Post-Larval Lobster (*Homarus americanus*) Distributions in Penobscot Bay in Relation to Hydrography, Circulation and Remote Sensing Information

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"Applications of Remote Sensing and Geographical Information Systems for Marine Resources Management in Penobscot Bay, Maine"

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INTRODUCTION

In 1999, the first year of larval lobster sampling, we sampled a series of nine transects radiating outward from the Vinalhaven/North Haven archipelago in the center of Penobscot Bay, Maine (Fig. 1). The transects, consisting of 39 stations, were organized to detect temporal and spatial changes in larval abundance between the west and east channels of lower Penobscot Bay and around the central island mass. At each station we sampled the abundance of planktonic lobsters, with an emphasis on the postlarval stage, and collected CTD, sea surface temperature (SST) and meteorological data (wind, air temperature, cloud cover). In conjunction with other components of this project (the "Penobscot Bay Collaborative"), our sampling program was designed to evaluate patterns and mechanisms of larval transport in and out of the bay and their influence on patterns of benthic recruitment. By understanding mechanisms and being able to model them, we are attempting to better understand the forces driving interannual and longer-term variations in recruitment as well as spatial relationships in the population (that is, the geography of egg production *vs*. the geography and variability of recruitment). Other components of the collaborative project (funded through a combination of NOAA/NESDIS and other sources) include satellite remote sensing (Andrew Thomas, UMaine), physical oceanography (Neal Pettigrew, UMaine), circulation modeling (Huijie Xue, UMaine), primary production (Maureen Keller, Bigelow Lab), benthic settlement and juvenile/adult lobster distribution patterns (Bob Steneck, UMaine), juvenile nursery-ground emigration and mortality rates (Rick Wahle, Bigelow Lab), fishery and sea-sampling data (Carl Wilson, Maine Dept. Marine Resources), and low inter-tidal lobster monitoring (Sara Ellis and Diane Cowan, The Lobster Conservancy).

Our data from 1999 are presented and discussed in last year's report and are mentioned only briefly here to explain our shift in sampling strategy for 2000. Our data from 1999 revealed the greatest number of first stage (SI) larvae south of Vinalhaven and in the western channel of the lower bay; few SI north and northeast of North Haven, and comparatively small numbers east of Vinalhaven (Fig. 1). Postlarvae were not at all abundant (Fig. 2). Our working hypothesis had two parts: (1) that the shelf (open coastal waters) is a particularly rich source of larvae, and that exchange between Penobscot Bay and the shelf is therefore an important determinant of recruitment abundance; and (2) that circulation in Penobscot Bay itself, coupled with development times and behavior of the planktonic stages of lobsters, favors recruitment in the lower west channel over other areas. While our data set from 1999 is very valuable, we spent a great deal of time sampling low numbers of larvae and postlarvae, and we felt that our efforts in 2000 should be directed toward the outer part of the bay. The patterns of circulation elaborated from 1999 and earlier years by Neal Pettigrew suggest that the main pathway for larval transport into the bay is via the western channel. Accordingly, for 2000, we established two new transects between the mainland (St. George peninsula) and Matinicus Island (Fig. 3, transects L & M) and continued sampling transects B and C from the prior year. We dropped one station from transect B, adjusting distances between the remaining five and renaming the transect B-2 (Fig. 3). Our plan was to sample these stations as before (neuston net, CTD, SST, meteorology) and move into the bay when and if the postlarval numbers became consistently large at the mouth of the bay.

METHODS

We sampled at 18 standard stations along four transects forming a polygon, roughly a triangle, which included the mouth of the western channel of Penobscot Bay and its approaches (Fig. 3; station locations given in Table 1). Sampling was done with a neuston sampler 1 m wide with a 0.5 m submerged portion which we towed at approximately 2 nm/h from a side boom. A mechanical flowmeter in the mouth of the net measured the distance towed, which was used to convert the catch rate to a standard area of 1000 m^2. The standard tow length was approximately 930 m. SST (to the nearest 0.1° C) was measured using a bucket sample at the beginning of each tow. Wind speed and direction, air temperature, cloud cover, and wave and swell height and direction were recorded during each tow. CTD profiles were collected from surface to near bottom using an internally recording Seabird Electronics SBE19 lowered and raised by hand over a davit and pulley. Net catches were sorted on deck. Larvae and postlarvae were removed and counted, placed in 4-oz jars of ambient seawater, and stored on ice and in the dark for later examination. Larval identifications and counts were later verified (sometimes the initial identification was difficult due to sea state) and the postlarvae were examined under a microscope to assess molt-cycle stage. Molt stage can be used in conjunction with SST to assign an approximate age to the organism (time since molt from SIII). Sampling was conducted by Nick Wolff, Ford Dye and Lew Incze (all from Bigelow Laboratory) and summer undergraduate student Phoebe Cohen from Cornell University. We used the University of Maine's R/V Nucella captained by John Higgins.

