Atlantic States Marine Fisheries Commission

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MEMORANDUM

June 1, 2015

To: **Northern Shrimp Section and Advisory Panel**

From: **Max Appelman, Fishery Management Plan Coordinator**

RE: **Technical Committee Report on 2015 Winter Sampling under the Research Set Aside Program**

At its December 2014 meeting, the Section approved a 25 metric ton research set aside that would collect biological samples similar to those that might have been collected from commercial shrimp catches if there had been a fishery. The purpose of the project is to collect data on egg-hatch timing, and the size, gender, and developmental stage of the shrimp, and to continue the TC's time series of catch data that are vital to the annual stock assessments for the Gulf of Maine northern shrimp fishery. Enclosed is a report of the 2015 winter sampling program that occurred under the research set aside.

Enclosed: 2015 Winter Sampling Report

2015 WINTER SAMPLING

FOR

GULF OF MAINE NORTHERN SHRIMP

Photo by Shlomit Auciello

Photo by Elaine Jones

Prepared
May 29, 2015
by the
Atlantic States Marine Fisheries Commission's
Northern Shrimp Technical Committee

Kelly Whitmore, Chair (Massachusetts)
Dr. Anne Richards, (NMFS NEFSC)
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SUMMARY

In the absence of a commercial fishery, four trawlers and five trappers collected northern shrimp samples in the Gulf of Maine during January – March 2015 under the northern shrimp research set-aside (RSA). They caught a total of 6.7 mt, or 27% of the 25 mt RSA. Very few northern shrimp were caught in eastern Maine, where catches were dominated by the small striped shrimp, *P. montagui*. Forty-nine trawl and fifteen trap samples were collected and evaluated for shrimp size and sex-stage, and the timing of egg hatch was estimated. An unusually high proportion of the northern shrimp catches comprised small ovigerous females, probably from the 2013 year class. Egg hatch was later than recent years, and continued to be correlated with temperature.

INTRODUCTION

Fisheries for northern shrimp (*Pandalus borealis*) in the Gulf of Maine (GOM) during the past thirty years have been conducted in the winter when egg-bearing (ovigerous) female shrimp move inshore, and sometimes in the spring while the shrimp return offshore after egg hatch. The highest landings usually occur in the months of January and February (Table 3 in Whitmore et al., 2014). Shrimp are caught by trawlers and trappers, with trawlers averaging about 86% of the Maine catch in 2009–2013 (Table 4 in Whitmore et al., 2014). Shrimp samples from commercial catches have been collected by member states (Maine, Massachusetts, and New Hampshire) each season for over thirty years, and have informed annual stock assessment updates.

The 2014–2015 GOM fishery was closed by the Atlantic States Marine Fisheries Commission (ASMFC) due to low stock abundance. In the absence of a fishery, the ASMFC Northern Shrimp Technical Committee (TC) recommended a limited winter sampling program. The purpose of the project was to collect samples similar to those that might have been collected from commercial shrimp catches if there had been a fishery, in order to:

- Continue the TC's time series of samples from GOM northern shrimp fishery catches, estimating the winter size (carapace length) and sex-stage composition of the shrimp stock in traditionally fished areas, and
- Estimate the timing of egg hatch. Northern shrimp in the GOM extrude eggs onto their abdomens in the late summer to early fall and egg hatch has generally begun in February and ended in early April (Clark et al., 2000), but has started earlier and lasted longer in recent years (Richards 2012). It also tends to begin and end earlier in the western GOM and later in the east (e.g. Whitmore et al., 2013, Figures 3–4), so the location of the sampling may influence the results.

At their November 5, 2014 meeting, the ASMFC Northern Shrimp Section established a 25-mt research set aside quota (RSA) to support data collection during the winter of 2014–2015. The program was further defined during Section and TC meetings with industry on December 16, 2014.

METHODS

Trawl samples: The traditional spatial range of the trawl fishery was divided into four regions: Massachusetts-New Hampshire, Western Maine (Kittery to Phippsburg), Midcoast Maine (Phippsburg to Rockland), and Eastern Maine (Vinalhaven to Lubec). Experienced GOM shrimp trawlers were solicited to participate in the project by e-mail and web announcements. One trawl captain for each of the four sampling regions was picked at random from among the qualified applicants from that region. The selected vessels were from Gloucester (MA-NH region), Portland (Western ME region), South Bristol (Midcoast ME region), and Stonington (Eastern ME region) (Figure 1) and ranged in length from 38–45 feet (11.6–13.7 m). Each trawler was asked to fish about once every two weeks during the period in which northern shrimp migrate into inshore waters to hatch eggs (usually January through March), using their standard shrimp-fishing gear. Each trawler made no more than five trips. Trips were scheduled, weather allowing, on a mutually agreed upon date, after discussion between the captain and the state TC member. Participants were asked to conduct at least three tows per day in areas where they would normally fish for shrimp at that time of year. They provided their TC member with a 2-kg sample from the catch from each of three tows, and other information such as date, tow duration, location, depth, and estimated catch weight. The sample was chosen randomly from each tow's catch, and bagged and kept on ice (MA) or frozen (ME) for later delivery to MA DMF or ME DMR. Similar 1-kg samples were also collected for further analysis by scientists at the University of Maine. U. Maine also provided temperature loggers (Onset Tidbit v2) to affix to each fisherman's net, which recorded temperature every five minutes continuously throughout the survey. Trawlers were paid $500 per trip and were also allowed to keep or sell up to 1,800 pounds (817 kg) of shrimp per day to defray expenses. The first trawl trip was made on January 21 and the last was on March 25, 2015.

Trap samples: Shrimp trappers were also invited to participate, and the five most experienced applicants were chosen, all from Midcoast and Eastern Maine. The trappers were allowed to fish only ten traps, tended as often as needed, keeping no more than 100 lbs (45 kg) of shrimp per week, for personal use only (no sales). Each trapper was asked to combine the catches of all ten traps and collect one randomly chosen 2-kg sample from his day's combined catch about once every two weeks, also on a mutually agreeable schedule. Trappers also collected samples for U. Maine and were provided with a temperature logger to secure to one of their traps. The trappers used their standard shrimp traps and bait (usually herring) and most traps were fished in pairs (two traps per string). The first traps were set out on January 30 and the last ones were hauled March 21, 2015.

Sample work-up: At the labs, samples were analyzed following the usual procedures for commercial shrimp samples. Frozen Maine samples were thawed, and each trawl or trap sample was weighed, and then separated by shrimp species. *P. borealis* specimens were counted, measured (dorsal carapace length (CL)), sexed (male, transitional, or female), and female stage (I, II, or ovigerous) was determined. Female stage I shrimp have not yet carried eggs; female stage II shrimp are not carrying eggs but have in the past, as determined by the presence/absence of sternal spines (McCrary 1971). All other shrimp species in the samples, usually *Pandalus montagui* or *Dichelopandalus leptocerus*, were counted and measured.

Calculations for trawl data: The numbers of northern shrimp of each sex, stage and size (CL in 0.5 mm categories) in each sampled tow were estimated ("raised" or "expanded") by multiplying the numbers in the sample by the tow catch weight divided by the sample weight. The proportion of northern shrimp females that had carried and hatched off their eggs was calculated for each day as the total female II shrimp in sampled tows divided by the sum of female II shrimp plus ovigerous females in sampled tows. Relative size-sex-stage frequency distributions for each day were calculated by dividing the number of northern shrimp in each sex-stage-size category by the total number in the sampled catches. Shrimp counts per pound for each sample were calculated by dividing the number of shrimp of all species in the sample by the total sample weight. The counts were then expanded to the tow to estimate the total number of shrimp in the tow. The total number of shrimp in all the sampled tows was then divided by the total catch weights of all the sampled tows to give a weighted mean count per pound for each day. Catch rates were calculated for each trip as the estimated total catch weight of shrimp of all species divided by the total number of hours towing.

Calculations for trap data: The proportion of northern shrimp females that had carried and hatched off their eggs was calculated for each trap catch as the total female II shrimp in the sample divided by the sum of female II shrimp and ovigerous females in the sample. Relative size-sex-stage frequency distributions for each catch were calculated by dividing the number of northern shrimp in each sex-stage-size category by the total number in the sample. Shrimp counts per pound for each catch were calculated by dividing the number of shrimp of all species in the sample by the total sample weight. The numbers of shrimp in each trap sample were also expanded to the trip's catch by size-sex-stage category, for combining with the trawl samples (Figure 13).

Hatch timing: A time series of hatch timing estimates was developed using data collected by the Maine DMR from the commercial shrimp fishery beginning in 1980 (Richards 2012). Samples were not available from Massachusetts and New Hampshire until later years, so in order to be consistent, the time series only uses data collected from Maine ports. Probit analysis was used to define the timing of hatch initiation (taken as the day of each year on which 10% of females had hatched their brood), hatch midpoint (50% hatched), and hatch completion (90% hatched). Duration of the hatch period is the number of days from initiation to completion (inclusive). In many years, hatch completion can be more difficult to estimate because fewer samples are

available at the end of the season. Samples from 2015 were weighted by the size (pounds) of the catch they were collected from. Samples from both trawl and trap gear were included in all years, except hatch metrics for the 2013–2014 winter, when there also was no fishery, are from limited trawl samples collected off Pemaquid Point in Midcoast Maine (Hunter 2014).

RESULTS

Trawl Catches and Samples

The four trawlers fished from the ports of Gloucester (MA), Portland (Western ME), South Bristol (Midcoast ME), and Stonington (Eastern ME) (Figures 1–2). They all made five fishing trips, except the Stonington boat, which made four trips. A summary of their results is in Table 1. A total of 13,600 pounds (6.2 mt) were caught in trawls, or 25% of the 25 mt RSA. Fourteen samples were delivered to the MA DMF, and 35 to the ME DMR. All four captains mentioned having to relocate or take steps to avoid fixed gear in their traditional tows. Locations fished are charted in Figures 1–2.

Size and sex-stage composition in trawl samples: The mean number of shrimp of all species per pound (Number/Lb, Table 1) was about 45, and varied from 30 (Stonington, Feb. 18) to 60 (Portland, Mar. 21) shrimp per pound. In general, the *P. borealis* size-frequency distributions (Figures 7–11) showed a bimodal distribution with a mode at about 19–21.5 mm CL and another at about 28 mm CL, probably from the 2013 and 2010–2011 year classes respectively. All of the Maine boats caught large proportions of small (19–22 mm CL) ovigerous female northern shrimp (Figures 6 and 8–11). The Massachusetts boat also caught shrimp in this size range, but they were more likely to be males or transitionals (Figure 7). Out of all the seventeen trawl trips sampled, there were only five in which the large shrimp (>22 mm CL) outnumbered the small shrimp (<=22 mm CL) (two MA trips (Figure 7), one Midcoast ME trip (Figure 9), and both Eastern ME trips (Figure 11)). Note that the 50% retention level for standard shrimp trawl gear with grate is at about 22.5 mm CL (Cadrin et al. 1999).

The Massachusetts boat was more likely to catch small shrimp when fishing in Scantum Basin, and avoided small shrimp on the two days when the majority of tows were further inshore, about five miles west of Scantum Basin (Figure 2, top left).

The assumed 2013 year class was first identified in the fall 2013 Maine-New Hampshire inshore trawl survey, and appeared again as a weak (about the ninth smallest in the summer survey time series) and unusually fast growing year class in the 2014 summer shrimp survey (Age 1.5 in Table 10 in Whitmore et al. (2014)). See Figure 14 for its progress throughout recent surveys.

