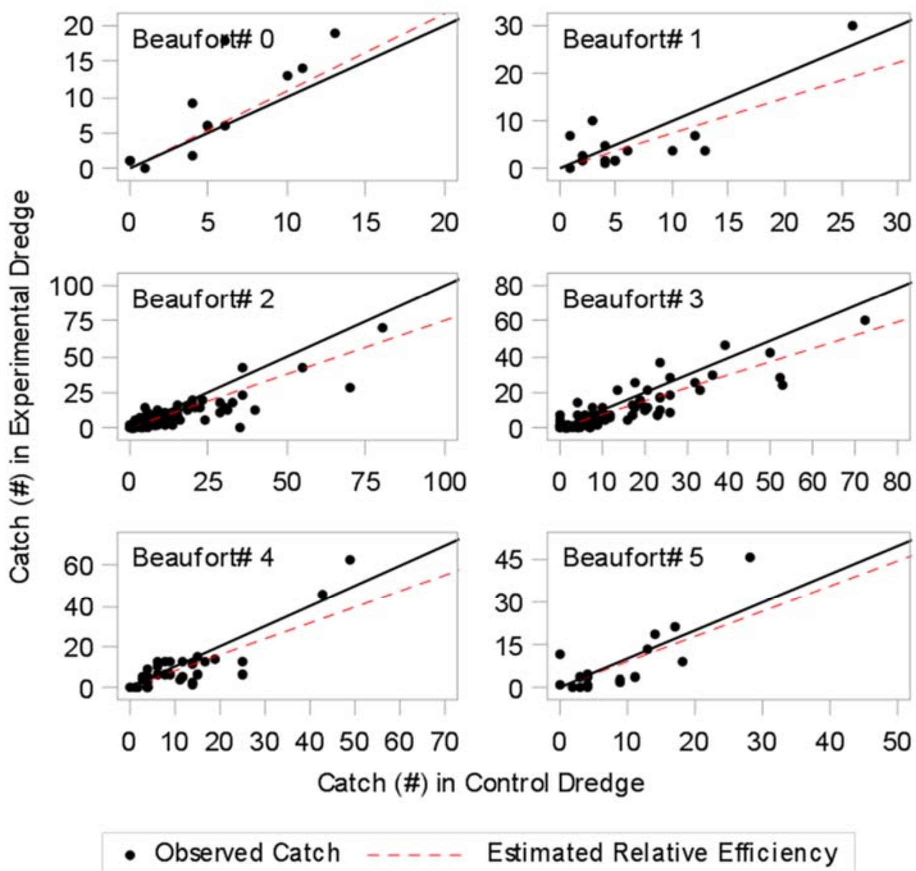



**Figure D6.** Total pooled catches for windowpane flounder for the experimental dredge vs. the control dredge. Model output from the analysis of the pooled data indicated that the model that included Beaufort Number as a predictor was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

## Appendix E: Statistical analysis of gray meat histology scores

**Table E1.** Cellularity scores

| **ANOVA(cellularityScore~meatColor)** | | | | | |
|---|---|---|---|---|---|
| | **Df** | **SS** | **Mean Sq** | **F value** | **Pr (>F)** |
| Meat color | 3 | 251.3 | 83.75 | 20.86 | 2.19E-12 |
| Residuals | 326 | 1309.1 | 4.02 | | |
| --- | | | | | |

| **Tukey multiple comparison of means (95% family-wise confidence level)** | | | | |
|---|---|---|---|---|
| | **Difference** | **Lower** | **Upper** | **p adj** |
| **Tan-White** | **1.425** | **0.376** | **2.473** | **0.003** |
| **Brown-White** | **1.479** | **0.520** | **2.438** | **<0.001** |
| **Gray-White** | **1.879** | **1.237** | **2.522** | **<0.001** |
| Brown-Tan | 0.054 | -1.237 | 1.345 | 1.000 |
| Gray-Tan | 0.455 | -0.623 | 1.532 | 0.696 |
| Gray-Brown | 0.401 | -0.590 | 1.391 | 0.723 |

**Table E2.** Muscle condition

| **ANOVA(muscleConditione~meatColor)** | | | | | |
|---|---|---|---|---|---|
| | **Df** | **SS** | **Mean Sq** | **F value** | **Pr (>F)** |
| Meat color | 3 | 15.96 | 5.319 | 7.232 | 1.04E-04 |
| Residuals | 326 | 239.79 | 0.736 | | |
| --- | | | | | |

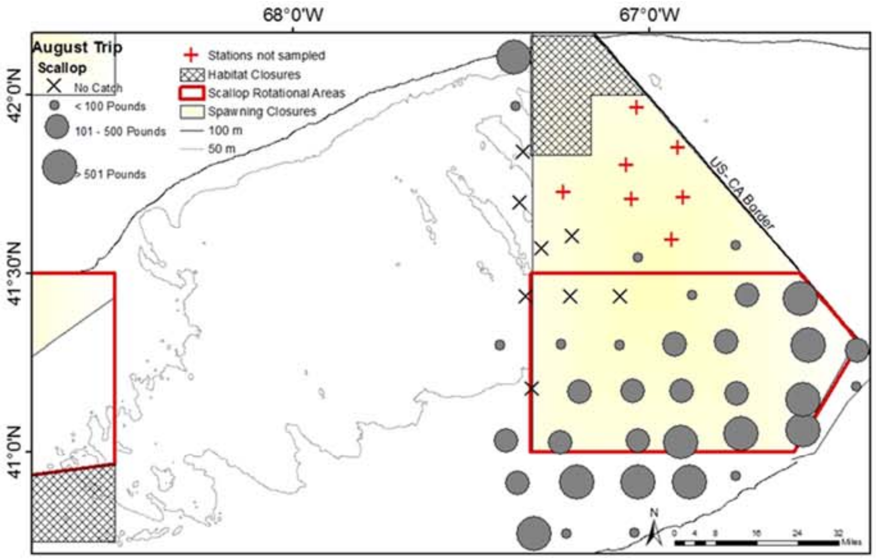
| **Tukey multiple comparison of means (95% family-wise confidence level)** | | | | |
|---|---|---|---|---|
| | **Difference** | **Lower** | **Upper** | **p adj** |
| Tan-White | -0.042 | -0.490 | 0.407 | 0.995 |
| **Brown-White** | **0.476** | **0.066** | **0.887** | **0.016** |
| **Gray-White** | **0.420** | **0.145** | **0.695** | **0.001** |
| Brown-Tan | 0.518 | -0.035 | 1.070 | 0.075 |
| **Gray-Tan** | **0.462** | **0.001** | **0.923** | **0.050** |
| Gray-Brown | -0.056 | -0.480 | 0.368 | 0.986 |