When postlarval abundances became low in mid-August (see RESULTS), we conducted some nearshore sampling along the windward shores of Vinalhaven (south shore) and Isle au Haut (west and south shores). Previous results showed that one usually can find postlarvae along shorelines exposed to the prevailing winds (Wahle and Incze 1997, Incze et al. 2000). We also conducted two offshore transects south of Isle au Haut (Fig. 4). Finally, we note the close proximity (by design) of sampling stations occupied by graduate student Eric Annis (Fig. 4). Although Eric's data will not be reported here, our results eventually will be combined to provide coverage of a significant portion of the midcoast region from Penobscot Bay to the 100 m isobath. Extra CTD work and tidal current observations (direction and speed from GPS drift rates) was conducted August 21 and 22 aboard R/V Alice Siegmund, with Capt. Corrie Roberts.

We thank John Higgins and Corrie Roberts for their extraordinary efforts and cooperation with our sampling program.

RESULTS AND DISCUSSION

We sampled one to two days per week from June 28 to September 22 for a total of 15 neuston sampling days over 12 weeks. We missed the first week in July due to mechanical problems and a full boat schedule that did not permit a make-up day; and we lost a half-day each at other times due to weather and to mechanical problems while at sea. With only a few exceptions, all 18 standard stations were sampled each week. Two extra days were spent with hydrographic surveys. In total, we collected 214 neuston samples and 243 CTD casts. Eighty-nine net tows (42%) contained either larvae or postlarvae.

Stage I Larvae

Nearly all of the larvae in the neuston nets were in first stage (SI), which was expected because this stage is more positively phototaxic than the next two (SII and SIII, of which we caught only a few). Neuston tows are not quantitative for SI, however, because this stage is not concentrated in the neuston layer (top 0.5 m in our sampling protocol). The proportion of SI that are in the neuston is not known and likely varies due to diel and weather-related changes in light level and probably other factors. Thus, SI distributions in the neuston layer are indicative of the presence of this stage, but the absolute abundance remains uncertain.

The total (seasonal) catch of SI is shown in Figure 5. Abundances along transects B-2 and C were not very different from those observed in 1999 (quantitative comparisons will be made in the final, synthesis, year of this grant). There was a large difference between the abundance at B-2 and C compared with transects L and M to the south. These differences existed over several weeks (Fig. 6) and warrant separation into two groups. We measured optical depths with a Secchi disk for two weeks at the beginning of our study and did not find much difference between the transects. Had there been a difference, it would suggest at least one factor that might lead to differences in vertical position of the larvae. We have looked at the depths of the pycnocline in the various transects through time to see if differences in hydrographic structure might create a more vertically restricted habitat for larvae along transects B-2 and C compared to L and M. The pycnocline at L-M appears to be a few meters deeper than at B-2, but similar to C. Surface temperatures were similar and should not have led to markedly different development times. As a result, we conclude that the differences in SI (standing stock) abundance in the neuston primarily reflect real differences in water column abundance. We will analyze this more closely in the coming year. At present, Transects L and M appear to have had either lower rates of supply (hatching) or higher rates of removal (advection/mortality), or both. Since we are dealing with the first larval stage, which we estimate was developing to second stage in about 4 days, differences in mortality rate would have to have been very high to explain the observed differences in SI abundance. Thus, lower supply or greater advective removal are more likely explanations.

