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

Final Report

Prepared for the 2018
Sea Scallop Research Set-Aside
(NA18NMF4540010)
November 2019

Submitted By

Luisa Garcia and Liese Siemann - Coonamessett Farm Foundation, Inc.
Ronald Smolowitz – Coonamessett Farm
Roxanne Smolowitz – Roger Williams University

Coonamessett Farm Foundation, Inc
277 Hatchville Road
East Falmouth, MA 02536

508-356-3601 FAX 508-356-3603
contact@cfarm.org

www.cfarm.org

Table of Contents

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report presents data and analysis from funding year 2018-2019 for the Coonamessett Farm Foundation (CFF) seasonal bycatch survey on Georges Bank (GB). Some sections also include analysis of data from this year's survey and previous seasonal bycatch surveys. 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 GB, covering the northern half of CAII (not currently open to the scallop fishery) and open areas to the west. Since 2017, the sampled area has been located in the eastern part of GB 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. Test a modified dredge bag design to reduce flatfish bycatch (i.e., comparing a modified industrial dredge with an extended link bag configuration 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.
5. Collect biological samples to identify seasonal changes in reproductive cycles and spawning aggregations of key fish bycatch species.
6. 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 the entire project, 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.

Scallop seasonal meat weights and bycatch: During the 2018-2019 project, scallop meat weight peaked in June in the deeper stations and in August and February in the shallower stations. 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 bycatch rates were less than 0.3 lbs. of fish/lb. of scallops. Lobster bycatch rates were less than 0.5 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 in February trip (< 0.2 lbs. of fish/lb. of scallops).

Testing a modified dredge bag: Since 2010, the control dredge used in the project has been a turtle deflector dredge (TDD) with a 7-row apron. Also, an experimental 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 our control dredge. Similar to last year's project, analysis of the paired catch data suggested that the extended link apron may be an effective gear modification for reducing flatfish bycatch (e.g., 48.2% reduction of yellowtail flounder), but this reduction in fish bycatch was coupled with a reduction in scallop catch as well (30.4% reduction).

Scallop meat quality: Understanding the cause of gray meats in scallops has been a focus of CFF research efforts since 2013. Samples of white, brown, and gray meat scallops were analyzed by the Aquatic Diagnostic Laboratory at Roger Williams University (RWU-ADL) to verify the presence of the apicomplexan parasite, which was believed the cause of gray meats. However, the parasite was found in white, brown and gray meat scallops, suggesting that the presence of the parasite is not the only cause of gray meats. Additional factors like scallop reproductive stage and age seem to play an important role in development of gray meats.

Seasonal changes in distributions and abundance: Significant work was also done to analyze spatiotemporal patterns in catch data and temporal patterns in fish and scallop reproductive stages. Monkfish was the most abundant fish species with the highest catch in June. The most abundant flatfish was windowpane founder, and we observed relatively high numbers of windowpane flounder across the entire sampling area, with catches peaking in April, primarily in CAII. Catches of yellowtail flounder and winter flounder were low overall.

Reproductive cycles: Scallop reproductive stages were determined through observation of macroscopic changes in the gonads and use of a gonadal mass index based on shell height and gonad weight. Flounder reproductive stages were assigned based on macroscopic changes in the gonads and the gonadosomatic index based on fish body and gonad weights. We observed two spawning periods for scallop and windowpane flounder. While two spawning periods have been reported for scallops previously, an observation of two distinct spawning periods for windowpane flounder is unusual. While we observed typical single spawning periods for yellowtail and winter flounder, we have observed unusual timing for yellowtail spawning during other bycatch projects.

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 GB. 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 determine adherence to Annual Catch Limits (ACLs) and devise Accountability Measures (AMs) so that scallop harvest can be optimized while minimizing bycatch. As new issues arise, the bycatch survey has adapted, and there has been increasing interest in using the bycatch survey data as a time series, due to the amount of data collected. For example, the scallop industry has become concerned about the observed distribution and magnitude of poor-quality scallops, and our recent work has demonstrated gray meats do not have one isolated cause such as the apicomplexan parasite, due to our deep, multi-year dataset on scallop meat quality.

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 $507,415,834 in 2017 (NOAA 2017). The stock has been rebuilt from its overfished status in 1997, and no overfishing occurs (NEFMC 2014). However, this profitable fishery is impacted by fish bycatch issues resulting in the potential loss of millions of dollars in revenues. Yellowtail (*Limanda ferruginea*) and windowpane (*Scophthalmus aquosus*) flounder Annual Catch Limits (ACLs) and Accountability Measures (AMs) have created a complex regulatory environment for the scallop fishery. Triggering the yellowtail flounder AM on Georges Bank (GB) results in scallop fishing area restrictions across eastern GB (NEFMC 2019a), and time/area closures and gear restrictions are currently being considered to minimize winter (*Pseudopleuronectes americanus*) and windowpane flounder bycatch (NEFMC 2019a).

Seasonal information pertaining to groundfish bycatch and scallop meat yield on GB 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 had been observed on GB in relation to depth, flow velocity, and water temperature (Sarro and Stokesbury 2009). Although variation in yellowtail flounder bycatch rates had been noted on GB 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 critical data gap for Closed Area I (CAI) and Closed Area II (CAII) south of 41°30'N (CAII S). In 2015, CFF started to fill this gap for the northern portion of GB, and in 2017, we began to supply data for the eastern portion of GB. During the course of this project, the important bycatch species under study have been windowpane, winter, and yellowtail flounders, American lobster (*Homarus americanus*), and monkfish (*Lophius americanus*), 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 GB 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.

Despite efforts to minimize bycatch, yellowtail and windowpane flounder quotas continue to impact the scallop fishery. The allocation of GB yellowtail flounder to the scallop fishery was substantially reduced in 2015 based on results from the 2014 GB 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 an overly-restrictive yellowtail sub-ACL 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 (Legault and McCurdy 2019).

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 (i.e., 5-row apron and 1.5:1 twine-top hanging ratio) that were put in place 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 seasonal 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, CFF's seasonal survey collects data about infections in yellowtail flounder and health condition of scallop meats. 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). Scallop meat is normally firm and creamy-white, however, when scallop meats have poor quality, fishermen need to discard them, which leads to low meat yield and subsequent economic losses for the fishery. Gray meats and orange nodules in the adductor muscle have occasionally been detected in our surveys. These anomalies have been associated with an apicomplexan parasite (Inglis *et al.* 2016) and *Mycobacterium* sp. infections (Grimm *et al.* 2016), respectively. *Mycobacterium* spp. are considered pathogenic in humans (Grimm *et al.* 2016), and an apicomplexan parasite has been linked to the total collapse of the Iceland scallop (*Chlamys islandica*) stock around Iceland (Kristmundsson *et al.* 2015). Other than the parasite, different meat colors have also been associated with the depletion of energy reserves and breakdown of the adductor muscle following spawning (Fisher 2000). This seasonal bycatch project has shown that there is more than one cause for the presence of gray meats, and it may be associated with location and reproductive stages (Siemann *et al.* 2019). A consistent collection of seasonal health data is needed to investigate the prevalence and potential causes of these different diseases and abnormalities.

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) Test a modified dredge bag design to reduce flatfish bycatch (i.e., a modified industrial dredge with an extended link bag configuration 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.

5) Collect biological samples to identify seasonal changes in reproductive cycles and spawning aggregations of key fish species.

6) 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). Two areas on GB, CAI and CAII, have been closed to all mobile bottom-tending gear since 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 2018 seasonal bycatch survey, eight research trips were conducted on eastern GB covering all of CAII but the HAPC (**Table 1**). The initial plan was to sample across CAII, including within the GB northern edge HAPC, but the final survey did not include stations in the HAPC due to permit restrictions (**Figure 1**).

Table 1. Trip dates and vessels used for the 2018 bycatch survey.

Month	Trip dates	Vessel Name
August	08 Aug – 14 Aug 2018	F/V Endeavor
September	13 Sep – 19 Sep 2018	F/V Blue Western
October	10 Oct – 16 Oct 2018	F/V Atlantic
December	13 Dec – 19 Dec 2018	F/V Vanquish
January	25 Jan – 31 Jan 2019	F/V Liberty
February	28 Feb – 5 Mar 2019	F/V Horizon
April	11 Apr – 17 Apr 2019	F/V Blue North
June	05 Jun – 11 Jun 2019	F/V Regulus

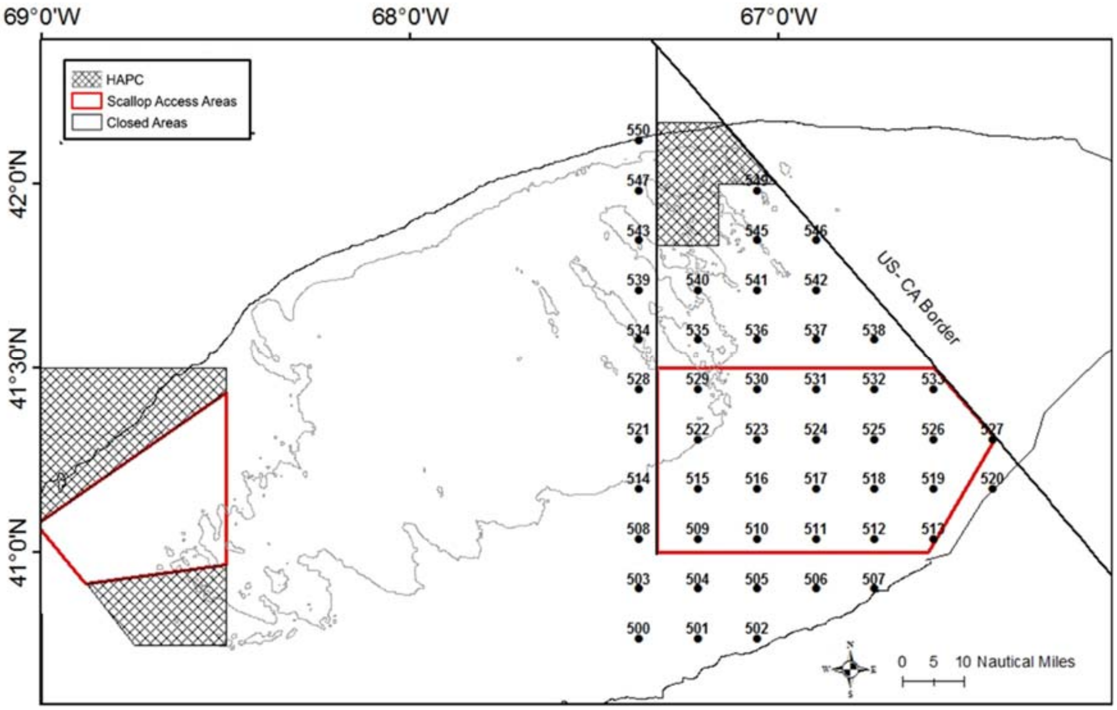


Figure 1. Location of the survey stations sampled for the 2018 seasonal bycatch survey on the eastern portion of GB. The HAPC is the cross-hatched area. Scallop access areas and the Hague line are shown in red and black, respectively. Stations are separated by ~13 km.

Sampling design

The survey grid, consisting of 49 stations across CAII and just outside its boundaries, was sampled every other month with additional trips in September and January. 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**).

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 (**Appendix A**, **Table A1**). Every industrial dredge was modified by replacing the standard apron with an extended link apron. 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.

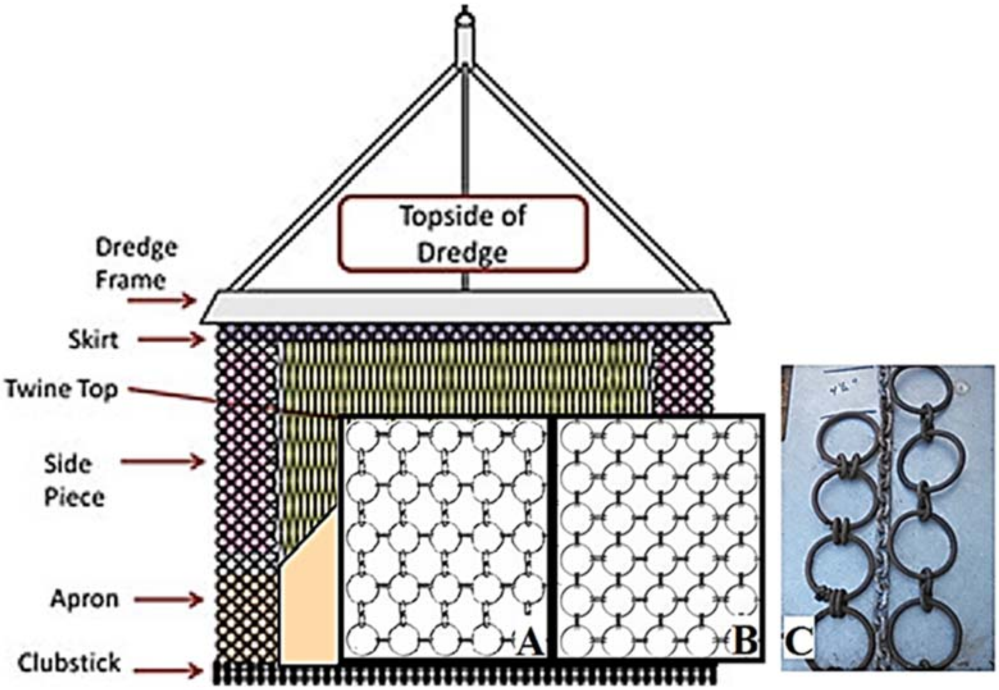


Figure 2. Diagram of the topside of a dredge illustrating the difference between **A)** an extended link apron and **B)** a standard linked apron. **C)** Chain or shackles are used to connect standard linked portions of the bag to the extended link.

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, and yellowtail flounder were sampled at each station to determine sex and reproductive stage. In order to determine gonadosomatic index (GSI) for these species, we measured whole body weight and gonad weight for each individual. 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, and scallop meat quality. 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**). One 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 preserved 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.

Finally, all lobsters 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), the occurrence of any visible orange nodules in the muscle or brownish linear discolorations during the SHMW analysis on the vessel. A longitudinal and cross-sectional portion of each muscle was processed, embedded in paraffin and stained with hematoxylin and eosin (Howard *et al*. 2004). For this year project, these sections were evaluated for the abundance of three forms of the apicomplexan parasite: sporozoite foci, meronts and sporoblast foci (Kristmundsson and Freeman 2018). Muscle thinning was evaluated using two criteria, severity and distribution, and was reported as follows: for severity of thinning, a scale of 0 to 3 (0 = normal, 1 = mild, 2 = moderate, and 3 = severe) was used. Distribution of muscle thinning was reported on a scale of 0 to 3 (0 = normal, 1 = focal/rare, 2 = multifocal, 3 = diffuse). The final score for muscle condition was determined by multiplying the score for thinning by the score for distribution. Similarly, cellularity was evaluated and reported as the product of two measurements: number of cells and distribution. The number of cells was based on the increase in visible nuclei, ignoring sporozoite and sporoblast foci, and was evaluated using a scale from 0 to 3 (0 = no increase, 1 = mild increase in cellularity, 2 = moderate increase, and 3 = severe increase). The distribution of the cell increase was also evaluated using a scale from 0 to 3 (0 = none, 1 = rare/focal increase in cellularity, 2 = multifocal increase in cellularity, 3 = diffuse increase in cellularity). Total cellularity values ranged from 0 to 9. Adductor muscles were also evaluated for the occurrence and severity of mycobacterial granulomas and linear tissue necrosis and associated inflammation due to probable ascarid larvae migration. Larvae were noted when identified. Any other conditions noted histologically in the tissues was reported. For thirteen poor meat quality individuals, the entire animal was submitted in 10% neutral buffered formalin. Samples of all other organs from these animals were examined histologically for the parasite or any other conditions.

As described last year, 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 in 2017, 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. However, the RWU ADL developed 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 has continued to develop a sensitive and specific test for the protozoan parasite now identified as *Merocystis kathae* (Kristmundsson and Freeman 2018). The PCR procedures were the same as the 2017-year project. However, RWU-ADL has developed better methods of processing the tissues that produces a well-homogenized sample. These methods both decrease the likelihood of false negatives that may result from low spotty levels of the parasite in the sampled tissues as well as false positives resulting from cross contamination between samples.

New method for isolation and extraction of DNA from adductor muscles: In the lab, the scallop adductor muscle tissues were sliced under sterile conditions, resulting in a square of muscle tissue (a biopsy) without contaminated edges. Biopsies were homogenized to form a fine suspension. Approximately 0.75g of tissue was minced and added to a 15-ml tube with 6 ml of sterilized filtered sea water and incubated overnight. Forty-eight pre-sterilized stainless-steel beads (3.175 mm diameter) were added to the tube of rehydrated tissue and placed in a bead homogenizer for a total of 6 minutes of actual homogenization. Two hundred µl of the homogenized tissue was used for DNA extraction using the GeneMATRIX Tissue DNA Purification Kit (EURx®, Gladsk, Poland). The eludate was frozen at -80°C until use. The quality and concentration of DNA in the eludates was determined using a Thermo Scientific NanoDrop 2000c Spectrophotometer.

Examination of yellowtail flounder for *Ichthyophonus*: Data collected over the past years indicates that the parasite enters the liver directly from various locations in the intestine (Huntsberger *et al*. 2017). To determine the level of infection, almost 80% of yellowtail flounder livers with and without apparent lesions (macroscopic examination) were collected and preserved in 10% formalin. In addition, for some individuals randomly selected other tissues were collected. Individuals with a moderate to severe *Ichthyophonus* infection usually presents macroscopic lesions different from those resulting from parasite infection by ascarid or cestode larvae, but animals with early/mild infections cannot be seen grossly. In the lab, two pieces of liver were selected from tissue submitted from each animal, processed in paraffin and stained with hematoxylin and eosin (Howard *et al*. 2004). If intestine or other tissues were also collected and fixed in formalin, sections of those organs were processed as well. Histological sections of processed tissues were examined for the occurrence of *Ichthyophonus* as well as any other lesions noted.

Data analysis

Shell height-meat weight (SHMW) relationship: A generalized linear mixed model (GLMM) with a gamma distribution (log link in R package “r2glmm”) was developed to estimate scallop meat weights using shell height and a suite of additional variables including month, depth, latitude, and meat color. Parameter estimates and the Akaike Information Criterion (AIC) selection table are shown in **Appendix B**.

Groundfish bycatch rates vs scallop meat yield: The seasonal catch rates of important bycatch species (windowpane, winter, and yellowtail flounders; monkfish; and lobsters) were calculated in relation to the scallop catch. For this analysis, both dredges were combined. To calculate the total meat weight (in pounds) of scallops caught per trip, the measured bushel from each tow 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).

Gear comparison: To estimate overall changes in catch based on gear type, linear models of the catch per tow in the experimental vs control dredge were used. Influential outliers were dropped based on Cook’s D statistics (function “ols_plot_cooksd_chart” in the R package “olsrr”) because single atypical tows were strongly influencing the regression lines (Hebbali 2018).

To investigate the importance of other variables in catch, generalized additive mixed models (GAMMs) were used to model the efficiency of the extended link dredges relative to the standardized control dredge (binomial distribution with logit link in the R package “mgcv”) (Fryer *et al*. 2003, Wood 2011). The mixed-model approach is appropriate when unknown sources of variation exist in the data, and the relative contributions of potential predictors can be assessed when multiple patterns seem to exist. As with frequently used linear length-based models, relative efficiency of the experimental dredge was estimated based on the proportion of scallops/fish caught in the experimental dredge (Holst and Revill 2009, Cadigen and Dowden

2010). Because the specifications of the dredges supplied by the vessels varied (**Table A1**), models were developed using length and a set of covariates based on the type of dredge frame, the length of the dredge bag, the percentage of the bag top that was covered with a twine top based on the opening size and the width of side pieces, the hanging ratio, and the number of turtle chains (**Table 3**). Final models for each species were selected based on AIC scores (Akaike 1973, **Appendix C**). Model results were plotted using the R packages "ggplot2" and "visreg" (Wickham 2016, Breheny and Burchett 2017).

Table 3. Model covariates based on gear specifications. Exp = experimental dredge with an extended-link apron supplied by the vessel. Ctrl = control dredge. RL = length of bag part in number of rings. RW = width of bag part in number of rings. MW = width of twine top in meshes.

Covariates	Variable	Details	Variable type
Dredge frame	TDD or NBD	Control dredge was a TDD	Categorical
Bag length	Exp - Ctrl	Based on side-piece RL: ranged from 0 to -11 rings	Continuous
Twine top coverage	Exp - Ctrl	Based on percent of bag width covered by twine top and calculated as [bag RW– (2* side-piece RW)]/bag RW : ranged from 0 to 0.1	Continuous
Hanging ratio	Exp - Ctrl	Hanging ratios calculated based on twine-top MW and opening RW as [opening RW/(twine top MW -2)]: ranged from -0.88 to 1.07	Continuous
Turtle chain spacing	(Exp - Ctrl)/Ctrl	Based on the width of the space between turtle chains: ranged from 0 to 2.75	Continuous

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 and PCR-based analysis from samples collected during bycatch trips from August 2017 to June 2019 (**Appendix D**).

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

$$GMI = \frac{GM}{SH^b}$$

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.

Gonadosomatic index of the female flounders were determined following the equation:

$$GSI = \frac{WG}{WF} x\ 100$$

where WG = wet weight of gonad and WF = total wet weight of the fish.

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

$$lnW = \ln a + b\ lnL$$

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, for windowpane flounder were less than 0.3 lbs. of fish/lb. of scallops (**Figure 4a**) and for lobster bycatch rates were less than 0.5 lbs. for one lb. of scallops (**Figure 4b**). Bycatch rates for monkfish were higher than the other species (> 1 lbs. of fish/lb. of scallops for two trips), 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 E**). Each of the species manifested a differential spatial distribution, but distributions were similar to what was observed in previous years. Scallops were distributed mostly in the south portion of the sampling area during the sampling period (**Figure E1**), with peak abundance in June (**Table 4**). Yellowtail flounder catch was low, and they were widely distributed throughout the sampling area (**Figure E2**); peak yellowtail abundance was in August (**Table 4**). Winter flounder were observed mostly in the northern portion of the sampling area (**Figure E3**), 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 E4 - E5**); windowpane flounder were the most abundant species throughout the sampling period, especially in April (**Table 4**). Monkfish were most abundant in June (**Table 4**). Summer flounder (*Paralicthyes dentatus*) catch was minimal, never exceeding 39 individuals per trip (**Table 4**); the catch was greatest during October trip, but was consistently low. Finally, lobsters were caught year round with the highest catch in August through October, with peaks in September (**Figure E6**; **Table 4**).

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

Year	Month	Scallops	Summer Flounder	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Monkfish	Lobster
2018	August	403	35	103	38	503	529	144
	September	297	30	6	28	539	245	244
	October	190	39	16	21	417	204	109
	December	342	18	35	31	835	234	6
2019	January	368	2	24	12	614	131	1
	February	401	1	44	5	798	85	2
	April	413	4	46	22	911	189	10
	June	479	16	37	42	153	594	47

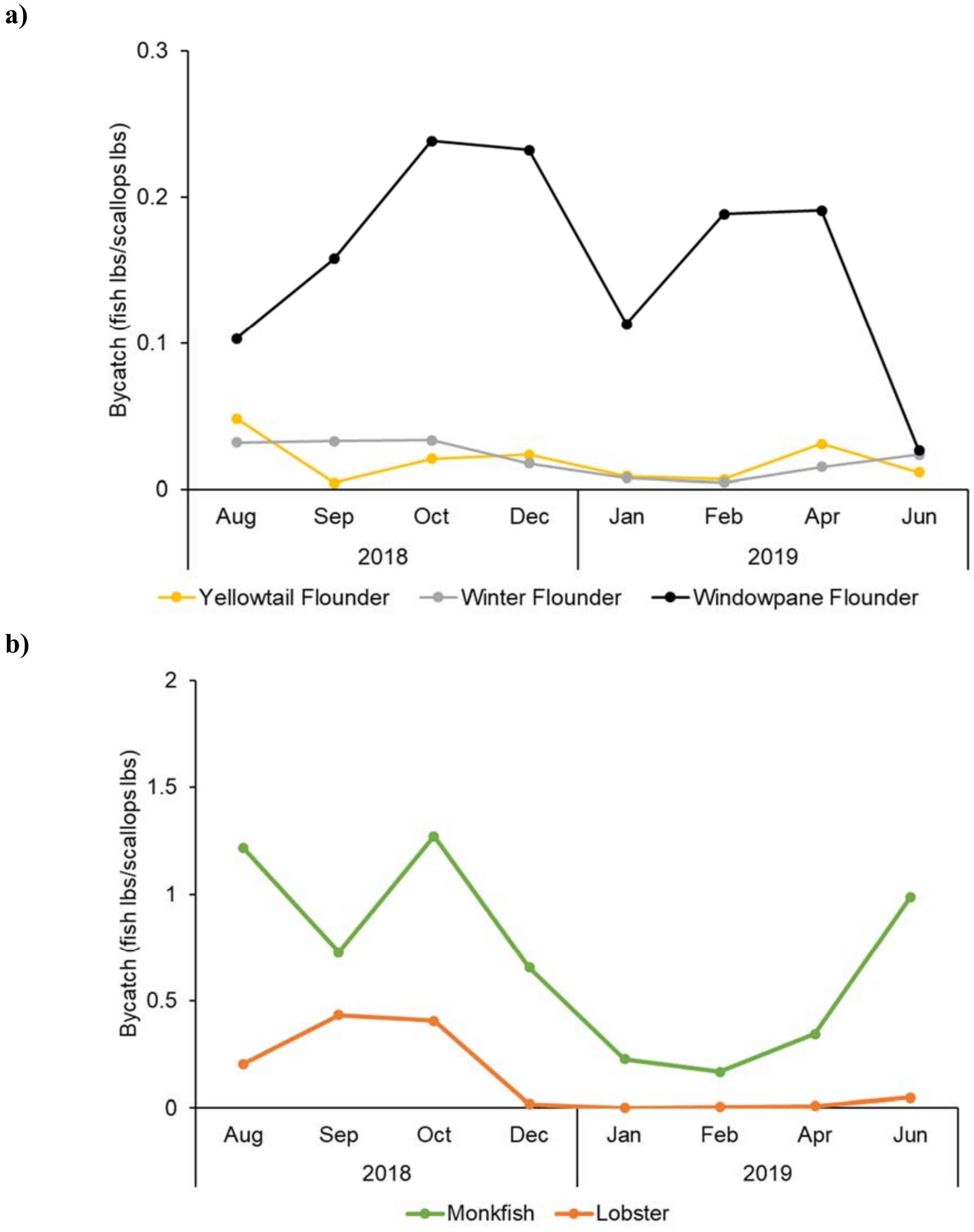


Figure 4. Bycatch rates for commercially important species, including **a)** flatfish and **b)** monkfish and lobster, in relation to scallop catch during this survey.

