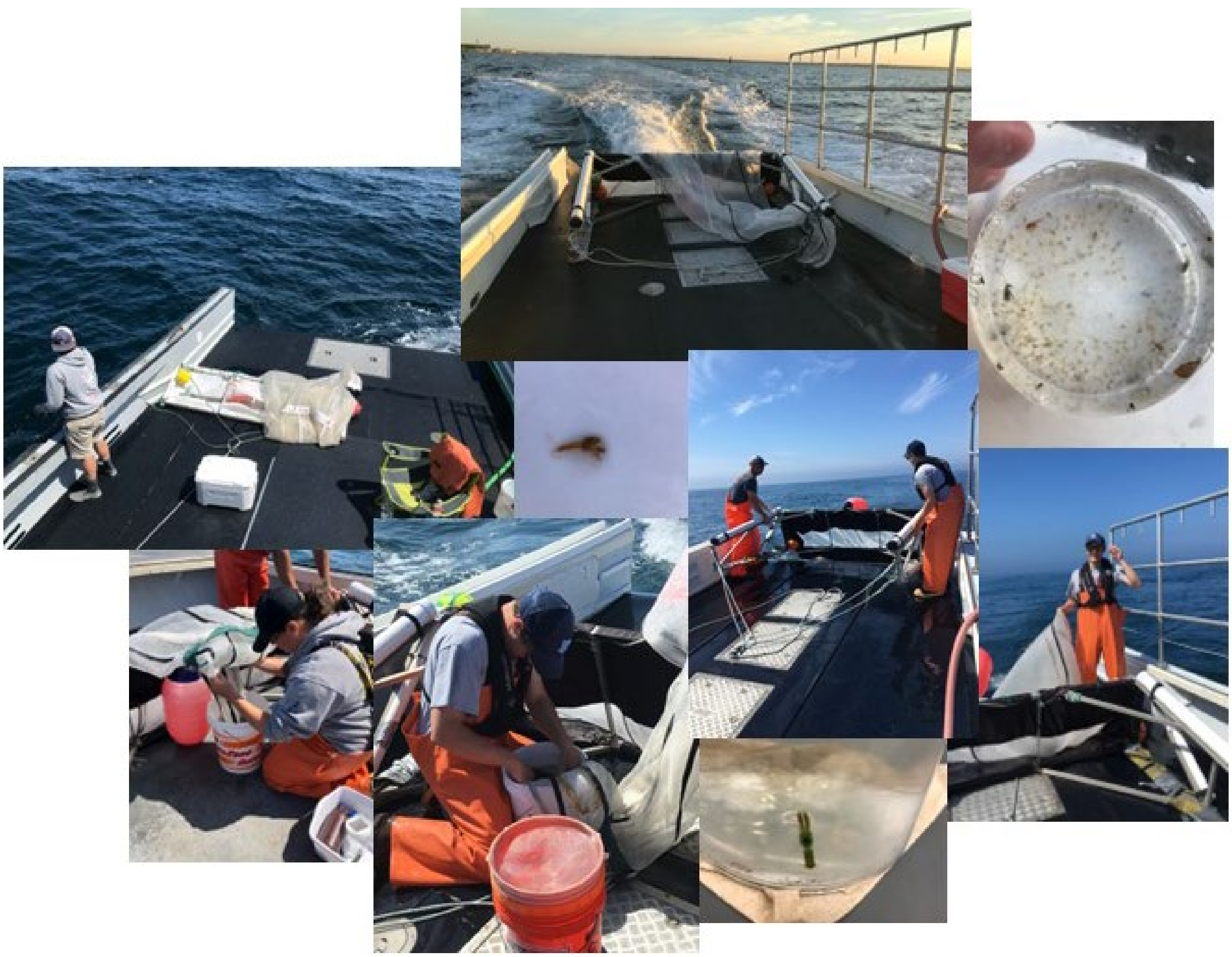
OCS Study
BOEM 2022-070

Larval Lobster and Fish Neuston Net Survey for Regional Fisheries Monitoring in Southern New England Offshore Wind Development



U.S. Department of the Interior
Bureau of Ocean Energy Management
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Larval Lobster and Fish Neuston Net Survey for Regional Fisheries Monitoring in Southern New England Offshore Wind Development

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U.S. Department of the Interior
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DISCLAIMER

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List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
EcoMon	Ecosystem Monitoring
MassCEC	Massachusetts Clean Energy Center
MADMF	Massachusetts Division of Marine Fisheries
MLA	Massachusetts Lobstermen’s Association
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
OCS-A	Outer Continental Shelf Area
NMFS	National Marine Fisheries Service
SMAST	School for Marine Science and Technology
UMass	University of Massachusetts

1 Project Snapshot

The University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) in conjunction with the Massachusetts Lobstermen's Association (MLA) sought to estimate the relative abundance and distribution of larval lobster and fish via neuston net. This study was conducted from May to September 2020 and May to June 2021 at 30 randomly distributed stations. This random selection was based on the proportional total area within each ten-meter depth contour of the 3,670 km^2 study area. One 10-minute tow was conducted at each station to assess pre-settlement abundance and distribution of larval lobster and fish. Results from this study 1) estimated distribution of larval species in the areas of concern, 2) correlated abundance data with environmental factors (temperature, salinity, pH, and dissolved oxygen), and 3) determined the seasonal variations of larval species in the wind energy lease areas. This work created strong baseline data to be used in future studies and analysis as the planned windfarm projects continue with development.

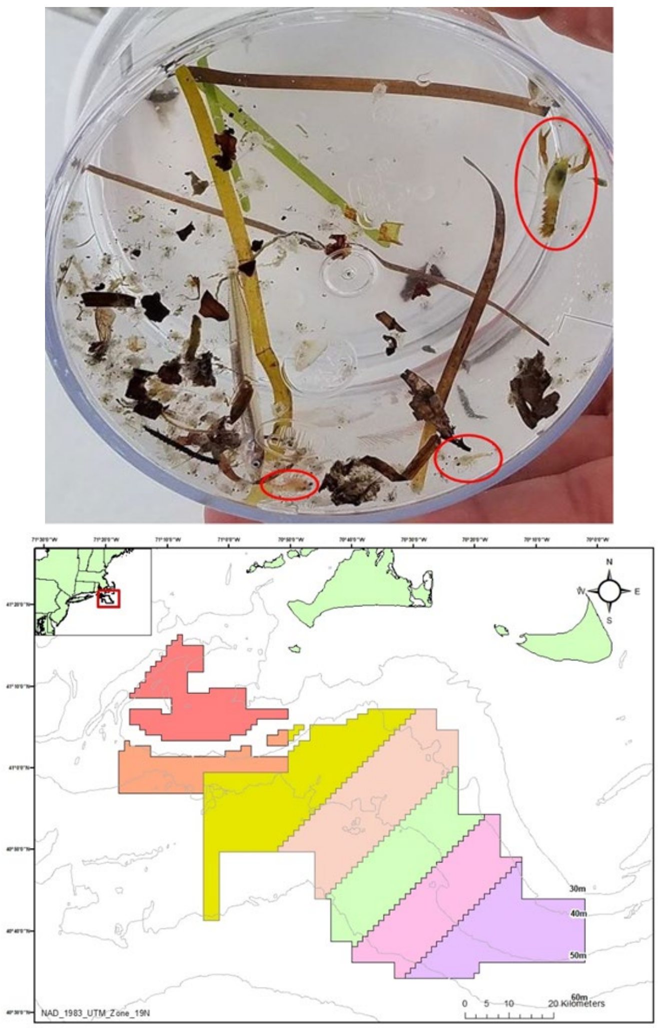

Figure 1. An example of a larval sample with stage II, II, and IV lobster larvae from Buzzards Bay (top). CEC study area (bottom), each color represents a different lease area.

2 Project Narrative

2.1 Rationale

The southern New England Offshore Wind lease areas begin roughly 25 km south of Rhode Island. The lease areas were awarded to companies for development and the first permitted projects began construction in 2022. As part of extensive pre- and post-construction research initiatives, the School for Marine Science and Technology (SMAST) was asked to conduct ventless lobster trap, black sea bass pot, and plankton surveys to assess the pre-construction environment of one of the first fully permitted lease areas, OCS-A 501. American lobster (*Homarus americanus*) larvae are planktonic for about 2 months and are distributed by ocean currents from offshore spawning locations to the nearshore of southern New England (Figure 2). These lobsters have a stage I duration of 2-7 days, a stage II duration of 3-8 days, a stage III duration of 3-10 days, and a stage IV duration of 11-27 days when exposed to 14-22°C (MacKenzie, 1988). Stage IV larvae are active directional swimmers that can search and settle in sheltered habitats (Katz et al., 1994). The first three stages are confined to the upper mixed layer above the thermocline but have been observed making vertical diel migrations to depths of 30 meters in deeper offshore waters in response to varying hours of sunlight (Harding et al., 1987). Ichthyoplankton nets have sampled all stages of *H. americanus* larvae in Buzzards Bay. Milligan (2010) used protocols developed by the Department of Fisheries and Oceans, Canada, the United States National Marine Fisheries Service, and Massachusetts Division of Marine Fisheries to effectively sample lobster larvae and compare results from 2006-2007 to historical data from 1976-1982 (Figure 3a). Casey (2019) modeled potential settlement sites of post-larvae in the same area based on location of egg-bearing females and the presence of larvae at varying stages of development (Figure 3b). Both studies successfully used zooplankton sampling to evaluate larval lobster relative abundance and distribution.

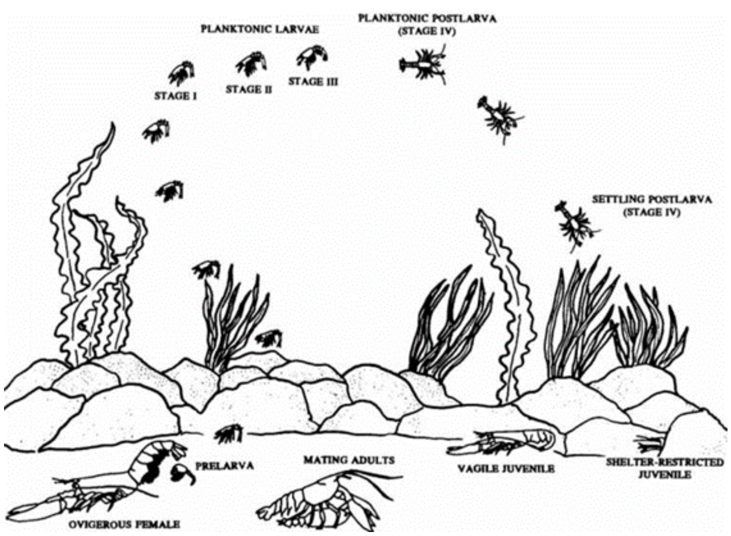

Figure 2. Life cycle of the American lobster (*Homarus americanus*), Factor (1995).

Lobster stocks in the Gulf of Maine have increased to record highs (ASMFC, 2019), while those in southern New England have declined to extreme low levels, effectively collapsing (Le Bris et al. 2018). The southern New England lobster resource and associated fishery have moved to offshore areas where the stock redistribution overlaps with windfarm lease areas (Figure 4) (Glenn et al., 2011). This redistribution was likely caused by increased water temperatures inshore and the thermosensitivity of lobsters (Wahle et al., 2015). The installation of offshore wind turbines may introduce an artificial reef effect (Degraer et al., 2020). The artificial reef effect occurs when a hard substrate is placed into an environment that provides a surface for species like bivalves, bryozoans, crustaceans, and sponges to colonize and form the basis of a food web. Larger predator and reef associated species visit or stay at this new structure for shelter and food availability. The potential of an increased number of predators and an increase in suitable habitat may affect post-settlement lobster densities (Petersen, et al. 2006). An established larval abundance baseline in the wind energy lease areas is important, as native species may be affected by the turbines generating noise, altering habitats, introducing electromagnetic fields, and shifting physical oceanographic parameters (De Troch et al., 2017).

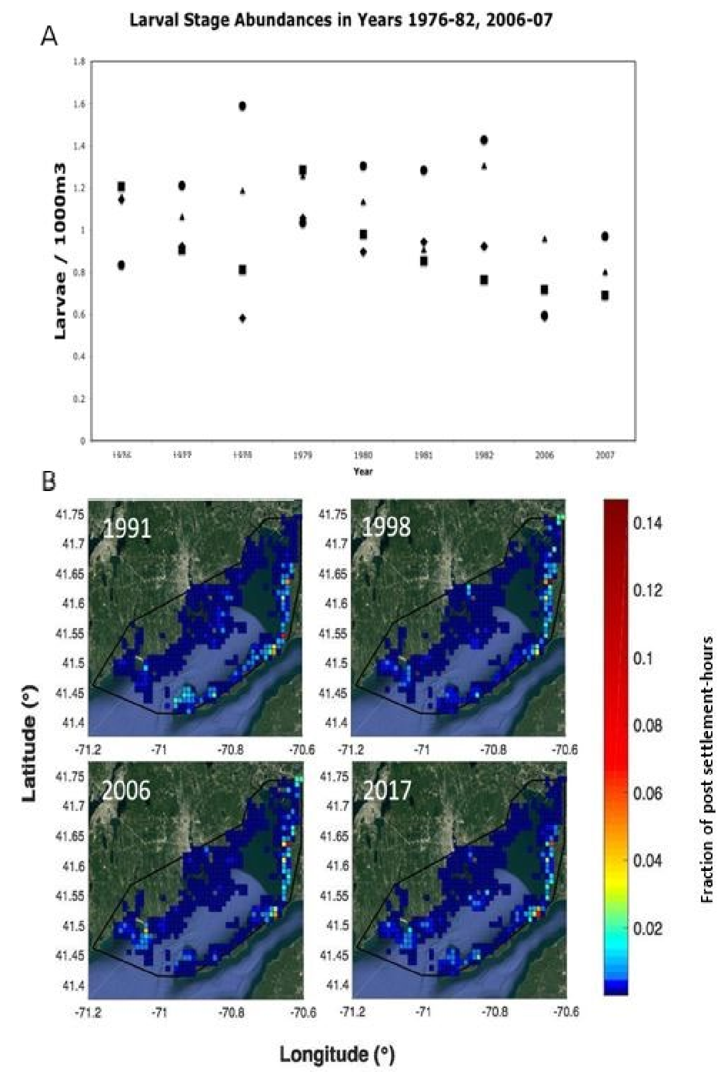

Figure 3. A (top) Mean stage-specific abundances (larvae / 1000m^3) of American lobster (*Homarus americanus*) larvae surveyed in Buzzards Bay by the NMFS / MADMF in the years 1976-1982, and SMAST in 2006-2007 (Milligan 2010). B (bottom) Fraction of post-larval settlement-hours occurring in Buzzards Bay by individuals originating from realized egger release locations for each model year (Casey, 2019).

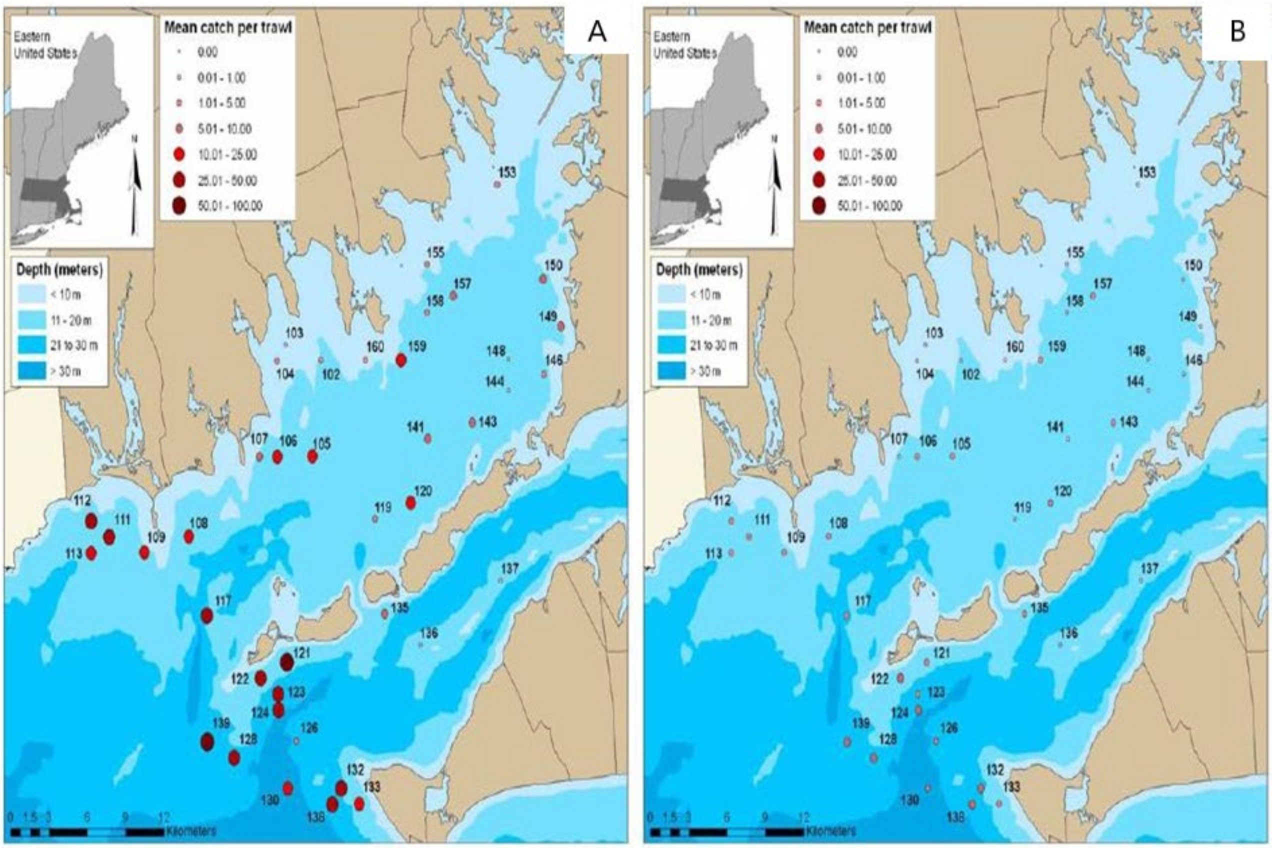

Figure 4. Catch distribution of the 2007 DMF trawl survey for (a) sublegal and (b) legal sized lobsters; labels represent sampling station IDs (Glenn et al., 2011).

2.2 Objectives

The goal of this project was to provide a baseline of the zooplankton, specifically lobster and fish larvae, for the environmental impact assessment for the windfarm lease areas (Figure 4). Our primary objectives of this study were to:

1) Estimate distribution of larval species over the windfarm area

2) Correlate larval abundance data with environmental factors (temperature, salinity, pH, and dissolved oxygen)

3) Determine the seasonal variations of larval species in the wind energy lease areas

2.3 Methods

Limited research exists on larval populations of lobster or fish in the offshore windfarm lease areas of southern New England. This survey generated robust estimates of relative lobster and fish larval abundance in the wind development region. Sampling locations were based on a stratified random design in which the area was divided into ten-meter depth contours, and stations were randomly selected within each depth stratum. The sample size of 30 stations was selected based on a power analysis of preliminary data collected from the Vineyard Wind lease area (OCS-A-0501) and two inshore surveys conducted utilizing the same design. A chart of the study area was overlaid with a latitude/longitude grid in ArcGIS® and shows station distribution within the region (Figure 5). Thirty locations were sampled with standard protocols demonstrated in previous larval studies (Milligan, 2010 and Casey, 2019).

An ichthyoplankton net was towed for 10 minutes at approximately four knots within the top 0.5 meters of the water column at each location. Two nets (one per vessel) were made of 1320 µm mesh and attached to a rectangular aluminum frame (Figure 6). The net and frame combinations had the same mouth dimensions of 2.44m x 0.61m for an opening of 1.49m^2. One Tidbit V2 Temperature Logger, Dissolved Oxygen sensor, pH meter, and salinity sensor were attached to the net opening and set at 30 second recording intervals. At the beginning and end of each tow, when the tow line was taut, and the vessel stopped hauling the net, date, time, latitude, and longitude were recorded. The net was towed from the stern of the vessel with enough scope of line to avoid any propeller wash.

After the nets were hauled back with a pot hauler, the nets were rinsed by the deck hose to allow the contents to collect in the cod end. The contents from the cod end were rinsed into a bucket and run through a fine sieve of 1320 µm mesh. Samples were taken from the sieve and washed into a collection tray. The whole sample was then placed in a 20 oz collection jar and stored on ice until it was examined in the laboratory. American lobster larvae were staged according to Herrick (1911). The larvae were removed from the sample and stored in 70% ethanol. Raw data were downloaded from the environmental loggers and means from each tow were calculated by matching the recorded tow-times with the 30 second data intervals. These values corresponded with the time the net was actively collecting samples in the water.

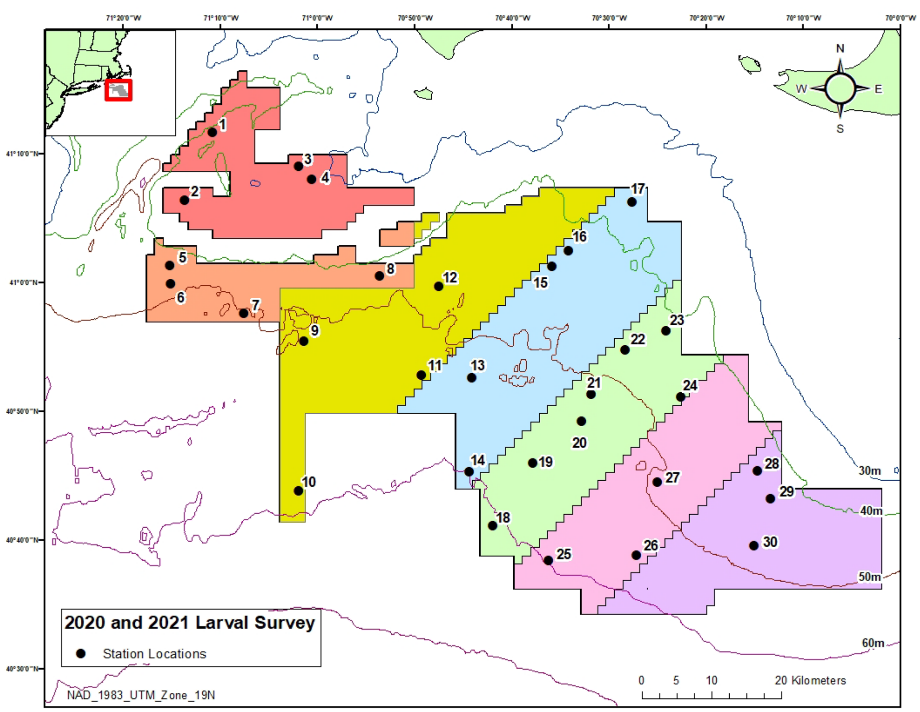

Figure 5. Sampling sites for 2020 and 2021 in the southern New England offshore development areas.

Once all samples were sorted and staged in the laboratory via dissecting microscope, the larval abundance was calculated per thousand cubic meters of water sampled for each of the four lobster larval stages. Larval fish were evaluated and classified in the same manner. Estimates of densities were then compared to previous inshore studies to provide a metric of productivity. Given the duration of the survey campaign, seasonal changes of larval densities and environmental factors (surface temperature, pH, dissolved oxygen, and salinity) were tracked. Refer to Table 1 and Table 6 for a list of sampling dates in 2020 and 2021.

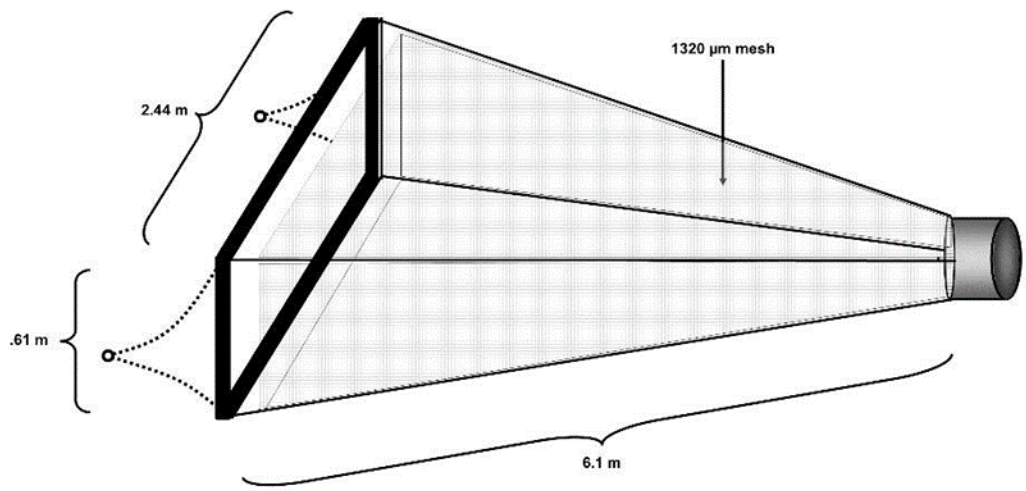

Figure 6. Diagram of the larval sampling net and frame.

3 2020 Results

The Covid-19 pandemic delayed all components of this program. The University research team, administration, and the MLA were able to work collaboratively to develop an approved Covid-19 plan of operations and began conducting surveys on the 9th of June 2020, approximately a month later than originally planned. This survey is time sensitive, as larval lobster development from stage I to post larvae can range from 11-25 days depending on influence of abiotic factors, especially temperature. All field research sampling identified in the list of tasks from the scope work were successfully completed. The final sampling was conducted on the 24th of September 2020 (Table 1).

Table 1. List of sampling dates, the number of stations sampled, the vessel that operated on the sampling date, the minimum tow length (minutes), and the lobster counts across all developmental stages in 2020.

Date	Stations Sampled	Vessel	Tow Length (Min)	Lobster Counts
6/9/2020	30	Both	10	64
6/25/2020	30	Both	10	74
7/8/2020	30	Both	10	3
7/29/2020	30	Both	10	0
8/12/2020	15	Encourager	10	0
8/13/2020	15	Rock & Roll	10	0
8/27/2020	15	Encourager	5*	0
8/29/2020	15	Rock & Roll	10	0
9/24/2020	30	Both	10	0
5/13/2021	15	Rock & Roll	10	0
5/14/2021	15	Encourager	10	0
5/27/2021	30	Both	10	1
6/9/2021	30	Both	10	62
6/25/2021	30	Both	10	32

Note: 8/27/2020 had large aggregation of a species of tunicate. Tow length was decreased by 5 minutes to minimize further damage to the net.

3.1 Estimate distribution of larval species over the windfarm area

Results show highly temporal and aggregate distributions of larval lobster, crab, shrimp, and fish. Most of all of the larval specimens were collected in the northwest region of Massachusetts-Rhode Island wind energy lease areas (Figure 7-10). For each sampling period all larval species were counted and presented as the mean with standard deviation, and number per 1,000 m^3 (Table 2-4). Ten fish species were identified; white hake were the most abundant (Table B1).

Table 2. Total counts of fish, crab, shrimp, and lobster observed for each sampling period in 2020.

Sampling Date (2020)	Species Counts							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
6/9	2	1946	0	35	25	4	0	64
6/25	15	896	0	42	21	9	2	74
7/8	89	281	3	1	1	1	0	3
7/29	369	1192	116	0	0	0	0	0
8/12 - 8/13	506	110	4	0	0	0	0	0
8/27 - 8/29	326	31	36	0	0	0	0	0
9/24	1174	34	1	0	0	0	0	0
Total	2481	4490	160	78	47	14	2	141

Table 3. Mean counts of fish, crab, shrimp, and lobster per tow for each sampling period in 2020.

Sampling Date	Mean Species Larvae / Tow (StdDev)							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
6/9	0.07 (0.25)	64.87 (97.84)	0	1.17 (2.77)	0.83 (1.39)	0.13 (0.43)	0	2.13 (3.88)
6/25	0.50 (1.41)	29.87 (54.4)	0	1.4 (6.22)	0.7 (3.12)	0.3 (1.06)	0.07 (0.25)	2.47 (9.86)
7/8	2.97 (5.31)	9.37 (26.98)	0.1 (0.4)	0.03 (0.18)	0.03 (0.18)	0.03 (0.18)	0	0.1 (0.31)
7/29	12.3 (27.68)	39.73 (157.37)	3.87 (8.34)	0	0	0	0	0
8/12 - 8/13	16.87 (22.60)	3.67 (10.84)	0.13 (0.43)	0	0	0	0	0
8/27 - 8/29	10.87 (9.35)	1.03 (1.81)	1.2 (2.68)	0	0	0	0	0
9/24	39.13 (118.7)	1.13 (1.87)	0.03 (0.18)	0	0	0	0	0
Total	11.81 (48.05)	21.38 (76.21)	0.76 (3.53)	0.37 (2.6)	0.22 (1.32)	0.07 (0.44)	0.01 (0.1)	0.67 (4.08)

Table 4. Mean abundance of fish, crab, shrimp, and lobster per 1000 m^3 of water for each sampling period in 2020.

Sampling Date (2020)	Mean Species Larvae / 1000 m³ (StdDev)							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
6/9	0.04 (0.16)	44.9 (80.77)	0	0.81 (1.91)	0.53 (0.91)	0.1 (0.32)	0	1.43 (2.68)
6/25	0.30 (0.87)	17.42 (31.33)	0	0.89 (3.97)	0.44 (1.99)	0.17 (0.58)	0.05 (0.18)	1.54 (6.28)
7/8	1.82 (3.47)	6.1 (18.68)	0.05 (0.2)	0.03 (0.15)	0.02 (0.08)	0.02 (0.11)	0	0.06 (0.2)
7/29	6.92 (16.27)	20.71 (79.12)	2.24 (4.96)	0	0	0	0	0
8/12 - 8/13	10.98 (15.24)	2.8 (8.73)	0.1 (0.34)	0	0	0	0	0
8/27 - 8/29	9.25 (10.89)	0.97 (1.51)	0.85 (1.77)	0	0	0	0	0
9/24	23.41 (73.37)	0.61 (0.97)	0.02 (0.11)	0	0	0	0	0
All	7.53 (29.88)	13.36 (46.81)	0.47 (2.12)	0.25 (1.69)	0.14 (0.84)	0.04 (0.26)	0.01 (0.07)	0.43 (2.63)

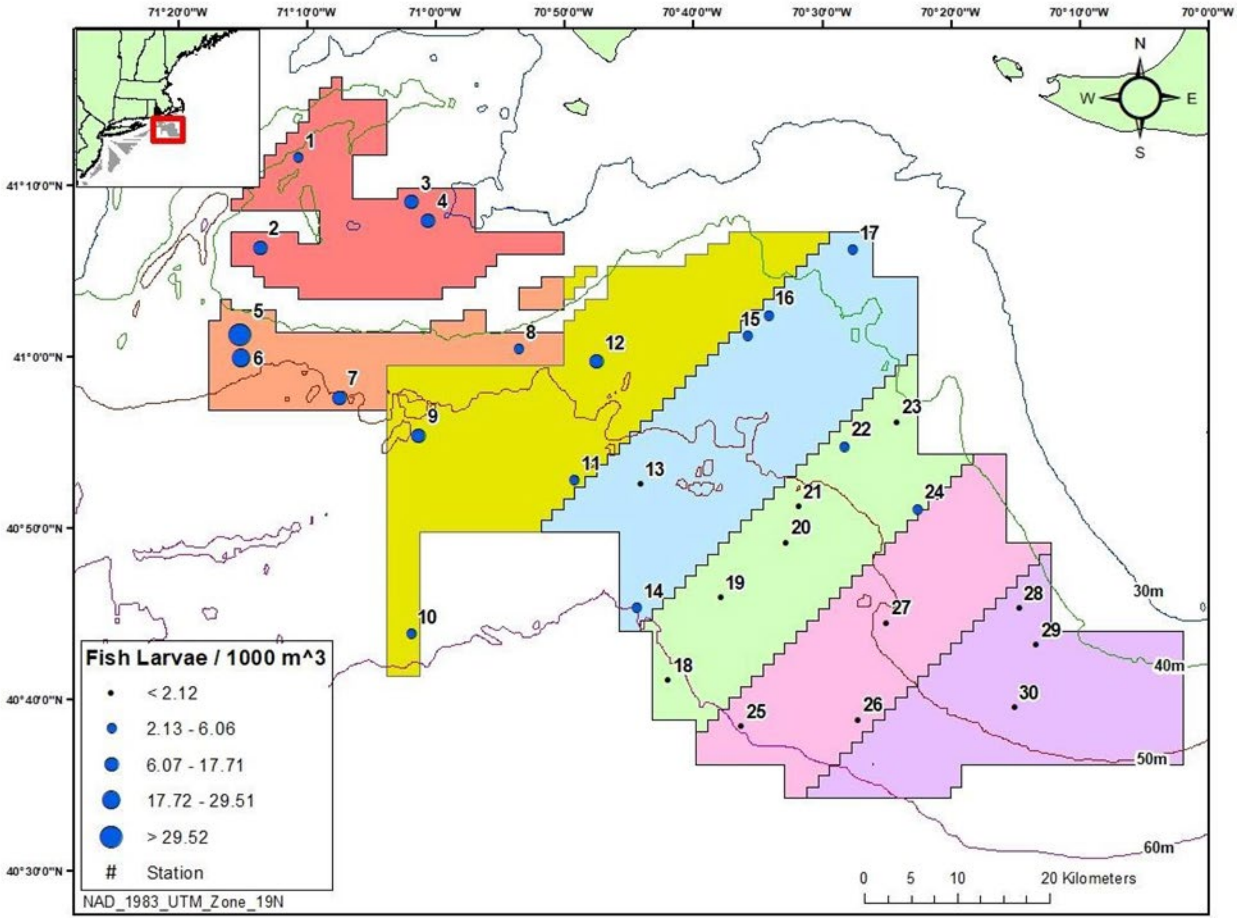

Figure 7. Larval fish abundance per 1000 m^3 of water sampled throughout the 2020 survey (June to September).

