2020 Winter Acoustic Survey and Trapping for Gulf of Maine Northern Shrimp

Margaret Hunter
Maine Department of Marine Resources
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Photo by Elaine Jones, DMR, 2015

In Memoriam

Gratefully remembering our collaborator, Arnie Gamage,
for his generosity and good sense.

Photo by Elaine Jones, DMR, 2015

Summary

A small project was conducted to explore whether acoustic methods might be a useful survey tool for determining Gulf of Maine northern shrimp stock conditions during a fishing season. A fishing vessel with acoustic equipment made four overnight survey trips during January–February 2020 in the inshore Boothbay Harbor area, while nine experienced shrimp trappers set and hauled their shrimp trap gear in the same area. The trappers made 160 trips to tend their gear and caught about 3.12 mt of shrimp. They each recorded data about each trap string hauled and each provided DMR with a sample of their catch about once a week. Catch rates, which were generally lower than past commercial rates, were compared with acoustic signals. The results of the acoustic survey are discussed in a separate companion report. This reports describes the trapping portion of the project, and some of the challenges in using trapping to verify acoustic results.

Introduction

Fisheries for northern shrimp (*Pandalus borealis* (Krøyer)) in the Gulf of Maine (GOM) have been conducted in the winter when egg-bearing (ovigerous) female shrimp migrate inshore, and sometimes in the spring while the shrimp return offshore after egg hatch (Clark *et al.* 2000). The highest landings usually occurred in the months of January and February. Shrimp were caught by trawlers and trappers; trappers caught about 17% of the Maine landings, and Maine accounted for about 90% of GOM landings, in 2009–2013 (see Tables 2.3 and 2.4 in ASMFC 2018a).

The GOM northern shrimp fishery is managed by Maine, Massachusetts, and New Hampshire, participating in a cooperative program of fishery oversight and management through the Northern Shrimp Section of the Atlantic States Marine Fisheries Commission (ASMFC). After the 2012–13 shrimp season, the Section declared a commercial fishing moratorium due to low stock abundance. The moratorium was renewed each year until the Section established a three-year moratorium in 2018, which closed the fishery for the 2018–19, 2019–20, and 2020–21 seasons.

Assessments of the GOM northern shrimp stock and its fishery have been supported by data from the commercial fishery and from bottom trawl surveys. In addition, small, cooperative sampling programs were conducted by a few commercial vessels most winters during the fishing moratorium. NOAA's Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey, the NEFSC/ASMFC summer shrimp trawl survey, and the ME-NH inshore spring trawl survey provide important fishery-independent biomass and abundance indices and size-sex-stage distribution data for the ASMFC's annual northern shrimp stock assessment updates (*e.g.* ASMFC 2018b).

Hydroacoustic surveys have been utilized in fisheries stock assessment and management for many years (Thorne 1983, Mann *et al.* 2008, Koslow 2009). They offer improved sampling power with lower operating costs, are non-destructive, and have fewer interactions with fixed gear, compared with traditional trawl surveys. However, acoustic methods had not been successfully deployed for the GOM shrimp stock (*e.g.* Schick and Rosen, 2005) until a 2016–2017 pilot project (Sherwood and Baukus, 2019) by researchers at the Gulf of Maine Research Institute (GMRI) built upon earlier work with GOM Atlantic herring (Wurtzell *et al*. 2016, Sherwood *et al.* 2017).

If the commercial northern shrimp fishery ever re-opens, it will likely be limited and extensively monitored. This project investigated whether brief, spatially targeted inshore acoustic surveys could provide indices of northern shrimp abundance that could be analyzed for spatial and temporal trends during a fishing season, and whether the survey indices would be correlated with commercial catch rates, assuming those catch rates would reflect local northern shrimp abundance. The project also sought to collect data on winter size and sex-stage data as well as the timing of egg hatch, that could be compared with data from past years and other sources.

METHODS

Location

An area around Boothbay Harbor in mid-coast Maine (Figure 1) was chosen for the project for a number of reasons. The Maine Department of Marine Resources' (DMR's) main research lab is located there, which offered some logistical advantages. More importantly, one of the boats that participated in the 2016–2017 project was moored in the region, on Southport Island, and still had the acoustic equipment installed — a Simrad ES70 echosounder system with a 38/200 Combi D transducer and computer with monitor. See Sherwood *et al.* 2017 for a more detailed description. The captain was willing and available to conduct weekly surveys from his home port, and also to participate as a trapper.

The region historically has supported an active northern shrimp fishery. In recent years, the fishery in this area has been prosecuted by more trappers than trawlers. Since trappers also operate less expensively than trawlers, nine trappers were contracted to fish no more than 40 traps apiece for about eight weeks, weather permitting, beginning the last week of January 2020. The participating trappers were all experienced — with significant trapped shrimp landings in at least two commercial seasons — and had participated or applied to participate in shrimp research projects in the past. To reduce their expenses, most were able to tend their shrimp traps during lobstering trips.

The area chosen was from the mouth of the Sheepscot River, bounded on the west by the island of Georgetown, to Pemaquid Point in Bristol, about 12 miles (16 km) to the east, and extending offshore about 5 miles (8 km) (Figure 1). The size of the area was limited by the distance the surveying vessel could cover in one night. During the winter of 2009–10, the most recent full-length shrimp trapping season without trip limits (which we refer to as the 2010 season), about 40% of all Maine trapped shrimp were landed at harbors in this area.

Acoustic Survey

Researchers at GMRI were contracted to analyze the acoustic data collected by the survey vessel and produce a report. They were also given the trapper data with dates, locations, depths, and catch rates. The survey methods and results are described in GMRI's report by Sherwood and Whitman (2020), a companion to this report.

The survey vessel was a 36-ft (11.0-m) lobster boat, the *F/V Morning Star*. For analysis, three sub-regions were designated as "West" (west of -69.675º longitude or 69° 40.50' W), "East" (east of -69.600° longitude or 69° 36.00' W), and "Mid" (the sub-region in between) (Figure 1).

A planning meeting was held with the survey captain, the trappers, and staff from DMR and GMRI; the trappers indicated on a chart where they planned to set their traps so the survey captain would know where to survey. About three weeks into the project he was supplied with coordinates of locations where trappers were catching the most shrimp.

The survey captain was contracted to make one survey trip per week, for eight weeks. Unfortunately, the vessel was only able to make four trips, due to bad weather in late February and early March followed by the onset of the COVID19 pandemic. Survey trips were made on January 31 and February 8, 16, and 22. They began in the evenings at about 10 p.m. and ended at about 5 or 6 a.m. the next morning, since northern shrimp generally stay on the bottom during the day, but move up into the water column to feed at night. However, ovigerous females are much less likely to be found in the water column at night, compared with males and non-ovigerous females (Apollonio *et al*. 1986, Haynes and Wigley, 1969).

Trap Data Collection

The trappers were allowed to fish up to forty traps, tended (hauled) as often as needed. Shrimp sales were not allowed. All catch was thrown back as soon as possible, except for one sample per week, and one 5-gallon bucket (about 24 lbs or 11 kg) per trip, kept for personal use only. Each trapper was asked to collect one randomly chosen 1-kg sample from his day's catch once a week, for eight weeks, frozen for later delivery to the DMR. They were also provided with a temperature logger to secure to one trap. The logger recorded the temperature every five minutes throughout the project. Other information such as date set, date hauled, haul location, depth (fathoms), and estimated catch weight (pounds, of all shrimp species) was recorded for each trap string by the trapper captains. The trappers used their standard wire shrimp traps and bait in bait bags or wire mesh boxes. They all fished pairs or triples (two or three traps per string respectively). Traps were first set out on January 23 and the last hauls were made March 28. The nine trappers fished from the ports of Five Islands, Southport, Boothbay Harbor, South Bristol, and Pemaquid Harbor. The locations where traps were hauled are shown in Figure 1.

Sample Work-Up

Shrimp samples were analyzed following the usual procedures for commercial shrimp samples. The samples were thawed and weighed, and then separated by shrimp species. Northern shrimp (*P. borealis*) specimens were counted, measured (dorsal carapace length (CL)), and sexed (male, transitional, or female), and female stage (I, II, or ovigerous) was determined. Female stage I shrimp have not yet carried eggs, and female stage II shrimp are not carrying eggs but have in the past, as determined by the presence/absence of sternal spines (McCrary 1971). Ovigerous females were identified as those carrying at least 50 eggs. All other shrimp species in the samples, usually *Pandalus montagui* (Leach) or *Dichelopandalus leptocerus* (Smith), which are generally smaller than *P. borealis*, were counted and measured.

Trap Data Calculations

Region — A region (Western, Middle, or Eastern) was assigned to each trip based on reported trap location longitudes as described above. For six trips in which traps were hauled in more than one region, the region with the largest catch during that trip was assigned to the trip.