Shell height-meat weight (SHMW) relationship

A total of 6,219 scallops were sampled at 38 stations located across the eastern portion of GB in CAII N, CAII S, CAII Ext, and the southern flank (SF). Scallop shell heights ranged from 36 mm to 168 mm and meat weights varied from 0.1 g to 94.0 g. Temporal distributions of the collected shell heights and meat weights are shown in **Figure 5.**

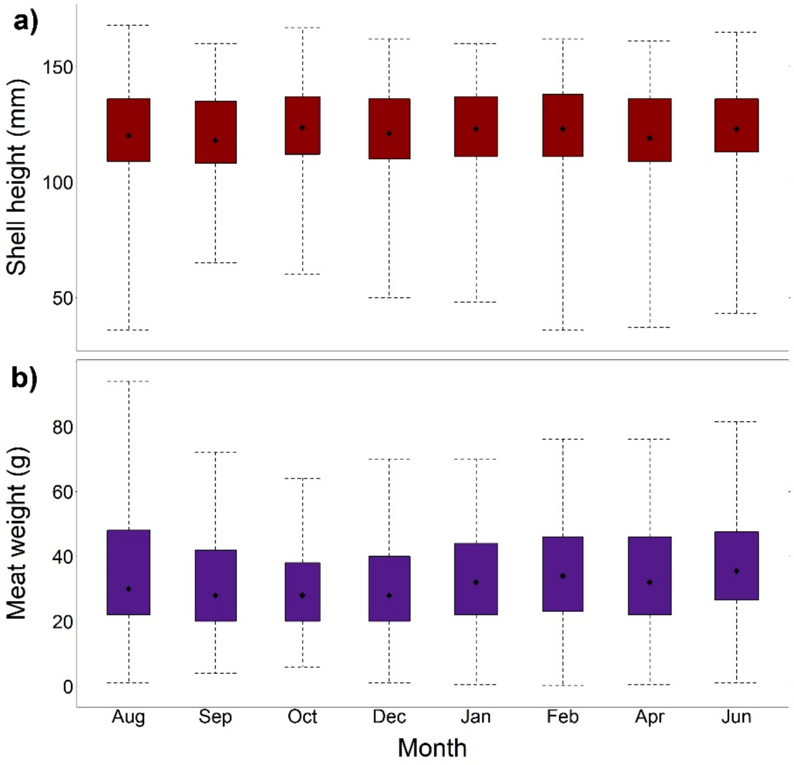


Figure 5. Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples from eastern GB. The markers inside the boxes show the median values for each month. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers extending to the minimum and maximum values.

Scallop meat weight was modeled using a gamma distribution with the function "pqlmer" in R package "r2glmm" (Jaeger 2017), and model selection was based on AIC values using the "aictab" function in R package "AICcmodavg" (Mazerolle 2019). Fixed effects for predicting meat weight included shell height, month, latitude, depth, and meat color. Survey station was included as a random effect. The selected model is shown below:

$$MW = e^{(\beta_0+\beta_1 (\ln SH)+\beta_2(M)+\beta_3(\ln D)+\beta_4 (\ln L) +\beta_5(C)+\beta_6 (\ln SH*M)+\beta_7 (\ln D*M)+\delta)}$$

Where δ is the random effect term (i.e., station as a random intercept), MW is scallop meat weight in grams, SH is shell height in millimeters, M is trip month, D is depth in meters, L is the latitude projected into UTM space, and C is meat color. Interaction terms between SH and month and depth and month were also included. Parameter estimates and the AIC selection table are shown in **Appendix B**.

Predicted meat weights were estimated for white and gray scallops at three stations, which were selected to include locations at two different depths and two different latitudes. Station 500 was 90-m deep and located on the SF, Station 513 was 90-m deep in CAII S, and Station 509 was 60-m deep at the same latitude in CAII S. SHMW curves for white and gray scallops at the three stations are shown in **Figure 6**. Scallops with gray meats had lower meat weights than those with white meats, a trend that has been noticed during previous seasonal bycatch surveys. Meat weights were highest in June at the two deeper stations (500 and 513). At the shallower station (509), meat weights were highest in August for scallops over 150-mm SH and highest in February for scallops under that size. Closer examination of the temporal trends in predicted meat weights for 120-mm scallops highlights both the reduced meat weights of gray scallops and the different seasonal trends in meat weights for stations located at different depths (**Figure 7**). Two peaks in meat weight, in August and February, were predicted at the shallower 60-m station, while a single peak was predicted at the deeper 90-m station in June. Similar peaks in meat weights have been predicted based on data from earlier seasonal bycatch surveys. A February peak in meat weights was predicted for scallops from the northern edge of GB based on analysis of data collected during the 2017 seasonal bycatch survey, while a single summer peak was predicted for scallops from the CAII S based on analysis of data collected during the 2013 seasonal bycatch survey (**Appendix B**).

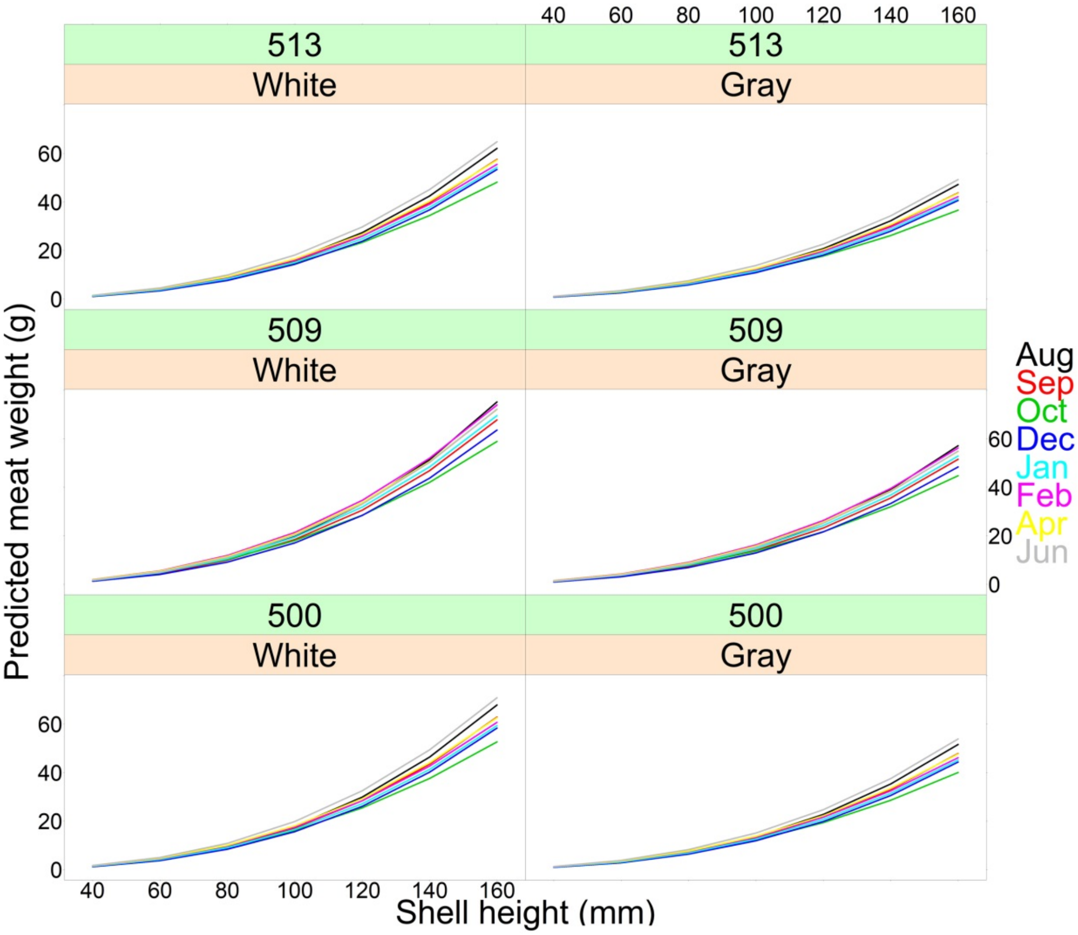


Figure 6. Estimated SHMW curves for white and gray scallops from Station 500 on the SF and Stations 509 and 513 in CAII S.

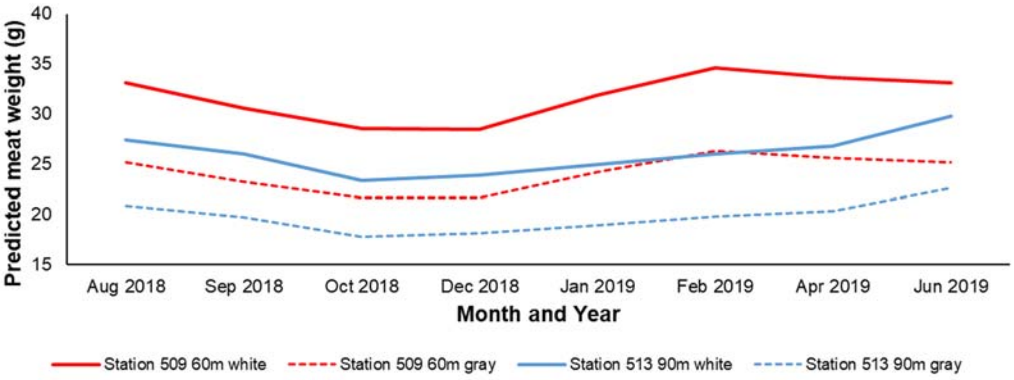


Figure 7. Temporal trends for the predicted meat weights of white and gray 120-mm scallops from Stations 509 and 513 in CAII S. Station 509 was a 60-m station and Station 513 was a 90-m station.

Objective 2: Testing of a modified dredge with an extended link bag configuration against the standard CFF dredge

Similar to last year, the control dredge gear was consistent for all tows, but the experimental dredge was different during every trip because each 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.

Models were developed for scallops and six fish species including yellowtail, windowpane, winter, and fourspot (*Hippoglossina oblonga*) flounders; monkfish; and barndoor skate (*Dipturus laevis*). Catch of all analyzed species was reduced in the dredges with extended link aprons relative to the control dredge (**Figure 8**, **Table 5**, and **Table C1**). This reduction was significant for scallops (30.4%), yellowtail flounder (48.2%), and monkfish (15.2%).

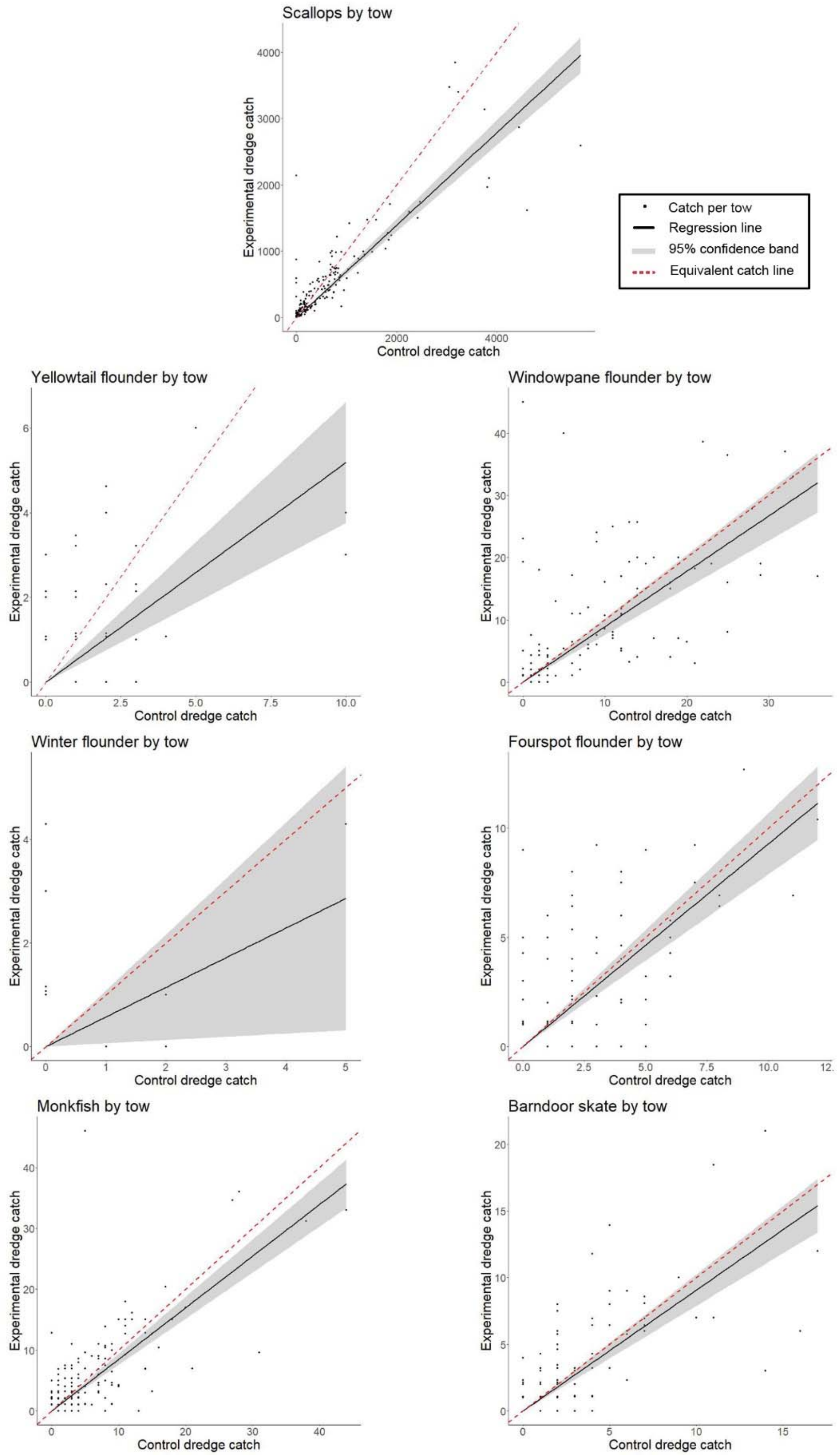


Figure 8. Linear model fits for each species using tow-by-tow data

Table 5. The estimated reduction in catch based on the linear regression model using tow-by-tow data

Species	Percent Difference	Significance	p-value
Scallops	**30.4%**	**Yes**	**<0.001**
Yellowtail flounder	**48.2%**	**Yes**	**<0.001**
Windowpane flounder	11.1%	No	0.10
Winter flounder	42.9%	No	0.08
Fourspot flounder	7.1%	No	0.32
Monkfish	**15.2%**	**Yes**	**0.001**
Barndoor skate	9.4%	No	0.12

The full GAMMs included shell height/length and five covariates based on differences in gear specifications between the control and experimental dredges other than the apron type (**Table 5**). Model selection tables and model outputs for the final GAMM for each species are shown in **Tables C2 and C3**. The intercept-only model was selected for fourspot flounder and monkfish. For the other five species, relative catch efficiency predictions were improved using models with length or gear variables as fixed effects.

Length was a significant predictor for scallops and yellowtail flounder (**Figure 9** and **Tables D2-D3**). Examination of the length-based model smooth for scallops indicates that the control apron was more efficient for catching 100-150mm scallops, while the extended link apron caught a higher proportion of 50-100mm scallops. Catch of yellowtail flounder was reduced overall using the extended link apron, but the size trend was opposite that seen for scallops, with the extended link apron catching fewer small yellowtail flounder in the <32 cm size range (**Figure 9**). The results for yellowtail flounder make intuitive sense because small flounder could escape through the bigger openings between rings in an extended link bag more easily than larger flounder. However, the scallop results are harder to interpret. Notably, the results from the 2017 project using a polynomial GLMM to fit the scallop data were similar to this year's results; the control dredge caught more large scallops and fewer small scallops (**Figure C1**). Understanding this result will require a better understanding of the impacts of changing the apron ring pattern or weight.

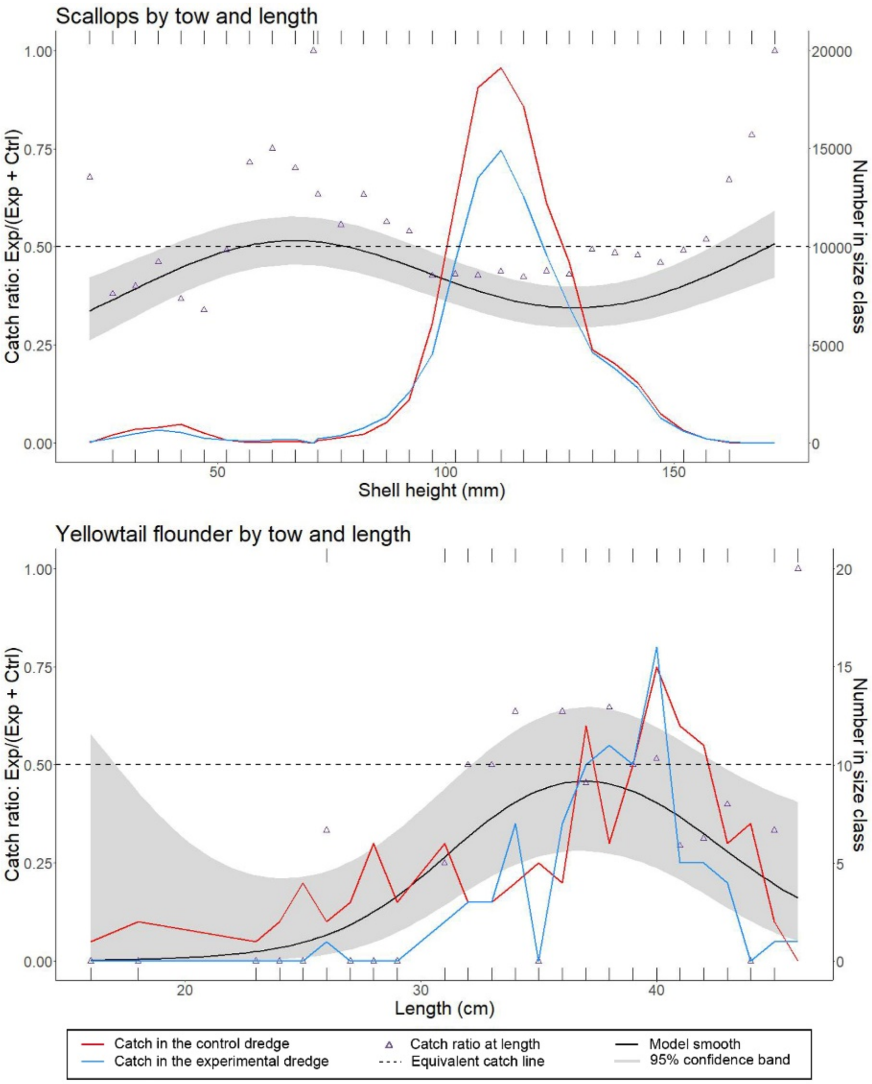


Figure 9. Length-based model fits for scallops and yellowtail flounder and length-frequency plots for the control and experimental catch. The triangles represent the observed proportion at length (Exp catch/Ctrl catch + Exp catch), with a proportion >0.5 representing more animals at length captured by the experimental dredge. The grey area represents the 95% confidence band for the model smooth. Exp = experimental dredge with an extended-link apron supplied by the vessel. Ctrl = control dredge.

Gear variables were retained in the models for windowpane founder, winter flounder, and barndoor skate, although the gear effect was not significant for winter flounder (**Figure 10** and **Tables C2-C3**). Bag length was a significant predictor for catch of windowpane flounder, with more flounder caught by the experimental dredge when the bag was shorter. Twine top coverage and hanging ratio were significant predictors for catch of barndoor skate, with more skate caught when the experimental dredge had a wider twine top or a higher hanging ratio. The results for windowpane flounder could be explained based on CFF research using fluid dynamics modelling of fish escape behind dredge frames. These models indicate that the majority of the fish escape in the lower half of the twine top close to the ring bag (unpublished results). Because of this, flounder that would escape through the twine top in a longer bag might be blocked from escape by the apron rings in a shorter bag. The results for barndoor skate seem contradictory, but further examination of the gear covariates provides a possible explanation. While the hanging-ratio result makes intuitive sense, with skate more likely to escape through a twine top with looser meshes, the twine-top-coverage result makes less sense since higher twine-top coverage would seem to offer a larger area for escape. However, while the two covariates were not correlated overall, the twine top with the lowest hanging ratio (1.2-to-1) had the highest coverage (80%) and the twine top with the highest hanging ratio (3.1-to-1) had the lowest coverage (70%).

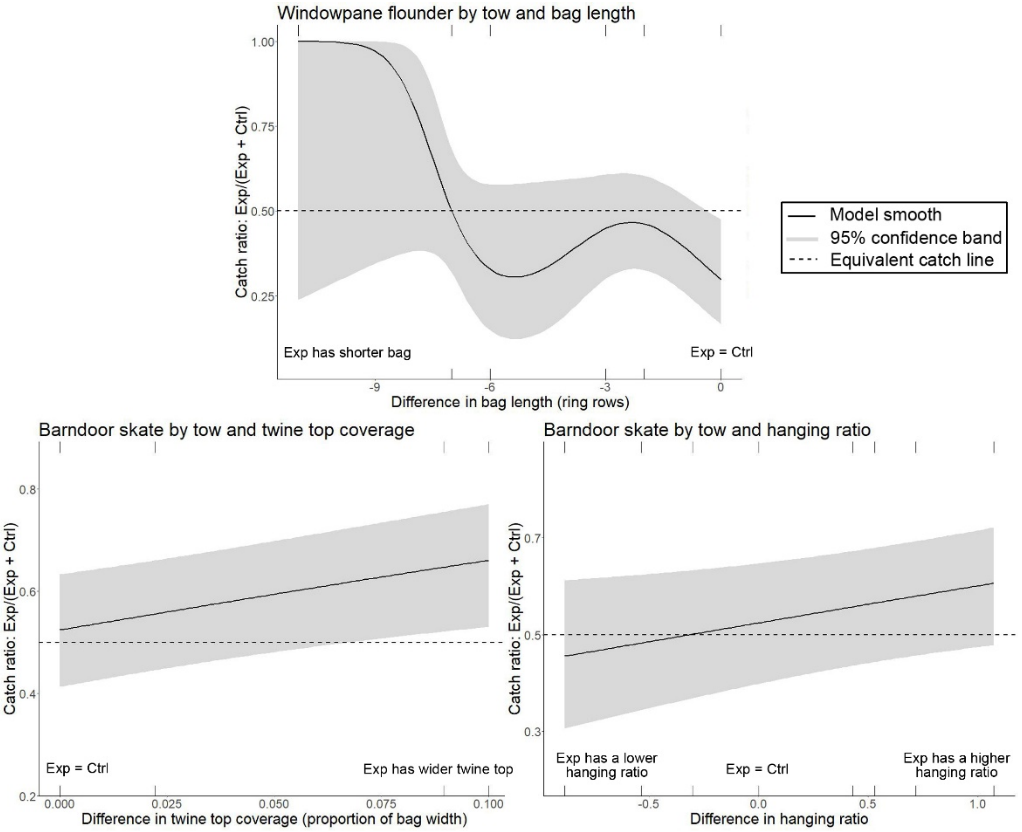


Figure 10. Gear-based model fits for windowpane flounder and barndoor skate. The grey area represents the 95% confidence band for the model smooth.

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

At each station where scallops were caught, a subsample of 30 meat scallops (< 30 if the catch was lower) were assessed for meat condition. Overall, only 1.18% of scallop meats were observed with poor condition (1% brown meats and 0.18% gray meats). The monthly variation of brown and gray meats during 2018-2019 seasonal survey are shown in **Table 6**; the highest numbers of brown and gray meats were collected in October. Spatial analysis indicated that low numbers of gray meats (one-three meats) were observed at only six of the stations (**Figure 11**). Where gray meat scallops were observed, the percentages by station were: 1.3% for station 508 (3 of 231 samples), 1.26% for station 516 (3 of 238 samples), 0.83% for station 524 (2 of 240 samples), 0.47% for station 525 (1 of 210 samples), and 0.42% for station 513 and 517 (1 of 240 samples). Additionally, 58 brown meats were found during the survey at 17 stations located mainly inside CAII (**Figure 11**). Brown meats were collected at five out of six of the stations where gray meats were found.

Table 6. Number of scallop meat analyzed by color and month.

Year	Month	White	Brown	Gray
2018	August	815	12	1
	September	764	10	2
	October	535	19	4
	December	770	5	1
2019	January	842	4	1
	February	746	5	0
	April	848	4	1
	June	841	3	1
Total		**6161**	**62**	**11**

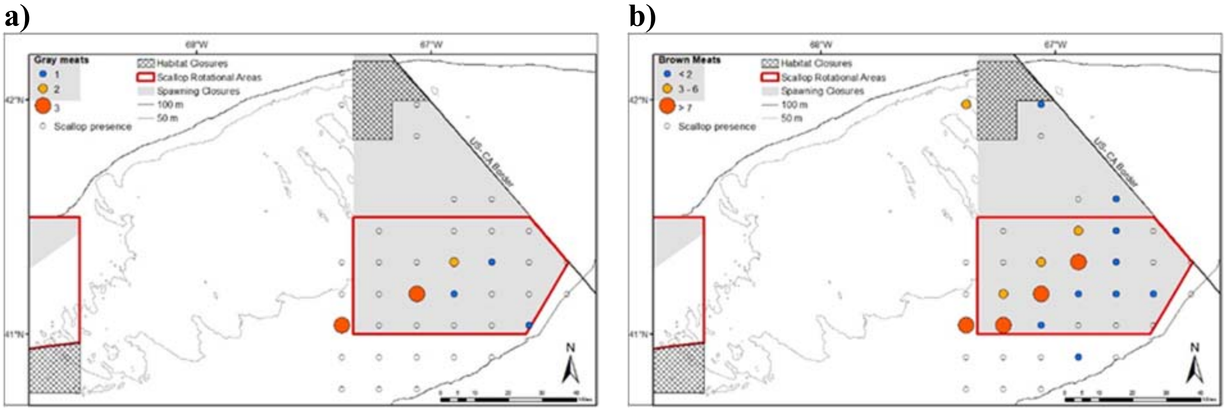


Figure 11. Locations where **a)** gray and **b)** brown meats have been identified during the 2018 seasonal bycatch survey on the eastern portion of GB.

Histological evaluation: White and discolored (gray of brown) 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 12**). In general, based on histological evaluation of scallop meats, the appearance of gray or brown meats is not always different than white meats. To date, the only forms of the parasite identified in the adductor muscles are foci of sporozoites (most common, **Figure 12d**), meronts (rare, **Figure 12e**) and sporoblasts (low number, **Figure 12f**). Other forms as described in Kristmundsson and Freeman (2018) have not been identified in the adductor muscle. Additionally, no forms of this parasite have been identified in other scallop tissues that we have examined.