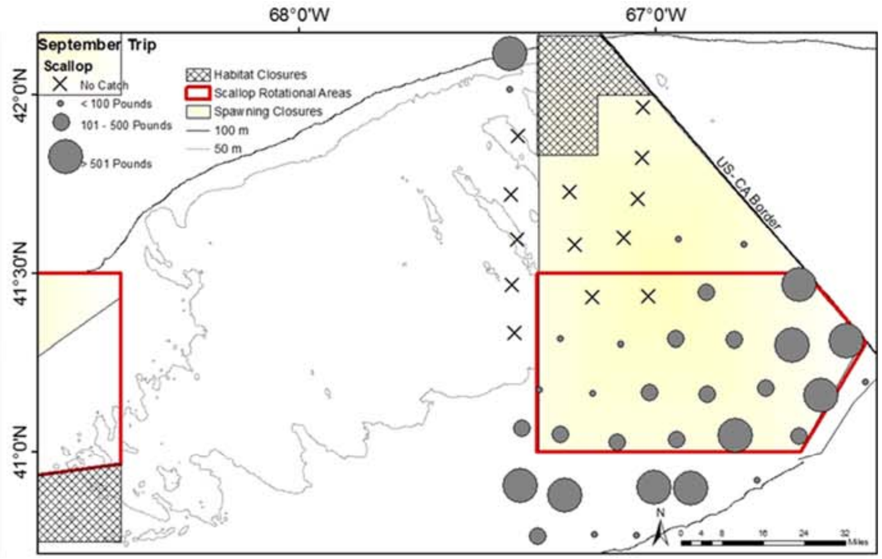
**Table E3.** Zoite number

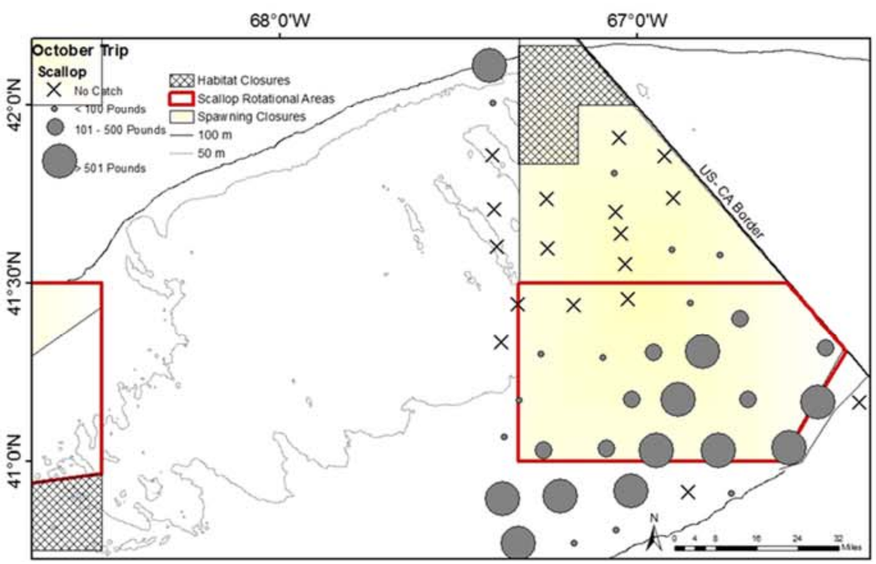
| **ANOVA(zoiteNumber~meatColor)** | | | | | |
|---|---|---|---|---|---|
| | **Df** | **SS** | **Mean Sq** | **F value** | **Pr (>F)** |
| Meat color | 3 | 406 | 135.41 | 8.823 | 1.22E-05 |
| Residuals | 326 | 5003 | 15.35 | | |
| --- | | | | | |

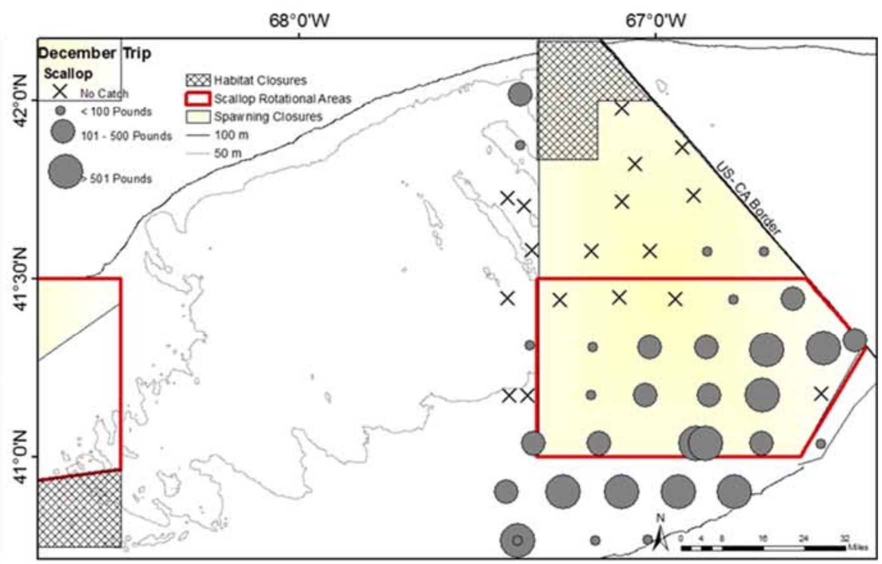
| **Tukey multiple comparison of means (95% family-wise confidence level)** | | | | |
|---|---|---|---|---|
| | **Difference** | **Lower** | **Upper** | **p adj** |
| **Tan-White** | **3.182** | **1.132** | **5.232** | **<0.001** |
| **Brown-White** | **2.441** | **0.566** | **4.316** | **0.005** |
| **Gray-White** | **1.631** | **0.375** | **2.888** | **0.005** |
| Brown-Tan | -0.741 | -3.266 | 1.783 | 0.873 |
| Gray-Tan | -1.551 | -3.657 | 0.555 | 0.229 |
| Gray-Brown | -0.810 | -2.746 | 1.126 | 0.702 |