Catch Rate — The pooled average pounds per trap-haul was calculated for each vessel, each week, and each vessel-week by dividing the total catch for the vessel, week, or vessel-week by the total trap-hauls for the vessel, week, or vessel-week respectively. Likewise, the overall catch rate by region, week, or the project was the sum of all catch weights for the region, week, or project divided by the total number of trap-hauls for the region, week, or project respectively.

Bottom Temperature — The median bottom temperature for each vessel-week was calculated from all the 5-minute temperature recordings made by that vessel's temperature logger during the week. Medians were used instead of means, to avoid the influence of brief temperature spikes or troughs that occurred when the trap was hauled to the surface.

Depth — The mean depth fished for each vessel, week, and vessel-week was found by averaging all the reported depths of each trap string hauled for that vessel, week, or vessel-week.

Size-sex-stage distribution —The numbers of northern shrimp of each sex, stage and size (CL in 0.5 mm categories) in each sample were "raised" or "expanded" to the vessel's catch for the week by multiplying the numbers in the sample by the vessel-week's total catch weight divided by the sample weight. Then the raised distributions were summed by region. The overall size distribution for the project was the sum of the three region distributions. Catches made by vessels with no sample for the week were not characterized.

Count per pound — Shrimp counts per pound (all species) for each vessel-week's sample were calculated by dividing the total number of shrimp of all species in the sample by the sample weight. Multiplying this by the vessel-week's catch weight gave an estimate of the total number of shrimp caught; summing these over all sampled weeks gave an estimate of the total number of shrimp caught by that vessel during weeks that were sampled. Dividing this by the total weight of the catches from the sampled weeks gave a pooled mean count per pound for the vessel. Similarly, the pooled mean count per pound for each week and for the entire project's catch was calculated as the estimated total number of shrimp caught during the week or project divided by the total pounds caught during the week or project respectively, including only the catches for vessel-weeks that were sampled.

Percent of catch that was *Pandalus borealis* — The proportion of the catch, in numbers, that was *P. borealis* was calculated for each vessel-week's sample as the numbers of *P. borealis* in the sample divided by the total number of shrimp of all species in the sample. Pooled weekly means were calculated by weighting each vessel's weekly percent *P. borealis* by the vessel's weekly catch, summing by week, and dividing by the week's total catch, including only the catches for vessel-weeks that were sampled.

Percent of egg hatch — The proportion of female *P. borealis* whose eggs had hatched off was calculated for each vessel-week from the expanded size-sex-stage distributions described above, as the number of female IIs divided by the sum of the female IIs plus ovigerous females. Pooled weekly means were calculated by weighting each vessel's weekly percent egg hatch by the vessel's weekly catch, summing by week, and dividing by the week's total catch, including only the catches for vessel-weeks that were sampled.

Hatch timing — Probit analysis was used to estimate the timing of hatch midpoint, the day of the year on which 50% of *P. borealis* females that had carried eggs had hatched their brood, by region, based on the percent egg hatch in each sample from that region. For all regions combined, sample data from the same date were weighted by catch abundance and combined.

RESULTS

Catches and Effort: Traps were first set out on January 23 and the last hauls were made March 28, spanning ten weeks. Some trappers started or ended sooner than others, but all fished for seven to ten weeks. Data collected, by vessel, week, and sub-region, are listed in Table 1. The trappers estimated a total of 6888 pounds (3.12 mt) of shrimp were caught, of which at least 3500 lbs were discarded at sea. There were 2000 trap-hauls made during 160 fishing trips in total (Table 2). Trappers set about 10 to 40 traps each, and averaged 12.5 trap-hauls per trip.

Catch Rates: Catch rates were generally low, compared with past commercial seasons, and included five species of shrimp, mostly the northern shrimp, *P. borealis*. The pooled mean catch rate was 3.4 lbs/trap-haul (1.6 kg/trap-haul). The mean Western region catch rate was 4.5 lbs/trap-haul (2.0 kg/trap-haul), the Middle region rate was 1.7 lbs/trap-haul (0.8 kg/trap-haul), and the Eastern rate was 5.4 lbs/trap-haul (2.4 kg/trap-haul).

Catch rates were generally highest during the last three weeks of February and lowest during the first week of the project in January and the last two weeks of the project in the second half of March (Table 3 and Figure 4C). For comparison, trapper mean monthly catch rates during Maine's commercial shrimp fisheries varied from 6.6 to 16.3 lbs/trap-haul (3.0 to 7.4 kg/trap-haul) in the 2006–2010 seasons, then declined until the fishery was closed after the 2013 season. Rates were usually highest during February, which ranged from 10.1 to 16.3 lbs/trap-haul during 2006–2010 (Maine DMR, unpublished data from port interviews). Only the vessel from Five Islands (Western region) was able to achieve a catch rate in that range in February 2020. The average for the nine vessels combined in February 2020 was 5.3 lbs/trap-haul (Table 1 and Figure 4C). Catch rates increased as egg hatch progressed, up to a point, then declined, probably due to the female shrimp leaving the area shortly after hatching their eggs (Table 3 and Figure 5). The fall-winter inshore and spring offshore migrations of female northern shrimp in the GOM and their importance to the fishery have been well documented (*e.g.* Clark *et al*. 2000).

The boats that fished exclusively in the Western region had their highest rates between the weeks of February 17 to March 2, the vessels that fished in the Middle region all achieved their highest catch rates during the week of February 10, while the Eastern region boats peaked the week of February 24, except the *Miss Jennifer*, which had the highest weekly catch rate of all (17.5 lbs/trap-haul) the week of March 9 based on only one pair of traps hauled (Table 1 and Figure 4C).

In general, catch rates increased until egg hatch was 70-80 percent, then declined, but there was a great deal of variation (R^2=0.19, Figure 5).

The trappers were generally disappointed in their catch rates. One suggested the project started too late.

Samples, Sex-Stage Composition, and Size: During the project period, the nine trappers hauled their traps during a total of 73 trapper-weeks. Samples were collected during 65 of those weeks. There were two weeks in which a trapper collected an extra sample, for a total of 67 samples collected and analyzed, and a total of 6169 shrimp measured. During the trapper-weeks with samples, about 6561 lbs of shrimp were caught compared with 6888 lbs caught during the entire project, so 95% of the total catch was characterized by samples.

There were 3966 northern shrimp (*P. borealis*) in the samples. None of them were male or transitional, and only two were female I (which have not carried eggs yet). Trapped shrimp samples usually have few male, transitional, or female I northern shrimp since those shrimp stages generally stay offshore during the winter (*e.g.* ASMFC 2010, Figure 3). Ovigerous females made up 39% of the northern shrimp catch by count, and the other 61% (Table 3) were females caught after egg hatch (blue vs orange in Figure 6). This proportion of ovigerous females is lower than in four of the five commercial trap fisheries during 2006–2010 (from ASMFC annual assessment updates), and lower than the three trapping portions of winter sampling programs for 2015–2017. See the Egg Hatch section below for more information.

The pooled mean count of shrimp of all species per pound for the project was 36 (Table 2). This agrees well with values of monthly mean counts per pound in 2010 commercial trapped catches (34–37, ASMFC 2010). In 2020, counts were the highest during the second and third weeks of the project, declined, and then rose again in the last 2 weeks (Table 3). Sample counts varied from 29 (*Whistle Gear*, week of February 24) to 98 (*Sea Star*, week of March 16 when no *P. borealis* were in the sample, which comprised only the smaller *P. montagui* and *D. leptocerus*) (Table 1 and Figure 4D).

In general, the *P. borealis* size-frequency distributions (Figure 6) showed a mode at about 23–25 mm CL, and another larger mode at 27-29 mm, consistent with the two female modes observed in the 2019 summer survey data, probably from the early-maturing 2017 year class (female I in the summer) and the 2015 year-class (female II in the summer) respectively (ASMFC 2019). There were very few (47) small northern shrimp (less than 20 mm CL, the assumed 2018 year class) in the trapped catch samples. This is consistent with past findings of few small *P. borealis* in trapped catches (*e.g.* ASMFC 2010, Figure 3), but may also be due in part to the 2018 year class being very weak (ASMFC 2019).

Species Composition: Of the 6169 shrimp measured in the samples, 64% were *P. borealis* by count, 24% were *P. montagui*, and 12% were *D. leptocerus*, plus one *Crangon septemspinosa* (Say) and three *Lebbeus groenlandica* (Fabricius). Compare this with 82% *P. borealis* in 2017 Five Islands and South Bristol samples (three vessels, 23 samples, Maine DMR unpublished 2017 winter data), 66% *P. borealis* in 2016 Boothbay Harbor samples (one vessel, 5 samples, Maine DMR unpublished 2016 winter data) and 89% *P. borealis* in 2015 South Bristol samples (one vessel, 6 samples, Maine DMR unpublished 2015 winter data).

