Northeast Consortium

The Lobster Conservancy

Mapping Spawning and Hatching Grounds of the American Lobster

Final Report

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Abstract
The purpose of this study was to investigate the relationship between temperature, movements and body size for ovigerous (egg-bearing) lobsters tagged recently after spawning and tracked throughout the 9-13 month brooding period. We made predictions about where and under what temperature conditions small (< size at 50% maturity) versus large ($\geq$ size at 50% maturity) lobsters would brood.

We found that although small female lobsters were abundant in Muscongus Bay, most were not ovigerous. Small ovigerous lobsters tended to spawn and remain inside the bay where they brooded at lower winter, but higher spring and summer temperatures than large ovigerous lobsters. In contrast, large ovigerous lobsters ($\geq$size at 50% maturity) were relatively rare, but most were ovigerous. They tended to spawn at greater distances from shore and while many stayed near where they spawned, others achieved a maximum displacement of up to 240 km. Large ovigerous lobsters were at more moderate temperatures throughout the year regardless of how far they traveled. Both small and large ovigerous lobsters experienced (1) sufficiently low winter temperatures for successful ovarian maturation, and (2) approximately the same number of degree days for egg development.

These findings suggest that known thermal requirements of optimal cold temperature for successful ovarian maturation are balanced with sufficient numbers of degree-days for egg development via two distinct behaviors. Small ovigerous lobsters remain in shallow water where they experience colder winter but warmer spring and summer temperatures than large ovigerous lobsters that move to deeper water with warmer winter but colder spring and summer temperatures.

Introduction
Although record high landings have been reported in the Gulf of Maine in recent years, two stock assessments define the lobster population as overfished (ASMFC 2000, NMFS 1996). This identifies lobsters as a species under stress, whose basic biology may be under pressures that put the population at risk. The phenomenon of stock collapse has been observed in many other fisheries including halibut, striped bass, cod and haddock (Hutchings 2000). Some of these species may never recover to their previous population levels. To increase the likelihood that lobster stocks will not suffer a similar fate, we need to increase our knowledge about the large-scale patterns of distribution of reproductively active lobsters. This will allow us to more intelligently approach understanding the lobster's capacity to withstand the pressure that intensive harvesting is placing on the lobster population.

Gaining a better understanding of lobster reproductive biology is important to fishing regulations aimed at protecting the lobster brood stock. It is strictly prohibited to land egg-bearing lobsters anywhere in the United States. In some management areas, large, sexually mature lobsters are also protected through v-notching of ovigerous lobsters and maximum legal size restrictions for both male and female lobsters. Protecting reproductively active animals is a common sense management measure, but there currently exists little means for assessing how well various management practices are working. With an increased understanding of the temporal and spatial distribution of reproductive female lobsters, alternative management measures, such as the protection of critical spawning and hatching areas, could be possible. This knowledge may eventually lead to a better understanding of larval dispersal, another critical phase in the lobster life cycle that has been the subject of numerous studies in recent years.

The relationship between egg production and recruitment to the fishery cannot be fully understood without knowledge of the spatial distribution of spawning, brooding and hatching females. To date, much information about the distribution of reproductively active females comes from fisheries-dependent tag/recapture studies done in the 1960's and 1970's – a time when harvests were much lower than they have been for the past two decades. A shortcoming of these studies was that multiple captures were rare, so it was impossible to know how many tagged lobsters traveled and returned to a location versus how many stayed in one location for long periods of time. Advances in technology made it possible for us to gain a better understanding of the large scale patterns and environmental covariates of reproductively active female lobsters in space and time.

Large, sexually mature female lobsters in Canadian waters show a variety of migratory behavior defined by Pezzack and Duggan (1986) as: (1) ground keepers, that do not migrate, (2) seasonal migrators, that move from deep to shallow waters to thermoregulate for optimal egg development during brooding; and (3) long-distance migrators. Campbell (1986) observed that most sexually mature female lobsters from Grand Manan Island were ground keepers, while a few migrated hundreds of kilometers annually.

This project investigated where and at what temperatures female lobsters that spawn (egg out) in Muscongus Bay, Maine, overwinter (brood), and hatch their eggs. Inshore lobsters generally spawn during late summer; brood their eggs for 9 – 12 months; then hatch their eggs the following spring and summer. The prevailing view is that female lobsters migrate to deeper, warmer water in winter to achieve suitable temperatures for egg development (Campbell 1982, Cooper & Uzmann 1971, Uzmann *et al.* 1977, Estrella & Morrissey 1997, Campbell *et al.* 1984, Fogarty *et al.* 1980, Campbell & Stasko 1985, Krouse 1981, Campbell 1983; Campbell & Stasko 1986, Campbell 1986, Pezzack & Duggan 1986, Robichaud & Lawton 1995).

Project Objectives and Scientific Hypothesis

The objectives of this study were to investigate the relationships between temperature, maximum displacement and body size for ovigerous (egg-bearing) lobsters tagged recently after spawning and tracked throughout the brooding period. We made predictions about where and under what temperature conditions spawning, brooding and hatching would occur for small versus large ovigerous lobster. The size at 50% maturity for the Gulf of Maine (93 mm CL; Anonymous 1993, Krouse 1973, Estrella and McKiernan 1989) was chosen as the cut off to define small versus large brooders.

Project Objectives

1. Map the spawning and hatching grounds of the American lobster in Muscongus Bay, Maine.

2. Test the Inshore Spawning/Inshore Hatching hypothesis (Table 1).
3. Determine temperature regimes experienced by egg-bearing female lobsters within Muscongus Bay.

Scientific Hypotheses

1. Do reproductive female lobsters exhibit preferences for certain areas for spawning, brooding and hatching their eggs within Muscongus Bay? If certain areas are identified as critical to the reproductive cycle of lobsters within Muscongus Bay, steps could be taken to protect these areas from fishing, and other possible anthropogenic effects.

2. Is there a clear pattern of female movement associated with the events of hatching, brooding and spawning? (Table 1)

a. Inshore Spawning/Inshore Hatching with migration hypothesis
This hypothesis predicts that female lobsters will spawn in shallow water then migrate to deeper warmer water where egg development will be accelerated during the brooding period, resulting in an early hatch upon their return migration to shallow water. This pattern has been detected between Grand Manan Island and the Grand Manan Basin via tag/recapture studies (Campbell 1986). A similar shallow-deep-shallow migration has also been observed for offshore lobsters migrating to and from the Scotian Shelf (Pezzack and Duggan 1986).

b. Inshore Spawning/Inshore Hatching without migration hypothesis
This hypothesis predicts that female lobsters will spawn in shallow water then remain in cold shallow water during the brooding period, resulting in a prolonged period for egg development and a later hatch. To the best of our knowledge, this pattern has not been observed perhaps due to an inability of fishing gear to detect inshore lobsters in winter because lobsters lack motivation to trap in cold water.

c. Inshore Spawning/Offshore Hatching with no return migration hypothesis
This hypothesis predicts that female lobsters will spawn in shallow water then migrate to warmer water during the brooding period, resulting in accelerated egg development leading to an early hatch. To the best of our knowledge, this pattern has not been observed perhaps due to an inability to detect hatching females in deep water.

d. Offshore Spawning with no migration hypothesis
The possibility of offshore spawning will not be investigated during this study. To the best of our knowledge, this pattern has not been observed.

Table 1. Summary of Inshore Spawn-Brood-Hatch hypotheses.

Hypothesis	**Spawning Prediction**	**Brooding Prediction**	**Hatching Prediction**
Inshore Spawn – Offshore Brood – Inshore Hatch	Near shore spawning aggregates	Accelerated egg development in deep water in winter	Early release of larvae near shore

Inshore Spawn – Inshore Brood – Inshore Hatch	Near shore spawning aggregates	Prolonged egg development in shallow water in winter	Late release of larvae near shore
Inshore Spawn – Offshore Brood – Offshore Hatch	Near shore spawning aggregates	Accelerated egg development in deep water in winter	Early release of larvae off shore

3. Do egg-bearing female lobsters occupy a certain thermal range while brooding their eggs, and if so, do they move in response to temperature change? If this were the case it could be possible to predict what areas egg-bearing lobsters might occupy if bottom temperatures are known.

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Methods
To map lobster spawning and hatching grounds, we integrated traditional mark/recapture with sonar tracking and temperature recording techniques. Sea sampling trips aboard lobster boats established baseline data on size distribution, sex ratio and location of lobsters in Muscongus Bay. To the best of our knowledge this is the first project to record temperature directly from freely moving lobsters in the wild and to track ovigerous lobsters acoustically over an extended period of time. Lobsters captured in commercial traps were tagged and immediately released in shallow water spawning grounds of Muscongus Bay, Maine 5 Sep – 10 Oct 2002 and 16 Aug – 9 Sep 2003, then followed for up to two years.

A sphyrion (2002) or ribbon (2003) tag with lobster identification and contact phone number was inserted into the dorsoanterior musculature beneath the carapace where the body meets the abdomen. Individually coded acoustic transmitters (Sonotronics® CT-82-2, battery life 14 mo, outer diameter 65 x 16 mm, weight 8 g, range 1000 m) were attached to the lobster carapace using cyanoacrylate glue and drab olive green duct tape. Temperature data loggers (HOBO® TidbiT by Onset Computer; range –4 to +37^{o}C; accuracy +0.2^{o}C; dimensions 30 x 41 x 17 mm) affixed to the right cheliped with a plastic cable tie recorded hourly temperature (Fig 1). Although the equipment looks a bit cumbersome it did not appear to interfere with lobster behavior as evidenced by observations in a field enclosure at The Lobster Conservancy as well as by similarities in extent of lobster movements observed as compared with previous mark/recapture studies (reviewed in Krouse 1980, Cooper and Uzmann 1980, Haakonsen and Anoruo, 1994; Lawton and Lavalli, 1995).

