# Seasonal Survey in the Atlantic Sea Scallop Fishery

## Final Report

**Prepared for the 2021**
**Sea Scallop Research Set-Aside**
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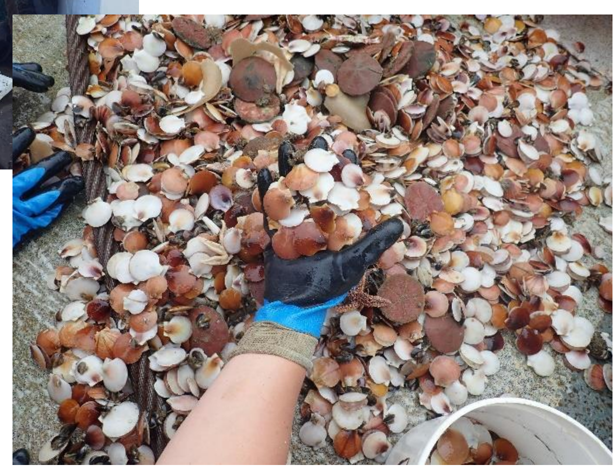

Submitted By

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## EXECUTIVE SUMMARY

This report presents data and analysis from the Sea Scallop Research Set-Aside (RSA) 2021 Award of funding to Coonamessett Farm Foundation (CFF) for the seasonal survey of Georges Bank (GB). This seasonal survey has been conducted since October 2010 and has been modified and adapted to address current management concerns. The survey has used a fixed-grid design, and the same standardized tow parameters since 2010. From 2010-14, survey stations were located in both the Closed Area I (CAI) and Closed Area II (CAII) access areas. Beginning in 2015, the survey stations were moved to encompass the northern portion of GB, including 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. Collect biological samples to identify seasonal changes in the reproductive cycles of scallops.
2. Compare abundance of scallop predators, such as moon snails, sea stars, whelks and crabs, with mortality rates in scallops and environmental parameters.
3. Determine seasonal distribution and abundance of the main bycatch species to establish distribution ranges and quantify groundfish bycatch rates.
4. Collect biological samples to identify seasonal changes in the reproductive cycles of key fish species including yellowtail, winter, and windowpane flounder.
5. Evaluate dredge selectivity for scallops and main bycatch species, as well as assess the seasonal distribution and abundance of pre-recruit and recruit scallops and juvenile flatfish, through use of a dredge cover net.
6. Determine seasonal scallop meat quality using macroscopic observation, a CFF colorimeter device, and a certified quality reader (CQR).
7. 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.

The standardized commercial dredge was towed at all stations surveyed this funding year and a covered dredge was towed simultaneously at select stations. At each station sampled, the dredges were towed at a target speed of 4.8 knots for 15 minutes. The catch data, for both dredges and cover net, were 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 also collected to assess scallop meat yield and quality.

Seasonal changes in distributions and abundance: Significant work was done to analyze spatiotemporal patterns in catch data and temporal patterns in fish and scallop reproductive stages. Monkfish was the most abundant fish species caught in the dredges, with the highest catch in August 2021. The most abundant managed flatfish species was windowpane flounder, and we observed relatively high numbers of this species across the entire sampling area, with catches peaking in March 2022. Catches of yellowtail, winter, and summer flounder were low overall.

<u>Scallop meat quality</u>: From the 3,413 scallop meats examined with the CQR device, only 2.8% showed signs of poor condition. Impedance values for meats classified as white were lower than meats classified with poor condition. Differences between impedance values and scallop

meat colors showed that the CQR reader was able to accurately measure differences in scallop condition based on electrical bioimpedance.

Reproductive cycles: Scallop reproductive stages were determined through observation of macroscopic changes in the gonads and use of a gonadal mass index (GMI) based on shell height and gonad weight. Flounder reproductive stages were assigned based on macroscopic changes in the gonads and the gonadosomatic index (GSI) based on fish body and gonad weights. We observed a fall spawning period for scallops, which coincides with the historic spawning period for this species. A possible spawning period for windowpane flounder was observed in fall. The spawning period for yellowtail flounder was observed in late-spring and early-summer.

Cover net selectivity analysis: The scallop catch-at-length data for each tow was analyzed with the trouser trawl SELECT model. For this analysis, the catch-at-length data for the uncovered dredge were compared to catch-at-length data for the covered dredge. The model indicated that the uncovered dredge was fishing with a higher efficiency. A retention curve for sea scallops was also generated using the cover SELECT model. The predicted L50 for the covered portion of the dredge bag to be 93.81 mm using this method.

Calibration analysis: During the November trip, a total of 31 tows were completed across the sampling area in order to compare catch rates from 30-min vs 15-min tows. For scallops, the agreement is quite good up to a mean catch of ~400kg/tow. Catches of fish species during a 30-min tow were similar to doubled catch during a 15-minute tow when catches were low. As the mean catch increased, the difference values approached and then exceeded the limits of agreement. GLMM results show that scallop catches at 15-minute tows are approximately half of the catches of the 30-minute tows ($p < 0.05$, coefficient: 0.54). Due to low catches, other species were not analyzed with GLMM.

The CFF seasonal 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 data provided by this project 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 seasonal survey has adapted to encompass additional sampling. Due to the variety of data collected by the seasonal survey, different stakeholder objectives can be achieved. Continuation of the seasonal survey of GB addresses the following stakeholder objectives:

- Monitoring seasonal distribution and demographics of scallop aggregations on GB
- Monitoring distribution and magnitude of diseases in scallop population on GB
- Monitoring seasonal spawning variations in scallop and flatfish species
- Monitoring seasonal distribution of commercially important bycatch species
- Monitoring seasonal distribution of scallop predators (i.e. moon snails, whelks, sea stars, cancer sp. crabs)
- Monitoring seasonal environmental parameters that influence scallop health, scallop predator's abundance and bycatch distribution.

## 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 $669,896,074 in 2021 (NOAA 2022). The stock has been rebuilt from its overfished status in 1997, and no overfishing is occurring (NEFMC 2014). Under Amendment 10 of the Sea Scallop Fishery Management Plan, 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. This bycatch issue is the particular interest due to yellowtail (*Limanda ferruginea*) and windowpane (*Scophthalmus aquosus*) flounder Annual Catch Limits (ACLs) and Accountability Measures (AMs), which have created a complex regulatory environment for the scallop fishery. Triggering the yellowtail flounder AM on GB results in scallop fishing area restrictions across eastern GB (NEFMC 2019), and time/area closures and gear restrictions (i.e., 5-row apron and 1.5:1 twine-top hanging ratio) are currently being considered to minimize windowpane flounder bycatch (NEFMC 2019), with CFF gear and seasonal bycatch research providing data needed to inform these measures.

Seasonal information pertaining to groundfish bycatch and scallop meat yield on GB was limited before CFF received Sea Scallop RSA funding to conduct seasonal bycatch surveys beginning 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). Data collected during the CFF seasonal bycatch surveys conducted between 2011 and 2013 identified the seasonal coincidence of low scallop meat yield with peak yellowtail flounder (*Limanda ferruginea*) bycatch (NA10NMF4540473, NA11NMF4540027, NA12NMF4540034, NA13NMF4540011). Based on the coincidental seasonal overlap of scallop meat yield and yellowtail bycatch, managers were able to develop a seasonal closure to mitigate the scallop fishery's impact to yellowtail flounder within the CAII rotational access area (Smolowitz *et al.* 2016). However, in recent years this seasonal trend for yellowtail flounder is no longer evident. This, coupled with the fact that windowpane and yellowtail flounders occupy CAII during different seasons, has led to managers considering changes to the seasonal closure, adjusting it to follow the windowpane flounder seasonal trend instead. The time series of data collected by CFF in CAII highlights these changes and provides the information managers need to create adjustment to the scallop fishing season.

The scallop RSA program is one of the most successful and effective approaches for funding cooperative research that can address scallop fishery-specific science and management needs. Dredge and optical surveys funded through this program provide annual scallop biomass estimates for managers setting specifications for the upcoming fishing year, including designation of closed areas and open bottom and access to rotational areas. Unfortunately, these surveys do not capture fine-scale trends in scallop and bycatch species abundance nor physiological parameters. Further, these metrics are impacted by environmental conditions that can be highly variable over space and time. Patterns due to spatial and temporal heterogeneity, combined with increasing temperatures, altered weather patterns, and changes in sea level (Kleisner *et al.* 2017), will generate even greater uncertainties in estimates of seasonal distributions, abundance, and life and reproductive cycles (i.e. altered spawning periods) of many marine species. The CFF seasonal survey provides this fine scale information for many species, addressing a critical need for successfully tackling future challenges during the management process.

## OBJECTIVES

**1)** Collect biological samples to identify seasonal changes in the reproductive cycles of scallops.

**2)** Compare abundance of scallop predators, such as moon snails, sea stars, whelks and crabs, with mortality rates in scallops and environmental parameters.

**3)** Determine seasonal distribution and abundance of the main bycatch species to establish distribution ranges and quantify groundfish bycatch rates.

**4)** Collect biological samples to identify seasonal changes in the reproductive cycles of key fish species including yellowtail, winter, and windowpane flounder.

**5)** Evaluate dredge selectivity for scallops and main bycatch species, as well as assess the seasonal distribution and abundance of pre-recruits and recruit scallops and juvenile flatfish, through use of a dredge cover net.

**6)** Determine seasonal scallop meat quality using macroscopic observation, a CFF colorimeter device, and a CQR.

**7)** 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

### Sampling design

Four research trips, one per season, were conducted on eastern GB, covering the Scallop Area Management Simulator (SAMS) areas where bycatch of yellowtail and windowpane flounder has historically been high (**Table 1**, **Figure 1**). Fixed stations were located inside of the CAII southeast (CAII-SE), CAII southwest (CAII-SW), CAII Extension (CAII-Ext), and Southern Flank (SF) SAMS areas. The start position for each of the 50 stations was randomly selected prior to each trip using four points 0.25 miles away from the fixed station position. In order to sample the most stations possible, the tow time for the standard or uncovered dredge was changed from 30 minutes to 15 minutes. To evaluate the impact of this change in the survey, a calibration trip was conducted in November. During this trip, identical turtle deflector dredges (TDDs) were towed simultaneously; one was towed for 15 minutes and the other was towed for 30 minutes. All other sampling procedures followed standard seasonal survey protocols.

**Table 1.** Trip, dates and vessels used for the 2021 bycatch survey.

| Trip Month | Trip dates | Vessel |
|---|---|---|
| August | 25-31 Aug 2021 | F/V Atlantic |
| October | 27 Oct - 02 Nov 2021 | F/V Endeavor |
| March | 01-07 Mar 2022 | F/V Concordia |
| May | 11-17 May 2022 | F/V Vanquish |

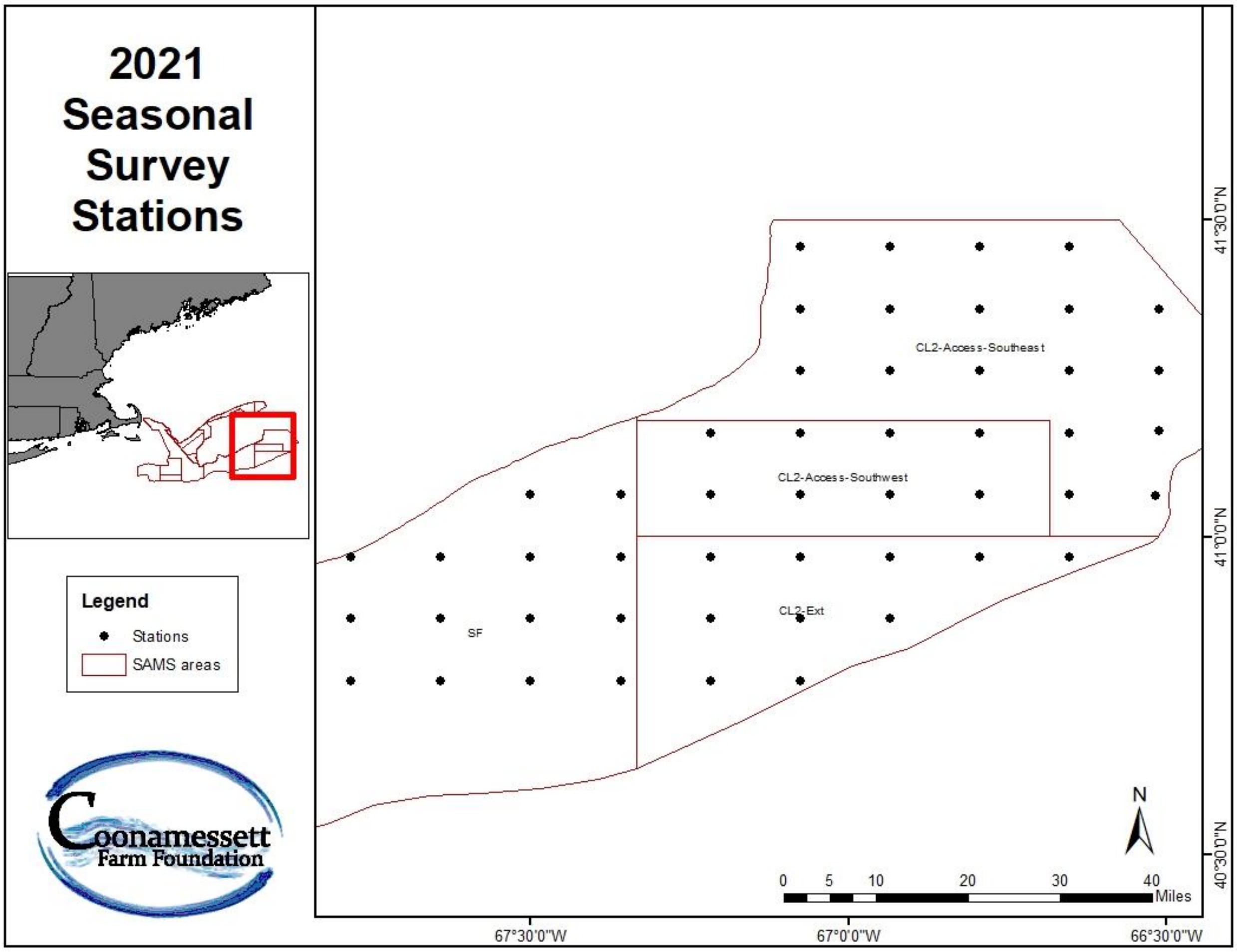



**Figure 1**. Location of the survey stations sampled for the 2021 seasonal survey on the eastern portion of GB. Stations are separated by ~6 nm.

A covered and an uncovered 15-foot wide (4.57 m) CFF TDD were used during each of the non-calibration trips. The covered dredge had a 45-mm mesh net over the topside of the dredge that extends from the skirt to the clubstick (**Figure 2**). The cover was designed to retain animals that pass through the top portion of a dredge being towed at commercially representative speeds. Both dredges were towed simultaneously, but the covered dredge was towed at select stations to avoid areas with high density of sand dollars or reported rocks and boulders. The dredges were towed at a target speed of 4.8 knots for 15 minutes at all of the stations during each trip. Vessel position, speed, and heading were recorded every 15 seconds using a tablet with built-in GPS capabilities. In addition to the tow data, a Lotek data logger was affixed to the uncovered dredge to record temperature and depth every 30 seconds.