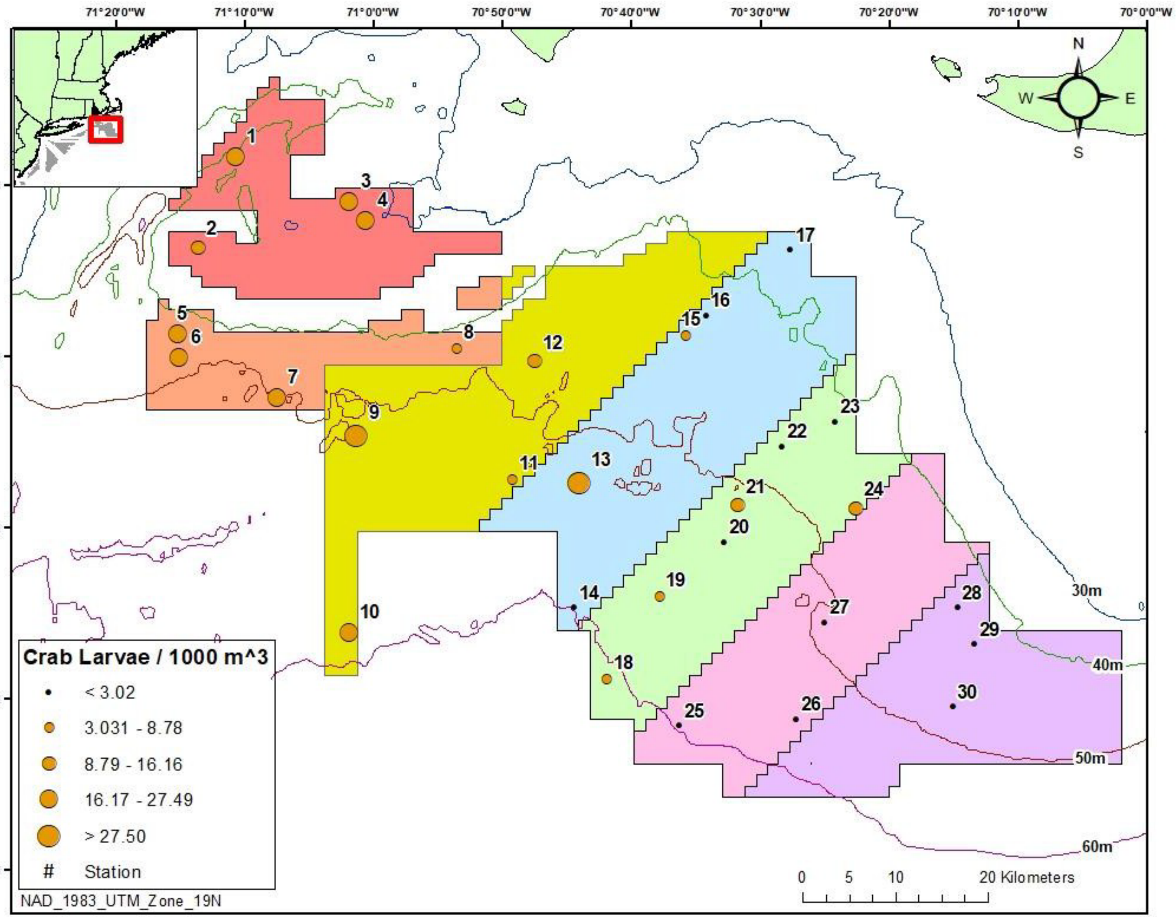

Figure 8. Larval crab abundance per 1000 m^3 of water sampled throughout all sampling dates (June to September 2020).

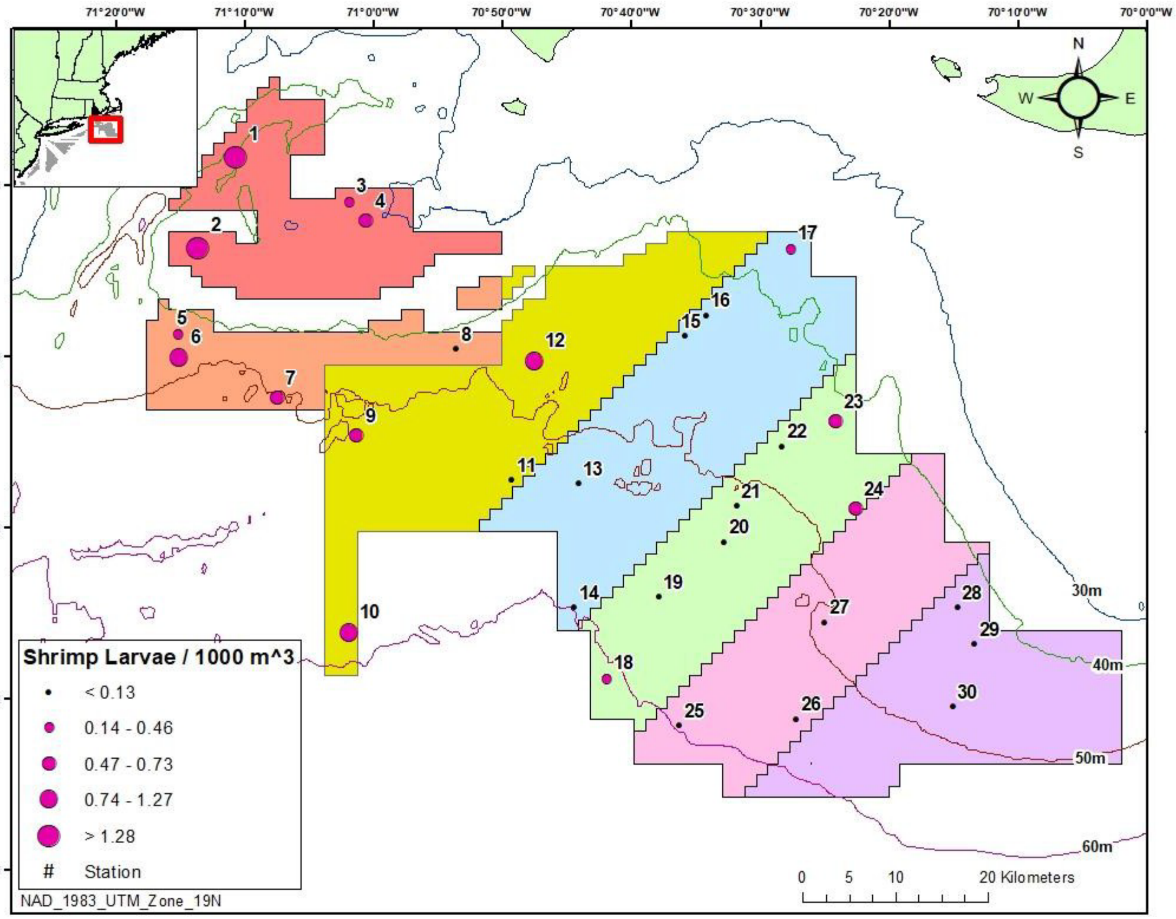

Figure 9. Larval Mysis shrimp abundance per 1000 m^3 of water sampled throughout all sampling dates (June to September 2020).

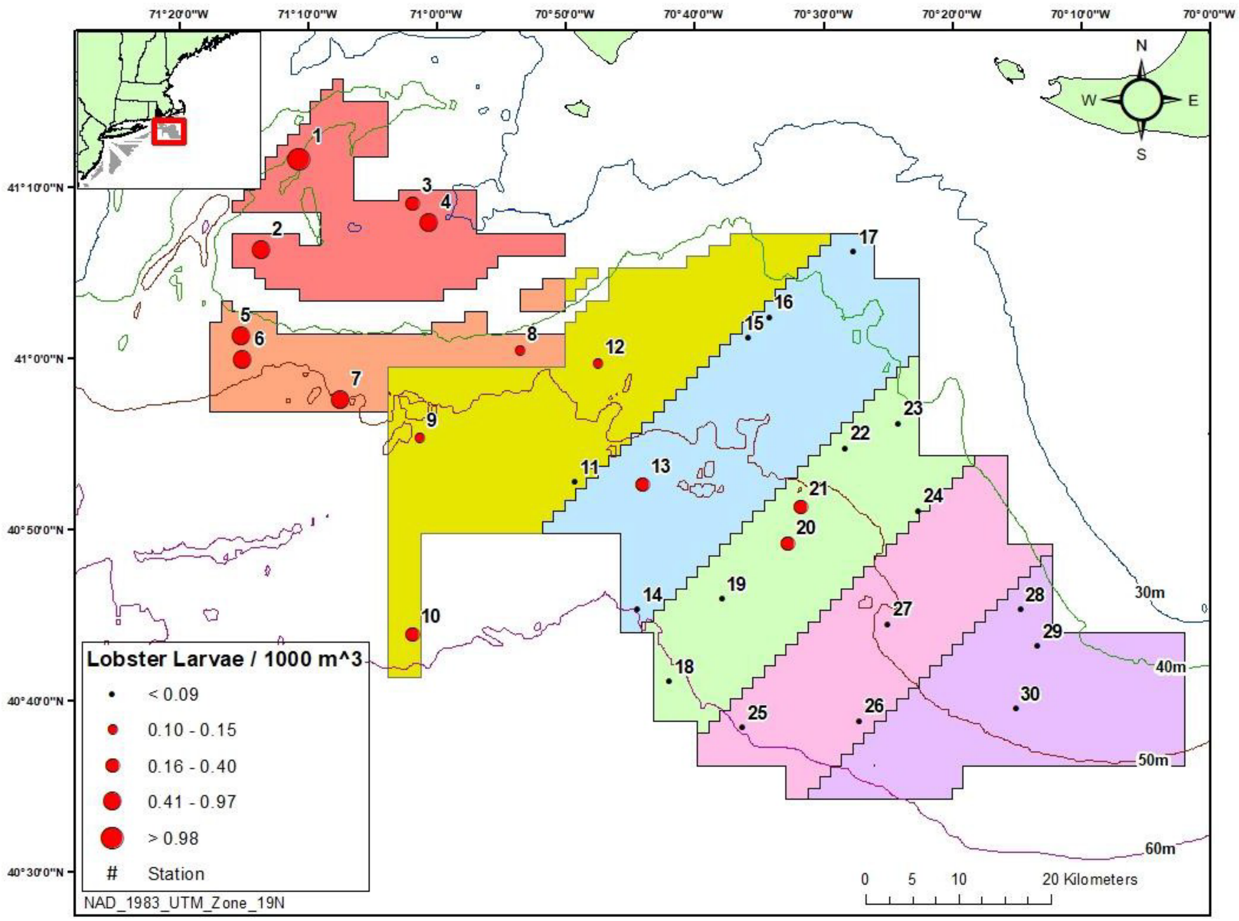

Figure 10. Larval lobster abundance per 1000 m^3 of water sampled throughout all sampling dates (June to September 2020).

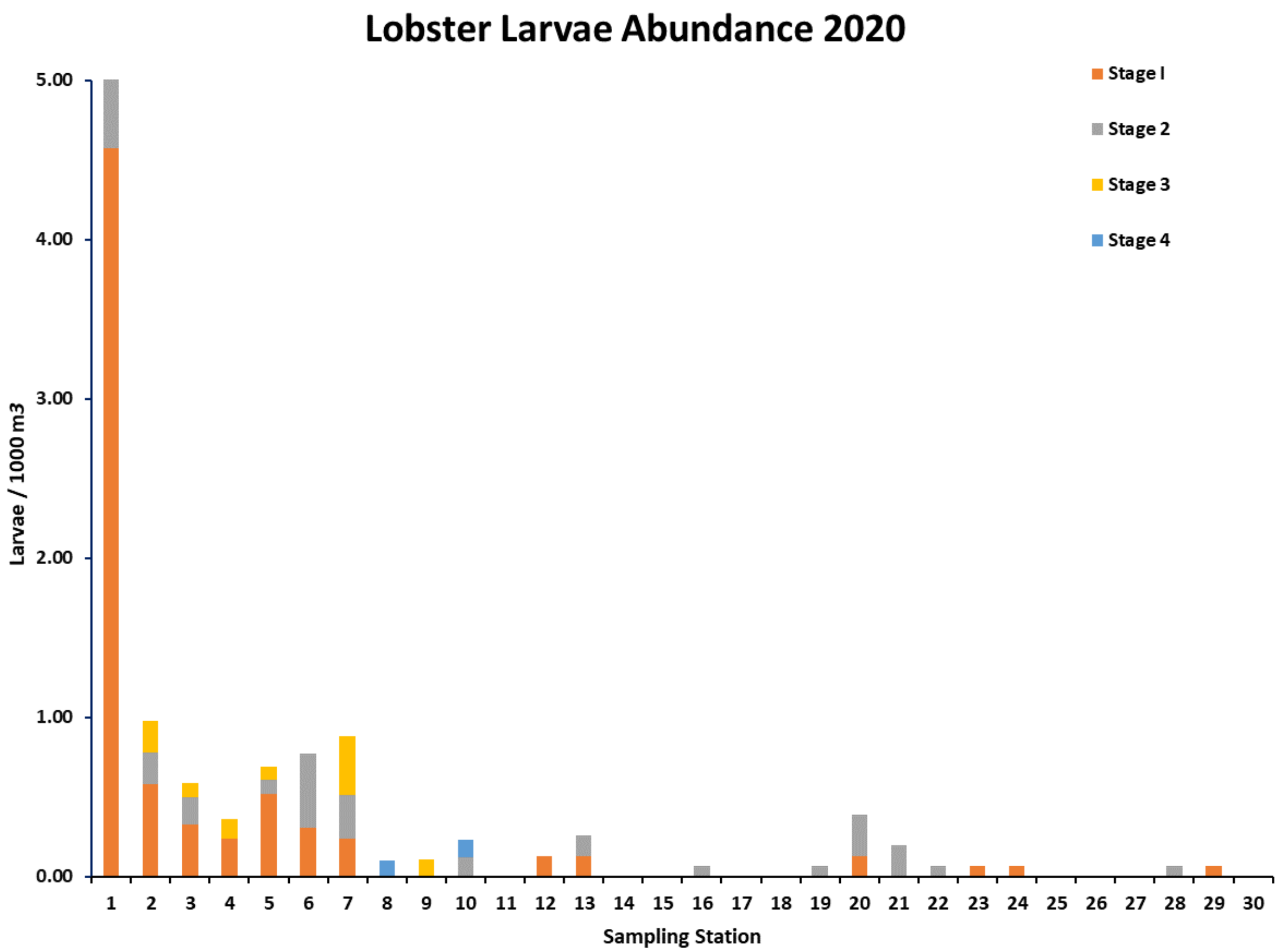

Figure 11. Cumulative lobster larval abundance by stage at each of the 30 sampling locations from June through September 2020. The highest abundance was observed at station one.

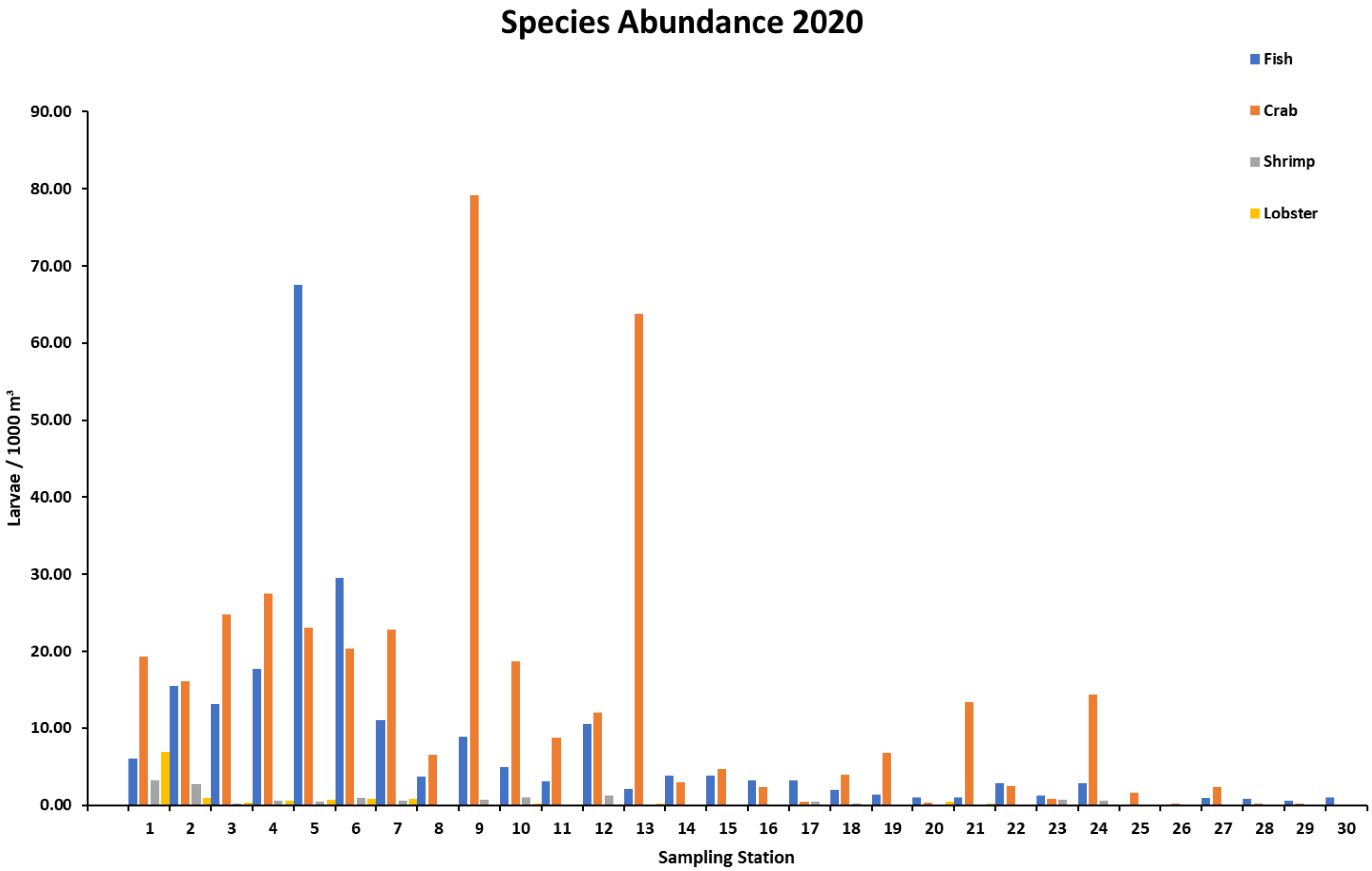

Figure 12. Cumulative comparison of larval species abundance at each sampling location for the 4 main specimens collected from June through September 2020.

Species abundance was calculated as the mean larval abundance per 1000 cubic meters of water sampled to standardize the counts per tow and consider variations in tow duration and vessel speed. With respect to lobster larvae, there was a significant difference in abundance ($p = 0.009$) between sampling locations. Over half (53%) of all lobster larvae were collected at station one (Figure 11). No significant differences in overall abundance were observed for both crab and fishlarvae. However, at the station level, 30% of all fish larvae observed were collected at sampling location 5 (Figure 12).

3.2 Larval abundance data and environmental factors correlation

Temperature and salinity data were recorded continuously throughout sampling while dissolved oxygen and pH were measured from sampling period three forward. Breaks in data resulted from malfunctioning devices and/or backordered environmental sensors. For all areas the temperature averaged 19.7 °C ± 3.2, we had an observed range of 11.7 to 25.6°C. Other mean environmental factors were salinity at 24.6 PPT ± 4.3, dissolved oxygen at 9.19 ±1.4, and pH at 8.2 ± 0.1. At the station level, temperature did not vary significantly between sampling areas. Factoring in all environmental variables we found there was a significant negative relationship between temperature and salinity ($p = 0.006$), dissolved oxygen ($p < 0.001$), and pH ($p = 0.02$)

(Figure 13).

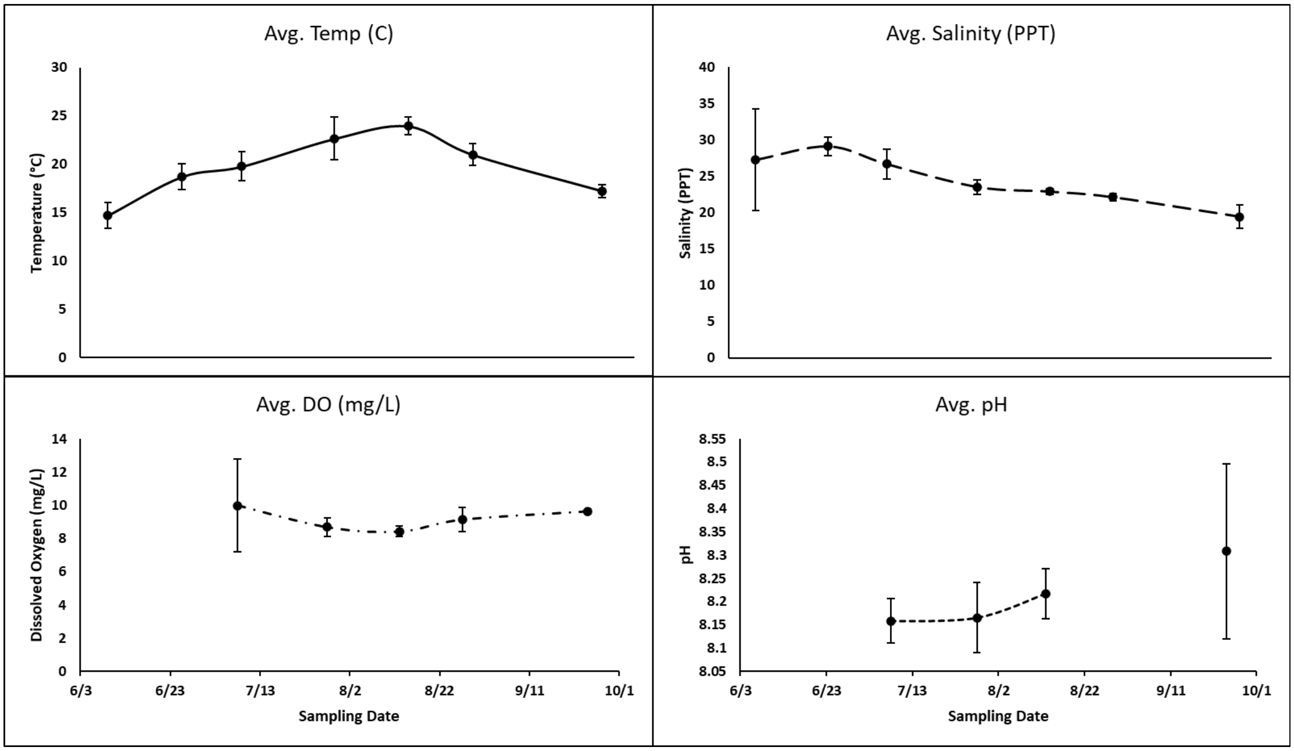

Figure 13. Environmental data by sampling period as A) mean temperature in degrees Celsius, B) mean salinity in parts per thousand, C) mean dissolved oxygen (DO) in milligrams per liter, and D) mean pH. The timeframe of this dataset is June through September 2020. All data points have their respective standard deviations included (error bars).

Table 5. The mean environmental data by sampling period and standard deviation in parentheses in 2020.

Sampling Date (2020)	Environmental Factor			
	Temp (C)	**Salinity (PPT)**	**DO (mg/L)**	**pH**
6/9	14.69 (1.31)	27.26 (6.98)	-	-
6/25	18.70 (1.36)	29.11 (1.30)	-	-
7/8	19.78 (1.50)	26.67 (2.08)	9.99 (2.79)	8.16 (0.05)
7/28	22.64 (2.21)	23.53 (1.03)	8.70 (0.55)	8.17 (0.08)
8/13	23.94 (0.91)	22.90 (0.42)	8.44 (0.31)	8.22 (0.05)
8/27	20.99 (1.10)	22.12 (0.49)	9.15 (0.75)	-
9/24	17.23 (0.66)	19.45 (1.63)	9.64 (0.16)	8.31 (0.19)
Total	19.71 (3.17)	24.43 (3.37)	9.18 (0.64)	8.21 (0.07)

No lobster larvae were observed after sampling period 3 in early July. A regression analysis indicated that there was a slight ($p = 0.049$) significant relationship between temperature and larval abundance. Temperature is a large driving factor of larval abundance and distribution, particularly in lobsters. As temperatures increase throughout the summer the abundance of larval lobster decreased (Figure 14 and 15). No significant ($p = 0.65$) relationship was observed between surface water temperature and abundance for larval fish. Similarly, no significant relationships were observed for crab larvae ($p = 0.23$). Both fish and crab larvae experienced highly variable catch rates throughout sampling.

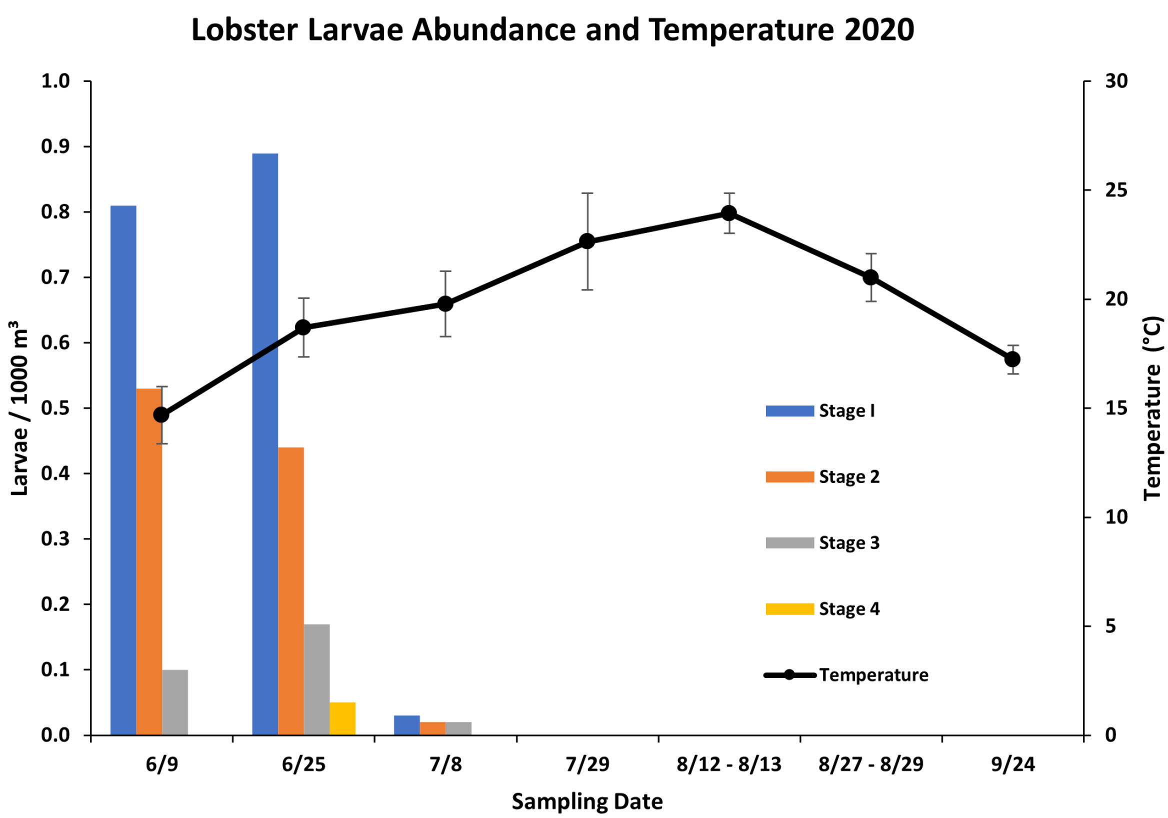

Figure 14. Stages I – IV of lobster larval abundance (larva/1000 m^3) in 2020. Means (circles) $\pm$ standard deviation (error bars) are plotted for observed temperature (^{o}C) of each sampling date.

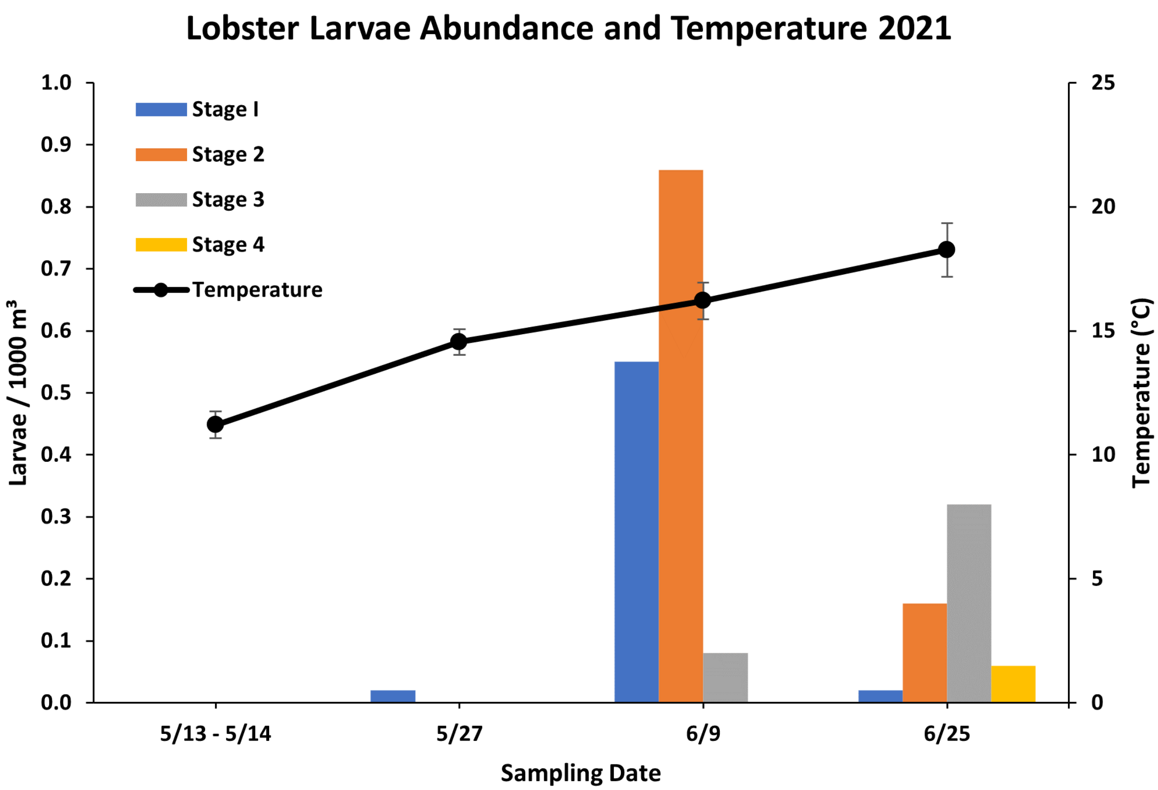

Figure 15. Stages I – IV of lobster larval abundance (larvae/1000 m^3) in 2021. Means (circles) ± standard deviation (error bars) are plotted for observed temperature (°C) of each sampling date. Temperature slightly increased in each sampling period.

Mean station level temperature throughout sampling indicated that stations in the southwest portion of the region experienced high surface water temperatures with the eastern sections having the lowest. For other environmental variables, pH and dissolved oxygen were lowest near the middle of the MA-RI wind energy area. The highest mean dissolved oxygen values were observed at sampling station seven. As expected, given seasonal variations and location, there was a significant change in temperature between sampling dates and station. Similarly, salinity exhibited a significant change over sampling periods, although no difference was observed between sampling locations ($p = 0.51$). More data are needed to compare dissolved oxygen and pH.

3.3 Determine the seasonal variations of larval species in the wind energy lease areas

Abundance indices of larval lobster were highest, with stage 1 lobsters the most abundant, at the beginning of sampling in June and declined drastically until no larvae at any stage were observed after sampling period 3 in early July (Figure 16). Crab larvae had the highest counts in the beginning of June followed by a decline and a second pulse of high abundance in mid-July (Figure 17). Fish larval abundance gradually increased throughout sampling with 47% collected in the final sampling period in mid-September (Figure 17).

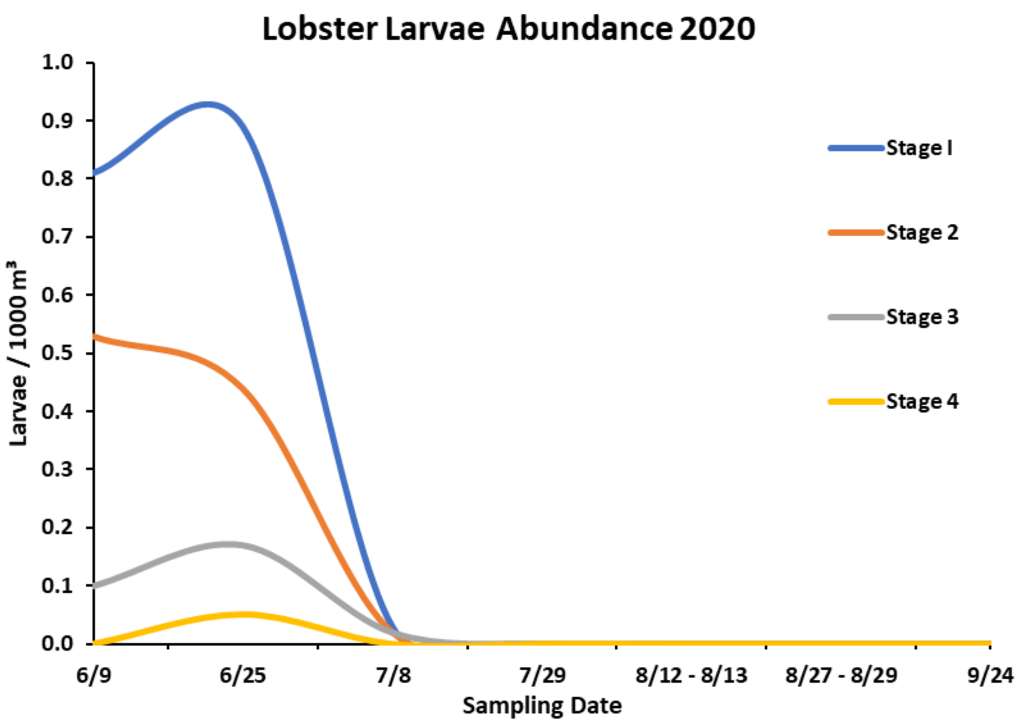

Figure 16. Mean abundance of lobster (stages 1, 2, 3, and 4) per 1000 m^3 of water for each sampling date in 2020. Abundance of all four stages peaked within the first three sampling trips.

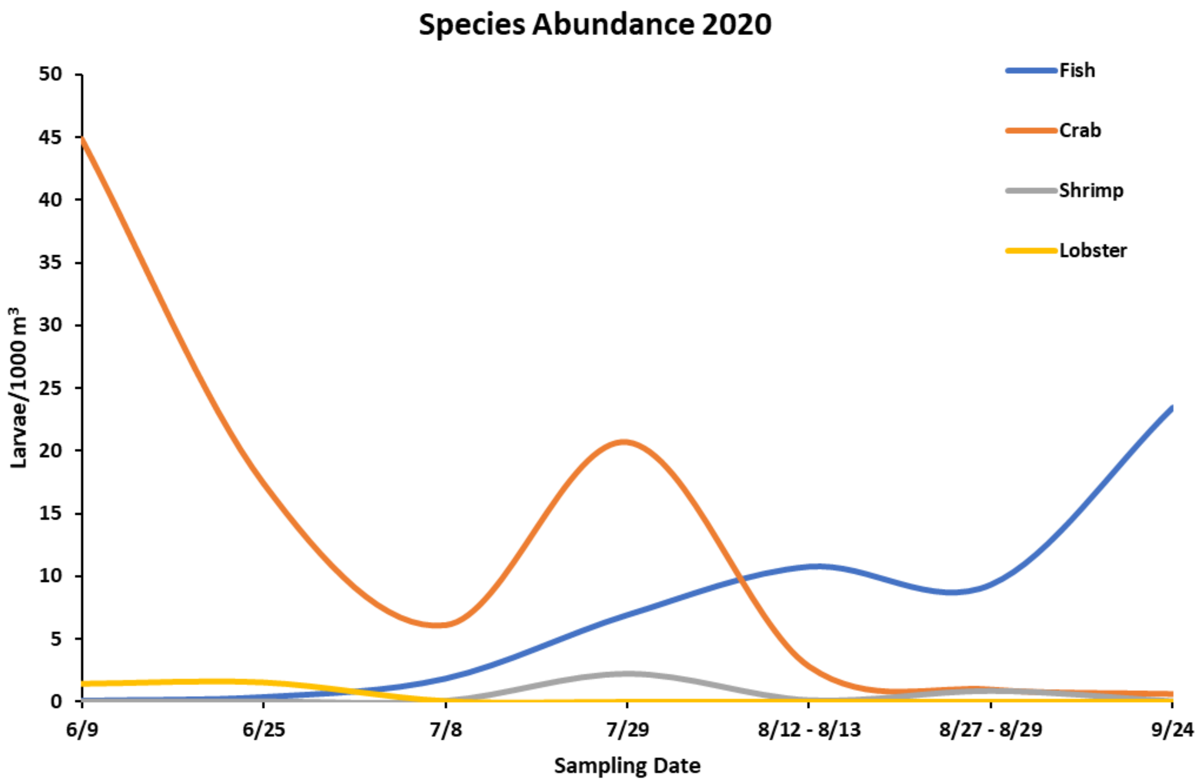

Figure 17. Comparison of mean larval species abundance at each sampling date in 2020 for the 4 main specimens collected.