**Appendix F: Distribution of scallops and the main bycatch species**



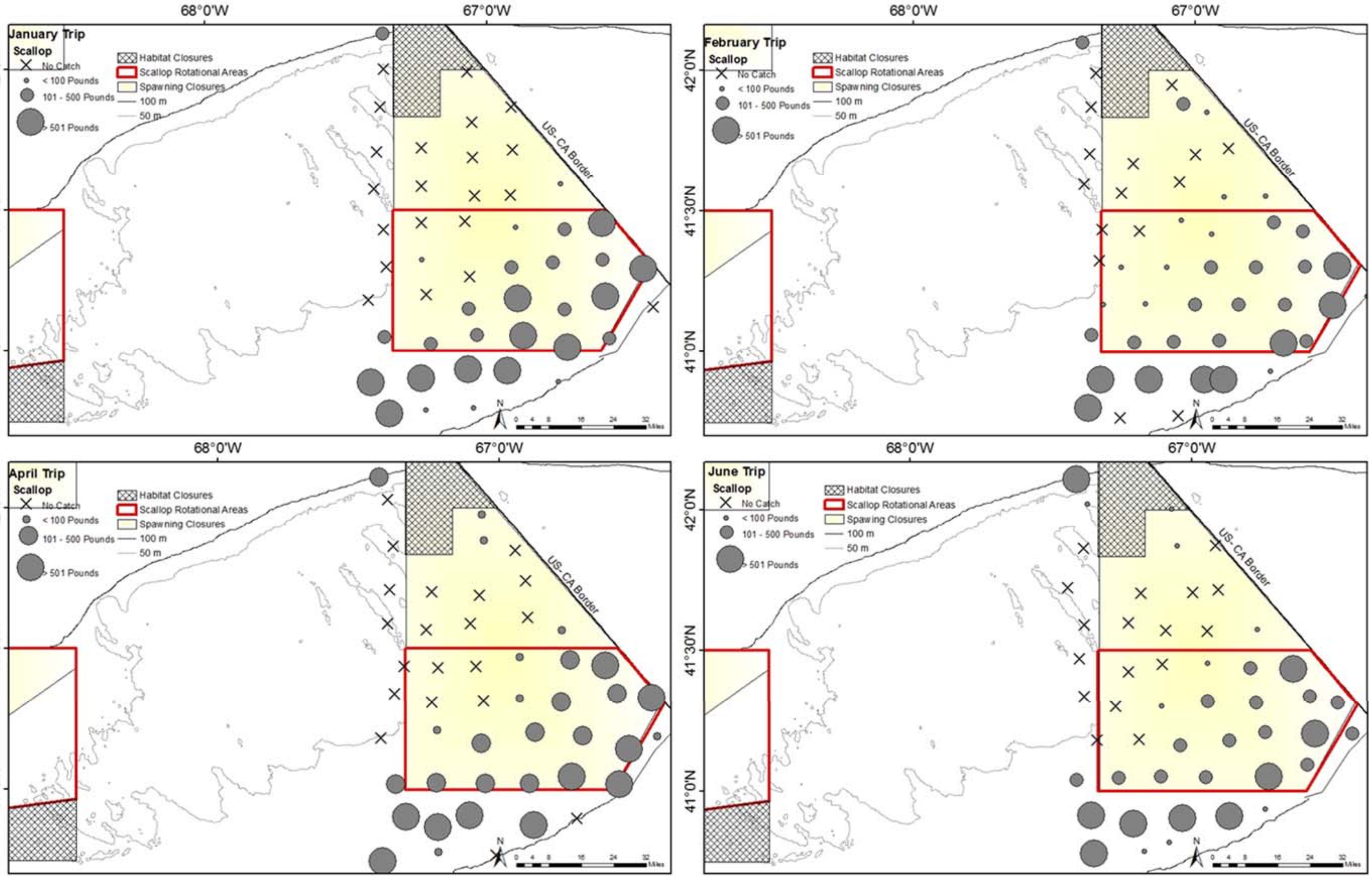
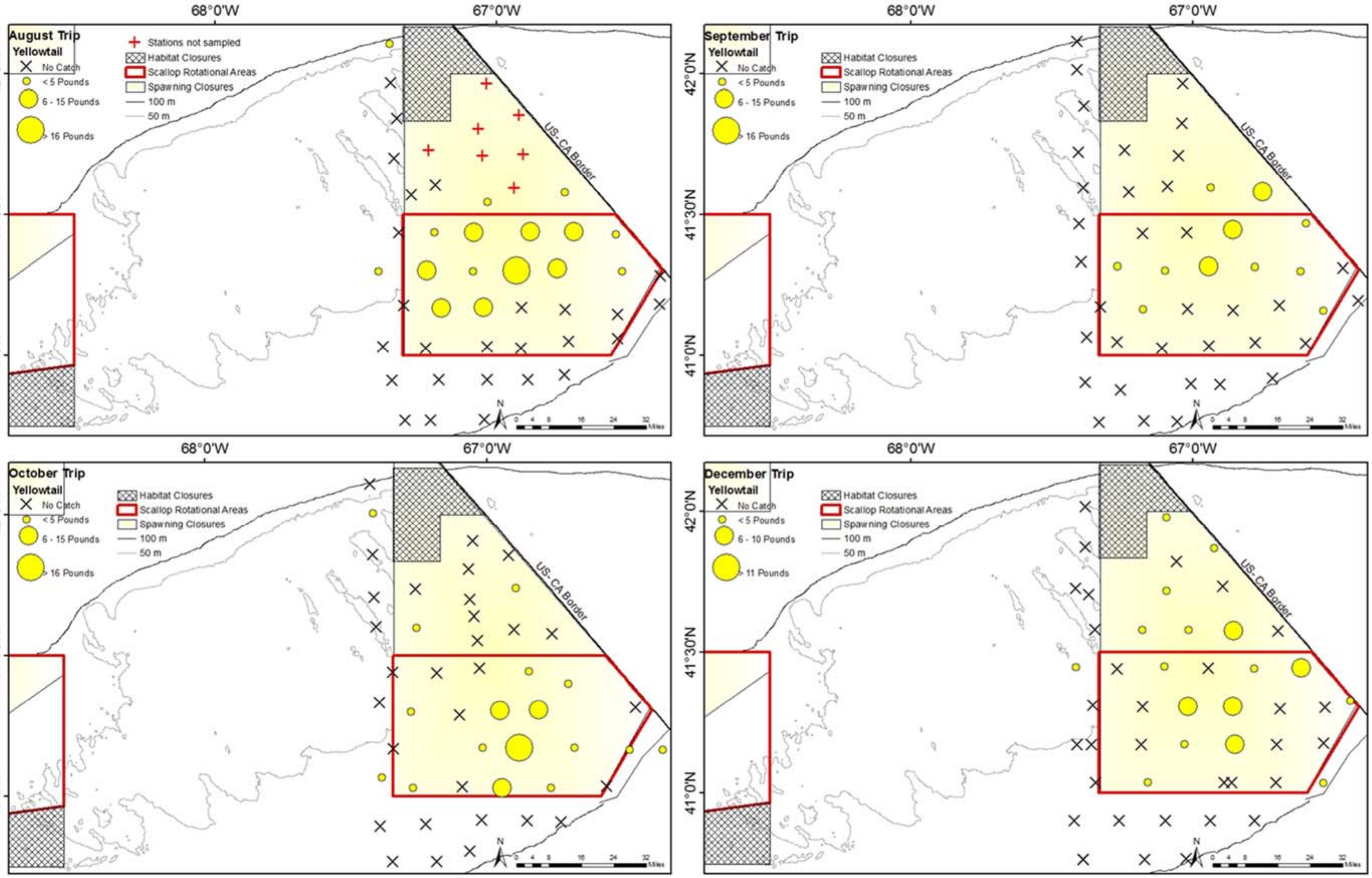



**Figure F1.** Distribution of sea scallops during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.



August Trip
Yellowtail
No Catch
< 5 Pounds
6 - 15 Pounds
> 16 Pounds
Stations not sampled
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US-CA Border
September Trip
October Trip
December Trip
6 - 10 Pounds
> 11 Pounds
68°0'W
67°0'W
42°0'N
41°30'N
41°0'N
N
Miles