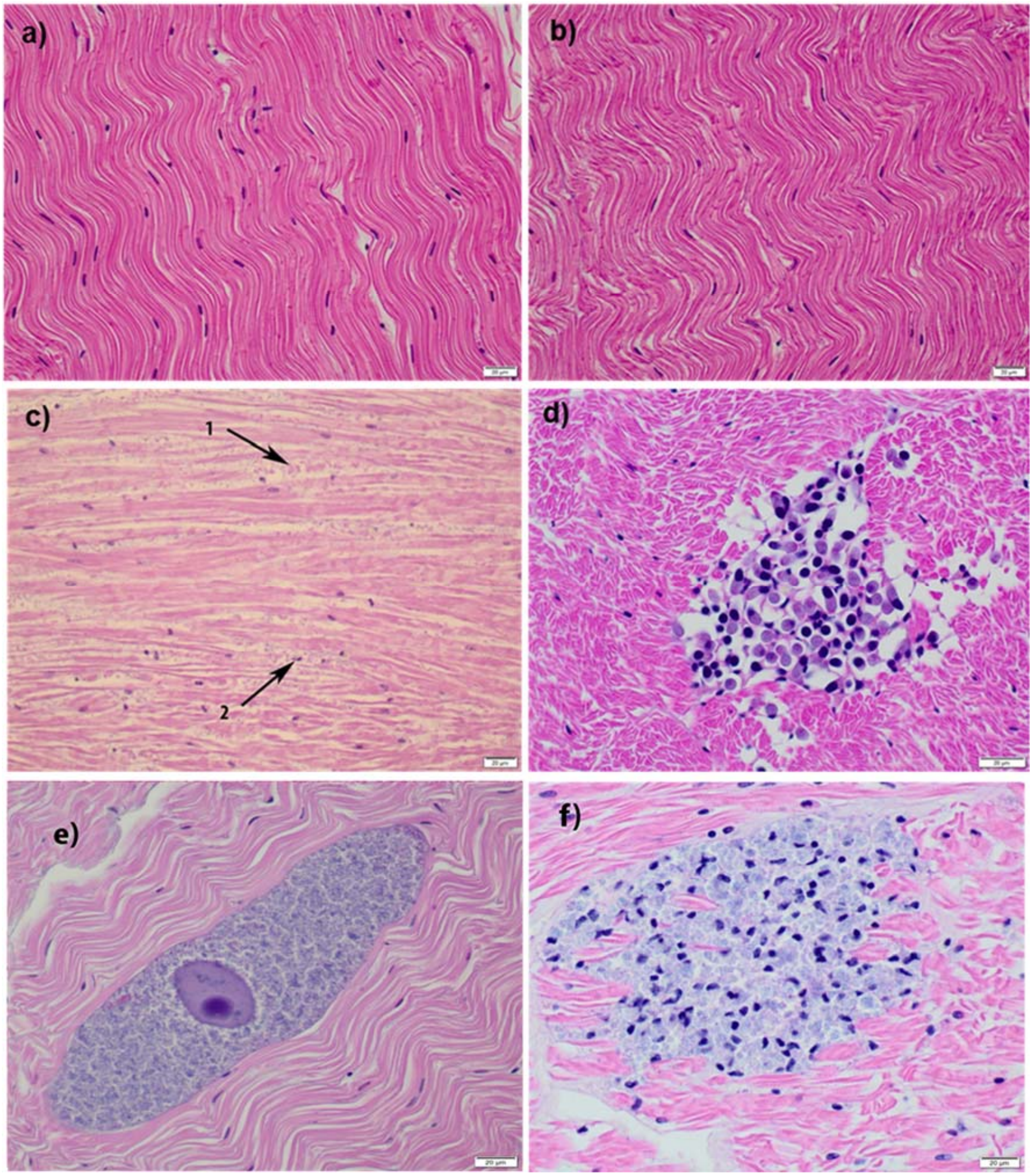


Figure 12. Histological appearance of adductor muscle from three sea scallops: **a)** Gray muscle with no significant abnormalities. **b)** White muscle with no significant lesions. **c)** Brown muscle with significant changes characterized by coagulation [(1) necrosis and (2) inflammation]. **d)** Adductor muscle section from an infected animal with a focus of sporozoites. **e)** Meront in the adductor muscle of a sea scallop. **f)** a focus of sporoblasts. All tissues were paraffin embedded and stained with hematoxylin and eosin.

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). 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 7**). Positive signals were detected in the majority of the samples of white and discolored meats, further supporting our hypothesis that a mechanism other than just the presence of apicomplexan zoites is responsible for gray meat scallops (Siemann *et al*. 2019).

Table 7. Summary statistics by meat color for meat-weight-to-shell-height ratio, reproductive stage, cellularity, muscle thinning, zoite number, and PCR results for samples collected from 2017 to 2019 and analyzed using all methods (assessments using on-vessel SHMW protocol, histology, and PCR-based parasite detection). The number of samples analyzed per meat color category are shown in parentheses

Meat color	Meat-weight-to-shell-height ratio	Percentage of samples from spent or partially spent scallops	Cellularity score	Muscle thinning score	Zoite number	Percentage of samples with parasite present
White (N = 39)	0.74	67%	1.49	2.59	2.97	82%
Brown (N = 63)	0.73	83%	1.95	3.26	4.19	84%
Gray (N = 10)	0.67	100%	3.95	3.80	3.10	90%

While white meats generally had the lowest values for cellularity, muscle thinning, and the number of zoite foci (**Table 7** and **Figure 13**), this difference in the scores used for histological rating of samples was not statistically significant for muscle thinning scores or zoite numbers. Differences in each of these scores and the meat-weight-to-shell-height (MWtoSH) ratios 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 the MWtoSH ratios and cellularity scores by color (MWtoSH ratio: $F_{(2,109)} = 6.137$, $p = 0.003$; cellularity score: $F_{(33,109)} = 6.636$, $p = 0.002$). Both were significantly different between gray meats and white/brown meats, with no significant differences between white and brown meats (see **Appendix D** for ANOVA tables and Tukey HSD pairwise comparisons of means). Differences in reproductive stage and detection of the apicomplexan parasite using PCR (positive/negative) by color were compared using chi-square tests for independence with pairwise comparisons done using the R function “pairwiseNominalIndependence” in the package “rcompanion” (Mangiafico 2019). There was a significant relationship between the number of scallops in each reproductive stage and meat color ($X^2_{(6,\ N=112)} = 14.102$, $p = 0.029$) with gray meats found in scallops that were spent or partially spent (see **Appendix D** for chi-square output, contingency tables, and pairwise comparisons). There was no significant association between the results of the PCR-based screening and meat color.

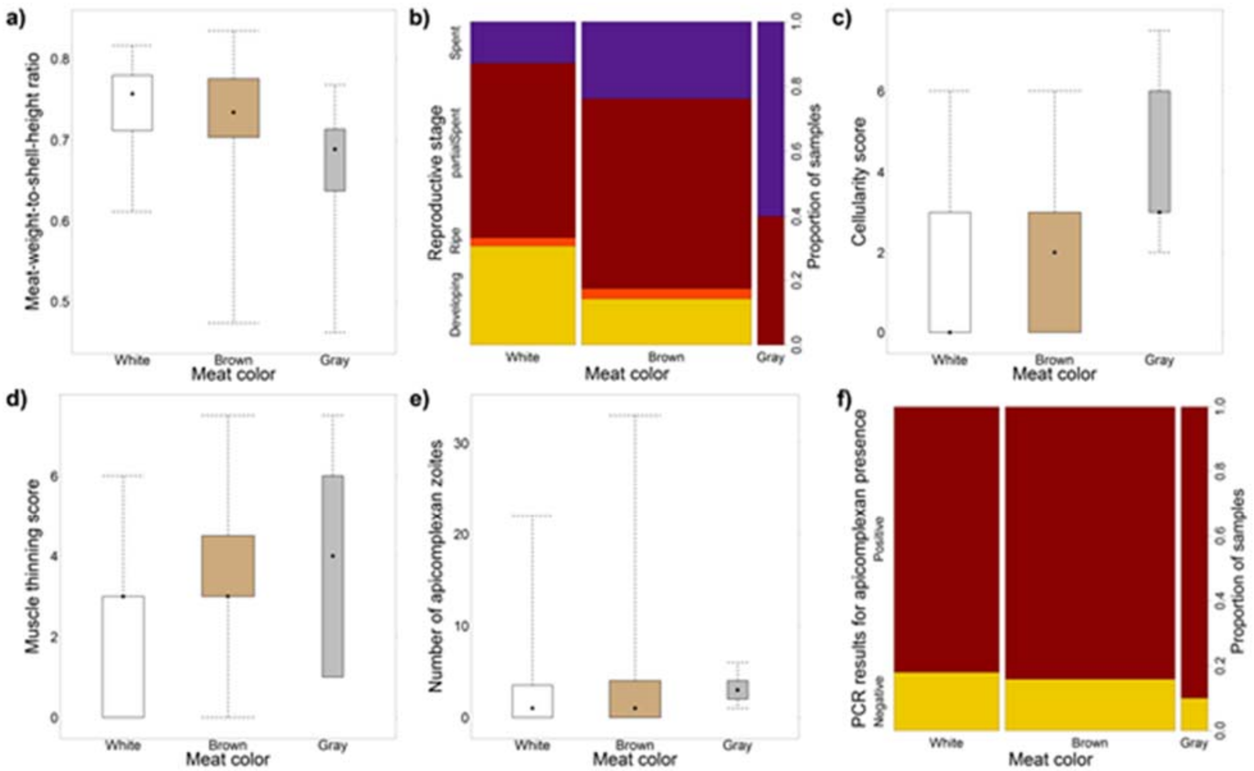


Figure 13. Summary plots of meat color against **a)** meat-weight-to-shell-height ratios, **b)** reproductive stages, **c)** cellularity scores, **d)** muscle thinning scores, **e)** numbers of zoites per sample, and **f)** PCR-based detection of apicomplexan parasites. For the box and whisker plots, the markers inside the boxes show the median values for each color, and 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.

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 mostly in the northern portion of the survey area. Windowpane flounder catches were relatively high across the survey area, with catches peaking in April. High catches of monkfish occurred in August and June, 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 **Appendix E**.

Scallops: A total of 1,815 bushels (119,842 lbs) were collected during the 2018 project (**Table 8**). The highest monthly percentages of mature females occurred from August through September and April, which coincide with the spawning seasons reported by Thompson *et al.* 2014 (**Figure 14**). Additionally, based on GMI, two spawning periods were evident, a strong one in the spring and a less clear one in the fall. This result coincides with last year's result (**Figure 14**).

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

Year	Month	Number of bushels		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2018	**August**	106	89.9	7222	5958
	September	163.3	100.8	10768	6478
	October	57.5	58.8	3694	3866
	December	122.7	101.3	7975	6422
2019	**January**	73.2	100.7	5001	6750
	February	151	149	9995	9758
	April	160.7	143.3	10699	9420
	June	141.4	95.6	9536	6297

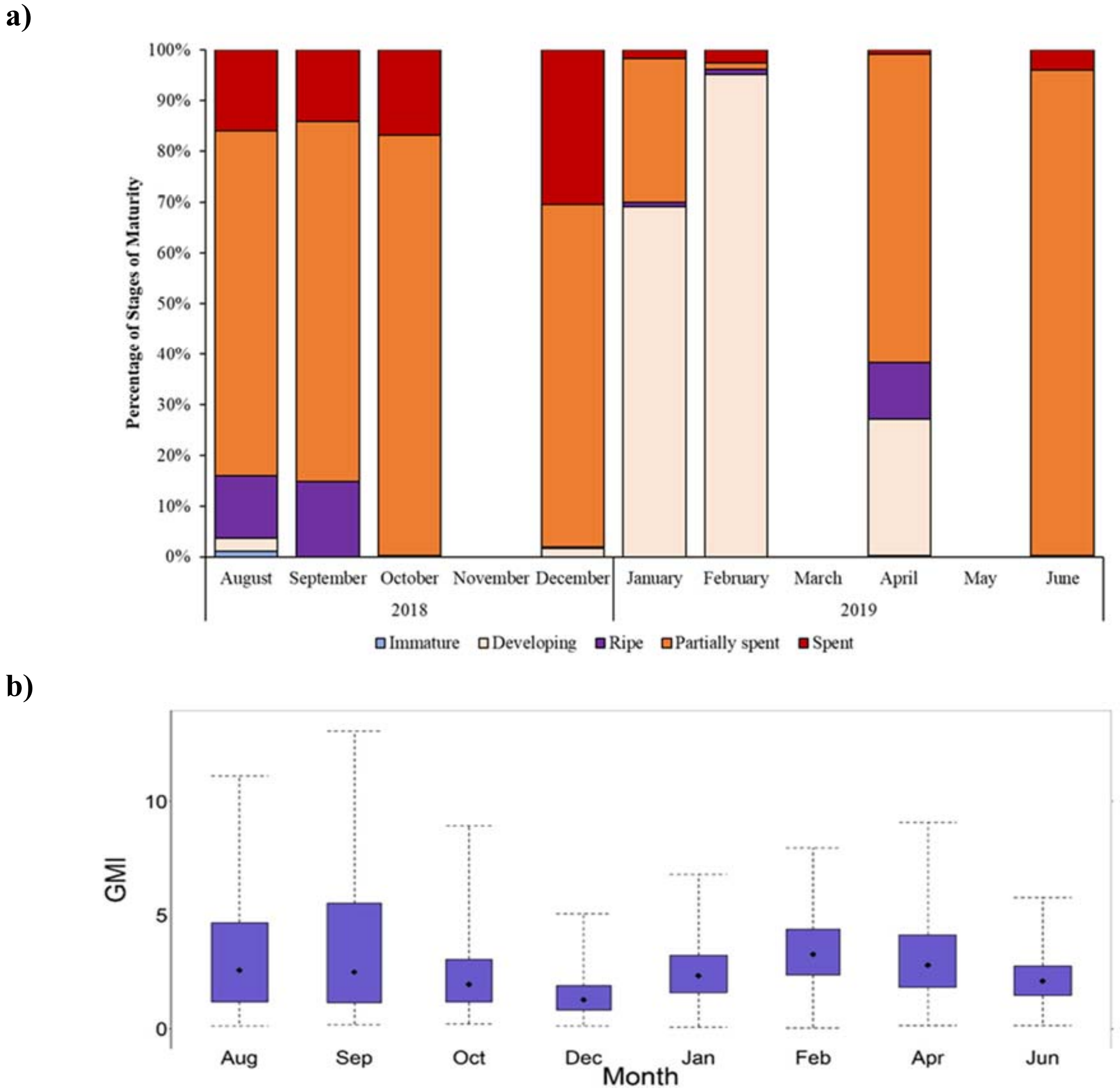


Figure 14. Seasonal **a)** maturity results determined through macroscopic observations and **b)** changes in the gonadal mass index (GMI) for female scallops for each month during the 2018 seasonal bycatch survey on the eastern portion of GB. For the GMI plot, boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

Winter flounder: A total of 180 winter flounder were captured during this year, mostly in the northern portion of the sampled area (**Figure E3**). Most individuals were evaluated to assess sex and reproductive stages. Approximately 56% of winter flounder caught were male. The June trip had the highest winter flounder catch overall (19 females and 18 males), while February was the trip with the lowest catch (1 female and 4 males; **Table 9**). Mature females were seen in January and April (**Figure 15a**). The GSI peaked in February, and spent females were observed during the following trip in April (**Figure 15b**).

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

Year	Month	Number		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2018	August	25	13	55.15	29.83
	September	21	7	46.22	18.43
	October	7	14	9.94	24.57
	December	6	6	23.25	13.79
2019	January	5	7	11.06	14.49
	February	1	4	2.37	9.944
	April	12	10	30.16	12.27
	June	25	17	46.15	43.25
Total		102	78	224.33	166.61

Windowpane flounder: Windowpane flounder was the most abundant flounder caught (4,770 fish), with catch peaking in April (911 fish; **Table 10**). They were caught at nearly every station (**Figure E4**), with catches often exceeding 20 fish per dredge. There were two spawning periods based on GSI values. The first one was in the fall after GSI values peaked and ripe and running females were observed in September, and the second one occurred in late spring after GSI values peaked in April (**Figure 16**). However, spent females were observed during every trip, suggesting that a low level of spawning activity may occur year-round.

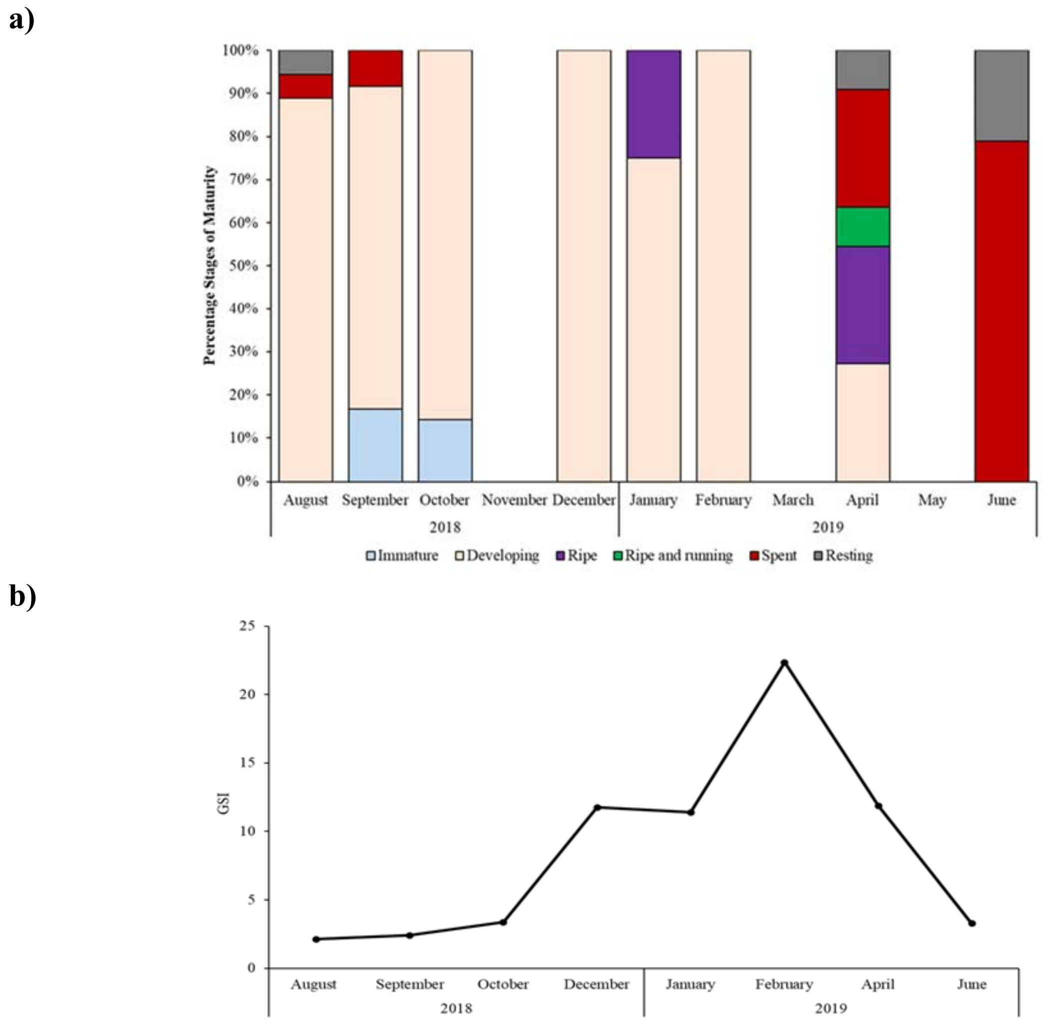
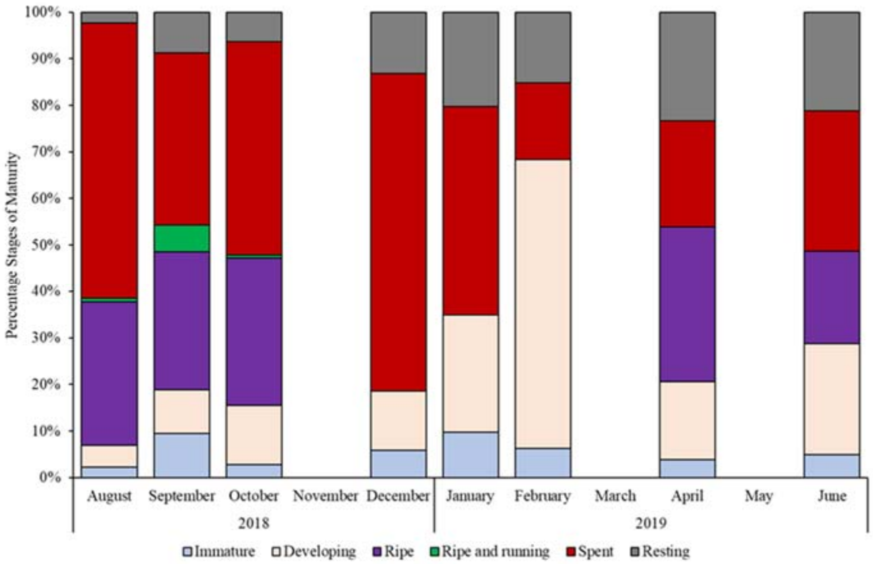


Figure 15. Seasonal **a)** maturity results through macroscopic observations and **b)** changes in the GSI of female winter flounder for each month during the 2018 seasonal bycatch survey on the eastern portion of GB.

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

Year	Month	Number		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2018	August	264	239	137.126	136.774
	September	336	203	185.526	124.982
	October	164	253	98.384	147.444
	December	465	369	282.942	204.952
2019	January	230	384	137.148	224.092
	February	332	467	224.334	270.732
	April	415	496	243.188	288.112
	June	73	80	66.616	33.33
Total		2279	2491	1375.26	1430.42

a)



b)

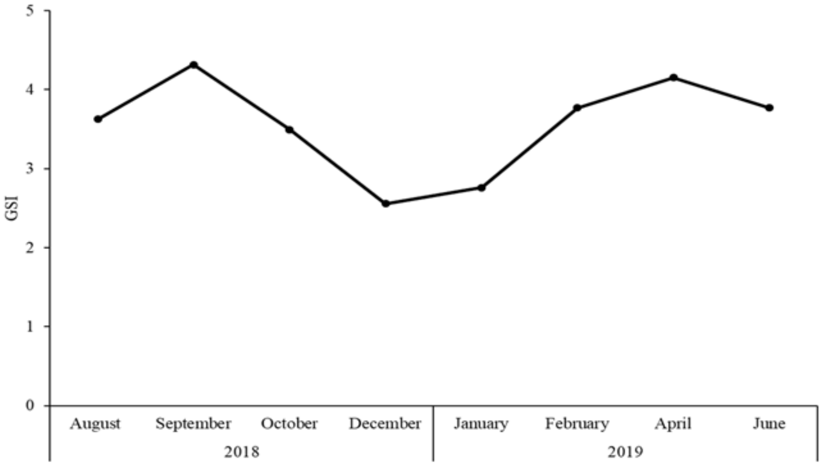


Figure 16. Seasonal **a)** maturity results through macroscopic observations and **b)** changes in the GSI of female windowpane flounder for each month during the 2018 seasonal bycatch survey on the eastern portion of GB.

Yellowtail flounder: A total of 304 yellowtail flounder were captured during the 2018 project (**Table 11**), of which 89.5% were females. The peak catch of yellowtail flounder occurred in August (**Figure E2**), and the lowest catch occurred in September. They were observed in ripe and running condition in June. Few females were ripe in April and June (**Figure 17a**). The GSI analysis indicated a spawning peak between April and June (**Figure 17b**). This result coincides with previous bycatch and the historical yellowtail flounder spawning season on GB 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).

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

Year	Month	Number		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2018	**August**	41	55	68.57	68.57
	September	5	1	1.28	1.28
	October	4	12	16.41	16.41
	December	15	20	29.06	29.06
2019	**January**	13	11	12.89	12.89
	February	33	11	10.45	10.45
	April	27	19	21.67	21.67
	June	21	16	18.41	18.41
Total		159	145	287.36	197.63

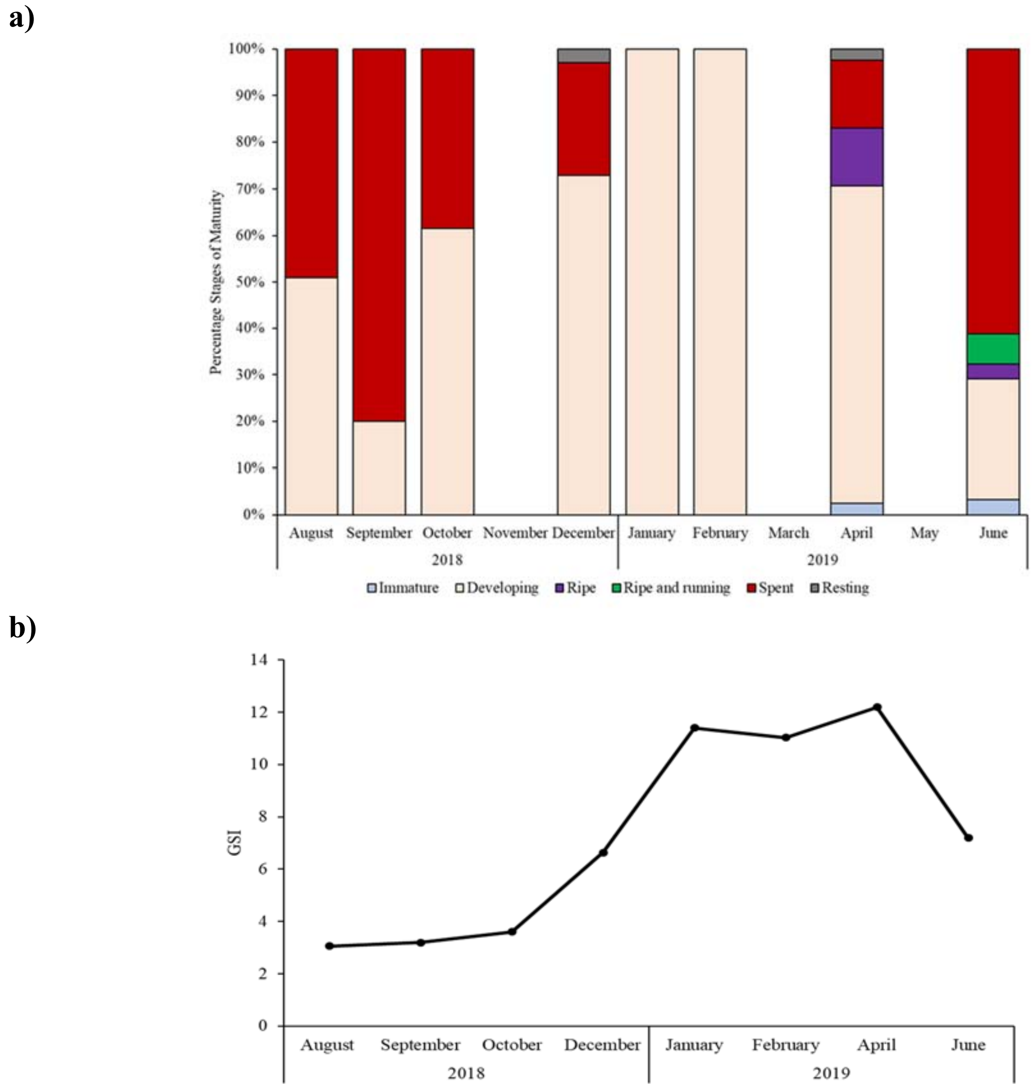


Figure 17. Seasonal **a)** maturity results through macroscopic observations and **b)** changes in the GSI of female yellowtail flounder for each month during the 2018 seasonal bycatch survey on the eastern portion of GB.

A total of 76 of seemingly healthy livers were analyzed for *Ichthyophonus* infection. Histological examination indicated that four of them were infected with *Ichthyophonus* even though macroscopic inspection found no evidence of the disease. *Ichthyophonus* infections were identified in the liver of three flounders and in the spleen of one individual (**Figure 18**).

