SIZE, STRUCTURE, MOVEMENT, AND SURVIVAL OF AMERICAN LOBSTER, *Homarus americanus*, POPULATIONS IN AREAS WITH AND WITHOUT COMMERCIAL HARVESTING

SHERRYLYNN ROWE

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by

Sherrylynn Rowe

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Department of Biology
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ABSTRACT

To determine the potential effectiveness of no-take reserves as a fisheries conservation tool for American lobsters (*Homarus americanus*), I quantified the size, structure, movement, and survival of lobsters inside and outside of two small no-take reserves (Round Island and Duck Islands) in Bonavista Bay, Newfoundland during 1997-1999. These no-take reserves were established by harvesters as part of a co-management plan for the local fishery and supported approximately 1.5% of the local lobster population. Although this study only concerned the first three years following reserve establishment, there were clear differences in lobster population parameters inside and outside of the no-take reserves. At the Round Island reserve, population density was high and stable over time, and female and male size increased, as did the proportion of ovigerous females. However, at the Duck Islands reserve, population density increased dramatically between 1997 and 1998, and male size increased over time, but there was no detectable change in female size or in the proportion of ovigerous females. Lobster density, female and male size, and the proportion of ovigerous females were greater within the Round Island reserve compared to an adjacent harvested area. At the Duck Islands, females and males were larger in size within the reserve but I found no difference in lobster density or the proportion of females that were ovigerous between the reserve and an adjacent harvested area. Differences in the response of some lobster population components to small no-take reserves can be explained by patterns of lobster movement and survival. Because the frequency of lobster emigration from the reserves was low (only 8.7% of tagged lobsters recaptured were in an area with a harvesting status different from that of where they were tagged) and harvesting pressure outside of the reserves was intense (annual harvesting mortality amounted up to 87.2% for lobsters eligible for commercial harvest), my results indicated that no-take reserves can offer increased survival to lobsters and may provide direct benefits to the local fishery.

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CHAPTER 1:

INTRODUCTION AND OVERVIEW

NO-TAKE RESERVES

No-take reserves have long been part of fishery conservation practices. Prior to the 1950s, there were de facto no-take reserves all around the globe, areas protected because they could not be affordably accessed with the technology of the day. However, technological advances in vessel capabilities, navigation and harvesting equipment now allow harvesters to go farther from port for extended periods of time and to extensively harvest marine resources in areas perhaps never exploited previously. Consequently, few of the world's marine regions remain undisturbed by human activities (Vitousek et al. 1997) and many populations of exploited fish and invertebrates are declining in numbers and average size despite the efforts of fisheries managers (Roberts 1997). During the past several decades, there has been a growing realization of the need to formally designate marine areas that are protected from human activities. Restricting harvesting in nursery and spawning habitats or closing areas seasonally to rebuild depleted stocks is not new to fishery management practice (Fogarty 1999). However, the establishment of permanent no-take reserves has received much less attention despite the potential of reserves to improve fishery stocks and to support fisheries and fisheries management.

There are many possible benefits to establishing marine no-take reserves. No-take reserves can protect ecosystem structure and function by protecting habitats and communities from harvesting activities that can lead to loss of biodiversity and changes in species interactions (Dayton et al. 1995; Boehlert 1996; Hixon and Carr 1997). No-take reserves can also increase our understanding of marine ecosystems by serving as sites for research. Without unexploited areas against which to measure change, scientists are unable to fully evaluate the true impacts of harvesting and other forms of human disturbance on marine populations and communities (Roberts 1997; Dayton et al. 1998). Baseline information from unexploited stocks can vastly improve estimates of population parameters for harvested species (Smith et al. 1998). In addition, no-take reserves can provide benchmark sites for separating the effects of human harvesting from those caused by natural shifts in ecological regimes.

Perhaps the most common reason for establishing no-take marine reserves is to benefit exploited populations and fisheries. It has been repeatedly demonstrated that the abundance, mean size of individuals, and spawning biomass of exploited populations tend to be greater inside no-take reserves than in comparable areas subjected to harvesting (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). These changes are a predicted outcome of protection from exploitation because many fish and invertebrates live longer, reach larger body size, and produce significantly more eggs in the absence of harvesting mortality (Bohnsack 1992, 1996; Roberts and Polunin 1993). No other form of fishery management provides the opportunity for a component of the targeted population to realize its full ecological and demographic potential.

No-take reserves have the potential to conserve exploited populations and fisheries in three major ways. First, no-take reserves can provide a direct benefit by exporting larvae that may increase recruitment into regional fishery stocks (Carr and Reed 1993; Rowley 1994; Bohnsack 1998). Second, no-take reserves can provide a direct benefit by exporting biomass in the form of emigrating juveniles and adults to adjacent harvesting grounds (Rowley 1994; Russ and Alcala 1996; Bohnsack 1998). Third, no-take reserves can offer numerous indirect benefits by protecting portions of exploited stocks from genetic changes, altered sex ratios, and other disruptions caused by selective harvesting mortality (Ricker 1981; Bohnsack 1992, 1998).

Consequently, no-take reserves can also benefit fisheries management. Effective fisheries management must consider the effects of changing environmental conditions and uncertainty or inaccuracies in stock assessment and projected sustainable catch levels (Roberts 1997; Dayton 1998; Lauck et al. 1998). No-take reserves can help in a number of ways. For example, they can decrease the likelihood of stock collapse by acting as regional buffers against unanticipated harvesting mortality, unforeseen management errors, or environmental changes. In addition, because of the increased spawning stock located within no-take reserves, they can accelerate the rate of recovery of overexploited populations (Bohnsack 1998).

BIOLOGY OF THE AMERICAN LOBSTER

The American lobster (*Homarus americanus*) is a decapod crustacean found along the continental shelf and upper slope of the northwestern Atlantic from the Strait of Belle Isle to Cape Hatteras (Herrick 1909; Lawton and Lavalli 1995). Although lobsters are found intertidally and to depths of 700 m on the edge of the continental shelf, they typically live along a narrow band of shallow rocky bottom close to shore (Herrick 1909; Prudden 1962; Cooper and Uzmann 1971; Pringle and Burke 1993).

Lobsters are long-lived organisms and exhibit delayed reproduction. Sexual maturity is reached after five to eight years of growth (Wilder 1953). Typically, mating takes place immediately following female molt in the Summer, spawning occurs approximately one year later so that eggs become evident on the underside of the female, and larvae hatch from the eggs the Summer thereafter (Waddy et al. 1995). Fecundity increases exponentially with female size, ranging from a few thousand eggs in small animals to several tens of thousands in larger individuals (Aiken and Waddy 1980a, 1980b; Ennis 1981). Moreover, large lobsters produce eggs with a higher energy content per gram of egg, which should increase the ability of the larvae to survive adverse conditions (Attard and Hudon 1987). Consequently, large individuals can contribute substantially to egg production and recruitment within a population.

Larvae hatch in Summer and are planktonic for six to eight weeks before settling to the bottom (Ennis 1995). It is during the larval stage that most mortality is believed to occur. Scarratt (1964) provided an estimate of average mortality of 98.9% between the first larval stage and the approximate midpoint of the settling stage. Adult lobsters are believed to have few natural predators and most mortality is due to commercial harvesting (Fogarty 1995). Although it has not been directly measured, adult natural mortality rate (i.e. mortality not caused by commercial harvesting) has been estimated to range from 2 to 35% per year (Thomas 1973; Ennis 1979). Lower natural mortality rates are consistent with the apparent longevity of this species.

Movement patterns are highly variable throughout the range of this species and are not well understood. Some offshore lobster populations undertake extensive inshore-offshore migrations and commonly disperse long distances (e.g. Cooper and Uzmann 1971; Dow 1974; Fogarty et al. 1980; Campbell 1986; Pezzack and Duggan 1986). Lobsters tagged off Grand Manan showed seasonal shallow-deep movements exceeding 20 km in horizontal extent (Campbell 1986) and lobsters in other areas have exhibited homing behaviour after more than ten months abroad and 200 km of movement (Pezzack and Duggan 1986). By comparison, lobster populations in coastal areas, such as those around Newfoundland, are non-migratory and remain within localized areas but exhibit small-scale seasonal movements between shallow and deep water (e.g. Wilder 1963a; Fogarty et al. 1980; Ennis 1984a, 1984b). Considerable variation in the extent of movements exists among coastal areas. Average distances moved by American lobsters at large in coastal areas for about one year have ranged from 0.4 to 16.4 km (Templeman 1935, 1940; Wilder 1963b; Fogarty et al. 1980; Krouse 1981; Ennis et al. 1989, 1994; Comeau et al. 1998). Generally, it is believed that exchange between large geographical areas due to adult migration is limited and most dispersal occurs during the planktonic larval stages (Cobb 1995).

HARVESTING AND CONSERVATION OF THE AMERICAN LOBSTER

American lobsters are a popular and valuable seafood that has been commercially harvested in Canada and the United States since the early 1800s (Fogarty 1995). Like all fisheries today, the American lobster fishery is suffering problems. Canada's Fisheries Resource Conservation Council (FRCC 1995) has raised concerns about the future of lobster stocks in Atlantic Canada. In many areas, current exploitation rates are high (harvesters take up to 85% of the animals present that are eligible for legal harvest each year) and primarily immature animals are harvested (FRCC 1995). This is a problem because intense harvesting results in extremely low levels of egg production and risks recruitment failure during periods when environmental or ecological conditions that influence survival to recruitment are unfavorable.

In its lobster conservation framework, the Fisheries Resource Conservation Council (FRCC 1995) recommended that measures be taken to increase egg production, reduce exploitation rate, and improve stock structure. One measure that might facilitate these goals is the establishment of no-take lobster reserves. Closing a part of the total harvesting area may allow an unexploited portion of the population to develop. Egg production would be higher in an unexploited population than an exploited one because lobsters are more likely to survive to maturity. Thus, total egg production for a region with no-take reserves should be higher than in a region totally open to exploitation. However, no-take reserves could only be effective if adult lobster movement out of the reserves occurs at a low enough rate to permit increased adult survival. Although never used as a conservation tool for American lobster, no-take reserves appear to work for a variety of other species including spiny lobster, *Jasus edwardsii* (Cole et al. 1990; MacDiarmid and Breen 1992). Moreover, theoretical modelling predicts that no-take reserves can effectively increase egg production and recruitment levels in a population provided there is long-term protection from exploitation (FRCC 1995). To assess the actual success of no-take reserves, direct measures of lobster population parameters inside and outside of reserves are required.

OBJECTIVES OF THIS STUDY

On the initiative of local lobster harvesters, two small areas of prime lobster habitat near the Eastport Peninsula in Bonavista Bay, Newfoundland were closed to harvesting in 1997, following declines in the local lobster abundance. These were the first American lobster reserves ever established for fisheries conservation. Examining the potential effectiveness of these reserves was the focus of my research. Specifically, I employed fishery monitoring and capture-mark-recapture techniques to investigate the lobster harvest around the Eastport Peninsula and compare population parameters and movement of adult lobsters between no-take reserves and nearby harvested areas.

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CHAPTER 2:

CO-MANAGEMENT IN A LOBSTER FISHERY

ABSTRACT

Canada's Fisheries Resource Conservation Council (FRCC) has identified a resource conservation problem in Atlantic Canada's lobster fishery. Intense harvesting has resulted in extremely low levels of egg production and risks recruitment failure during periods when environmental or ecological conditions that influence survival to recruitment are unfavorable. In response to both a recent decline in local lobster landings and the findings of the FRCC, the Eastport Peninsula Lobster Protection Committee was established in 1995 to implement conservation management practices that would protect the lobster resource in their area. This chapter describes the means by which these harvesters are integrating their local knowledge with fisheries science and have developed an alternative co-management plan for their local fishery. The results of recent lobster harvesting seasons show the success of conservation measures implemented. The Eastport Peninsula Lobster Protection Committee's expectations for the future are very high and their success offers a model for effective fishery management and establishment of similar programs elsewhere.

Once there is mutual trust and understanding between those people managing the resource and those harvesting it, better management of the resource is likely to follow. When given an opportunity to participate in the management process, harvesters will work towards conservation.

-- Pringle (1985)

INTRODUCTION

American lobsters (*Homarus americanus*) are a popular and valuable seafood harvested in the coastal waters of the northwest Atlantic, mainly by community-based small boat harvesters. Like all fisheries today, the American lobster fishery is suffering problems. Canada's Fisheries Resource Conservation Council (FRCC 1995) has raised concerns about the future of lobster stocks in Atlantic Canada. Lobsters are long-lived bottom-dwelling invertebrates in which female maturation occurs after several years of growth and egg production increases exponentially with increasing size (Prudden 1962; Aiken and Waddy 1980a, 1980b; Ennis 1981). In many areas, current exploitation rates are high (harvesters take up to 85% of the animals present that are eligible for legal harvest each year) and primarily immature animals are harvested (FRCC 1995). This is a problem because intense harvesting results in extremely low levels of egg production and risks recruitment failure during periods when conditions that influence survival to recruitment are unfavorable.

In its lobster conservation framework, the FRCC (1995) recommended that harvesters take measures to increase egg production, reduce exploitation rate, improve stock structure, and minimize waste. Some measures suggested that might meet these goals include a reduction in harvesting effort, an increase in minimum carapace size, the V-notch marking and release of ovigerous females, and establishment of areas protected from harvesting. Rather than prescribe specific measures to be implemented, the FRCC suggested several possible conservation strategies that might prove beneficial and recommended that local stakeholders and management officials work together in developing a program best suited to their particular region (FRCC 1995).

