Seasonal Survey for the Atlantic Sea Scallop Fishery on the Eastern Part of Georges Bank

Final Report

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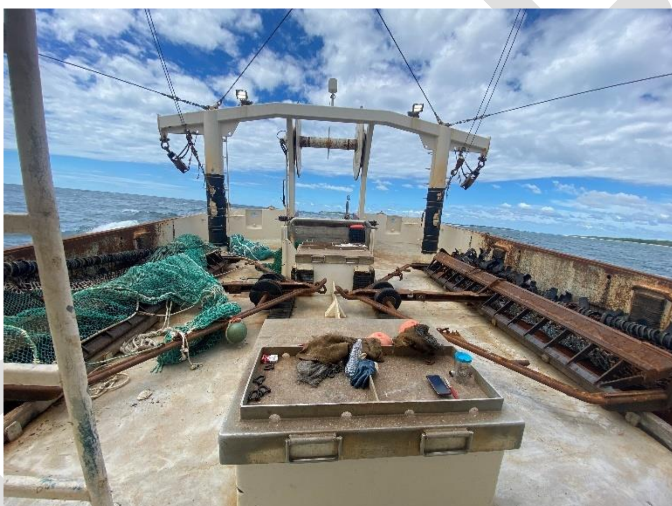

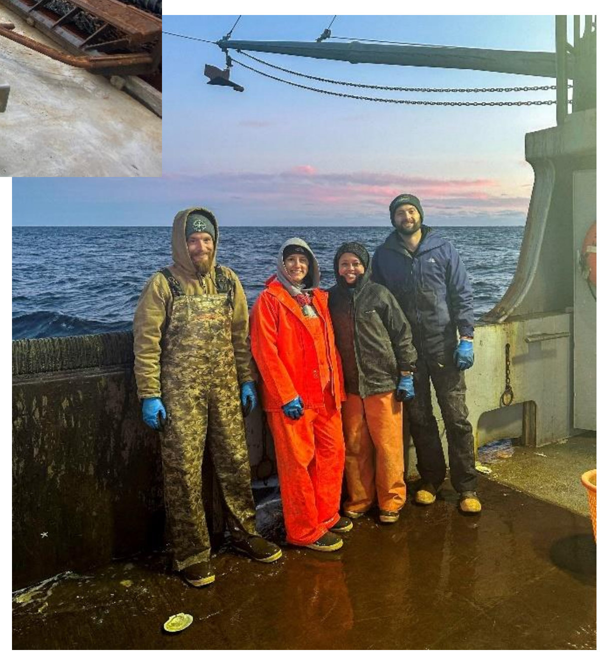

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EXECUTIVE SUMMARY

This report summarizes the data and analysis from the Coonamessett Farm Foundation (CFF) seasonal survey on Georges Bank (GB) for the 2023-2024 funding year. The survey was supported by a 2023 Sea Scallop Research Set-Aside (RSA) award. Conducted since October 2010, the survey has evolved to address emerging management priorities. From 2010 to 2014, sampling focused on Closed Area I (CAI) and Closed Area II (CAII). In 2015, survey stations shifted to the northern portion of GB, covering the northern half of CAII and adjacent open areas to the west. During 2017 and 2018, sampling expanded to the eastern GB region, covering CAII and open areas to the north, west, and south. Since 2019, the survey has concentrated on CAII, the CAII Extension (CAII-Ext), and the Southern Flank (SF).

This year the project goals and objectives were:

1. Evaluate seasonal biomass changes of pre-recruit, recruit, and adult scallops using a dredge cover net in Closed area II (CAII)-Southeast (SE), CAII-Southwest (SW), CAII-Extension (Ext) and Southern Flank (SF) Scallop Area Management Simulator (SAMS) areas.

2. Collect scallop gonad samples to investigate seasonal and spatial variations in scallop spawning within Georges Bank (GB) SAMS areas.

3. Evaluate seasonal changes in scallop health status by macroscopically inspecting nematodes, orange pustules, and shell blisters.

4. Evaluate seasonal sea scallop epibiont abundance and assemblage composition in relation to meat yield.

5. Investigate relationships between predator distribution/abundance and the distribution/abundance of scallops and clappers.

6. Evaluate seasonal changes in the distribution and abundance of key bycatch species in relation to scallop aggregations on GB SAMS areas.

7. Collect gonad samples to more precisely determine when yellowtail and windowpane flounder are spawning within the GB SAMS areas.

At each station, an uncovered standard commercial scallop dredge was towed. Simultaneously, a second dredge equipped with a cover net was deployed at selected stations, provided conditions allowed (i.e., minimal risk of damage from rocks, boulders, or abundant sand dollars). Tow parameters were standardized across all stations: a target speed of 4.8 knots for a duration of 15 minutes. Catch data from both dredges and the cover net were processed onboard. Scallop catches and bycatch species were quantified, including counts, weights, and lengths, with particular attention given to key bycatch species such as yellowtail flounder, windowpane flounder, winter flounder, and lobster. Additionally, scallops were closely examined to evaluate their overall health. Six trips were accomplished over a one-year period.

Seasonal changes in scallop relative biomass: With the addition of the cover net to this long-term project, CFF is aiming to have a more accurate estimation of scallop biomass by season in order to document recruitment events occurring in important scallop fishing grounds. Relative biomass was observed to fluctuate by trip. Recruitment events were observed in several regions of the sampling area. CAII-Ext was the area with higher pre-recruit, recruit and adult scallop relative biomass. In this report, we describe biomass in terms of relative biomass because the cover net needs to be evaluated compared to a survey dredge.

Scallop biology: Scallop reproductive stages were determined through observation of macroscopic differences in the gonads and use of a gonadal mass index (GMI) calculated from shell height and gonad weight. Consistent with last year's findings, a fall spawning period for scallops was observed, which coincides with the historic spawning period for this species. Scallop health was evaluated through visual inspection of meat quality and shell condition. Of the scallops examined, only 1.48% showed poor meat quality and 1.23% had shell blisters. No spatial aggregation of poor-quality scallops was observed. Additionally, the abundance of scallop shell epibionts was quantified by epibiont density and shell coverage. Model analysis revealed that scallop meat weight decreases with increasing *Polydora* sp. density inside the valves and higher mussel density on the upper valve.

Bycatch species distribution, abundance, and biology: During the survey year, species with the highest relative abundance were unclassified skates, red hake, and fourspot flounder. Monkfish was the most abundant commercially important fish species during this survey, with peak catch in December 2023. Model output for this species showed a consistent hot spot towards the southeast of the sampling area. The most abundant flatfish was windowpane flounder, with catches peaking in February 2024. Model outputs identified seasonal hot spots for windowpane flounder: the middle-western portion of the sampling area in fall, the central portion in winter, the western portion in spring, and the northwestern portion in summer. In contrast, catches of yellowtail, winter, and summer flounder were low throughout the survey. Flounder reproductive stages were assigned based on macroscopic changes in the gonads and the gonadosomatic index (GSI) based on fish body and gonad weights. Two spawning periods, in fall and spring, were observed for windowpane flounder. The spawning period for yellowtail flounder was observed in spring.

Cover net selectivity analysis: The scallop catch-at-length data for each tow, where the two dredges were towed simultaneously, 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 + cover net. The models indicated that both dredges had similar relative efficiency (split-p=0.54). A retention curve for sea scallops was also generated using the cover SELECT model. The predicted L50 for the covered dredge ranged from 95.24 – 111.94 mm using this method.

The CFF seasonal survey continues to provide a wealth of data essential for addressing a wide range of ecosystem-related issues on GB. The data collected through this project has been instrumental in evaluating populations of several commercially important fish species, providing fisheries managers with critical insights to determine Annual Catch Limits (ACLs) and develop Accountability Measures (AMs); these measures have helped to optimize scallop harvests while minimizing bycatch. As new issues arise, the seasonal survey has consistently adapted to meet stakeholders needs. The seasonal survey can continue to address the following specific stakeholder concerns:

- Monitoring seasonal distribution and demographics of scallop aggregations on GB
- Monitoring distribution and extent of poor-quality scallop meats on GB
- Monitoring seasonal spawning variations in scallop and key flatfish species
- Monitoring seasonal distribution of commercially important bycatch species
- Monitoring seasonal and spatial distribution of scallop predators (i.e. moon snails, whelks, sea stars, cancer s*p*. crabs)
- Monitoring seasonal environmental parameters that influence scallop health, scallop predator's abundance and bycatch distribution.

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INTRODUCTION

Atlantic sea scallops (*Placopecten magellanicus*) have historically been ubiquitous on Georges Bank and an abundant fishery resource providing 35.7 million pounds of wild-caught seafood to consumers in 2022 with an ex-vessel value of over US $343 million (NOAA 2024). The fishery is one of the most successfully managed and lucrative wild-caught in the northeastern United States. 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 finfish bycatch, in part due to a lack of knowledge of local life history trends of each fish species. This bycatch issue is of 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.

The CFF RSA funded seasonal survey is a collaborative research program which accomplishes large-scale data collection on commercially important target and bycatch species on Georges Bank. With the collective efforts of scallop vessels, captains, and crew, the research program has had success in tracking seasonal bycatch trends since the project's inception in 2010. Once-a-year surveys do not capture fine-scale trends in scallop and bycatch species abundance nor physiological parameters. Further, these metrics are impacted by local environmental conditions that can be highly variable over space and time. By conducting research trips several times over a one-year period, sampling can address management issues quickly and effectively. In addition to the goals regarding bycatch species' trends, scallop biomass, meat yield, and spawning habits, the research aims to establish greater understanding by addressing a new objective each year.

Sea scallops on Georges Bank inhabit dynamic benthic environments where water flow stresses can exceed the critical levels of sediment stability by two to nine times. These forces, coupled with natural processes, can cause sediment turnover approximately every two weeks (Harris *et al*. 2012, Stokesbury *et al*. 2016). Maintaining a height of three to four centimeters above the seafloor, sea scallops offer a stable substrate for sedentary and sessile organisms to feed, grow, and reproduce in an otherwise unstable habitat (Barnes 1974). By providing this surface, sea scallop shells support diverse species, fostering the development of an epibiont community. This year, the project aims to explore the interactions between sea scallops and their epibiont communities, with a particular focus on how these communities may influence scallop meat yield. This goal could yield valuable insights into optimal sea scallop habitats and guide efforts to enhance their populations.

By incorporating the cover net to one of the dredges (described below), CFF has been able to collect valuable data on a range of topics including pre-recruit and recruit scallop bed locations and numbers, scallop predators such as moon snails (*Euspira heros*) and sea stars (*Asterias* and *Astropecten* species), and other small organisms that normally easily escape through the dredge. Understanding spatiotemporal variability in the presence of scallop predators, clappers, and live scallops in an area can lend itself to a greater understanding of how natural mortality trends affect the fishery. Annual project reports update maps of species distributions, spawning patterns, scallop meat quality and yields, and bottom temperature. This detailed, fine-scale data provides essential information for many species, addressing a pressing need to inform and adapt to future challenges in fishery management.

OBJECTIVES

1. Evaluate seasonal biomass changes of pre-recruit, recruit, and adult scallops using a dredge cover net in Closed area II, CAII-Extension (Ext) and Southern Flank (SF) Scallop Area Management Simulator (SAMS) areas.

2. Collect scallop gonad samples to investigate seasonal and spatial variations in scallop spawning within Georges Bank (GB) SAMS areas.

3. Evaluate seasonal changes in scallop health status by macroscopically inspecting for nematodes, orange pustules, and shell blisters.

4. Evaluate seasonal sea scallop epibiont abundance and assemblage composition in relation to meat yield.

5. Investigate relationships between predator distribution/abundance and the distribution/abundance of scallops and clappers.

6. Evaluate seasonal changes in the distribution and abundance of key bycatch species in relation to scallop aggregations on GB SAMS areas.

7. Collect gonad samples to more precisely determine when yellowtail and windowpane flounder are spawning within the GB SAMS areas.

GENERAL SAMPLING METHODS

Sampling design

Six research trips were conducted from August 2023 to June 2024 on eastern GB, covering SAMS areas where scallop biomass is high and bycatch of yellowtail and windowpane flounder has historically been high (**Table 1**, **Figure 1**). Fixed stations were located inside of the CAII (CAII southeast, CAII southwest), CAII-Ext, and SF SAMS areas. The start position for each of the 49 stations was randomly selected prior to each trip using four points 0.25 miles away from the fixed-station position.

Table 1. Trip, dates and vessels used for the 2023 bycatch survey.

Year	Trip Month	Trip Dates	Vessel
2023	August	9th – 14th	F/V Regulus
	October	23rd – 28th	F/V Beiningen
	December	Nov. 30th – Dec. 5th	F/V Atlantic
2024	February	16th – 21st	F/V Endeavor
	April	7th – 12th	F/V Concordia
	June	4th – 9th	F/V Vanquish

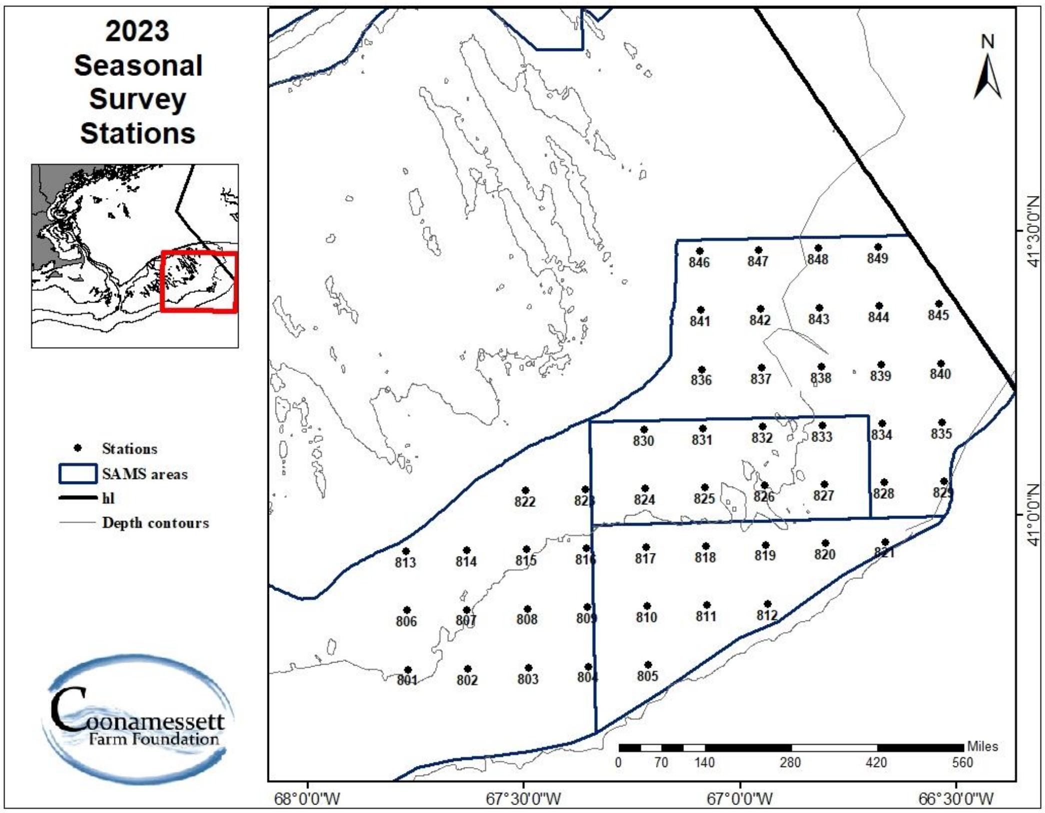


Figure 1. Survey station locations sampled for the 2023 seasonal survey on the eastern portion of GB. Stations are separated by approximately 6 nautical miles.

A covered and an uncovered 15-foot wide (4.57 m) CFF Turtle Deflector Dredge (TDD) were deployed each trip. The covered dredge employs a 45-mm mesh net over the topside of the dredge that extends from the skirt to the clubstick (**Figure 2**) and retains animals that pass through the dredge while towing at commercially representative speeds. The uncovered dredge was towed at every station while the covered dredge was towed at select stations to avoid areas with large aggregations of sand dollars or reported rocks and boulders. At stations where both dredges were deployed, they were towed simultaneously. The dredges were towed at a target speed of 4.8 knots for 15 minutes at all stations during each trip. Vessel position, speed, and heading were recorded every 15 seconds using a GPS enabled ruggedized tablet. 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. Picture of the cover net during the 2023 August seasonal survey trip.

Catch was processed in three discrete categories: the uncovered dredge, the covered dredge, and the cover net. Catch processing was identical. For each tow/gear, the catch was separated by species and weighed using a Marel 1100-series motion compensated scale. A 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. A maximum of ten fish were randomly selected from the uncovered dredge to evaluate the gonadosomatic index (GSI) of windowpane, winter (*Pseudopleuronectes americanus*), and yellowtail flounder. Whole-body weight and gonad weight were collected for these individuals.

The total scallop catch was quantified in bushels (bu=35.2 liters) for 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. For the selected basket from the uncovered dredge all scallops were shucked and weighed. In addition, at each station, 30 scallops (or fewer if the total catch < 30 scallops) from that selected basket were randomly set aside to collect biological data including 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 scallop health. Meat quality was assessed on a qualitative color scale (**Figure 3**), and presence of nematodes and orange pustules was noted. The presence of shell blisters, found on the inside of the scallop shells, was recorded.

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.

A subset of 15 scallops, selected from the 30 shells designated for the biological data collection, were photographed with a Sony digital camera with a ZEISS Vario Sonnar T* lens to document the epibionts present on the outside and inside of their shells. The camera was mounted on a stand at a fixed height and paired with two LED lights and a checkered calibration board for consistent image quality and scale (**Figure 4**). For each scallop, the interior and exterior surfaces of both the upper and lower valves were photographed, resulting in four images per individual. Each scallop was assigned a unique identifier linked to its station and biological data, ensuring accurate integration of the photographic and biological datasets.

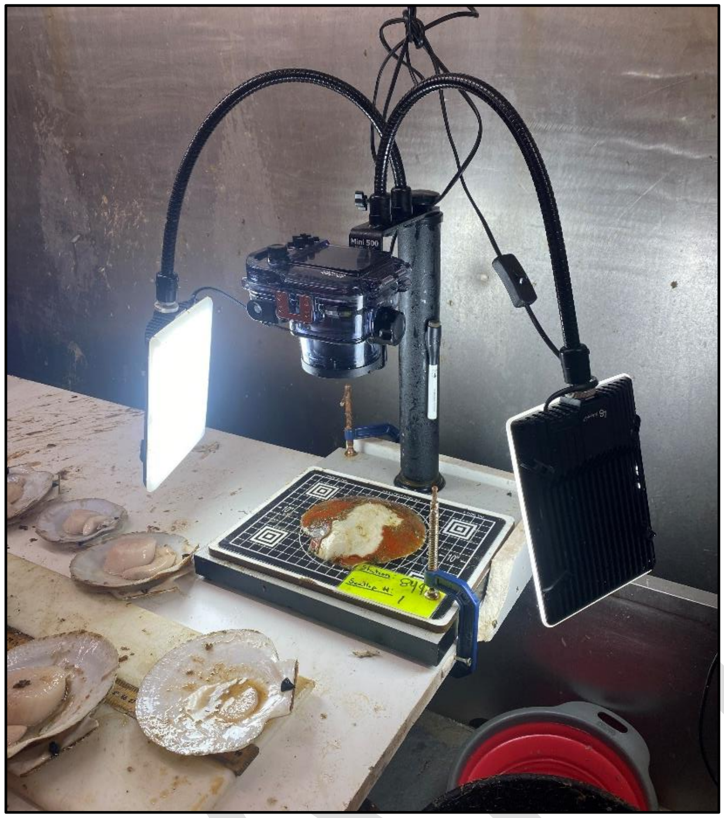


Figure 4. The camera station used to photograph scallop shells at sea for image annotation and subsequent epibiont analysis.

Data for all lobsters caught were collected by gear type and recorded by individual. Carapace length, weight, sex, presence of eggs, shell hardness and incidence of shell disease was determined. In addition to demographic data, the extent of damage caused by the catch process was 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	

Data analysis

Scallop relative biomass by size: Scallop biomass per tow by size class was estimated based on the shell heights of the measured bushel and the number of bushels per tow. Shell heights were converted to meat weights with the GB-specific equation used in recent scallop stock assessments (NEFSC 2018). In order to calculate swept area for each station from August 2023 to June 2024, the dredge width (km) and the tow distance (km) were multiplied. In each trip, the start and end position of each tow was recorded, and the following Haversine equation was used to calculate tow distance:

$$Tow\ length = Arcosine\ \Big(Cosine\big(Radians(90 - Start\ latitude)\big)\ x\ Cosine\big(Radians(90 - End\ latitude)\big) + Sine\big(Radians(90 - Start\ latitude)\big) x Sine\big(Radians\ (90 - End\ latitude)\big) x Cosine\big(Radians\ (End\ longitude - Start\ longitude)\big)\Big)\ x\ 6731$$

Catchability coefficients (q) of 0.4, 0.65, and 1 were used to calculate area-swept total biomass (kg/tow) estimates by month. The relative biomass of scallops (kg/km^2) for each station was calculated as:

$$scallop\ biomass\ = \frac{SB(kg)}{swept\ area(km2)} x A x \frac{1}{q}$$

To calculate the total biomass (mt) of pre-recruit, recruit, and adult scallops by month and SAMS area, the average scallop biomass (SB) per km^2 for all tows in each SAMS area was multiplied by the area (A) for each SAMS area. These calculations were done for the uncovered dredge with all stations included and for the covered dredge + cover net for the stations that were sampled using this gear.

Scallop reproductive cycle: The reproductive stages of sea scallops were plotted by trip to examine seasonal changes and estimate spawning periods. Reproductive cycles were described based on macroscopic observations and gonadal mass index (GMI). 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 (SH, Bonardelli and Himmelman 1995).

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 GLMMs in the R package "glmmTMB" (Brooks *et al*. 2017) with cruise included as random effect.

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 using the total meat yield from the bushel that was shucked and weighed. 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).

Flatfish gonadosomatic index (GSI): The reproductive stages of winter, windowpane and yellowtail flounders were plotted by trip to examine seasonal changes and estimate spawning periods for each species. Reproductive stages were described based solely on macroscopic observations. Female flounders GSI 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 (Bougis 1952).

Shell height-meat weight (SHMW) relationship: Scallop meat weight was modeled using generalized linear mixed models with a gamma distribution and a log link using the function "pqlmer" in R package "r2glmm" (Jaeger *et al.* 2017). 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:

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

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, and C is meat color. Interaction terms between depth and month were also included. Parameter estimates and the AIC summary table are shown in **Appendix B**.

Predicted meat weights were estimated for white, brown and gray scallops at four stations, which were selected to include locations at different depths and areas, using the model selected using AIC values.

Estimating epibiont abundance and diversity: Scallop shell epibionts were annotated using photoQuad, a custom image processing software (Trygonis and Sini 2012). The images were first calibrated using the checkered image background and photoQuad's calibration tool (1 box segment = 1.2 cm). After outlining the scallop as the active quadrat area, the total shell and each annotation object's area were calculated in square centimeters by the software. Annotation categories included barnacles, annelids (*Polydora* sp.), blue mussels (*Mytilus edulis*), unknown sponge species, encrusting bryozoans, stalked hydrozoans, common jingle shells (*Anomia* species), slipper snails (*Crepidula* species), and limpet species.

Epibiont community structure was summarized for each month by annotation category on the outside and inside of each valve of the shell. The impact of epibiont communities on scallop meat weight was analyzed using generalized additive mixed models. Scallop shell epibionts were quantified using parameters that summarized epibiont communities on the outside of the upper and lower valves and inside each scallop including:

- Proportion of valve surface covered by epibionts
- Shannon diversity index
- Species with the maximum abundance
- Density of *Polydora* sp. (number per cm^2)
- Density of bryozoans (number per cm^2)
- Density of hydrozoans (number per cm^2)
- Density of *Anomia* sp. (number per cm^2)
- Density of mussels (number per cm^2)
- Density of live and dead barnacles (number per cm^2)
- Density of barnacle scars (number per cm^2)
- Density of macroalgae (number per cm^2)

Other annotated species or groups were not included in the models because the total numbers were low (<100 total on all scallops). Prior to running models, outliers were removed from the dataset if the abundance of one of the epibiont species was greater than four standard deviations above the mean abundance for that species.