Egg hatch in trawl samples: Most of the female shrimp were still carrying eggs in late January and early February, and most had hatched off their eggs by the middle of March (Figures 7–11). Egg hatch rates in samples are plotted in Figures 15–16. The approximate date of 50% egg hatch was day-of-the-year (DOY) 47 (February 16) in Massachusetts, and much later in Maine, about DOY 71 (March 12) in Western Maine, and about DOY 72 (March 13) in Midcoast Maine. Egg hatch was not evaluated for Eastern Maine, because the boat did not obtain *P. borealis* samples after February 18. The approximate DOY of 50% egg hatch from samples in Midcoast Maine in 2015 (DOY 72) was about 12 days later than the approximate DOY 60 from samples collected in the same area in 2014 (Figure 16 and Hunter 2014).

Trawl catch rates: Daily mean catch rates varied tremendously, from a low of 9 lbs/hr (Eastern Maine, February 18) to a high of 837 lbs/hr (Western Maine, March 10) (Table 1). The Western Maine boat consistently had the highest catch rates throughout the sampling season. The overall catch rate for all regions and dates (total estimated pounds caught divided by total trawl hours) was 149 lbs/hr. The overall catch rate for the Maine trawlers was 200 lbs/hr. The average commercial catch rate for Maine shrimp trawlers during the previous ten fishing seasons (2004–2013) was 356 lbs/hr (Table 8, Whitmore et al. 2014).

Trap Catches and Samples

The selected trappers fished in the South Bristol, Tenants Harbor, Vinalhaven, Stonington, and Winter Harbor areas (Figures 3–4). The first Tenants Harbor fisherman chosen was not able to fish due to illness in the family, and his replacement did not begin trapping until March 17. Although 90% of GOM northern shrimp trap landings are landed on or between the Georgetown and Bristol peninsulas in Midcoast Maine (from 2010 and 2011 harvester logbook data, Maine DMR unpublished), only one of the five participants fished in this area (South Bristol); the rest fished further east. Most of the trap catches east of South Bristol had relatively high proportions of the small striped shrimp, *P. montagui*, and would have been considered unmarketable (as in Figure 5). After working up several samples from these catches, the trappers were instructed not to provide more samples until there were more *P. borealis* (Table 2). A total of 1,108 pounds (0.50 mt) were caught in traps, or 2% of the 25 mt RSA, and 15 samples were collected.

Size and sex-stage composition in trap samples: The mean number of shrimp of all species per pound (Number/Lb, Table 2) was about 58, and varied from 31 (South Bristol, March 2) to 130 (Stonington, March 11). The mean would have been higher if more trap samples had been collected, due to the prevalence of the smaller species, *P. montagui*. Only the South Bristol (Figure 9), Tenants Harbor (Figure 12), and Vinalhaven (Figure 12) catch samples had enough *P. borealis* to develop a complete distribution. In general, the *P. borealis* size-frequency distributions (Figures 9, 11, and 12) showed a bimodal distribution with a mode at about 21 mm CL and another at about 28 mm, probably from the 2013 and 2010–11 year classes respectively.

The trappers were not as likely to catch small northern shrimp (<= 22 mm CL) as the trawlers — see Figure 9 for a side-by-side comparison at South Bristol. The smaller northern shrimp did not outnumber the large in any trap samples from any of the areas.

Length data from the March 17 Tenants Harbor sample were lost.

Egg hatch in trap samples: Most female shrimp caught in traps were still carrying eggs in late January and early February, and most had hatched off their eggs by the middle of March (Figures 9, 11, and 12). Egg hatch rates from samples are plotted in Figure 17. The approximate date of 50% egg hatch was about DOY 65 (March 6) in the South Bristol trap samples, compared with about DOY 72 (March 13) in the South Bristol trawl samples, probably because trappers are more likely to catch shrimp after egg hatch than trawlers fishing at approximately the same time and place (e.g. Figure 3b in Whitmore et al. 2013).

Size and Sex-Stage Composition for Trawl and Trap Samples Combined

When all samples were weighted by catch and combined, 60% of northern shrimp in the sampled catches were <= 22 mm CL. Of the females that were ovigerous or had carried eggs, 55% were <= 22 mm CL (Figure 13). Small shrimp have never outnumbered the large shrimp, and small ovigerous females have never outnumbered the large ovigerous females, in any season's catch in the 1985–2013 GOM northern shrimp fishery time series (Figure 13 and Whitmore et al. 2014 Figure 3). This suggests that an unusually high proportion of the 2013 year class was ovigerous (at only two years old) and available inshore, and/or that ovigerous females in the older year classes (2010 and 2011) were less abundant or less available inshore.

Hatch Timing for Trawl and Trap Samples Combined

In 2015 the estimated hatch initiation day was DOY 49 (February 18), the midpoint was DOY 70 (March 11) completion was DOY 92 (April 2), and duration of the hatch period was 44 days (Figure 18). The 2015 hatch occurred relatively late; the hatch midpoint was one of the latest in the time series (Figure 19).

Hatch timing continues to be correlated with temperature (Figures 20 and 21), with the hatch occurring later in cooler years. Sea surface temperature measured at Boothbay Harbor was generally cooler in 2014 and 2015 than in other recent years (Figure 22).

DISCUSSION

The 2015 winter research sampling effort met the goals of providing winter length and sex-stage composition information, and continuing the time series of egg hatch timing for the Gulf of Maine northern shrimp stock. The expansion of geographic and temporal coverage, and the

inclusion of trap samples in 2015 compared to 2014 (Pemaquid Point, ME trawl samples only) were beneficial; however it is important to recognize that the effort was still limited in comparison to the resolution of data collected during a typical commercial fishing season. On average, over 200 samples were taken annually in the fishery over the last ten years (2004–2013) through the shrimp port sampling project.

For winter 2015, 49 research samples were analyzed from 17 trawl trips made in the MA-NH, Western ME, Midcoast ME, and Eastern ME regions, as well as 15 trap samples from Midcoast and Eastern Maine. Differences among tows made on the same day within a few miles of each other suggest that the results could be influenced by moving even very short distances. The presence of fixed gear influenced tow operations in all regions. Trap samples provided limited information on northern shrimp, as other shrimp species dominated most catches.

Nonetheless, the samples were important for continuing the time series of hatch timing estimates and tracking the year classes now in the population. Interesting findings emerged, foremost, that small shrimp (<=22 mm CL) outnumbered large shrimp (>22 mm CL) in 12 out of the 17 trawl trips sampled. The high relative abundance of small shrimp is notable and suggests that an unusually high proportion of the 2013 year class was ovigerous (at only two years old) and available inshore, and/or that ovigerous females in the older year classes (2010 and 2011) were less abundant or less available inshore. The pattern of early maturing shrimp is consistent with the 2014 summer survey results, where the 2013 year class (at age 1.5) appeared to be fast growing with some having transitioned to female (stage I). The high proportion of small shrimp is also likely to be an indication that early life survival (the number of shrimp surviving per spawning female) of the 2013 year class was higher than for the very poor 2010–2012 year classes (see Whitmore et al. 2014). However, the apparently higher survival should not be equated with high recruitment (the number of new shrimp entering the population), as recruit abundance of the 2013 year class was the ninth lowest in the 31-year summer shrimp survey time series (Whitmore et al. 2014).

Egg hatch trends observed in the 2015 winter sampling were consistent with historical regional trends of hatch beginning and ending earlier in the western GOM and later in the eastern GOM. Hatch timing continues to be correlated with temperature, with hatch occurring later in cooler years, including 2015. The 2015 hatch midpoint was on March 11 (DOY 70), one of the latest in the Maine time series. Hatch completion occurred on April 2. This is in contrast to the warm year of 2012, for example, where the midpoint of hatch occurred on February 13 (DOY 44) and hatch completion on March 22 (DOY 82). It appears that hatch metrics in 2014 and 2015 were similar to pre-2000 fisheries, when hatch duration was shorter and initiated later than post-2000 fisheries.

ACKNOWLEDGEMENTS

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Table 1. Summary statistics for the trawl data: estimated total shrimp catch, number of tows, total towing time, average depth, average catch rate, number of samples collected for the TC, shrimp (all species) count per pound, and percent of *P. borealis* females whose eggs had hatched off, by area (west to east) and day.

Area	Date	Est. Total Catch	Tows	Tow Time	Avg Depth	Avg Rate	Samples	Avg Count	Egg Hatch
		Pounds	Count	Total hours	Fathoms	Lbs/Hr	Count	Number/Lb	%
MA-NH	26-Jan-15	190	3	4.9	43	39	3	38	22%
	04-Feb-15	210	2	5.0	31	42	2	34	8%
	18-Feb-15	100	3	4.9	49	20	3	50	58%
	17-Mar-15	390	3	6.7	64	59	3	47	100%
	25-Mar-15	330	3	6.8	69	49	3	50	100%
Western ME	21-Jan-15	440	4	5.4	55	81	3	55	1%
	18-Feb-15	1,850	5	5.2	47	358	3	50	10%
	28-Feb-15	2,000	4	3.9	43	512	3	47	20%
	10-Mar-15	1,950	4	2.3	38	837	3	47	46%
	21-Mar-15	1,725	7	8.6	48	200	3	60	75%
Midcoast ME	07-Feb-15	1,490	6	5.9	37	252	3	43	5%
	17-Feb-15	820	6	4.9	37	167	3	37	11%
	28-Feb-15	1,200	6	7.6	38	159	3	42	11%
	13-Mar-15	465	6	4.9	38	96	3	51	50%
	24-Mar-15	340	3	4.1	58	83	3	51	93%
Eastern ME	04-Feb-15	75	3	3.6	41	21	3	40	1%
	14-Feb-15	*4	3	2.3	39	*		no sample, mostly *P.montagui*	
	18-Feb-15	16	2	1.8	36	9	2	30	9%
	10-Mar-15	*5	3	2.9	38	*		no samples	
Totals		13,600 Lbs, 6.2 mt	76	91			49		
	** estimated P. borealis catch only*								

Table 2. Summary statistics for the trap data: estimated total shrimp catch, number of traps, number of set-over days, average depth, shrimp (all species) count per pound, and percent of *P. borealis* females whose eggs had hatched off, by area (west to east) and day.

