Final Technical Report
for
Fishing Year 2022 Scallop Research Set Aside
Award Number: NA22NMF4540050

Sea Scallop Growth and Reproduction Research to Support Improved Resource Management

Award Period: 04/01/2022 – 07/31/2024
Report Date: 10/01/2024

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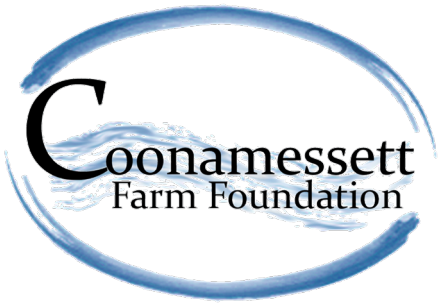

This report was prepared by CCCFA and CFF using Federal funds under Cooperative Agreement Award NA22NMF4540050 from NOAA Fisheries, U.S. Department of Commerce. NOAA Fisheries is responsible for the stewardship of the nation's ocean resources and their habitat. The statements and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA Fisheries or the U.S. Department of Commerce.

EXECUTIVE SUMMARY

RSA Project Title: Sea Scallop Growth and Reproduction Research to Support Improved Resource Management

Year Awarded: 2022

RSA Priorities Addressed By This Research: scallop biology

Industry Partners Collecting Data: LAGC Scallopers: F/V Tricia Lynn, F/V Nemesis, F/V Midnight Our, F/V Helltown, F/V Kahuna, F/V Three Graces, F/V Three Sons, F/V White Cap, F/V Outlaw, F/V Godzilla, F/V Bada Bing, F/V Isabel & Lilee, F/V Joanne A III, F/V Sandra Anne

Industry Partners Compensation Fishing: LAGC Scallopers: F/V Tricia Lynn, F/V Nemesis, F/V Midnight Our, F/V Helltown, F/V Kahuna, F/V Three Graces, F/V Three Sons, F/V White Cap, F/V Outlaw, F/V Godzilla, F/V Bada Bing, F/V Isabel & Lilee, F/V Joanne A III, F/V Sandra Anne, F/V Jessica Heather, F/V Ernest & Michael, F/V Miss Emma, F/V Roen Keil, F/V Rolex, F/V Small Stuff

In collaboration with 14 sea scallop captains, the Cape Cod Commercial Fishermen's Alliance and Coonamessett Farm Foundation piloted an industry-based biological sampling program that provides monthly insights into how meat yields and spawning seasonality changes throughout the year. The lessons learned during the pilot serve as a foundation to create a cost-effective, long term sampling program to track gonad-based reproductive potential and support more accurate scallop stock assessments in the face of changing climate and a shrinking scallop biomass.

This pilot project was designed to create an affordable way for dayboat fishermen to bring 25 live sea scallops (*Placopecten magellanicus*) to a shoreside lab where technicians recorded size, weight of soft tissues, sex, and reproductive stage. This data is regularly collected at sea during traditional summer surveys, but is not collected year round to track seasonal changes. Over the course of 22 months (4/21/2022 to 1/9/2024) and 73 trips, 25 scallops were collected weekly, weather permitting, resulting in 1763 individual samples.

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, gonadal mass index (GMI) and gonadosomatic index (GSI). Shell height-meat weight relationships were also modelled. A conversion factor was developed to allow comparisons between wet weights and dry weights. From this, two models were developed to evaluate the relationship between the wet and dry weights of two important sea scallop soft tissues: the abductor muscle (meat) and the gonad.

The results of this project provide a template to collect important data needed by fisheries managers, for science-driven management decisions that strengthen the country's valuable commercial scallop fishery.

GOAL & OBJECTIVES

Our broad goal for this study was to contribute to the body of knowledge needed to improve sea scallop stock assessment for the Georges Bank Stock Area and ensure sustainable management of this fishery in the face of changing oceanographic conditions. We worked cooperatively with the commercial fishing industry to accomplish the following objectives:

1. Identify spawning seasonality through examination of gonads.
2. Explore the seasonality of relationships between scallop morphometrics and soft tissue weights.
3. Develop a conversion factor to allow comparisons between wet weights (typically collected in the federal survey) and dry weights (a standardized value that requires more time and effort to obtain and is not practical at sea).
4. Pilot an affordable industry-supported biological sampling program that could be expanded more broadly in the scallop fishery as well as transferred to other fisheries to support applied science and management with finer scale temporal data than are available through traditional sampling means. Work closely with NEFSC to ensure resulting data is useful to management.

BACKGROUND

Sea scallops (*Placopecten magellanicus*) are bivalves that inhabit the Northwest Atlantic Ocean between Newfoundland, Canada and North Carolina, USA (NOAA 2020). Although they can live for several decades, sea scallops are thought to reach sexual maturity around age two. Sea scallops are harvested by a dredge fishery based primarily in the Mid-Atlantic and Southern New England states. In recent years, this fishery has consistently ranked as one of the most valuable fisheries in the nation (NMFS 2020). Scallop harvesters are permitted in two main groups: Limited Access (LA) and Limited Access General Category (LAGC; GARFO 2020). As of Fishing Year 2024, LA vessels are limited in access areas to 12,000 lbs of shucked meats per trip and LAGC vessels are limited to 600 lbs of shucked meats per open bottom trip and 800 lbs of shucked meats per access area trip. Due to this difference in limits, LA trips can last for a week or more, while LAGC trips typically last for under two days.

The Northwest Atlantic Ocean is currently undergoing major oceanographic shifts, including increases in water temperature and acidity, both of which have the potential to alter sea scallop biology (Cooley *et al.* 2015). Previous research has noted that scallop spawning typically takes place during the maximum water temperature and periods of mixing, when warm water from the surface reaches the bottom of the water column (Bonardelli *et al.* 1996). In the Mid-Atlantic Bight, where waters are warmer, sea scallops reliably spawn in the late spring and early summer (Kirkley and DuPaul 1991). An additional spawning event may take place in the late summer and early fall, but is not consistent. In New England, the majority of spawning takes place in the late summer and early fall (Thompson *et al.* 2014), while sea scallops off the coast of Newfoundland spawn in the mid-summer (Bonardelli *et al.* 1996). As water temperatures increase off the coast of New England, marine species from the Mid-Atlantic are projected to move north (Hare *et al.* 2016) and in some cases, have already begun to move (McMahan *et al.* 2020). For species whose range spans both regions, such as sea scallops, the change may manifest more subtly as a shift in life history strategies such that scallops in New England may grow and reproduce more like scallops in the Mid-Atlantic as waters warm. Similar shifts in life history for other scallop species are expected based on climate change forecasts (Gourault *et al.* 2019), although such simulations have not been designed for our region yet. In addition to oceanographic shifts impacting sea scallop reproduction,

sea scallop density also impacts reproductive output and challenge expected outcomes of rotational management (Kowaleski *et al.* 2024). Changes in life history could have profound impacts on stock assessments and commercial fisheries.

Current stock assessments of scallops rely on estimates of reproductive potential associated with meat weight. The use of gonad-based estimates is more closely linked to the biological reality and may reduce uncertainties associated with meat weight-based estimates. As part of the 2018 stock assessment for sea scallops, the idea of using a gonad-based estimate of spawning stock biomass was discounted due to needing additional work, but the panel recommended "further development of the gonad-based spawning stock biomass metrics" (NEFSC 2018). In June 2020, the New England Fishery Management Council identified the development of a standard way to measure scallop gonads and a better understanding of gonad weight changes over time as important, near-term research priorities necessary to continue the sustainable harvest of sea scallops from our changing environment (NEFMC 2020). In response, this project was designed to address these Council research priorities while also addressing scallop RSA priority #2 – scallop biology, specifically reproduction, timing of spawning, age, growth, and yield.

Current federal survey efforts for the sea scallop resource only take place over a one-month period between mid-May and mid-June every year, making the data generated from this survey ill-suited for evaluating monthly changes in gonads. In addition, despite the availability of other RSA funded projects collecting this type of data in a near real-time basis on Eastern Georges Bank (CFF seasonal bycatch surveys), the government has not yet integrated this limited data in the stock assessment process. Commercial fishing takes place nearly year-round, providing potential platforms to collect samples in all seasons across a wide geography. For example, meat weights are already collected year-round through the sea scallop observer program, although that requires sending additional scientific staff to sea. Because of their low trip limits and correspondingly short trips, the LAGC fleet is well-equipped for delivering fresh, live samples to scientists on shore. Many of these vessels maintain seawater tanks on board to land live scallops for specialty markets. Bringing the samples to shore allows for more cost-effective sample collection (as vessels do not need to be chartered and scientists are not at sea for days on end). Additionally, shoreside sampling removes some of the known problems associated with taking morphometric measurements at sea (Jacobson *et al.* 2010).