**Figure 2.** Cover net catch during the 2021 August seasonal survey trip.

Processing of the catch from the uncovered and covered dredges and the cover net was identical. For each tow/gear, the catch was separated by species and weighed using Marel 1100-series motion compensated scales. A random subset of relevant bycatch species was 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 classified as "unclassified skates." **Table A1** lists the species and the number and weight caught during the project. To evaluate GSI of windowpane, winter, and yellowtail flounder, a maximum of ten fish were randomly selected from the uncovered dredge for sampling. Whole-body weight and gonad weight was collected for each of these individuals.

The entire scallop catch was quantified in bushels (bu=35.2 liters). From each tow, a one-bushel subsample of scallops was selected at random from each dredge and the cover net, and shell height was measured in 5-mm increments. At each station, 30 scallops (or fewer if the total catch < 30 scallops) from the uncovered dredge were randomly selected to collect data on their shell height, meat weight, gonad weight, sex, reproductive stage, and meat quality. These scallops were measured to the nearest millimeter from the umbo to the shell margin and then carefully shucked for evaluating meat quality. Meat quality was assessed on a qualitative color scale (**Figure 3**). A CQR and a colorimeter were used to evaluate quantitative metrics of meat color/quality.


**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.

Demographic data for all lobsters caught in either the covered or uncovered dredge were collected. The carapace length, sex, presence of eggs, shell hardness and incidence of shell disease was recorded for each lobster. In addition to demographic data, the extent of damage caused by the dredges was also recorded for all lobsters. 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 | |

## Data analysis

General biology of the target and main bycatch species: The reproductive stages of sea scallops and winter, windowpane and yellowtail flounders were plotted by season to examine seasonal changes and estimate spawning periods for each species. Reproductive cycles were described based solely on macroscopic observations. Scallops were assessed using the GMI:

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

where *b* = slope of the regression line for gonadal mass (GM) against shell height (Bonardelli and Himmelman 1995).

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.

Bycatch crustacean and gastropod vs scallop mortality: A natural mortality (M) index was calculated as the ratio between the abundances of clappers (D) to live scallops (L), multiplied by the rate at which the shell ligament degrades (52/33 weeks, Merril and Posgay 1964):

$$M = \left(\frac{D}{L}\right)\left(\frac{52}{t}\right)$$

For each dredge (covered and uncovered), M was modeled in relation to predator abundance (gastropods, crustaceans, and sea stars) and environmental covariates using generalized linear mixed models (GLMMs) with station and cruise included as random effects.

Groundfish bycatch rates vs scallop meat yield: The seasonal catch rates of important bycatch species (windowpane and yellowtail flounders, monkfish, and lobsters) were calculated in relation to the scallop catch. For this analysis, only the standard uncovered dredge was used. 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).

Cover net selectivity: To estimate the retention properties, the catch-at-length data for each tow were analyzed with the SELECT model (Millar 1992, Yochum and DuPaul 2008). See details in **Appendix B**.

Scallop meat quality: To investigate the relationship between qualitative measures of scallop meat quality and CQR measurements, CQR impedance values by month were compared between meat quality categories using a two-way ANOVA with pairwise comparisons using Tukey honest significant difference (HSD) post-hoc tests. Due to the low numbers of discolored (brown and gray) meats observed during the trips, discolored and stringy meats were combined for the analysis. Colorimeter readings for each qualitative meat color were tabulated.

Shell height-meat weight (SHMW) relationship: Scallop meat weight was modeled using a gamma distribution with a log link using the function "pqlmer" in R package "r2glmm" (Jaeger 2017), and model selection was based on Akaike Information Criterion (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. A 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.

General biology of American lobster: Sex ratios and damage scores (**Table 2**, grouped in three categories) were plotted.

Calibration analysis: To compare the difference between 30-minute vs 15-minute tows, Bland-Altman plots for expanded number of scallops, monkfish, yellowtail, windowpane and fourspot flounders were generated. These plots are commonly used to compare data collected using two different methods, often to determine if data collected using a new method agrees with the data collected using the previous standard method.

Catch data (number of individuals) from paired tows were also analyzed with a generalized linear mixed model (GLMM) as developed in Holst and Revill (2009). The GLMM analysis attempted to construct a model that would predict the efficiency of the 15-minute tows relative to 30-minute tows. The overall change in the relative proportion (15-minute tow/(15-minute tow + 30-minute tow)) was tested using the pooled catch data (summing catch over all lengths for a given tow). For this analysis the expected efficiency of the 15-minute tow is half the efficiency of the 30-minute tow.

## RESULTS BY OBJECTIVE

### Objective 1: Collect biological samples to identify seasonal changes in reproductive cycles of scallops.

Shell height-meat weight analysis was completed for a total of 4,705 scallops during the 2021 project. Same as the 2019-year project, the results suggested a fall spawning period, which coincide with previous research about sea scallops in that area (Thompson *et al*. 2014, Garcia *et al*. 2018, Garcia *et al*. 2019, **Figure 4**).

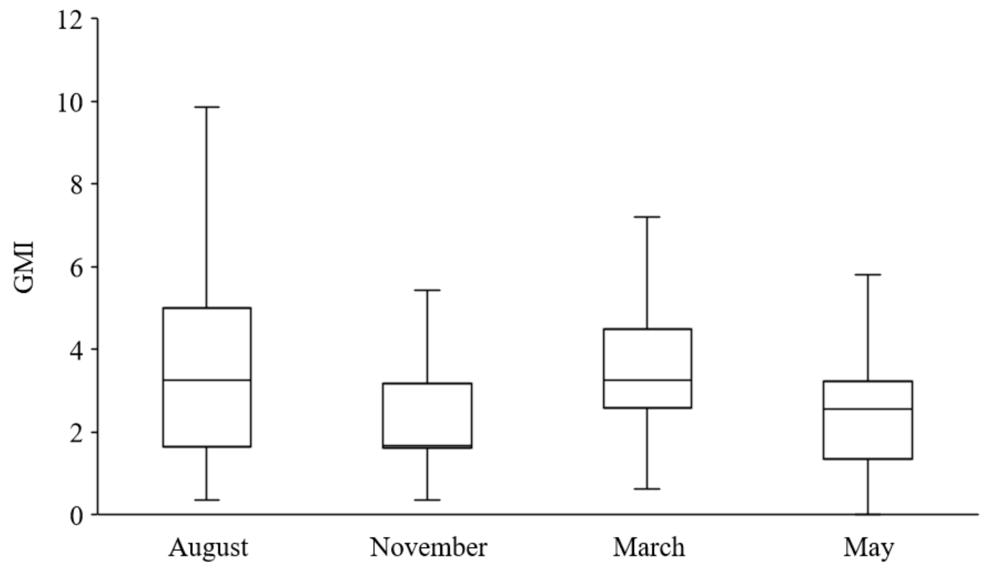



**Figure 4.** Seasonal changes in the GMI for female scallops for each month during the 2021 seasonal survey on the eastern portion of GB. Boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

### Objective 2: Compare abundance of scallop predators, such as moon snails, sea stars, whelks and crabs with mortality rates in scallops and environmental parameters

For this analysis data from each dredge was separately analyzed. For the uncovered dredge, analysis of M as a function of predator abundance and environmental parameters found a relation between M and depth (m) and *Asterias sp*. abundance (**Table 3**), while analysis of the covered dredge data found no relation between M and predator abundance or depth and temperature.

**Table 3.** Summary statistics for the relation of M, predator abundance and environmental parameters, data collected from the a) uncovered dredge and b) covered dredge

**a)**

```
Random effects:

Conditional model:
 Groups          Name        Variance Std.Dev.
 CruiseID:Station (Intercept) 1.0013   1.0007
 Station         (Intercept) 0.6135   0.7833
Number of obs: 178, groups:  CruiseID:Station, 178; Station, 50

Dispersion parameter for tweedie family (): 0.0476

Conditional model:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)    -8.646219   1.249333  -6.921  4.5e-12 ***
Depth           0.112422   0.029311   3.835 0.000125 ***
starfishasteNo  0.011096   0.005128   2.164 0.030484 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

**b)**

```
Random effects:

Conditional model:
 Groups          Name        Variance Std.Dev.
 CruiseID:Station (Intercept) 1.1061   1.0517
 Station         (Intercept) 0.5503   0.7418
Number of obs: 66, groups:  CruiseID:Station, 66; Station, 36

Dispersion parameter for tweedie family (): 0.0284

Conditional model:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.5253     0.2723  -16.62   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

## Objective 3: Determine seasonal distribution and abundance of the main bycatch species to establish distribution ranges and quantify groundfish bycatch rates

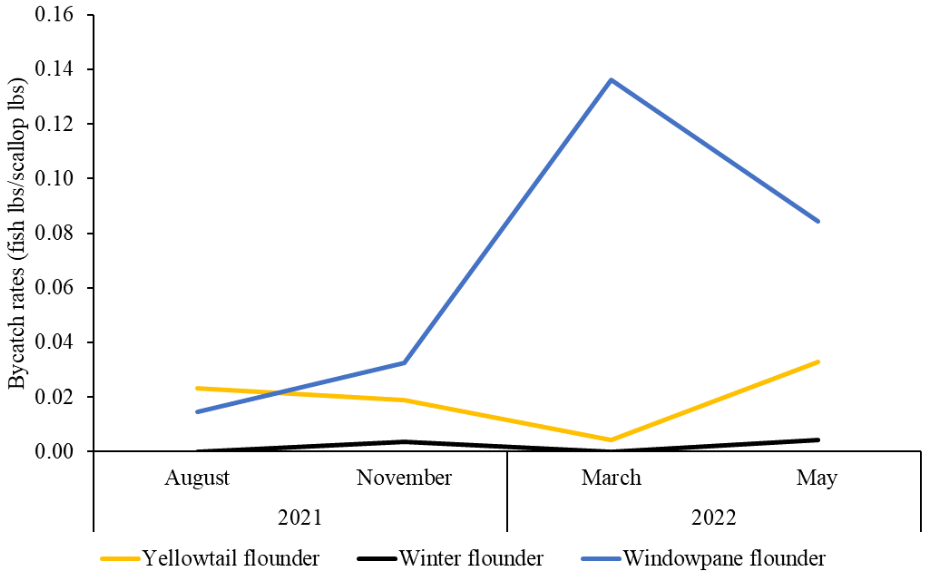
Total catches by survey month of the relevant bycatch species from the uncovered dredge is displayed in **Table 4**. The seasonal catch rates of important bycatch species were calculated in relation to the scallop catch (i.e. lbs. of fish/lbs. of scallops). The overall bycatch rates for all the commercially important species sampled during this project were low (< 1 lbs. of fish/lb. of scallops). Bycatch rates were never greater than 0.03 lbs. of fish/lb. of scallops for yellowtail flounder and for windowpane flounder the bycatch rate never exceeded 0.14 lbs. of fish/lb. of scallops (**Figure 5a**). Yellowtail exhibited the highest abundance during the summer trip; windowpane flounder were the most abundant species observed during the winter trip and for both lobster and monkfish catches were highest in August (**Table 4**). Other flatfish, like summer flounder (*Paralicthyes dentatus*) and winter flounder showed minimal catches in the area.

Mapping the distributions of the sampled species reveals that, for the most part, their distributions and abundances are spatially heterogeneous (**Appendix C**). **Figures C1** to **C3** show scallop catches with the uncovered and covered dredges, **Figures C4** to **C6** show scallop catches from the calibration trip and **Figure C7** shows the commercial scallop yield per tow per trip. Pre-recruit scallops were observed only in the cover net catches; for winter and spring catches of pre-recruits were concentrated in the southeastern portion of the sampling area while for the summer trip a high concentration was observed in the northern portion of the CAII SAMS area (**Figure C1**). Recruit scallop concentrations were observed in all cases in the southeastern portion of the sampling area. In addition, a station located northwestern portion of the sampling area was observed to have a high concentration of recruit scallops during summer, and spring trips (**Figure C2**). Adult scallops were distributed throughout entire sampling area, but with higher concentrations in the southeastern portion (**Figure C3**). For the calibration trip executed in Fall pre-recruits were observed on the northern portion of the sampling area (**Figure C4**), the recruits were observed in the northern and southern portion (**Figure C5**), and adult scallops were observed widely distributed throughout the sampling area (**Figure C6**). Yellowtail flounder was observed mostly on the northeastern portion of the sampling area (**Figure C8**); windowpane flounder, and monkfish were widely distributed throughout the sampling area with relatively uniform concentrations (**Figure C9-C10**).

**Table 4.** Total catches by trip with the uncovered dredge. Scallop catch is quantified in bushels and fish/crustacean in number of fish/crustaceans

| Year | Month | Scallops | Yellowtail Flounder | Windowpane Flounder | Monkfish | Lobster |
|---|---|---|---|---|---|---|
| 2021 | August | 203 | 50 | 19 | 168 | 5 |
| | November | 152 | 22 | 64 | 161 | 1 |
| 2022 | March | 150 | 6 | 188 | 23 | 0 |
| | May | 256 | 28 | 156 | 126 | 1 |

**a)**




**b)**

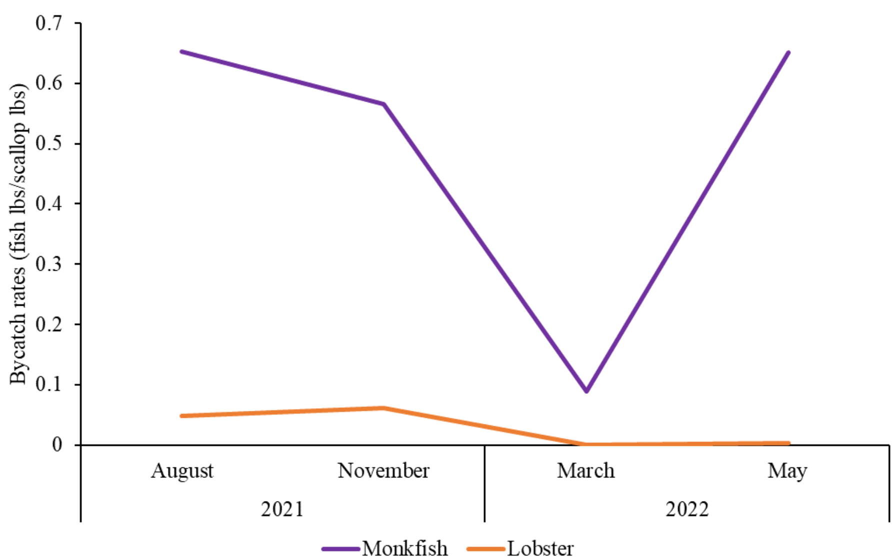



**Figure 5.** Bycatch rates for commercially important species, including **a)** yellowtail, winter and windowpane flounders **b)** monkfish and lobster in relation to scallop catch during the 2021 seasonal survey. Only the uncovered dredge was used for this analysis.

**Objective 4: Collect biological samples to identify seasonal changes in reproductive cycles of key fish species including yellowtail, winter, and windowpane flounder**

Yellowtail flounder: A total of 106 yellowtail flounder were captured during the 2021 project (**Table 4**), of which 87% were females. The peak catch of yellowtail flounder occurred in May and the lowest catch occurred in March (**Table 4**, **Figure C8**). The GSI analysis indicated a possible spawning period in late-spring and early-summer (**Figure 6**), which coincide with the historical yellowtail flounder spawning and some previous CFF seasonal survey observations (Huntsberger *et al.* 2015, Garcia *et al.* 2018).