Scallop meat weight was modeled using a gamma distribution in the R package "mgcv" (generalized additive model function "gam" with family=Gamma, link=log, and thin plate splines; Wood 2011). The models included the epibiont factors listed above as well as shell height, month, latitude, depth, and meat color. Survey station was included as a random effect. The final model was selected based on AIC scores (Akaike 1973), with model fit assessed based on the deviance explained by and histograms of observed-predicted values from each final model. See details in **Appendix C.**

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). A GLMM with a gamma distribution (log link in R package "r2glmm") was developed to compare the relative efficiency of the control dredge catch to the covered dredge. See details in **Appendix D**.

Distribution model: Seasonal trends of bycatch species distribution were analyzed with Generalized Additive mixed models (GAMMs; Wood 2006, 2011). Catches per tow were expressed in terms of catch per unit effort (CPUE) as the ratio of the number of fishes caught in the control dredge and the time of the tow in minutes. CPUE were scaled accordingly to account for variation around the target tow time of 15 minutes. Though depth and temperature are expected to correlate with catch rates and were recorded throughout the survey period, these environmental covariates were not including in the model presented in this report. Instead, CPUE was modeled as a function of geographic location and day of the year (Julian day) as both these covariates are correlated with longitude and Julian day, respectively. Previous spatial-temporal models of windowpane CPUE used month to describe temporal trends (Winton *et al.* 2017); however, Julian day provided a better fit to these data. Additionally, these data were collected from a one-year survey period and Julian day is more representative of when the data were collected relative to dates that mark seasonal transitions within a year i.e. the winter solstice or spring equinox. Since a different vessel was utilized for each survey trip, a random effect for vessel was incorporated into the model to account for variability due to differences in vessel handling, engine power, etc. All models were fit using the R package "mgcv" (Wood 2006, 2011).

RESULTS BY OBJECTIVE

Objective 1: Evaluate seasonal biomass changes of pre-recruit, recruit, and adult scallops using a dredge cover net in CAII-SE, CAII-SW, CAII-Ext and SF SAMS areas.

For the both dredges, CAII-Ext showed greater relative biomass than the other areas for prerecruit, recruit and adult scallops, except for recruits caught with the covered dredge which showed greater relative biomass in the SF (**Table 3, 4 and 5**). For pre-recruits, covered dredge catches showed higher relative biomass estimation relative to the uncovered dredge catches (**Table 3**). The months with higher scallop pre-recruit relative biomass were April for CAII and CAII-Ext, and December for SF (**Table 3**). For recruits, covered dredge showed the highest scallop relative biomass estimates only for SF (**Table 4**). For CAII and CAII-Ext uncovered dredge had the peak of relative biomass (**Table 4**). The months with the higher recruit biomass were October for CAII, February for CAII-Ext, and June for SF (**Table 4**). For adult scallops, high relative biomass was observed with the uncovered dredge, except for SF (**Table 5**). The months with higher adult relative biomass were February for CAII, and April for CAII-Ext and SF (**Table 5**).

Table 3. Total scallop pre-recruit (< 35 mm) relative biomass estimates for each SAMS areas by gear type by month in eastern GB. Since the cover net has not been calibrated, three catchability coefficients (q) were used to calculate area-swept total biomass estimates by month.

Year	Month	Covered dredge			Uncovered dredge
		q=1 (mt)	q=0.65 (mt)	q=0.4 (mt)	q=0.65 (mt)
		CAII			
2023	October	0	0	0	0.05
2024	February	0.11	0.17	0.28	0.09
	April	0.50	0.77	1.25	0.21
	June	0	0	0	0.59
		CAII-Ext			
2023	August	0	0	0.00	2.06
	October	0.28	0.43	0.70	0.00
2024	February	0.00	0.00	0.00	11.57
	April	27.61	42.47	69.02	0.00
	June	1.72	2.64	4.29	9.96
		SF			
2023	August	0.00	0.00	0.00	0.27
	October	0.72	1.10	1.79	0.00
	December	10.21	15.70	25.52	0.00

	February	4.46	6.87	11.16	0.46
2024	April	0.87	1.33	2.17	0.00
	June	4.50	6.93	11.26	0.64

Table 4. Total scallop recruit (35-75 mm) relative biomass estimates for each SAMS areas by gear type by month in eastern GB.

Year	Month	Covered dredge			Uncovered dredge
		q=1 (mt)	q=0.65 (mt)	q=0.4 (mt)	q=0.65 (mt)
CAII					
	August	16.6	25.6	41.6	40.0
2023	October	1.0	1.6	2.6	542.2
	December	93.3	143.6	233.3	6.6
	February	86.7	133.4	216.8	31.7
2024	April	53.2	81.9	133.1	0.0
	June	48.0	73.9	120.1	10.1
CAII-Ext					
	August	374.5	576.1	936.2	320.2
2023	October	218.6	336.3	546.4	70.9
	December	0.0	0.0	0.0	194.4
	February	301.3	463.5	753.2	12768.0
2024	April	135.5	208.5	338.8	23.4
	June	478.0	735.4	1195.0	301.2
SF					
	August	273.8	421.2	684.4	19.6
2023	October	342.7	527.2	856.7	12.0
	December	488.2	751.1	1220.5	12.9
	February	680.1	1046.3	1700.3	27.1
2024	April	801.3	1232.8	2003.2	6.5
	June	909.9	1399.8	2274.7	49.6

Table 5. Total adult scallop (>75 mm) relative biomass estimates for each SAMS areas by gear type by month in eastern GB.

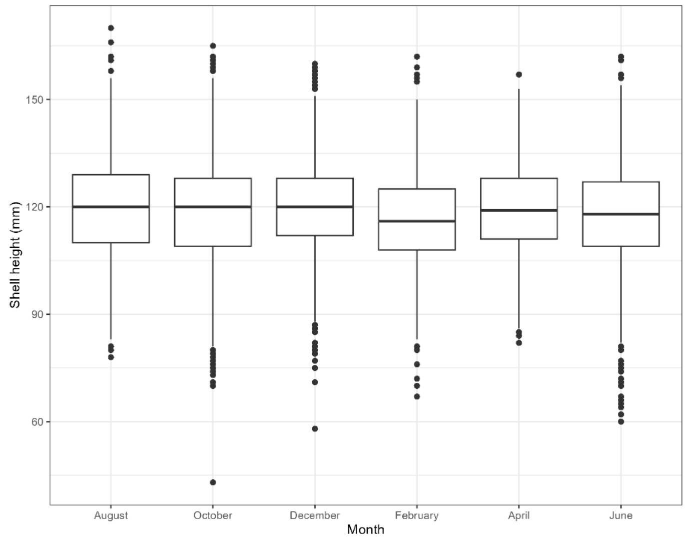
Year	Month	Covered dredge			Uncovered dredge
		q=1 (mt)	q=0.65 (mt)	q=0.4 (mt)	q=0.65 (mt)
CAII					
2023	August	5859.9	9015.3	14649.8	8349.2
	October	436.9	672.1	1092.2	13907.1
	December	7383.0	11358.5	18457.5	7115.9
2024	February	5825.6	8962.5	14564.1	14267.1
	April	5895.3	9069.6	14738.1	9280.8

	June	2750.6	4231.7	6876.5	6881.6
CAII-Ext					
2023	August	11562.8	17788.9	28907.0	12031.0
	October	4304.5	6622.3	10761.3	10458.4
	December	0.0	0.0	0.0	16785.1
2024	February	8477.3	13042.0	21193.2	116898.6
	April	19785.7	30439.5	49464.2	1675749.9
	June	7938.7	12213.4	19846.8	9207.1
SF					
	August	1656.9	2549.1	4142.4	1137.9
2023	October	2850.7	4385.7	7126.8	2785.4
	December	2961.2	4555.6	7402.9	1013.6
	February	2931.4	4509.8	7328.4	1179.2
2024	April	3210.8	4939.7	8027.0	1320.9
	June	2289.9	3523.0	5724.9	1247.6

Mapping the distributions of the different scallop sizes sampled reveals that, for the most part, their distributions and abundances are spatially heterogeneous (**Appendix E**). **Figures E1** to **E3** show scallop catches with the uncovered and covered dredges. Pre-recruit scallop catches were observed similar on both dredges; April had the highest pre-recruit catches, while October had the lowest catch (**Figure E1**). Recruit scallop concentrations were observed spread out in the sampling area, but with higher catches towards the south (**Figure E2**). Adult scallops were distributed throughout entire sampling area, but with higher concentrations in the southeast (**Figure E3**).

<u>Shell height-meat weight analysis</u>**:** A total of 6,619 scallops were sampled at 49 stations located across the eastern portion of GB. Scallop shell heights ranged from 43 mm to 170 mm and meat weights varied from 2 g to 96 g. Temporal distributions of the collected shell heights and meat weights are shown in **Figure 5.** Parameter estimates and the (AIC) selection table are shown in **Appendix B**.

a)



b)

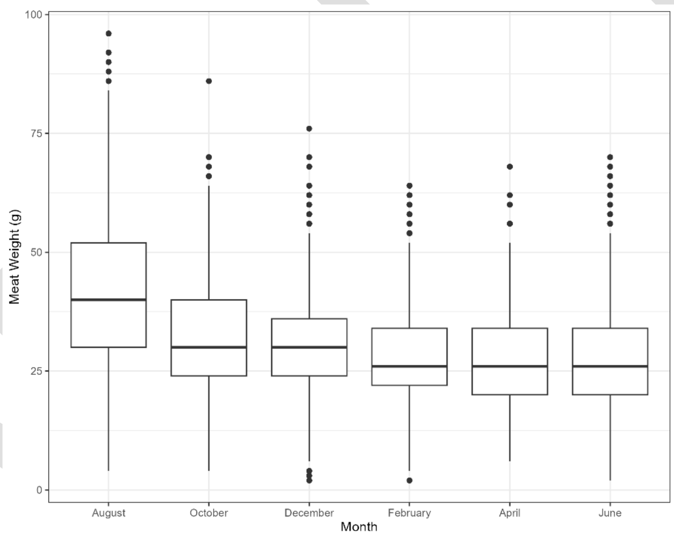


Figure 5. Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples from eastern GB. The markers inside the boxes show the median values for each month. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers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

Predicted meat weights for white, brown and gray scallop meats were analyzed by depth (**Figure 6**). Temporal trends in predicted meat weights for 120-mm scallops highlights the reduced meat weights of brown scallop meats relative to white scallop meats, and the different seasonal trends in meat weights for stations located at different depths (**Figure 6**). The peak in meat weight was observed in August for all depths. The shallower 38-ftm (69 m) station, located in CAII-south, showed the highest meat weight for most months relative to the other depths, and the deeper 50-ftm (91 m) station, located also in CAII-south, showed the lowest meat weight for all months relative to other depths (**Figure 6**).

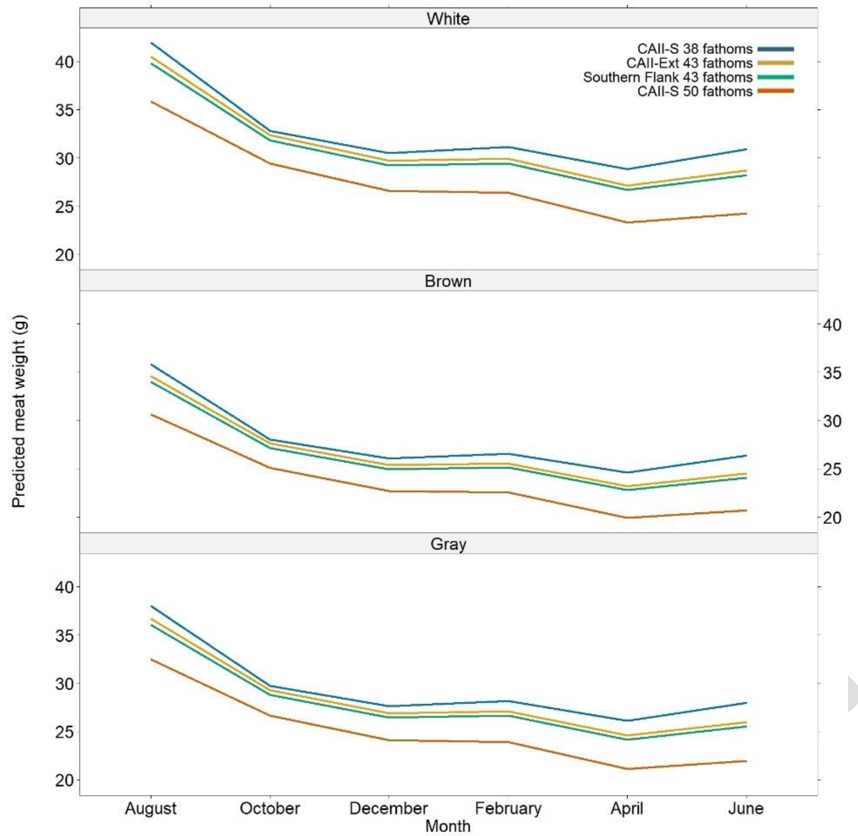


Figure 6. Estimated SHMW curves for white, brown and gray scallop meats from stations at different depths.

<u>Objective 2: Collect scallop gonad samples to investigate seasonal and spatial variations in scallop spawning</u>

Shell height-meat weight analysis was completed for a total of 6,619 scallops during the 2023 project period. Combining GMI with macroscopic observations of the gonad stages, the results suggested a possible fall scallop spawning period, which coincides with previous years in the area (Thompson *et al*. 2014, Garcia *et al.* 2018, Garcia *et al*. 2019, **Figure 7**).

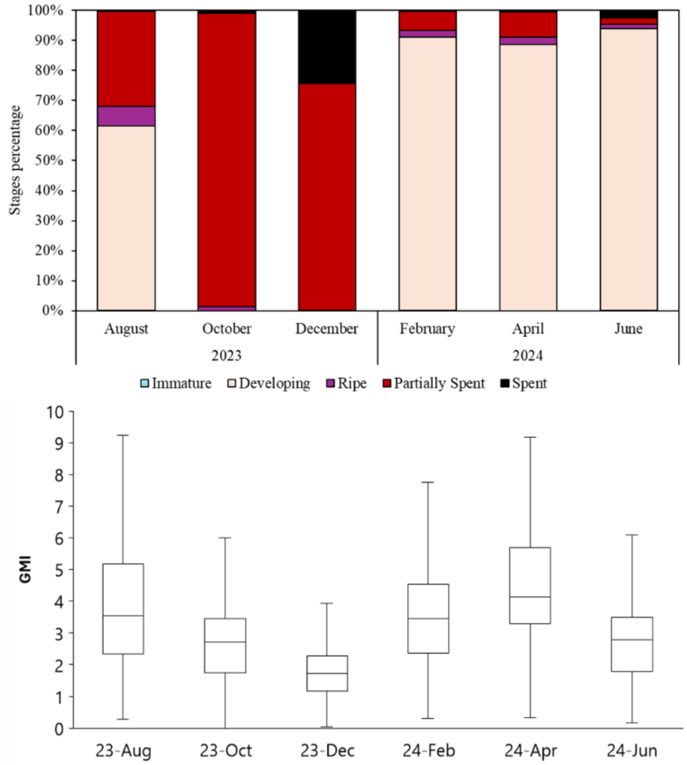


Figure 7. Seasonal changes in the GMI for female scallops for each month during the 2023 seasonal survey on the eastern portion of GB. Boxes end at the first and third quartiles of the distribution of GMI values, with the whiskers extending to the minimum and maximum values.

Objective 3: Evaluate seasonal changes in scallop health status by macroscopically inspecting for nematodes, orange pustules, and shell blisters

During the SHMW analysis, researchers recorded scallop shell and meat health status. Only 1.48% of scallops showed poor meat quality and 1.23% shell blisters (**Table 6**). The few poor-quality scallops observed were broadly distributed throughout the sampling area each month; during the December trip, there were no signs of poor-quality meats, only shell blisters were observed (**Figure 8**).

Table 6. Number of scallops analyzed by health condition and month.

Year	Month	Meat Color			Stringy meat	Shell blisters
		White	Brown	Gray		
2023	August	1216	3	0	10	24
	October	962	2	1	12	15
	December	1074	0	0	0	19
2024	February	1127	5	2	26	8
	April	1094	3	1	15	10
	June	1143	5	0	13	6

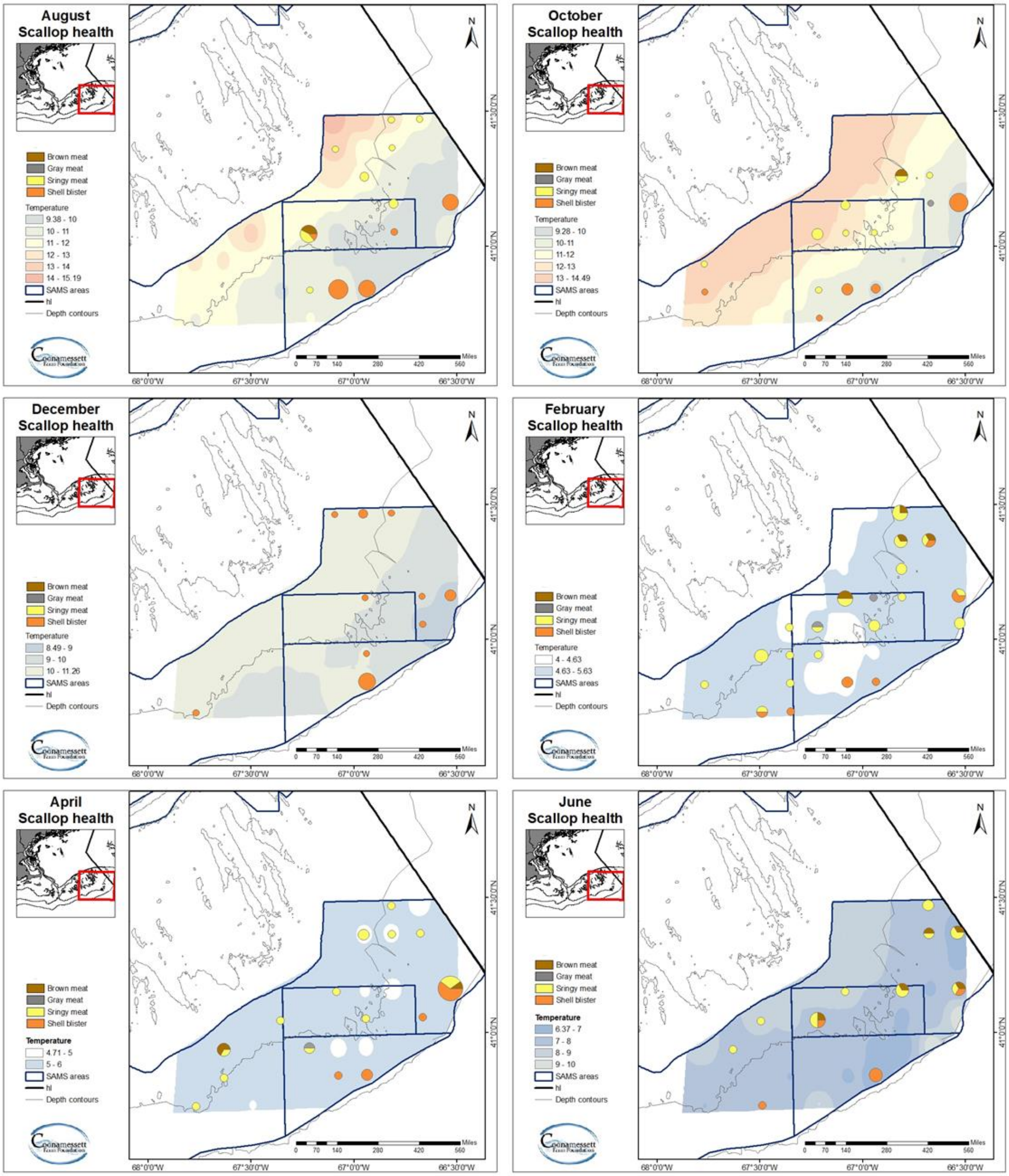


Figure 8. Stations with poor quality scallop meats over observed bottom temperature. Bubble size represent total number of poor-quality meats and colors represent health status. Temperatures (°C) were interpolated using the inverse distance weighted (IDW) method and illustrated with cooler and warmer colors associated with respective temperatures.

Objective 4: Evaluate seasonal sea scallop epibiont abundance and assemblage composition in relation to meat yield.

For this analysis, epibiont coverage and counts were recorded on both sides of each scallop valve. Epibionts were most abundant on the upper valve and least abundant on the lower inside valve (**Table 7**). Consistent with epibiont density patterns, the upper valve had the highest epibiont coverage, predominantly barnacles, while the lower inside valve had the lowest coverage, with the annelid *Polydora* sp. being the most prevalent epibiont on this valve (**Table 8, Table 9**).

The top model for estimating scallop meat weight as a function of typical SHMW equation parameters and epibiont summary statistics included shell height, depth, survey month, *Polydora* sp. density inside the valves and blue mussel density on the upper valve. Model summaries, parameter estimates, and the AIC summary table are shown in **Appendix C**. The results suggest that scallop meat weight decreases with higher *Polydora* sp. density inside the valves and higher mussel densities on the upper valve (**Figure 9**). Other epibiont species did not appear to have significant impacts on scallop meat weights.

Table 7. Epibiont numbers by valve and month during the 2023 seasonal survey on GB.

Year	Month	Upper valve	Upper inside valve	Lower valve	Lower inside valve
2023	August	6986	1935	1583	974
	October	955	424	300	154
	December	877	242	330	189
2024	February	1122	433	202	169
	April	479	297	139	75
	June	2899	660	468	255
Total		17627	4350	3501	2035

Table 8. Epibiont coverage in cm^2 for the upper valve, by species and month during the 2023 seasonal survey on GB.

Year	Month	Upper valve												Upper inside valve
		Barnacle	Barnacle scar	Bryozoans	Dead Barnacle	Hydrozoans	Jingle shells	Limpet shells	Mussels	*Polydora* sp.	Slipper shells	Sponge	Macroalgae	*Polydora* sp.
2023	August	356.6	489.2	0.0	125.6	13.1	48.3	0.7	26.7	173.6	14.4	41.4	125.9	395.5
	October	892.8	97.2	5.2	214.8	10.9	9.8	0.0	11.3	57.5	0.6	3.9	4.9	294.1
	December	239.7	215.9	0.0	99.2	10.9	12.0	4.4	32.2	114.3	16.0	6.2	16.6	87.3
2024	February	167.0	152.0	0.4	20.8	4.3	23.0	0.5	48.2	204.2	0.0	0.7	6.9	231.8
	April	26.2	177.5	0.0	41.8	11.6	4.7	0.0	0.0	130.5	0.0	78.4	0.0	93.4
	June	105.0	98.9	1.1	2.2	1.3	0.0	0.0	0.0	129.7	124.3	0.0	26.1	112.8
Total		1787.3	1230.8	6.8	504.4	52.0	97.8	5.6	118.4	809.8	155.3	130.6	180.5	1214.9

Table 9. Epibiont coverage in cm^2 for the lower valve, by species and month during the 2023 seasonal survey on GB.