The relationship between morphometrics (such as shell height) and soft tissue weights (such as meat weight) can vary over space and time (Sarro and Stokesbury 2009; Rothschild *et al.* 2009). Within a single year, seasonal changes in energy allocation results in scallops putting more energy into gonads (before spawning) or growth (post-spawning) at the expense of the other. The balance between somatic growth and gonad development interacts with the cyclical availability of food resources (Shumway *et al.* 1987) such that meat weight is highest in the midsummer when resources are abundant and midwinter when gonad development is deemphasized (Hennen and Hart 2012). The relationship between meat weight and shell height can also vary between years (Sarro and Stokesbury 2009; Rothschild *et al.* 2009) with growth varying based on factors such as food availability (Shumway *et al.* 1987), water temperature (Hart and Chute 2009), scallop density (Harris and Stokesbury 2006), and water depth (Shumway and Schick 1987; Hennen and Hart 2012).

Understanding how morphometrics and tissue weights are related can be beneficial to resource managers and stock assessment biologists. Because shells are shelf-stable and can be measured in-situ using drop video or still frame imagery (Bethoney and Stokesbury 2018), large quantities of morphometric data can be efficiently collected and processed. However, in order to make these data meaningful to stock projections, assessment biologists and managers must understand the relationship between the size of the shell and the size of the animal contained inside (Hennen and Hart 2012). Additionally, understanding how the animals apportion growth between somatic tissue and gonads during different parts of the year (which may shift as climate changes) can help inform biomass estimates generated during that time of year.

Both wet weights (Bayer *et al.* 2016) and dry weights (Thompson *et al.* 2014) are used in scallop research to measure tissue. Wet weights are typically collected by patting the tissue sample dry with a paper towel and then placing it on a balance (Hennen and Hart 2012; Bayer *et al.* 2016). Dry weights require placing the tissue into a drying oven for several days (Thompson *et al.* 2014) and monitoring its weight loss during that time. Once the tissue's weight stabilizes, it is presumed to be dry (Mo and Neilson 1994). Collection of wet weight data offers several advantages that make it a more attractive option for sampling at sea including faster sample processing (minutes instead of days), reduced equipment footprint (just a balance instead of a balance and a drying oven), and lower electrical demand. However, patting tissue dry with a paper towel is not a standardized process, introducing a source of potential variability into data collection that would not exist if dry weights were used instead.

METHODOLOGY

Protocols were developed prior to the RSA award by Dr. George Maynard, former CCCFA Research Director now a Marine Resources Management Specialist at the Northeast Fisheries Science Center, and Dr. Dvora Hart, lead assessment biologist for Atlantic sea scallops at the Northeast Fisheries Science Center, in collaboration with LAGC scallopers (Capt. Jesse Rose, F/V Midnight Our and Capt. Robert Dutra, F/V Rolex).

Participating scallopers landed samples from the Georges Bank Stock Area and Northern Gulf of Maine Stock Area based on their fishing practices, with a goal of collecting a sample of 25 live scallops from one vessel each week, throughout the year and from a range of geographies. When selected for sampling, the participating scallopers fished as normal, setting aside at least 25 randomly selected scallops from a single tow (preferably their last), taking note of approximate location (GPS coordinates), depth fished, time brought on deck, time landed in port, if stored on ice or in chilled seawater, and surface water temperature (if possible). Whole live scallops were delivered to PI Sanderson or other project staff shoreside and transported to the CCCFA lab in Chatham, MA on ice within 15 minutes for immediate dissection by CCCFA staff.

Scallops were assigned a unique identification number prior to dissection to track all records associated with the animal. Each individual was weighed, then cleaned with a wire brush (Figure 1, Hennen and Hart 2012), and weighed again. Shell height, width, and length (Figure 2) was collected using iGaging Model 100-700-B12 digital calipers (San Clemente, CA) with a resolution of ± 0.01 mm, following standard procedures (Pedersen 1994). Animals were carefully shucked opened, sexed and visually assessed for gonad development stage (ripe, developing, partially spent, spent, resting) using photographic guide provided by Coonamesset Farm Foundation. A

photograph was taken of the animal in the shell for future QA/QC of gonad development stage. Animals were dissected into four parts (Figure 3); shell (upper and lower), meat (the adductor muscle), gonad, and viscera (i.e., all soft tissue excluding the meat and the gonad). Each part was blotted dry with paper towels, following existing scallop survey protocols. Wet weights were collected for the whole animal, gonad, meat, shells, and viscera following standard procedures (Hennen and Hart 2012; Bayer *et al.* 2016) and using a Fristaden Labs JNB30002 digital balance (Reno, NV) with a resolution of ± 0.01 g. Shells were labelled with identification number and photographed on a measuring grid (Figure 4). Tissue parts were placed into separate pre-weighed stainless steel cups and set on stainless steel trays with the shells and dried in a Quincy Lab 20AF drying oven (Chicago, IL) at 105°C for no less than 24 hours. Immediately upon removal from the oven, each sample was reweighed to record dry weights of the parts and the whole. Lab standards were measured using both the balance and the calipers before each sampling session to ensure quality of measurements.

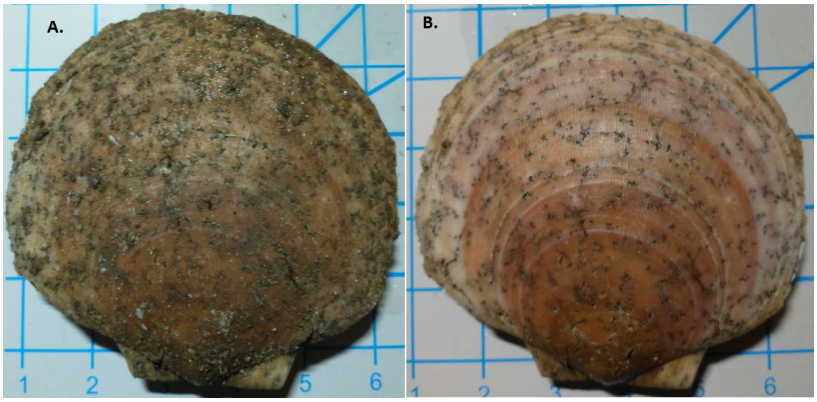

Figure 1 – Fresh scallop shell (A) and shell cleaned with wire brush (B)

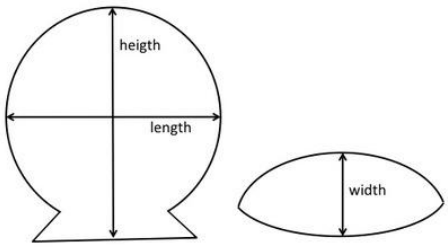

Figure 2 – Standard shell height, length, and width measurements (modified from Pedersen 1994).

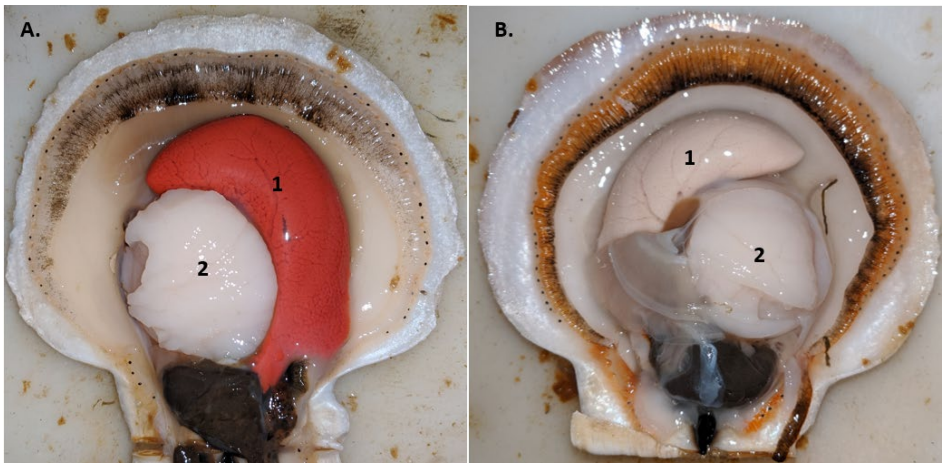

Figure 3 – A female (A) and male (B) scallop with the gonad (1) and meat (2) labeled.

Figure 4 – Image of a cleaned scallop shell on a measuring grid with identification number

All recorded data records were transferred electronically to Coonamessett Farm Foundation (CFF) for QA/QC, data management and storage, and analyses. The data was imported into CFF's Access Database and gonad development stage was confirmed by CFF experienced scallop biologists by review of photographs.

Identification of Spawning Seasonality: One way to assess the timing of the spawn is to monitor the gonadosomatic index (GSI) of the organisms over time (e.g., Thompson *et al.* 2014; Bayer *et al.* 2016). However, Bornadelli and Himelman (1995) examined the assumptions of gonadal indices for assessment of relative gametogenic state of *P. magellanicus* and found that the assumptions were not respected due to differences between maturing and fully mature individuals (Barber and Blake 2016). In addition, they recommended using a gonadal mass index (GMI): $GMI = \left[gonadal \frac{mass}{(shell\ height)b}\right] x\ k$, where b is slope of the regression line for GM against SH, and k is a constant to obtain a value greater than zero. We assessed the wet weight GMI of a minimum of 100 scallops per month during the study period.