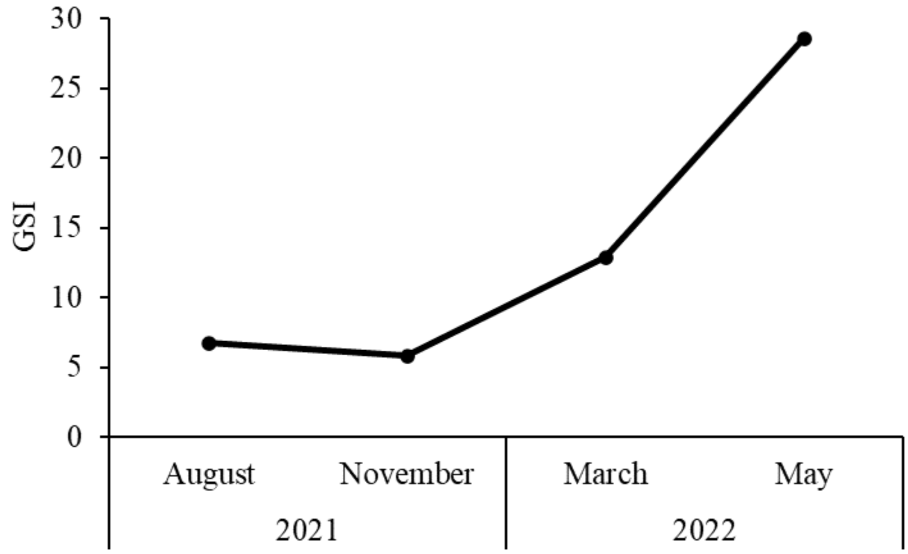



**Figure 6.** Seasonal changes in the GSI of female yellowtail flounder for each month during the 2021 seasonal survey on the eastern portion of GB.

Windowpane flounder: A total of 427 windowpane flounder were caught during this project, with catches peaking in March (**Table 4**). They were caught at most stations in spring and winter (**Figure C9**). Based on the GSI values, one spawning period likely occurred in fall (**Figure 7**). However, spent females were observed during every trip, suggesting that a low level of spawning activity may occur year-round.

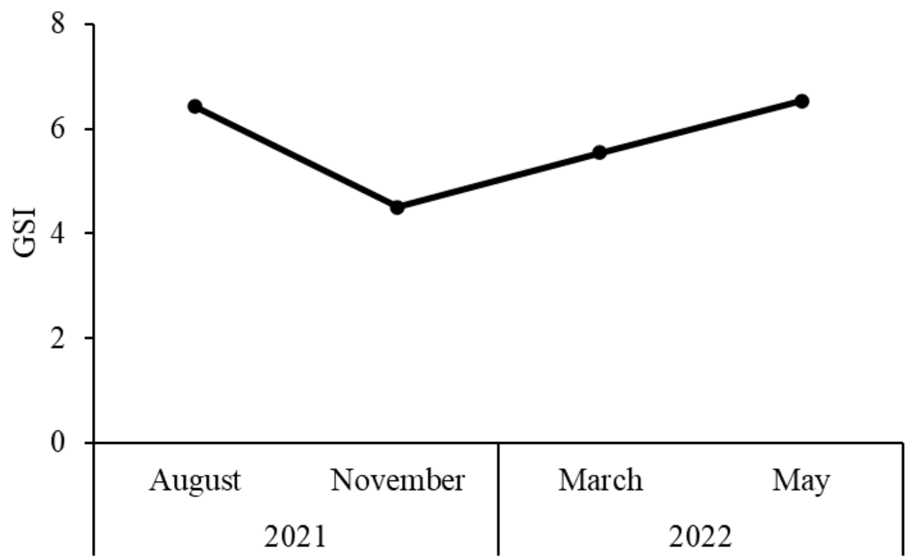



**Figure 7.** Seasonal changes in the GSI of female windowpane flounder for each month during the 2021 seasonal survey on the eastern portion of GB.

**Objective 5: Evaluate selectivity of scallops and main bycatch species, as well as assess the seasonal distribution and abundance of pre-recruits and recruit scallops and juvenile flatfish through a dredge cover net**

Sea scallop selectivity analysis: The scallop catch-at-length data for each tow was analyzed with the trouser trawl SELECT model (Millar 1992). For this analysis, the catch-at-length data for the uncovered dredge were compared to catch-at-length data for the covered dredge. The covered dredge is assumed to be nonselective, retaining a sample that is representative of the sea scallop population available to the gear. The L50 for the uncovered dredge was 92.8 mm (**Table 5 and Figure 8**). The model-estimated split parameter *p* was 0.74 ± 0.01, indicating that the uncovered dredge was fishing with a higher efficiency. Since the width of both the covered and uncovered dredges was the same, the split parameter would have been 0.5 if the two gears were fishing equivalently. A retention curve for sea scallops was also generated using the cover SELECT model (Millar 1992, Tokai *et al*. 1996). Unlike the trouser trawl model, this model compares the catch-at-length data for the dredge bag to the codend data. The predicted the L50 for the covered portion of the dredge bag to be 93.81 mm using this method (**Table 5 and Figure 8**).

**Table 5.** The estimated sea scallop retention parameters from the trouser trawl and codend cover models

| | Trouser Trawl Model | | Cover Model | |
|---|---|---|---|---|
| | Estimate | S.E | Estimate | S.E |
| L25 = | 80.788 | 1.417 | 82.508 | 0.144 |
| L50 = | 92.834 | 2.023 | 93.811 | 0.098 |
| L75 = | 104.881 | 2.837 | 105.114 | 0.126 |
| Split parameter p = | 0.74 | 0.014 | N/A | N/A |
| REP | 28.139 | | N/A | N/A |

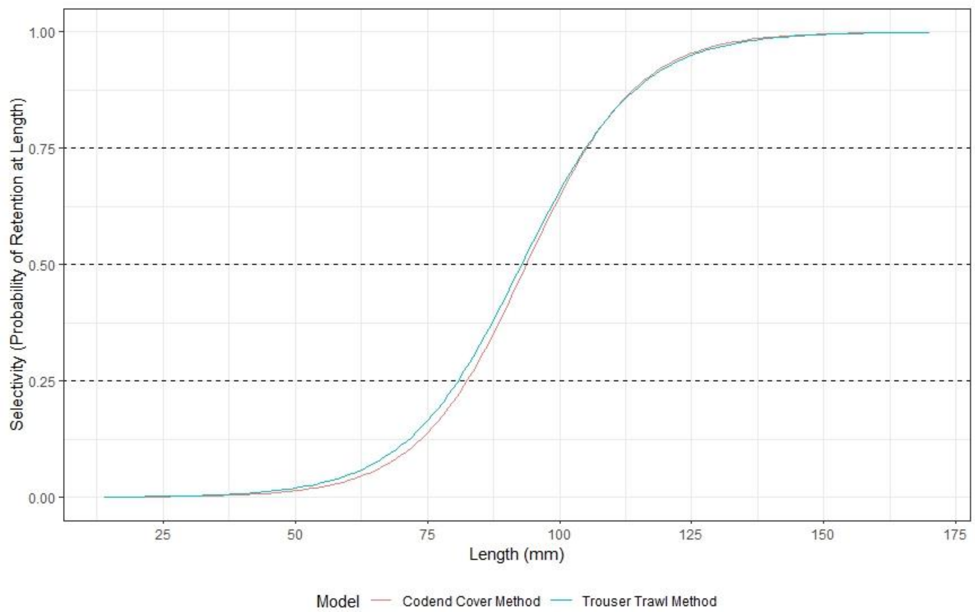



**Figure 8.** Sea scallop selectivity curves as generated by the trouser trawl and codend cover models.

**Objective 6: Determine seasonal scallop meat quality using macroscopic observation, a CFF colorimeter device, and a CQR**

For 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 2.8% of scallop meats were observed with poor condition (0.56% brown meats, 0.06% gray meats and 2.18% stringy meats), observation of discolored meats (0.62%) decreased from what was observed during the previous CFF seasonal survey (2.8%). The monthly variation of brown, gray and stringy meats during 2021 seasonal survey are shown in **Table 6**; the highest numbers of brown meats were collected in August, while gray meats observations were minimal. Gray and brown meats were observed in lower numbers compared with last year project (Garcia *et al*. 2021).

**Table 6.** Number of scallop meat analyzed by health condition and month

| Year | Month | White | Brown | Gray | Stringy |
|---|---|---|---|---|---|
| 2021 | August | 1287 | 11 | 1 | 29 |
| | November | 997 | 7 | 0 | 35 |
| 2022 | March | 1201 | 3 | 2 | 23 |
| | May | 1197 | 5 | 0 | 15 |

Certified Quality reader analysis:

Overall, 3,413 meats were measured with the CQR, and researchers observed high R values and therefore low impedance values correlated with whiter, better-quality meats. Overall, 3,340 meats were classified as white, fifteen as brown, two as gray and fifty-six as stringy through visual scoring. Impedance values for meats classified as white were lower than meats classified with poor condition (**Figure 9**). Further, ANOVA tests indicated significant differences between colors only for November trip and post-hoc Tukey tests show that the CQR reader is able to accurately measure differences in scallop condition based on electrical bioimpedance (**Table 7**).

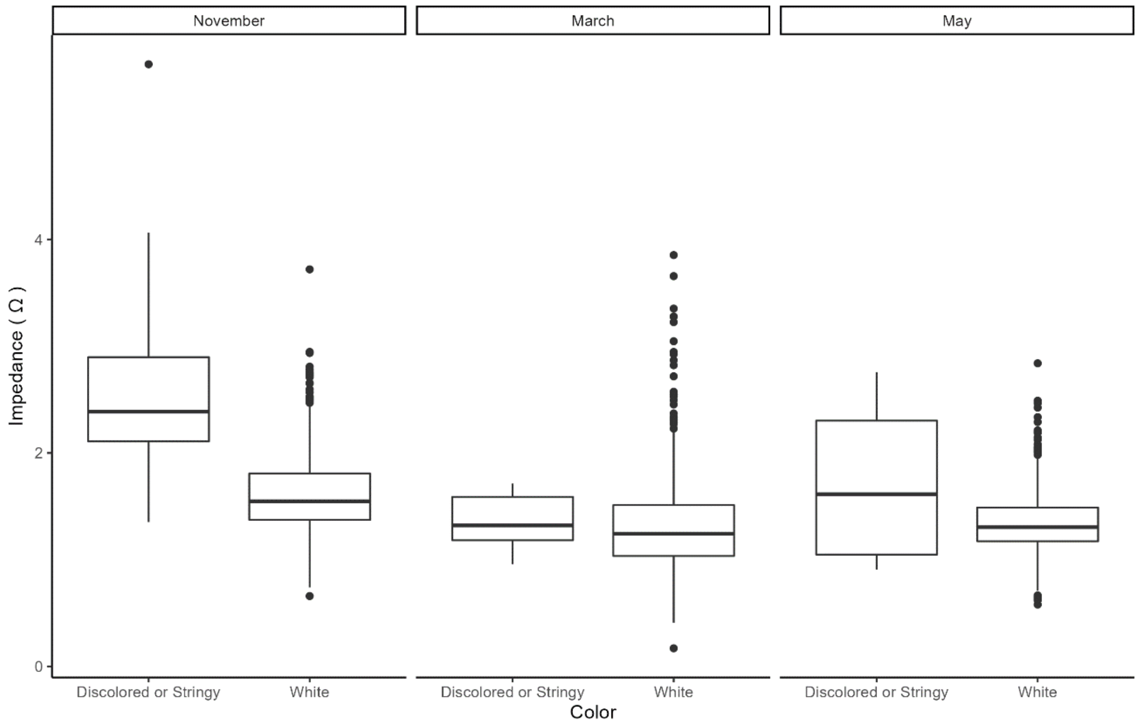



**Figure 9.** Trends in measured impedance for healthy and poor condition meat scallops for the 2021 seasonal bycatch project.

**Table 7.** Tukey tests between colors for the November trip for the 2021 seasonal project

| Contrast | Estimate | Conf.low | Conf.high | Adj.p.value |
|---|---|---|---|---|
| White-Discolored or Stringy meats | -0.84435 | -0.96161 | -0.72708 | 6.38E-11 |
| March trip-November trip | -0.30016 | -0.34916 | -0.25115 | 6.38E-11 |
| May trip-November trip | -0.28847 | -0.33454 | -0.2424 | 6.38E-11 |
| May trip-March trip | 0.011689 | -0.03555 | 0.05893 | 0.830683 |
| November trip white vs discolored/stringy meats | -0.95435 | -1.15955 | -0.74915 | 6.38E-11 |
| March trip white vs discolored/stringy meats | -0.0244 | -0.46806 | 0.419259 | 0.999987 |
| May trip white vs discolored/stringy meats | -0.37605 | -0.81924 | 0.067136 | 0.14963 |

Colorimeter analysis: To determine if meat color could be measured quantitatively, a colorimeter was used to collect a red, green, and blue (RGB) tuple of scallop meats. The colorimeter costs less than $50 and consists of an Adafruit RGB Color Sensor with IR filter and White LED - TCS34725 and Atmega328 Microcontroller (**Figure 10**). RGB values were collected from 696 sea scallops, of these only seven individuals' brown meats and none were classified as gray meats. Average observed color values for the two observed meat categories were similar to what had been observed during previous testing of the colorimeter (**Table 8**). The insufficient observations of brown and gray meats preclude a more in-depth analysis of the data.

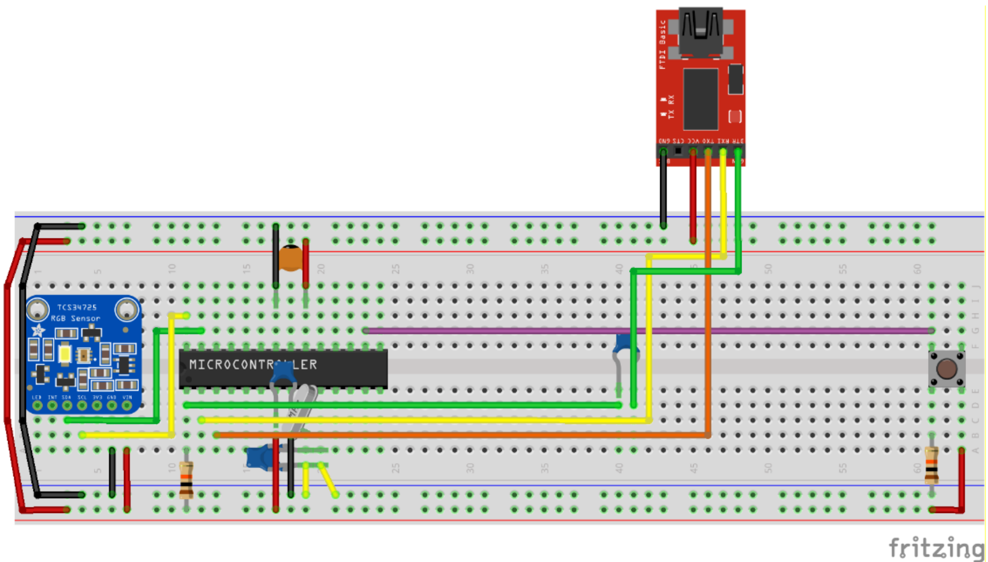


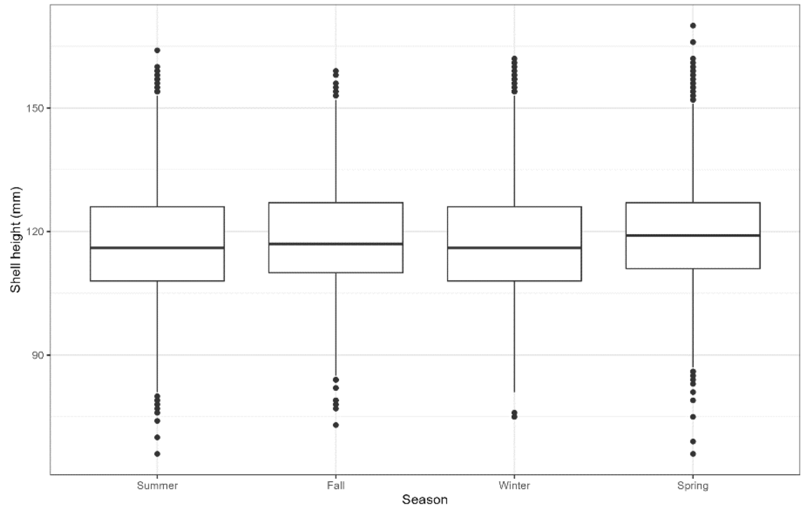

**Figure 10.** Breadboard diagram of the colorimeter, the microcontroller is an ATMega328 which interprets the sensor values and outputs them via an FTDI adapter.