We used three methods for relocating lobsters and recovering data: (1) traditional recaptures trapped via harvest were phoned in by lobstermen, (2) remote detection of lobster location using a Sonotronics® DH-4 hand-held hydrophone, Sonotronics® USR-96 receiver and Radio Shack® 33-1169 headphones (Fig 2), and (3) recapture via SCUBA divers using a Sonotronics® underwater dive receiver (UDR, Fig 3).

Temperature data were downloaded using Onset Computer Boxcar® Program and examined for start and stop date and time easily discerned by looking for abrupt change from water to air temperature when the tag was brought to the surface.

Data
Three data sets have been submitted in Excel format:
1. Temperature Data recordings from 48 lobsters and 12 fixed stations
2. Sea Sampling Data from commercial lobster traps
3. Lobster Movement Data based on mark/recapture and sonar tracking

Results and conclusions

We accomplished the goals outlined above in Objectives 1, 2, and 3.

1. *Map the spawning and hatching grounds of the American lobster in Muscongus Bay, Maine.*

Recently spawned ovigerous (egg-bearing) lobsters were generally found throughout the shallow, but not deep waters of Muscongus Bay (Figs 4 & 5). Larger lobsters tended to be found at the mouth of the bay (Fig 6). Note that Friendship lobstermen fish the middle part of the bay.

On sea sampling trips we captured 3,375 female lobsters (ovigerous and non-ovigerous) in 1,190 traps. Two factors prevented us from tagging the targeted 150 lobsters from each size class within Muscongus Bay. Firstly, only 79 ovigerous lobsters of the smaller size class were captured on tagging trips (3% of those captured; Figs 7 & 8). The remaining small females were non-ovigerous. Secondly, few large ovigerous lobsters were captured in the bay – we had to fish the mouth and outside of the bay to encounter sufficient numbers of large brooders. Of the 3,376 females sampled, only 301 (<1%) were at or above the size at 50% maturity. We tagged 112 (37%) of them.

We conclude from these data that there is not a great deal of egg production occurring inside of Muscongus Bay. This may be due to the small size of the lobsters encountered inside the bay. Egg production inside the bay appears to be coming from small lobsters (<size at 50% maturity).

2. *Test the Inshore Spawning/Inshore Hatching hypothesis*

A total of 82% (92% of small and 73% of large size class) of all egg-bearing female lobsters tagged Sep-Oct 2002 were detected via hydrophone or recapture at least once by mid-Nov 2003 (Fig 9); one was subsequently recaptured in the fall of 2004. Of these, 46% were recaptured, 63% were detected remotely via hydrophone, an overlapping 27% were both heard and recaptured, and 18% were not detected.

We detected the same individual up to 27 times (mean 2.33 ± 4.22 sd) via sonar tracking, while the greatest number of times an individual was recaptured in commercial traps was 6 (mean 0.69 ± 0.98 sd). Recapture information was especially useful for lobsters that traveled great distances. Once the lobsters left the areas fished by project participants, finding them via hydrophone detection became difficult. However, if a transmitter was not detected where the lobster had been tagged, at least we knew that the lobster had departed from the original location - which was the case with 35 (30 large and 5 small) of the 191 (112 large and 79 small) lobster tagged. Recapturing the lobster was the only way we could recover temperature data and determine the condition of the lobster and her brood.

By combining mark/recapture and sonar tracking techniques we eliminated some of the disadvantages and uncertainties associated with both methods and managed to ascertain patterns of movements, temperature conditions, and condition of eggs for many of the tagged lobsters. For example, female #54 (Fig 10) was tagged with a full batch of newly spawned eggs in Morse Channel Sep 2002. She was subsequently detected in the same location via sonar tracking each month except Feb when ice covered the channel. We tried to find her using the UDR in May, but the signal took us to a large boulder where we could not see the lobster. She was captured near the boulder by a lobsterman who recovered the temperature data logger and reported that her eggs where hatching in July. She had moved no more than 700 m. Her empty shell was retrieved – presumably after she molted in Aug – about seven miles from where she had stayed from Sep 2002 – Jul 2003. #54 illustrates the usefulness of all three methods of detection.

A vast majority of relocated lobsters traveled less than 20 km (Fig 11). Large ovigerous lobsters traveled up to 240 km and tended to travel greater distances than small brooders (Fig 12).

These behaviors may or may not be related to reproductive behavior. In an attempt to determine whether these behavioral patterns are specific to reproductively active females, both males and females were tagged for the 2003-2004 season.

A total of 86 lobsters (45 ovigerous and 41 male) were tagged between 16 Aug and 9 Sep 2003 when newly spawned females began to appear in lobster traps. Males were tagged only if they:

1) had already molted during 2003; to minimize the possibility that transmitters would be lost during ecdysis
2) were protected from the fishery by minimum or maximum legal size limits, to reduce the likelihood that tagged lobsters would be harvested, and
3) were captured within 2 km of an egg-bearing female that was also tagged, so that movement data would have a similar starting location.
4) We had hoped to tag males that came from the same traps as ovigerous lobsters, but that was not possible (Fig 5). Even tagging males and females within the 2 km radius was a challenge because the males were rarely captured in the same vicinity as ovigerous lobsters. We had also wanted to tag males and females of similar body size but did not catch a sufficient number of undersized ovigerous lobsters (Fig 13).

Similar numbers of tagged male and ovigerous lobsters were detected via recapture and sonar tracking with an overall detection rate of 98% (Fig 14). Of the 52% of tags that were recovered 37% were still attached to lobster while the remainder had become detached and were retrieved by divers (UDR in Fig 14).

Unfortunately, the only temperature data we recovered from male lobsters were retrieved from tags found on the bottom. These were not counted as “recaptures” but rather as “UDR’s” because the lobster was not found (Fig 14). One tag was from a male who had been consistently tracked with another male. These two males (both sublegal) were tagged, then subsequently tracked to a location where they apparently overwintered together in the western part of the bay before they moved – again, apparently together – to a location toward the middle of the bay where one temperature data logger and two acoustic transmitter tags were found together on the bottom. We suspect the males molted at that final location. Another temperature data logger from a sublegal male was recovered with an acoustic transmitter more than two years after tagging. We assume this male also molted and consider the first time it was detected at the location where the tag was retrieved to be its final location and the date when it first arrived there as a stop date. The temperature profiles from their data loggers resembled those of small, not large females.

There appear to be no evidence in these data to suggest that winter movements of males differ from those of ovigerous lobsters. However, we were not able to collect the quality and quantity of data that was possible to collect from ovigerous lobster who have a longer intermolt period and are protected from harvest for long periods of time while brooding eggs and through v-notching.

3. *Determine temperature regimes experienced by egg-bearing female lobsters within Muscongus Bay.*

Temperature records were recovered from 48 data loggers that had been attached to lobsters. Hourly temperature data were recovered from 30 ovigerous lobster (20 small and 10 large) at large for 224-358 days (mean 297 ± 6.8 s.e.). Temperature data from ovigerous lobster tagged in Muscongus Bay were all recovered within Gulf of Maine waters (Fig 15). The maximum horizontal displacement for an individual lobster was 240 km. Mean maximum horizontal displacement tended to be greater for large (54.6+24.2 s.e. km) than small (10.5+2.3 s.e. km) ovigerous lobster.

Each lobster remained in bottom water temperatures below 8^{o}C from Jan – May 2003, and below 6 ^{o}C from 28 Feb – 28 Apr 2003 (Fig 16). The greatest range in temperatures occurred during Jan and Feb when small lobster were in waters as cold as –1^{o}C while large lobster were in waters as warm as 8^{o}C (Fig 16). All ovigerous lobsters recorded temperatures between 2 and 5^{o}C during April. This is important because such low temperatures are apparently required for maturation of the ovaries that leads to production of the subsequent brood (Waddy and Aiken 1992).

Daily mean bottom temperature was lower during Nov-Apr but higher from May through mid-July for small (<93 mmCL) ovigerous lobsters (Fig 17). In contrast, large ($\geq$93 mmCL) ovigerous lobsters experienced higher water temperature during the winter but lower temperatures in the spring (Fig 17). Small ovigerous lobsters spent the coldest winter months in temperatures hovering around 0^{o}C while large ovigerous lobsters maintained temperatures ranging from 4-6^{o}C (Fig 17). Large ovigerous lobsters experienced less extreme absolute temperatures and less dramatic fluctuations in temperature than small ovigerous lobsters (Fig 17).

Templeman (1940) and Perkins (1972) established that the embryonic development rate of eggs is closely related to temperature in the laboratory. Embryonic development ceased in some egg masses and was barely discernable in others at temperatures below 6^{o}C (Perkins 1972). Campbell (1986) calculated a threshold temperature for egg development of 3.4^{o}C and estimated that embryos require a total of 1,832-degree days to hatch. The mean number of degree-days for egg development above a 3.4^{o}C threshold temperature recorded by lobsters in this study was 952.82 for small and 983.64 for large ovigerous lobsters. The mean number of degree-days above 0^{o}C was 1,842 for small and 2,023 for large ovigerous lobsters.

These findings suggest that known thermal requirements of optimal cold temperature for successful ovarian maturation are balanced with sufficient numbers of degree-days for egg development via two distinct behaviors. Small ovigerous lobsters remain in shallow water where they experience colder winter but warmer spring and summer temperatures than large ovigerous lobsters that move to deeper water with warmer winter but colder spring and summer temperatures.

Main conclusions

a. Lobsters appear to spawn (extrude eggs) in shallow waters.
b. Larger lobsters tend to be found at the mouth of the bay, while smaller lobsters are found further up inside the bay.
c. Although female lobsters measuring below the minimum legal size are extremely common in traps, and females below the size at 50% maturity are fairly common, few of these lobsters were carrying eggs. In contrast, larger female lobsters were rare but many were carrying eggs.
d. Although most ovigerous lobsters do not travel far from the place where they spawn while brooding their eggs, those who do, tend to be larger than those who do not.
e. Regardless of how far they traveled, larger ovigerous lobsters overwintered at warmer temperatures than small ovigerous lobsters.

