Assessing the Temperature Tolerance of Atlantic Sea Scallop Early Life Stages

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1.0 EXECUTIVE SUMMARY

Project Title: Assessing the Temperature Tolerance of Atlantic Sea Scallop Early Life Stages

Year Awarded: 2025

RSA Priorities Addressed By This Research: 2. Scallop Biology

Industry Partners: Not Applicable

The sea scallop is highly sensitive to changes in marine conditions, is commonly found in waters between 0 and 17°C, and spawns semiannually (Fall and Spring). At present, prior research on larval scallop temperature tolerances has been examined either *in-situ* or within mesocosms which mimic current temperature profiles, yet no studies have experimentally assessed the organismal impacts of future climate conditions on larval Atlantic sea scallops. To-date modeling studies on *Placopecten magellanicus* have shown that the combined stressors of ocean acidification and warming may substantially decrease the scallop stock and size-structure due to negative effects on recruitment and other life history traits. Thus, to better project the health of the sea scallop stock under future conditions, experiment-model integration is needed to validate and enhance models. Therefore, the proposed research would allow us to experimentally assess the effects of future temperature conditions on early life stages of scallops at each of their spawning periods, when they are planktonic in the upper water column and likely the most susceptible to warming temperatures, by examining key developmental and physiological traits. Hence, the goals of this project are to provide fishery resource managers, marine scientists, and fishing communities with 1) experimentally derived data on the thermal tolerance of sea scallop early life stages, 2) an assessment of the influence of temperature on larval development and settlement distribution derived from Individual-Based Models, and 3) an analysis of *in-situ* temperature data for the Mid-Atlantic Bight (MAB) to identify conditions that were potentially too warm for the long-term survival of scallop larvae.

To-date two experiments which reared larval scallops from embryo to veliger under eight representative temperature treatments have been completed at the Downeast Institute in Beals, ME. Throughout these experiments, stage-specific (embryo, trochophore, veliger) durations, growth, developmental abnormalities, survival, respiration, and clearance rates were quantified. Logistic regressions were used to calculate the time at which 50% of larvae were estimated to die at a certain temperature (LT_{50}). Concurrently, development of an individual-based model is underway. This model incorporates biological parameterization from the literature and our experiments to assess how temperature influences larval development and settlement across their range, with particular emphasis on the Mid-Atlantic Bight. Finally, temperature data from Coonamessett Farm Foundation (CFF) sea turtle tagging program was used to develop a general additive model (GAM) which was validated using NOAA CTD cast data from the region. The resulting GAM was used to develop annual predicted temperature maps for the mixed layer depth for the spring (4/1 – 5/31) and fall (9/1 – 10/10) spawns from 2010 to 2024. These maps are being used to determine the number of days within a set temperature range for each year to identify suitable habitat for larvae following each spawn.

2.0 PRELIMINARY RESULTS AND DISCUSSION

Larval Experiments:

Our experiments quantified stage-dependent mortality rates, growth, and development. Further, we quantified key physiological traits (respiration rate, clearance rate, and scope for growth) for veliger larvae. At present we are still conducting analyses on physiological rates and statistical analysis. Estimated times at which mortality occurred in 50% of all larvae (LT_{50}) ranged from 30 to 40 hours for embryos, 45 to 70 hours for trochophores, and 3 to 14 days for veligers (Figure 1). Embryo and trochophore LT_{50} were not temperature dependent; however, veliger LT_{50} decreased with increasing temperature (Figure 1). For surviving embryos and trochophore stage durations (hours) exhibited a bimodal distribution (Figure 2). Embryonic development was slowest at temperatures ≤ 12°C (54 to 86 hours) and at 18°C (28 to 58 hours) while embryonic development was fastest between 14 and 16°C and 20 – 22°C (18 to 28 hours; LM: $F_{7,16} = 3.26$, $p = 0.02$; Figure 2). Similarly, trochophore development was slowest at temperatures ≤ 12°C (48 to 76 hours) and at 18°C (23 to 36 hours) while trochophore development was fastest at 14 and 16°C (< 8 hours; LM: $F_{7,14} = 68.0$, $p < 0.01$; Figure 2). No embryonic or trochophore developmental abnormalities were observed. Embryonic growth was slowest at 8 and 10°C with a mean (± SE) growth rate of 0.12 (0.04) µm $hour^{-1}$ while growth at temperatures ≥ 12°C was 0.35 (0.04) µm $hour^{-1}$ (LM: $F_{7,333} = 11.7$, $p < 0.001$; Figure 3). In contrast, preliminary analysis of trochophore growth shows no relationship with temperature (Figure 3). Veliger growth in both length and height varied by temperature (Length: LM: $F_{1,14} = 52.64$, $p < 0.01$; Height: LM: $F_{1,14} = 65.3$, $p < 0.01$; Figure 4) with larvae growing slowest at 8 and 10°C (Figure 4) at a mean rate (± SE) of 0.71 (0.01) and 0.73 (0.01) µm day^{-1} in length and height, respectively. Mean veliger growth did not differ at temperatures ≥ 12°C (Figure 4) with larvae growing at a mean rate (± SE) of 1.67 (0.02) and 1.73 (0.04) µm day^{-1} in length and height, respectively. These experimental results will fill knowledge gaps in larval scallop biology, allowing for parameterization of population-level individual based models.