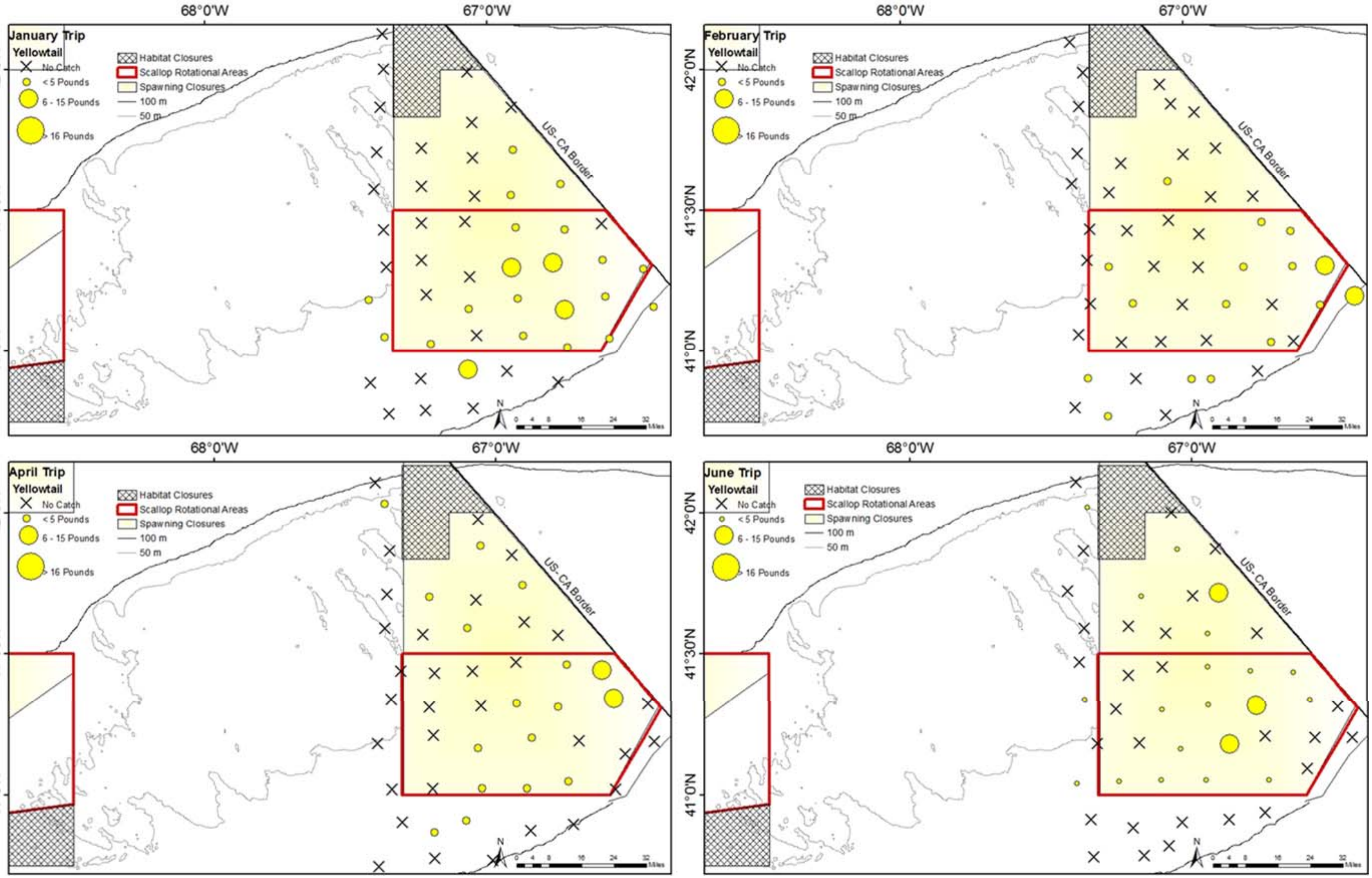
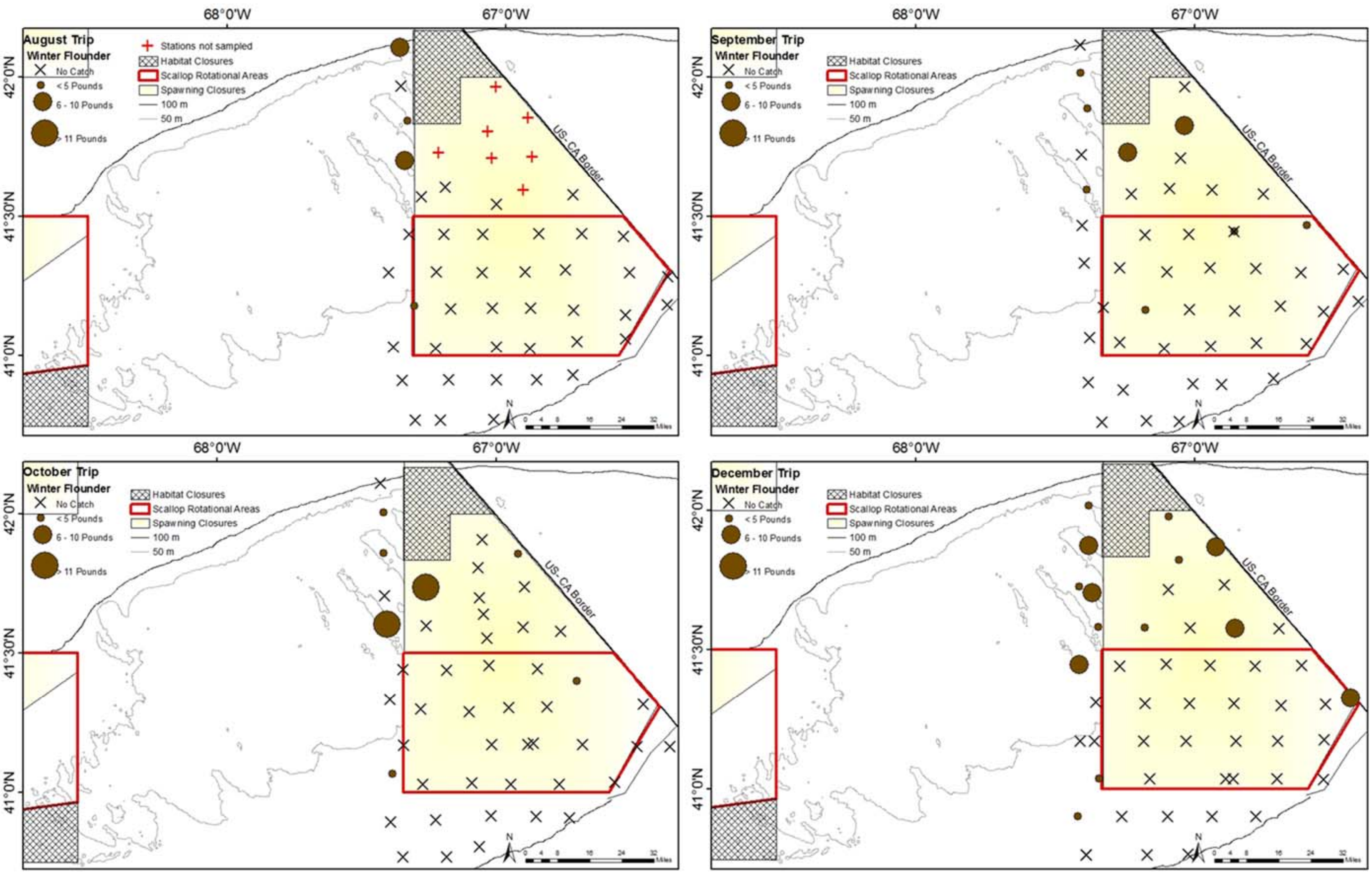