Lower valve												
Year	**Month**	**Barnacle**	**Barnacle scar**	**Bryozoans**	**Dead Barnacle**	**Hydrozoans**	**Jingle shells**	**Limpet shells**	**Mussels**	**Polydora**	**Slipper shells**	**Unknow macroalgae**
2023	August	1.7	3.0	0.1	2.3	4.2	100.3	36.2	7.2	122.3	65.1	32.0
	October	11.7	5.9	0.0	0.2	5.5	28.1	0.0	0.0	93.2	1.3	0.0
	December	0.0	1.0	5.2	0.0	0.2	31.5	8.8	27.1	95.5	15.4	0.0
2024	February	0.2	0.0	0.0	0.0	0.2	9.2	6.7	0.0	49.3	2.2	1.9
	April	0.0	0.0	0.0	0.3	0.2	10.5	0.0	0.0	46.6	5.8	0.0
	June	0.5	1.1	0.1	0.0	0.0	8.3	5.1	0.0	28.6	0.0	0.0
Total		14.0	11.0	5.4	2.7	10.3	187.8	56.8	34.3	435.5	89.8	33.9

Lower inside valve							
Year	**Month**	**Barnacle scar**	**Hydrozoans**	**Jingle shells**	**Limpet shells**	***Polydora* sp.**	**Slipper shells**
2023	August	0.0	0.0	0.6	0.9	368.4	2.2
	October	0.0	0.0	0.0	0.0	132.8	0.0
	December	0.0	0.7	0.0	0.0	166.0	0.0
2024	February	0.0	0.0	0.0	0.0	47.3	0.0
	April	0.2	0.0	0.0	0.0	26.3	0.0
	June	0.0	0.0	0.0	0.0	21.8	0.0
Total		0.2	0.7	0.6	0.9	762.4	2.2

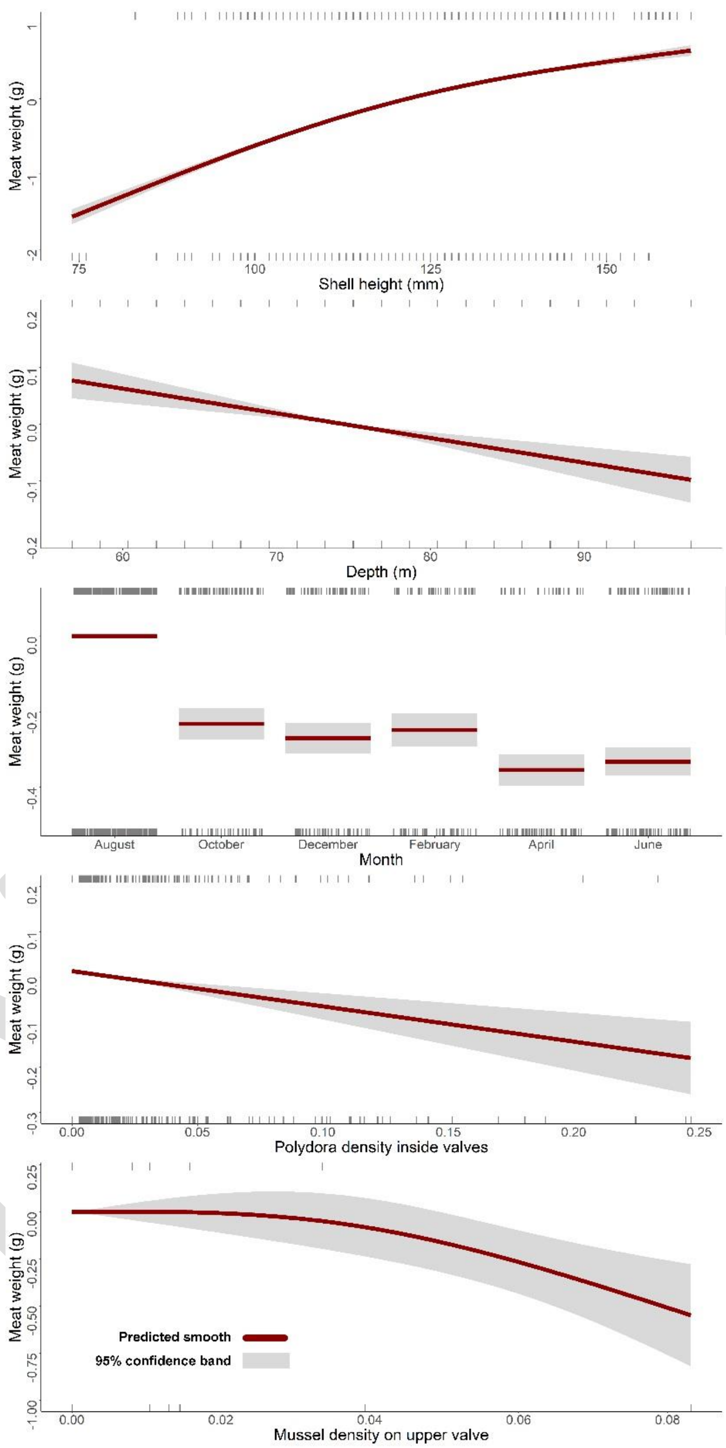


Figure 9. Predicted smoothed relationships between scallop meat weight and shell height, bottom depth, month, *Polydora* sp. density inside the scallop valves, and mussel density on the upper valve. The red lines represent model predictions, and the shaded areas indicate 95% confidence intervals.

<u>Objective 5: Investigate relationships between predator distribution/abundance and the distribution/abundance of scallops and clappers</u>

For this analysis, data from each dredge was separately analyzed. Crabs, moon snails, whelks, and sea stars were weighed and counted by dredge and cover net (**Table 10**). Predators were more abundant with the cover net in comparison with the uncovered dredge, except for Jonah crabs (**Table 10** and **11**). Predators exhibited broad seasonal distributions across the sampling area, with Astropecten sp. and Jonah crabs showing slightly higher concentrations towards the southeastern region (**Figure E7 – E12**).

For the uncovered dredge, the top model for estimating M as a function of predator abundance and environmental parameters included depth:temperature + depth + moonsnail + whelks + jonah crabs + rock crabs (*Cancer irroratus*) + *Asterias* sp. + *Astropecten* sp. + sea stars. The model results indicated that the interaction between depth and temperature (estimate = 0.007, $p < 0.001$), the presence of rock crabs (estimate = 0.085, $p < 0.001$), and *Asterias* sp. (estimate = 0.021, $p = 0.039$) had a positive and statistically significant effect on scallop natural mortality. Whelks also showed a marginally significant positive effect (estimate = 0.115, $p = 0.082$). Conversely, the presence of Jonah crabs had a significant but negative effect on scallop natural mortality (estimate = -0.041, $p = 0.034$; **Table 12a**). For the covered dredge, the top model included depth:temperature + moonsnail + whelks + jonah crabs + rock crabs + *Asterias* sp. + Astropecten sp. + sea stars. The model results indicated that the interaction between depth and temperature (estimate = 0.011, $p < 0.001$), and the presence of moonsnail (estimate = 0.015, $p < 0.001$) had a positive and statistically significant effect on scallop natural mortality (**Table 12b)**.

Table 10. Number and weight of scallop predators caught with the uncovered dredge during the 2023 seasonal survey on GB.

Year	Month	Jonah crab No.	Jonah crab (kg)	Rock crab No.	Rock crab (kg)	Moonsnail No.	Moonsnail (kg)	Whelk No.	Whelk (kg)	*Astropecten* sp. No.	*Astropecten* sp. (kg)	*Asterias* sp. No.	*Asterias* sp. (kg)	Other sea stars No.	Other sea stars (kg)
2023	August	320	69.75	48	4.97	50	7.74	6	0.61	759	3.89	196	19.38	17	0.32
	October	55	16.63	33	2.14	0	0	1	0.1	1629	7.75	82	10.84	24	0.4
	December	91	7.6	96	2.86	17	2.91	1	0.04	1363	8.71	14	2.79	15	0.5
2024	February	21	7.36	15	0.96	29	3.75	8	0.76	122	0.52	238	37.9	11	0.46
	April	18	12.8	4	0.23	197	20.46	25	1.62	0	0	115	11.84	12	0.1
	June	62	20.22	23	1.17	239	27.84	5	0.28	40	0.18	273	36.98	0	0

Table 11. Number and weight of scallop predators caught with the covered dredge+cover net during the 2023 seasonal survey on GB.

Year	Month	Jonah crab No.	Jonah crab (kg)	Rock crab No.	Rock crab (kg)	Moonsnail No.	Moonsnail (kg)	Whelk No.	Whelk (kg)	*Astropecten* sp. No.	*Astropecten* sp. (kg)	*Asterias* sp. No.	*Asterias* sp. (kg)	Other sea stars No.	Other sea stars (kg)
2023	August	263	42.62	944	14.58	380	26.48	17	1.33	1220	33.35	425	13.26	2342	7.75
	October	7	1.71	93	2.97	3	0.18	19	1.35	37	0.23	362	10.48	3797	11.34
	December	21	4.3	8	0.29	167	11	21	1.47	17	0.11	180	5.17	1727	6.04
2024	February	10	1.26	44	1.87	422	41.23	128	8.91	976	19.16	807	26.61	3602	13.55
	April	13	3.08	221	5.29	947	62.44	126	8.68	2387	138.84	938	9.6	1785	5.14
	June	17	5.21	92	2.52	559	45.83	118	8.1	306	45.74	430	23.58	239	8.74

Table 12. Summary statistics for the relation of M, predator abundance and environmental parameters, data collected from the **a)** uncovered dredge and **b)** covered dredge.

a)

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-6.9366732	1.3808573	-5.023	5.08E-07	***
Depth	0.0114146	0.0312558	0.365	0.715	
Moonsnails	0.0031625	0.0059081	0.535	0.5925	
Whelks	0.1146662	0.0659482	1.739	0.0821	.
Jonah crabs	-0.0408868	0.019282	-2.12	0.034	*
Rock crabs	0.0848083	0.02047	4.143	3.43E-05	***
Asterias sp.	0.0213294	0.0103181	2.067	0.0387	*
Astropecten sp.	0.0005846	0.0013189	0.443	0.6576	
Sea stars	-0.0835948	0.0885189	-0.944	0.345	
Depth:Temperature	0.0065214	0.0010137	6.433	1.25E-10	***

b)

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-8.95168	1.120092	-7.992	1.33E-15	***
Moonsnails	0.014198	0.004637	3.062	0.0022	**
Whelks	0.02209	0.027279	0.81	0.4181	
Jonah crabs	-0.00989	0.016464	-0.601	0.548	
Rock crabs	-0.00436	0.003958	-1.101	0.271	
Asterias sp.	0.00198	0.004198	0.472	0.6372	
Astropecten sp.	-0.00133	0.001397	-0.955	0.3394	
Sea stars	-0.00023	0.000515	-0.446	0.6558	
Depth:Temperature	0.011851	0.002381	4.977	6.45E-07	***

Objective 6: Evaluate seasonal changes in the distribution and abundance of key bycatch species in relation to scallop aggregations on Georges Bank

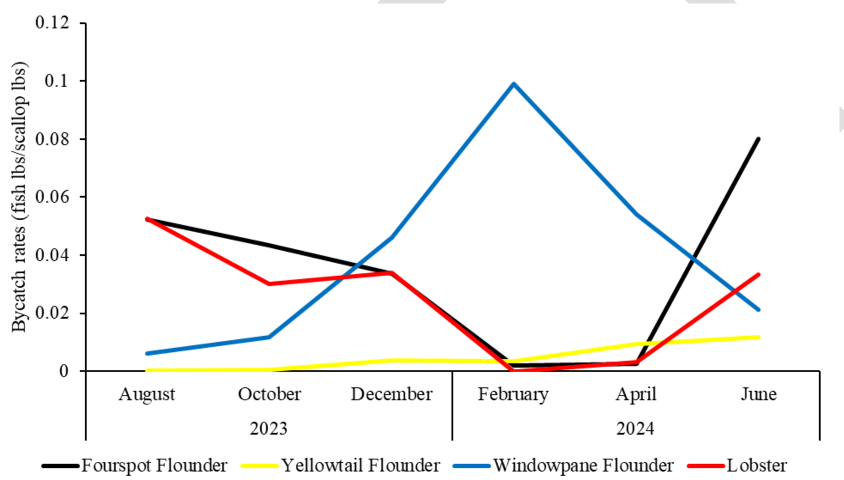
Total catches by survey month of the relevant bycatch species from the uncovered dredge are displayed in **Table 13**. The seasonal catch rates of important bycatch species were calculated in relation to the scallop catch (i.e. lbs. of fish/lbs. of scallops). The overall bycatch rates for all the commercially important species sampled during this project were low (< 1 lbs. of fish/lb. of scallops). Bycatch rates were never greater than 0.01 lbs. of fish/lb. of scallops for yellowtail flounder, and for windowpane and fourspot flounder the bycatch rate never exceeded 0.1 lbs. of fish/lb. of scallops (**Figure 10a**). Yellowtail exhibited the highest bycatch rates during the June trip; windowpane flounder the highest rate during the February trip and fourspot flounder during the June trip (**Figure 10a**). The highest lobster bycatch rates were observed during the August and (0.05 lbs. of lobster/lb. of scallops). Monkfish bycatch rates were the highest among the species analyzed in this section, with the highest observed during the December trip (0.48 lbs. of fish/lb. of scallops **Figure 10b**). Other flatfish, like summer flounder (*Paralicthys dentatus*) and winter flounder showed minimal catches in the area (**Table 13**).

Distribution maps of some sampled species are shown in **Appendix E**. Yellowtail flounder was observed mostly on the northeastern portion of the sampling area (**Figure E4**); windowpane flounder was widely distributed throughout the sampling area with relatively uniform concentrations; however, in August, October and June, individuals were mostly located towards the northwest of the sampling area (**Figure E5**). In the months when monkfish were abundant, they were observed widely distributed throughout the sampling area (**Figure E6**).

Table 13. Total catches by trip with the uncovered dredge. Scallop catch is quantified in bushels and fish/crustacean in number of individuals.

Year	Month	Scallop	Summer Flounder	Yellowtail Flounder	Winter Flounder	Windowpane Flounder	Monkfish	Lobster
2023	August	270	0	0	0	13	76	21
	October	292	5	1	0	23	43	11
	December	128	15	2	1	63	87	9
2024	February	195	3	3	0	183	2	0
	April	187	4	10	0	130	10	2
	June	148	0	8	3	32	54	15

a)



b)

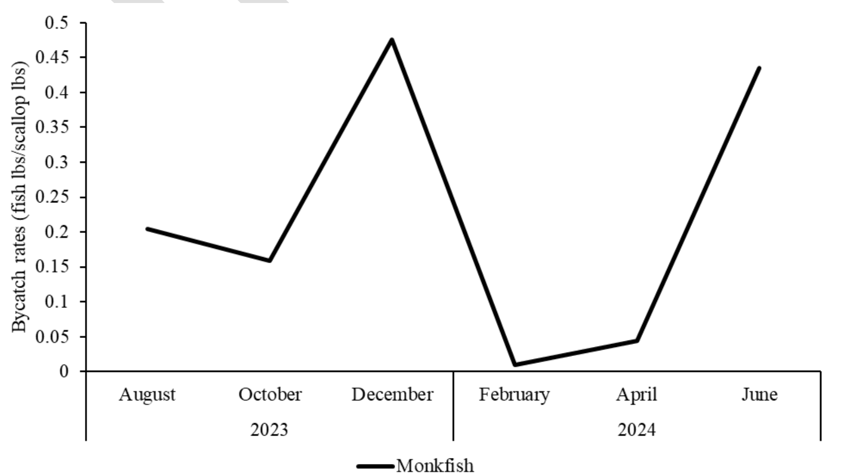


Figure 10. Bycatch rates for commercially important species, including **a)** fourspot, yellowtail and windowpane flounders, lobsters and **b)** monkfish in relation to scallop catch during the 2023 seasonal survey. Only the uncovered dredge was used for this analysis.

Objective 7: Collect gonad samples to more precisely determine when yellowtail and windowpane flounder are spawning within the eastern and southeastern Georges Bank SAMS areas

Yellowtail flounder: A total of 38 yellowtail flounder were caught, of which 92% were females. The peak catch of yellowtail flounder occurred in April (**Table 13**, **Figure E4**). The GSI analysis indicated a possible spawning period in spring (**Figure 11**), which coincide with the historical yellowtail flounder spawning and some previous CFF seasonal survey observations (Pereira *et al*. 2012, Garcia *et al.* 2018).

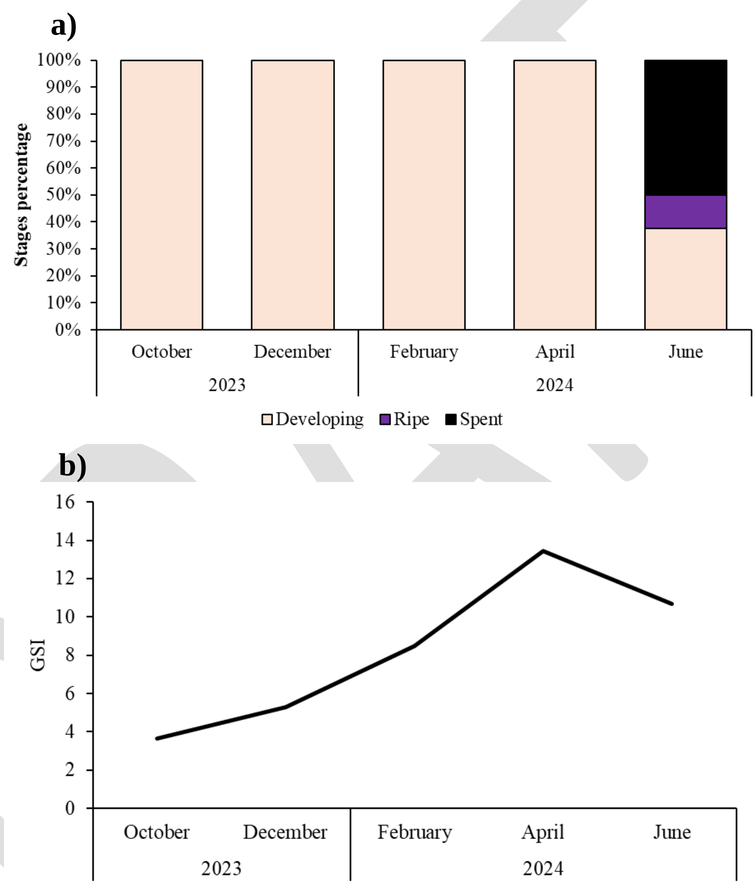


Figure 11. Seasonal changes in the GSI of female yellowtail flounder for each month during the 2023 seasonal survey on the eastern portion of GB; **a)** percentage of individuals sampled by trip spawning stage and **b)** GSI level by trip.

Windowpane flounder: A total of 317 windowpane flounder were caught, with catches peaking in February (**Table 13**). They were caught at most stations in December, February and April (**Figure E5**). Based on the GSI values, two spawning periods likely occurred in fall and spring (**Figure 12**). However, spent females were observed during every trip, except June, suggesting that a low level of spawning activity may occur year-round.

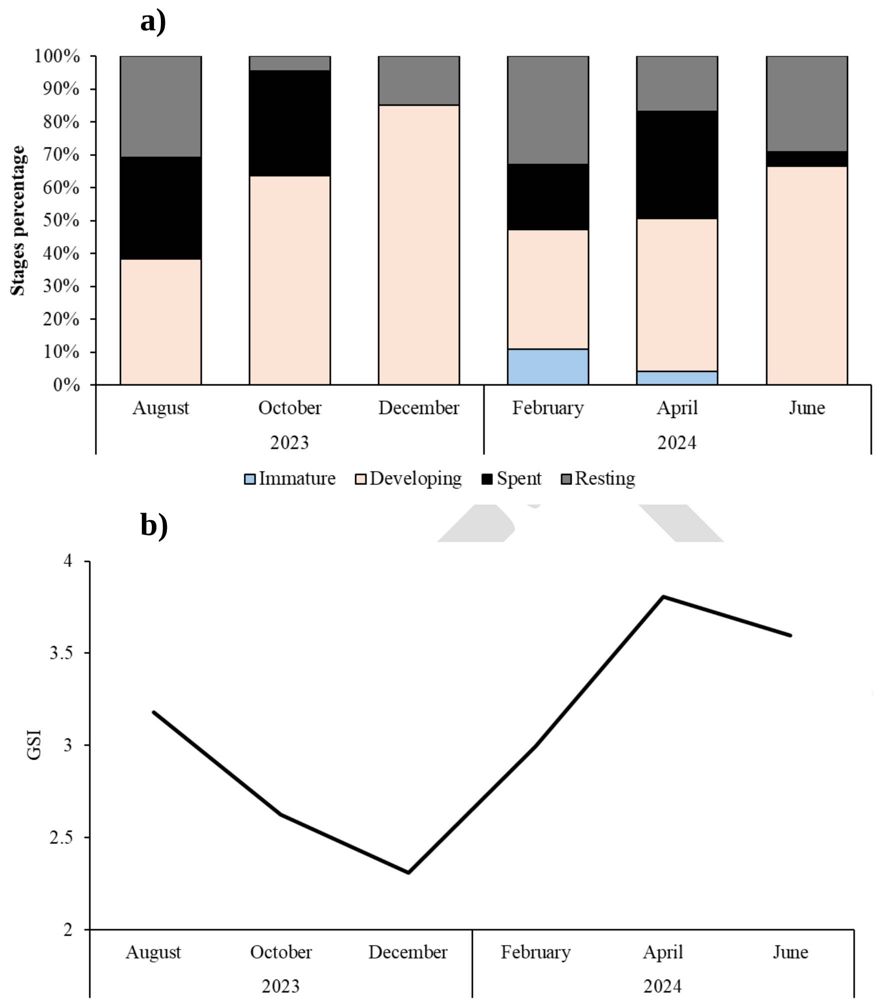


Figure 12. Seasonal changes in the GSI of female windowpane flounder for each month during the 2023 seasonal survey on the eastern portion of GB; **a)** percentage of individuals sampled by trip spawning stage and **b)** GSI level by trip.

Add-on objective 8: 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: For these analyses, the covered dredge is assumed to be nonselective, retaining a sample that is representative of the sea scallop population available to the gear. The scallop catch-at-length data for each tow were analyzed using the covered codend and trouser trawl SELECT models (Millar 1992, Millar 1993). The covered codend model evaluates catch-at-length of the covered dredge bag relative to the catch-at-length of the cover codend, while the trouser trawl model compares the catch-at-length of the combined covered dredge catch-at-length (Covered Dredge + Codend) relative to the uncovered (Control) dredge. Two trouser trawl models were evaluated, a model that calculated the selectivity parameters using pooled catch-at-length data and that calculated the selectivity parameters using individual tow catch-at-length data. The predicted Length at 50% retention (L50) values predicted by the

SELECT models ranged from 95.24 – 111.94 mm (**Table 14 and Figure 13**). For the trouser trawl models, the relative efficiency estimates (split-p) for both models were 0.54 indicating that the covered dredge had a similar relative efficiency than the control dredge.

Table 14. The estimated sea scallop retention parameters from the trouser trawl and codend cover models.

	Covered Codend Model		**Trouser Trawl Model**		**REP Model**	
	Estimate	***S.E.***	***Estimate***	***S.E.***	***Estimate***	***S.E.***
L50	95.24	0.093	108.05	0.651	111.94	1.228
SR	19.46	0.142	29.10	0.480	26.66	0.791
p	N/A		0.54	0.005	0.54	0.012
Log-Likelihood	-75.28		-97.91		-77.41	
AIC	2724.08		1372.05		517.44	

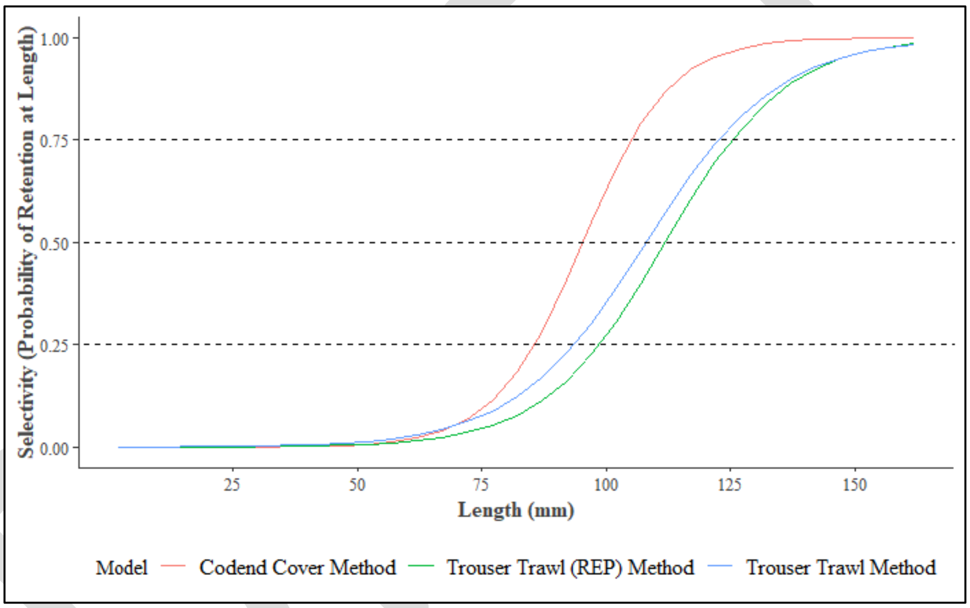


Figure 13. Sea scallop selectivity curves as generated by the trouser trawl and codend cover models.