Area	Date	Est. Total Catch	Traps	Set Time	Avg Depth	Count	Egg Hatch	Comments
		Pounds	Number	Days	Fathoms	Number/Lb	%	
South Bristol	07-Feb-15	35	10	3	43	44	13%	
	12-Feb-15	25	10	5	43			no sample
	18-Feb-15	140	10	6	33	34	33%	
	24-Feb-15	150	10	6	33	33	39%	
	02-Mar-15	170	10	6	33	31	40%	
	09-Mar-15	90	10	7	33	32	40%	
	17-Mar-15	75	10	8	33	37	75%	
Tenants Harbor	17-Mar-15	3	10	3	25	39	38%	length data lost
	21-Mar-15	3	10	4	25	49	47%	14% *P. montagui*
Vinalhaven	12-Feb-15	5	10	1	31	58	23%	48% *P. montagui*
	14-Feb-15	8	10	2	31			no sample
	18-Feb-15	40	10	4	33			no sample
	22-Feb-15	16	10	4	34	45	15%	27% *P. montagui*
	25-Feb-15	23	10	3	34			no sample
	27-Feb-15	10	10	2	33			no sample
	02-Mar-15	20	10	3	36			no sample
	05-Mar-15	0.25	10	3	34			no sample
	08-Mar-15	5	10	3	34			no sample
Stonington	02-Feb-15	9	10	3	35	118	0%	98% *P. montagui*
	11-Feb-15	20	10	9	31			no sample
	27-Feb-15	10	10	16	30			no sample
	01-Mar-15	1	10	2	35	n/a	6%	sample did not include the *P. montagui*
	11-Mar-15	20	10	10	35	130	100%	99.5% *P. montagui*
Winter Harbor	11-Feb-15	35	10	4	32	83	0%	99.5% *P. montagui*
	17-Feb-15	40	10	6	32	83	0%	99.8% *P. montagui*
	28-Feb-15	40	10	11	30			no sample
	08-Mar-15	30	10	4	31			no sample
	11-Mar-15	52	10	3	31			no sample
	14-Mar-15	18	10	3	31			no sample
	17-Mar-15	10	10	3	30			no sample
	04-Mar-15	6	10	4	30			no sample

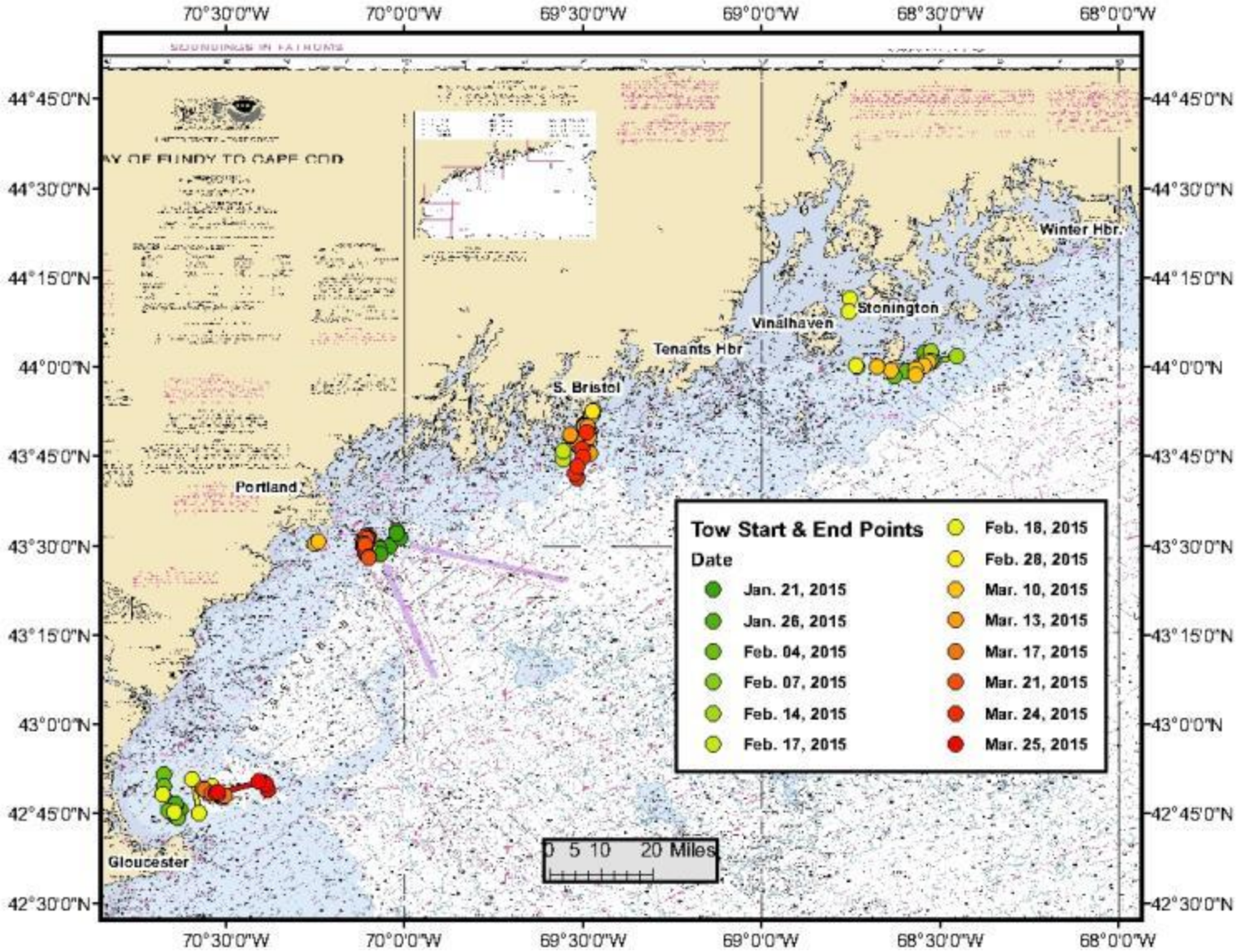


Figure 1. Locations of 2015 Gulf of Maine northern shrimp sampling tows. Color palette (green to red) indicates fishing date.

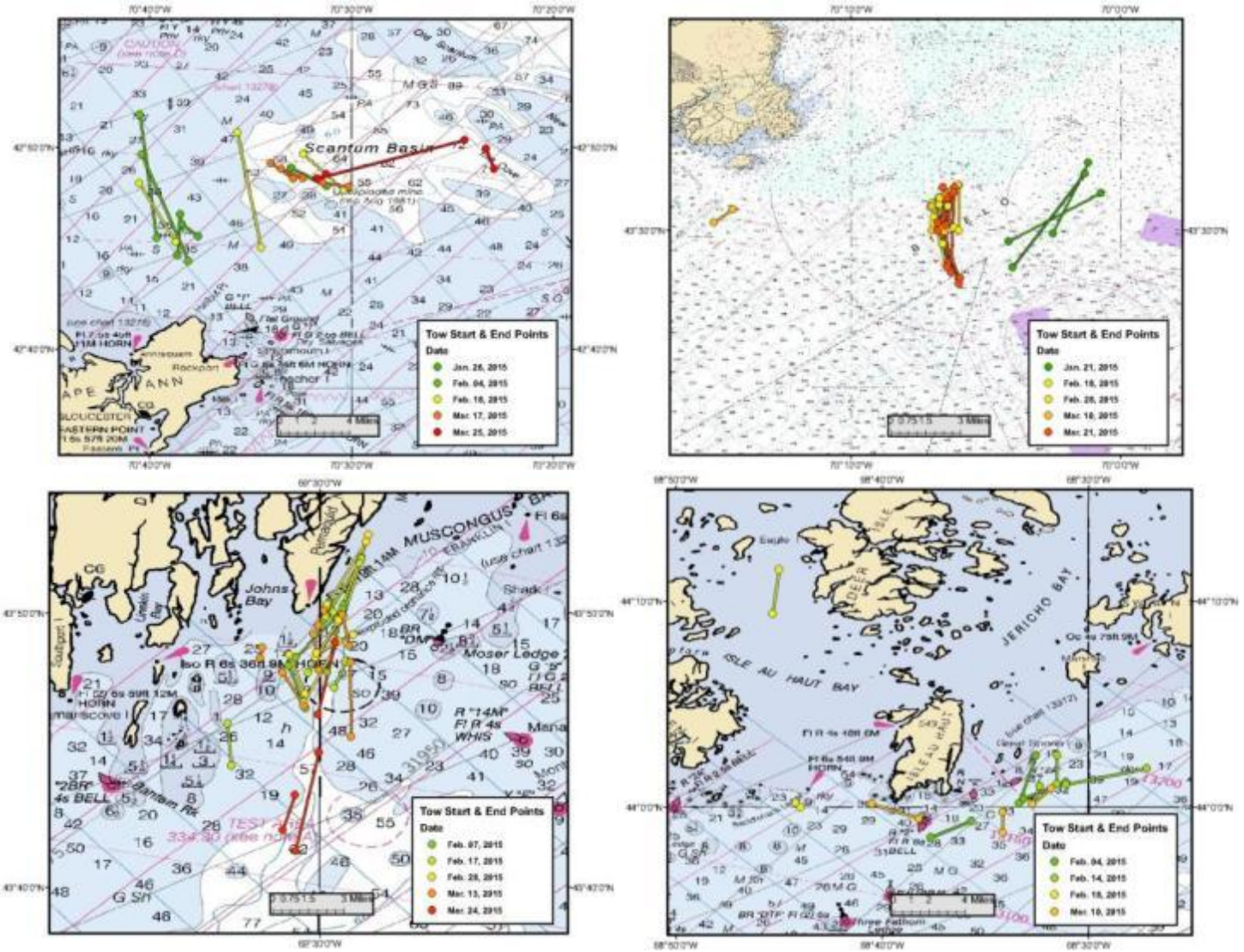


Figure 2. Locations of 2015 Gulf of Maine northern shrimp sampling tows by region: Massachusetts (top left), Western Maine (top right), Midcoast Maine (bottom left), and Eastern Maine (bottom right).

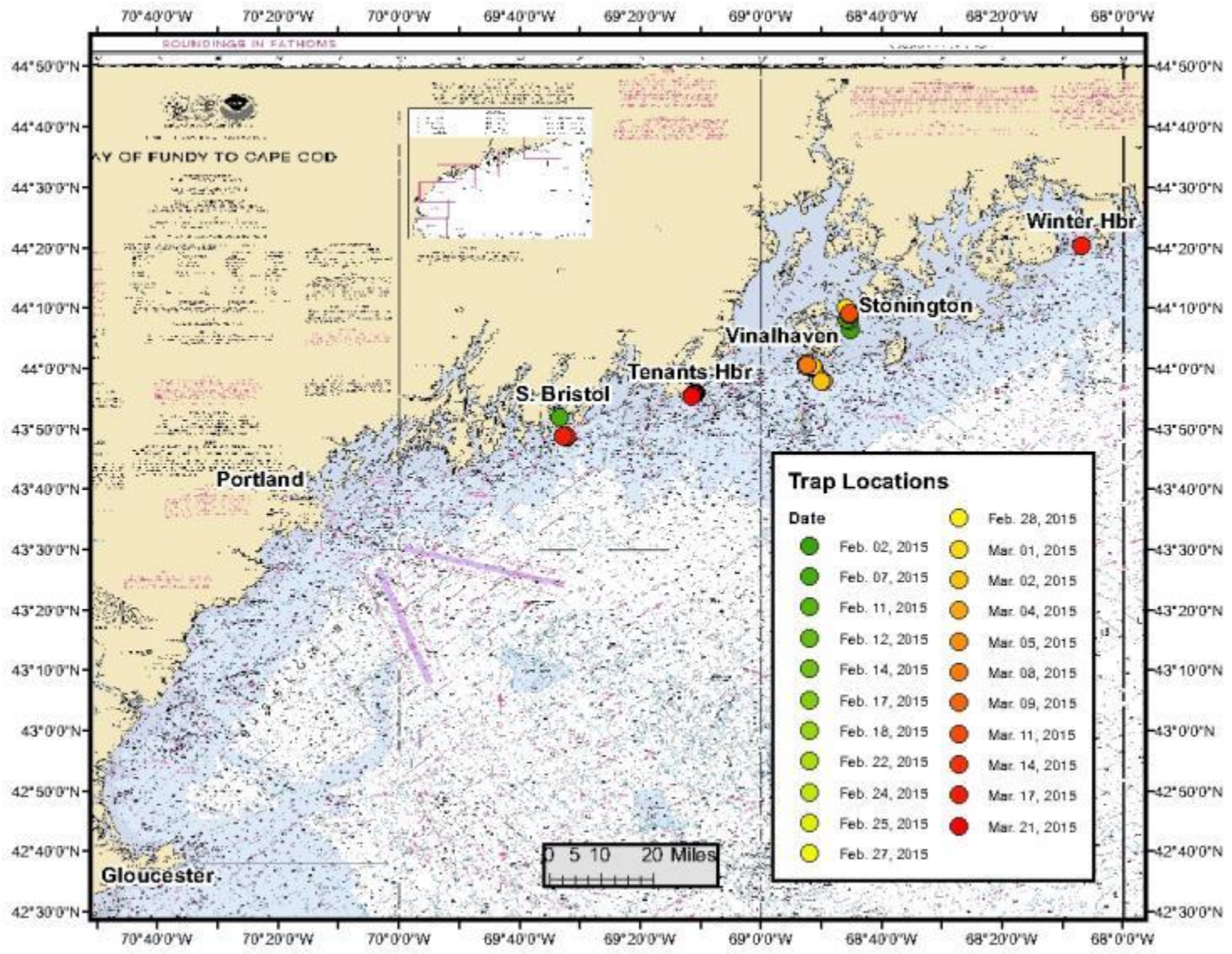


Figure 3. Locations of 2015 Gulf of Maine shrimp sampling traps. Color palette (green to red) indicates fishing date.