From these conclusions, we speculates that:
In spite of a year-long brooding period and several weeks long larval life it appears that local recruitment may be an important component in the American lobster breeding pattern. The results of The Lobster Conservancy’s tagging study show that most ovigerous lobsters (especially of the small size class) brooded and hatched their eggs near spawning grounds. This suggests local recruitment. Local recruitment may translate into restricted gene flow in the presence of confined larval dispersal. Genetic diversity makes stocks stronger, especially in the face of adversity. It follows that a lack of large, migrating brooders may result in restricted gene flow that could in turn contribute to the collapse of a local fishery by making the genetically isolated population more susceptible to environmental stressors. It may be prudent to safeguard against potential problems associated with over dependency on local recruitment by encouraging greater potential for larval dispersal. Our results suggest that having more large lobsters in the population may lead to a greater degree of migration and dispersal.

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Partnerships

Industry participants:

1. helped to develop protocols for retrieving, reporting and sharing data
2. gathered location and temperature data from tagged lobster using sonar tracking and recapture techniques
3. learned to use an Underwater Dive Receiver to recover data via SCUBA
4. helped to test and develop new tracking techniques
5. made presentations to share experiences and disseminate results of the project

Science participants:

6. trained industry participants
7. managed data
8. mapped tracking and recapture locations reported by fishermen
9. analyzed movement data for changes in depth, distance and direction traveled
10. analyzed temperature data
11. met regularly with industry participants
12. made presentations and wrote articles and papers to disseminate results of project

Impacts and Applications

The sea sampling data submitted with this report and shown in Fig 7 reveal that the majority of female lobsters trapped in Muscongus Bay are below the minimum legal size. The size at 50% maturity for the Gulf of Maine is more than one molt full group above the minimum legal size. That means that even if a lobster at or below the minimum legal size escapes harvest and molts again, she will still not reach the size at 50% maturity the next time she molts. She would have to somehow escape harvest again to gain sufficient size to assure reproduction. This appears to result in a situation where few females have the opportunity to bear eggs (Fig 8). The chances of a female surviving to molt into the size at maturity are questionable. In addition, trap data can give a false sense of abundance if one is encountering the same animals repeatedly. We recorded repeated recapture of the same individual lobsters which – in the absence of identifying tags – could give the impression that egg-bearing lobsters are common – even if they are not. Based on these observations it stands to reason that it would be a good idea to find a way to allow more female lobsters to reach maturity and reproduce before they are harvested. In the original grant proposal, I wrote that immature lobsters are protected from harvest. They are not. Most lobsters of the minimum legal size in this location are not sexually mature. It appears to me that too many juveniles are being harvested.

The location of recently spawned female lobsters was confined to shallow water near shorelines and ledges (Figs 4 & 5). Such areas may be particularly vulnerable to the anthropogenic impacts of coastal development. Lobster spawning habitat is barely below the surface of waters that are subject to threats presented by runoff from land sources of pollutants and siltation.

The lobster with greatest maximum displacement in this study, traveled to a management area where she is not protected by a maximum size limit and may be harvested after her eggs hatch (Fig 15 & Appendix).

These findings may be applied to management measures – both fisheries and habitat protection – that would better protect reproductively active lobsters.

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Related Projects
Jim Manning's emolt project
Win Watson's "The influence of water temperature on the distribution of berried females and the duration of egg development in American lobsters"

Presentations
"Doing science with the lobstering community", presented by Diane Cowan

- Jan 21, 2003 Kennebec Naturalists Society, Augusta, Maine
- Mar 25, 2003 Mainely Women in Science, Southern Maine Technical College
- Jun 3, 2003 Isle of Shoals Marine Lab, Appledore Island
- Jul 11, 2003 Maine Maritime Academy, Castine, Maine
- Oct 18, 2003 Cundy's Harbor Community Center, Harpswell, Maine
- Oct 19, 2003 Grange, West Harpswell, Maine
- Oct 30, 2003 Cliff Island Community Center, Cliff Island, Maine
- Oct 22, 2003 Friends of Casco Bay Annual Meeting, South Portland, Maine
- Nov 1, 2004 University of Massachusetts Amherst
- Nov 12, 2004 University of New Hampshire, Durham, NH
- Jan 5, 2005 Penobscot East Resource Center, Stonington, Maine
- Feb 5, 2005 Massachusetts Lobstermen's Association, Annual Meeting
- 5, 12, 19 Jul 2005 Audubon Society, Hog Island, Maine
- Sep 14, 2005 American Association of University Women, Rockland, Maine

"Lobster Sonar Tracking Project: Summary of Results", presented by Tim Thompson, *F/V Haley & Amy*, Mark Havener, *F/V Sarah Ashley* and Diane Cowan
Mar 23, 2005 Penobscot East Resource Center, Stonington, Maine
Mar 29, 2005 The Lobster Conservancy, Friendship, Maine
"Mapping the movements of egg-bearing female lobsters and bottom temperature", presented by Diane Cowan and Tim Thompson, *F/V Haley & Amy*
Dec 9, 2003 Northeast Consortium Annual Meeting, Portsmouth, New Hampshire
Site visit and project demonstration on board *F/V Amanda Kate* by Philip Bramhall, *F/V Amanda Kate*, Diane Cowan, Linda Archambault, Sara Ellis, Jane Roundy.
Aug 24, 2004 Congressional Aides and National Fish and Wildlife Foundation staff.
"Mapping spawning and hatching grounds of the American lobster", presented by Andrew Mountcastle, Linda Archambault and Diane Cowan
Oct 28, 2004 Northeast Consortium Annual Meeting, Portsmouth, New Hampshire

Publications

Cowan, D.F. 2003. Mapping the movements of egg-bearing female lobsters and bottom temperatures. In: Prototype Biophysical Maps of the Gulf of Maine. E. Richert and Lewis Incze eds., Island Institute pp. 26-28.
Cowan, D.F. 2004. Achieving a healthy size/age structure. Ask the Lobster Doc. Commercial Fisheries News, June.
Cowan, D.F. 2004. Maine lobster landings by county. Ask the Lobster Doc. Commercial Fisheries News, August.
Cowan, D.F. 2004. Lobster landings and fishing pressure. Ask the Lobster Doc. Commercial Fisheries News, September.
Cowan, D.F. 2004. Lobster and temperature. Ask the Lobster Doc. Commercial Fisheries News, October.
Cowan, D.F. 2004. Lobster landings: How have they coincided with management measures? Ask the Lobster Doc. Commercial Fisheries News, November.
Cowan, D.F. 2004. Lobster landings conclusions. Ask the Lobster Doc. Commercial Fisheries News, December.
Cowan, D.F. 2005. Lobster resource stewardship. Ask the Lobster Doc. Commercial Fisheries News, February.
Cowan, D.F., W.H. Watson, A.R. Solow, A. Mountcastle and L. Archambault. 2005. Lobster movements and vulnerability to environmental stressors: size matters. Proceedings from the State of Lobster Science: Shell Disease Workshop. University of Massachusetts Boston pp. 101-105.
Cowan, D.F., W.H. Watson, A.R. Solow, and A. Mountcastle. In Review. Size matters: Temperature and brooding behavior in lobster, *Homarus americanus*. Marine Biology
O'Grady, D. 2002. "You from away?" Tagging study may show where lobsters are born. Working Waterfront, Dec 11.
"Tracking Maine's Crustacean Bounty", The Washington Post, Nov 30, 2003.
"Lobster Study Moves East: High Tech Monitoring Tracks Movements", Ellsworth American, Ellsworth, Maine, Jan 3, 2005. Aaron Porter.
"Lobster Expert Hears Local Lore", Ellsworth American, Ellsworth, Maine, Jan 7, 2005. Aaron Porter.

Images
Submitted as JPG files on CD.

Future research
Future directions for research related to this project include (1) continued analyses of the data sets generated by the project, (2) research projects that have already spun off this project, and (3) other potential projects. The following list is far from exhaustive.

1. Temperature Data recordings from 48 lobsters and 12 fixed stations
2. Sea Sampling Data from commercial lobster traps
3. Lobster Movement Data based on mark/recapture and sonar tracking

(1) Continue Analyses of Existing Data Sets

Temperature Data. Known bottom temperatures could be compared with temperatures recorded by lobsters to determine the path lobsters traveling >20 km traversed.

Sea Sampling Data. Additional data on the distribution of spawning and hatching are included in the sea sampling data set. These data can be used to identify the location of egg-bearing and non-egg bearing lobsters by egg stage to augment the data shown in the maps. These data have not yet been analyzed.

Lobster Movement Data. This report concentrated on overall movements and the best location data. There are far more data submitted with the report. One could look at more detail and perform a fuller analysis. In addition, none of the location data for where lobsters did not go have been analyzed.

(2) Projects Inspired by this one

This project provided the first empirical data on temperature and brooding in wild lobsters. Win Watson at University of New Hampshire has expanded on this study to continue gathering data and delving deeper into the role of temperature in egg development in free ranging lobsters.

Body size of breeding lobsters may have potential implications on the genetic diversity of a population, possibly playing a role in population fragmentation or isolation. Relying too heavily on small brooders for local egg production would restrict gene flow under two conditions: (1) if small brooders fail to migrate – resulting in local larval hatching, and (2) if their larvae fail to disperse due to larval retention via local currents. More information on local current patterns would help to strengthen our assertions concerning how lobster populations can become fragmented or isolated. The ultimate test to demonstrate the relative importance of local recruitment would be to determine whether postlarvae settling locally are primarily the offspring of female lobsters spawning, brooding and hatching their eggs in local waters. To address questions of genetic relatedness of lobsters from various regions throughout the Gulf of Maine I have started working with molecular biologists at the Marine Biological Laboratory in Woods Hole.

(3) Potential Research Projects

I hope this research will lead to a better understanding of lobster recruitment patterns by linking hatching to settlement and subsequent survival of offspring in space and time. Even if larvae manage to disperse, there may be local conditions that favor the survival of local larvae. Do more eggs, larvae, juveniles survive to harvestable size if brooded by large versus small females? Ultimately, I hope we can understand what it takes to continue having enormous numbers of lobsters survive the journey from egg to plate.

