Abundance, Migration and Recruitment of Northern Shrimp in the Gulf of Maine: An Industry-Initiated Verification Survey and Environmental Monitoring Pilot Program

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ABSTRACT

Two essential information needs were addressed by this project. The first need was an evaluation of the effectiveness of the existing annual Gulf of Maine northern shrimp summer survey. The second was an understanding of what drives the inshore-offshore migration of female shrimp and the related timing and location of egg hatching and the ultimate chances for survival of the larvae. To address the first need, an industry-based survey was conducted at the same time as the summer state-federal research survey, using a stratified random design like the research survey (Clark, 1989), but with a higher sampling intensity. The *R/V Gloria Michelle* cruise successfully sampled 54 stations and the two industry cruises each successfully sampled 57 stations, for a total of 168 tows. The two industry cruise results were not significantly different from each other and may be combined to form a single survey. However, the state-federal research survey produced significantly higher biomass and abundance indices than did the industry survey.

Environmental and biological data were collected for two years to evaluate the timing of shrimp migration inshore; the different distributions and movements of ovigerous and post-hatch females and males; and the timing of hatching in relation to water temperature to address the second need. A total of 626 shrimp trawls were conducted using a combination of six fixed transect stations extending across the coastal shelf from nearshore to approximately the 160 m isobath and fishermen-selected stations. Hatching began earlier in 2002, probably because of the warmer water temperatures encountered on the shelf in fall and early winter. Interestingly, the hatching curve for 2002 progressively caught up with the curve for 2003, so while the curves differed by >30 d at 1% hatch, they differed by only 11 days at 50% hatch and only a few days at 90 and 99% hatch (Table II-3). In both areas and years, hatching was virtually completed by YD85 (March 26; Fig II-5). Although hatching began earlier in 2002, it did not begin while shrimp were farther offshore: the ovigerous females were already inshore when hatching commenced. Conversely, the earlier arrival of shrimp in 2003 did not result in earlier hatching, which may have been delayed by the colder water temperatures. Thus, despite different migration times and different hatching times, larvae were in both years released into the water at a similar distance offshore.

BACKGROUND

This project arose out of informal and formal discussions with members of the shrimp industry, scientists, and technical advisors to the shrimp management process. Many of the ideas presented here are also found in the Maine Department of Marine Resources research agenda that outlines the highest priority topics identified by industry, science, and management concerning the status and management of the northern shrimp resource (Alden and Perkins, 2001). Two essential information needs were addressed by this project. The first need was an evaluation of the effectiveness of the existing annual Gulf of Maine northern shrimp summer survey. The second was an understanding of what drives the inshore-offshore migration of female shrimp and the related timing and location of egg hatching and the ultimate chances for survival of the larvae. This final report includes an analysis of industry-based data collected during the summer of 2002 and environmental transect data collected from November 2002 through May 2003 and from November 2003 through June 2004 under two separate Northeast Consortium awards.

The Gulf of Maine fishery for northern shrimp (*Pandalus borealis*) has seen landings ranging from a high of 11,000 metric tons per year in the 1960's to a closure of the fishery in 1978. Over the last 22 years, the shrimp fishery has experienced occasional good year classes followed by a drop in landings until the next strong year class grows into the fishery. For example, the landings in 1996 topped 9,100 metric tons in response to comparatively strong year classes in 1992 and 1993. Landings subsequently declined. A brief rise in landings in 2000 resulted from the 1996 year class, but the fishing season was shortened due to poor stock conditions, and landings ultimately were not very good. Landings in 2001 were low and characterized by occasional catches of small, two-year-old shrimp mixed with larger shrimp. The two-year-old shrimp were from the 1999 year-class, which showed some improvement over the prior two cohorts.

The 2002 shrimp fishery was limited to only 25 days long starting February 15. Aside from a few good catches during the opening days as small concentrations of shrimp were targeted, the catch rate and the total catch were both very low. The two year-classes of females this year (1997 and 1998 year-classes) were among the smallest on record. Close to 25% of the 1999 year- class became primary females, skipping the (normally first) male stage and showing up as small females in the catch. This is unusual and probably a sign of stress in the population.

During the 2002 summer survey, a strong 2001 year-class was detected. A relatively high proportion of these were already maturing as females, unusually early. In a 38-day fishing season in 2003, the catch consisted of mostly 1999 year-class females and some of this 2001 year-class, and catch rates were moderate. In both the 2002 surveys and the 2003 fishery, the 2000 year-class was missing.

In the 2003 summer survey, abundances of all year-classes were disappointingly low, the 2001 year-class appeared to be only moderate, and there was speculation that a high incidence of black gill syndrome detected during the 2003 fishery had caused high mortality. This was refuted by higher abundances of the 2001 year-class detected during the 2004 survey. There is now speculation that unusually cold summer bottom water temperatures in inshore areas may be

related to shrimp possibly failing to return to offshore areas during the summer in 2003 where the survey is conducted. Catch rates in the 2004 fishery were high. Fishermen reported that the shrimp were already inshore when the 40-day fishery opened.

The 2005 survey showed the 2001 year-class stronger than ever, the 2002 year-class virtually missing (as it had been in the 2003 survey and the 2004 fishery), a much stronger 2003 year-class than had been seen in the previous survey, and a welcome, very strong 2004 year-class. In response to these improved stock conditions, the 2006 fishing season was increased from 70 days to 140 days. Catch rates in 2006 were very high but the total catch was low because of low harvester participation and poor market conditions. (From ASMFC northern shrimp stock assessments, available at www.asmfc.org/northernShrimp.htm).

Verification Survey for Abundance

The Gulf of Maine fishery for northern shrimp (*Pandalus borealis*) is managed under the Interstate Fishery Management Program of the Atlantic States Marine Fisheries Commission (ASMFC) through an interstate agreement among the states of Maine, New Hampshire, and Massachusetts. Within this structure, the Northern Shrimp Technical Committee provides annual stock assessments to the ASMFC Northern Shrimp Section for use in setting the management regime (mainly seasonal closures and mesh restrictions) for the next fishing season. A key component of the annual northern shrimp assessment is a fishery-independent survey conducted each summer in the offshore waters of the Gulf of Maine. This research vessel survey is conducted cooperatively by NMFS and the states of Maine, New Hampshire, and Massachusetts to monitor the relative abundance and demographics of northern shrimp. The survey has been conducted since 1983 on the *R/V Gloria Michelle* using a stratified random sampling design and trawl gear specifically designed for northern shrimp habitat in the Gulf of Maine. The state-federal survey is considered by stock assessment scientists to provide the most reliable information available on abundance and size structure of the northern shrimp. However, there is sometimes a discrepancy between the assessed status of the stock and the commercial catch in the following winter. This has raised questions about the survey methodology among industry members. Credibility in the management process, as well as an understanding of what drives the abundance of northern shrimp, requires that we establish greater confidence in these summer surveys.

The approval of Amendment #1 to the Fishery Management Plan for Northern Shrimp (ASMFC, 2004) provided the opportunity to develop new management options such as quota management for the fishery. A key component to implementing these options is a reliable estimate of stock biomass. The industry-based survey, with more temporal and spatial coverage and larger sampling size compared with the traditional summer survey, was viewed as necessary to improve the stock biomass estimate and provide an opportunity to evaluate the summer survey program. Have failures in prediction been due to faulty assessments or processes occurring after assessment? The industry-based survey was conducted to specifically address fishermen's concerns about effectiveness of the research vessel net deployment methods, the survey area coverage, timing of the survey, number of tows, and the effects of tidal currents on gear performance.

Environmental Monitoring for Migration and Recruitment:

In addition to verifying the relative abundance of northern shrimp, the need for information about environmental (oceanographic) parameters affecting shrimp movements was identified. As female shrimp migrate inshore to release their eggs, they become available to coastal fishing vessels for harvest. These in-shore vessels, which make up a large portion of the Gulf of Maine shrimp industry, are generally not equipped to venture further offshore for groundfish during the winter months. To date, the factors that control timing and extent of the inshore migration of female shrimp, timing of egg release, and larval survival have not been determined, although a relationship to temperature has been suggested (Apollonio et al, 1986). Female shrimp may come into 25 fathoms of water, or they may only come in as far as the 50 fathom isobath. They may aggregate into sizeable concentrations, or remain in smaller aggregations, and the timing of the migration may vary from December to February. This information comes primarily from monitoring the catch and interviewing captains for fishing location and effort. Prior monthly and seasonal sampling for the location of shrimp along the coast funded by NMFS Saltonstall-Kennedy program, the Maine Outdoor Heritage Fund and the Maine Fishing Industry Development Center corroborate the fishery interview information.

The northern shrimp fishery in the Gulf of Maine is primarily a winter fishery that has provided a valuable supplemental income to small- and medium-sized fishing vessels. However, the fluctuations in shrimp year-class strength and timing of the inshore migration of shrimp each year makes it difficult and frustrating for both fishermen and managers to plan. The Northern Shrimp Technical Committee has supported the need for more environmental monitoring to better understand the conditions that are favorable or unfavorable to shrimp migration and that influence aggregation patterns and the timing of the hatching of eggs and release of larvae. The current uncertainty as to what the rate of shrimp harvest will be impacts both the vessels at sea and the processing side of the fishery, where equipment needs to be set up and staff hired in order to process any appreciable volume of shrimp. The ability to predict the timing and extent of the inshore migration of shrimp is valuable information for managers as well coastal fishing communities in the Gulf of Maine. The project also contributed to other efforts to understand the mechanisms that determine the strength of the incoming year classes of shrimp.

PART I: *Verification Survey for Abundance*

Objectives

The objectives of this part of the project were to:

1) Develop an estimate of northern shrimp biomass in the Gulf of Maine; and
2) Evaluate the state-federal summer shrimp survey.

Methods

An industry-based survey was conducted at the same time as the summer state-federal research survey, using a stratified random design like the research survey (Clark, 1989), but with a higher sampling intensity. For both surveys, the western Gulf of Maine region was divided into 12

strata bounded by 68^0 0' W longitude to the east and the 50-fathom contour to the west, with the exception of the Massachusetts Bay-Stellwagen Bank areas where the survey region extends inshore to the 30-fathom contour (Figure 1a). The remaining area was divided into two principal depth zones, 50-100 fm and >100 fm. Stratification is based primarily on depth, latitude/longitude, and historical fishing patterns. Fifty to 60 stations were allocated to strata roughly in proportion to area and were assigned to specific locations within strata at random, with the provision that intensity was doubled in strata known to harbor large concentrations of shrimp. The industry-based survey used these same strata with a minimum of twice the number of tows.

The industry-based survey was carried out in conjunction with the summer research survey in late July-early August 2002, using a vessel of similar size and fishing power to the R/V *Gloria Michelle*, which is a 65-foot, 96 gross ton stern trawler powered by a 365 HP Caterpillar diesel. The net used in the research survey was a modified west coast 4-seam design that has been in use since 1983. The trawl was constructed of nylon twine (1 3/8-inch stretch mesh in the body of the trawl and 1-inch stretch mesh in the extension piece and cod end) with a 70-foot headrope and an 80-foot footrope. "Rockhopper" ground gear, consisting of rubber disks 9-14 inches in diameter, was used to permit sampling on rough bottom. The initial research plan was for two commercial vessels to use their own nets, take out the Nordmore grate and restrict their headrope spread through the use of restrictor cables. A cod end of the same mesh as the research survey net was to be used. Instead, the fishermen closely measured the research trawl in Woods Hole, MA and then constructed two nets that were identical in every way possible to that net except that the two industry nets had Nordmore grates installed to minimize the catch of fish.

The industry survey was originally designed to be conducted by two industry vessels. The design of the two industry cruises was made by Dr. Josef Idoine, NEFSC, in an identical fashion to the survey to be done by the *R/V Gloria Michelle*. A cruise plan was developed for each vessel so that the three vessels would be conducting their surveys in about the same locations at the same times in the Gulf of Maine. Scientific crew were recruited, organized and set to go on the same day as the *R/V Gloria Michelle*. Unfortunately, two nights before the three cruises were to get underway, one of the fishing vessels hit a ledge and sank just outside of Boothbay Harbor, ME. While no one was hurt, the vessel and the net that had been made for the survey were suddenly unavailable. The other industry vessel (*F/V Bad Penny*, 54 ft, 51 tons, 300 hp Volvo Penta engine) started its cruise on time and continued by conducting the second cruise as well, once the first cruise was completed, as no replacement vessel had been found. All three surveys were completed.

The industry-based survey followed the same protocols for sampling as the research survey (Clark, 1989) with one exception – see discussion of tow duration below. At each station, hydrographic data were recorded and the tow taken at a vessel speed of two knots. Sampling was confined to daylight hours to minimize variability due to diel changes in shrimp availability. Reference/hull surface temperatures and meteorological observations were recorded at each station. The Vemco minilogger for Windows Base stations was used to record bottom temperatures during the surveys. Northstar Technical Inc. Netmind Trawl Monitor System was utilized opportunistically on the research vessel survey when sea-state and weather permitted for

the length of the survey. Headrope height, wingspread and door spread of the trawl were recorded.

Catch weights in kilograms (kg) of pandalid shrimp, finfish species, and key invertebrate species (e.g., scallops) were recorded during all three surveys. A 2-kg sample of pandalid shrimp was retained to determine species composition and, for northern shrimp, length measurements and sex/spawning stage. All northern shrimp in the sample were measured (mid-dorsal carapace length to nearest 0.5 mm below) and determinations of sex made for a 1-kg subsample.

Tow duration for the state-federal survey was 15 minutes, but, because of miscommunication, for the industry cruises it was generally about 20 minutes. Tows were standardized to 15 minutes duration for the calculations of catch weight and abundance per tow (kg/tow, and number/tow respectively).

Statistical distributions of catch per tow from past shrimp research surveys are positively skewed, and arithmetic stratum means are correlated to stratum variances (Cadrin et al, 1999). Log-transformed catches are more normally distributed, and geometric means are estimated with more precision (Cadrin et al, 1999, and see data in Table 2), so a $\log_e$ (natural log) transformation was used on the shrimp catch weight and abundance data.

Mean catch weights (kg/tow) and abundances (number/tow), transformed and untransformed, were calculated for each cruise and for each stratum for each cruise, as well as stratified means. Results of the three cruises were compared using non-parametric statistics. An analysis to determine the minimum number of tows required was performed.

Data Analysis

The *R/V Gloria Michelle* cruise successfully sampled 54 stations and the two industry cruises each successfully sampled 57 stations, for a total of 168 tows. See Figure 1b and Table 1 for station dates and locations. The two industry cruises are referred to as “first” and “second”.

Unstratified, untransformed mean weight (kg) and number of *P. borealis* per tow, and $\log_e$-transformed mean weight (kg) and number of *P. borealis* per tow, and other basic statistics for each cruise are listed in Table 2. The unstratified, untransformed mean weight for the state-federal cruise was 20.4 kg/tow (Table 3). The mean weights for the first and second industry cruises were 7.5 and 9.1 kg/tow, respectively. The unstratified, untransformed mean abundance for the state-federal cruise was 4,181 shrimp/tow. The mean abundance for the first and second industry cruises were 1,520 shrimp/tow and 1,845shrimp/tow, respectively.

A Kruskal-Wallis single factor analysis of variance by ranks test (Zar, 1999) was performed on the unstratified ranked data to test whether the catch weights from the three cruises (Table 2) were significantly different. The resulting test statistic H=525.0 was highly significant (p<0.001). The same test performed on the ranked abundances (Table 2) gave almost identical results (H=524.1, p<0.001). There were highly significant difference(s) among the three cruises.

Dunn's non-parametric multiple comparison test (Zar, 1999) was performed to identify cruise differences among the ranked unstratified catch weights. The state-federal catch weights were highly significantly different from both the first (Q=4.00, p< 0.001) and second (Q=3.45, 0.001< p< 0.002) industry cruises. The first and second industry cruise catch weights were not significantly different from each other (Q=0.55, 0.5 < p). The same test performed on the ranked abundances (Table 2) gave almost identical results.

Size-frequency distributions of northern shrimp, expanded to total catch at size for each tow, and summed over all tows standardized to 15 minutes, were developed for each of the three cruises (Figure 2). All three cruises show a peak between 15-18 mm carapace length, representing an exceptionally strong 2001 year class, and another, smaller mode at 24-26 mm, probably the moderate 1999 year class. A lack of shrimp in the 19-23 mm and 26mm+ sizes likely indicates very weak 2000 and weak 1998 year classes respectively. The size distributions for the three cruises are not discernibly different from each other, except for an overall higher abundance for the state-federal research cruise.

Mean weights and abundances for each cruise, by stratum, are presented in Table 4 and Figure 3. Weights and abundances were generally highest in strata 1, 3, 6, and 8, which were also the strata sampled most heavily, as intended.

Indices for total biomass and abundance within the survey area, which can serve as total biomass and abundance proxies, can be calculated by weighting the stratum $\log_e$-transformed means (Table 4) by the stratum area (Table 3). These indices were calculated for each cruise and are listed in Table 4. The stratified, retransformed biomass index for the state-federal cruise was 8.52 kg/tow. The biomass indices for the first and second industry cruises were 3.75 and 4.21 kg/tow, respectively. The stratified, retransformed abundance index for the state-federal cruise was 1,384 shrimp/tow. The abundance indices were 597shrimp/tow for the first and 609shrimp/tow for the second industry cruises.

