Northeast Consortium Final Report 2006

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Project: *The influence of water temperature on the distribution of berried females and duration of egg development in American lobsters*

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I. Rationale & Summary

The continued success of the North American lobster fishery is largely attributed to a high degree of broodstock conservation through the preservation of berried (egg-bearing) females. Several studies of berried lobster movements indicate that some, if not most, move offshore during the colder months and inshore during the warmer months waters to incubate their eggs and release their larvae (Campbell, 1986; Cowan *et al.,* 2006). The overall goal of the current study is to test the hypothesis that berried lobsters undertake these seasonal migrations in order to expose their eggs to a thermal regime that optimizes egg development and maximizes the survival of larvae. The project objectives were addressed by tagging and releasing berried lobsters and then monitoring both their movements and thermal history. All field studies were carried out in cooperation with commercial lobstermen who fished in NH, Maine and offshore waters. Initial results of large-scale tracking from two seasons combined indicates a trend by some inshore lobsters in maximizing degree days by moving short distances (5-10 km) offshore where eggs are subject to minimal degree days below 4^0C, a physiologically restraining temperature for positive egg development (Helluy and Beltz, 1991). In contrast, a select number of large female lobsters (> 100 mm CL) appear to be moving larger distances (> 15 km) from inshore to offshore locations in an overall south-southwest direction. These initial results confirm that lobster movements do influence the temperatures experienced by developing eggs. Ongoing data analyses coupled with current ultrasonic tracking laboratory studies should help determine the extent to which large movements actually enhance egg development and larval survival.

II. Objectives

The overall goal for this project has been to test the long-standing hypothesis that the movements of berried females serve to enhance the rate of egg development by maintaining their eggs at an optimal temperature. This hypothesis was tested by completing the following specific objectives:

1. Measure the thermal history of berried females in the wild, in four distinct geographical locations, using temperature data-loggers attached to their carapace.
2. Determine if the movements of berried female lobsters results in an overall increase in the number of degree-days they experience.
3. Assess if the migration of berried females serves to increase the rate of egg development and subsequently decreases the incubation time.

Our goals and objectives remain the same as originally stated above.

III. Approach and Work Plan

A. Tagging

Berried females were tagged with HOBO Tidbit® temperature loggers in the fall and winter of both 2004 and 2005 in cooperation with permitted lobstermen (see Table A1). Tagging was carried out in the vicinity of Portsmouth NH, Friendship ME, and in offshore (*e.g.,* George's Bank, Veatch Canyon) waters. Funding for the second season of tagging was not received until the middle of the fall, so we were not able to tag quite as many lobsters as we had originally planned. However, in general, the tagging process was successful, as indicated in Table 1A.

B. Eggs

When lobsters were first tagged, egg samples (typically 5-15) were carefully removed from each female, added to a tube of fixative, and sent back to our lab for later analyses at UNH. This process went very smoothly and lobstermen were very interested in sharing their information with us. Subsequently, we developed consistent methodologies for staging eggs and taking digital photographs to archive the data.

C. Recaptures

A number of lobsters have been recaptured and we received additional calls and temperature loggers via mail somewhat regularly at times (Tables 1A, 1B). Our biggest challenge was obtaining data from lobstermen who routinely harvest lobsters, but who are not participants, because they lack the proper permits to take eggs and the equipment to download tidbit tags. To help resolve this difficulty we added 8 participants to our 2005 scientific permits and expanded our efforts in publicizing our activities by placing informational flyers at local wharfs, fishermen co-op centers, and monthly newsletters (for example see Fig. A1, Table A1). We also sent out two batches of informational flyers (n_{total} ~ 350) via postal mail to selected groups of fishermen in New Hampshire and the Kittery-York Maine areas.

D. Data analyses

Data analyses are currently underway and remain as described in the original proposal (see below).

IV. Work completed to date

Most of the work that we had planned to accomplish by this time has been completed. Lobsters were tagged in the fall and winter of both 2004 and 2005 and we have been receiving a steady stream of recapture data. We are now in the process of analyzing those data and preparing a summary of our findings to share with the participants, publicize on our website and publish in scientific journals. We are also continuing smaller-scale tracking studies in NH waters that complement the data and progress from this project. We have purchased additional tidbit data loggers and we have a number of local lobstermen who have become very interested in the project and continue to help us with this work. Highlights and details are summarized below. This work was legally permitted (all permits on file) under the NH Dept. of Fish and Game, Maine Dept. of Marine Resources, NOAA and the Massachusetts Division of Marine Fisheries.

A. Lobster Tagging and Data Collection

Over the period 2004-2005 a total of 174 berried females were tagged with HOBO Tidbit® temperature loggers and released (Table 1A). From that total an average recapture rate of 39% (n = 68 individuals) was obtained from the three study regions combined.

A.

Region	NH	ME	OF	TOTALS
Tagged	49	57	68	174
Recaptured	17	21	30	68
Recaptured (%)	35 %	37 %	44 %	39 %

B.

Region	New Hampshire			Maine			Offshore		
Season	Fall	Winter	SpSum	Fall	Winter	SpSum	Fall	Winter	SpSum
Tagged	45	4	0	51	6	0	29	39	0
Recaptured	13	1	3	7	9	5	7	19	4

Tables 1A and 1B. *(A) Summary of tagged and recaptured berried lobsters by region fished. (B) Summary of tag/recaptures by season for each region. All data are for the years 2004-2006. Note that recaptures include multiple recaptures from some of the same individuals.*

For each tagged and recaptured lobster the latitude and longitude corresponding to either a tag or recapture event was recorded by commercial lobstermen and entered into our database. In the fall of 2004, we purchased a comprehensive GPS chart-plotting software package (Offshore Navigator v.5.04, Maptech, Amesbury, MA, http://www.maptech.com), which allows us to graphically plot and track lobster movements throughout their range and calculate their mean direction and distance traveled. We have plotted all tag and recapture data throughout each region to date (for examples see Figs. 1-3) and plan on translating these data to an ArcView GIS database. An associated table (Table A2) will provide information about all the lobsters in a particular study area and the tables will be linked to each location by a number code (Map ID in table). Together, the regional maps and tables will provide us, and the lobstermen, with a detailed profile of every lobster in the study along with information about where it has moved, including bottom temperatures and associated egg development.

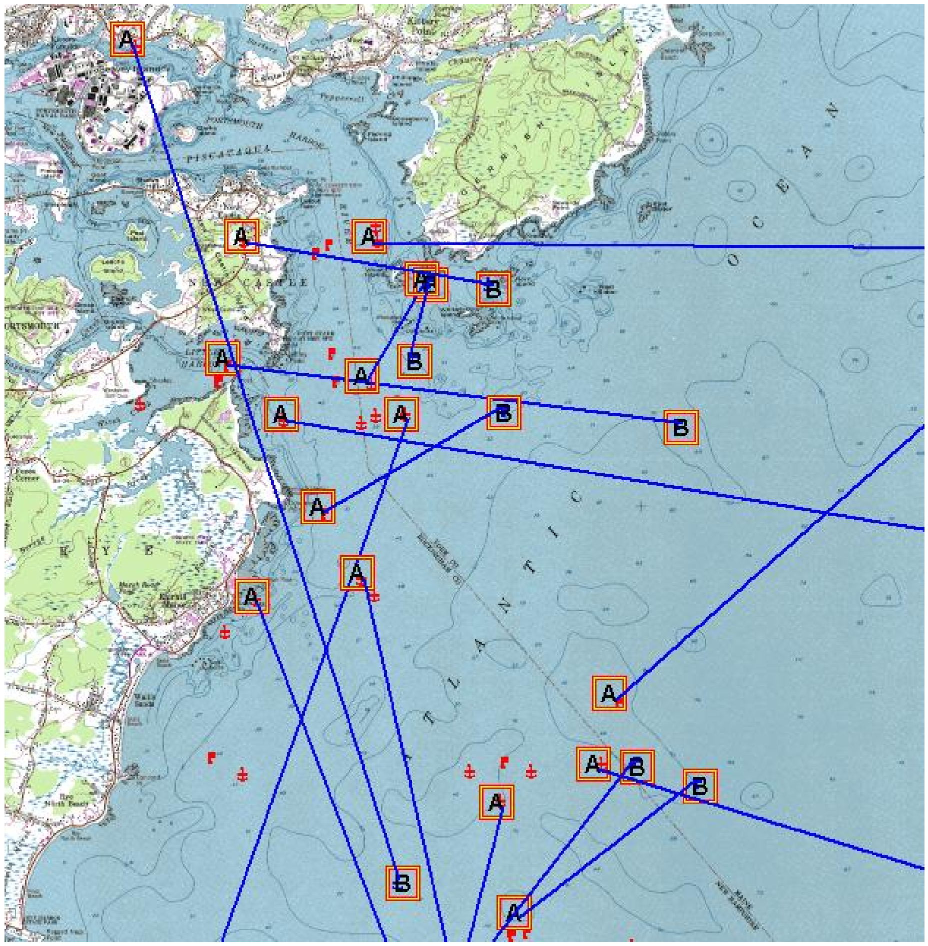


Figure 1. *Graphical representation of geo-referenced points of lobster tags and associated recaptures along the New Hampshire Seacoast region for fall 2004-summer 2006. Red flags and anchors correspond to 2004 and 2005 tags respectively. Not pictured are tags and recaptures from the Isle of Shoals. 'A' to 'B' boxes represents origin and recapture locations connected by blue lines. Note that blue lines continuing off the map are indicative of longer-distance movements.*