Lobster Postlarvae

We caught only 19 lobster postlarvae at the standard stations in 2000 (29 in the season, including all other tows). The total caught at transects B-2 and C was similar to the number caught at those locations in 1999 (*cf*. Figs. 7 and 2). There were slightly more PLs caught at transects B and C compared to L and M, although the differences between the two groups are small (smaller than with SI) and some sampling dates are missing from L and M (see Fig. 6). The more even distribution of postlarvae compared with SI are consistent with an expected increased dispersion of the later stages. Although differences between the two groups of transects were small, we preserved the grouping for consistency with the SI analysis. The peaks in mean postlarval abundance at B-2 & C and at L & M occurred on the same sampling dates (Fig. 6). The timing of the postlarval "season" and of the peak abundance is similar to timing reported for other areas of the coast of Maine and New Hampshire (Incze et al. 1997, 2000a).

By early August (August 9 sampling date), the PL catches along our standard transects became low again (none were found on that day). Concerned that we might be missing them, that measurable numbers might be found along the shores on the windward sides of Vinalhaven and Isle au Haut, we spent a day conducting extra-long tows (> 2x our normal tows) within about 100 m of shore. Although shown as open circles in Figure 8, the tows were often contiguous. For example, in four tows we covered most of the southern shore of Vinalhaven, and in two tows most of the southern shore of Isle au Haut. This effort yielded only one PL, and provided some assurance that we were not missing an important part of the population by sampling at our open-water transects. The single PL found along the south shore of Vinalhaven translates to 1 PL/6761 m^2.

The two offshore transects proceeding south from Isle au Haut provided small but useful additions to our data. On August 16, the transect began offshore and was not completed due to deteriorating weather. However, it did show postlarvae (1-2/1000 m^2) in the warm, stratified layer offshore of the Eastern Maine Coastal Current, and nothing in the current itself (Figs. 9 & 10). This was at a time when PL abundance in outer Penobscot Bay was low (< 0.5 PL/1000 m^2), and it adds to other observations of significant PL numbers offshore (Incze et al. 2000a; E. Annis, 1999 unpubl. data). The source and ultimate fate of these postlarvae is of obvious interest to the larger question of lobster population dynamics in the Gulf as a whole (Incze and Naimie 2000). The second transect, on August 22, caught no postlarvae at all (Fig. 9). Its significance is primarily in extending the geographical coverage of our study for the later part of the PL season.

Preliminary Population Analyses

We combined postlarval (PL) data from transects B-2 and C and calculated an annual abundance by summing daily abundances over the season using a trapezoidal integration. This gave 42 PL/1000 m^2/year for the 2000 season. This is a low number compared to average values of around 200 PL/1000 m^2/year at Johns Bay, ME and Seabrook, NH for the period 1989-1995 (Incze et al. 2000a). However, it is not unprecedented, as we have had a series of low years at Seabrook since 1995 (Incze, unpubl. data) and a corrresponding decrease in settlement in the Boothbay region (indicative of low PL years there as well: R. Wahle, unpubl. settlement data; the relation between PL supply and YOY recruitment in the Boothbay region is shown by Incze et al. 1997). The lowest PL year at Seabrook was in 1998, with 47/1000 m^2/year. Both time-series are being readied for publication (Wolff, Incze, Cohen and DeVincentes for Seabrook postlarvae; Wahle, Incze and Fogarty for Boothbay settlement).

The annual abundance of PLs can be used to predict average settlement (=Young-of-Year recruitment) at a hypothetical shallow-water recruitment site using an empirical model of settlement success derived for Damariscove Island (Incze et al. 2000b). While no two settlement sites are completely alike, Damariscove Island is a well-known site to us and consistently one of the best recruitment sites we have measured (Incze et al. 1997; Wahle and Incze 1997). According to our model, settlement can be predicted as:

> [0.003 ∗ the tidally-driven excursion of water past the recruitment site/time ∗ the abundance of postlarvae/time] (Incze et al. 2000b).

Using this model with a hypothetical tidal velocity maximum of 20 cm/s, a sinusoidal tidal velocity function, and our PL data from Penobscot Bay this year, we estimate an average settlement density (YOY) of 0.12/ m^2. This is a low number, but not unrealistic: the average settlement density in the Johns Bay/Boothbay region this year was 0.13/m^2, with the highest density of 0.5/ m^2 observed at Damariscove Island (from R. Wahle, unpubl. data, with permission).