Figure Legends

Figure 1. Sonar-tagged ovigerous lobster showing blue tag with identification and phone numbers; yellow temperature data logger attached to right cheliped; and acoustic transmitter attached to carapace.

Figure 2. Philip Bramhall "listens" to a sonar tagged lobster, while his sternman, Normand Collamore tunes receiver and records data.

Figure 3. Dan O'Grady "listens" to sonar tagged lobster with Underwater Dive Receiver, while Diane Cowan reaches out to capture and retrieve temperature data.

Figure 4. Tag/release locations of recently-spawned lobsters tagged Sep – Oct 2002.

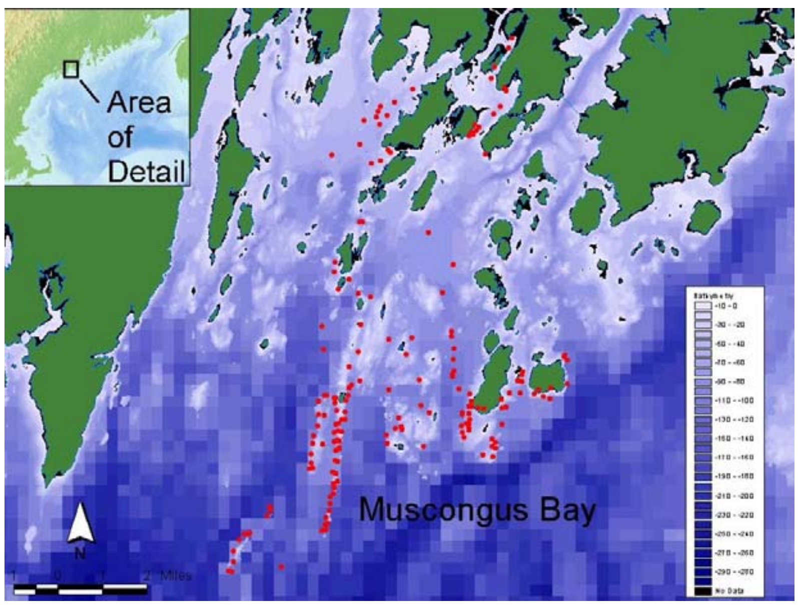


Figure 5. Tag/release locations of male (blue dots) and female (pink dots) lobsters tagged Aug – Sep 2003.

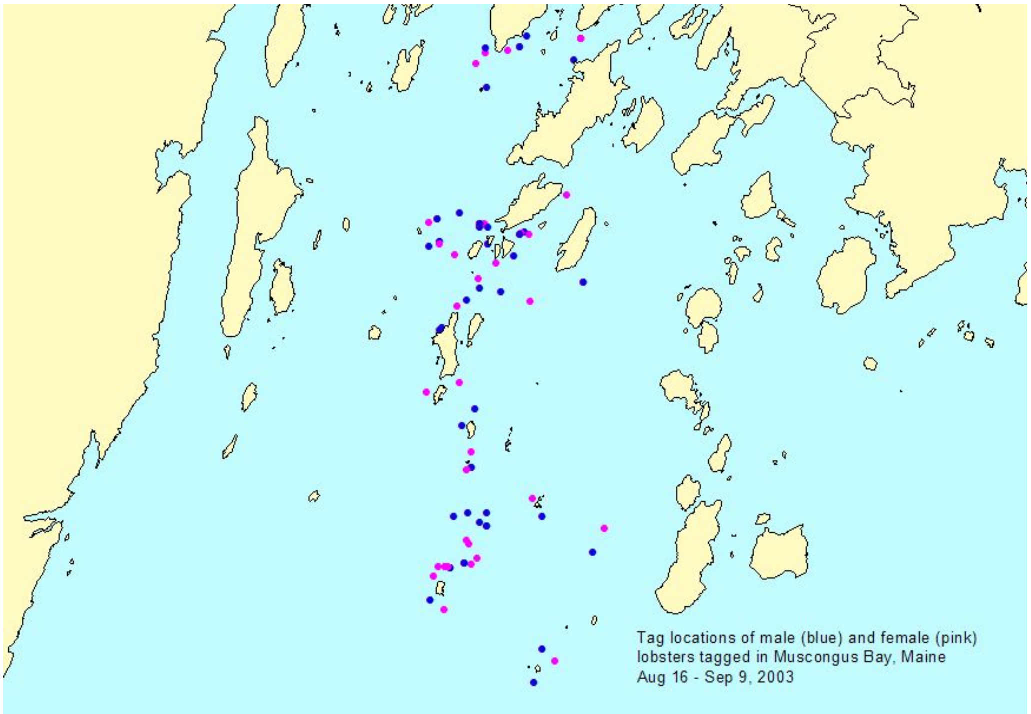


Figure 6. Tag/release locations with size of points indicating relative size of lobster.

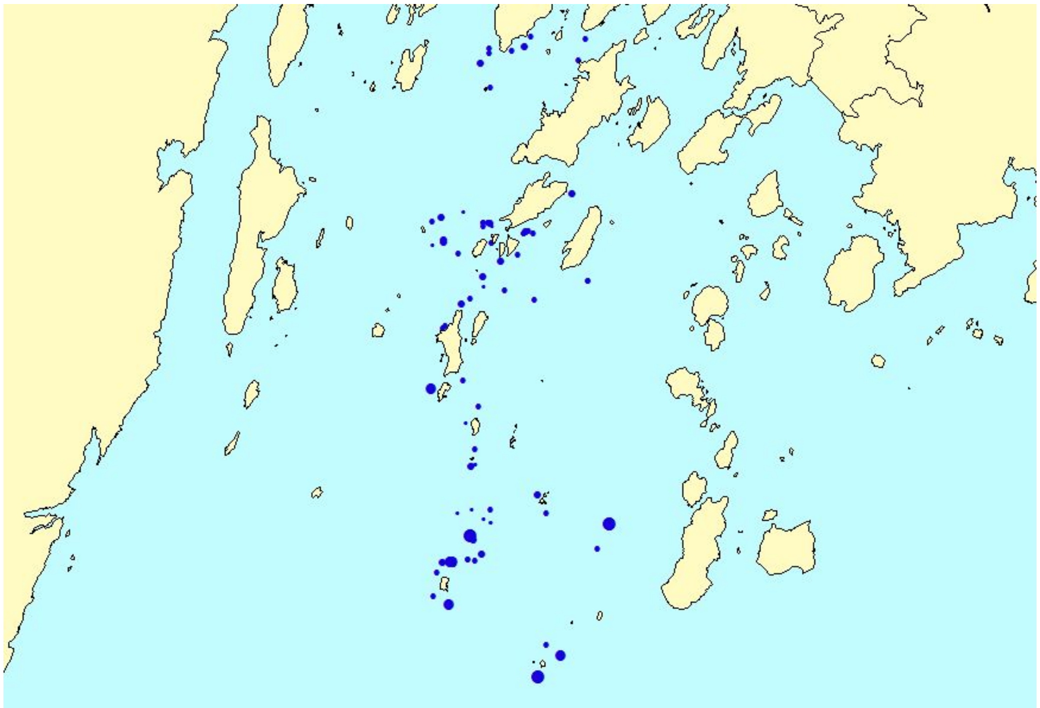


Figure 7. Size-frequency histogram showing size distribution of female lobsters available in the local population. Dashed vertical lines represent minimum and maximum legal size, respectively. Solid vertical line represents size at 50% maturity. N = 3,376: 3,075 < 93mmCL and 301 ≥ 93mmCL.

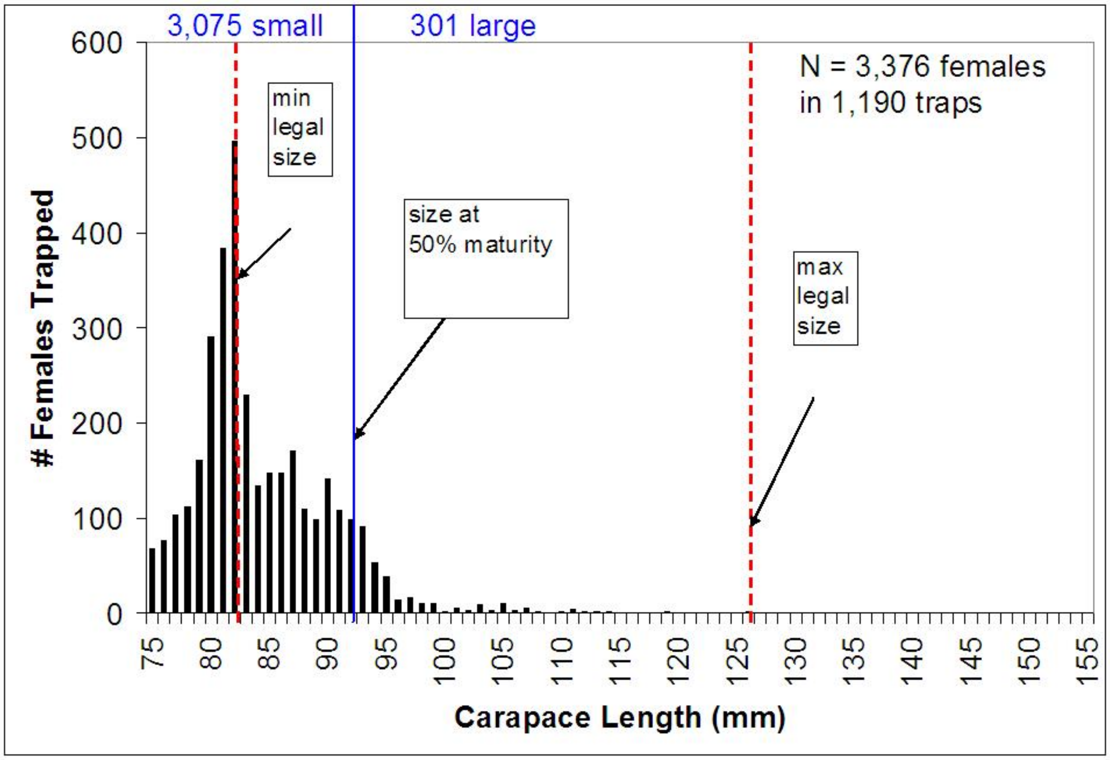


Figure 8. Size-frequency histogram showing size distribution of ovigerous female lobsters tagged in 2002. Dashed vertical lines represent minimum and maximum legal size, respectively. Solid vertical line represents size at 50% maturity. N= 191: 79 < 93 mmCL and 112 $\geq$ 93mmCL.

