The relationship between traps, effort and fishing mortality in the Maine lobster fishery: Manipulative experiments in the Monhegan Lobster Conservation Area

Final Report

Project Development Award
 # PO P4UZE112

Project Duration:
12/1/2003 through 6/30/2005

Submission Date:
January 25, 2006

Carl Wilson
Principal Investigator
Maine Department of Marine Resources
PO Box 8, McKown Point Road
W. Boothbay Harbor, Me 04575
(207) 633-9538 or Carl.Wilson@maine.gov

Carl J. Wilson

1. Abstract

Four experimental trapping areas were established within the Monhegan Lobster Conservation Area (MLCA) to determine how the number and spatial arrangement of traps affects catch rates and fishing impacts. The number of traps and size of the experimental areas were designed to determine the joint effects of trap density and the aerial extent of fishing on lobster catch rates, population depletion, and mortality. High trap density areas significantly lowered the catch rates as compared to low density areas. The cumulative catch was higher in high trap density areas than low density areas over the course of the experiment, yet gross economic gains were largely offset when expenses were factored in. Methodologies were successfully developed that allowed accurate and high resolution quantification of the impacts of removals by lobster traps in discrete experimental sampling areas. Recaptured lobsters were easily identified by daily batch tags, and provided reliable estimates of recapture through the course of the experiment. This project development grant lead to the application of the methodologies to a larger experiment within the MLCA, funded by NEC in FY04, that involved seven fishermen, and 1,500 traps placed at different densities in eight 1 km^2 experimental areas. This work will benefit lobster management in the future as we begin to understand how trap increases or reductions could impact the lobster population and associated fishery.

2. Introduction

The lobster fishery is closely linked with the social and economic prosperity of coastal Maine and New England. In Maine, 70.9 million pounds of lobsters valued at $285.9 million were landed in 2004. In the last two decades landings have nearly tripled the one hundred year average. During this period fishing effort and efficiency has increased, with over 3.1 million trap tags sold in Maine in 2004. Additionally, as other fisheries have declined or become limited; there is an increasingly high reliance on lobsters as the primary fishery for many fishermen. Scientists, managers and industry all point to an inevitable stock decline as a major source of concern both biologically and economically.

The American lobster fishery is cooperatively managed under the Atlantic States Marine Fisheries Commission management plan. Fishing mortality biological reference points are set as management targets. Current fishing mortality rates in the Gulf of Maine exceed the biological reference point necessitating management action to reduce fishing mortality (ASMFC 2000, 2005). Trap reductions are often looked at as traditional option for reducing fishing mortality rates as traps are the primary method of harvest in the fishery. However, trap reductions are unlikely to be directly related to fishing mortality; as the ability of fishermen to increase trapping efficiency will likely confound the intent of trap reductions measures (Russell 1994, Rothschild 1972). To undertake large trap reductions, in Maine and New England, would begin an experiment that might have unknown biological benefit and huge economic costs. We proposed to quantify fishing effort (removal by traps) in the lobster fishery by empirically testing basic assumptions of fishing mortality by investigating trap capacity, interference between traps and the population effects of removing legal lobsters by a fishery.

Situated in the heart of lobster country (mid-coast Maine), the waters surrounding Monhegan Island are ideally suited for experimental trapping because they are closed to lobster fishing during the summer months. Nearly 70% of the annual catch in Maine is landed between July and September. The Monhegan lobster fishery is a traditional fishing territory dating back to before 1900; in 1998, the Maine legislature officially recognized this area as the Monhegan Lobster Conservation Area (MLCA). The MLCA is approximately 30 mi.^{2}, defined by two arcs; two miles north of the island and three miles to the south (Figure 1). In addition to area restrictions MLCA participants are constrained to fishing 180 days during winter months; participation is limited to 17 berths; and participants are limited to 600 traps. An explicit aim of the Maine legislature, when establishing MLCA, was to promote closed season scientific studies, a goal that complements the Northeast Consortium goal of evaluating closed areas and improving fishing practices.

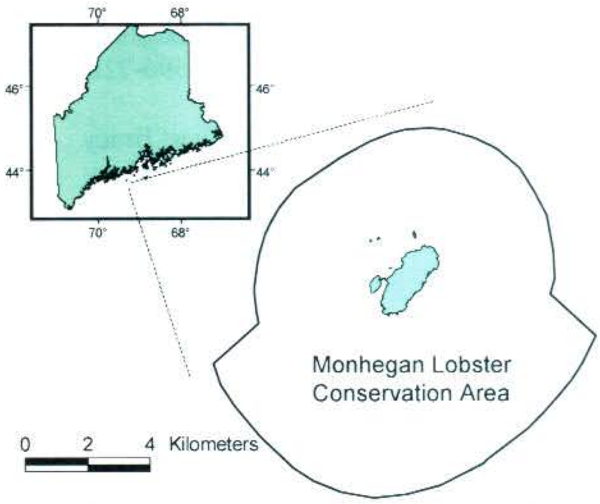


Figure 1. The Monhegan Lobster Conservation Area. Established over 100 years ago, it is home to New England's only seasonal lobster fishery.

3. Project objectives and scientific hypotheses

We proposed to conduct manipulative trapping experiments in the waters surrounding Monhegan Island, to set the stage for a larger project to determine how the number and spatial arrangement of traps affects exploitation rates and fishing mortality. Multiple experimental trapping areas were established within the Monhegan Lobster Conservation Area (MLCA). The number and size of the experimental areas were designed to determine the joint effects of trap density and the aerial extent of fishing on catch rates, population depletion, and mortality.

Specific objectives of this development project were to:

- Conduct short term trapping experiments in multiple areas with varying densities of traps and size of area.
- Develop practical methodologies for discrete experimental trapping areas
- Develop on-board industry data collection techniques using electronic logbooks.
- Develop easy mark-recapture techniques for tagging all lobster encountered during the study.
- Determine the impacts of study area size on catch rates and recaptures.
- Determine lobster population densities before during and after experimental fishing activity.

4. Participants

Carl Wilson
Maine Department of Marine Resources
PO Box 8, McKown Point Road
W. Boothbay Harbor, Me 04575
(207) 633-9538 or
Carl.Wilson@maine.gov

Mathew Thomson
F/V Shearwater II
PO Box 42
Monhegan, ME 04852
207-594-1778

Matt Weber
F/V Griffin
PO Box 42
Monhegan , ME 04852
207-596-7289

Robert Bracy
F/V Pandora
PO Box 312
Monhegan, ME 04852
596-6748

5. Methods

5.1 Study Sites

Four experimental trapping areas within the Monhegan Lobster Conservation Area were chosen using participating fishermen knowledge of the bottom topography, substrate type and lobster population. All areas ranged in depth from 20-30 fathoms and were composed primarily of ledge, boulder and cobble substrates. Two treatments of study site size (0.141 and 0.016 km^2) were used to test for impacts of area and edge effects (Figure 2, Figure 3).

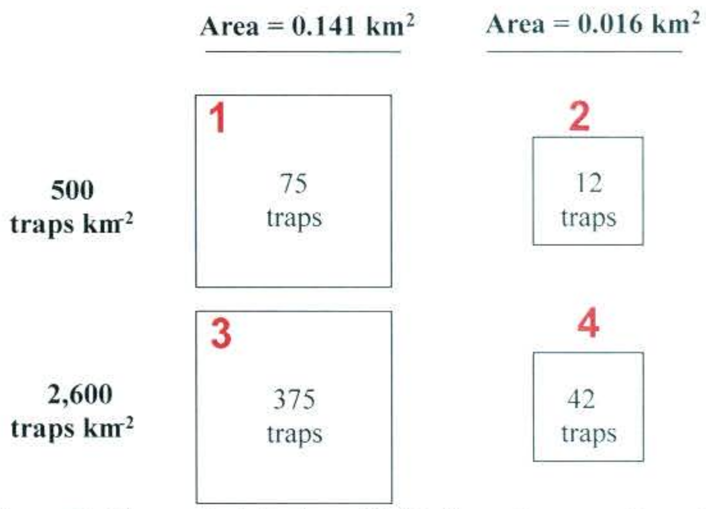


Figure 2. Conceptual design of initial trapping experiments in the Monhegan Lobster Conservation Area. Trap densities bracket reported trap densities along the coast of Maine.

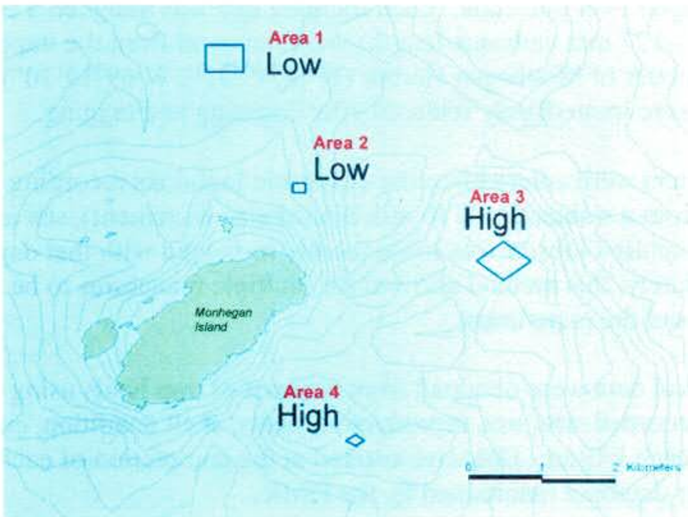


Figure 3. Location and trap density treatment of four experimental study areas within the Monhegan Lobster Conservation Area. Two sizes (0.141 and 0.016 km^2) and two trap densities (low = 500 and high = 2,600 km^{-2}) were employed for the duration of the experiment.

5.2 Experimental design

Two different trap densities were applied to the four experimental areas for this study (Figure 2). Determination of trap densities are based on recently published observations of trap densities along the coast of Maine (Steneck and Wilson 2001, Kelly 1994), density of traps were 500 and 2,600 traps km^{-2}. A total of 504 traps were used and were distributed to each study area according to area size and trap density.