THE EASTPORT PENINSULA LOBSTER FISHERY

The lobster fishery in Newfoundland on the east coast of Canada shows symptoms of the problems identified by the FRCC (1995). In this area, the lobster harvesting season typically lasts nine weeks, beginning in late April or early May. Newfoundland's lobster harvesters fish on traditional grounds close to their home port using small (6-9 m) open boats and conventional wooden-lathed traps. Traps are set individually in depths of less than 20 m and every 1-2 days during the harvesting season, they are hauled (often manually), checked, and baited using whole herring (*Clupea harengus*) that is fresh or salted, winter flounder (*Pseudopleuronectes americanus*), or cod (*Gadus* spp.). Harvesters are permitted to set only a limited number of traps (200 per harvester in most areas) and ovigerous females, as well as all lobsters smaller than 82.5 mm in carapace length, are protected from exploitation (the minimum legal size limit was increased from 81 mm to 82.5 mm on 24 May 1998). Annual lobster landings in Newfoundland have ranged from 2021-3206 metric tons during the last twenty years (Statistics Branch of Canada's Department of Fisheries and Oceans, unpublished data).

The Eastport Peninsula is located in the central portion of Bonavista Bay on the northeast coast of Newfoundland (48.65°N, 53.70°W; Figure 2.1). The local lobster grounds are a relatively narrow band of rocky substrate that extends from the mainly 5-10 m high cliff shoreline to depths generally less than 25 m at approximately 25-100 m offshore. Many islands, inlets and smaller bays in the area provide extensive shoreline that has been traditionally used as harvesting grounds by approximately 50 individuals from seven small nearby communities (Burnside, Eastport, Happy Adventure, Salvage, Sandringham, Sandy Cove, and St. Chad's). In 1994, these harvesters recognized that a serious decline in their lobster stocks had occurred over the preceding decade, and that it had accelerated by increased harvesting effort directed towards the local lobster resource as a result of groundfish closures. Traditionally, lobster harvesting was a secondary fishery in this area; harvesters took lobsters for only the first few weeks of the season before changing over to pursue groundfish. With the collapse of local groundfish stocks due to overfishing (Hutchings and Myers 1995; Sinclair and Murawski 1997), a moratorium on commercial cod harvesting off the northeast coast of Newfoundland was announced in 1992. Since the moratorium, lobstering has become a more important source of income for many individuals (Hamilton and Haedrich 1999). Previously inactive licences have been reactivated and active licences are being more fully utilized as lobsters are heavily harvested during the entire season because there are few alternative fisheries. In addition, this fishery has been characterized by such poor harvesting practices as the regular violation of trap limits and retention of sub-legal sized or ovigerous female lobsters. Lobster harvesters reported catch rates in 1993 as being the worst in memory (Figure 2.2).

THE EASTPORT PENINSULA LOBSTER PROTECTION COMMITTEE

In response to both the recent decline in local lobster landings and the FRCC report (FRCC 1995), the Eastport Peninsula Lobster Protection Committee, consisting of local lobster harvesters, was established in 1995 to address the issues raised and to implement conservation management practices that would protect the lobster resource in their area. Specifically, the aims of the Committee were:

- to conserve and enhance the lobster industry for themselves and future generations by encouraging responsible harvesting of the stocks;

- to learn and educate by using sound professional methods and practices in harvesting lobster;
- to provide vital information and statistics necessary to the management of the lobster industry; and
- to demonstrate that professional fish harvesters can successfully harvest and manage the fishery to its fullest potential.

The Committee was fully supported by the vast majority of harvesters in the area; this support continues today. In 1995, the Committee held meetings to inform culpable individuals of the potentially negative consequences of using illegal traps, excessive effort, and the retention of ovigerous or sub-legal sized lobsters. Although these practices often lead to increased catches in the short-term, they ultimately reduce the number of breeders in the population and thereby jeopardize future harvesting success. By refraining from harvesting lobsters that are just below the minimum legal size and waiting an extra year, harvesters can increase their profits substantially because these individual lobsters can increase in mass (and thus value) by almost 50% through growth during the molt. This type of information was all the incentive that most harvesters needed to start working more responsibly and obey the regulations.

During the second year, 1996, the practice of V-notching ovigerous females was initiated. V-notching is the process of cutting a shallow notch mark into the tail of an ovigerous female. When marked animals are recaptured later, after having released their eggs, they are returned to the water. Marks are retained for up to two molts and this measure has the effect of protecting known spawners for several additional years. Under current regulations in Newfoundland, V-notching by harvesters is voluntary but landing of V-notched animals is prohibited. Release of ovigerous females is one of the oldest conservation measures for lobsters and serves to preserve existing clutches of eggs to hatching (Miller 1995). However, because female lobsters typically bear eggs only every second year (Waddy et al. 1995), unless coupled with V-notching, this measure only protects mature females while carrying eggs.

In 1996, approximately 1500 ovigerous females were marked and released in the Eastport area. This harvesting season was one of the best ever recorded (Figure 2.2). Most harvesters reported a significant improvement in landings from the previous year despite a reduction in effort. However, it is not known if this increase resulted from the Committee's efforts, or natural fluctuations.

In 1997, the Committee realized that more conservation measures were necessary so they applied to the Department of Fisheries and Oceans to restrict lobster harvesting in the Eastport area to traditional users and to protect two areas of prime lobster habitat from all lobster harvesting (Round Island and Duck Islands; Figure 2.1). V-notching continued and recoveries and subsequent release of these females were common. Although water conditions were poor in 1997, overall landings were still much greater than 1993 (Figure 2.2).

REVERSING THE TRAGEDY OF THE COMMONS

The restriction of harvesting for lobster in the Eastport area to traditional users was a pivotal point in the success of conservation efforts. Typically, lobster harvesters in Bonavista Bay have licences that allow them to trap anywhere within this bay. However, Eastport harvesters gave up the right to trap outside of the area in which they traditionally took lobsters on the condition that harvesters outside of the area gave up the right to trap around Eastport. The reason was that it was easier to manage the lobster resource when fewer people, with restricted landing points, were involved. Also, because Newfoundland lobsters are believed to be rather localized in their movements (Ennis 1984a, 1984b), by having exclusive access to their lobster grounds, harvesters could be confident that they would be the recipients of the fruits of their conservation efforts. Consequently, exclusive access increased, even further, the willingness and desire of harvesters to work towards conservation. Thus, in 1997, they also requested that two areas of prime lobster habitat be protected from harvesting and V-notching continued. The involvement of only known, local harvesters allowed the Committee to reverse the 'tragedy of the commons' (Hardin 1968). Previously, a mentality existed among harvesters that if they did not take the sub-legal sized or ovigerous lobsters or fish more traps than they were permitted, other harvesters would do so and reap the benefits. Now, individuals in the Eastport area know that other harvesters around them will not take these actions so they do not either.

INTEGRATING HARVESTERS' LOCAL KNOWLEDGE AND FISHERIES SCIENCE

From the early stages of the Committee's work, the need for the collection and dissemination of quantitative biological information was apparent. Scientific research conducted in the Eastport area in previous years and the FRCC report (FRCC 1995) provided the Committee with the information needed to address the problem of poor harvesting practices, but local data were required to measure the effectiveness of local conservation measures. Without such quantitative data, the value of various conservation tools would be difficult to demonstrate to both harvesters and scientists.

In 1997, with the establishment of the Eastport Peninsula Lobster Management Area and the two no-take lobster reserves therein (Figure 2.1), the Committee engaged in a partnership with the Department of Fisheries and Oceans, Memorial University of Newfoundland, and Parks Canada. Together, these partners would draw on their different knowledge bases to identify questions that were relevant to lobster conservation in the Eastport area, formulate hypotheses and decide how best to test them, collect the necessary data, and interpret the results. Instead of trying to insert harvesters' knowledge into fisheries science and management, the Committee decided to take a different approach:

integrating scientific methodology into their local ecological knowledge base. As a result, the group has been able to gather scientifically rigorous data (quantitative in nature and collected using standardized techniques) and has benefited from local knowledge (typically qualitative in nature) particularly during the planning and interpretive stages.

The process involved in assessing the effectiveness of the two no-take lobster reserves as a conservation tool is an excellent example of how the partners cooperate to do research. The local Committee first learned of how no-take reserves might be used for conservation through the FRCC (1995). Subsequently, they used their local ecological knowledge to identify two areas of prime lobster habitat that had an appropriate pattern of water circulation (possibly important for retaining the planktonic lobster larvae within the management area; Ennis 1986) for closure. However, they realized that it would be critical to quantify the movement of adults between the no-take lobster reserves and harvested areas and asked for assistance from the scientific members of the group. Collectively, the partners decided that the best way to monitor the development of the protected populations over time would be by conducting catch-mark-and-release biological sampling. To pay for this research, they applied to the Canadian Centre for Fisheries Innovation for a small amount of financial support. This assistance was used to purchase items such as lobsters tags, boat fuel, and lobster bait, and allowed the group to hire qualified university students to help with the research.

During 1997, baseline population size structure and reproductive state information was collected for lobsters within and outside the no-take lobster reserves. Research trapping was conducted during a two-week period in September, following the normal lobster season. Harvesters that normally trapped lobsters in the areas before closure did the work, using their own boats and traps. A research assistant helped the crew to measure, sex, and determine the reproductive condition of each captured lobster. In addition, before being returned to the water, each animal was marked with a tag that persists through the annual molt and makes each individual recognizable.

Subsequent to the Fall research fishery, tagged lobsters were monitored by harvesters during the commercial harvesting season. Whenever a tagged lobster was observed in one of their traps, they recorded the date, tag number, location of capture, and some biological information about the individual. This information was compiled at the end of the season to determine the extent of movement, particularly between the no-take lobster reserves and harvested areas. It also allowed an assessment of whether certain components (i.e. certain sexes or sizes) of the lobster population were more likely than others to move.

Most of the data were analyzed at Memorial University and results were presented during a meeting of the lobster conservation group. Harvesters had an opportunity to compare these results with their personal predictions based upon current local knowledge of the subject. Strengths and weaknesses of the information were discussed among the partners and used to plan future research and conservation directives. Fall research trapping and monitoring of tagged lobsters have continued since 1997.

In addition to assessing the effectiveness of the no-take lobster reserves, the Committee is also working to monitor the overall lobster resource in their area. This is partially being done by the maintenance of log books in which participating harvesters record their daily catch by category and effort. Also, research assistants periodically join harvesters at sea to conduct more detailed sampling to evaluate the relative abundance of various population components. The information pertaining to catch rate is being used to generate indices of abundance for commercial sized lobsters to monitor exploitation rates and annual variability in production. In addition, information about the relative abundance of sub-legal sized and ovigerous female lobsters can help predict landings in the following year and more distant future, respectively. Harvesters' knowledge of local conditions and how they may have influenced the results obtained can contribute greatly in the interpretation of these data.

COMMUNITY INVOLVEMENT

Not only has the Committee designed and implemented a conservation plan to better manage their resource, but they have also taken an active role in enforcement and education. For example, harvesters on the Eastport Peninsula have established a system of peer enforcement. Unlike the previous system in which harvesters reported infractions directly to the appropriate government regulatory agency, information on suspicious activity is now conveyed to the Committee. A group warning is issued to the perpetrator and the local fisheries officers are informed of the violation in case legal actions are required. Within the partnership, the Department of Fisheries and Oceans responds to the Committee's concerns through enhanced surveillance of problem areas and routine monitoring of the traps used to ensure that they are registered to licenced individuals.

The harvesters involved have undertaken these initiatives so that they, their community, and future generations can earn a reasonable portion of their living from lobsters. The Committee has taken measures to educate both harvesters and non-harvesters about the importance of lobster conservation and many individuals now interested in the project do not actually harvest lobsters themselves. In many cases, family members of licenced harvesters have become actively involved in managing data collected during the commercial harvesting season. In addition, the local school has supported the harvesters by taking on management and analysis of the lobster fishery monitoring data as a class project. The students' work provides the Committee with information on stock status and gives the young people an opportunity to learn more about the fishery and fisheries management. The involvement of the school has made this a truly community-based project and serves to strengthen the link between the local fishery and the future.

THE FUTURE

The results of recent lobster harvesting seasons continue to show the success of conservation measures implemented by the Committee, particularly their agreement to comply with pre-existing regulations. Harvesters on the Eastport Peninsula have reported improved landings while those in other parts of Newfoundland have observed a decline (Figure 2.2; ANCOVA; location by year: $F_{1, 12} = 6.28$, $P = 0.0276$). News of the initial successes of the Eastport Peninsula Lobster Protection Committee has spread far beyond the Eastport Peninsula. Many other communities throughout the province are now investigating the possibility of establishing their own conservation committees and no-take reserves for lobster. The Eastport Committee is also continuing its partnership with scientific groups and investigating the use of additional conservation measures. For instance, they are exploring the possibility of a total closure to harvesting for any species in the areas now designated as no-take lobster reserves.

As the Committee looks to its future, there are many things that can be learned from their experiences in the past few years:

- Conservation measures initiated from the grass roots are widely accepted and thus are more effective.
- The key to effective enforcement and compliance with conservation measures is an effective local education program and acceptance by stakeholders of a serious stewardship role.
- Both harvesters' local knowledge and fisheries science can make important contributions to fisheries knowledge and management.
- Harvesters and scientists can work cooperatively for effective management and betterment of a resource.