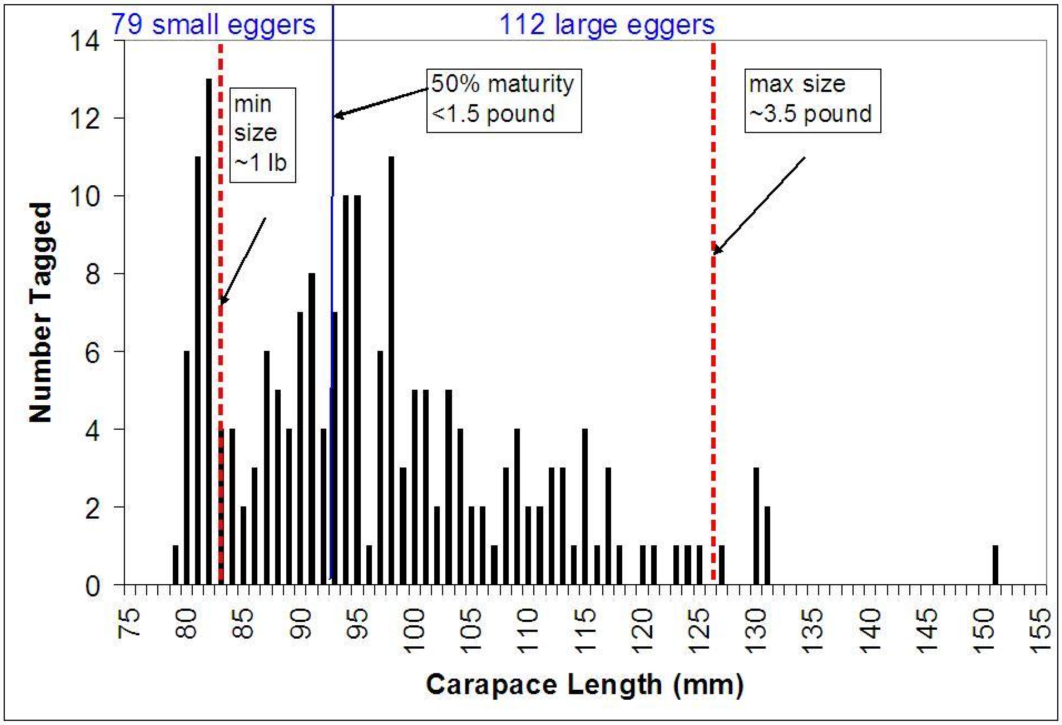


Figure 9. Rates of detection of lobsters tagged in 2002.

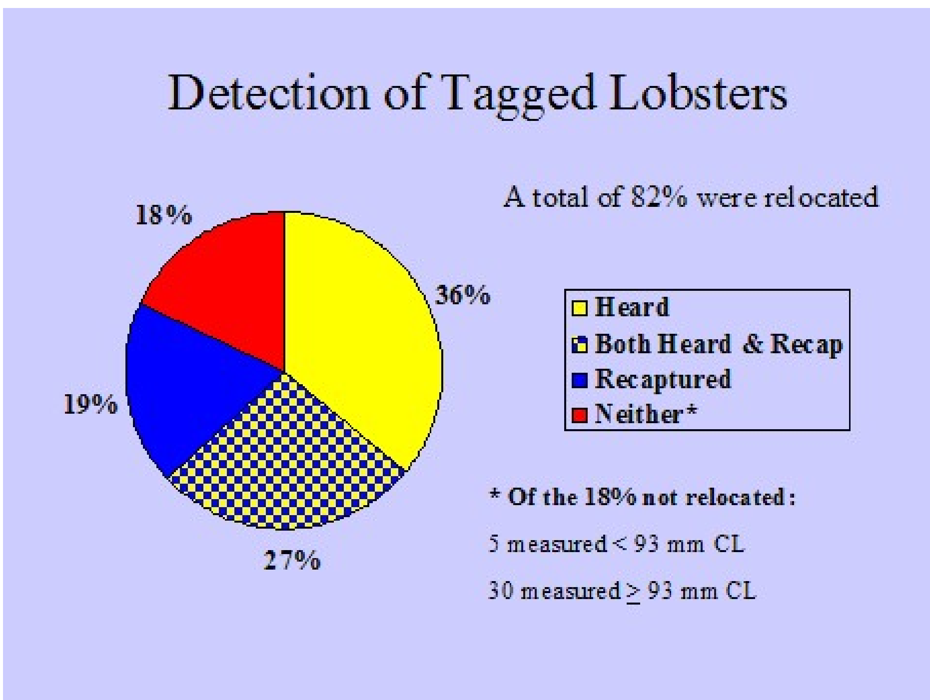


Figure 10. Lobster track for ovigerous lobster #54.

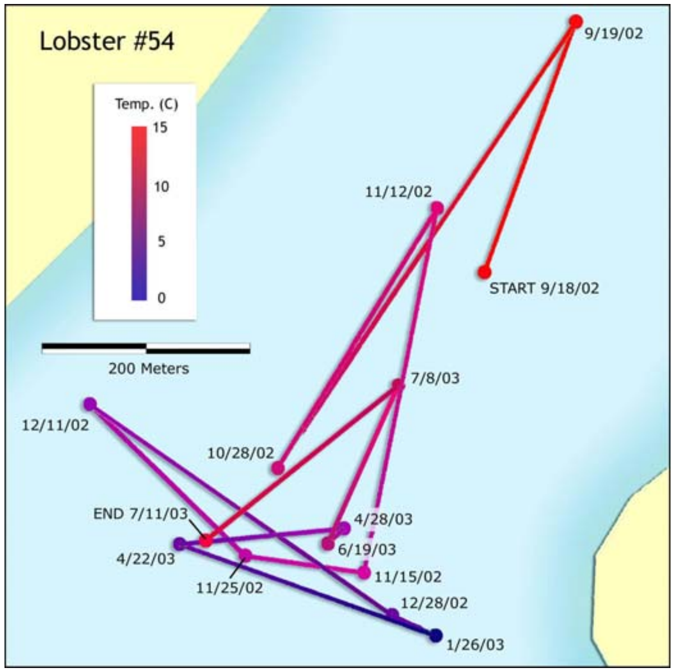


Figure 11. Location of ovigerous lobsters with maximum displacement of less than 20 km. Yellow dots indicate small and red dots, large ovigerous lobsters.

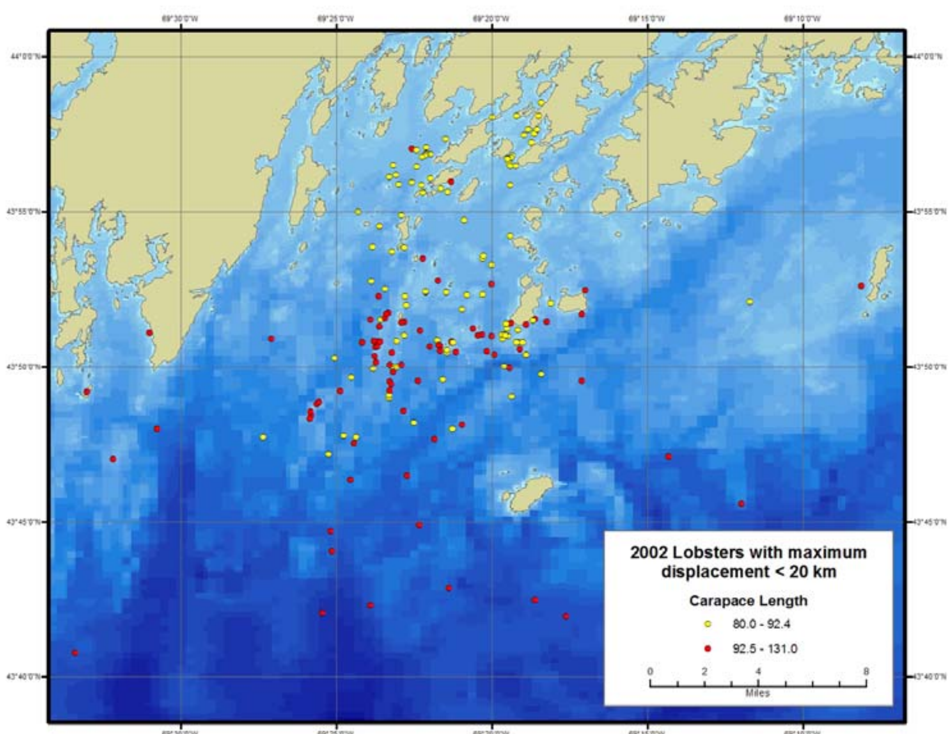


Figure 12. Location of ovigerous lobsters with maximum displacement of greater than 20 km. Yellow dots indicate small and red dots, large ovigerous lobsters.