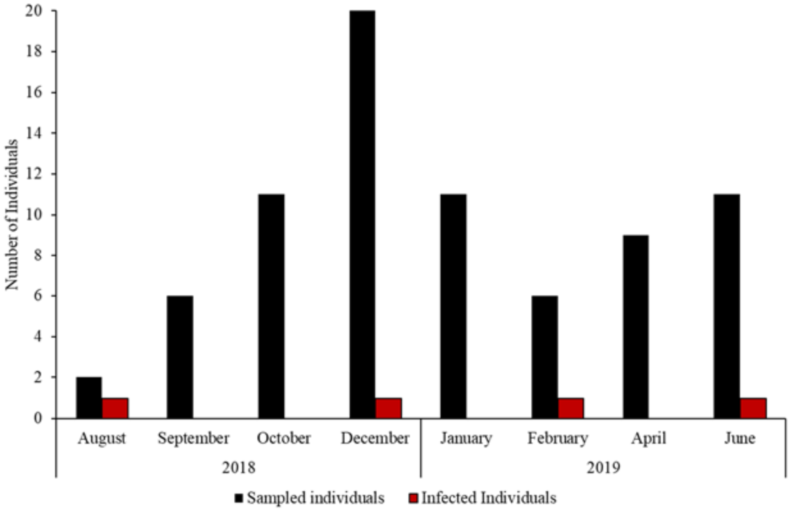


Figure 188. Numbers of yellowtail flounder analyzed for *Ichthyophonus* infection by trip during the 2018 seasonal bycatch survey on the eastern portion of GB.

<u>Length-weight relationships for flounder species</u>: the length-weight data was analyzed for winter, windowpane, and yellowtail flounders from the eastern portion of GB from August 2017 to June 2019. For each species, the parameters used to describe the length-weight relationship were determined for females, males, and the two sexes combined. The values 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 GB. 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 12**. 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 12. Length-weight relationship for the three flounder species, estimated from data collected during the 2018, 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 GB August 2017- June 2019				Northern portion of GB 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	142	22-55	0.017	2.92	722	29 - 64	0.076	2.53	5322	9-60	8.56E-06	3.12
	Male	160	17-52	0.014	2.97	705	26 - 56	0.137	2.35	3796	5-54	1.13E-05	3.02
	Combined	302	17-55	0.013	2.99	1427	26 - 64	0.058	2.59	9325	4-60	9.22E-06	3.09
Windowpane Flounder	Female	2249	9-45	0.034	2.68	2949	16 - 39	0.061	2.5	2754	7-40	1.37E-05	2.98
	Male	1700	12-37	0.048	2.57	3212	16 - 38	0.108	2.31	2153	4-36	1.47E+05	2.92
	Combined	3949	8-45	0.026	2.76	6161	16 - 39	0.042	2.6	8009	2-44	1.28E-05	2.97
Yellowtail Flounder	Female	527	18-47	0.301	2.04	1055	21-49	0.096	2.35	4356	6-55	3.93E-06	3.27
	Male	76	18-45	0.055	2.48	221	25-45	0.045	2.52	4290	11-49	7.41E-06	3.05
	Combined	603	18-47	0.108	2.31	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 13**). More than half of the monkfish caught during this survey were adults (72.7%) 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 June (**Table 13**). 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 (Siemann *et al.* 2018).

Table 13. Catch of monkfish for each trip by gear type.

Year	Month	Number		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2017	**August**	209	258	1438.3	1789.5
	September	140	104	744.1	687.2
	October	103	101	699.3	611.5
	December	124	110	766.9	611.4
2018	**January**	64	67	348.3	379.4
	February	35	50	155.3	286.9
	April	96	89	488.7	472.0
	June	316	278	1970.5	1758.0
Total		1087	1057	3005.2	2998.2

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 August (**Table 14** and **Figure 19**), and lobsters were caught across the entire survey area (**Figure E6**). Catch started to drop off during the October trip, and few lobsters were present from December through April; in June, the catch began to increase (**Table 14** and **Figure E6**).

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

Year	Month	Number		Weight (lbs.)	
		Control	Experimental	Control	Experimental
2018	**August**	76	68	293.9	250.6
	September	124	120	419.4	431.8
	October	50	59	197.4	221.8
	December	2	4	5.2	31.4
2019	**January**	1	0	3.7	0
	February	1	1	4.2	6.2
	April	2	8	6.6	15.8
	June	26	21	102.5	80.2
Total		282	281	1032.9	1037.8

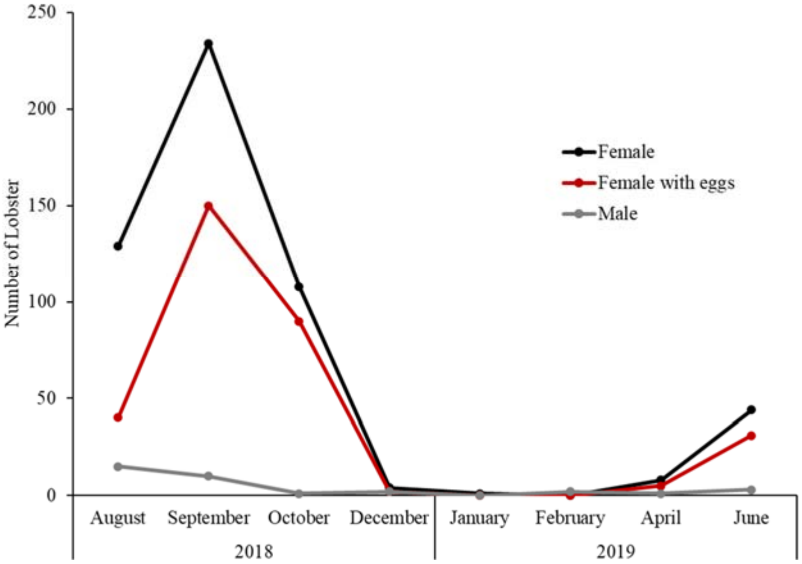


Figure 199. Catch of lobsters by trip separated by sex during the 2018 seasonal bycatch survey on the eastern portion of GB.

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 August trip (15 males; **Figure 19**). A total of twelve incidences of shell disease were observed. Overall, 219 lobsters had no damage, 176 were moderately damaged (missing claws or a walking leg), and 168 were classified as lethally damaged **(Figure 20**). A total of 56 females and 6 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.

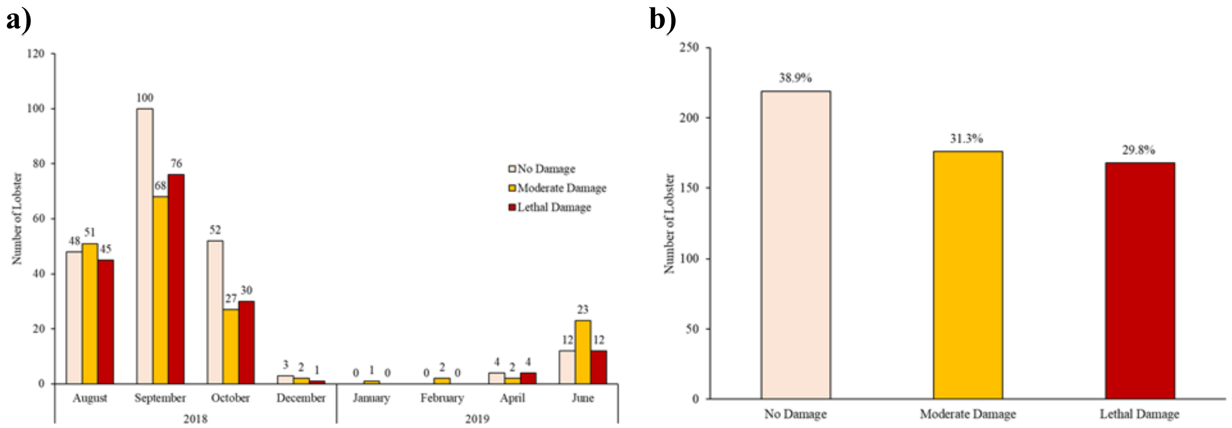


Figure 20. Dredge-induced damage to lobsters **a)** by trip and **b)** in total during the 2018 seasonal bycatch survey on the eastern portion of GB.

Other fish species: Unclassified skate catch was typically comprised of little and winter skates but may have included thorny skate (*Amblyraja radiate*), clearnose skate (*Raja eglanteria*), or other species (**Table 15**). Skates were present in high numbers at nearly every station sampled. Barndoor skate were relatively abundant, with the lowest catch in December (60 barndoor skate caught) and the highest catch in June (228 barndoor skate caught). Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), American plaice (*Hippoglossoides platessoides*) and witch flounder (*Glyptocephalus cynoglossus*) catches were low for the entire project (**Table 15**).

Table 15. Catch of additional species for each trip by gear type during the 2018 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
2018	August	2523	2332	88	77	5	1	0	2	2	1	3	3
	September	2737	1819	32	34	1	0	4	2	1	0	0	3
	October	1847	1937	62	47	0	3	0	2	5	4	3	11
	December	2597	2315	32	28	2	2	1	0	10	12	14	7
2019	January	2015	2407	31	63	1	0	6	4	8	18	20	5
	February	2282	2779	27	40	1	1	9	2	1	2	3	3
	April	3453	3950	47	75	5	1	0	2	2	1	0	3
	June	3000	2327	135	93	1	0	4	2	1	0	3	11
	Total	20454	19866	454	457	10	7	20	12	27	37	40	29

DISCUSSION

Since 1963 the National Marine Fisheries Service-Northeast Fisheries Science Center (NMFS-NEFSC) has conducted two bottom trawl surveys, one in the fall and one in the spring, providing time series of fisheries-independent data for GB. However, thanks to the 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), managers were able 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). In addition to this, during all the years of this project, we have observed the relative abundance of important commercial species peak in winter and summer months, when the bottom trawl surveys are not being conducted. For example, during these two years dedicated to the eastern part of GB, we have observed that the relative abundance of species like winter flounder peaked in June, yellowtail and monkfish peaked in summer months, and windowpane flounder peaked in winter months (Winton *et al*. 2017, Siemann *et al*. 2018, Garcia *et al*. 2018b). Therefore, current stock assessments may underestimate the annual abundance of these commercially important species on GB.

The scallop meat-weight peak we have observed in February during the last two bycatch projects was unexpected. Scallop meat weights typically peak in the summer on GB, and fleet effort focuses on summer months in this region as a result. Yet bimodal patterns in meat weights of GB scallops have been previously reported. Sarro and Stokesbury (2009) reported a bimodal pattern for scallops on the SF with meat weight peaks in February and July, Hennen and Hart (2012) also reported a bimodal pattern with peaks in December and June. Meat weights vary monthly following a seasonal pattern depending on scallop reproductive cycle and on primary productivity (Sarro and Stokesbury 2009, Thompson *et al*. 2014). The peak in meat weights in February at the 60-m station could be explained based on a combination of the bimodal reproductive cycle we observed, with a GMI peak in February, and the spring plankton bloom on GB, which begins in late winter/early spring (Townsend and Thomas 2002). At the shallower station, more food may be reaching the bottom due to more complete mixing (MacDonald and Thompson 1985, Townsend and Thomas 2002) generating more somatic growth due to the food availability (Sarro and Stokesbury 2009). Additional analysis is needed to better understand the spatiotemporal relationship between meat weight, gonad weight, and primary productivity on GB.

An important biological data set captured by this project over the years has been quantified reproductive cycles for three important flounder bycatch species. We have observed distinct changes in the timing of peak spawning of these species with respect to previous studies. Historically, yellowtail flounder spawning has been documented to occur in the late spring to early summer by CFF, the National Marine Fisheries Service, and the Canadian Department of Fisheries (Huntsberger *et al*. 2015, Garcia *et al*. 2017, DFO 1999, NMFS 1999). However, the 2016 CFF bycatch project documented ripe yellowtail flounder in September-November on the northern GB (Garcia *et al*. 2018b), and the 2017 CFF bycatch project documented ripe flounder in August-October on the eastern GB (Garcia *et al*. 2018a). For reasons we do not yet understand, the results from this year's project coincide with the historical spring spawning period for yellowtail flounder. A single summer spawning period for GB windowpane was documented in 1977 (Lange and Lux 1978), and an extended June-to-October spawning period was observed from1985 to 1990 (O'brien *et al.* 1993). Our study has documented an even longer extended spawning period from spring through fall. Altered spawning behavior has been cited as a potential 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). These examples could indicate that the spawning periods of other species in the North Atlantic may be changing. Given the poor condition of the yellowtail flounder stock on GB, this possibility is particularly important to investigate. Therefore, it is necessary for the continuous monitoring to determine how much the reduction of catch over the years in this area is attributed to variations in the timing of spawning periods in response to a host of external variables including changes in temperature regimes.

CFF constantly explores gear modifications designed to reduce bycatch while maintaining scallop catch. This is done to mitigate the impact of scallop dredges on groundfish species and to avoid the possible negative economic consequences to the scallop industry when AMs are implemented for impacted flatfish species on GB. Since 2017, the seasonal bycatch project has been testing an extended link apron that in theory facilitates the escapement of flatfish. During dedicated gear trips, this theory was supported with 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). During this year's bycatch project, there was a significant reduction of yellowtail flounder catch with the extended link apron. But in contrast to the dedicated gear study, there was also a significant reduction in scallop catch and the extended link apron became less efficient as scallop size increased.

The differences in results from the dedicated gear project and the seasonal survey projects are attributed to the experimental design. For the gear project, the control and experimental dredges were the same except for the extended link apron on the experimental dredge. In contrast, the experimental dredge for the seasonal survey project was supplied by the industry vessel, and an extended link apron that we provided was fitted onto their dredge. This design was intended to offer a full examination of the impact of the gear modification at the fleet level and an assessment of whether management objectives would be met in light of any variability. However, we believe that by adding more variables that are difficult to control (e.g. dredge style, dredge width, sweep), this design made it difficult to assess changes in relative catch due to the gear modification that was the main focus of the project and other gear differences that were present due to the variety of vessel-supplied gear setups. 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.

Examination of longer-term changes in species catch distributions and abundance patterns point to the continued need for a seasonal bycatch survey of GB. For instance, seasonal trends in yellowtail and windowpane flounder abundance in CAII S may be changing. Catch data from the seasonal bycatch survey shows that the relative abundance of both species are decreasing on GB (**Table F1**, Garcia *et al.* 2018a). Furthermore, the regular cycles in abundance for yellowtail flounder, previously described by CFF and used to adjust seasonal access by the scallop fishery to CAIIS, are no longer evident in recent years (**Appendix F**). From 2011-2014, yellowtail flounder abundance peaked in the late summer/fall during months corresponding to the current closure (August 15-November 15). Over that same time period, a shifted cycle was observed for windowpane flounder, with abundance peaking in January-April. However, during recent years the abundance and distribution patterns are more irregular with the highest abundance of yellowtail flounder observed in late winter/early spring. The causes for these changes need further investigation, although it is notable that some unusual bottom temperature patterns have been observed during CFF surveys in recent years.

Finally, the results from our ongoing gray meat research indicate that multiple factors have an influence on poor quality meat scallop on GB. Gray meats have been associated with the presence of the apicomplexan parasite; however, during this project we have found positive signals for the presence of the parasite in samples of both white and discolored meats, suggesting that another mechanism besides the accumulation of apicomplexan parasites in the muscle contribute to degradation in scallop muscle tissue. We recently published a paper using seasonal bycatch data collected from 2013 to 2016. Our results indicated that in the southern part of GB, location was a significant factor for presence of gray meats, and in the northern part of GB, reproductive stage was a significant factor, with scallops more likely to have discolored meats after spawning (Siemann *et al*. 2019). These results suggest that gray meats are a symptom of poor condition that could be caused by multiple factors, including costly reproduction, poor habitat, or other stressors (Siemann *et al*. 2019). In order to better understand the causes of poor-quality meats in scallops, it is necessary to expand our efforts and use new techniques that allow us to better correlate biological and environmental factors with the quality of scallop meats. In 2019, CFF started to utilize a Certified Quality Reader (CQR) to assign numeric scores based on bioimpedance to scallop meats and correlate these values with the macroscopic observations of meat quality to determine the feasibility of using this new tool for rapid assessment of meat quality. For the first two trips of the 2019 seasonal bycatch project, 1171 scallop meats have been analyzed with the CQR, and significant differences were observed between colors (white, brown and gray), with trends that corresponded with the coloration criteria (**Appendix G**).

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 GB. This long-term seasonal data set is unique and 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 GB in the scallop access areas in CAI and CAII, two years (August 2015 – June 2017) of surveys on the northern portion of GB, and two years (August 2017 – June 2019) of surveys on the eastern portion of GB. 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 improved methods to evaluate scallop meat quality such as the CQR and, with our collaborators at RWU, qPCR methods for quantified detection of parasites. These efforts will be accompanied by increased collection of other biological and environmental variables associated with scallop disease, improving our ability to detect disease and quantify disease impacts.

In summary, CFF seasonal bycatch data provides information on many of the aspects of the scallop fishery. Surveys are conducted in a systematic fashion, using full-scale dredges over a range of scallop densities to provide information on gear selectivity for bycatch species in these areas. This data, when combined with data from the NEFSC bottom trawl survey data and scallop dredge surveys conducted by the Virginia Institute of Marine Science, can be used to estimate the impact that the scallop fishery has on bycatch species and offer solutions to address potential fishery closures. The ecological changes brought about by anthropogenic disturbance, management decisions, and climate change need to be tracked continually to keep informing best management practices as the spatiotemporal patterns of fisheries species change in unexpected ways. To meet this need, seasonal surveys will be necessary to fill in the data gaps present in current government surveys.

REFERENCES

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In: B.N. Petrov & F. Csaki, editors. Second international symposium on information theory. Akademiai Kiado: Budapest. pp. 267-281.

Bachman, M.S. 2009. Determinants of Yellowtail Flounder Bycatch in the Closed Area II Scallop Access Fisheries on Georges Bank. Master's Thesis. University of Massachusetts School of Marine Sciences, Dartmouth, MA.

Bonardelli, J.C. and Himmelman, J.H. 1995. Examination of assumptions critical to body component indices: application to the giant scallop *Placopecten magellanicus*. Canadian Journal of Fisheries and Aquatic Sciences, 52(11), pp.2457-2469.

Breheny, P. and Burchett, W. 2017. Visualization of regression models using visreg. The R Journal 9: 56-71.

Byron, J. 2017. r2glmm: Computes R Squared for Mixed (Multilevel) Models. R package version 0.1.2. https://CRAN.R-project.org/package=r2glmm

Caddy, J. F. 1989. A perspective on the population dynamics and assessment of scallop fisheries with special reference to the sea scallop, *Placopecten magellanicus* (Gmelin). In: JF Caddy (ed.). Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley & Sons, Inc., pp. 559-589.

Cadigan, N.G. and Dowden, J. J. 2010. Statistical inference about relative efficiency of a new survey protocol, based on paired-tow survey calibration data. Fish. Bull. 108:15-29.

Davis, F., Siemann, L. and Alexander, R. 2018. Development of an Extended Link Apron: A Broad Range Tool for Bycatch Reduction. Final Report. Sea Scallop Research Set-Aside.

Fisher, R. A. 2000. Biology of certain commercial species: scallops. In: Martin, R. E, E. P. Carter, G. J. Flick & L. M. Davis, editors. Marine and freshwater products handbook. Boca Raton, FL: CRC Press. pp. 83–110.

Fryer, R.J., Zuur, A.F. and Graham, N. 2003. Using mixed models to combine smooth size-selection and catch-comparison curves over hauls. Canadian Journal of Fisheries and Aquatic Sciences, 60(4), pp.448-459.

Fogarty, M., Incze, L., Hayhoe, K., Mountain, D. and Manning, J. 2008. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change, 13(5-6), pp.453-466.

Garcia, L., Siemann, L., Smolowitz, R., Rudders, D. and Smolowitz, R., 2018a. Optimizing the Georges Bank scallop fishery by maximizing meat yield and minimizing bycatch. Final report for the 2017 NOAA sea scallop research set-aside program.

Garcia, L., Siemann, L., Smolowitz, R., Rudders, D. and Smolowitz, R., 2018b. Optimizing the Georges Bank scallop fishery by maximizing meat yield and minimizing bycatch. Final report for the 2016 NOAA sea scallop research set-aside program.

Garcia, L., Siemann L. and Huntsberger, C. 2017. Optimize the Georges Bank Scallop Fishery by Maximizing Meat Yield and Minimizing Bycatch. Final report for the 2015 NOAA sea scallop research set-aside program.

Goetting K., Thompson, K. Davis, F. and Huntsberger, C. 2013. Seasonal Bycatch Survey of the Georges Bank Scallop Fishery. Final report for the 2011 NOAA sea scallop research set-aside program.

Grimm, C., Huntsberger, C., Markey, K., Inglis, S. and Smolowitz, R. 2016. Identification of a Mycobacterium sp. as the causative agent of orange nodular lesions in the Atlantic sea scallop *Placopecten magellanicus*. Diseases of aquatic organisms, 118(3), pp.247-258.

Hebbali A. 2018. olsrr: Tools for Building OLS Regression. Models. R package version 0.5.2. Available at: https://CRAN.R-project.org/package=olsrr

Hennen, D.R. and Hart, D.R. 2012. Shell height-to-weight relationships for Atlantic sea scallops (*Placopecten magellanicus*) in offshore US waters. Journal of Shellfish Research 31(4), pp. 1133-1145.

Holst R. and Revill, A. 2009. A simple statistical method for catch comparison studies. Fisheries Research. 95: 254–259.

Howard, D.W., Lewis, E.J., Keller, B.J. and Smith, C.S. 2004. Histological techniques for marine bivalve mollusks and crustaceans.

Huntsberger, C.J., Hamlin, J.R., Smolowitz, R.J. and Smolowitz, R.M. 2017. Prevalence and description of Ichthyophonus sp. in yellowtail flounder (Limanda ferruginea) from a seasonal survey on Georges Bank. *Fisheries Research*, *194*, pp.60-67.

Huntsberger, C., Thompson, K., Winton, M. and Siemann, L. 2015. Seasonal Bycatch Survey of the Georges Bank Scallop Fishery. Final report for the 2013 sea scallop research set-aside program.

Inglis, S.D., Kristmundsson, Á., Freeman, M.A., Levesque, M. and Stokesbury, K., 2016. Gray meat in the Atlantic sea scallop, Placopecten magellanicus, and the identification of a known pathogenic scallop apicomplexan. *Journal of invertebrate pathology*, *141*, pp.66-75.

Kleisner, K.M., Fogarty, M.J., McGee, S., Hare, J.A., Moret, S., Perretti, C.T. and Saba, V.S. 2017. Marine species distribution shifts on the US Northeast Continental Shelf under continued ocean warming. *Progress in Oceanography*, 153, pp.24-36.

Kristmundsson, Á. and Freeman, M.A. 2018. Harmless sea snail parasite causes mass mortalities in numerous commercial scallop populations in the northern hemisphere. Scientific reports, 8(1), p.7865.

Kristmundsson, Á., Helgason, S., Bambir, S.H., Eydal, M. and Freeman, M.A. 2011. Previously unknown apicomplexan species infecting Iceland scallop, Chlamys islandica (Müller, 1776), queen scallop, Aequipecten opercularis L., and king scallop, Pecten maximus L. Journal of invertebrate pathology, 108(3), pp.147-155.

Kristmundsson, Á., Erlingsdóttir, Á. and Freeman, M.A. 2015. Is an apicomplexan parasite responsible for the collapse of the Iceland scallop (Chlamys islandica) Stock?. PloS one, 10(12), p.e0144685.

Lange, A.M. and Lux, F.E. 1978. Review of the Other Flounder Stocks (Winter Flounder, American Plaice, Witch Flounder, and Windowpane Flounder) Off the Northeast United States, August 1978. National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole Laboratory.

Legault, C. and McCurdy, Q. 2019. Stock Assessment of Georges Bank Yellowtail Flounder for 2018. Transboundary Resources Assessment Committee. NMFS, Woods Hole, MA. 64 pp. Available at https://www.nefsc.noaa.gov/saw/trac/2019_REF%20DOC%20Georges%20Bank%20Yellowtail%202018%20DRAFT.pdf

Legault, C. M. and Busawon, D. 2016. Stock Assessment of Georges Bank Yellowtail Flounder for 2016. Transboundary Resources Assessment Committee. NMFS, Woods Hole, MA. 67 pp. Available at https://www.nefsc.noaa.gov/saw/trac/TRAC_GBYT_2016.pdf

MacDonald, B.A. and Thompson, R.J. 1985. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. 2. Reproductive output and total production. Marine Ecology Progress Series 25, pp.295-303.

Mastrostefano, A. 2018. Development of Diafnostic PCR Assay to Detect an Unknown Apicomplexan Parasite in Atlantic Sea Scallops (*Placopecten Magellanicus*) with Gray Meat Disease. Senior Thesis. Roger Williams University, Bristol, RI.

Marc, J. M. 2019. AICcmodavg: Model selection and multimodel inference based on (Q)AIC(c). R package version 2.2-2. https://cran.r-project.org/package=AICcmodavg.

NOAA. 2017. Commercial fisheries statistics. Available online: https://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html

NEFMC. 2017. Draft Alternatives Framework Adjustment 56 to the Northeast Multispecies FMP. 21 pp. Available at http://s3.amazonaws.com/nefmc.org/170316_Groundfish_Framework_Adjustment_56_draft_alternatives.pdf

NEFMC. 2019a. Framework Adjustment 58 to Northeast Multispecies Fishery Management Plan. MA. 346 pp. Available at https://s3.amazonaws.com/nefmc.org/190319_Groundfish_FW58_EA_formal_submission_CORECTED_190418.pdf

NEFMC. 2019b. Scallop Fishery Management Plan Framework Adjustment 32 Including an Environmental Assessment, Regulatory Flexibility Analysis, and Stock Assessment and Fishery Evaluation. https://s3.amazonaws.com/nefmc.org/Doc.3-Draft-FW32-191115-for-AP-CTE_191115_200833.pdf

NEFMC. 2014. Final Framework 25 to the Atlantic Sea Scallop Fishery Management Plan with Environmental Assessment, Regulatory Impact Review, Environmental Impact Statement, and Regulatory Flexibility Analysis. Newburyport, MA. 319 pp. Available at http://s3.amazonaws.com/nefmc.org/Final_USE_fw_25_with_correct_maps.pdf

NEFMC. 2013. Final Framework 24 to the Atlantic Sea Scallop Fishery Management Plan with Environmental Assessment, Regulatory Impact Review, Environmental Impact Statement, and Regulatory Flexibility Analysis. Newburyport, MA. 354 pp. Available at http://www.nefmc.org/scallops/index.html

O'Brien, L., Burnett, J. and Mayo, R.K. 1993. Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990.

Perry, A.L., Low, P.J., Ellis, J.R. and Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes. science, 308(5730), pp.1912-1915.

Salvatore, M. 2019. rcompanion: Functions to Support Extension Education Program Evaluation. R package version 2.3.7. Available at: https://CRAN.R-project.org/package=rcompanion.

Sarro, C.L. and Stokesbury, K.D. 2009. Spatial and temporal variation in the shell height/meat weight relationship of the sea scallop *Placopecten magellanicus* in the Georges Bank fishery. *Journal of Shellfish Research*, *28*(3), pp.497-504.

Siemann, L.A., Garcia, L.M., Huntsberger, C.J. and Smolowitz, R.J. 2019. Investigating the Impact of Multiple Factors on Gray Meats in Atlantic Sea Scallops (*Placopecten magellanicus*). Journal of Shellfish Research, 38(2), pp.233-243.

Siemann, L.A., Huntsberger, C.J., Leavitt, J.S. and Smolowitz, R.J. 2018. Summering on the bank: Seasonal distribution and abundance of monkfish on Georges Bank. *PloS one*, *13*(11), p.e0206829.

Siemann, L., Garcia, L., Huntsberger, C., Davis, F., Alexander, R., Parkins, C., and Smolowitz, R. 2017. Reduction of flounder bycatch in the sea scallop fishery on Georges Bank: the yellowtail versus windowpane problem. Available at http://s3.amazonaws.com/nefmc.org/Doc3-CFF-YTF-WPF-bycatch-for-PDT.pdf.