However, all of these gains are based upon trust; trust between harvesters, trust between harvesters and scientists, and trust between harvesters and government. Trust between all of these groups must develop and be maintained if projects such as this one are to succeed. The Eastport Lobster Protection Committee's expectations for the future are very high. This has been made possible by their conscious decision to participate in effective management of the lobster fishery around the Eastport Peninsula. They are integrating their local knowledge with fisheries science and have developed an alternative co-management plan for their local fishery that seems to be working to their advantage. The Eastport Peninsula provides an example of a community that, by taking direct action in the local environment, is avoiding the common pattern of harvesting decline, outmigration, and community disintegration found elsewhere across the north Atlantic (Hamilton and Otterstad 1998; Hamilton and Haedrich 1999). The Committee's success offers a model for effective fishery management and establishment of similar programs elsewhere.

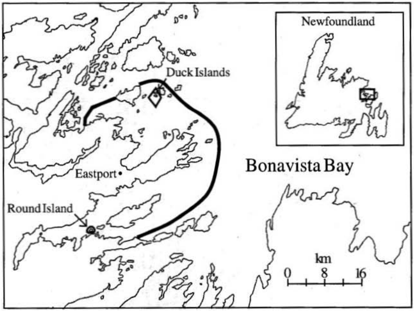

Figure 2.1. Eastport Peninsula Lobster Management Area with no-take lobster reserves at Round Island and Duck Islands indicated.

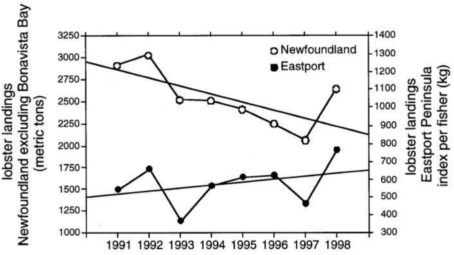

Figure 2.2. Lobster landings for Newfoundland excluding Bonavista Bay and a 'typical' harvester on the Eastport Peninsula, 1991-1998. Values for the Eastport Peninsula based on annual lobster landings as recorded by three local harvesters and averaged among them. Newfoundland data obtained from the Statistics Branch of Canada's Department of Fisheries and Oceans.

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CHAPTER 3:

STREAMER TAG LOSS FROM LOBSTERS

ABSTRACT

The polyethylene Streamer Tag is commonly used in field studies of the American lobster, *Homarus americanus*, yet there has been no attempt to investigate loss rate of this tag or any potential sources of variability in tag loss. Through use of a secondary mark, I estimated that Streamer Tag loss from lobsters recaptured after about eight months was 17.8% (24/135) and after one year was 18.1% (15/83). After one year, there was a significant difference in Streamer Tag loss in relation to molting (40.0% tag loss for lobsters that had molted and 11.1% for lobsters that had not molted). However, I found no significant difference in Streamer Tag loss in relation to lobster sex or size. The results of this study demonstrate that there can be substantial loss of Streamer Tags from American lobsters and therefore, the possibility that tag loss may introduce serious bias should be considered for any estimates of population characteristics based on Streamer-Tagged animals.

INTRODUCTION

Tagging experiments are a useful tool for studying ecology and population biology of a vast array of organisms. Typically, members of a population are captured and marked using some form of metal, plastic, or dye and then resampled later to observe individuals that were previously marked. The first ecological use of capture-mark-recapture was carried out by the Danish fisheries biologist C.G.J. Petersen in 1896 (Ricker 1975). Tagging of fish was first used to study movements and migration of individuals, but it was soon realized that tagging could also be a powerful tool used to estimate population size and mortality rates. However, a critical assumption of methods that use capture-mark-recapture to estimate population characteristics such as population size and mortality is that individuals do not lose marks between sampling periods (Krebs 1999). Estimates can be seriously biased if tag loss is not taken into account.

Much of our knowledge about the American lobster (*Homarus americanus*) has been obtained through tagging. An absence of simple methods for direct age determination of individual animals highlights the importance of tagging for growth studies (Fogarty 1995) but because growth involves shedding of the complete exoskeleton, it has been particularly difficult to find a suitable tag. Many attempts have been made to develop a tag that would be retained through the molt (Wilder 1953; Scarratt and Elson 1965; Cooper 1970; Scarratt 1970; Landsburg 1991; Moriyasu et al. 1995). For many years, the Sphyrion Tag (Scarratt and Elson 1965) was widely used. Nevertheless, the Sphyrion Tag is imperfect; tag loss for lobsters recaptured one year after tagging amount to 36% for individuals that had molted and 24% for those that had not molted (Ennis 1986; also see Scarratt and Elson 1965; Cooper 1970; Scarratt 1970).

The polyethylene Streamer Tag, initially developed for tagging shrimp, was adapted for use on American lobsters in 1989 (Landsburg 1991; Moriyasu et al. 1995). Relative to the Sphyrion Tag, the Streamer Tag is smaller, more stream-lined, makes a smaller entry wound, and anchors in both abdominal muscles instead of just one. These features were thought to offer a higher retention rate, an idea supported in a comparative field study in which lobsters marked with Streamer and Sphyrion Tags had recapture rates of 43.8% and 19.2%, respectively (Landsburg 1991; Moriyasu et al. 1995). Although the Streamer Tag is now commonly used in field studies on the American lobster, there has not been a comprehensive study to investigate loss rate of this tag and any sources of variability. The Streamer Tag was designed to remain attached for long periods, even during molting but considering its design, method of attachment, and the ecology of the American lobster, it was not anticipated that all tagged individuals would retain the tag indefinitely.

In 1997, a capture-mark-recapture study on lobsters using the Streamer Tag was initiated near the Eastport Peninsula in Bonavista Bay, Newfoundland to assess the effectiveness of closing two areas to harvesting as a conservation tool. Within the first year, preliminary observations suggested that tag loss may have been substantial (S. Rowe, personal observation). Because estimates of local population characteristics were to be based on recaptures of Streamer-Tagged lobsters and these estimates would be biased if tag loss was not taken into account, I began a study in 1998 to determine the frequency of tag loss and whether it was related to individual characteristics.

Specifically, I addressed the following questions: 1) What was the frequency of Streamer Tag loss? 2) Was Streamer Tag loss related to lobster molting, sex, or size (sub-legal sized: $\leq$ 82 mm carapace length versus commercial sized: $\geq$ 83 mm carapace length)?

METHODS

During 26 September to 7 October 1998 (after the molting season), 348 American lobsters ranging from 67 to 120 mm carapace length (CL) were captured using conventional traps, marked with numbered Streamer Tags and released in Newman Sound, Bonavista Bay, Newfoundland. Tags were manufactured by Hallprint Pty. Ltd. (27 Jacobsen Crescent, Holden Hill, South Australia, Australia 5088) and were made of a thin strip of blue polyethylene (94 mm total length x 4 mm maximum width) with a narrow band in the middle (50 mm long x 2 mm wide) and an embroidery needle glued to one end (Figure 3.1). Tagging was done onboard the vessel as lobsters were taken from the traps. In general, for animals < 100 mm CL, the tagging technique described by Moriyasu et al. (1995) was used. Streamer Tags were threaded through the thoraco-abdominal membrane and the abdominal muscle on one side, over the dorsal artery, through the abdominal muscle of the other side, and out the membrane at the opposite side of its entry point. However, due to the size of the narrow portion of the tag, tagging of larger animals (≥ 100 mm CL) was done with the tag inserted in only one of the abdominal muscles. In both techniques, only the narrow portion of the tag was positioned inside the animal leaving both ends with the information visible (Figure 3.2). After the tag was correctly positioned, the needle was detached and discarded. Lobsters were tagged immediately after removal from the traps. All lobsters examined were given a Streamer Tag (unless a tag remained from the previous year, in which case the individual was excluded from this study) and a secondary mark was applied. The secondary mark consisted of a 5 mm diameter hole punched in the endopodite of the left uropod (Figure 3.2). In addition, to assist in another component of lobster research at this site, lobsters were marked with a Claw Band displaying a two-letter combination unique for each individual. Claw Bands were placed around the carpus and consisted of a rubber band that had a small piece of white polystyrene (21 mm x 24 mm), with orange letters, attached using stainless steel wire (Figure 3.2). The carapace length, sex, and shell condition (Ennis 1977) of all tagged individuals were recorded and lobsters were released immediately afterwards close to the place where they were caught.

In 1999, recapture efforts were made during the Spring (3 May to 9 July), before the annual molt, and Fall (24 August to 15 September), after the molt. Spring recaptures were made by a combination of the annual commercial harvest (covering a relatively large geographic area) and underwater observation using SCUBA, as well as catch-and-release research trapping in the immediate study area. Fall recaptures were made using only underwater observation and catch-and-release research trapping. Claw Bands applied in Fall 1998 were known to have a high retention rate among non-molted lobsters thus allowing individual identification of lobsters that had lost their Streamer Tags by the following Spring and minimization of the possibility of double-counting if a lobster that had lost its Streamer Tag was recaptured twice during the study.

Prior to the 1999 commercial fishery, a major public awareness and advertising campaign was conducted to maximize the participation of harvesters in reporting marked lobsters. Letters were sent to all lobster harvesters in the area describing the project, providing instructions for handling marked lobsters and returning tag information, and asking for cooperation. Harvesters in this area were extremely supportive of the project (Chapter 2), diligently followed the instructions, and provided the information requested. If eligible for legal harvest, marked lobsters captured in the commercial fishery were retained by harvesters for me to examine; otherwise, the necessary information was recorded by the harvesters at sea and the lobster was released close to the site of capture.

All lobsters caught during the 1999 recapture periods were carefully examined for Streamer Tags, Claw Bands, and secondary marks. Upon capturing a marked individual, the Streamer Tag number, Claw Band letter code, presence of a hole punched in the endopodite of the left uropod, carapace length, sex, and shell condition were noted. In cases where the marked lobster was not eligible for legal harvest and was observed only by the harvester, size was noted in relation to the minimum legal size (82.5 mm CL).

RESULTS

What was the frequency of tag loss?

Among lobsters tagged in Fall 1998, 38.8% (135/348) and 23.3% (83/348) were recaptured in Spring 1999 and Fall 1999, respectively. Based on recaptures with Streamer Tags attached, 16.2% (11/68) of lobsters recaptured in Fall 1999 had also been recaptured in Spring 1999. Among lobsters recaptured during Spring 1999, none had molted and 17.8% had lost the Streamer Tag (Table 3.1). By comparison, during Fall 1999, 18.1% of recaptured lobsters had lost the Streamer Tag.

Because of the design of this study, there was a possibility of double-counting if a lobster that had lost its Streamer Tag was recaptured twice during the study. During Spring 1999, nine lobsters that had lost their Streamer Tags were released with the Claw Bands attached (no lobsters were observed to have lost both marks) and thus had the potential to be counted again in the Fall. However, during the Fall recapture period, only eight lobsters were observed with no individually identifiable marks (i.e. a hole was present in the endopodite of the left uropod but both the Streamer Tag and Claw Band were absent) and only two of these individuals fit the characteristics of lobsters caught and released during the Spring after having lost the Streamer Tag. Consequently, taking these two individuals into account, the overall Streamer Tag loss observed in the Fall may have actually been only 16.0% (13 lobsters with tag lost/81 recaptured). Considering the number of lobsters marked in 1998 and the proportion recaptured, it is unlikely that double-counting occurred.

Was tag loss related to molting?

Among lobsters recaptured during Fall 1999, there was a significant difference in Streamer Tag loss between non-molted and molted individuals with losses of 11.1% and 40.0%, respectively ($G_1 = 7.56$, $P = 0.0060$; Table 3.1).

Was tag loss related to sex?

There was no significant difference in the frequency of Streamer Tag loss between female and male lobsters (Table 3.2) recaptured during Spring 1999 ($G_1 = 0.12$, $P = 0.7277$) or Fall 1999 while controlling for molt (non-molters: $G_1 = 0.08$, $P = 0.7743$; molters: $G_1 = 0.31$, $P = 0.5808$).

Was tag loss related to size?

There was no significant difference in the frequency of Streamer Tag loss between sub-legal and commercial sized lobsters (Table 3.3) recaptured during Spring 1999 ($G_1 = 1.18$, $P = 0.2767$) or Fall 1999 while controlling for molt (non-molters: $G_1 = 0.60$, $P = 0.4383$; molters: Fisher's Exact test, $P = 0.1474$).

DISCUSSION

The results of this study show that, over a period of one year, American lobsters that molted were more likely to lose Streamer Tags than those that did not molt. The difference in percentage tag loss between molters and non-molters for lobsters recaptured in Fall 1999 gives an estimate of an additional 28.9% Streamer Tag loss due to molting. This compares with 12% loss for Sphyrion Tags due to molting and measured over a similar time period (Ennis 1986).

Considerable tag loss was caused by factors other than molting. During the overwinter period (i.e. Fall 1998 to Spring 1999), approximately 17.8% of lobsters lost their Streamer Tags. This percentage is surprisingly high considering that none of the individuals had molted and lobsters are relatively inactive throughout the Winter (Ennis 1984a, 1984b). Factors other than molting that could account for tag lost have not been clearly established. Ennis (1986) attributed some Sphyrion Tag loss to substrate entanglement and removal by other lobsters. This may also apply for the Streamer Tag but considering its small size and stream-lined design relative to the Sphyrion Tag, these factors may be less significant.