The temporal peaks in abundance that are quite clear in the SI and PL data from transects B-2 and C (Fig. 6) provide an opportunity to determine whether our data for the two ends of the planktonic period might have been derived from the same population. The peaks are about 15 d apart (Fig. 11), which is possible given the age spread within each group and the 6-7 d intervals between sampling (15-20 d is consistent with a revision of published development rates which we are now working on). If the timing is reasonable, what about the abundances? To answer this question we must estimate the total abundance of SI, recalling that the neuston is only a fraction of the water column total. We assume that SI are distributed above the pycnocline (Ennis 1995) and, for lack of other detail, that the distribution is homogeneous. The pycnocline on transects B-2 and C typically was no deeper than 10 m and sometimes was shallower. Recognizing that this is a very rough approximation, we assume that the SI are in the upper 8 m and that we sampled $1/16^{th}$ of the population by sampling the neuston (upper 0.5 m). Using the SI abundance thus estimated, and assuming that we sampled 90% of the postlarvae (see review by Ennis 1995, Incze et al. 1997), we determine an average exponential decay rate of 0.34/d. This decay rate, Z, is a generalized loss term comprised of mortality, advection and diffusion. We estimate that average mortality cannot exceed ~0.15/d and is probably less. The balance is due to dispersion and/or inaccuracies in the assumptions about abundance and time. This is a very preliminary calculation and is useful only to point out that we can account for the sampled postlarvae with local production based on the relative concentrations of early and late planktonic stages. To validate this interpretation, we must couple the development times and vertical behavior of life history stages with the circulation field to ascertain that the early stages are not completely removed from the area.

We have performed similar calculations working backward from the standing stock of SI, to the estimated daily SI production, and the egg production needed to support it. From there we have calculated the abundance and possible densities of ovigerous female lobsters. These calculations are preliminary and would not be very robust on their own, but are promising. Independent estimates of ovigerous female abundance and egg production should be possible from the fishery and sea sampling data. Hopefully, the two approaches will converge on a reasonable range of values that will guide further refinement of population estimates and vital rates for 1999 and 2000. We anticipate this as part of the synthesis effort in 2001.

Hydrography

Weekly CTD surveys showed hydrographic structures that differed a relatively small amount from week to week along each transect. Typical transects are shown for July 12 in Figures 12-14. The average stage of tide (in tenths) is indicated in the upper right above the top panel in each figure. A minus indicates a dropping tide; a positive number, a flooding tide (*e.g.*, "-0.2" means 2/10 of the ebb period following high water; "0.2" means 2/10 of the flood period following low water).

A slightly freshened layer from the Penobscot River outflow can be seen in the western portion of transect B-2 (Fig. 12). This layer appears to be more spread out (laterally) across transects L and M and with weaker vertical density gradients in the upper layer (Fig. 13). The small band of colder, saltier water at the eastern end of transect M appears to be the same feature seen at the southern end of transect C (Fig. 14). This band shows up to varying degrees in all samplings of these two transects and appears to originate from the shoreward margin of the Eastern Maine Coastal Current (EMCC). The northern, majority portion of transect C is stratified and warmer at all times compared to the southern end, and it is along this stratified portion that larvae and postlarvae were found (Fig. 7). In 1999 and 2000, the northern part of transect C most often resembled conditions along the eastern end of transect B-2, and it was warmer than water at the eastern entrance to Penobscot Bay (the area between Vinalhaven and Isle au Haut). Our observations of currents and hydrography during flooding and ebbing tides, August 21-22, are consistent with some degree of isolation between the eastern channel and the broad, comparatively shallow region south of Vinalhaven.

LITERATURE CITED

Ennis GP (1995) Larval and postlarval ecology. In: Factor JR (ed) Biology of the lobster *Homarus americanus*. Academic Press, San Diego, p 23-46

Incze LS, Aas P, Ainaire T, Bowen M (2000a) Neustonic Postlarval Lobsters, *Homarus americanus*, in the Western Gulf of Maine: Spatial and interannual variations. Can. J. Fish. Aquat. Sci. 57: 755-765.

Incze LS, Naimie CE (2000) Modeling the transport of lobster (*Homarus americanus*) larvae and postlarvae in the Gulf of Maine. Fish. Oceanogr. 9: 99-113.

Incze LS, Wahle RA, Cobb JS (1997) Quantitative relationships between postlarval production and benthic recruitment in lobsters, *Homarus americanus*. Mar. Freshwat. Res. 48:729-743

Incze LS, Wahle RA, Palma A (2000b) Advection and settlement rates in a benthic invertebrate: recruitment to first benthic stage in *Homarus americanus*. ICES J. Mar. Sci. 57: 430-437.