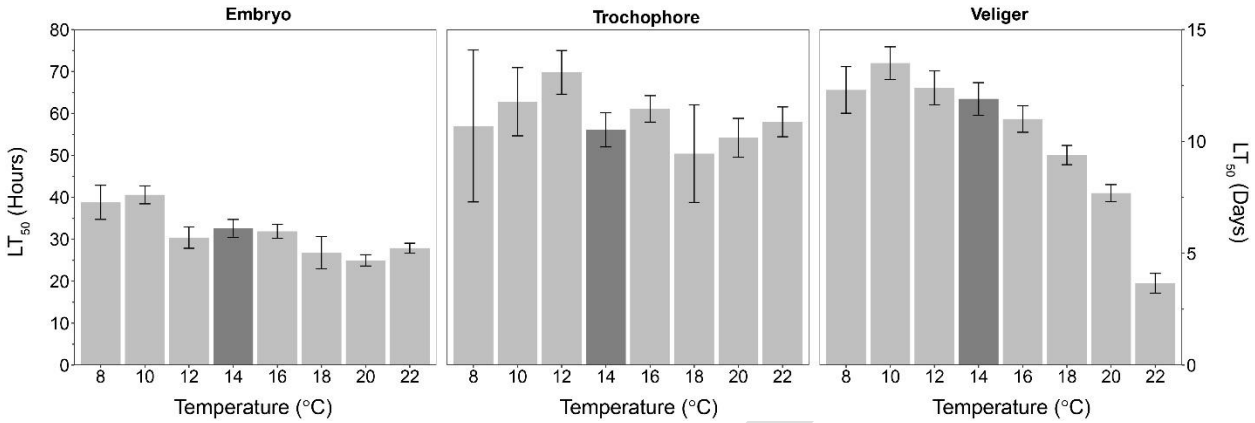

Figure 1. Stage-dependent lethal times at which mortality occurs in 50% of larvae (LT_{50}) for embryos (hours), trochophores (hours), and veligers (days). Bars represent the mean LT_{50} values while errorbars represent the standard error of the mean. The dark grey bar (14°C) represents the control treatment.