To determine a sufficient sample size (n=number of tows) for a random design survey, the tow data for the two industry cruises (from Table 1 b and c) were combined. The unstratified mean $\log_e$-transformed catch weight was calculated to be 1.808 (n=114, SD=0.96). Assuming that $\log_e$-transformed catch weights (kg/tow) are normally distributed, the required sample size, to estimate the mean to within ± d with a confidence of 1-α, can be estimated as

$$n = \frac{s^2 t^2_{a(2),(n-1)}}{d^2}$$

The solution for n was achieved by iteration (Zar 1999) using a starting value of n=1000, α=0.05 throughout, and a range of values of d. Results are displayed in Figure 4, with d expressed as a percentage of the mean. To estimate the $\log_e$-transformed catch weight within ± 10% with a confidence of 95%, a minimum of 111 tows would be required. The same calculations were performed for $\log_e$-transformed catch abundances (number/tow) (Figure 4). To estimate the $\log_e$-transformed abundance within ± 10% with a confidence of 95%, a minimum of 20 tows would be required. The minimum number of tows required to estimate non-transformed means with the same precision and confidence were much higher (402 for untransformed weights and 384 for untransformed abundances). To estimate the $\log_e$-transformed catch weight within ± 20%

with a confidence of 95%, a minimum of 51 tows would be required. To estimate the $\log_e$-transformed abundance within ± 20% with a confidence of 95%, a minimum of 10 tows would be required.

This analysis was also repeated using the state-federal research cruise data. A minimum of 71 tows would be required to estimate the $\log_e$-transformed catch weight within ± 10% with a confidence of 95%. To estimate the $\log_e$-transformed abundance within ± 10% with a confidence of 95%, a minimum of 16 tows would be required. A minimum of 33 tows would be required to estimate the $\log_e$-transformed catch weight within ± 20% with a confidence of 95%. To estimate the $\log_e$-transformed abundance within ± 20% with a confidence of 95%, a minimum of 8 tows would be required. These results are lower than those from the industry survey above, probably because there was greater variability in the industry survey, as evidenced by higher CVs in Table 2.

Note that these analyses are appropriate for a non-stratified design. The determination of a suitable minimum sample size for a stratified design will require further investigation.

Results and Discussion

The two industry cruise results were not significantly different from each other and may be combined to form a single survey. This is not surprising, since they were conducted by the same vessel and gear, but it is encouraging to find that two cruises, each with about 57 stations and 20-minute tows, using a gear configuration similar to the research vessel, conducted during various weather and tidal conditions, gave similar, consistent results. It is also encouraging to note that performing the second industry cruise about 16 days later than the first did not cause detectable differences between the two cruises.

However, the state-federal research survey produced significantly higher biomass and abundance indices than did the industry survey (Table 3). The most likely reasons for this were suggested by the captain of the second industry cruise, who was also aboard the state-federal cruise the following year (2003). He noted that the gear was set and hauled much more slowly on the *Gloria Michelle* than on the industry vessel. He suggested that the net was actually fishing (on bottom) much longer than the 15-minute tow time would indicate. To confirm this, we looked at inclinometer data from the 2002 research survey, and found that the net appeared to be on bottom for an average of 28 minutes per tow. As long as the setting and hauling procedures are standardized for the research cruises, this is not a problem for the research survey data. However, it does create a problem for comparing data from different vessels using different protocols. Unfortunately, inclinometer data are not available for the industry vessel tows to determine actual fishing time.

A second possibility was also suggested by the industry captain, who thought that flatfish might occasionally be plugging the Nordmore grate, the finfish separator used on the industry gear but not the research gear. This might account for both the lower abundances, and the higher CVs in the industry data. Few flatfish were retained by the gear in earlier Nordmore grate trials (Kenny et al, 1992), but it is possible they could stay on the grate for awhile, affecting shrimp retention, before leaving the net (Lessie White from video observations, personal communication).

However, Kenny et al (1992) report that the grate does not affect shrimp retention. Further work on these issues is required before the data from the two surveys can be compared or combined.

The industry survey and the state-federal survey agreed well on the relative spatial distribution of the stock, that is, shrimp weights and abundances were highest in strata 1, 3, 6, and 8. and lowest in 4, 5, and 7, in all surveys. The surveys also agreed well in shrimp size composition. This would suggest that the industry surveys confirmed the findings of the state-federal survey for those items which could be compared.

Table 1a. Station dates, locations, and northern shrimp catches for the state-federal research survey aboard the *R/V Gloria Michelle*.

										Pandalus borealis			
										Weight*		Abundance*	
Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Bot Temp (ºC)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	kg/tow	$\log_e$(kg/tow+1)	no/tow	$\log_e$(no/tow+1)
4	3	F	15	138	6.4	42º 6.55"	69º 52.38"	42º 6.99"	69º 52.77"	0.7	0.53	218	5.39
5	4	F	15	211		42º 47.14"	69º 37.25"	42º 47.20"	69º 36.73"	7.7	2.16	1,435	7.27
5	3	R	15	263		42º 42.49"	69º 34.79"	42º 42.80"	69º 34.57"	2.9	1.36	504	6.22
6	1	R	15	142		42º 49.18"	69º 14.71"	42º 49.57"	69º 15.04"	14.3	2.73	3,385	8.13
7	5	F	15	183		42º 38.25"	69º 12.30"	42º 38.64"	69º 11.95"	4.9	1.77	741	6.61
6	2	R	15	148	7.1	42º 43.44"	69º 6.35"	42º 43.05"	69º 6.65"	11.7	2.54	2,515	7.83
6	3	R	15	166	7.3	42º 46.49"	69º 3.46"	42º 46.10"	69º 3.70"	17.0	2.89	3,418	8.14
6	4	R	15	132	7.0	42º 54.41"	69º 0.00"	42º 53.98"	69º 0.00"	27.0	3.33	6,146	8.72
8	6	F	15	177	8.1	42º 58.86"	68º 49.95"	42º 58.43"	68º 50.45"	13.2	2.65	2,394	7.78
8	8	R	15	208	8.3	42º 55.02"	68º 44.29"	42º 55.42"	68º 44.42"	4.0	1.61	793	6.68
8	2	R	15	183	7.8	43º 5.58"	68º 40.85"	43º 5.18"	68º 41.06"	11.6	2.53	2,418	7.79
6	7	R	15	121	6.7	43º 3.54"	69º 1.07"	43º 3.51"	69º 0.39"	5.7	1.90	1,816	7.50
8	5	R	15	161	7.4	43º 7.63"	69º 0.00"	43º 7.46"	69º 0.00"	21.7	3.12	3,188	8.07
8	1	R	15	170	7.8	43º 11.28"	68º 54.33"	43º 11.21"	68º 54.98"	26.2	3.30	5,844	8.67
8	4	R	15	147	7.1	43º 18.01"	68º 58.56"	43º 17.57"	68º 58.58"	12.9	2.63	2,798	7.94
8	3	R	15	153	7.3	43º 36.43"	68º 42.40"	43º 35.93"	68º 42.43"	23.8	3.21	6,579	8.79
8	7	R	15	134	7.3	43º 39.12"	68º 38.82"	43º 39.63"	68º 38.79"	8.2	2.22	1,438	7.27
6	8	R	15	127	6.4	43º 30.62"	69º 7.16"	43º 30.81"	69º 6.58"	20.3	3.06	3,876	8.26
6	9	R	15	147	6.2	43º 28.18"	69º 13.61"	43º 28.58"	69º 13.18"	34.0	3.56	8,719	9.07
3	5	R	15	127	6.4	43º 40.58"	69º 31.23"	43º 40.21"	69º 31.55"	14.8	2.76	4,098	8.32
3	2	R	15	157	6.1	43º 33.30"	69º 36.38"	43º 32.97"	69º 36.34"	33.3	3.54	8,168	9.01
3	8	R	15	165	6.1	43º 28.68"	69º 32.11"	43º 29.12"	69º 32.46"	15.5	2.80	3,239	8.08
6	10	R	15	165	6.5	43º 22.94"	69º 24.45"	43º 23.01"	69º 25.13"	16.7	2.87	3,555	8.18
6	11	F	15	176	7.0	43º 20.15"	69º 21.17"	43º 20.20"	69º 22.42"	18.5	2.97	3,731	8.22
6	5	R	15	157	6.7	43º 19.97"	69º 16.01"	43º 20.46"	69º 16.08"	47.3	3.88	12,580	9.44
6	6	R	15	165	7.0	43º 6.42"	69º 26.52"	43º 5.96"	69º 26.76"	20.0	3.04	4,013	8.30
3	6	R	15	163	7.0	43º 11.27"	69º 46.56"	43º 11.80"	69º 46.63"	27.6	3.35	5,939	8.69
3	1	R	15	166	6.7	43º 18.99"	69º 42.99"	43º 18.55"	69º 42.76"	15.3	2.79	2,738	7.92
3	3	R	15	158	6.7	43º 22.64"	69º 47.01"	43º 22.93"	69º 46.50"	22.8	3.17	5,346	8.58
3	11	F	15	154	6.4	43º 20.97"	69º 56.17"	43º 20.52"	69º 55.89"	55.1	4.03	11,570	9.36
3	9	R	15	174	7.0	43º 19.44"	69º 49.36"	43º 19.43"	69º 49.98"	20.1	3.05	4,155	8.33

Table 1a continued.

Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Bot Temp (ºC)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	*Pandalus borealis* Weight* kg/tow	Weight* $\log_e$(kg/tow+1)	Abundance* no/tow	Abundance* $\log_e$(no/tow+1)
3	10	F	15	163	6.8	43º 5.25"	69º 46.83"	43º 4.82"	69º 46.44"	43.1	3.79	10,742	9.28
3	4	R	15	175	7.3	43º 7.41"	69º 52.49"	43º 7.81"	69º 51.93"	16.0	2.83	3,275	8.09
3	7	R	15	167	7.3	43º 4.91"	69º 58.33"	43º 5.13"	69º 57.85"	9.7	2.37	2,123	7.66
1	2	R	15	162	5.5	42º 58.61"	70º 13.12"	42º 58.92"	70º 13.61"	64.2	4.18	10,776	9.29
1	1	R	15	144	5.9	43º 5.88"	70º 15.38"	43º 5.44"	70º 15.79"	38.6	3.68	5,246	8.57
1	4	R	15	129	5.8	43º 6.55"	70º 19.11"	43º 6.92"	70º 18.72"	24.2	3.23	3,924	8.28
1	3	R	15	108	5.9	43º 1.54"	70º 24.38"	43º 1.92"	70º 23.95"	12.3	2.59	3,215	8.08
1	7	F	15	155	5.5	42º 58.39"	70º 15.13"	42º 57.94"	70º 14.91"	91.7	4.53	15,322	9.64
1	8	F	15	117	5.5	42º 52.54"	70º 27.94"	42º 53.00"	70º 27.90"	54.5	4.02	8,904	9.09
1	6	R	15	135	5.5	42º 50.15"	70º 23.92"			79.8	4.39	17,324	9.76
1	5	R	15	118	5.3	42º 48.93"	70º 28.07"	42º 48.63"	70º 27.61"	59.1	4.10	11,290	9.33
2	2	F	15	91	5.8	42º 23.84"	70º 29.69"	42º 24.11"	70º 30.20"	3.9	1.59	455	6.12
2	1	F	15	98	6.5	42º 31.59"	70º 25.06"	42º 31.14"	70º 25.12"	7.9	2.19	2,055	7.63
4	1	R	15	105	6.3	42º 39.62"	70º 8.10"	42º 39.48"	70º 8.79"	0.2	0.18	64	4.17
4	2	F	15	203	7.3	42º 38.01"	69º 58.13"	42º 37.63"	69º 58.00"	5.8	1.92	1,224	7.11
5	2	F	15	230	7.7	42º 21.22"	69º 50.75"	42º 21.64"	69º 50.75"	0.8	0.59	146	4.99
7	2	R	15	233	7.8	42º 19.04"	69º 13.36"	42º 18.96"	69º 12.83"	1.8	1.03	218	5.39
7	4	R	15	226	8.0	42º 23.93"	69º 8.23"	42º 23.50"	69º 8.43"	3.9	1.59	422	6.05
7	6	F	15	211	7.7	42º 25.93"	69º 2.70"	42º 25.55"	69º 2.97"	0.9	0.64	108	4.69
7	1	R	15	197	7.1	42º 11.52"	69º 20.56"	42º 11.99"	69º 20.32"	5.8	1.92	767	6.64
7	3	R	15	209	7.3	41º 59.06"	69º 22.61"	41º 59.53"	69º 22.51"	2.8	1.34	348	5.86
5	1	R	15	193	7.0	41º 51.80"	69º 36.95"	41º 52.08"	69º 36.53"	0.3	0.26	37	3.64
12	1	R	15	158	6.7	41º 59.85"	69º 44.85"	42º 0.28"	69º 45.12"	1.7	0.99	433	6.07

*Tows are standardized to 15 minutes duration for the calculations of weight and abundance.

Table 1b. Station dates, locations, and northern shrimp catches for the first industry cruise aboard the *F/V Bad Penny*, July 23 – August 2, 2006.

											Pandalus borealis			
											Weight*		Abundance*	
Date	Station	Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	kg/tow	$\log_e$(kg/tow+1)	no/tow	$\log_e$(no/tow+1)
7/23/2002	1	5	3	F	22	185	42º 21.09"	69º 53.08"	42º 20.79"	69º 52.58"	0.8	0.58	151	5.03
7/23/2002	2	4	4	F	23	186	42º 36.88"	69º 57.51"	42º 37.58"	69º 57.81"	1.0	0.72	226	5.43
7/23/2002	3	4	1	R	20	187	42º 41.41"	69º 59.41"	42º 41.34"	69º 58.48"	0.6	0.47	118	4.78
7/23/2002	4	5	4	R	24	208	42º 53.67"	69º 44.57"	42º 54.31"	69º 44.13"	1.0	0.69	149	5.01
7/24/2002	5	5	5	F	20	224	42º 47.53"	69º 39.29"	42º 47.46"	69º 38.35"	3.8	1.56	561	6.33
7/24/2002	6	5	1	R	21	198	42º 44.92"	69º 31.14"	42º 44.18"	69º 31.59"	5.0	1.79	727	6.59
7/24/2002	7	5	2	R	21	251	42º 42.33"	69º 32.30"	42º 41.45"	69º 32.63"	0.6	0.49	93	4.54
7/24/2002	8	7	5	F	20	216	42º 38.23"	69º 16.36"	42º 39.05"	69º 15.88"	1.4	0.88	212	5.36
7/24/2002	9	4	6	R	21	166	42º 40.71"	69º 13.24"	42º 40.84"	69º 12.73"	4.1	1.63	1,008	6.92
7/24/2002	10	7	8	R	20	163	42º 46.87"	69º 7.84"	42º 46.53"	69º 7.26"	11.4	2.52	2,410	7.79
7/25/2002	11	8	3	R	21	187	42º 43.75"	68º 46.75"	42º 43.72"	68º 46.46"	2.7	1.32	346	5.85
7/25/2002	12	8	4	R	20	176	42º 46.65"	68º 50.34"	42º 45.31"	68º 47.44"	3.8	1.56	552	6.32
7/25/2002	13	8	8	F	20	169	42º 58.99"	68º 50.95"	43º 0.04"	68º 51.37"	3.1	1.40	334	5.81
7/25/2002	14	8	5	R	20	185	43º 1.68"	68º 51.05"	43º 2.57"	68º 51.76"	3.5	1.50	639	6.46
7/25/2002	15	6	11	R	20	185	43º 8.42"	69º 8.02"	43º 9.14"	69º 8.02"	3.8	1.57	655	6.49
7/25/2002	16	6	5	R	20	198	43º 9.61"	69º 8.21"	43º 10.42"	69º 8.67"	1.1	0.75	158	5.07
7/25/2002	17	6	7	R	20	172	43º 15.77"	69º 15.43"	43º 16.66"	69º 15.62"	4.4	1.69	911	6.82
7/25/2002	18	6	12	F	20	172	43º 19.47"	69º 21.07"	43º 20.55"	69º 21.37"	8.5	2.25	1,718	7.45
7/26/2002	19	6	10	R	20	171	43º 23.75"	69º 22.77"	43º 24.10"	68º 22.66"	9.0	2.30	2,107	7.65
7/26/2002	20	3	5	R	20	176	43º 22.81"	69º 34.77"	43º 23.09"	69º 36.02"	9.9	2.38	2,382	7.78
7/26/2002	21	3	2	R	20	140	43º 34.77"	69º 31.29"	43º 35.84"	69º 30.94"	11.5	2.53	3,168	8.06
7/26/2002	22	3	9	R	22	114	43º 35.09"	69º 36.50"	43º 35.78"	69º 37.65"	13.3	2.66	4,012	8.30
7/27/2002	23	1	5	R	20	178	43º 24.33"	70º 2.32"	43º 23.90"	70º 3.04"	2.0	1.09	424	6.05
7/27/2002	24	3	11	F	24	165	43º 21.35"	69º 59.19"	43º 20.18"	69º 58.74"	18.2	2.95	3,981	8.29
7/27/2002	25	3	3	R	20	160	43º 15.17"	69º 54.95"	43º 14.58"	69º 54.06"	13.4	2.67	2,992	8.00
7/27/2002	26	3	4	R	20	186	43º 17.98"	69º 50.45"	43º 18.76"	69º 49.90"	4.7	1.75	1,410	7.25
7/27/2002	27	3	6	R	20	166	43º 14.86"	69º 33.73"	43º 15.82"	69º 33.27"	8.3	2.23	1,301	7.17
7/27/2002	28	3	1	R	20	133	43º 10.81"	69º 33.94"	43º 11.54"	69º 33.26"	3.5	1.50	892	6.79
7/27/2002	29	3	7	R	20	110	43º 4.98"	69º 38.92"	43º 5.07"	68º 39.85"	0.8	0.60	188	5.24
7/27/2002	30	6	4	R	20	176	43º 1.70"	69º 11.62"	43º 2.33"	69º 12.49"	7.8	2.18	1,411	7.25

Table 1b continued.