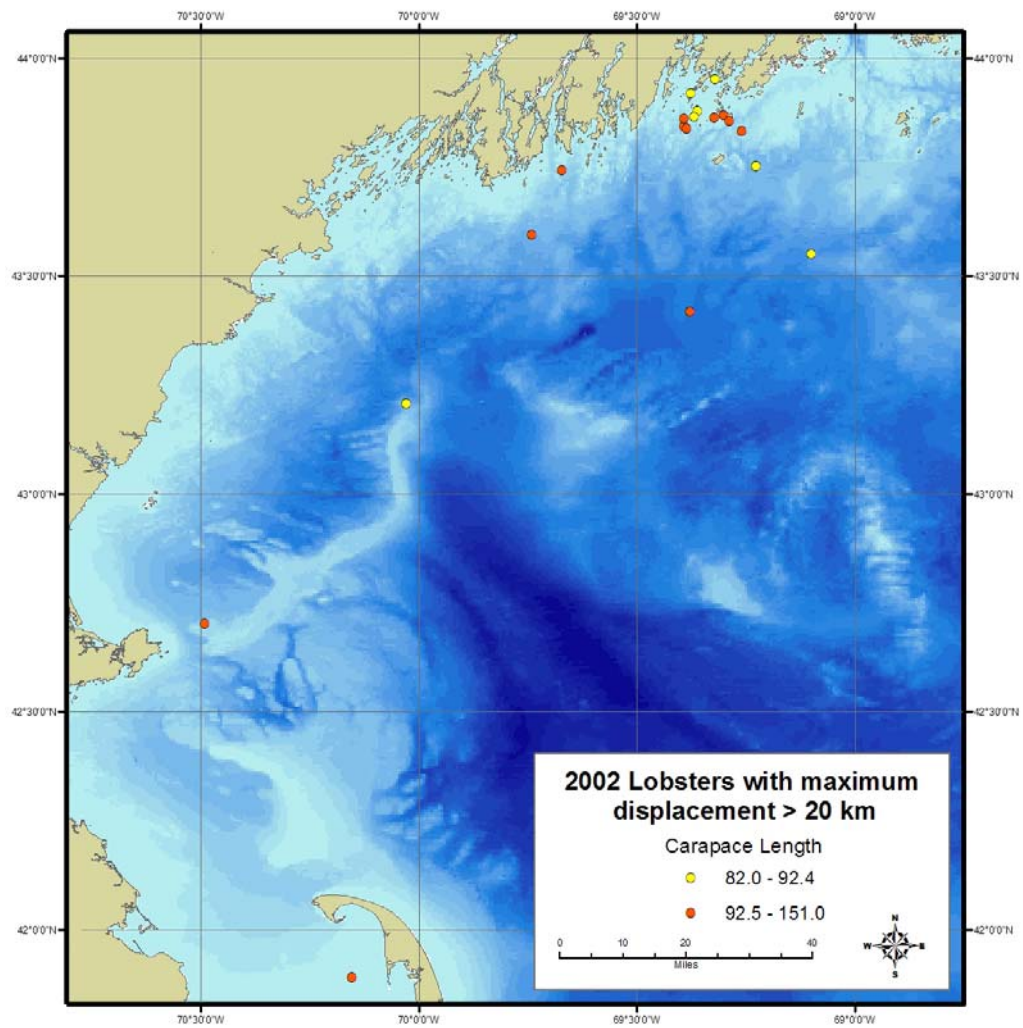


Figure 13. Size-frequency histogram showing size distribution of male (blue) and ovigerous female (pink) lobsters tagged in 2003.

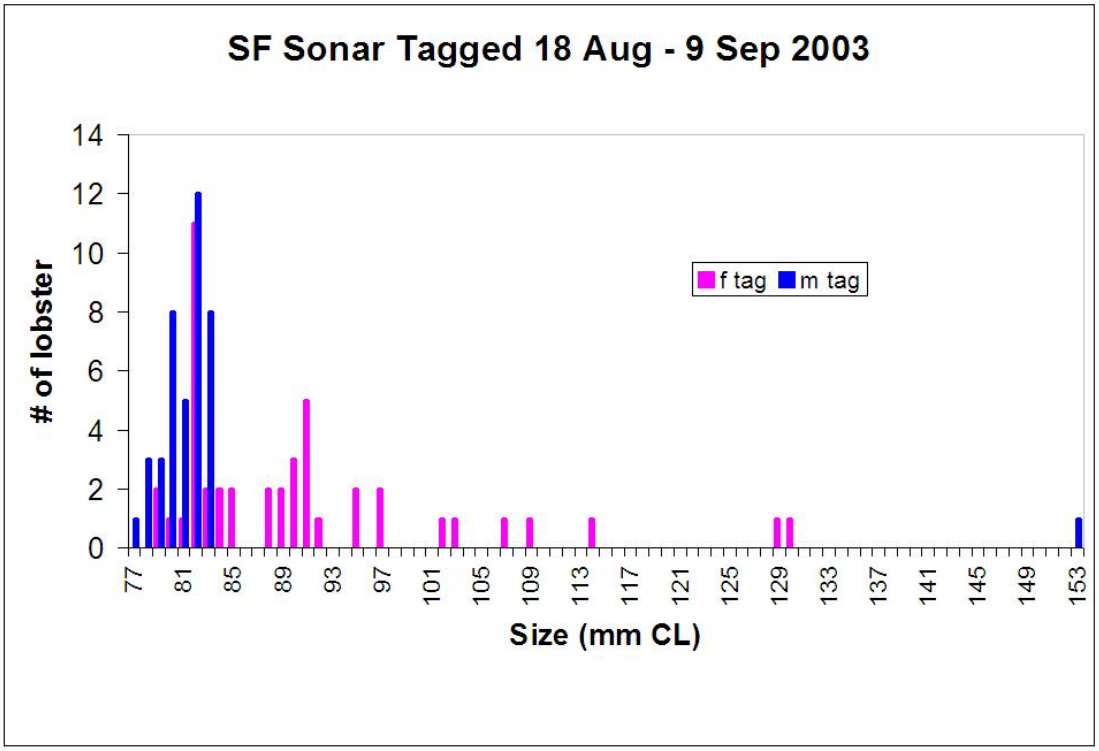


Figure 14. Rates of detection of lobsters tagged in 2003.

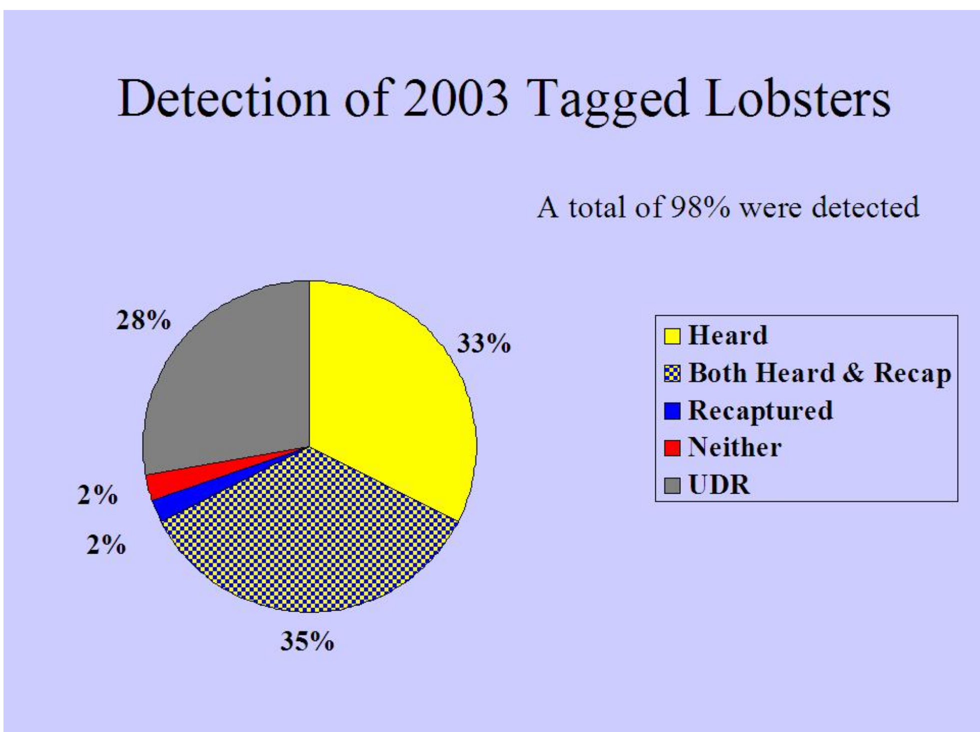


Figure 15. Locations where 30 recently spawned ovigerous lobster tagged between Sep 5 and Oct 10, 2002 in Muscongus Bay, Maine recorded hourly temperature for 224-358 days. Lines connect points of detection for individuals that moved. Arrow indicates mean direction of travel. Closed circles designate small and open circles large ovigerous lobsters.

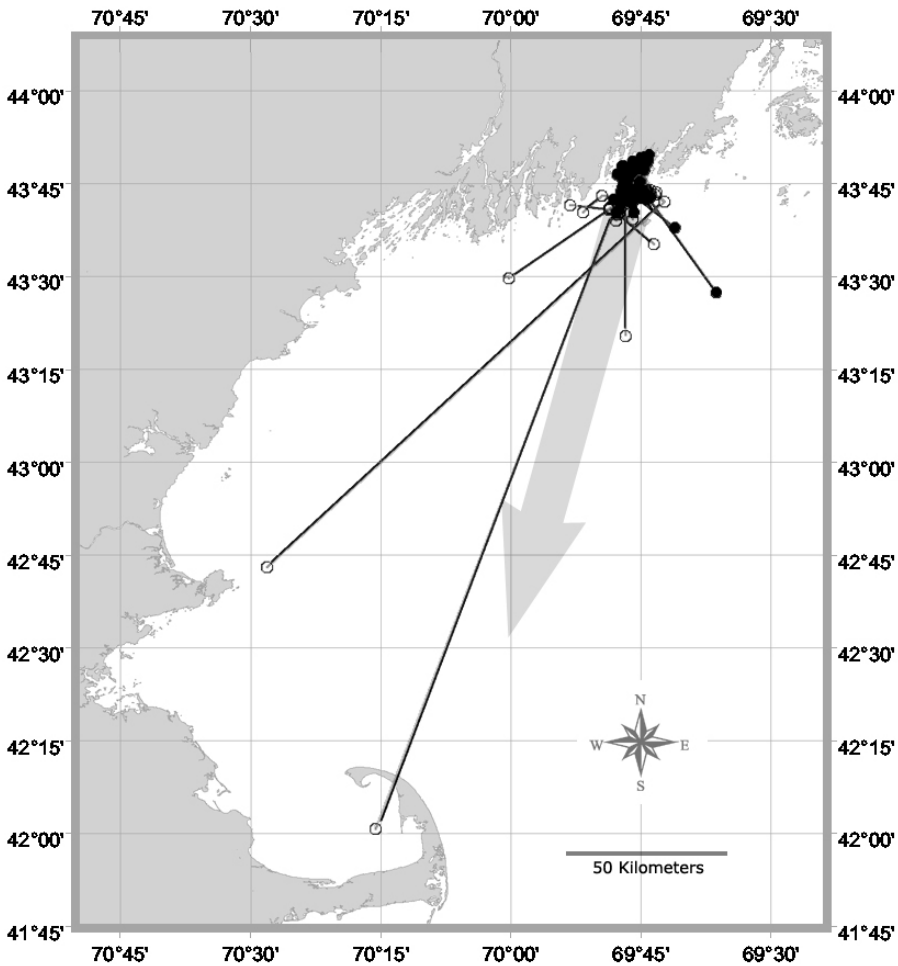


Figure 16. Daily mean bottom temperature recorded by 30 ovigerous female lobster, *Homarus americanus*, from Sep 2002 through Jul 2003. Each line represents one lobster. Temperature data loggers attached to lobster recorded hourly temperature.