In 49 of the 67 samples in 2020, or 73% of samples, species other than *P. borealis* made up more than 10% of the sample by count. Note that count per pound goes up as the percentage of *P. borealis* goes down and the percentages of the smaller *D. leptocerus* and *P. montagui* go up (Table 3 and Figure 4D vs 4E). Also note that the percentages of *P. borealis* were higher when expanded to the catches, since the catches were largest when the incidence of *P. borealis* in the catches was high (Table 1, Table 3). When expanded to the catch, 81% were *P. borealis* by count, 13% were *P. montagui*, and 6% were *D. leptocerus.* Since one *P. borealis* weighs more than one *P. montagui* or *D. leptocerus*, the proportion of the catch made up of *P. borealis* by weight was about 93%.

Egg Hatch: Most northern shrimp were still carrying eggs when samples were collected during the week of January 27 (10-31% egg hatch), and all samples had reached 80% or more egg hatch by the week of March 9 (Table 1 and Figure 4F). The estimated date of 50% egg hatch was day of year (DOY) 28 (January 28) for the Western region samples, 51 (February 20) for the Middle region, and 39 (February 8) for the Eastern region, a surprisingly broad range (Figure 7).

Some of the variation might be related to trap locations and depths within a region. For example, the Five Islands trapper's first sample from 36 fa (66 m) depth had 63% egg hatch. But during the following two weeks, he moved the traps shallower to 32 and then 28 fa and his *P. borealis* samples exhibited reduced egg hatch (50% and 47% respectively), but a higher proportion of shrimp of other species. The following week the traps were back in 36 fa, egg hatch had jumped to 97%, and the proportion of shrimp of other species in the catch had gone down (Table 1).

When data for all regions were combined, 50% egg hatch occurred at about DOY 43 (February 12). The Western region date (January 28) was 1 day earlier than the comparable Five Islands date (January 29) in 2017 (ASMFC 2017). The Middle region date (February 20) was 10 days earlier than the comparable Boothbay Harbor area date (March 1) in 2016 (Hunter 2016). The Eastern region date (February 8) was 7 days earlier than the comparable Pemaquid Point area date (February 15) in 2017 (ASMFC 2017) and 26 days earlier than the comparable South Bristol area date (March 6) in 2015 (ASMFC 2015).

Depth: Depths fished varied from 21 to 47 fa (38–86 m) and means for vessel-weeks ranged from 27 to 37 fa (49–68 m) (Table 1 and Figures 3 and 4B). The trapper with the highest catch rates fished 28 to 37 fathoms (52–68 m) and had his best weekly catch rate at the shallowest depth. He moved his traps deeper during the last two weeks but was not able to maintain a high catch rate (see data for *Miss Maris*, Table 1 and Figure 4C). Trappers sometimes move their traps to deeper water later in the season as the shrimp hatch their eggs and begin to migrate offshore (DMR: unpublished data from port interviews and Lessie White, personal comm.). During this project, two or three of the vessels moved their traps deeper as the season progressed (Figure 4B).

Bottom Temperature: One temperature logger malfunctioned after the first week (*Gail Patricia*) and one was lost along with its data when the trap was lost (*Miss Maris*). Median weekly bottom temperatures are displayed in Table 1 and Figure 4A, and ranged from a high of 6.0 to a low of 4.3 °C. The highest temperatures were observed during the week of February 10 in the Eastern region and the following week in the Middle and Western regions, and declined from there to the lowest values during the last two weeks of March. In 2017, the most recent previous year in which temperature loggers were placed on shrimp traps, the highest temperatures in this region (Midcoast Maine) were observed the week of January 30 (6.7 °C) and then declined to 3.2 °C during the week of March 20 (ASMFC 2017).

Acoustic Survey: The results of the acoustic survey were described by Sherwood and Whitman (2020). There did not appear to be a strong correlation between shrimp abundance estimated from acoustics and shrimp catch rates from traps. They did find general agreement in depth distributions between the acoustic and trapping data with shrimp abundance peaking around 50 – 70 m (27-38 fa), and there was some agreement that the shrimp moved slightly offshore over time. There was also an interesting increase in acoustic activity around the time of the full moon (February 8–9).

DISCUSSION

It is difficult to draw conclusions about the status of the GOM northern shrimp stock from such a limited project, and in no way should the trapping component of this project be considered either a "survey", or approximating a commercial fishery. Since the trappers participating in this project were not allowed to sell their catch, there was little incentive to move traps to possibly better locations, to put out more traps (incurring further expenses) to find better locations, or to stop fishing before they had collected their eight weekly samples.

The purpose of the project was to determine whether acoustic methods might be a useful survey tool, especially for determining stock conditions and fishing impacts during a winter fishing season. An attempt was made to verify acoustic results by comparing with trapping catch rates. Sherwood and Whitman (2020) concluded that acoustics and trapping results may not always agree since they sample shrimp in different states — acoustics relies on shrimp activity off the bottom and trapping relies on shrimp activity near the bottom. We suggest this would also present a problem for an acoustic survey during winter when the bulk of the inshore stock are egg-bearing females, since they are believed to stay near the bottom even at night (Apollonio *et al*. 1986, Haynes and Wigley, 1969). It is unclear to us whether egged shrimp stay close enough to the bottom to be undetectable by acoustic methods.

Sherwood and Whitman noted that according to the acoustic survey, the shrimp seemed to be less abundant as the season progressed through February, and wondered why this was not reflected in the trapper catch rates. Most vessels, especially those with the highest overall catch rates, had increasing catch rates until late in the month or into March (Figure 4C). Trap catch rates increased during February as egg hatch progressed. During this project, 61% of the trapped northern shrimp had already hatched their eggs when caught, and there was evidence that egg hatch was earlier than usual. Fishermen have told us that shrimp are more trappable after their eggs have hatched, and this could account for increasing catch rates. They attribute this to the eggless shrimp being either hungrier or more active (DMR unpublished data from port interviews, Lessie White, personal comm.). The egg mass on the pleopods (swimming legs under the tail) "must be a handicap in swimming" (Apollonio *et al*. 1986) so it is likely that female shrimp are more active after egg hatch. If catchability is changing in this way, trap catch rates will not be a reliable indicator of shrimp abundance. There was also tremendous spatial variation in catch rates among the nine vessels, all fishing within about a 12-mile span of coastline.

It is more difficult to explain why the acoustic shrimp signal showed a declining trend during February. We might expect that, as the females' eggs hatched and they became more active, they would be more apt to appear in the water column at night, thus increasing the acoustic signal. Perhaps the acoustics were detecting the reduction in females as they left the area shortly after egg hatch to begin their offshore migration, but that would mean the acoustics were picking up the ovigerous shrimp to begin with. Perhaps the acoustic signal was coming only from juveniles. Apollonio *et al*. (1986) describe one- to two-year-old juveniles remaining inshore after they are hatched, but gradually moving offshore, and it may have been this offshore migration of the 2018 and 2019 year classes that caused the declining signal. Another possibility is that the lunar cycle described by Sherwood and Whitman, with a full moon during the February 8-9 survey trip, and a new moon two weeks later, may have influenced shrimp activity in the water column. As they described it, shrimp tended to be in the water column in the evening and pre-dawn, but during the full moon they were there with a strong signal all night, strongest at about 2 a.m.; two weeks later during the new moon, the overall signal was its lowest. This suggests shrimp behavior may be influenced by the level of illumination in the water column, or it may be coincidental, based on only four nights.

Sherwood and Whitman made useful suggestions for refining the acoustic survey process during a trap fishery, including having the acoustic survey vessel follow trap locations and haul times more closely, surveying over more hours of the day and night to pinpoint when shrimp are most active, and examining the possible influence of lunar cycles. We also suggest that it would be important to have a better understanding of the vertical position and detectability of ovigerous shrimp.

It appears that both commercial trapping and acoustics as survey tools are confounded by the timing and spatial characteristics of shrimp behaviors such as inshore and offshore migration, diel vertical migration, and egg hatch.