To better determine if the control and covered dredges were fishing similarly, a GLMM developed compared the scallop catches of the covered and control dredges (Holst and Revill 2009). Scallop shell height was the only covariate investigated with this model. In past years, a low order polynomial of shell height was included in the model to account for non-linearity of the response and more accurately describe the mean proportion of the total catch from the covered dredge at length (Holst and Revill, 2009). Although a model that included a low order polynomial of shell height was evaluated it was not found to be a significant predictor. Instead, the model with shell height provided a better fit to these data. Relative to the control dredge, the covered dredge was marginally more efficient with a greater proportion of smaller scallops being retained by the gear (**Table 15**). A model of the pooled catch data further confirms that the covered dredge had a higher relative efficiency than the control dredge (**Figure 14**). Based on both the split parameter *p* estimate and the GLMM model of scallop catch, the covered dredge retained proportionally more sea scallops as shell height decreased. This may be due to a combination of factors like smaller scallops in the cover falling through dredge when the catch is being dumped and/or the cover masking the dredge bag which prevents smaller scallops from passing through dredge bag (Millar and Naidu 1991; Millar 1993).

Table 15. GLMM modelling coefficient estimates for sea scallop catch.

Fixed Effect	***Estimate***	***Std. Error***	***t-value***	***p-value***
(Intercept)	0.370	0.146	2.539	0.0111
Length	-0.142	0.030	-4.677	2.92E-06

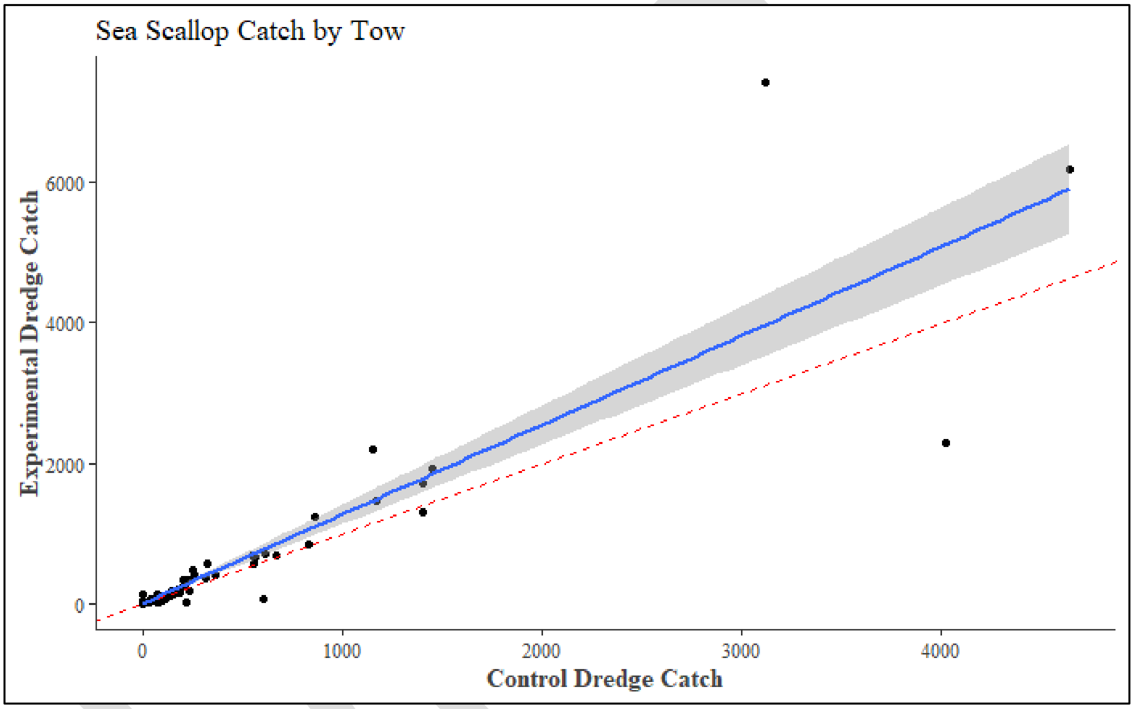


Figure 14. The modelled pooled efficiency of the covered dredge relative to the control (uncovered) dredge.

Add-on objective 9: Spatial-temporal trends for common bycatch species

Changes in spatiotemporal distribution of some species in GB have an important impact on the scallop fishery, as some of them can trigger AMs probably causing economic consequences for the fleet, and other species, which can also be marketed, present additional opportunities for the fishery. To better understand these changes, distribution models considering the effect of geographic location and day of the year, were run for several species caught during this year project. However, modelling spatial-temporal trends of bycatch was challenged by relatively sparse catches and for one key species like yellowtail flounder no parsimonious models could be generated due to low overall catches during the research period. The species presented here had the least amount of zero-inflation allowing for the further evaluation of the observed seasonal trends. The results of the GAMM analysis help further describe the spatial distribution underlying the seasonal trends in barndoor skate, monkfish and windowpane flounder catches within the study area. For windowpane flounder, the bycatch species of greatest concern to managers, the variation in CPUE was best described by models including a tensor product interaction of a two-dimensional isotropic smooth for location and a one-dimensional smooth for Julian day, suggesting difference in the spatial distribution by month/season (**Table 16**). Barndoor skate highest catches were predicted in the southern part of the sampling area, peaking during summer (**Figure 15**). Monkfish catches were predicted to be highest in the southeastern region, predominantly during the summer months (**Figure 16**). For windowpane flounder, higher catches were predicted along the western boundary of the study area, with the peak occurring mainly during the winter months (**Figure 17**). The overall spatial-temporal trends predicted by the GAMM analysis match the observed trends in the spatial-temporal distribution of these species during the research period within the study area (**Figure E5** and **Figure E6**).

Table 16. Relative goodness-of-fit for **a)** barndoor skate, **b)** monkfish and **c)** windowpane flounder CPUE models in the study area. All models include vessel as a random effect.

a)

Model	EDF	AIC	Deviance Explained	MSE	CV_MSE	CV_wMAPE
SurveyYr_te_Y_X_julian_day_with_station_effects	65.20	1096.19	0.48	1.29	2.11	0.87
SurveyYr_te_Y_X_julian_day_s_DepthbyJulian_none	52.08	1096.83	0.45	1.38	2.06	0.86
SurveyYr_te_Y_X_julian_day_none	50.77	1103.70	0.44	1.40	1.99	0.86
te_Y_X_julian_day_s_DepthbyJulian_none	51.77	1108.35	0.44	1.41	2.01	0.86
te_Y_X_julian_day_none	50.21	1132.82	0.42	1.45	1.91	0.87

b)

Model	EDF	AIC	Deviance Explained	MSE	CV MSE	CV wMAPE
SurveyYr_te_Y_X_julian_day_s_DepthbyJulian_with_station_effects	87.17	1425.15	0.59	0.90	1.50	0.79
te_Y_X_julian_day_s_DepthbyJulian_with_station_effects	87.23	1425.24	0.59	0.90	1.51	0.80
te_Y_X_julian_day_s_Depth_with_station_effects	85.23	1443.63	0.58	0.93	1.59	0.81
SurveyYr_te_Y_X_julian_day_s_Depth_with_station_effects	85.33	1444.18	0.58	0.93	1.59	0.81
SurveyYr_te_Y_X_julian_day_s_DepthbyJulian_none	66.08	1449.32	0.56	1.00	1.50	0.79

c)

Model	edf	AIC	Deviance Explained	MAPE
f(Julian Day, northing, easting)	38.45	1575.62	0.54	1.41
f(Julian Day, northing, easting) + Survey Year	38.42	1577.27	0.54	1.42
f(Julian Day, northing, easting) + f(Depth)	35.03	1577.92	0.54	1.41
f(Julian Day, northing, easting) + f(Depth) + Survey Year	35.54	1580.73	0.54	1.41
f(Julian Day, northing, easting) + f(Depth:Julian Day) + f(Station)	40.19	1581.37	0.55	1.42

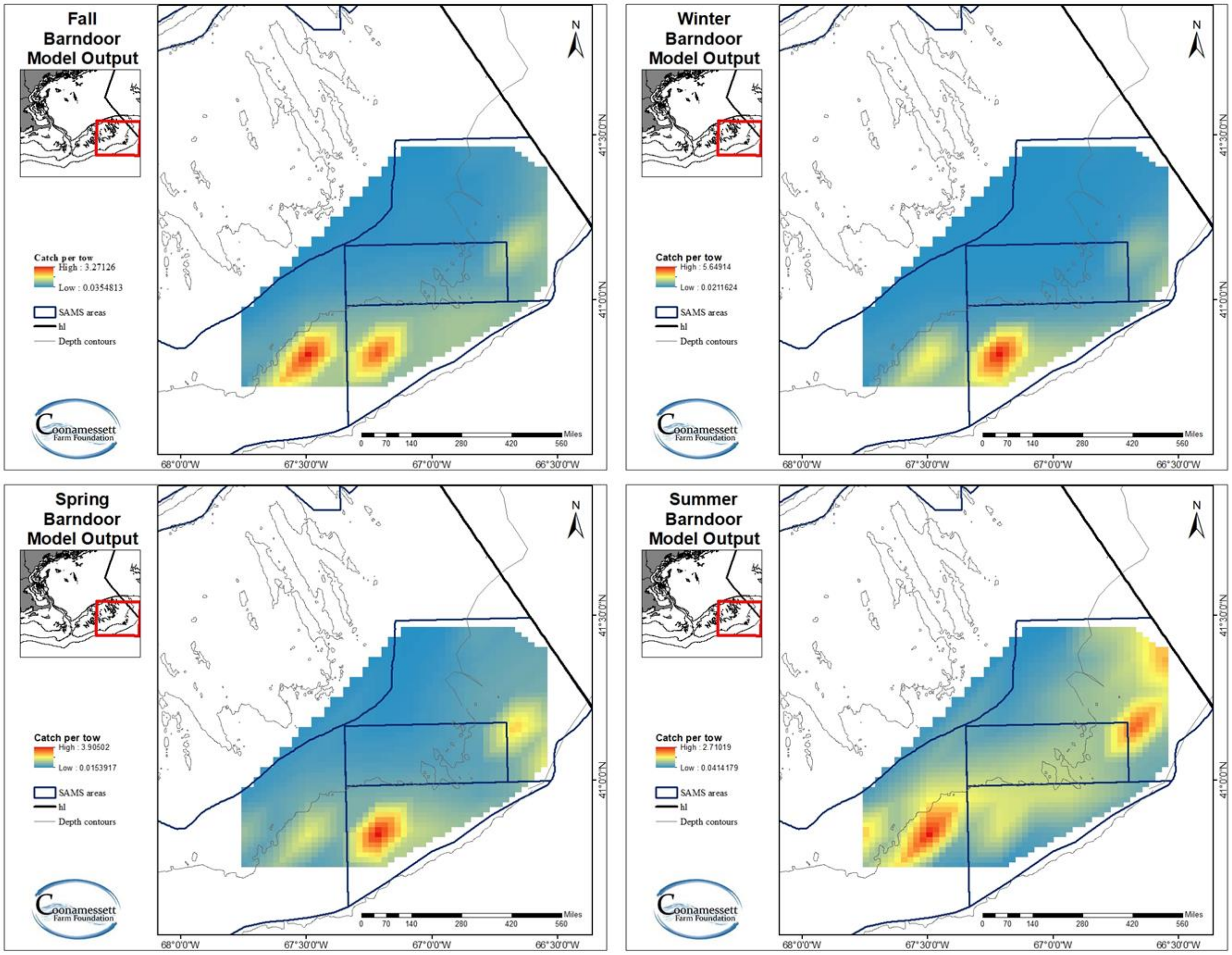


Figure 15. Predicted mean spatial variation of barndoor skate by season on eastern GB.

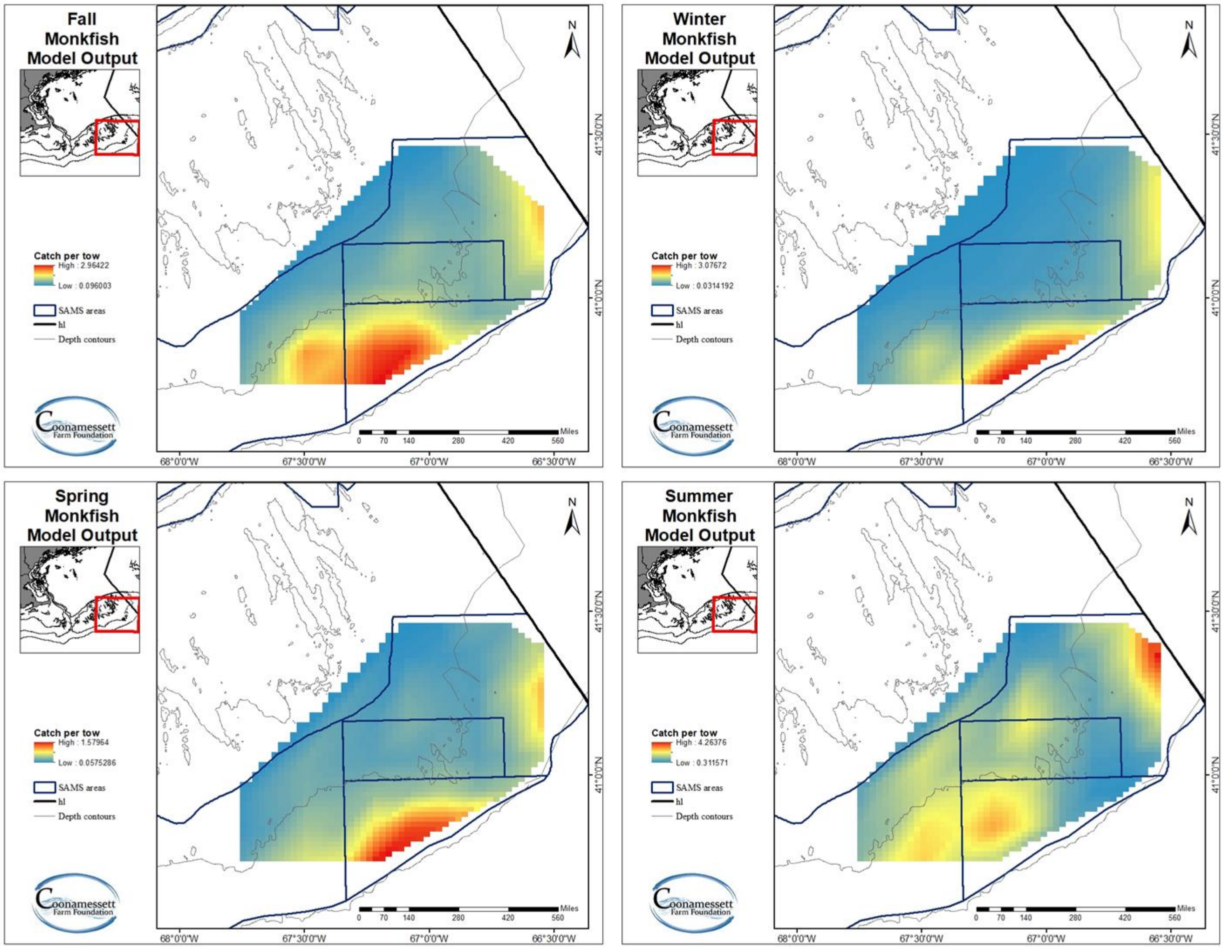


Figure 16. Predicted mean spatial variation of monkfish by season on eastern GB.

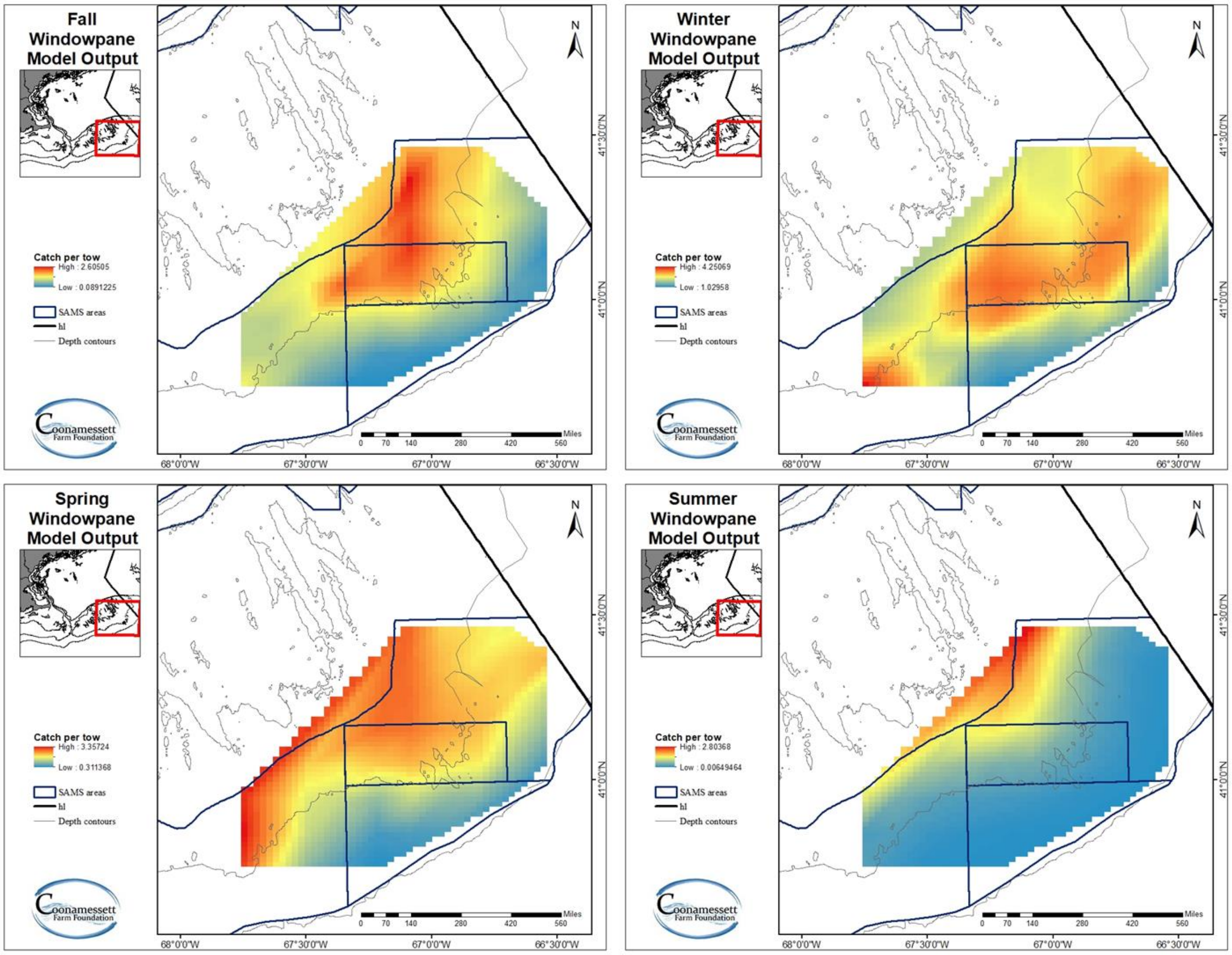


Figure 17. Predicted mean spatial variation of windowpane flounder by season on eastern GB.

<u>Add-on Objective 10: Conduct biological sampling of American lobster caught in scallop dredges.</u>

During the project, all lobsters caught were assessed for carapace length, sex, shell disease status (present/absent), egg status (presence, absence, and developmental stage), and any dredge-induced damage. Lobster catches were generally low throughout the 2023 seasonal survey, with most of the catch concentrated in the northern portion of the sampling area (**Table 17, Figure 18**).

Table 17. Lobster catches by trip.

Year	Month	Uncovered dredge Number	Uncovered dredge Weight (lbs)	Covered dredge + cover net Number	Covered dredge + cover net Weight (lbs)
2023	August	21	96.03	1	0.54
	October	11	53.64	2	14.67
	December	9	37.24	30	50.96
2024	February	0	0	1	6.03
	April	2	6.26	2	1.45
	June	15	43.49	8	34.75

The majority of the lobsters caught during the survey were females, with the exception of the December trip, where males constituted 53% of the catch (**Table 17, Figure 19**). Shell disease was observed in six lobsters: three during the August trip, two in December, and one in June. Of the 103 lobsters caught, 60% showed no damage, 15% were moderately damaged (e.g., missing claws or walking legs), and 19% had lethal damage (**Figure 20**). The highest incidence of lethal damage occurred during the August trip (**Figure 20**).

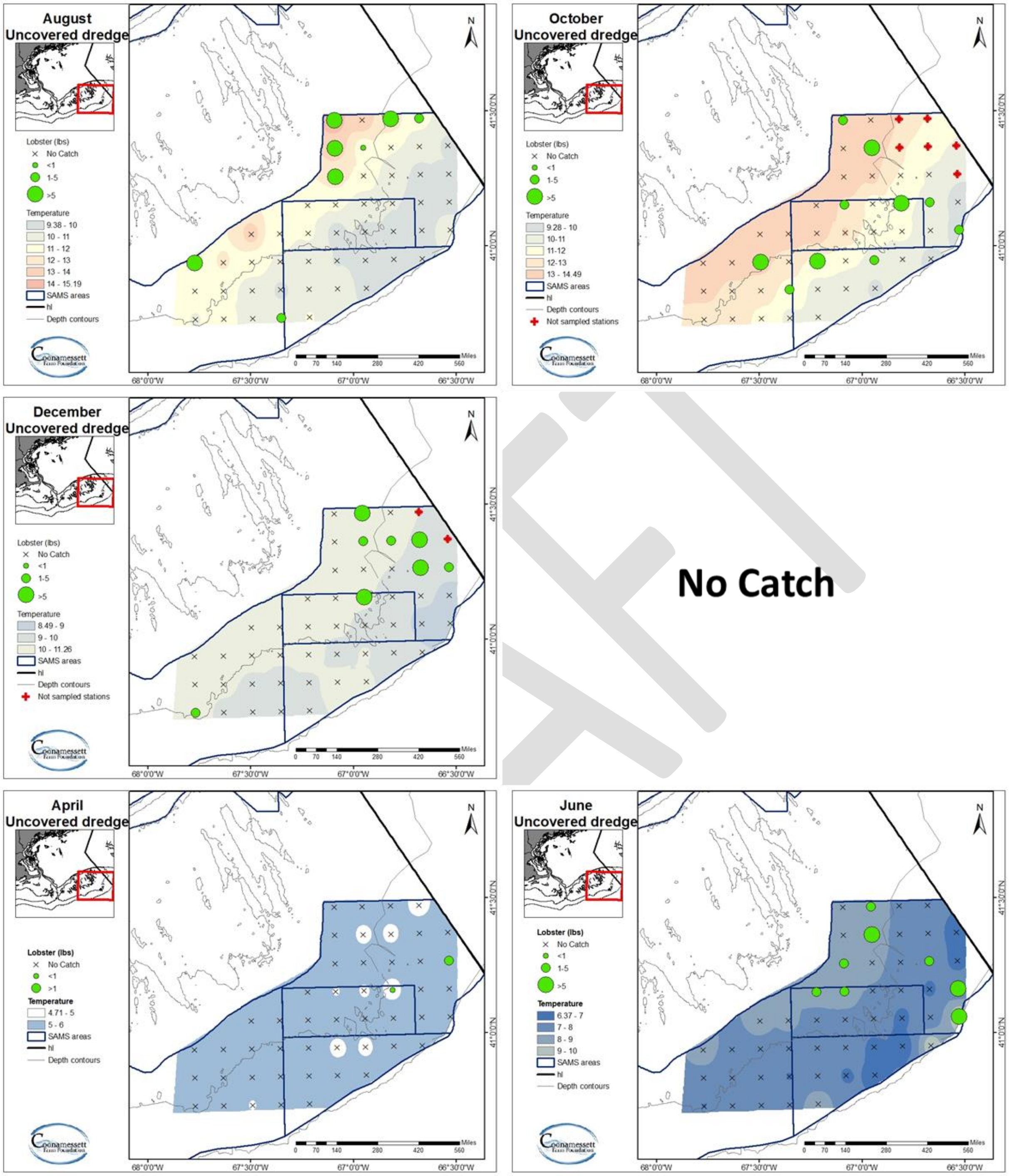


Figure 18. Distribution of lobster caught with the uncovered dredge during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

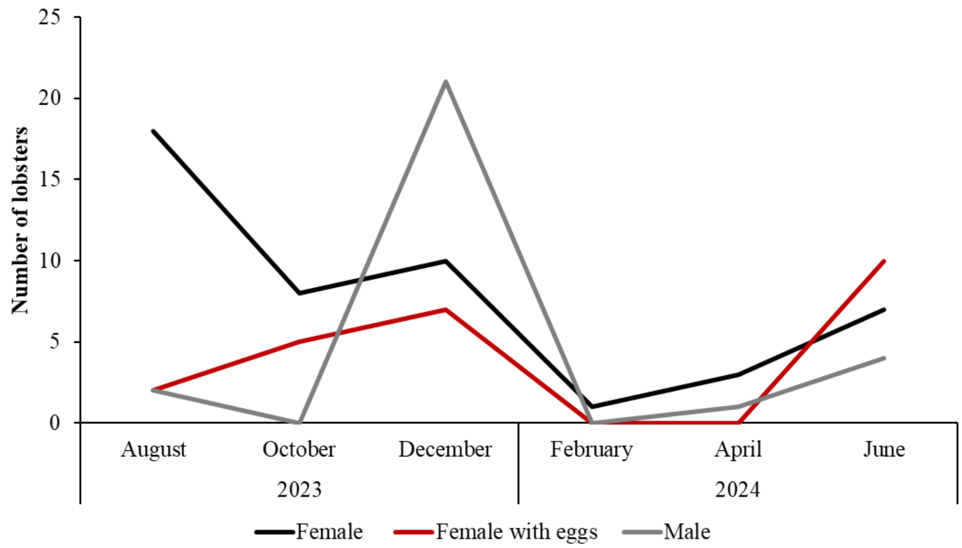


Figure 19. Catch of lobsters by trip separated by sex during the 2022 seasonal survey on the eastern portion of GB.