**Table 8.** Colorimeter values for white and brown meats collected during the 2021 seasonal survey project

| Year | White | | | Brown | | |
|---|---|---|---|---|---|---|
| | **Red** | **Green** | **Blue** | **Red** | **Green** | **Blue** |
| 2021 | 77 | 89 | 77 | 81 | 89 | 74 |
| 2022 | 80 | 90 | 76 | 82 | 89 | 72 |

Shell height-meat weight (SHMW) relationship: A total of 4,715 scallops were sampled at 50 stations located across the eastern portion of GB. Scallop shell heights ranged from 11 mm to 177 mm and meat weights varied from 2.0 g to 84.0 g. Temporal distributions of the collected shell heights and meat weights are shown in **Figure 11.** Parameter estimates and the (AIC) selection table are shown in **Appendix D**.

**a)**




**b)**

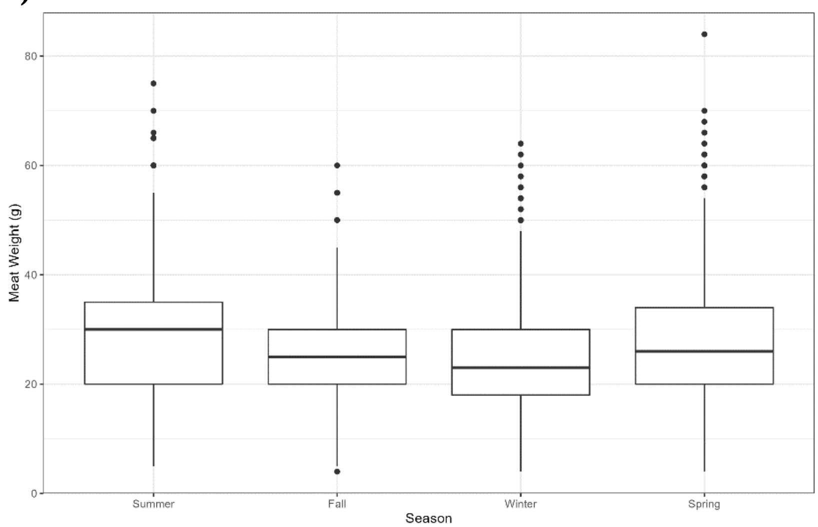



**Figure 11.** Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples from eastern GB. The markers inside the boxes show the median values for each month. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers extending to the minimum and maximum values.

SHMW curves for white and gray scallops at the three stations are shown in **Figure 12**. Station 734 was 90-m deep and located on the SF, Station 704 was 90-m deep in CAII S, and Station 730 was 60-m deep at the same latitude in CAII S. Scallops with gray meats had lower meat weights than those with white meats, a trend that has been noticed during previous seasonal bycatch surveys.

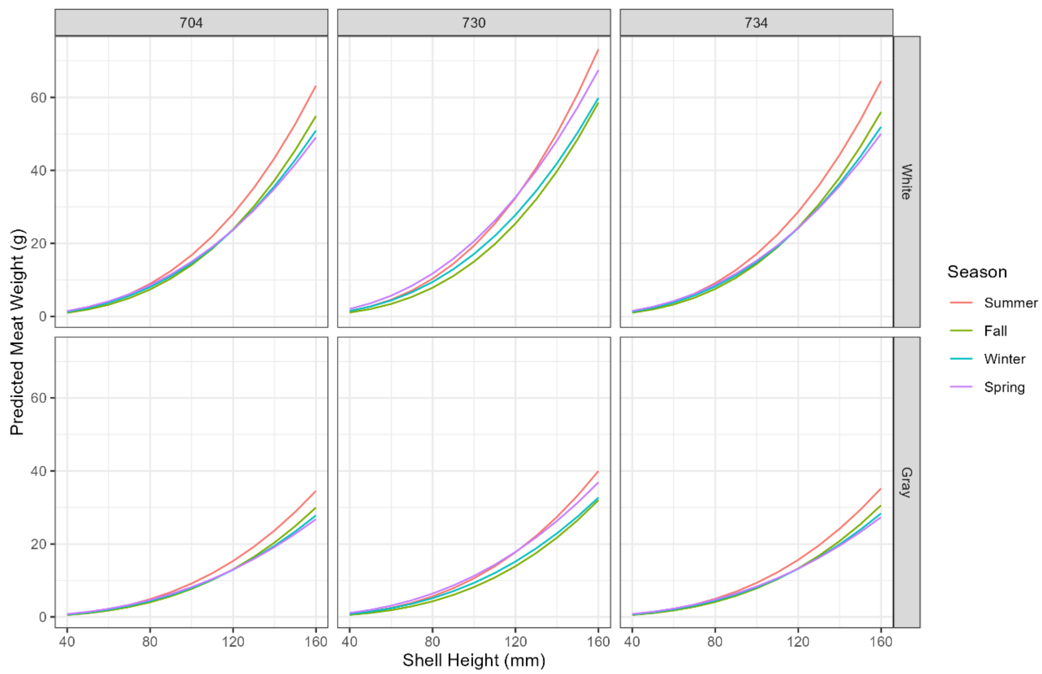



**Figure 12.** Estimated SHMW curves for white and gray scallops from Station 734 on the SF and Stations 704 and 730 in CAII S.

Predicted meat weights were analyzed by depth. 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 13**). Two peaks in meat weight, in August and March, were predicted at the shallower 60-m station, while a single peak was predicted at the deeper 90-m station in August.

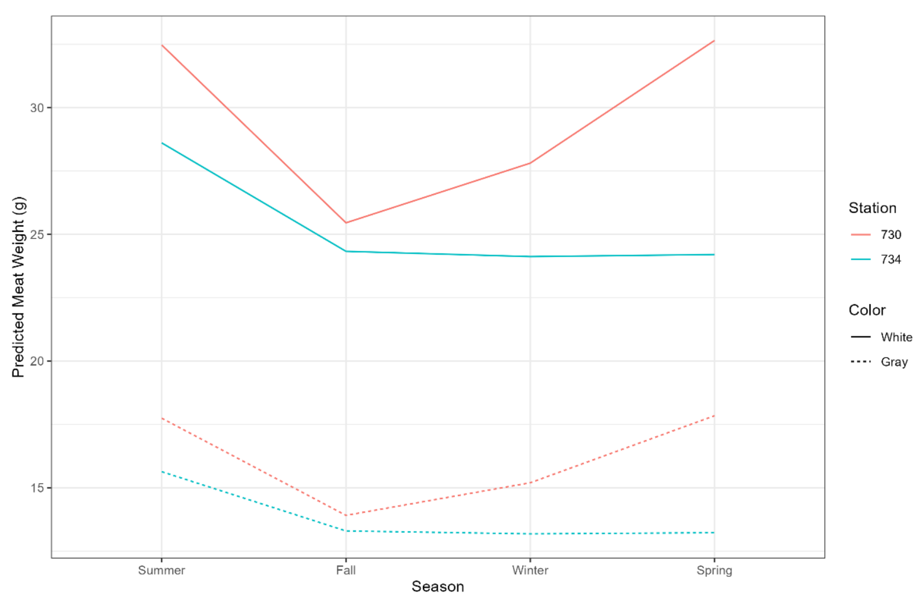



**Figure 13.** Temporal trends for the predicted meat weights of white and gray 120-mm scallops from Stations 509 and 513 in CAII S. Station 509 was a 60-m station and Station 513 was a 90-m station.

**<u>Objective 7: 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</u>**

All lobsters caught during the project had their carapace lengths, sex, shell disease status (Y/N), egg status (presence/absence and stage), and dredge-induced damage recorded. Overall, lobster catch was low during all 2021 seasonal survey project (**Table 9**).

**Table 9.** Catch of lobster for each trip

| Year | Month | Number | Weight (lbs.) |
|---|---|---|---|
| 2021 | August | 17 | 30.9 |
| | November | 12 | 25 |
| 2022 | May | 2 | 2.2 |

A majority of the catch was female lobsters with only two males caught during the November trip (**Figure 14**). Shell disease was not observed. Of the 31 lobsters caught, 14 lobsters had no damage, four were moderately damaged (missing claws or a walking leg), and 13 were lethally damaged **(Figure 15**). November was the month with the highest incidence of lethal damage, which coincides with the physiological recovery from molting period for the species (**Figure 15**). A total of 31 females and 1 male 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.

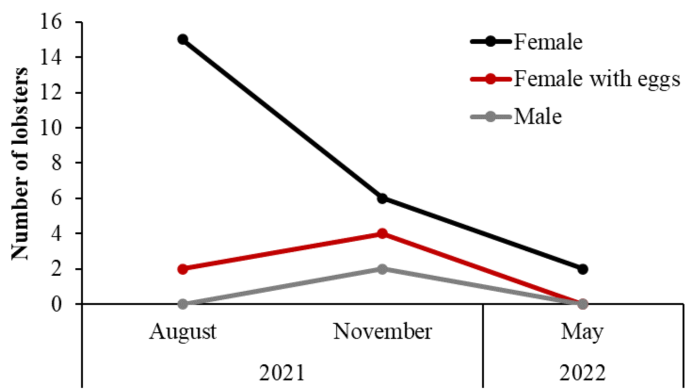



**Figure 14.** Catch of lobsters by trip separated by sex during the 2021 seasonal survey on the eastern portion of GB.

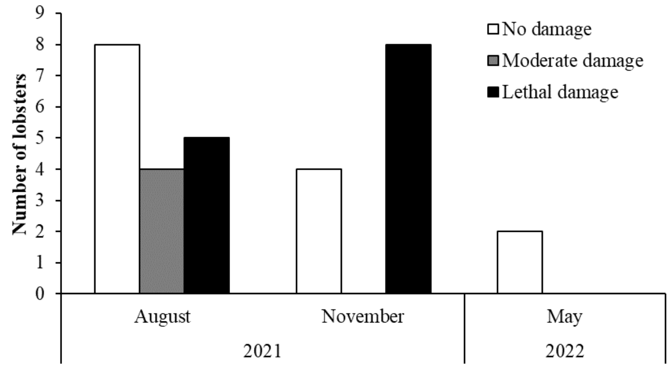
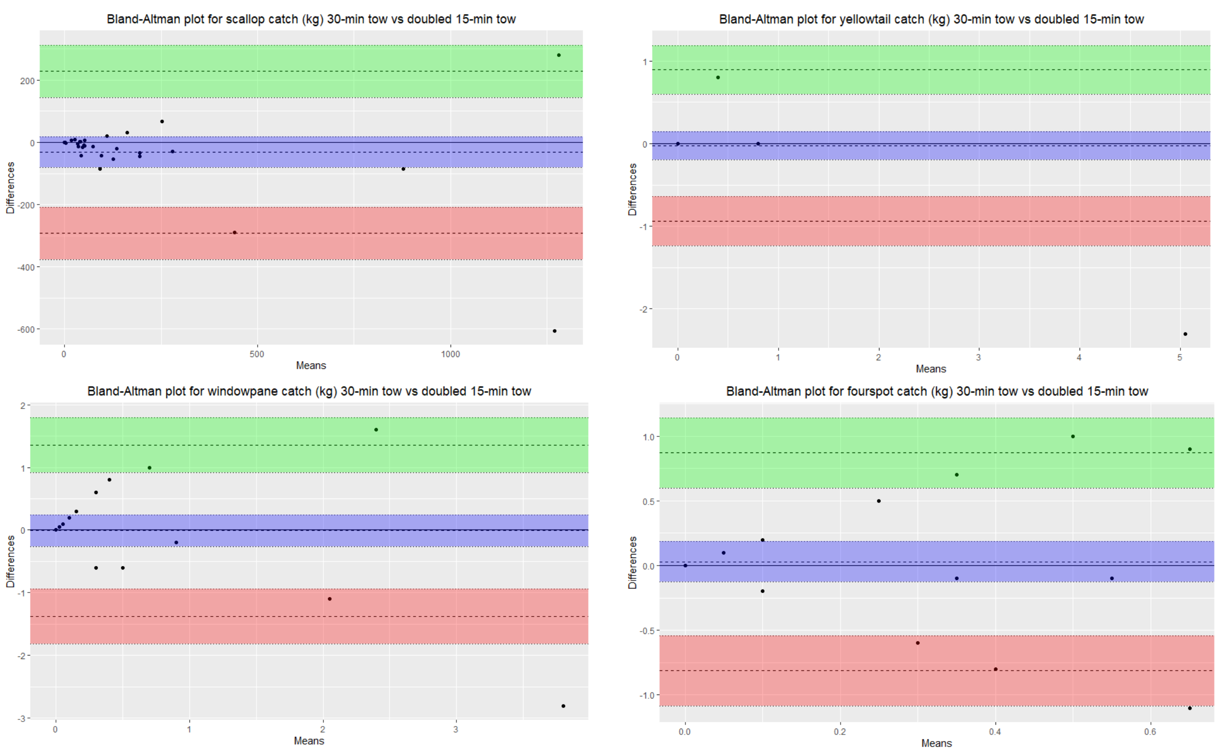



**Figure 15.** Dredge-induced damage to lobsters by trip during the 2019 seasonal survey on the eastern portion of GB.

## Add-on objective: 30 minutes and 15 minutes tows calibration analysis

A total of 31 tows were completed across the sampling area. For the species analyzed, catch from the 30-min tows agrees with doubled catch from the 15-min tows when catch is low (**Figure 16**). For scallops, the agreement is quite good up to a mean catch of ~400kg/tow (**Figure 16**). Catches of fish species during a 30-min tow were similar to doubled catch during a 15-minute tow when catches were low. As the mean catch increased, the difference values approached and then exceeded the limits of agreement. GLMM results show that scallop catches at 15-minute tows are approximately half of the catches of the 30-minutes tows ($p < 0.05$, coefficient: 0.54; **Figure 17**). Due to low catches, other species were not analyzed with GLMM.



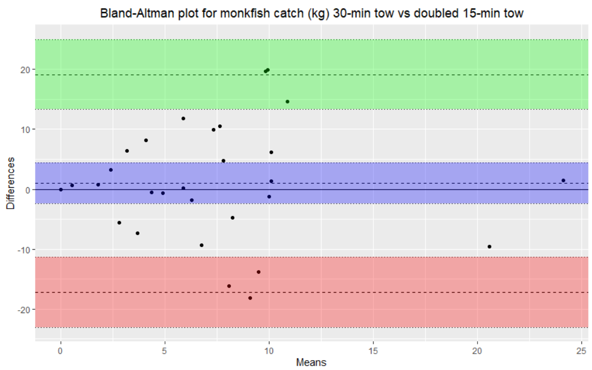



**Figure 16.** Bland-Altman plots by species. Data collected during the Fall trip in the 2021 seasonal survey project. The x axis is the mean of the paired catch. The y axis is the difference between the paired catches (doubled 15-min catch - 30-min catch). The middle-dashed line is the mean of the difference and the upper and lower dashed lines are the upper and lower limits of agreement (±1.96 SD). The colored bands are the 95% confidence intervals around the mean and limits of agreement.