Seasonal variations were evident throughout the four-month survey season. Lobster abundance was significantly different between sampling periods ($p = 0.019$) with all specimens collected in the first half of survey work. Fish ($p = 0.022$) and crab ($p = 0.001$) larval observations were also different when abundance was compared to collection time ($p = 0.022$ and $p = 0.001$).

4 2021 Results

In May and June of 2021, the MassCEC sample area was revisited twice per month and the same sampling and analysis methods were used as in 2020. With the commonwealth reopening due to the availability of Covid-19 vaccines, all work was completed on time. Our first survey was conducted on the 15th of May 2021 and the final sampling period was conducted on the 25th of June 2021 (Table 6).

Table 6. List of sampling dates, the vessel that operated on the sampling date, the minimum tow length, and lobster counts in 2021.

Sampling Date	Stations Sampled	Vessel	Tow Length (Min)	Lobster Counts
5/13/2021	15	Rock & Roll	10	0
5/14/2021	15	Encourager	10	0
5/27/2021	30	Both	10	1
6/9/2021	30	Both	10	62
6/25/2021	30	Both	10	32

4.1 Estimate distribution of larval species over the windfarm area

Samples were preserved after each trip and the environmental data were downloaded at SMAST. Samples were speciated with 9 fish species identified, haddock being the most abundant (Table B2). Results show highly temporal and aggregate distributions of larval lobster, crab, shrimp, and fish. The majority of all larval specimens were collected in the northwest region of Massachusetts-Rhode Island wind energy lease areas as in 2020. For each sampling period all larval species were counted and presented by mean ($\pm$StdDev), and number per 1,000 m^3 (Table 7-9). The mean abundance of larval fish, crab, shrimp, and lobsters was determined per 1000 m^3 by station (Figure 18-21).

Table 7. Total counts of fish, crab, shrimp, and lobster observed for each sampling period in 2021.

Sampling date (2021)	Species Counts							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
5/13 - 5/14	57	34	0	0	0	0	0	0
5/27	2	19	5	1	0	0	0	1
6/9	0	95	10	22	36	4	0	62
6/25	31	1669	36	1	10	18	3	32
Total	90	1817	51	24	46	22	3	95

Table 8. Mean counts of fish, crab, shrimp, and lobster per tow for each sampling period in 2021.

Sampling Date (2021)	Mean Species Larvae / Tow (StdDev)							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
5/13 - 5/14	1.90 (7.25)	1.13 (3.23)	0	0	0	0	0	0
5/27	0.07 (0.25)	0.63 (1.30)	0.17 (0.59)	0.03 (0.18)	0	0	0	0.03 (0.18)
6/9	0	3.17 (9.98)	0.33 (0.76)	0.73 (1.87)	1.20 (4.13)	0.13 (0.43)	0	2.07 (5.60)
6/25	1.03 (1.07)	55.63 (104.06)	1.20 (2.58)	0.03 (0.18)	0.33 (0.76)	0.60 (1.04)	0.10 (0.31)	1.07 (1.48)
Total	0.75 (3.70)	15.14 (56.73)	0.43 (1.44)	0.20 (0.98)	0.38 (2.13)	0.18 (0.61)	0.03 (0.16)	0.79 (2.99)

Table 9. Mean abundance of fish, crab, shrimp, and lobster per 1000 m^3 of water for each sampling period in 2021.

Sampling Date (2021)	Mean Species Larvae / 1000 m³ (StdDev)							
	Fish	Crab	Shrimp	Lobster				
				I	II	III	IV	Total
5/13 - 5/14	0.96 (3.43)	0.56 (1.54)	0	0	0	0	0	0
5/27	0.04 (0.14)	0.38 (0.80)	0.10 (0.36)	0.02 (0.11)	0	0	0	0.02 (0.11)
6/9	0	2.35 (7.64)	0.25 (0.59)	0.55 (1.43)	0.86 (2.97)	0.08 (0.29)	0	1.49 (4.09)
6/25	0.54 (0.63)	27.25 (48.21)	0.72 (1.59)	0.02 (0.08)	0.16 (0.36)	0.32 (0.53)	0.06 (0.17)	0.55 (0.72)
Total	0.39 (1.77)	7.63 (26.67)	0.27 (0.90)	0.15 (0.75)	0.25 (1.52)	0.10 (0.33)	0.01 (0.09)	0.52 (2.14)

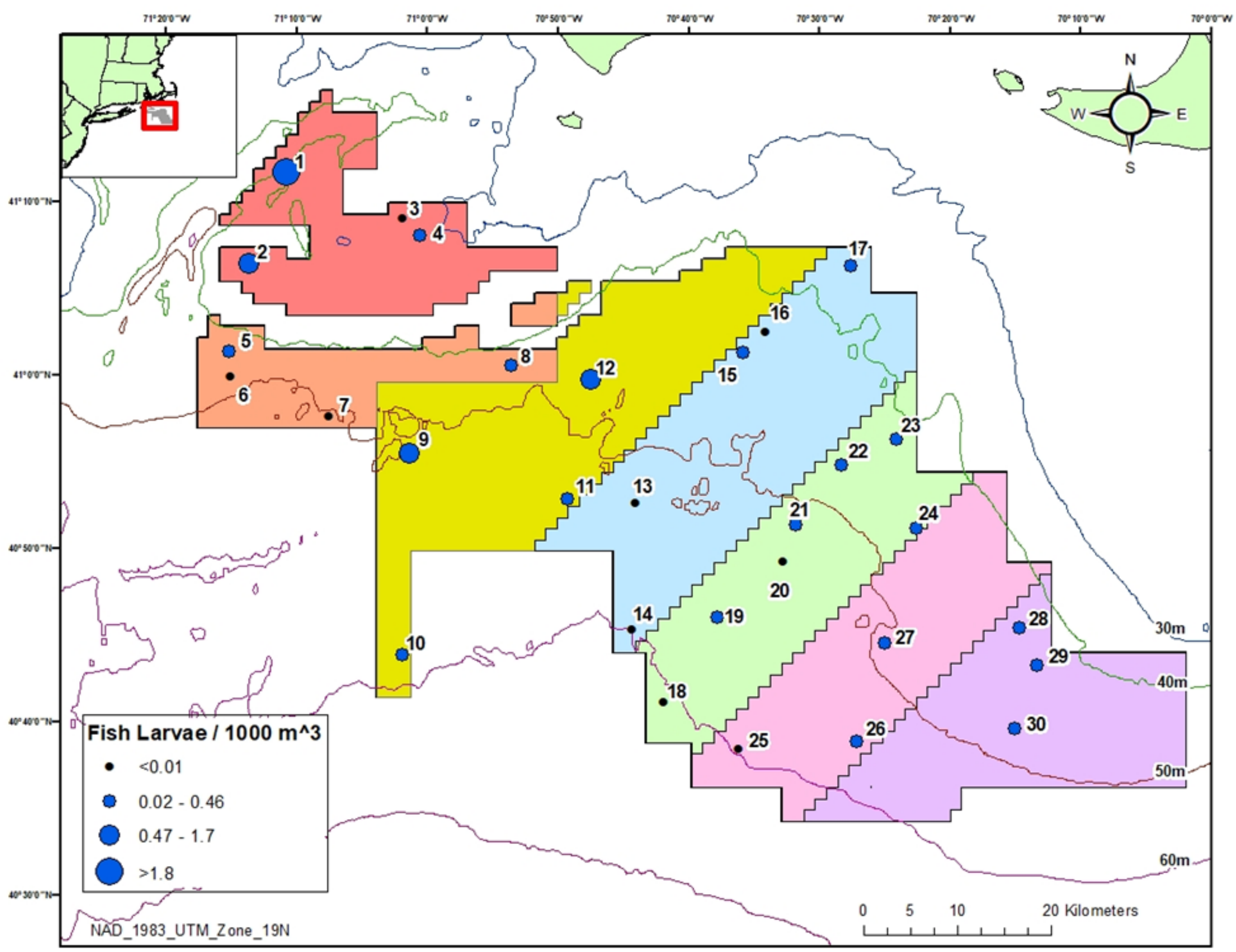

Figure 18. Larval fish abundance per 1000 m^3 of water sampled throughout all sampling periods (May and June 2021).

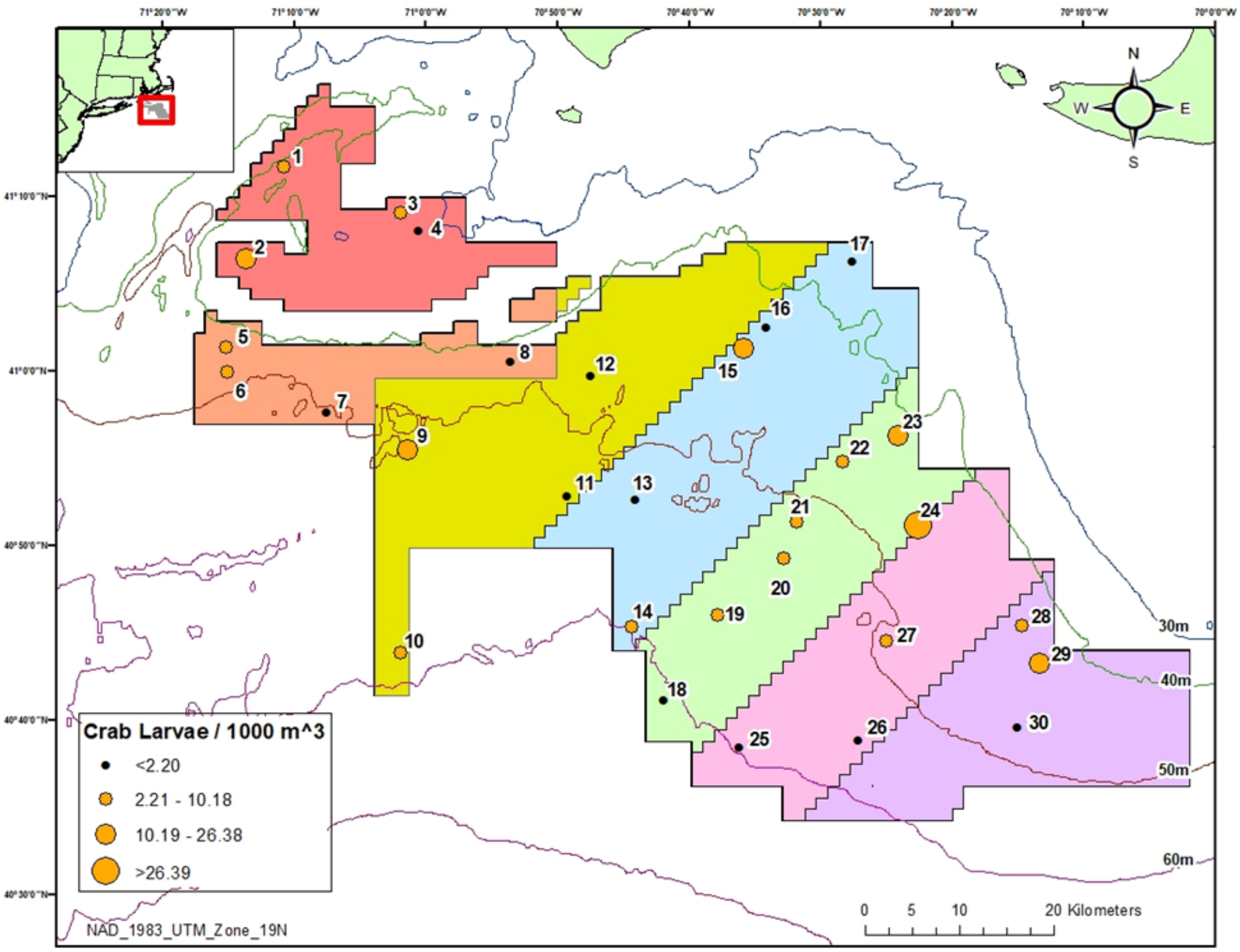

Figure 19. Larval crab abundance per 1000 m^3 of water sampled throughout all sampling periods (May and June 2021).

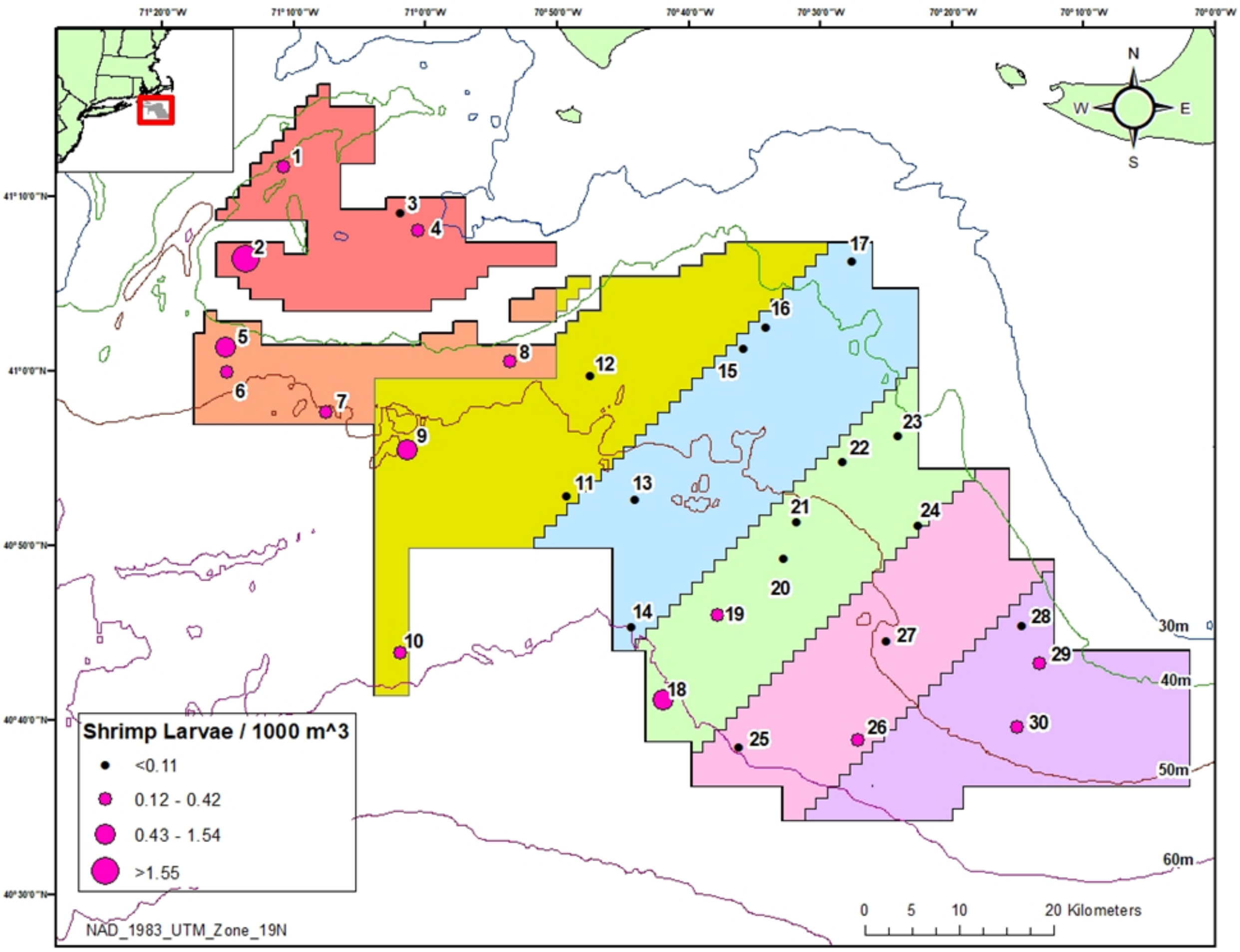

Figure 20. Larval Mysis shrimp abundance per 1000 m^3 of water sampled throughout all sampling periods(May and June 2021).

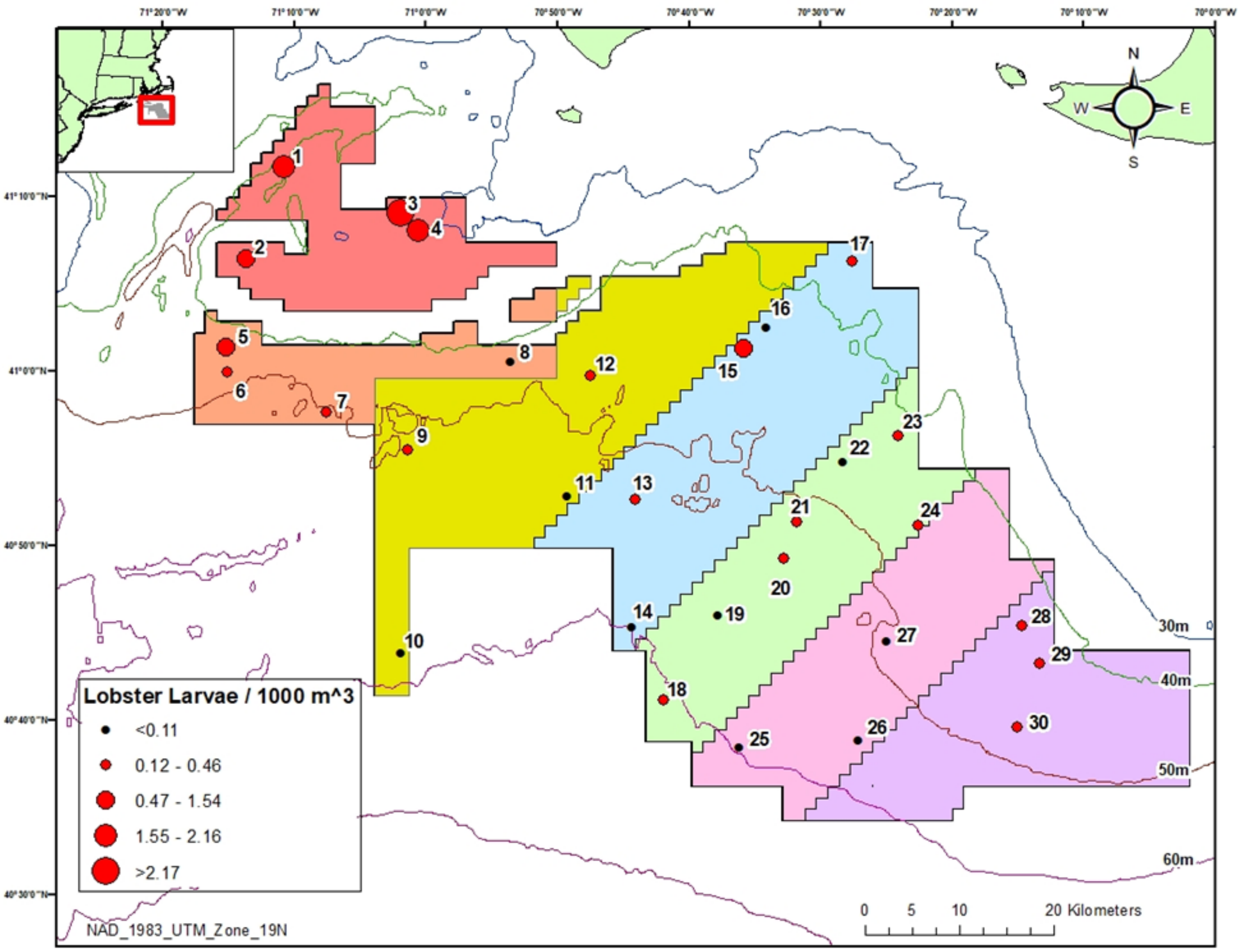

Figure 21. Larval lobster abundance per 1000 m^3 of water sampled throughout all sampling periods (May and June 2021).

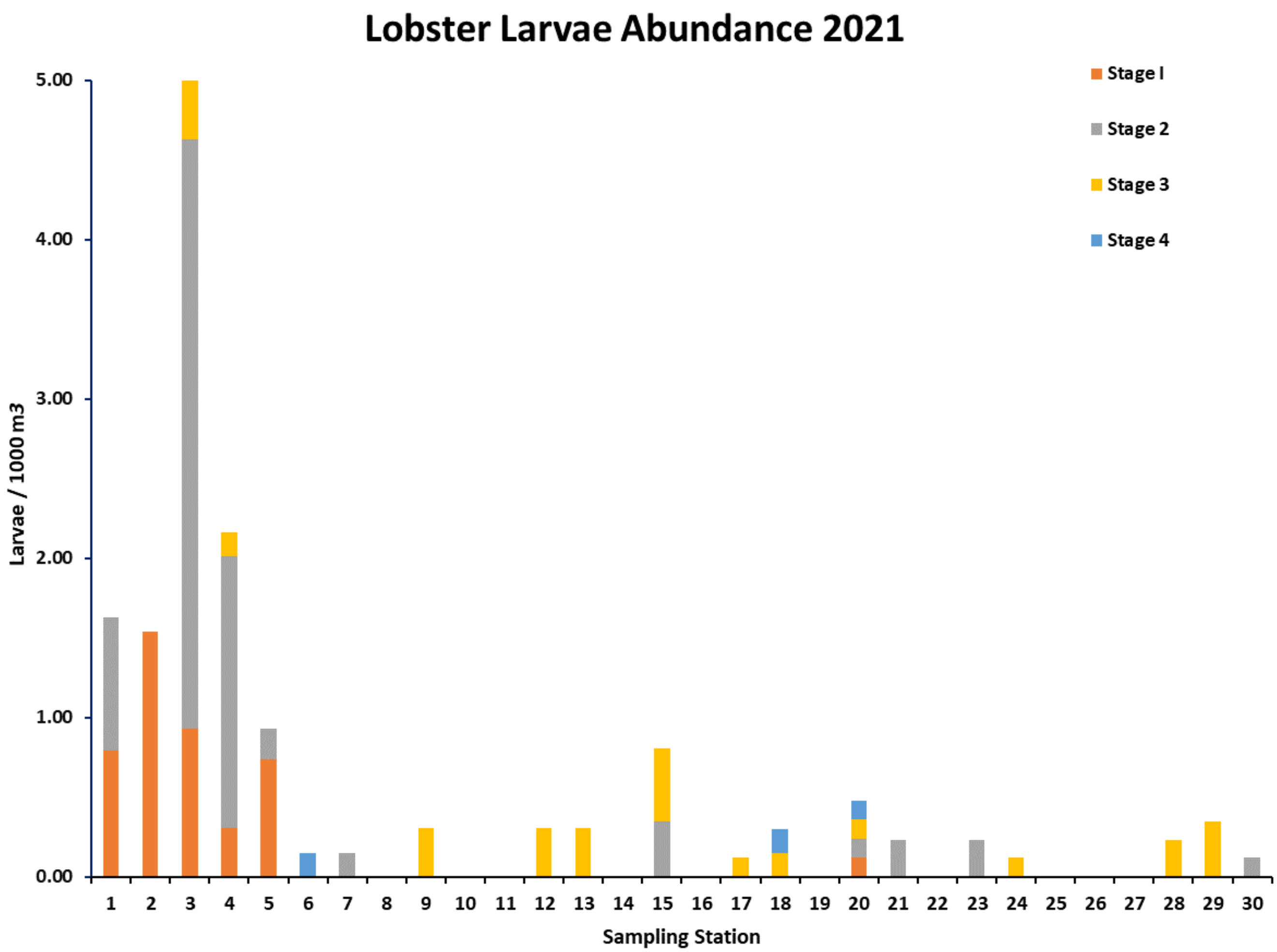

Figure 22. Cumulative lobster larval abundance by stage at each of the 30 sampling locations from May and June 2021.

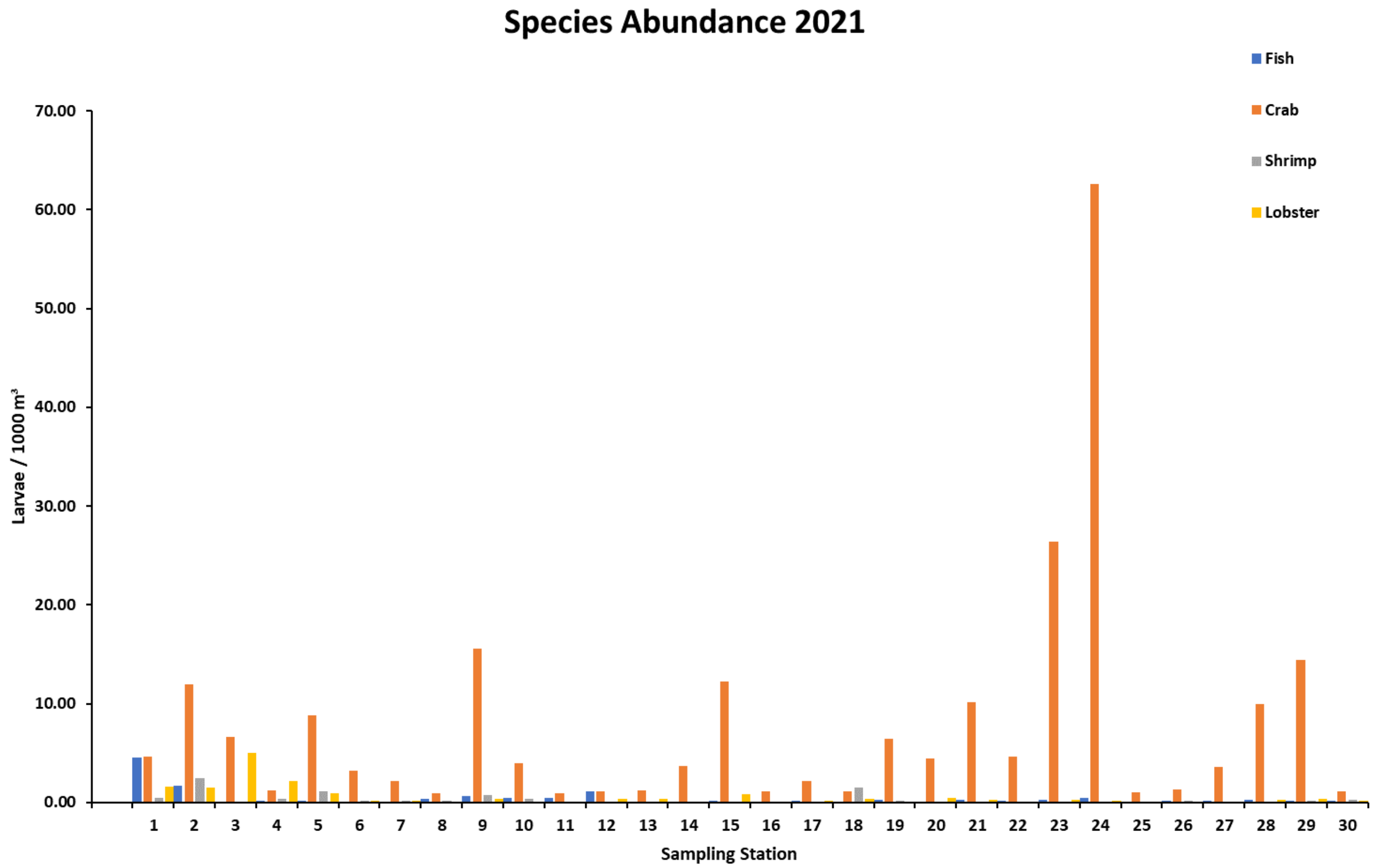

Figure 23. Cumulative comparison of larval species abundance at each sampling location in 2021 for the 4 main specimens collected.

Species abundance was calculated as the mean larvae per 1000 cubic meters of water sampled. This was a means of standardizing species counts for any variations in tow duration and the speed of the vessel. No significant difference was observed in larval lobster abundance between all sampling locations. Of all lobster larvae collected, 43% were observed at station three and four (Figure 21 and 22). Both crab and fish larvae exhibited no significant difference in the overall observed abundance; however, at the station level, sampling location two collected 43% of all fish larvae observed (Figure 18 and 23).

4.2 Larval abundance data and environmental factors correlation

Temperature and salinity data were recorded continuously throughout all sampling periods; however, the conductivity sensor malfunctioned during sample period 3 on 6/9/2021 for stations 1-14 and 18. For all areas the temperature averaged 15.1°C ± 2.7 with an observed range of 10.2 to 20.3°C. Other mean environmental factors monitored were salinity at a mean of 27.3 PPT ± 1.4 PPT, dissolved oxygen at 10.4 (mg/L) ±0.6, and mean pH of 8.4 ± 0.3. Station-specific temperature varied significantly between sampling areas ($p=0.001$). When all environmental variables were factored for, there was significant negative relationship between temperature and salinity ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p = 0.03$).

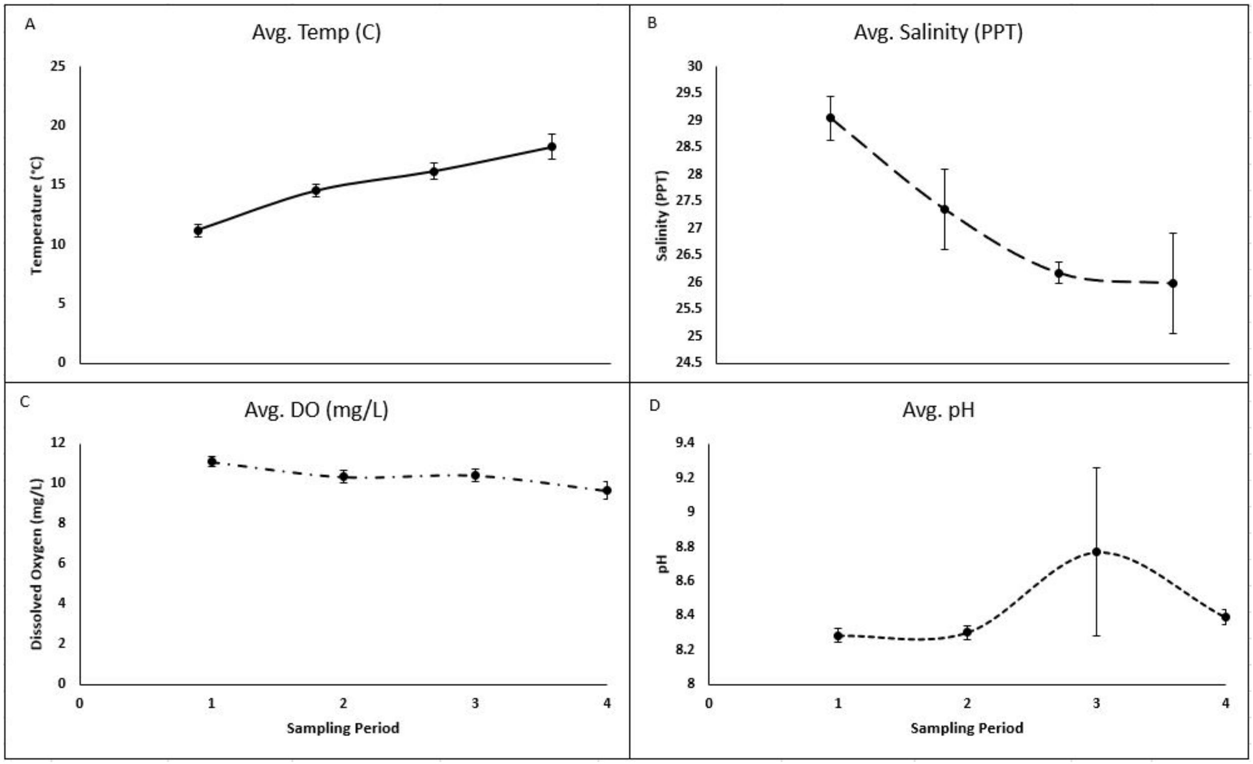

Figure 24. Environmental data by sampling period A) Average temperature in degrees Celsius B) Average salinity in parts per thousand C) Average dissolved oxygen in milligrams per liter D) Average pH. The timeframe of this dataset is May and June 2021. All data points have their respective standard deviations included.

Table 10. The mean environmental data by sampling period and standard deviation in 2021.

Sampling Date (2021)	Environmental Factor			
	Temp (C)	Salinity (PPT)	DO (mg/L)	pH
5/13 - 5/14	11.21 (0.55)	29.05 (0.40)	11.11 (0.24)	8.29 (0.04)
5/27	14.55 (0.51)	27.36 (0.75)	10.36 (0.30)	8.3 (0.04)
6/9	16.20 (0.73)	26.18 (0.19)	10.43 (0.31)	8.77 (0.49)
6/25	18.26 (1.07)	25.98 (0.92)	9.68 (0.45)	8.39 (0.04)
Average	15.06 (2.70)	27.28 (1.42)	10.40 (0.61)	8.44 (0.31)

Temperature is a large driving factor of larval abundance and distribution (Rodriguez, 2019). A regression analysis indicated that there was a significant ($p = 0.038$) relationship between temperature and larval abundance. The density of larval lobsters increased substantially as water temperatures reached around 16°C during sample period 3 in June, with 65% of lobster larvae captured within sample period 3. Crab larvae experienced a similar significant relationship with temperature ($p = 0.003$). No significant ($p = 0.20$) relationship was observed between surface water temperature and density for larval fish. Both fish and crab larvae experienced highly variable catch rates throughout the duration of sampling.

Average station level temperature over the course of the four sampling periods indicated that stations near the middle region of the MA-RI wind energy area experienced lower surface water temperatures. For other environmental variables, pH, dissolved oxygen, and salinity also experienced their lowest values near the middle region, with high values shown throughout. The highest dissolved oxygen values on average were observed at station twenty-four. As expected, given seasonal variations and location, there was a significant change in temperature between sampling periods and station ($p < 0.001$). Similarly, salinity exhibited a significant change over sampling periods and sampling locations ($p < 0.001$).

4.3 Determine the seasonal variations of larval species in the wind energy lease areas

Abundance indices of larval lobster peaked at the beginning of sampling in June, with stage 2 lobsters as the most abundant. Only 1 lobster larvae was observed in May; however, counts dramatically increased in June (Figure 25). Crab larvae were present in low numbers within sample periods 1-3 and had the highest observations in the end of June during sample period 4. Fish, shrimp, and crab larval abundance remained relatively stable throughout sampling periods, although 92% of crab larvae were caught in sampling period 4 (Figure 26).