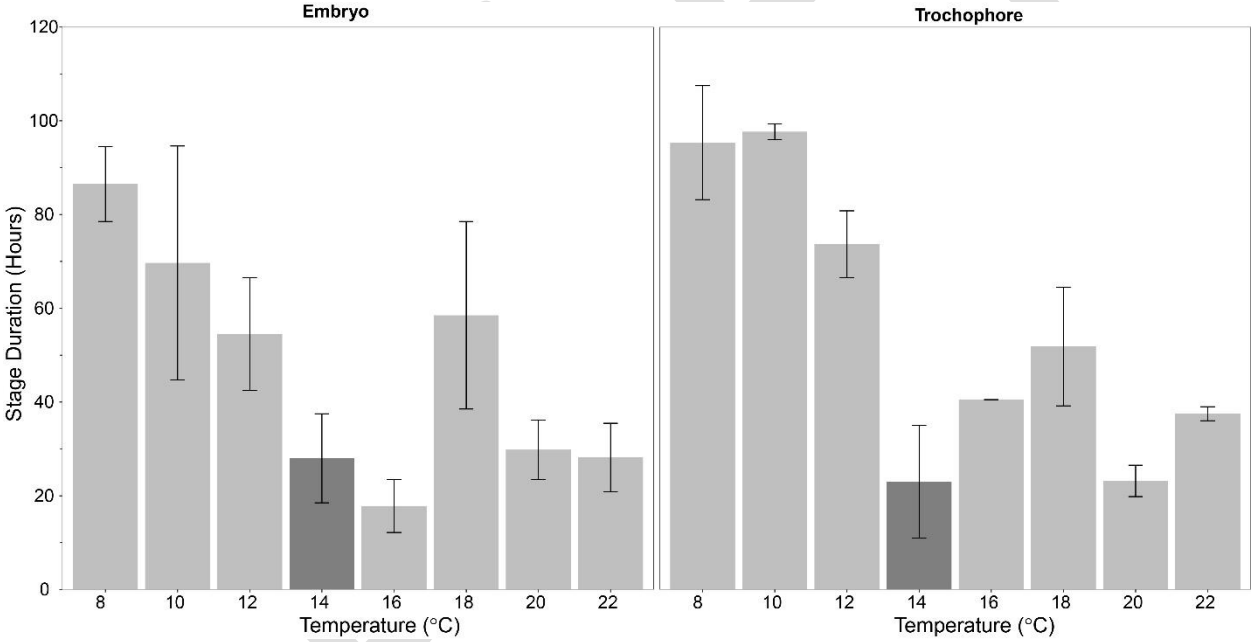

Figure 2. Larval stage durations (hours) for embryos (hours), and trochophores (hours). Bars represent the mean developmental times for each life stage and errorbars represent the standard error of the mean. The dark grey bar (14°C) represents the control treatment.