Date	Station	Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	*Pandalus borealis* Weight* kg/tow	Weight* $\log_e$(kg/tow+1)	Abundance* no/tow	Abundance* $\log_e$(no/tow+1)
7/28/2002	31	6	1	R	20	176	42º 57.13"	69º 22.40"	42º 57.49"	69º 23.58"	6.7	2.04	1,411	7.25
7/28/2002	32	6	9	R	20	176	43º 0.53"	69º 25.50"	43º 1.31"	69º 24.93"	3.6	1.52	686	6.53
7/28/2002	33	3	8	R	20	131	43º 3.20"	69º 42.52"	43º 3.77"	69º 41.71"	0.5	0.37	141	4.96
7/28/2002	34	3	10	F	20	163					14.5	2.74	3,841	8.25
7/28/2002	35	1	2	R	20	170	43º 1.26"	70º 8.88"	43º 2.06"	70º 9.95"	16.1	2.84	3,873	8.26
7/28/2002	36	1	4	R	20	188	42º 58.89"	70º 12.37"	42º 58.75"	70º 13.55"	23.4	3.19	4,523	8.42
7/28/2002	37	1	7	F	20	182	42º 58.73"	70º 13.40"	42º 58.56"	70º 14.63"	30.1	3.44	5,940	8.69
7/29/2002	38	2	2	F	20	91	42º 24.42"	70º 30.07"	42º 23.55"	70º 29.58"	4.9	1.77	685	6.53
7/29/2002	39	2	1	F	20	174	42º 30.23"	70º 25.10"	42º 31.21"	70º 24.93"	2.9	1.35	604	6.41
7/29/2002	40	1	3	R	20	116	42º 50.20"	70º 28.37"	42º 50.79"	70º 28.88"	23.0	3.18	3,568	8.18
7/29/2002	41	1	8	F	30	111	42º 52.29"	70º 28.22"	42º 53.27"	70º 27.90"	18.5	2.97	2,609	7.87
7/29/2002	42	1	6	R	20	137	43º 2.87"	70º 17.73"	43º 3.13"	70º 16.70"	27.7	3.36	3,310	8.10
7/29/2002	43	1	1	R	20	143	43º 10.52"	70º 8.82"	43º 9.80"	70º 8.67"	16.4	2.86	3,130	8.05
7/30/2002	44	8	9	R	20	154	43º 32.88"	68º 47.09"	43º 32.65"	68º 48.21"	4.2	1.65	1,020	6.93
7/30/2002	46	8	2	R	20	136	43º 21.76"	68º 56.78"	43º 21.49"	68º 58.00"	5.5	1.87	1,382	7.23
7/30/2002	47	6	2	R	20	155	43º 21.15"	69º 4.85"	43º 21.90"	69º 5.31"	8.8	2.29	1,447	7.28
7/30/2002	48	6	3	R	20	136	43º 31.57"	69º 8.97"	43º 32.40"	69º 8.15"	20.9	3.09	5,603	8.63
8/1/2002	50	7	3	R	20	230	42º 17.83"	69º 24.78"	42º 17.02"	69º 28.88"	1.0	0.71	126	4.84
8/1/2002	51	7	1	R	20	203	41º 52.90"	69º 25.49"	41º 52.01"	69º 25.97"	1.1	0.74	154	5.05
8/1/2002	52	7	4	R	20	208	41º 57.37"	69º 17.42"	41º 58.20"	69º 16.32"	1.9	1.07	206	5.33
8/1/2002	53	7	2	R	21	225	42º 17.48"	69º 10.72"	42º 18.58"	69º 10.49"	1.1	0.75	125	4.84
8/1/2002	54	7	6	F	20	225	42º 25.99"	69º 4.46"	42º 26.16"	69º 3.54"	0.9	0.66	104	4.65
8/2/2002	55	6		R	20	188	43º 9.98"	69º 18.91"	43º 10.53"	69º 20.05"	2.0	1.09	466	6.15
8/2/2002	56	6		R	20	176	43º 20.20"	69º 31.54"	43º 20.98"	69º 32.50"	10.1	2.41	2,364	7.77
8/2/2002	57	3		R	20	165	43º 27.11"	69º 44.55"	43º 27.87"	69º 45.49"	11.4	2.52	2,620	7.87
8/2/2002	58	3		R	20	111	43º 33.01"	69º 46.87"	43º 33.81"	69º 46.48"	3.1	1.40	981	6.89
8/2/2002	59	3		R	20	241	43º 37.14"	69º 39.64"	43º 38.08"	69º 39.55"	1.8	1.04	466	6.15

*Tows are standardized to 15 minutes duration for the calculations of weight and abundance.

Table 1c. Station dates, locations, and northern shrimp catches for the second industry cruise aboard the *F/V Bad Penny*, August 8 – August 19, 2006.

											Pandalus borealis			
											Weight*		Abundance*	
Date	Station	Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	kg/tow	$\log_e$(kg/tow+1)	no/tow	$\log_e$(no/tow+1)
8/8/2002	1	3	8	R	21	174	43º 9.26"	69º 54.00"			4.5	1.70	1,078	6.98
8/8/2002	2	3	10	F	20	163	43º 6.25"	69º 46.28"			11.0	2.48	2,200	7.70
8/8/2002	3	3	9	R	20	132	43º 4.54"	69º 43.46"			17.5	2.92	4,818	8.48
8/8/2002	4	3	5	R	20	170	43º 3.43"	69º 46.68"	43º 2.69"	69º 47.01"	9.9	2.39	2,093	7.65
8/8/2002	5	3	2	R	20	193	42º 58.74"	69º 47.05"	42º 58.76"	69º 47.90"	10.5	2.44	2,488	7.82
8/8/2002	6	5	4	R	20	201	42º 54.25"	69º 44.60"	42º 53.48"	69º 44.46"	7.0	2.07	1,407	7.25
8/8/2002	7	4	2	R	19	127	42º 48.63"	70º 4.71"	42º 48.37"	70º 3.85"	1.8	1.04	516	6.25
8/8/2002	8	4	4	F	20	183	42º 38.18"	69º 58.28"	42º 37.50"	69º 58.03"	1.5	0.90	299	5.70
8/9/2002	9	7	4	R	20	175	43º 7.57"	69º 43.96"	42º 6.08"	69º 17.31"	0.7	0.52	66	4.20
8/9/2002	10	7	3	R	25	205	41º 52.24"	69º 25.90"			0.2	0.19	38	3.66
8/9/2002	11	5	1	R	22	199	41º 53.44"	69º 33.21"	41º 53.47"	69º 36.30"	0.1	0.11	29	3.39
8/9/2002	12	4	3	F	12	128	42º 6.21"	69º 51.56"			0.2	0.15	54	4.00
8/9/2002	13	5	3	R	20	221	42º 12.30"	69º 47.57"	42º 12.59"	69º 48.31"	1.1	0.75	238	5.48
8/10/2002	14	4	1	R	20	171	42º 28.77"	69º 59.91"	42º 29.41"	69º 59.68"	0.9	0.64	305	5.72
8/10/2002	15	2	2	F	21	66	42º 24.07"	70º 30.03"	42º 23.54"	70º 30.63"	13.9	2.70	2,518	7.83
8/10/2002	16	2	1	F	20	95	42º 29.71"	70º 22.93"	42º 28.23"	70º 22.37"	2.4	1.22	307	5.73
8/10/2002	17	1	5	R	20	136	42º 47.94"	70º 26.68"	42º 48.58"	70º 27.08"	37.2	3.64	6,869	8.83
8/10/2002	18	1	8	F	21	117	42º 52.53"	70º 27.24"	42º 53.19"	70º 27.34"	24.6	3.24	3,245	8.09
8/10/2002	19	1	3	R	20	128	42º 55.81"	70º 22.72"	42º 55.96"	70º 21.86"	34.3	3.56	6,928	8.84
8/10/2002	20	1	6	R	20	156	42º 54.45"	70º 19.16"	42º 54.96"	70º 18.50"	16.4	2.86	2,691	7.90
8/10/2002	21	1	7	F	21	172	42º 56.63"	70º 15.45"	42º 67.03"	70º 14.65"	32.5	3.51	5,126	8.54
8/10/2002	22	1	1	R	21	144	43º 0.88"	70º 17.45"	43º 1.20"	70º 18.54"	27.6	3.35	3,762	8.23
8/10/2002	23	1	4	R	29	132	43º 10.04"	70º 4.16"	42º 9.75"	70º 4.18"	8.0	2.19	1,345	7.20
8/11/2002	24	3	1	R	22	155	42º 17.56"	69º 54.56"	43º 18.22"	69º 54.79"	6.5	2.02	1,818	7.51
8/11/2002	25	3	11	R	23	154	42º 20.32"	69º 57.47"	43º 20.84"	69º 58.26"	0.6	0.46	177	5.18
8/11/2002	26	1	2	R	20	116	43º 23.53"	70º 6.14"	42º 22.84"	70º 6.19"	0.5	0.39	125	4.84
8/11/2002	27	3	3	R	20	153	43º 25.15"	69º 58.25"	43º 24.55"	69º 68.74"	7.3	2.12	1,920	7.56
8/13/2002	28	3	4	R	20	95	43º 36.16"	69º 42.96"	43º 35.47"	69º 43.20"	0.0	0.03	53	4.00
8/13/2002	29	6	2	R	21	138	43º 29.82"	69º 27.17"	43º 30.17"	69º 26.26"	26.8	3.33	6,250	8.74
8/13/2002	30	6	5	R	20	137	43º 32.13"	69º 22.03"	43º 33.54"	69º 21.27"	13.5	2.67	3,394	8.13

Table 1c continued.

Date	Station	Stratum	Tow	Fixed/ Random	Duration (minutes)	Mean Depth (m)	Begin Latitude	Begin Longitude	End Latitude	End Longitude	*Pandalus borealis* Weight* kg/tow	Weight* $\log_e$(kg/tow+1)	Abundance* no/tow	Abundance* $\log_e$(no/tow+1)
8/13/2002	31	6	8	R	20	170	43º 28.54"	69º 17.93"	43º 27.92"	69º 18.26"	11.7	2.54	2,347	7.76
8/13/2002	32	6	6	R	20	165	43º 22.89"	69º 18.93"	43º 22.41"	69º 18.48"	19.2	3.01	4,485	8.41
8/13/2002	33	6	12	F	20	165	43º 19.82"	69º 22.15"	43º 20.42"	69º 21.66"	20.1	3.05	2,480	7.82
8/14/2002	34	8	1	R	20	101			43º 47.47"	68º 41.03"	0.3	0.29	128	4.86
8/14/2002	35	8	9	R	20	154	43º 33.14"	68º 46.72"	43º 34.41"	68º 46.94"	8.4	2.24	2,593	7.86
8/14/2002	36	8	3	R	22	147	43º 28.44"	68º 58.72"	43º 27.82"	68º 39.18"	2.5	1.24	519	6.25
8/14/2002	37	8	4	R	20	146	43º 25.43"	68º 37.22"	43º 25.63"	68º 36.22"	11.4	2.52	3,533	8.17
8/14/2002	38	8	6	R	21	150	43º 17.87"	68º 43.24"	43º 16.62"	68º 44.20"	5.1	1.80	1,269	7.15
8/14/2002	39	8	5	R	22	170	43º 12.67"	68º 45.22"	43º 12.94"	68º 47.11"	5.4	1.86	1,095	7.00
8/15/2002	40	6	11	R	20	199	43º 8.62"	69º 7.42"	49º 9.11"	69º 7.79"	5.9	1.93	947	6.85
8/15/2002	41	6	4	R	24	187	43º 8.2"	69º 14.37"	43º 7.89"	69º 15.04"	2.0	1.11	353	5.87
8/17/2002	42	8	7	R	20	177	43º 6.67"	68º 41.94"	43º 6.06"	68º 42.03"	6.8	2.06	1,634	7.40
8/17/2002	43	8	8	F	22	188	43º 0.32"	68º 49.12"	43º 0.18"	68º 50.40"	6.3	1.98	1,384	7.23
8/17/2002	44	6	9	R	23	188	42º 55.96"	69º 2.89"	42º 56.37"	69º 3.56"	9.1	2.31	1,708	7.44
8/18/2002	45	6	7	R	20	159	42º 52.12"	69º 13.72"	42º 52.92"	69º 13.69"	18.6	2.98	4,261	8.36
8/18/2002	46	6	10	R	20	168	42º 45.44"	69º 4.11"	42º 44.75"	69º 3.63"	15.8	2.82	3,933	8.28
8/18/2002	48	8	2	R	21	168	42º 44.24"	68º 59.54"	42º 44.38"	69º 0.48"	14.4	2.73	3,104	8.04
8/18/2002	49	7	5	F	20	199	42º 38.43"	69º 14.72"	42º 38.23"	69º 15.59"	2.0	1.10	279	5.64
8/18/2002	50	7	6	F	24	230	42º 26.85"	69º 4.12"	42º 26.14"	69º 4.21"	0.0	0.03	5	1.79
8/18/2002	51	7	1	R	20	221	42º 24.58"	69º 1.15"	42º 24.50"	69º 7.92"	3.7	1.56	427	6.06
8/19/2002	52	5	2	R	26	247	42º 24.18"	69º 37.89"	42º 24.91"	69º 38.20"	0.5	0.38	54	4.00
8/19/2002	53	7	2	R	20	258	42º 28.05"	69º 29.01"	42º 28.37"	69º 28.25"	0.3	0.26	40	3.71
8/19/2002	54	5	5	F	20	258	42º 46.13"	69º 38.50"	42º 46.63"	69º 38.22"	4.4	1.69	1,021	6.93
8/19/2002	55	3	6	R	25	181	42º 48.29"	69º 33.80"	42º 48.43"	69º 33.11"	4.4	1.69	830	6.72
8/19/2002	56	6	3	R	20	155	42º 49.64"	69º 24.20"	42º 50.62"	69º 24.80"	5.3	1.83	684	6.53
8/19/2002	57	3	7	R	20	168	42º 56.17"	69º 30.30"	42º 66.76"	69º 30.86"	11.5	2.52	3,054	8.02
8/19/2002	58	6	1	R	20	172	43º 5.69"	69º 25.18"	43º 06.41"	69º 25.46"	5.3	1.83	856	6.75

*Tows are standardized to 15 minutes duration for the calculations of weight and abundance.

Table 2. Basic statistics for weight (above) and abundance (below) of northern shrimp, untransformed and $\log_e$ transformed, for each of the three cruises, and the two industry cruises combined.

	State-Federal Research (*Gloria Michelle*) July 22 - August 2	First Industry (*Bad Penny*) July 23 - August 2	Second Industry (*Bad Penny*) August 8 - 19	Industry Combined July 22 - August 19
Number of Tows	54	57	57	114
***Weight (kg/tow)**				
Mean	20.4	7.5	9.1	8.3
Std Dev	20.6	7.4	9.4	8.5
C.V.	100.9	99.4	102.9	102.0
Median	15.1	4.2	6.3	5.2
$\log_e$(kg/tow+1)				
Mean	2.58	1.77	1.84	1.81
Std Dev	1.09	0.87	1.05	0.96
C.V.	42.3	48.8	57.3	53.2
Median	2.78	1.65	1.98	1.82
Sum of ranks R	5,823	4,043	4,330	
Mean Rank	107.9	70.9	76.0	
***Abundance (num/tow)**				
Mean	4,181	1,520	1,845	1,682
Std Dev	4,112	1,515	1,822	1,676
C.V.	98.4	99.7	98.7	99.6
Median	3,227	911	1,345	1,050
$\log_e$(num/tow+1)				
Mean	7.67	6.72	6.71	6.71
Std Dev	1.44	1.22	1.64	1.44
C.V.	18.8	18.2	24.5	21.5
Median	8.08	6.82	7.20	6.96
Sum of ranks R	5,795	4,062	4,339	
Mean Rank	107.3	71.3	76.1	

*Tows are standardized to 15 minutes duration for the calculations of weight and abundance.