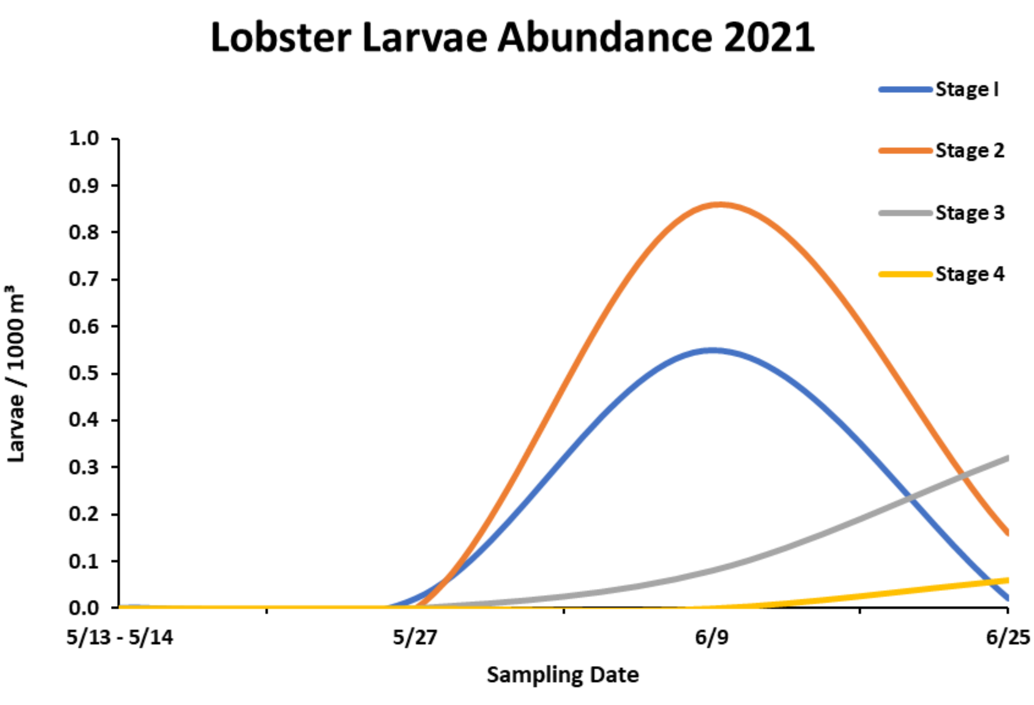

Figure 25. Mean abundance of lobster (stages 1, 2, 3, and 4) per 1000 m^3 of water for each sampling period in 2021.

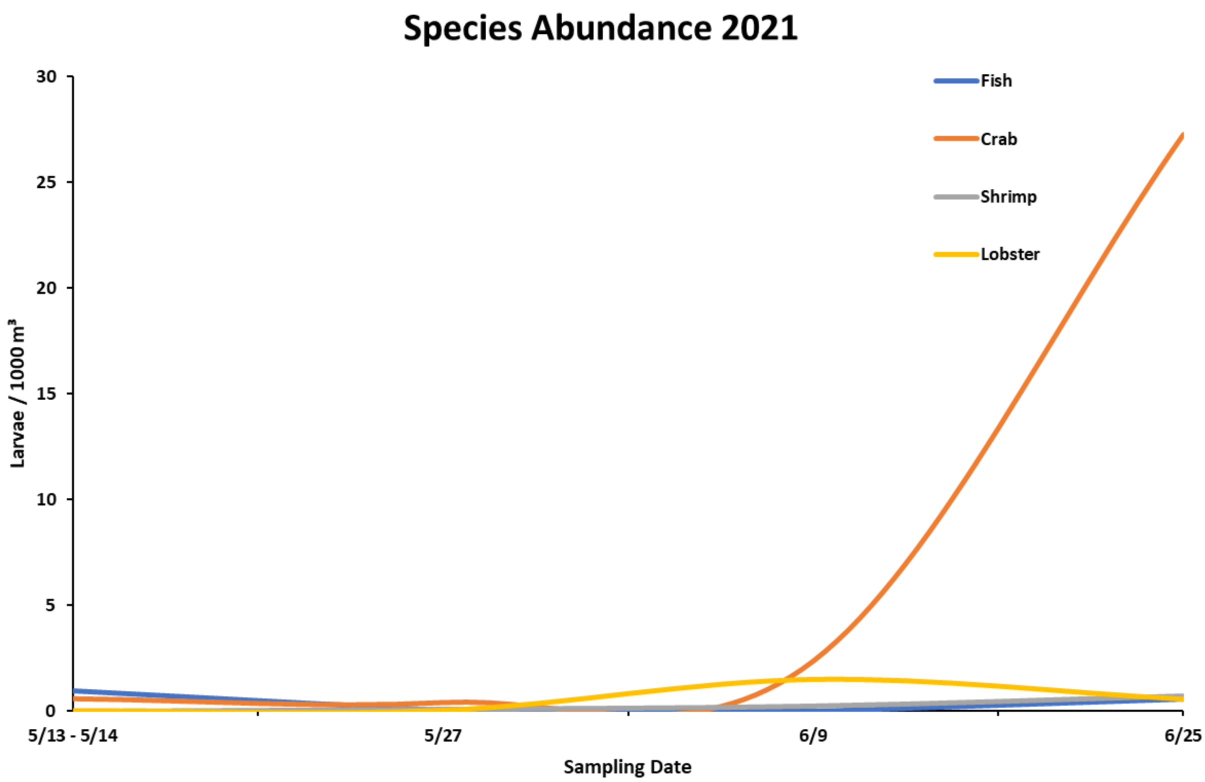

Figure 26. Comparison of larval species abundance at each sampling period in 2021 for the 4 main specimens collected.

Larval lobster abundance was significantly different between sampling periods ($p = 0.024$) with 65% of all specimens collected in sample period 3. While collection time did not have a significant impact on fish abundance, there was a significant difference in larval crab abundance ($p = < 0.001$) when compared to collection time.

5 June 2020 and June 2021 Comparison

June was the only month that was sampled in both 2020 and 2021. Therefore, June was used to compare interannual variations in species abundance. Abundance indices of larval lobster peaked in June during both years (Table 13). There was no significant difference for lobster abundance ($p=0.385$). A significant difference in fish ($p=0.008$), crab ($p=0.030$), and shrimp ($p = < 0.001$) abundance was observed. Black seabass (*Centropristis striata*) was the only common fish species caught in June for both years.

During June 2020 and June 2021 there was no significant difference between temperature (p=0.175) but there was a significant difference in salinity (p=<0.001) (Table 15). Dissolved oxygen and pH could not be compared as sensors were not deployed until July of 2020.

Table 11. Total counts of fish, crab, shrimp, and lobster observed in June 2020 and 2021.

Date	Year	Species Counts							
		Fish	Crab	Shrimp	Lobster				
					I	II	III	IV	Total
6/9/2020	2020	2	1946	0	35	25	4	0	64
6/25/2020	2020	15	896	0	42	21	9	2	74
6/9/2021	2021	0	95	10	22	36	4	0	62
6/25/2021	2021	31	1669	36	1	10	18	3	32
June	2020	17	2842	0	77	46	13	2	138
June	2021	31	1764	46	23	46	22	3	94

Table 12. Mean abundance of fish, crab, shrimp, and lobster per 1000 m^3 of water in June 2020 and 2021.

Date	Year	Mean Species Larvae / 1000 m³ (StdDev)							
		Fish	Crab	Shrimp	Lobster				
					I	II	III	IV	Total
6/9/2020	2020	0.04 (0.16)	44.9 (80.77)	0	0.81 (1.91)	0.53 (0.91)	0.1 (0.32)	0	1.43 (2.68)
6/25/2020	2020	0.30 (0.87)	17.42 (31.33)	0	0.89 (3.97)	0.44 (1.99)	0.17 (0.58)	0.05 (0.18)	1.54 (6.28)
6/9/2021	2021	0	2.35 (7.64)	0.25 (0.59)	0.55 (1.43)	0.86 (2.97)	0.08 (0.29)	0	1.49 (4.09)
6/25/2021	2021	0.54 (0.63)	27.25 (48.21)	0.72 (1.59)	0.02 (0.08)	0.16 (0.36)	0.32 (0.53)	0.06 (0.17)	0.55 (0.72)
June	2020	0.17 (0.63)	31.16 (62.30)	0	0.85 (3.09)	0.48 (1.53)	0.13 (0.46)	0.02 (0.13)	1.49 (4.79)
June	2021	0.28 (0.52)	14.80 (36.45)	0.49 (1.21)	0.28 (1.04)	0.51 (2.12)	0.20 (0.44)	0.03 (0.13)	1.02 (2.95)

Table 13. The mean environmental data by sampling period and standard deviation in June 2020 and 2021.

Date	Environmental Factor			
	Temp (C)	Salinity (PPT)	DO (mg/L)	pH
6/9/2020	14.69 (1.31)	27.26 (6.98)	-	-
6/25/2020	18.70 (1.36)	29.11 (1.30)	-	-
6/9/2021	16.20 (0.73)	26.18 (0.19)	10.43 (0.31)	8.77 (0.49)
6/25/2021	18.26 (1.07)	25.98 (0.92)	9.68 (0.45)	8.39 (0.04)
All	16.96 (1.98)	27.27 (3.99)	10.05 (0.54)	8.58 (0.39)

The data collected in 2020 and 2021 indicate that June is an important month for larval sampling, specifically lobsters and crabs. This research shows the distribution of larval species within the Massachusetts-Rhode Island Wind energy lease areas.

There is limited ichthyoplankton sampling in southern New England; however, other regional sampling efforts include the federal Ecosystem Monitoring (EcoMon) ichthyoplankton survey. The EcoMon survey studies the abundance and proportion of ichthyoplankton from 1977-1987, 1999-2021 from Cape Hatteras to Cape Sable, Nova Scotia within the NMFS statistical areas. Samples were collected both day and night using a 61-cm bongo net. Double oblique tows were a minimum of 5-mintues in duration, and fished from the surface to within 5-m of the seabed or to a maximum depth of 200-m. The bongo net is adaptable to capture larvae from the surface to a maximum depth of 200-m and may be more representative of the smaller, early-stage larvae and may capture the vertical migrations of larvae that a neuston net does not. Spatial distribution of 23 taxa shifted northward, particularly larvae found in the Mid-Atlantic bight and southern New England, as examined from the 1977 -1987 to 1999 – 2008 datasets potentially in response to increased water temperatures (Walsh et al., 2015). The results from neuston net sampling provide finer scale data which can be compared to the ecosystem level collected from the EcoMon data set.

The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) buoy observations buoy provides continuous long-term data sets of environmental observations like temperature, wind direction, speed, gust, and wave height. NERACOOS is a long-term data set that provides reliable observations which can be used in comparison to larval abundance in the region. Collecting continuous information on physical oceanographic parameters may help to understand the passive drift of early-stage larvae combined with effects from temperature. The opportunity to further baseline analysis in wind lease areas exists in utilizing data sets like EcoMon and NERACOOS. This larval survey is the first regional assessment of its kind and is intended to provide strong baseline data for future comparisons as the wind companies develop lease areas.

6 References

Atlantic States Marine Fisheries Commission (ASMFC). (2019). American Lobster. Retrieved February 7,2019, from http://www.asmfc.org/species/american-lobster

ASMFC American Lobster Stock Assessment Review Panel. (2015). *American Lobster Benchmark Stock Assessment for Peer Review Report* (Accepted for Management Use, pp. 31-493, Rep. No. NA10NMF4740016). ASMFC.

Casey, E.F. (2019). Modeling the impact of climate change on American lobster, *Homarus americanus,* larval connectivity in southern New England (Unpublished master's thesis). University of Massachusetts Dartmouth.

Degraer, S., Carey, D. A., Coolen, J. W., Hutchison, Z. L., Kerckhof, F., Rumes, B., & Vanaverbeke, J. (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning. *Oceanography*, *33*(4), 48-57.

De Troch, M., Reubens, J.T., Heirman, E., Degraer, S., & Vincx, M., (2013). Energy profiling of demersalfish: A case-study in wind farm artificial reefs. *Marine environmental research*. 92.10.1016/j.marenvres.2013.10.001.

Factor JR (1995) Introduction, anatomy, and life history. In: Factor JR (ed) Biology of the lobster *Homarus americanus*. Academic Press, New York, 1-11.

Herrick, F. H. (1911). *Natural History of the American Lobster* (Document No. 747). Washington D.C.:United States Bureau of Fisheries

Le Bris, A., Mills, K. E., Wahle, R. A., Chen, Y., Alexander, M. A., Allyn, A. J., Schuetz, J. G., Scott, J.D., &Pershing, A. J. (2018). Climate vulnerability and resilience in the most valuable North American fishery. *Proceedings of the National Academy of Sciences, 115*(8), 1831-1836. doi:10.1073/pnas.1711122115

Milligan, P. J. (2010). *Abundance, distribution and size of American lobster (Homarus Americanus) larvaein Buzzards Bay, Massachusetts: a thesis in marine science and technology- living marine resources management.* University of Massachusetts Dartmouth School of Marine Sciences. Unpublished Master'sThesis

Petersen, J.K., and Malm, T. (2006). Offshore Windmill Farms: Threats to or Possibilities for the MarineEnvironment. Ambio. 35(2): 75 – 80.

Rodriguez, J. (2019). Assemblage structure of ichthyoplankton in the NE Atlantic in spring under contrasting hydrographic conditions. Scientific Reports, 9(1), 8636–16. https://doi.org/10.1038/s41598-019-44918-5

Wahle, R.A., Dellinger, L., Olszewski, S., and Jekielek, P. (2015). American lobster nurseries ofsouthern New England receding in the face of climate change. Journal of Marine Science

Walsh HJ, Richardson DE, Marancik KE, Hare JA (2015) Long-Term Changes in the Distributions of Larval and Adult Fish in the Northeast U.S. Shelf Ecosystem. PLoS ONE 10(9): e0137382. doi:10.1371/journal.pone.0137382

Appendix A: Distribution Maps

The distribution of larval species varied throughout each sampling period. Maps depicting larvae / 100 m^3 for Fish, Lobster, Crab, and Shrimp are shown below.

A.1 Fish

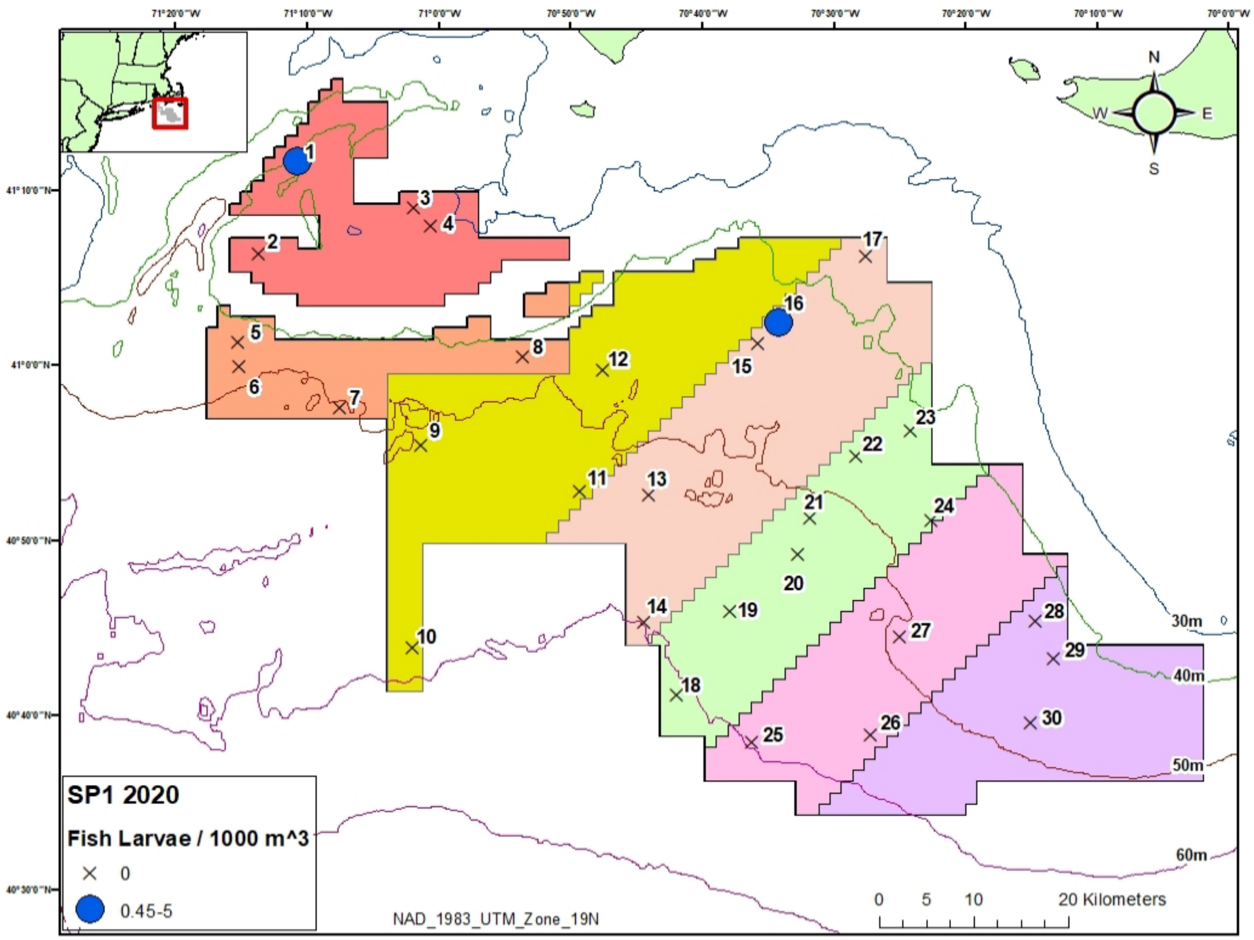

Figure 1. Larval fish abundance per 1000 m^3 of water sampled on 6/9/2020.

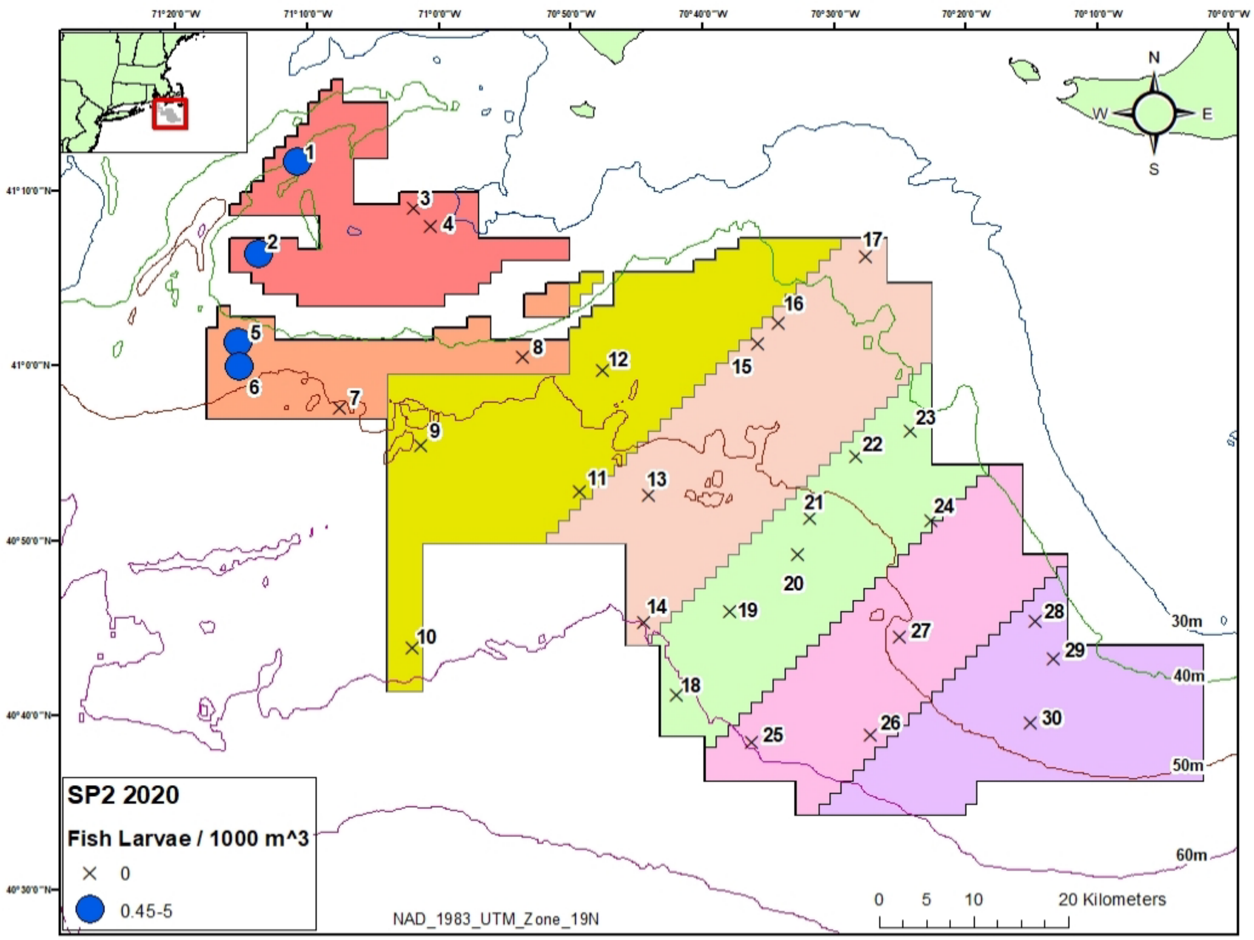

Figure 2. Larval fish abundance per 1000 m^3 of water sampled on 6/25/2020.

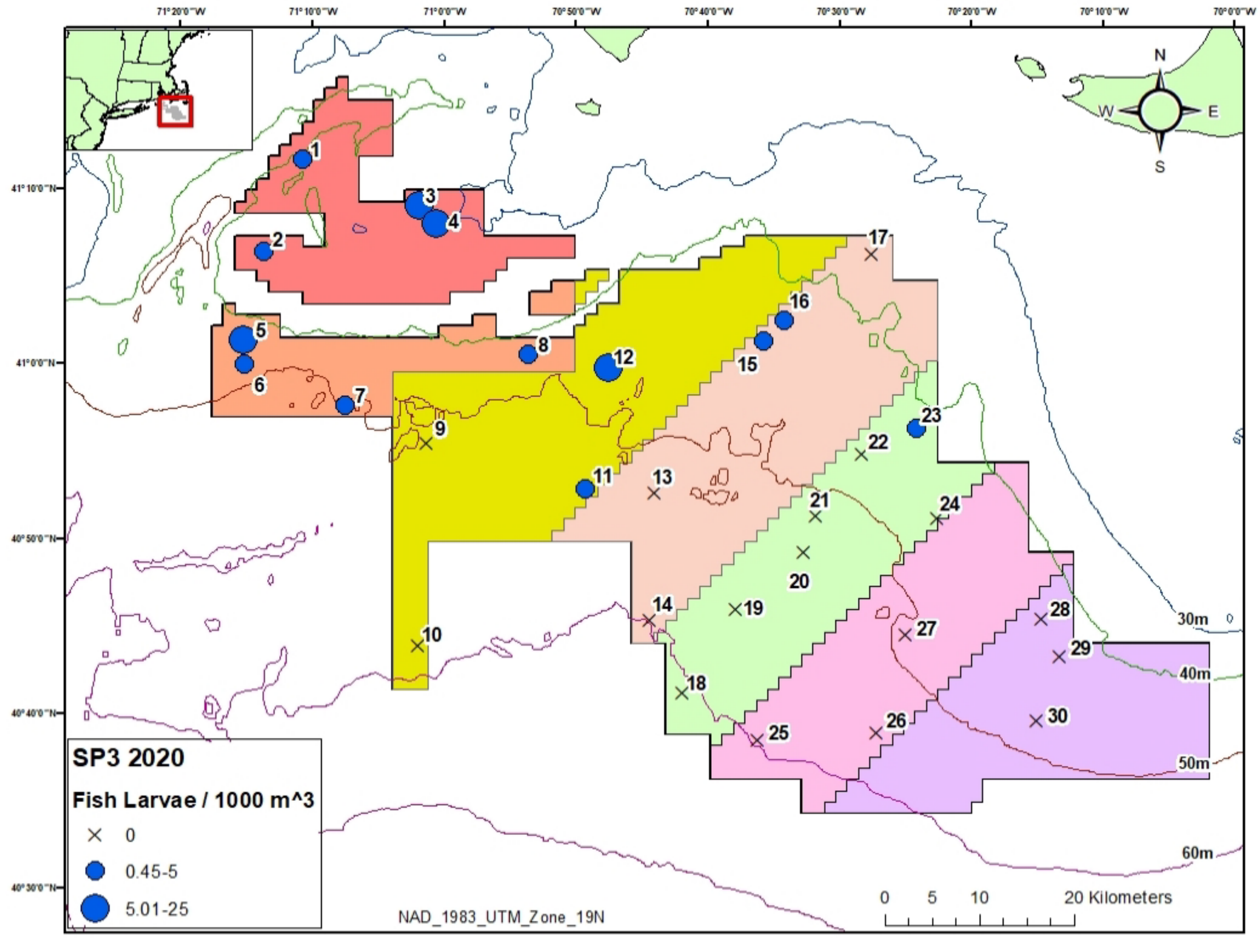

Figure 3. Larval fish abundance per 1000 m^3 of water sampled on 7/8/2020.

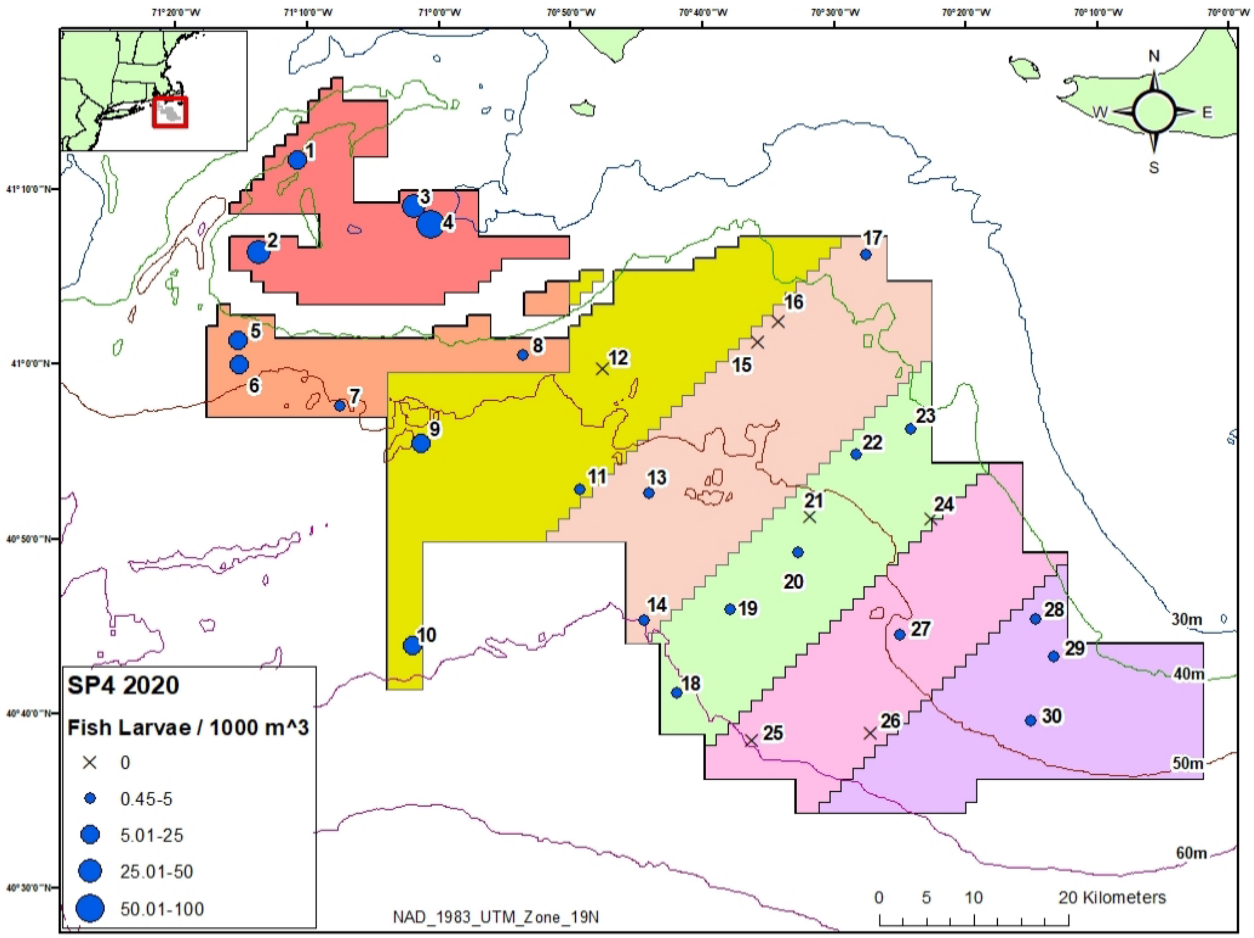

Figure 4. Larval fish abundance per 1000 m³ of water sampled on 7/29/2020.

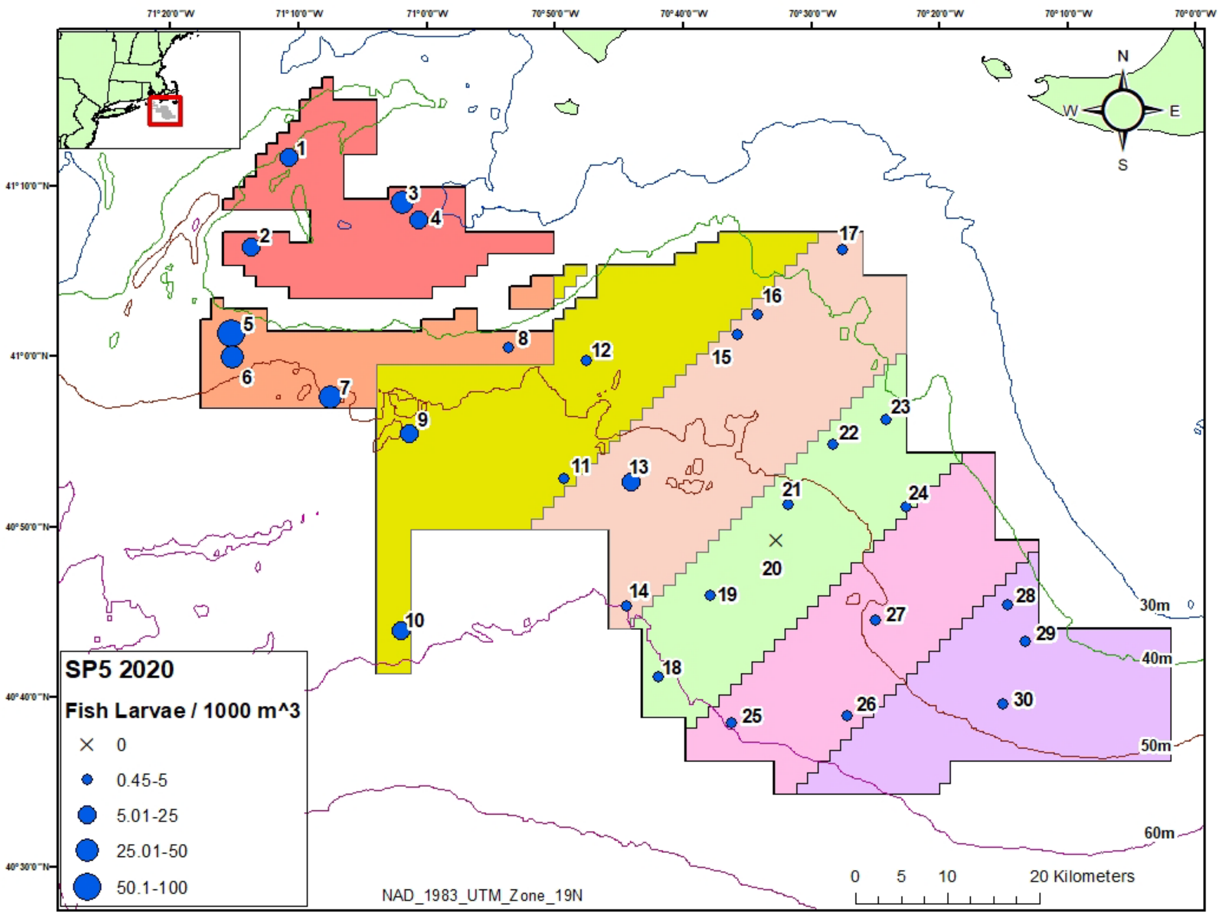

Figure 5. Larval fish abundance per 1000 m^3 of water sampled on 8/12/2020 and 8/13/2020.

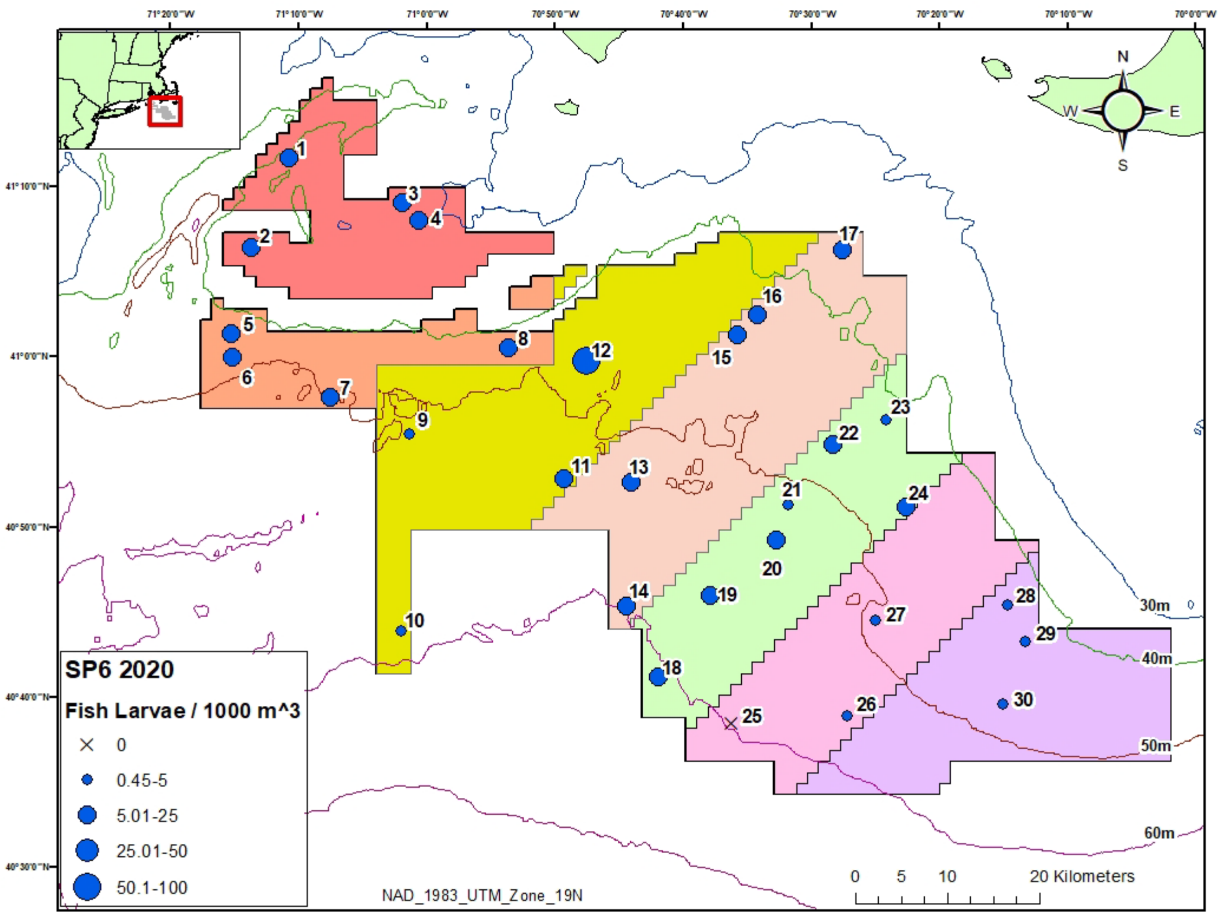

Figure 6. Larval fish abundance per 1000 m^3 of water sampled on 8/27/2020 and 8/29/2020.