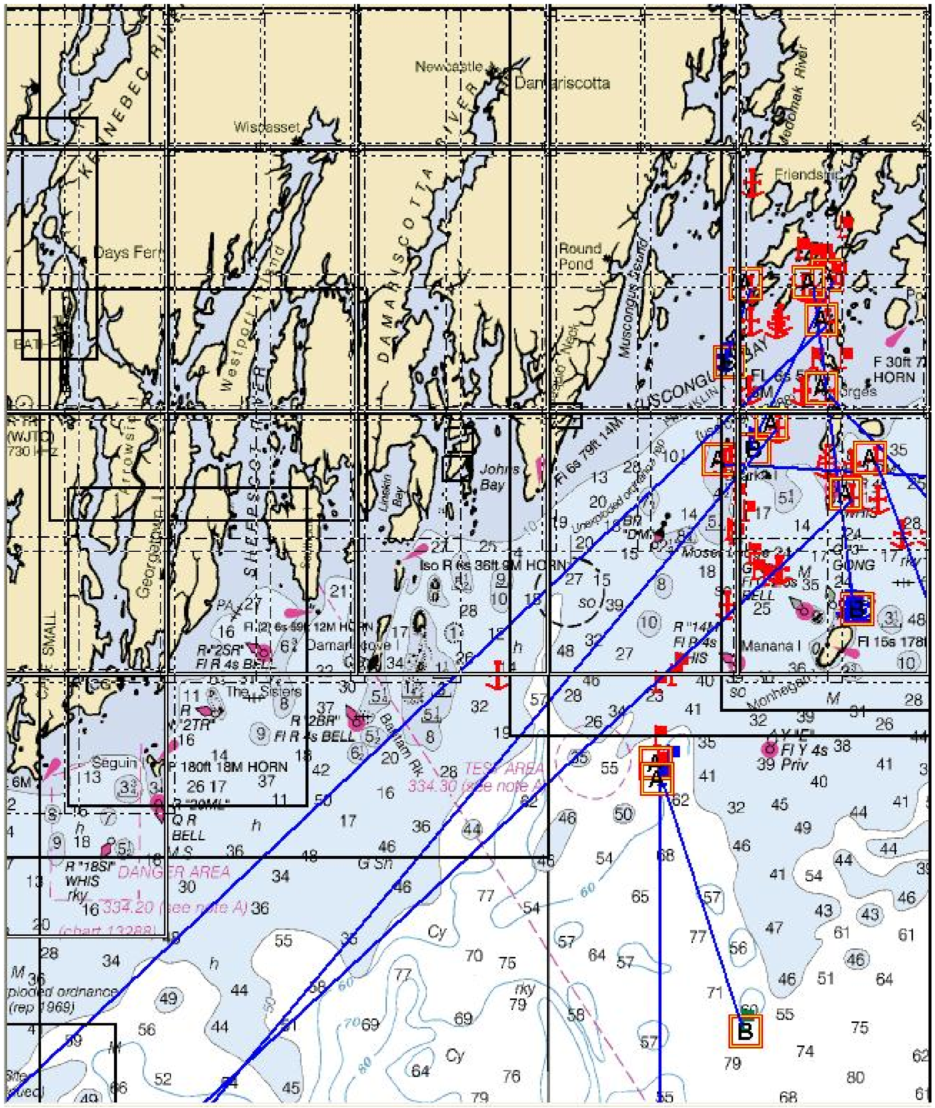


Figure 2. *Graphic sample of geo-referenced points of lobster tags and associated recaptures along mid-coast Maine near Friendship for fall 2004-summer 2006. Red flags and anchors correspond to 2004 and 2005 tags respectively. Not pictured are tags and recaptures from points east including Monhegan Island. 'A' to 'B' boxes represents origin and recapture locations connected by blue lines. Note that blue lines continuing off the map are indicative of longer-distance movements.*

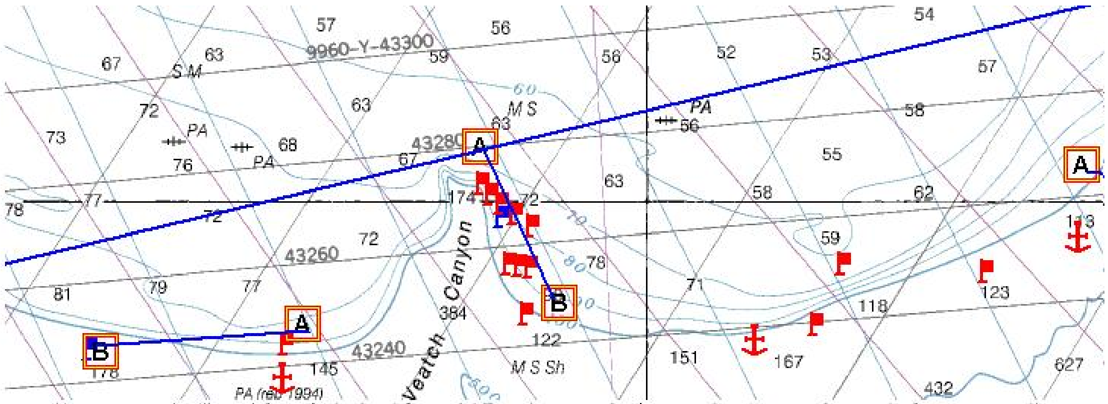


Figure 3. *Graphic sample of geo-referenced points of lobster tags and associated recaptures offshore for Veatch Canyon adjacent to George's Bank for fall 2004-summer 2006. Red flags and anchors correspond to 2004 and 2005 tags respectively (observe the pattern of tags placed along canyon contour lines). 'A' to 'B' boxes represents origin and recapture locations connected by blue lines. Note that blue lines continuing off the map are indicative of longer-distance movements.*

B. Egg Staging and Analysis

A total of 180 egg samples (6 eggs per vial) have been digitally analyzed and archived for a cumulative lot of 1,080 eggs. All eggs were processed in the lab using a Nikon SMZ-2T dissecting scope along with a Nikon CoolPix 995 digital camera. Digital egg pictures were then electronically measured and recorded using the shareware software Image J. v.1.38 (http://rsb.info.nih.gov/ij/). From this we have developed a consistent and efficient lab protocol to measure egg diameter, along with eye spot length and width. Thus, we can also compare our results with that of previous egg-staging studies (Helluy and Beltz, 1991). Quantifying egg size parameters has allowed us to correlate egg development rate to temperature data so that we can determine how temperatures experienced by berried females in the field influences egg development rate. We also plan to construct a digital library of egg pictures and make them available to project participants, lobster biologists, and the public on our website.

Egg Samples	**ME**	**NH**	**OF**	**Totals**
2004	30	19	37	**86**
Total # Eggs	180	114	222	**516**
2005	22	28	28	**94**
Total # Eggs	132	168	168	**564**

Table 2. *Summary to date of egg samples analyzed and archived 2004-2006. The total number of eggs is calculated from the multiplying the total number of samples by 6, the average number of eggs analyzed per each sample for this study.*

C. Temperature Logging

StowAway® TidbiT® temperature loggers (Onset Computer Corp., Bourne, MA, http://www.onsetcomp.com) were purchased in the fall of 2004 and summer of 2005 were used to tag each berried lobster using the methods developed by Cowan *et al.* (2006). Presently, lobstermen continue to send us these units when they capture animals we tagged last year. An example of the type of data we obtain from these loggers is shown in Figures 4A and 4B.