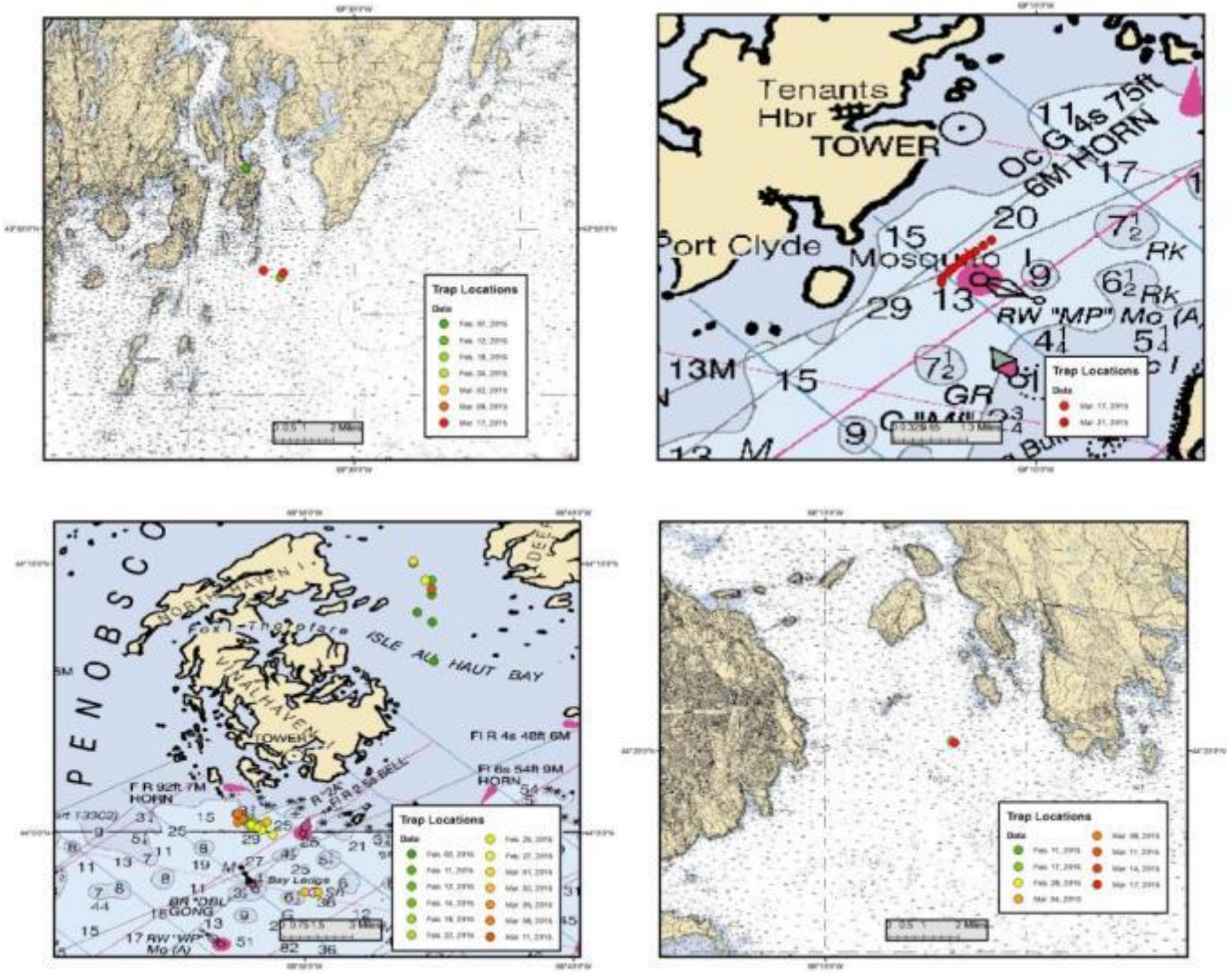


Figure 4. Locations of 2015 Gulf of Maine northern shrimp sampling traps by region: South Bristol (top left), Tenants Harbor (top right), Vinalhaven (bottom left, lower), Stonington (bottom left, upper) and Winter Harbor (bottom right).

Figure 5. Three northern shrimp (*Pandalus borealis*, large and red), and many striped shrimp (*P. montagui* and/or *Dichelopandalus leptocerus*), smaller and pale) from February 14 Stonington trawl catch (Eastern Maine). *Photo by Shlomit Auciello*.

Figure 6. Large and small female ovigerous northern shrimp, from January 26 Massachusetts trawl sample. Calipers are measuring the dorsal carapace length (19.6 mm) of one of the small females. *Photo by MA DMF*.

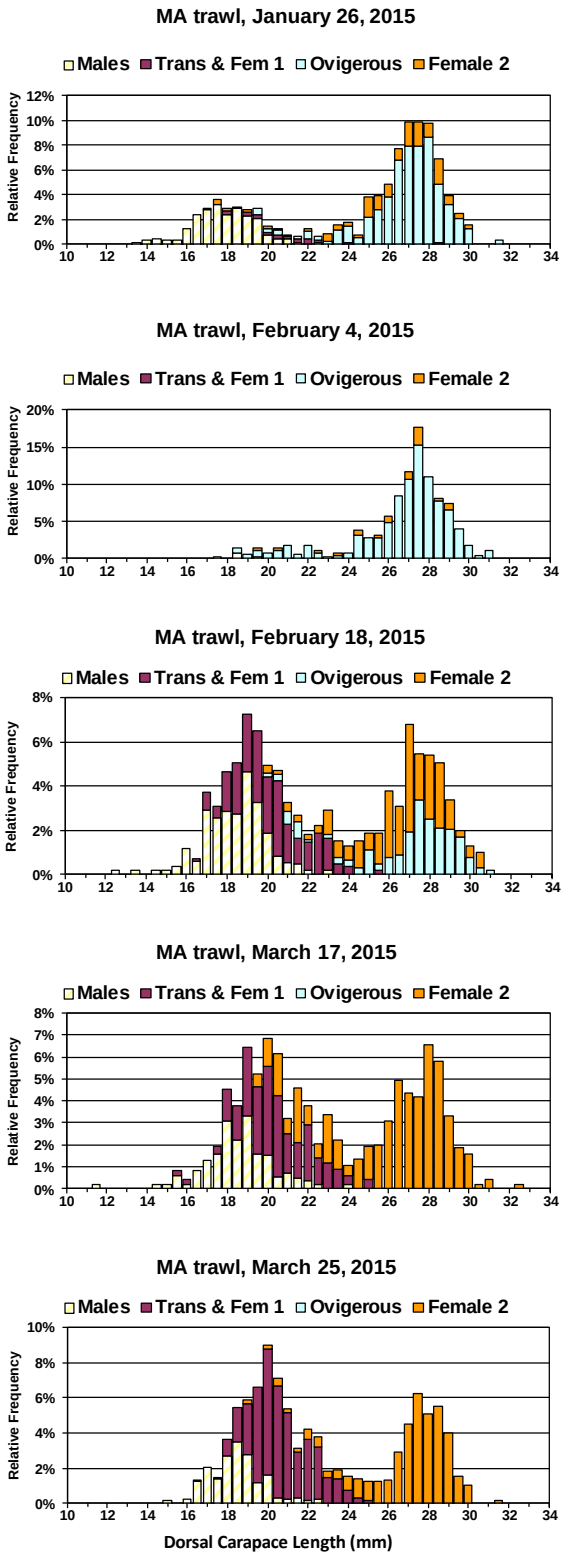


Figure 7. Northern shrimp relative size-sex-stage frequency distributions from Massachusetts trawl samples.

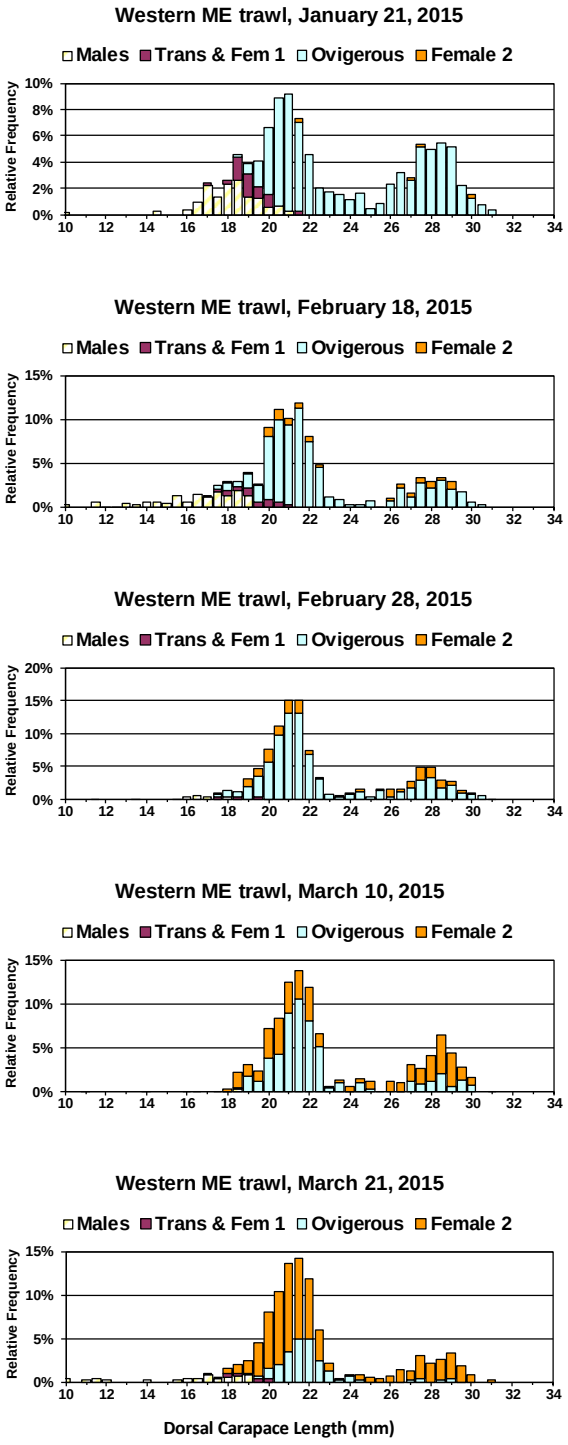


Figure 8. Northern shrimp relative size-sex-stage frequency distributions from Western Maine (Portland) trawl samples.