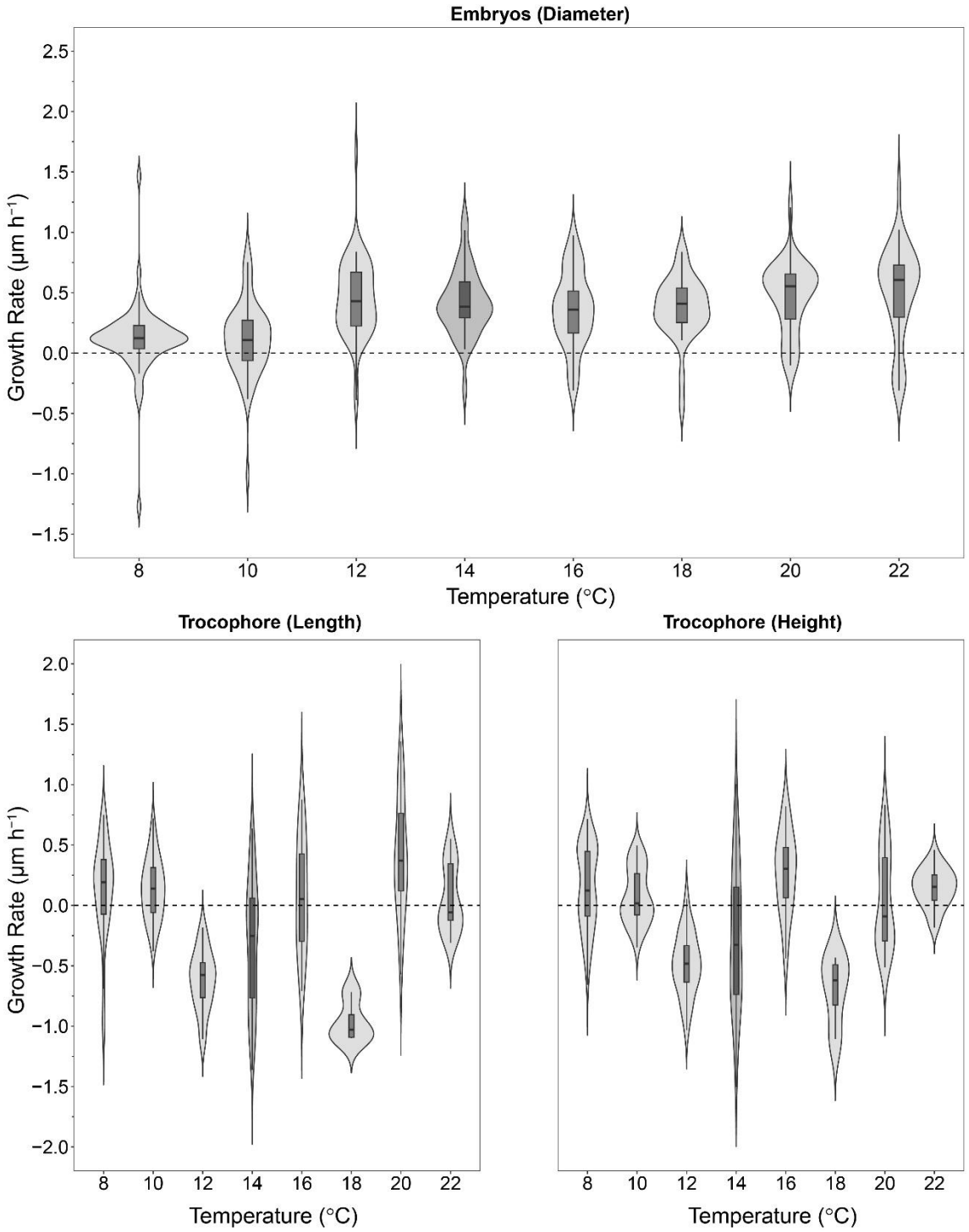

Figure 3. Stage-dependent growth rate (µm h^{-1}) for embryo diameter, trochophore length, and trochophore height. Upper and lower whiskers represent the 90th and 10th percentile, respectively. While the upper and bottom edges of the boxplot represent the 75th and 25th percentile, respectively, and the bold center line represents the median. The dark grey violin and boxplot (14°C) represents the control treatment.