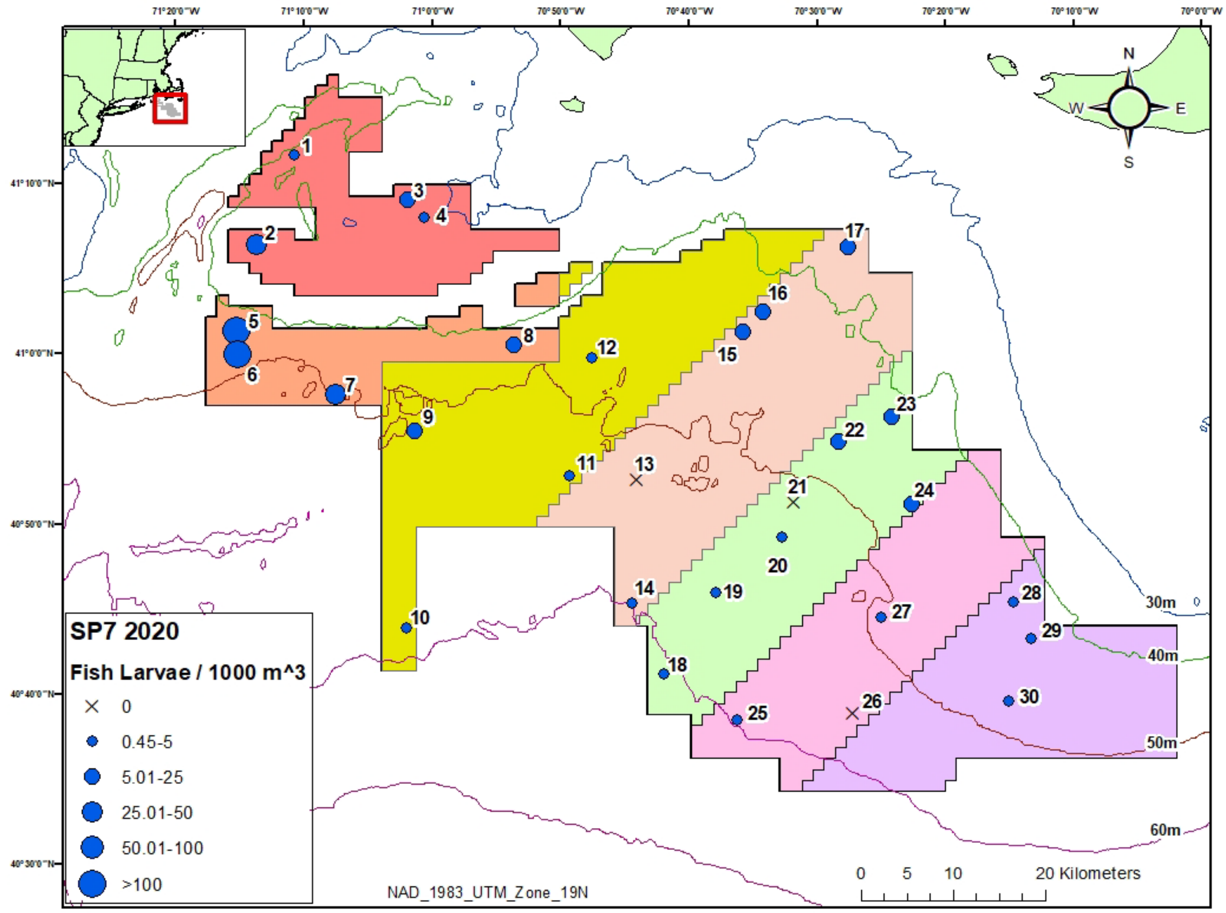

Figure 7. Larval fish abundance per 1000 m^3 of water sampled on 9/24/2020.

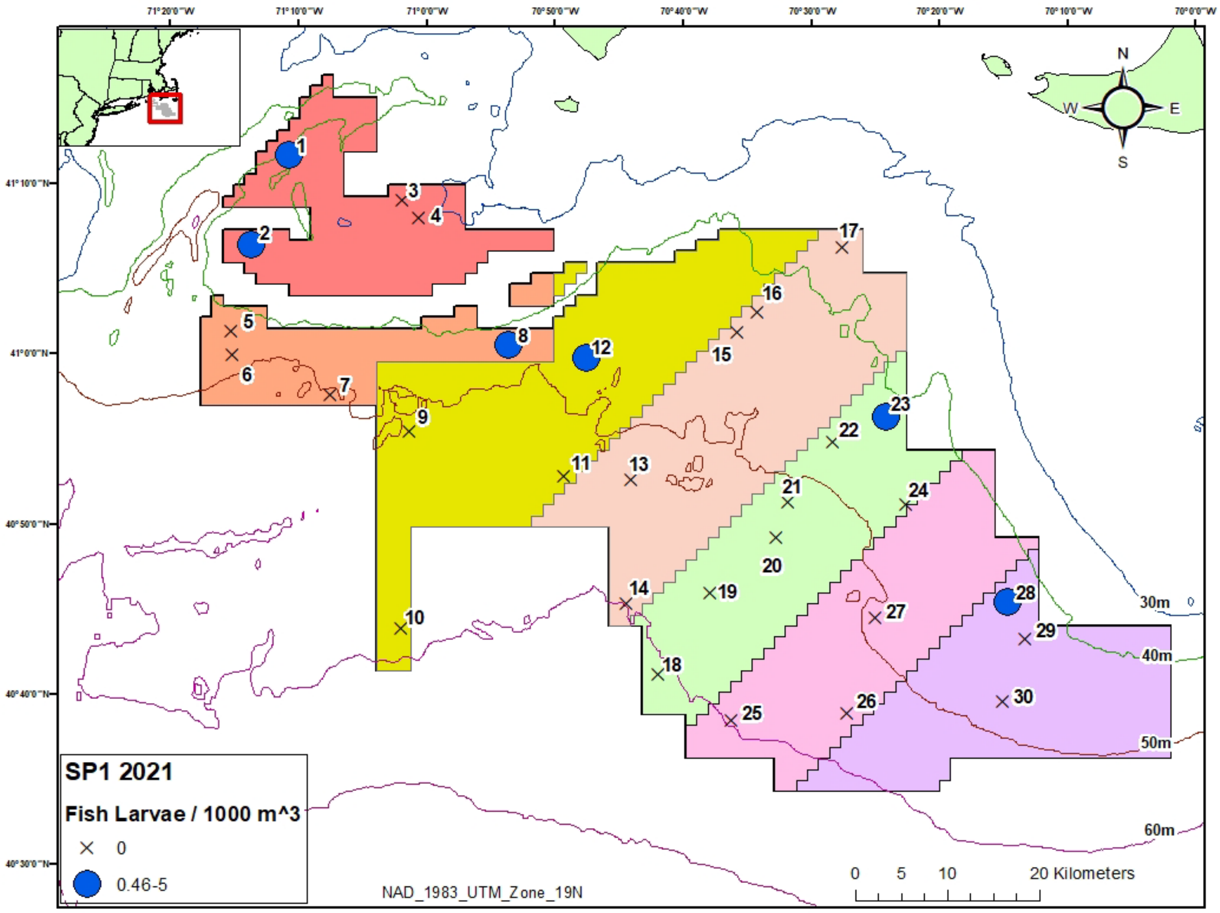

Figure 8. Larval fish abundance per 1000 m^3 of water sampled on 5/13/2021 and 5/14/2021.

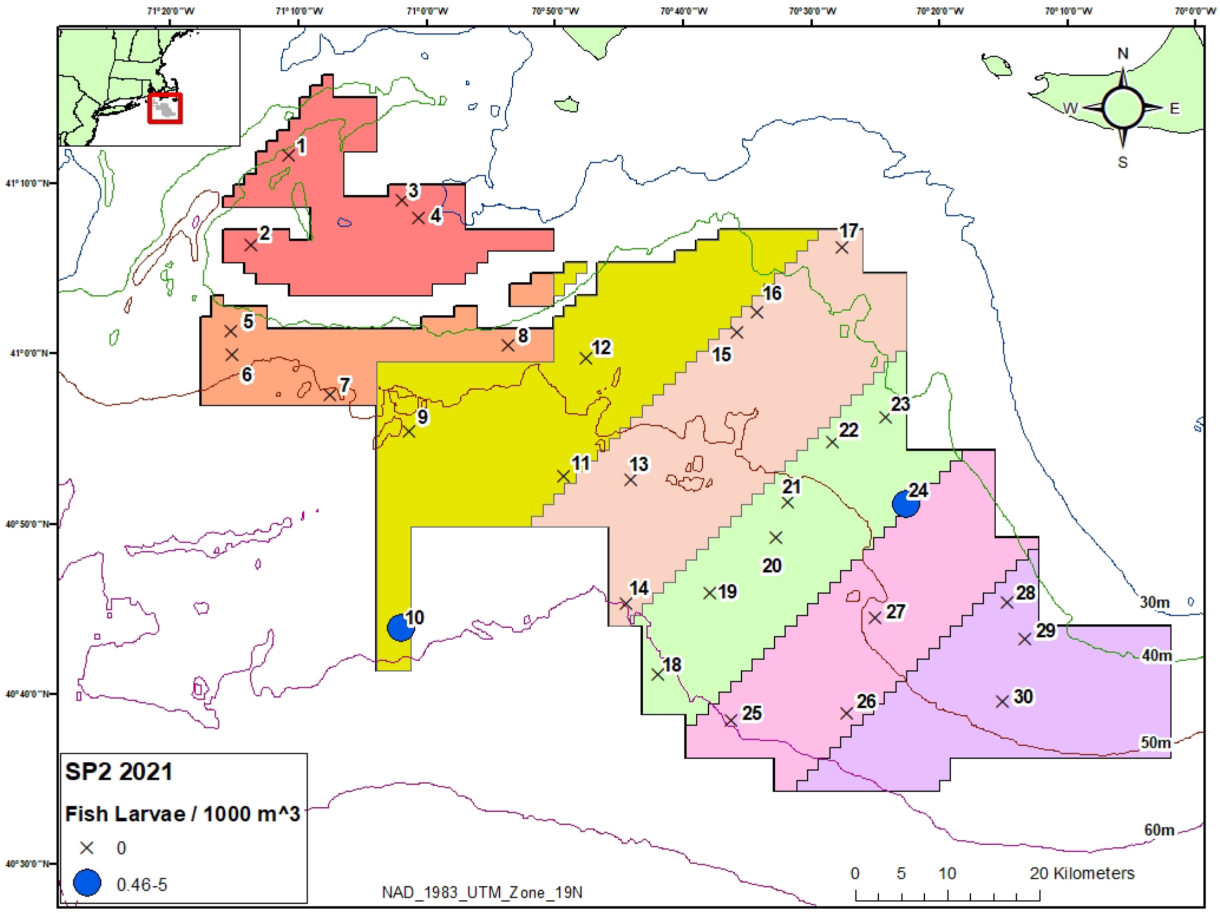

Figure 9. Larval fish abundance per 1000 m^3 of water sampled on 5/27/2021.

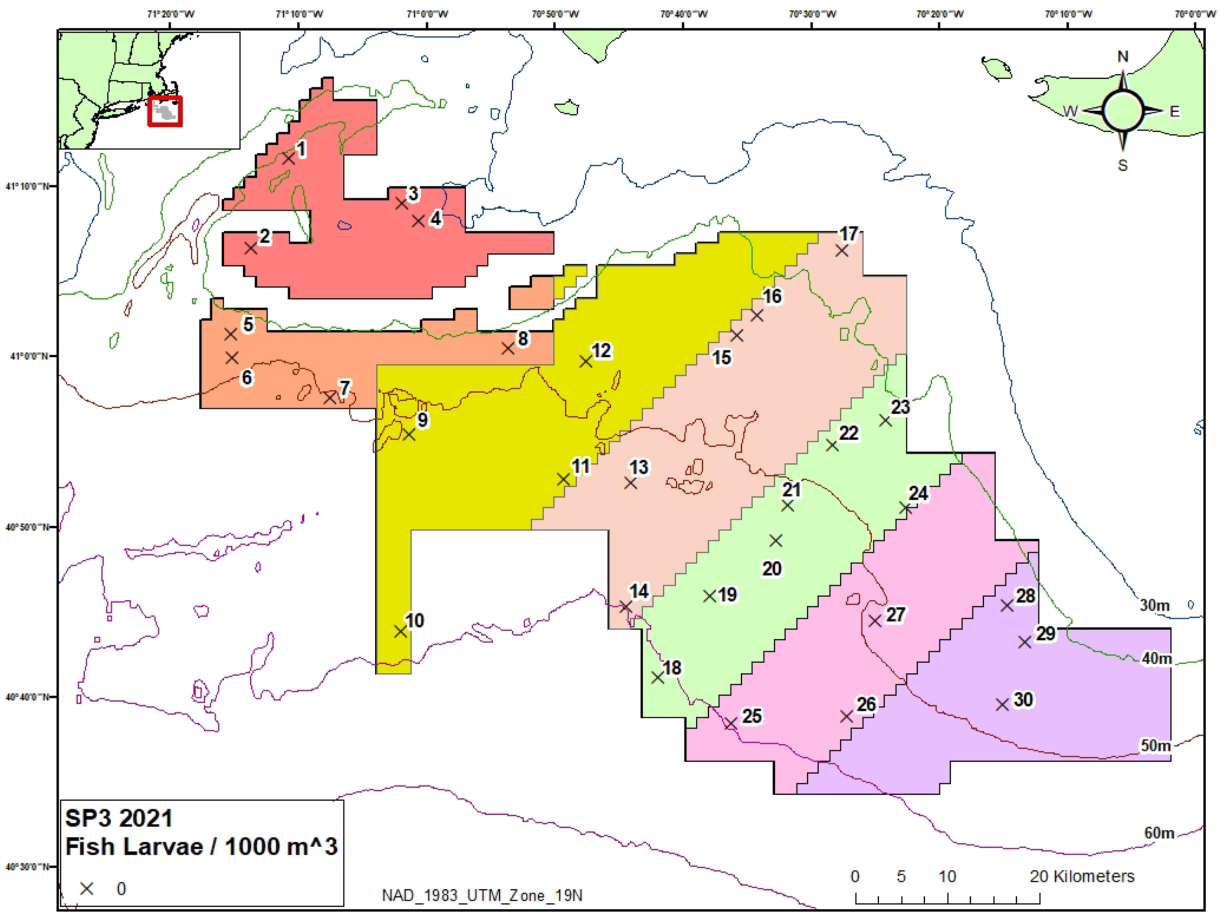

Figure 10. Larval fish abundance per 1000 m^3 of water sampled on 6/9/2021.

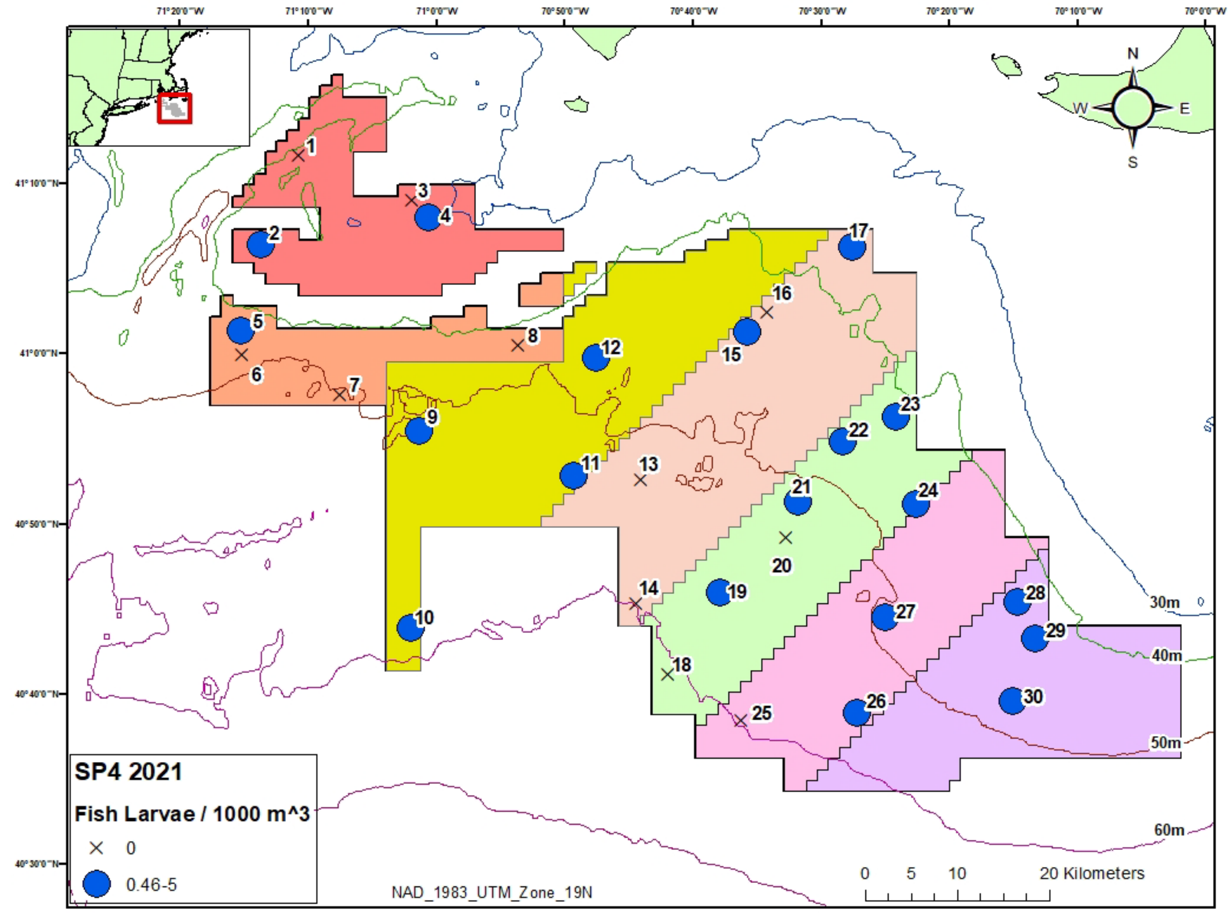

Figure 11. Larval fish abundance per 1000 m^3 of water sampled on 6/25/2021.

A.1 Lobster

A density distribution map of Larval lobster abundance per 1000 m3 of water sampled during sample period 1 on 6/9/2020

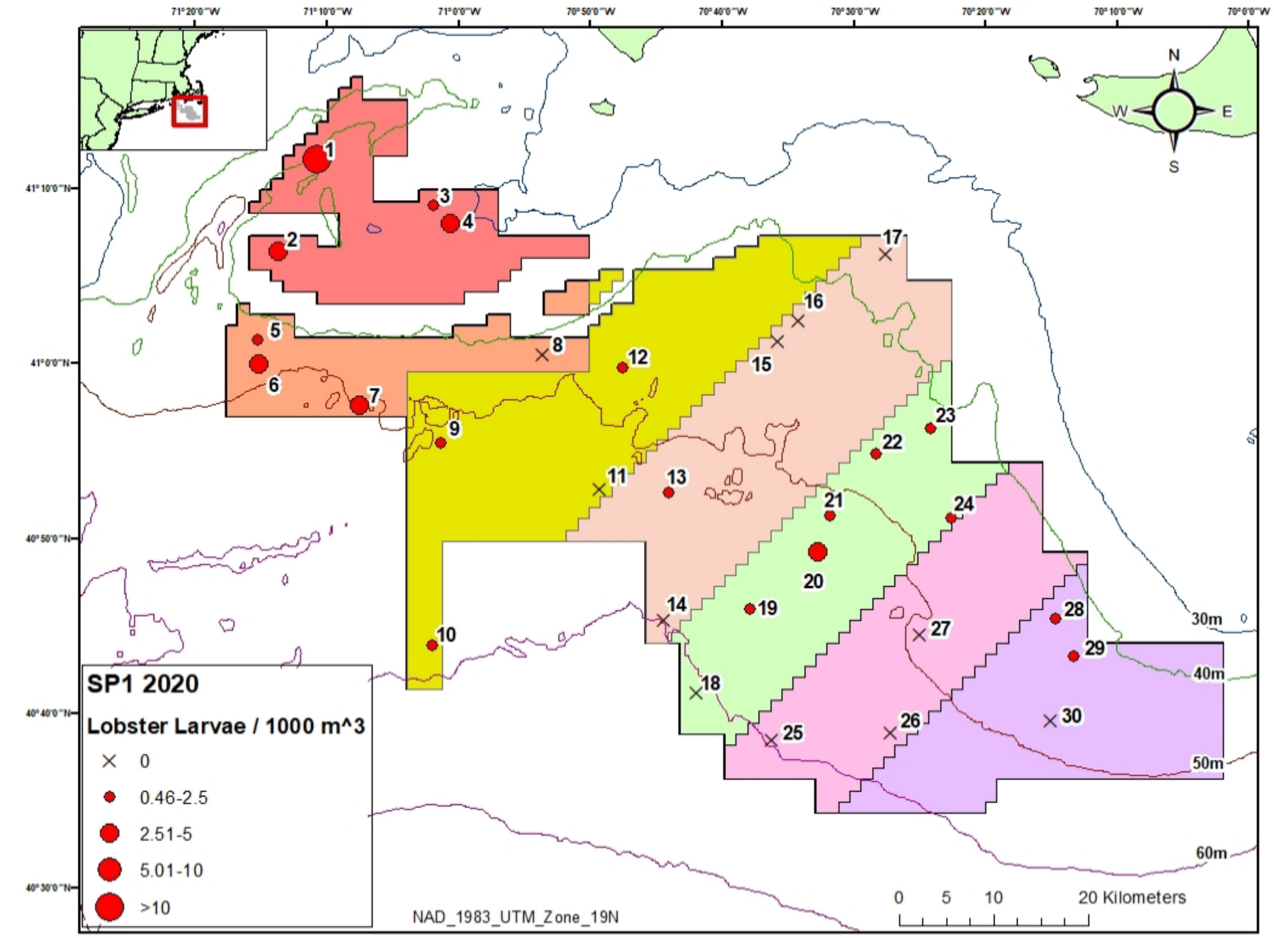

Figure 1. Larval lobster abundance per 1000 m^3 of water sampled on 6/9/2020.

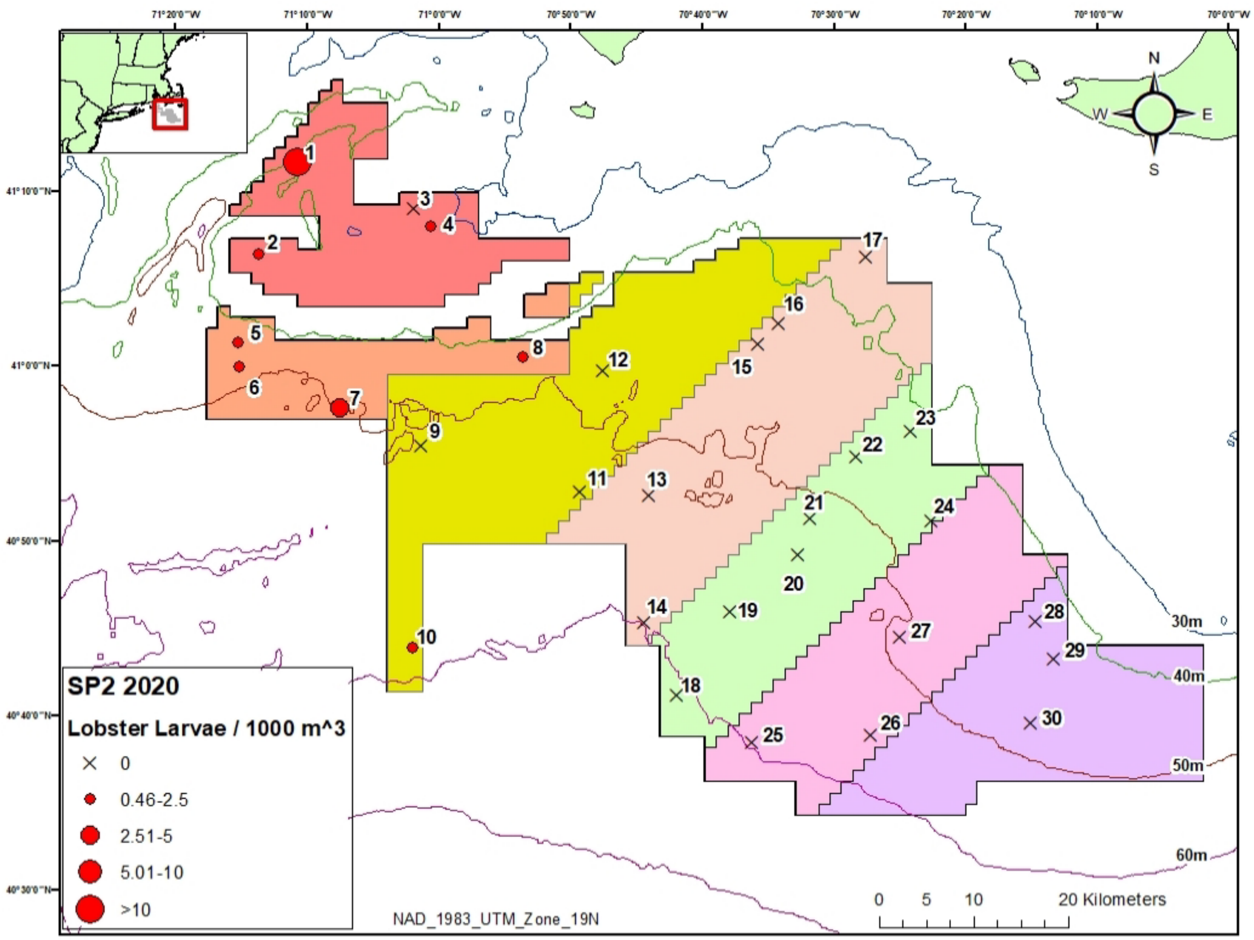

Figure 2. Larval lobster abundance per 1000 m^3 of water sampled on 6/25/2020.

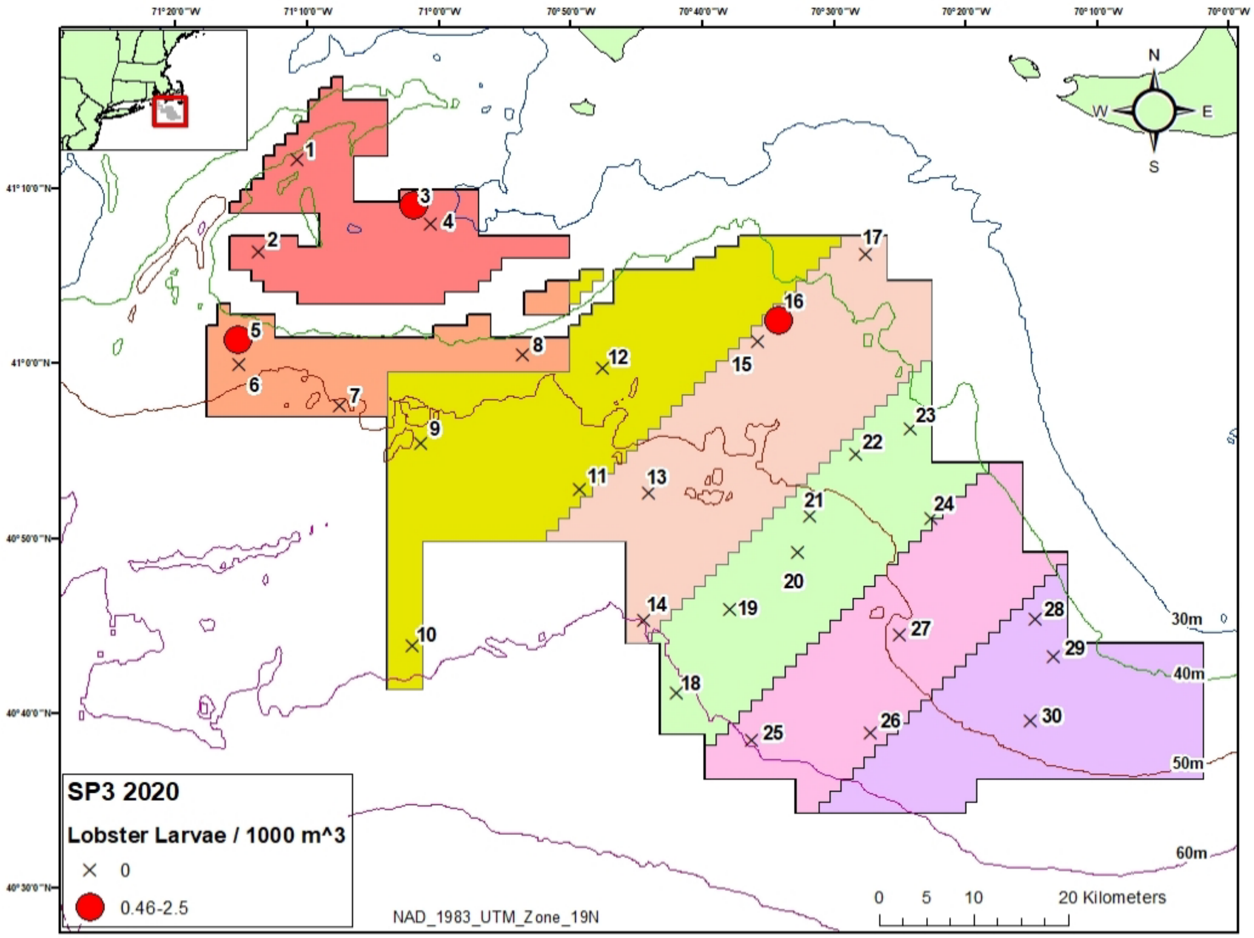

Figure 3. Larval lobster abundance per 1000 m^3 of water sampled on 7/8/2020.

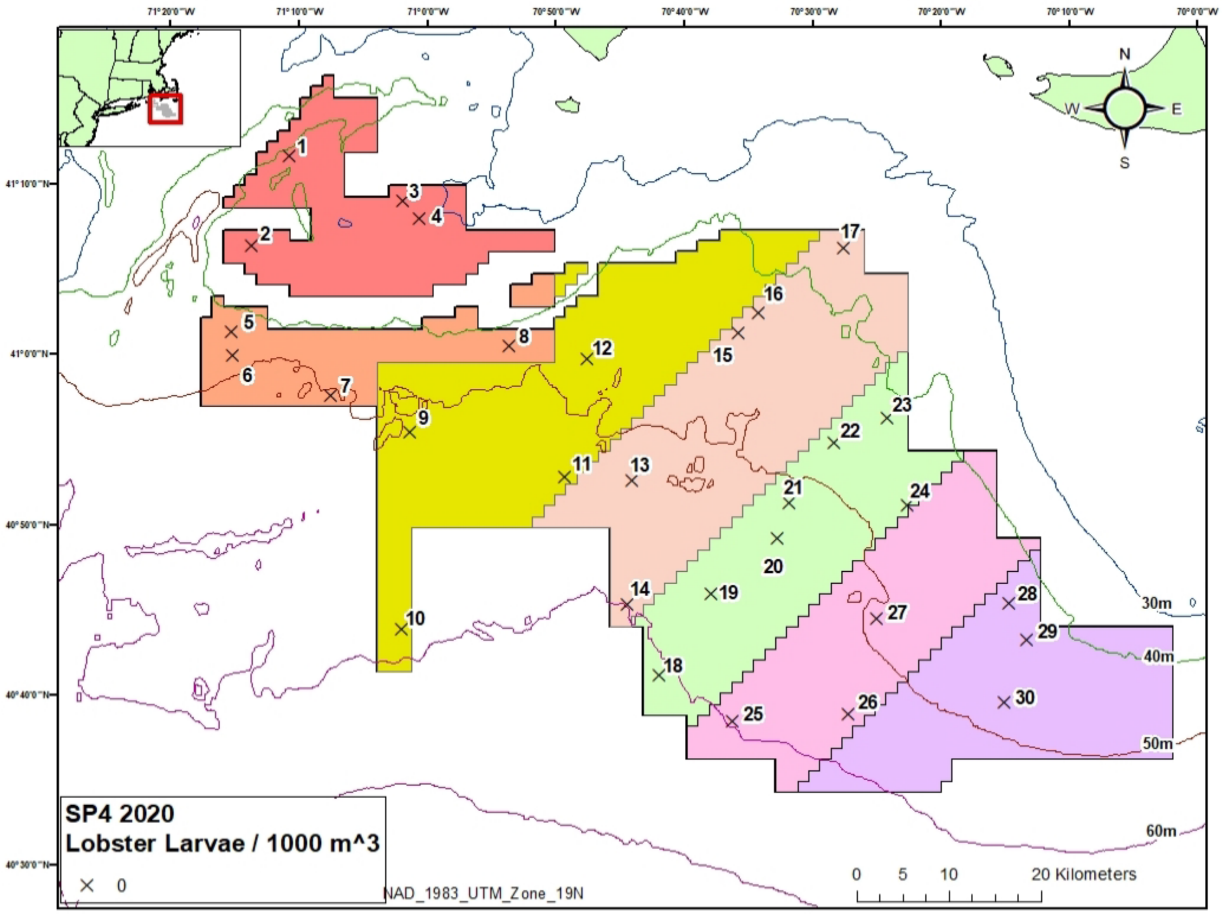

Figure 4. Larval lobster abundance per 1000 m^3 of water sampled on 7/29/2020.