Explore seasonality of relationships between scallop morphometrics and soft tissue weights:
Shell height meat weight (SHMW) analysis was plotted by trip to examine seasonal changes (spring, summer, fall, winter), including shell height/width, meat dry/wet weight, gonad dry/wet weight. Scallop meat weight was modeled using a gamma distribution with a log link using the function "pqlmer" in R package "r2glmm" (Jaeger *et al.* 2017). Fixed effects for predicting meat weight included shell height and season.

Develop a conversion factor to allow comparisons between wet weights and dry weights of soft tissues: In the interest of ensuring our morphometric measures and tissue weight relationships are as precise and accurate as possible, all relationships were developed using dry weights. In order to make those dry weights comparable to the bulk of the federal scallop survey data (which collects wet weights), we will use the wet weights to develop conversion factors describing how much water is lost by different soft tissues during the drying process.

DATA COLLECTED

Twenty five scallops were collected weekly, weather permitting, for 22 months, from 4/21/2022 to 1/9/2024, on 73 trips. They were processed following the described methodology. This resulted in 1763 individual samples which had morphometric measurements and wet weights recorded, of which 1738 were included in the analysis. 429 of these scallops were dried, of which 400 were used to develop wet to dry conversion factors.

DATA ANALYSIS

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, gonadal mass index (GMI) and gonadosomatic index (GSI). 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).

Scallop GSI were determined following the equation:

$$GSI = \frac{DGW}{DMW}\ x\ 100$$

where DGW = dry gonad weight and DMW = dry meat weight (Bougis 1952).

Shell height-meat weight (SHMW) relationship: Scallop meat weight was modeled using a gamma distribution with a log link using the function "pqlmer" in R package "r2glmm" (Jaeger *et al.* 2017). Fixed effects for predicting meat weight included shell height and season. Model outputs are presented in **Table 1**.

RESULTS BY OBJECTIVES

Objective 1: Identify spawning seasonality through examination of gonads.

A total of 1,738 scallops distributed on the tows shown in **Figure 5** were collected and examined for shell height/width, meat wet weight, gonad wet weight. A total of 1,486 scallops were included on the visual examination of reproductive stages (**Figure 6a and 7a**); the highest percentages of ripe scallops occurred from July through September in both years. A total of 1,565 scallops were included in the GMI analysis, and 380 scallops were included on the GSI analysis;

with both analysis two spawning periods were evident, in spring and fall (**Figure 6b,c and Figure 7b,c**).

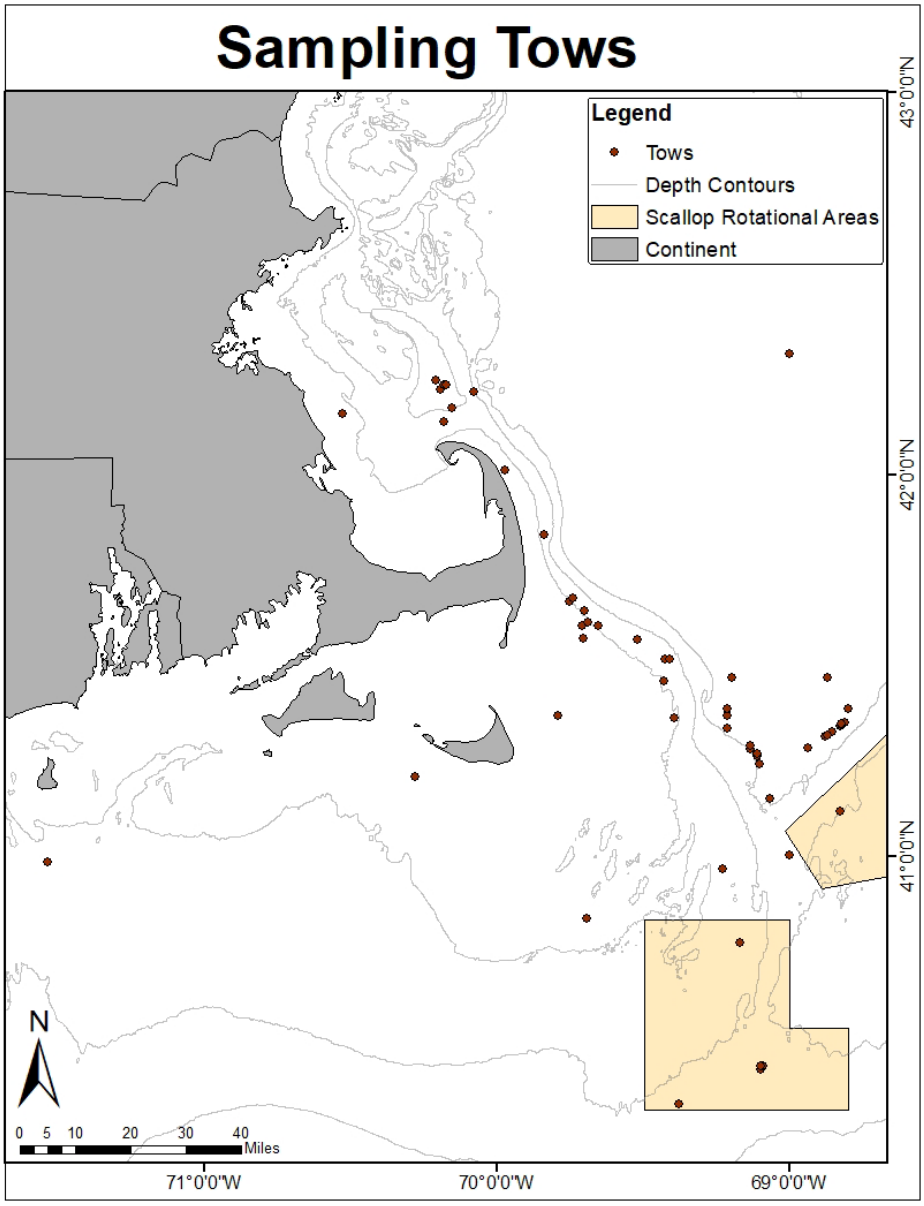

Figure 5. Location of the tows sampled from April 2022 to January 2024.