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Literature Cited

Apollonio, S., D.K. Stevenson, and E.E. Dunton. 1986. Effects of temperature on the biology of the Northern Shrimp, *Pandalus borealis*, in the Gulf of Maine. NOAA Tech. Rep. NMFS 42. https://repository.library.noaa.gov/view/noaa/23116

ASMFC. 2010. Assessment report for Gulf of Maine northern shrimp — 2011. Atlantic States Marine Fisheries Commission. Arlington, VA. 75 pp. http://www.asmfc.org/uploads/file/2010ShrimpAssessment.pdf

ASMFC. 2017. 2017 winter sampling for Gulf of Maine northern shrimp. Atlantic States Marine Fisheries Commission. Arlington, VA. 32 pp. https://www.maine.gov/dmr/science-research/species/shrimp/documents/winter2017.pdf

ASMFC. 2015. 2015 winter sampling for Gulf of Maine northern shrimp. Atlantic States Marine Fisheries Commission. Arlington, VA. 75 pp. 30 pp. https://www.maine.gov/dmr/science-research/species/shrimp/documents/winter2015.pdf

ASMFC. 2018a. Northern Shrimp Benchmark Stock Assessment and Peer Review Report. Atlantic States Marine Fisheries Commission. Arlington, VA. 356 pp. http://www.asmfc.org/uploads/file/5bc798aaNShrimpBenchmarkAssessment_PeerReviewReport_2018_web.pdf

ASMFC. 2018b. Assessment report for Gulf of Maine northern shrimp – 2018. Atlantic States Marine Fisheries Commission. Arlington, VA. 78 pp. http://www.asmfc.org/uploads/file/5c000eb2NShrimpAssessmentUpdateReport_2018.pdf

ASMFC. 2019. Data update for Gulf of Maine northern shrimp – 2019. Atlantic States Marine Fisheries Commission. Arlington, VA. 36 pp. http://www.asmfc.org/uploads/file/5dee9a69NShrimpAssessmentUpdateReport_2019.pdf

Clark, S.H., S.X. Cadrin, D.F. Schick, P.J. Diodati, M.P. Armstrong, and D. McCarron. 2000. The Gulf of Maine northern shrimp (*Pandalus borealis*) fishery: a review of the record. *J. Northw. Atl. Fish. Sci*. 27: 193-226. http://dx.doi.org/10.2960/J.v27.a18

Haynes, E.B. and R.L. Wigley. 1969. Biology of the Northern Shrimp, *Pandalus borealis*, in the Gulf of Maine. *Trans. Am. Fish. Soc.* 98:60–76.

Hunter, M. 2016. 2016 winter sampling for Gulf of Maine norther shrimp. Maine Department of Marine Resources. 32 pp. https://www.maine.gov/dmr/science-research/species/shrimp/documents/winter2016.pdf

Koslow, J. A. 2009. The role of acoustics in ecosystem-based fishery management. *ICES Journal of Marine Science*, 66: 966–973.

Mann D.A., Hawkins A.D., Jech J.M. 2008. Active and passive acoustics to locate and study fish. In: Webb J.F., Fay R.R., Popper A.N. (eds) *Fish Bioacoustics*. Springer Handbook of Auditory Research, Vol 32. Springer, New York, NY. https://doi.org/10.1007/978-0-387-73029-5_9

McCrary, J.A. 1971. Sternal spines as a characteristic for differentiating between females of some Pandalidae. *J. Fish. Res. Board Can.*, 28: 98–100.

Schick, D.F., and S. Rosen. 2005. Exploring the addition of an acoustic survey to the summer Gulf of Maine shrimp survey. Final report submitted to the Northeast Consortium, NEC 04-863. 10 pp.

Sherwood, G.D., A. Baukus, and J. Chawarski. 2017. Continuation of the Maine inshore acoustic herring survey: collaborative research to support the Maine lobster industry. Final report submitted to the 2013/2014 Saltonstall-Kennedy Grant Program. Gulf of Maine Research Institute, Portland, Maine. https://www.researchgate.net/publication/328026137

Sherwood, G.D. and A. Baukus. 2019. Maine inshore acoustic survey for northern shrimp (*Pandalus borealis*). Final report submitted to the 2014/2015 Saltonstall-Kennedy Grant Program. Gulf of Maine Research Institute, Portland, Maine.

Sherwood, G.D. and A. Whitman. 2020. Acoustic survey of northern shrimp (*Pandalus borealis*) distribution/abundance in relation to trap catches in midcoast Maine. Report to the Maine Department of Marine Resources. Gulf of Maine Research Institute, Portland Maine. 15 pp. https://www.maine.gov/dmr/science-research/species/shrimp/documents/GMRI2020acoustics.pdf

Thorne, R. E. 1983. Assessment of population abundance by hydroacoustics, *Biological Oceanography*, 2:2-4, 253-262.

Wurtzell, K.V., A. Baukus, C. Brown, J.M. Jech, A. Pershing, G.D. Sherwood. 2016. Industry-based acoustic survey of Atlantic herring distribution and spawning dynamics in coastal Maine waters. *Fisheries Research* 178: 71-81.

Table 1. Summary statistics by vessel and week, with vessels ordered roughly by fishing location from west to east: number of trips, region fished (Western, Middle, or Eastern), estimated total shrimp catch (pounds), number of traps hauled, pooled mean catch rate (pounds per trap-haul), median bottom temperature, mean depth in fathoms, number of samples collected, pooled mean count per pound of shrimp of all species, percent of the shrimp catch that was *Pandalus borealis* (by count), and percent of *P. borealis* females whose eggs had hatched.

Vessel	Port	Week of …	Trips	Region Fished	Est. Catch	Trap Hauls	Catch Rate	Bottom Temp.	Depth	Samples	Count	*Pandalus borealis*	Egg Hatch
					Lbs		Lbs/TH	°C	Fath		No/Lb	%	%
Morning Star	Southport	1/27/20	2	West	118	80	1.5	4.6	30	1	59	36%	31%
		2/3/20	2	West	246	80	3.1	4.3	31	1	51	53%	79%
		2/10/20	1	West	136	40	3.4	5.2	32	1	34	89%	59%
		2/17/20	3	West	517	74	7.0	5.6	32	2	36	83%	93%
		3/2/20	1	West	155	22	7.0	5.3	36	1	31	87%	100%
		3/9/20	1	West	90	40	2.3	4.9	33	1	37	77%	94%
		3/16/20	1	West	53	40	1.3	4.4	33	1	44	62%	100%
Miss Maris	Five Islands	2/3/20	2	West	270	24	11.3	na	36	1	32	94%	63%
		2/10/20	2	West	265	20	13.3	na	32	1	32	89%	50%
		2/17/20	2	West	310	20	15.5	na	28	1	37	88%	47%
		2/24/20	1	West	150	10	15.0	na	36	1	32	91%	97%
		3/2/20	2	West	270	20	13.5	na	33	1	35	100%	95%
		3/9/20	2	West	190	20	9.5	na	33	1	32	98%	98%
		3/16/20	1	West	10	10	1.0	na	37	1	52	54%	98%
		3/23/20	1	West	10	10	1.0	na	37	1	47	23%	100%
Catch 22	Boothbay Harbor	1/20/20	2	Mid	6	30	0.2	na	33	0	–	–	–
		1/27/20	3	Mid	90	45	2.0	4.6	31	0	–	–	–
		2/3/20	4	Mid	93	60	1.6	5.1	32	1	32	81%	3%
		2/10/20	4	Mid	201	36	5.6	5.5	29	1	32	96%	28%
		2/17/20	3	Mid	64	27	2.4	5.9	29	1	31	86%	10%
		2/24/20	2	Mid&West	23	30	0.8	5.7	34	1	64	33%	91%
		3/2/20	2	West	40	30	1.3	5.4	35	1	34	99%	99%
		3/9/20	2	West	69	30	2.3	5.1	37	1	35	89%	97%
		3/16/20	1	West	29	15	1.9	4.5	36	1	56	35%	100%
		3/23/20	1	West	7	15	0.5	na	35	1	57	31%	95%
Sea Star	Boothbay Harbor	1/27/20	2	Mid&West	95	30	3.2	4.8	32	1	60	29%	10%
		2/3/20	2	Mid&West	87	28	3.1	5.3	31	0	–	–	–
		2/10/20	1	Mid	74	16	4.6	5.6	28	0	–	–	–
		2/17/20	1	Mid	18	14	1.3	6.0	28	1	39	61%	30%
		2/24/20	2	Mid	23	32	0.7	5.5	28	1	37	77%	26%
		3/2/20	3	Mid	16	54	0.3	5.5	29	1	45	57%	64%
		3/9/20	2	Mid&West	2	36	0.1	5.1	30	0	–	–	–
		3/16/20	1	Mid&West	3	18	0.2	4.6	31	1	98	0%	–
Three Belles	Southport	1/20/20	1	Mid	10	15	0.7	na	35	0	–	–	–
		1/27/20	4	Mid	112	60	1.9	4.7	32	1	37	75%	13%
		2/3/20	2	Mid	44	30	1.5	5.0	31	1	51	48%	17%
		2/10/20	3	Mid	128	45	2.8	5.5	30	1	34	78%	26%
		2/17/20	2	Mid	47	30	1.6	5.9	29	1	35	73%	21%
		2/24/20	1	Mid	10	15	0.7	5.5	29	1	43	65%	47%
		3/2/20	1	Mid	16	15	1.1	5.2	28	1	38	70%	80%
		3/9/20	1	Mid	3	15	0.2	4.8	29	1	93	10%	100%