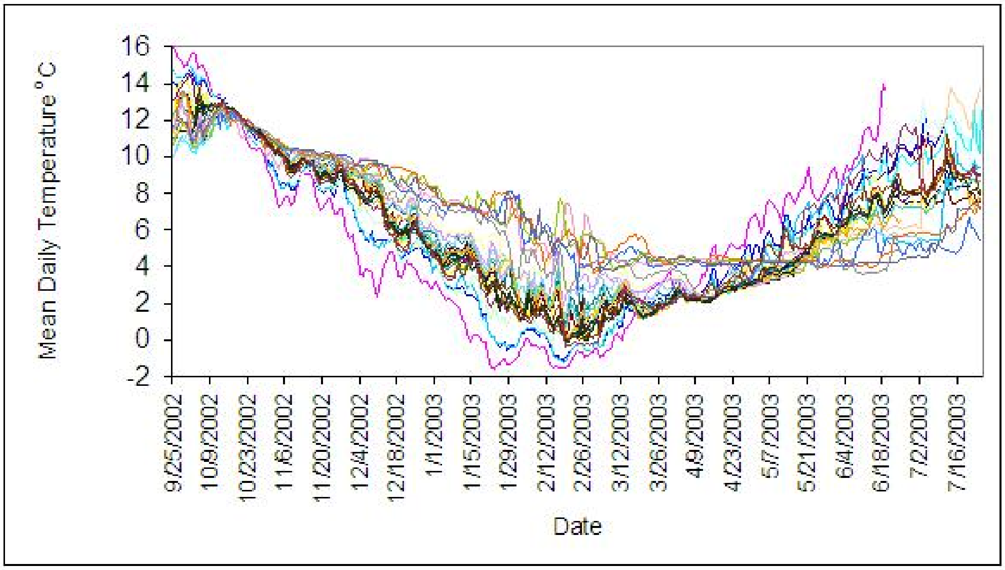
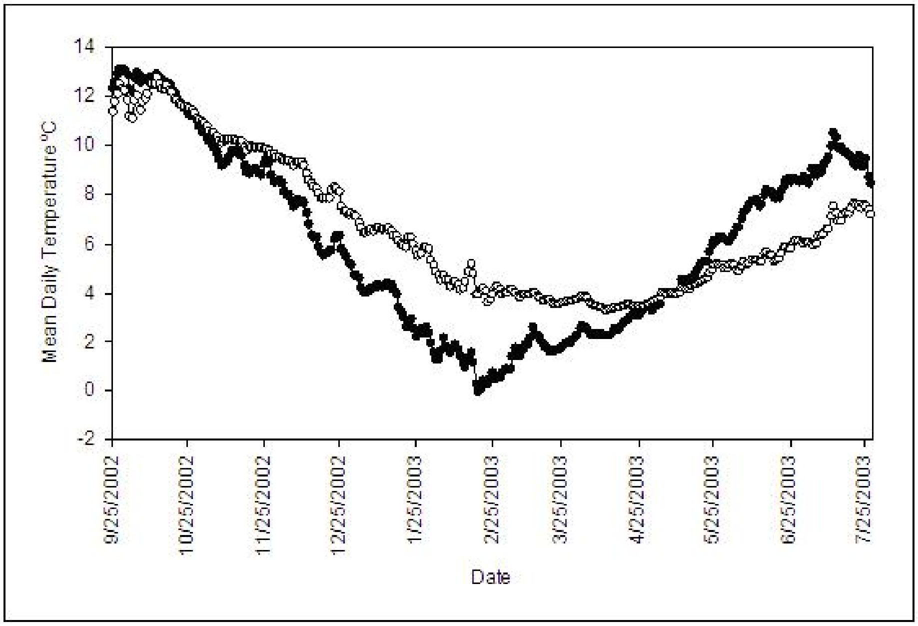


Figure 17. Average daily mean bottom temperature recorded by small (<93 mm CL; open squares) and large ($\geq$93 mm CL; closed squares) ovigerous female lobster, *Homarus americanus*, from Sep 2002 through Jul 2003. 93 mm CL represents the size at 50% maturity for female lobster in the Gulf of Maine.



APPENDIX. Map of Lobster Management Areas.

FEDERAL LOBSTER MANAGEMENT AREA LATITUDE/LONGITUDE COORDINATES

March 2003

The following lobster management areas are established for purposes of implementing the management measures specified in the Code of Federal Regulations §697. Follow listed coordinates down and then across in the order stated. Current Federal lobster management measures can be found at the following NOAA Fisheries Northeast Region website: http://www.nero.noaa.gov.

Nearshore Lobster Management Area 1.

Nearshore Lobster Management Area 1 is defined by the area, including state and Federal waters that are nearshore in the Gulf of Maine, bounded by straight lines connecting the following points, in the order stated, and the coastline of Maine, New Hampshire, and Massachusetts to the northernmost point on Cape Cod:

Point	Latitude	Longitude	Point	Latitude	Longitude
A	43/58' N.	67/22' W.	G	42/05.5' N.	70/14' W.
B	43/41' N.	68/00' W.	G1	42/04.25' N.	70/17.22' W.
C	43/12' N.	69/00' W.	G2	42/02.84' N.	70/16.1' W.
D	42/49' N.	69/40' W.	G3	42/03.35' N.	70/14.2' W.
E	42/15.5' N.	69/40' W.			
F	42/10' N.	69/56' W.			

From point “G3" along the coastline of Massachusetts, including the southwestern end of the Cape Cod Canal, continuing along the coastlines of Massachusetts, New Hampshire, Maine, and the seaward EEZ boundary back to point A.

Nearshore Lobster Management Area 2.

Nearshore Lobster Management Area 2 is defined by the area, including state and Federal waters that are nearshore in Southern New England, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude	Point	Latitude	Longitude
H	41/40' N.	70/05' W.	N	40/45.5' N.	71/34' W.
I	41/15' N.	70/05' W.	O	41/07' N.	71/43' W.
J	41/21.5' N.	69/16.5' W.	P	41/06.5' N.	71/47' W.
K	41/10' N.	69/06.5' W.	Q	41/11.5' N.	71/47.25' W.
L	40/55' N.	68/54' W.	R	41/18.5' N.	71/54.5' W.
M	40/27.5' N.	72/14' W.			

From point “R” along the maritime boundary between Connecticut and Rhode Island to the coastal Connecticut/Rhode Island boundary and then back to point “H” along the Rhode Island and Massachusetts coast, including the northeastern end of the Cape Cod Canal.

Area 2/3 Overlap.

The Area 2/3 Overlap is defined by the area, comprised entirely of Federal waters, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude	Point	Latitude	Longitude
K	41/10' N.	69/06.5' W.	M	40/27.5' N.	72/14' W.
L	40/55' N.	68/54' W.	N	40/45.5' N.	71/34' W.

Offshore Management Area 3.

Offshore Management Area 3 is defined by the area, comprised entirely of Federal waters, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude	Point	Latitude	Longitude
A	43/58' N.	67/22' W.	U	40/12.5' N.	72/48.5' W.
B	43/41' N.	68/00' W.	V	39/50' N.	73/01' W.
C	43/12' N.	69/00' W.	X	38/39.5' N.	73/40' W.
D	42/49' N.	69/40' W.	Y	38/12' N.	73/55' W.
E	42/15.5' N.	69/40' W.	Z	37/12' N.	74/44' W.
F	42/10' N.	69/56' W.	ZA	35/34' N.	74/51' W.
K	41/10' N.	69/06.5' W.	ZB	35/14.5' N.	75/31' W.
N	40/45.5' N.	71/34' W.	ZC	35/14.5' N.	71/24' W.
M	40/27.5' N.	72/14' W.			

From point “ZC” along the seaward EEZ boundary to point “A”.

Nearshore Lobster Management Area 4.

Nearshore Lobster Management Area 4 is defined by the area, including state and Federal waters that are nearshore in the northern Mid-Atlantic, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude
M	40/27.5' N.	72/14' W.
N	40/45.5' N.	71/34' W.
O	41/07' N.	71/43' W.
P	41/06.5' N.	71/47' W.

From Point "P", boundary follows the 3 mile limit of New York as it curves around Montauk Point to Point “S”

Point	Latitude	Longitude
S	40/58' N.	72/00' W.
T	41/00.5' N.	72/00' W.

From Point "T", along the New York/New Jersey coast to Point "W"

Point	Latitude	Longitude
W	39/50' N.	74/09' W.
V	39/50' N.	73/01' W.
U	40/12.5' N.	72/48.5' W.

From Point "U" back to Point "M".

Nearshore Lobster Management Area 5.