Siemann, L.A., Huntsberger, C.J., Leavitt, J.S. and Smolowitz, R.J. 2018. Summering on the bank: Seasonal distribution and abundance of monkfish on Georges Bank. *PloS one*, *13*(11), p.e0206829.

Smith, E.M. and Howell, P.T. 1987. The effects of bottom trawling on American lobsters, *Homarus americanus*, in Long Island Sound. *Fishery Bulletin*, *85*(4), pp.737-744.

Smolowitz, R., Siemann, L.A., Huntsberger, C. and Boelke, D. 2016. Application of seasonal closures to reduce flatfish bycatch in the US Atlantic sea scallop fishery. *Journal of shellfish research*, *35*(2), pp.475-481.

Smolowitz R., K. Goetting, B. Valenti. 2012a. Testing of Modifications to the Cfarm Turtle Deflector Dredge for Bycatch Reduction. Final Report for the 2012 sea scallop research set-aside program.

Smolowitz R., K. Goetting, F. Davis, and D. Ward. 2012b. Optimizing the Georges Bank Scallop Fishery by Maximizing Meat Yield and Minimizing Bycatch. Final Report for the 2012 sea scallop research set-aside program.

Thompson, K.J., Inglis, S.D. and Stokesbury, K.D. 2014. Identifying spawning events of the sea scallop *Placopecten magellanicus* on Georges Bank. *Journal of Shellfish Research*, *33*(1), pp.77-88.

Townsend, D.W. and Thomas, M. 2002. Springtime nutrient and phytoplankton dynamics on Georges Bank. Marine Ecology Progress Series, 228, pp.57-74.

Wickham, H. 2016. Ggplot2: elegant graphics for data analysis. Springer-Verlag, New York.

Wieland, K., Jarre-Teichmann, A. and Horbowa, K. 2000. Changes in the timing of spawning of Baltic cod: possible causes and implications for recruitment. *ICES journal of marine science*, *57*(2), pp.452-464.

Wigley, S.E., McBride, H.M. and McHugh, N.J. 2003. Length-weight relationships for 74 fish species collected during NEFSC research vessel bottom trawl surveys, 1992-99.

Winton, M., Huntsberger, C., Rudders, D., DeCelles, G., Thompson, K., Goetting, K. and Smolowitz, R. 2017. Spatiotemporal patterns of flatfish bycatch in two scallop access areas on Georges Bank. *J. Northw. Atl. Fish. Sci*, *49*, pp.23-37.

Wood, S.N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 73(1), pp.3-36.

APPENDICES

Appendix A: General

Table A1. Specifications of CFF dredges used during the 2018 seasonal bycatch survey on the eastern portion of GB. Dredge characteristics for the control dredges used for each trip. Dredges varied by vessel preference. Month: August 2018 = 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	No	Yes	No	Yes	No	Yes
New Shoes/Heels		No	Yes	No	Yes	Yes	No	No	No	Yes
New Twine Top		No	Yes	No	No	Yes	No	No	No	Yes
Frame		TDD	NBD	TDD	TDD	NBD	TDD	TDD	TDD	TDD
Dredge Width		15	15	14	15	14	15	15	14	13
Turtle Chains		13	13	11	3	3	3	13	5	6
Ticklers		9	7	5	3	2	3	8	3	5
Chain Link Size		5/8	5/8	1/2	1/2			5/8		1/2
Diamond		14	14	11	14	13	15	12	11	12
Sweep		121	113	117	137	109	144	141	117	101
Hanging Ratio		2.1:1	2.9:1	2.7:1	3.2:1	2.1:1	1.6:1	1.3:1	2.5:1	1.9:1
Bag Rings	**Width**	40	40	38	40	38	40	40	40	36
	Length	10	6	10	10	7	10	10	10	9
Apron Rings	**Width**	40	40	38	40	40	40	40	40	36
	Length	7	7	7	6	5	5	7	7	7
Side Piece	**Width**	6	6	4	6	6	6	4	4	5
	Length	20	17	14	20	18	20	18	13	9
Twine Top	**Mesh size**	10.5	10	11	11	12	12	10	10	11
	Width	60	80	80	90	60	45	40	82	48
	Length	9	7	7	8.5	7.5	11	8	6.5	7.5

Table A2. Species captured during the 2018 seasonal bycatch survey on the eastern portion of GB. 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*	64	Weigh/Measure
Atlantic cod	*Gadus morhua*	17	Weigh/Measure
Atlantic Menhaden	*Brevoortia tyrannus*	1	Count/Weigh
Barndoor skate	*Dipturus laevis*	917	Weigh/Measure
Crabs	*Cancer sp.*	527	Count/Weigh
Fourspot flounder	*Paralichthys oblongus*	630	Weigh/Measure
Gulfstream flounder	*Citharichthys arctifrons*	22	Count/Weigh
Haddock	*Melanogrammus aeglefinus*	32	Weigh/Measure
Jonah crab	*Cancer borealis*	791	Count/Weigh
Lady crab	*Ovalipes ocellatus*	16	Count/Weigh
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	46	Count/Weigh
Monkfish	*Lophius americanus*	2211	Weigh/Measure
Northern pipefish	*Syngnathus fuscus*	1	Count/Weigh
Northern searobin	*Prionotus carolimus*	419	Count/Weigh
Ocean pout	*Zoarces americanus*	7	Count/Weigh
Red hake	*Urophycis chuss*	742	Count/Weigh
Rock Crab	*Cancer irroratus*	89	Count/Weigh
Sea raven	*Hemitripterus americanus*	32	Count/Weigh
Sea Scallops (bushels)	*Placopecten magellanicus*	36290	Weigh/Measure/ Reproductive/Disease
Silver hake	*Merluccius bilinearis*	149	Count/Weigh
Spiny dogfish	*Squalus acanthias*	11	Weigh/Measure
Summer flounder	*Paralichthys dentatus*	145	Weigh/Measure
Tautog	*Tautoga onitis*	3	Count/Weigh
Unclassified skates	*Rajidae*	40629	Count/Weigh
White hake	*Urophycis tenuis*	1	Count/Weigh
Windowpane flounder	*Scopthalmus aquosus*	4769	Weigh/Measure/ Reproductive
Winter flounder	*Pseudopleuronectes americanus*	199	Weigh/Measure/ Reproductive
Witch flounder	*Glyptocephalus cynoglossus*	72	Weigh/Measure
Yellowtail flounder	*Limanda ferruginea*	311	Weigh/Measure/ Reproductive/Disease

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

R output for SHMW models: GLMMs run with function “pqlmer” in R package “r2glmm” with model selection using “aictab” function in R package “AICcmodavg”

```
Linear mixed model fit by REML ['lmerMod']
Formula: MW ~ lSH+Month+lDepth+lLat+fColor+lSH:Month+Month:lDepth+(1|fStation)
REML criterion at convergence: -3709.6

Scaled residuals:
   Min       1Q      Median     3Q        Max
-5.2922   -0.5879   0.0022    0.5999    6.3898

Random effects:
Groups   Name          Variance    Std.Dev.
fStation (Intercept)    0.006092    0.07805
Residual               0.031082    0.17630
Number of obs: 6219, groups:  fStation, 38
```

Table B1. Fixed effects

	Estimate	Std. Error	t value
(Intercept)	-15.71529	5.40595	-2.907
lSH		2.84913	0.03862
Sep		0.03734	0.43388
Oct		1.5133	
Dec		-0.07954	0.4886
Jan		1.15764	0.47083
Feb		2.00048	0.45392
Apr		1.37384	0.36761
Jun		-0.15303	0.4404
lDepth		-0.1381	0.06013
lLat		1.62356	1.43212
fColorBrown	-0.26201	0.02419	-10.832
fColorGray	-0.27417	0.07256	-3.778
lSH:Sep	-0.08126	0.06162	-1.319
lSH:Oct	-0.32592	0.0746	
lSH:Dec	-0.04857	0.06186	-0.785
lSH:Jan	-0.13443	0.0629	
lSH:Feb	-0.20988	0.06042	-3.474
lSH:Apr	-0.20334	0.05145	-3.952
lSH:Jun	-0.13959	0.06382	-2.187
Sep:lDepth	0.07634	0.05908	1.292
Oct:lDepth	-0.02895	0.06934	-0.417
Dec:lDepth	0.04473	0.07308	0.612
Jan:lDepth	-0.15569	0.06606	-2.357

	Estimate	Std. Error	t value
Feb:lDepth	-0.26772	0.06653	-4.024
Apr:lDepth	-0.10795	0.05705	-1.892
Jun:lDepth	0.23111	0.05889	3.924

Table B2. Model selection based on AICc

	k	AICc	Delta AICc	AICcWt	Cum.Wt	Res.LL
mFull	29	-3651.34	0.00	0.66	0.66	1854.81
m_Lat	28	-3649.27	2.08	0.23	0.89	1852.76
m_lSH_Month	22	-3647.04	4.31	0.08	0.97	1845.6
m_Lat_lSH_Month	21	-3645.33	6.01	0.03	1.00	1843.74
m_Depth_Month	22	-3610.55	40.8	0.00	1.00	1827.36
m_Lat_Depth_Month	21	-3608.15	43.2	0.00	1.00	1825.15
m_Lat_Depth_lSH_Month	13	-3607.91	43.44	0.00	1.00	1816.98
m_Depth	21	-3602.93	48.42	0.00	1.00	1822.54
m_Lat_Depth	20	-3597.18	54.17	0.00	1.00	1818.66
m_Color	27	-3595.77	55.57	0.00	1.00	1825.01
m_Color_Lat	26	-3593.86	57.48	0.00	1.00	1823.05
m_Color_lSH_Month	20	-3590.77	60.58	0.00	1.00	1815.45
m_Color_Lat_lSH_Month	19	-3589.26	62.08	0.00	1.00	1813.69
m_Color_Depth_lSH_Month	12	-3556.08	95.26	0.00	1.00	1790.07
m_Color_Depth_Month	20	-3553.55	97.8	0.00	1.00	1796.84
m_Color_Lat_Depth_Month	19	-3551.16	100.18	0.00	1.00	1794.64
m_Color_Lat_Depth_lSH_Month	11	-3550.86	100.48	0.00	1.00	1786.45
m_Color_Depth	19	-3548.12	103.23	0.00	1.00	1793.12
m_Color_Lat_Depth	18	-3542.72	108.62	0.00	1.00	1789.42

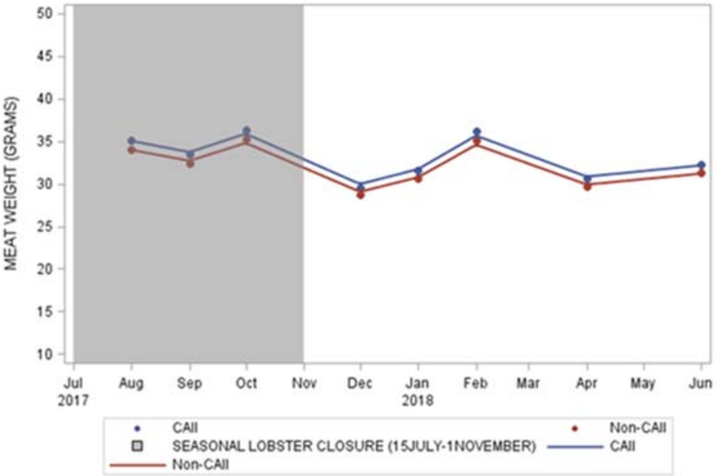


Figure B1. Temporal trends for the predicted meat weight of a white-meat 120-mm shell height scallop from the two areas on the eastern edge of GB. From the 2017 Seasonal Bycatch Final Report.

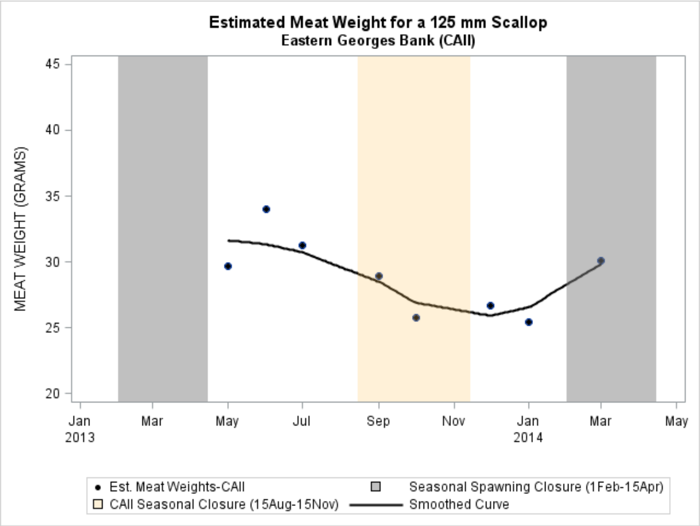


Figure B2. Temporal trends for the predicted meat weight of a white-meat 125-mm shell height scallop from CAII S. From the 2013 Seasonal Bycatch Final Report.

Appendix C: Gear Comparison

Table C1. Results from the linear regression models using the R function "lm". All models were forced through the origin with control catch as the independent and experimental catch as the dependent variable.

Species	Estimated slope	SE	t-value	p-value	Dfs	F-statistic	R^2
Scallops	0.6963	0.0237	29.42	<2E-16	1176	865.5	0.831
Yellowtail flounder	0.5183	0.0715	7.25	5.5E-10	1,67	52.52	0.4394
Windowpane flounder	0.8893	0.0667	13.33	<2E-16	1112	177.6	0.6133
Winter flounder	0.5714	0.2401	2.38	0.0301	1,16	5.663	0.2614
Fourspot flounder	0.9294	0.0706	13.17	<2E-16	1103	173.5	0.6275
Monkfish	0.8477	0.0458	18.51	<2E-16	1162	342.6	0.6789
Barndoor skate	0.9063	0.0593	15.27	<2E-16	1114	233.3	0.6717

Table C2. Generalized additive mixed model selection based on AIC values. Table shows AIC values for the intercept-only model, the full model, the length-based model, the model with all gear covariates, and when needed, the final selected model. Not that the selected model for windowpane flounder was the simplest model with a Δ_{AIC} value less than 4. Edf = estimated degrees of freedom, AIC = Akaike Information Criteria, HR = hanging ratio, and TT = twine top coverage.

Species	Model	Edf	AIC	Δ_{AIC}
Scallops	**Length**	**178.576**	**8523.499**	
	Full	178.598	8523.539	0.04
	Intercept only	175.589	8647.687	124.188
	All gear covariates	175.613	8647.728	124.229
Yellowtail flounder	**Length**	**8.661**	**251.71**	
	Full	16.271	254.899	3.189
	Intercept only	13.22	260.046	8.336
	All gear covariates	19.644	262.925	11.215
Windowpane flounder	All gear covariates	68.789	1520.899	
	Full	70.361	1522.21	1.311
	Bag length	**71.17**	**1522.754**	**1.855**
	Intercept only	75.1	1528.151	7.252
	Length	76.027	1529.033	8.134
Winter flounder	**HR**	**10.616**	**55.801**	
	All gear covariates	12.022	56.865	1.064
	Full	12.069	58.255	2.454
	Intercept only	12.011	58.849	3.048
	Length	15.87	60.368	4.567
Fourspot flounder	**Intercept only**	**30.764**	**644.243**	
	Length	31.451	646.042	1.799
	All gear covariates	35.125	648.418	4.174
	Full	35.76	650.213	5.97
Monkfish	**Intercept only**	**64.734**	**2074.826**	

	Length	65.762	2076.433	1.607
	All gear covariates	68.497	2077.354	2.528
	Full	69.555	2079.093	4.267
Barndoor skate	**TT and HR**	**14.03**	**901.63**	
	All gear covariates	15.41	903.004	1.374
	Full	15.695	904.396	2.766
	Intercept only	19.552	907.545	5.915
	Length	20.343	908.766	7.136

Table C3. R outputs for the selected models for each species (GAMMs run with function “gam” in R package “mgcv”)

Species **Model output**

Scallops

```
summary(fit.length)

Family: binomial
Link function: logit

Formula: CatchRatio ~ s(Length, k = 4, bs = "tp") + s(Tow, bs = "re")

Parametric coefficients:
              Estimate   Std. Error   z value   Pr(>|z|)
(Intercept)   0.668        2.036       0.328     0.743

Approximate significance of smooth terms:
               edf      Ref.df    Chi.sq      p-value
s(Length)    2.982        3        127       <2e-16 ***
s(Tow)     174.593      176       1763       <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.302    Deviance explained = 57.6%
UBRE = 0.98456   Scale est. = 1        n = 1961
```

Yellowtail flounder

```
summary(fit.length)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(Length, k = 4, bs = "tp") + s(Tow, bs = "re")

Parametric coefficients:
              Estimate   Std. Error   z value   Pr(>|z|)
(Intercept)   -0.3864     0.1738      -2.223    0.0262 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Approximate significance of smooth terms:
              edf     Ref.df    Chi.sq    p-value
s(Length)  2.077    2.392     11.339    0.00899 **
s(Tow)     5.584   68.000      6.737    0.16291
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.126    Deviance explained = 14.5%
UBRE = 0.4128   Scale est. = 1         n = 165
```

Windowpane flounder

```
summary(fit.gearSide)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(Side, k = 4, bs = "tp") + s(Tow, bs = "re")

Parametric coefficients:
              Estimate    Std. Error    z value    Pr(>|z|)
(Intercept)    0.0313       0.1078        0.29       0.772

Approximate significance of smooth terms:
           edf       Ref.df     Chi.sq      p-value
s(Side)   2.881       2.92       9.097       0.0168 *
s(Tow)  67.289      111.00    179.279     9.31e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.264    Deviance explained = 27.9%
UBRE =  0.286   Scale est. = 1         n = 761
```

Winter flounder

```
summary(fit.gearHR)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(HR, k = 4, bs = "tp") + s(Tow, bs = "re")

Parametric coefficients:
              Estimate    Std. Error    z value     Pr(>|z|)
(Intercept)    0.1209       0.9984       0.121        0.904

Approximate significance of smooth terms:
            edf      Ref.df     Chi.sq     p-value
s(HR)     2.302      2.543      1.662       0.525
s(Tow)    7.314     16.000     10.573       0.115

R-sq.(adj) =  0.371    Deviance explained = 47%
UBRE = 0.27984   Scale est. = 1         n = 38
```

Fourspot flounder

```
summary(fit.constant)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(Tow, bs = "re")

Parametric coefficients:
             Estimate   Std. Error   z value   Pr(>|z|)
(Intercept)    0.1798     0.1169      1.538     0.124

Approximate significance of smooth terms:
          edf   Ref.df   Chi.sq    p-value
s(Tow)  29.76    104      53.3    4.29e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =   0.12   Deviance explained = 14.5%
UBRE = 0.50903   Scale est. = 1        n = 379
```

Monkfish

```
summary(fit.constant)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(Tow, bs = "re")

Parametric coefficients:
             Estimate   Std. Error   z value   Pr(>|z|)
(Intercept)   0.00747    0.07666      0.097     0.922

Approximate significance of smooth terms:
          edf   Ref.df   Chi.sq    p-value
s(Tow) 63.73     162     123.5    3.45e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.101    Deviance explained = 10.3%
UBRE = 0.18751   Scale est. = 1        n = 1486
```

Barndoor skate

```
summary(fit.gearTT_HR)

Family: binomial
Link function: logit

Formula:
CatchRatio ~ s(Twine, k = 4, bs = "tp") + s(HR, k = 4,
    bs = "tp") + s(Tow, bs = "re")
```

```
Parametric coefficients:
             Estimate    Std. Error    z value    Pr(>|z|)
(Intercept)   0.06832     0.08477       0.806       0.42

Approximate significance of smooth terms:
            edf    Ref.df     Chi.sq     p-value
s(Twine)  1.00       1          7.877    0.00501 **
s(HR)      1.00      1           5.518    0.01883 *
s(Tow)    11.03     113        14.106    0.06774 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0496    Deviance explained = 4.97%
UBRE = 0.26318   Scale est. = 1        n = 660
```

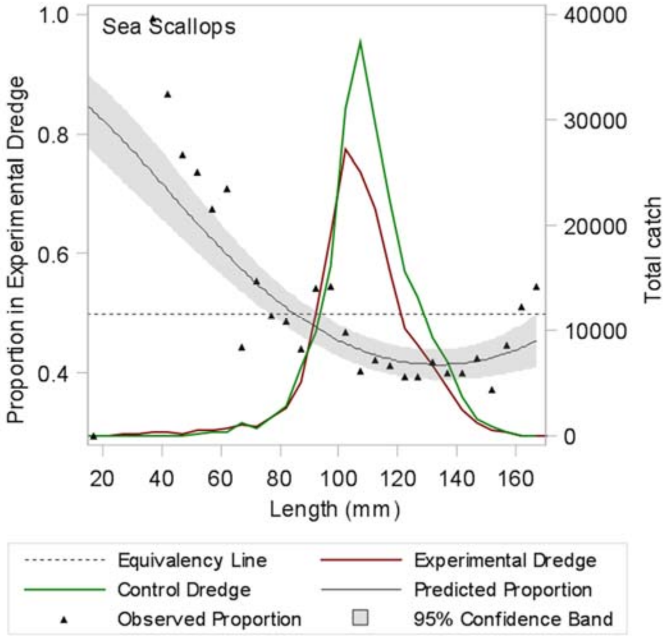


Figure C1. Length-based model results for relative scallop catch. The triangles represent the observed proportion at length (Exp catch/Ctrl catch + Exp catch), with a proportion >0.5 representing more animals at length captured by the experimental dredge. The grey area represents the 95% confidence band for the GLMM model smooth. From the 2017 Seasonal Bycatch Final Report.

Appendix D: Statistical analysis of gray meat

Table D1. Continuous variables: One-way ANOVA with pairwise Tukey post-hoc tests if significant

MW to SH ratio

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Color	2	0.0474	0.023714	6.137	0.00298
Residuals	109	0.4212	0.003864		

	diff	lwr	upr	p adj
Brown-White	-0.01063576	-0.04073061	0.01945910	0.6792060
Gray-White	-0.07663109	-0.12898637	-0.02427581	0.0020852
Gray-Brown	-0.06599533	-0.11627425	-0.01571642	0.0065187

Cellularity score

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Color	2	48.3	24.157	6.636	0.00191
Residuals	109	396.8	3.641		

	diff	lwr	upr	p adj
Brown-White	0.4652015	-0.4585578	1.388961	0.4577344
Gray-White	2.4628205	0.8557792	4.069862	0.0012030
Gray-Brown	1.9976190	0.4543116	3.540926	0.0074301

Muscle thinning score

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Color	2	16.6	8.320	1.765	0.176
Residuals	109	514.0	4.715		

Zoite number

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Color	2	39	19.59	0.524	0.594
Residuals	109	4076	37.39		

Table D2. Categorical variables: Chi square test for independence with pairwise nominal independence post-hoc tests if significant

Stage

	Stage			
Color	Developing	Ripe	Partially spent	Spent
White	12	1	21	5
Brown	9	2	37	15
Gray	0	0	4	6

Chi-squared = 14.102, df = 6, p-value = 0.02851

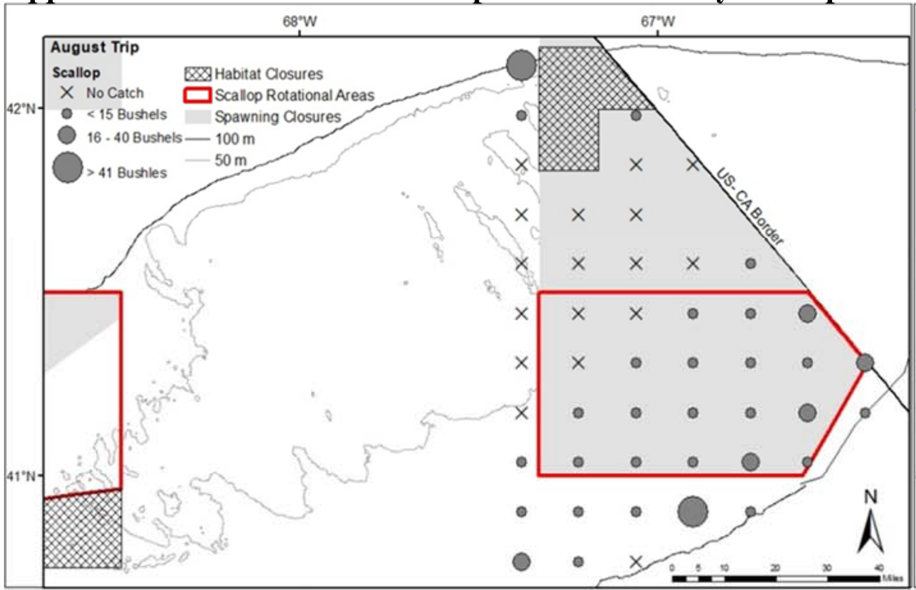
Comparison	**p.Chisq**	**p.adj.Chisq**
White : Brown	0.1880	0.1880
White : Gray	0.0092	0.0276
Brown : Gray	0.1020	0.1530

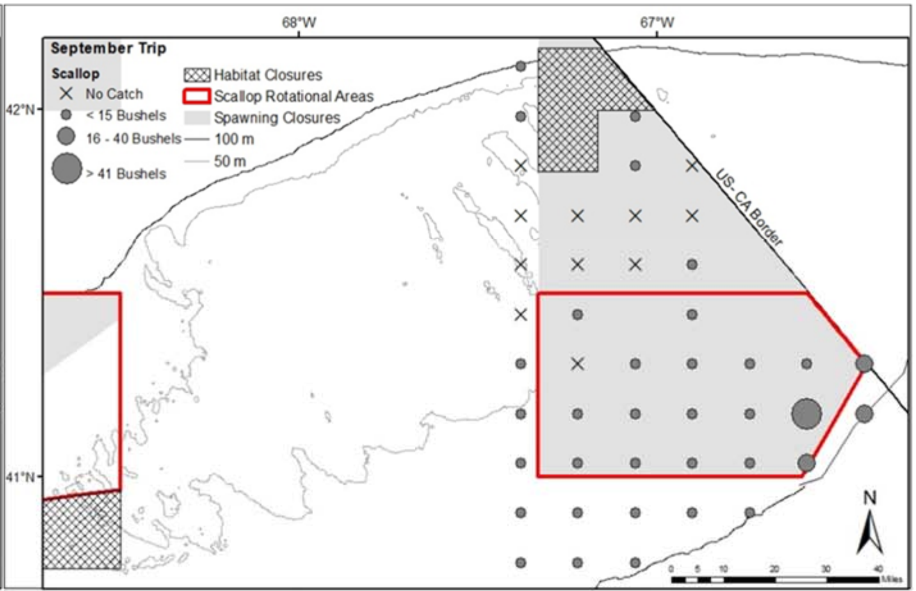
PCR results

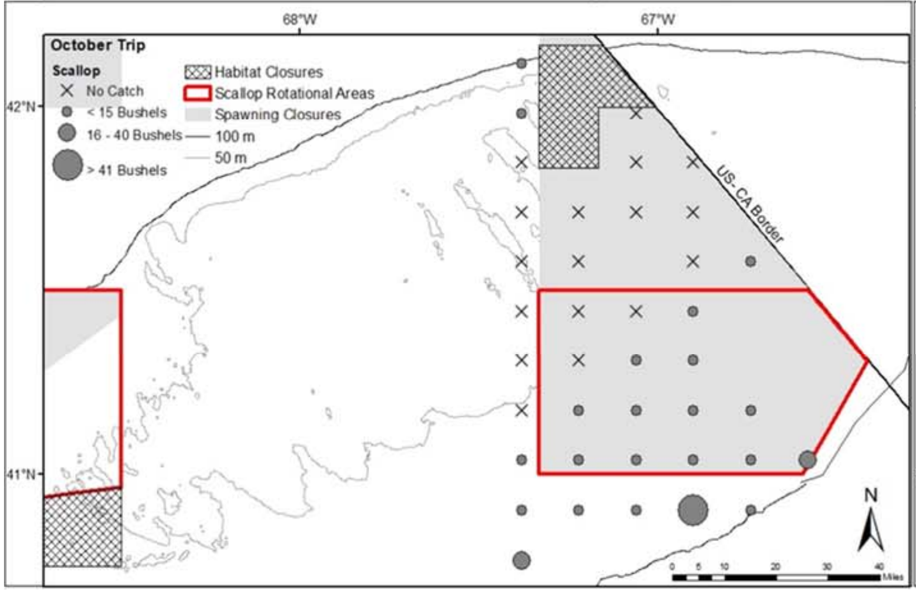
	PCR	
Color	Negative	Positive
White	7	32
Brown	10	53
Gray	1	9