Each area was randomly assigned a size and trap density (Figure 2). Traps were hauled a total of six times during the experiment with a standardized soak time of 5 nights. All traps were baited with salted herring at a rate of 3 bushels per 100 traps. Traps were rigged as triples (one buoy line for three traps) and were distributed evenly throughout the study area in a manner to facilitate ease of recovery. Standard commercial four foot double parlor traps were used throughout the experiment, each trap was equipped with a minimum of one legal escape vent (1 15/16 rectangular or 2 7/16" circular).

Catch statistics were recorded by participating fishermen using an electronic logbook with counts of sublegal, legal, and illegal (oversize, egg bearing and V-notched) lobsters entered for each triple hauled. As the catch was entered, a latitude/longitude position was generated for use in subsequent spatial analysis.

In high trap density areas some traps were missed on each haul (10-22%) due to gear loss or were inaccessible (buoy sunk by adjacent gear). When lost gear was recovered later in the experiment the catch was ignored, and the trap was re-baited and reset.

Each lobster encountered during the experiment was batch tagged using a standard lobster band slipped over one claw. Each trapping day was assigned a unique tag color. Legal lobster (83-127 mm carapace length) were removed from the trapping areas and released at the mouth of Monhegan Harbor (N 43°45'35", W 69°19'30"). Sublegal and illegal lobsters were immediately released after counting and tagging.

Recaptured lobsters were entered into the electronic logbooks recording tag number (day number), size (from a standardized 10 mm binned size increment), sex and reproductive status. Each recaptured lobster was subsequently re-tagged with that days' tag color and released immediately, this method allowed for multiple recaptures to be recorded and tracked through out the experiment.

Detailed biological data were obtained from a subset of trap hauls using onboard observers who recorded size, sex, reproductive status, shell condition, cull status and tag information for each lobster. Data was entered at the completion of each day into an existing observer database maintained by the DMR.

Fishery independent estimates of population density were determined with a drop camera system. The video system was mounted to provide a downward picture, with a viewable area of approximately 1.0 m^2 when suspended just off the bottom. Drift transects surveys were conducted in each experimental area at night. Transect length varied as frequent gear entanglement limited the effectiveness of this method. Electrical failures hampered the three proposed surveys (before, during and after).

5.3 Project timeline

The project was initiated at the conclusion of the 2003-2004 Monhegan Island fishing season which ran from December 1, 2003 through May 31, 2004. On the final day of the fishing season participants moved the required number of traps to the designated areas, baited them and hauled for the first time five days later on June 4, 2004. Throughout the duration of the experiment a soak time of 5 days was maintained. In one instance (on the fifth hauling day), one participant was forced to haul traps on a 6 night soak due to mechanical problems. At the completion of the experiment on June 29, 2004, traps were immediately removed from the experimental areas.

The video cable was damaged limiting the project to two video days; one day during the second week of the project (June 11, 2004) and one day ten days after the completion of the project (July 11, 2004).

5.4 Data analysis

Raw logbook data was reviewed for obvious outliers in catch composition and location. Data was entered in logbooks as triples, but for analysis this data was converted to per trap haul. A comparison between logbook and observer recorded catch rates were highly correlated for sublegal and legal lobsters.

Mean catch per trap haul were generated for each day and area. Tests for statistical significance between areas and over time were performed using ANOVA and Tukey's post hoc pairwise comparisons. A significance level of 0.01 was used for all tests.

Recaptured lobster were evaluated by area size and trap density, to determine the average return rate. Carapace length (10 mm bin), sex, reproductive status and location were recorded for each recapture within the electronic logbook.

The impacts of edge effects were investigated by (1) comparing the average catch rates between treatments (trap density and area size) and (2) by calculating the distance of each trap haul location from the perimeter of each study area. The catch rate of legal lobster was plotted with respect to distance to the edge in each study area. Area 3, a large area with high trap density, was further investigated to identify changes in edge effects over the course of the experiment.

Cumulative impacts for the experiment were evaluated by area size and trap density. The number of legal lobster relative to the number of trap hauls was compared. The daily proportion and number of legal lobsters was compared between Area 1 (large area and low density) to Area 3 (large are and high density).

The economic consequences of trap density and trapping area were investigated. The 2004 average price per pound of \$4.03 and an average size of 1.25 lb per legal was used to determine the value of lobsters removed from each area. A per trap haul cost of \$0.50 was used to determine bait expense, based on a cost of \$18 per bushel used at a rate of 3 bushel per 100 trap hauls. The crew share was considered to be 20% of the gross. Gear, fuel and vessel depreciation costs were not considered in this analysis.

Lobster density was estimated by constructing a trace of the track of each camera transects. Locations were recorded for each transect at one minute intervals or when the bottom type and a lobsters or crabs were observed. Total number of lobsters were then divided into transect area to determine number m^{-2}. Lobster density was compared to total catch per trap haul by area in each half of the experiment.

6. Data

Table 1. Numbers of trap hauls and lobster caught, and catch rate of sublegal, legal and illegal lobster (egg bearing, V-notch and oversize) during the course of the experiment for each area and day. The experiment ran from June 4-29, 2004. All lobsters were tagged and released, legal lobster were removed from the trapping areas and released.

Area	June Day	Trap Hauls	Total Lobsters	Catch per trap haul					
				Sublegal	Legal	Oversize	V-notch	Eggs no V	Eggs and V
1	4	66	243	1.91	0.86	0.015	0.70	0.08	0.12
	9	81	199	1.41	0.46	0.025	0.46	0.07	0.04
	14	78	219	1.94	0.31	0.000	0.46	0.01	0.09
	19	78	192	1.58	0.31	0.000	0.40	0.00	0.18
	24	78	221	1.96	0.41	0.013	0.37	0.01	0.06
	29	78	179	1.47	0.42	0.000	0.37	0.00	0.04
2	4	12	46	2.42	0.83	0.000	0.58	0.00	0.00
	9	12	35	2.17	0.58	0.000	0.17	0.00	0.00
	14	15	29	0.73	0.47	0.000	0.47	0.13	0.13
	19	12	36	1.83	0.67	0.000	0.42	0.00	0.08
	24	12	21	1.08	0.50	0.000	0.17	0.00	0.00
	29	9	15	0.67	0.56	0.000	0.33	0.00	0.11
3	4	294	691	1.52	0.38	0.000	0.35	0.02	0.08
	9	408	702	1.03	0.30	0.002	0.32	0.01	0.06
	14	363	487	0.83	0.18	0.003	0.28	0.01	0.06
	19	408	411	0.62	0.13	0.005	0.23	0.01	0.02
	24	324	360	0.72	0.18	0.003	0.19	0.01	0.01
	29	363	251	0.38	0.13	0.000	0.17	0.01	0.01
4	4	57	104	0.86	0.39	0.018	0.42	0.05	0.09
	9	57	80	0.44	0.26	0.000	0.54	0.05	0.11
	14	60	135	0.73	0.63	0.000	0.65	0.02	0.22
	19	66	82	0.65	0.26	0.000	0.21	0.03	0.09
	24	69	92	0.64	0.23	0.000	0.33	0.03	0.10
	29	60	49	0.32	0.15	0.000	0.20	0.00	0.17
Grand Total		3,060	4,879	1.163	0.399	0.003	0.366	0.024	0.078

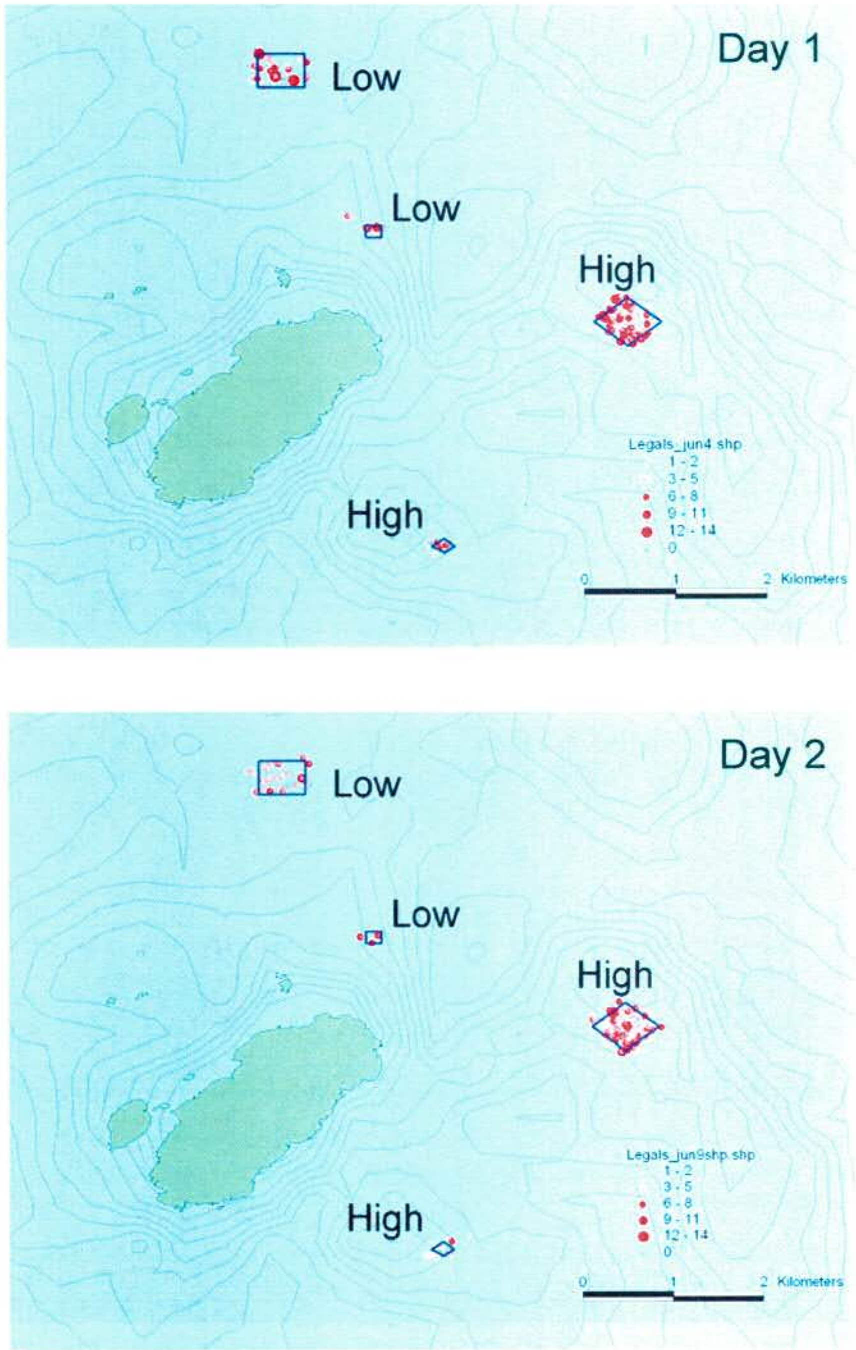
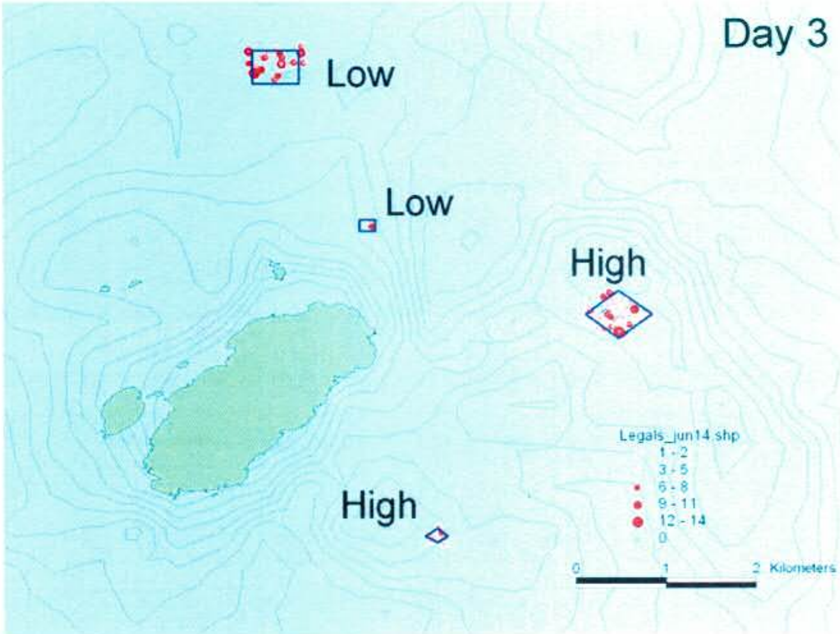