Table 1. Continued

Vessel	Port	Week of …	Trips	Region Fished	Est Catch Lbs	Trap Hauls	Catch Rate Lbs/TH	Bottom Temp. °C	Avg Depth Fa	Samples	Avg Count No/Lb	*Pandalus borealis* %	Egg Hatch %
Robin Lyn	Boothbay Harbor	1/27/20	2	Mid	35	28	1.2	5.3	30	1	32	90%	17%
		2/3/20	1	Mid	20	14	1.4	5.1	31	0	–	–	–
		2/10/20	3	Mid	78	40	2.0	5.6	29	1	31	80%	25%
		2/17/20	5	Mid	98	57	1.7	6.0	28	1	30	85%	4%
		2/24/20	2	Mid	36	36	1.0	5.6	27	1	45	56%	38%
		3/2/20	3	Mid	64	51	1.3	5.3	28	1	33	83%	61%
		3/9/20	1	Mid	8	18	0.4	4.8	27	1	54	39%	98%
		3/16/20	1	Mid	4	18	0.2	4.8	29	1	88	11%	100%
Gail Patricia II	South Bristol	1/27/20	6	East	174	66	2.6	5.0	32	1	37	73%	13%
		2/3/20	2	East	62	15	4.1	na	32	1	35	89%	26%
		2/10/20	3	East	108	24	4.5	na	32	1	36	87%	60%
		2/17/20	3	East	133	27	4.9	na	32	1	39	66%	59%
		2/24/20	4	East	279	33	8.5	na	32	2	32	92%	90%
		3/16/20	1	East	6	6	1.0	na	31	1	35	86%	100%
		3/23/20	1	East	2	6	0.3	na	32	1	68	27%	100%
Miss Jennifer	South Bristol	1/27/20	1	East	25	6	4.2	5.3	30	0	–	–	–
		2/3/20	1	East	36	6	6.0	5.3	30	1	37	82%	32%
		2/10/20	3	East	120	14	8.6	5.9	32	1	34	99%	67%
		2/17/20	4	East	195	18	10.8	5.2	32	1	34	92%	58%
		2/24/20	2	East	80	8	10.0	4.8	32	1	37	76%	54%
		3/2/20	1	East	50	4	12.5	4.9	31	1	30	94%	81%
		3/9/20	1	East	35	2	17.5	4.4	30	1	34	96%	86%
		3/16/20	1	East	12	6	2.0	4.5	33	1	39	80%	100%
		3/23/20	1	East	6	12	0.5	4.5	32	1	53	50%	100%
Whistle Gear	Pemaquid Harbor	1/27/20	5	East	124	32	3.9	5.1	31	1	35	83%	17%
		2/3/20	6	East	144	40	3.6	5.3	33	1	33	87%	13%
		2/10/20	4	East	97	22	4.4	5.8	32	1	32	99%	27%
		2/17/20	5	East	201	34	5.9	5.2	33	1	31	100%	49%
		2/24/20	4	East	271	20	13.6	4.9	34	1	29	100%	90%
		3/2/20	4	East	241	28	8.6	4.9	35	1	34	95%	92%
		3/9/20	1	East	25	10	2.5	4.4	34	1	32	92%	89%
		3/16/20	1	East	20	18	1.1	4.8	34	1	39	83%	89%

Table 2. Summary statistics by vessel, ordered roughly from west to east by fishing locations: number of trips, estimated total shrimp catch, number of trap-hauls, pooled mean catch rate (pounds per trap-haul), mean depth (fathoms), number of samples collected, and pooled mean shrimp (all species) count per pound.

Vessel	Port	Region Fished	Trips Count	Est. Catch Pounds	Trap Hauls Count	Catch Rate Lbs/Trap-Haul	Depth Fathoms	Samples Count	Count Number/Lb
Morning Star	Southport	West	11	1,315	376	3.5	32	8	41
Miss Maris	Five Islands	West	13	1,475	134	11.0	34	8	34
Catch 22	Boothbay Harbor	Mid&West	24	622	318	2.0	33	8	35
Sea Star	Boothbay Harbor	Mid&West	14	318	228	1.4	30	5	53
Three Belles	Southport	Mid	15	370	225	1.6	31	7	38
Robin Lyn	Boothbay Harbor	Mid	18	343	262	1.3	29	7	34
Gail Patricia II	South Bristol	East	20	764	177	4.3	32	8	36
Miss Jennifer	South Bristol	East	15	559	76	7.4	32	8	35
Whistle Gear	Pemaquid Harbor	East	30	1,123	204	5.5	33	8	32
	Totals & Averages		**160**	**6,888 lbs 3.12 mt**	**2,000**	**3.4**	**32**	**67**	**36**

Table 3. Summary statistics by week: number of trips, estimated total shrimp catch, number of trap-hauls, pooled mean catch rate (pounds per trap-haul), mean depth (fathoms), number of samples collected, pooled mean shrimp (all species) count per pound, percent of the shrimp catch that was *Pandalus borealis* (by count), and percent of *P. borealis* females whose eggs had hatched.

Week of ...	Trips Count	Est. Catch Pounds	Trap Hauls Count	Catch Rate Lbs/Trap-Haul	Depth Fathoms	Samples Count	Count Number/Lb	*P. borealis* Percent	*Egg Hatch* Percent
1/20/20	3	16	45	0.4	34	0	–	–	–
1/27/20	25	773	347	2.2	31	6	44	58%	17%
2/3/20	22	1,002	297	3.4	32	7	39	73%	47%
2/10/20	24	1,207	257	4.7	31	8	33	90%	43%
2/17/20	28	1,583	301	5.3	31	10	35	84%	59%
2/24/20	18	872	184	4.7	31	9	33	88%	84%
3/2/20	17	852	224	3.8	32	8	34	93%	91%
3/9/20	11	422	171	2.5	32	7	35	88%	96%
3/16/20	8	136	131	1.0	33	8	48	54%	98%
3/23/20	4	25	43	0.6	34	4	53	32%	99%
Totals & Averages	**160**	**6,888 lbs 3.12 mt**	**2,000**	**3.4**	**32**	**67**	**36**	**81%**	**61%**