Wahle RA, Incze LS (1997) Pre- and post-settlement processes in recruitment of the American lobster. J. Exp. Mar. Biol. Ecol. 217:179-207

DATA PRODUCTS

We are submitting:

(1) an electronic version of the report with figures for use on the project web site;

(2) a single digital data file in GIS format of the neuston collections, including meteorological observations;

(3) a tarred file of all of the CTD data in GIS format; and

(4) a metadata file describing data collection, processing methods and file stuctures for the data sets.

Table 1. Neuston sampling stations and the standard stations and extra stations during 2000. Positions are in decimal degrees.

Station	Transect	Lon_dec	Lat_dec	Notes
12	C	-68.861	44.007	Standard
13	C	-68.861	43.985	Standard
14	C	-68.861	43.958	Standard
15	C	-68.861	43.938	Standard
16	C	-68.861	43.915	Standard
211	B2	-68.91	44.028	Standard
212	B2	-68.938	44.023	Standard
213	B2	-68.966	44.018	Standard
214	B2	-68.994	44.013	Standard
215	B2	-69.023	44.008	Standard
300	L	-69.15	43.953	Standard
301	L	-69.141	43.939	Standard
302	L	-69.125	43.925	Standard
303	M	-69.09	43.886	Standard
304	M	-69.052	43.88	Standard
305	M	-69.001	43.872	Standard
306	M	-68.972	43.864	Standard
307	M	-68.932	43.856	Standard
8090017	Extra	-68.828	44.028	8/09/00 0nly
8100001	Extra	-68.654	44.064	8/10/00 0nly
8100002	Extra	-68.648	44.046	8/10/00 0nly
8100003	Extra	-68.629	44.013	8/10/00 0nly
8100004	Extra	-68.621	44.018	8/10/00 0nly
8100005	Extra	-68.707	44.009	8/10/00 0nly
8100006	Extra	-68.807	44.034	8/10/00 0nly
8100007	Extra	-68.842	44.032	8/10/00 0nly
8100008	Extra	-68.85	44.026	8/10/00 0nly
8160001	Extra	-68.415	43.743	8/16/00 0nly
8160002	Extra	-68.416	43.747	8/16/00 0nly
8160003	Extra	-68.404	43.728	8/16/00 0nly
8160004	Extra	-68.403	43.727	8/16/00 0nly
8160005	Extra	-68.383	43.693	8/16/00 0nly
8160006	Extra	-68.45	43.778	8/16/00 0nly
8160007	Extra	-68.496	43.823	8/16/00 0nly
8220001	Extra	-68.658	43.995	8/22/00 0nly
8220001	Extra	-68.658	43.995	8/22/00 0nly
8220002	Extra	-68.616	43.946	8/22/00 0nly
8220003	Extra	-68.576	43.898	8/22/00 0nly
8220004	Extra	-68.539	43.85	8/22/00 0nly
8220005	Extra	-68.513	43.805	8/22/00 0nly
8220006	Extra	-68.458	43.751	8/22/00 0nly
8220007	Extra	-68.425	43.717	8/22/00 0nly

Table 1 (cont.)

8220008	Extra	-68.425	43.703	8/22/00 0nly
8220009	Extra	-68.388	43.652	8/22/00 0nly
8220010	Extra	-68.373	43.624	8/22/00 0nly
8220011	Extra	-68.367	43.621	8/22/00 0nly
8220012	Extra	-68.364	43.62	8/22/00 0nly
8220013	Extra	-68.357	43.616	8/22/00 0nly
8220014	Extra	-68.862	44.022	8/22/00 0nly
8220015	Extra	-68.828	44.028	8/22/00 0nly
8220015	Extra	-68.828	44.028	8/22/00 0nly
9140014	Extra	-69.165	43.957	9/14/00 0nly
206	Extra	-68.642	43.872	8/22/00 0nly
207	Extra	-68.642	43.9	8/22/00 0nly
208	Extra	-68.642	43.929	8/22/00 0nly
209	Extra	-68.642	43.957	8/22/00 0nly
210	Extra	-68.642	43.987	8/22/00 0nly