Table 3. Stratum areas.

Stratum	Stratum Name	Stratum Area (nautical miles^2)
1	JEFFREYS LEDGE	427
2	MASSBAY-TILLIES	508
3	PLATTS BANK	851
4	WILDCAT KNOLL	427
5	WILKINSON BASIN	1,053
6	3DORY-TOOTHRAKER	1,289
7	WILKINSON BASIN	1,061
8	CASHES-JEFFREYS	1,466
9	RODGERS-HOWELL	667
10	NEWFOUND GROUND	1,621
11	FRANKLIN BASIN	1,234
12	FRANKLIN SWELL	1,926

Table 4. Mean $\log_e$-transformed weights/tow** (above) and mean $\log_e$-transformed numbers/tow** (below) for each stratum, and stratified means, for each of the three cruises.

$\log_e$(kg/tow+1)	**State-Federal Research (*Gloria Michelle*) July 22 - August 2**			**First Industry (*Bad Penny*) July 23 - August 2**			**Second Industry (*Bad Penny*) August 8 - 19**		
Stratum	n	mean	std dev	n	mean	std dev	n	mean	std dev
1	8	3.84	0.65	8	2.86	0.75	8	2.84	1.10
2	2	1.89	0.42	2	1.56	0.30	2	1.96	1.05
3	11	3.13	0.50	14	1.95	0.84	11	1.89	0.89
4	3	0.88	0.92	3	0.94	0.61	4	0.68	0.40
5	4	1.09	0.85	5	1.02	0.61	5	1.00	0.85
6	11	2.98	0.52	12	1.93	0.64	12	2.45	0.66
7	6	1.34	0.56	7	1.05	0.66	6	0.61	0.60
8	8	2.66	0.57	6	1.55	0.20	9	1.86	0.73
12	1	0.99	-						
stratified*	8	2.25	0.23	8	1.56	0.22	8	1.65	0.29
retransformed kg/tow (antilog-1)		8.52	1.26		3.75	1.24		4.21	1.33

$\log_e$(num/tow+1)									
Stratum	n	mean	std dev	n	mean	std dev	n	mean	std dev
1	8	9.00	0.63	8	7.95	0.81	8	7.81	1.32
2	2	6.88	1.06	2	6.47	0.09	2	6.78	1.49
3	11	8.48	0.56	14	7.21	1.11	11	7.06	1.33
4	3	5.56	1.48	3	5.71	1.10	4	5.42	0.98
5	4	5.53	1.57	5	5.50	0.90	5	5.41	1.71
6	11	8.35	0.55	12	7.03	0.91	12	7.58	0.89
7	6	5.82	0.86	7	5.41	1.08	6	4.18	1.54
8	8	7.87	0.69	6	6.43	0.57	9	7.11	1.03
12	1	6.07	-						
stratified*	8	7.23	0.35	8	6.39	0.33	8	6.41	0.49
retransformed num/tow (antilog-1)		1,384	1.42		597	1.39		609	1.63

*weighted by stratum area, strata 1-8 only

**Tows are standardized to 15 minutes duration for the calculations of weight and abundance.

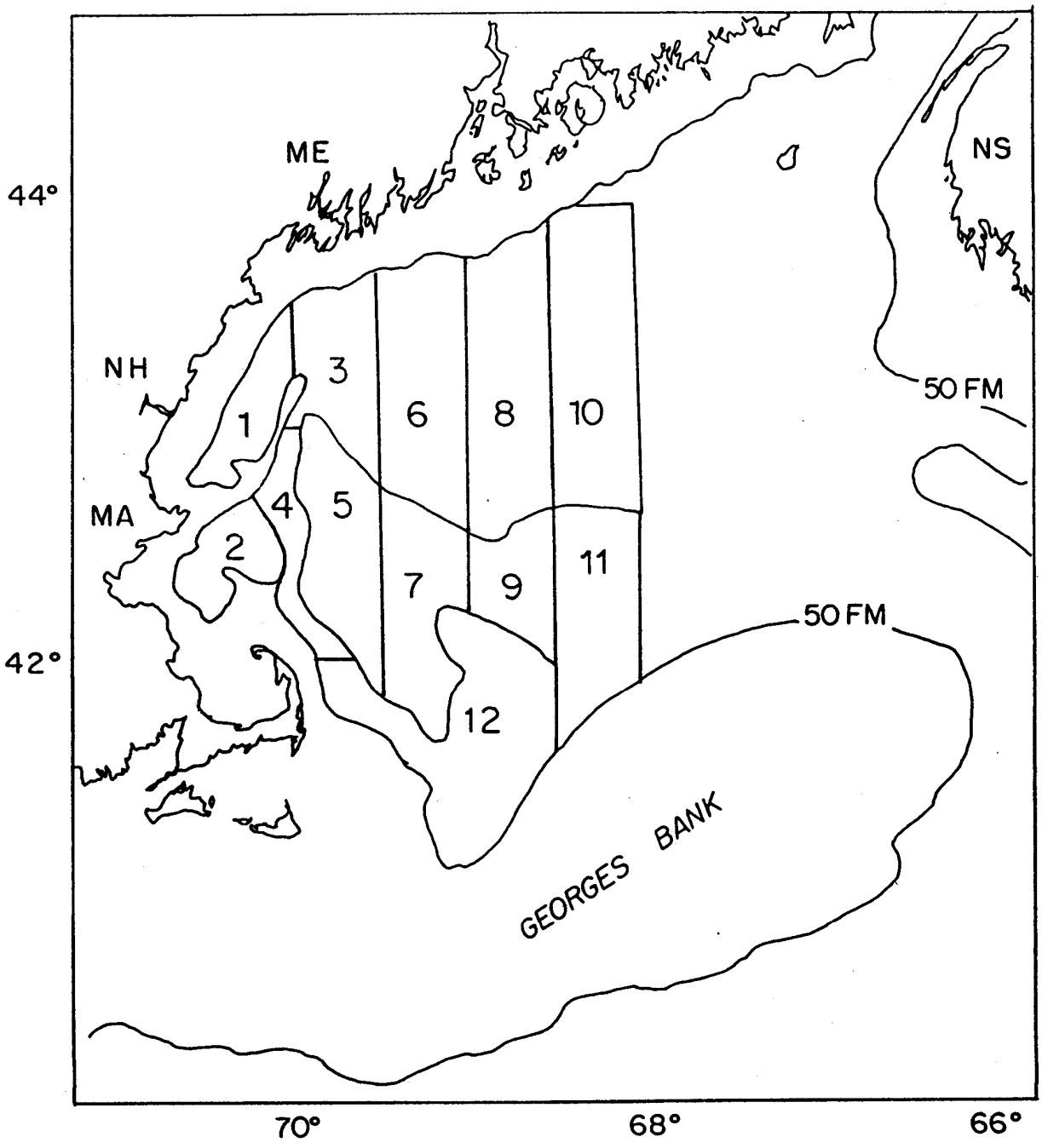


Figure 1a. The Gulf of Maine showing the northern shrimp survey strata (numbered 1-12).

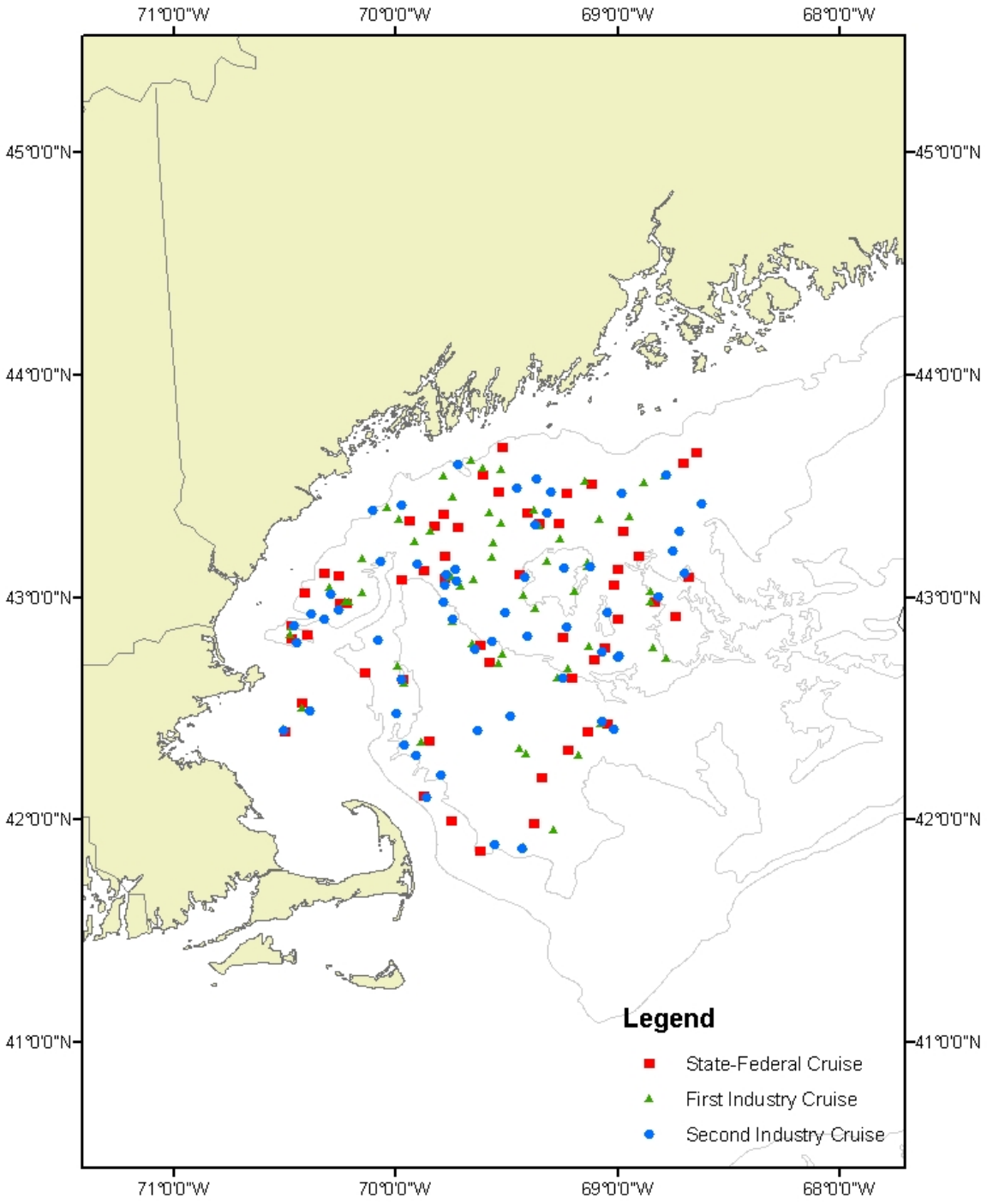


Figure 1b. The Gulf of Maine showing the three northern shrimp survey cruise tow locations.

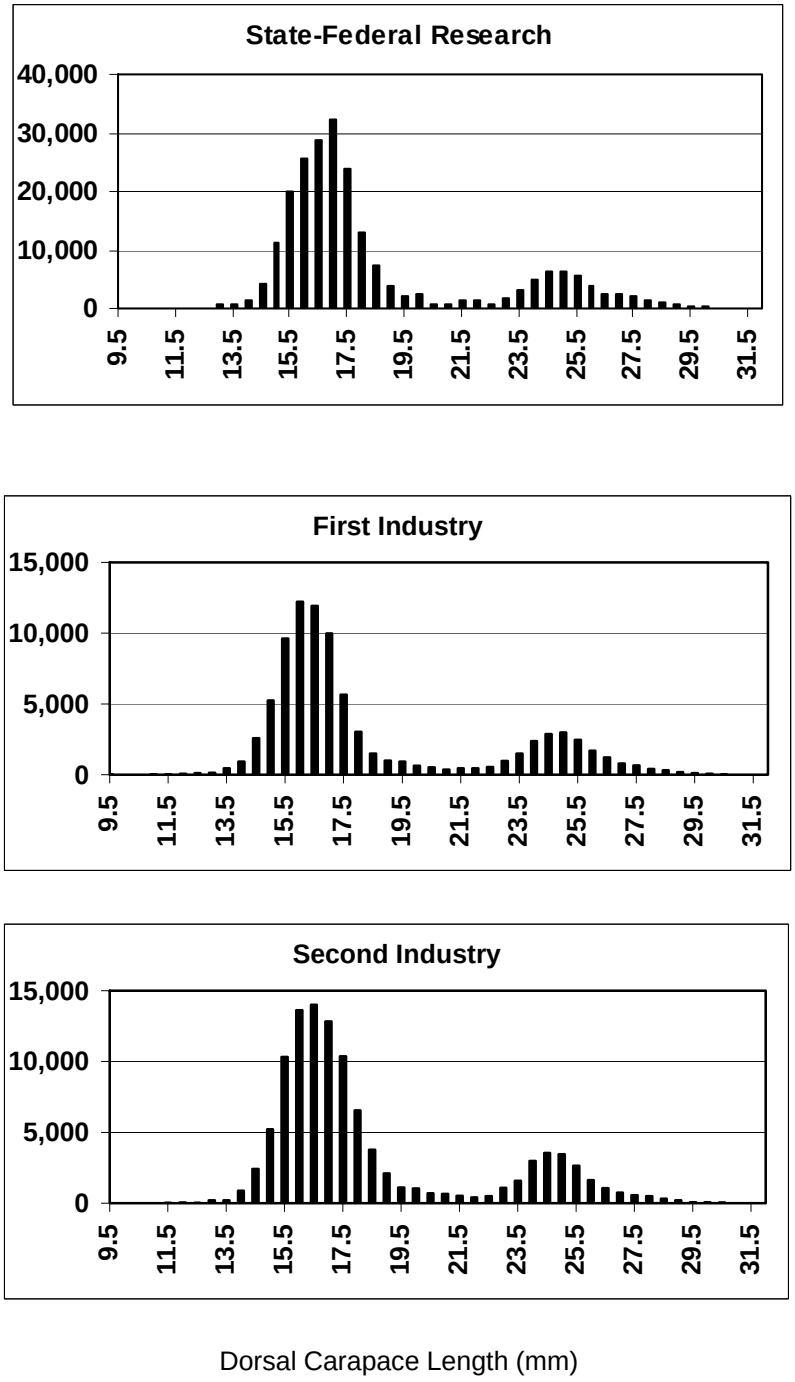
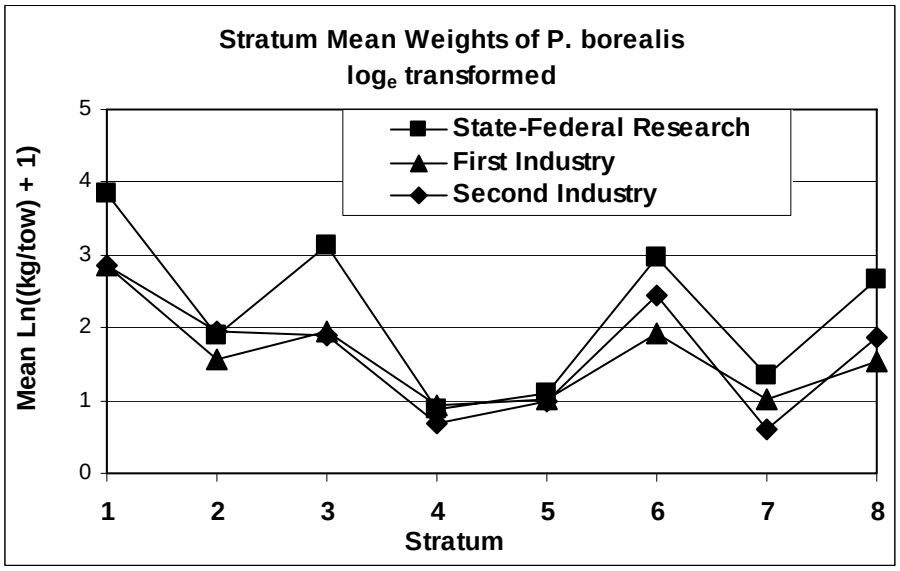


Figure 2. Size-frequency distributions for each cruise, expanded to total catch in numbers for the cruise.