**Figure F2.** Distribution of yellowtail flounder during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.


August Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Stations not sampled
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
68°0'W
67°0'W
42°0'N
41°30'N
41°0'N
Miles
September Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
October Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
December Trip
Winter Flounder
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border

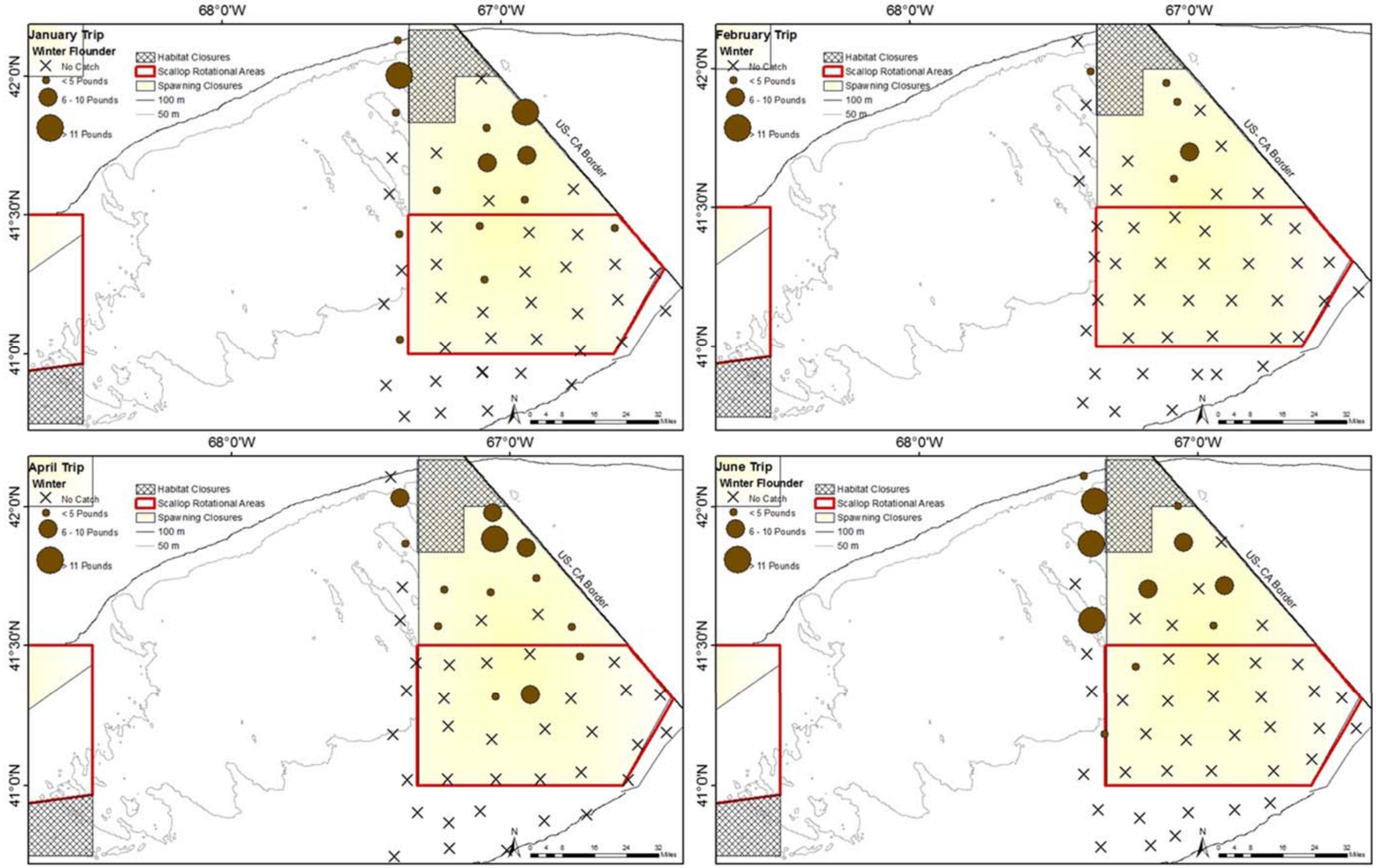
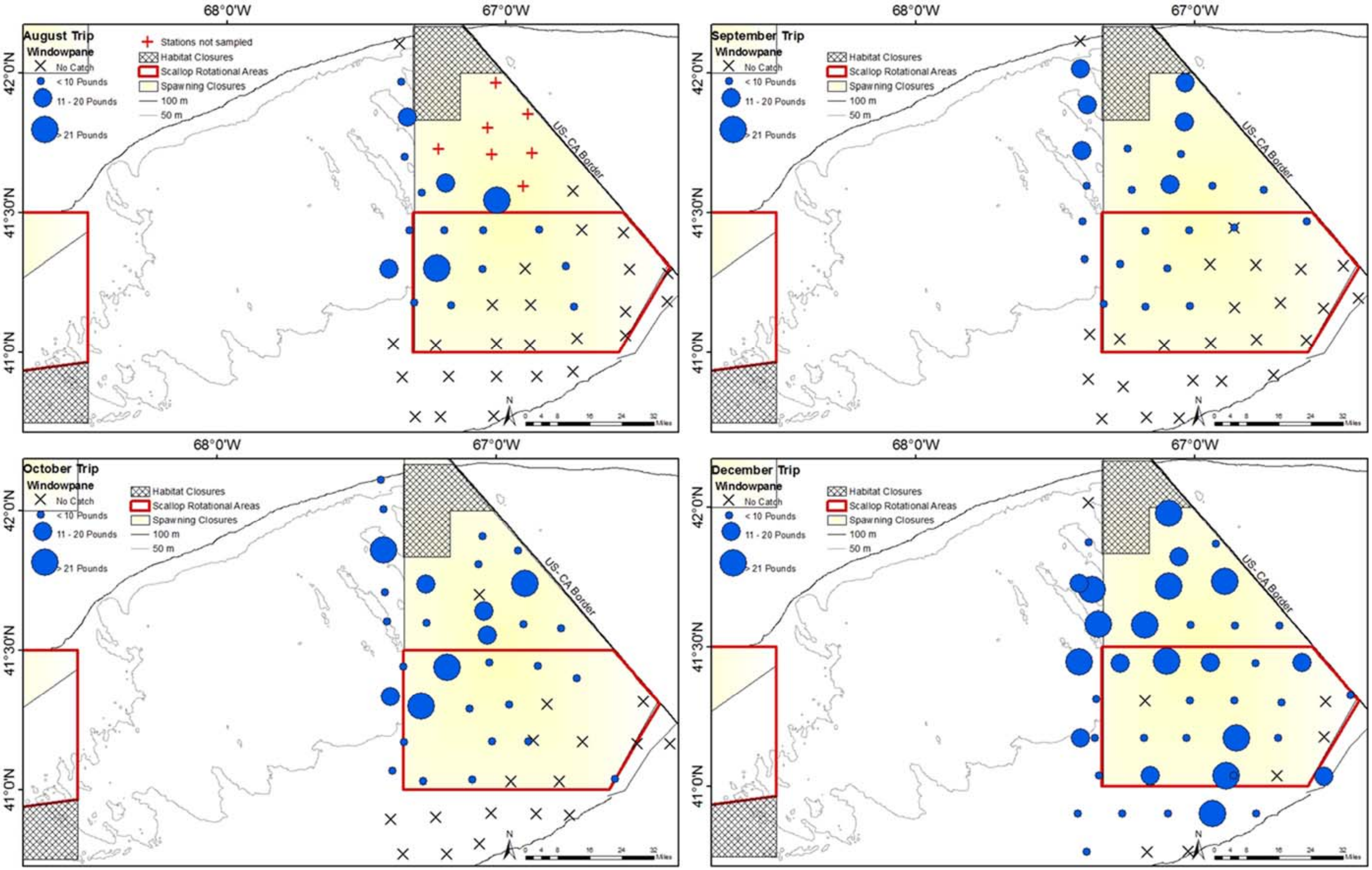