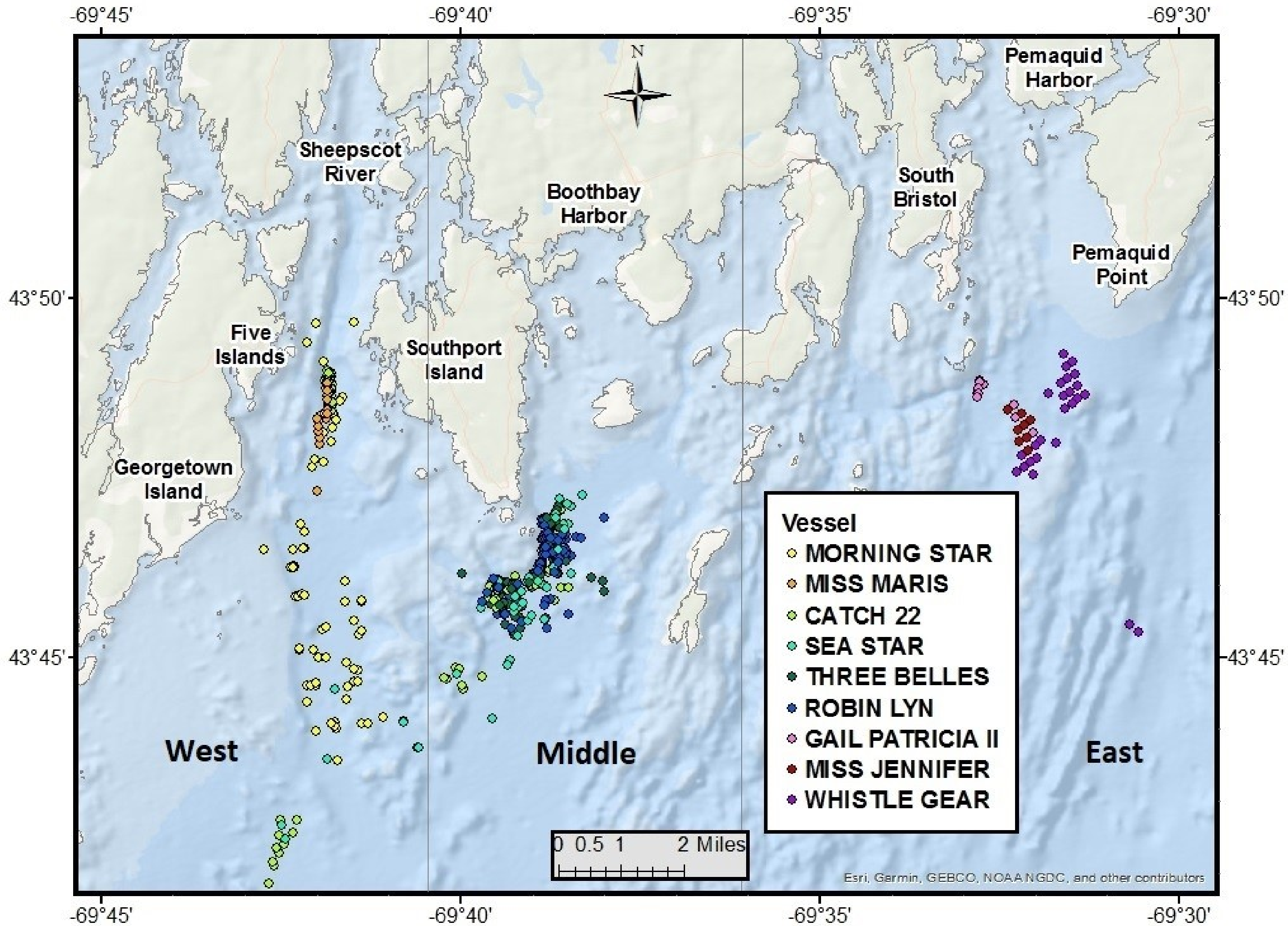


Figure 1. Trap locations by vessel, showing the three fishing sub-regions. Each point represents one or more trap string hauls.

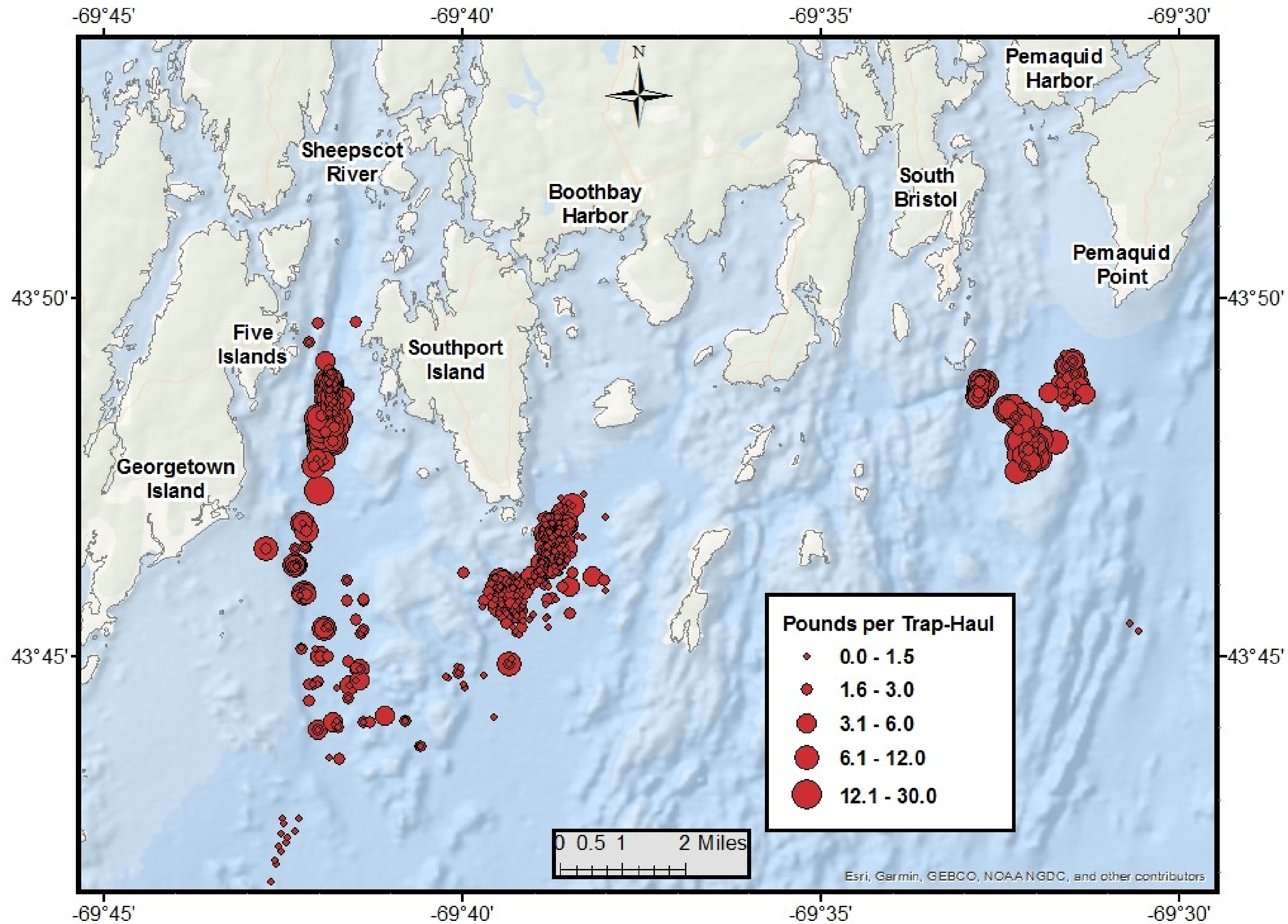


Figure 2. Shrimp catch rates (pounds per trap-haul). Each circle represents one trap string haul.