Figure 4A. Spatial distribution of trap hauls and catch of legal lobster within each area over the first and second days of the experiment. Two trapping area sizes (0.141 and 0.016 km^2) and two trap densities (low = 500 and high = 2,600 km^{-2}) were employed for the duration of the experiment.



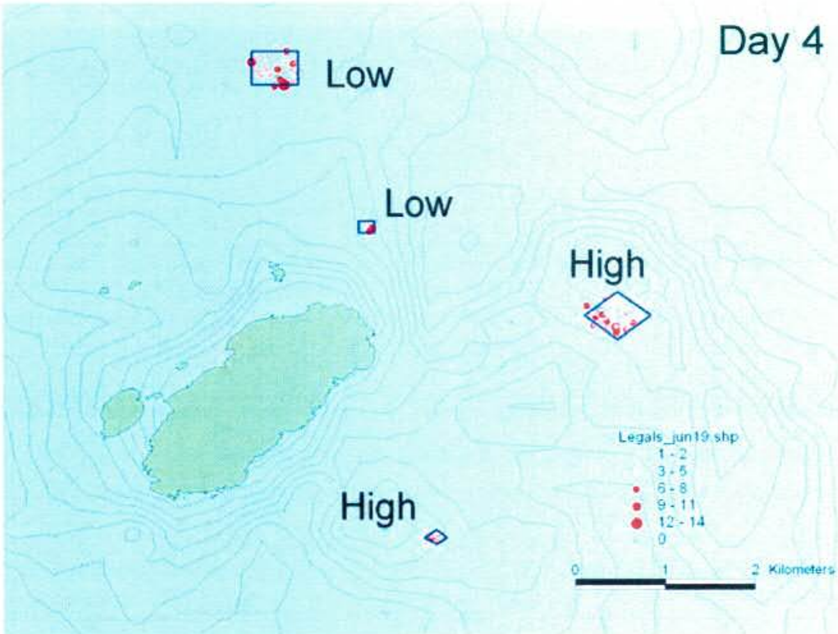
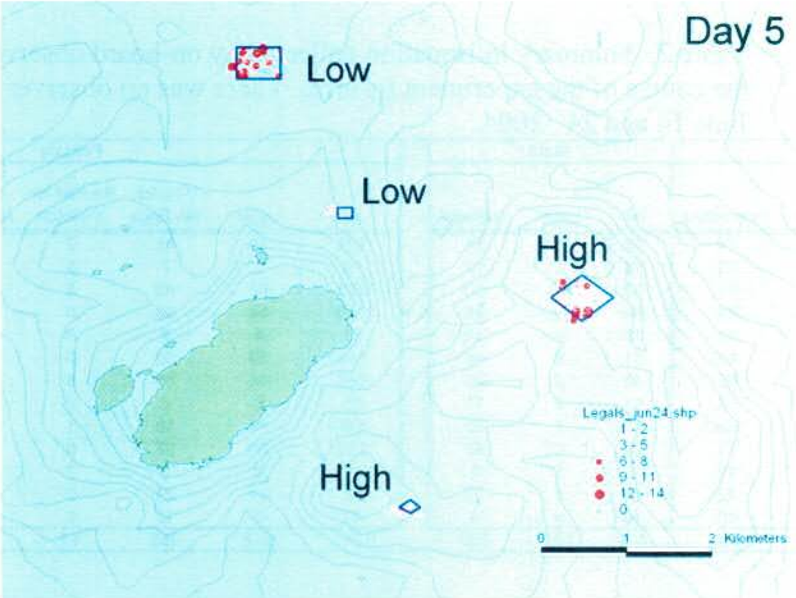


Figure 4B. Spatial distribution of trap hauls and catch of legal lobster within each area over the third and fourth days of the experiment.



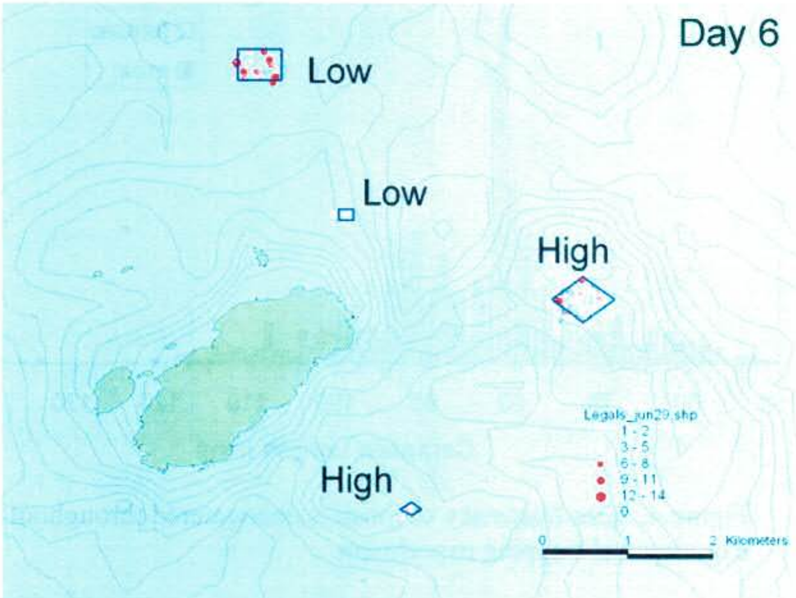


Figure 4C. Spatial distribution of trap hauls and catch of legal lobster within each area over the fifth and sixth days of the experiment.

Table 2. Summary information collected by on-board observers during the course of the experiment by area. There was no observer coverage on June 14 and 24 , 2004.

			Male			Female					
Date	Area	Trap Hauls	All	Legal	Sublegal	All	Legal	V-Notch No Eggs	Berried No V-Notch	Berried and V-Nothced	Sublegal Female
6/4	1	74	72	28	44	183	46	41	2	8	86
6/4	2	12	18	6	12	33	10	7	0	1	15
6/4	3	10	63	13	50	203	47	40	4	11	101
6/9	1	73	54	19	35	138	14	36	0	2	86
6/9	2	12	15	4	11	21	4	2	0	0	15
6/9	3	83	51	8	43	140	22	32	0	12	74
6/19	1	72	43	8	35	146	14	35	5	7	85
6/19	2	12	13	3	10	25	5	5	0	1	14
6/19	3	104	30	7	23	66	12	18	1	6	29
6/29	1	71	55	12	43	126	20	27	0	4	75
6/29	2	15	9	3	6	17	2	3	2	0	10
6/29	3	22	18	6	12	73	11	24	0	3	35
6/29	4	60	10	4	6	40	5	12	3	5	15
Totals		620	451	121	330	1211	212	282	17	60	640

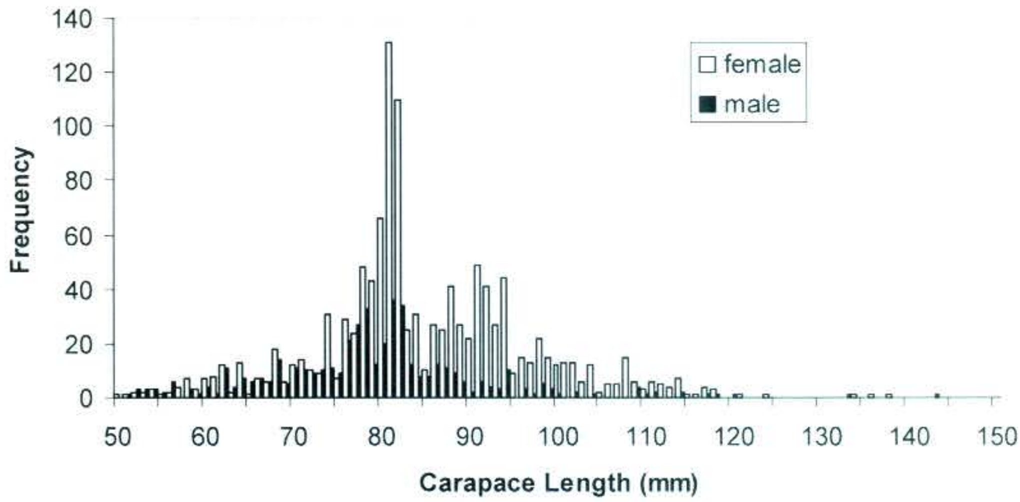


Figure 4. Size frequency of lobsters encountered throughout the experimental trapping experiment.