**Figure F3.** Distribution of winter flounder during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.


68°0'W
67°0'W
42°0'N
41°30'N
41°0'N
August Trip
Windowpane
No Catch
< 10 Pounds
11 - 20 Pounds
> 21 Pounds
Stations not sampled
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
September Trip
October Trip
December Trip
Miles

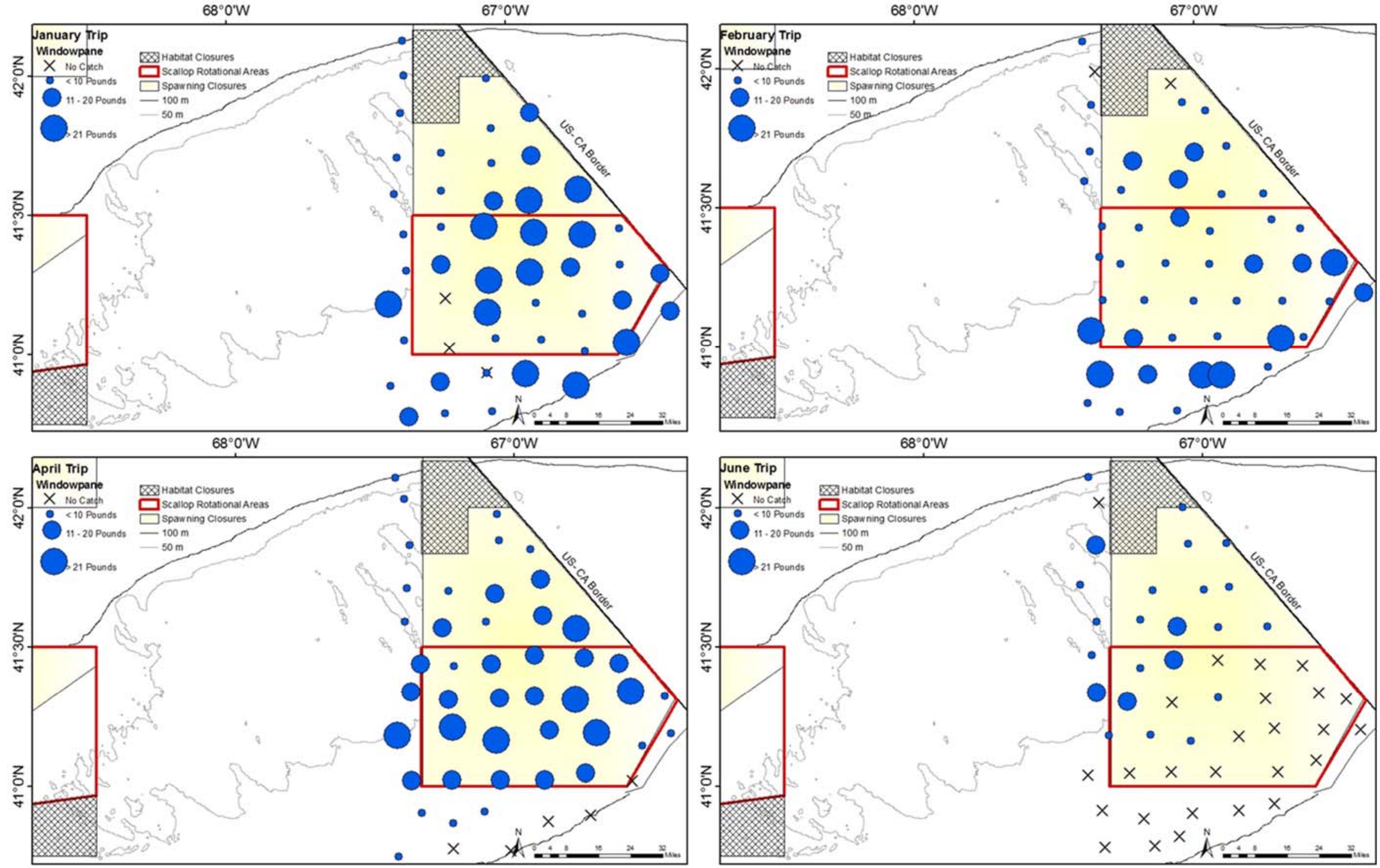
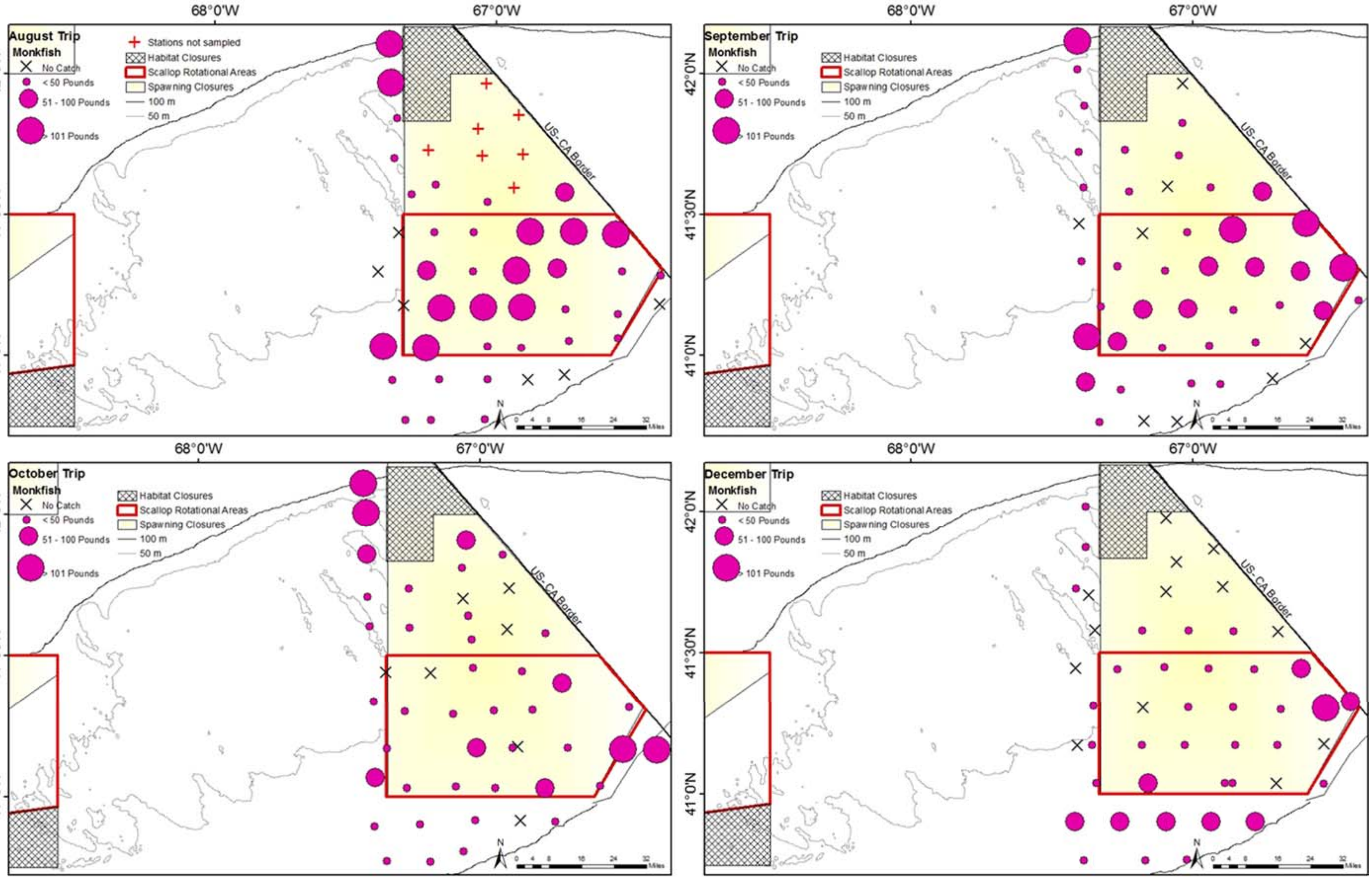