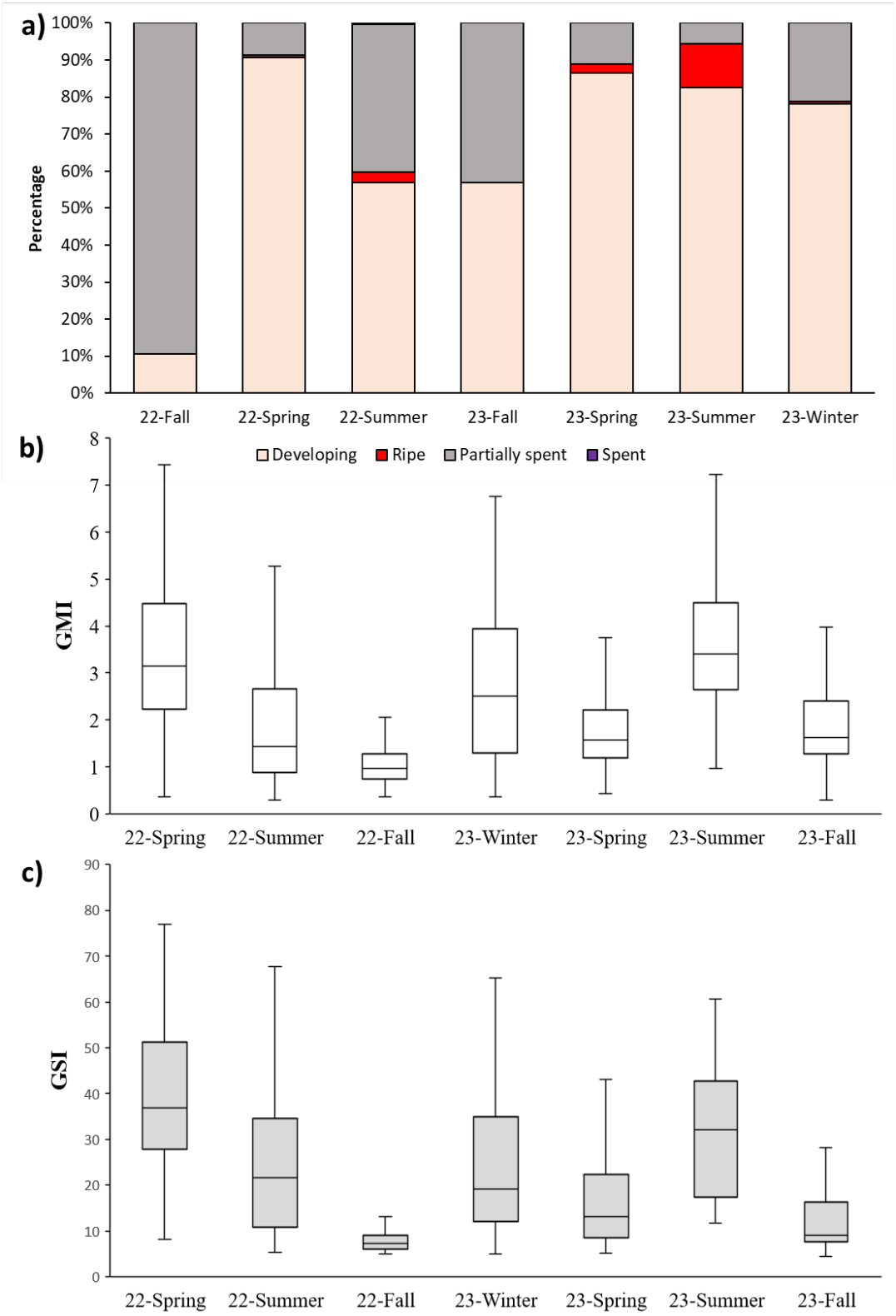

Figure 6. Seasonal **a)** stage results determined through macroscopic observations and **b)** changes in the GMI and **c)** changes in the GSI for scallops by season. For the GMI and GSI plots, boxes end at the first and third quartiles of the distribution of GMI and GSI values, with the whiskers extending to the minimum and maximum values.

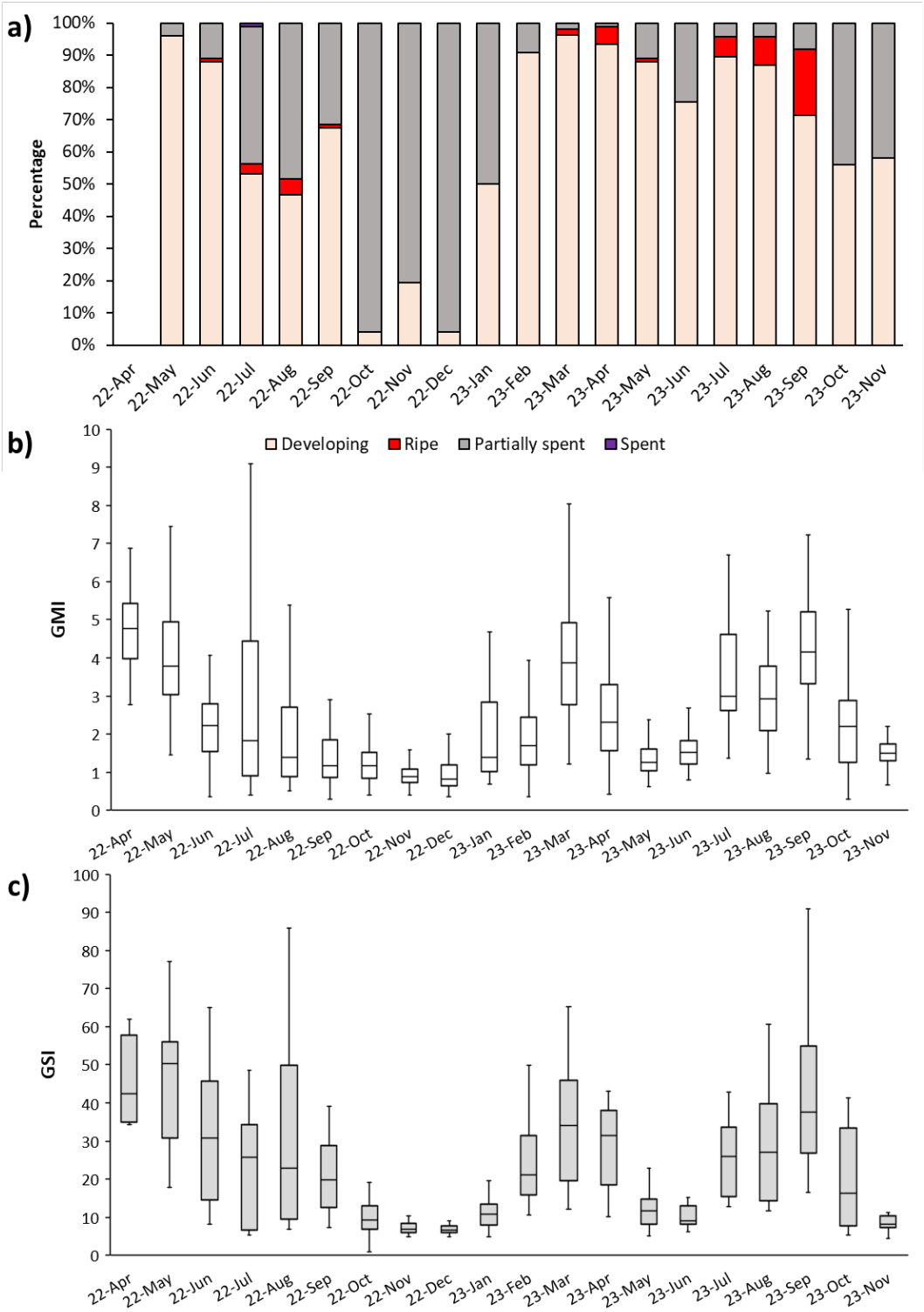

Figure 7. Seasonal **a)** stage results determined through macroscopic observations and **b)** changes in the GMI and **c)** changes in the GSI for scallops by month. For the GMI and GSI plots, boxes end at the first and third quartiles of the distribution of GMI and GSI values, with the whiskers extending to the minimum and maximum values.

Objective 2: Explore the seasonality of relationships between scallop morphometrics and soft tissue weights.

A total of 1,738 scallops were examined for shell height/width, meat dry/wet weight, gonad dry/wet weight. After QAQC 1,587 scallops were included in the SHMW analysis. Scallop shell heights ranged from 73.39 mm to 163.57 mm and meat weights varied from 5.85 g to 76.17 g. Temporal distributions of the collected shell heights and meat weights are shown in **Figure 8.** Predicted meat weights were estimated for all scallops combined by season, meat weights were predicted to be highest during the Spring and lowest during the Fall. (**Figure 9**).