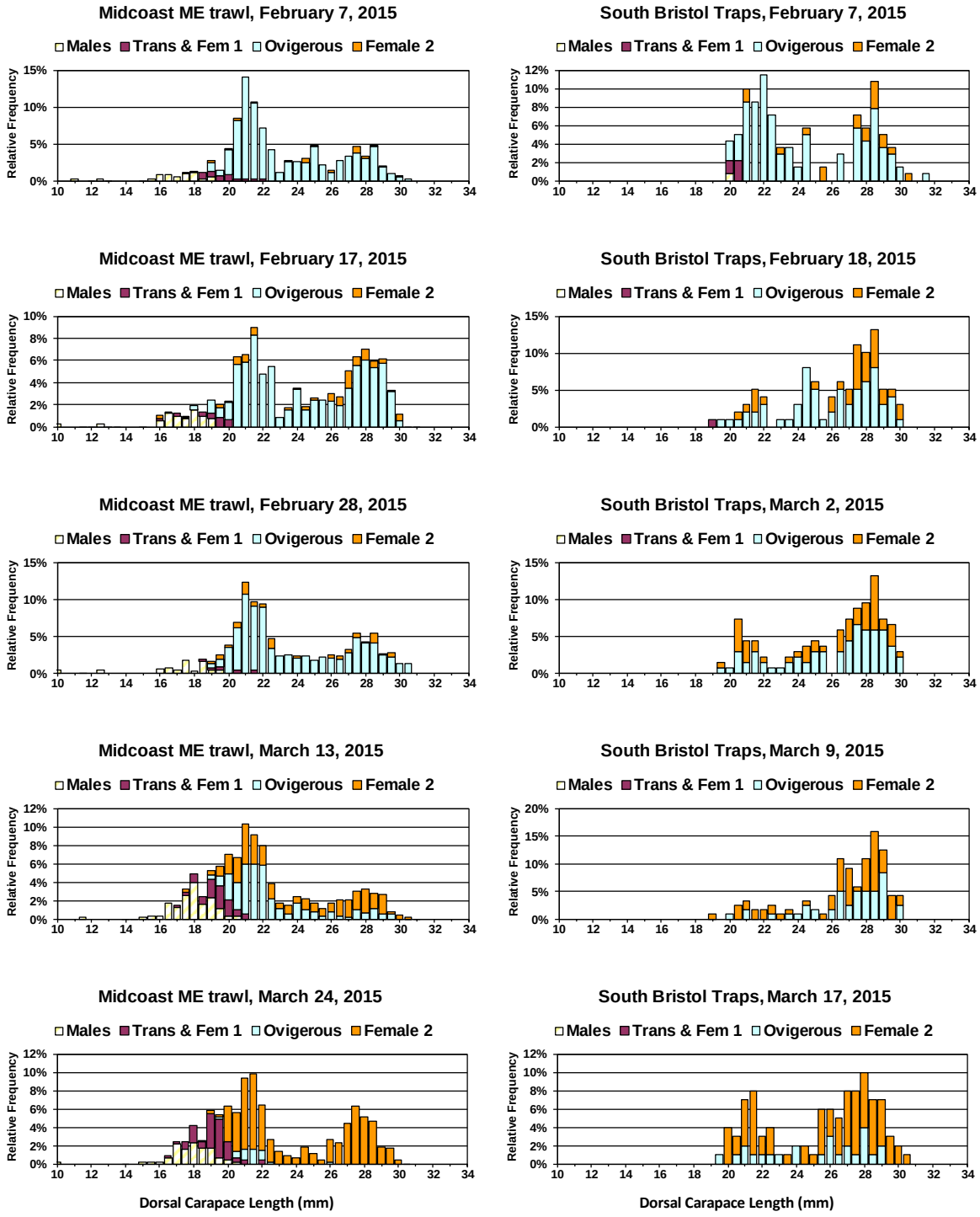


Figure 9. Northern shrimp size-sex-stage frequency distributions from Midcoast Maine (South Bristol) trawl samples (left) and trap samples (right).

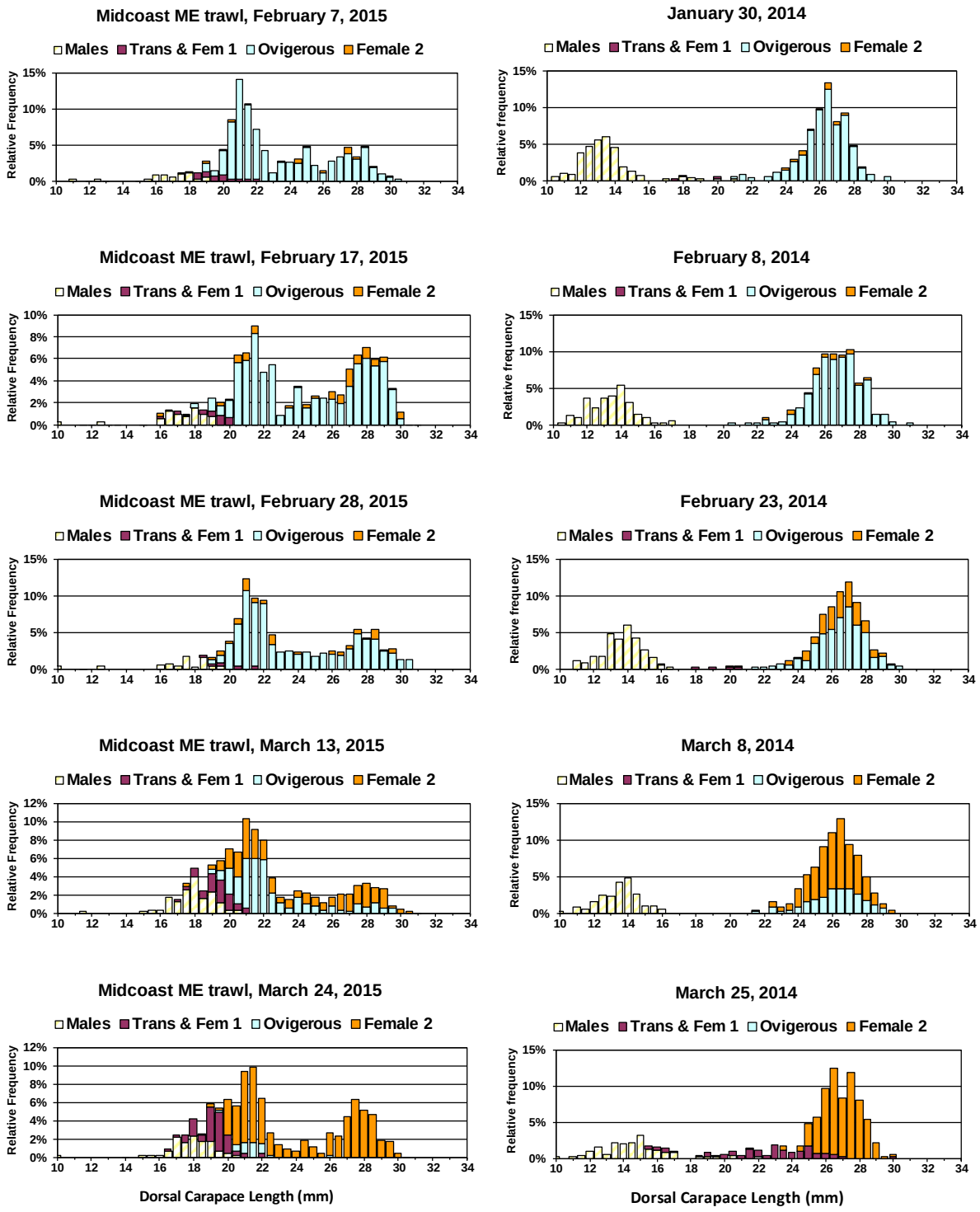


Figure 10. Northern shrimp size-sex-stage frequency distributions from 2015 Midcoast Maine (South Bristol, off Pemaquid Point) trawl samples (left) and 2014 Pemaquid Point trawl samples (right).

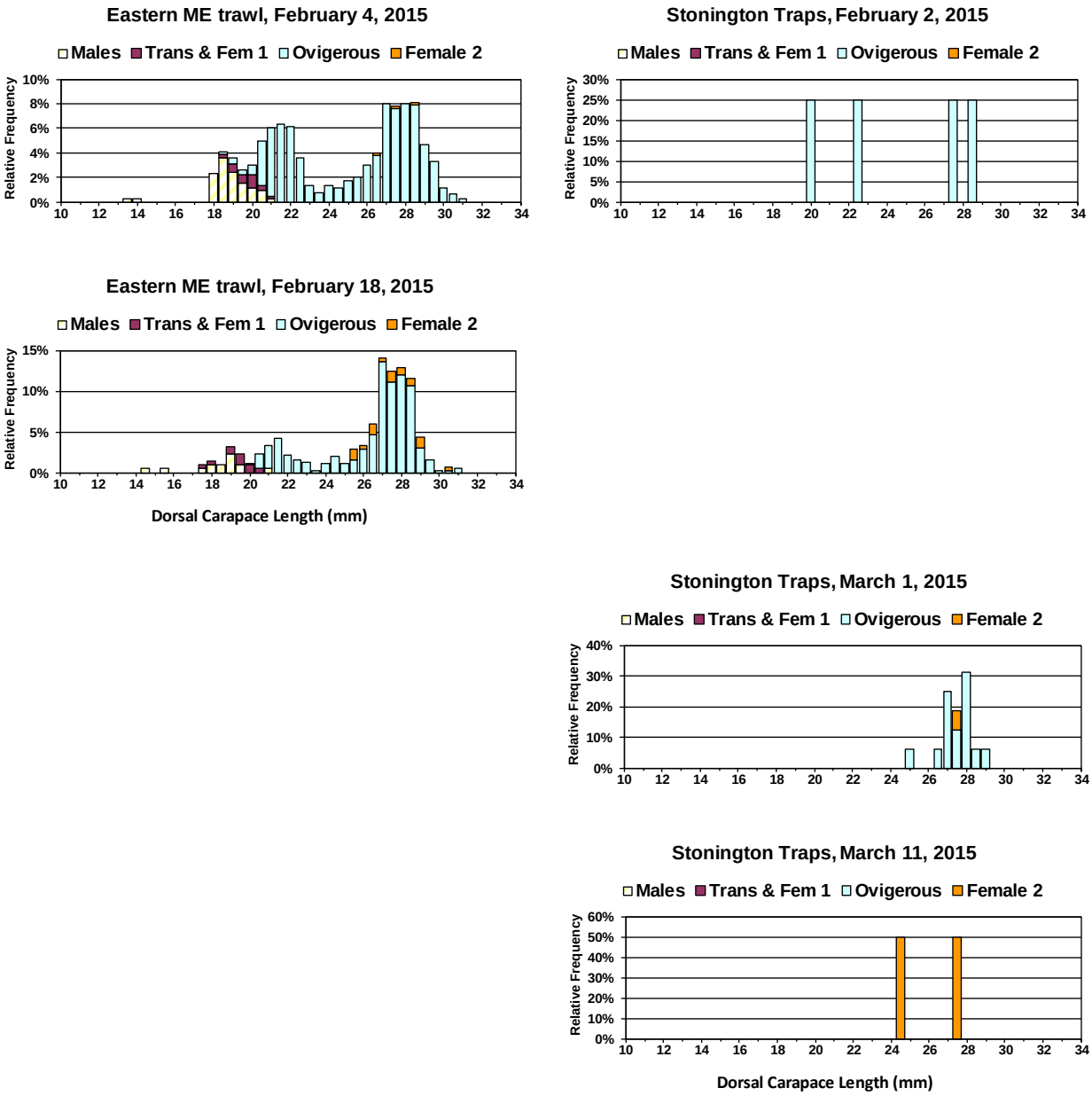


Figure 11. Northern shrimp relative size-sex-stage frequency distributions from Eastern Maine (Stonington) trawl samples (left) and trap samples (right).