I found that Streamer Tag loss among individuals that had not molted was not continuous over time but rather that it was high initially and then decreased. Specifically, Streamer Tag loss was 17.8% after approximately eight months but only 18.1% after twelve months and the molt period (loss after twelve months was only 11.1% for lobsters that did not molt; Table 3.1). A similar result was found by Ennis (1986) for the Sphyrion Tag but he applied the marks during Spring so that most Sphyrion Tag loss unrelated to molting occurred during Summer when lobsters are most active. In both studies, the period of marking was confounded with lobster activity cycle (i.e. I tagged lobsters in the Fall, after the peak of lobster activity whereas Ennis tagged lobsters during the Spring, before the peak of activity). Therefore, it was not possible to conclude whether the high proportion of tag loss during the initial months was more due to lobster activity (and hence likelihood of entanglement in the substrate or removal by conspecifics) or an increased susceptibility of the tags to be lost during the period immediately following application. However, it has been suggested that most Sphyrion Tag loss unrelated to molting occurs within the first five days after tagging, regardless of season (Krouse 1981; Moriyasu et al. 1995).

I believe that a potential source of Streamer Tag loss among individuals that had not molted was due to removal by fish, specifically cunners (*Tautogolabrus adspersus*). During 1999, it was observed that upon release, tagged lobsters would settle to the bottom and sometimes cunners would swarm towards the marked individual, possibly because they were attracted to the blue coloured Streamer Tags. During the Spring, cunners undergo colour change from brown to blue, particularly in the ventral region (Pottle 1979). This colour change is associated with reproductive behaviour and it is plausible that blue colour is a signal involved in mate choice. Many of the tags later observed on recaptured lobsters were stretched and jagged on the ends, often with small holes, possibly caused by the sharp pointed teeth of cunners. In addition, it would have been easiest for these fish to remove tags from lobsters soon after they were applied because a period of at least one week seems to be required for the abdominal muscles to heal and tighten around the Streamer Tag (S. Rowe, personal observation).

Because of behavioural differences, particularly in the way in which they interact with conspecifics, it might be anticipated that Streamer Tag loss is different for lobsters of varying sex and size. However, my results suggest that there was no difference in Streamer Tag loss in relation to either factor.

Compared to the Sphyrion Tag, it appears that the Streamer Tag has a higher retention rate in the absence of molting but is much more prone to loss related to molt (Table 3.1; Ennis 1986). Consequently, it is surprising that in the only comparative field study of these tags, a much higher recapture rate was reported for Streamer- than Sphyrion-Tagged lobsters after approximately one year at large, particularly considering that 72.9% of these lobsters had molted (Landsburg 1991; Moriyasu et al. 1995). Some differences in tag loss among these studies may be due to lobster molt stage at tagging. Moriyasu et al. (1995) found that lobster molt stage (i.e. postmolt, intermolt, early premolt, late premolt) at tagging had considerable effects on the amount of Sphyrion Tag loss and research is needed to examine this issue for the Streamer Tag.

Further research and development is necessary to find a tag that has improved retention ability, even during molting; this is particularly important for long-term studies of individual lobsters. Meanwhile, use of the Streamer Tag can contribute significantly to our knowledge of various aspects of population biology and ecology of the American lobster. However, the results of this study demonstrate that there can be substantial loss of these tags and therefore, the possibility that tag loss may introduce serious bias should be considered for any estimates of population characteristics based on Streamer-Tagged animals.

Table 3.1. Percentage losses of Streamer Tags from 348 American lobsters tagged at Newman Sound, Bonavista Bay, Newfoundland, in Fall 1998 and recaptured in Spring and Fall 1999. The number of animals recaptured is given in parentheses.

Spring 1999 recaptures	Fall 1999 recaptures		
non-molters	non-molters	molters	overall
17.8	11.1	40.0	18.1
(135)	(63)	(20)	(83)

Table 3.2. Percentage losses of Streamer Tags from 189 female and 159 male American lobsters tagged at Newman Sound, Bonavista Bay, Newfoundland, in Fall 1998 and recaptured in Spring and Fall 1999. The number of animals recaptured is given in parentheses.

Spring 1999 recaptures		Fall 1999 recaptures			
non-molters		non-molters		molters	
female	male	female	male	female	male
16.9	19.2	9.5	11.9	33.3	45.5
(83)	(52)	(21)	(42)	(9)	(11)

Table 3.3. Percentage losses of Streamer Tags from 92 sub-legal (≤ 82 mm CL) and 256 commercial sized (≥ 83 mm CL) American lobsters tagged at Newman Sound, Bonavista Bay, Newfoundland, in Fall 1998 and recaptured in Spring and Fall 1999. The number of animals recaptured is given in parentheses.

Spring 1999 recaptures		Fall 1999 recaptures			
non-molters		non-molters		molters	
sub-legal	commercial	sub-legal	commercial	sub-legal	commercial
24.2	15.7	18.2	9.6	100.0	33.3
(33)	(102)	(11)	(52)	(2)	(18)

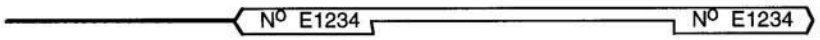

Figure 3.1. Streamer Tag with attached embroidery needle (actual size) used for American lobster tagging in Newman Sound, Bonavista Bay, Newfoundland.

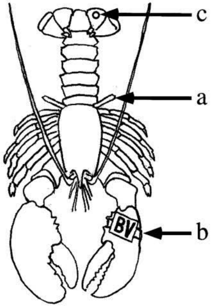

Figure 3.2. Illustration of the Streamer Tag (a), Claw Band (b), and 5 mm diameter hole punched in the endopodite of the left uropod (c) used to mark American lobsters released in Newman Sound, Bonavista Bay, Newfoundland.

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CHAPTER 4:

LOBSTER POPULATIONS IN AREAS WITH AND WITHOUT COMMERCIAL HARVESTING

ABSTRACT

To determine the potential effectiveness of no-take reserves as a fisheries conservation tool for American lobsters (*Homarus americanus*), I quantified the consequences to population structure of eliminating harvesting pressure within two small no-take reserves (Round Island, 3.3 ha of lobster habitat, and Duck Islands, 11.4 ha of lobster habitat) in Bonavista Bay, Newfoundland during 1997-1999. These no-take reserves supported approximately 1.5% of the local lobster population within their boundaries. Although this study concerned only the first three years following reserve establishment, there were obvious differences in lobster population parameters inside and outside of the no-take reserves. At the Round Island reserve, population density was high and stable over time, and female and male size increased, as did the proportion of ovigerous females. However, at the Duck Islands reserve, population density increased dramatically between 1997 and 1998, and male size increased over time, but there was no change in female size or in the proportion of ovigerous females. Lobster density, female and male size, and the proportion of ovigerous females were greater within the Round Island reserve compared to an adjacent harvested area. At the Duck Islands, females and males were larger in size within the reserve but I found no difference in lobster density or the proportion of females that were ovigerous between the reserve and an adjacent harvested area. Taken together, these data suggested that no-take reserves offered increased survival to lobsters (particularly at the Round Island site) and thereby may provide direct benefits to the local fishery.

INTRODUCTION

Marine no-take reserves, defined as areas closed to harvesting, have been used for many years to conserve exploited populations and fisheries, yet there has been little evaluation of whether they achieve the goals for which they were established. In the presence of intense harvesting pressure on many marine species, no-take reserves are often portrayed as an effective tool to prevent over-exploitation by making part of the population at risk inaccessible to harvesters. It has been repeatedly demonstrated that the abundance, mean size of individuals, and spawning biomass of exploited populations tend to be greater inside no-take reserves than in comparable areas subjected to harvesting (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). These changes are a predicted outcome of protection from exploitation because many fish and invertebrates live longer, reach larger body size, and produce significantly more eggs in the absence of harvesting mortality (Bohnsack 1992, 1996; Roberts and Polunin 1993).

As a result of population changes caused by protection from harvesting, no-take reserves have the potential to conserve exploited populations and fisheries in three major ways. First, reserves can provide a benefit by exporting larvae that may increase recruitment into regional fishery stocks (Carr and Reed 1993; Rowley 1994; Bohnsack 1998). Second, reserves can export biomass in the form of emigrating juveniles and adults to adjacent harvesting grounds (Rowley 1994; Russ and Alcala 1996; Bohnsack 1998). Third, reserves can offer numerous advantages by protecting portions of exploited stocks from genetic changes, altered sex ratios, and other disruptions caused by selective harvesting mortality (Ricker 1981; Bohnsack 1992, 1998). All of these effects are dependent upon the reserves offering a survival advantage to the individuals that live there.

Reef species targeted by harvesting are usually more abundant and larger inside marine reserves than outside (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). Whether this is because of increased survival due to protection from harvesting or simply site-related differences (i.e. pre-existing inherently superior habitat quality within the locations selected for reserves compared to nearby areas) is often difficult to determine. For example, many areas have specifically been made marine reserves because they contained unusually abundant fauna, large individuals, or rare species (Björklund 1974). Simple comparisons of populations in marine reserves with populations in other areas cannot reveal the cause of any differences that exist between them. A rigorous test of population improvement created by a no-take reserve would involve a comparison of populations within the reserve to populations within a similar nearby control area, with information on both of these areas available before and after reserve establishment. However, most studies have made only static comparisons of harvested and no-take areas after reserve establishment; before-and-after or time-series data are relatively scarce (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994).

American lobsters (*Homarus americanus*) are a popular and valuable seafood harvested in the coastal waters of the northwest Atlantic, mainly by community-based small boat harvesters. Like all fisheries today, the American lobster fishery is suffering problems. Canada's Fisheries Resource Conservation Council (FRCC 1995) has raised concerns about the future of lobster stocks in Atlantic Canada. Lobsters are long-lived bottom-dwelling invertebrates characterized by slow growth, late maturation, and long intervals between matings. Female maturation occurs after several years of growth and egg production increases exponentially with increasing size (Prudden 1962; Aiken and Waddy 1980a, 1980b; Ennis 1981). In many areas, current exploitation rates are high (harvesters take up to 85% of the animals present that are eligible for legal harvest each year) and primarily immature animals are harvested (FRCC 1995). This is a problem because intense harvesting results in extremely low levels of egg production and risks recruitment failure during periods when environmental or ecological conditions that influence survival to recruitment are unfavorable.

No-take reserves have been suggested as a conservation measure for American lobsters (FRCC 1995). It is believed that they can help increase egg production by allowing an unexploited portion of the population to develop and more lobsters to survive to maturity. However, because of intense harvesting pressure on surrounding lobster grounds, no-take lobster reserves could only be effective if adult movement out of the reserves occurs at a low enough rate to permit increased adult survival. During the early months of 1997, two small no-take reserves were established for the conservation of American lobsters, one at Round Island and one at Duck Islands, near the Eastport Peninsula in Bonavista Bay, Newfoundland (Figure 4.1). These reserves encompassed a marine area of 2.1 km^2 that surrounded three small islands and extended well beyond the rocky substrate that was considered suitable for lobsters. To determine the potential effectiveness of these no-take lobster reserves as a conservation tool, direct measures of lobster population parameters inside and outside the reserves were required.

In this study, I attempted to quantify the results of eliminating harvesting pressure within the Round Island and Duck Islands no-take reserves. Specifically, I addressed the following questions: 1) How much lobster habitat was available in the study areas? 2) How many lobsters lived inside the reserves and in nearby control areas? 3) What was the lobster population density inside the reserves versus nearby control areas? 4) Did the sex ratio of lobsters differ between reserves and harvested areas and did it change over time? 5) Did the proportion of ovigerous to non-ovigerous female lobsters differ between reserves and harvested areas and did it change over time? 6) Did the mean size of lobsters differ between reserves and harvested areas and did it change over time?

METHODS

Habitat mapping

A combination of a Global Positioning System (Trimble Explorer II with differential correction using a surveyed base station offering ± 1 m accuracy) and a Geographic Information System (SPANS, combined either with digitized data from 1:12500 aerial photographs that were georeferenced using a digital terrain model with ± 30 m accuracy for areas in the vicinity of Round Island, or digitized 1:50000 topographic maps prepared by Energy, Mines and Resources Canada with approximately ± 100 m accuracy for the areas in the vicinity of the Duck Islands) was used to estimate the amount of lobster habitat present in the no-take lobster reserves and the nearby control areas that were exposed to harvesting. Lobster habitat was defined using the local ecological knowledge of Eastport Peninsula lobster harvesters. Using this technique, shallow water areas with rocky substrate were typically considered suitable habitat for lobsters. The shoreline was considered to be the inner boundary of the habitat and the outer boundary was defined to be farthest distance from shore that harvesters could set a conventional lobster trap during the harvesting season and expect to catch lobsters, usually at the point where the nearshore bottom sloped rapidly into deeper water (generally to a maximum depth of about 20 m). Geographic co-ordinates of the outer boundary were determined by moving along the line in a boat directed by local harvesters while a Global Positioning System fixed on the vessel recorded the position every few seconds. These co-ordinates were imported into a Geographic Information System and overlaid onto topographic maps of the region so that the sea surface areas between the outer boundaries and shorelines (as indicated on the topographic maps) could be calculated.

Biological sampling

During 23 September to 3 October 1997, after the reserves had been established for several months (including one lobster harvesting season and one lobster molting period), baseline population structure and reproductive state information was collected for lobsters within and outside the no-take lobster reserves (Figures 4.1, 4.2, and 4.3). This was done through catch-and-release sampling. Harvesters that normally trapped lobsters in the areas before closure assisted with the work, using their own boats and conventional lobster traps. During the research period, 25 traps were set inside each of the two reserves (referred to as Round Closed and Duck Closed hereafter) and 25 traps were set in each of two nearby control areas that were exposed to harvesting (referred to as Round Open and Duck Open hereafter). Traps were checked every day that weather conditions permitted. For each lobster captured, the location of capture was recorded, the carapace length (CL) was measured using vernier calipers, the sex and shell condition (i.e. new versus old; Ennis 1977) were determined, and reproductive condition of females (i.e. ovigerous or non-ovigerous) was noted. In addition, each animal was marked with an individually numbered Streamer Tag that was easily visible to potential observers and made each individual lobster recognizable (Chapter 3). Because conventional traps typically did not retain lobsters < 65 mm CL, most individuals in my sample were above this size limit.