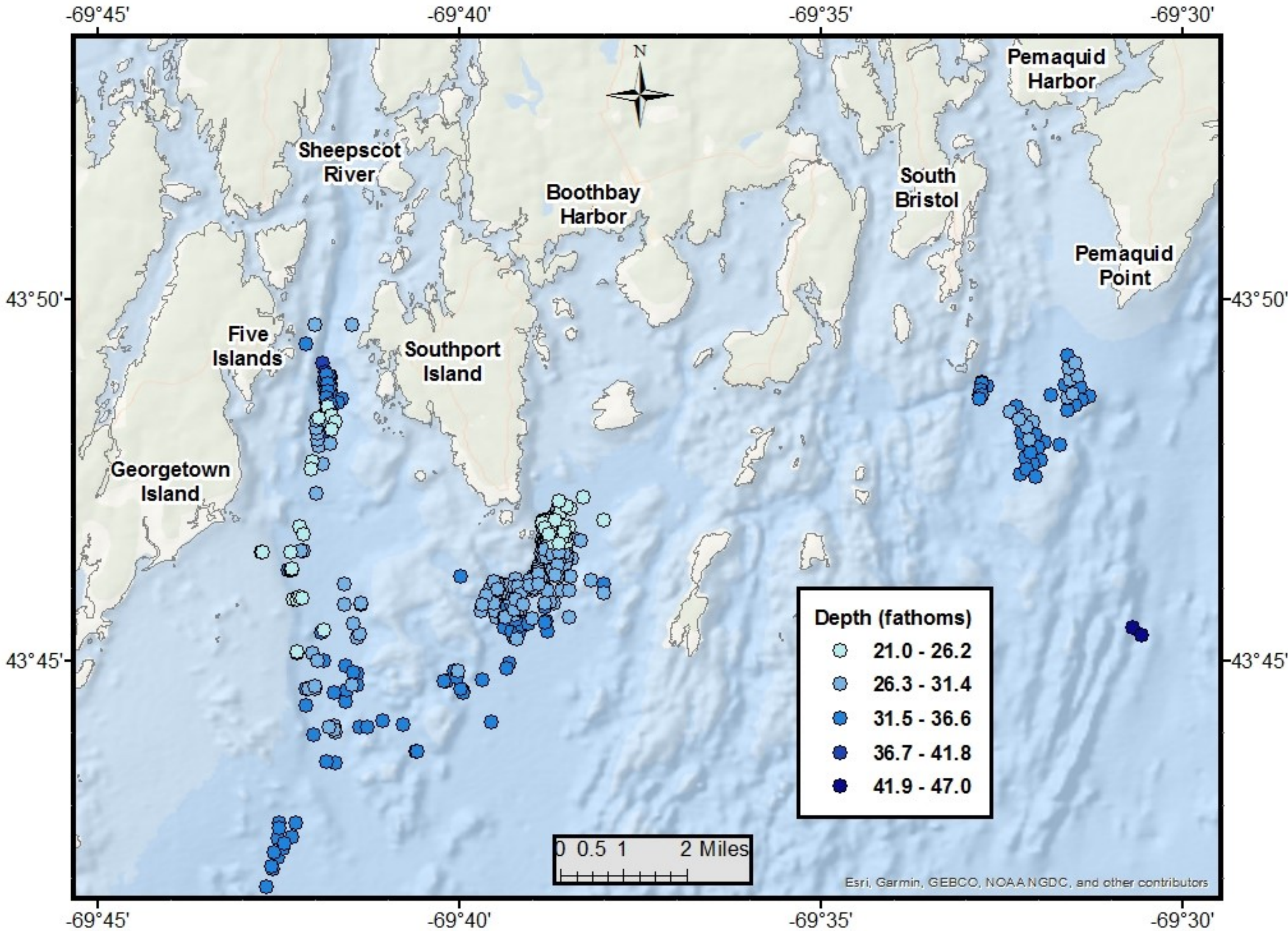
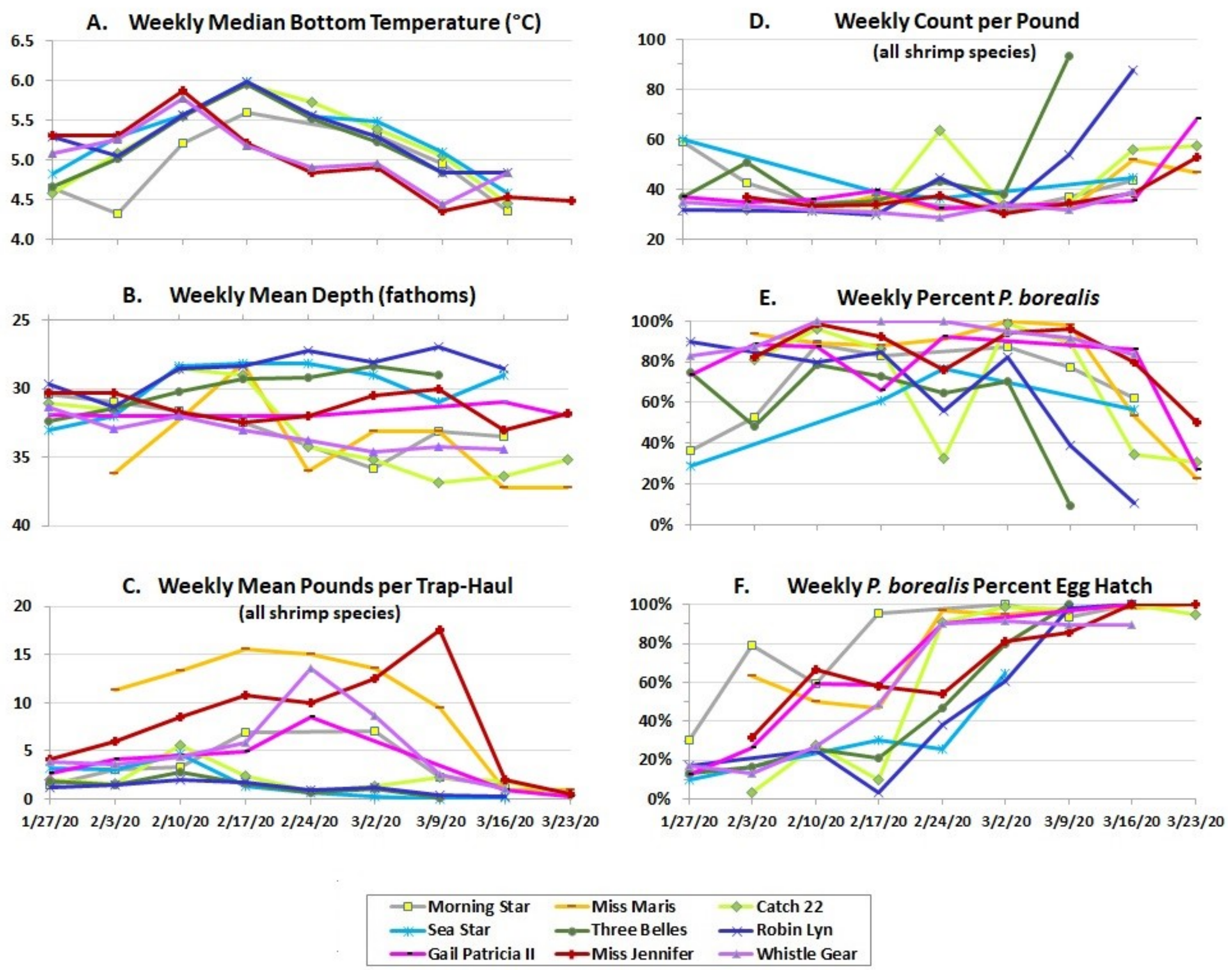


Figure 3. Depth (in fathoms), as recorded by the trappers. Each point represents one or more trap string hauls.



Figures 4A–F. Weekly data by vessel:

A – median bottom temperature (°C from data loggers)
B – mean depth (fathoms) (Note vertical axis direction)
C – mean pounds per trap-haul
D – mean count per pound of shrimp of all species in samples
E – percent of *Pandalus borealis* in samples
F – percent egg hatch in *Pandalus borealis* in samples.

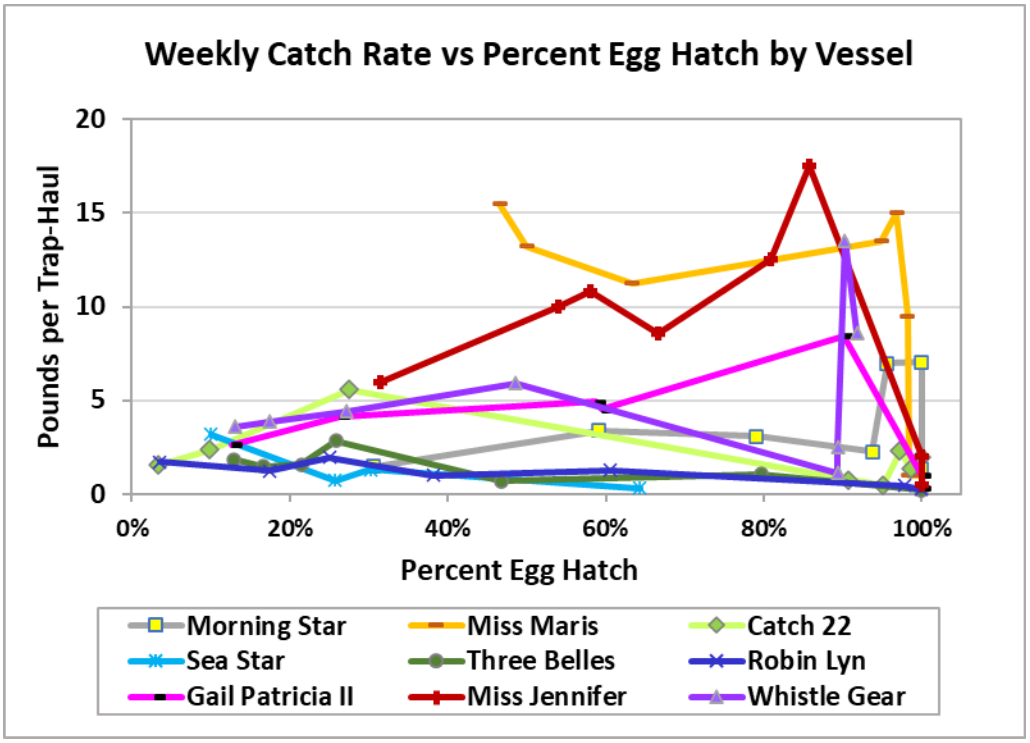


Figure 5A. Weekly mean catch rate vs percent *P. borealis* egg hatch by vessel.

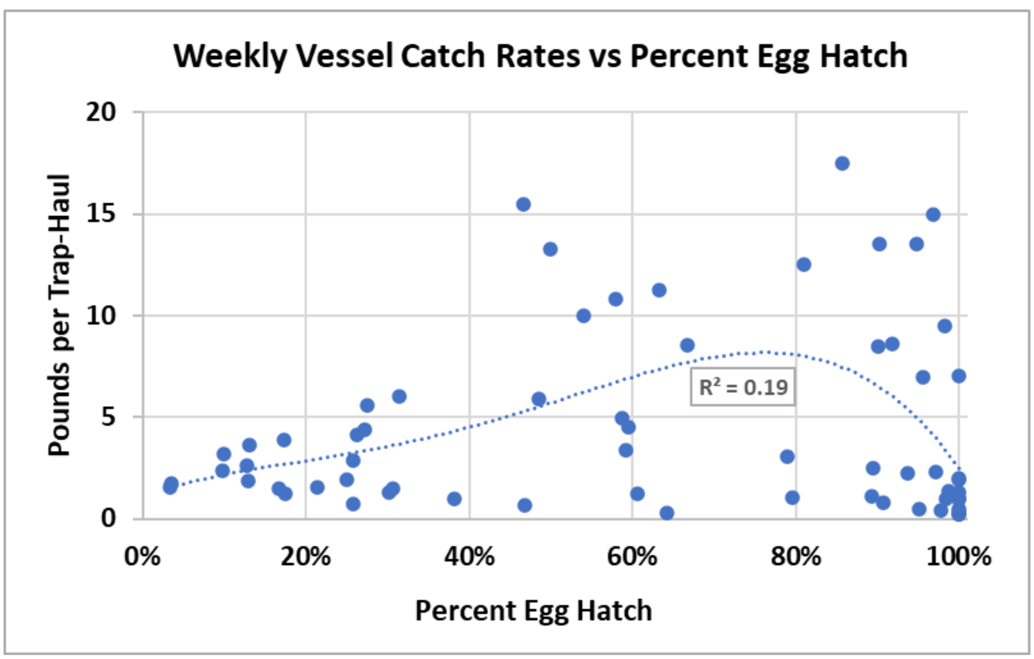


Figure 5B. Weekly mean vessel catch rates vs percent *P. borealis* egg hatch; fitted line is a 4th-order polynomial.