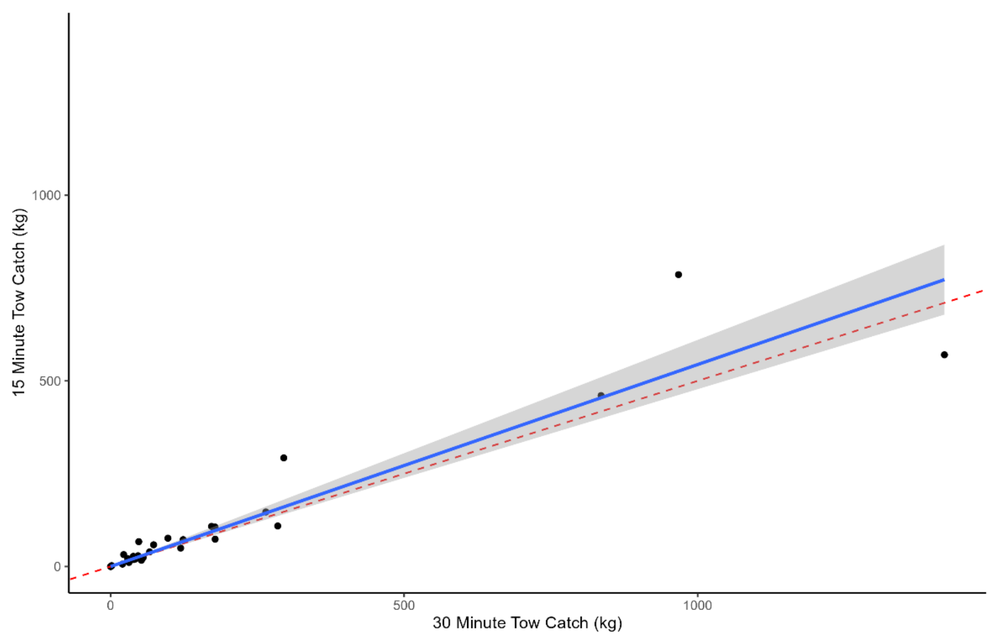



**Figure 17.** A comparison of the total scallop catches of the 15 min towed vs 30 min towed TDD dredge during the Fall trip in the 2021 seasonal survey project.

## DISCUSSION

CFF has been conducting a seasonal survey on GB with relative consistency since 2012, providing important information to managers about seasonal trends in sea scallop meat yield and reproductive physiology as well as the bycatch of groundfish. Examination of longer-term changes in species catch distributions and abundance patterns point to the continued need for this survey. For instance, familiar seasonal trends in yellowtail and windowpane flounder abundance in CAII are changing. Catch data from the seasonal bycatch survey indicates that the regular cycles of yellowtail flounder abundance, previously described by CFF and used to adjust seasonal access by the scallop fishery to CAII-South (Smolowitz *et al.* 2016), are no longer evident in recent years (Garcia *et al*. 2019). From 2011-2014, yellowtail flounder abundance would peak in the late summer/fall, corresponding to the current closure (August 15-November 15). However, in more recent years the abundance and distribution patterns are irregular, with yellowtail flounder peaking in mid-summer (Garcia *et al*. 2018), late spring/early summer (Garcia *et al*. 2019), winter (Garcia *et al*. 2021) and in summer during the most recent survey (**Figure 5**).

Marine species are experiencing increasing temperatures, altered weather patterns, and changes in sea level, circulation patterns, nutrient loads, and the acidity of the oceans (Kleisner *et al*. 2017), which may impact normal physiological responses amongst populations. Currently, annual stock assessment surveys conducted by the Northeast Fisheries Science Center (NEFSC) can only investigate interannual or biannual variation of reproductive indices like GMI and GSI. These reproductive indices are key to identifying when spawning has occurred and relative fecundity for many marine species (Jorgensen and Fath 2008). Like seasonal abundance and distribution trends, the previously established spawning cycle of yellowtail flounder appears to be breaking down (Garcia *et al.* 2019). The cause is not known, but it may be related to the decline in overall yellowtail flounder biomass or climate change. In the 2019 seasonal survey, spawning likely occurred mid-summer (Garcia *et al*. 2019). Data from the 2021 seasonal survey indicates spawning occurred May/June, which coincides with the historic yellowtail flounder spawning season observed by CFF, the National Marine Fisheries Service, and the Canadian Department of Fisheries (**Figure 6**; Hart and Cadrin 2004, Huntsberger *et al.* 2015, Garcia *et al.* 2018, Garcia *et al.* 2019). Inconsistent spawning behavior may result in poor recruitment due to the egg and larval stages not experiencing the environmental conditions needed to grow and survive (Wieland *et al.* 2000). Based on these observations, continued seasonal monitoring of reproductive physiology is necessary to effectively manage fisheries in an increasingly changing environment.

Like the previous seasonal survey, a covered TDD was used to expand sampling to include younger scallop and flatfish demographics. The results from this year's project continue to indicate that a covered dredge is a good tool for locating areas with pre-recruit and recruit scallops. In addition, the covered dredge may also catch comparable numbers and sizes of flounder species relative to the NEFSC bottom trawl (Garcia *et al*. 2021). Unlike the previous seasonal survey, the cover net was used simultaneously with uncovered TDD and across a greater range of the sampling area. This was done to provide information about the factors influencing yearly changes in scallop biomass as well as seasonal trends in bycatch. However, to accomplish this, the standardized tow duration was decreased from 30 minutes to 15 minutes.

Due to an interaction between the vessel and the cover net which caused extensive damage the cover net at the onset of the November trip, a calibration study was carried out to efficiently make use of our industry partner's vessel and minimize overall disruption to the proposed survey schedule. Thirty-one paired tows were conducted to evaluate the impact that decreasing the standard tow time would have on scallop catch and other commonly caught important fish species. Analysis of these data indicate that scallop catch for a 30-minute tow relative to a doubled 15-minute tow is similar. However, for the few tows where scallop catches exceeded 400kg, catch from 30-minute tows did not agree with double the catch from the 15-minute tow (**Figure 16**). This suggests that the dredges may have become saturated before the tow ended due to high densities of scallops. Previous studies have documented reduced dredge efficiency at high scallop densities due to dredge saturation (Rudders *et al.* 2019). Catches of the fish species during 30-min tows were also similar to the doubled catches from 15-minute tows when catches were low, but as catches increased, catch estimates from these two methods were no longer in agreement. Overall relatively few fish were encountered during the calibration trip, precluding our ability to make strong inferences about the impact of a reduced tow time. With a larger dataset the relationship between dredge tow time and fish catches can be more thoroughly evaluated.

As mentioned previously, the covered dredge was towed simultaneously with an uncovered dredge facilitating a selectivity analysis of the scallop catch. Unlike what had been previously observed, the split-parameter estimate was significantly higher than the expected estimate of 0.5, indicating the cover was negatively impacting the efficiency of the dredge (**Table 5**). Stretched links, which had not been observed during the previous seasonal survey and field trials developing the cover net, may be the reason why the cover net was observed to significantly impact the performance of the dredge. While the dredge bags are routinely maintained throughout the trip, the addition of the cover can make it difficult to identify potential repairs needed to the apron. Observations of holes forming in the top panel of the cover net above the apron indicate that stretched links due to age or improper installation were snagging the net. When snagged on the apron, the cover would likely impact the performance of the sweep by causing unwanted lifting. Also, during some trips significant tidal currents were encountered, which could have increased the likelihood that the cover snagged on the apron or even fouled on the headbale. To address this potential issue, brand new dredge bags are being used for the on-going seasonal survey and the apron is being monitored more closely. This appears to be working as preliminary data from the on-going survey indicates that the covered dredge is performing similar to the uncovered dredge.

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 have been observed in regions of GB. 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 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 increased food availability (Sarro and Stokesbury 2009). Continuing a seasonal survey of GB is needed to better evaluate spatiotemporal relationships between meat weight, gonad weight, and primary productivity on GB.

In addition, monitoring seasonal scallop meat quality is a priority for CFF. In 2018 CFF incorporated new technologies in order to provide metrics to track changes in scallop quality. Scallop meat value depends on the quality of the product, which is scored based on size, color, weight, and taste in the inspection process (CA 2017). The seasonal bycatch survey was able to demonstrate that meat quality issues (i.e., gray meats at harvest) can be assessed quantitatively using a colorimeter and/or CQR (Garcia *et al*. 2019, Garcia *et al*. 2021). By integrating data from these devices into a scallop bag tag it would be possible to track scallop quality from harvest to consumer. Further research on these technologies is needed to understand which metrics correlate to post-harvest changes in meat quality.

## CONCLUSIONS AND FUTURE RESEARCH

The CFF seasonal 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 collected data has a direct impact on scallop management by supplying fisheries managers with critical information required to adhere to ACLs and devise AMs to optimize the harvest of scallops while minimizing bycatch. Information on spatiotemporal patterns in bycatch rates in the scallop fishery have been used to devise time-area closures to mitigate yellowtail flounder bycatch (Smolowitz *et al*. 2016) and gear-based AMs, like the five-row apron, to reduce windowpane flounder bycatch (Huntsberger *et al*. 2015).

CFF seasonal survey data provides information on many of the aspects of the scallop fishery that are not provided by any other surveys. Because our surveys are conducted in a systematic fashion, using full-scale dredges over a range of scallop densities, they provide spatiotemporally explicit information about scallop and bycatch stocks in these areas. With the addition of the cover net, the survey will expand on the species composition and length distributions of the catch, providing data that will increase our understanding of scallop recruitment, predation, and scallop-fishery impacts on bycatch species like yellowtail and windowpane flounder. 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.

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# APPENDICES

## Appendix A: General

**Table A1.** Species captured during the 2021 seasonal 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 |
|---|---|---|---|
| Unclassified skates | *Rajidae* | 7742 | Count/Weigh |
| Silver hake | *Merluccius bilinearis* | 1073 | Count/Weigh |
| Red hake | *Urophycis chuss* | 4049 | Count/Weigh |
| Gulfstream flounder | *Citharichthys arctifrons* | 421 | Count/Weigh |
| Longhorn sculpin | *Myoxocephalus octodecemspinosus* | 101 | Count/Weigh |
| Sea raven | *Hemitripterus americanus* | 8 | Count/Weigh |
| Northern searobin | *Prionotus carolimus* | 259 | Count/Weigh |
| Jonah crab | *Cancer borealis* | 777 | Count/Weigh |
| Rock crab | *Cancer irroratus* | 224 | Count/Weigh |
| Northern moon snail | *Euspira heros* | 778 | Count/Weigh |
| Waved whelk | *Buccinum undatum* | 128 | Count/Weigh |
| Spiny dogfish | *Squalus acanthias* | 23 | Weigh/Measure |
| Barndoor skate | *Dipturus laevis* | 193 | Weigh/Measure |
| Atlantic cod | *Gadus morhua* | 1 | Weigh/Measure |
| Haddock | *Melanogrammus aeglefinus* | 20 | Weigh/Measure |
| American plaice | *Hippoglossoides platessoides* | 6 | Weigh/Measure |
| Summer flounder | *Paralichthys dentatus* | 73 | Weigh/Measure |
| Fourspot flounder | *Paralichthys oblongus* | 1026 | Weigh/Measure |
| Witch flounder | *Glyptocephalus cynoglossus* | 5 | Weigh/Measure |
| Monkfish | *Lophius americanus* | 478 | Weigh/Measure |
| Illex squid | *Illex illecebrosus* | 10 | Weigh/Measure |
| Loligo squid | *Doryteuthis pealeii* | 9 | Weigh/Measure |
| Winter flounder | *Pseudopleuronectes americanus* | 2 | Weigh/Measure/ Reproductive |
| Windowpane flounder | *Scopthalmus aquosus* | 427 | Weigh/Measure/ Reproductive |
| Yellowtail flounder | *Limanda ferruginea* | 106 | Weigh/Measure/ Reproductive/Disease |
| Sea scallop (retained) | *Placopecten magellanicus* | 216301 | Weigh/Measure/ Reproductive/Disease |

## Appendix B: SELECT Model

This model defines the proportion of an animal of length *l* that is caught in the uncovered dredge out of the total catch from both dredges ($\Phi_c(l)$) as:

$$\Phi_c(l) = \frac{p_c r_c(l)}{p_c r_c(l) + (1 - p_c)}$$

The probability that an animal of length *l* contacts the uncovered dredge is $r_c(l)$ and a split-parameter, $p_c$, describes the relative efficiency of the uncovered dredge. For most species selectivity tends to reflect a logistic function which equates to:

$$\mathrm{r}_c\,(l) = \frac{\exp(a + bl)}{1 + \exp(a + bl)}$$

For some species a Richard curve provided a better fit to the data (Tokai *et al.* 1995):

$$\mathrm{r}_c\,(l) = \left\{\frac{\exp(a + bl)}{1 + \exp\,(a + bl)}\right\}^{\frac{1}{\delta}}$$

When substituted into the SELECT model it yields:

$$\Phi_c\,(l) = \frac{p_c \exp(a + bl)}{(1 - p_c) + \exp\,(a + bl)}$$

Estimates for *a* and *b* (the logistic parameters) and the split-parameter $p_c$ were generated by maximizing the likelihood:

$$L(a, b, pc|data) = \prod_{l=22}^{167} \left(\frac{p_c \exp(a + bl)}{(1 - p_c) + \exp(a + bl)}\right)^{C_{cov}} \left(\frac{p_c \exp(a + bl)}{(1 - p_c) + \exp(a + bl)}\right)^{C_{ctrl}}$$

$C_{cov}$ is the number of length *l* animals in the covered dredge and $C_s$ is number of length *l* animals in uncovered dredge. The selection parameters L50 and the selection range (SR) are calculated with the following equations:

$$L50 = \frac{-a}{b} \text{ and } SR = \frac{2\ln{(3)}}{b}$$

Uncontrollable factors like wind speed, sea state, animal density result in variation in selectivity estimates from tow to tow. To determine if the variation is exceeding the model predictions (overdispersion) a test is necessary when combining tows. This can be done using the replication estimate of between-haul variation (REP) combined-hauls approach (Millar et al. 2004). REP is the Pearson chi-square statistic for model goodness of fit divided by the degrees of freedom, the number of terms in summation minus the number of fitted parameters. The REP provides an estimate of overdispersion and the standard errors of the parameters are multiplied by the square root of REP if the null hypothesis that there is no extra variation is rejected (Millar et al. 2004). This approach has been used to estimate selectivity parameters of commercial sea scallop dredges paired with lined survey dredges (Yochum and DuPaul 2008).

The R-Statistical Program was used to evaluate the data (R Core Team 2015). The "trawlfunction" package was used to estimate the selectivity coefficients and parameters (Millar 2009).