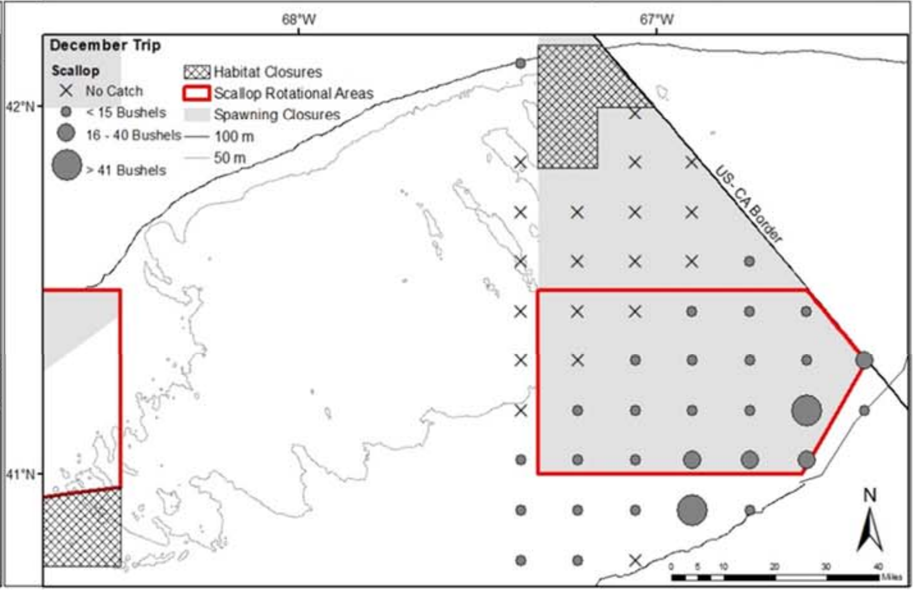
Chi-squared = 0.37702, df = 2, p-value = 0.8282

Appendix E: Distribution of scallops and the main bycatch species









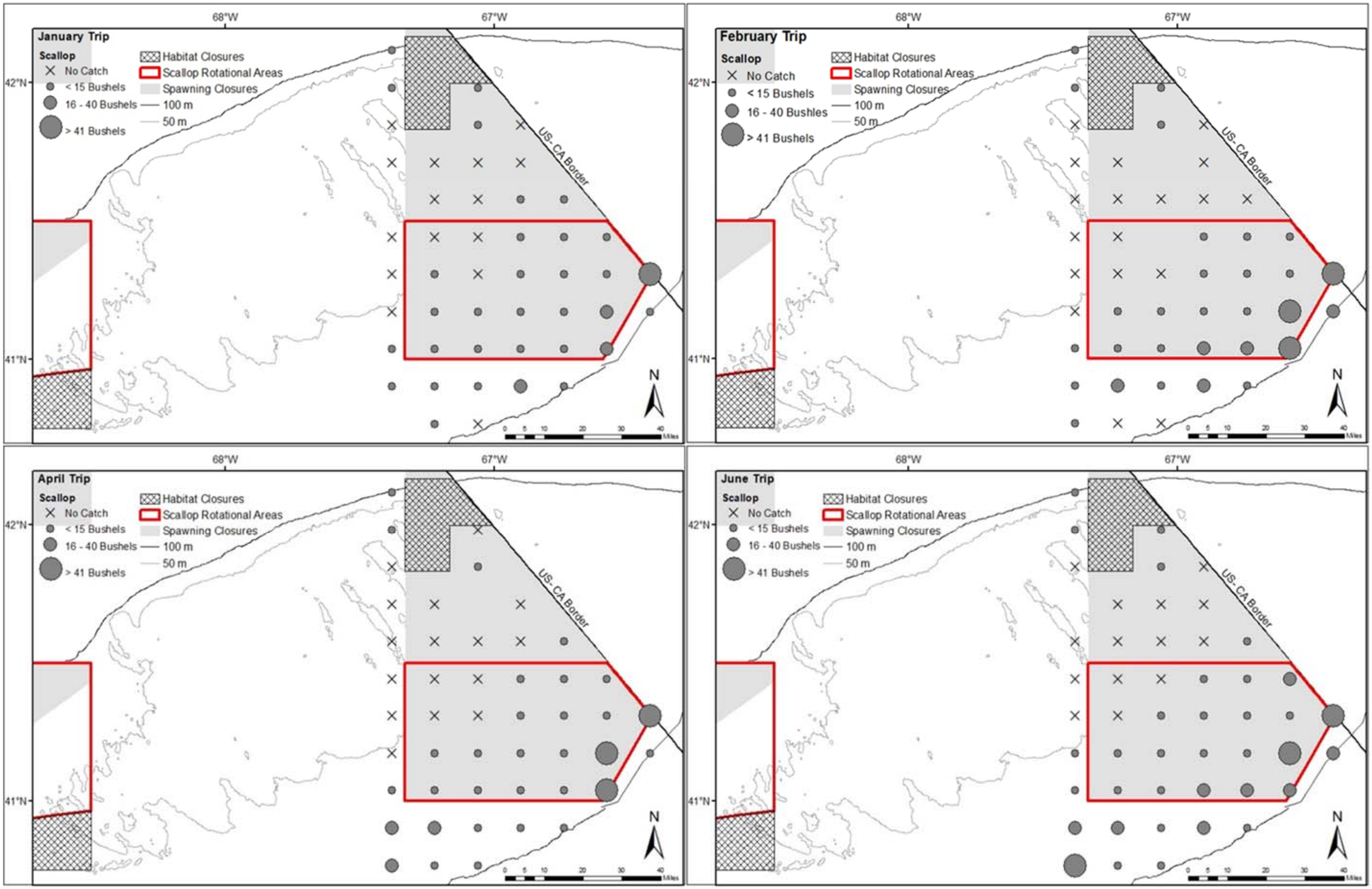
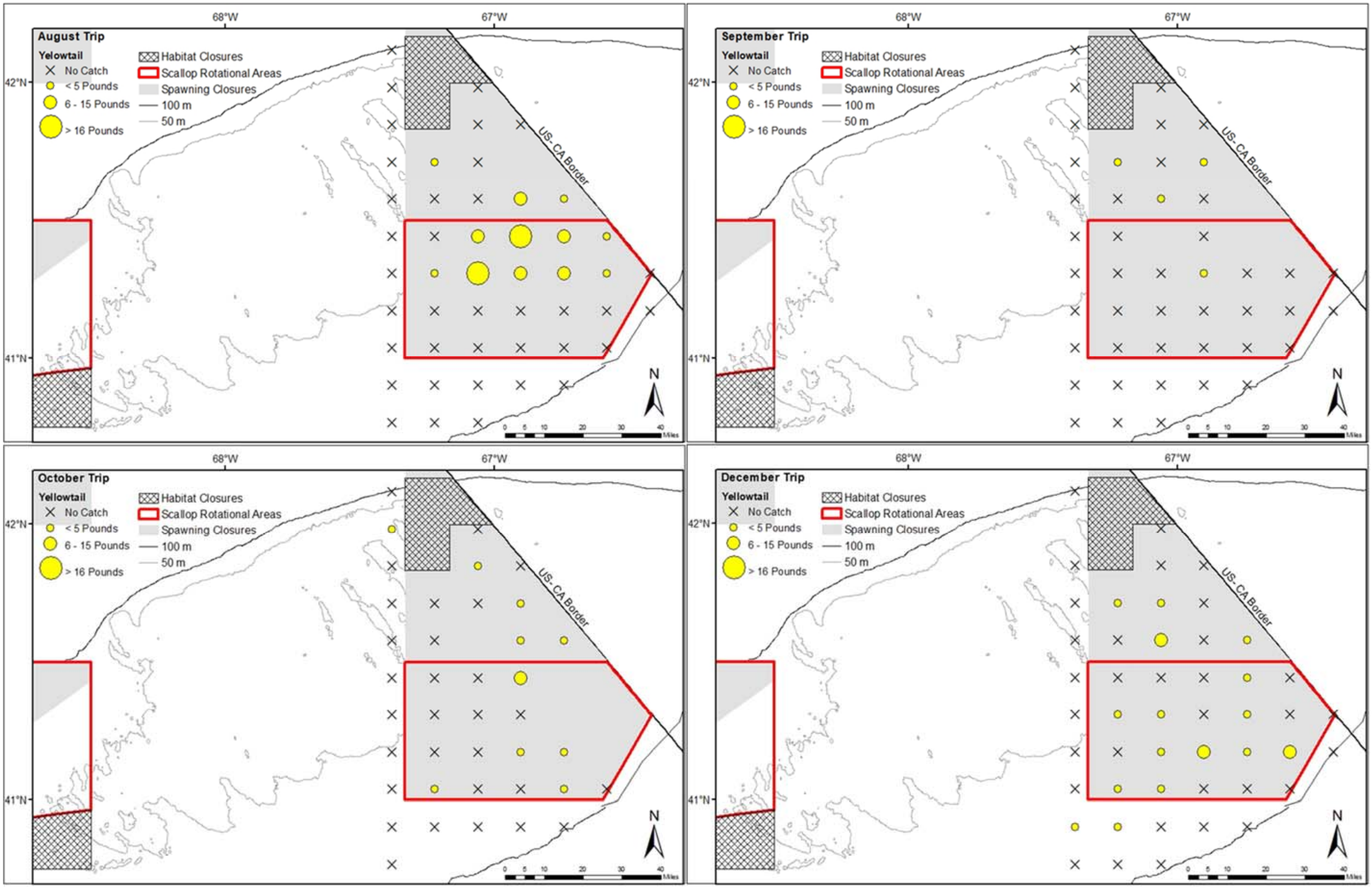


Figure E1. Distribution of sea scallops during the 2018 seasonal bycatch survey on the eastern portion of GB.


August Trip
Yelowtail
No Catch
< 5 Pounds
6 - 15 Pounds
> 16 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US- CA Border
N
0 5 10 20 30 40
Miles
September Trip
Yellowtail
No Catch
< 5 Pounds
6 - 15 Pounds
> 16 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US- CA Border
N
0 5 10 20 30 40
Miles
October Trip
Yellowtail
No Catch
< 5 Pounds
6 - 15 Pounds
> 16 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US- CA Border
N
0 5 10 20 30 40
Miles
December Trip
Yellowtail
No Catch
< 5 Pounds
6 - 15 Pounds
> 16 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US- CA Border
N
0 5 10 20 30 40
Miles

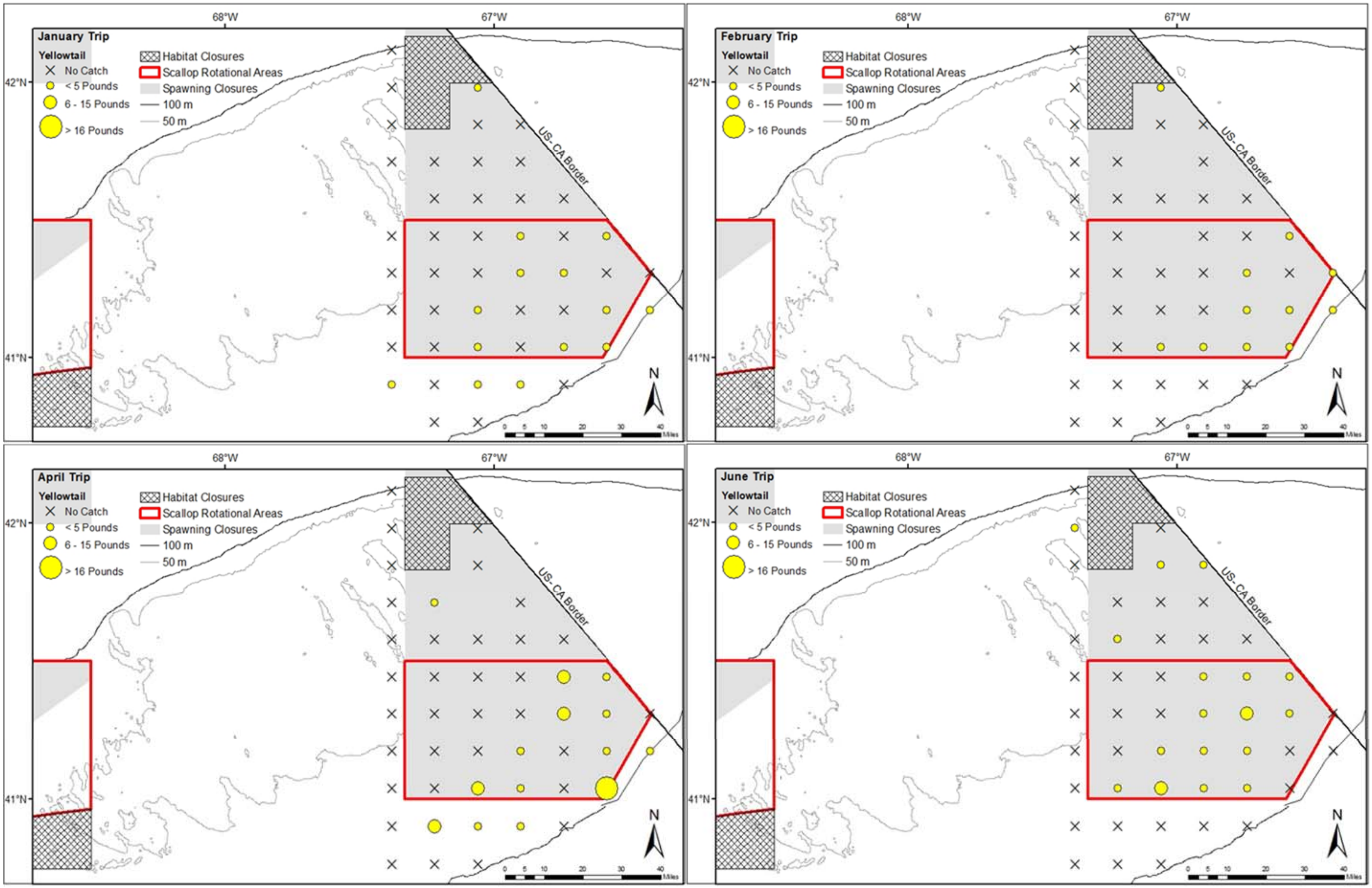
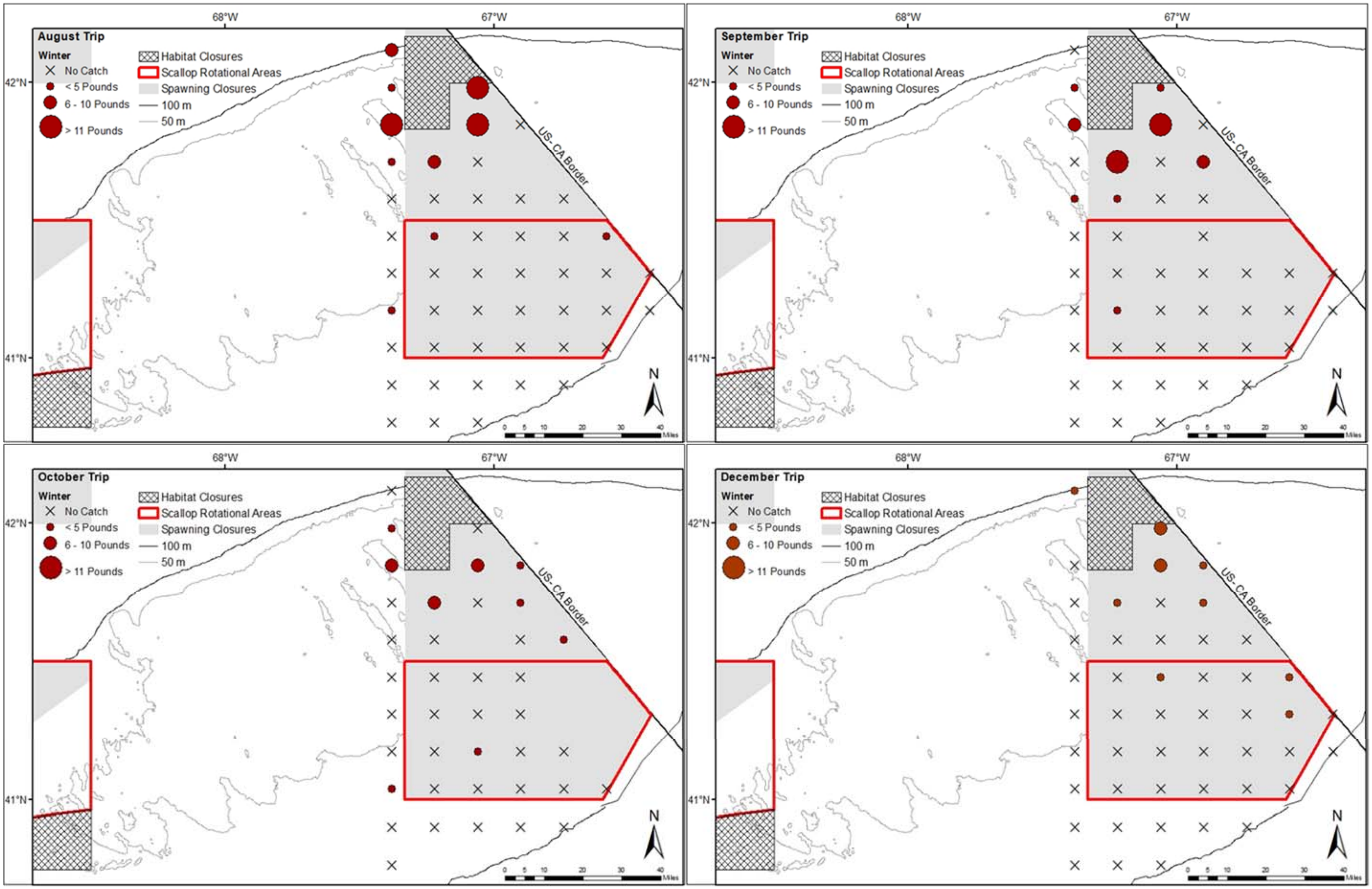


Figure E2. Distribution of yellowtail flounder during the 2018 seasonal bycatch survey on the eastern portion of GB.


August Trip
September Trip
October Trip
December Trip
Winter
No Catch
< 5 Pounds
6 - 10 Pounds
> 11 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US- CA Border
68°W
67°W
42°N
41°N
N
0
5
10
20
30
40
Miles

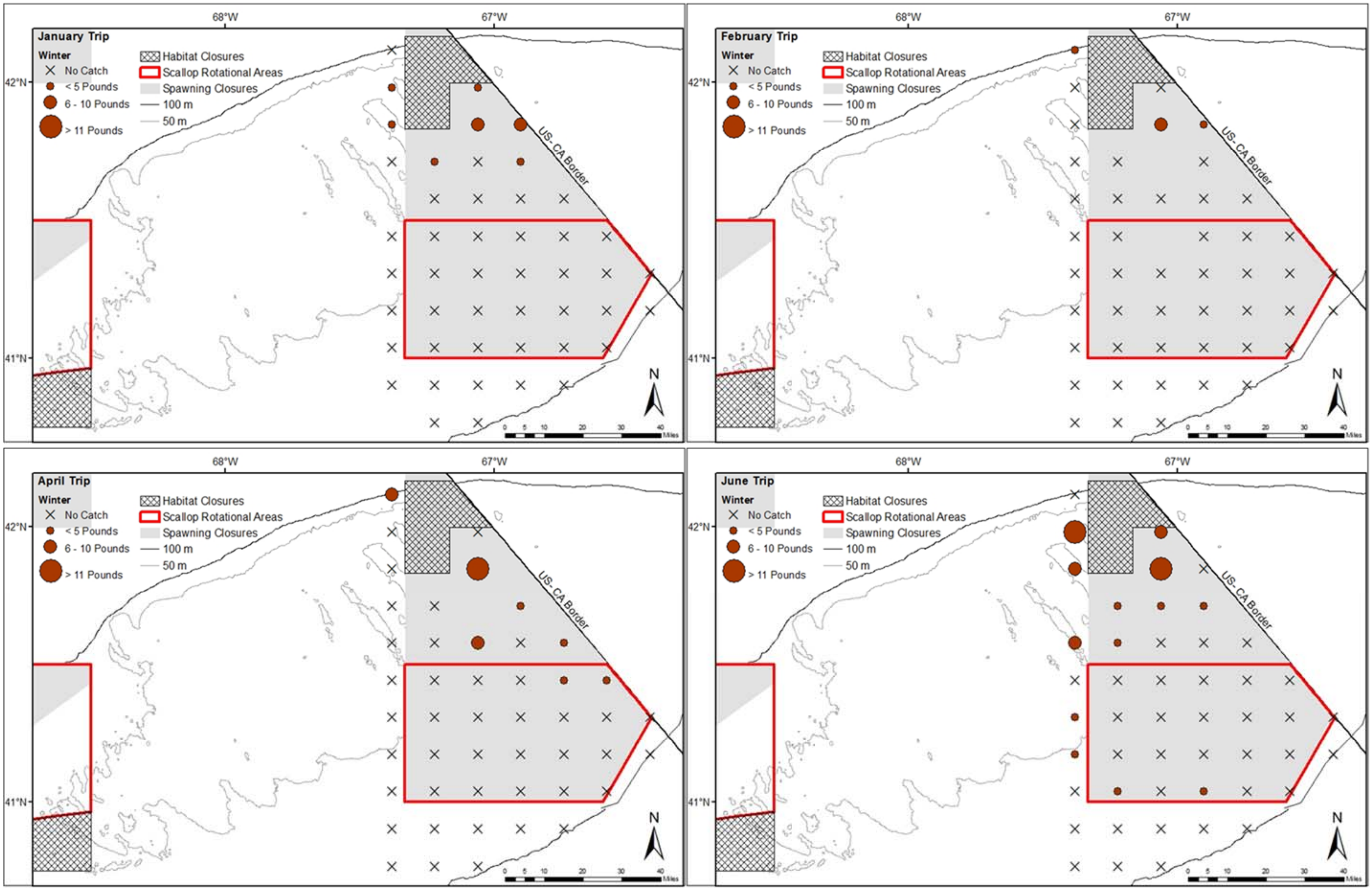
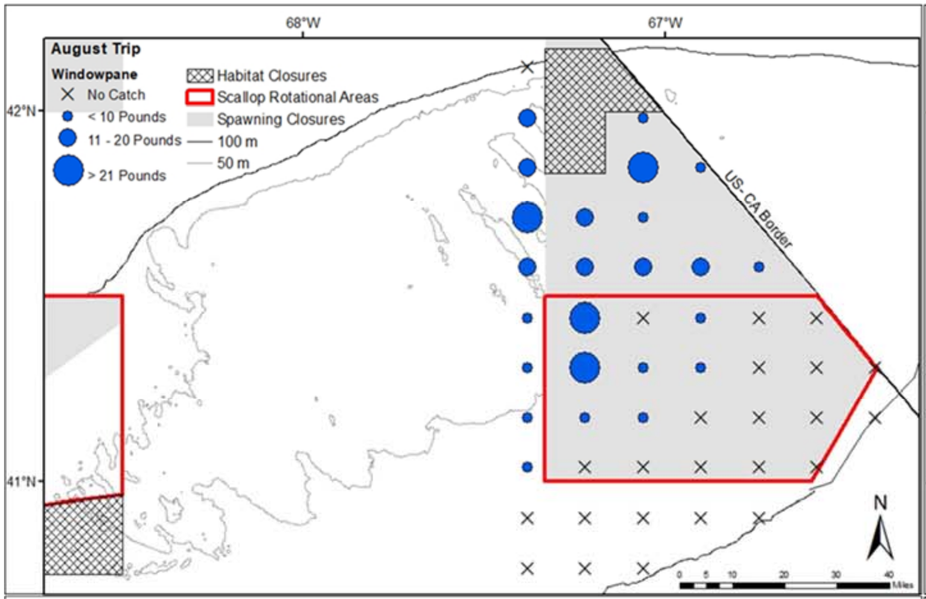
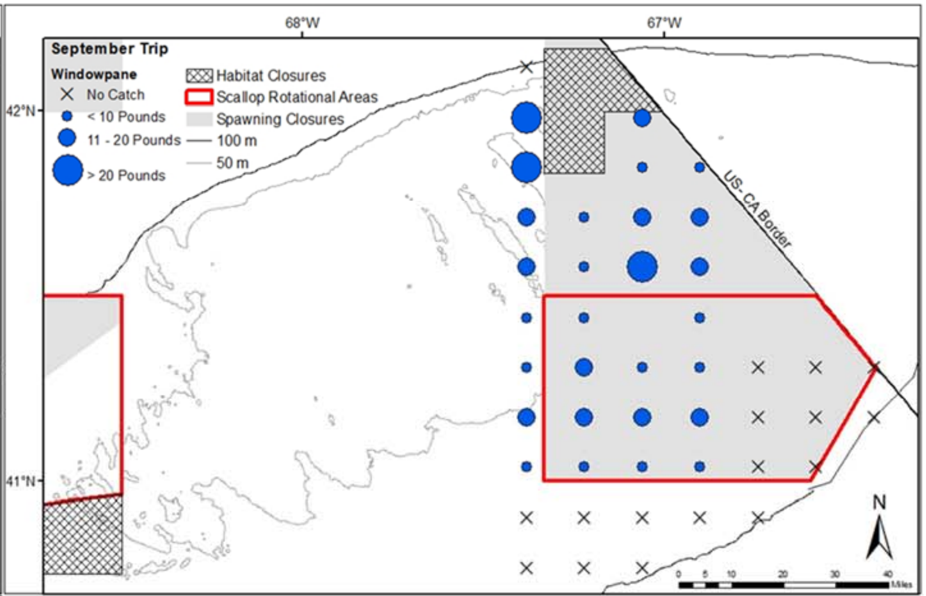
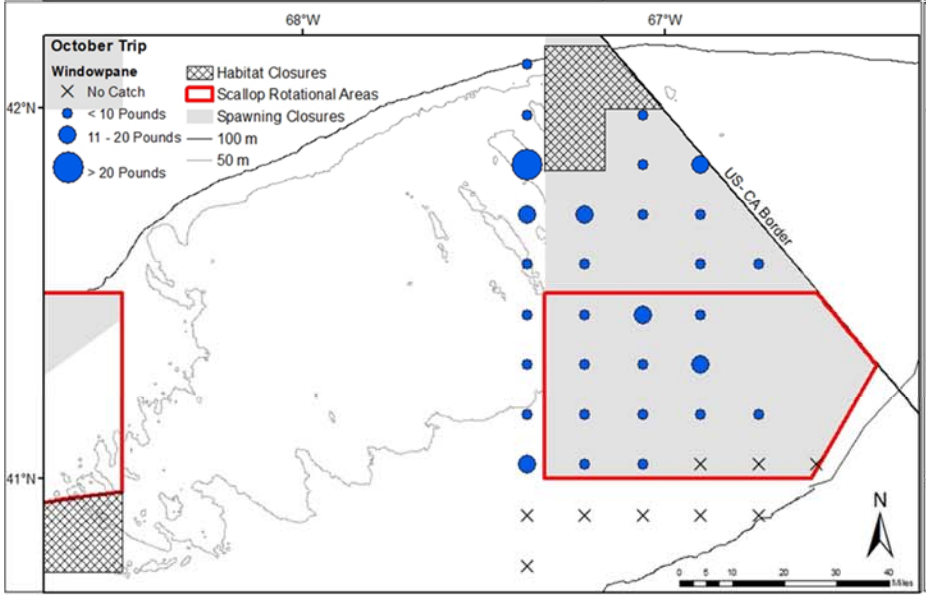
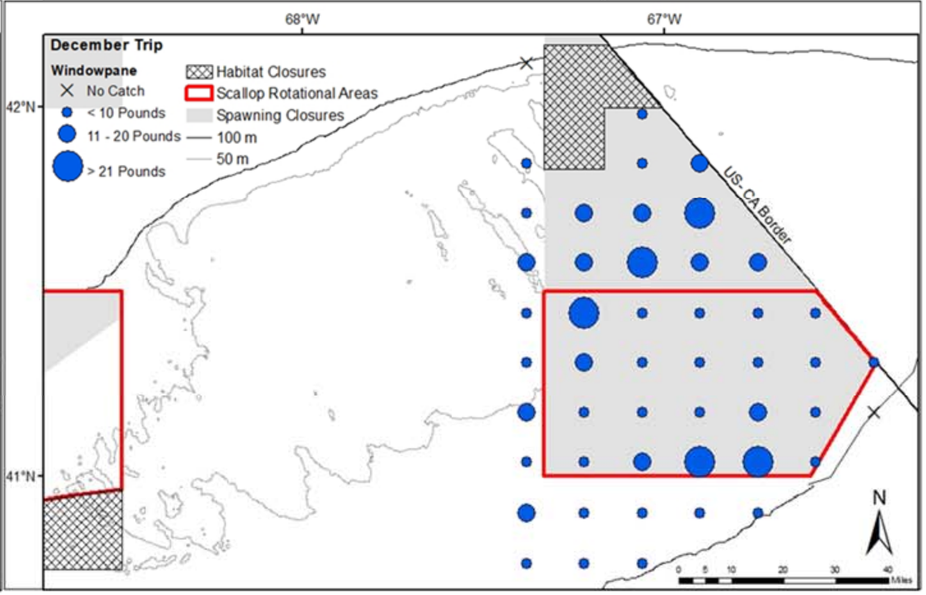


Figure E3. Distribution of winter flounder during the 2018 seasonal bycatch survey on the eastern portion of GB.