This protocol was repeated during Fall 1998 (26 September to 7 October) and Fall 1999 (6 to 15 September). Although recaptures were common, each lobster was only counted once per year except for analyses relating to population size and density.

Estimates of population size and density

Lobster population size within the no-take lobster reserves and nearby harvested areas was determined for each year of the study using the Schumacher and Eschmeyer (1943) method (reviewed by Krebs 1999), a multiple markings and recaptures approach. If an estimate provided by the Schumacher and Eschmeyer (1943) method is to be an accurate estimate of population size, five assumptions of the model must hold (in italics below; Krebs 1999). The extent to which these assumptions were met in the present study was as follows:

1) *The population is closed so that the population size is constant.* Tagging studies of lobsters in Newfoundland waters have indicated that movement is restricted (Ennis et al. 1989; Chapter 5). However, movement in and out of the study area was likely to occur due to its small size. Therefore, violation of this assumption was minimized by sampling over a short time period (e.g. two weeks). At this temporal scale, natural mortality, which is believed to occur at very low rate for adult lobsters (Thomas 1973; Ennis 1979), and recruitment to the catchable population, which would occur through molting during July and August (S. Rowe, personal observation), were also unlikely to be factors for concern.

2) *All animals have the same chance of getting caught in the first sample.* By sampling over a short time period, I have limited the potential for immigration of new individuals into the catchable population (both through movement and recruitment) so that all individuals within an area have the same chance of getting caught in the first sample. There is some suggestion that during Fall, males may be more catchable than females (Ennis 1983) but because all sampling occurred during Fall, this bias should be consistent over time and among areas (providing that sex ratios are similar).

3) *Marking individuals does not affect their catchability.* In the present study, there was no a priori reason to suspect that catchability of lobsters was altered by tagging or the presence of the tag. Because of the design of the Streamer Tag (and other secondary marks; Chapter 3) and the tagging operation itself (lobsters were tagged and released immediately after the trap was hauled), it was unlikely that there was any mortality or trauma associated with tagging. Moreover, many lobsters were recaptured again within 24 hours of tagging, consistent with the idea that tagging did not induce trap-shyness. A related assumption is that in the second sample, tagged animals were randomly distributed

throughout the population. In this study, the tagging operation ensured a high degree of mixing; traps used to catch lobsters for tagging were distributed throughout the area and each trap was moved repeatedly during the tagging period.

4) *Animals do not lose their marks between sampling periods.* There was some data to suggest that Streamer Tag loss from the American lobster is relatively high (e.g. 17.8% after eight months and in the absence of molting; Chapter 3) and it has been suggested that most tag loss unrelated to molting occurs within the first five days after tagging (Krouse 1981; Moriyasu et al. 1995). However, many of the lobsters used in this study were also given a secondary mark that was known to have a high retention rate among non-molted lobsters. Among lobsters given both types of marks, none were observed to have lost the Streamer Tag within a Fall research trapping period.

5) *All marks are reported upon discovery in the second sample.* Streamer Tags and other secondary marks applied were highly visible and the catch per trap haul was quite low (i.e. 0-5 lobsters per trap). These factors, combined with all tagging and recapturing being done by trained observers, ensured that this assumption was not violated.

Where potential violations of the five assumptions could be identified, corrections were made to limit their effects on my population estimates. Some assumptions could not be tested but as far as can be judged there were no major violations that would introduce serious bias.

Lobster density estimates were obtained by dividing the estimated population size by the estimated amount of lobster habitat available. To examine the accuracy of this technique, lobster population size and density were estimated using a second method in 1999. During a two week period (23 August to 1 September 1999) immediately preceding the Fall research trapping, lobster density inside and outside the Round Island no-take reserve was estimated by counting the number of lobsters observed by SCUBA diving along underwater transects. Sixty points (30 inside the reserve and 30 in the nearby control area) along the shoreline of the study area were selected as starting points for transect surveys. Selection was accomplished by spacing the transect starting points approximately evenly along the shoreline in each of the areas. Transects began at the shoreline and were set to extend off shore, running perpendicular to the shoreline. The survey area included a 2 m region on each side of the transect line. The survey distance was 30 m along the line or the distance reached when the depth was 12 m. The survey did not extend beyond the depth of 12 m because most lobsters are found within this depth range during this period (Ennis 1984). Each transect was surveyed by two divers, one covering each side of the transect line. Divers would slowly swim through the area, looking into crevices among the rocks for the presence of lobsters and counting any that were encountered. Typically six randomly selected transects were surveyed each day, always including an equal number inside and outside of the reserve. The density estimates obtained were then used to estimate lobster population size inside and outside the reserve by multiplying the mean densities by the amount of lobster habitat available in each case.

RESULTS

How much lobster habitat was available in the study areas?

Mapping based on the local ecological knowledge of Eastport Peninsula lobster harvesters indicated that the study areas contained approximately 40.4910 ha of suitable lobster habitat. This habitat was distributed as follows: 3.3036 ha at Round Closed, 20.8163 ha at Round Open, 11.4431 ha at Duck Closed, and 4.9280 ha at Duck Open.

How many lobsters lived inside the reserves and in nearby control areas?

The Schumacher and Eschmeyer (1943) method was used to estimate population size within each of the reserves and nearby control areas for each year of the study (Figure 4.4). Population size was greater at Round Open than Round Closed and greater at Duck Closed than Duck Open. The estimated population size for each site was fairly similar over time, except for Duck Closed and Round Open. Duck Closed showed a drastic increase in population size from 1997 to 1998, whereas at Round Open, the population size decreased over time. Overall, Round Closed appeared to have about 545 lobsters and Round Open had a mean of 863 lobsters. By comparison, Duck Closed had a mean of 777 lobsters and there were 422 lobsters at Duck Open. Estimates of population size based on diving observations at Round Island in 1999 were similar to those obtained using the Schumacher and Eschmeyer (1943) method (Figure 4.4).

What was the lobster population density inside the reserves versus nearby control areas?

The Schumacher and Eschmeyer (1943) method was used to estimate population size which was divided by the estimated amount of lobster habitat to calculate lobster density within each of the reserves and nearby control areas for each year of the study (Figure 4.5). Population density was much greater at Round Closed than Round Open in all years. However, population density between Duck Closed and Duck Open were more similar by comparison. The estimated population density for each site was fairly similar over time, except for Duck Closed and Round Open. Duck Closed showed a large increase in population density from 1997 to 1998, whereas at Round Open, the population density decreased over time. Overall, Round Closed appeared to have about 165 lobsters/ha and Round Open had a mean of 42 lobsters/ha. By comparison, Duck Closed had a mean of 68 lobsters/ha and there were 85 lobsters/ha at Duck Open. Estimates of population density based on diving observations at Round Island in 1999 were similar to those obtained using the Schumacher and Eschmeyer (1943) method and estimates of the amount of lobster habitat present (Figure 4.5).

Did the sex ratio of lobsters differ between reserves and harvested areas and did it change over time?

Both at the Round Island and Duck Islands sites, I found no significant difference in the sex ratio of lobsters captured during 1997, 1998, or 1999, between the no-take reserves and nearby control areas (Table 4.1). In addition, there were no apparent changes in the sex ratio over time (Round Closed: $G_2 = 2.65$, $P = 0.2660$; Round Open: $G_2 = 1.55$, $P = 0.4603$; Duck Closed: $G_2 = 0.57$, $P = 0.7528$; Duck Open: $G_2 = 0.87$, $P = 0.6465$; Table 4.1).

Did the proportion of ovigerous to non-ovigerous female lobsters differ between reserves and harvested areas and did it change over time?

At Round Island, I found a significant difference in the proportions of ovigerous and non-ovigerous females captured each year between the no-take reserves and nearby control areas (Table 4.2). At this site, there was a much higher proportion of females that were ovigerous inside the reserve than outside in all years. In addition, within the reserve, the proportion of females that were ovigerous was significantly different among years (Round Closed: $G_2 = 6.51$, $P = 0.0385$; Round Open: $G_2 = 0.57$, $P = 0.7535$; Table 4.2).

By comparison, at the Duck Islands site, I found no significant difference in the proportions of ovigerous and non-ovigerous females captured each year, between the no-take reserves and nearby control areas (Table 4.2). Also, at the Duck Islands, there was no difference among years in the proportion of females that were ovigerous inside or outside the reserve (Duck Closed: $G_2 = 4.96$, $P = 0.0838$; Duck Open: $G_2 = 0.36$, $P = 0.8357$; Table 4.2).

Did the mean size of lobsters differ between reserves and harvested areas and did it change over time?

Because of differences between the sexes in growth rate (Ennis et al. 1989; Waddy et al. 1995), I examined females and males separately to assess differences in the size of individual lobsters between protected and harvested areas and across years. For females at the Round Island site, there was a significant interaction between treatment (i.e. no-take reserve versus control area) and year (ANCOVA; $F_{1, 638} = 10.68$, $P = 0.0011$; Figure 4.6). Further regression analysis indicated that there was a significant increase in mean female lobster size over time at Round Closed ($F_{1, 347} = 26.13$, $P = 0.0001$, $R^2 = 0.07$) and that there was no significant difference in mean female lobster size across years at Round Open ($F_{1, 291} = 0.21$, $P = 0.6465$). For males at the Round Island site, there was no significant interaction between treatment and year (ANCOVA; $F_{1, 655} = 2.34$, $P = 0.1266$; Figure 4.6). Subsequent analysis with the interaction term removed revealed significant differences in mean male lobster size between the reserve and nearby control area and across years (ANCOVA; treatment: $F_{1, 656} = 10.71$, $P = 0.0011$; year: $F_{1, 656} = 41.24$, $P = 0.0001$). For females at the Duck Islands site, there was no significant interaction between treatment and year (ANCOVA; $F_{1, 509} = 0.32$, $P = 0.5696$; Figure 4.7). Subsequent analysis with the interaction term removed revealed a significant difference in mean female lobster size between the reserve and nearby control area but no significant difference in mean size across years (ANCOVA; treatment: $F_{1, 510} = 7.79$, $P = 0.0054$; year: $F_{1, 510} = 1.54$, $P = 0.2152$). For males at the Duck Islands site, there was a significant interaction between treatment and year (ANCOVA; $F_{1, 602} = 9.85$, $P = 0.0018$; Figure 4.7). Further regression analysis indicated that there was a significant increase in mean male lobster size over time at Duck Closed ($F_{1, 394} = 14.37$, $P = 0.0002$, $R^2 = 0.04$) and that there was no significant trend in mean male lobster size across years at Duck Open ($F_{1, 208} = 1.42$, $P = 0.2347$).

DISCUSSION

The relationship of population estimates derived from census techniques to actual population sizes is a key issue in any study of population biology. Because lobsters are benthic marine invertebrates, often hidden in rocky crevices, an actual count of the number of individuals present within an area is difficult or impossible. I attempted to deal with this issue by having a study design with two different methods of population estimation that were applied independently to the same populations: 1) a capture-mark-recapture method and 2) a method of direct density estimation by observation of individuals within areas of known size. Because the size at which lobsters are readily retained in conventional traps is similar to the size at which lobsters become apparent to divers, these methods sampled animals of a similar size range. I believe that the present study fit the assumptions of the Schumacher and Eschmeyer (1943) model reasonably well. Any bias that may have been present should have been consistent from year to year and any substantial differences in the estimates should have reflected real changes in population size over time. However, it was possible that differences in trap density and hence possibly sampling effort compromised the comparison of estimates from different areas. Nonetheless, finding that both methods produced remarkably similar estimates of population size and density was encouraging. It would be valuable to have such comparative data for multiple years, as well as for the Duck Islands site for which no comparative data was available.

Ennis (unpublished data) estimated that during 1997-1998, about 53000 lobsters eligible for commercial harvest (i.e. lobsters ≥ 82.5 mm CL, the minimum legal size, and not ovigerous or V-notched) were present annually in the Eastport Peninsula Lobster Management Area. Based on this estimate, the no-take reserves support approximately 1.5% of the local lobster population within their boundaries, 0.6% at Round Island and 0.9% at the Duck Islands (no-take reserve samples also based on lobsters eligible for commercial harvest only).

Although the no-take lobster reserves had only been closed for three annual lobster harvesting seasons, there were obvious differences between the lobster populations in the no-take reserves and nearby control areas. However, over this three year period, the response of American lobsters to small no-take reserves was variable both between sites and sexes. At the Round Island site, lobsters seemed to have responded well to local protection: within the reserve, population density was high and apparently stable over time, and female and male size increased, as did the proportion of ovigerous female lobsters. However, at the Duck Islands reserve, the response was quite different: population density increased dramatically between 1997 and 1998, and male size increased over time, but there was no change in female size or the proportion of ovigerous females. Spatial comparisons between the reserve and nearby control area at the Round Island site indicated that although population size was greater outside of the reserve (in a larger adjacent control area), density was greater within the reserve. Furthermore, females and males were larger within the reserve than the nearby control area and more of these females were ovigerous. Spatial comparisons between the reserve and nearby control area at the Duck Islands site indicated that although there were more lobsters inside the reserve, population densities in the two areas were quite similar. Also, although both females and males were larger within the reserve, I found no difference in the proportion of females that were ovigerous between the two areas. Taken together, these data were consistent with the notion that no-take reserves improved the lobster populations within them, particularly at the Round Island site.