Nearshore Lobster Management Area 5 is defined by the area, including state and Federal waters that are nearshore in the southern Mid-Atlantic, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude	Point	Latitude	Longitude
W	39/50' N.	74/09' W.	Z	37/12' N.	74/44' W.
V	39/50' N.	73/01' W.	ZA	35/34' N.	74/51' W.
X	38/39.5' N.	73/40' W.	ZB	35/14.5' N.	75/31' W.
Y	38/12' N.	73/55' W.			

From Point "ZB" along the coasts of North Carolina, Virginia, Maryland, Delaware, New Jersey back to Point "W".

Nearshore Lobster Management Area 6.

The Nearshore Lobster Management Area 6 is defined by the area, including New York and Connecticut state waters, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude
T	41/00.5' N.	72/00' W.
S	40/58' N.	72/00' W.

From Point "S", boundary follows the 3 mile limit of New York as it curves around Montauk Point to Point “P”

Point	Latitude	Longitude
P	41/06.5' N.	71/47' W.
Q	41/11'30" N.	71/47'15" W.
R	41/18'30" N.	71/54'30" W.

From point “R”, along the maritime boundary between Connecticut and Rhode Island to the coast; then west along the coast of Connecticut to the western entrance of Long Island Sound; then east along the New York coast of Long Island Sound and back to Point “T”.

Nearshore Outer Cape Lobster Management Area.

Nearshore Outer Cape Lobster Management Area is defined by the area, including state and Federal waters off Cape Cod, bounded by straight lines connecting the following points, in the order stated:

Point	Latitude	Longitude	Point	Latitude	Longitude
F	42/10' N.	69/56' W.	G2	42/02.84' N.	70/16.1' W.
G	42/05.5' N.	70/14' W.	G4	41°52! N.	70°07.49! W.
G1	42/04.25' N.	70/17.22' W.	G5	41°54.46! N.	70°03.99! W.

From Point G5 along the outer Cape Cod coast to Point H:

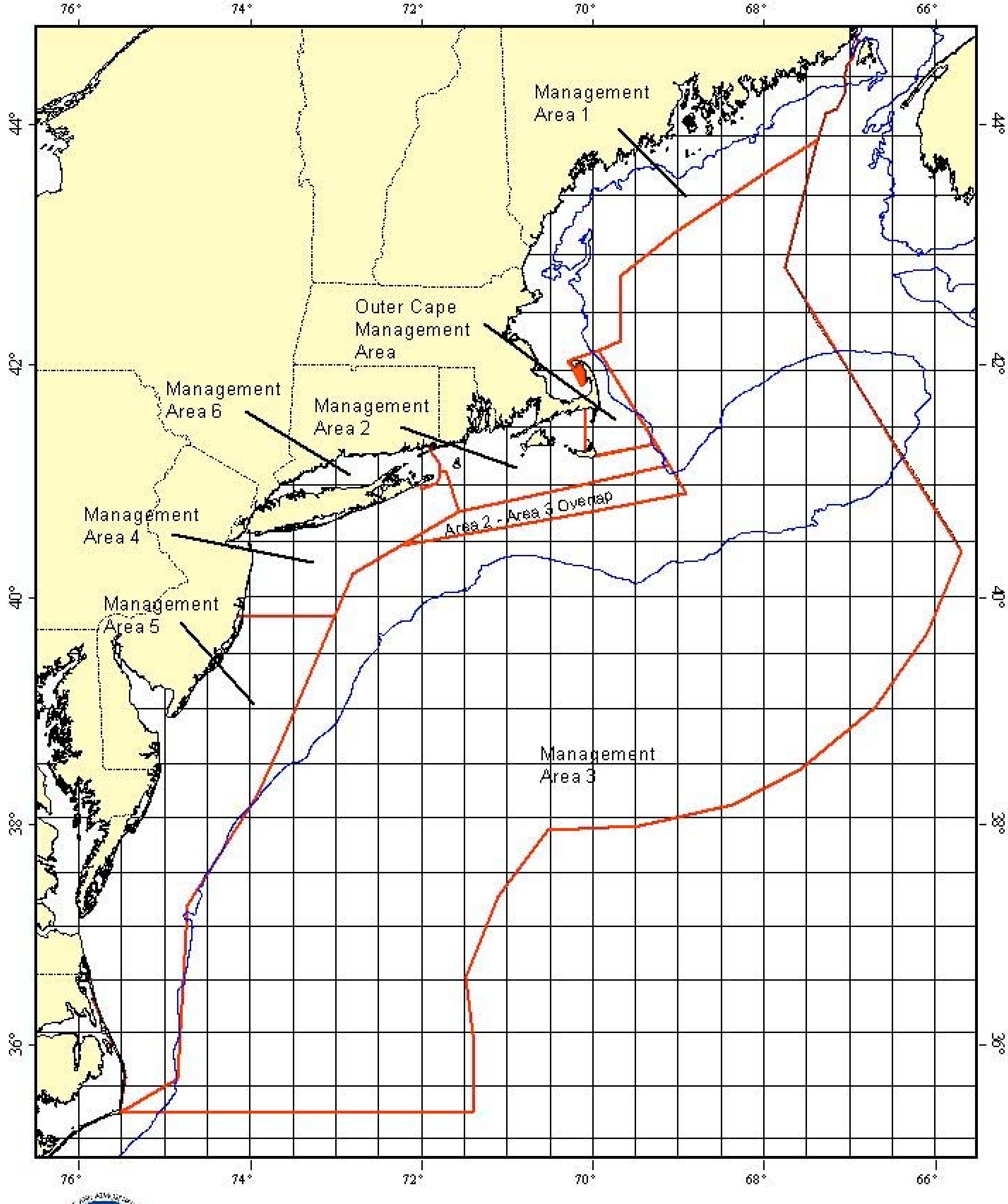
Point	Latitude	Longitude
H	41/40' N.	70/05' W.
H1	41°18! N.	70°05! W.

From Point “H1" along the eastern coast of Nantucket Island to Point “I”:

Point	Latitude	Longitude
I	41/15' N.	70/00' W.
J	41/21.5' N.	69/16' W.

From Point "J" back to Point "F".

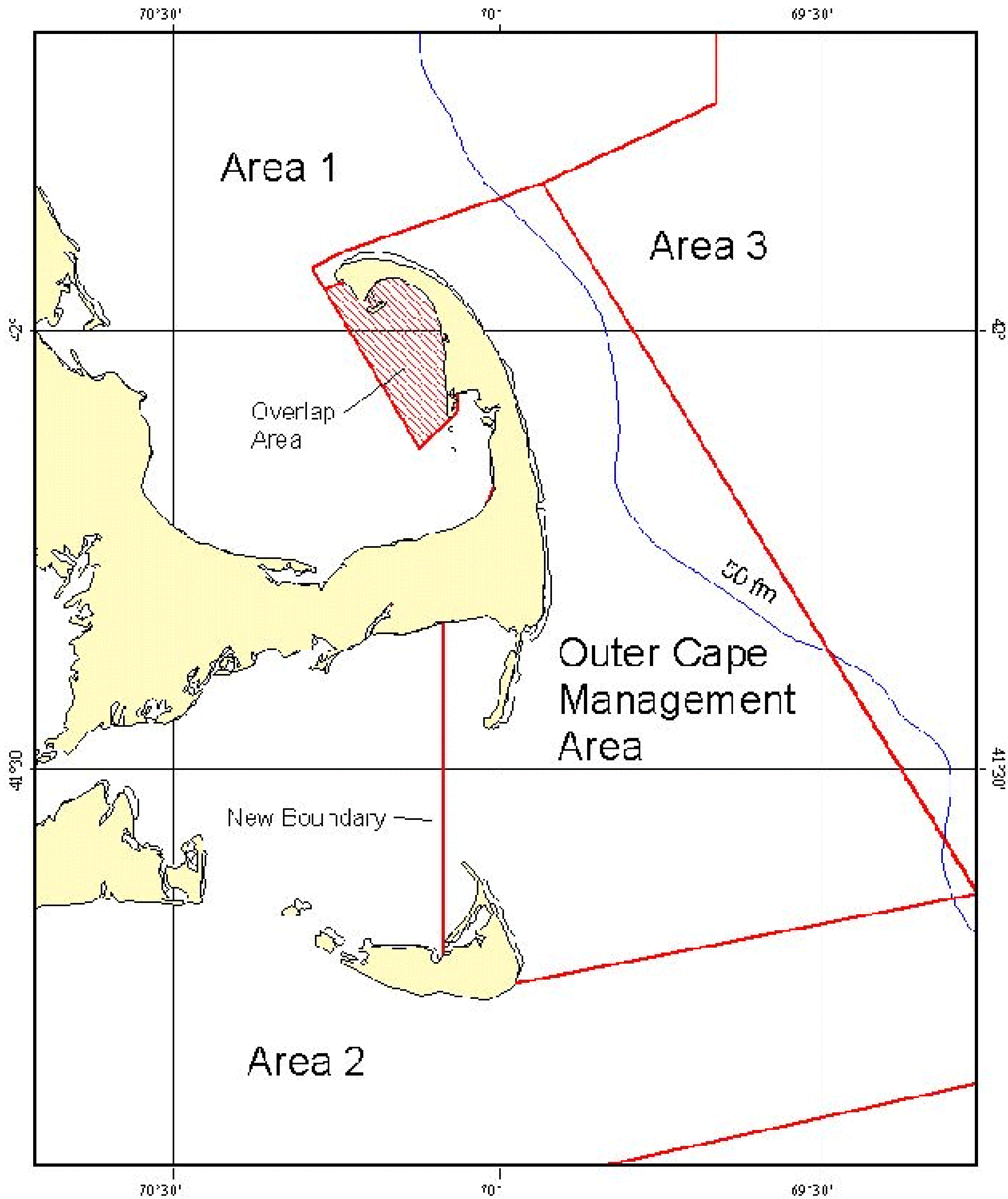
American Lobster Management Areas



NOAA Fisheries
Northeast Regiional Office
Gloucester, MA

3/18/03

American Lobster Management Areas



NOAA Fisheries
Northeast Regional Office
Gloucester, MA

3/13/03