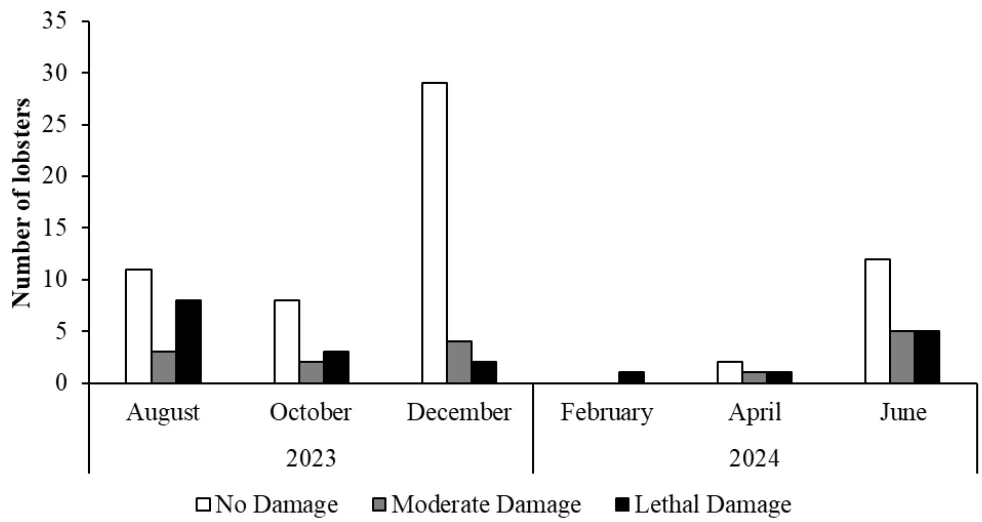


Figure 20. Dredge-induced damage to lobsters by trip during the 2023 seasonal survey on eastern GB.

DISCUSSION

The CFF seasonal survey has consistently provided valuable insights about seasonal trends of sea scallops and other commercially important species on Georges Bank, particularly during months when the National Marine Fisheries Service Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are not conducted. Since 2010, this survey has been executed with relative consistency, offering critical data to resource managers on sea scallop meat yield, reproductive physiology, and groundfish bycatch. Examination of longer-term changes in species catch distributions and abundance patterns point to the continued need for this survey. For instance, 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, Garcia *et al*. 2021), late spring/early summer (Garcia *et al*. 2019), winter (Garcia *et al*. 2021) and again spring/early summer for this year project (**Table 13**, **Figure E4**).

The use of two commercial dredges, one of which is equipped with a cover net to capture all sizes of scallops and flatfish species, provides valuable insights into the seasonal abundance and distribution patterns of these species in eastern GB. The results show that the covered dredge is an effective tool for identifying areas with pre-recruit and recruit scallops (**Tables 3 - 5**). Seasonal survey estimates for CAII were generally in line with those reported by the survey groups, though slightly lower (**Table 18**). It is important to highlight that while the survey groups provide annual estimates, the seasonal survey collects data year-round. This continuous sampling, coupled with potential fishing pressures and other environmental variables, may have influenced the observed results. For CAII-Ext, estimates from both dredges were notably higher than those reported by the survey groups (**Table 18**). This suggests that conducting year-round surveys in this area could provide a more comprehensive understanding of scallop dynamics in the region. In contrast, the seasonal survey estimates for the SF were lower compared to those from the survey groups, likely because this project did not cover the full extent of the SF (**Table 18**). Only 2205 km² of the total 4225 km² were surveyed, leaving a significant portion unsampled, where scallops are known to be present.

Table 18. Mean biomass by area with CFF uncovered and covered dredge vs the 2023 exploitable scallop biomass estimates.

	CAII	CAII-ext	SF
Uncovered dredge	7513	7531	1057
Covered dredge	6281	10,996	2518
2023 Survey estimates*	8443	3865	7992

*These estimates are the mean from the survey dredge, drop camera and HabCam estimates by area (NEFMC 2024).

In addition, our results suggest seasonal variations in scallop biomass among different scallop sizes (**Table 3 – 5**). These variations can be attributed to fishing pressure, biological cycles, and environmental parameters such as seasonal temperature fluctuations, nutrition, and predation (mostly for pre-recruits and recruits, Shank *et al*. 2012, Hart and Chang 2022). Our analysis of mortality (M) as a function of scallop predators and environmental parameters shows a significant correlation with depth and temperature for both dredges. Temperature fluctuations are a major cause of scallop M, usually scallops are found in depths greater than 45 m (Hart and Chute 2003) to avoid lethal temperatures. When scallop beds are located in shallower areas without optimal temperature regimes, scallops become vulnerable to natural predators (Elner and Jaimeson 1979). For the uncovered dredge, rock crabs and *Asterias* sp. had a significant relationship with scallop M; while the covered dredge showed moonsnails catch significantly affects scallop M (**Table 12**). Rock crabs and *Asterias* sp. are major predators for scallop recruits (Wong 2003) and they are commonly found on the same substrates as adult and juvenile sea scallops. In nature, temperature fluctuations within the sublethal range are thought to temporarily weaken scallops, increasing their susceptibility to slow-moving predators like *Asterias* sp. and moonsnails (Barbeau and Scheibling 1994, Dickie and Medcof 1963). Moonsnails are known for their ability to envelop and digest the soft tissues of scallops when the opportunity arises (Seasonal survey field observations). Rock crabs are fast-moving predators. When given a choice in scallop size, rock crabs will actively select large pre-recruit scallops (20–25 mm SH), as these individuals are easier to find and handle (Barbeau and Scheibling 1994, Wong 2003). These results highlight the need to measure seasonal temperature fluctuations on eastern GB as they have effects not only on individual scallops, but also on scallop ecology, including natural mortality and predator availability.

This year, data was collected concerning the presence and density of epibionts to investigate their potential impact on scallop meat weight, which could ultimately influence scallop biomass overall. The model identified *Polydora* sp. density inside the valves and mussel density on the upper valve as influential factors affecting scallop meat weight. The result suggested that high *Polydora* sp. density is associated with reduced scallop meat weight. High *Polydora* sp. levels have been associated with gray or brown muscles, which results in lower meat weights and are typically considered unmarketable (Levesque 2016). Although *Polydora* sp. do not penetrate the soft tissues, their tunneling in scallop shells can severely impact physiology and survival. Tunnel excavation often perforates the inner shell surface, particularly near the adductor muscle attachment, allowing irritants, abrasion, and secondary infections to damage soft tissues. This weakens the adductor muscle, impairing critical functions like shell closure, swimming, feeding, and escape behaviors (Shumway and Parsons 2016). The severity of these effects depends on infestation intensity and burrow type. Chronic impacts include the formation of mud blisters, as irritants breach the shell's nacre layer. This triggers the secretion of conchiolin and nacre, resulting in structural deformities, mantle retraction, and diminished scallop growth and overall health (Shumway and Parsons 2016, Blake 1969, Bergman *et al*. 1982, McGladdery *et al*. 1993).

The model also indicated that high mussel density is associated with decreased scallop meat weight, suggesting that elevated mussel densities may contribute to stress within the scallop population. During the seasonal survey, station 842 consistently showed the presence of mussels, with some trips revealing large mussel aggregation (**Figure 21a**). Dense mussel beds can have significant ecological impact, including control over phytoplankton and local influence on local current velocity patterns (Strohmeier 2009, Dame and Prins1996). Since both sea scallops and mussels are filter feeders, primarily consuming phytoplankton, diatoms, and microscopic animals (Hart 2004), the overlap of these two species in the same area may lead to intraspecific competition for food resources. Furthermore, the location of some of the mussels on the scallops (**Figure 21b**) may affect their mobility, ultimately impacting their ability to feed effectively.

a) **b)**

Figure 21. a) Catch from station 842, August trip, 2023; **b)** scallop with mussels attached to the upper valve.

An additional factor influencing seasonal scallop biomass fluctuations can be attributed to their spawning cycle. Metabolic energy is directed toward the production of gametes during the spawning period and the somatic tissue weight is at some of their lowest levels relative to shell size (Smolowitz *et al*. 1989). Our results indicate the lowest relative biomass of individuals larger than 75 mm (**Table 5**) occurred in the Fall for the CAII-Ext SAMS areas, and in the Spring for CAII. These declines align with the spawning period observed in this year's data (**Figure 5**). Current scallop surveys occur once a year and miss the interannual scallop biomass variation, which has the potential to be critical in stock assessment processes. To address this, a programmatic goal for the seasonal survey project is to investigate the efficiency of the covered dredge relative to a lined survey dredge to allow for the submission of this crucial data to the scallop stock assessment managers.

As noted above, environmental conditions can be highly variable over space and time. 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 NEFSC can only investigate interannual or biannual variation of distribution, abundance and reproductive indices for scallops and groundfish populations. Two of the most important species for eastern GB are yellowtail and windowpane flounders, and despite the mitigation strategies to avoid the decline of these two species in this area, their abundance is not showing signs of recovery (Legault and McCurdy 2017, Garcia *et al.* 2019). Collecting reproductive cycle data at multiple points in a one-year period allows tracking in near-real time when changing environmental conditions can alter established patterns. For yellowtail flounder, our results suggest a spring spawning period consistent with the past two year's observations from this survey (Garcia *et al.* 2022, Garcia *et al.* 2023) and the historical spawning period for this species (Pereira *et al.* 2012). However, an atypical winter spawning period was recorded during the 2019 seasonal survey (Garcia *et al.* 2021), which is unusual for this species in this region. For windowpane, our findings show a fall spawning period, aligning with previously reported spawning activity for this species in this area (Hendrickson 2008, Garcia *et al.* 2022). 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.

CONCLUSIONS AND FUTURE RESEARCH

Marine environmental changes are reshaping the distribution and abundance of many marine species. Coupled with fishing pressure and emerging ocean uses such as wind farms, these changes are driving shifts in several populations. To address these challenges, real-time monitoring of marine species in areas under high fishing pressure is essential. Such surveys provide critical data that enables resource managers to develop effective, adaptive strategies to specific regions. The CFF seasonal survey plays a pivotal role in this effort, offering a wealth of data to address ecosystem-level challenges on GB. This information directly supports scallop management by equipping fisheries managers with essential insights needed to meet ACLs and implement AMs. These measures optimize scallop harvests while minimizing bycatch, balancing ecological sustainability with economic productivity. 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 delivered by other surveys. The survey is conducted in a systematic fashion, using full-scale dredges over a range of scallop densities, providing spatiotemporally explicit information about scallop and bycatch stocks in these areas. CFF is planning to calibrate the cover net with a lined survey dredge to expand on the species composition and length distributions of the catch. This effort aims to provide deeper insights into scallop recruitment, predation, and scallop-fishery impacts on bycatch species such as yellowtail and windowpane flounder. Despite these efforts, the survey has observed low catches of certain species that were once abundant in this part of GB. Monitoring depleted populations remains challenging with traditional survey methods due to their low catchability. To address this, CFF plans to incorporate environmental DNA (eDNA) as a complementary tool to traditional survey techniques. eDNA offers a powerful method to detect and monitor low-abundance species, providing a more comprehensive understanding of population dynamics, particularly for yellowtail and windowpane flounder. Overall, 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 patterns of commercial 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 2023 seasonal survey on the eastern portion of GB. Total lengths were measured for some fish while mantle length was taken for squid.

Common Name	Scientific Name	Sample Procedure	Weight (kg)	Number Caught
American Lobster	Homarus americanus	Weigh/Measure	4.54	103
American Plaice	Hippoglossoides platessoides	Weigh/Measure	1.94	4
Atlantic Cod	Gadus morhua	Weigh/Measure	4.67	3
Barndoor Skate	Dipturus laevis	Weigh/Measure	495.8	418
Butterfish	Peprilus triacanthus	Weigh/Count	61.46	10
Cunner	Tautogolabrus adspersus	Weigh/Count	0.14	1
Cusk Eel	Lepophidium profundorum	Weigh/Count	0.02	1
Fourspot Flounder	Paralichthys oblongus	Weigh/Measure	146.66	735
Gulfstream Flounder	Citharichthys arctifrons	Weigh/Count	23.12	722
Haddock	Melanogrammus aeglefinus	Weigh/Measure	4.9	11
Illex Squid	Illex illecebrosus	Weigh/Measure	2.33	10
Jonah Crab	Cancer borealis	Weigh/Count	192.54	891
Loligo Squid	Doryteuthis pealeii	Weigh/Measure	0.96	19
Longhorn Sculpin	Myoxocephalus octodecemspinosus	Weigh/Count	29.98	217
Monkfish	Lophius americanus	Weigh/Measure	840.08	347
Northern Moon Snail	Euspira heros	Weigh/Count	38.38	1566
Northern Searobin	Prionotus carolimus	Weigh/Count	50.75	149
Ocean Pout	Zoarces americanus	Weigh/Count	21.9	62
Red Hake	Urophycis chuss	Weigh/Count	487.64	2813
Rock Crab	Cancer irroratus	Weigh/Count	39.85	1621
Sea Raven	Hemitripterus americanus	Weigh/Count	26.9	30
Silver Hake	Merluccius bilinearis	Weigh/Count	154.29	935
Spiny Dogfish	Squalus acanthias	Weigh/Measure	4.2	15
Spotted Hake	Urophycis regia	Weigh/Count	1.22	8
Summer Flounder	Paralichthys dentatus	Weigh/Measure	64.18	32
Unclassified Skates	Rajidae	Weigh/Count	10013.51	13464
Waved Whelk	Buccinum undatum	Weigh/Count	3.56	212
White Hake	Urophycis tenuis	Weigh/Count	4.43	3
Windowpane Flounder	Scopthalmus aquosus	Weigh/Measure	171.89	444
Winter Flounder	Pseudopleuronectes americanus	Weigh/Measure	5.72	6
Witch Flounder	Glyptocephalus cynoglossus	Weigh/Measure	5.1	13
Yellowtail Flounder	Limanda ferruginea	Weigh/Measure	20.26	24

Appendix B: SHMW analysis

Linear mixed model fit by REML in with function pqlmer R package r2glmm

Full model MW~lSH+Month+lDepth+lLat+(lSH*Month)+(lDepth*Month)+Color+(1|Station), family=Gamma(link="log"))

Top model MW~lSH+Month+lDepth+(lDepth*Month)+Color+(1|Station), family=Gamma(link="log"))

Abbreviations:
lSH = log(shell height in mm)
lLat = log(latitude)
lDepth = log(depth in meters)
Color = meat color
Month = survey month
AIC = Akaike information criteria

	Number of estimated parameters	AIC	Delta AIC
Top model	16	-552.53	0
Full model	23	-529.41	23.12

Summary of top model:

REML criterion at convergence: -585.3

Scaled residuals:

```
   Min      1Q  Median      3Q     Max
-3.9086 -0.5871  0.0424  0.6051  5.6507
```

Random effects:

```
 Groups   Name        Variance Std.Dev.
 Station  (Intercept) 0.003055 0.05527
 Residual             0.023924 0.15467
```

Number of observations: 744
Number of groups: Station, 42

Fixed effects:

```
                 Estimate Std. Error t value
(Intercept)        9.58778    8.62684   1.111
lSH                2.45418    0.08877  27.645
MonthOctober      -2.32376    0.66361  -3.502
MonthDecember     -2.32481    0.77286  -3.008
MonthFebruary     -1.16076    0.83714  -1.387
MonthApril        -0.72591    1.02867  -0.706
MonthJune         -2.52590    0.79372  -3.182
lDepth            -0.34834    0.08002  -4.353
lLat              -4.35034    2.30724  -1.886
lSH:MonthOctober   0.43197    0.13875   3.113
lSH:MonthDecember  0.42333    0.16117   2.627
lSH:MonthFebruary  0.19164    0.17472   1.097
lSH:MonthApril     0.07922    0.21392   0.370
lSH:MonthJune      0.45454    0.16538   2.748
```

Appendix C: Epibiont analysis

Generalized additive mixed model fit by REML in with function gam R package mgcv

Full model:
MW~s(lSH)+s(lDepth)+s(lLat)+
s(CovProp_Upper)+s(CovProp_Lower)+s(CovProp_Inside)+
s(ShDiv_Upper)+s(ShDiv_Lower)+s(ShDiv_Inside)+
s(PolyDens_Upper)+s(PolyDens_Lower)+s(PolyDens_Inside)+
s(BryoDens_Upper)+s(BryoDens_Lower)+
s(HydroDens_Upper)+s(HydroDens_Lower)+
s(JingleDens_Upper)+s(JingleDens_Lower)+
s(MusDens_Upper)+s(MusDens_Lower)+
s(BarnDens_Upper)+s(BarnDens_Lower)+
s(ScarDens_Upper)+s(ScarDens_Lower)+
s(AlgaDens_Upper)+s(AlgaDens_Lower)+
s(MaxSp_Upper)+s(MaxSp_Lower)+s(MaxSp_LowerIn)+
Month+Color+s(Station),family=Gamma(link="log"))

Top model:
MW~s(lSH)+s(lDepth)+s(PolyDens_Inside)+s(MusDens_Upper)+Month+s(Station),
family=Gamma(link="log"))

Abbreviations:
lSH = log(shell height in mm)
lLat = log(latitude)
lDepth = log(depth in meters)
Color = meat color
Month = survey month
Upper = outside of upper valve
Upper = inside of upper valve
Lower = outside of lower valve
Inside = inside of both valves
CovProp = proportion of valve surface covered by epibionts
ShDiv = Shannon diversity index
PolyDens = density of *Polydora* sp. (number per cm^2)
BryoDens = density of bryozoans (number per cm^2)
HydroDens = density of hydrozoans (number per cm^2)
JingleDens = density of *Anomia* sp. (number per cm^2)
MusDens = density of blue mussels (number per cm^2)
BarnDens = density of live and dead barnacles (number per cm^2)
ScarDens = density of barnacle scars (number per cm^2)
AlgaDens = density of macroalgal species (number per cm^2)
MaxSp = most abundant epibiont species
AIC = Akaike information criteria

	Deviance explained	AIC	Delta AIC
Top model	86.4%	3916.12	0
Full model	87.7%	3935.87	19.75

Summary of top model:

Family: Gamma
Link function: log

Parametric coefficients:

```
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)    3.68601    0.01197  307.94   <2e-16 ***
MonthOctober  -0.23196    0.02094  -11.08   <2e-16 ***
MonthDecember -0.27030    0.02100  -12.87   <2e-16 ***
MonthFebruary -0.24804    0.02262  -10.96   <2e-16 ***
MonthApril    -0.35448    0.02159  -16.42   <2e-16 ***
MonthJune     -0.33252    0.01900  -17.50   <2e-16 ***
---
```