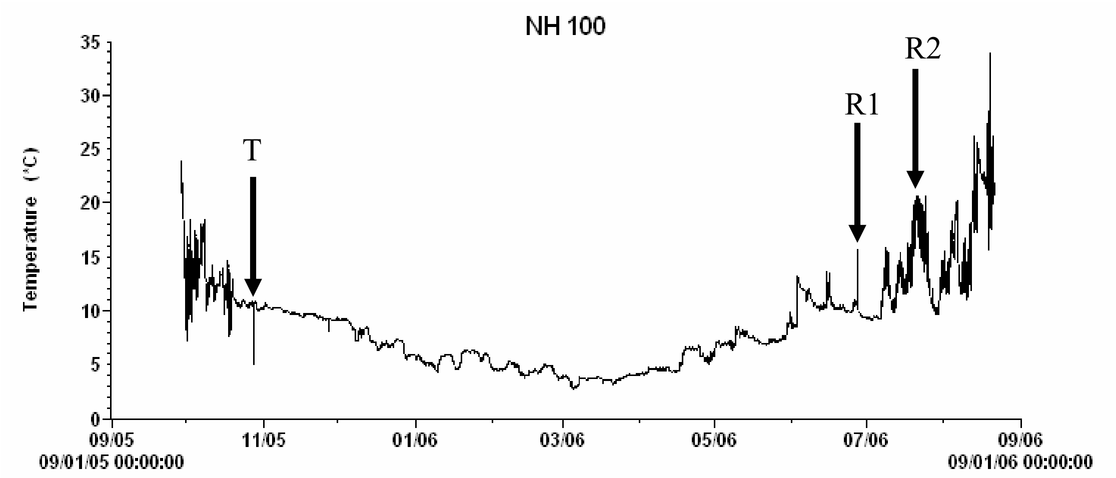


Figure 4A. *Example of downloaded temperature data from a HOBO tidbit. This tidbit was on a lobster (CL = 84.7 mm) that was tagged (T symbol) and released along the Seacoast in New Hampshire. On two occasions it was recaptured near Gunboat Shoals, NH (R1) and then just off of Fort Foster, NH (R2). When this lobster was brought on deck in July the air temperature was higher than the water temperature, causing the upward spikes in the record. Also note that the water temperature this female experienced along the NH Seacoast averaged about 7.3°C over the timeframe Oct 2005 to July 2006.*

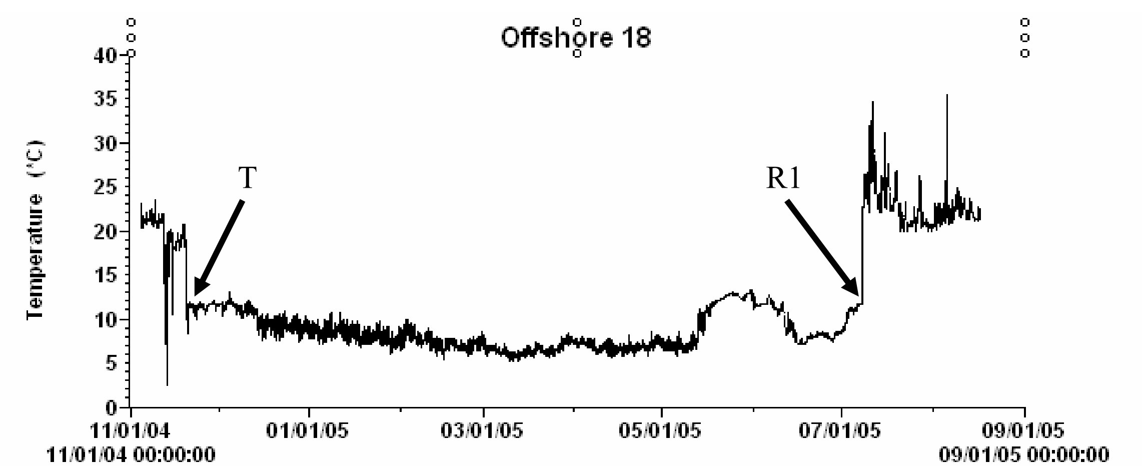


Figure 4B. *Example of downloaded temperature data from a HOBO tidbit. This tidbit was on a lobster (CL = 100.3 mm) that was tagged (T symbol) and released offshore (Veatch Canyon) and recaptured in July 2006 in a shallow shoal area near Veatch Canyon. Notice the slightly elevated and more stable temperature profile (avg = 7.9°C) compared with the inshore (NH) example and the gradually elevated portion (between May and July) indicative of movement from a deeper canyon area to a shoal area.*

IV. Results to Date

We have collected all of the data described above under the "work completed" section of the progress report. We are now in the process of compiling those data to determine: a) the relationship between lobster movements and the degree-days experienced; b) the relationship between degree-days experienced by females and the rate of egg development and; c) differences between each of the three regions were the studies were carried out. We anticipate our analyses of the data obtained from the first year of the study will be fully completed this winter after we have received the last of our recaptured temperature loggers.

<u>A. Movement</u>

A directional movement analysis of all recaptured lobsters in terms of their cumulative direction of movement was plotted using the circular statistical package Oriana v.2.0 (Kovach Computing Services, Pentraeth, Wales, U.K). Results from pooling all movement data from all locations using a Rayleigh's Z test analysis showed that in general lobsters of all sizes moved in a southward direction irrespective of region (mean angle = 192^0, Z = 18.77; p = 0.001) (Fig 5).

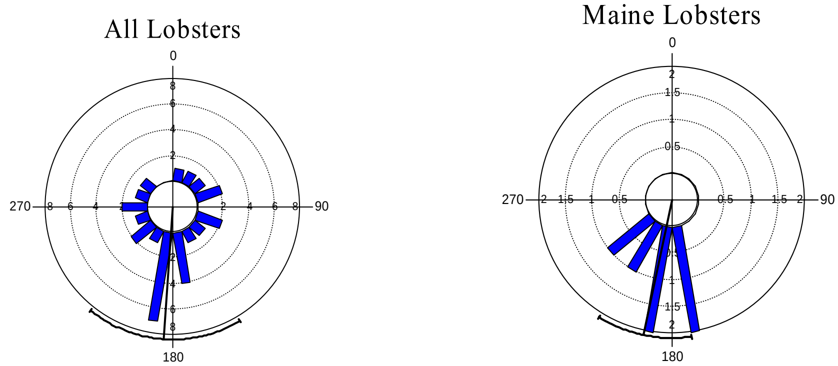


Figure 5. *The direction moved between tagging and recapture by all lobsters (left graph) and just the lobsters from midcoast Maine (right). The light gray line indicates the average direction of movement. Also shown (under blue bars) is the mean vector line and associated variance (bold-blackened 'T' line).*

Overall movement by berried females was greatest in offshore regions (mean = 80.3 ± 19.6 km., n= 8, max = 228 km), followed by Maine (mean = 41.8 km ± 24.0) and New Hampshire (mean = 27.0 km ± 19.6). Although movement was not statistically significant between regions, a strong trend was evident (SAS PROC Mixed Model ANOVA, F = 1.93; df = 2,37; p = 0.159, 1-β = 0.45; n = 40) and warrants further analyses. Follow up statistical contrasts (SAS 9.1, SAS Institute, Cary, NC USA, <u>http://www.sas.com</u>) did indicate no significant differences between offshore and Maine lobster movements (F = 0.18; df = 1,37; p = 0.673) but did yield borderline significance for movements between offshore and New Hampshire animals (F = 3.68; df = 1,37; p = 0.0623).

Larger lobsters (> 90.0 mm CL) tended to move much further than smaller ones (large = 57.2 km; small = 4.8 km), however, due to the large range of distances moved by small lobsters, size differences were only borderline significant (SAS PROC mixed model ANOVA, $F = 2.03$; df = 1,38; $p = 0.162$; $n = 40$). This latter variation with small lobsters may be indicative of the many episodes of short and erratic movements as quantified by our mapping program and observed by fishermen throughout the year (see Golet *et al.,* 2006)

Patterns of movement were generally tied to seasonal periods of overall lobster movement typically observed by lobstermen and documented in related studies (Fogarty *et al.,* 1980; Krouse, 1980; Campbell, 1986; Comeau and Savoie, 2002; Cowan *et al.,* 2006). Although many berried females (regardless of size) moved very small distances (< 5 km), animals that exhibited larger movements (> 15 km) tended to congregate in some cases at similar locations and were recaptured in areas that we would refer to as aggregative 'hot-spots'. For example, five lobsters (3 from NH and 2 from ME) were all found in the vicinity of Cape Ann, Massachusetts and several other lobsters tagged just at the mouth of the Piscataqua River in Portsmouth, NH tended to be caught in the Kittery Point area of Maine. In offshore locations, tagged animals were often recaptured in shallow shoal areas (100-300 m) after presumably residing at much deeper (and thermally stable) depths in the winter. Related studies with other mobile crustaceans (*e.g.,* dungeness crab and spiny lobster) have correlated seasonal movements and brooding-site fidelity in relation to habitat use (Groeneveld and Branch, 2002; Stone and O'Clair, 2002). These models need to be tested more rigorously and quantified for small-scale movement patterns in order to more fully discern potential ecological connections to habitat type (*e.g.,* known mating or hatching areas) (Gonzalez-Gurriaran and Freire, 1994), or for residing in favorable thermal zones (Cowan *et. al.,* 2006).