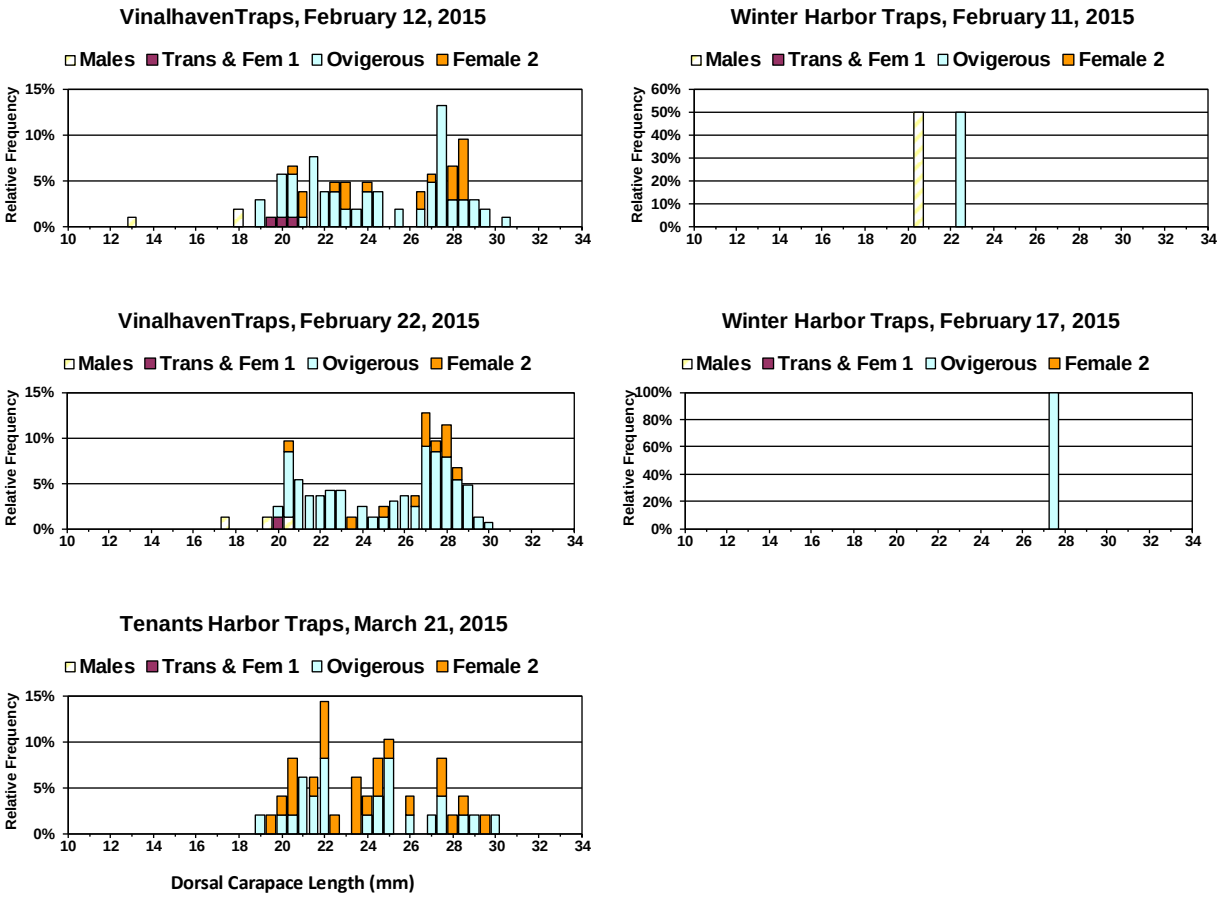


Figure 12. Northern shrimp relative size-sex-stage frequency distributions from other Maine trap samples, Vinalhaven and Tenants Harbor (left) and Winter Harbor (right).

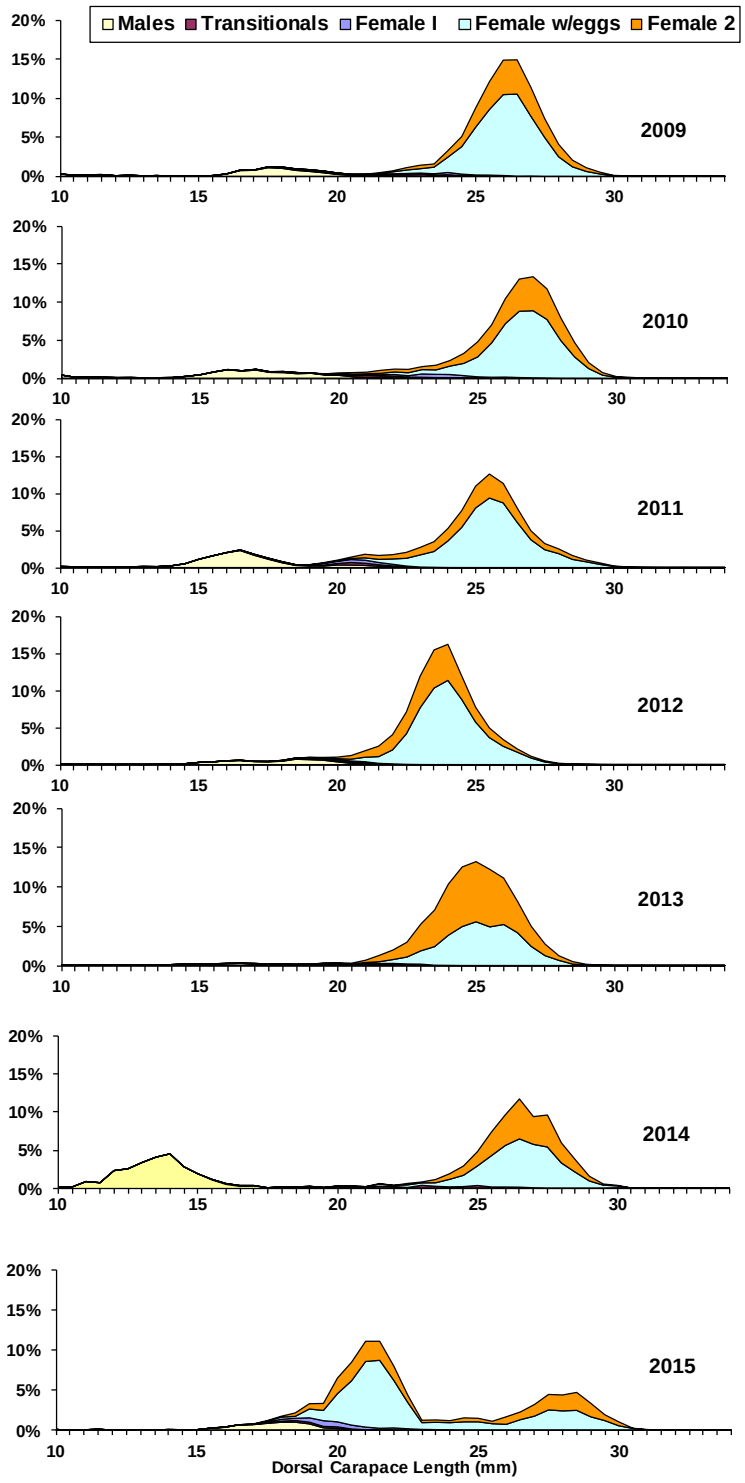


Figure 13. Northern shrimp relative size-sex-stage frequencies from winter sampling with data from 2009–2013 GOM fishery samples expanded to landings, modified from Whitmore et al. (2014); 2014 Pemaquid Point, Maine samples (Hunter 2014); and 2015 GOM winter samples expanded to sampled catches.

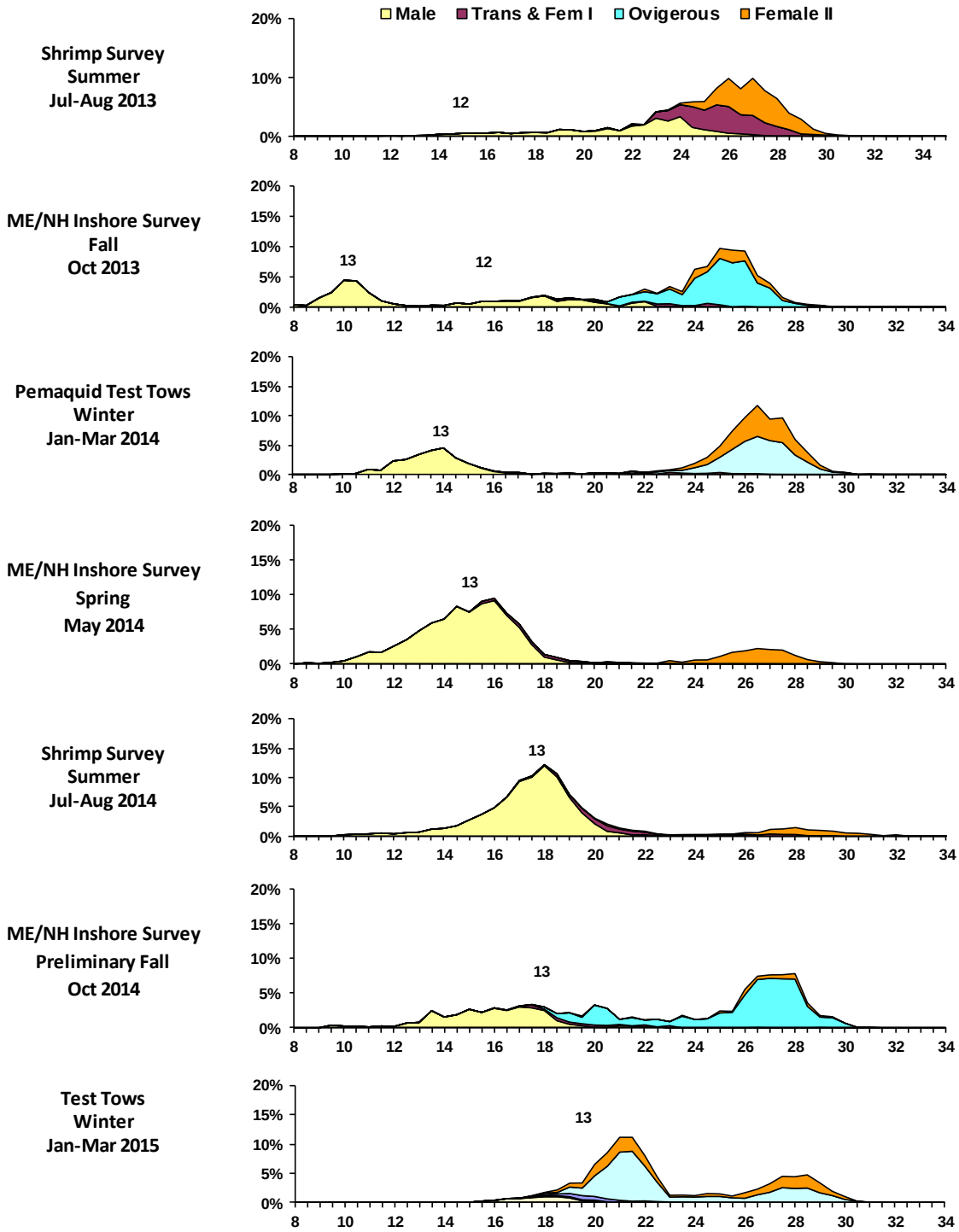
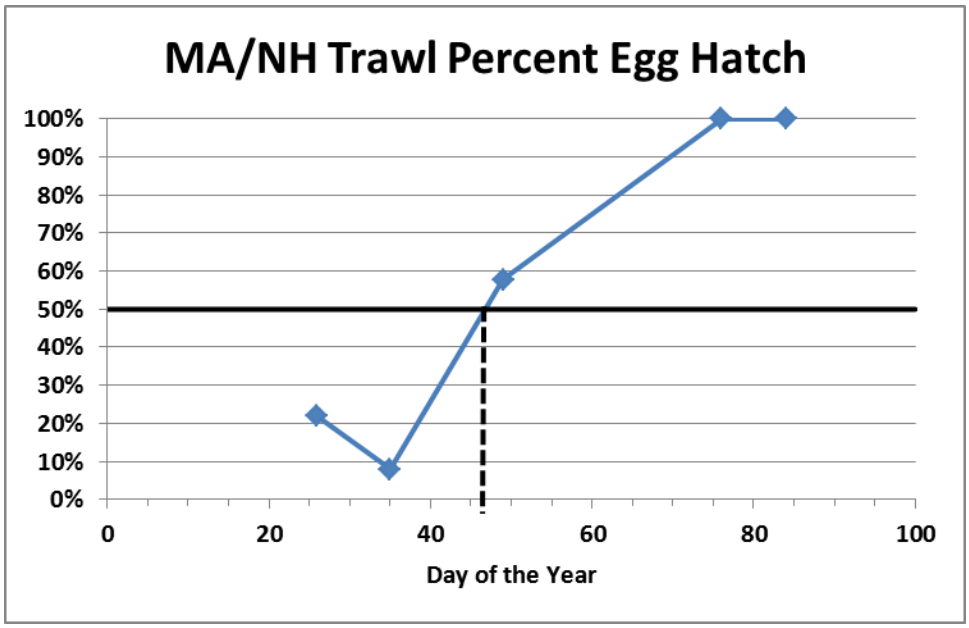


Figure 14. Northern shrimp relative size-sex-stage frequencies from 2013–2015 GOM surveys and sampling programs. Two-digit years denote the mode of assumed 2012 and 2013 year classes.