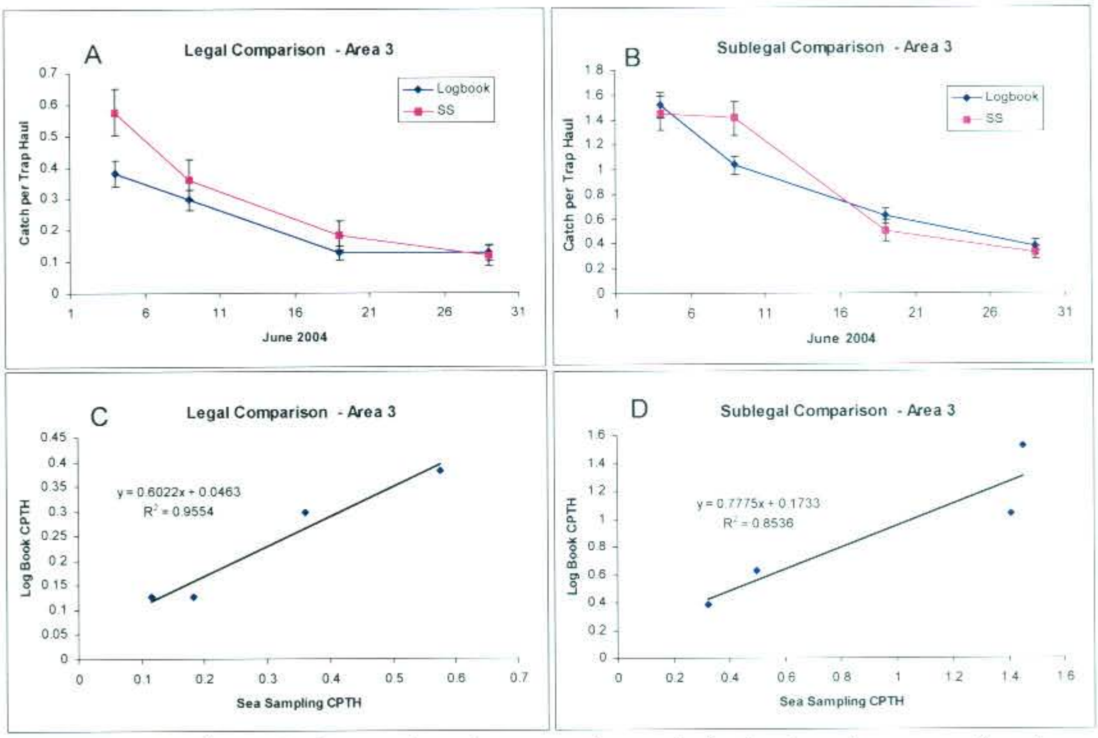


Figure 5. Comparison between electronic logbook and sea sampling in Area 3 (large area, high density).

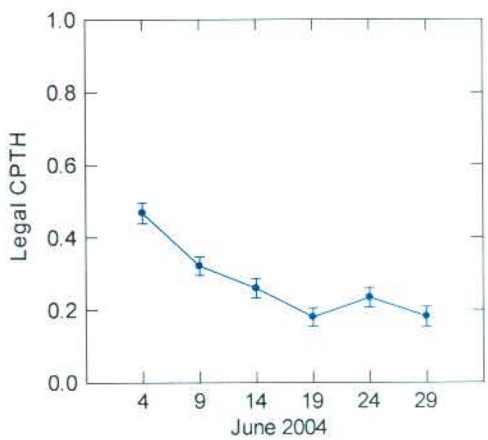


Figure 6. Legal catch rate by day from all areas during the experiment in June 2004.

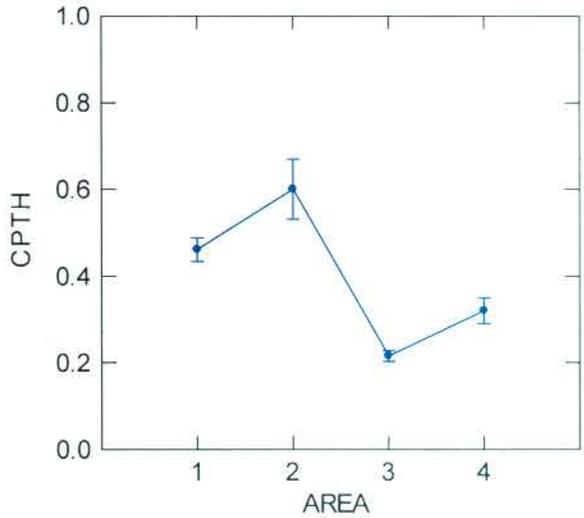


Figure 7. Average legal lobster caught per trap haul by area over the course of the experiment. Significant differences ($p < 0.001$) were observed overall areas.

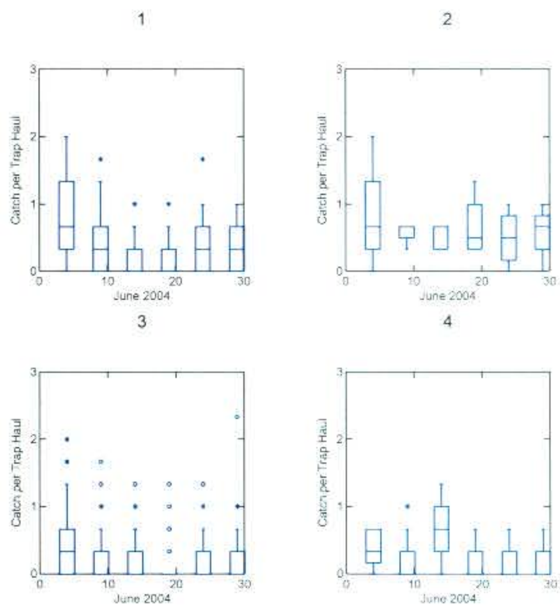


Figure 8. Box whisker plots of legal catch rate by area and day over the six hauling days.

Table 3. Total captures (minus legal lobsters that were removed) by area for each hauling day (highlighted in yellow). Subsequent recaptures by day are cascaded down for each trapping day.

Area 1 : Low Density Large Area

	day num	1	2	3	4	5	6
day num	date	4-Jun	9-Jun	14-Jun	19-Jun	24-Jun	29-Jun
1	4-Jun	186					
2	9-Jun	10	162				
3	14-Jun	19	3	195			
4	19-Jun	5	9	12	168		
5	24-Jun	6	7	7	10	189	
6	29-Jun	2	5	2	13	7	146

Area 2: Low Density Small Area

	day num	1	2	3	4	5	6
day num	date	4-Jun	9-Jun	14-Jun	19-Jun	24-Jun	29-Jun
1	4-Jun	36					
2	9-Jun	2	28				
3	14-Jun	1	0	22			
4	19-Jun	0	0	0	28		
5	24-Jun	0	0	0	0	15	
6	29-Jun	0	0	1	1	1	10

Area 3: High Density Large Area

	day num	1	2	3	4	5	6
day num	date	4-Jun	9-Jun	14-Jun	19-Jun	24-Jun	29-Jun
1	4-Jun	579					
2	9-Jun	55	581				
3	14-Jun	47	39	423			
4	19-Jun	38	10	7	359		
5	24-Jun	16	25	18	17	301	
6	29-Jun	10	11	10	15	21	208

Area 4: High Density Small Area

	day num	1	2	3	4	5	6
day num	date	4-Jun	9-Jun	14-Jun	19-Jun	24-Jun	29-Jun
1	4-Jun	82					
2	9-Jun	0	65				
3	14-Jun	3	0	97			
4	19-Jun	14	2	0	65		
5	24-Jun	5	1	7	2	76	
6	29-Jun	1	1	6	3	6	40

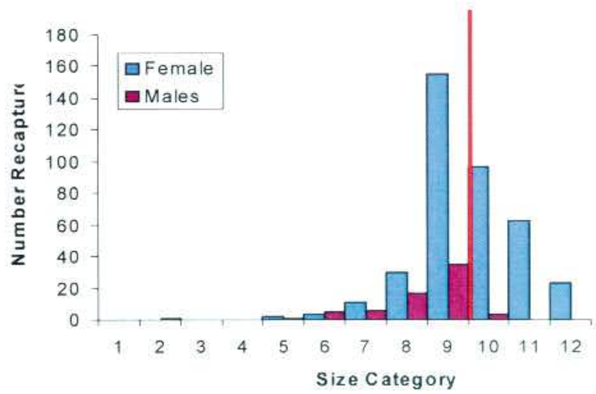


Figure 9. Recaptures by sex and ten mm bin increments. Red line indicates division between sublegal and legal sized lobster.

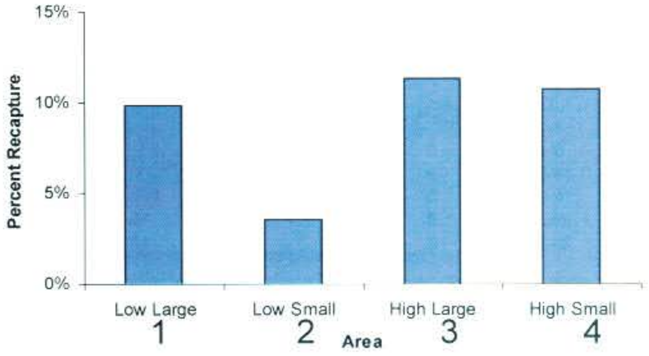


Figure 11. Percent recapture by area.