<u>B. Egg Development</u>
Egg development based on the Perkins Eye Index Formula (PEI) (Perkins, 1972) was calculated and expressed for all tagged lobsters (Table 3) as described in previous reports and is expressed as total % development (% D). Additionally, egg volumes were calculated for these spherically-shaped eggs as: $V=4/3*\pi r^3$, where r is the radius similarly to other studies (Garcia-Guerrero and Hendrickx, 2004; Sibert *et al.,* 2004). Initial egg development was not significantly different within the two inshore regions (ME and NH) (mean = 23.5%) ($p = 0.790$, REGWF post-hoc test, $\alpha = 0.05$) but did differ from offshore locations (mean = 34%) ($p = 0.032$, REGWF post-hoc test, $\alpha = 0.05$). Part of this disparity might be that offshore lobsters were typically tagged 2-3 months later than inshore animals and were therefore slightly accelerated in their egg development. Egg volume did not significantly differ by lobster size or location ($p = 0.792$, Tukey's HSD post-hoc test, $\alpha = 0.05$). In general, lobster egg volume increases with development and was quantified in a related study (see section VI below).

			2004	2005	
Region	***Egg Vol (um^3)***	***PEI***	***% D***	***% D***	***AVG***
OF	3032	199-210	35	32	34
ME	2572	92-160	16	28	22
NH	2819	152-160	27	23	25

Table 3. *Egg volume in µm^3 and Perkins eye indicies (translated to % development) for all eggs sampled from berried lobsters tagged in 2004-2005. Note that this includes all initial egg data and is not representative of subsequent recaptures.*

C. Temperature

For all the lobsters from which we successfully retrieved Tidbit loggers (n = 40) we calculated the average temperature they each experienced over their total days at liberty (for examples see Table 4). In addition we tabulated the average cumulative number of degree days for these animals based on a threshold value of 4^0C, below which embryonic development ceases (Templeman, 1936; Helluy and Beltz, 1991).

We broke up our temperature and degree day analyses into a) lobsters that were recaptured and demonstrated short (< 5 km) movements within a particular region (*i.e.,* resident lobsters); b) lobsters that were recaptured and showed marked movement (> 5 km) into a different region (*e.g.,* Maine to offshore); and c) lobsters that presumably moved to a nearshore (5-10 km) (*e.g.,* Isle of Shoals, NH) or offshore location (*e.g.,* Jeffery's Ledge) (> 10 km) and later returned back to an inshore location. Temperature profiles for all treatments differed with respect to their max/min values, and rate of cooling or heating (Tables 4).

Lobster ID	Temp Avg (C)	DD Avg	Depth (m)
ME	6.5	902	8
ME	8.5	135	5
ME	5.4	288	49
ME	4.1	300	91
ME	2.2	162	79
ME	3.2	69	46
ME	4.6	90	44
NH	5.5	384	31
NH	6.1	393	27
NH	6.2	978	34
OFF	8.2	1131	201
OFF	6.8	591	241
OFF	6.5	534	216
OFF	9.2	1089	256
OFF	8.3	897	247
OFF	7.9	789	271
OFF	7.7	561	305

Table 4. *Average temperature and associated degree days (calculated from a 4^0C egg development threshold) for a subset of berried female lobsters tagged and recaptured from NH, ME, and offshore locations for 2004-2006. Also shown are average depths for tagging (in meters).*

Over the period of temperature logging (typically Oct-June), lobsters that showed minimal movement were exposed to average temperatures of 5.1 ± 0.87, 6.1 ± 0.73, and 7.8 ± 0.41 for NH, ME, and offshore locations respectively at an average depth of 30 m (NH), 46 m (ME), and 200 m (Offshore). Temperature profiles from offshore showed the most stability indicated by the SEM (also see Fig 4B). At these profiles for this period of ~ 9 months our calculations for degree days (DD) (*i.e.*, total number of days below the 4^{0}C threshold) afforded offshore animals with the largest segment of DD at 800 followed by ME with 650 and finally NH at 275. By contrast lobsters that showed movement to another region typically gained additional degree days. For example, one lobster tagged along the NH Seacoast gained ~ 150 more DD enroute to Cape Ann, MA compared with staying resident at the original tagging location. Similarly there were a few tagged animals whose data we collected indicated an additional accumulation of DD when moving offshore and then inshore again in the spring and summer. By contrast, we were not able to pick up a discernable difference in DD between berried lobsters moving intermediate distances (5-10 km) such as from the NH Seacoast (Portsmouth) to Isle of Shoals or ME midcoast (Friendship) to Monhegan Island. In general the data we obtained from HOBOs located on lobsters corresponded well to patterns found in data logged by fixed buoys (GOMOOS, http://www.gomoos.org) as represented in Figure 6.

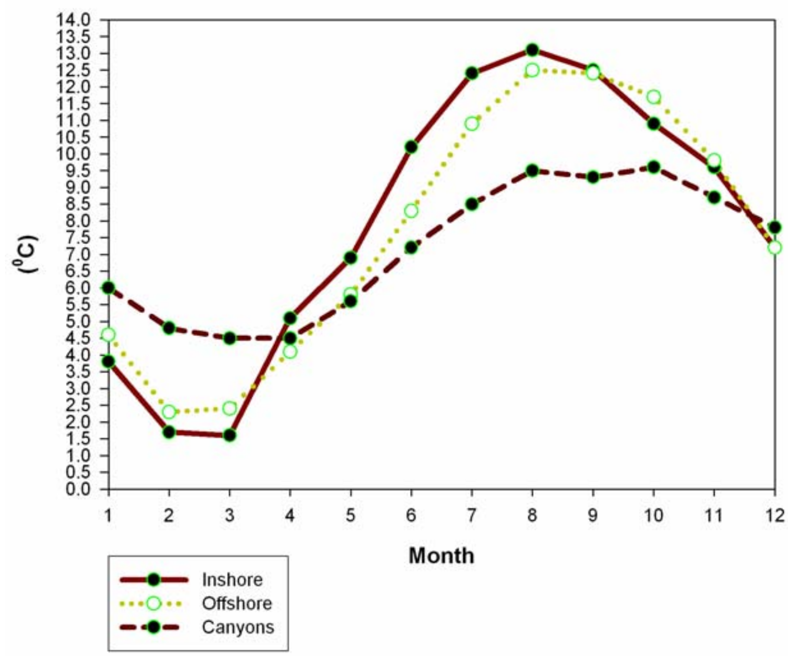
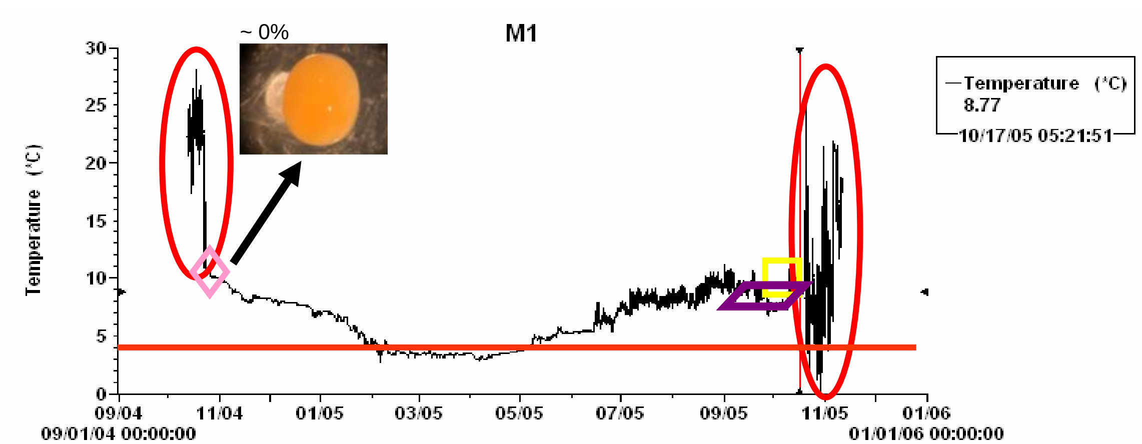


Figure 6. *Inshore, offshore and deep canyons temperature profiles at representative depths from 2003-2005. Differences in max/min as well as overall fluctuations are apparent and represent thermally distinct zones.*

D. Modeling

A key component to this project is being able to link temperature data with corresponding egg development and predict a relative hatch time and in some cases the location of larvae release. Many of our comprehensive lobster profiles (temperature plus tag/recapture information) are predicated on the notion that exposure to changing temperatures results in varying rates of egg development that can act favorably on egg quality and to synchronize the timing of hatch with optimal abiotic (light, temp) and biotic (spring plankton bloom) conditions (Cushing, 1990; ongoing study in our lab). Obtaining a sufficient number of DDs does not necessarily mean movement to, and residence at, the warmest possible temperatures. Extensive lab studies by Aiken and Waddy (1986) have shown that successful timing to hatch includes a period of cold winter temperatures (DD < 4^0C) that may help to prolong time of hatch and allow egg development to occur without prematurely catabolizing valuable egg lipid reserves (Ouellet and Plante, 2004).