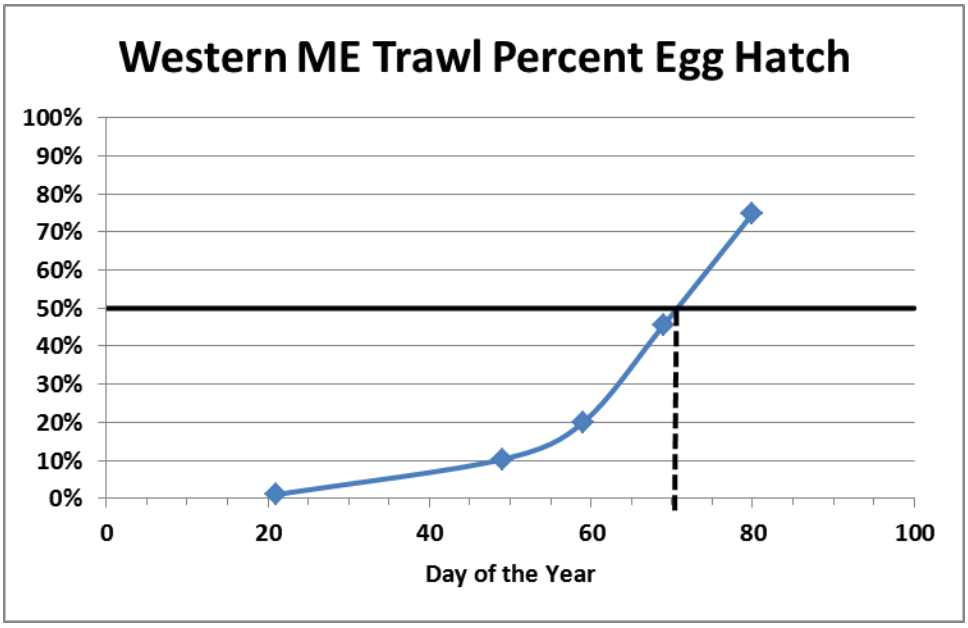
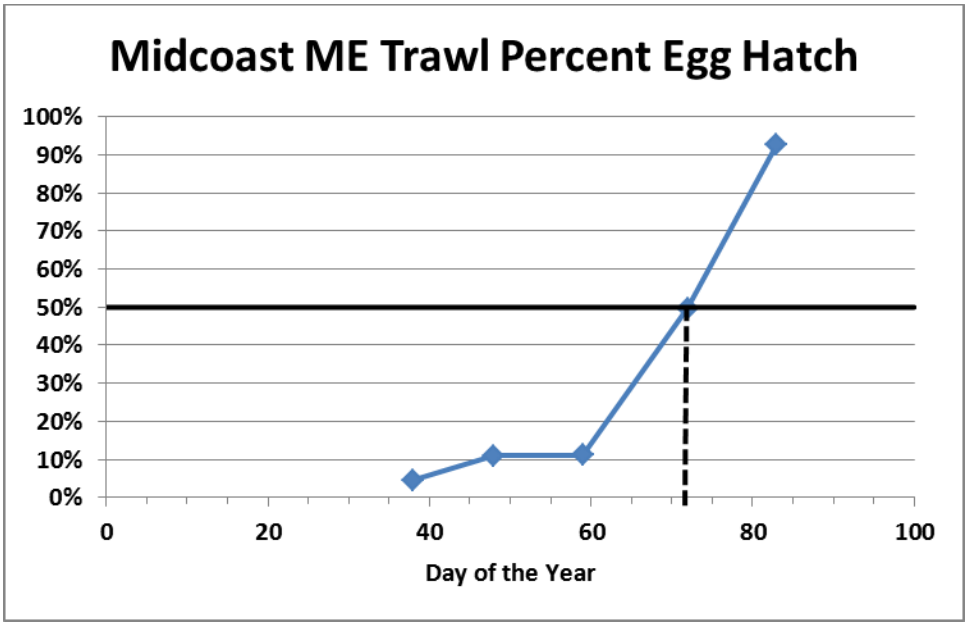


Figure 15. Mean percentage of egg hatch by day of the year (2015) for northern shrimp, for Massachusetts samples (above) and Western Maine samples (below). Dotted line indicates approximate day of 50% hatch.



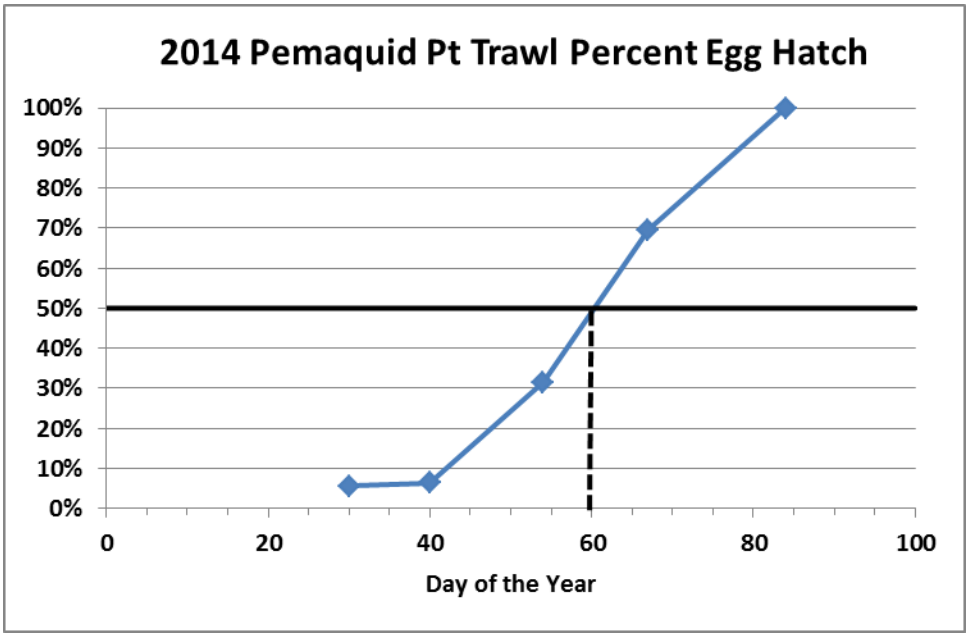
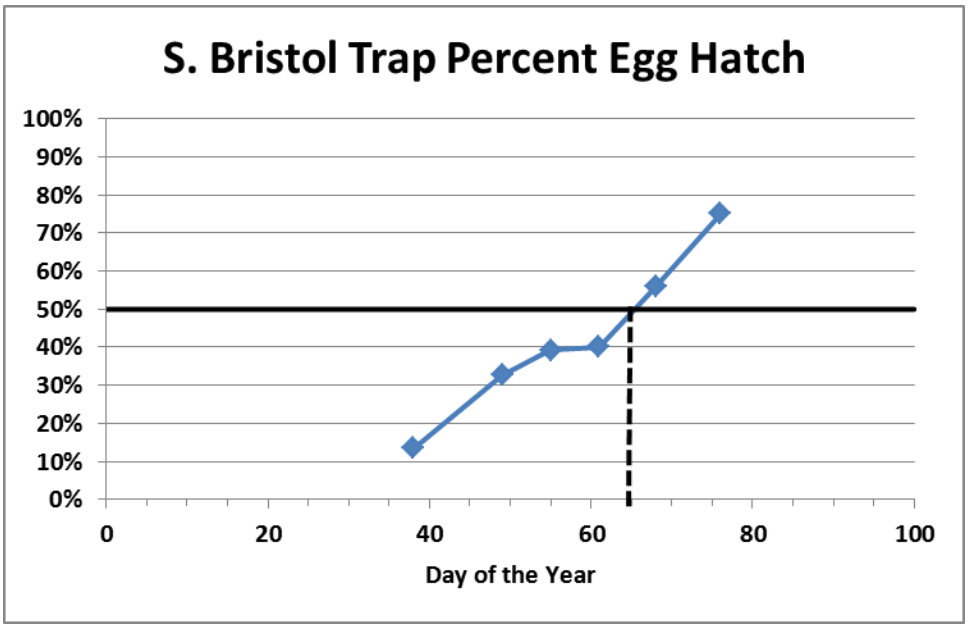


Figure 16. Mean percentage of egg hatch by day of the year for northern shrimp, for 2015 Midcoast Maine (Pemaquid Point, South Bristol) samples (above) and 2014 Pemaquid Point samples (below). Dotted line indicates approximate day of 50% hatch.



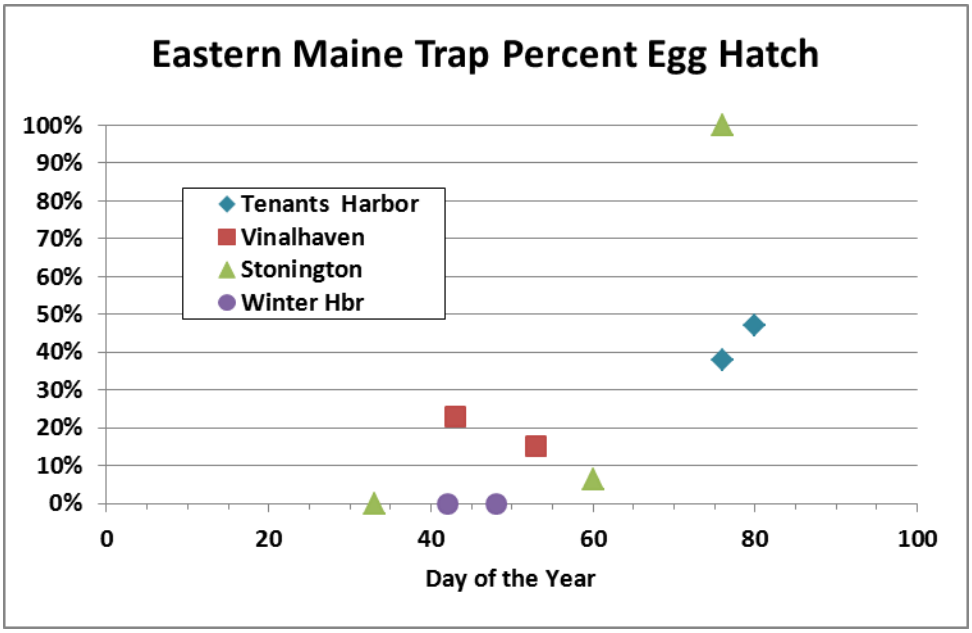


Figure 17. Mean percentage of egg hatch by day of the year (2015) for northern shrimp, for South Bristol trap samples (above) and other Maine trap samples (below, by port). Dotted line indicates approximate day of 50% hatch.