The lack of an increase in mean lobster size within the no-take reserves, independent of such an increase in the nearby control areas, among males at Round Island and females at Duck Islands, coupled with the lack of a difference in the proportion of ovigerous females at the Duck Islands reserve relative to outside was difficult to interpret. American lobsters are long-lived organisms characterized by slow growth, late maturation, and long intervals between matings and as a result, three years is a very short period in the life of a lobster or a no-take reserve (Prudden 1962; Thomas 1973; Ennis 1979; Aiken and Waddy 1980a, 1980b). Consequently, it may be premature to try to rationalize any perceived differences in the response of various population components to localized protection or any failure of them to achieve some general long-term expectation.

Round Island and Duck Islands have very different topography and substrate (and hence distribution of lobster habitat) and it is possible that an interaction of these factors and/or the level of harvesting pressure contributed to the observed responses. For example, the relatively high density of lobsters at Round Closed during all years may be due to some combination of particularly abundant lobster habitat in this area and increased survivorship afforded by protection from harvesting. Also, the larger mean lobster sizes and high proportions of ovigerous females at the Duck Islands relative to Round Island are consistent with a lower exploitation rate in the Duck Islands' area. This could also explain the lack of improvement in mean female lobster size at Duck Closed independent of changes at Duck Open and the lack of a difference in the proportion of ovigerous females between the two areas; this component of the lobster population may have been in better condition at reserve establishment. If the lobster population was in better condition at the onset, then considering that older/larger lobsters molt less frequently (Waddy et al. 1995), improvements in mean lobster size will be slow to come about, and considering the alternate year reproductive cycle (Waddy et al. 1995), the proportions of females that are ovigerous may be approaching its upper limit. Another possibility is that observed differences may be explained by variation in lobster movement patterns (i.e. variation among various population components in their tendency to move between the no-take reserves and nearby harvested areas). For example, differences in migration patterns between female and male spiny lobsters are believed to be responsible for variation between the sexes in their response to reserve protection (MacDiarmid and Breen 1992).

My conclusions could have been stronger if my study had begun several years before the reserves were established, in order to quantify pre-existing differences between the selected reserve areas and nearby control areas. This would have provided an experimental design with complete before and after comparisons of populations in and outside the reserves. Without data on the density and size of lobsters at sites inside and outside of the reserves prior to reserve implementation, I cannot conclude with certainty that differences between the reserves and nearby control areas were due to protection from harvesting within the reserves. However, because the proportion of ovigerous female lobsters and lobster size was observed to increase over time within reserves and remain stable outside the reserves, I believe that these differences were attributable to the protection of lobsters within the reserves from the effects of harvesting. Similar conclusions were reached in studies of spiny lobster where single comparisons between no-take reserves and harvested areas showed higher densities and mean lobster sizes within the reserves, and time-series data within these same reserves also showed increases in both factors over time (although comparable time-series data was unavailable for the harvested areas; Cole et al. 1990; MacDiarmid and Breen 1992). It will be interesting to observe the development of American lobster populations within the no-take reserves and the nearby control areas over longer time periods. In the case of spiny lobster, density and mean size of some population components were observed to still be increasing after 16 years of reserve protection (MacDiarmid and Breen 1992). To improve our ability to assess the effectiveness of marine no-take reserves, quantitative population monitoring before and after reserve establishment should be a feature of any future reserve planning and implementation (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994).

Relative to males, female lobsters may be offered additional protection from fishing mortality by the presence of eggs and/or a V-notch. Release of ovigerous females is one of the oldest conservation measures for lobsters and serves to preserve existing clutches of eggs to hatching (Miller 1995). However, female lobsters typically bear eggs every second year (Waddy et al. 1995) so unless coupled with V-notching, this measure only protects mature females while ovigerous. V-notching is the process of cutting a shallow notch mark into the tail of an ovigerous female. When V-notched animals are recaptured later, after having released their eggs, they are returned to the water. Marks are retained for up to two molts and this measure has the effect of protecting known spawners for several additional years. Under current regulations in Newfoundland, V-notching by harvesters is voluntary but landing of V-notched animals is prohibited. Because of intense harvesting pressure and increased protection offered to females, it was suspected that harvesting might result in altered sex ratios. However, I found no evidence for a difference in sex ratio between reserves and nearby areas exposed to harvesting. This may not be so surprising because there is some evidence to suggest that female lobsters may be more susceptible to capture than males during Spring (Ennis 1983; Chapter 5). Despite females receiving additional protection, their increased catchability may result in similar exploitation rates for both sexes.

Although these no-take reserves are still very young, my results suggest that they may offer increased survival to the lobsters within them and thereby have the potential to provide direct benefits to the local lobster population and fishery. This could occur in two ways: through increased egg production by lobsters within the reserve or by emigration of juvenile or adult lobsters from reserves to harvested areas (Roberts and Polunin 1991; Rowley 1992, 1994). Female fecundity of the American lobster increases exponentially with increasing size (Ennis 1981). Because of the greater mean size of female lobsters within the no-take reserves, their egg production would be high relative to females from adjacent harvested areas. However, considering the relatively small proportion of lobsters within the Eastport Peninsula Lobster Management Area that receive protection within no-take reserves, their contribution to total local egg production may be modest, although even a modest contribution could be vital in view of the extremely low levels of egg production that currently predominate (FRCC 1995). To increase local egg production substantially, a greater proportion of the area ought to be protected from harvesting.

Emigration of juvenile or adult lobsters from the no-take reserves to adjacent harvested areas may improve the local fishery. For this to happen, emigration from the no-take reserves must be greater than immigration to the no-take reserves and it must also compensate for the removal from exploitation of the now protected population (Roberts and Polunin 1991; Rowley 1992, 1994). As they mature, almost all juvenile spiny lobsters tagged within a no-take reserve in Florida Bay leave and enter adjacent harvesting grounds (Davis and Dodrill 1989). In addition, an unquantified proportion of large male spiny lobsters in a no-take reserve in New Zealand undergo an annual feeding migration across the reserve boundaries and are caught by commercial harvesters (MacDiarmid and Breen 1992). However, in both cases, the overall effect of reserve establishment on the fishery has not been determined. If the creation of no-take reserves is endorsed on the basis of benefits to local fisheries, it will be important to quantify such effects.

Initial assessment of these no-take American lobster reserves suggests that they may be a useful conservation tool for this species. However, the response of different population components to reserve protection was somewhat variable both between sites and sexes. Further study is needed to investigate the factors influencing lobster movement patterns and to make direct measures of survival for lobsters inside and outside of the reserves. Moreover, in order to understand whether larvae will be exported from the reserves to replenish nearby harvesting grounds, more information about the dispersal patterns of larvae is required.

Table 4.1. Number of lobsters captured and proportion female at Round Island and Duck Islands, 1997-1999, and *G*-test results for comparisons of proportions of females and males between no-take reserves and nearby control areas (open to harvesting).

	no-take reserve		control area			
	n	% female	*n*	% female	G_1	*P*
Round Island						
1997	231	44.2	241	52.7	3.45	0.0633
1998	234	51.3	158	51.3	0.00	0.9975
1999	255	49.8	182	46.7	0.41	0.5225
Duck Islands						
1997	141	44.7	78	55.1	2.20	0.1383
1998	218	44.0	154	48.7	0.79	0.3740
1999	335	41.5	193	50.3	3.80	0.0512

Table 4.2. Number of female lobsters captured and proportion ovigerous at Round Island and Duck Islands, 1997-1999, and G-test results for comparisons of proportions of ovigerous and non-ovigerous females between no-take reserves and nearby control areas (open to harvesting).

	no-take reserve		control area			
	n	% ovigerous	n	% ovigerous	G_1	P
Round Island						
1997	102	47.1	127	29.1	7.79	0.0053
1998	120	49.2	81	24.7	12.51	0.0004
1999	127	62.2	85	25.9	27.80	< 0.0001
Duck Islands						
1997	63	46.0	43	34.9	1.32	0.2509
1998	96	36.5	75	38.7	0.09	0.7672
1999	139	51.1	97	40.2	2.73	0.0988

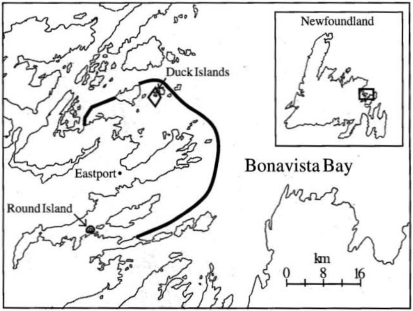

Figure 4.1. Eastport Peninsula Lobster Management Area with no-take lobster reserves at Round Island and Duck Islands indicated.

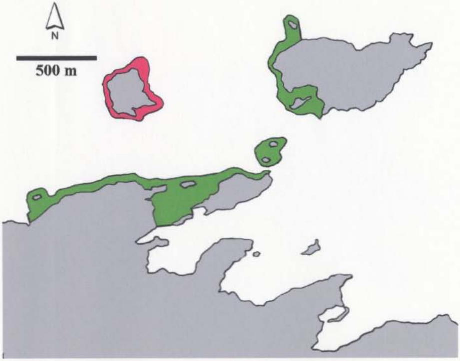

Figure 4.2. Lobster habitat available within the no-take lobster reserve (red) and nearby control area (open to harvesting; green) at Round Island site.

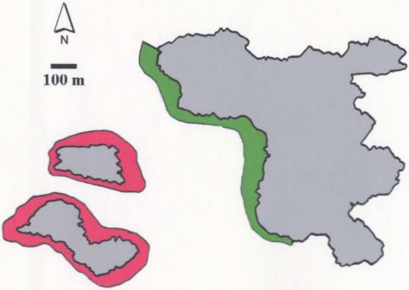

Figure 4.3. Lobster habitat available within the no-take lobster reserve (red) and nearby control area (open to harvesting; green) at Duck Islands site.

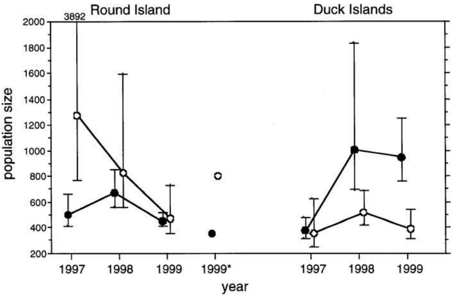

Figure 4.4. Lobster population size within no-take lobster reserves and nearby control areas (open to harvesting) at Round Island and Duck Islands, Bonavista Bay, Newfoundland, 1997-1999. Population size (means ± 95% confidence limits) during 1997-1999 estimated using Schumacher and Eschmeyer (1943) method. For Round Island, 1999, population size (means) also calculated using estimates of lobster density determined by diving transects and estimates of lobster habitat in each area (*). No-take lobster reserves (●); nearby control areas (○).

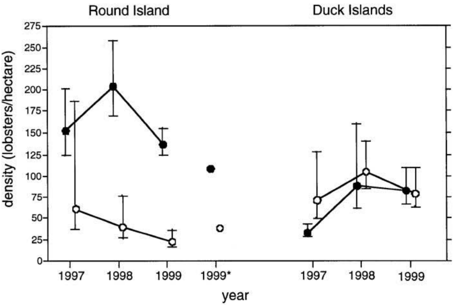

Figure 4.5. Lobster density within no-take lobster reserves and nearby control areas (open to harvesting) at Round Island and Duck Islands, Bonavista Bay, Newfoundland, 1997-1999. Density (means ± 95% confidence limits) calculated using estimates of population size based on Schumacher and Eschmeyer (1943) method and estimates of lobster habitat in each area during 1997-1999. For Round Island, 1999, density (means) also calculated based on diving transect observations (*). No-take lobster reserves (●); nearby control areas (○).

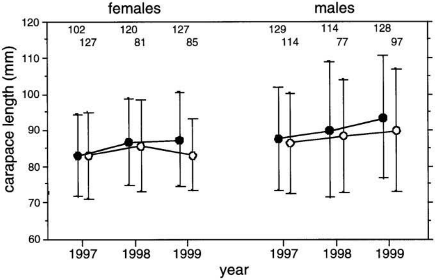

Figure 4.6. Size (means ± 95% confidence limits) of female and male lobsters within no-take lobster reserves and nearby control areas (open to harvesting) at Round Island site, Bonavista Bay, Newfoundland, 1997-1999. No-take lobster reserves (●); nearby control areas (○). Sample sizes given above estimates.

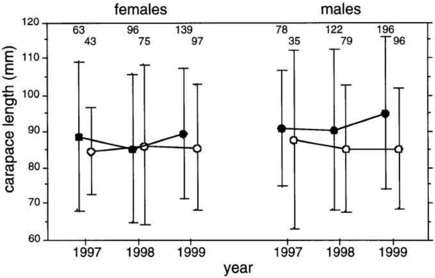

Figure 4.7. Size (means ± 95% confidence limits) of female and male lobsters within no-take lobster reserves and nearby control areas (open to harvesting) at Duck Islands site, Bonavista Bay, Newfoundland, 1997-1999. No-take lobster reserves (●); nearby control areas (○). Sample sizes given above estimates.