We examined several temperature and egg development profiles from recaptured lobsters in an attempt to begin to predict time and location of hatch over the array of temperatures experienced over the time at liberty. The Perkins Eye Index formula (PEI) attributes egg development to a model for temperature specific development times and was modified so that we could follow an egg's daily development at a specific temperature (calculated per average of each month) (Figs. 7A and 7B). We also were able to calculate the total number of DD that corresponded to each month and compare that figure with a relative number of DD necessary for hatch. Campbell (1986) notes that 1,832 degree days (calculated from Perkins, 1972) are needed for complete egg development. An example of this is given for an offshore lobster in Table 5.



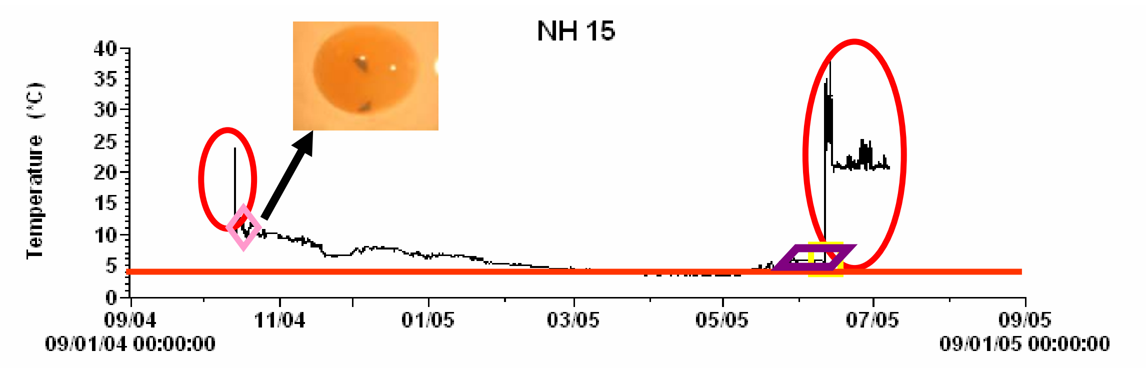


Figure 7A & 7B. *Temperature-predictive models for egg hatch based on a ~ 1 year temperature profile for tagged berried females carrying eggs that were calculated at 0% developed (i.e. no eyespot formation) in October, 2004 in Midcoast Maine (M1) and 20% developed (notice black eyespot patches) in New Hampshire (NH15). Red oval circles indicate surface interval time and were removed from the analysis, the pink diamond indicates date of tag and release, purple parallelogram represents predicted time of hatch while the yellow square was a recapture event by which a lobsterman reported visual signs of recent hatching. Predicted hatch was calculated by 1) adding up the degree days for each month and comparing them to the minimal number needed and 2) applying the PEI formula to each month's average temperature. The straight orange line at 4^0C indicates the threshold temperature below which embryo development is minimized. The 'M1' lobster was assumed to have resided in inshore waters for the duration of its tagging period while 'NH15' was recaptured once at Isle of Shoals, NH.*

V. Impacts and applications

The results reported herein support our hypotheses and previous reports (Cowan *et al.*, 2006). Some lobsters were resident nearshore during most of the year and some migrated distances > 5 km and spent colder months nearshore (>5 km from shore). Lobsters that moved to nearshore locations were exposed to temperature profiles that were characterized as more stable and less variable than those remaining inshore. We are currently attempting to determine if this migratory behavior is advantageous to egg development and larval survival. The gradual fluctuations experienced by nearshore lobsters may help to orchestrate a 'holding' period whereby larval release can coincide with gradually warming surface temperatures (> 10^0C) that promote better survivorship of newly hatched larvae (MacKenzie, 1988; Harding *et al.*, 1983).

The aforementioned data, taken together with results from ongoing studies, will help clarify existing ambiguities concerning the movements of berried lobsters. Most importantly, our data may explain how these movements influence the survival of new recruits and help to provide valuable biological inputs for future fisheries modeling and forecasting (Comeau and Savoie, 2002; Incze *et al.,* 2006). In addition, the information gained, combined with knowledge of the thermal limits of larvae should help scientists identify likely locations where berried females reside during different times of year. This information may help managers identify potential marine sanctuaries, help lobstermen avoid fishing these areas, and help modelers determine the source of new recruits.

Although female size was not a significant contributor to overall egg development up to 70%, it is reasonable to assume that large females confer distinct advantages in population replenishment and recruitment events solely based on their fecundity as has been documented by Attard and Hudon (1987) as well as Tully *et al.* (2001) for a related Homarid (*Homarus gammarus*). As such it was not surprising that these larger lobsters showed the largest movement events. By contrast, however, studies by Ouellet and Plante (2004) show that egg quality and larval size at hatching were independent of female size (CL). Instead, the largest contributor to egg weight, volume, and stage I larvae were the individual female itself. In other words, each female may possess a suite of internal factors (*e.g.,* nutritional, genetics, thermal profile) in determining egg quality. Other factors that have been recognized include ovarian maturation, egg production, and possibly egg viability (Gendron *et al.,* 2001; Ouellet and Plante, 2004). We suspect that many of these other traits may be highly correlated to movement and deserve a more rigorous examination.

VI. Related projects

We are currently in the middle of a related project designed to determine how exposure to different temperature regimes influences the growth of eggs and the survival of larvae. This work is a direct extension of the studies described above. Jason Goldstein, a PhD. student on this project, is also concurrently conducting some laboratory experiments looking at the effect of constant versus fluctuating temperatures that berried lobsters may experience during their long egg incubation periods. The data and results from this lab project will help guide these studies along this fall towards understanding the impact that degree days and manipulated temperatures have on egg development and successive larval survivorship. Some preliminary data suggests that differences in egg development and body size are related to the fluctuations and values in seawater temperature to the effect that at a constant (artificial) temperature regime, egg quality becomes negatively compromised. This data suggests that regardless of female size or maturity, lobster embryos progress steadily through their developmental periods attaining larger sizes prior to hatch. However the real implications arise in considering the effect on larval survival later on. This needs to be addressed in more detail as well as assessing other characteristics of egg quality and health such as protein, lipid, and carbohydrates. One way we will augment this existing study is to place berried lobsters in modified cages this fall and distribute them in inshore (NewCastle, NH) and nearshore (Isle of Shoals) locations and study egg development and changes to their biochemical composition over time at each temperature regime.

In the field, we will also be looking at the fine scale movements of berried females using ultrasonic telemetry (VEMCO VRAP system, http://www.vemco.com/index.php) around the NH Seacoast and comparing those movements to that of non-berried animals to test the hypothesis that berried females exhibit movement patterns (*e.g.,* rate, distance traveled) to thermally distinct habitats compared with non-berried females that may not. This particular study will track approximately 10 berried and 10 non-berried lobsters of both small and large sizes. In addition we will continue to collect data on bottom temperatures around the study area by mounting underwater temperature loggers at selected sites.

In all these companion studies, we will compare and contrast our results with that of this existing study and use our new data in helping to further bolster our modeling for predicting hatch, larval release, and the overriding affect of temperature on berried lobster movement.

VII. Partnerships

This project had originally involved 23 participants who are commercial lobstermen. Since that time we have added an additional 6 participants which not only facilitated our ability to add more tags, moreover, it created a larger community by which to monitor and communicate our goals and results with. We have also forged informal partnerships with both the Maine and Massachusetts Lobstermen Associations and they have allowed us to post at no cost updates and informational flyers in their monthly newsletters (see Appendix) covering three states and over 2,000 lobstermen.

In both of two tagging seasons lobstermen were given the appropriate supplies (*e.g.,* tags, data sheets, egg preservation tubes) a copy of a current permit, and any instructions on modifications to previous tagging or data collection. On several occasions one or more UNH students joined lobstermen on their vessels and worked together at tagging and taking egg samples.