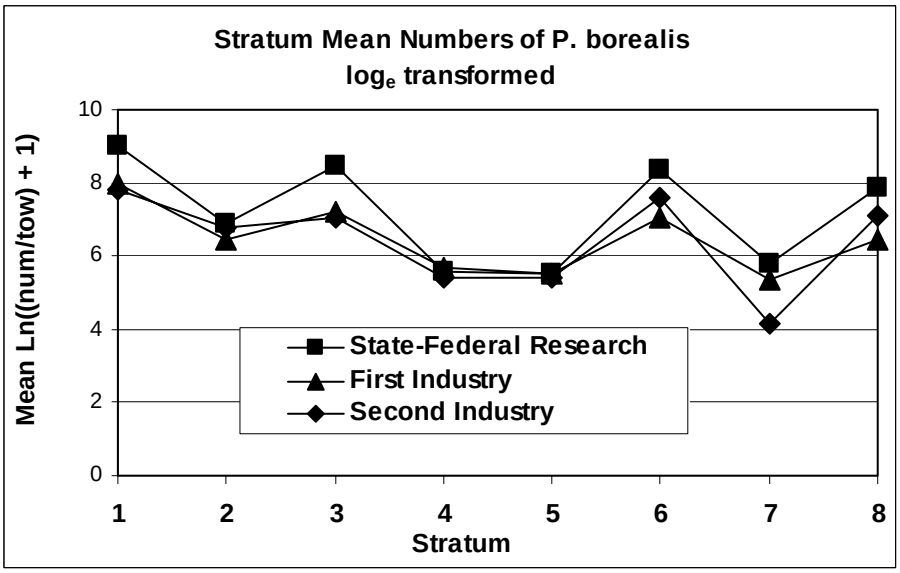


Figure 3. Mean $\log_e$-transformed weights/tow (above) and mean $\log_e$-transformed numbers/tow (below) for each stratum, for each of the three cruises.

From Industry Survey Data

From State-Federal Research Survey

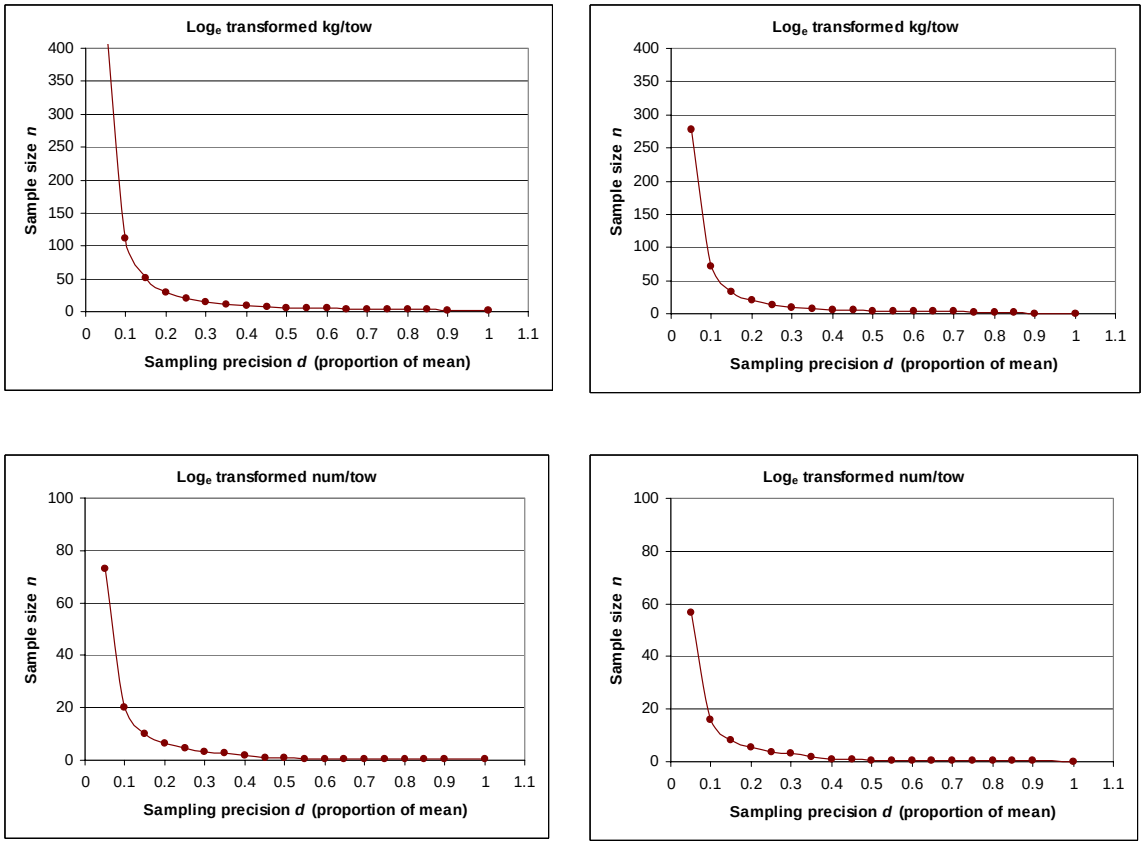


Figure 4. Minimum sample size required to estimate $\log_e$-transformed weight/tow (above) and $\log_e$-transformed number/tow (below) to within the stated precision with a confidence of 95%, using data from the industry survey (left) and the state-federal research survey (right).

PART II: *Environmental Monitoring for Migration and Recruitment*

Objectives

There were three objectives of the second part of this project. They included the following:

1) Utilize shrimp fishing vessels for environmental monitoring within the coastal waters of the Gulf of Maine;
2) Begin to correlate the inshore migration of shrimp and timing of egg release to environmental conditions; and
3) Contribute to a study of the spring bloom and larval survival funded by Sea Grant.

Methods

Environmental and biological data were collected for two years to evaluate the timing of shrimp migration inshore; the different distributions and movements of ovigerous and post-hatch females and males; and the timing of hatching in relation to water temperature. Four commercial fishing boats were used from mid-November through early May, 2002-2003, and early November through early June, 2003-2004, to conduct approximately biweekly cruises within two study areas off Portland (Cape Elizabeth) and the Pemaquid Peninsula. Fishing vessels were: *F/V Bad Penny*, *F/V Jeanne C*, *F/V North Star*, and *F/V Susan and Caitlyn*, each measuring between 12 and 16 m (40-54 ft) over-all length.

Stations locations are shown in Figure II-1. The two study areas were sampled following two strategies. One strategy used a fixed transect of six stations extending across the coastal shelf from nearshore to approximately the 160 m isobath. Details of these stations are given in Table II-1. In the second strategy, fishermen pursued shrimp according to their own instincts and experience, forming a corridor of sampling stations associated with each study area. Transects provided data across the full width of the coastal shelf throughout the season, while the "fishing stations" shifted over time and provided a large sample size for biological data. We compared the two strategies for what they revealed in terms of maximum abundance: Does a fixed-station approach reveal the same maximum abundances as the "fishing" approach? Finally, the fishing stations gave us an estimate of the variance of catch rates when effort was directed at finding shrimp.

Tow times averaged approximately 15 minutes at the transect stations and 25 minutes at the fishing stations. The number of tows was approximately evenly divided between the two methods. The number of fishing (transect) stations were: Pemaquid: 70(70) and 93(92) in the first and second year, respectively. The corresponding numbers for Portland were 67(70) and 78(86).

Since half the samples came from a non-standard array of sample locations, we needed a way to standardize their locations in order to compare shrimp movements. To do this, we drew a reference line connecting the major headlands (Fig. II-1) and used GIS software to calculate the shortest (orthogonal) distance of each station from the line. Data are plotted as distance inshore or offshore of this line. Bottom topography is very irregular throughout this region; the depths of

all stations sampled during this study are shown in Fig. II-2. Only the general depth distributions and patterns are discussed in this report.

Each trip consisted nominally of two days of sampling. By design, transect sampling was conducted on the first day with six tows made at approximate 10 fathom (18.2 m) depth intervals moving from inshore to offshore. On the second day, 5-6 tows were made at locations selected by the fishermen ("fishing days", see above). The sampling plan sometimes had to be altered because of weather, but both sets of samples were obtained on each "trip". Sampling consisted of a hydrographic (temperature-salinity-depth) profile collected with an internally-recording CTD (Seabird Electronics SBE 19), and a shrimp trawl.

The trawl gear used was the fishermen's own shrimp net with 2.54 cm (1¾ in) mesh equipped with a Nordmore grate. Tows were taken at a vessel speed of 3.7 km/h (2 nm/h). Sampling was confined to daylight hours. Catch weights in kilograms (kg) of pandalid shrimp, finfish, and selected invertebrate species (*e.g.*, scallops) were recorded. A 1-kg sample of pandalid shrimp was retained for laboratory analysis. Biological samples were weighed and separated by species (*Pandalus borealis*, *P. montagui* and *Dichelopandalus leptocerus*), with northern shrimp (*P. borealis*) further separated by sex and spawning stage [ovigerous or posthatch (FII) females]. The central carapace length was obtained for each individual northern shrimp by stage along with the total weight of all shrimp in that stage. A total weight for other shrimp species in the sample was recorded. All other material in the sample was weighed in aggregate and recorded. All data are included in the project database (conveyed to NEC); we confine this report to an analysis of the northern shrimp and temperature data.

Other environmental data collected at each sampling location included air temperature, wind speed and direction, and sea state. In the course of data analysis, we also used sea surface temperature (SST) data from Boothbay Harbor (where a time series dates back to 1905), and temperature from various depths at GoMOOS Buoys C (12 km off Cape Elizabeth, 43° 34'10" N, 70° 03' 18" W) and E (18 km off Pemaquid Neck, 43° 42' 47" N, 69° 21' 20" W). Locations are shown in Figure II-1; see www.maine.gov/dmr and www.gomoos.org for details of the Boothbay Harbor temperature record and the offshore buoys, respectively).

Results and Discussion

We abbreviate the two study areas as POR (Portland) and PEM (Pemaquid). Our study encompassed two 'winters' (2002-03 and 2003-04), beginning in the fall and extending into spring of the following year. For convenience, we sometimes refer to these two study periods by the year in which they began, 2002 and 2003, respectively.

The seasonal cooling of bottom waters off Portland and Pemaquid are shown in Figure II-3. Bottom temperatures are averages of the bottom 5 m of the CTD profiles. In 2002, inshore bottom temperatures cooled earlier and remained generally cooler compared to offshore. Minimum bottom temperatures of approximately 2-3 °C were found inshore (within 15 km of the reference line) from late January to early April. Beyond 15 km, bottom temperatures ranged from 4-6.5 °C. The 15 km distance corresponds to average water depths deeper than 100 m off

Pemaquid and Portland (Fig. II-2). There was a transient warming event in the bottom water off Portland around YD 70.

There were large data gaps in the CTD records for winter 2003-04, but it can be seen that November to December bottom temperatures in both areas were at least 2 ºC cooler than the previous year, and the minimum temperatures in early March (YD 60-75) were also cooler (especially off Pemaquid) and extended farther offshore (both areas). The earlier cooling in autumn 2003 in both areas compared to the previous year is consistent with data from the nearby GoMOOS buoys (Fig. II-4). The colder minimum temperatures in March (more prominent at Pemaquid) agree with a period of rapid cooling seen at 20 and 50 m depths at Buoy E in late February. Buoy C does not show this particular period of cooling. The differences between years also were not detected in the monthly averages of the Boothbay Harbor sea surface temperature record (Table II-2), where, in fact, the *first* year was 0.1-0.7 ºC colder in all months from October through April. Both years were warmer than the long-term averages for the site.

We conducted a total of 626 shrimp trawls. The hatching period was defined by examining the proportion of ovigerous to total reproductive females (ovigerous + FII). We used the weighted sample means from each day to obtain an estimate for the population. Within each year, fitted curves for the two areas were only slightly different, so we pooled the data to calculate a single hatching curve for each year (Fig. II-5). Hatching began earlier in 2002, probably because of the warmer water temperatures encountered on the shelf in fall and early winter. Interestingly, the hatching curve for 2002 progressively caught up with the curve for 2003, so while the curves differed by >30 d at 1% hatch, they differed by only 11 days at 50% hatch and only a few days at 90 and 99% hatch (Table II-3). In both areas and years, hatching was virtually completed by YD85 (March 26; Fig II-5). Because of the earlier start, the hatching season (defined as the time between 1% and 99% hatched) lasted 101 days in 2002 and 57 days in 2003.

The across-shelf positions of ovigerous females, FII (post-hatch females) and male shrimp are shown in Figures II-6, II-7 and II-8, along with temperature isopleths for 2002. Although hatching began earlier in 2002, it did not begin while shrimp were farther offshore: the ovigerous females <u>were already inshore</u> when hatching commenced. Conversely, the earlier arrival of shrimp in 2003 did not result in earlier hatching, which may have been delayed by the colder water temperatures. <u>Thus, despite different migration times and different hatching times, larvae were in both years released into the water at a similar distance offshore.</u>

Figure II-7 shows a steady offshore movement of FII shrimp after the hatch. Male patterns are harder to discern. The large abundance of males at the end of the season and across most of the shelf in the 2003-04 Portland samples was made up mostly of small shrimp (10-15 mm carapace length) that comprised a small portion of the earlier catches.

The different behavior of the two sexes and comparisons between areas and years are easier to make if one condenses the data into mean weighted positions for each group (Fig. II-9). By so doing, it appears that ovigerous females came closer to shore at Pemaquid compared to Portland in both years (by about 5 km), while the center of abundance of males was similar in both areas and years, and remained farther offshore than the ovigerous females, especially during the

hatching season. The differences in the depths of the female/male centers of abundance was 20 m or more (*cf*. Fig. II-2).

Fig. FII-10 shows the detail of female movements before, during and after hatch (*cf*. Fig II-5). Here one can see the on- and off-shelf movements, the increased aggregation during hatching (note changes in values on the y-axes), and the significant within-period variances in catch rate. Note also the earlier on-shore movement of females in the colder year (2003-04), and their greater over-all abundance.

The distribution of "fishing stations", reflecting fishermen's knowledge about where to find shrimp, helps to illustrate the movement of shrimp, including their on- and off-shelf movements associated with hatching, the earlier onshore movement in 2003-04 (possibly related to the earlier cooling of bottom waters, and the post-hatch dispersion of females (Fig. II-11).

We made a quick graphical inspection of the distribution of catch rates over time among the "fishing" and transect stations. The two approaches showed similar maximum catch rates.

Table II-1. Locations and depths of fixed "transect" stations. Note changes in Portland stations between years.

Location	Station	Season	Latitude (N)	Longitude (W)	Depth (m)
Pemaquid	1	Both	43.8367	-69.4836	65.2
Pemaquid	2	Both	43.7844	-69.4964	94.2
Pemaquid	3	Both	43.7115	-69.5060	114.5
Pemaquid	4	Both	43.6070	-69.5532	111.8
Pemaquid	5	Both	43.5284	-69.5887	158.7
Pemaquid	6	Both	43.4773	-69.6248	120
Portland	1	Both	43.4883	-70.2100	66.5
Portland	(2)	2003-04	43.5133	-70.1183	77.1
Portland	2 (3)	Both	43.5018	-70.0485	100.6
Portland	3 (4)	Both	43.4393	-70.0893	123.7
Portland	4 (5)	Both	43.3430	-70.0975	142.2
Portland	5 (6)	Both	43.2892	-70.0843	153
Portland	6	2002-03	43.3013	-70.0530	167.8

Table II-2. Monthly mean sea surface temperatures in Boothbay Harbor, ME, for shrimp sampling seasons of 2002-03 and 2003-04 (upper), and the "20th century" mean, maximum and minimum values.

	OCT	NOV	DEC	JAN	FEB	MAR	APR
2002-03	13.6	9.7	6.1	2.8	1.8	3.0	5.2
2003-04	13.7	9.9	6.5	3.5	3.0	3.1	5.9
20th century (1905-1999)							
Mean	10.8	7.8	4.5	2.2	1.3	2.1	4.8
Max	13.3	10.7	9.1	6.1	5.5	6.1	7.5
Min	8.2	4.0	-0.1	-2.1	-1.7	-1.1	1.5

Table II-3. Summary of fitted hatching curves showing YD when 1, 10, 50, 90 and 99% of mature females had hatched their eggs.

Season	1% Hatched	10% Hatched	50% Hatched	90% Hatched	99% Hatched
2002-03	356	29	60	80	91
2003-04	32	53	71	82	88

Fig. II-1. Study area. Upper panel shows “transect” stations (note change in Portland stations from first to second year), and positions of Boothbay Harbor (BBH) and GoMOOS Buoys E and C. Lower panel shows “fishing” stations. The broken line separates Portland and Pemaquid sampling. The red line is drawn along the shoreward end of major headlands and is used as a distance reference in other figures.