Approximate significance of smooth terms:

```
                          edf Ref.df        F  p-value
s(Shell_Height)        1.9892      2 2513.321  < 2e-16 ***
s(Depthm)              0.9559      2   64.602 1.54e-06 ***
s(PolyDens_Inside)     0.9480      2   14.043 7.97e-06 ***
s(MusDens_UpperValve)  1.7183      2    8.925 0.000154 ***
s(Station)            20.6737     40    1.551  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

R-sq.(adj) = 0.84
Deviance explained = 86.4%
-REML = 1983.9
Scale est. = 0.020171
n = 643

Appendix D: 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:

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

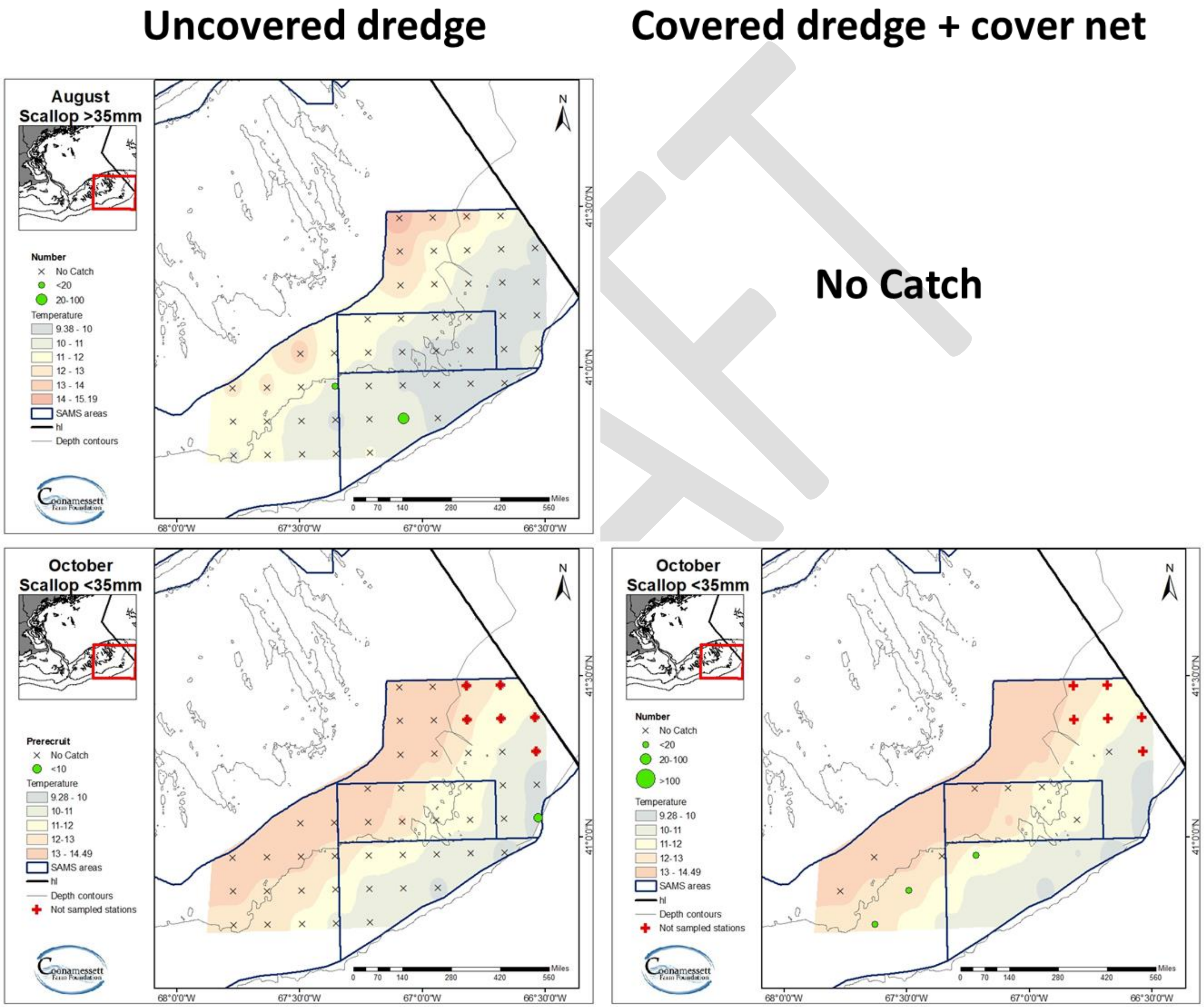
C_{cov} is the number of length *l* animals in the covered dredge and C_s is number of length *l* animals in uncovered dredge. The selection parameters L50 and the selection range (SR) are calculated with the following equations:

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

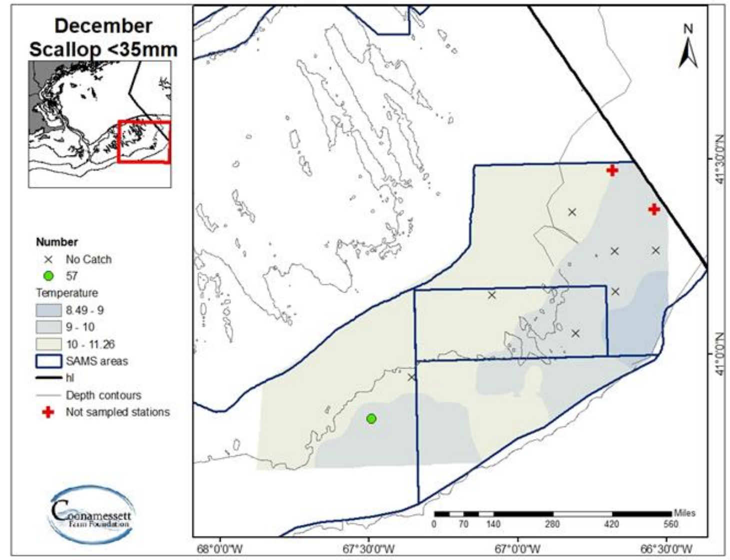
Uncontrollable factors like wind speed, sea state, animal density result in variation in selectivity estimates from tow to tow. To determine if the variation is exceeding the model predictions (overdispersion) a test is necessary when combining tows. This can be done using the replication estimate of 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).

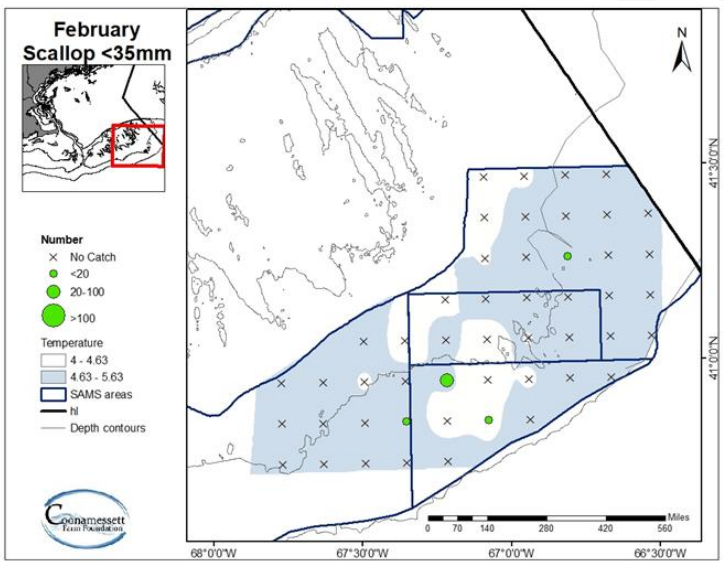
The R-Statistical Program was used to evaluate the data (R Core Team 2015). The "trawlfunction" package was used to estimate the selectivity coefficients and parameters (Millar 2009).

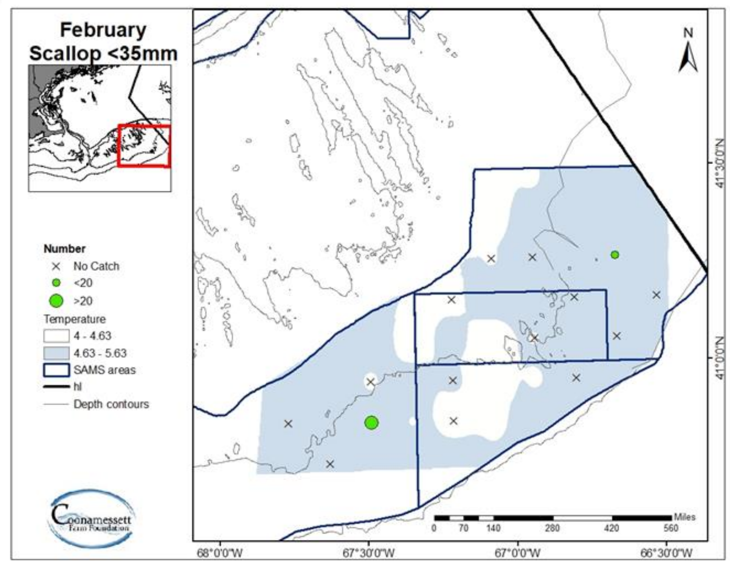
Appendix E: Distribution of scallops, main bycatch species and scallop's predators



No Catch


December
Scallop <35mm
Number
No Catch
57
Temperature
8.49 - 9
9 - 10
10 - 11.26
SAMS areas
hl
Depth contours
Not sampled stations
N
Miles
0 70 140 280 420 560
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N


February
Scallop <35mm
Number
No Catch
<20
20-100
>100
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours
N
Miles
0 70 140 280 420 560
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N


February
Scallop <35mm
Number
No Catch
<20
>20
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours
N
Miles
0 70 140 280 420 560
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N