## Appendix C: Distribution of scallops and the main bycatch species

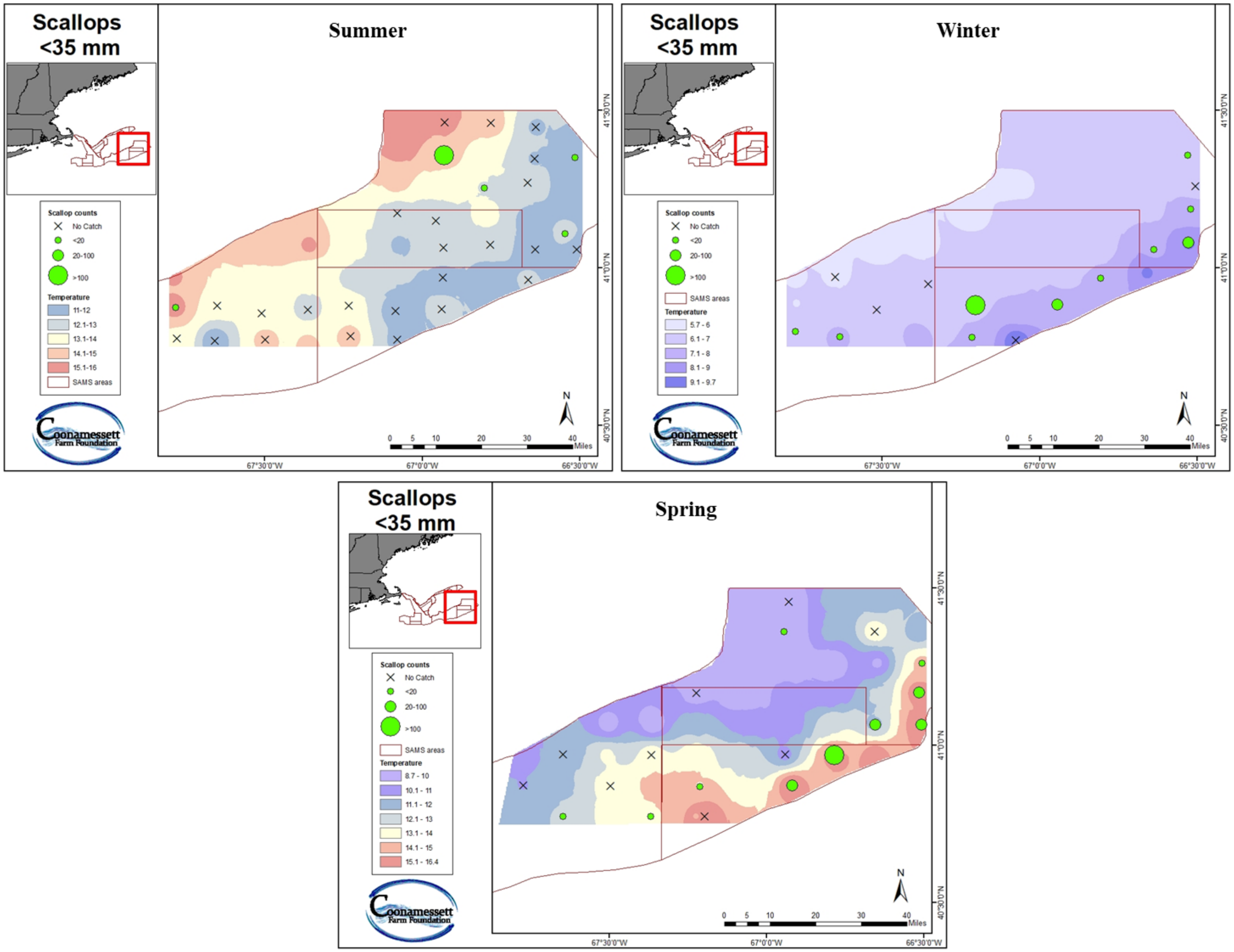
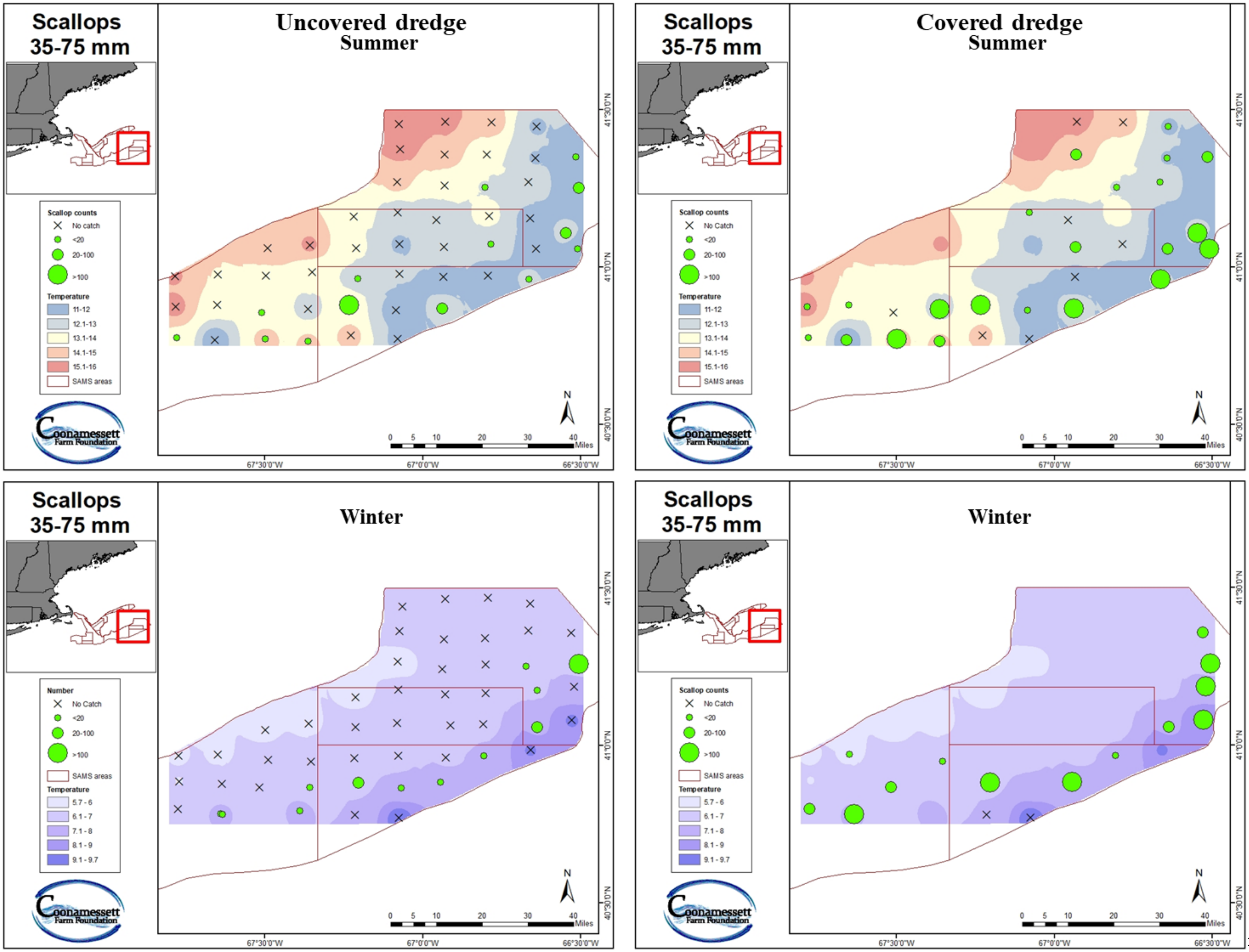



**Figure C1.** Distribution of pre-recruit scallops caught with the cover net during the 2021 seasonal survey on the eastern portion of GB.


Scallops 35-75 mm
Uncovered dredge
Summer
Scallop counts
No catch
<20
20-100
>100
Temperature
11-12
12.1-13
13.1-14
14.1-15
15.1-16
SAMS areas
Coonamessett Farm Foundation
0 5 10 20 30 40 Miles
N
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N
40°30'0"N
Scallops 35-75 mm
Covered dredge
Summer
Scallop counts
No Catch
<20
20-100
>100
Temperature
11-12
12.1-13
13.1-14
14.1-15
15.1-16
SAMS areas
Coonamessett Farm Foundation
Scallops 35-75 mm
Winter
Number
No Catch
<20
20-100
>100
SAMS areas
Temperature
5.7 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 9.7
Coonamessett Farm Foundation
Scallops 35-75 mm
Winter
Scallop counts
No Catch
<20
20-100
>100
SAMS areas
Temperature
5.7 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 9.7
Coonamessett Farm Foundation

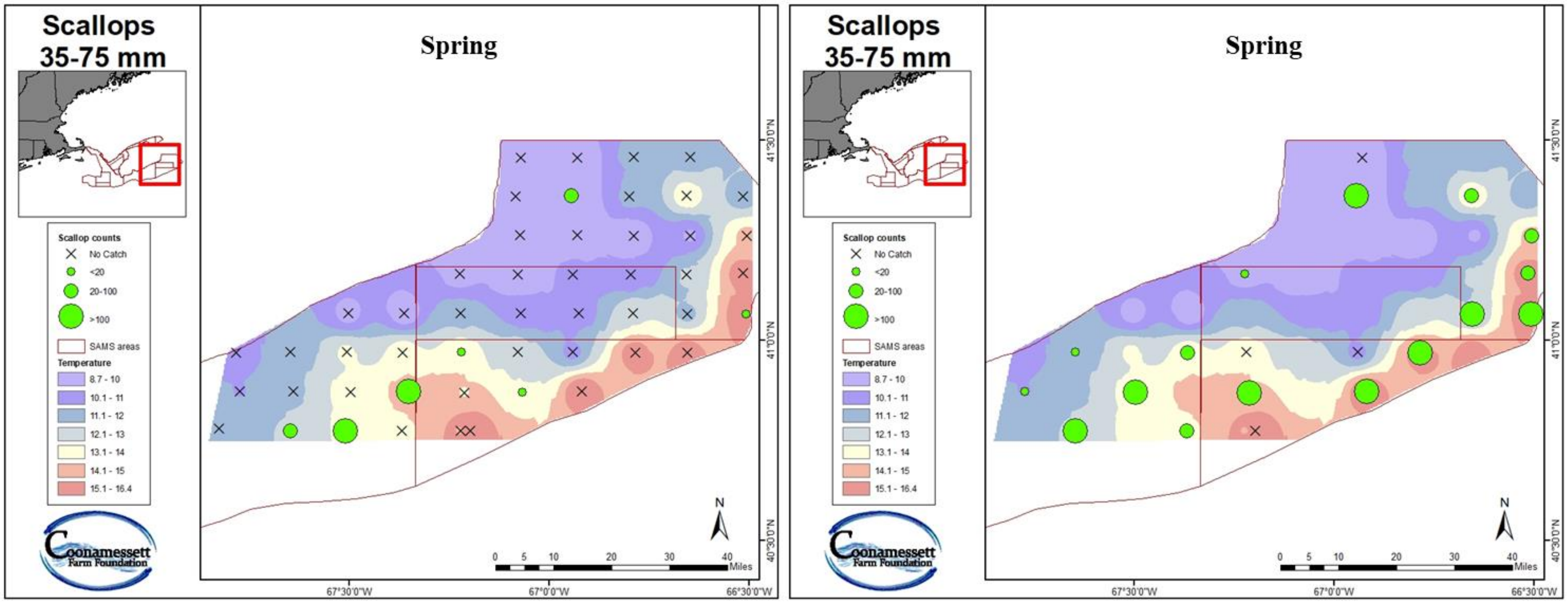
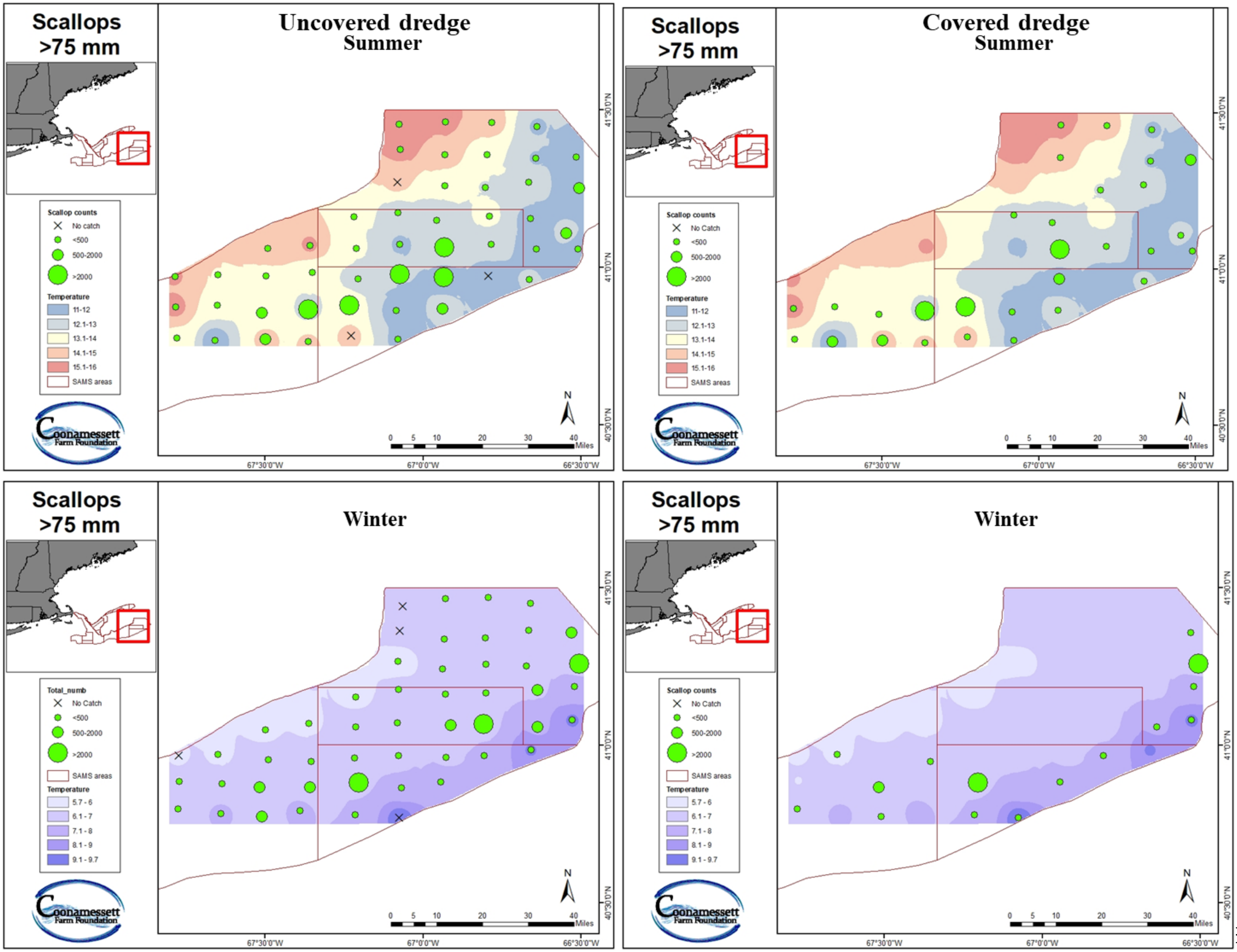



**Figure C2.** Distribution of recruit scallops caught with the uncovered dredge (left maps) and the covered dredge (dredge + cover net; right maps) during the 2021 seasonal survey on the eastern portion of GB.