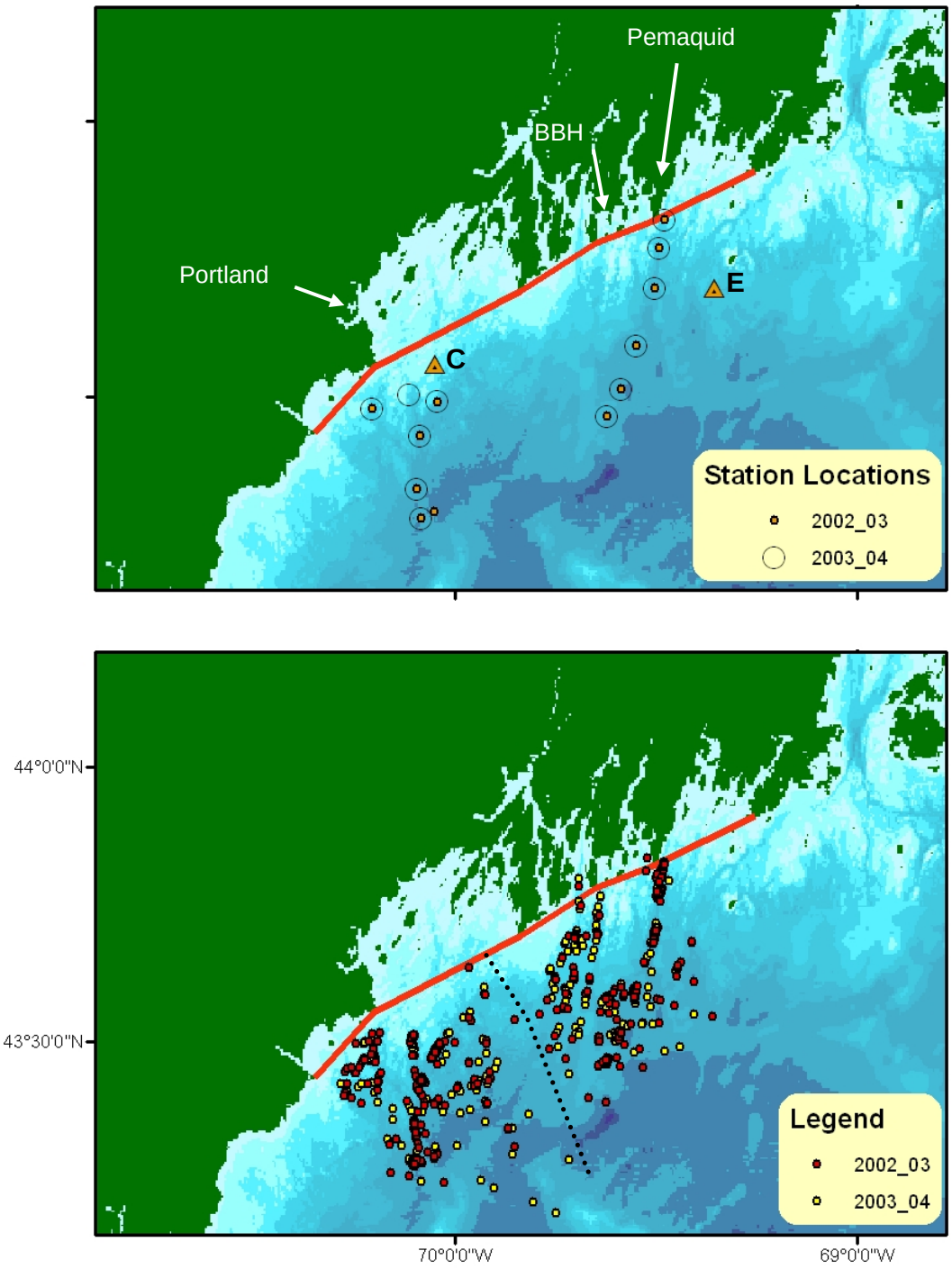


Fig. II-2. Scatterplot of station depths sampled off Pemaquid (PEM) and Portland (POR). Distances are orthogonal to the reference line shown in Fig. II-1. Most of the deep Pemaquid stations inshore of 15 km are from the transect (Fig. II-1, upper panel).

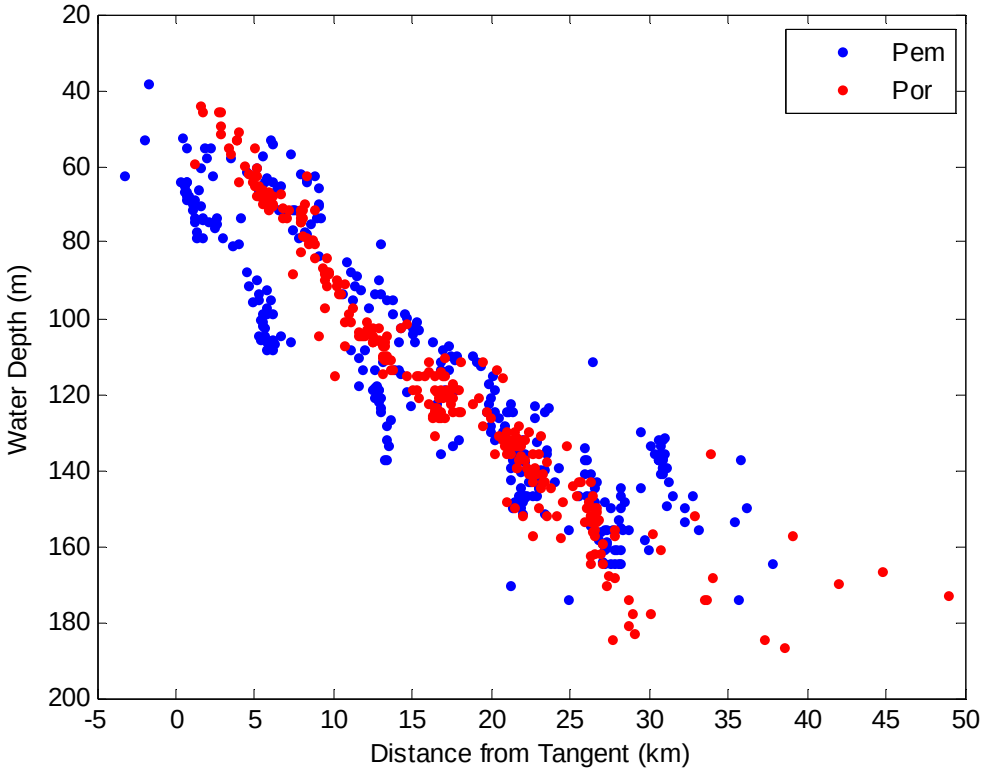


Fig. II-3. Bottom temperatures (°C) off Pemaquid (PEM, upper panels) and Portland (POR, lower panels) in 2002-03 (left column) and 2003-04 (right column). Data are from all CTD casts (transect and fishing stations). Distances are from the reference line in Fig. II-1, and corresponding depths from the casts are shown in Fig. II-2.

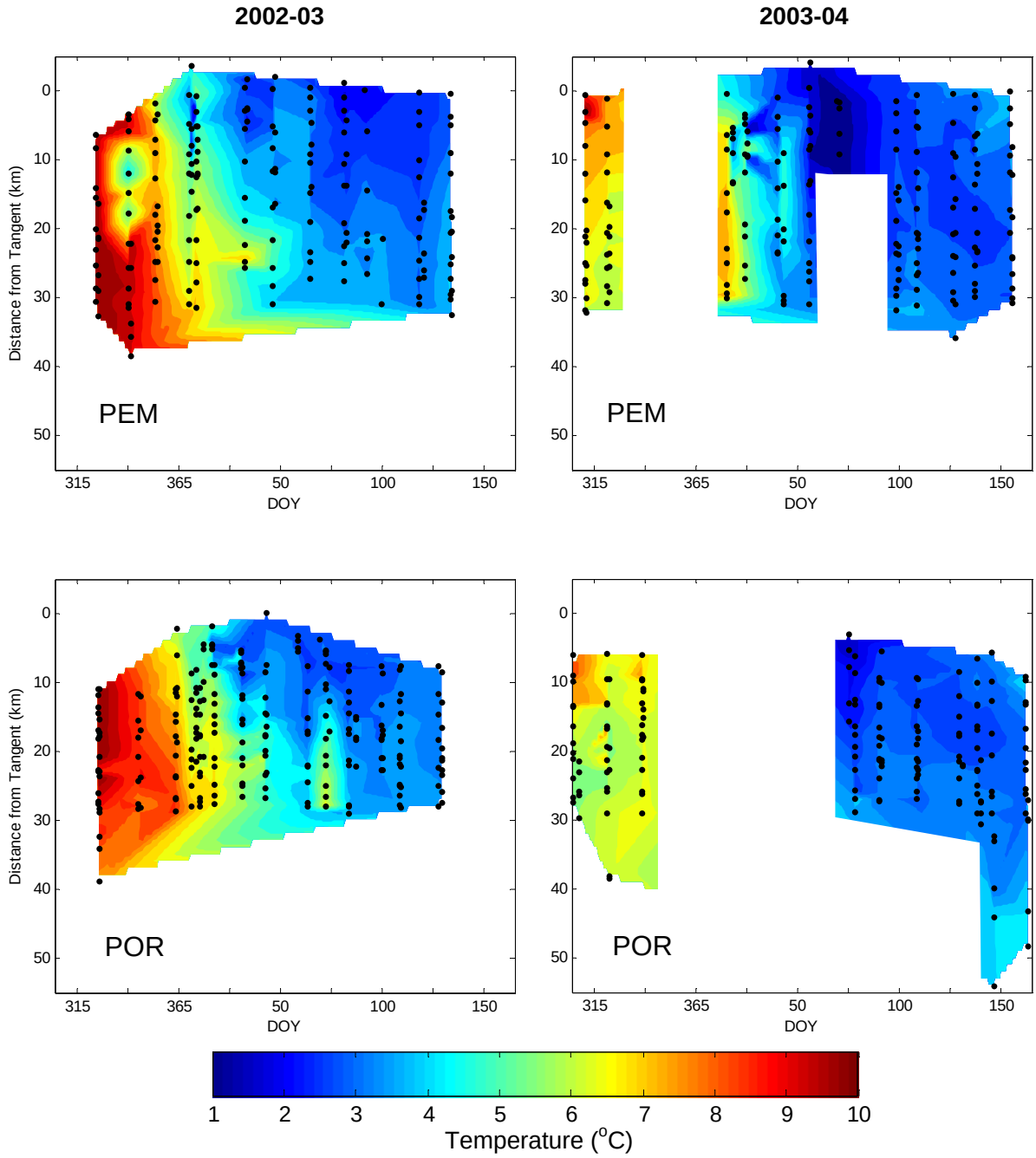


Fig. II-4a. Temperatures at 20 m depth at GoMOOS Buoys E and C. Temperatures are virtually isothermal with the surface until after YD 100 (April 10).

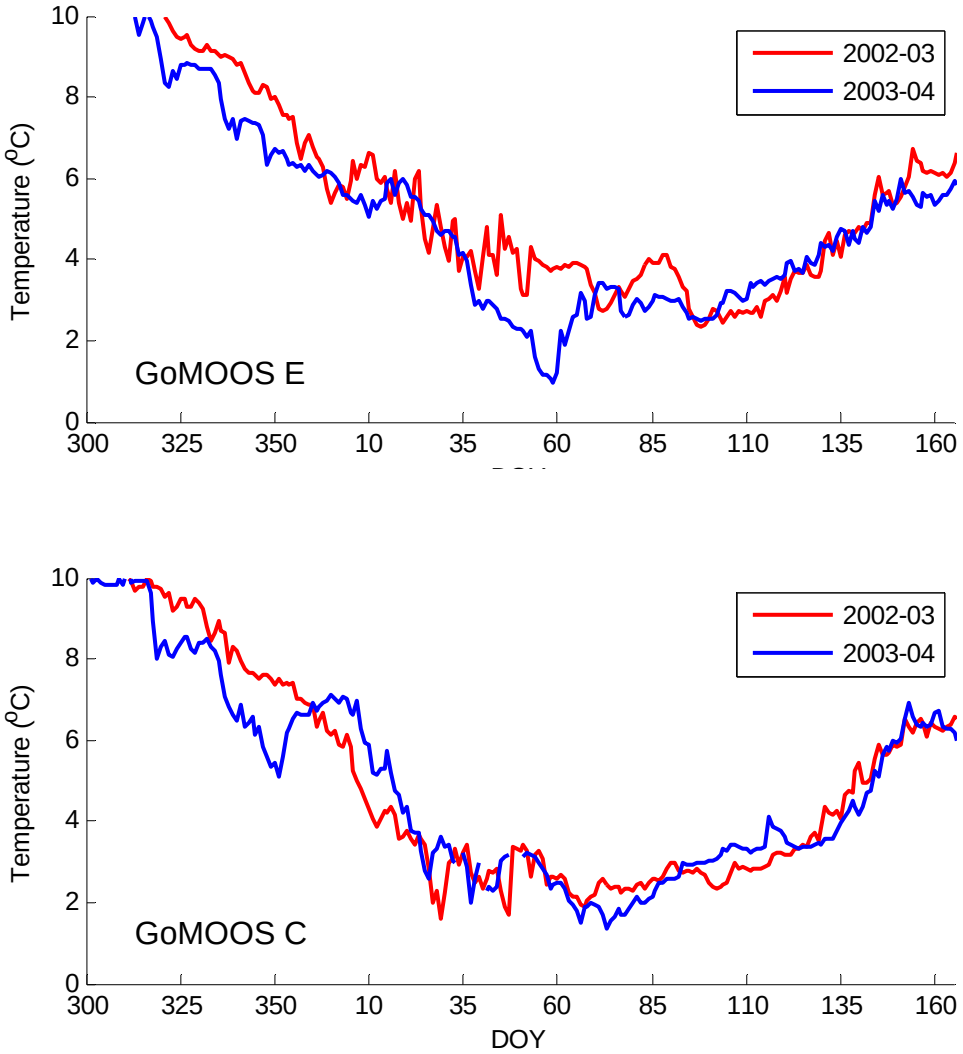


Fig. II-4b. Temperatures at 20 m and 50 m depth at GoMOOS Buoy E. Temperatures at 20 and 50 m were virtually the same from YD 10 (January 10) to YD 100 (April 10).

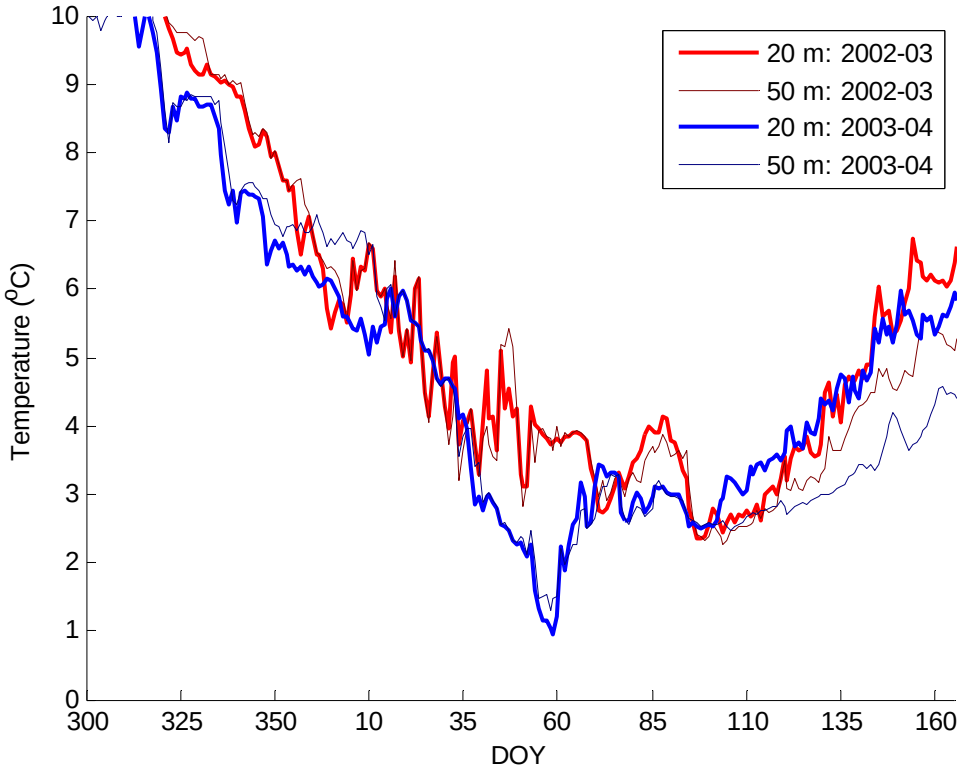


Fig. II-5. Proportion of reproductive shrimp carrying eggs. Lines are fit to the combined data (both areas) for each year. Values are given in Table II-2.