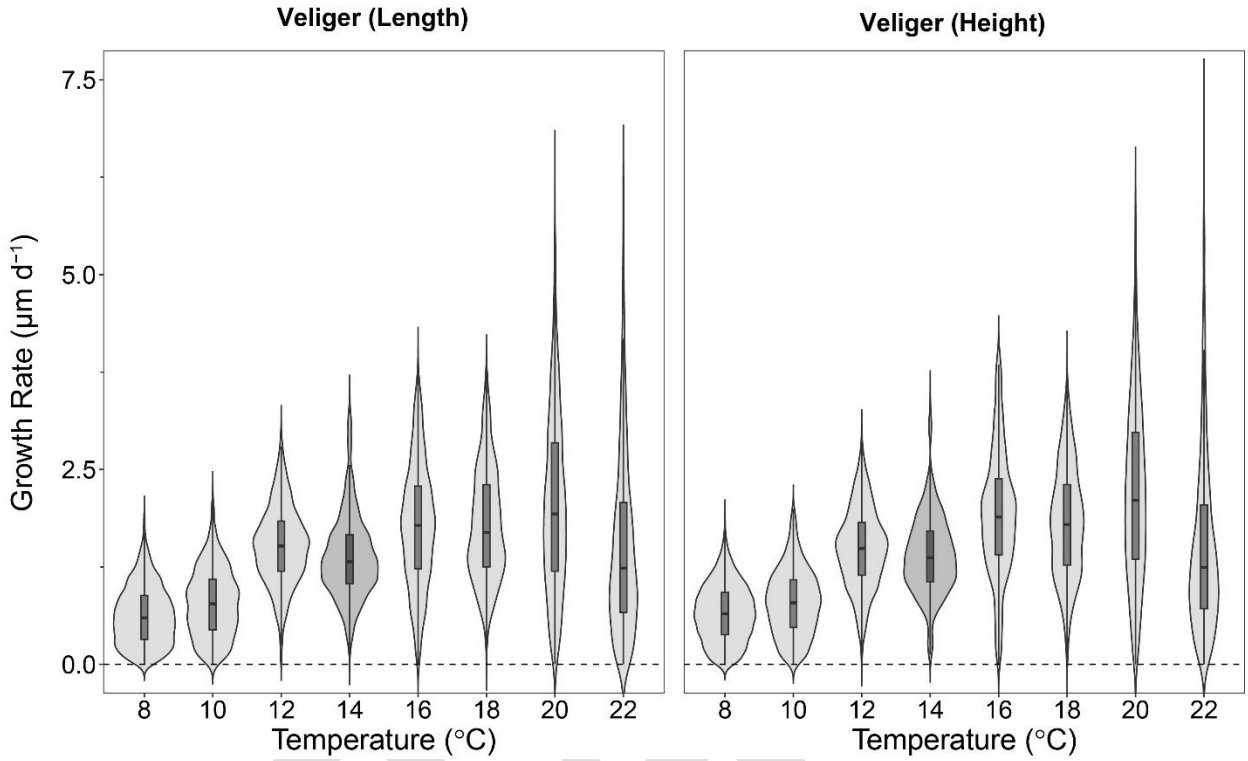

Figure 4. Veliger growth rate (µm day^{-1}) for length, and height. Upper and lower whiskers represent the 90th and 10th percentile, respectively. While the upper and bottom edges of the boxplot represent the 75th and 25th percentile, respectively, and the bold center line represents the median. The dark grey violin and boxplot (14°C) represents the control treatment.

Projecting Favorable Habitats using Loggerhead Turtle derived data:

A total of a 523,174 temperature-depth profiles were collected over 17 consecutive years from satellite tags on 350 individual turtles. General additive models (GAMS) were then used to quantify annual temperature predictions for the entire Mid-Atlantic Bight. The final GAM incorporates two tensor products (a flexible, non-linear interaction surface, allowing different units of measurement for each predictor) of longitude/latitude/depth and depth/day along with year as a smoothed term and satellite tag as a random effect. The resulting model was then validated using 369,451 NOAA CTD casts. Annual predictions of water temperature within the mixed-water depth were then generated and used to map the number of days when the temperature above the mixed-layer depth was within a temperature range for the period after a spring (4/1-5/31) and fall (9/1-10/10) bloom in the Mid-Atlantic Bight. Predicted water temperature showed a decrease in favorable larval temperatures of 12-16°C in the later years (2012 Vs. 2024) along with an increase in temperatures of 18-22°C. The spring spawn had the

clearest examples of these trends with temperatures of 8-14°C showing a clear negative anomaly and bins of 14-20 C° showing a positive trend (Figures 5,6). The fall spawn had more variation but the >22°C temp bin increased in both degree days and spatial size (Figures 7,8). The warming seen during both spawning periods increases the chance that larvae are exposed to unsuitable temperature habitat.