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CHAPTER 5:

LOBSTER MOVEMENT AND SURVIVAL IN AREAS WITH AND WITHOUT COMMERCIAL HARVESTING

ABSTRACT

To determine the potential effectiveness of no-take reserves as a fisheries conservation tool for American lobsters (*Homarus americanus*), I quantified lobster movement and survival inside and outside of two small no-take reserves (Round Island and Duck Islands) in Bonavista Bay, Newfoundland during 1997-1999. My study showed that most (58.7%) tagged lobsters were recaptured in the immediate vicinity of their original capture location. Among lobsters that moved, 77.1% had traveled less than 1000 m; the maximum distance traveled by an individual was 4942 m (after about 8 months at large). The observed lobster movement patterns resulted in exchange of lobsters between no-take reserves and nearby harvested areas, however, the amount of exchange was relatively low (8.7% of lobsters recaptured were in an area different from their location of tagging). Overall, I found little evidence to suggest that there was a relationship between lobster sex or size, or time at large, and lobster movement. Annual harvesting mortality amounted up to 87.2% for lobsters eligible for commercial harvest. However, many more lobsters tagged outside of the no-take reserves were harvested than lobsters that were tagged in the no-take reserves, likely a result of the low frequency of movement between these two areas. In addition, I found little evidence for a difference between female and male mortality due to the commercial fishery. Differences in the response of lobster population components to small no-take reserves can be explained by patterns of lobster movement and survival. Because the frequency of lobster emigration from the reserves was relatively low and harvesting pressure outside of the reserves was intense, my results indicated that no-take reserves can offer increased survival to lobsters and thereby may, over time, provide direct benefits to the local fishery.

INTRODUCTION

Marine no-take reserves, areas closed to harvesting, are increasingly being used to conserve exploited populations and fisheries but there have been few assessments of whether they achieve the goals for which they were created. In the presence of intense harvesting pressure on many marine species, no-take reserves are frequently portrayed as being able to prevent over-exploitation by making part of the population inaccessible to harvesters. It has been shown that the abundance, mean size of individuals, and spawning biomass of exploited populations are often greater inside no-take reserves than in comparable areas subjected to harvesting (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). These changes are a predicted outcome of protection from exploitation because many fish and invertebrates live longer, reach larger body size, and produce significantly more eggs in the absence of harvesting mortality (Bohnsack 1992, 1996; Roberts and Polunin 1993).

As a result of population changes caused by protection from harvesting, no-take reserves may conserve exploited populations and fisheries by providing direct and/or indirect benefits. Reserves can provide direct benefits by exporting larvae that may increase recruitment into regional fishery stocks (Carr and Reed 1993; Rowley 1994; Bohnsack 1998) or by exporting biomass in the form of emigrating juveniles and adults to adjacent harvesting grounds (Rowley 1994; Russ and Alcala 1996; Bohnsack 1998). Also, reserves can offer indirect benefits by protecting portions of exploited stocks from genetic changes, altered sex ratios, and other disruptions caused by selective harvesting mortality (Ricker 1981; Bohnsack 1992, 1998). All of these results are dependent upon the reserves offering a survival advantage to the individuals within. However, at small spatial scales, the success of local reserves will be greatly affected by factors such as adult movement patterns and larval supply and settlement, which are often poorly understood and rarely quantified. In this respect, empirical studies of how populations respond to local protection are urgently needed, yet there have been few studies addressing the issue (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). Moreover, most investigations make only static comparisons of population parameters such as abundance and individual size, and give no consideration to movement and survival of individuals between the reserves and other nearby control areas that are subjected to harvesting. Such simple comparisons of populations in reserves with populations in other areas cannot reveal the cause of any differences that exist between them.

Because of the intense harvesting pressure typically directed towards many marine fish and invertebrates, the amount of protection offered to individuals by a no-take reserve will largely depend on the size of the reserve in relation to the extent of individual movement (Kramer and Chapman 1999). For instance, if harvesting pressure is intense and daily foraging ranges typically extend beyond the reserve boundaries, these movement patterns will likely negate any effect that the reserve might otherwise have. Understanding the way that certain habitats can promote or limit movement may improve our ability to select appropriate areas for protection. The proximate success of any reserve will depend upon the individuals therein having a greater survival rate than individuals outside. Survival is an important demographic parameter used by fisheries managers to make decisions about harvest rates and to elucidate population trends. Although vital for these decisions, survival rates are sometimes difficult to estimate and rarely measured in reserve monitoring programs. Because many marine fish and invertebrates are slow-growing, measures of individual survival inside and outside of no-take reserves are especially useful for assessing short-term success of a reserve as a conservation tool.

American lobsters (*Homarus americanus*) are a popular and valuable seafood harvested in the coastal waters of the northwest Atlantic, mainly by community-based small boat harvesters. However, the American lobster fishery is suffering problems and Canada's Fisheries Resource Conservation Council (FRCC 1995) has raised concerns about the future of lobster stocks in Atlantic Canada. Lobsters are long-lived bottom-dwelling invertebrates characterized by slow growth, late maturation, long intervals between matings, and egg production that increases exponentially with increasing female size (Prudden 1962; Aiken and Waddy 1980a, 1980b; Ennis 1981). In many areas, current exploitation rates are high (harvesters take up to 85% of the animals present that are eligible for legal harvest each year) and primarily immature individuals are taken (FRCC 1995), resulting in extremely low levels of egg production and risk of recruitment failure during periods when conditions that influence survival to recruitment are unfavorable.

No-take reserves have been suggested as a conservation measure for American lobsters (FRCC 1995). It is believed that they can help increase egg production by allowing an unexploited portion of the population to develop and more lobsters to survive to maturity. However, because of intense harvesting pressure on surrounding lobster grounds, no-take lobster reserves could only be effective if adult movement out of the reserves occurs at a low enough rate to permit increased adult survival. In this respect, adult American lobsters are believed to be rather localized in their movements throughout parts of their range (e.g. Ennis 1984a, 1984b) and may be ideal candidates for protection within reserves.

During the early months of 1997, two small no-take lobster reserves were established for the conservation of American lobsters, one at Round Island and one at Duck Islands, near the Eastport Peninsula in Bonavista Bay, Newfoundland (Figure 5.1). These reserves encompassed a marine area of 2.1 km^2 that surrounded three small islands and extended well beyond the rocky substrate that was considered suitable for lobsters. To determine the effectiveness of these no-take lobster reserves as a conservation tool, direct measures of lobster movement and survival inside and outside of the reserves were required.

In this study, I employed capture-mark-recapture techniques to quantify movement and survival of adult lobsters between the Round Island and Duck Islands reserves and nearby harvested areas. Specifically, I addressed the following questions: 1) What was the frequency of lobster movement (i.e. movement between zones) and was it related to time at large, lobster sex, or lobster size (sub-legal sized: ≤ 82 mm carapace length versus commercial sized: ≥ 83 mm carapace length)? 2) Among individuals that moved, how far did they travel and was the distance traveled related to time at large, lobster sex, or lobster size (sub-legal sized: ≤ 82 mm carapace length versus commercial sized: ≥ 83 mm carapace length)? 3) What was the frequency of lobster emigration from, and immigration to, the no-take lobster reserves and was it related to time at large, lobster sex, or lobster size (sub-legal sized: ≤ 82 mm carapace length versus commercial sized: ≥ 83 mm carapace length)? 4) Was the proportion of lobsters harvested in the commercial fishery different for lobsters tagged in the no-take lobster reserves compared to nearby harvested areas? 5) Were lobsters of both sexes equally likely to be harvested in the commercial fishery?

METHODS

Assessing lobster habitat and movement of lobsters

A combination of a Global Positioning System (Trimble Explorer II with differential correction using a surveyed base station offering ± 1 m accuracy) and a Geographic Information System (SPANS, combined either with digitized data from 1:12500 aerial photographs that were georeferenced using a digital terrain model with ± 30 m accuracy for areas in the vicinity of Round Island, or digitized 1:50000 topographic maps prepared by Energy, Mines and Resources Canada with approximately ± 100 m accuracy for the areas in the vicinity of the Duck Islands) was used to map the lobster habitat present within the no-take lobster reserves and the surrounding areas that were subjected to harvesting (some that were used as control areas during Fall research trapping - see below). I defined lobster habitat using the local ecological knowledge of Eastport Peninsula lobster harvesters.

Generally, they considered shallow water areas with rocky substrate suitable habitat for lobsters. The shoreline was viewed to be the inner boundary of the habitat and the outer boundary was defined as the farthest distance from shore that they could set a conventional lobster trap during the harvesting season and expect to catch lobsters, usually the point where the nearshore bottom sloped rapidly into deeper water (generally to a maximum depth of about 20 m). Geographic co-ordinates of the outer boundary were determined by moving along the line in a boat directed by local harvesters while the Global Positioning System fixed on the vessel recorded the position every few seconds. These co-ordinates were imported into the Geographic Information System and overlaid onto topographic maps of the region so that the sea surface areas between the outer boundaries and shorelines (as indicated on the topographic maps) could be mapped.

Subsequently, the local lobster habitat was divided into smaller zones that were defined by obvious physical land marks (Figures 5.2 and 5.3). These zones would form the level of accuracy to which I would determine the locations of individual lobsters. The mid-point of each zone was determined by eye using estimates from four different observers and averaging among them. The distance that a lobster moved was considered to be the minimum distance from the mid-point of the zone of origin to the mid-point of the zone of termination, keeping the lobster in water. Distances were calculated using the Geographic Information System and maps described above by drawing the path from the mid-point of the zone of origin to the mid-point of the zone of termination.

Biological sampling during Fall

During 23 September to 3 October 1997, after the reserves had been established for several months (including one lobster harvesting season and one lobster molting period), lobsters within and outside the no-take lobster reserves (Figures 5.1, 5.2, and 5.3) were captured, marked, and released. Harvesters that trapped lobsters in the areas before closure assisted with the work, using their own boats and conventional lobster traps. During the research period, 25 traps were set inside each of the two reserves (referred to as Round Closed and Duck Closed hereafter) and 25 traps were set in each of two nearby control areas that were subjected to harvesting (referred to as Round Open and Duck Open hereafter). Traps were checked every day that weather conditions permitted. For each lobster captured, the location of capture was recorded, the carapace length (CL) was measured using vernier calipers, the sex and shell condition (i.e. new versus old; Ennis 1977) were determined, and reproductive condition of females (i.e. ovigerous or non-ovigerous) was noted. In addition, before release, each animal was marked with an individually numbered Streamer Tag that was easily visible to potential observers (Chapter 3). Because conventional traps typically did not retain lobsters < 65 mm CL, most individuals in my sample were above this size limit.

This protocol was repeated during Fall 1998 (26 September to 9 October - although no measurements or tagging occurred on 9 October) and Fall 1999 (6 to 15 September). In addition, during 1998 and 1999, some Fall recaptures at the Round Island site were made by underwater observation using SCUBA (19 to 24 August 1998 and 23 August to 1 September 1999) and catch-and-release research trapping using traps designed to target juvenile lobsters (28 September to 3 October 1998) in the general tagging area.

Biological sampling during Spring

During 1998 (4 May to 5 July) and 1999 (3 May to 9 July), recapture efforts were made primarily by the annual commercial harvest (covering a relatively large geographic area), although underwater observation using SCUBA, as well as catch-and-release research trapping using traps designed to target juvenile lobsters were also employed in the general tagging area at the Round Island site.

Prior to each commercial lobster harvesting season, a major public awareness and advertising campaign was conducted to maximize the participation of harvesters in reporting marked lobsters. Letters were sent to all lobster harvesters in the area describing the project, providing instructions for handling marked lobsters and returning tag information, and asking for cooperation. Local harvesters were extremely supportive of the project, diligently followed the instructions, and provided the information requested (Chapter 2). If eligible for legal harvest, marked lobsters captured in the commercial fishery were retained by harvesters for me to examine; otherwise, the necessary information was recorded by the harvesters at sea and the lobster was released close to the site of capture.

All lobsters caught during the Spring recapture periods were carefully examined for Streamer Tags. Upon capturing a marked individual, the Streamer Tag number, carapace length, sex, shell condition, and location of capture were noted. In cases where the marked lobster was not eligible for legal harvest and was observed only by the harvester, size was noted in relation to the minimum legal size (82.5 mm CL).

Analyzing lobster movement patterns

Although multiple recaptures were common, only the first recapture for each individual lobster was considered for the analyses concerning movement, thus avoiding pseudoreplication. Lobsters were recaptured either during the Fall research trapping period in which they were tagged (Fall 1: 1-13 days post-tagging), during the next Spring commercial fishery (Spring 1: 209-282 days post-tagging), during the next Fall research trapping period (Fall 2: 324-379 days post-tagging), during the Spring commercial fishery approximately one and a half years later (Spring 2: 580-644 days post-tagging), or during the Fall research trapping period approximately two years later (Fall 3: 704-721 days post-tagging). This presented some complications for the analyses because lobsters were recaptured during periods that were separated by long time intervals and commercial harvesting (and hence sampling) occurred intensely and over a large geographic area during the Spring while sampling effort during the Fall was less intense and restricted to a relatively small geographic area. I began by checking for differences in movement patterns among the recapture periods using contingency tests for frequency data (i.e. frequency of movement between zones and frequency of immigrants within no-take reserves and nearby control areas) and ANOVA combined with post hoc Fisher's PLSD tests for continuous data. Generally, recapture periods were combined when possible for analyses concerning sex and size (see Results section).

I analyzed tagging or recapture areas and some recapture periods separately (see Results section) to assess the effects of sex and size on movement. Frequency data were analyzed using a Generalized Linear Model with a binary response variable (moved versus did not move and immigrant versus non-immigrant) using a logit link function. Continuous data were analyzed using ANOVA. I included in the original models sex, size, and the interaction of sex by size as independent variables. If statistically non-significant, the interaction term was excluded from the final model. All statistical tests were two-tailed and the tolerance for type 1 error was set at 0.0500.