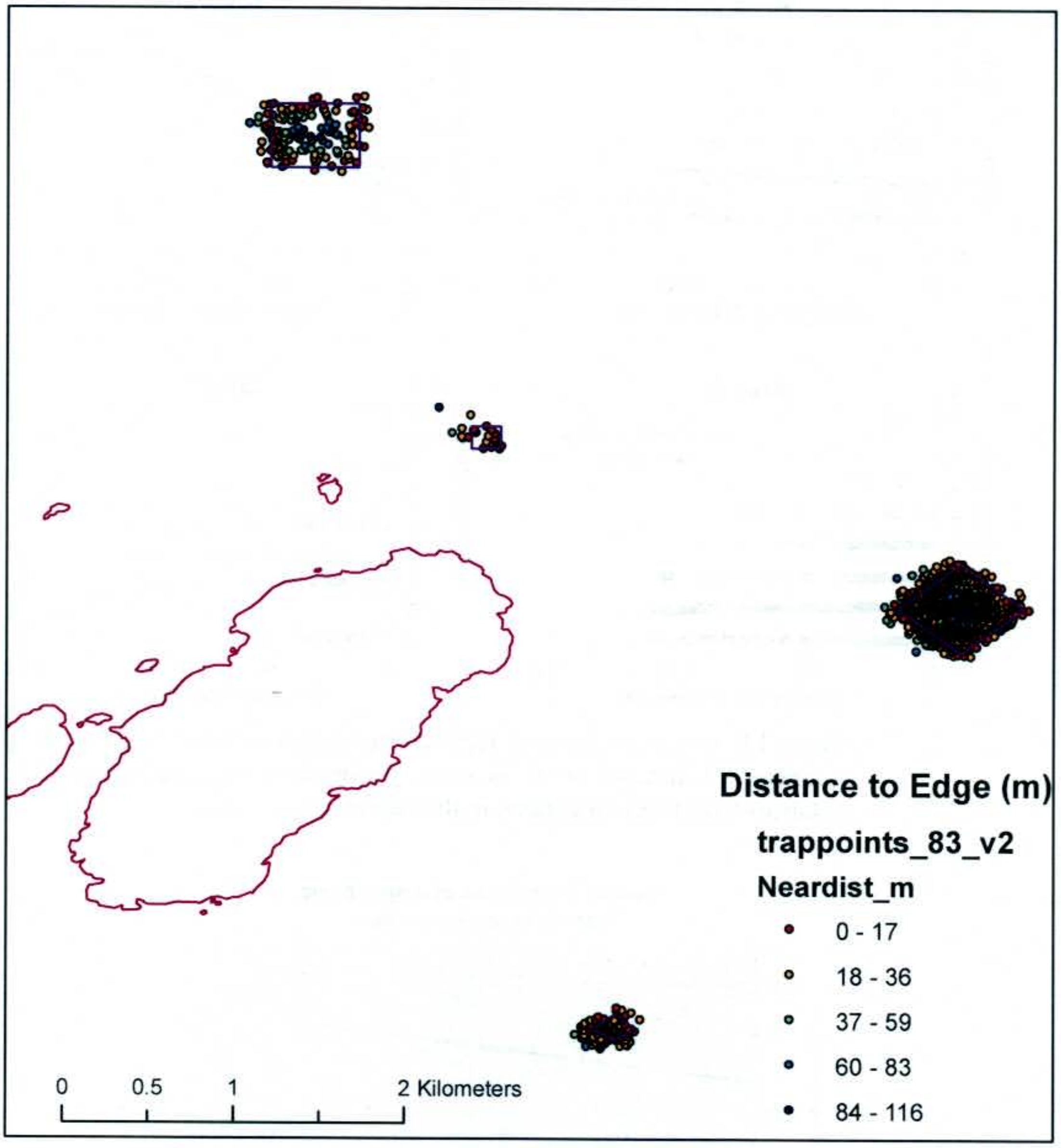


Figure 12. The location of all trap hauls and calculated distance from the edge of each trapping areas.

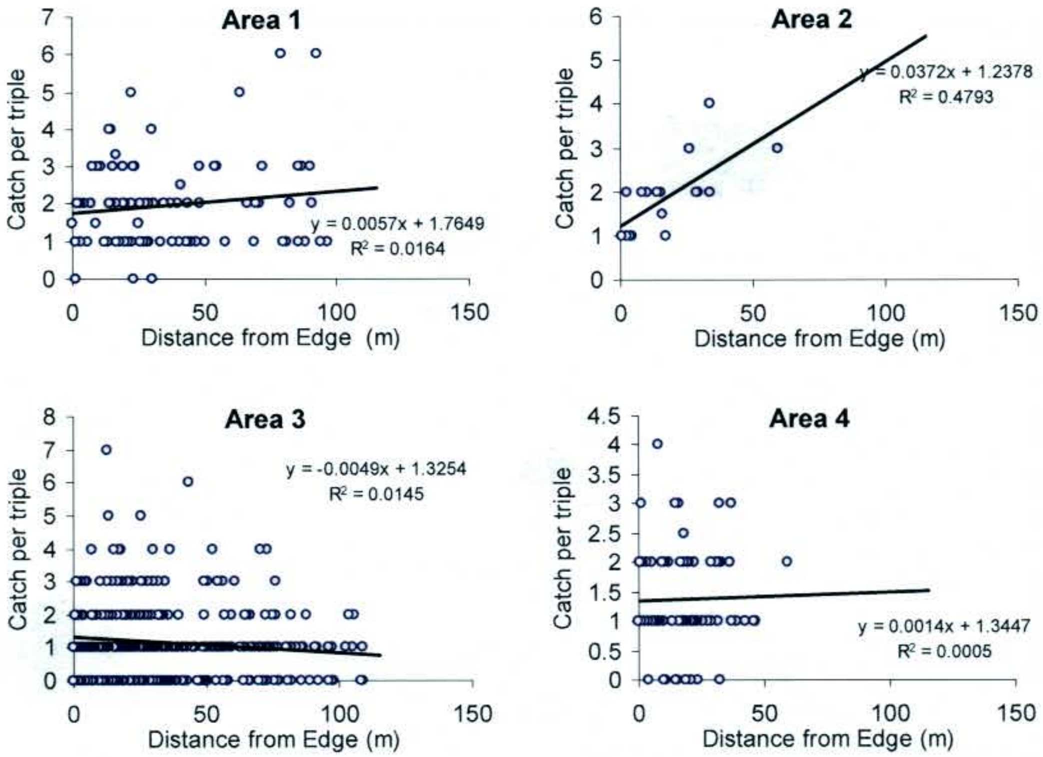


Figure 13. Catch per triple of legal lobster relative to each trapping area's perimeter. A distance of "0" is on the perimeter of the area, increased distances translate to locations in the center of each area.

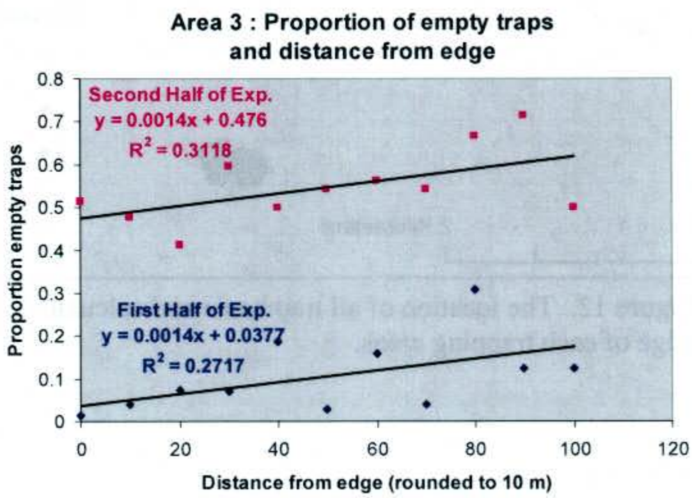


Figure 14. The proportion of empty traps relative to distance from the perimeter in Area 3 (large area and high density) during the first half (blue) and second half (pink) of the experiment.

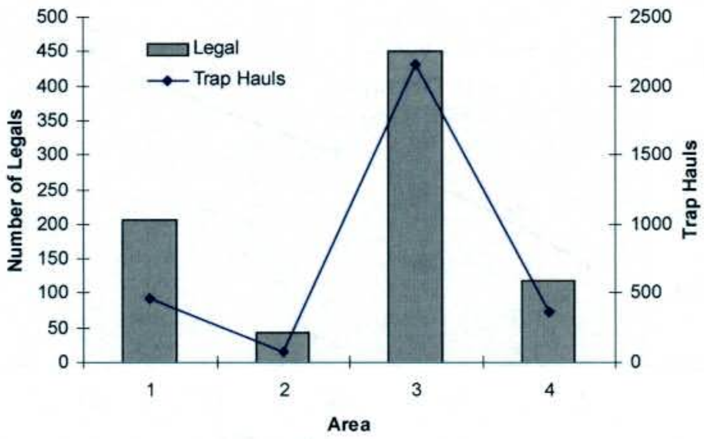


Figure 15. Cumulative number of legal lobster captured (primary axis) and traps hauled (secondary axis) by area over the course of the experiment.

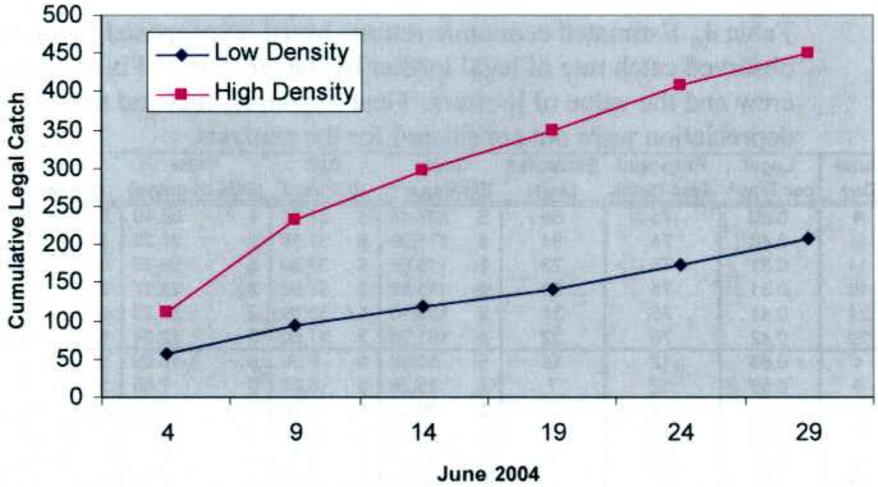


Figure 16. Cumulative catch of legal lobsters over the course of the experiment in low density and high density areas. Only large size experimental areas (0.141 km^2) were used for comparisons.