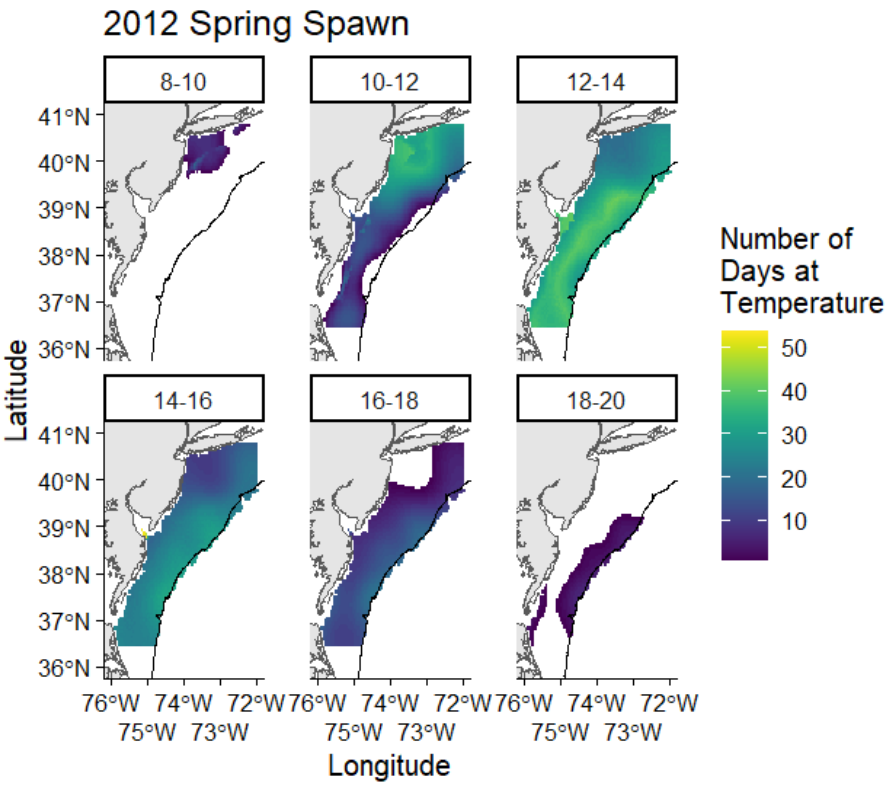

Figure 5. Number of days within a 2°C temperature range for the mixed-water depth in the Mid-Atlantic Bight for the 2012 Spring Spawn (4/1 – 5/31).

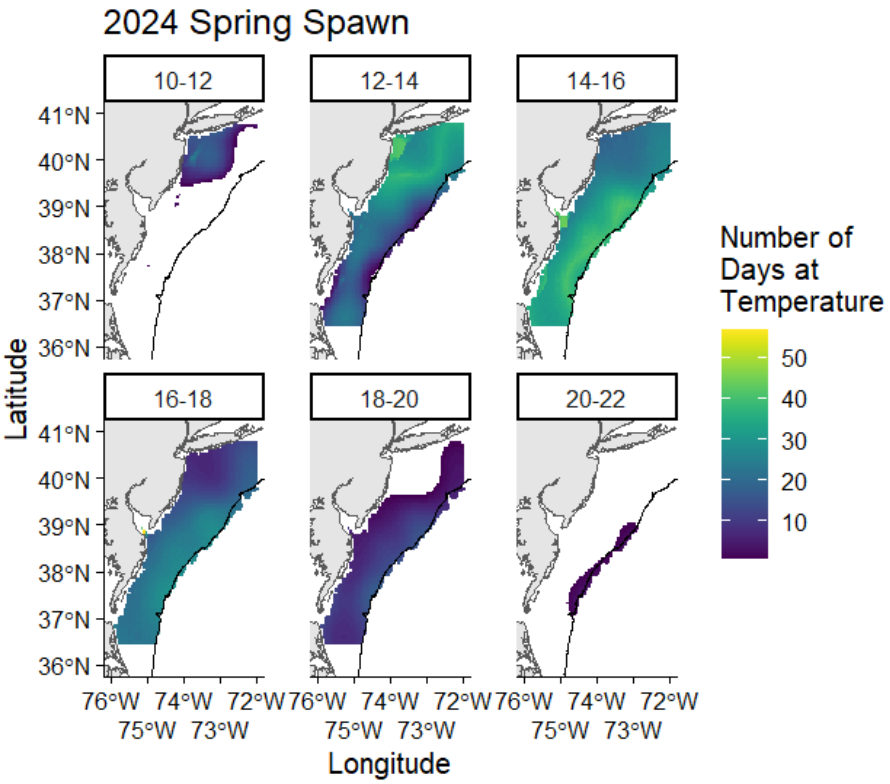

Figure 6. Number of days within a 2°C temperature range for the mixed-water depth in the Mid-Atlantic Bight for the 2024 Spring Spawn (4/1 – 5/31).