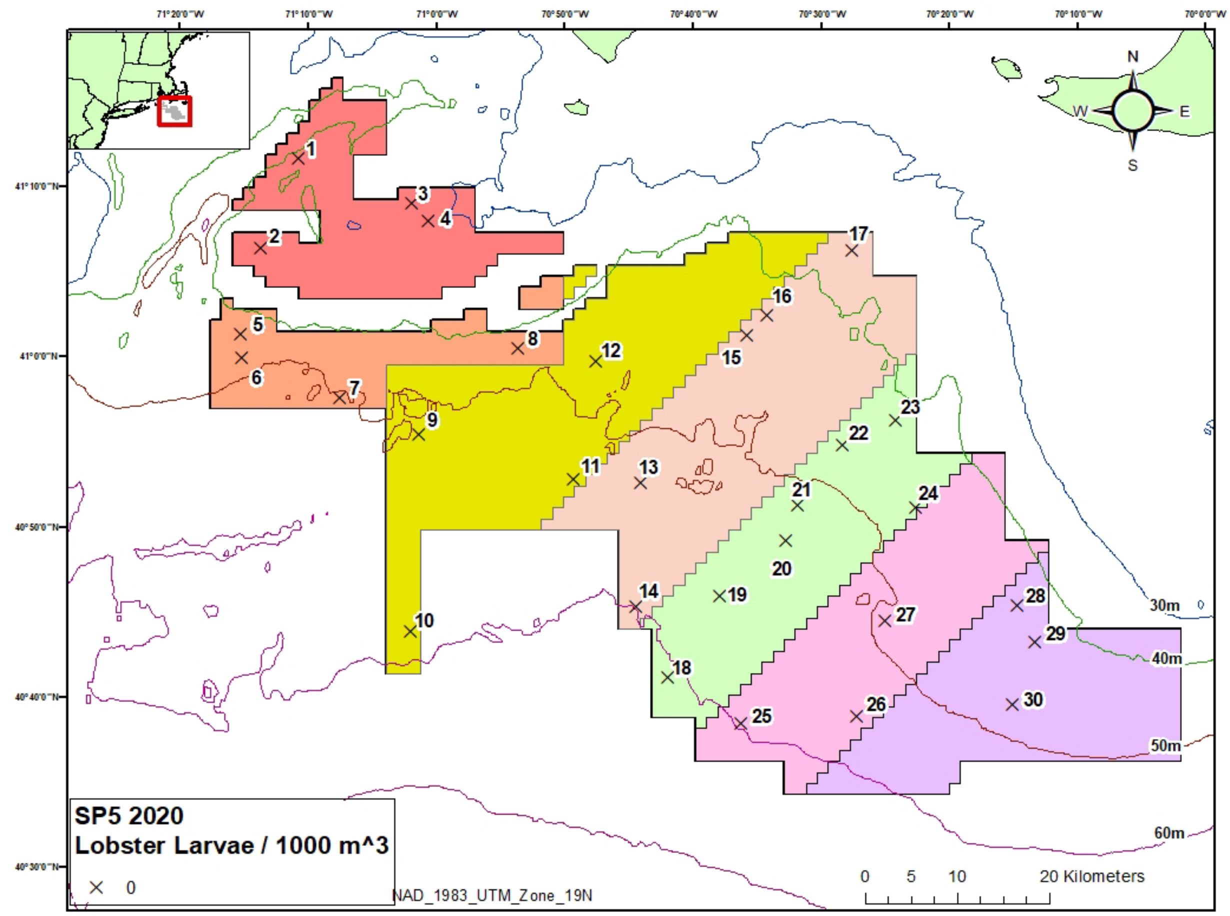

Figure 5. Larval lobster abundance per 1000 m^3 of water sampled on 8/12/2020 and 8/13/2020.

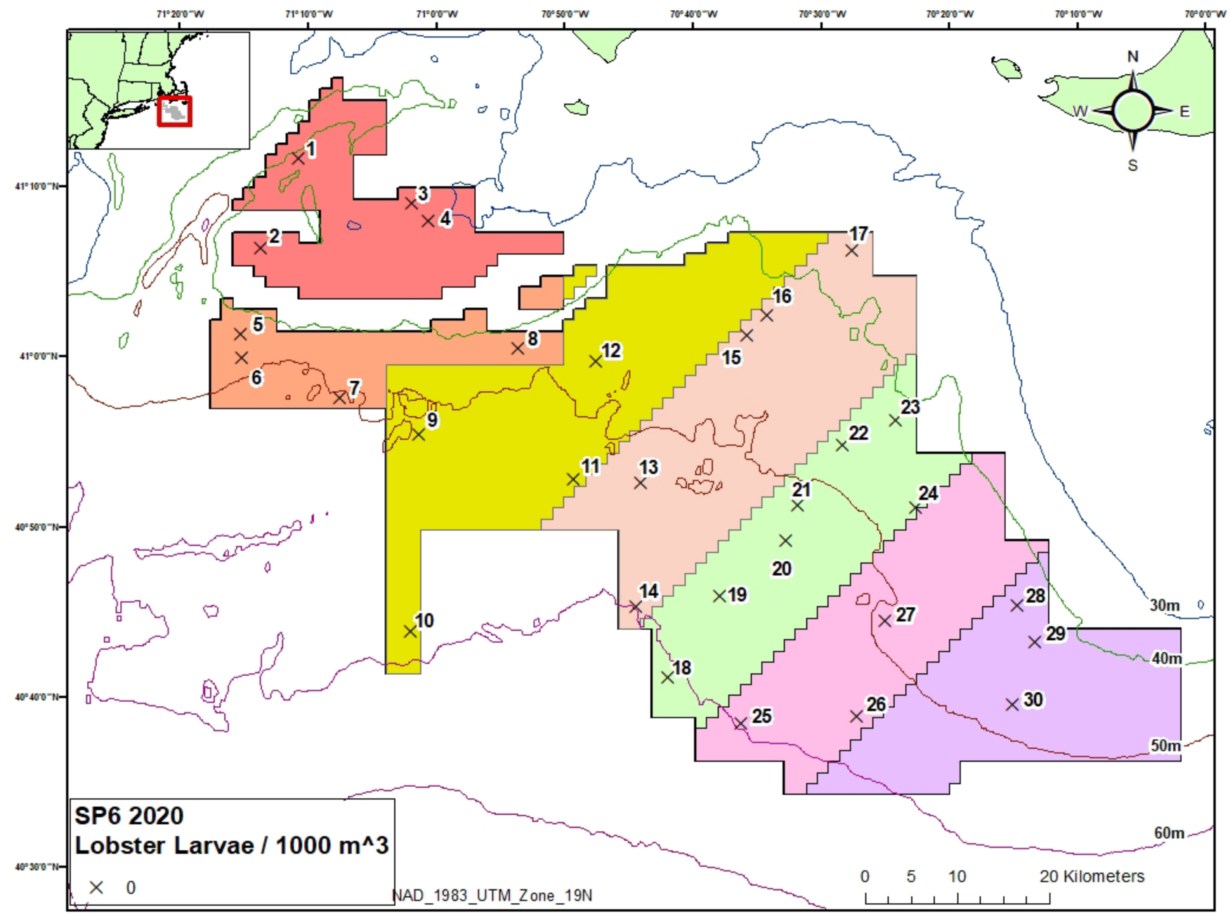

Figure 6. Larval lobster abundance per 1000 m^3 of water sampled on 8/27/2020 and 8/29/2020.

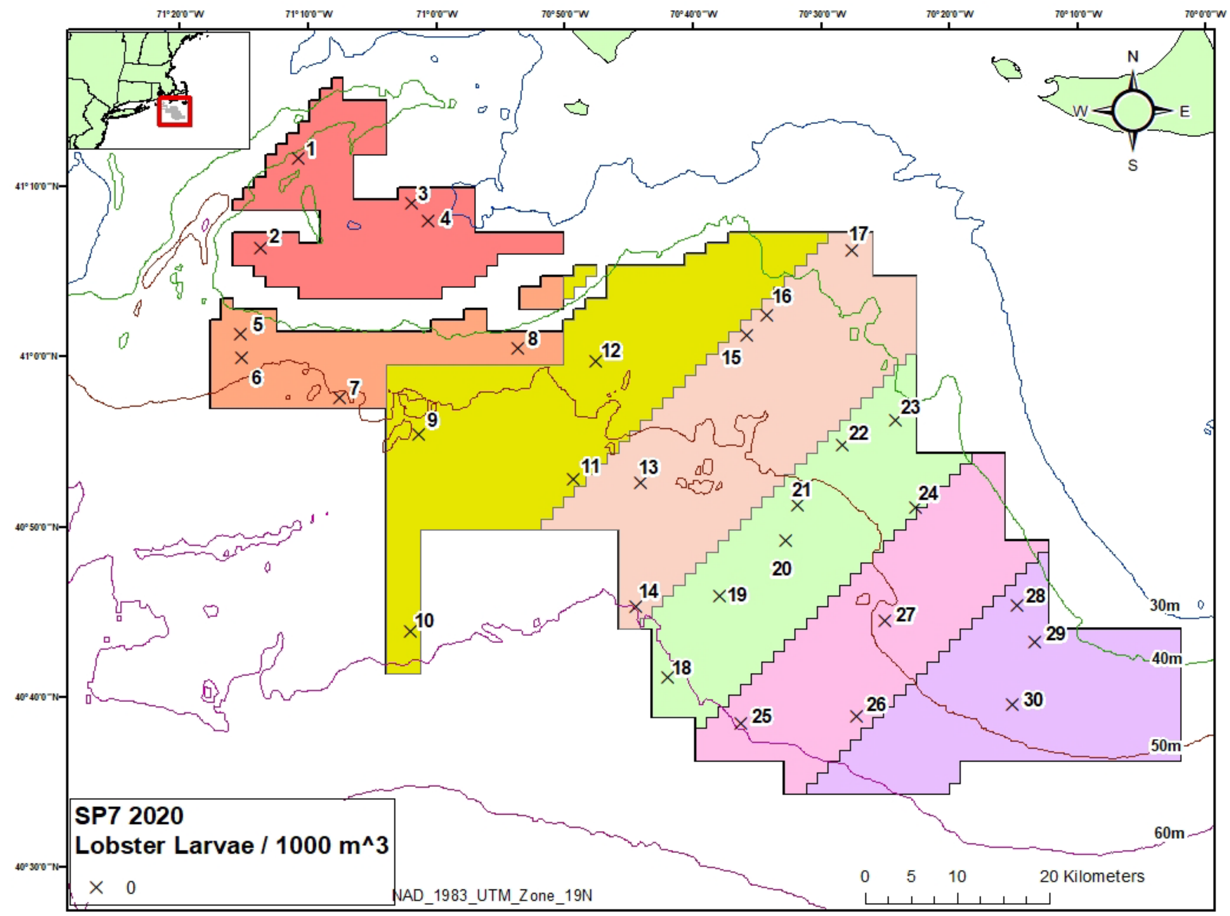

Figure 7. Larval lobster abundance per 1000 m^3 of water sampled on 9/24/2020.

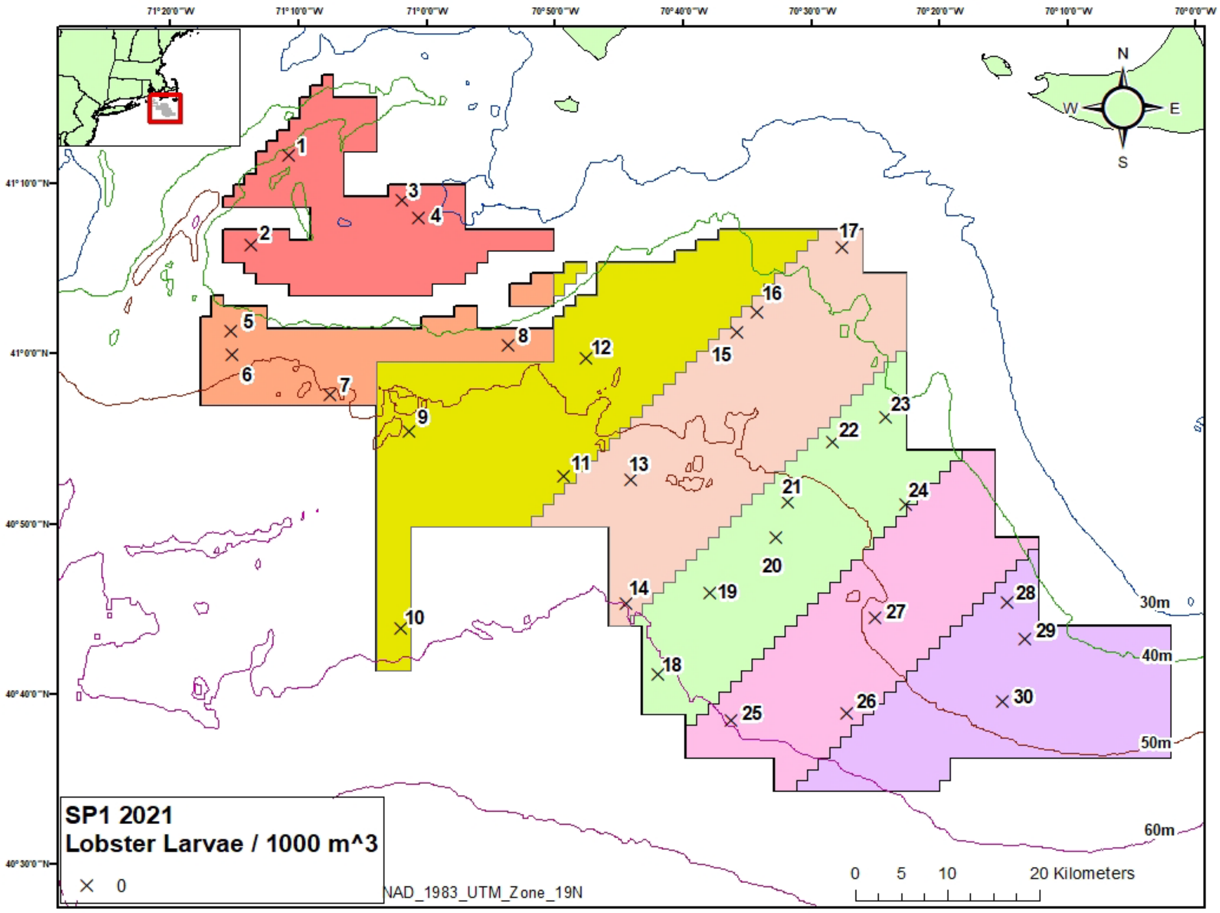

Figure 8. Larval lobster abundance per 1000 m^3 of water sampled on 5/13/2021 and 5/14/2021.

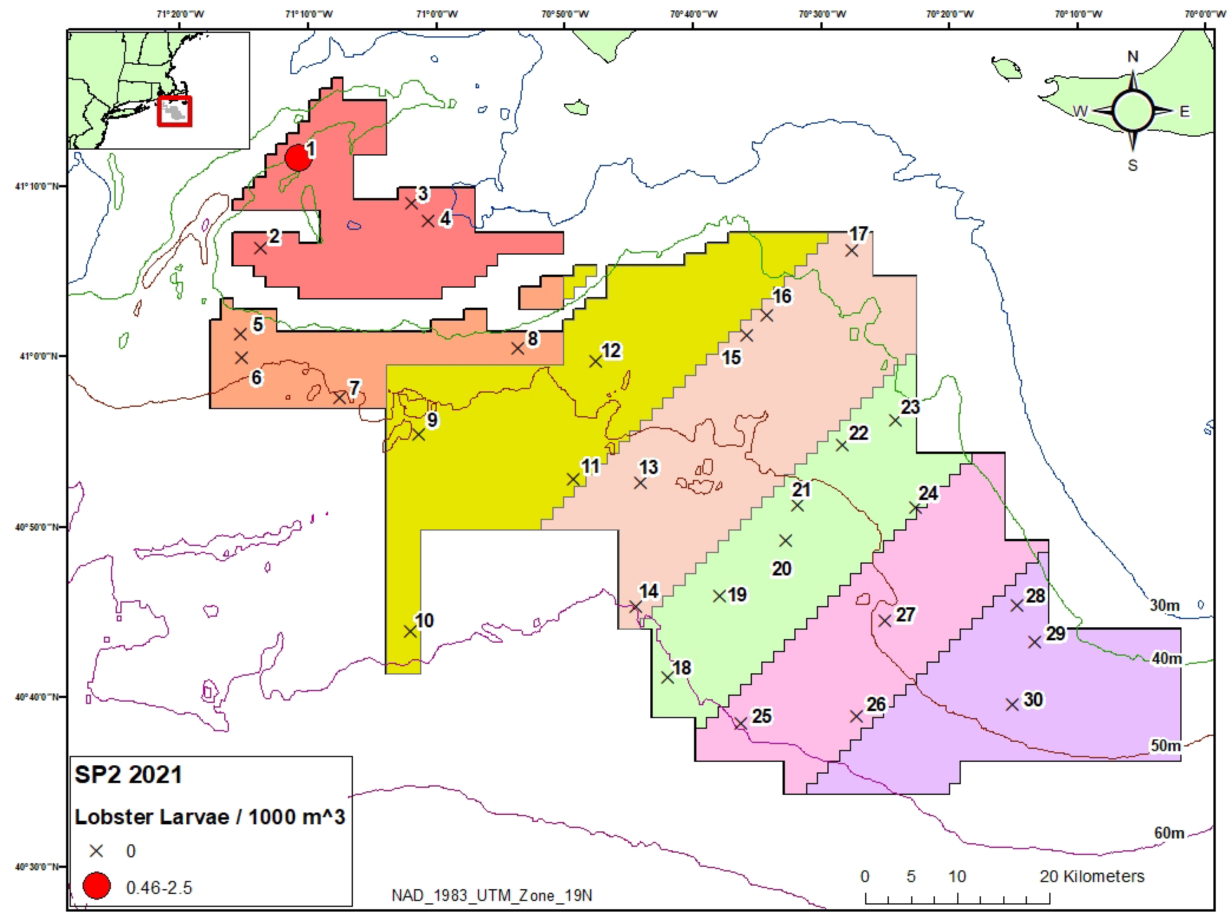

Figure 9. Larval lobster abundance per 1000 m^3 of water sampled on 5/27/2021.

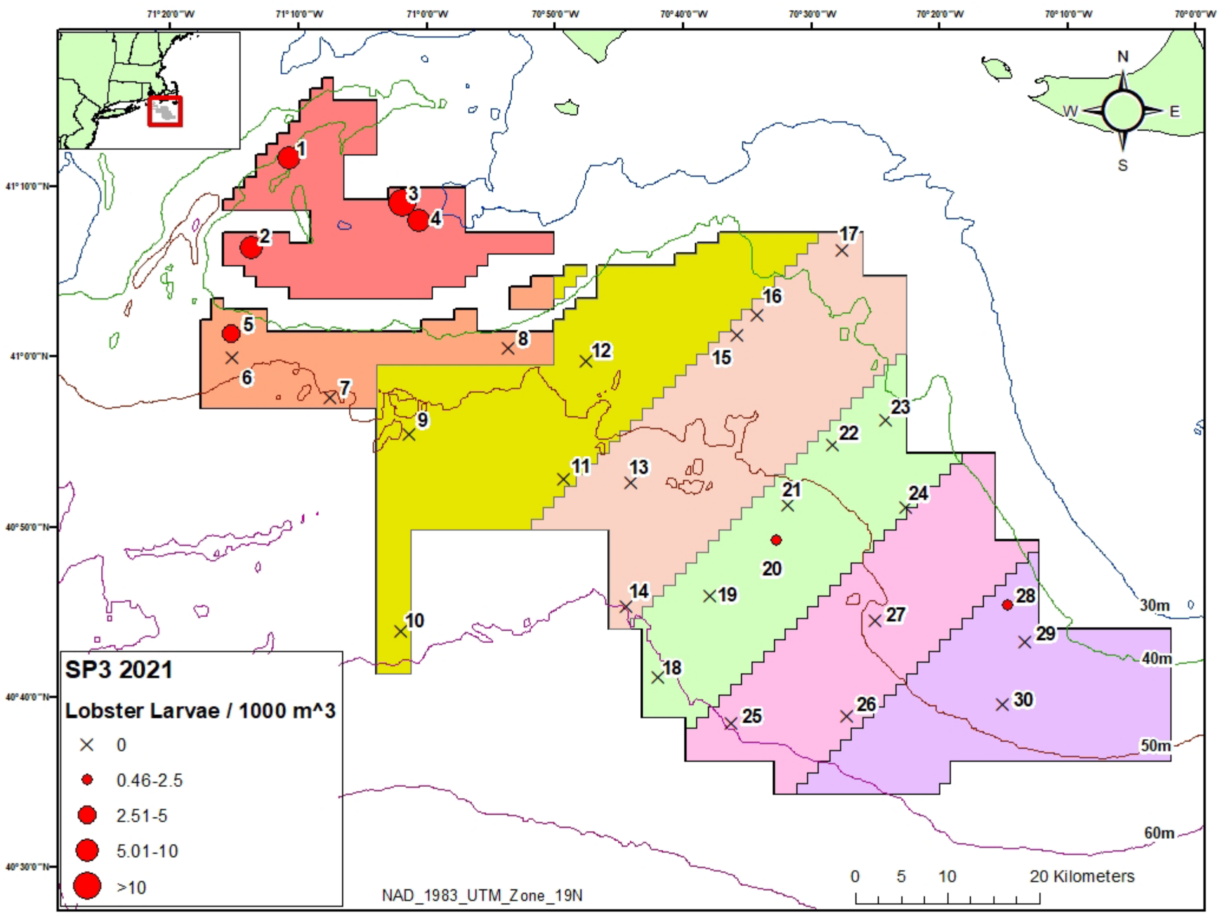

Figure 10. Larval lobster abundance per 1000 m^3 of water sampled on 6/9/2021.

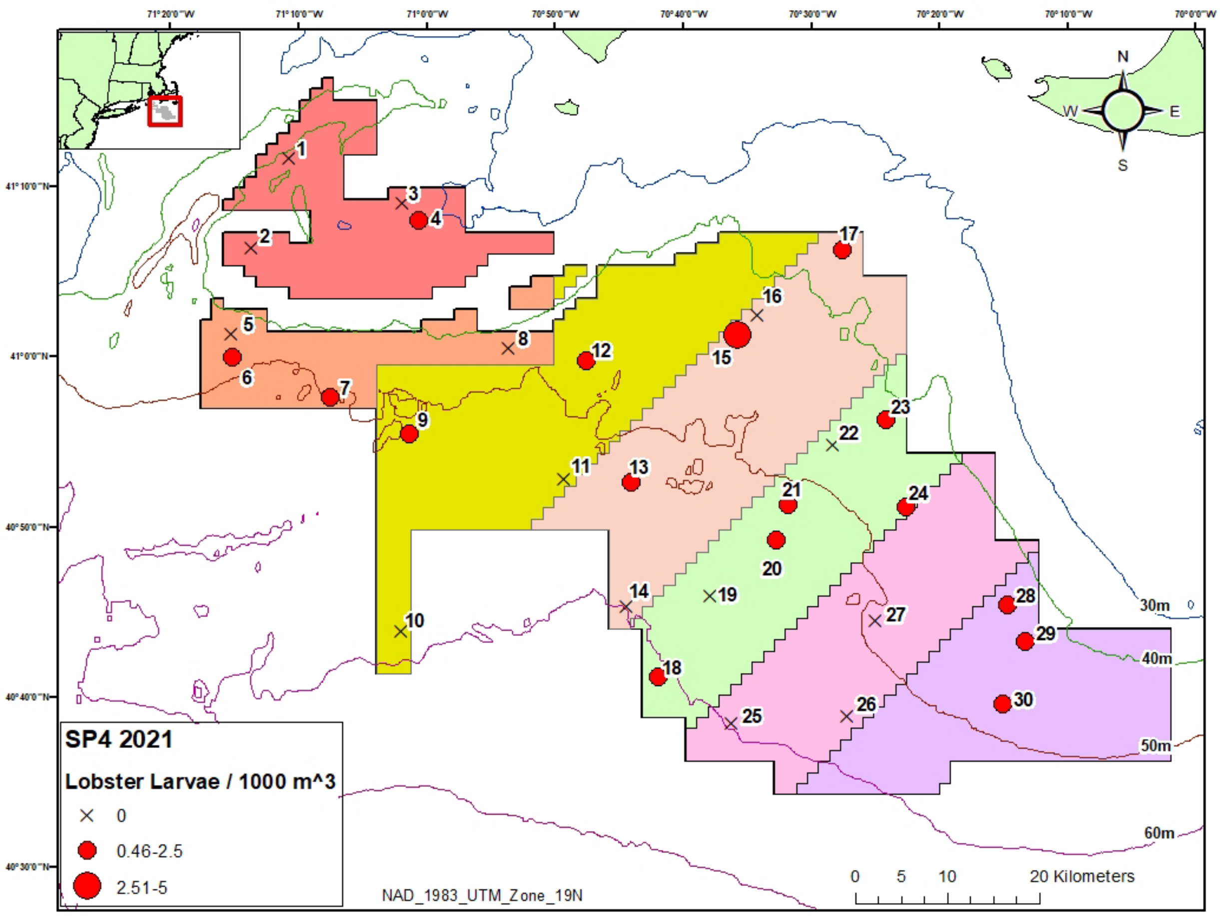

Figure 11. Larval lobster abundance per 1000 m³ of water sampled on 6/25/2021.

A.2 Crab

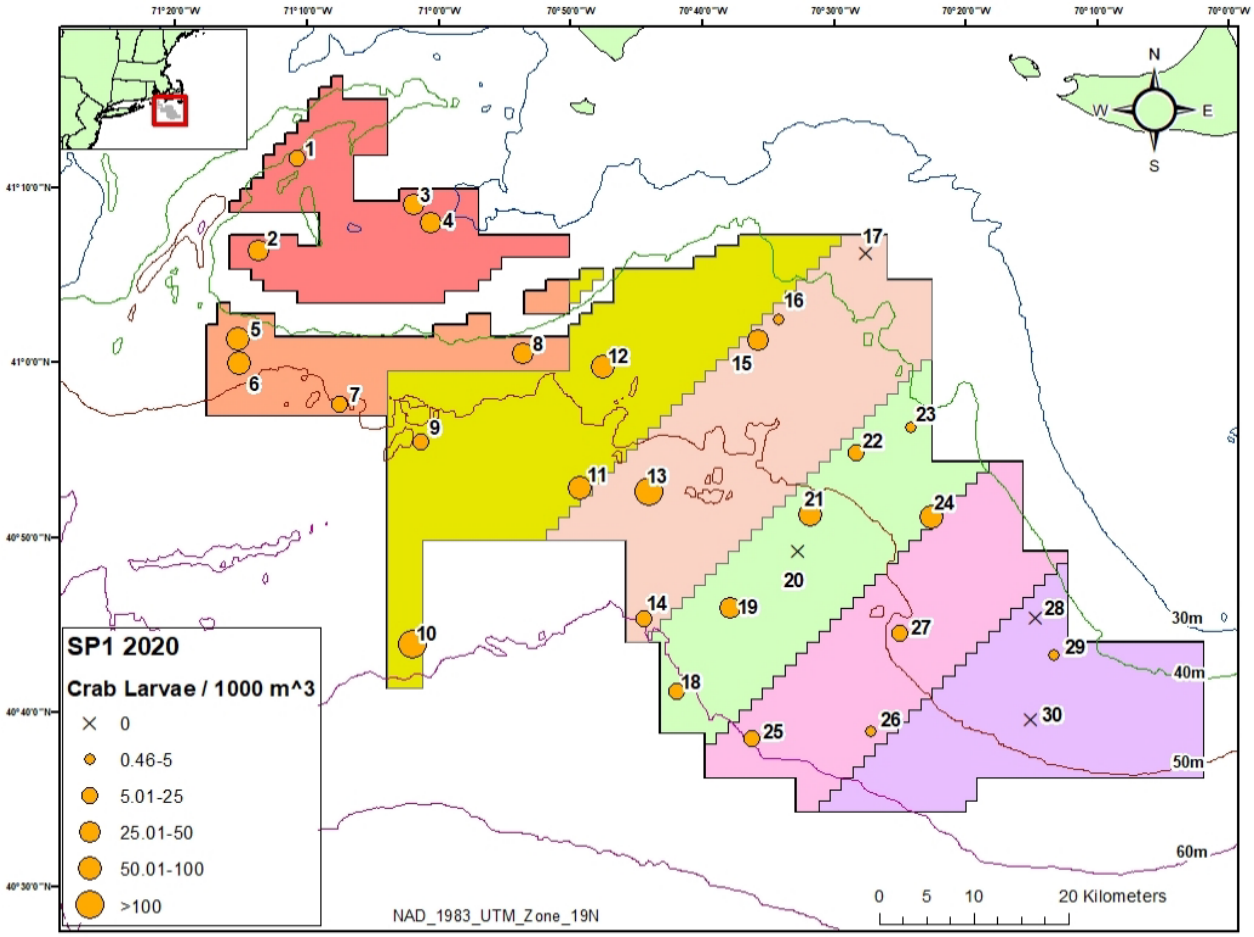

Figure 1. Larval crab abundance per 1000 m^3 of water sampled on 6/9/2020.

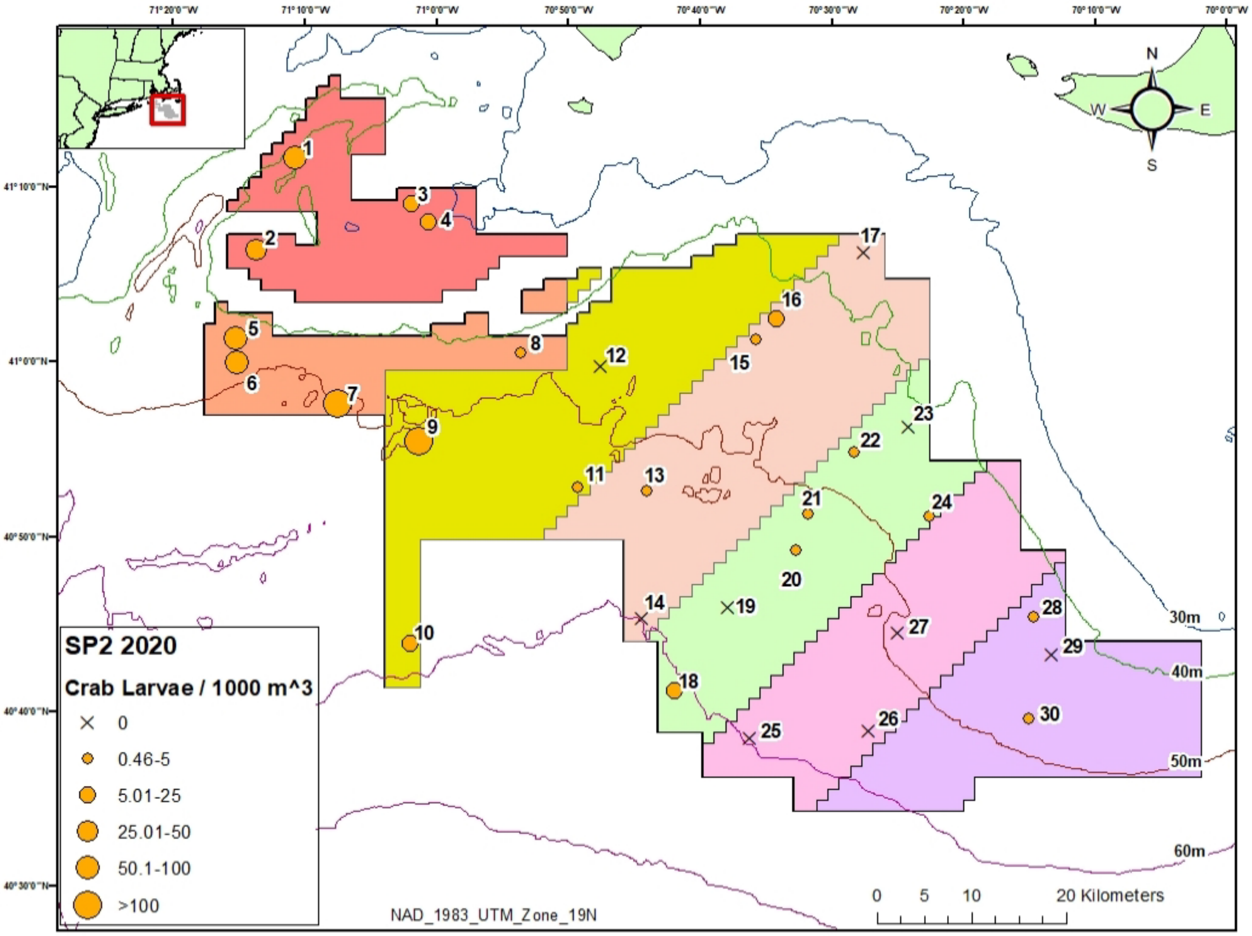

Figure 2. Larval crab abundance per 1000 m^3 of water sampled on 6/25/2020.

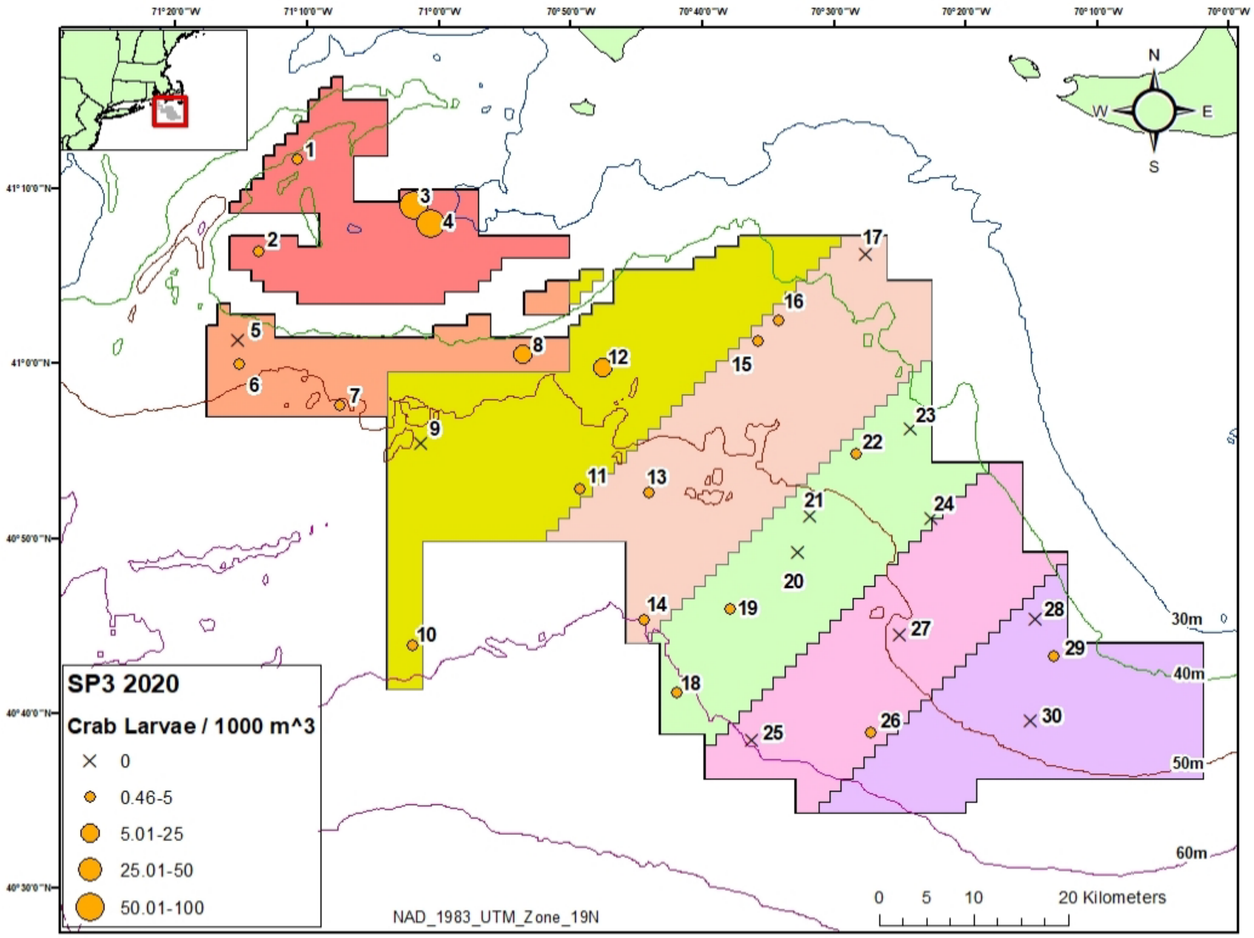

Figure 3. Larval crab abundance per 1000 m^3 of water sampled on 7/8/2020.