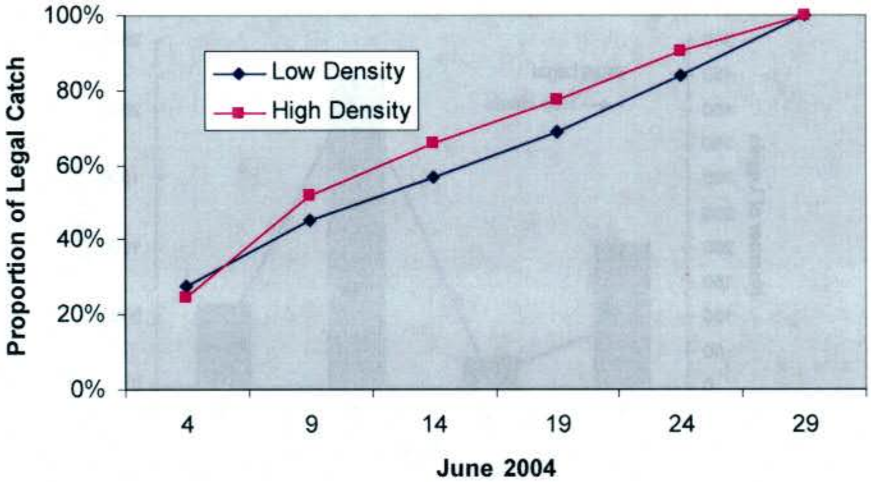


Figure 17. Cumulative proportion of legal catch over the course of the experiment in low density and high density areas. Only large size experimental areas (0.141 km^2) were used to compare.

Table 4. Estimated economic returns based on proposed trap hauls and observed catch rate of legal lobster by day and area. Fixed costs of bait, crew and the value of lobsters. Gear expenses, fuel and vessel depreciation were not considered for the analysis.

Area	June Day	Legal per Trap*	Proposed Trap Huals	Estiamted Legal	Gross Earnings***	Bait (0.5/trap)	Crew (20% of gross)	Net per day	Net per Area
1	4	0.86	75	65	$ 327.44	$ 37.50	$ 65.49	$ 224.45	
	9	0.46	75	34	$ 171.28	$ 37.50	$ 34.26	$ 99.52	
	14	0.31	75	23	$ 115.86	$ 37.50	$ 23.17	$ 55.19	
	19	0.31	75	23	$ 115.86	$ 37.50	$ 23.17	$ 55.19	
	24	0.41	75	31	$ 156.16	$ 37.50	$ 31.23	$ 87.43	
	29	0.42	75	32	$ 161.20	$ 37.50	$ 32.24	$ 91.46	$ 613.24
2	4	0.83	12	10	$ 50.38	$ 6.00	$ 10.08	$ 34.30	
	9	0.58	12	7	$ 35.26	$ 6.00	$ 7.05	$ 22.21	
	14	0.47	12	6	$ 30.23	$ 6.00	$ 6.05	$ 18.18	
	19	0.67	12	8	$ 40.30	$ 6.00	$ 8.06	$ 26.24	
	24	0.50	12	6	$ 30.23	$ 6.00	$ 6.05	$ 18.18	
	29	0.56	12	7	$ 35.26	$ 6.00	$ 7.05	$ 22.21	$ 141.33
3	4	0.38	375	143	$ 720.36	$ 187.50	$ 144.07	$ 388.79	
	9	0.30	375	111	$ 559.16	$ 187.50	$ 111.83	$ 259.83	
	14	0.18	375	68	$ 342.55	$ 187.50	$ 68.51	$ 86.54	
	19	0.13	375	48	$ 241.80	$ 187.50	$ 48.36	$ 5.94	
	24	0.18	375	69	$ 347.59	$ 187.50	$ 69.52	$ 90.57	
	29	0.13	375	47	$ 236.76	$ 187.50	$ 47.35	$ 1.91	$ 833.58
4	4	0.39	42	16	$ 80.60	$ 21.00	$ 16.12	$ 43.48	
	9	0.26	42	11	$ 55.41	$ 21.00	$ 11.08	$ 23.33	
	14	0.63	42	27	$ 136.01	$ 21.00	$ 27.20	$ 87.81	
	19	0.26	42	11	$ 55.41	$ 21.00	$ 11.08	$ 23.33	
	24	0.23	42	10	$ 50.38	$ 21.00	$ 10.08	$ 19.30	
	29	0.15	42	6	$ 30.23	$ 21.00	$ 6.05	$ 3.18	$ 200.43

* Oberserved catch per trap haul of legal lobsters under experimental conditions

** Based on the 2004 average price per pound of $4.03

*** Based on avearge size of 1.25 lb. for legal lobsters

Table 5. Average number m^{-2} of lobster and crab as recorded by drop camera video transect.

Date	Transect #	Area	*Length (m)*	*# crabs*	*# lobsters*	***crab/m2***	***lob/m2***
6/11/2004	1	4	24.9	1	0	0.040	0.000
6/11/2004	2	4	219.3	16	1	0.073	0.005
6/11/2004	3	4	46.4	0	0	0.000	0.000
6/11/2004	4	4	794.0	0	0	0.000	0.000
6/11/2004	5	4	82.7	1	0	0.012	0.000
6/11/2004	6	3	43.3	1	0	0.023	0.000
6/11/2004	7	3	35.9	3	3	0.084	0.084
6/11/2004	8	3	109.3	0	0	0.000	0.000
6/11/2004	9	2	116.6	2	4	0.017	0.034
7/11/2004	10	4	167.5	4	0	0.024	0.000
7/11/2004	11	3	239.9	4	2	0.017	0.008
7/11/2004	12	2	148.9	7	8	0.047	0.054
7/11/2004	13	1	182.8	4	1	0.022	0.005

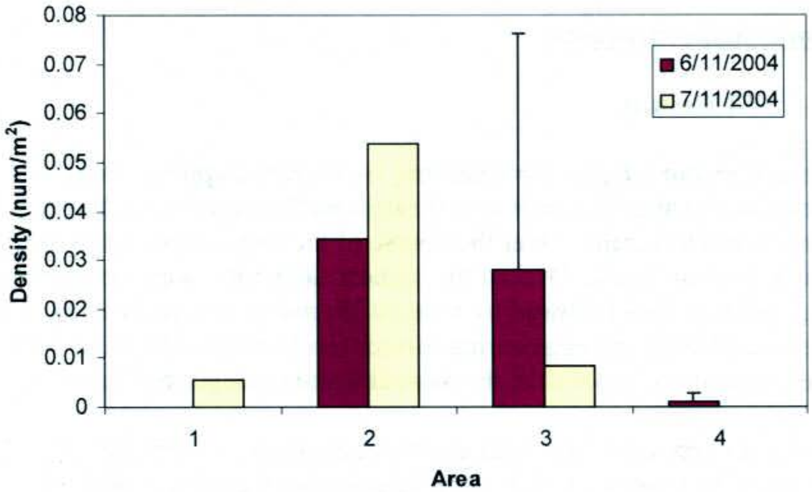


Figure 18. Density of lobster observed during video transect in experimental trapping areas on June 11 and July 11, 2004.

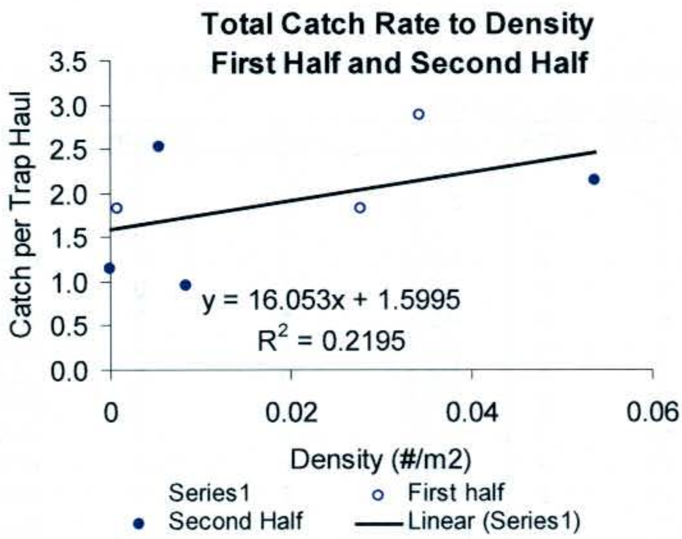


Figure 19. Comparison of average catch rates of all lobster from each area in the first and second half of the experiment against the observed lobster density on June 11 (first and half) and July 11, 2004 (second half).

7. Results and conclusions

7.1 Results

Development of methodologies for sampling in discrete trapping areas
Recorded trap hauls varied for each area throughout the experiment due to electronic reporting errors and lost traps. Over the course of the experiment 4,879 lobster were caught from 3,060 trap hauls. Overall the highest catch rates were observed in sublegal lobster at 1.2 per trap haul followed by legal (0.39) and V-notched (0.37). The catch rates of oversize (0.003) and egg bearing lobster (no V-notch 0.024 and with V-notch 0.078) were consistently lower than the most abundant categories (Table 1).

Traps were evenly spaced within each area throughout the experiment (Figure 4 A-C). Small trapping areas (Areas 2 and 4) were found to have a greater proportion of trap hauls reported outside of the actual trapping areas as participating fishermen reported drifting out of the trapping areas when hauling, counting lobsters and setting traps. Operationally the small areas provided challenges to set and record traps in the specified coordinates while high density areas provided further challenges in setting and retrieving triples without serious tangles with nearby traps.