Scallops >75 mm
Uncovered dredge
Summer
Scallop counts
No catch
<500
500-2000
>2000
Temperature
11-12
12.1-13
13.1-14
14.1-15
15.1-16
SAMS areas
Coonamessett Farm Foundation
Scallops >75 mm
Covered dredge
Summer
Scallop counts
No Catch
<500
500-2000
>2000
Temperature
11-12
12.1-13
13.1-14
14.1-15
15.1-16
SAMS areas
Coonamessett Farm Foundation
Scallops >75 mm
Winter
Total_numb
No Catch
<500
500-2000
>2000
SAMS areas
Temperature
5.7 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 9.7
Coonamessett Farm Foundation
Scallops >75 mm
Winter
Scallop counts
No Catch
<500
500-2000
>2000
SAMS areas
Temperature
5.7 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 9.7
Coonamessett Farm Foundation
N
0 5 10 20 30 40 Miles
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N
40°30'0"N

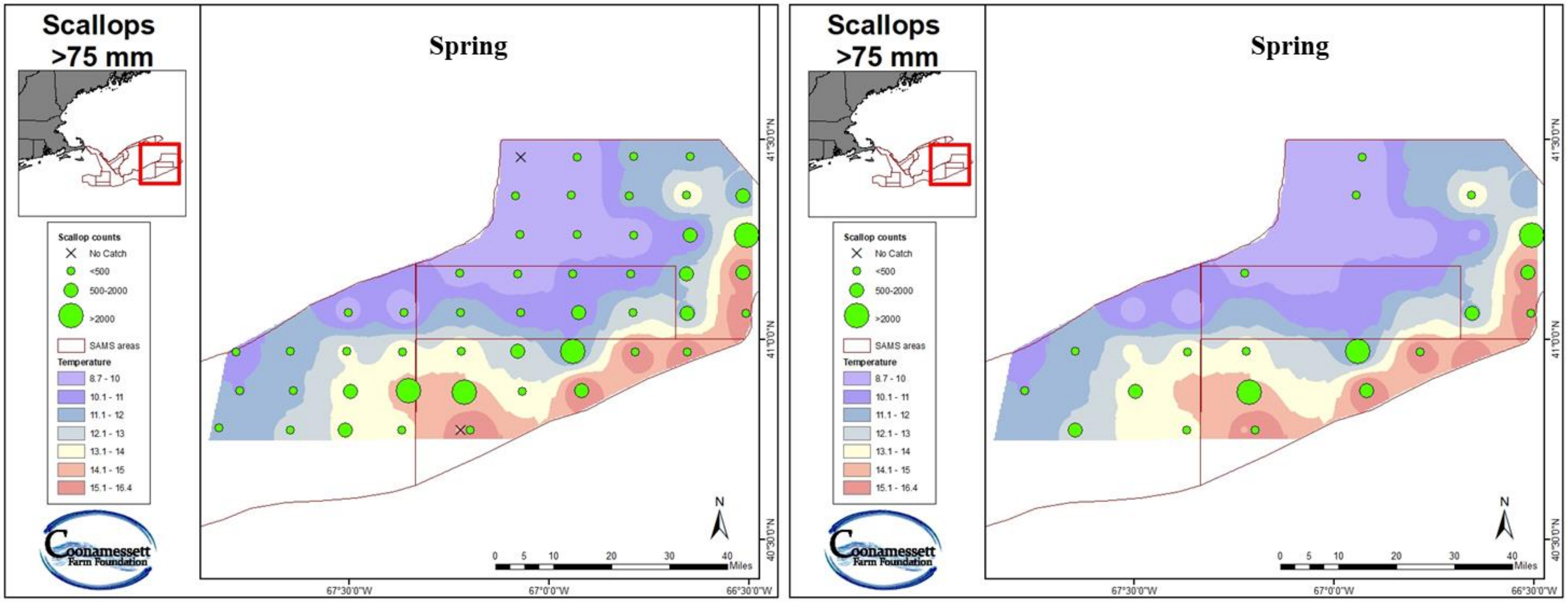



**Figure C3.** Distribution of adult scallops caught with the uncovered dredge (left maps) and the covered dredge (dredge + cover net; right maps) during the 2021 seasonal survey on the eastern portion of GB.

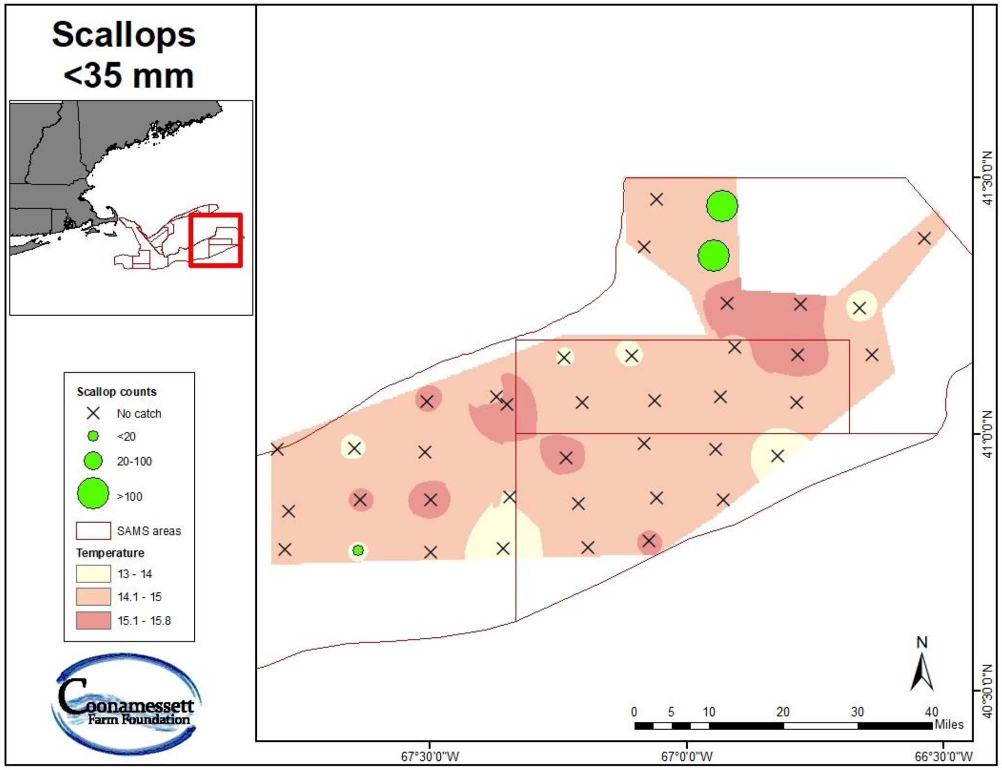



**Figure C4.** Distribution of pre-recruit scallops caught during the calibration trip (Fall) with both dredges combined during the 2021 seasonal survey on the eastern portion of GB.

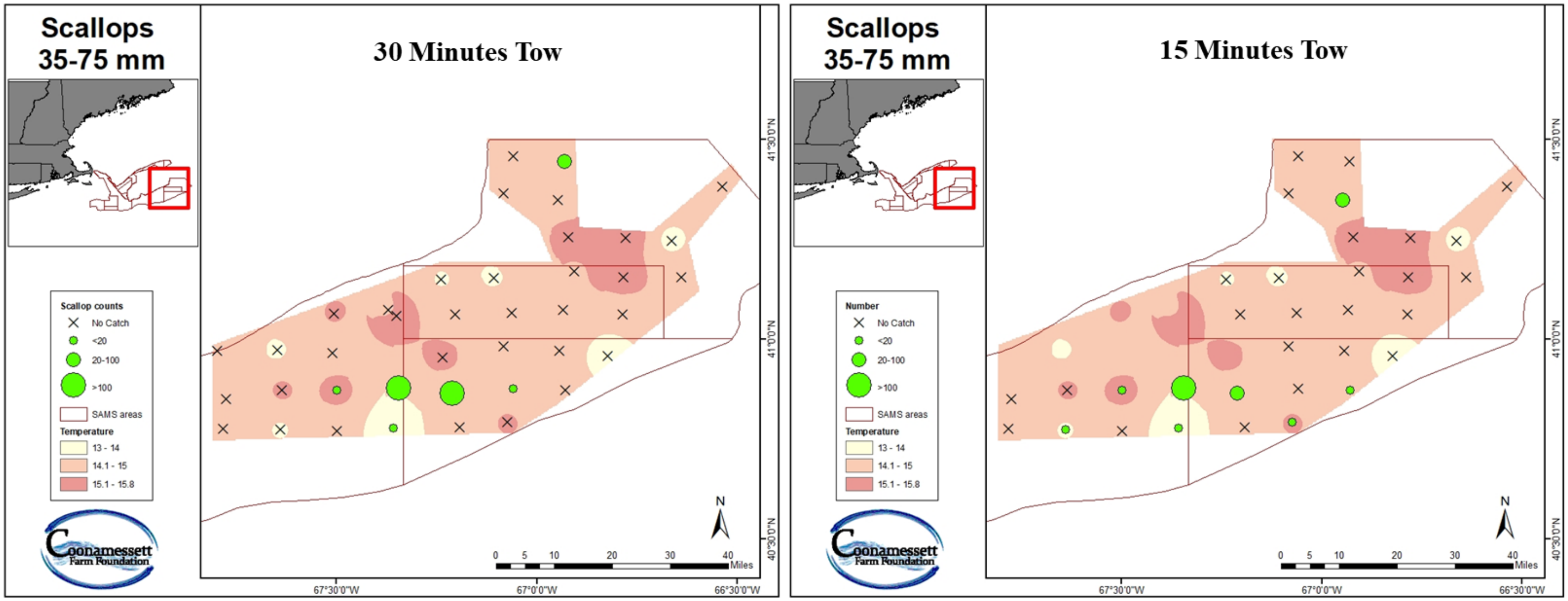
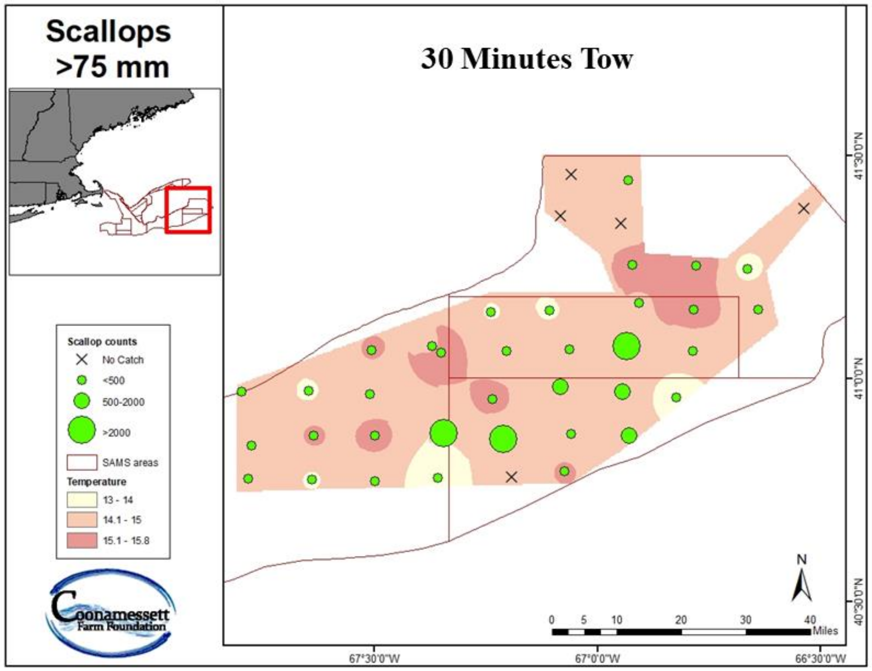



**Figure C5.** Distribution of recruit scallops caught during the calibration trip (Fall) during the 2021 seasonal survey on the eastern portion of GB.



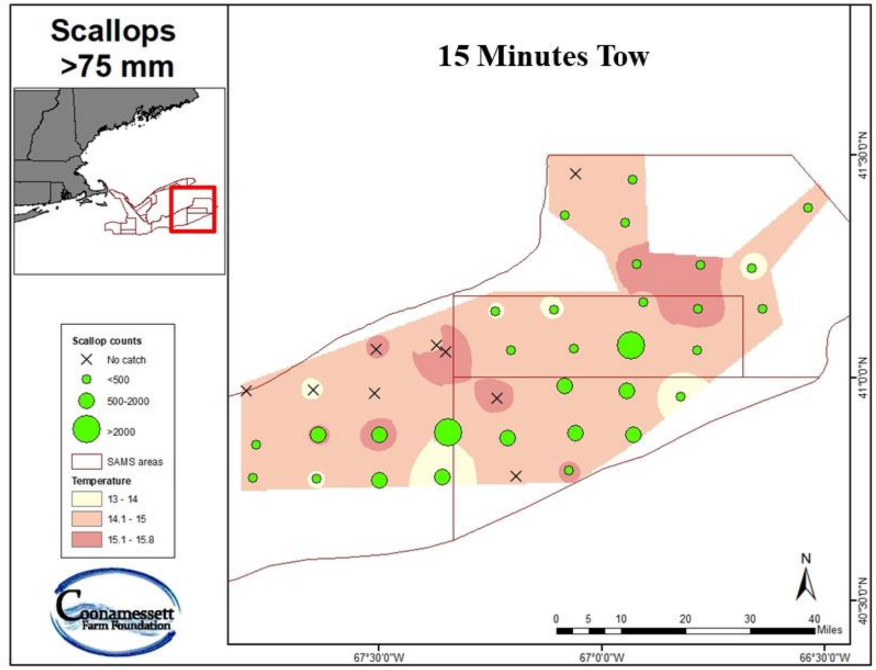




**Figure C6.** Distribution of adult scallops caught during the calibration trip (Fall) during the 2021 seasonal survey on the eastern portion of GB.

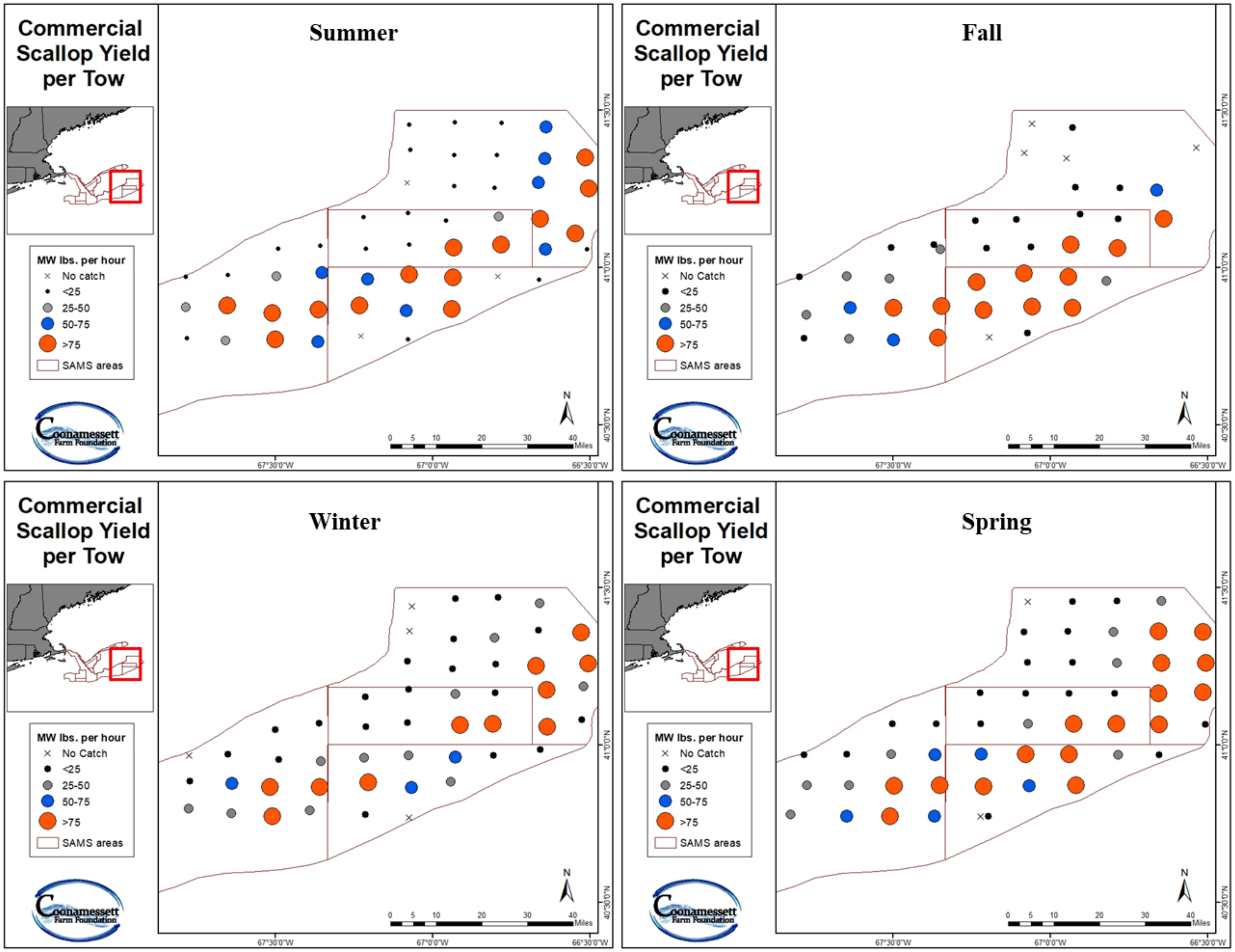



**Figure C7.** Commercial scallop yield (lbs.) per tow during the 2021 seasonal survey project. Tows greater or equal to 50 lbs. per tow is a viable area.