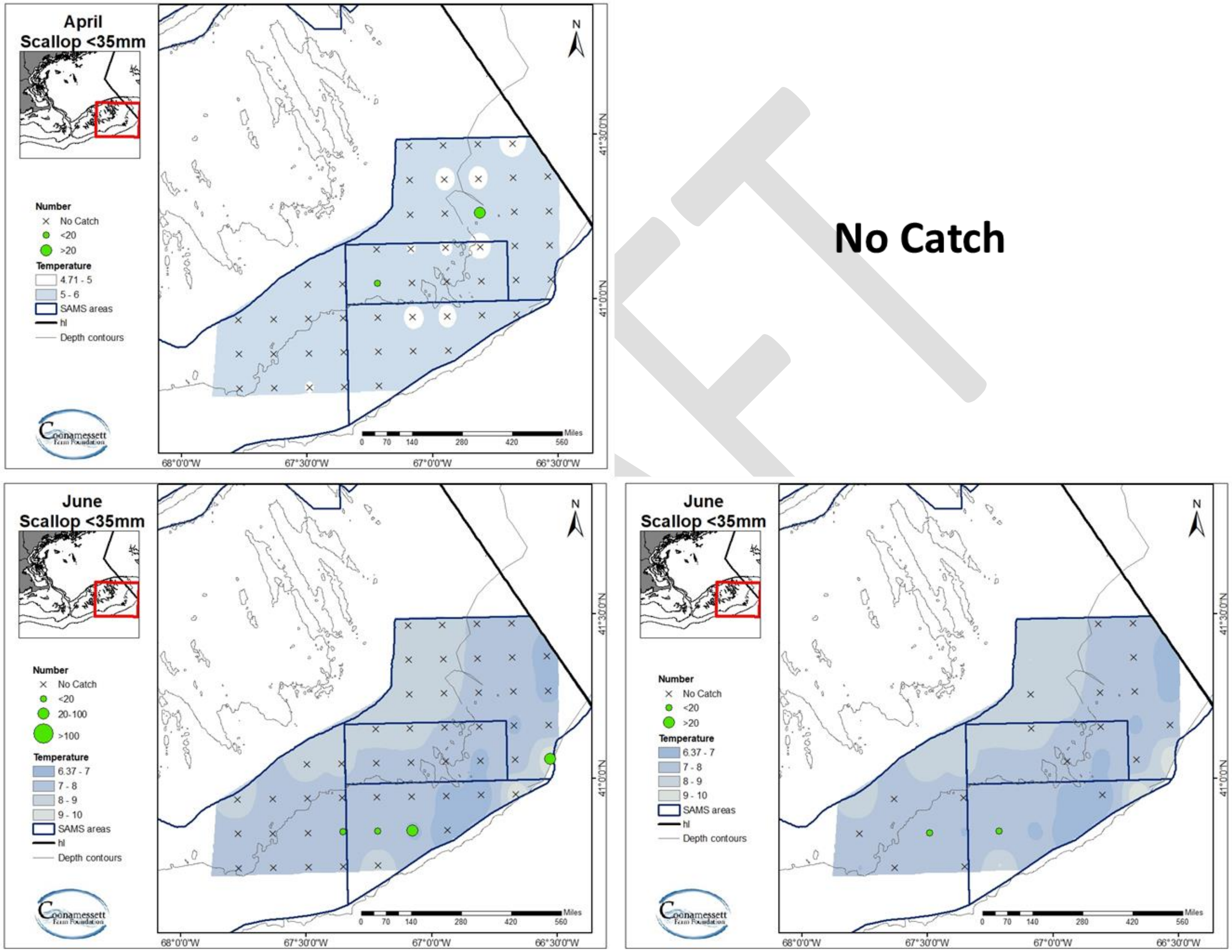
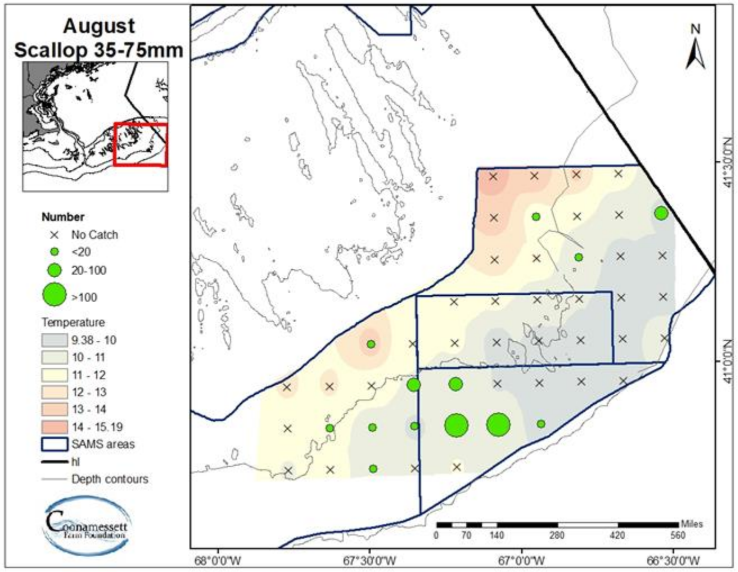
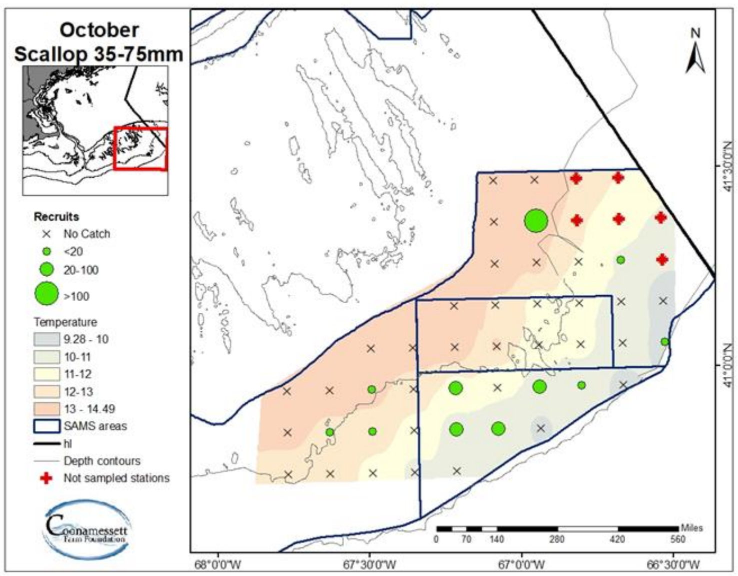


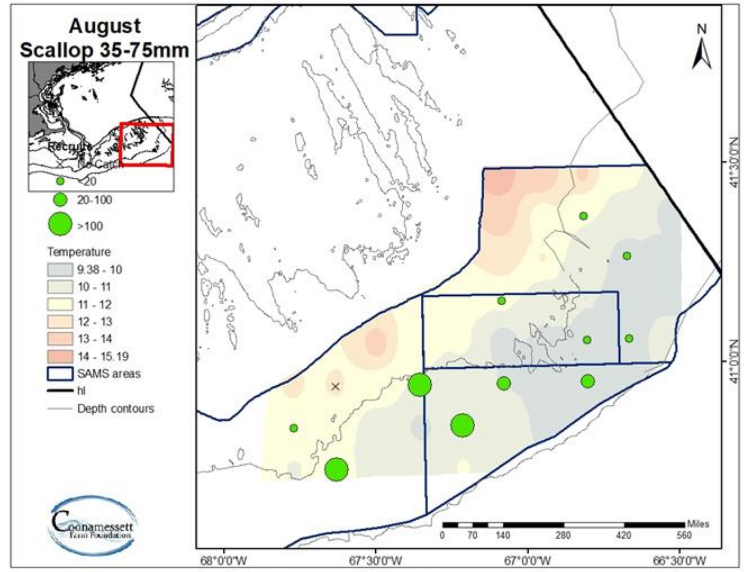
Figure E1. Distribution of pre-recruit scallops caught with the uncovered dredge (left maps) and the covered dredge (dredge + cover net; right maps) during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

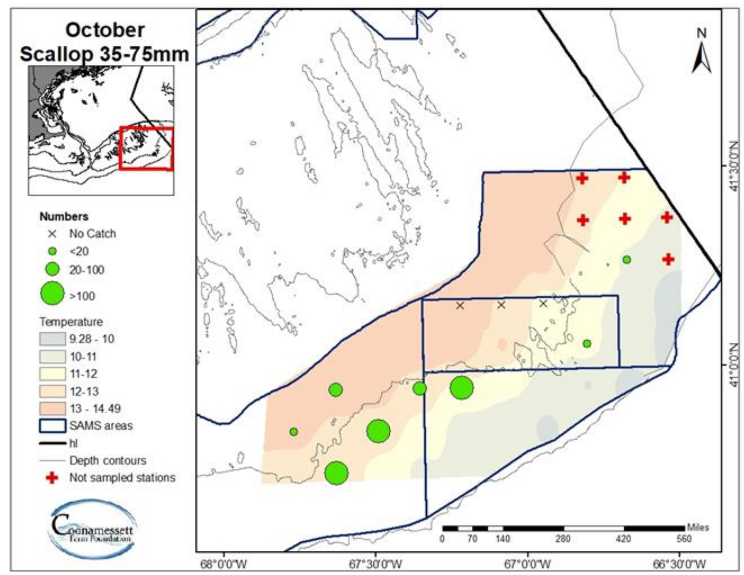
Uncovered dredge

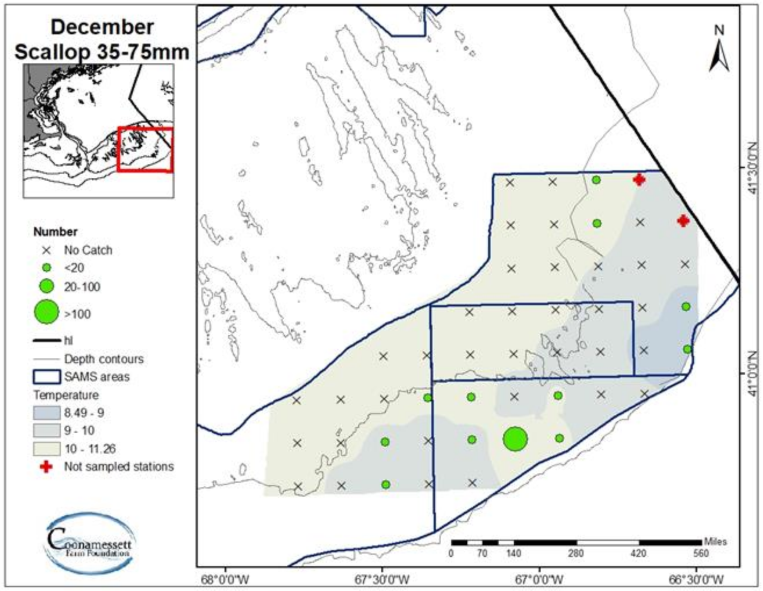


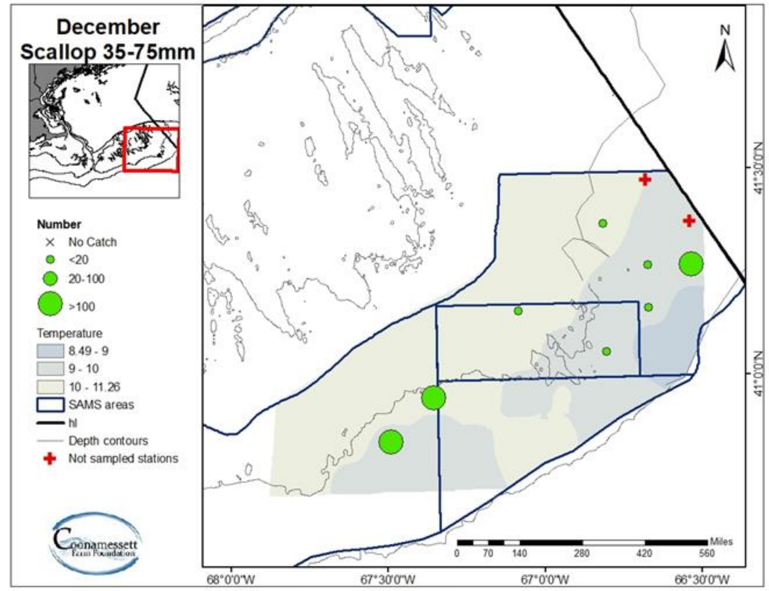


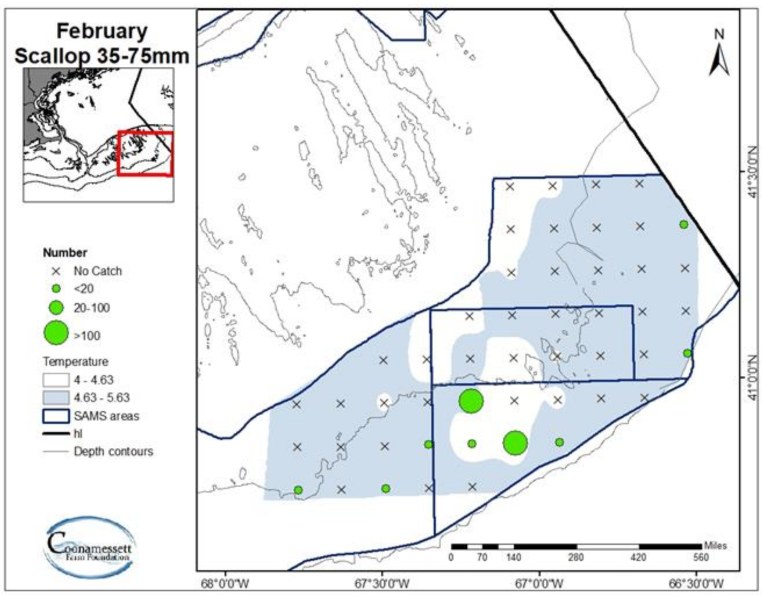
Covered dredge + cover net

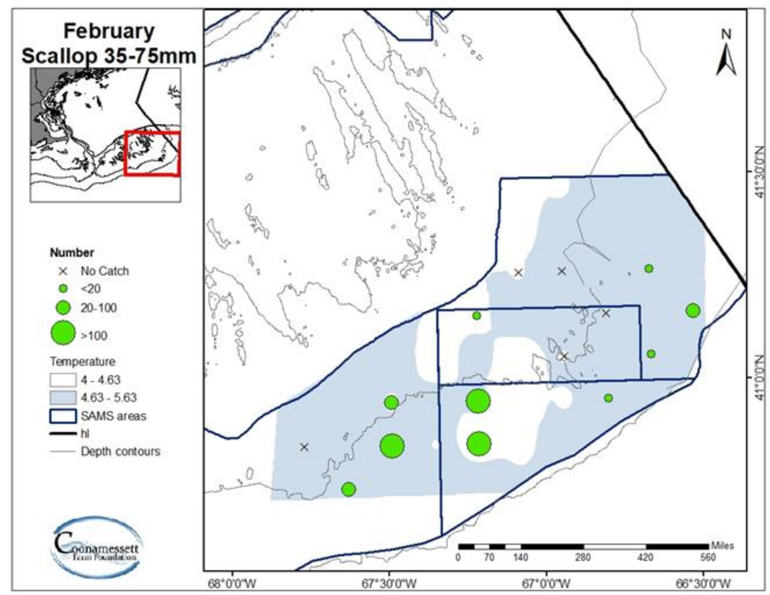





December
Scallop 35-75mm
Number
No Catch
<20
20-100
>100
hl
Depth contours
SAMS areas
Temperature
8.49 - 9
9 - 10
10 - 11.26
Not sampled stations
N
41°30'0"N
41°0'0"N
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
0 70 140 280 420 560 Miles
Coonamessett Farm Foundation


December
Scallop 35-75mm
Number
No Catch
<20
20-100
>100
Temperature
8.49 - 9
9 - 10
10 - 11.26
SAMS areas
hl
Depth contours
Not sampled stations
N
41°30'0"N
41°0'0"N
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
0 70 140 280 420 560 Miles
Coonamessett Farm Foundation


February
Scallop 35-75mm
Number
No Catch
<20
20-100
>100
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours
N
41°30'0"N
41°0'0"N
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
0 70 140 280 420 560 Miles
Coonamessett Farm Foundation


February
Scallop 35-75mm
Number
No Catch
<20
20-100
>100
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours
N
41°30'0"N
41°0'0"N
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
0 70 140 280 420 560 Miles
Coonamessett Farm Foundation

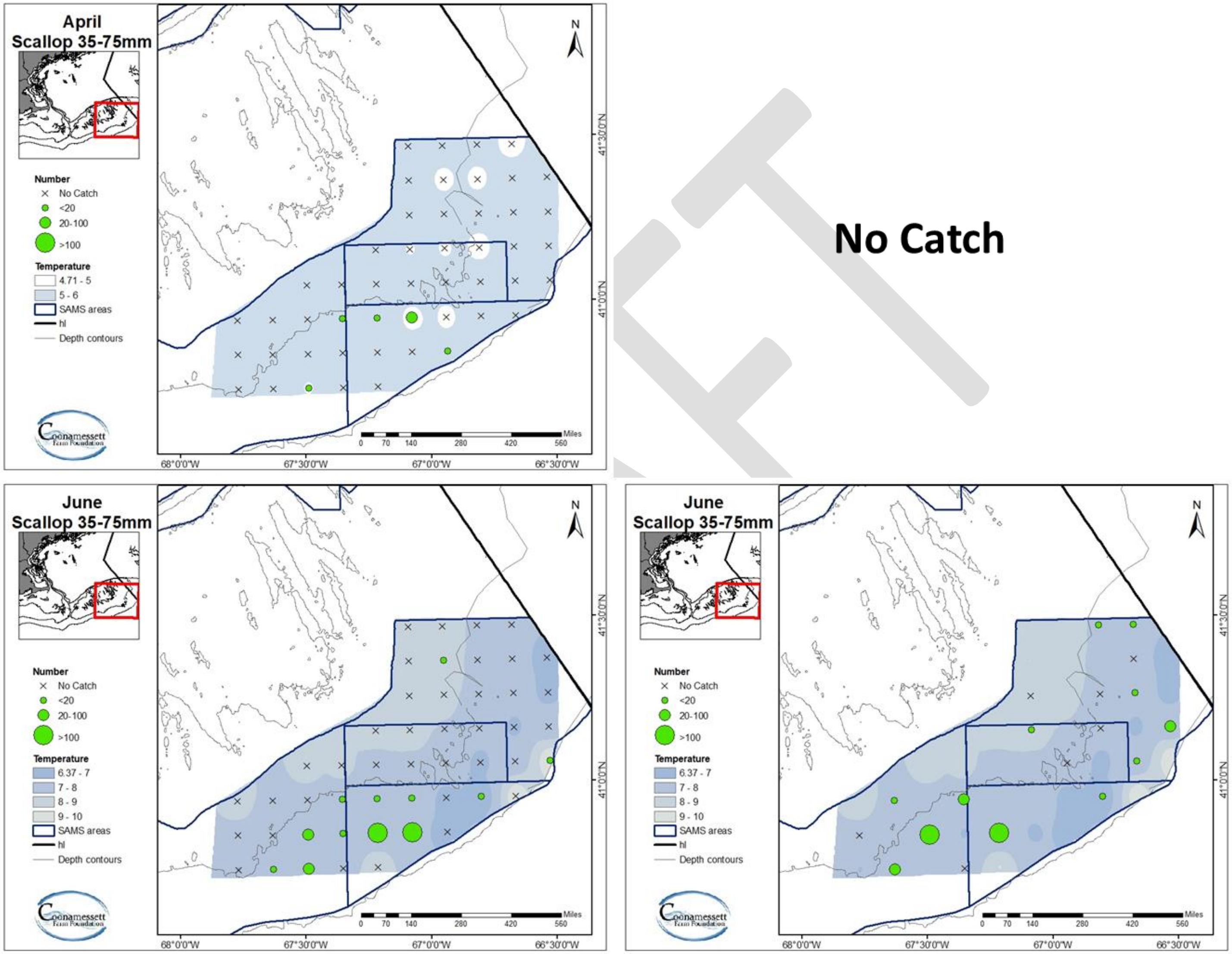
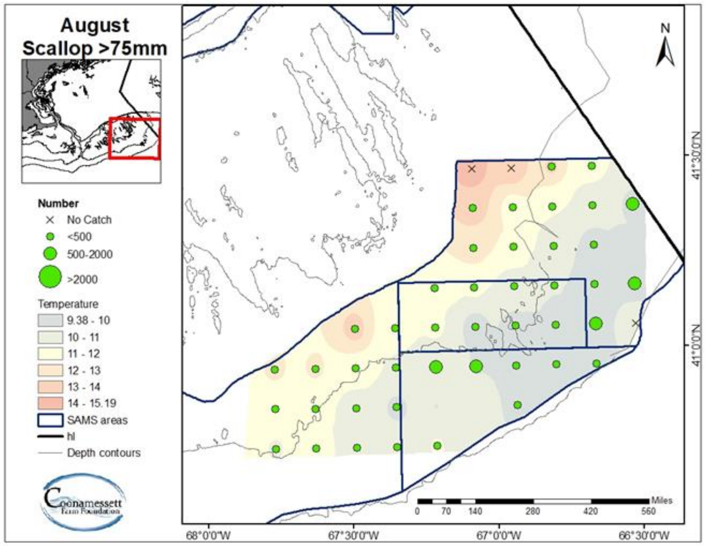
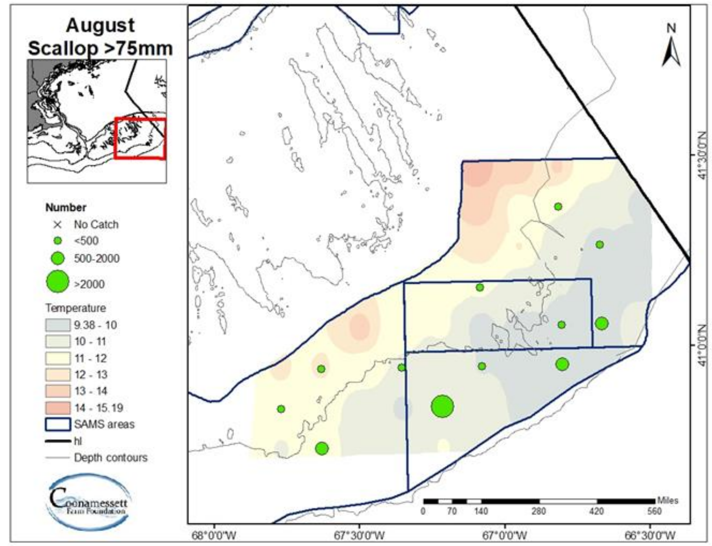
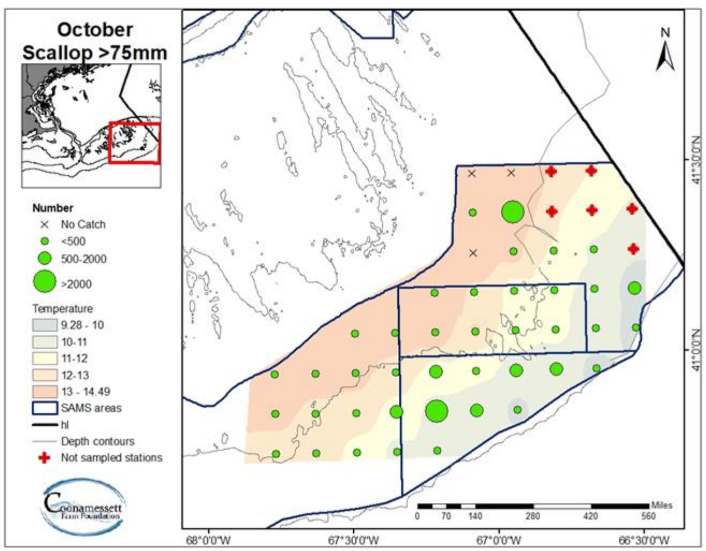


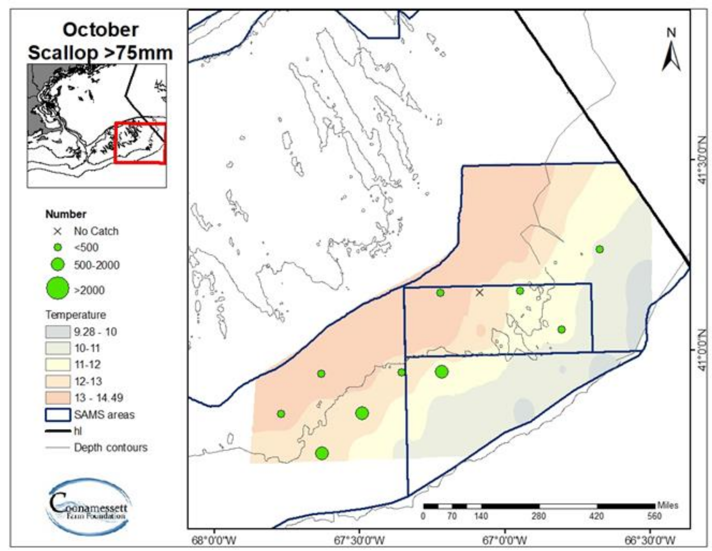
Figure E2. Distribution of recruit scallops caught with the uncovered dredge (left maps) and the covered dredge (dredge + cover net; right maps) during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

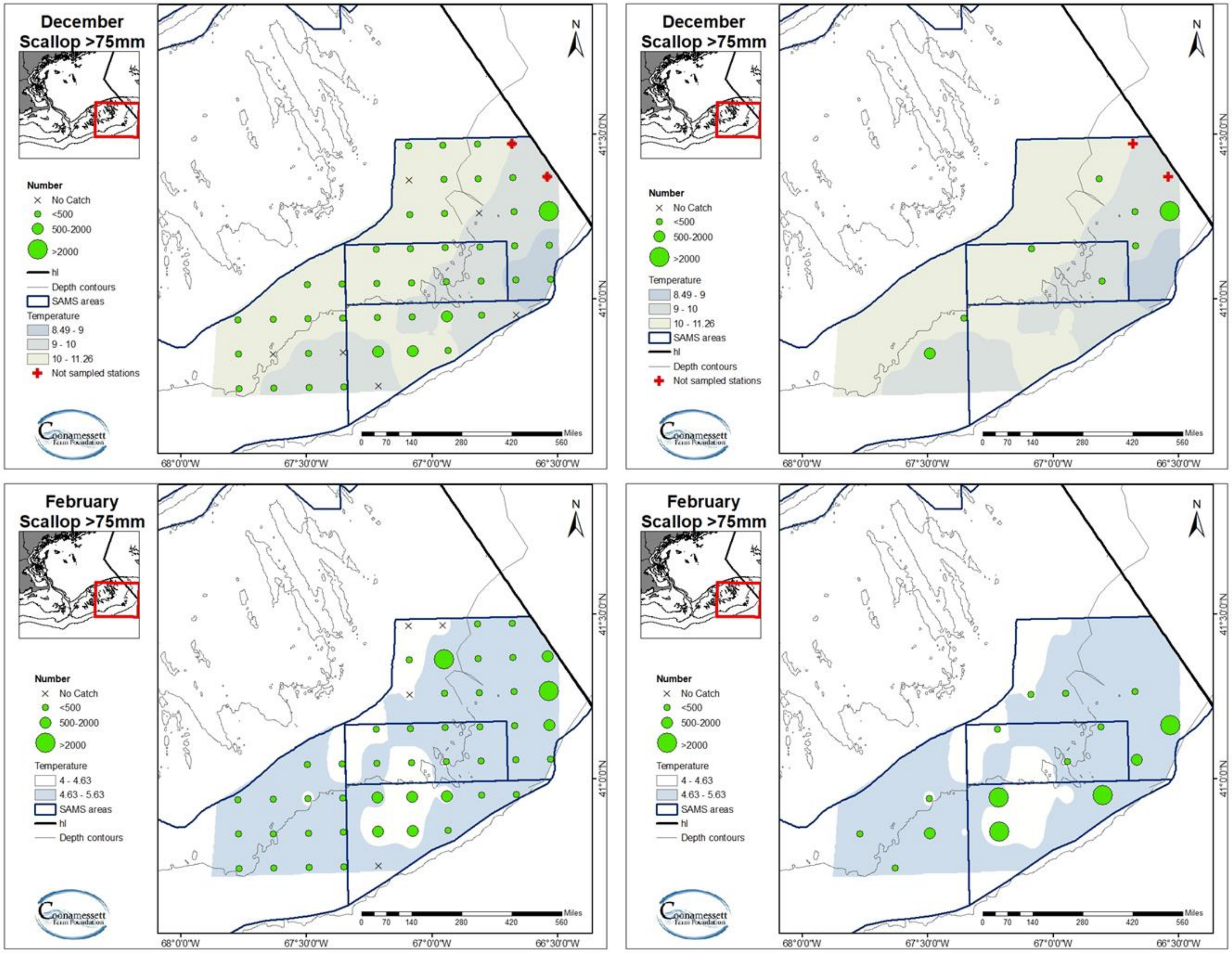
Uncovered dredge | Covered dredge + cover net










December
Scallop >75mm
Number
No Catch
<500
500-2000
>2000
hl
Depth contours
SAMS areas
Temperature
8.49 - 9
9 - 10
10 - 11.26
Not sampled stations
N
Miles