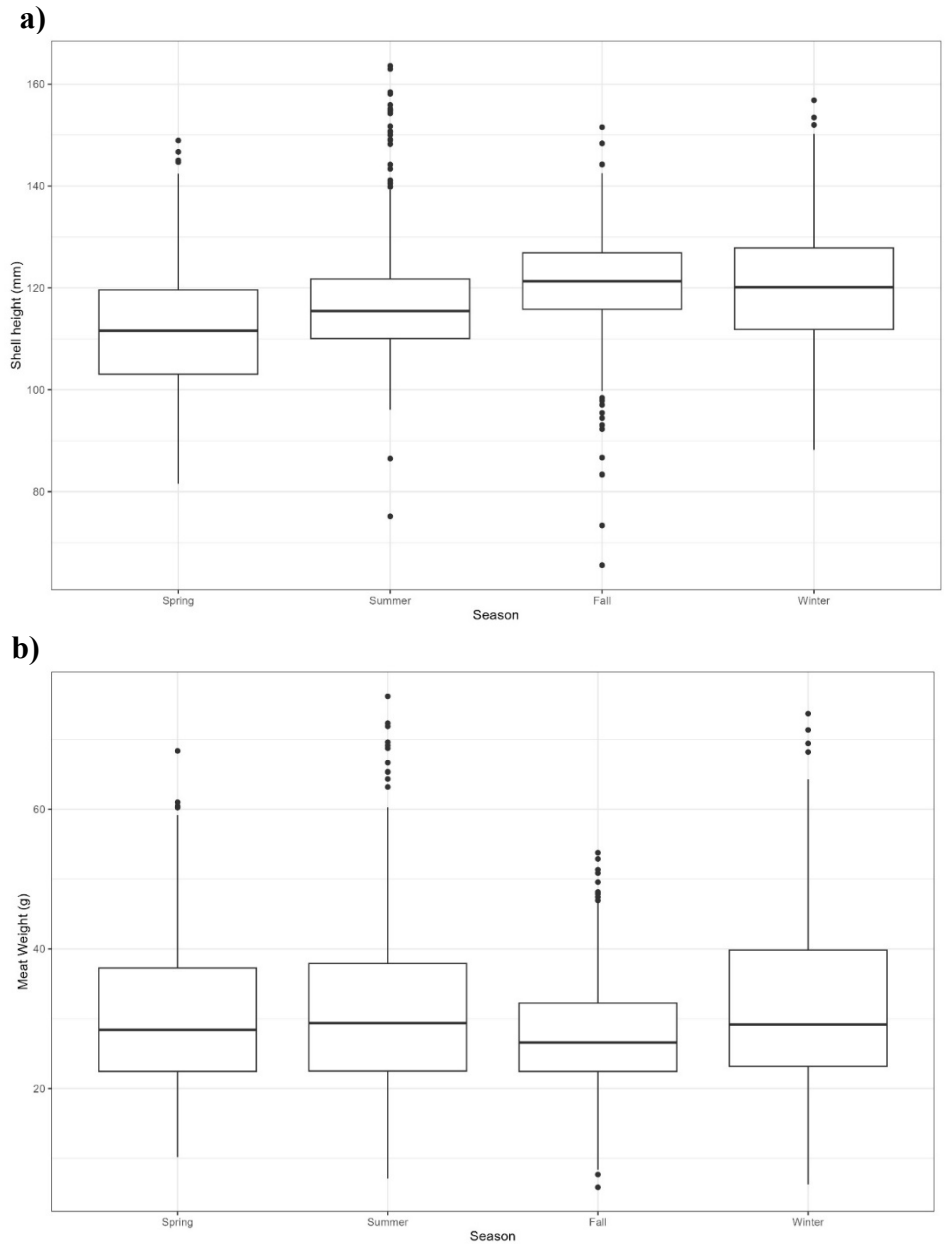

Figure 8. Temporal changes in the distributions of collected **a)** shell height and **b)** meat weight samples. The markers inside the boxes show the median values for each month. Boxes end at the first and third quartiles of the distribution of values for each variable, with the whiskers extending to the minimum and maximum values.

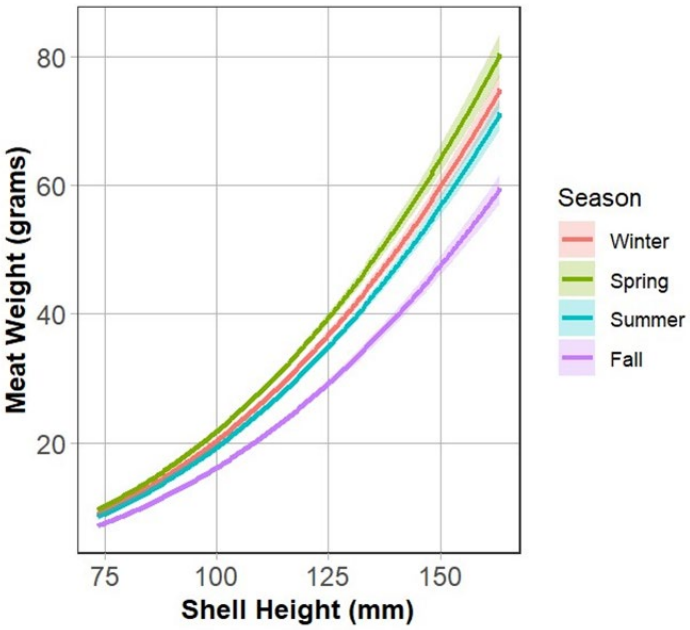

Figure 9. Estimated SHMW curves by season.

Table 1. Modelled scallop meat weight coefficients.

	Estimate	Std.Error	t value	Pr(>|t|
(Intercept)	3.190	0.013	248.77	<2e-16
scale(log(Shell_Height), scale = F)	2.665	0.054	48.67	<2e-16
SeasonSpring	0.300	0.016	18.36	<2e-16
SeasonSummer	0.179	0.016	10.91	<2e-16
SeasonWinter	0.230	0.017	13.85	<2e-16

Objective 3: Develop a conversion factor to allow comparisons between wet weights and dry weights.

After QAQC, dry sea scallop meat and gonad weight pairs were modelled for 400 of the scallops sampled for this project. Conversion factors for wet weights and season as predictors of dry weight were obtained after fitting models to the paired data using R Statistical Software (v4.3.0 R Core Team 2023).

For both the dry sea scallop meat and gonad weight, season was found to be a significant predictor of the observed trend (**Tables 2 & 3; Figures 10 & 11**). For both meat and gonad dry weights, the ratio of wet-to-dry weight was observed to be the highest in Fall (**Tables 4A & 5A**). The ratio of wet-to-dry meat weight was lowest in the Spring (**Table 4A**). While the ratio of wet-to-dry gonad weights was lowest in both the Spring and Summer (**Table 5A**). The seasonal dry weights as predicted by the models using the observed wet weights also follow the observed seasonal wet-to-dry ratio trend (**Tables 4B & 5B**).

The inclusion of area was investigated as a predictor of the relationship between wet and dry tissue weights; however, since sea scallops were not collected from all of the fished areas throughout all four seasons, only three areas were evaluated: Closed Area I-Sliver, the Great South Channel, and Cape Cod (***N=294***; **Tables 6A & 6B**). For the relationship between wet and dry meat weight, the most parsimonious model was the one that included area and wet meat weight, with both being significant predictors of the observed trend (**Tables 7 & 8; Figure 12**). The most parsimonious model for predicting the relationship between wet and dry gonad weights was one that included an interaction between season and area (**Tables 9 & 10; Figure 13**).

Two models were developed to evaluate the relationship between the wet and dry weights of two important sea scallop soft tissues: the abductor muscle (meat) and the gonad. For both tissues, season was found to be a significant predictor of the relationship between the wet and dried tissues. The seasonal trend observed during this project indicates that there is more water in the tissues during the Fall than the other seasons. This is likely due to the spawning condition of the sea scallops during the Fall when a majority of the animals were observed to be partially spent. The relationship between wet and dry gonad weights is more pronounced than the relationship between wet and dry meats. This intuitively makes sense because the composition of the gonad tissue undergoes greater changes throughout the reproductive cycle than the meat.

Though the relationship between season and sea scallop reproductive condition is well established, the reproductive stage of the gonad was not included in either model as a predictor of dry tissue weight. This decision was made, in part, because incorporation of season into the model would already account for changes in reproductive stage during the year. Another reason that the reproductive stage was not incorporated into the model was due to a limited sample size of spent and ripe individuals. Of the 1,738 sea scallops sampled for this project only 29 individuals were observed to be spent and only 33 individuals were observed to be ripe. While great care was taken to ensure the accuracy of assigning reproductive stages visually, there is inherent subjectivity when a categorical variable is used to assess reproductive stage and other research has found that the resting stage between reproductive cycles appears to be uncommon in sea scallops (Clark et al. 2024). Ambiguity between reproductive stages could decrease the accuracy of visual assessment of reproductive stages.

Despite some limitations with these data, we were able to successfully model the relationship between wet and dry meat and gonad weight and provide a means for converting wet weights to dry weights. A general conversion factor (Wet-to-Dry) across all seasons for the abductor muscle is 4.29 and 6.73 for the gonad tissues (**Tables 4A & 5A**). The application of the Generalized Linear Models (GLM) accounts for variation of the conversion factor by season and area (**Tables 7 & 9**).

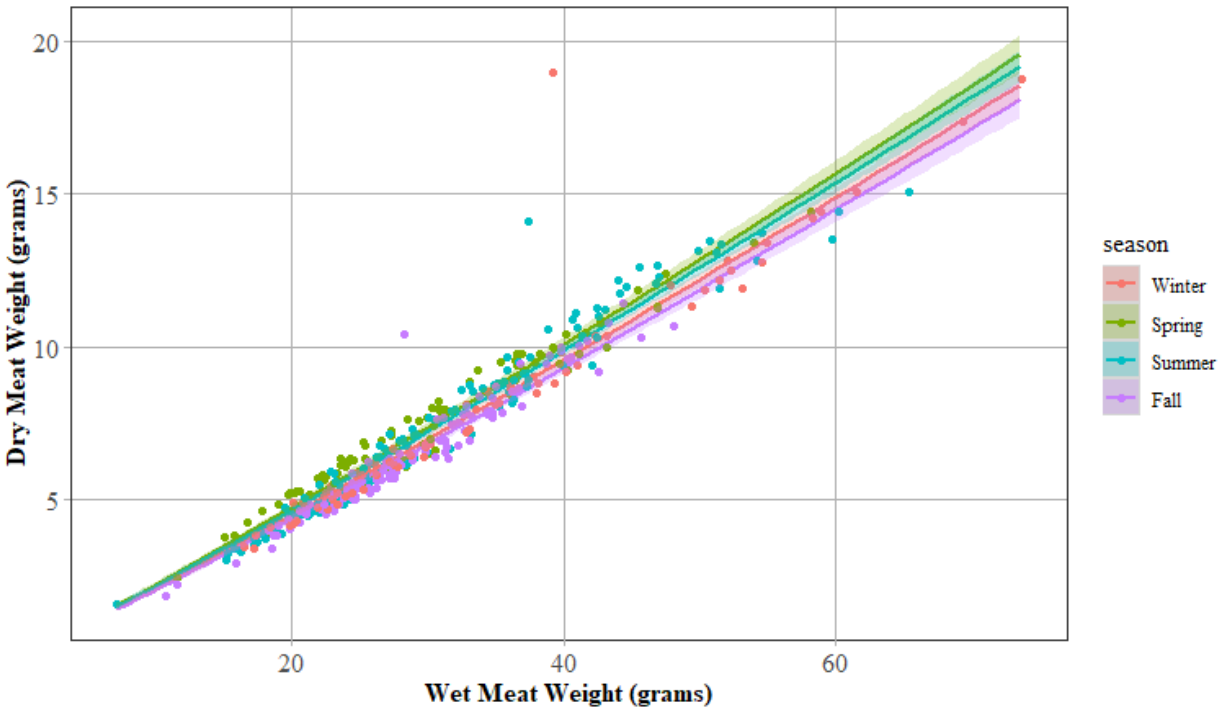

Figure 10. Predicted dry scallop to wet scallop meat weight (g) by season relative to observed trends.