For the most part, all participants had no trouble tagging lobsters and saving eggs for our analyses. Our major problem was that lobstermen who were not participants and therefore did not have an appropriate permit, often recaptured tagged lobsters but they could not save the eggs. Also, due to financial limitations, we could not provide non-participants with devices necessary to download the tidbit data. We often spent time on the phone (> 50 hours) talking with lobstermen who called in recaptured lobsters and were not participants on the project. Many of these individuals wanted to know something about the project or had related questions.

VIII. Presentations

"Do seasonal movements of ovigerous lobsters (*Homarus americanus*) enhance egg quality and larval survival? Jason Goldstein and Win Watson, 7th International Conference on Larval Biology, Summer, 2006, Coos Bay, Oregon.

"The influence of water temperature on the distribution of berried females and duration of egg development in American lobsters", Win Watson and Jason Goldstein, NH, SeaGrant Fisheries Round Table, Winter 2006, Urban Forestry Center, Portsmouth, NH.

"The 'true' secret life of lobsters", Jason Goldstein, UNH Marine Docent Program, Winter, 2006, UNH Alumni Center, Durham, NH.

"Long-term influence of water temperature on the distribution and egg development in berried female American lobsters"**,** Jason Goldstein and Win Watson, NEC Annual Meeting, Fall 2006, Sheraton Hotel, Portsmouth, NH.

We will organize and schedule at least one informal meeting with lobstermen participants at UNH this fall in order disseminate our summary findings to them, receive feedback for future studies, and pay our thanks for their hardwork and efforts.

IX. Student Participation

So far the project has employed several graduate (Jason Goldstein, Heidi Henninger, Darren Scopel and Chris Rillahan, all UNH) and undergraduate (Sarah Havener, Adam Chouinard, Lisa Bedford, Michelle Provencier, Nicolette Pocius, May Grose, all UNH) students who have participated in field, and/or laboratory work related to this project. One undergraduate student, Sarah Havener, is the daughter of one of the Maine lobstermen and continues to be active on this project. Olivia Hutton, a junior at Berwick Academy H.S. in Maine has also been involved in some of the recent data entry. Currently, the main Project Assistant is a PhD graduate student, Jason Goldstein.

X. Published Reports and Papers

None yet.

XI. Images

The following files and images were submitted electronically at the last progress report:

- lobster egg digital pictures of eggs throughout varying stages of development
- contents of lobster kits put together for lobstermen participants
- lobster with Tidbit attached
- excel spreadsheet with tag and recapture data for all lobsters to date

The following new files and images will be submitted electronically:

- excel spreadsheet with tag and recapture data for all lobsters 2004-2006
- representative pictures from project
- CD-ROM of all lobster tracking profiles to date including their thermal history in cases we have it

XII. Literature Cited

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NEC FINAL REPORT
APPENDIX

Table A1. *Compiled list of participant vessels and their associated efforts in lobster tagging from 2004-06. This does not include vessel time involved in processing recaptured animals which included a more extensive list of vessels including many non-participants.*

Vessel	Region	# Lobsters Tagged
ASAP	ME	21
Maureen R	ME	13
Miss Jemepa	ME	1
Sarah Ashley	ME	20
Three Sons	ME	7
Gretchen D	NH	11
Molly Too	NH	6
Prospector	NH	13
Special K	NH	18
Barbara Ann	OF	4
Eulah McGrath	OF	18
Hedy Brenna	OF	8
Nathaniel Lee	OF	19
Virginia Marie	OF	6
William Bowe	OF	9

Figure A1. *A sample flyer that was posted at local wharfs and published in two regional lobstermen newsletters. Flyers were often updated to reflect recent changes in tagging or seasons and allowed to contact us by phone or email.*

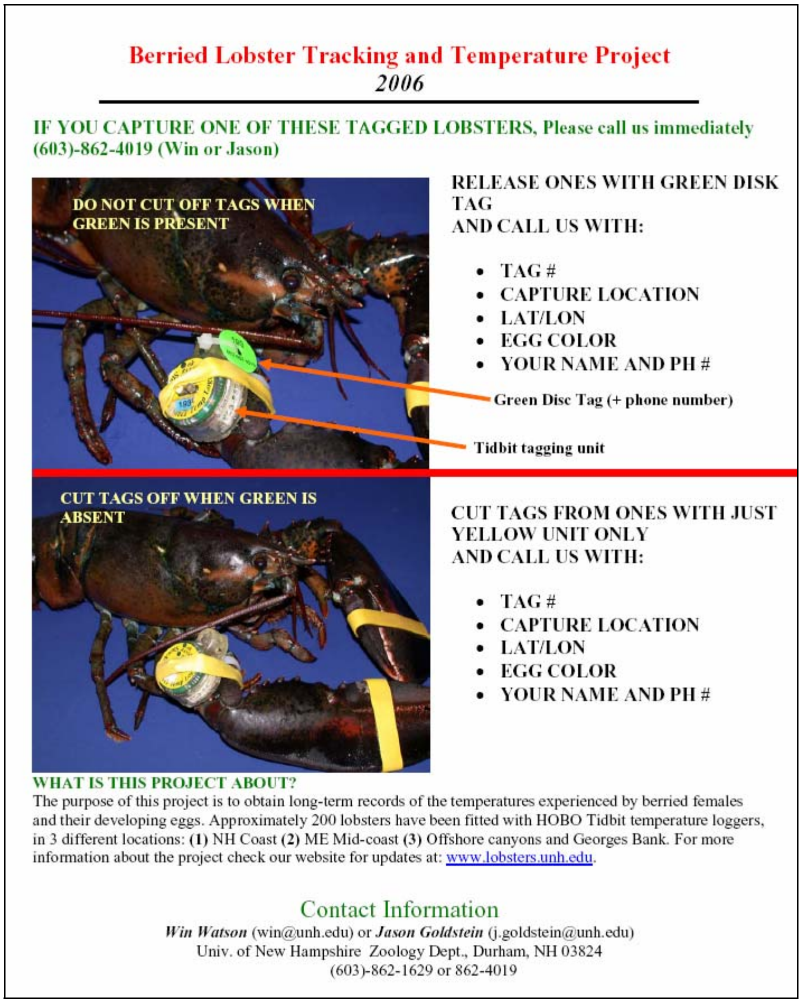
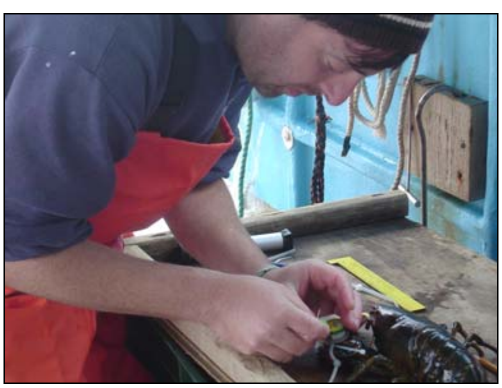
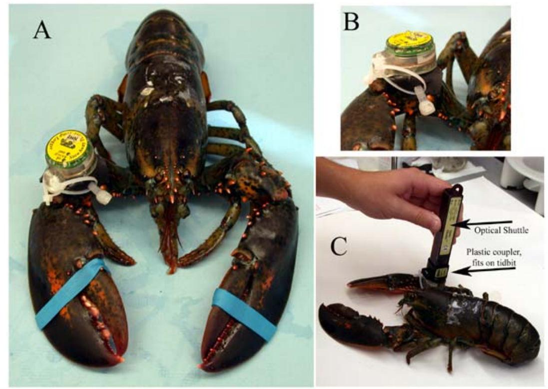


Figure A2. *Representative graphic images from the NEC berried lobster project. From top left to right: Jason Goldstein prepares a tagged lobster aboard the F/V Special K; Mark Havener measures an egg-bearing lobster too small to tag on the F/V Sarah Ashley; part of the offshore lobster fleet in the port of Pt. Judith, Rhode Island; composite view of a Tidbit temperature logger and optically downloading data; lobster field tagging kit components; digital images of an early-stage lobster egg (<20% developed) and a late-stage egg (>70% developed).*




A
B
C
Optical Shuttle
Plastic coupler,
fits on tidbit

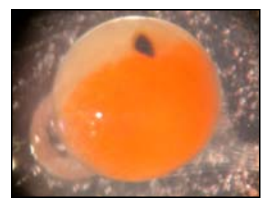


Table A2. *Summary to date of tagged and recaptured berried lobsters for all regions fall 2004 – summer 2006. A # + R in the 'Tidbit ID' category indicate a recapture. % Egg D (development) was quantified as described in report. For purposes of fishermen confidentiality, lat-long coordinates in some cases have been altered slightly.*