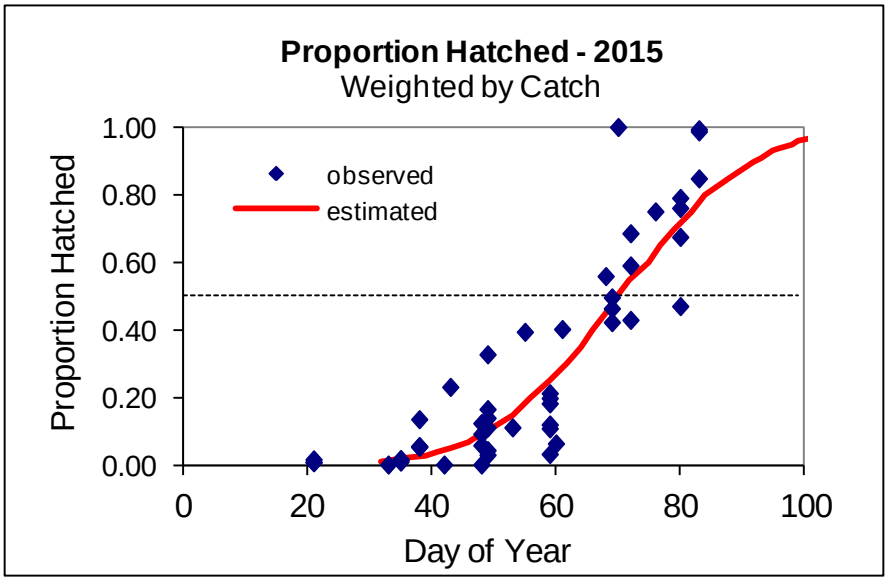


Figure 18. Proportion hatched over time in all Maine samples during 2015. Blue dots are observed proportions in samples; red line is fitted estimate from probit analysis.

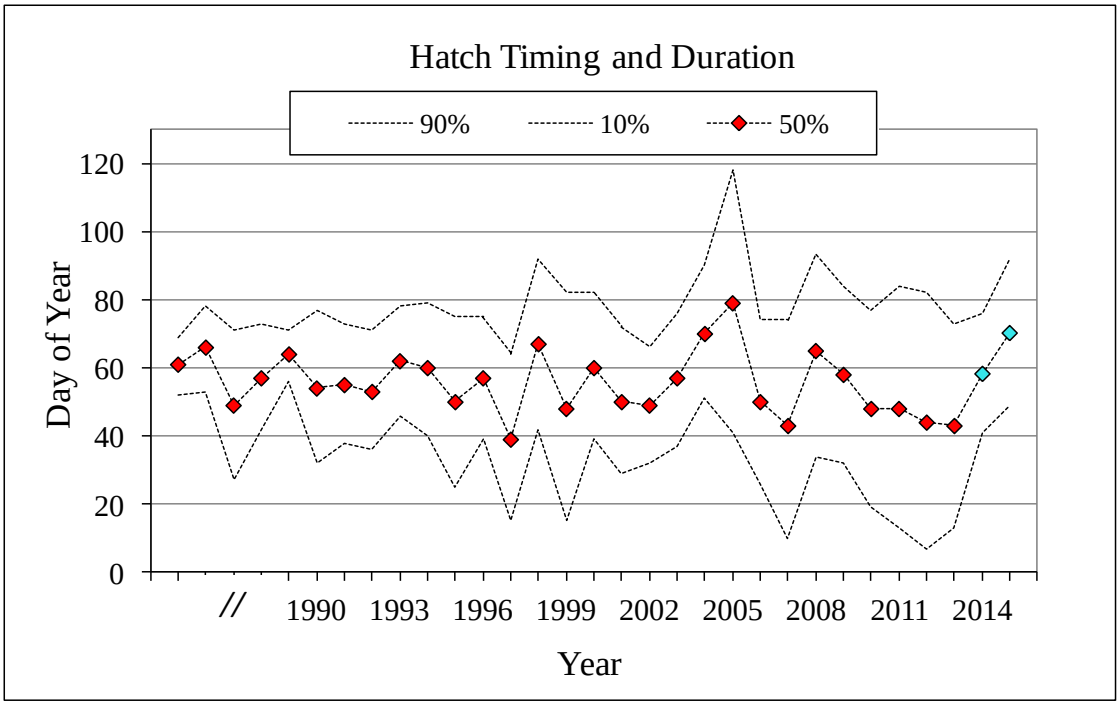


Figure 19. Time series of hatch timing estimates from sampling of the Maine commercial fishery (1980–1984, 1989–2013) and NSTC winter sampling in Maine (2014–2015).

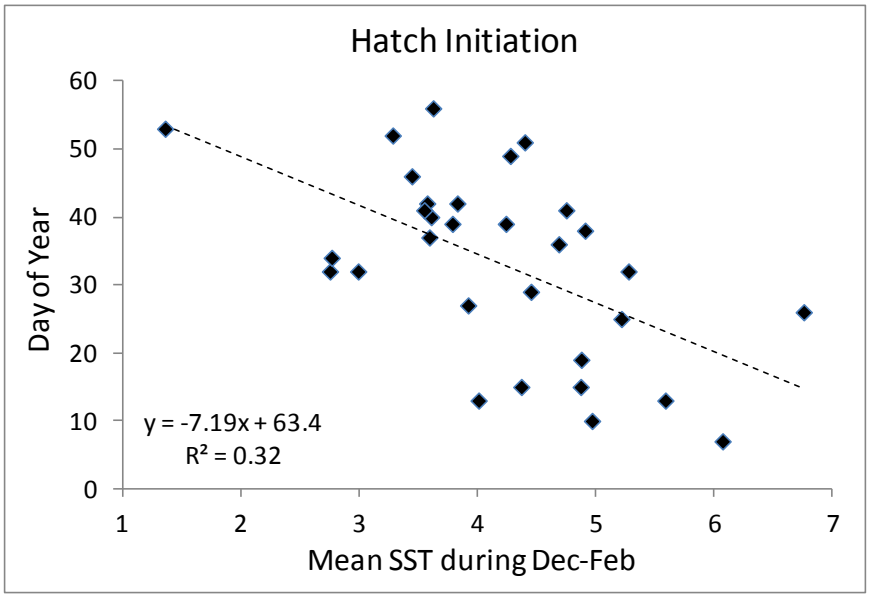


Figure 20. Relationship between average SST (°C measured at Boothbay Harbor) during December through February and initiation of the hatch period.

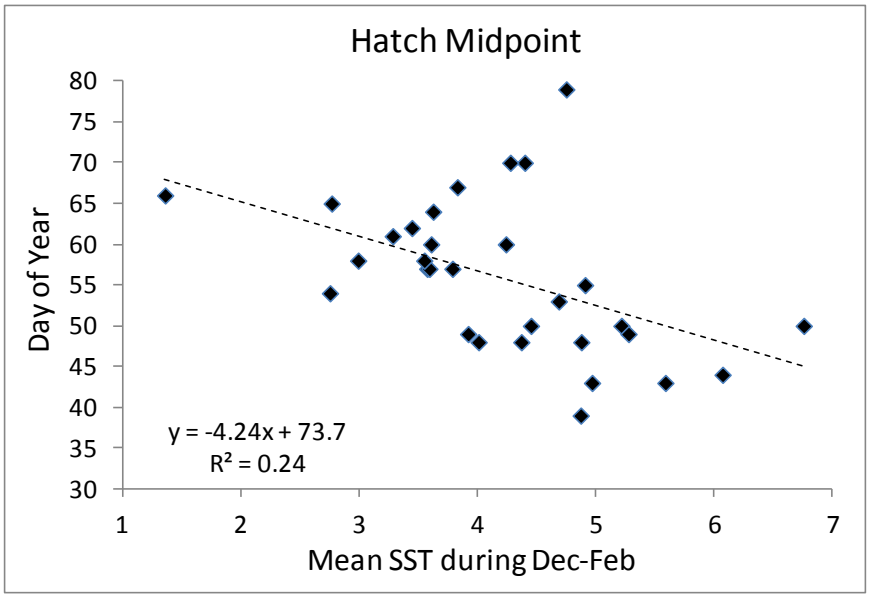


Figure 21. Relationship between average SST (°C measured at Boothbay Harbor) during December through February and timing of the hatch midpoint.

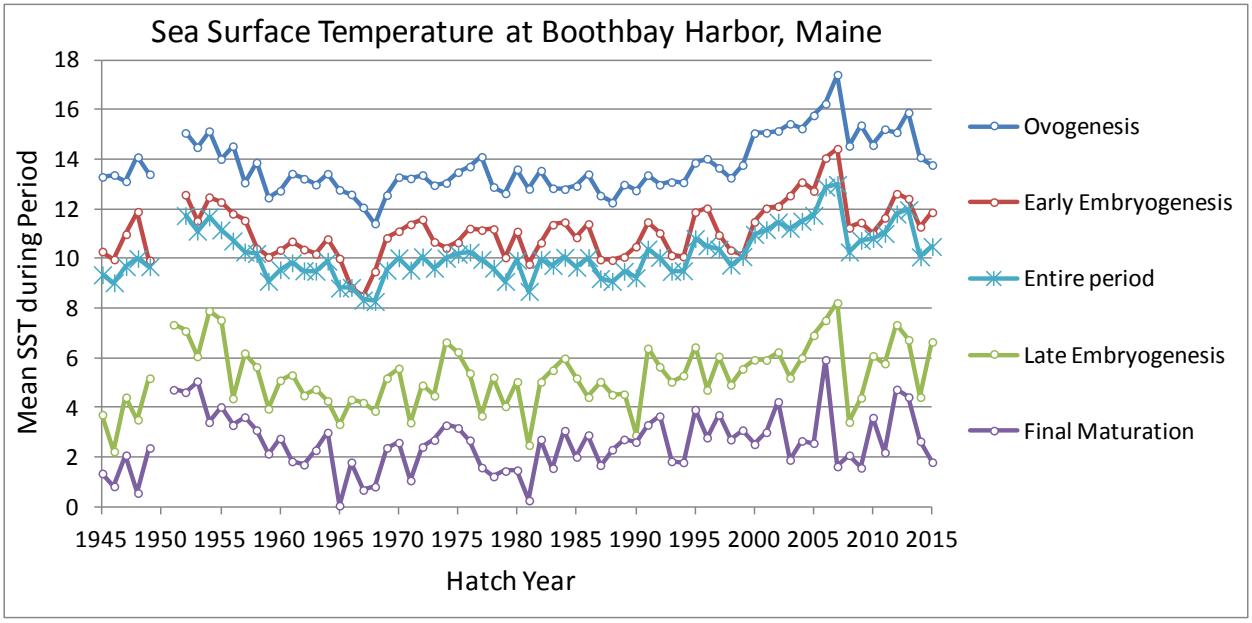


Figure 22. Sea surface temperature (°C) measured at Boothbay Harbor Maine during stages of the shrimp reproductive cycle, 1945–2015.