August Trip
Windowpane
× No Catch
● < 10 Pounds
● 11 - 20 Pounds
● > 21 Pounds
▨ Habitat Closures
🟥 Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US-CA Border
N
0 5 10 20 30 40 Miles


September Trip
Windowpane
× No Catch
● < 10 Pounds
● 11 - 20 Pounds
● > 20 Pounds
▨ Habitat Closures
🟥 Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US-CA Border
N
0 5 10 20 30 40 Miles


October Trip
Windowpane
× No Catch
● < 10 Pounds
● 11 - 20 Pounds
● > 20 Pounds
▨ Habitat Closures
🟥 Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US-CA Border
N
0 5 10 20 30 40 Miles


December Trip
Windowpane
× No Catch
● < 10 Pounds
● 11 - 20 Pounds
● > 21 Pounds
▨ Habitat Closures
🟥 Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US-CA Border
N
0 5 10 20 30 40 Miles

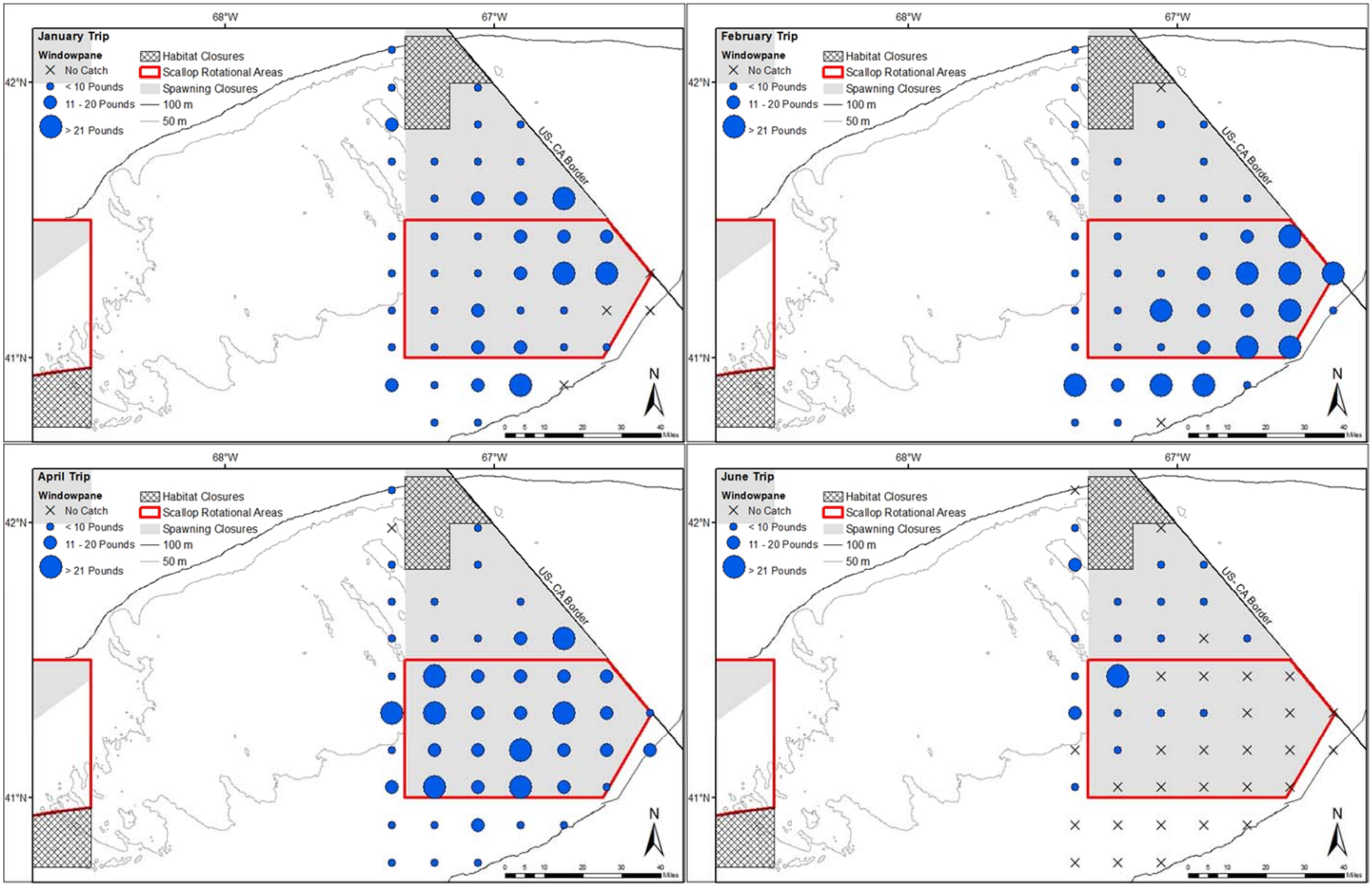
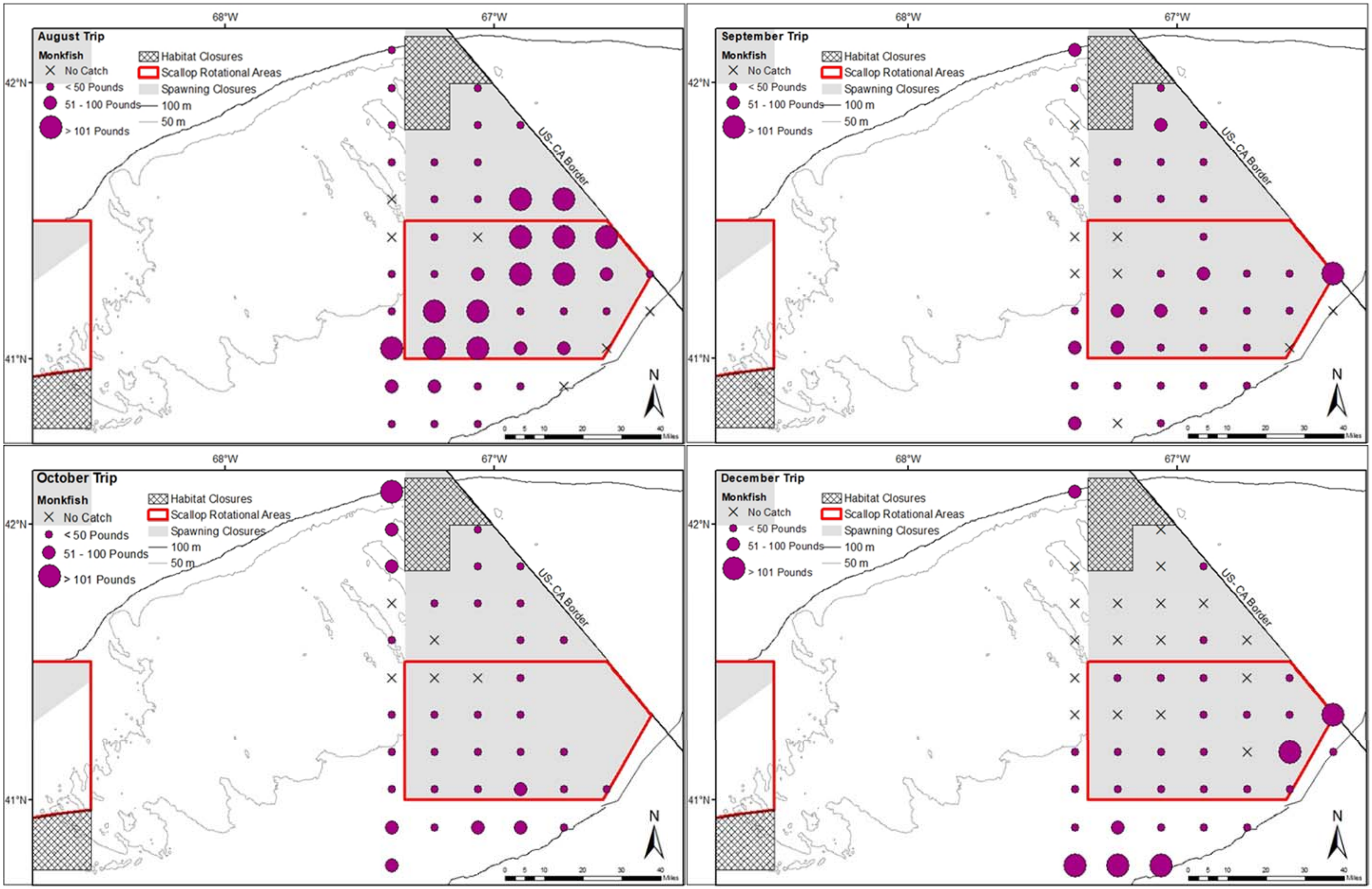


Figure E4. Distribution of windowpane flounder during the 2018 seasonal bycatch survey on the eastern portion of GB.


August Trip
Monkfish
No Catch
< 50 Pounds
51 - 100 Pounds
> 101 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US-CA Border
68°W
67°W
42°N
41°N
N
0 5 10 20 30 40 Miles
September Trip
Monkfish
No Catch
< 50 Pounds
51 - 100 Pounds
> 101 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US-CA Border
October Trip
Monkfish
No Catch
< 50 Pounds
51 - 100 Pounds
> 101 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US-CA Border
December Trip
Monkfish
No Catch
< 50 Pounds
51 - 100 Pounds
> 101 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
US-CA Border

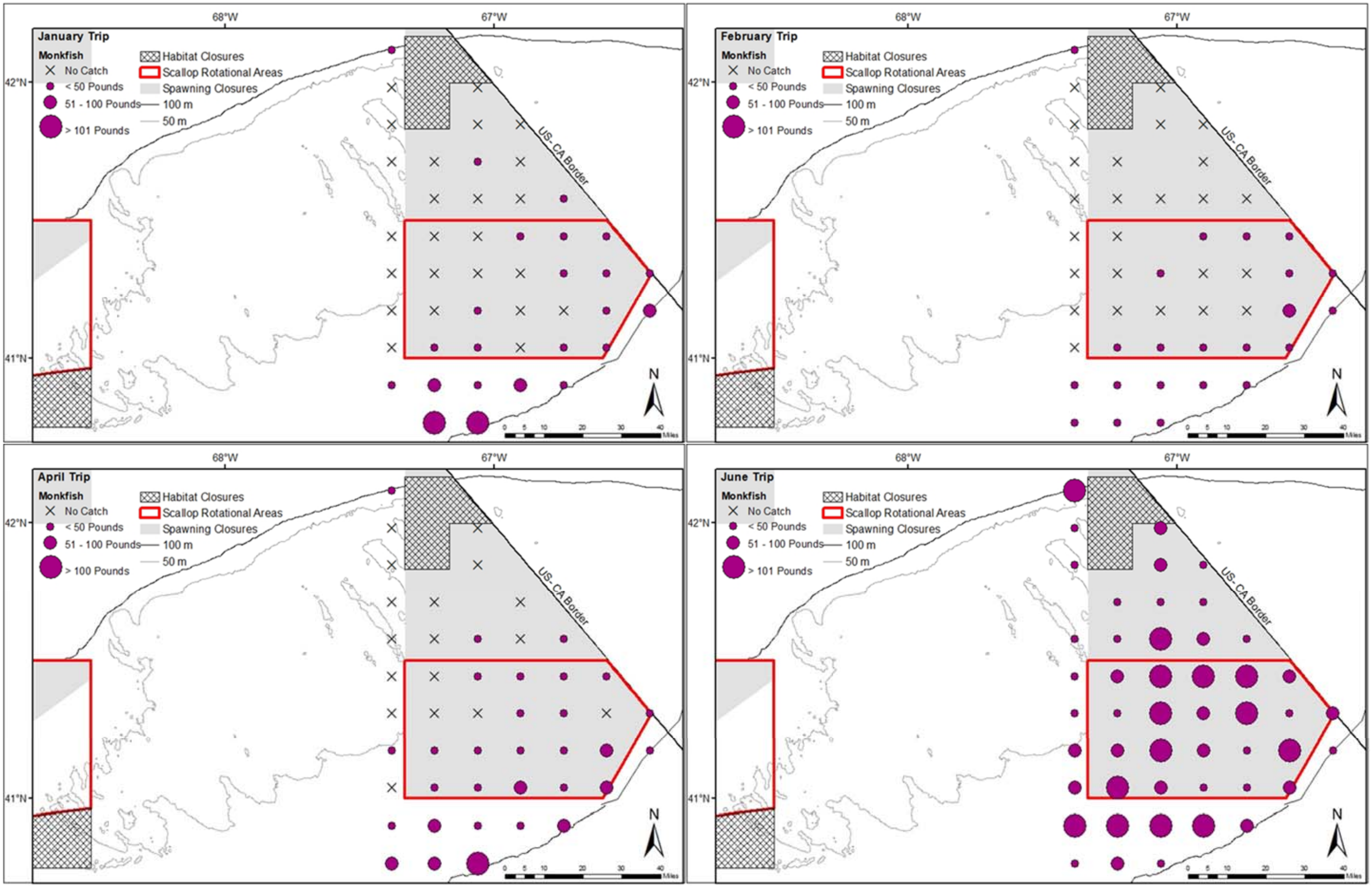
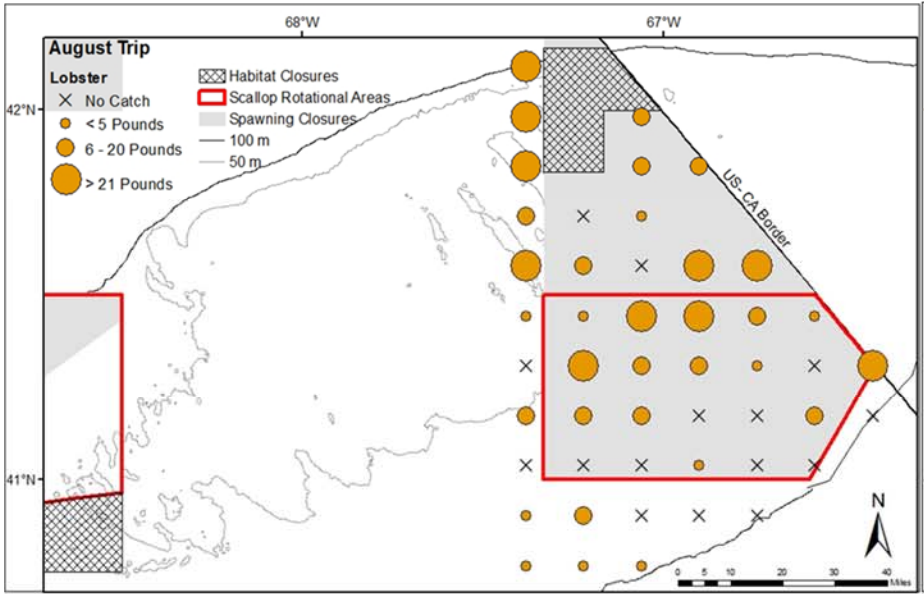
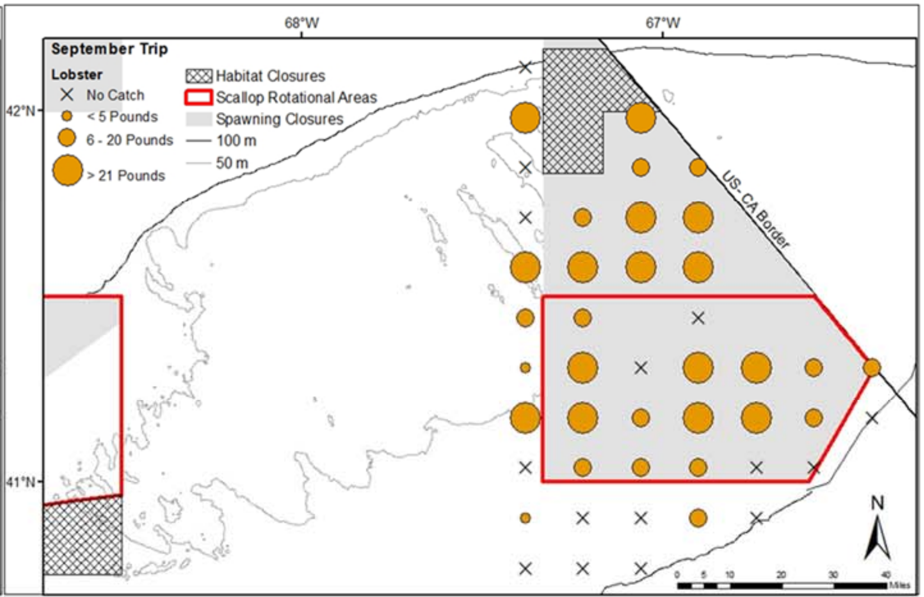
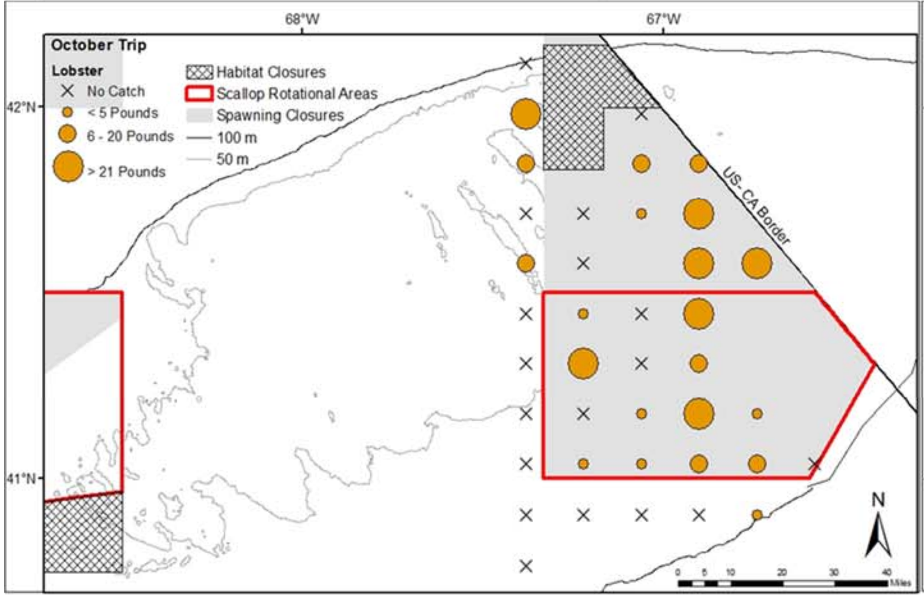
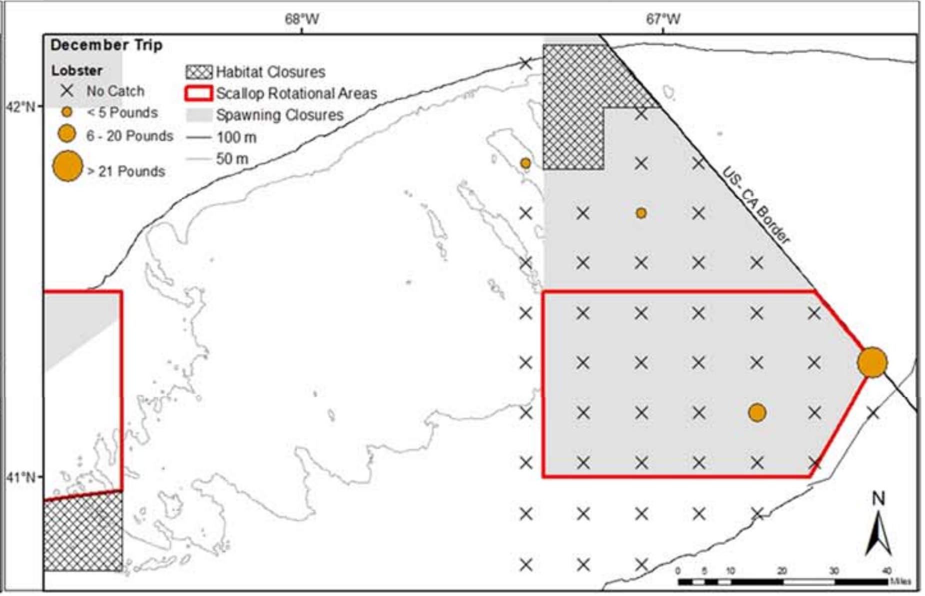


Figure E5. Distribution of monkfish during the 2018 seasonal bycatch survey on the eastern portion of GB.


August Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US - CA Border
N
0 5 10 20 30 40 Miles


September Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US - CA Border
N
0 5 10 20 30 40 Miles


October Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US - CA Border
N
0 5 10 20 30 40 Miles


December Trip
Lobster
No Catch
< 5 Pounds
6 - 20 Pounds
> 21 Pounds
Habitat Closures
Scallop Rotational Areas
Spawning Closures
100 m
50 m
68°W
67°W
42°N
41°N
US - CA Border
N
0 5 10 20 30 40 Miles

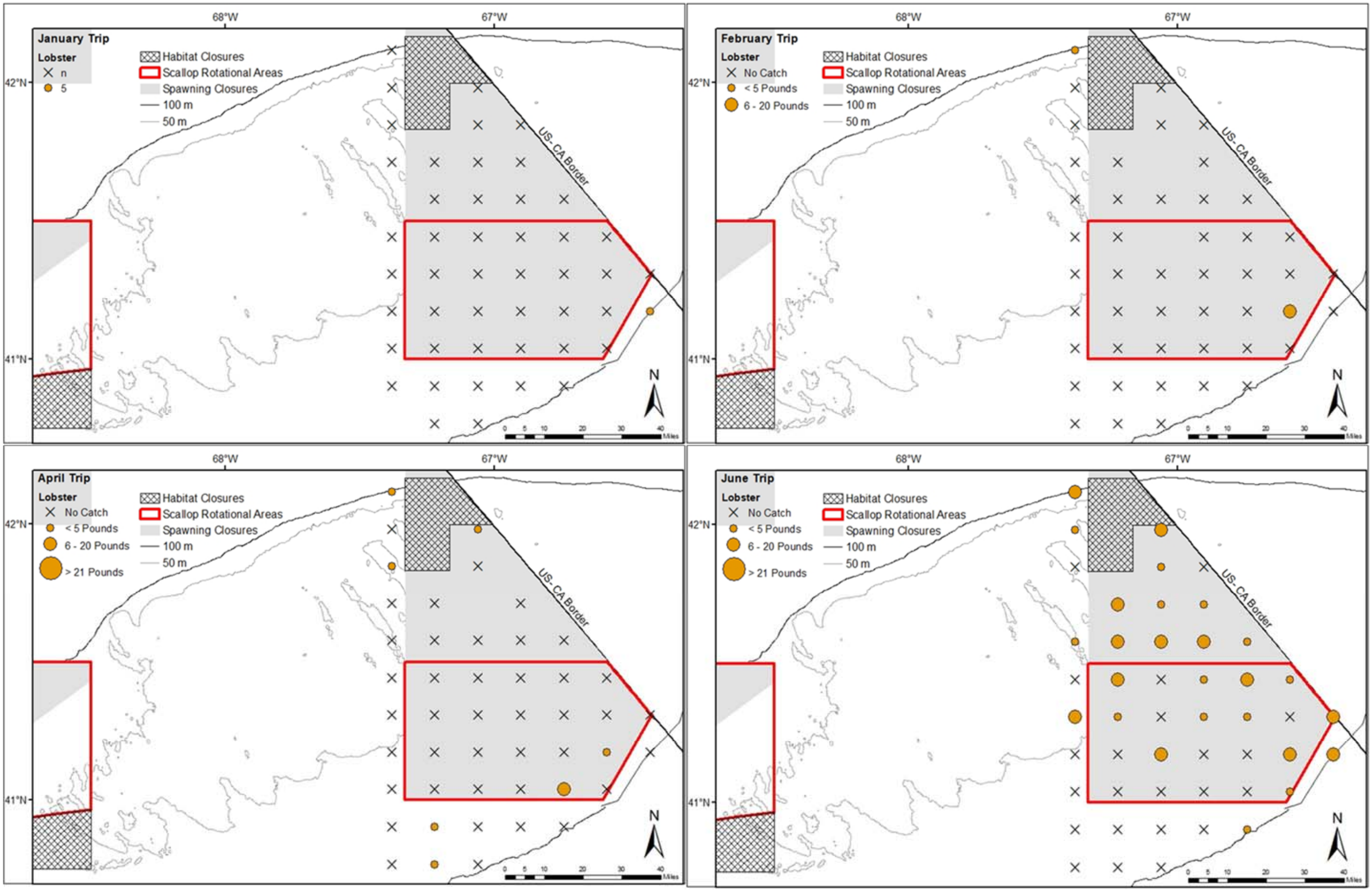


Figure E6. Distribution of American lobster during the 2018 seasonal bycatch survey on the eastern portion of GB.