Tidbit ID	Tag Date	Location	Depth (m)	Size	Berring^0	Mean Dist (km)	% Egg D	LAT	LONG
2	10/13/04	NH	30	b			0	13.712.5	25.964.3
2R	10/19/04	NH	32		54	3.5	0	43.01.37	70.40.16
2R	10/27/04	NH			61	5.9		13.665.9	25.946.3
3	10/14/04	NH	17	s			0	13.692.5	26.002.3
4	10/14/04	NH	9	s			17	13.693.2	26.002.8
5	10/13/04	NH	27	b			0	13.710.3	25.971.6
6	10/26/04	NH	20	b			61	43.01.37	70.41.33
8	10/21/04	NH	6	b			53	43.03.34	70.42.36
10	10/26/04	NH	25	b			0	43.00.06	70.40.86
10R	10/28/04	NH	30		64	2.4		13.693.6	25.951.9
11	11/04/04	NH	4	b			22	43.03.18	70.43.22
11R	11/22/04	NH	24		112	4.8		136805.6	25979.8
12	10/21/04	NH	5	b			45	43.02.41	70.42.32
13	10/27/04	NH	6	b			0	43.02.44	70.42.41
13R	08/11/06	NH	15		75	2.1		43.03.42	70.41.54
14	10/19/04	NH	23	b			0	43.01.37	70.40.16
14R	07/31/05	MA	40		145	44.7		41.24.2	67.55.6
15	10/13/04	NH	26	b			41	13.715.1	25.973.6
16	10/26/04	NH	27	b			62	43.00.08	70.40.89
18	10/29/04	NH	34	b			13	42.59.21	70.41.21
20	11/04/04	NH	4	b			44	43.03.18	70.43.22
21	10/26/04	NH	24	b			20	43.00.06	70.40.98
24	10/29/04	NH	35	b			68	42.58.54	70.41.79
25	10/29/04	NH	28	b			42	42.58.34	70.42.47
29	10/29/04	NH	26	b			0	42.58.52	70.42.66
172	10/15/05	NH	8	s				43.04.05	70.42.54
172R	11/16/05	NH				28.3	0	13.664	25.954
1	10/19/05	NH	6	b				43.03.90	70.42.61
2	11/01/05	NH	8	b				43.02.66	70.42.52
3	11/15/05	NH	6	b				43.03.63	70.42.59
3R	10/05/05	NH			216	21.6		42.52.029	70.47.960
3R2	10/06/05	MA			203	1.6		42.51.797	70.47.741
4	11/15/05	NH	5	b				43.03.575	70.45.5
7	11/15/05	NH	4	b				43.03.6	70.42.656
10	10/19/05	NH	26	b				42.59.402	70.42.248
14	10/19/05	NH	25	b				43.01.239	70.41.426

17	10/19/05	NH	23	b				43.01.291	70.41.507
18	10/19/05	NH	24	b				43.01.394	70.41.356
18R	02/16/06	NH	120		210	11.1		13.747.4	25.946.5
20	10/19/05	NH	24	s				43.01.340	70.40.900
20R	11/03/05	NH			123	6.2			
23	12/29/05	NH	31	b				13.709.9	25.980.5
23R	07/10/06	MA			183	43.8	no eggs	13.782.2	25.788.1
29	12/29/05	NH	31	b				42.58.250	70.42.486
30	12/29/05	NH	33	b			14	42.58.482	70.41.011
31	12/29/05	NH	23	s				43.00.331	70.40.406
34	09/23/05	NH	15	b				42.53.398	70.44.752
36	09/23/05	NH	16	s				42.53.415	70.47.702
38	09/23/05	NH	16	b				42.53.415	70.42.702
40	09/24/05	NH	12	b				42.53.591	70.47.685
43	09/27/05	NH	9	b				42.51.877	70.479.18
53	10/01/05	NH	16	b				42.52.723	70.48.030
55	10/18/05	NH	15	b				13.699.5	25.993.8
56	10/18/05	NH	12	b				13.708.6	25.987.7
57	10/18/05	NH	25	b				13.708.8	25.972.3
60	10/19/05	NH	20	b				13.704.9	25.985.1
60R	11/20/05	MA			175	53.0		42.35.101	70.29.811
65	10/19/05	NH	20	b				13.709.9	25.980.5
86	11/15/05	NH	12	b				43.03.6	70.42.6 656
86R	11/26/05	NH			115	10.5		13.666.6	25.937.2
100	10/13/05	NH	120	b			0	43.03.90	70.42.61
100R	10/19/05	NH			46	1.2			
100R2	11/27/05	NH			210	0.8			
100R3	08/15/05	NH			133	25.0		43.04.730	70.39.744
150	10/08/05	NH	50	b				13.699.5	25.993.8
150R	11/16/05	NH			178	9.1			
188	10/19/05	NH	20	s			0	43.04.33	70.43.85
188R	05/21/06	NH	65		116	2.6			
1	10/24/04	ME	7	b			0	43.56.19	69.18.70
2	10/22/04	ME	5	s			51	43.56.40	69.18.80
2R	11/18/04	ME	45		224	9.9		12889.1	25882.54
3	10/24/04	ME	4	b			0	43.56.76	69.19.29
4	11/09/04	ME	83	b			0	43.42.280	69.25.680
4R	12/09/04	ME	0		197	18.8		43.32.20	69.40.57
5	11/03/04	ME	8	b			16	43.53.80	69.19.58
6	11/03/04	ME	5	s			51	43.57.54	69.18.50
7	10/22/04	ME	5	s			13	43.56.51	69.19.17

8	11/09/04	ME	70	b			55	43.44.529	69.25.771
9	10/24/04	ME	3	b			17	43.56.91	69.20.15
10	11/09/04	ME	79	s			11	43.45.078	69.24.964
11	11/17/04	ME	49	b			0	12896.69	25882.82
12	11/17/04	ME	51	b			0	12912.01	25873.36
13	11/17/04	ME	52	b			24	12912.71	25872.73
15	11/17/04	ME	54	b			21	12904.38	25877.5
16	11/03/04	ME	7	b			18	43.55.37	69.19.36
17	11/09/04	ME	90	b			0	43.42.985	69.25.766
17R	11/27/04	ME	86		166	1.3	15	43.42.424	69.25.309
18	11/09/04	ME	77	b			0	43.44.742	69.25.181
18R	11/27/04	ME	85		203	5.4	0	43.41.880	69.25.584
18R2	01/30/05	ME	121		178	13.8	0	13 004	25797
19	11/03/04	ME	5	s			15	43.57.54	69.18.50
20	10/24/04	ME	5	b			27	43.56.74	69.19.67
21	11/10/04	ME	45	b			0	43.55.15	68.58.05
22	11/10/04	ME	38	b			0	43.54.38	68.57.63
22R	01/13/05	ME			184	51.7		12873.7	25654.5
23	11/10/04	ME	45	s			0	43.55.21	68.57.96
24	11/10/04	ME	43	s			28	43.55.41	68.57.90
25	11/10/04	ME	43	s			0	43.55.34	68.57.70
26	11/23/04	ME	57	s			22	12923.05	25868.69
27	11/23/04	ME	57	s			22	12923.05	25.868.69
28	11/10/04	ME	40	b			0	43.55.42	68.58.00
29	11/10/04	ME	41	b			29	43.54.34	68.57.68
30	11/23/04	ME	55	s			39	12916.35	25866.82
99	11/22/04	ME	63				45	12906.75	25873.43
130	10/21/05	ME	18	b				43.55.027	69.21.410
134	10/17/05	ME	39	s				12861.6	25886.6
135	11/05/05	ME							
136	11/05/05	ME							
139	01/06/06	ME	82	s				12927.19	25865.56
141	01/06/06	ME	82	s				12927.62	25865.57
142	01/06/06	ME	55	s				12915.74	25871.4
145	10/03/05	ME	16	b				43.52.344	69.21.222
145R	04/10/06	MA	60		237	164.0	hatched out	13784	44361
145R2	06/16/06	MA	60		217	4.0	new eggs	13783.6	25833.5
148	10/03/05	ME	17	s				43.53.766	69.20.372
150	10/03/05	ME	19	b				43.53.937	69.22.763
152	10/05/05	ME	5	b				43.56.708	69.19.737
152R	10/20/05	ME					black		