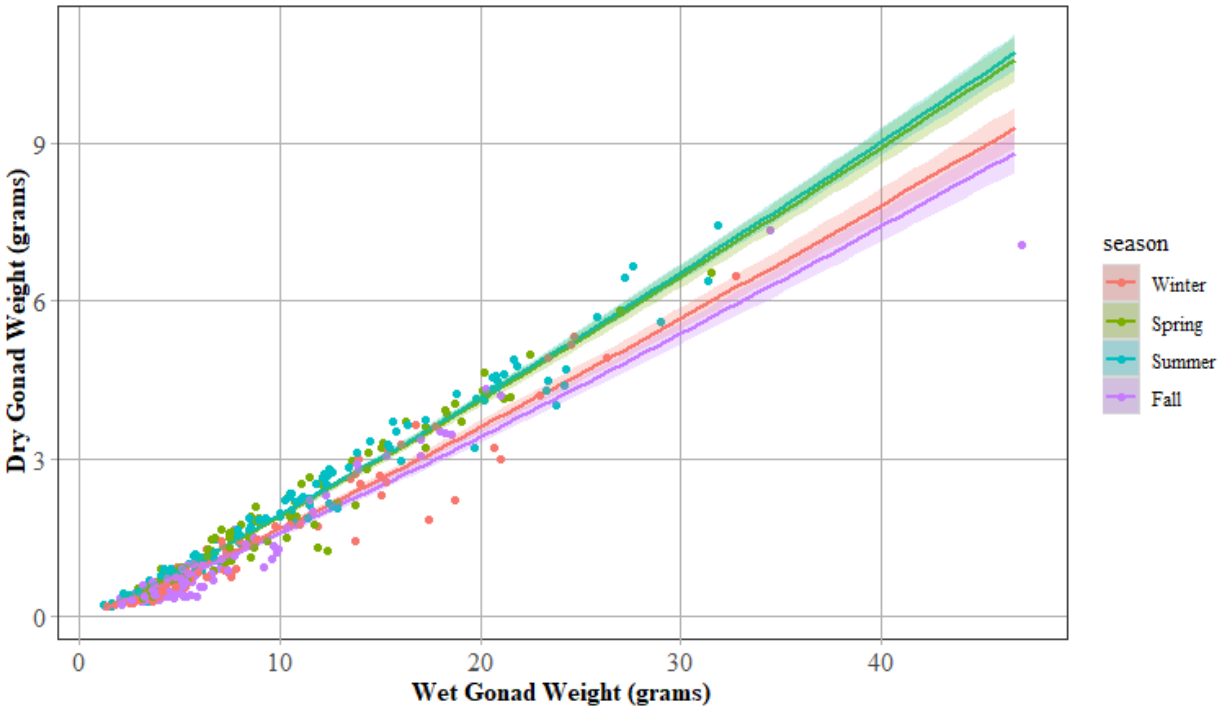

Figure 11. Predicted dry scallop to wet scallop gonad weight (g) by season relative to observed trends.

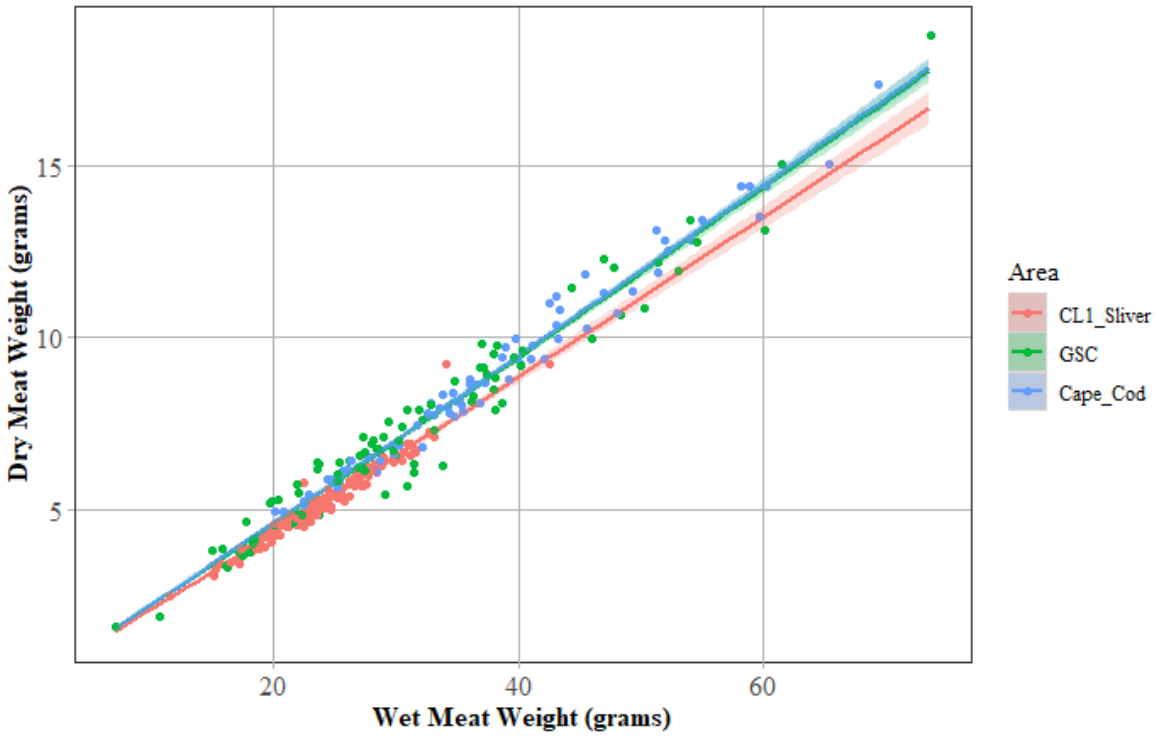

Figure 12. Predicted dry scallop to wet scallop gonad weight (g) by area relative to observed trends.

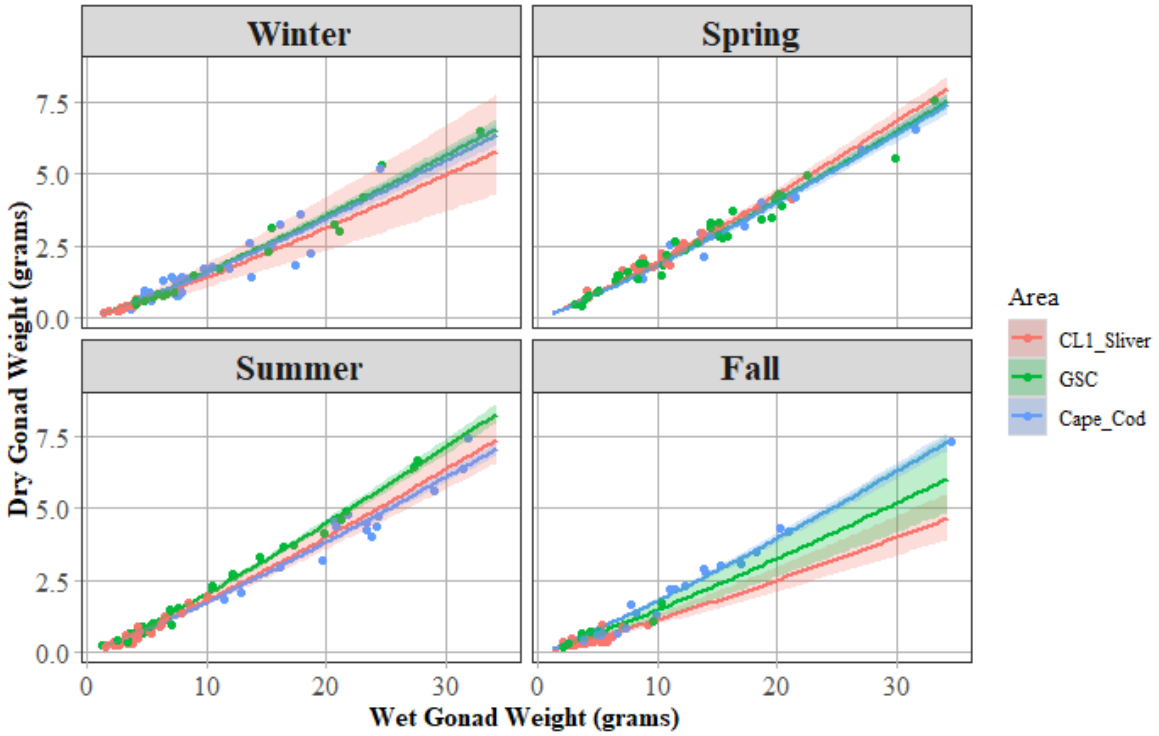

Figure 13. Predicted dry scallop to wet scallop gonad weight (g) by season and area relative to observed trends.