0 70 140 280 420 560
68°0'0"W
67°30'0"W
67°0'0"W
66°30'0"W
41°30'0"N
41°0'0"N
December
Scallop >75mm
Number
No Catch
<500
500-2000
>2000
Temperature
8.49 - 9
9 - 10
10 - 11.26
SAMS areas
hl
Depth contours
Not sampled stations
February
Scallop >75mm
Number
No Catch
<500
500-2000
>2000
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours
February
Scallop >75mm
Number
No Catch
<500
500-2000
>2000
Temperature
4 - 4.63
4.63 - 5.63
SAMS areas
hl
Depth contours

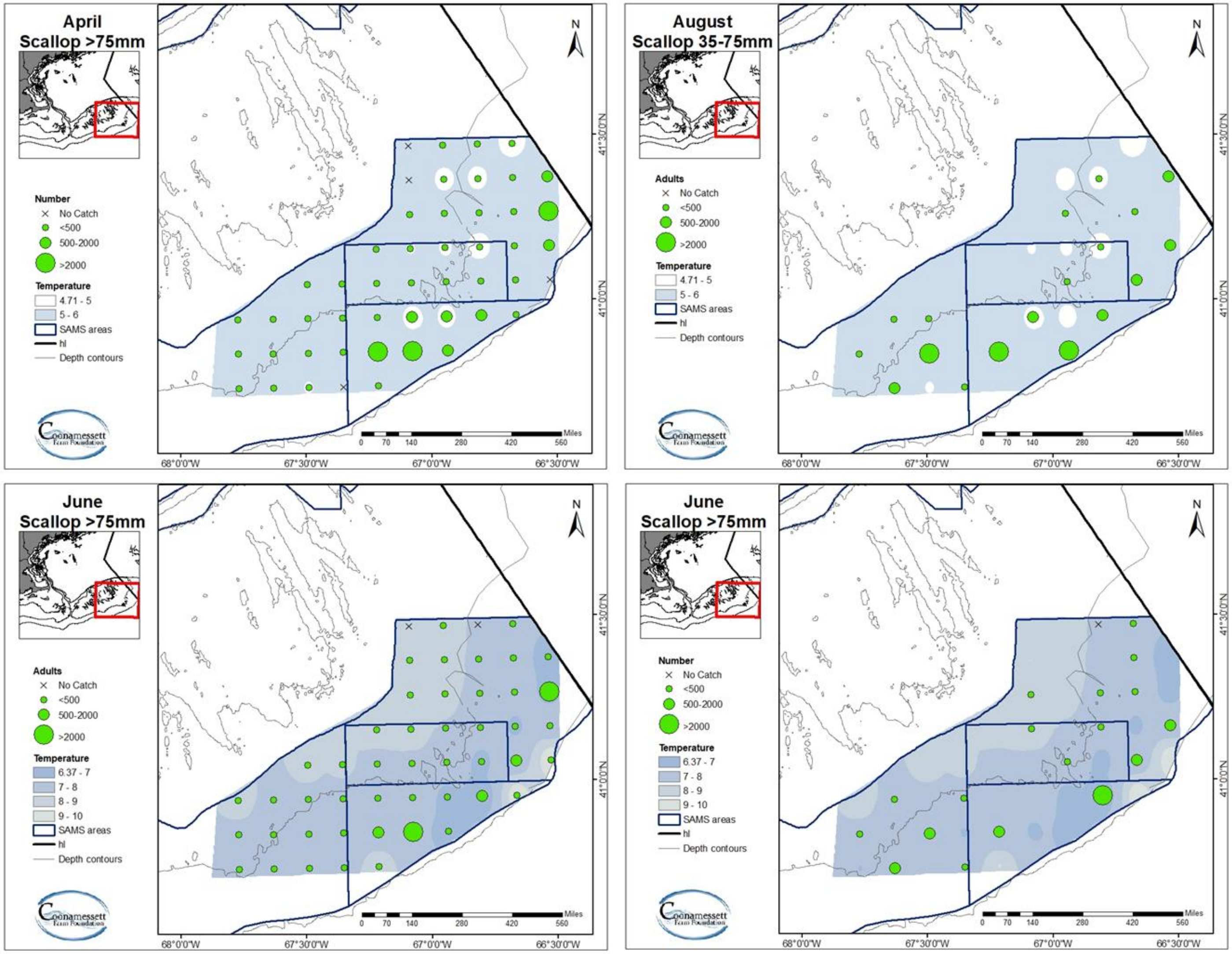


Figure E3. Distribution of adult scallops caught with the uncovered dredge (left maps) and the covered dredge (dredge + cover net; right maps) during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

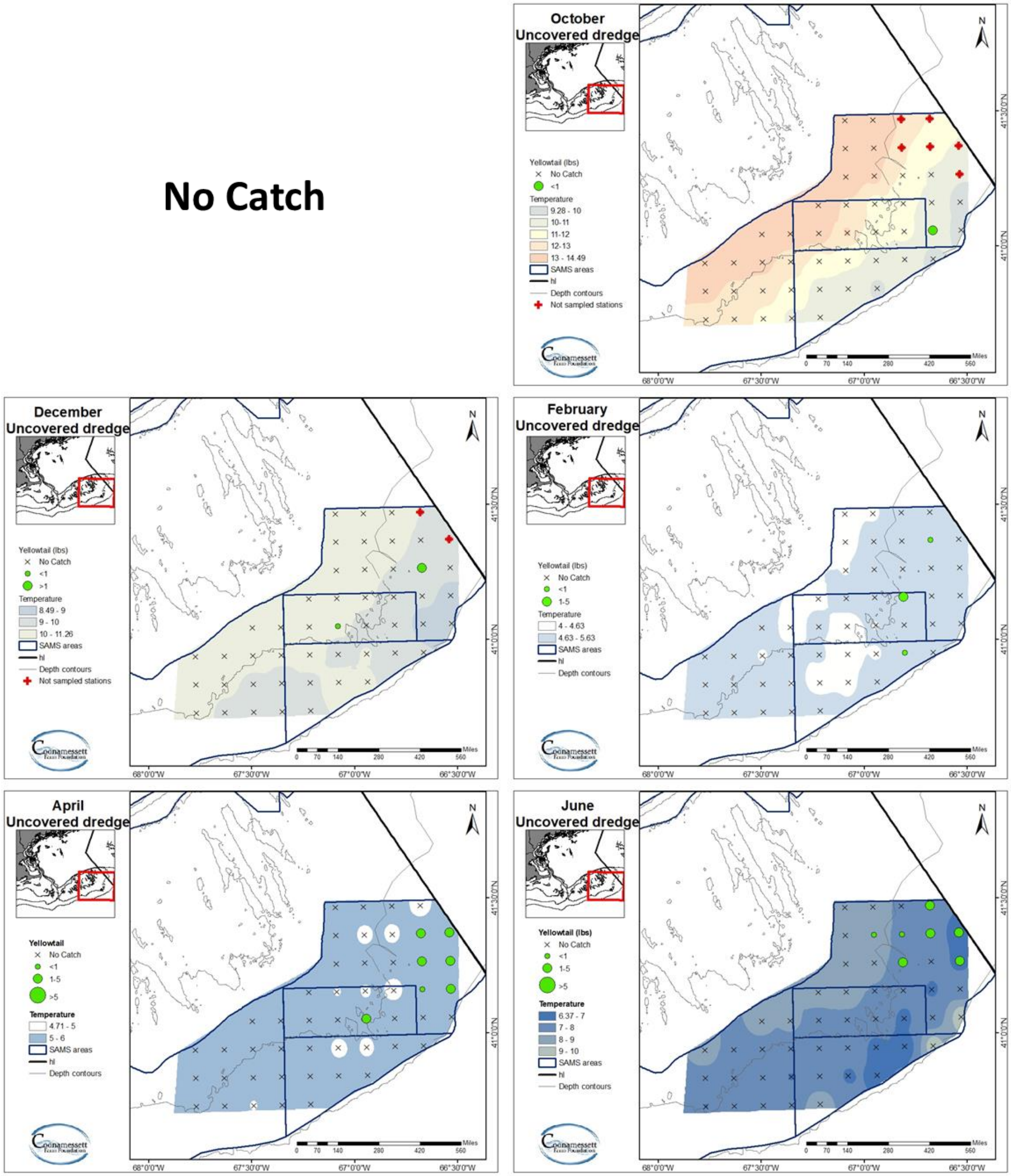


Figure E4. Distribution of yellowtail flounder caught with the uncovered dredge during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

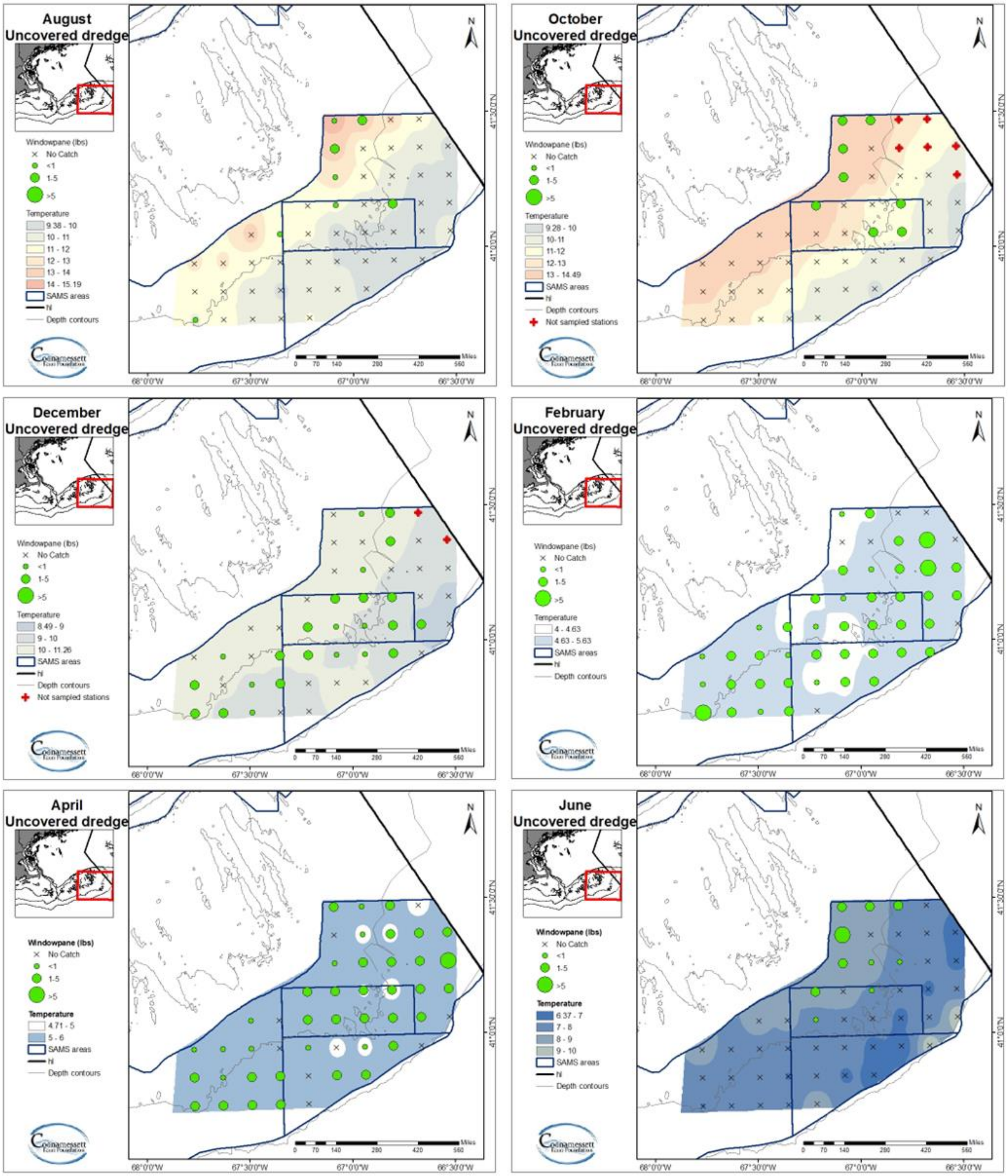


Figure E5. Distribution of windowpane flounder caught with uncovered dredge during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

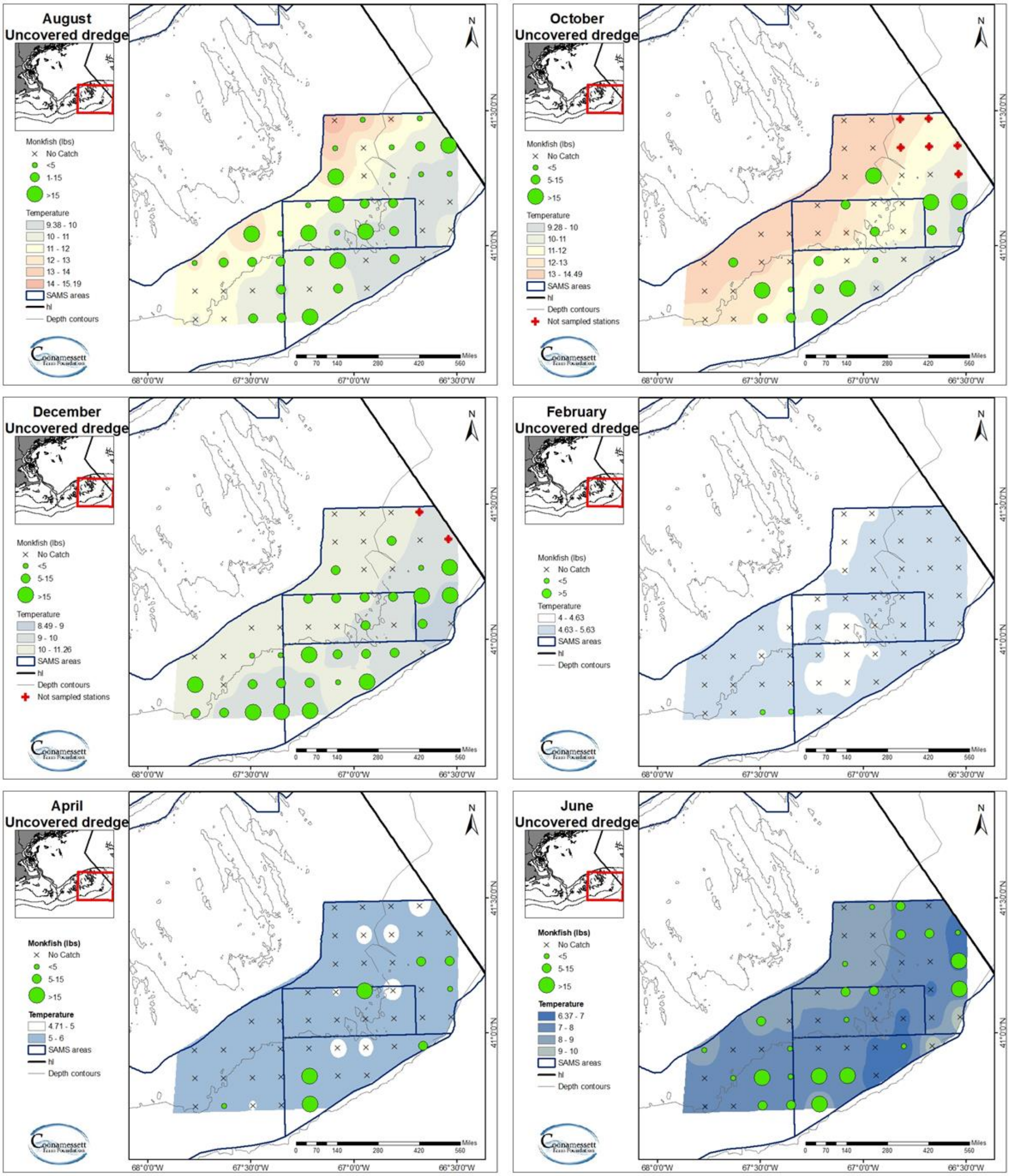


Figure E6. Distribution of monkfish caught during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

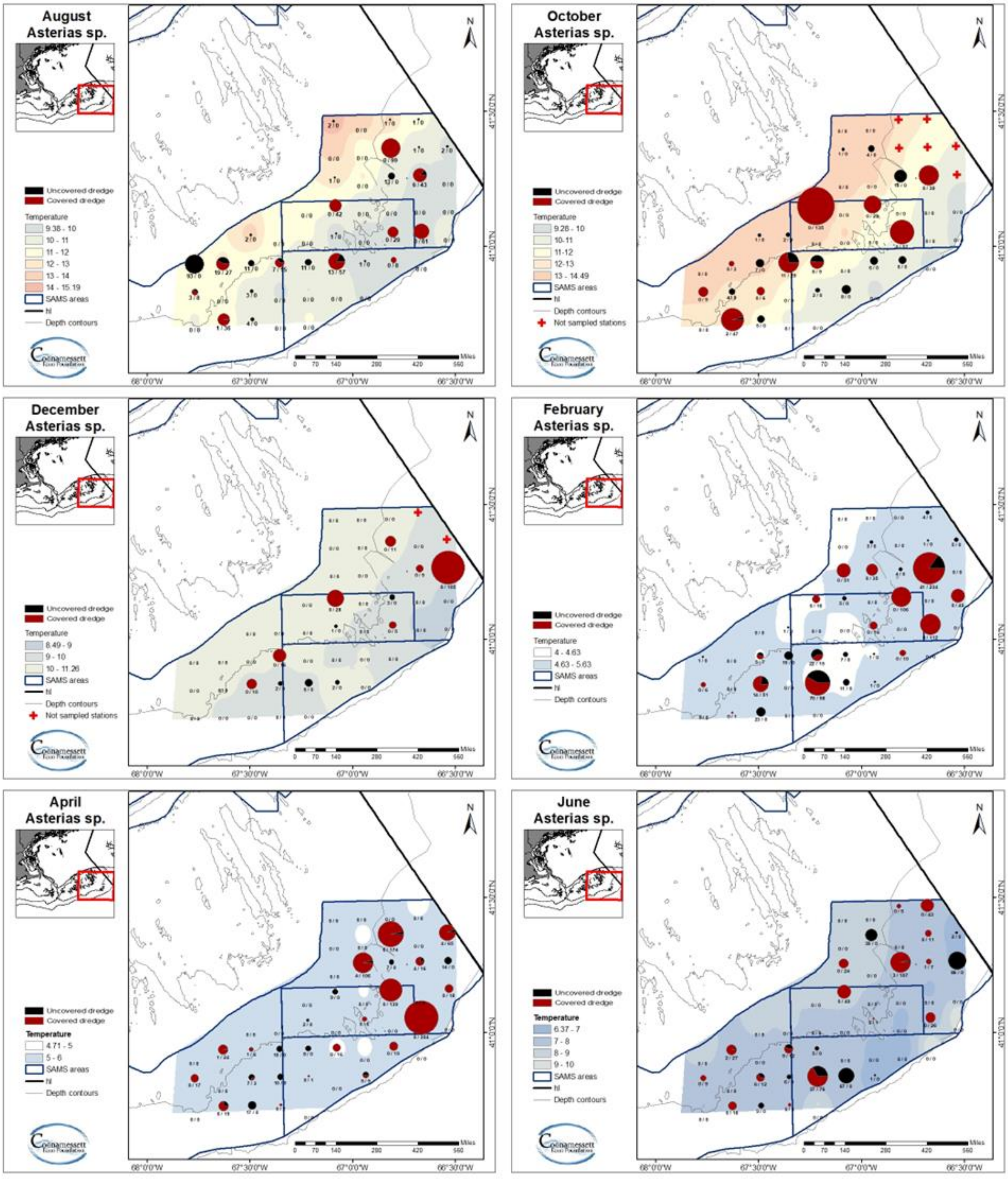


Figure E7. Distribution of Asterias sp. caught with both dredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

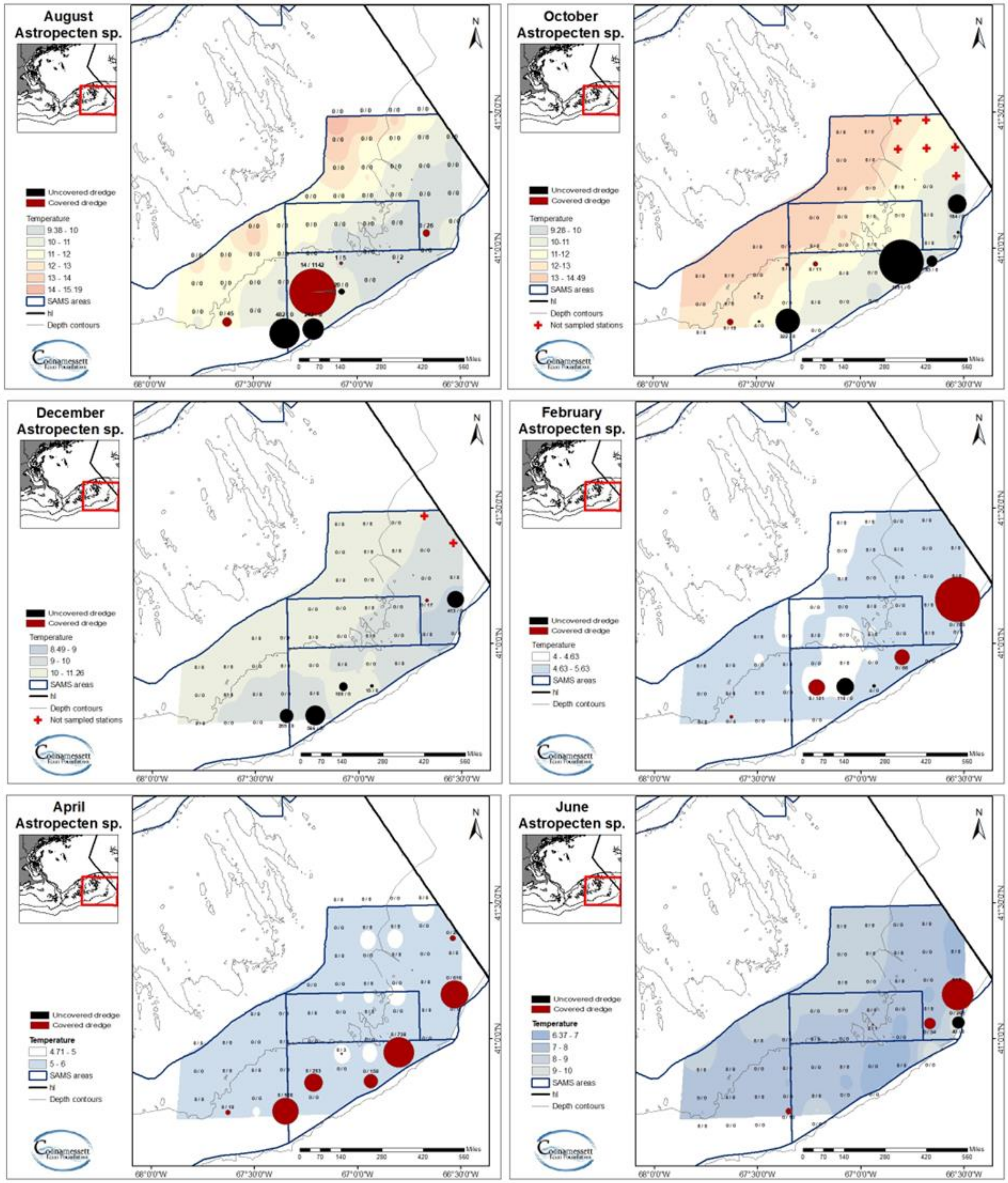


Figure E8. Distribution of Astropecten sp. caught with both dredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

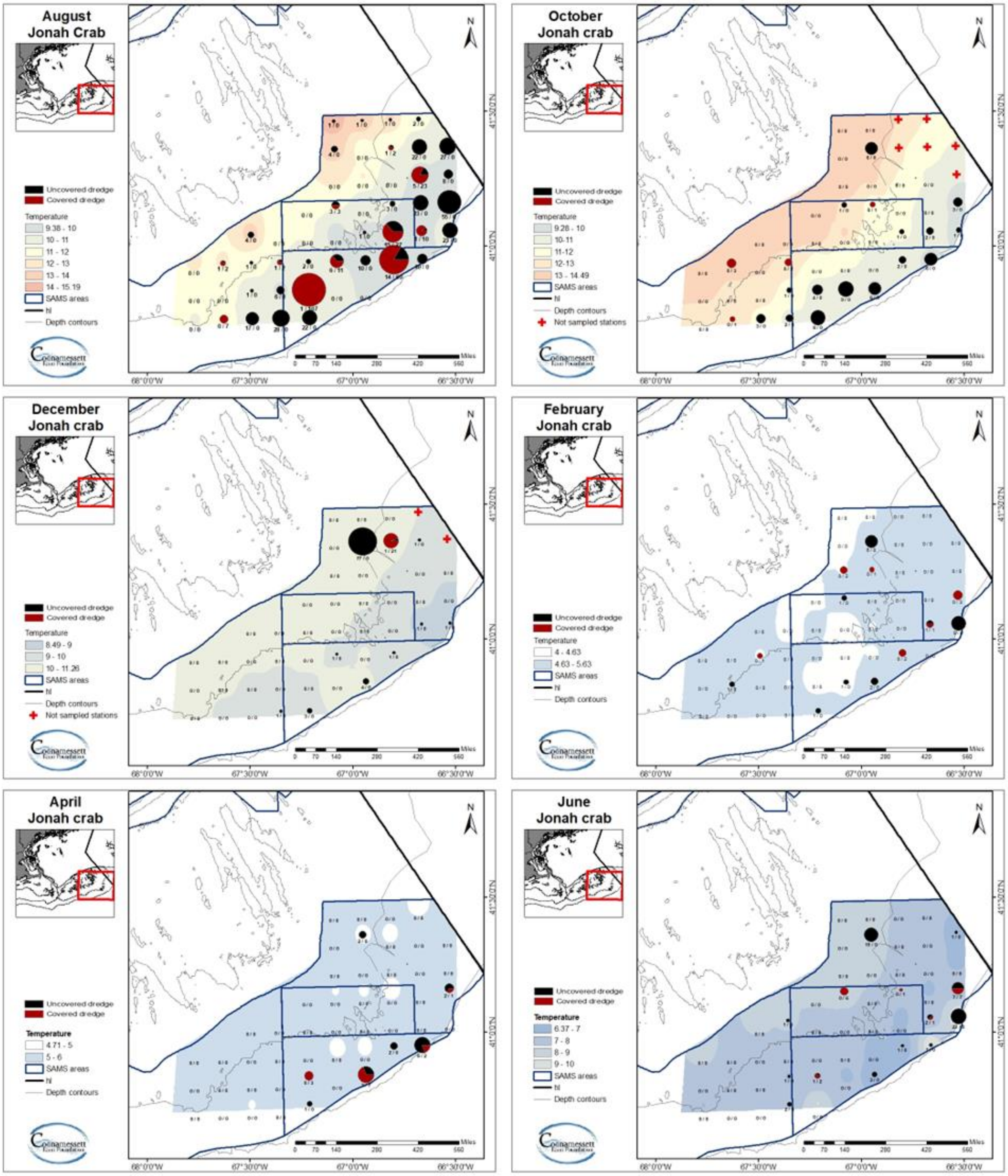


Figure E9. Distribution of Jonah crabs caught with both dredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

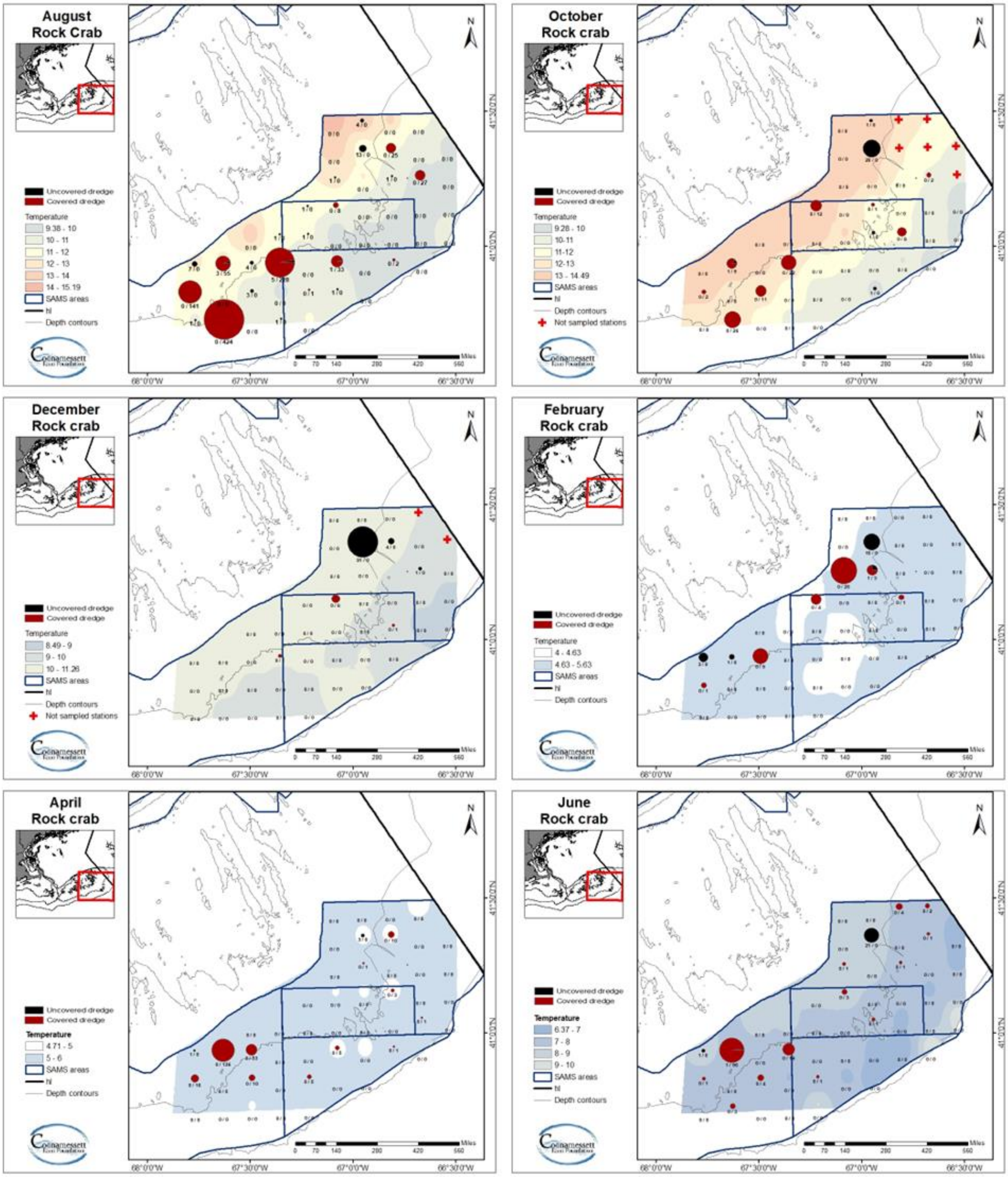


Figure E10. Distribution of rock crabs caught with both dredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

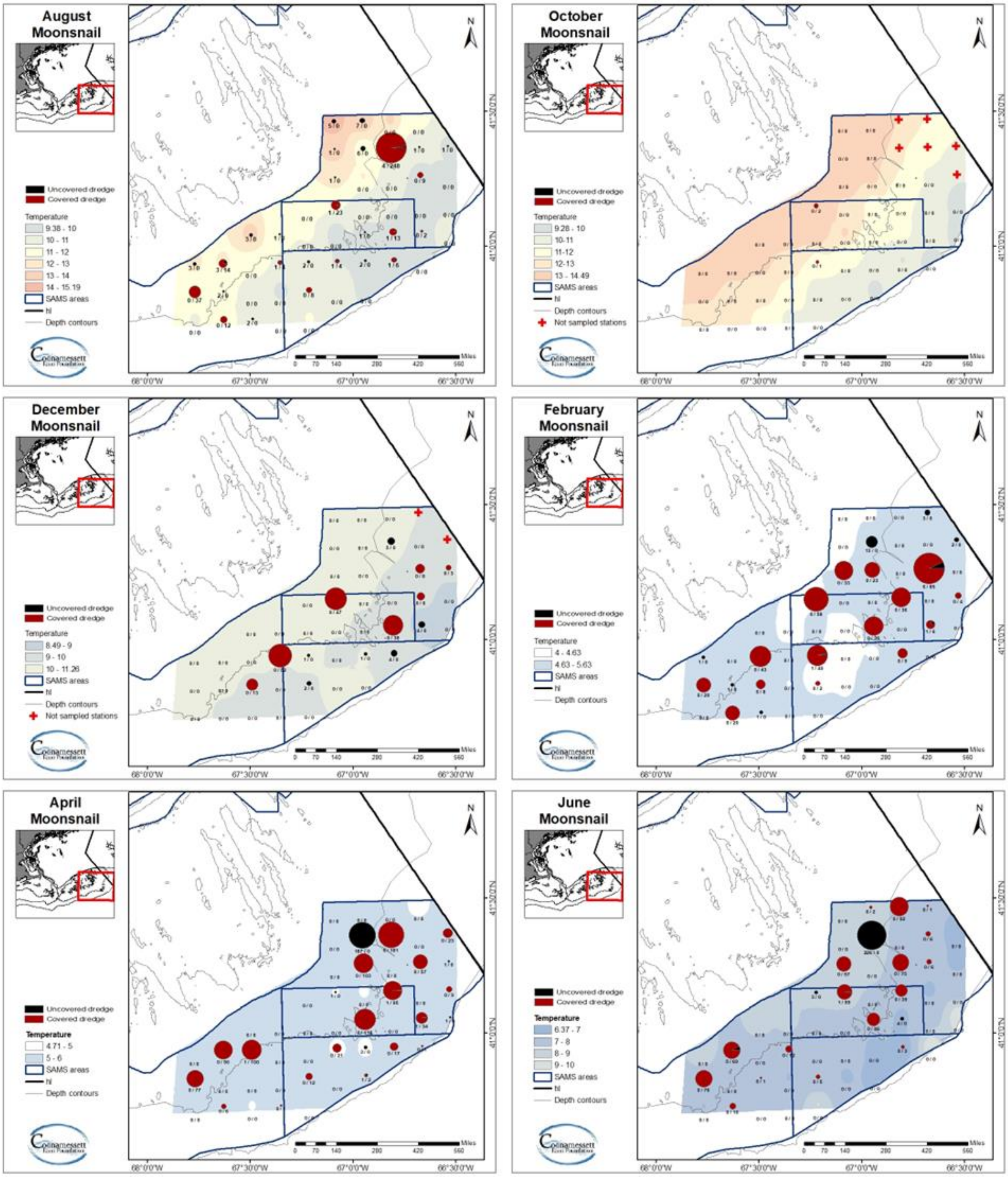


Figure E11. Distribution of moon snails caught with bothdredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.

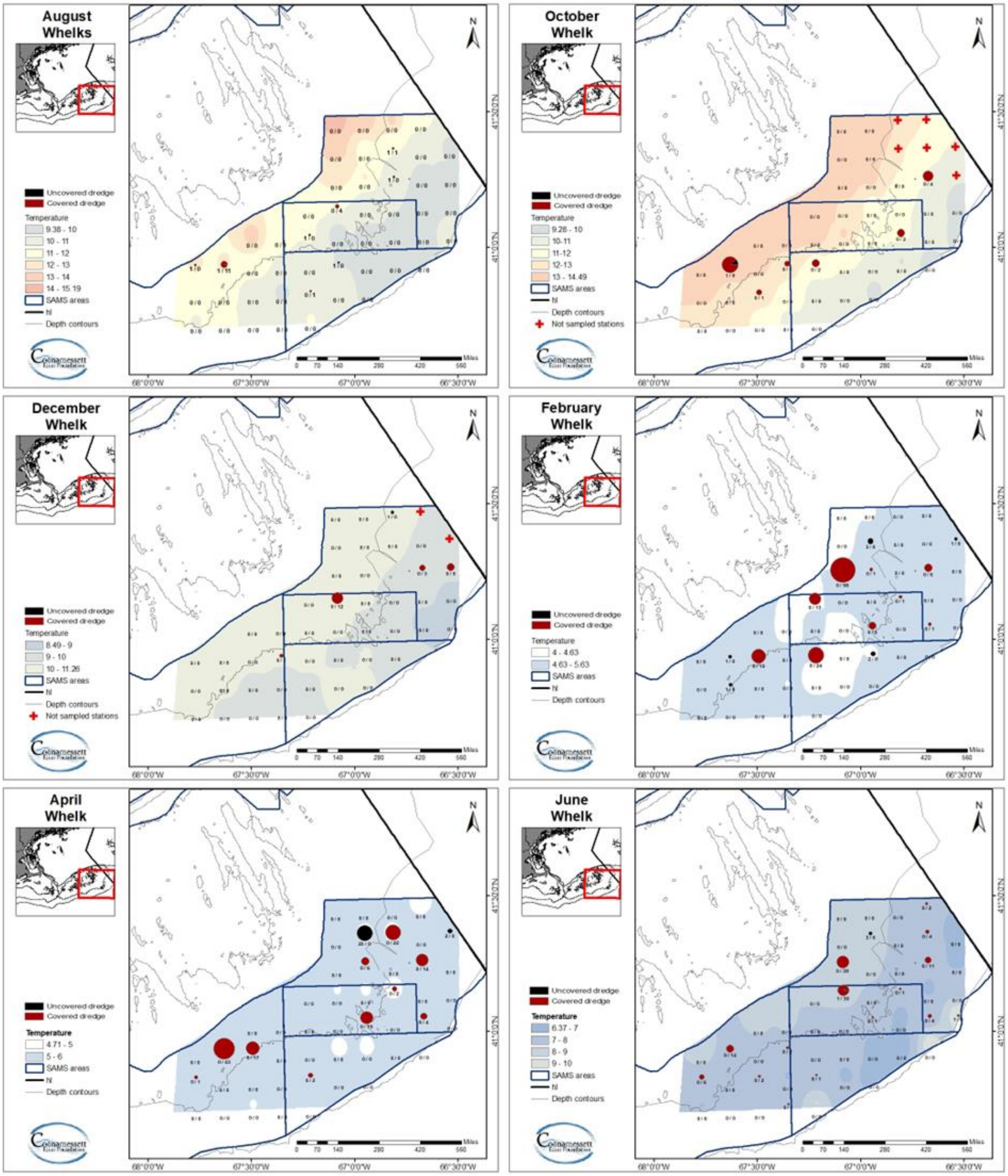


Figure E12. Distribution of whelks caught with both dredges during the 2023 seasonal survey on eastern GB shown over observed bottom temperature. Temperatures (°C) were interpolated using the IDW method and illustrated with cooler and warmer colors associated with respective temperatures.