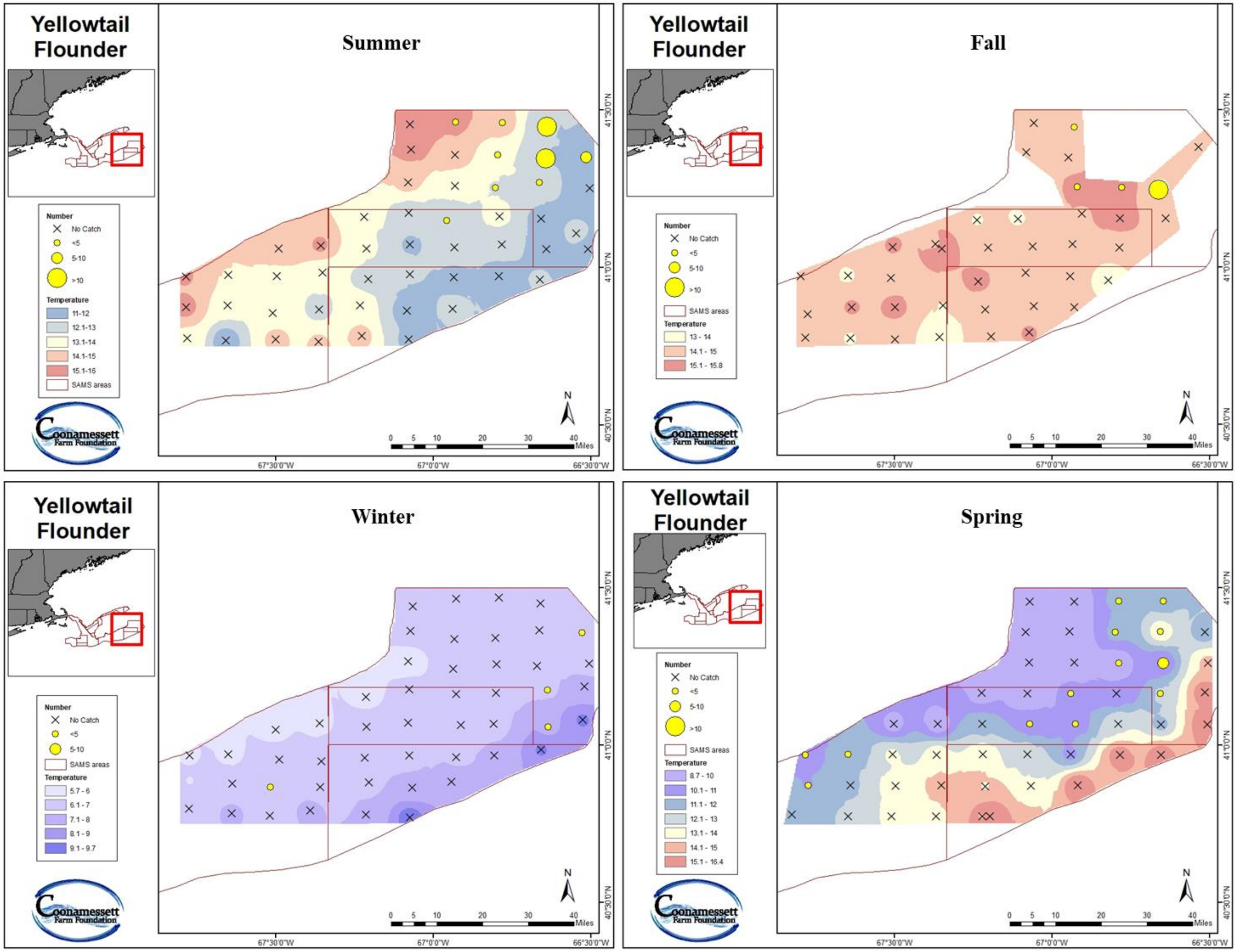



**Figure C8.** Distribution of yellowtail flounder caught during the 2021 seasonal survey on the eastern portion of GB. Data presented for summer, spring and winter combine uncovered and covered dredge, fall data combine 15- and 30-minutes tows.

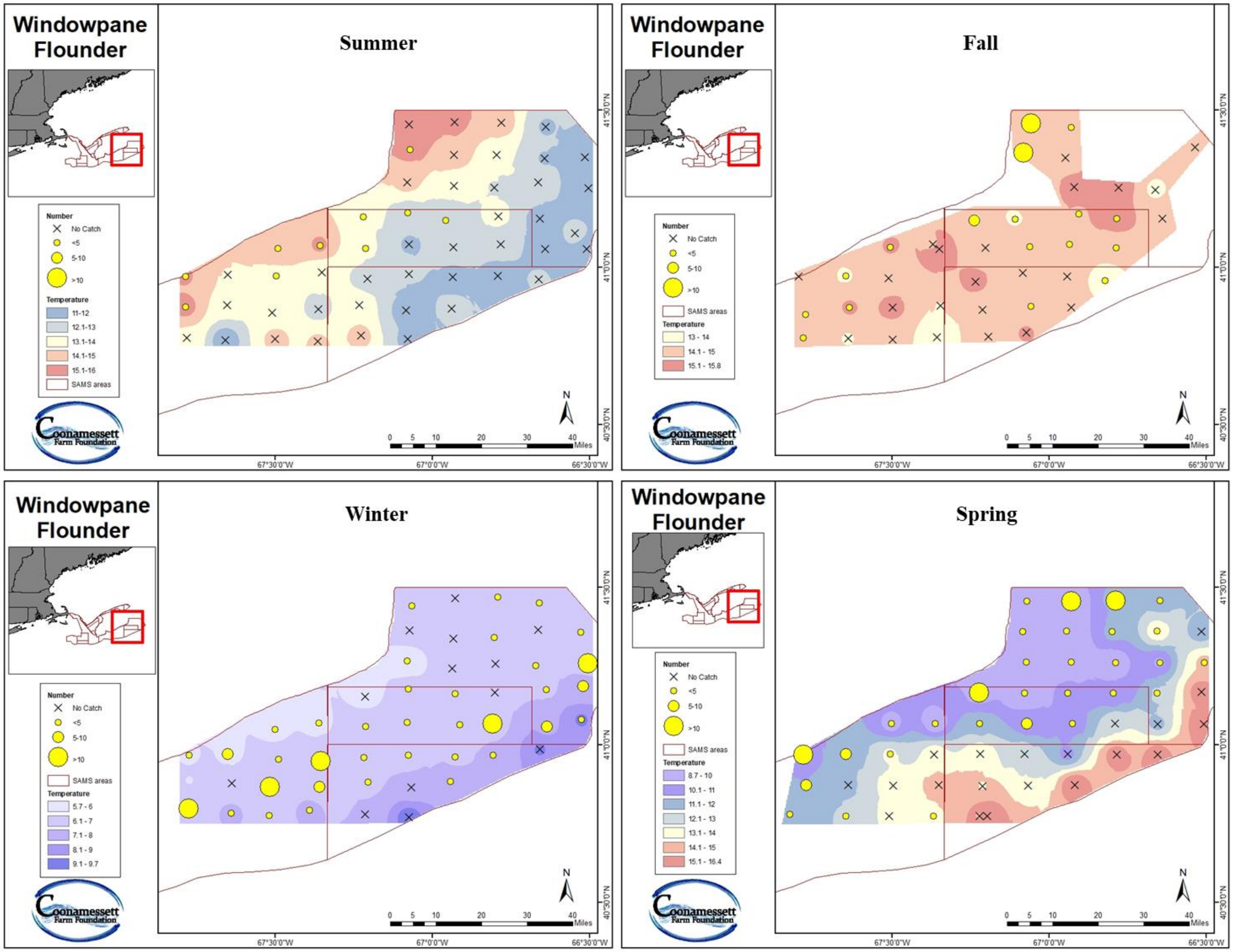



**Figure C9.** Distribution of windowpane flounder caught during the 2021 seasonal survey on the eastern portion of GB. Data presented for summer, spring and winter combine uncovered and covered dredge, fall data combine 15- and 30-minutes tows.

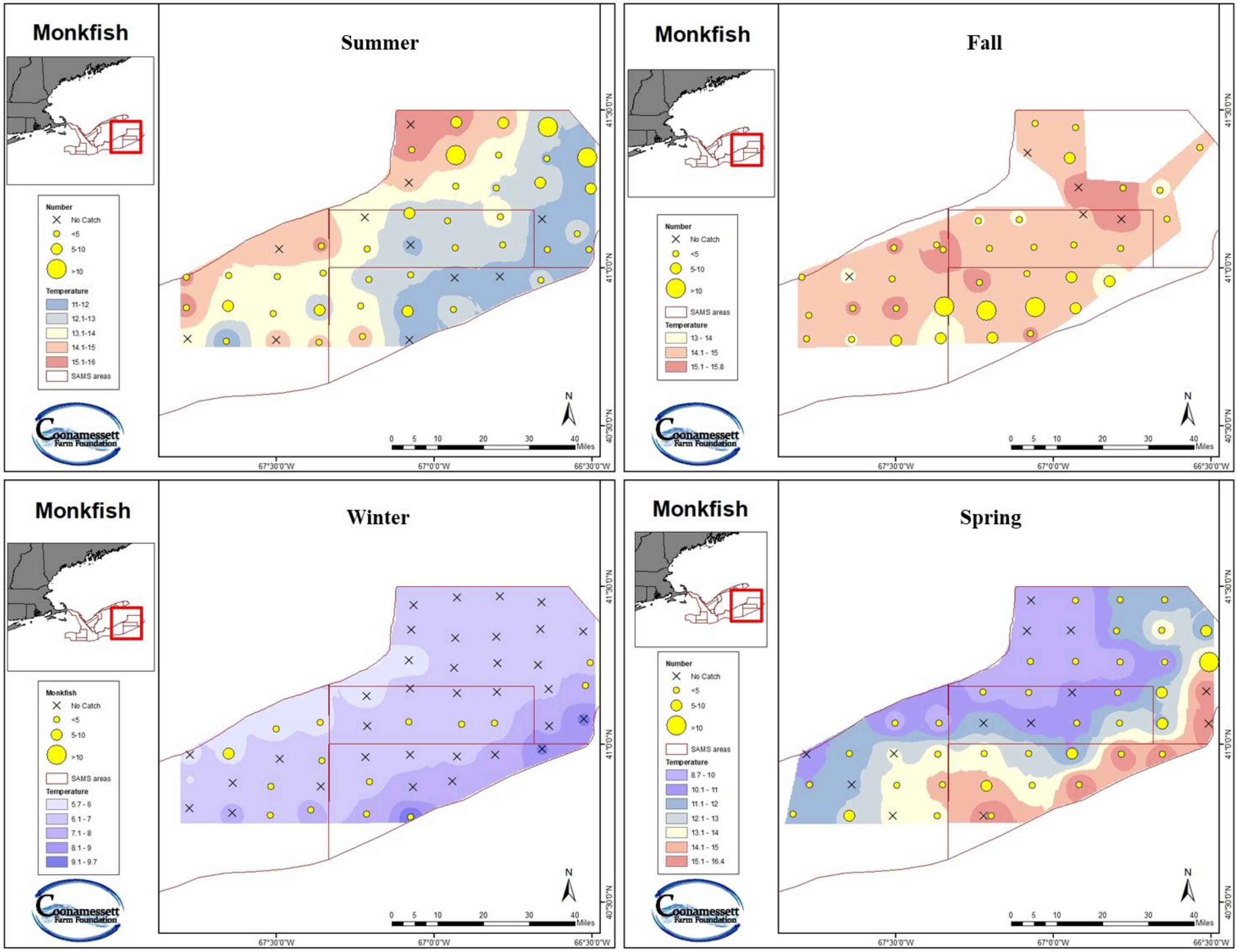



**Figure C10.** Distribution of monkfish caught during the 2021 seasonal survey on the eastern portion of GB. Data presented for summer, spring and winter combine uncovered and covered dredge, fall data combine 15- and 30-minutes tows.

**Appendix D: SHMW analysis**

Model selection based on AICc:

| | K | AICc | Delta_AICc | AICcWt | Cum.Wt | Res.LL |
|---|---|---|---|---|---|---|
| Full | 17 | -3556.40 | 0.00 | 1 | 1 | 1795.27 |
| Color_Lat_Depth_SH_Month | 11 | -3469.21 | 87.20 | 0 | 1 | 1745.63 |
| Color_Depth_SH_Month | 10 | -3457.61 | 98.79 | 0 | 1 | 1738.83 |
| Lat_Depth_SH_Month | 9 | -3445.22 | 111.18 | 0 | 1 | 1731.63 |
| Color_Lat_SH_Month | 10 | -3432.10 | 124.30 | 0 | 1 | 1726.08 |
| Color_SH_Month | 9 | -3418.83 | 137.57 | 0 | 1 | 1718.44 |
| Lat_SH_Month | 8 | -3408.76 | 147.64 | 0 | 1 | 1712.40 |
| SH_Month | 7 | -3395.57 | 160.84 | 0 | 1 | 1704.80 |
| Lat_Depth_Month | 8 | 2614.21 | 6170.61 | 0 | 1 | -1299.09 |
| Color_Lat_Depth_Month | 10 | 2619.90 | 6176.31 | 0 | 1 | -1299.93 |
| Depth_Month | 7 | 2646.12 | 6202.52 | 0 | 1 | -1316.05 |
| Color_Depth_Month | 9 | 2651.81 | 6208.22 | 0 | 1 | -1316.89 |
| Lat_Depth | 5 | 2906.80 | 6463.20 | 0 | 1 | -1448.39 |
| Color_Lat_Depth | 7 | 2913.30 | 6469.70 | 0 | 1 | -1449.64 |
| Depth | 4 | 2936.29 | 6492.70 | 0 | 1 | -1464.14 |
| Color_Depth | 6 | 2942.81 | 6499.21 | 0 | 1 | -1465.39 |
| Lat | 4 | 2974.13 | 6530.53 | 0 | 1 | -1483.06 |
| Color_Lat | 6 | 2980.90 | 6537.31 | 0 | 1 | -1484.44 |
| Color | 5 | 3004.91 | 6561.31 | 0 | 1 | -1497.45 |