Table 2. Modelled dry scallop meat weight coefficients for the most parsimonious model.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	1.900	0.012	161.567	0
log(WetMeatWeight)	1.088	0.016	69.859	2.02E-224
Spring	0.052	0.015	3.560	4.16E-04
Summer	0.032	0.013	2.442	0.015054969
Fall	-0.026	0.015	-1.703	8.93E-02

Table 3. Modelled dry scallop gonad weight coefficients for the most parsimonious model.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.134	0.021	6.257	1.02187E-09
log(WetGonadWeight)	1.118	0.014	81.875	6.89E-250
Spring	0.131	0.022	5.940	6.24E-09
Summer	0.144	0.020	7.130	4.82336E-12
Fall	-0.052	0.025	-2.050	4.10E-02

Table 4A & B. Mean observed dry and wet scallop meat weight and predicted mean dry meat weight by season. Also presented is the observed conversion factor (Wet/Dry Ratio) relative to the conversion factor using the dry meat weight as predicted by the generalized linear model.

	Observed Values					
	n	***Wet Meat Weight (g)***	***Std Dev.***	***Dry Meat Weight (g)***	***Std Dev.***	***Ratio (Wet/Dry)***
Winter	72	34.111	13.10	8.087	3.62	4.329
Spring	95	29.163	8.90	7.223	2.29	4.065
Summer	126	30.653	11.20	7.398	3.13	4.268
Fall	107	28.667	7.21	6.466	1.98	4.521

	Predicted Values		
	Dry Meat Weight (g)	***Std Dev.***	***Ratio (Wet/Dry)***
Winter	8.092	3.41	4.270
Spring	7.174	2.39	4.100
Summer	7.436	2.95	4.174
Fall	6.501	1.78	4.437

Table 5A & B. Mean observed dry and wet scallop meat weight and predicted mean dry meat weight by season. Also presented is the observed conversion factor (Wet/Dry Ratio) relative to the conversion factor using the dry gonad weight as predicted by the generalized linear model.

		Observed Values				
Season	***n***	***Wet Gonad Weight (g)***	***Std Dev.***	***Dry Gonad Weight (g)***	***Std Dev.***	***Ratio (Wet/Dry)***
Winter	72	9.570	7.04	1.578	1.44	7.165
Spring	95	9.775	6.01	1.874	1.34	5.701
Summer	126	10.404	7.42	2.061	1.65	5.707
Fall	107	6.947	6.38	1.045	1.26	8.351

	Predicted Values		
Season	***Dry Gonad Weight (g)***	***Std Dev.***	***Ratio (Wet/Dry)***
Winter	1.628	1.34	6.275
Spring	1.884	1.30	5.432
Summer	2.062	1.63	5.394
Fall	1.086	1.18	6.837

Table 6A & B. Mean observed wet and dry tissue weight by season for the three evaluated fishing areas.

Abductor Muscle (Meat)

			Wet Weight (g)		*Dry Weight (g)*		*Ratio (Wet/Dry)*	
Area	***Season***	***n***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
CL1_Sliver	Winter	18	23.1	4.34	4.94	1	4.69	0.144
	Spring	24	24.6	4.76	5.5	1.27	4.52	0.266
	Summer	33	22	4.13	4.72	0.913	4.67	0.13
	Fall	53	25.4	4.24	5.45	0.964	4.67	0.178
Cape Cod	Winter	30	35.4	12.5	8.39	3.13	4.24	0.125
	Spring	11	39.2	11.1	9.37	2.91	4.22	0.17
	Summer	15	44.2	12.6	10.5	3	4.23	0.224
	Fall	20	35.2	6.2	8.18	1.55	4.32	0.223
Great South Channel	Winter	17	39.8	9.34	3.89	4.4	4.31	0.187
	Spring	35	31.8	10.9	7.46	2.39	4.25	0.51
	Summer	30	25.3	8.33	5.86	2.25	4.42	0.325
	Fall	8	28.4	11.2	6.54	3.1	4.56	0.592

Gonad

			Wet Weight (g)		*Dry Weight (g)*		*Ratio (Wet/Dry)*	
Area	***Season***	***n***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
CL1_Sliver	Winter	18	3.32	0.91	0.401	0.142	8.52	1.2
	Spring	24	11.1	4.06	2.24	0.849	4.98	0.478
	Summer	33	4.54	2.34	0.726	0.492	7.02	1.75
	Fall	53	4.1	1.27	0.423	0.16	10	2.07
Cape Cod	Winter	30	9.63	5.22	1.52	1.05	7.02	2.06
	Spring	11	17	7.3	3.4	1.62	5.14	0.728
	Summer	15	22.3	5.92	4.34	1.47	5.3	0.619
	Fall	21	12.4	7.38	2.3	1.71	6.34	1.81
Great South Channel	Winter	17	12.8	8.77	2.14	1.82	6.85	1.32
	Spring	35	13.1	7.29	2.61	1.58	5.27	0.967
	Summer	30	9.85	7.52	2.06	1.84	5.54	1.29
	Fall	8	5.16	3.12	0.738	0.473	7.4	1.54

Table 7. Modelled dry abductor muscle (meat) weight coefficients for the area-based model.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.87286	0.00735	254.95	< 2e-16
log(WetMeatWeight)	1.04252	0.01175	88.712	< 2e-16
CL1_Sliver	-0.0683	0.01089	-6.277	1.26E-09
Great South Channel	-0.0057	0.00803	-0.71	0.478

Table 8. AIC values of the area-based dry meat weight models.

Model	AIC
Dry Meat Weight ~ log(Wet Meat Weight)+Area	346.277
Dry Meat Weight ~ log(Wet Meat Weight)+Area+Season	349.544
Dry Meat Weight ~ log(Wet Meat Weight)+Area+Season+Area:Season	352.393
Dry Meat Weight ~ log(Wet Meat Weight)+Season	382.277
Dry Meat Weight ~ log(Wet Meat Weight)	383.902

Table 9. Modelled dry gonad weight coefficients for the area-based model.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.05829	0.02935	1.986	0.04798
log(WetMeatWeight)	1.14429	0.01741	65.723	< 2e-16
Spring	0.15328	0.03467	4.422	1.40E-05
Summer	0.10733	0.03174	3.381	0.00083
Fall	0.14034	0.03406	4.12	4.98E-05
CL1_Sliver	-0.0964	0.1503	-0.641	0.52173
Great South Channel	0.03255	0.03578	0.91	0.36374
Spring:CL1_Sliver	0.16562	0.15231	1.087	0.2778
Summer:CL1_Sliver	0.14041	0.15804	0.888	0.37507
Fall:CL1_Sliver	-0.3574	0.17055	-2.096	0.03702
Spring:Great South Channel	-0.0166	0.04436	-0.375	0.7081
Summer:Great South Channel	0.12583	0.04343	2.897	0.00406
Fall:Great South Channel	-0.2257	0.11832	-1.908	0.05744

Table 10. AIC values of area-based dry gonad weight models.

Model	AIC
Dry Meat Weight ~ log(Wet Meat Weight)+Area+Season+Area:Season	57.0805
Dry Meat Weight ~ log(Wet Meat Weight)+Area+Season	119.587
Dry Meat Weight ~ log(Wet Meat Weight)+Season	128.464
Dry Gonad Weight ~ log(Wet Gonad Weight)+Area	167.994
Dry Meat Weight ~ log(Wet Meat Weight)	177.276

Objective 4: Pilot an affordable industry-supported biological sampling program that could be expanded more broadly in the scallop fishery as well as transferred to other fisheries to support applied science and management with finer scale temporal data than are available through traditional sampling means. Work closely with NEFSC to ensure resulting data is useful to management.

The project successfully piloted a biological sampling program that collected fine scale temporal data to improve our understanding of monthly trends in spawning cycles and meat yield, and created wet to dry conversion ratios. Access to Scallop RSA compensation fishing was used to compensate participating vessels, along with a stipend of $36/trip. Fourteen LAGC scallop vessels participated in collecting weekly samples; 43% (six) provided 86% of the samples. While there was strong support for and interest in participating in the project, it proved to be more efficient and effective to work with fewer vessels to coordinate sampling schedules with vessels that landed closer to the lab location.