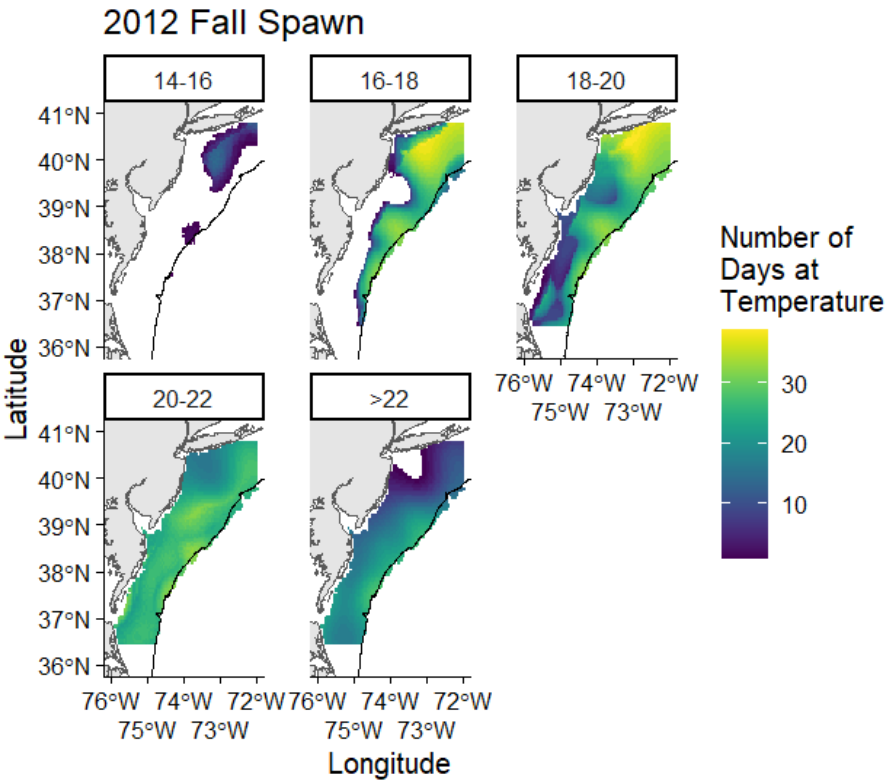

Figure 7. Number of days within a 2°C temperature range for the mixed-water depth in the Mid-Atlantic Bight for the 2012 Fall Spawn (9/1 – 10/10).

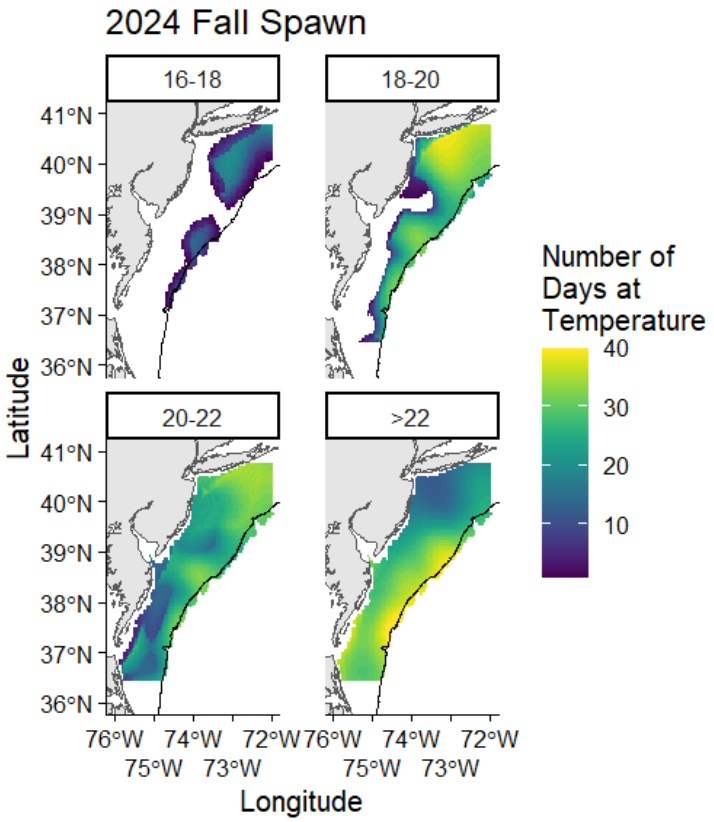

Figure 8. Number of days within a 2°C temperature range for the mixed-water depth in the Mid-Atlantic Bight for the 2024 Fall Spawn (9/1 – 10/10).

Next steps:

We are in the process of analyzing our physiological metrics (respiration rate, clearance rate, scope for growth) and once analyzed this will provide further insight into potential metabolic tradeoffs in larval sea scallop growth and survival. Further, we are continuing our analysis of all experimental parameters. To-date we have completed our literature review of scallop behavior to begin to parameterize our individual-based model (IBM). We will then begin to complete IBM simulations to best identify connectivity and dispersal and source-sink dynamics for larval sea scallops in the Mid-Atlantic bight.

Special Comments:

We have successfully reared sea scallop larvae under eight temperature regimes. This data provides important biological data which can be incorporated into future stock assessment models and fisheries management decisions. As previously stated, we will be incorporating this data into induvial based bio-physical models to identify population-level effects on early life stages of sea scallops.