In Area 3 (large area and high density) on the fourth hauling day of the experiment (June 19) seas of 5-8 feet, a 20 knot easterly wind, and a falling tide contributed to a 40 trap snarl that took two boats to untangle on the next hauling day. Recommendations from participating fishermen indicated that (1) larger areas were preferable to allow better organization of gear and (2) rigging traps as singles or pairs with a minimum of scope on buoy lines and between traps would reduce the number of snarls and facilitate in setting and retrieval of traps.

Biological composition of the catch

On-board observers measured 1,662 lobsters from 620 trap hauls, or approximately 20% of the total trap hauls and lobsters (Table 2). Female lobster (1211) outnumbered males (451) by nearly three to one. Commercial traps select for legal sized lobster, allowing escapement of sublegals through escape vents. Nearly 28% of female lobster encountered during the experiment were of legal size and protected by a V-notch or eggs, thus these lobsters were not affected by fishing removals.

As this experiment was conducted at the conclusion of the 2003-2004 Monhegan fishing season and all legal lobsters encountered during the experiment were removed from the areas, it is reasonable that more female lobsters would be caught than male. Yet, confounding the notion that removals by the commercial and experimental catch would contribute to the skewed sex ratio, female sublegal lobster (640) outnumbered male sublegals (330) by two to one. The average carapace length (CL) of males was 78.6 mm, below the minimum legal size (82.56 mm CL), while female average size was six mm larger at 84.7 mm CL (Figure 4). The underlying differences in sex ratio and average size go beyond the cumulative effects of the fishing season and this experiment. Unknown behavioral differences between males and females, likely associated with the annual molt, egg release and seasonal migrations complicate the observed pattern.

Changes in catch rate by area and trap density

A comparison between logbook and observer recorded catch rates were highly correlated for sublegal and legal lobsters respectively (R^2= 0.96 and 0.86) in Area 3 (Figure 5). As such, electronic logbook data is believed to be accurate and was used for all analysis of catch rates by area and through time.

Independent of the trap density and area, there was a significant decrease ($p < 0.001$) in the catch rate of legal lobsters over the course of the experiment in all areas over time. A peak of 0.47 legal lobster per trap haul was observed on the first day of the experiment and declined to 0.18 per trap haul on the final day (Figure 6).

Catch rate varied significantly over all areas ($p<0.001$) but not between treatments (Figure 7). For both trap densities, small trapping areas had higher (but not significant) catch rates than larger trapping areas. Low density areas (Areas 1 and 2) were not significantly different from each other ($p = 0.237$) but did have significantly higher catch rates ($p = 0.010$) than high density areas (Area 3 and 4), which again were not significantly different from each other ($p = 0.012$).

Within each area differential patterns of legal catch were observed (Figure 8). Area 1 (large area and low density) declined after the initial haul and remained stable throughout the remainder of the experiment. Area 2 (small area and low density) did not decline over the course of the experiment. Area 3 (larger area and high density) saw a similar pattern as Area 1, however catch rates were minimal after the initial hauling day. Area 4 (small area and high density) did not see the initial decline and actually had a peak catch on the third haul of the experiment. Large areas show a temporal pattern of catch while small areas remained stable over the time period irregardless of the trap density.

Patterns of marked and recaptured lobsters

Of the 4,879 lobsters counted during the experiment, 3,880 were susceptible to recapture once or multiple times (legal lobsters were removed the trapping areas and lobsters caught on the last day were not counted in recapture statistics). In total 466 lobsters were recaptured, for an overall rate of 12%. A total of 54 lobsters were recaught multiple times, but for the purposes of this analysis each recapture was considered a unique capture event. As was seen in catch statistics, female lobster dominated all recaptures at 85% (394 of 466), a similar percentage was seen for sublegal recaptures at 76% (202 of 267). As all legal males were removed from the study areas it is not surprising that females were 97% (183 of 187) of legal sized recaptures (Table 3, Figure 9). The greatest rate of recaptures were seen the subsequent hauling day following the tagging event. Overall large areas and high trap densities contributed to higher average recapture rates of 11% for Areas 1, 3 and 4. Area 2 (small area and low trap density) had less than 4% returns (Figure 11).

Patterns of recaptures were lower than was anticipated by industry participants, with 90% of lobsters never recaptured throughout the experiment. These loses were seen one haul after tagging on any day. Given similar recapture rates for large trapping areas of high and low density, this would suggest a common migration pattern into (new unmarked lobster) and out of (captured and marked lobster) the experimental trapping areas.

Cumulative impacts of trap density, area size and economic return

The distance of each trap haul location was calculated relative to the trapping area perimeter (Figure 12). No significant reductions in catch were observed as trapping locations approached the center of each square (Figure 13). If edge effects did impact catch in this experiment we would have expected the legal catch per trap haul to be higher on the perimeter of the areas. Area 3 (large area and high density) was the only area to show a decline in catch (but not significant) from the area's perimeter while the other areas actually increased. Area 3 did show a non-significant increase in the proportion of empty traps relative to the edge in the first and second half of the experiment (Figure 14). As the catch declined over the course of the experiment in Area 2 (Figures 6 and 8) the proportion of empty trap hauls in Area 3 increased. The slopes of lines describing the relationship remained identical (Figure 14), suggesting a limited but consistent influence of the area perimeter over the course of the experiment.

The cumulative catch of legal lobster in low density areas was approximately 50% that of high density areas but the high density areas had five times the number of trap hauls to catch this amount (Figure 15). When we compare the two large areas, we observed that

Area 3 (high density) saw immediate and larger gains in the cumulative catch than Area 1 (low density) (Figure 16). After the initial gains observed in the first two days of hauling, Area 3 continued to increase catch but the rate of catch declined to the lower rate of Area 1 (low density)(Figure 17).

While trap density does impact catch rates, migration likely contributes significantly to the observed patterns of catch in the experiment. . The lack of significant catch reductions in the interior of the trapping areas (Figures 13 and 14) and the pattern of small trapping areas having consistently higher and more stable catch rates than the large areas (Figure 7 and 8), would indicate migrations in to and out of the area confound the impacts of experimental treatments. Future experiments need to be significantly larger to demonstrate impacts of trap density and minimize the impact of migration in the experimental areas.

The spatial scale of the trapping areas tested in this experiment do not reflect the actual fishing territories available to the fishery participants. As an example, the 30 mi^2 (75 km^2) of the MLCA area is available to participants throughout their season, while during the experiment, all traps were confined to less than 1 km^2 combined. During the course of normal fishing, participants have the ability to move gear to seek out more profitable grounds, this was not an option during the experiment. Given the low catch returns (Figures 6, 7 and 8) for all areas, it is likely fishermen in the MLCA would have moved their traps to others areas after the first or second haul. Territories do exist in most areas of the Maine coast and these formal and informal boundaries do limit the spatial extent that fishermen in Maine can seek out profitable grounds (in the case of the MLCA boundaries are set by State law).

If experimental areas are representative of the impacts of trap density on catch rates and the confined nature of the lobster fishery regionally, then important economic lessons can be inferred from this experiment. We estimated the economic returns based on proposed trap hauls and observed catch rate of legal lobster by day and area; Area 3, with five times the number of trap hauls than Area 1 caught twice as many lobsters, but after expenses only realized a 25% gain in net profits after bait and crew expenses were factored (Table 4).

Fishery independent estimates of density and experimental impacts
Electrical problems limited the video survey to two days. Additionally night time surveys were limited by the need to avoid gear entanglement, this was especially the case in high density areas. Nonetheless, 13 video transects were conducted covering 2,211 m^2 and averaging 179 m^2 per transect. A total of 19 lobsters were observed for an overall density of 0.009 m^{-2} (Table 5).

Areas 2 and 3 had the highest densities of lobster for both survey days. When June 11 survey densities were compared to the average catch per trap of all lobsters for the first half of the experiment, and July 11 densities are compared to the second half catch per trap, a positive, but non-significant, relationship results. This suggests that there may be a relationship between catch rates and densities of lobster on the bottom; however, given the difficulties with electronics and gear entanglements it is impossible to conclude impacts of experimental fishing in the area based on the available video transects.

Providing a complementary measure of lobster density is an important additional component to any trapping study. Future density work should be conducted by divers (if reasonable) or by daytime drop camera surveys. Divers are not restricted by the presence of trap lines, while daytime video surveys could significantly reduce entanglements.

7.2 Conclusions

The Monhegan Lobster Conservation Zone is the ideal location to conduct manipulative experiments on lobster because it is closed to commercial fishing during the peak season for the rest of the coast. Industry collaborators provided the backbone of the study and were responsible for the successful execution of the experimental plan. This success is not a surprise as Monhegan fishermen already operate under unique rules to Maine and New England, and are therefore that much more open to what many might call extreme ideas involving the Maine lobster fishery.

We have successfully developed methodologies that allow accurate and high resolution quantification of the impacts of removals by lobster traps in discrete experimental sampling areas. The combination of electronic logbooks complemented by on-board observers serves to maximize industry participation and minimize the expense of putting a scientific observer on every boat. Tagging techniques were simple and employed equipment already available on all commercial lobster boats (lobster bands and banders). Recaptured lobsters were easily identified by daily batch tags, and provided reliable estimates of recapture through the course of the experiment.

Future experiments should significantly increase the size of experimental areas to maximize the impacts of experimental treatments and minimize underlying effects of uncontrolled factors. High trap density (2,600 traps km^{-2}) significantly lowered the catch rates as compared to low density areas (500 traps km^{-2}). All tested areas were impacted by migration in to and out of the areas; however, larger experimental areas minimized this impact.

The catch rate of legal lobster declined over the course of the experiment indicating an impact on the lobster population. After the initial two trap hauls the rate of removal was similar for high and low density areas. The cumulative catch was higher in high trap density areas than low density areas over the course of the experiment, yet gross economic gains were largely offset when expenses were factored in. Future experiments should cover a larger time span and at a time of year that is not immediately following the conclusion of a fishing season.

This development project has taken the first of several steps needed to demonstrate how lobster traps interact with the lobster population and associated fishery. Increasing the scale of experimental areas and the duration of the experiment will allow better comparisons to the existing lobster fishery. The Maine lobster fishery represents 80% of

Maine's fishing revenue. If there are ways to demonstrate the positive and negative impacts of proposed regulations, all participants will gain in the end. Economic and or biological collapse of the Maine lobster fishery is not an acceptable result for all participants.