**Figure F4.** Distribution of windowpane flounder during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.


68°0'W
67°0'W
42°0'N
41°30'N
41°0'N
August Trip
Monkfish
No Catch
< 50 Pounds
51 - 100 Pounds
> 101 Pounds
Stations not sampled
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
September Trip
October Trip
December Trip
N
0 4 8 16 24 32
Miles

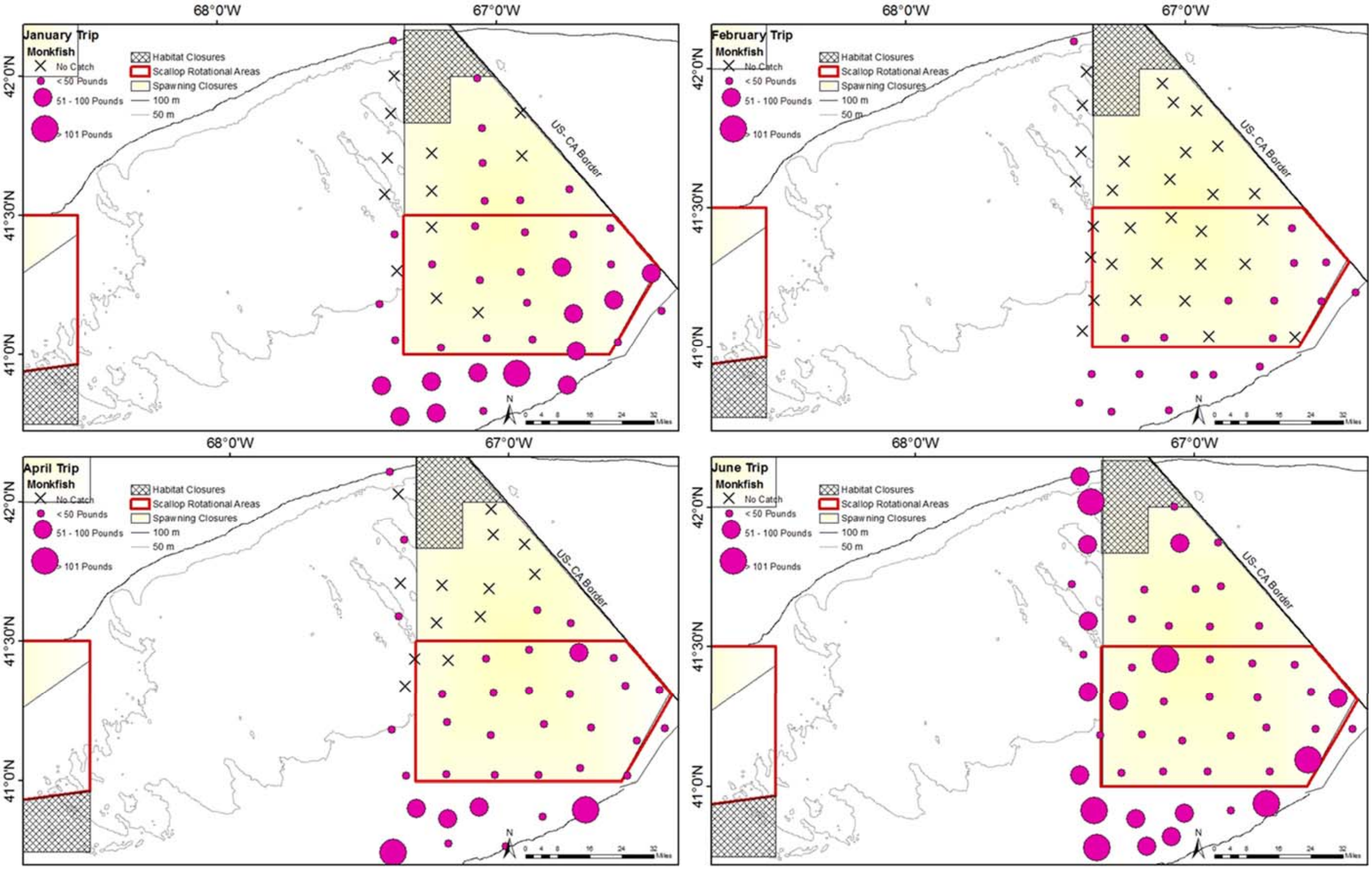
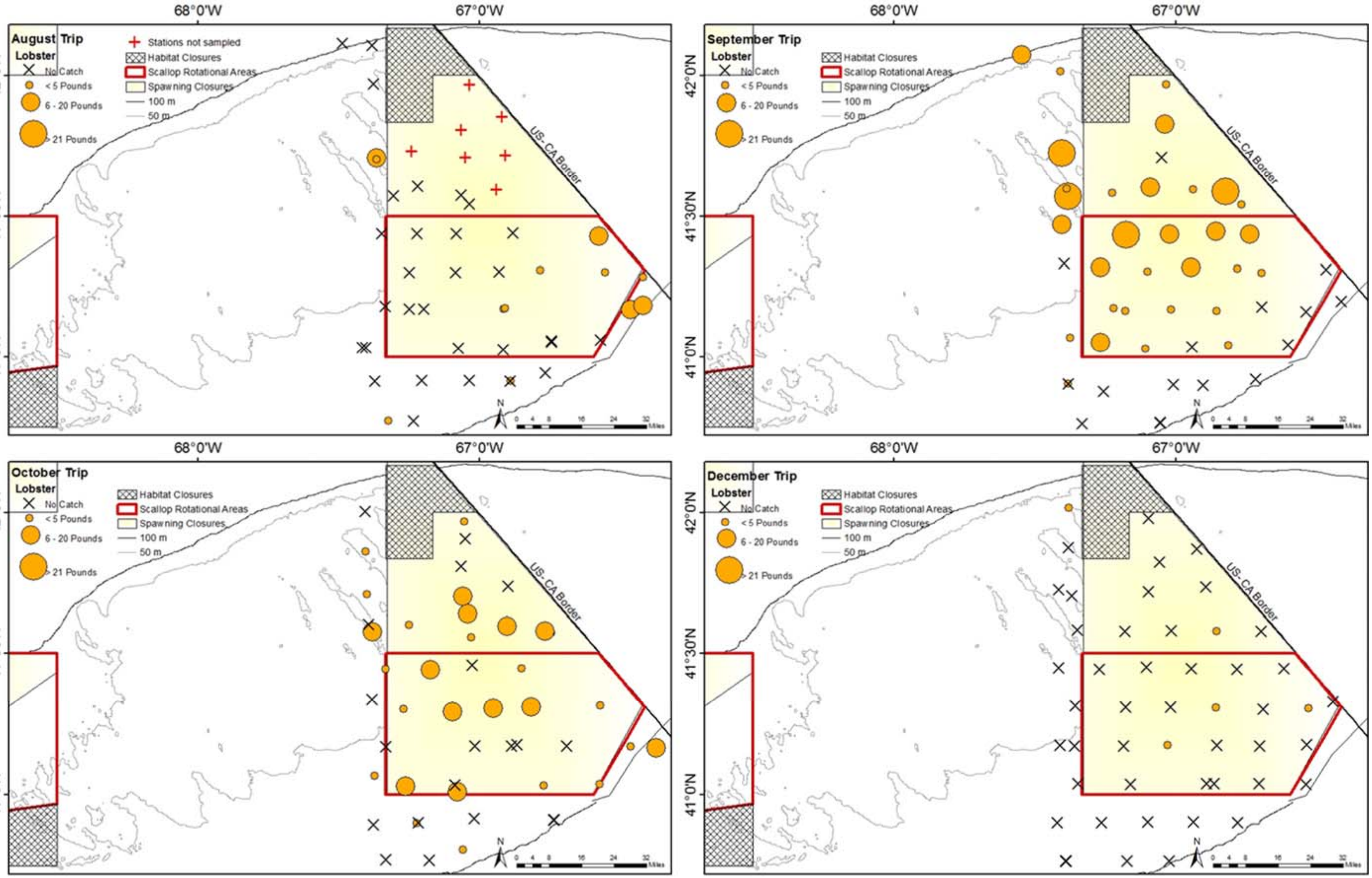