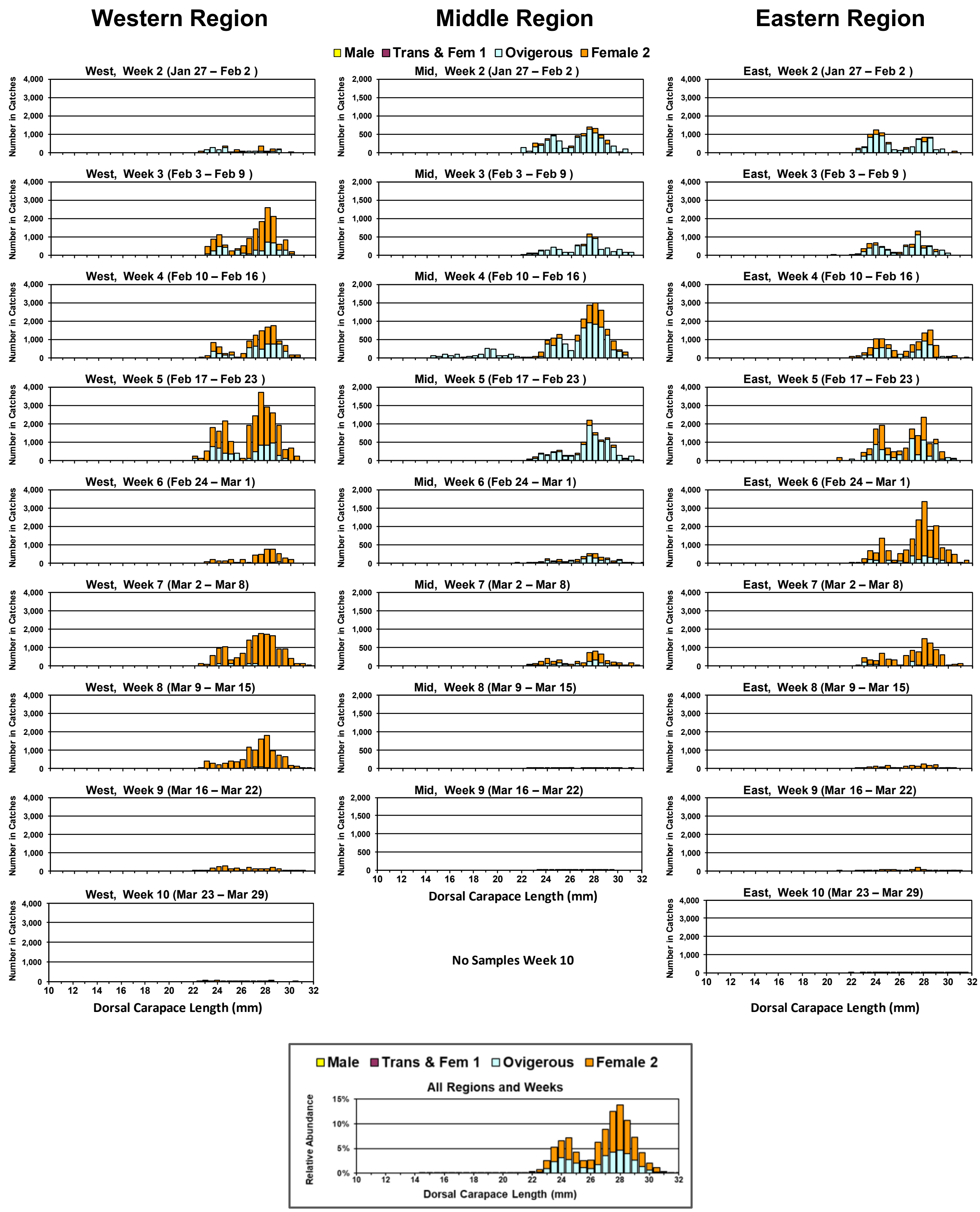


Figure 6. Northern shrimp size-sex-stage frequency distributions (in estimated total numbers of *P. borealis* in catches) by fishing region (left to right: west to east) and week (top to bottom) with all distributions combined (as relative abundance) at the very bottom. Note that the vertical scale for the Middle region is different from the others.

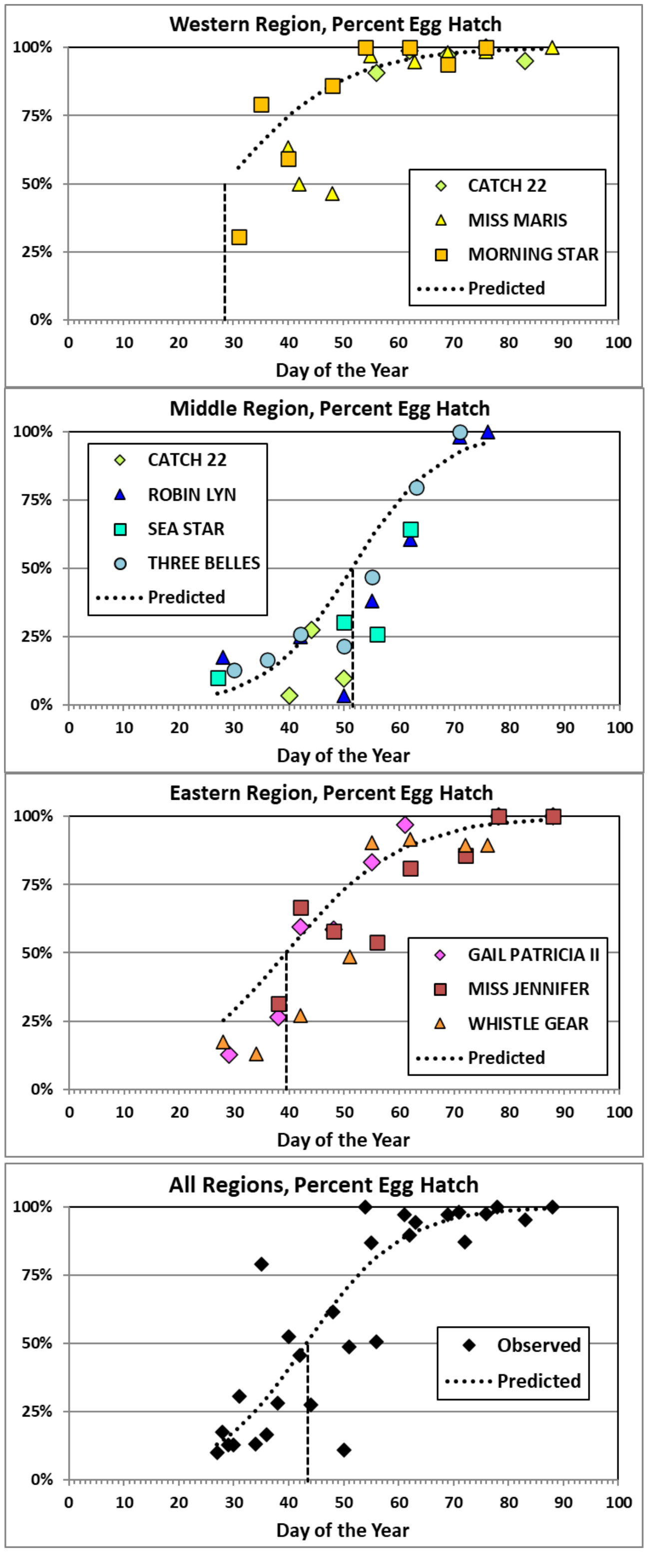


Figure 7. Percentage of egg hatch by day of the year (2020) for female northern shrimp, by region (Western, Middle, and Eastern) and regions combined (bottom). Vertical dashed lines indicate approximate day of 50% hatch.