8. Partnerships

Simply put, with out the direct involvement of industry participants this project would not have been possible. The Monhegan Lobster Conservation Zone is the ideal location to conduct manipulative experiments on lobster given it is closed to commercial fishing at the same time when the rest of the coast is at the peak of the lobster season. Industry collaborators provided the backbone of the study and were responsible for the successful execution of the experimental plan.

The strong partnerships have led to improvements in this experiment at all levels. Operational suggestions on trapping area size, gear configuration and tagging procedures will improve future experiments.

Even before the completion of the experiment, patterns of catch rate relative to trap density and in comparison with the existing Monhegan closed season have facilitated an open discussion on how we manage the Maine lobster fishery. It is the belief of all participants that the demonstration of proposed management measures is essential.

9. Collaboration with other projects

This project benefited from the direct collaboration of a NEC funded survey of Jonah Crab distribution and abundance in nearshore Gulf of Maine waters. Video survey equipment purchased by the Jonah Crab project was used to estimate lobster and crab density for the trapping experiment. All video survey work was supported by Brian McClain on F/V Silver Bullet, New Harbor Maine.

10. Impacts on end-users

This development project provided the initial proof of concept to warrant an expanded full proposal to NEC. A greatly expanded full proposal involving seven Monhegan fishermen was funded by NEC in the Fall of 2004, and was conducted in September and October 2005.

Although the demonstrated impacts of the project are limited, this development project has initiated a serious discussion of fishing effort in the Maine lobster fishery. The Maine DMR initiated a coast wide discussion of fishing effort during the winter of 2005 that continues today. The impact of traps on the population has impacted all Maine lobster fishermen and the results of this development project have benefited those conversations immeasurably.

11. Presentations

- Northeast Project Participant Meeting, Portsmouth NH, October 2004
- Monhegan Lobster Conservation Area, Monhegan ME, January 2005
- Zone D Lobster Management Zone, Rockland ME, February 2005
- Maine Fishermans Forum, Rockland ME, March 2005
- Conscook Bay Fishermans Forum, Eastport ME, March 2005
- ASMFC Lobster Technical Committee, Mansfield MA, April 2005

12. Student Participation

- Rory Jose, Connecticut College
- Trisha Cheney, MS Marine Policy Program, Dalhousie University
- Evelynn Smith, Boothbay High School

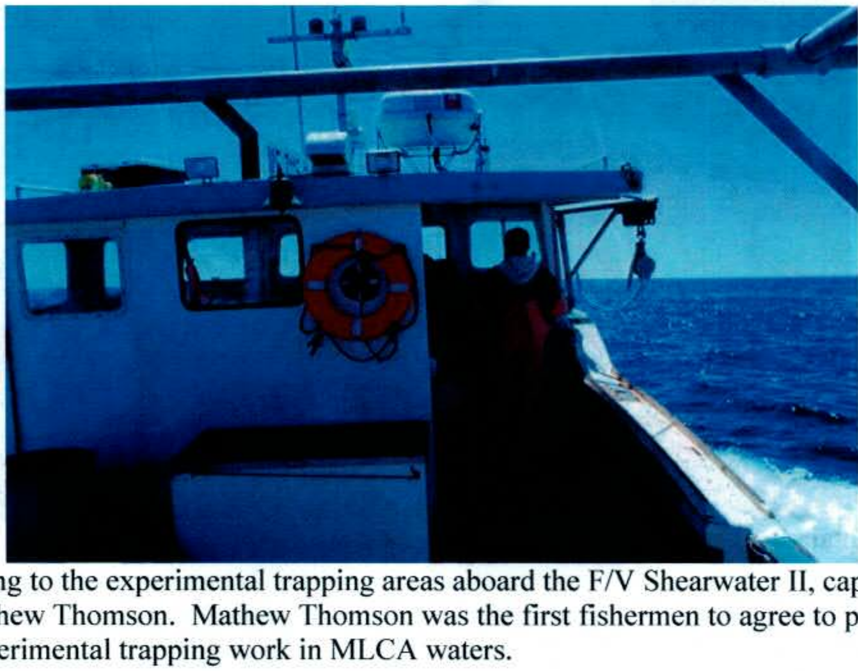
13. Published reports and papers

This completion report is the first report or paper describing the proposed work. However, preliminary results of this project have been published in:

- The Maine DMR Lobster Newsletter (http://www.maine.gov/dmr/Lobster%20Newsletter/Lobster%20Newsletter.htm)
- NAMA's Collaborations (http://www.namanet.org/collaborations/collab_apr_05.pdf).

14. Images

This cartoon originally published by the Portland Press Herald in 1998 underscores the legislative battle Monhegan Fishermen faced when the MLCA was established by Maine Law.



Steaming to the experimental trapping areas aboard the F/V Shearwater II, captained by Mathew Thomson. Mathew Thomson was the first fishermen to agree to pursue the experimental trapping work in MLCA waters.

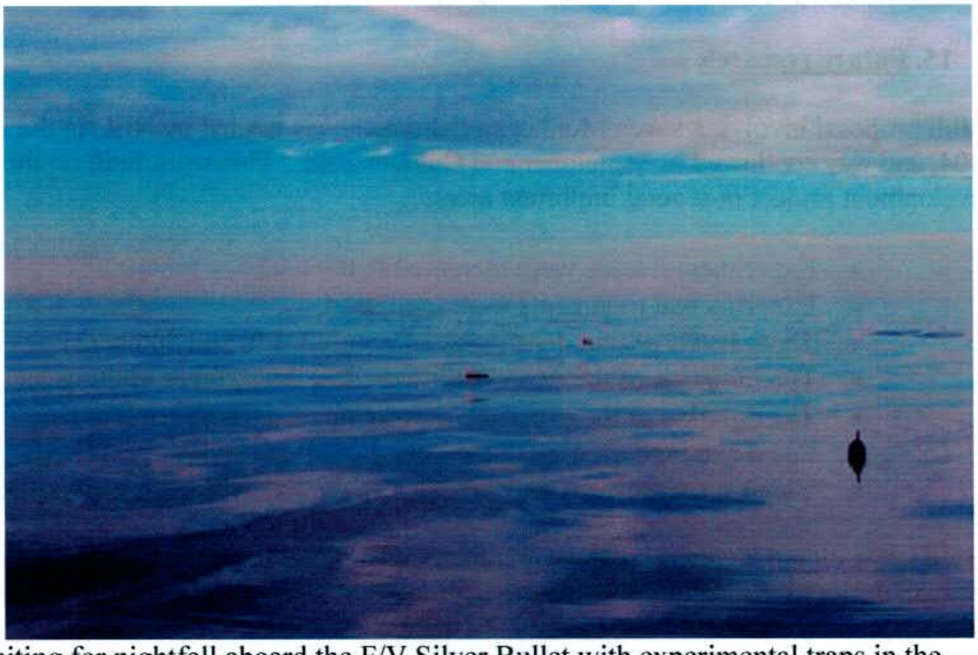
Experimental gear in the foreground with Monhegan Island in the distance. The MLCA is the only closed area for lobster in New England, covering 30 mi^2 in the most productive region for lobsters on the coast of Maine

Captain Robert Bracy aboard the F/V Pandora.

F/V Griffin, captained by Matt Weber with crew Lucas Chioffi. In the full proposal funded by NEC conducted in 2005 Weber would serve as research platform for a multibeam imagining initiative and Chioffi would participate fully using his boat, F/V Fenris.

Captain Mathew Thomson and crew Matt Schierer experiencing high trap density gear entanglements. Participating fishermen have suggested gear modifications to reduce entanglements and facilitate ease of hauling.

Crew Matt Schierer aboard the F/V Shearwater II returning the catch of the day. All legal lobsters were removed from the trapping areas and released at the mouth of Monhegan Harbor nearly 3 km away. Four legal lobsters were recaptured in the experiment.



Waiting for nightfall aboard the F/V Silver Bullet with experimental traps in the foreground. Nighttime video surveys resulted in many entanglements with experimental gear and reduced the utility of a fishery independent measure of lobster population density.

Steaming home aboard F/V Silver Bullet captained by Brian McClain from Monhegan Island after an aborted night of video surveys due to electrical problems. The video equipment was purchased by a previously funded NEC crab survey project.

15. Future research

A full proposal involving seven Monhegan fishermen was funded by NEC in the Fall of 2004, and was conducted in September and October 2005. This work built on the development project in several important areas:

- Experimental areas were increased to 0.9 km2
- Experimental treatments were replicated
- Three levels of trap density we chosen (50, 150 and 500 km2)
- The initiation of the experiment was after the summer molting season
- The duration of the experiment was extended for 12 hauling days
- Fixed and random soak times were evaluated
- Video surveys were conducted during the day with sufficient replication

Having now completed two experimental trapping studies within the MLCA, there is a growing desire to expand these studies to additional areas of the coast. Additionally, industry participants would like to structure the experiment so as to commercially fish under experimental conditions, rather than set traps dictated by the experimental design. Under this scenario, grant funds would provide scientific and administrative support and the catch would provide the economic incentive.

16. Works Cited

ASMFC (2000) American Lobster Stock Assessment Report for Peer Review, No. 00-01 (Supplement).

ASMFC (2005) American Lobster Stock Assessment Report for Peer Review, No. 05-01 (Supplement).

Kelly, Kevin H. (1993) Determination of Lobster Trap Density near Midcoastal Maine by Aerial Photography. *N. Am. J. Fish. Man.* 13:859-863.

Russell, Howard. (1994) Trap Limits as a Means for Effort Control in the American Lobster, *Homarus americanus*, Fishery. *NEFMC Lobster Technical Core Group Ref. Doc. 94-1.*

Rothschild, B.J. (1972) Fishing Effort. In Fish Population Dynamic. J.A. Gulland (ed.) FAO, Rome Italy pp. 96-115.

Steneck, R.S. and C.J. Wilson. (2001) Large-scale and long-term, spatial and temporal patterns in demography and landings of the American lobster, Homarus americanus, in Maine. Mar. Freshwater Res., 52:1303-1319.