There were five months during the 22-month sampling period where one week was missed due to weather windows or vessel breakdowns. There was one month where two weeks were missed and one month where all four weeks were missed due to no one fishing (very bad weather). Vessels were not directed to sample from a specific geography and the spatial distribution reflects normal fishing activity. Hot summer weather proved to be problematic for scallop survival, as the scallops often arrived at the lab almost or completely dead. Summer sampling required chilled seawater to ensure the scallops arrived at the lab alive.

Having 24/7 staff coverage available all week to accept and process one sample per week is unrealistic but trying to pre-schedule exact days and times is almost impossible except during the high season when the fleet is fishing almost every day. There were days when a breakdown forced a vessel to land earlier than planned – sometimes that meant meeting the boat at 10pm instead of 10am. Processing the 25 scallop samples in the lab took from 4 to 8 hours depending on how clean they were (recirculating holding tank vs. on ice changed the amount of mud and sand that had to be cleaned off the soft tissues) and the speed of the technician. We tried a few options to alleviate this scheduling:

1) A full time salaried CCCFA staff member would set aside 4 to 8 hours of their week to process scallops and try to be as flexible as possible. This often just turned into extra hours each week for the staff as the samples would come in late in the afternoon after a full day in the office or on the weekend, or the week would fill up with other priorities that made it difficult to balance with traditional work schedule full of meetings.
2) A part time hourly employee that was hired and trained for just this project who had daytime flexibility all week (worked nights elsewhere). Finding someone who was available one day a week and had the flexibility to change the day they worked each week was incredibly difficult and also meant that sometimes scallops had to be held overnight in the fridge if they arrived late in the afternoon, instead of being processed immediately.
3) Coordinate with vessels to land on the same day/time each week to make it easier to plan lab staff availability. While this was practical and worked well during the summer and early fall, the rest of the year weather windows made it difficult for vessels to meet the planned delivery date.

4) Contract with a fisheries monitoring company (at sea and electronic monitoring) whose staff has flexibility and is used to matching schedules with fishing trips. They provided staff who were already familiar with biological sampling protocols and who could come into the lab with 12 hours' notice to process the scallops. As long as the fisherman provided notice when they left on the trip, scheduling wasn't a problem unless the staff was on vacation.

Timely analysis of the data was delayed by other research commitments, including the Scallop HabCam Survey.

Mid-project results and challenges were presented at Scallop RSA Share Day and extensively discussed with colleagues at Commercial Fisheries Research Foundation (CFRF) to inform the development of the Sea Scallop Image-Based Research Fleet. Given current staffing constraints, CCCFA does not intend to continue supporting the lab-based weekly sampling of scallops but would be happy to hand a future long term LAGC sampling program over to another organization.

Best Practices for future program expansion
Considering the results and lessons learned in conducting this pilot, we did determine that weekly samples are valuable data that are accessible and should be continued to be collected, with several modifications to program design:

- Participating vessels should have a deck log (tablet or app) for collecting trip data and recording tow location, to standardize location collection, reduce error, increase consistency and streamline data entry.
- Participating vessels should have eMOLT temperature sensors installed on their dredge to record surface and bottom water temperature.
- Continue targeting weekly samples but be prepared for weather windows that may skip a week and ultimately set a monthly goal.
- Expand the program to three to five trips per week, to increase sample size for trend identification (especially of gonad development stage) and to make it easier to staff the lab (daily processing). Weather windows in the winter may mean that most LAGC vessels are fishing on the same day, which limits the number of samples that can be processed in a given week unless you have multiple technicians.
- Identify key areas to be sampled each year so at least a portion of the samples return to the same area each month to develop year round trends. This will require more coordination with the vessels to repetitively sample the same general area. It is most cost effective for this sampling to be opportunistic (wherever they are fishing). However, with compensation, some vessels would be willing to conduct a series of short tows at reference stations to track key areas over time.
- All summer and early fall trips (when the thermocline is present) should use a chilled seawater holding tank onboard to ensure the scallops arrive alive.
- Involve a fisheries monitoring company or an organization with several lab technicians that have the flexibility to match their sample processing schedule to align with the landing from each fishing trip. Train at least two technicians so there is coverage each week.
- To expand geography of live sampling, technicians would be needed in various ports to capture the range of the fishery (NY/NJ, RI/New Bedford, Cape Cod, Gloucester, ME)

- Careful scheduling of when analysis occurs to ensure that timely results are available to the management process.
- Ambiguity between reproductive stages indicates that future research should consider using histology to accurately assess the reproductive stage and its relation to dry tissue weights. Gonads should be subsampled for histological validation to increase confidence in the gonad development stage. (currently $18/slide for histological preparation plus shipping)

Cost Estimates for future program expansion
With protocols and analysis methodology now already in place, replication of the existing program would be cheaper than the pilot.

The cost estimates in Table 11 are for a future program include 1 trip per week (1300 samples/year) as well as 3 trips per week (3600 samples/year) and assume that non-consumable supplies/equipment must be purchased in the first year (calipers, scale, standards, knives, cooler). Estimate assumes RSA funding and has commensurate RSA compensation fishing management costs included. Contracts could be brought in house if appropriate skill sets are available. Additional expenses to continue dry weight sampling and histological verification of gonad development stage are included at the end as supplemental.

An alternate solution to staffing the lab and the expense of processing samples is to streamline and automate data collection with CFRF's Sea Scallop Image-Based Research Fleet, which was piloted in 2023-2024 and uses electronic monitoring technology to allow the captain to easily and accurately collect shell size, meat yields, sex, reproductive stage and location/date onboard the vessel. This would allow for an expanded geographic range and remove the need for an on-call technician to receive and process the samples upon landing. It is possible that the shortfall of soft tissue sampling in the Image-Based project could be overcome by a small amount of live animal subsampling in the lab.

Incorporating precise and accurate reproductive aspects during stock assessment processes is very important for the long-term sustainability of a fishery. The current scallop stock assessment depends on estimates of reproductive potential associated with meat weight, which makes it unsuitable for an accurate stock assessment for the species. Therefore, a long-term industry-based sampling program could provide ongoing basic life history and morphometric parameters (e.g., timing of spawning, morphometrics, soft tissue ratios). In addition, a long-term program would empower LAGC fishermen to participate in the scientific process and continue to build trust between the LAGC fishing industry and the NEFSC. Members of the LAGC fleet are supportive of this research because it allows them to contribute to better management of the resource they rely on for their livelihoods.

Data Availability:
The project data are stored by CFF following their data management plan. Data requests should be directed to CFF, Details available at their website:
www.coonamessettfarmfoundation.org/data-management

Table 11. Cost Estimates for Future Program

	1300 Samples Per Year	3900 Samples Per Year
Personnel		
Research Management ($50/hr)	$ 8,800.00	$ 16,600.00
RSA Leasing Coordination ($38/hr)	$ 6,384.00	$ 13,984.00
Data Entry ($40/hr)	$ 2,080.00	$ 6,240.00
Fringe (23%)	$ 3,970.72	$ 8,469.52
Consumable Supplies		
Paper towels	$ 157.00	$ 470.00
Wire brushes	$ 13.00	$ 40.00
Caliper Batteries	$ 15.00	$ 44.00
Lab Paper	$ 41.00	$ 124.00
Sponges/Cleaner/Trash Bags	$ 22.00	$ 66.00
Long Term Supplies		
Digital Calipers	$ 200.00	$ 400.00
Digital Balance	$ 125.00	$ 125.00
Balance Standards	$ 12.00	$ 12.00
Knives/Scalpel	$ 30.00	$ 40.00
Vessel Digital Logs	$ 400.00	$ 1,200.00
Data Server	$ 240.00	$ 720.00
Travel (Share Day/Presentation)	$ 375.00	$ 375.00
Contracts		
Sample Processing/Lab Tech **	$ 15,600.00	$ 46,800.00
Data Analysis/Reports	$ 13,629.00	$ 13,629.00
Data QA/QC / Management	$ 4,576.00	$ 13,728.00
Subtotal	$ 56,669.72	$ 123,066.52
15% Indirect	$ 8,500.46	$ 18,459.98
Total Budget	**$ 65,170.18**	**$ 141,526.50**
With Dry Weights & Histological Validation		
Salary	$ 988.00	$ 2,964.00
Fringe	$ 276.64	$ 829.92
Oven	$ 639.00	$ 639.00
Cups	$ 50.00	$ 50.00
Trays	$ 30.00	$ 30.00
Histology Subsample 33%	$ 8,580.00	$ 25,740.00
Data Analysis	$ 2,252.80	$ 2,252.80
Indirect	$ 1,922.47	$ 4,875.86
Supplemental Budget	**$ 14,738.91**	**$ 37,381.58**
* * assumes Fishery Monitoring Company		

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