Appendix F: A comparison of monthly changes in windowpane and yellowtail flounder relative abundance (mean catch/tow in CFF standardized turtle deflector dredge) between the 2011-2014 and 2017-2019 seasonal bycatch surveys

The analysis included tow and catch data from the 2011, 2012, 2013, 2017, and 2018 seasonal bycatch surveys. Stations in CAIIS and CAII-EXT were included in these surveys (**Figure F1**). Data from the 2015 and 2016 bycatch surveys were excluded from the analysis because those surveys focused on the northern half of Georges Bank.

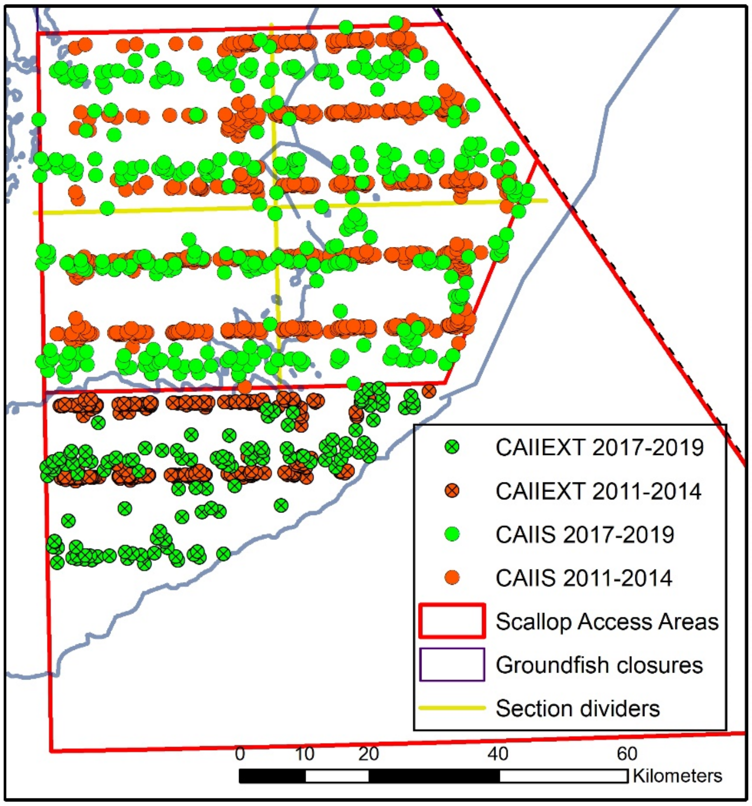


Figure F1. Locations of survey stations in CAIIS and CAII-EXT during the 2011-2014 and 2017-2019 seasonal bycatch surveys.

Tows were placed into one of five sections based on location: CAIIS-NW, NE, SW, or SE or CAII-EXT (**Figure F2**). The CAIIS E/W divider corresponds roughly to the 70-m depth contour (66.90° W). The N/S divider is at 41.25° N, midway between the N and S boundaries of the access area and slightly north of the northern boundary of the CAII Southwest (CAII-SW) area currently proposed by scallop management (NEFMC 2019b). Mean catch per tow for windowpane and yellowtail flounder was calculated for each section and plotted by month and bottom temperature (**Figures F3 and F4**). Each month has data from multiple years in the analyzed time period (May 2011-March 2014 or August 2017-June 2019). Additional plots of mean catch per tow for each species by month and year were also generated for the entire area (CAIIS plus CAII-EXT) to look for changes between years (**Figure F5**). Overall decreases in abundance of windowpane and yellowtail flounder were observed between 2011-2014 and 2017-2019 (**Table F1**).

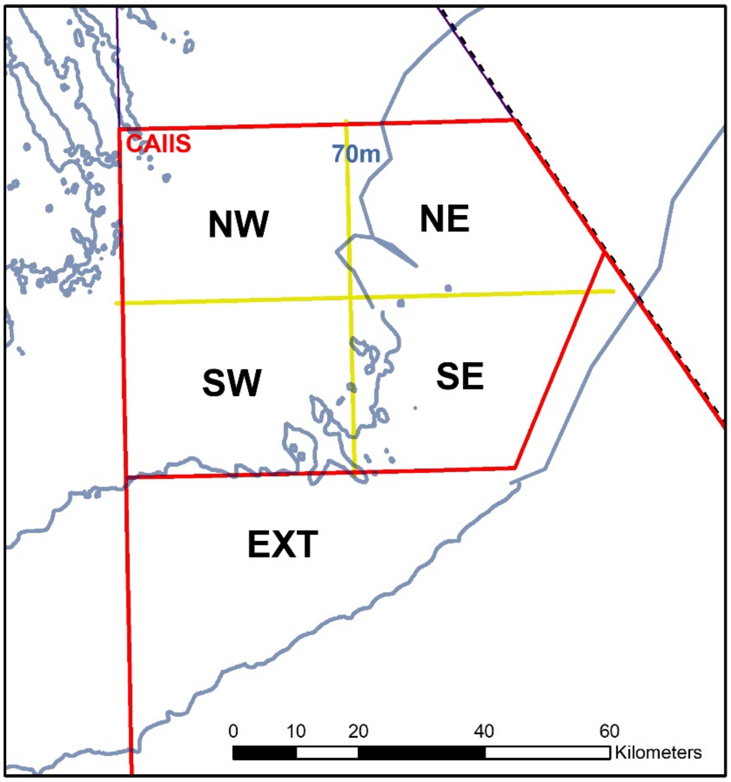


Figure 2. Sections used to analyze windowpane and yellowtail flounder seasonal abundance in CAIIS and CAII-EXT.

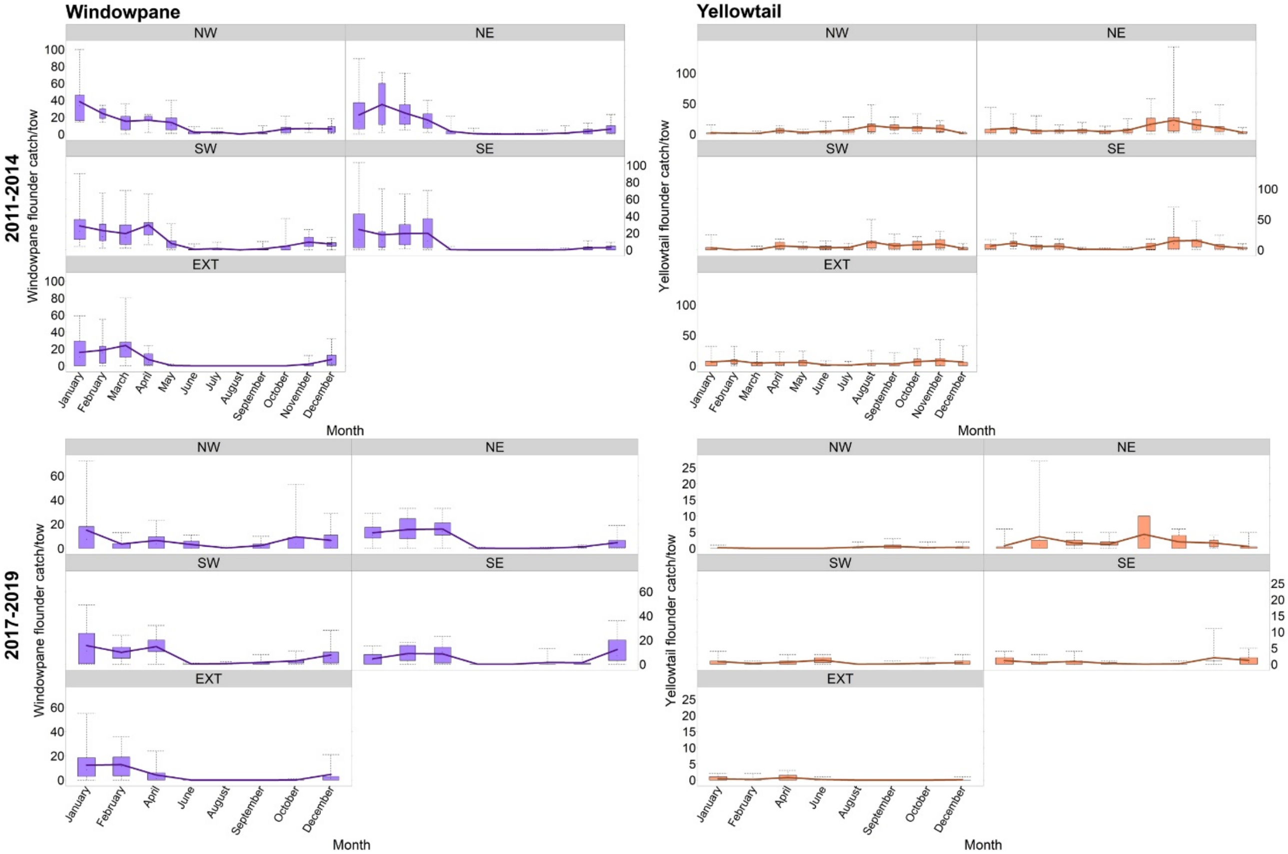


Figure 3. Mean/median catch per tow by month for windowpane and yellowtail flounder. The line shows the mean catch per month while the box plots show the median catch. Boxes end at the first and third quartiles of the distribution of catch/tow values, with the whiskers extending to the minimum and maximum values.

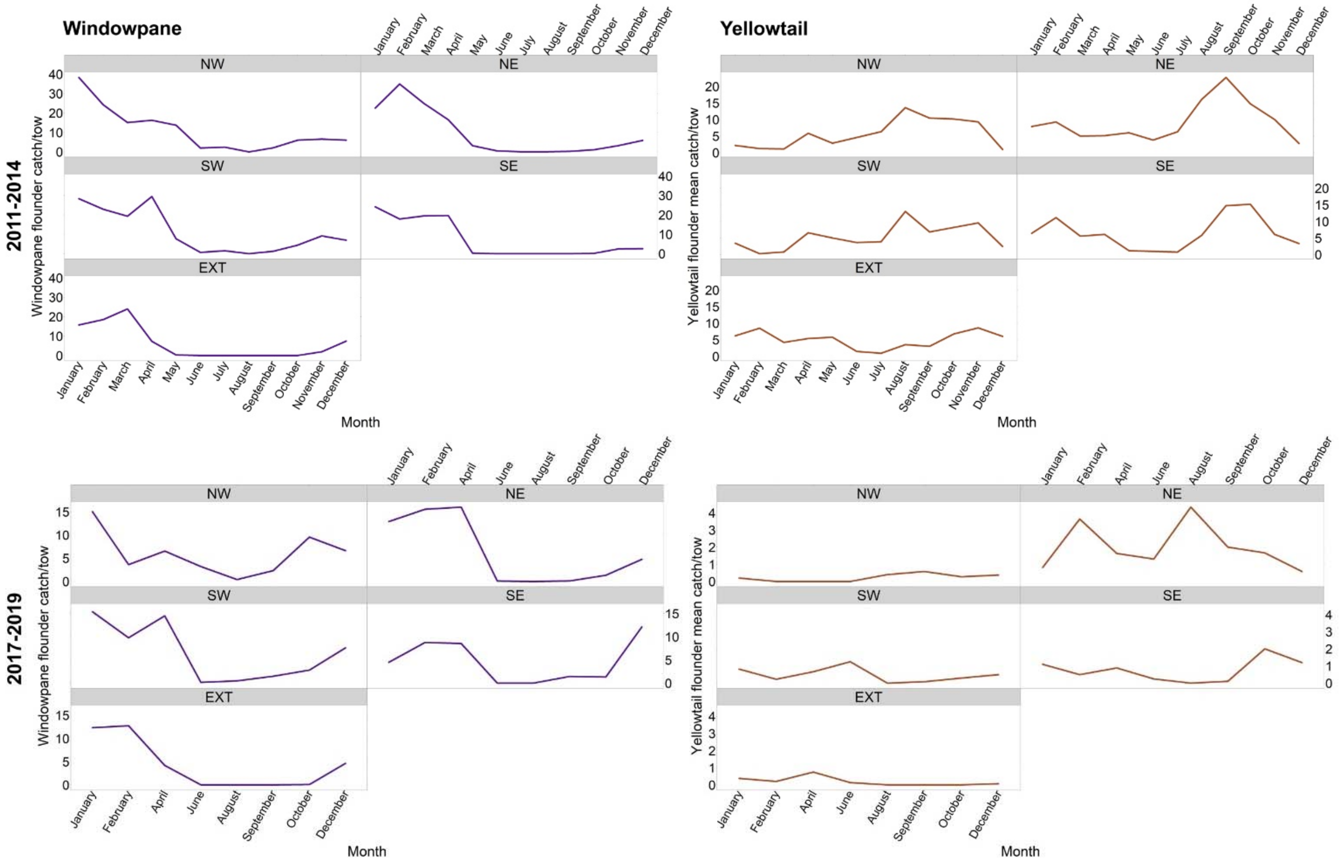


Figure 4. Mean catch per tow by month for windowpane and yellowtail flounder. The line shows the mean catch per month. Box plots were removed so the curves for the mean catch were easier to track.

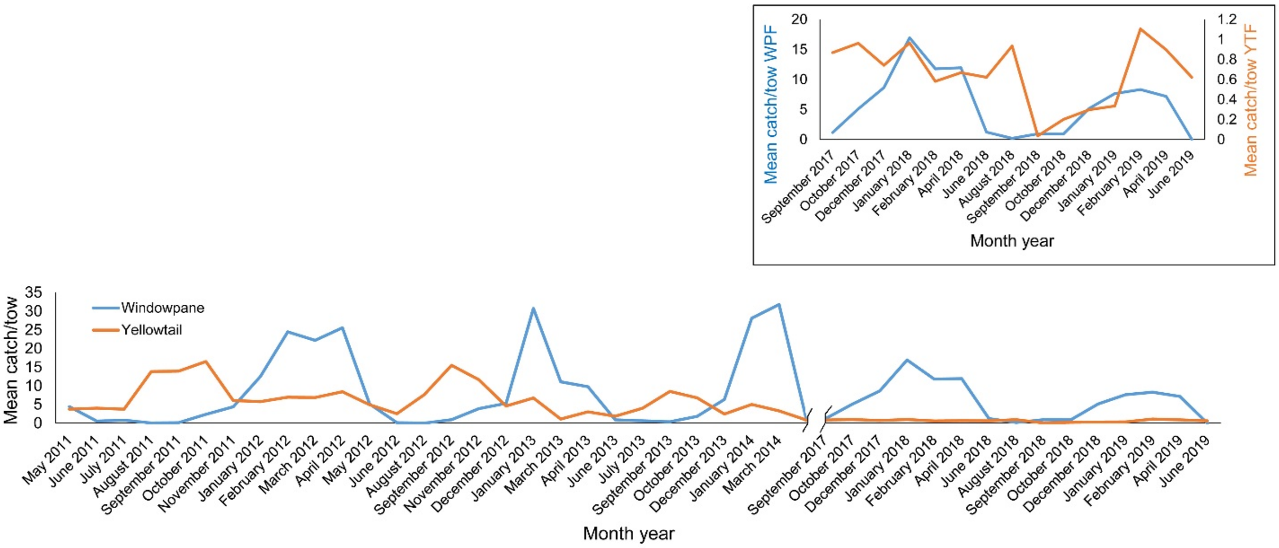


Figure F5. Mean catch per tow by month and year for windowpane and yellowtail flounder. Inset shows the catch in 2017-2019 with different axes for each species.

Table F1. Summary statistics for windowpane and yellowtail flounder catch during the 2011-2014 and 2017-2019 seasonal bycatch surveys.

Species	Years	Mean catch/tow Mean (range)	Mean catch/tow during seasonal closure	Mean catch/tow during access months	Maximum catch/tow
Windowpane flounder	2011-2014	8.7 (0-31.8)	1.5	12.2	103
	2017-2019	5.8 (0-16.9)	1.6	7.9	72
Yellowtail flounder	2011-2014	6.6 (1.1-16.5)	11.2	4.4	143
	2017-2019	0.7 (0.04-1.1)	0.6	0.7	27

Framework 32 of the Sea Scallop Fisheries Management Plan proposes significant changes to scallop vessel access to CAIIS/CAII-EXT based in data from the Virginia Institute of Marine Science scallop surveys (NEFMC 2019b). This change was motivated by a need to minimize both yellowtail and windowpane flounder bycatch in this area, a goal complicated by the different seasonal distributions of these two important bycatch species. As currently proposed, a new area CAII-SW will be closed year-round to scallop fishing. While the CFF bycatch survey has caught both flounder species in CAII-SW, catch was higher in the northeastern section of CAIIS (**Figures F3 and F4**). This area will be open to scallop fishing, and bycatch of windowpane and yellowtail flounder may be a continuing problem.

Because an unusually high mean temperature was observed in December for the 2017-2019 survey, bottom temperature at each station was mapped for December 2011, 2012, 2017, and 2018 (**Figure F6**). Unusually high temperatures were noted across CAII-EXT and the southern portions of CAIIS in December 2017 (**Figure F7**). Potential impacts of this warm bottom water need further investigation. Changing bottom temperatures have been linked to shifts in Atlantic cod distributions off the northeastern US (Fogerty *et al.* 2008) and changes in fish distributions, reproductive cycles, and overall body sizes in the North Sea (Perry *et al.* 2005). Major changes in fish distributions are predicted across the Northeast Continental Shelf as fish move to find suitable thermal habitats (Kleisner *et al.* 2017).

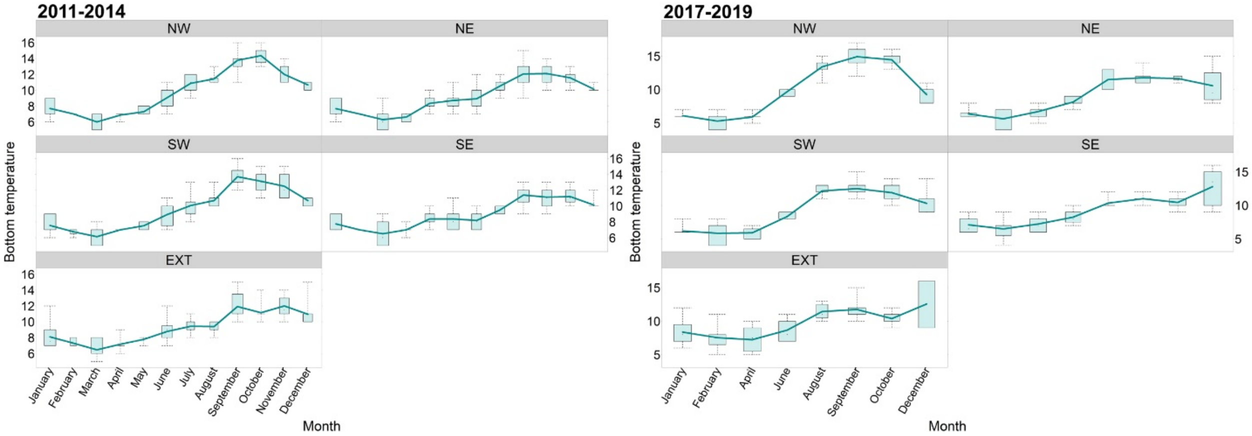


Figure F6. Mean/median temperature per month. The line shows the mean temperature per month while the box plots show the median temperature. Boxes end at the first and third quartiles of the distribution of catch/tow values, with the whiskers extending to the minimum and maximum values.

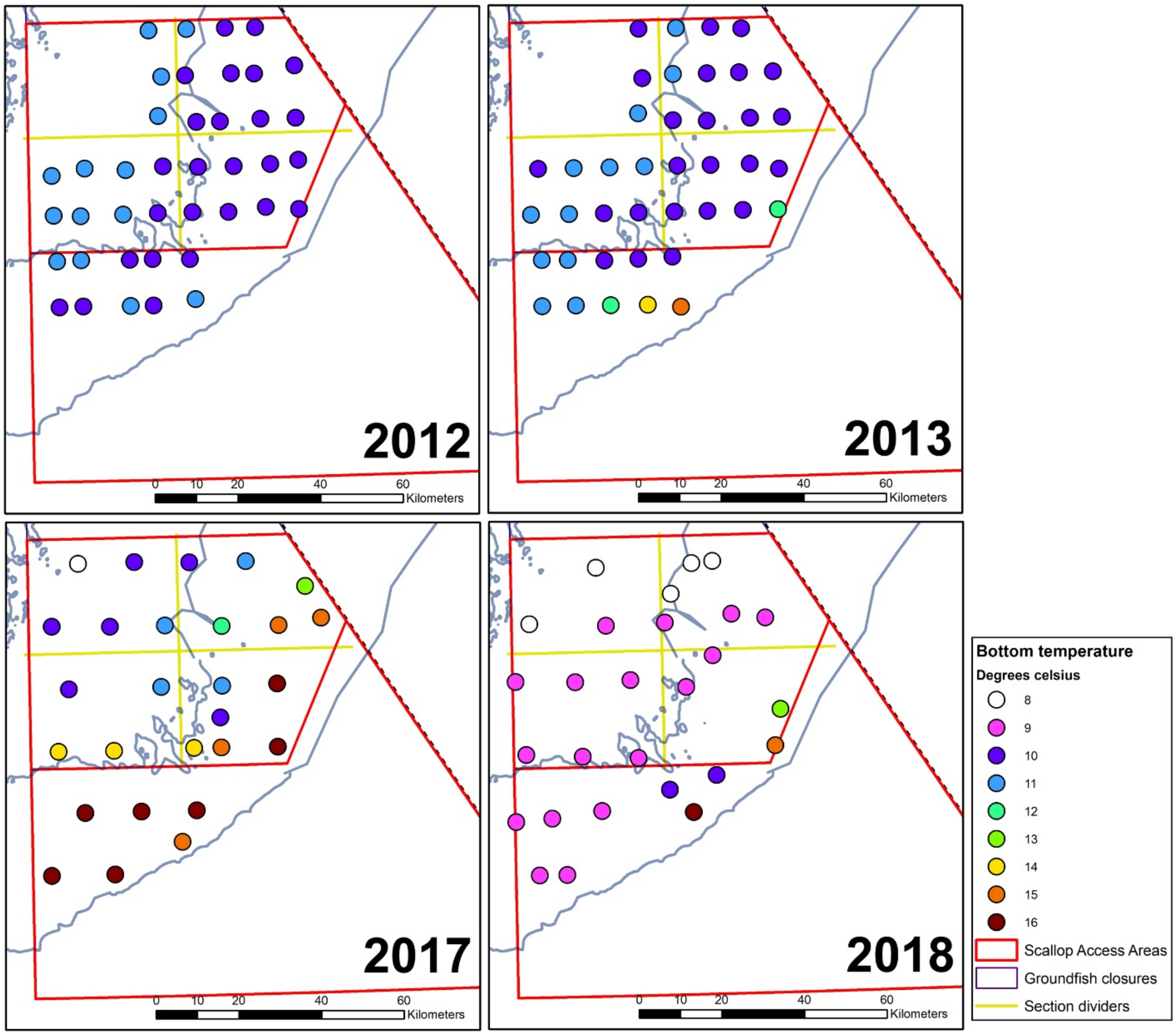


Figure F7. Maps showing bottom temperatures at each survey station during the month of December.

Appendix G: Preliminary meat quality data for the 2019 seasonal bycatch survey

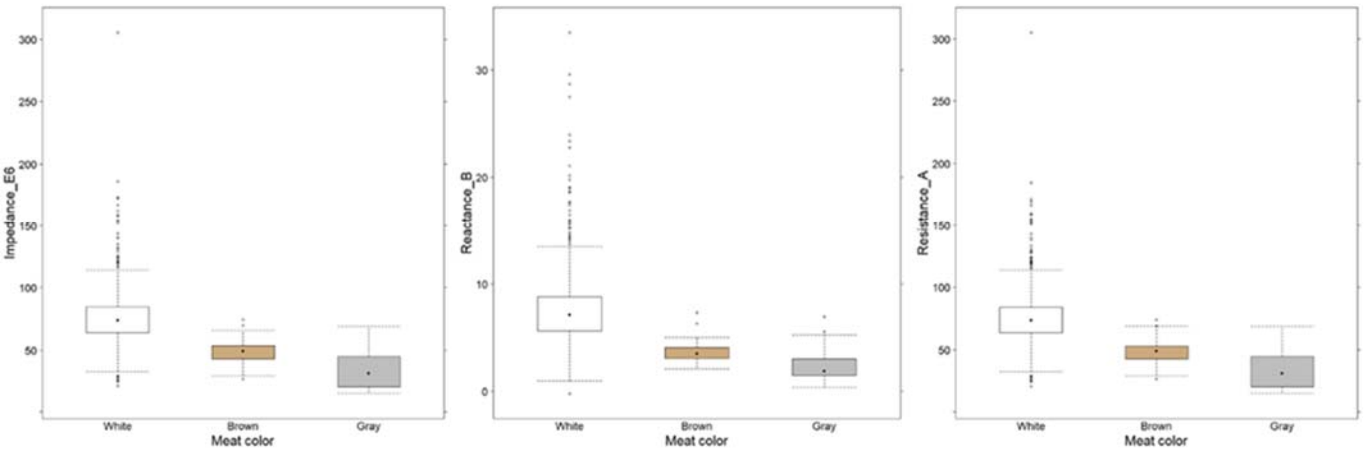


Figure G1. Trends in measured resistance and reactance for meat scallops across of different meat colors for the 2019 seasonal bycatch project, August trip.

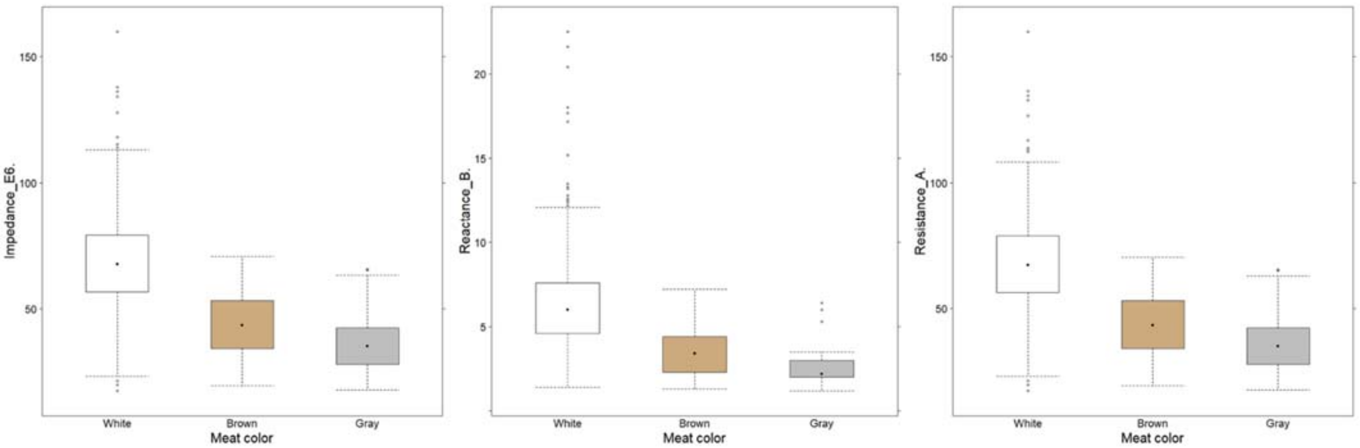


Figure G2. Trends in measured resistance and reactance for meat scallops across of different meat colors for the 2019 seasonal bycatch project, October trip.