**Figure F5.** Distribution of monkfish during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.



68°0'W
67°0'W
42°0'N
41°30'N
41°0'N
August Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Stations not sampled
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
September Trip
October Trip
December Trip
N
Miles

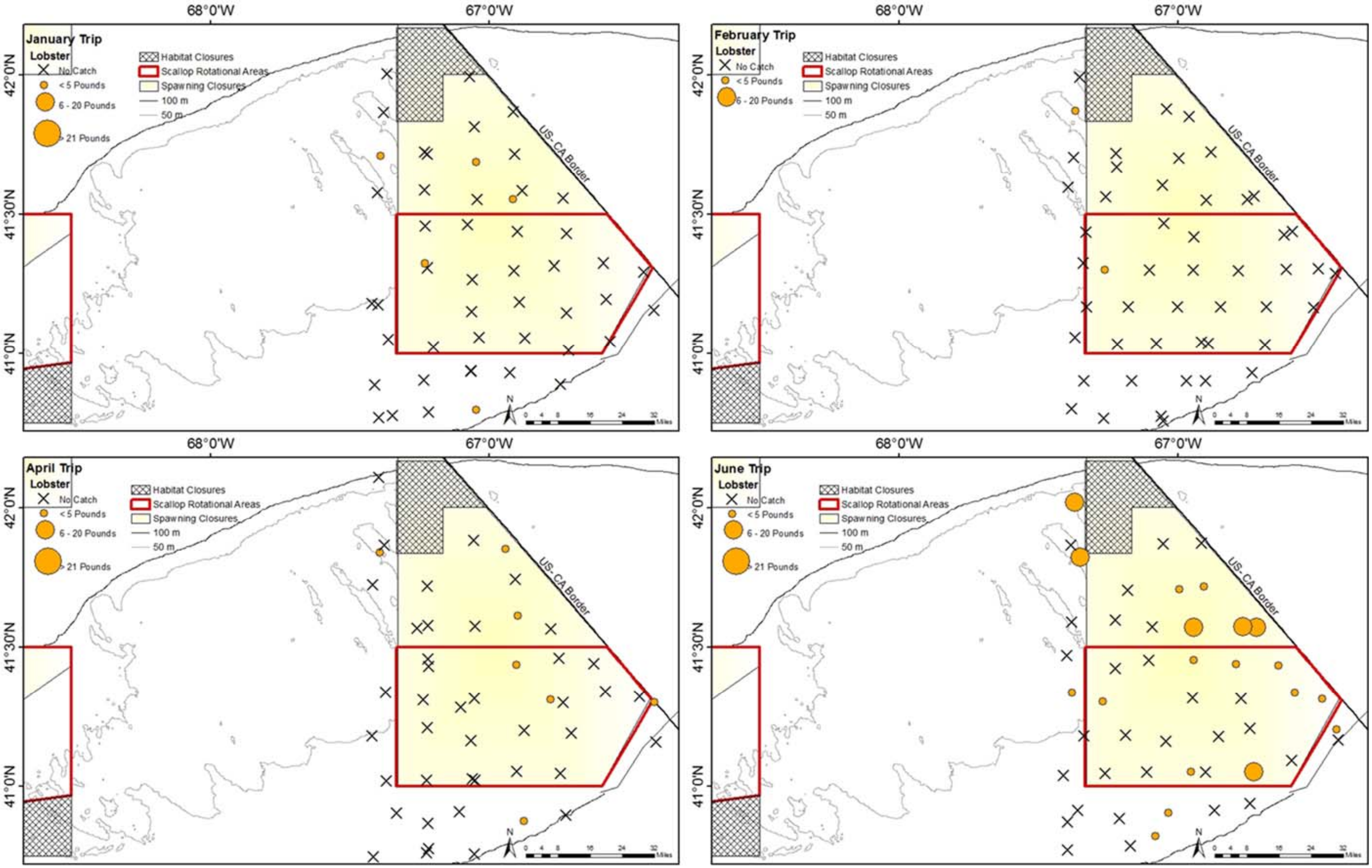



**Figure F6.** Distribution of lobster during the 2017 seasonal bycatch survey on the eastern portion of Georges Bank.