152R2	01/15/06	ME					black		
152R3	01/29/06	ME	180		190	16.9	black	43.47.29	69.18.70
152R4	03/30/06	ME	40						
152R5	04/05/06	ME	108					43.45.35	69.19.41
153	10/05/05	ME	14	b				43.56.525	69.20.000
160	10/05/05	ME	16	s				43.55.364	69.21.182
162	10/11/05	ME	16	b				43.59.173	69.22.272
170	10/11/05	ME	29	s				43.55.742	69.22.659
171	10/11/05	ME	26	s				43.56.024	69.22.926
171R	10/14/05	ME	18	s	217	3.8		43.54.591	69.23.133
171R2	10/14/05	ME	16	s				43.53.962	69.21.434
178	10/14/05	ME	29	b				43.51.655	69.23.246
178R	12/21/05	OF	708		110	156.7	2/3 gone (green)	43.46.28	67.26.05
180	10/01/05	ME	21	b				43.51.098	69.19.552
181	10/01/05	ME	21	b				43.51.142	69.19.559
182	10/18/05	ME	14	b				43.55.360	69.19.373
182R	11/08/05				243	142.5		13.660	25.948
182R2	11/30/05							13.661	25.948
183	10/18/05	ME	16	b				43.53.734	69.19.608
183R	12/31/05	OF	302		153	218.4	50-100 eggs	42.28.10	67.27.57
183R2	02/01/06	OF	330		160	9.3	20 eggs	42.24.75	67.23.25
187	10/21/05	ME	34	b				43.51.325	69.18.374
188	10/21/05	ME	33	b				43.51.622	69.17.964
188R	07/20/06	ME			177	15.9		12.887.0	25.881.0
192	10/21/05	ME	14	b				43.50.541	69.18.806
192R	05/25/06	NH			244	154.5	black	13 781.4	25 951.7
194	10/22/05	ME	27	s				43.50.186	69.17.189
195	10/23/05	ME	53	b				43.49.412	69.15.711
196	11/01/05	ME	55	b				43.49.193	69.16.634
198	10/15/05	ME						43.56.30	69.08.20
1	11/03/04	OF	198	b			64	39.55.662	69.43.506
1R	11/11/04	OF	274		284	10.5		39.55.554	69.50.719
2	11/30/04	OF	212	b			56	39.57.99	69.22.84
3	11/09/04	OF	326	b			0	42.23.74	67.22.79
3R	11/19/04	OF	308		240	8.3	0	42.20.44	67.26.87
3R2	11/20/04	OF	308		276	0.4	0	42.20.44	67.26.87
3R3	11/27/04	OF	308		272	0.6		42.20.40	67.27.30
4	11/22/04	OF	266	b				41.06.142	66.25.526
5	11/20/04	OF	220	b			0	43.42.13	67.28.02
5R	11/22/04	OF	243		180	306	56	41.05.431	66.22.631
6	11/19/04	OF	198	b			18	40.06.918	69.03.846

7	11/18/04	OF	108	b			48	40.44.613	66.46.879
7R	12/19/05						1 green egg		
7R2	12/19/05						1 green egg	42.31.41	67.29.84
7R3	12/24/05						no eggs	42.30.5	67.29.0
7R4	01/09/06						no eggs	42.29.3	67.28.9
7R5	03/16/06						no eggs	42.26.69	67.27.28
7R6	06/09/06						no eggs	42.26.30	67.27.60
8	12/02/04	OF	239	b			0	42.33.84	67.30.71
9	12/02/04	OF	164	b			72	39.57.94	69.34.84
10	11/20/04	OF	108	b			50	40.48.247	66.42.212
11	12/02/04	OF	238	b			0	42.33.40	67.30.50
11R	12/03/04	OF	221		19	1.0	0	42.32.91	67.30.46
11R2	12/15/04	OF	241		317	1.5	38	42.34.08	67.31.26
11R3	07/26/05	OF	15		262	224.5	hatched	41.44.58	69.54.27
12	11/17/04	OF	230	s			19	39.56.554	69.34.610
13	11/30/04	OF	241	s			51	39.56.25	69.23.90
14	12/02/04	OF	158	b			48	39.57.90	69.34.45
15	12/03/04	OF	212	b			41	42.37.74	67.33.73
15R	08/01/05	OF	119		115	204.1		42.24.21	65.07.48
16	11/20/04	OF	252	s			58	35.55.902	69.38.883
17	11/17/04	OF	153	b			71	40.39.626	67.04867
17R	11/20/04	OF	261		118	1.5	64	40.39.528	67.04.006
18	11/20/04	OF	243	b			71	39.57.759	69.17.585
19	12/02/04	OF	182	s			67	39.57.99	69.35.23
21	01/22/05	OF	266	b			180	42.31.00	67.30.00
21R	02/14/05	OF	288		25	1.9		42.31.86	67.29.93
21R2	02/26/05	OF	284		179	3.7	0	42.30.00	67.29.00
21R3	03/05/05	OF	302		189	3.5		42.29.89	67.28.68
21R4	03/16/05	OF	304		130	3.1		42.27.50	67.26.60
22	01/11/05	OF	302	b			74	40.06.34	69.02.43
23	01/11/05	OF	380	b			74	40.08.80	68.03.32
24	01/28/05	OF	310	s			0	42.20.00	67.28.00
27	01/11/05	OF	261	b			0	42.32.23	67.29.70
27R	01/16/05	OF	283		154	2.9	0	42.31.00	67.28.00
27R2	01/21/05	OF	301		185	3.2	0	42.29.39	67.27.62
27R3	02/14/05	OF	297		224	4.0		42.27.52	67.28.92
28	01/11/05	OF	288	b			0	42.29.00	67.29.00
28R	02/14/05	OF	297		199	2.9		42.27.52	67.28.92
31	01/11/05	OF	284	s			0	42.29.00	67.29.00
32	01/11/05	OF	515	b			34	40.07.19	69.02.59
33	01/11/05	OF	223	b			25	42.33.00	67.31.22
35	01/11/05	OF	506	b			71	40.07.78	69.02.75

37	01/10/05	OF	191	s			65	40.00.25	69.36.24
38	01/10/05	OF	166	s			73	39.59.97	69.35.89
38R	01/12/05	OF	214		199	1.4	72	39.58.62	69.35.51
41	01/10/05	OF	144	b			66	39.59.06	69.34.41
42	01/12/05	OF	301	b			0	42.26.00	67.29.00
42R	03/11/05	OF	315		173	4.8		42.23.61	67.27.60
42R2	06/29/06						lt. brown	13. 704	25. 984
48	01/10/05	OF	146	s			38	39.59.39	69.35.00
50	01/10/05	OF	153	b			63	39.59.69	69.35.50
51	01/11/05	OF	489	b			57	40.08.27	68.03.16
57	01/11/05	OF	279	s			0	42.29.00	67.29.00
58	01/16/05	OF	288	b			0	42.31.00	67.28.00
66	11/05/05	OF	207	b				40.01.893	69.05.337
68	11/06/05	OF	201	b				39.56.318	69.26.315
76	11/14/05	OF	205	b				39.55.653	69.44.074
83	12/28/05	OF	549	b				40.02.800	69.02.70
84	12/28/05	OF	274	b				40.00.77	69.08.18
84R	12/04/05							13624.4	25848.8
84R2	01/23/06				239	19.0	black	13.500	25.772
85	12/28/05	OF	258	b				40.00.11	69.12.46
85R	11/12/05				116	12.0		40.00.810	69.05.274
86	12/28/05	OF	238	b				39.59.36	69.14.77
87	10/30/05	OF	214	b				42.37.52	67.34.67
88	10/30/05	OF	218	b				42.36.80	67.33.80
89	10/30/05	OF	304	s				42.29.15	67.27.10
90	11/02/05	OF	183	b				42.11.86	67.14.51
92	11/24/05	OF	221	b				43.51.22	67.24.37
93	11/30/05	OF	282	b				42.31.81	67.29.76
96	11/30/05	OF	305	b				42.46.15	67.26.63
97	12/07/05	OF	210	s				42.31.41	67.26.32
98	01/08/06	OF	274	b				41.01.895	66.25.553
100	01/08/06	OF	227	b				41.08.949	66.19.907
105	12/20/05	OF	256	b				41.00.19	66.26.78
106	12/20/05	OF	223	b				40.55.83	66.31.78
107	12/21/05	OF	316	b				40.38.22	67.01.29
108	11/13/05	OF	95	s				40.32.326	67.52.431
109	11/13/05	OF	93	s				40.33.371	67.55.591
115	11/14/05	OF	192	b				40.11.292	68.23.046
117	11/14/05	OF	247	b				40.07.388	68.33.967
124	11/14/05	OF	293	b				40.11.310	68.35.593
124R	01/08/06	OF	282	b	272	311.0		39.33.95	72.03.57
128	01/08/06	OF	296	s				39.30.26	72.07.55

129	01/08/06	OF	294	s				39.30.89	72.15.51