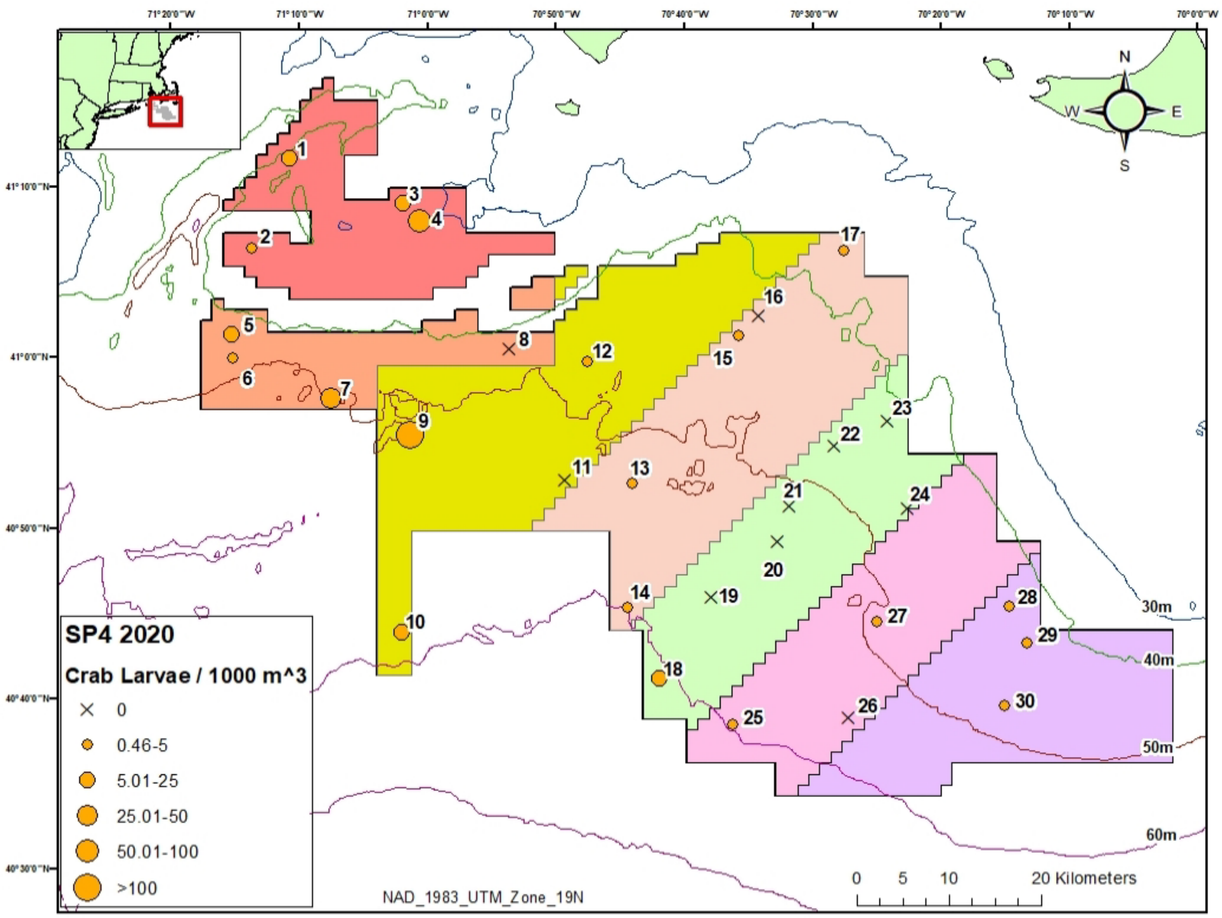

Figure 4. Larval crab abundance per 1000 m^3 of water sampled on 7/29/2020.

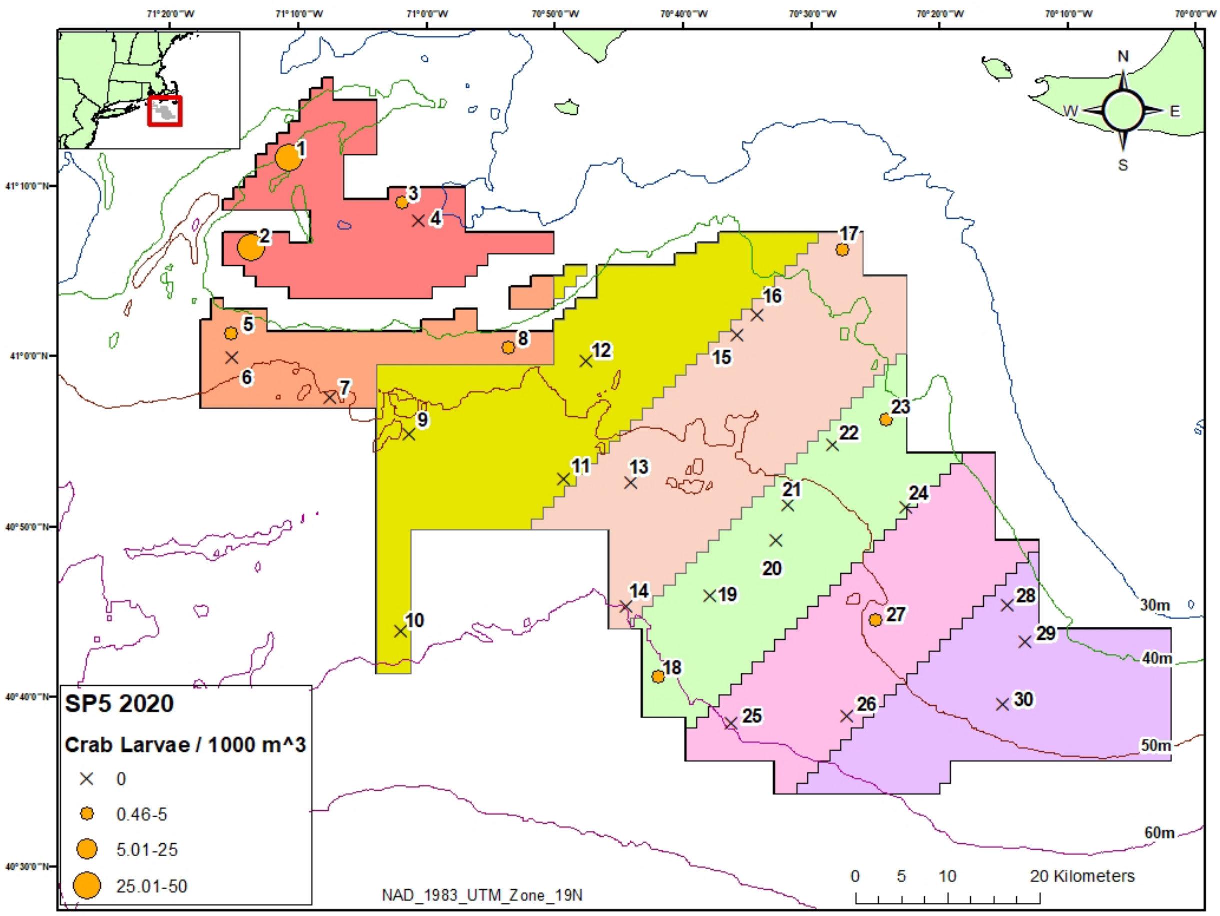

Figure 5. Larval crab abundance per 1000 m^3 of water sampled on 8/12/2020 and 8/13/2020.

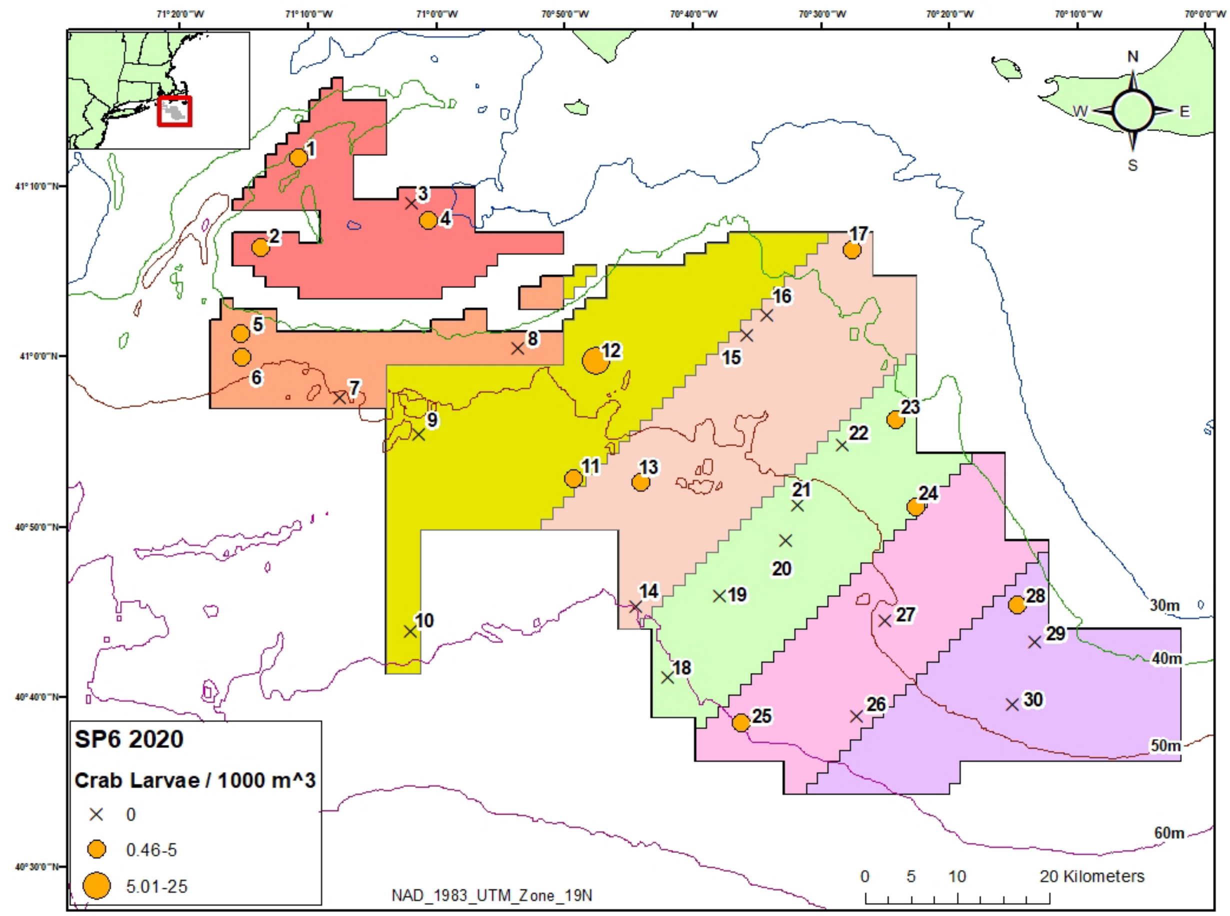

Figure 6. Larval crab abundance per 1000 m^3 of water sampled on 8/27/2020 and 8/29/2020.

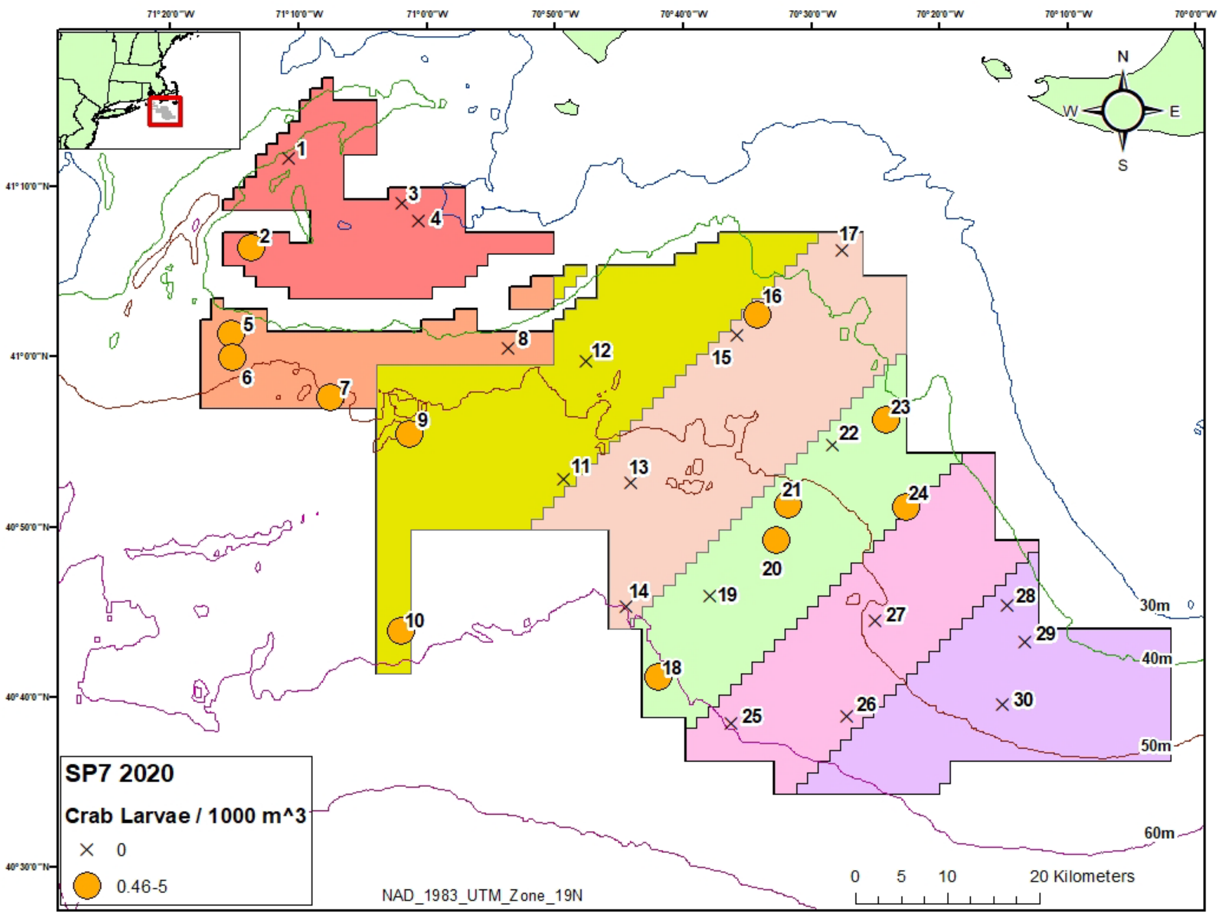

Figure 7. Larval crab abundance per 1000 m^3 of water sampled on 9/24/2020.

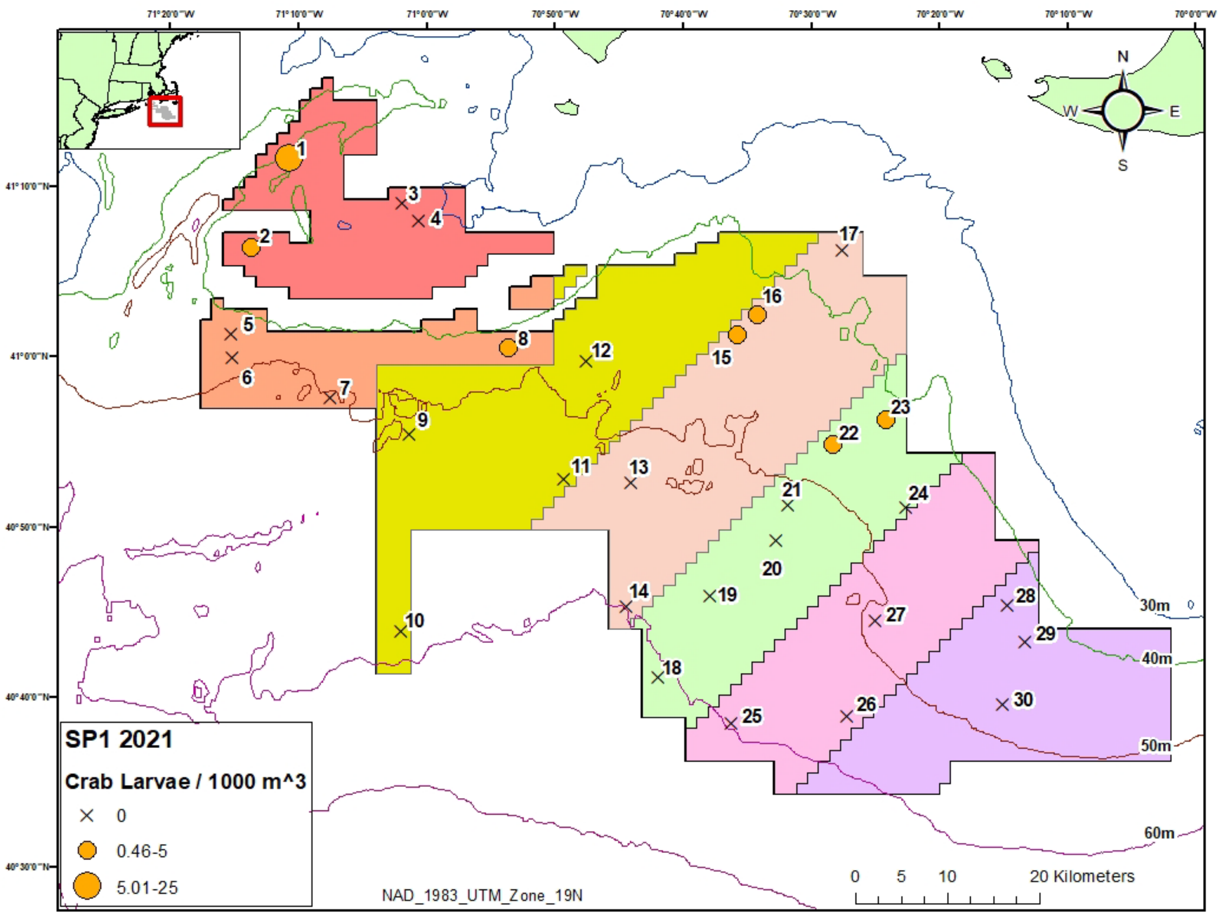

Figure 8. Larval crab abundance per 1000 m^3 of water sampled on 5/13/2021 and 5/14/2021.

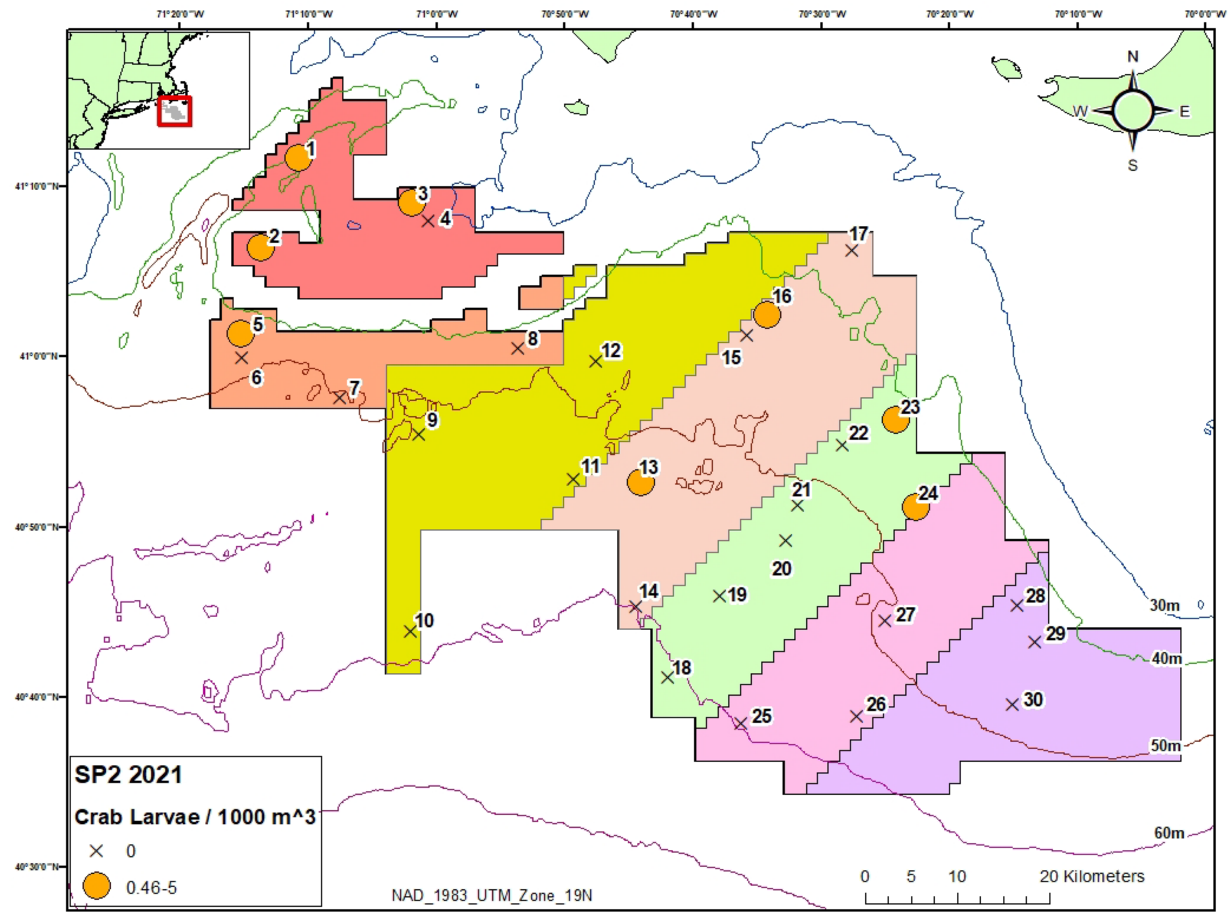

Figure 9. Larval crab abundance per 1000 m^3 of water sampled on 5/27/2021.

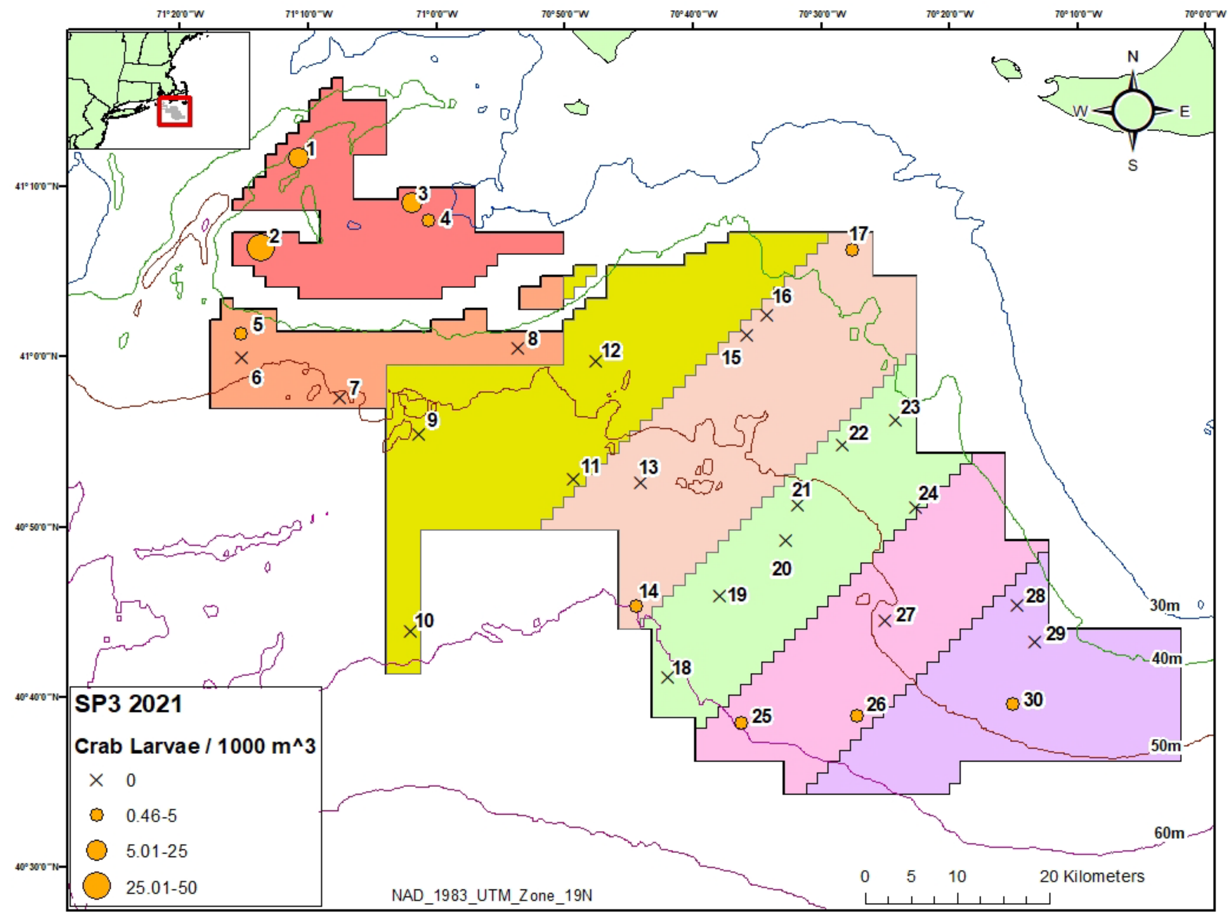

Figure 10. Larval crab abundance per 1000 m^3 of water sampled on 6/9/2021.

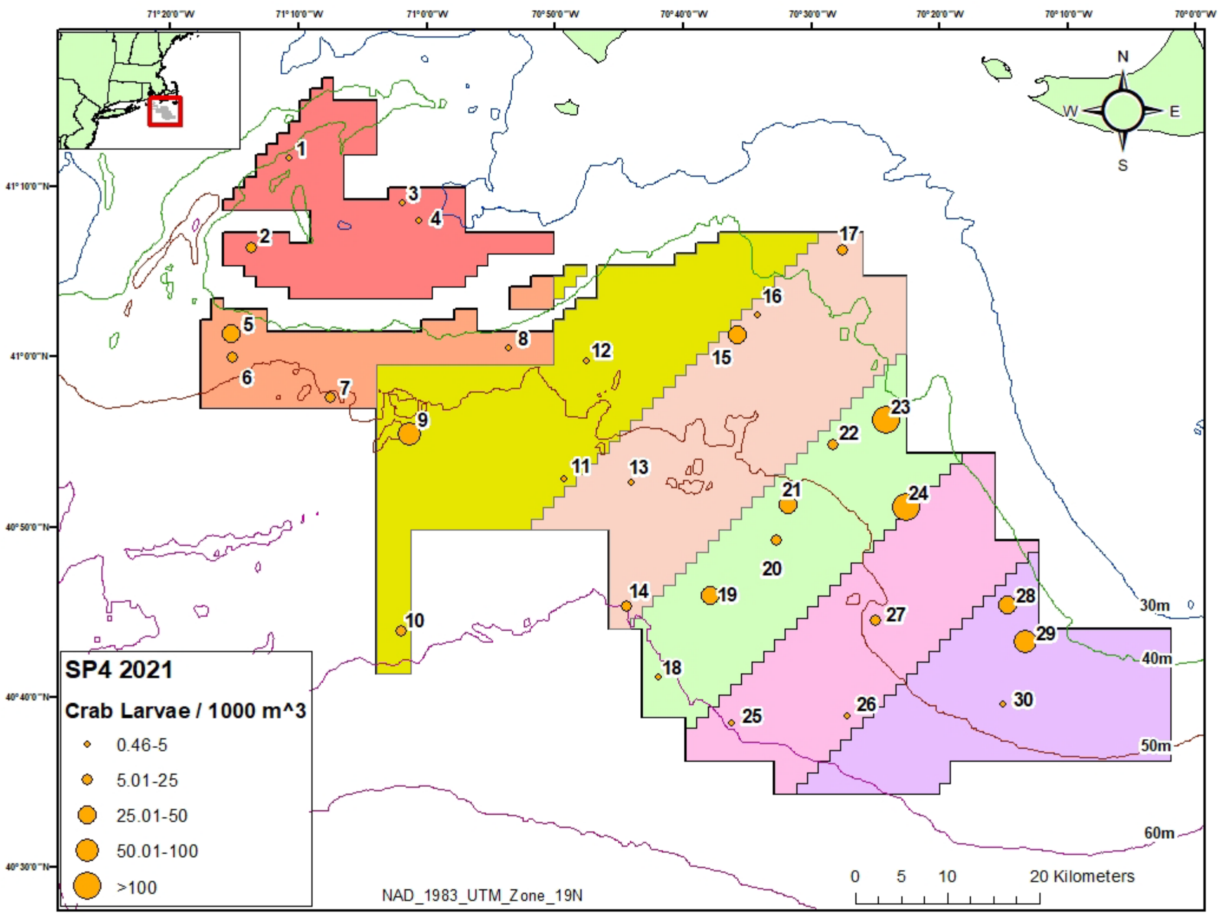

Figure 11. Larval crab abundance per 1000 m^3 of water sampled on 6/25/2021.

A.3 Shrimp

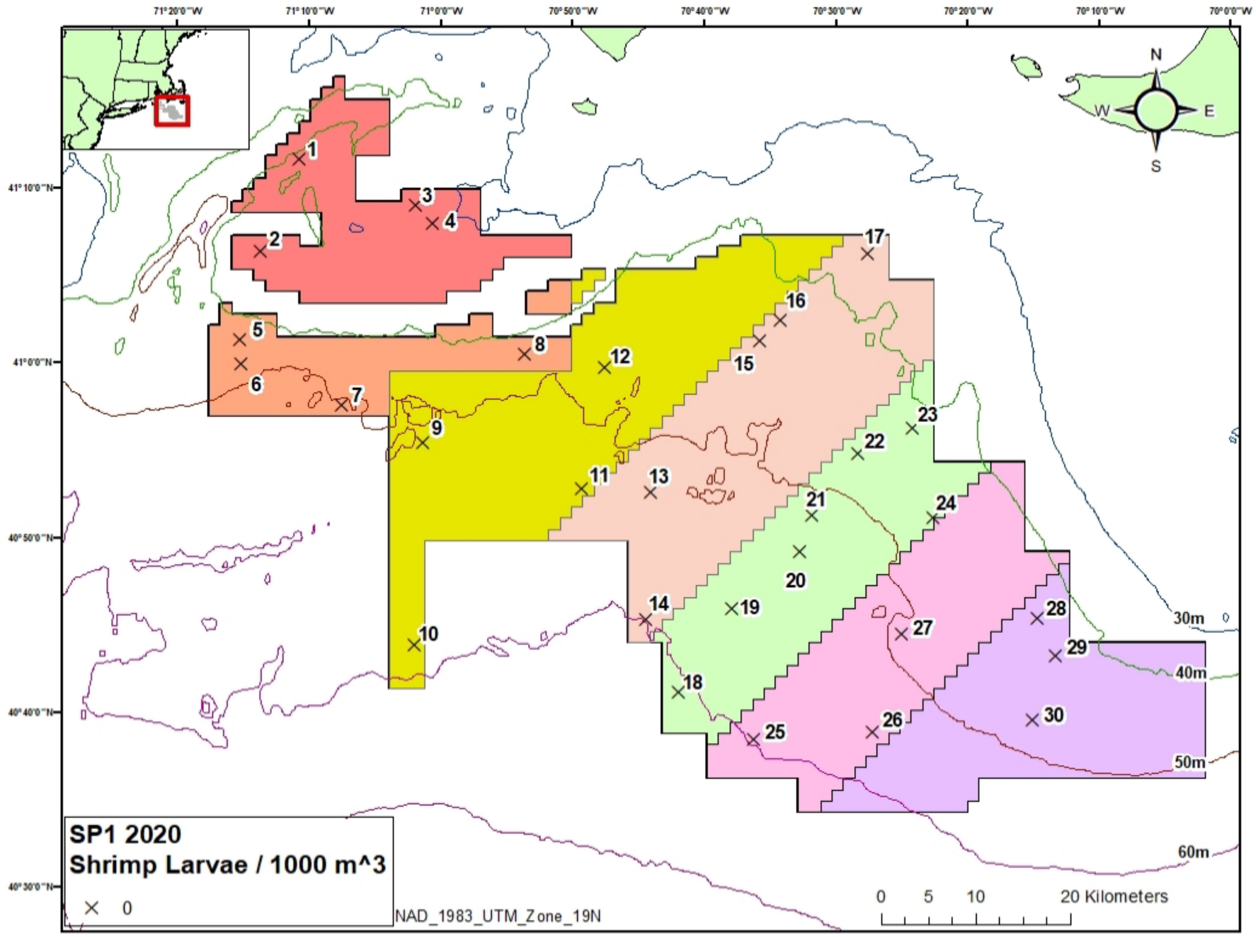

Figure 1. Larval shrimp abundance per 1000 m^3 of water sampled on 6/9/2020.

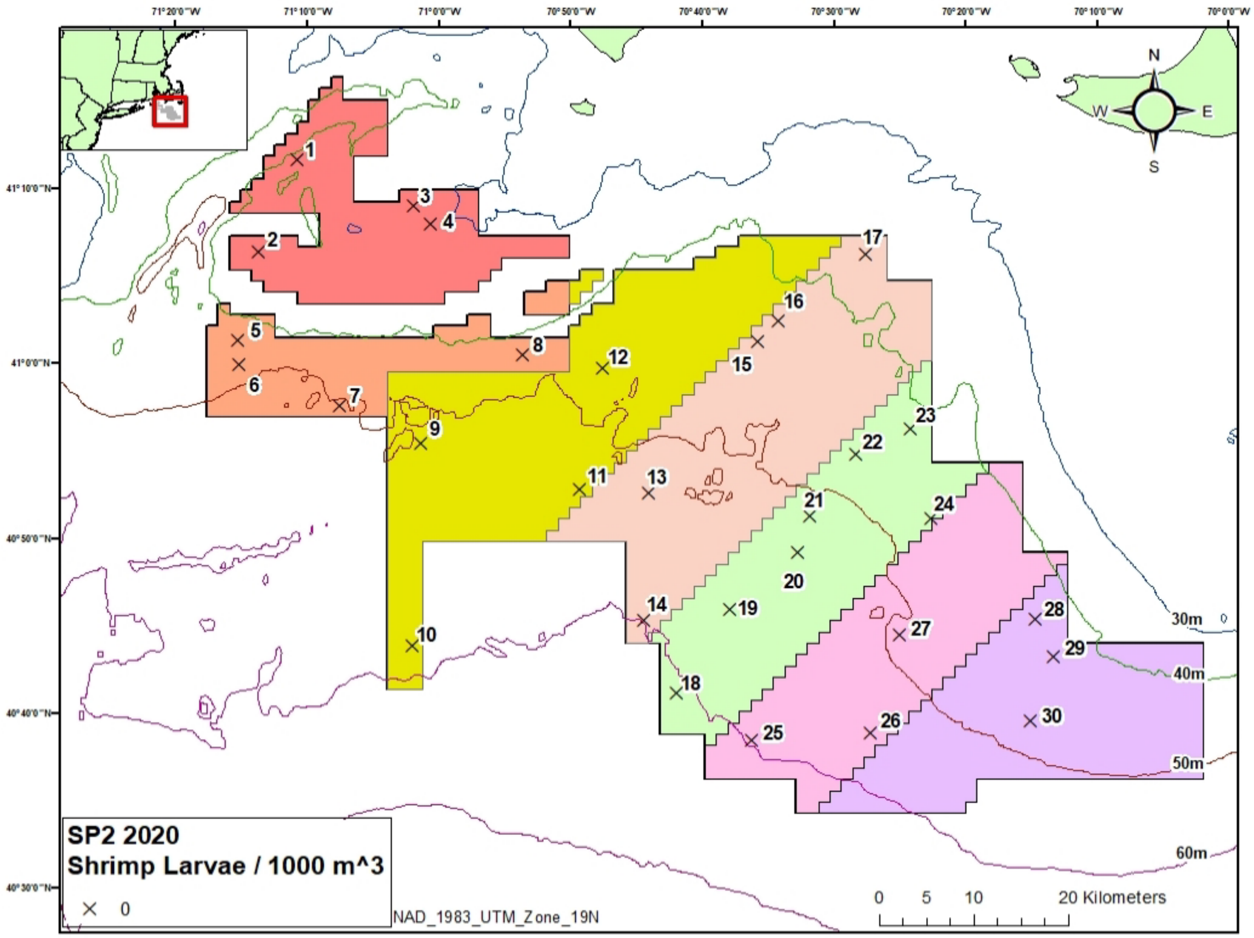

Figure 2. Larval shrimp abundance per 1000 m^3 of water sampled on 6/25/2020.