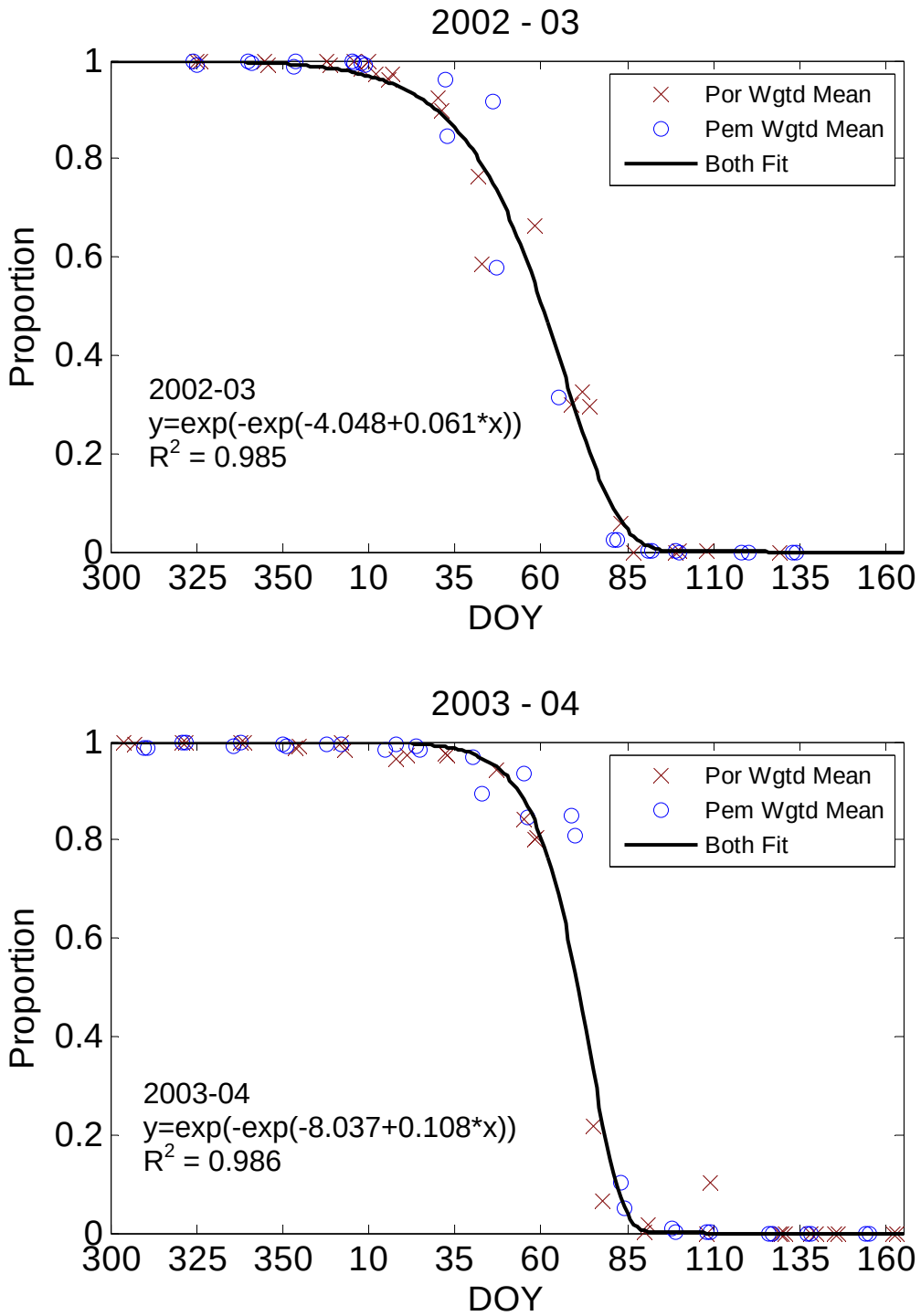


Fig II-6. Distribution and abundance of ovigerous female shrimp (No. / hr) for Pemaquid (top row) and Portland (bottom row), for winters of 2002 and 2003 (left and right columns, respectively). Bottom temperature isopleths (°C) for 2002 are shown. Bubbles are scaled the same in all plots except for Portland 2003, when shrimp were more abundant. The hatching scale just above the bottom axis in all figures shows the beginning, 50% (vertical line) and end of the hatching period for each year (*cf.* Fig. II-5 and Table II-2).

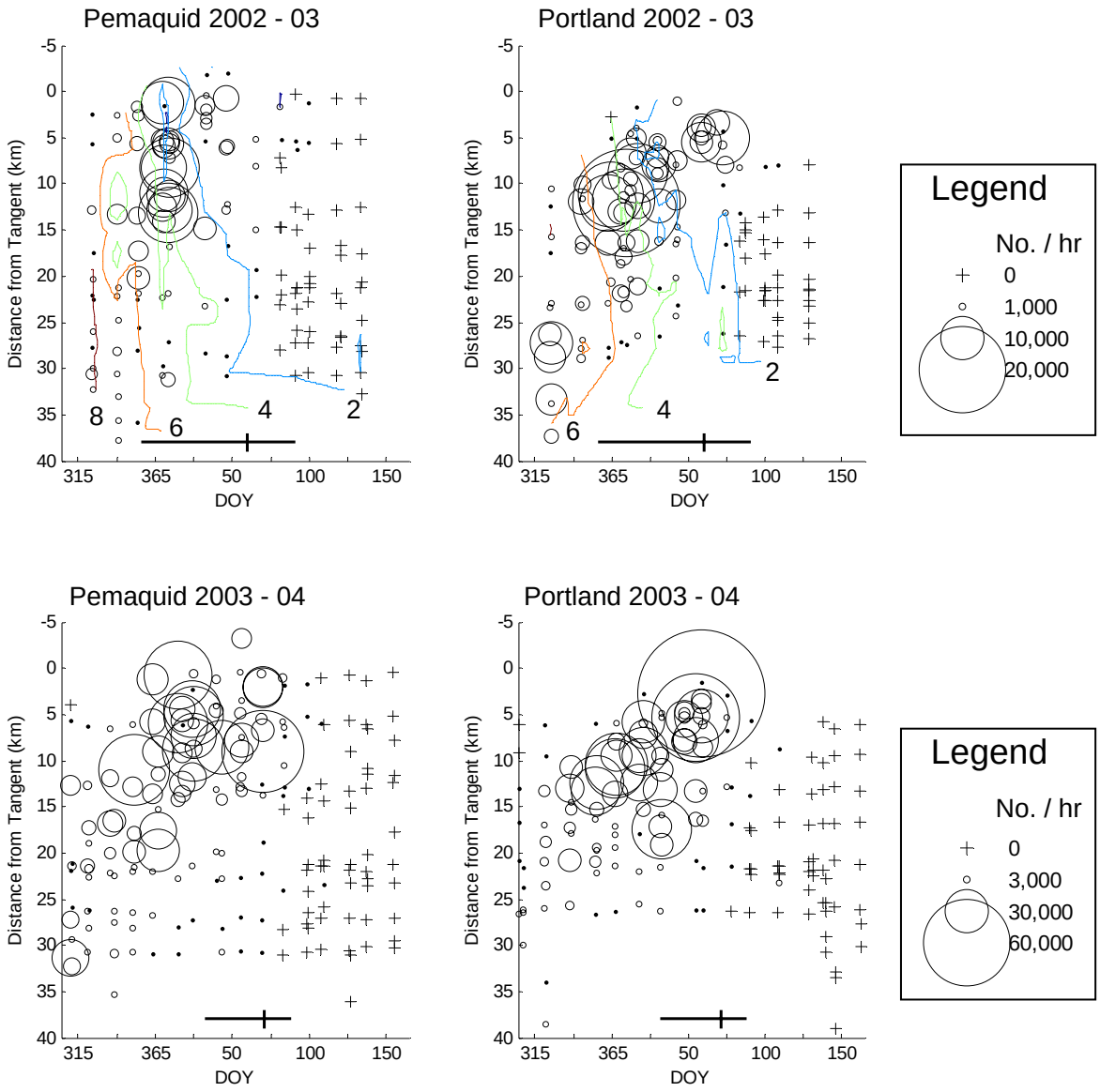


Fig. II-7. As in Fig. II-6, but for FII females (post hatch).

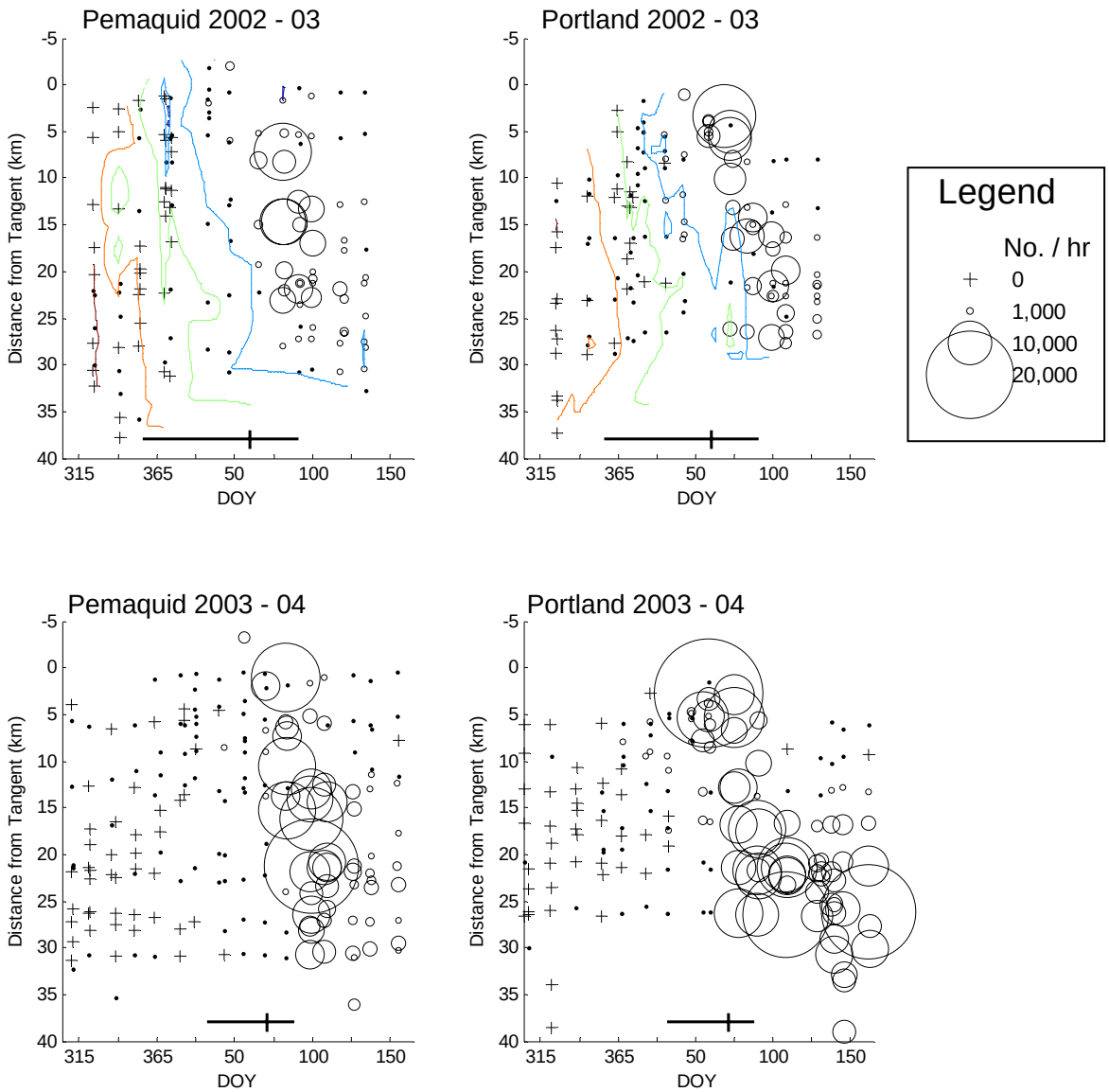


Fig. II-8. As in Fig. II-6, but for males.

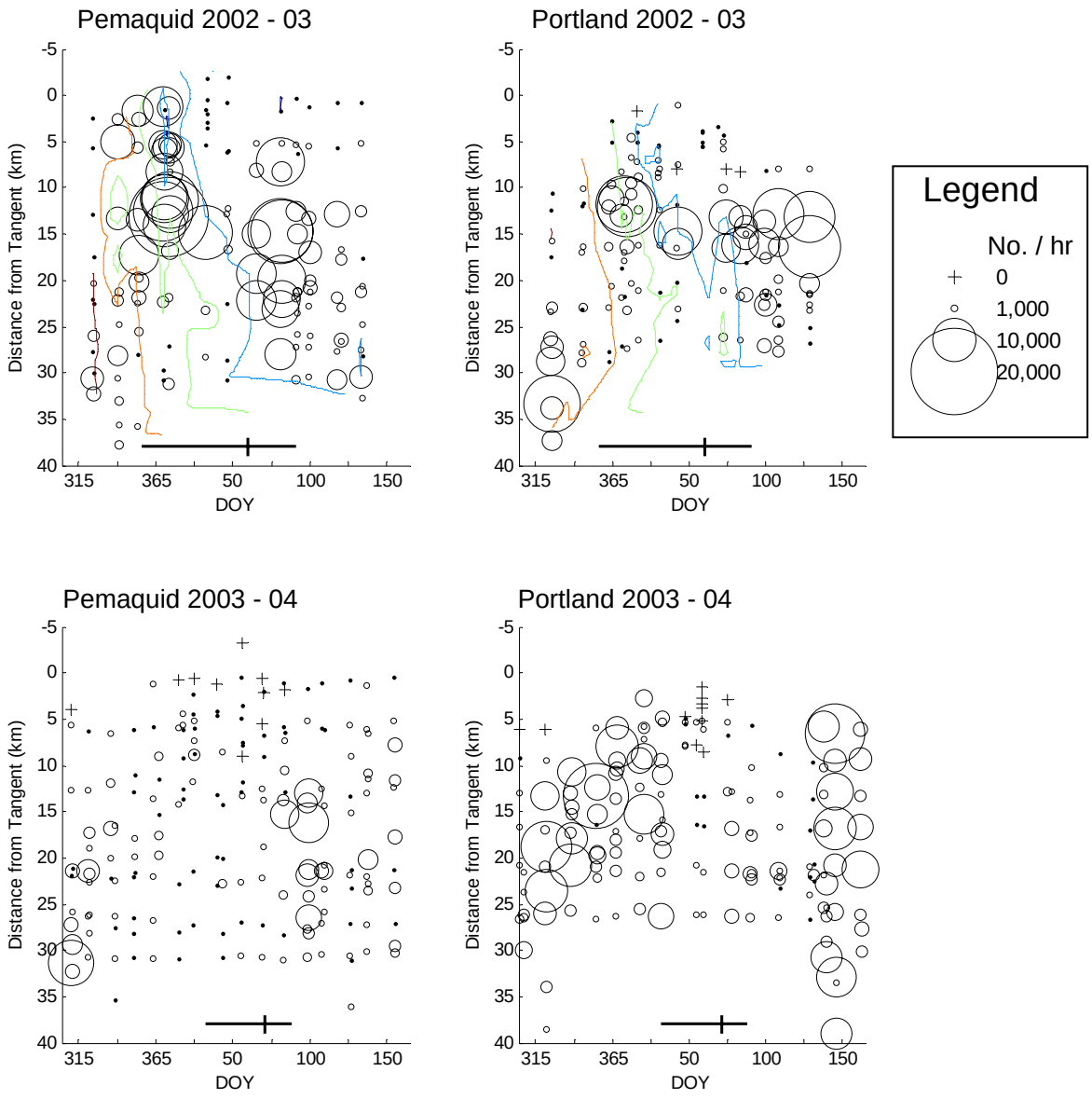
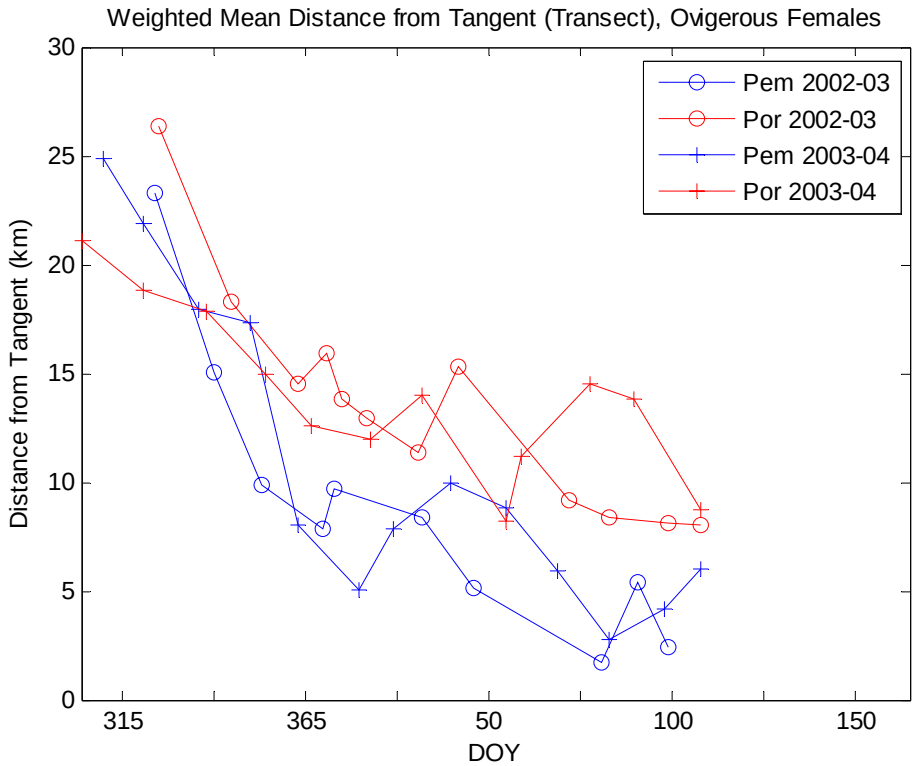


Fig. II-9. Weighted mean distance of ovigerous females (upper panel) and male shrimp (lower panel) from the reference line in Fig. II-1.