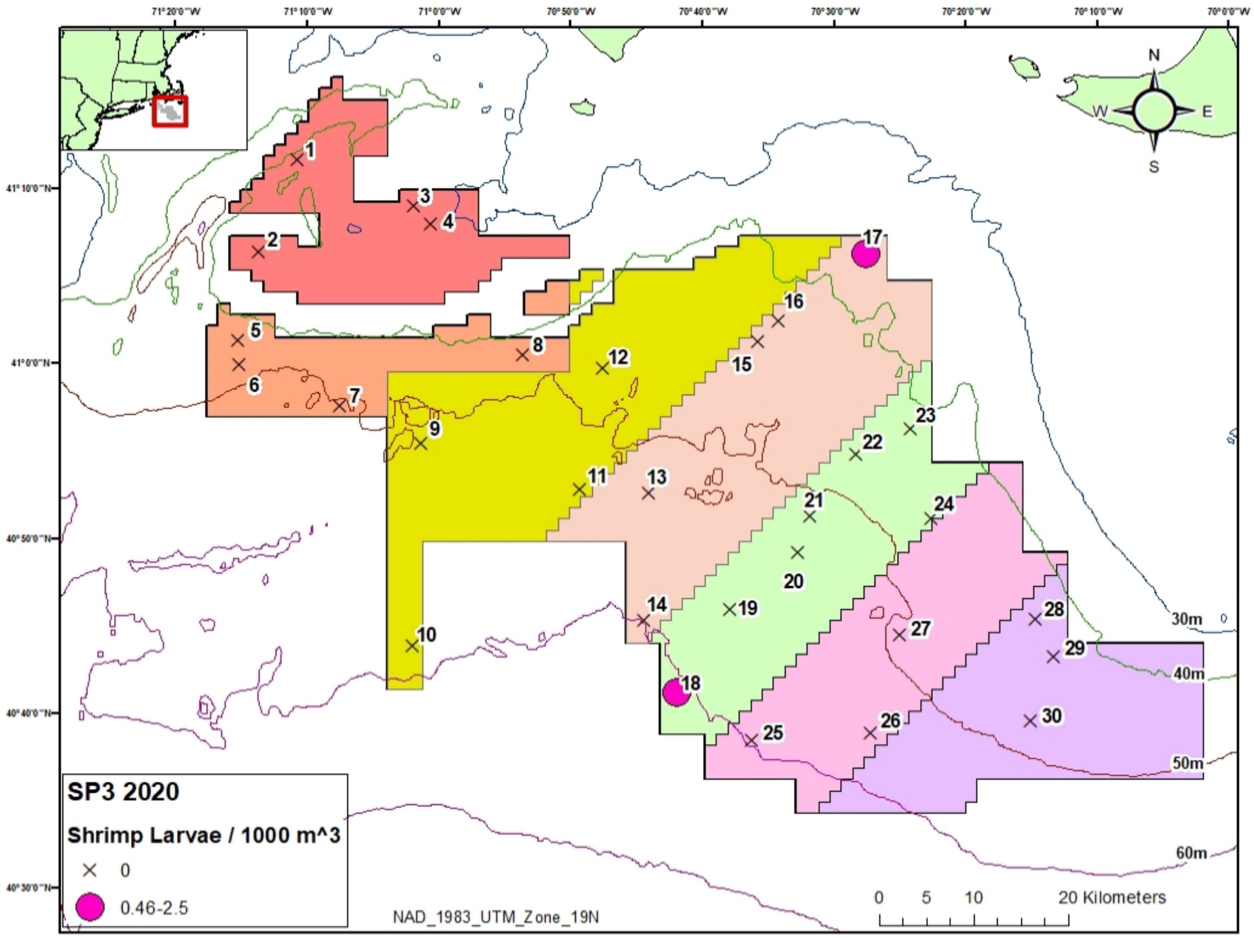

Figure 3. Larval shrimp abundance per 1000 m^3 of water sampled on 7/8/2020.

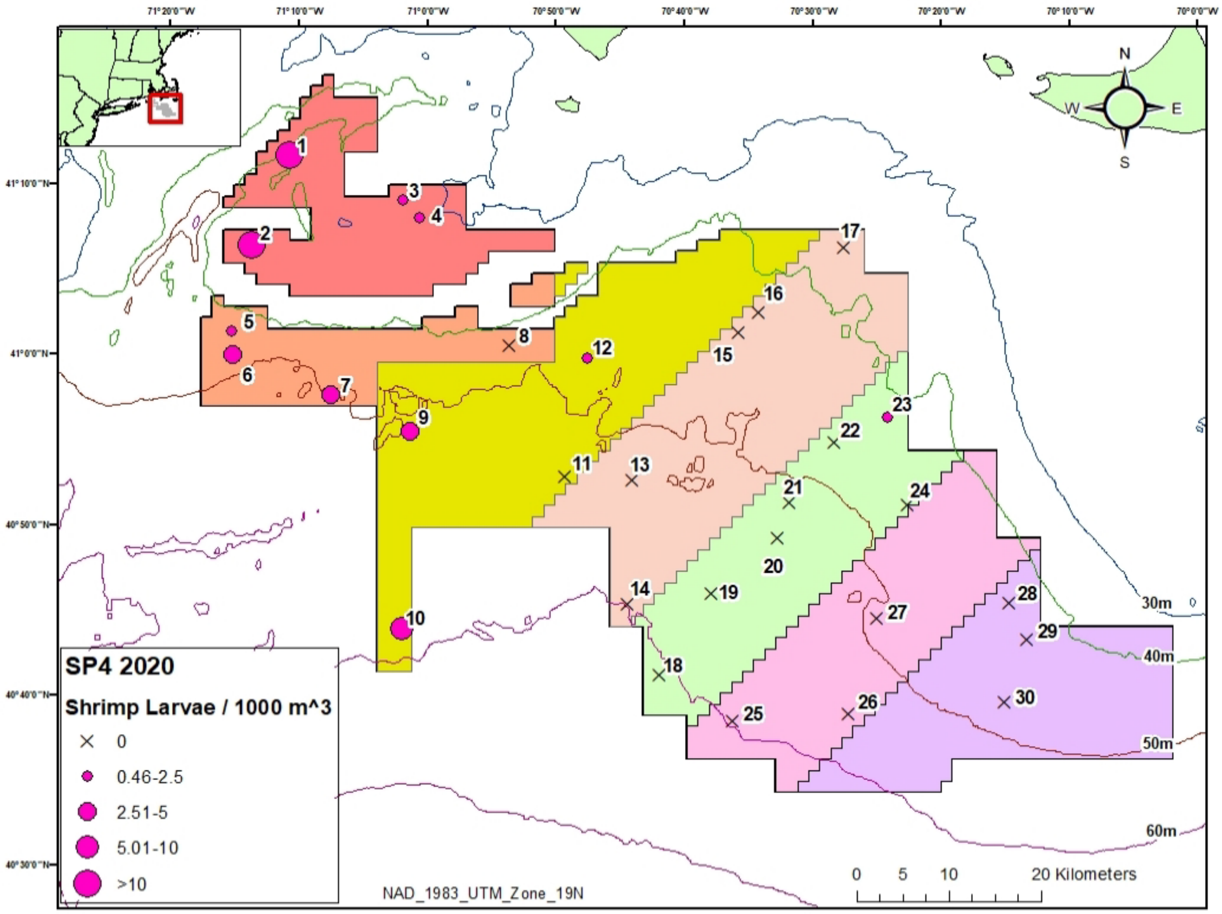

Figure 4. Larval shrimp abundance per 1000 m^3 of water sampled on 7/29/2020.

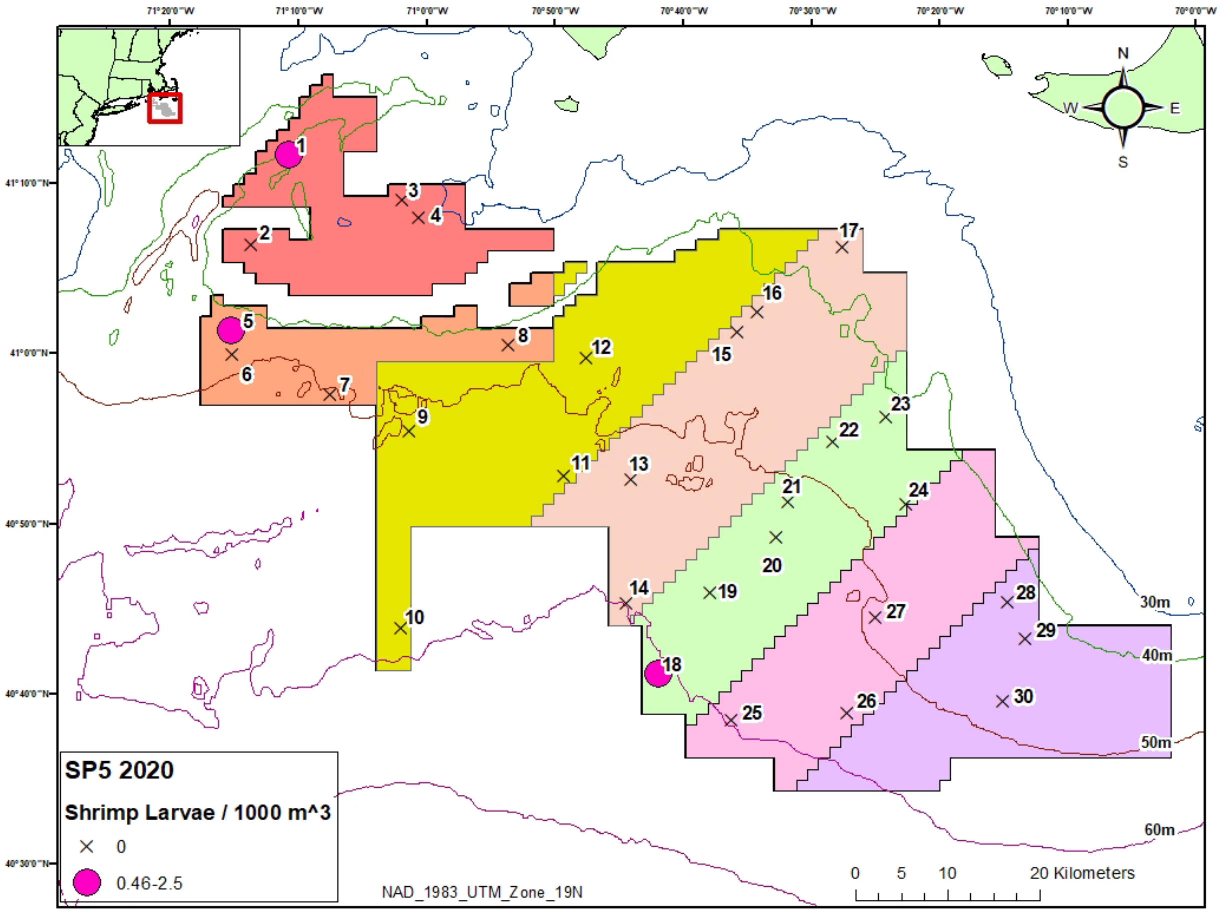

Figure 5. Larval shrimp abundance per 1000 m^3 of water sampled on 8/12/2020 and 8/13/2020.

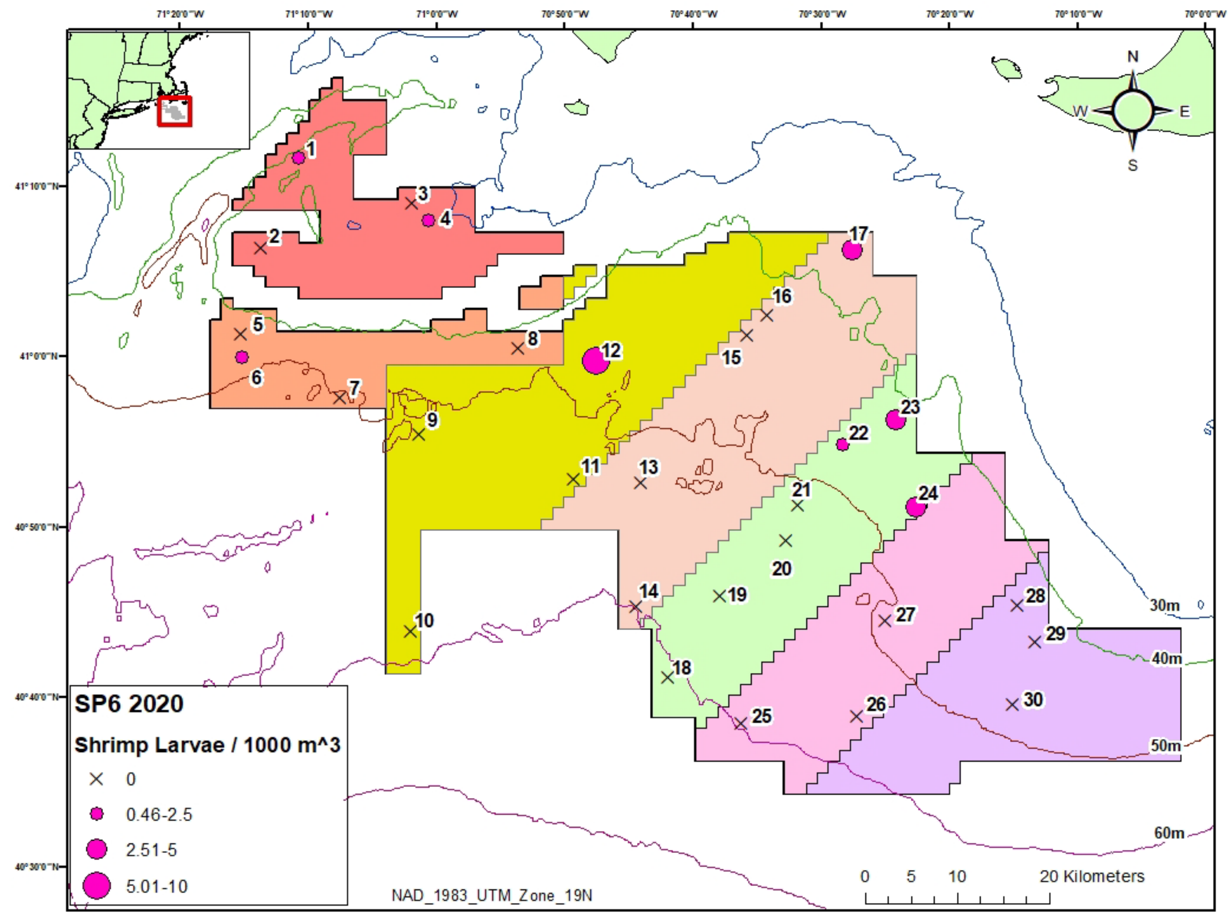

Figure 6. Larval shrimp abundance per 1000 m^3 of water sampled on 8/27/2020 and 8/29/2020.

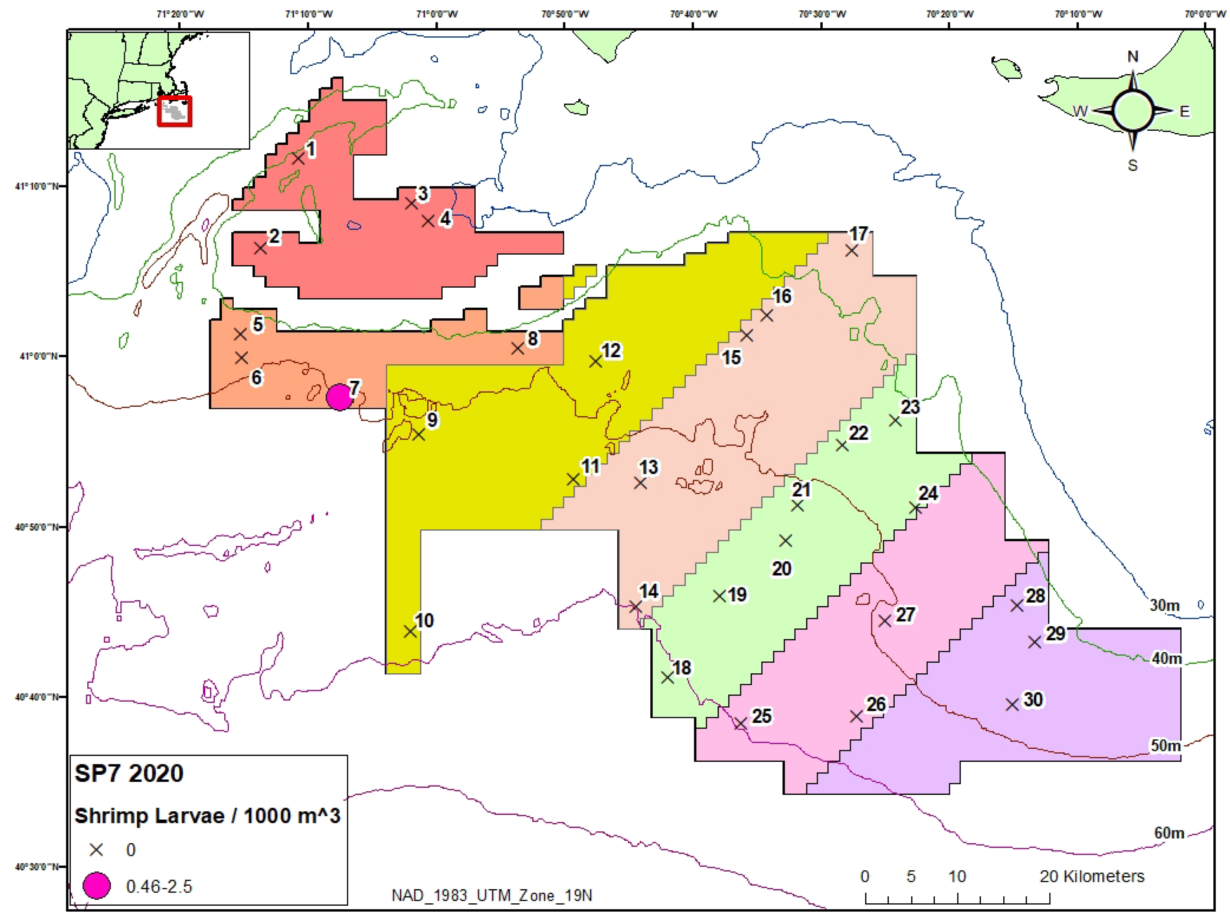

Figure 7. Larval shrimp abundance per 1000 m^3 of water sampled on 9/24/2020

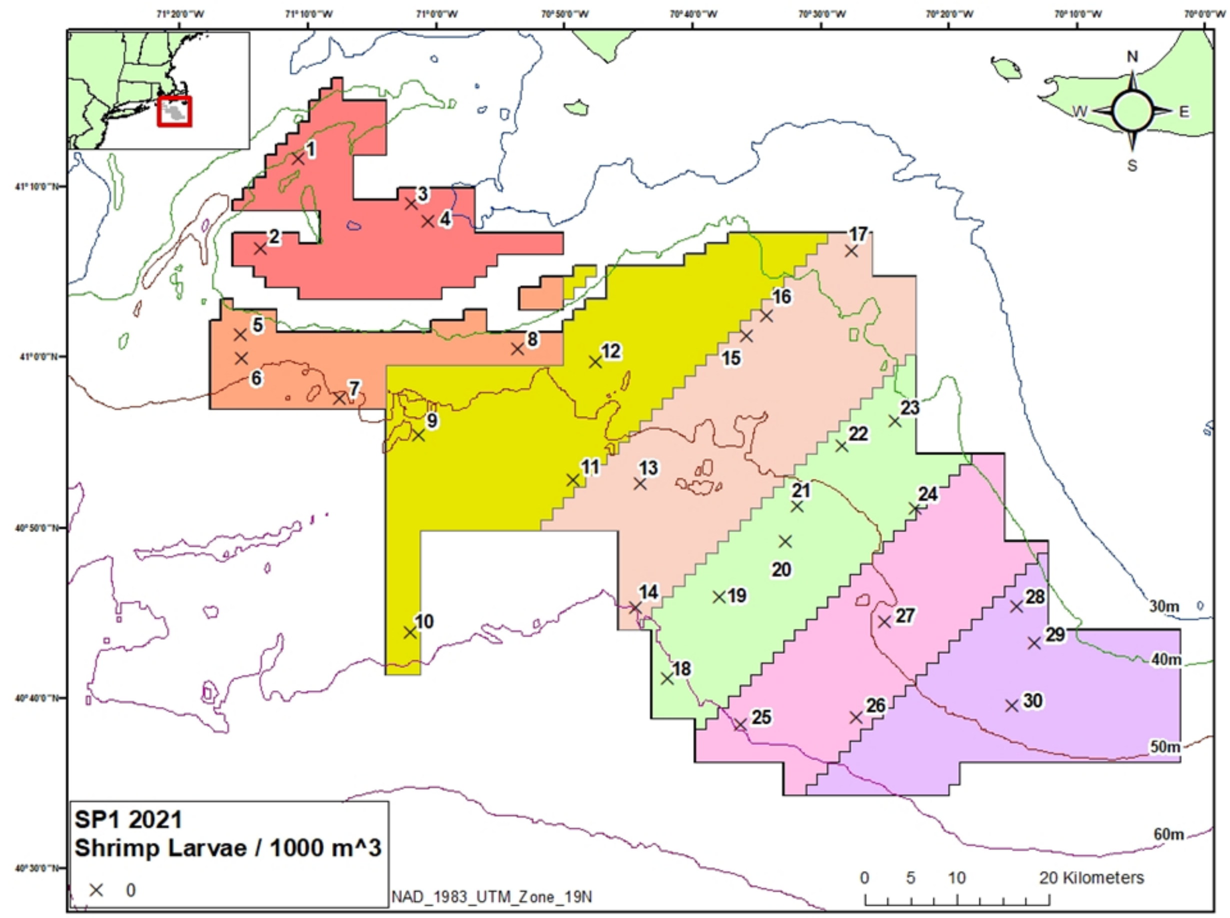

Figure 8. Larval shrimp abundance per 1000 m^3 of water sampled on 5/13/2021 and 5/14/2021

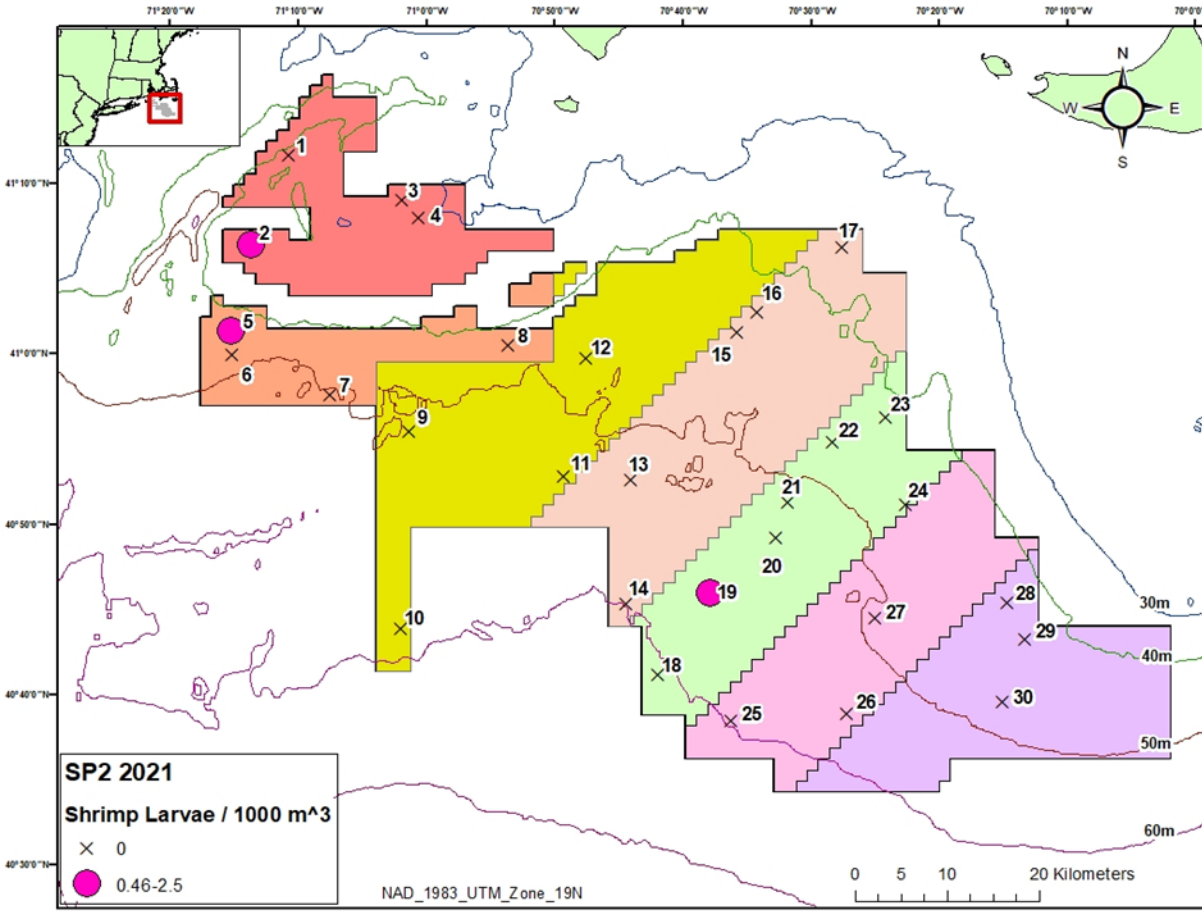

Figure 9. Larval shrimp abundance per 1000 m^3 of water sampled on 5/27/2021.

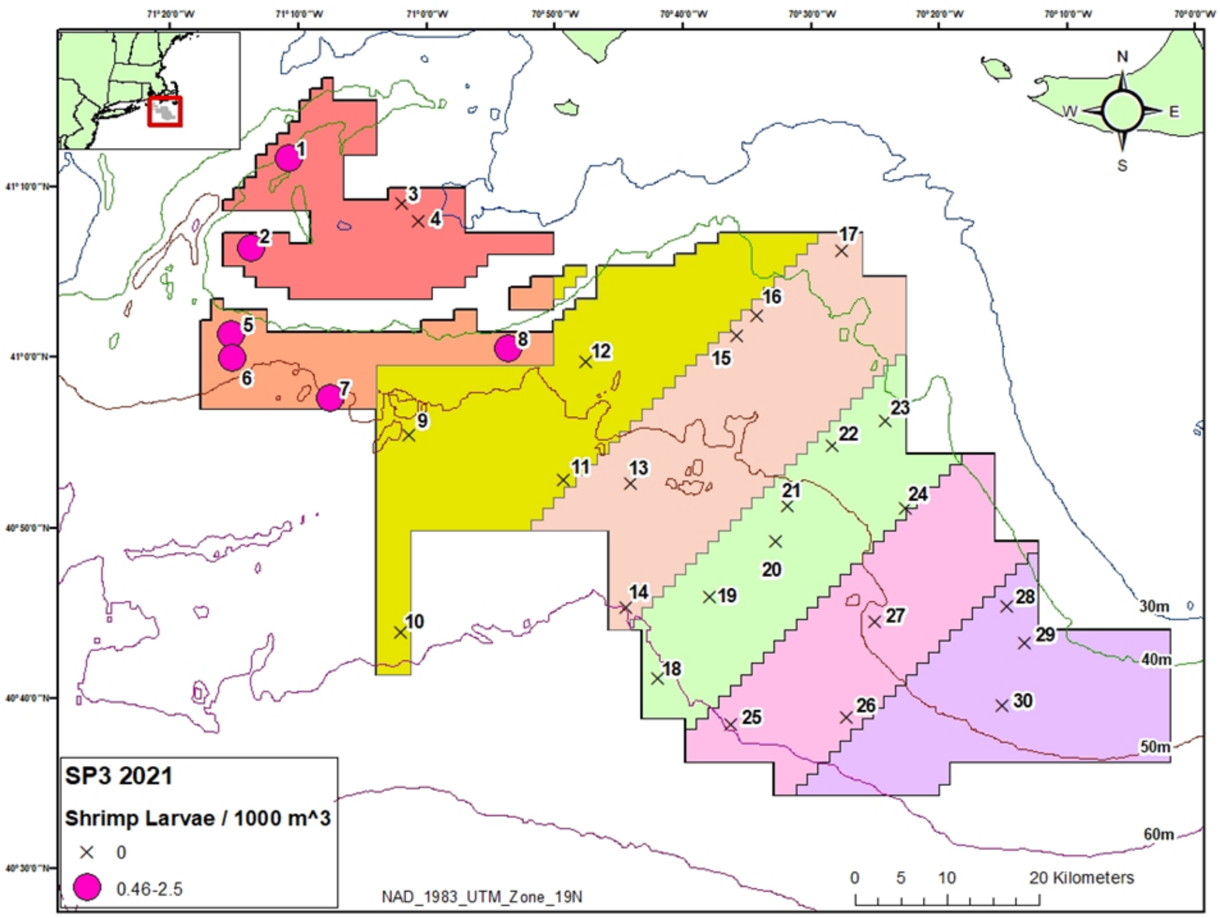

Figure 10. Larval shrimp abundance per 1000 m^3 of water sampled on 6/9/2021.

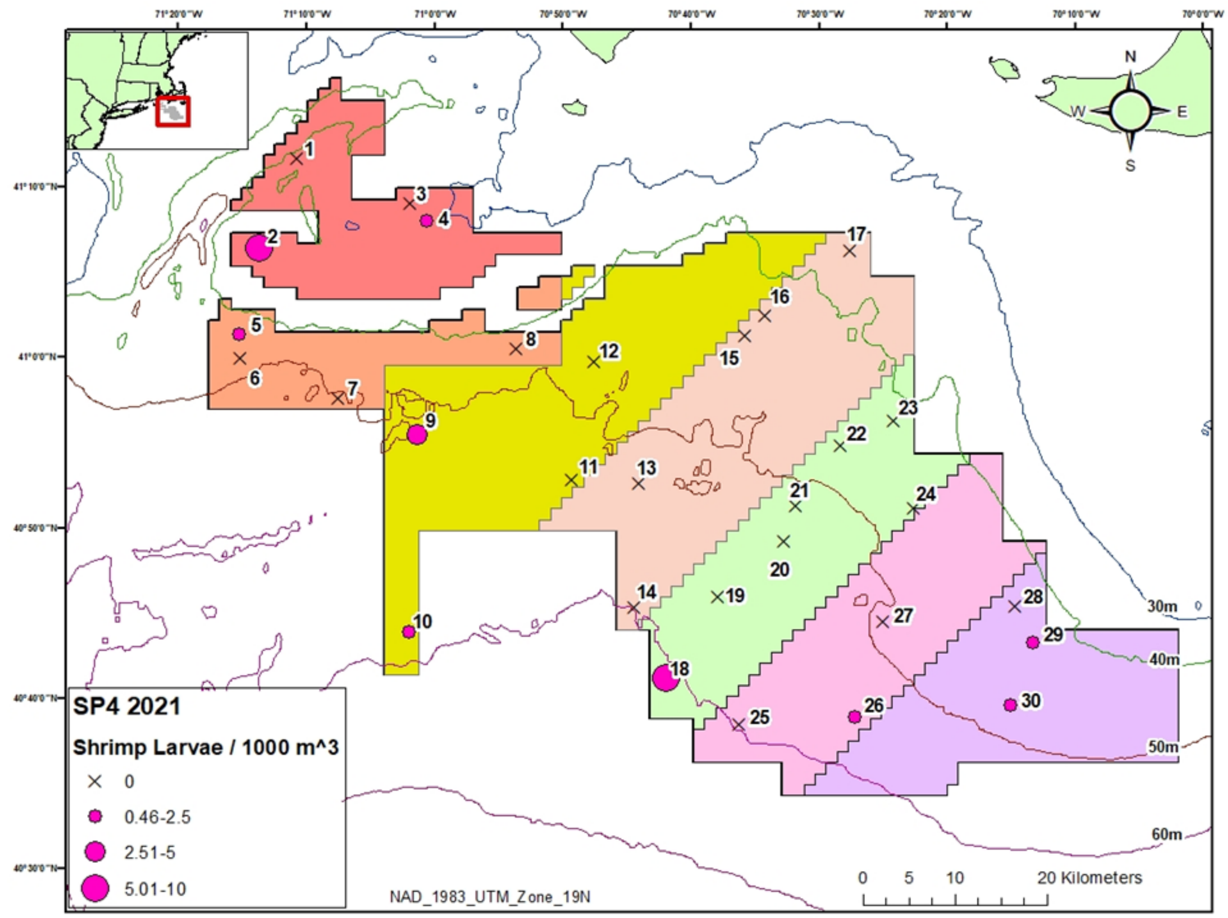

Figure 11. Larval shrimp abundance per 1000 m^3 of water sampled on 6/25/2021.

Appendix B: Fish Speciation Tables

Table B1. Larval fish speciation for all sampling periods in 2020.

Sampling Date (2020)	Urophycis chuss (white hake)	Peprilus triacantus (butterfish)	Centropristis striata (black seabass)	Clupea harengus (Atl. Herring)	Merluccius bilinearis (silver hake)	Euthynnus alleteratus (Little tunny)	Bothus ocellatus (two-spot flounder)	Sygnathus fuscus (Northern pipefish)	Citharichthys arctifrons (Gulf Stream flounder)	Cheilopogon melanurus (Atlantic Flying fish)	Unknown
6/9	2	0	0	0	0	0	0	0	0	0	-
6/25	7	1	2	4	1	0	0	0	0	0	-
7/8	1	83	0	0	0	0	0	0	0	0	5
7/29	179	177	0	1	1	7	1	2	0	0	1
8/12 - 8/13	355	82	0	0	0	63	0	0	1	0	5
8/27 - 8/29	243	68	0	0	0	0	7	0	0	1	7
9/24	1144	6	0	0	0	0	2	0	19	0	3
Total	1931	417	2	5	2	70	10	2	20	1	21

Table B2. Larval fish speciation for all sampling periods in 2021.

Sampling Date (2021)	Melonogrammus aeglefinus (Haddock)	Scomber sp. (Mackerel)	Urophycis chuss (white hake)	Sygnathus fuscus (Northern pipefish)	Euthynnus alleteratus (Little tunny)	Centropristis striata (Black sea bass)	Prionotus carolinus (Northern sea robin)	Sphoeroide s maculatus (Northern Puffer)	Stephanolpis hispidus (Planehead fielfish)	Unknown
5/14	49	8	0	0	0	0	0	0	0	0
5/27	1	0	1	0	0	0	0	0	0	0
6/9	0	0	0	0	0	0	0	0	0	0
6/25	0	0	15	2	1	1	2	4	1	5
Total	50	8	16	2	1	1	2	4	1	5

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BOEM Environmental Studies Program
The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).