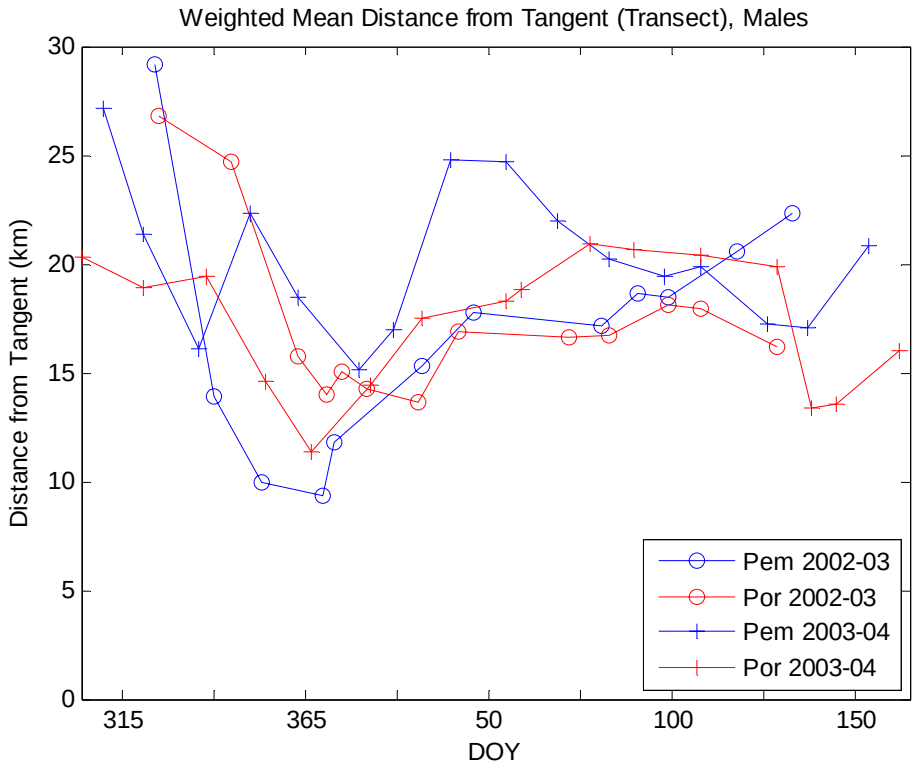


Fig. II-10. Across-shelf distribution and abundance of female shrimp at various times of the sampling seasons. Distributions are: A. ovigerous shrimp more than 2 weeks prior to the beginning of hatching in the population; B. as in "A", but within 2 weeks of hatching; C. ovigerous and FII females during the hatching period (Fig. II-5); and D. FII females after hatching. Distances are from the reference line in Fig. II-1.

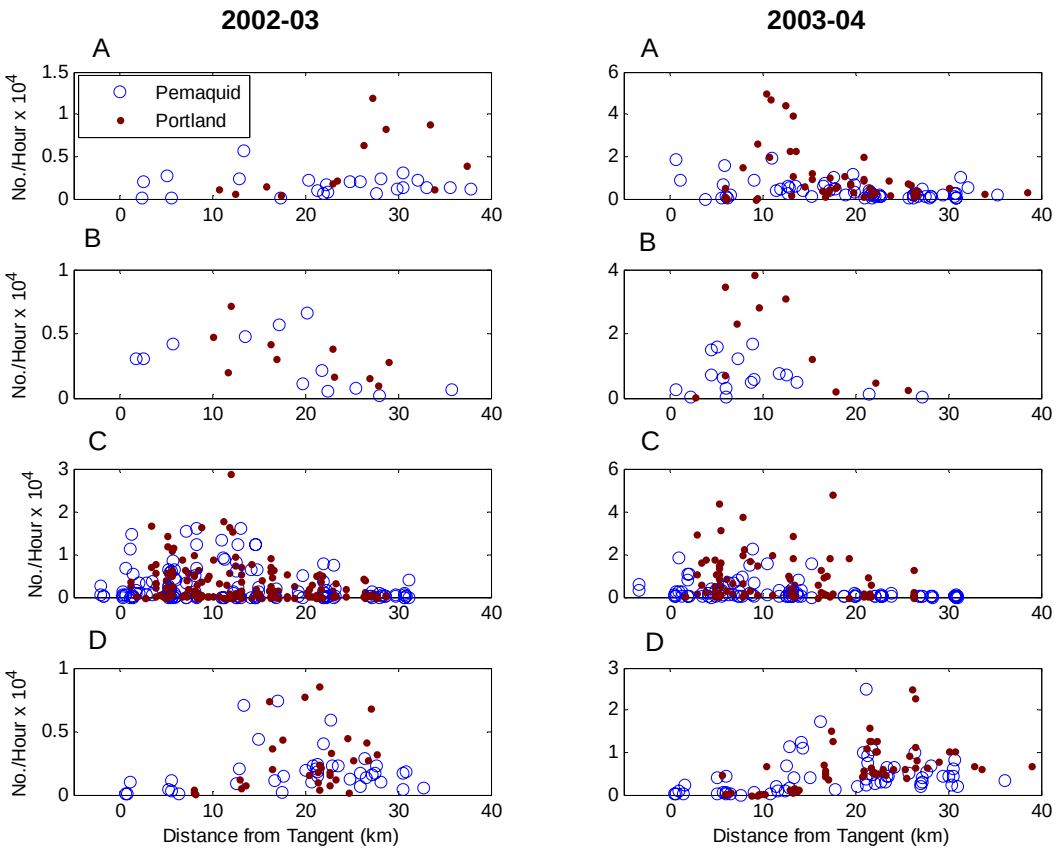
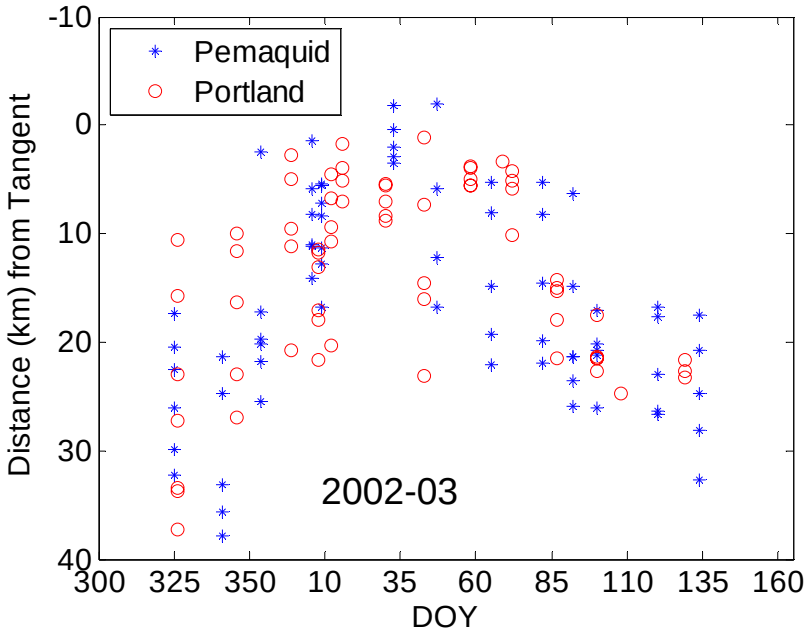
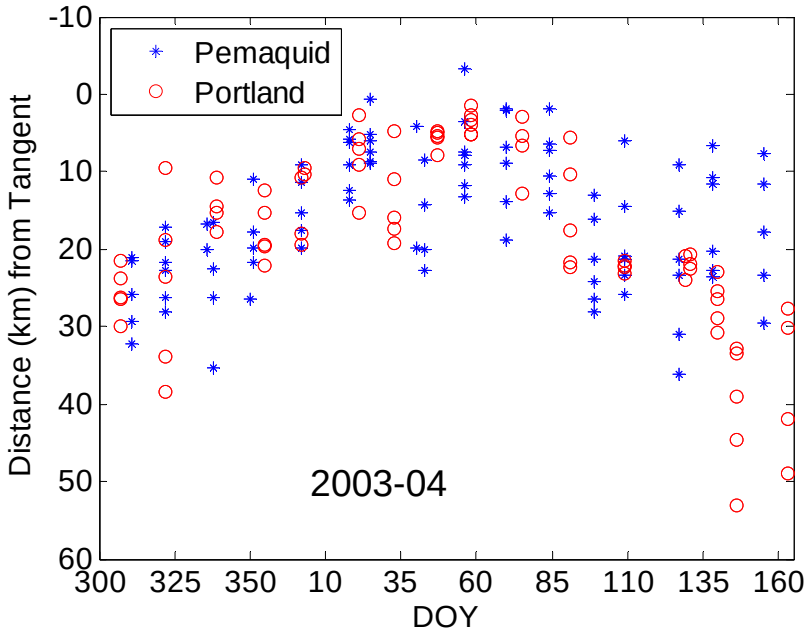


Fig. II-11. Location of “fishing stations” during the two years. Note earlier onshore concentration of effort in 2003-04.





PARTNERSHIPS

This project was a cooperative effort between the Maine Department of Marine Resources (DMR), the University of Maine (UMaine), the University of Southern Maine (USM), the Gulf of Maine Research Institute (GMRI), Vincent Balzano (F/V North Star), Stan Coffin (F/V Bad Penny), Dale Page (F/V Aaron & Sarah), Kelo Pinkham (F/V Jeanne C.) and Craig Pendleton (F/V Susan & Caitlyn). Roles of key personnel for this project were as follows:

Scientific Advisor and Year 1 Project Oversight, DMR: Daniel F. Schick provided scientific oversight and advice regarding experimental design, served as lead Principal Investigator, and reviewed project data and data analysis in Year 1. In Year 2 Schick served as scientific advisor and coordinator of the scientific team. Schick has a M.S. degree from the University of Maine and is an expert in shrimp stock assessments and conservation engineering.

Project Operations Oversight, GMRI: Laura Taylor Singer, Collaborative Fisheries Research Manager, served as a liaison between the five fishing vessels and the project scientists in Year 1 and served as overall project operations manager, providing vessel coordination and field operations for Year 2 of this project. .

Research Assistant and Field Coordinator, GMRI: Togue Brawn coordinated the vessels, served as an observer, and processed the shrimp samples in Year 2. Togue has experience working with diverse teams and coordinating project partners. She served as collaborative research assistant at the Gulf of Maine Research Institute, conducting a series of workshops for fishermen in early 2003.

Data Management Advisor, DMR: Margaret Hunter provided assistance to GMRI with data management and analyzed the results of the *Verification Survey of Abundance*. She is the Chairman of the Northern Shrimp Technical Committee for ASMFC and is in charge of shrimp research at DMR.

Field Operations and Laboratory Analysis Advisor, DMR: Lessie White assisted GMRI with training of observers and analysis of shrimp samples. White has a M.S. from the University of Maine, experience in fisheries, and is in charge of the DMR shrimp port-sampling program, including laboratory analysis of shrimp samples. He has regularly participated on the summer shrimp cruise and has served as crew chief on several gear trial trips.

Observer and Data Entry, GMRI: Temporary observers were hired to serve as scientific crew aboard the environmental monitoring transects by the Gulf of Maine Research Institute. These included: Gina Leduc, Sherrie White, Peter Brawn, Andrew Gowen, Lindsay Routt, Peter Faris and Shale Rosen.

Oceanographers, UMaine and USM: David Townsend (University of Maine) and Lew Incze (University of Southern Maine) oversaw sampling design, reviewed methodologies with the fishermen. Lew Incze analyzed the resulting data in terms of shrimp movements

and variability of the ocean's environment with Nick Wolff assisting with data manipulation and analysis.

Fishing Industry Participants: Captain Vincent Balzano (F/V North Star) and Craig Pendleton and Captain S. Mike Stinchfield (F/V Susan & Caitlyn): shared bi-weekly transects in the Portland area (8 trips per vessel) in both years of the environmental monitoring project. Each has a long history in the shrimp fishery.

Captain Stanley Coffin (F/V Bad Penny) and Captain Kelo Pinkham (F/V Jeanne C.): shared bi-weekly transects in the Pemaquid area (8 trips per vessel) in Year 2. The F/V Jeanne C. was involved in Year 1 of the environmental monitoring project while the F/V Bad Penny participated in the shrimp survey project during the summer of 2002.

Captain Dale Page (F/V Aaron & Sarah) served as an alternate vessel when needed. The F/V Aaron & Sarah was originally scheduled to participate in the shrimp survey project during the summer of 2002 but was not available. .

This collaborative research project included 21 different participants over the course of the project. It was clearly an ambitious undertaking and required a great deal of coordination. The first year of the project included several meetings to work through the logics of field operations and determine which vessels would participate in the summer survey and which vessels would participate in the environmental monitoring. The original plan was for both the F/V Bad Penny and F/V Aaron & Sarah to work on the summer survey portion of the project. However, prior to the start of the field work in the summer of 2002, the F/V Aaron & Sarah ran aground off of Boothbay Harbor and the vessel was under repair for the remainder of the project

It was difficult to maintain communications with all the partners during the field operations due to the amount of time and effort it took to schedule trips. The weather played a key role in the ability for trips to be successful during the environmental monitoring project. While attempts were made to shift vessels between the Portland transect and the Pemaquid transect, it became clear that having vessels familiar with the designated tows was most efficient. Therefore, in year two there was an attempt to have two vessels that would focus on the Portland transects and two vessels that would focus on the Pemaquid transects. The field schedule went more smoothly the second year as there was a dedicated project field coordinator, however, there were issues with the CTD equipment that were not recognized until after the field season was over.

It was difficult to run the field operations for the project from Portland at GMRI while the scientific leadership was at the Department of Marine Resources in Boothbay. Although the partners were very collaborative, the logistics and other demands placed on the participants made the coordination complicated. In addition, despite the dedicated staff support, there were still not enough resources for the scientific portion of the project to process all the shrimp environmental transect data in a timely fashion. The laboratory staff were part-time and in-kind participants so the work was delayed.

Regardless of the obstacles, the participants in the project were highly dedicated to the outcome and truly believe that the work was important to the Gulf of Maine shrimp fishery. There is a

strong desire to continue with this type of monitoring for the inshore areas of the Gulf of Maine to track the migration pattern of shrimp. Others who would like to undertake a project of this magnitude should budget for enough scientific support for both the field operations and the laboratory work-up. Agreements for in-kind support should be clear and a time table of deliverables should be agreed to by all parties and revisited as necessary. In addition, a regular conference call among key partners should be considered.

IMPACTS AND APPLICATIONS

Verification Survey for Abundance:
The project results showed that, where comparable, the industry surveys supported the findings of the state-federal survey. This should bolster management and industry confidence in the survey findings and the assessment which is so heavily based upon them. The project has also provided data which DMR plans to use to continue work on the question of adequate survey sample size. Project partner M. Hunter is Chairman of the Northern Shrimp Technical Committee for ASMFC and is in charge of shrimp research at DMR. Therefore, she is best positioned to use the information generated from this project to inform management decisions.

Environmental Monitoring for Migration and Recruitment:
A hypothesis going into this research was that a colder winter would favor more shoreward movement of shrimp, which would favor the larvae being hatched into nearshore waters where larval prey should be more abundant. Our results show a difference in the timing of shoreward movement of shrimp between years, and a difference in the time when hatching began (both earlier in the warmer winter), but no major differences in the location of hatching. While one year was 2-3 °C colder than the other, both were above the long-term mean for the area, so we do not have a truly cold winter for comparison. However, the data indicate that these comparatively warm winters did not cause shrimp to hatch offshore. These data provide a quantitative description of the onshore movement of ovigerous females and the different behaviors of females and male shrimp, previously described in general terms from fishing patterns. The hatching location and timing can be used for modeling larval drift, and for studying the spatial overlap between hatching patterns and winter zooplankton distributions.

Outreach

This project was presented at the Maine Fishermen's Forum as a poster in both 2003 and 2004 at the GMRI booth (see attached copy of the poster). In addition, the project was highlighted in the February 2003 addition of Collaborations (www.namanet.org/collaborations/collab_feb_03.pdf.)

This report will be presented to the ASMFC Northern Shrimp Technical Committee by M. Hunter at their February 2007 meeting, date and location to be determined.

Additionally, L. Incze will be presenting at the 2007 Fishermen's Forum to be held in March in Rockland, ME.

Data

All data collected for the Verification Survey and the Environmental Study will be provided to Northeast Consortium Fisheries and Ocean Database.

Related Projects

These results will be combined with data from a Sea Grant project awarded to D. Townsend and L. Incze to describe the distribution of larval shrimp in the Western Maine Coastal Current and the distribution of the late-winter phytoplankton bloom and zooplankton prey.

Future Research

A third year of data might have helped to better understand patterns of shrimp movement. A long-term monitoring program would be needed to figure out what is driving movements of reproductive shrimp. There is a strong desire to continue with this type of monitoring for the inshore areas of the Gulf of Maine to track the migration pattern of shrimp and other species. In addition, further work on determining adequate sample size for the summer survey would be of great benefit.

In 2000, DMR developed a series of research priorities for shrimp in partnership with the fishing industry (Alden and Perkins, 2001). There are still many questions identified in the Coastal Fisheries Research Priorities document that are worth pursuing.

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