Determining the proportion of lobsters harvested in the fishery

To derive a measure of the exploitation level for female and male lobsters tagged inside and outside of the no-take reserves, I first determined the number of lobsters that were tagged each Fall, in each area and sex category (e.g. Fall 1997 Round Closed females), that were eligible for commercial harvest (i.e. the number that were $\geq$ 82.5 mm CL, the minimum legal size, and were not ovigerous or V-notched). The proportion harvested was considered to be the number of lobsters from each category that were reported as having been harvested during the Spring, divided by the number from this category that were tagged the previous Fall and eligible for commercial harvest.

One complicating factor was that the minimum legal size limit changed from 81 mm to 82.5 mm CL on 24 May 1998, three weeks after the harvesting season began and was maintained at the increased level for the remainder of the study period. To simplify the analysis, I considered only lobsters that were $\geq$ 82.5 mm CL to be commercial sized.

However, lobsters that were 81-82 mm CL may have been eligible for harvest during the first three weeks of the 1998 harvesting season. Any tagged lobsters that were < 82.5 mm CL and harvested during this period were excluded from the analyses.

To better estimate the local exploitation rate, the proportions of lobsters harvested were corrected to account for Streamer Tag loss. Approximately 17.8% of lobsters lose their Streamer Tags during the overwinter period (Chapter 3) so I decreased the numbers of tagged lobsters eligible for commercial harvest by this amount and then recalculated the proportions harvested. Although this assumes that there is no mortality of lobsters during the overwinter period, this may be a reasonably valid assumption because adult lobsters have a very low natural mortality rate (Thomas 1973; Ennis 1979) and they are particularly inactive during the Winter (Ennis 1984a, 1984b) so that they may be less susceptible to predation or intra-specific aggression.

RESULTS

What was the frequency of lobster movement between zones and was it related to time at large, lobster sex, or lobster size?

Among 890 lobsters that were marked and recaptured, 522 (58.7%) were recaptured in the same zone in which they were marked (i.e. they did not move). The remaining 368 (41.3%) marked individuals were recaptured in a different zone between 1 and 721 days after tagging. The proportion of lobsters that moved was much greater among individuals recaptured during Spring than Fall (Table 5.1), most likely a result of increased sampling outside of the immediate tagging area during Spring. There were no significant differences in the frequency of lobsters that moved between Spring 1 and Spring 2 ($G_1 = 1.91$, $P = 0.1667$) or between Fall 2 and Fall 3 ($G_1 = 0.88$, $P = 0.3496$). Consequently, Spring 1 and Spring 2 were combined (hereafter referred to as Springs 1&2), as were Fall 2 and Fall 3 (hereafter referred to as Falls 2&3), for the remaining analyses. Subsequently, I found significant differences in the frequency of lobsters moved between Fall 1 and Falls 2&3 ($G_1 = 25.61$, $P < 0.0001$), between Fall 1 and Springs 1&2 ($G_1 = 172.8$, $P < 0.0001$), and between Falls 2&3 and Springs 1&2 ($G_1 = 42.31$, $P < 0.0001$), so none of these time periods were pooled.

To assess whether the frequency of lobster movement was related to lobster sex or size, I examined each area (Round Closed, Round Open, Duck Closed, and Duck Open) and sampling period (i.e. Fall 1, Falls 2&3, and Springs 1&2) separately. Initially, all models were run including an interaction term for sex by size but in all cases, this interaction term was non-significant. Generally, the proportions of lobsters that moved were similar for individuals of both sexes and sizes (Table 5.2). Further analysis indicated that the only significant difference in the proportion of lobsters that moved in relation to sex occurred at Round Open - Falls 2&3 (females: 5/5 or 100.0% moved; males: 8/19 or 42.1% moved) and that only significant differences in relation to size occurred at Round Closed - Falls 2&3 (sub-legal sized lobsters: 11/16 or 68.8% moved; commercial sized lobsters: 20/61 or 32.8% moved) and Duck Closed - Fall 1 (sub-legal sized lobsters: 0/10 or 0.0% moved; commercial sized lobsters: 14/64 or 21.9% moved; Table 5.2).

Among individuals that moved, how far did they travel and was the distance traveled related to time at large, lobster sex, or lobster size?

Among 890 lobsters that were marked and recaptured, 368 (41.3%) were recaptured in a different zone between 1 and 721 days after tagging. During this study, no lobsters were observed to move between the Round Island and Duck Island sites. The farthest distance traveled by any lobster was 4942 m (recaptured at Spring 1, after about 8 months at large). The distance moved was much greater for individuals recaptured during Spring than for individuals recaptured during Fall (Figure 5.4), most likely a result of increased sampling outside of the immediate tagging area during Spring. There was a significant difference in the distance moved among recapture periods ($F_{4, 363} = 22.73$, $P < 0.0001$). Further analysis indicated that there were no significant differences between Spring 1 and Spring 2 (Fisher's PLSD; $P = 0.7887$) or between Fall 2 and Fall 3 (Fisher's PLSD; $P = 0.6424$). Consequently, Spring 1 and Spring 2 were combined, as were Fall 2 and Fall 3, for the remaining analyses. Subsequently, I continued to find a significant difference among the recapture periods ($F_{2, 365} = 45.52$, $P < 0.0001$) and further analysis indicated that there was no significant difference between Fall 1 and Falls 2&3 (Fisher's PLSD; $P = 0.4668$), but that there were significant differences between Fall 1 and Springs 1&2 (Fisher's PLSD; $P < 0.0001$), and between Falls 2&3 and Springs 1&2 (Fisher's PLSD; $P < 0.0001$).

To assess whether the distance moved by lobsters was related to lobster sex or size, I examined each area (Round Closed, Round Open, Duck Closed, and Duck Open) and sampling period (i.e. Fall 1, Falls 2&3, and Springs 1&2) separately. Although, I found no difference in the mean distance moved by lobsters between Fall 1 and Falls 2&3, considering that the distance traveled by lobsters is much more likely to be limited by time during Fall 1 than the other recapture periods, I continued to separate these for the analysis. Generally, the distance moved was similar for lobsters of both sexes and sizes (Figure 5.5). No interaction term for sex by size was significant. There were no significant differences in the distance moved in relation to sex and the only significant difference in relation to size occurred at Round Open - Springs 1&2 (Table 5.3; Figure 5.5).

What was the frequency of lobster emigration from, and immigration to, the no-take lobster reserves and was it related to time at large, lobster sex, or lobster size?

Among 890 lobsters that were marked and recaptured, 813 (91.3%) were recaptured in the same area (no-take reserve or nearby control area) in which they were marked (i.e. they did not emigrate). The remaining 77 (8.7%) marked individuals were recaptured in the other area between 2 and 711 days after tagging. Initial examination of the data showed that the proportion of immigrants was greater during Spring (particularly Spring 2) than

Fall (Table 5.4). The proportion of immigrants between Fall 2 and Fall 3 was not statistically different ($G_1 = 0.39$, $P = 0.5307$), however, there was a significant difference between Spring 1 and Spring 2 ($G_1 = 14.24$, $P = 0.0002$). Examination of the data indicated that this difference was due to an increased proportion of immigrants in the nearby control areas during Spring 2 (e.g. Round Open - Spring 1: 12.6% immigrants; Round Open - Spring 2: 40.0% immigrants), likely a result of intense harvesting and a low exchange rate between the reserves and nearby harvested areas, rather than an increase in the frequency of emigration from the reserves during this period. Despite this difference, I chose to pool Spring 1 and Spring 2, as well as Fall 2 and Fall 3, to increase sample size and to present the results in a way consistent with the previous two sections. Subsequently, I found significant differences in the proportion of immigrants between Fall 1 and Falls 2&3 ($G_1 = 14.71$, $P = 0.0001$), between Fall 1 and Springs 1&2 ($G_1 = 46.89$, $P < 0.0001$), and between Falls 2&3 and Springs 1&2 ($G_1 = 5.36$, $P = 0.0207$), so none of these time periods were pooled.

To assess whether the frequency of lobster emigration/immigration was related to lobster sex or size, I examined each area (Round Closed, Round Open, Duck Closed, and Duck Open) and sampling period (i.e. Fall 1, Falls 2&3, and Springs 1&2) separately. Generally, the frequency of immigrants was similar for lobsters of both sexes and sizes (Table 5.5). Initially, all models were run including an interaction term for sex by size but in all cases, this interaction term was non-significant. Further analysis indicated that there were no significant differences in the proportion of immigrants in relation to sex and that the only significant difference in relation to size occurred at Duck Closed - Falls 2&3 (sub-legal sized lobsters: 3/18 or 16.7% immigrants; commercial sized lobsters: 0/61 or 0.0% immigrants; Table 5.5).

Was the proportion of lobsters harvested in the commercial fishery different for lobsters tagged in the no-take lobster reserves compared to nearby harvested areas?

For all years, sites, and sexes, the proportion of lobsters harvested in the commercial fishery was significantly different for lobsters that were tagged outside of the no-take reserves compared to those that were tagged inside of the reserves (Tables 5.6 and 5.7). Moreover, a much greater proportion of lobsters that were tagged at the Round Island site were harvested than at the Duck Island site, this was true for lobsters tagged both inside and outside of the reserve.

Streamer Tag loss from lobsters has been shown to be substantial (17.8% of lobsters lose their Streamer Tags during the overwinter period; Chapter 3). Exploitation rates, corrected for tag loss, were extremely high in some areas (e.g. 87.2% of females tagged in Fall 1997 that retained their tag were harvested during Spring 1998; Table 5.8).

Were lobsters of both sexes equally likely to be harvested in the commercial fishery?

Generally, I found little evidence for a difference between females and males in their frequency of mortality related to the commercial harvest (Tables 5.6 and 5.7). However, there was a significant difference between female and male lobsters tagged at Round Open during Fall 1997 and harvested during Spring 1998.

DISCUSSION

This study showed that most (58.7%) tagged lobsters were recaptured in the same zone in which they were marked (i.e. they did not move). In a previous study of lobsters near the Eastport Peninsula, Ennis et al. (1989) reported comparable results indicating that 53% of lobsters recaptured after 335-395 days at large were in the immediate vicinity of where they were initially caught and tagged. Moreover, among the lobsters that moved, the distances traveled over time were within a similar range between the two studies. The lobster movement patterns observed in this study did result in exchange of lobsters between the no-take reserves and nearby harvested areas, however, the amount of exchange was relatively low. Moreover, it seemed that more lobster exchange occurred at the Round Island site than Duck Islands.

My results corroborate other findings which indicate that American lobster movement patterns in Newfoundland waters are restricted to small geographic areas (Templeman 1940; Ennis 1984a, 1984b; Ennis et al. 1989, 1994). Around the Eastport Peninsula, many islands, inlets and smaller bays provide extensive shoreline with extensive lobster habitat in adjacent subtidal areas. The local lobster grounds are a relatively narrow band of rocky substrate that extend from the mainly 5-10 m high cliff shoreline to depths generally less than 25 m at approximately 25-100 m offshore. Such features of the coastal physiography and bottom topography may impede or restrict the movement of lobsters. For instance, during my study period, no lobsters were observed to leave the lobster grounds surrounding the islands that compose the Duck Islands site. Moreover, at the Round Island site, no lobsters were observed to move from the study area, on the south side of Newman Sound, to the north side of Newman Sound. In this study, all minimum path distances extending from zones of origin to zones of termination resulted in lobster movements that were oriented parallel to the coast and/or maintained the lobster in relatively shallow water (i.e. generally less than 20 m deep). Therefore, it is possible that lobster movement was inhibited by excessively deep water or the presence of seasonal thermoclines (see Ennis 1984b). These observations are consistent with some other studies of lobsters in coastal areas (e.g. Ennis et al. 1994; Comeau et al. 1998).

Generally, I found that my indices of lobster movement showed higher values during Spring than Fall but I believe that this was more due to the sampling design than any actual difference among seasons. During Spring, commercial harvesting (and hence sampling) intensely occurred over a large geographic area while during the Fall, sampling effort was less intense and restricted to a relatively small geographic area. Consequently, the Spring sample was likely to have contained a greater proportion of individuals that left the general tagging area and thus moved away from their zone of origin, possibly having traveled farther distances than those that had remained within the general tagging area. It may be considered surprising that I found no evidence to suggest that there was a relationship between time at large and the amount of lobster movement. However, other studies of lobsters in coastal areas have also failed to find such a relationship (e.g. Ennis et al. 1989, 1994; Comeau et al. 1998).

I found a significant difference between Spring 1 and Spring 2 in the proportion of immigrants in my sample. This difference was due to a high proportion of immigrants in the nearby control areas during Spring 2. Because I found no difference in the proportion of lobsters that moved or among the lobsters that moved, no difference in the distance traveled, between Spring 1 and Spring 2, I do not believe that emigration from the reserves increased during this period. In this study, only lobsters tagged during Fall 1997 would have had an opportunity to be recaptured 580-644 days post-tagging (Spring 2). Because most lobsters tagged and recaptured remained in their zones of origin and local harvesting pressure was intense, lobsters tagged in the control areas during Fall 1997 were likely to remain there and subsequently die upon capture during the following commercial fishery (Spring 1). Consequently, there would have been a much smaller number of lobsters originally tagged in the areas open to harvesting available for recapture during Spring 2, thus magnifying the proportion of immigrants to the area. Similarly, because movement rates were relatively low and most lobsters eligible for commercial harvest were removed from the control areas during the fishery, the proportion of immigrants in these areas was generally lower during Falls 2&3 (after the harvest and before much emigration from the reserves had occurred) than Spring 1&2 (after several months had passed and more new immigrants had an opportunity to arrive).

In general, there did not seem to be a relationship between lobster movement patterns and lobster sex or size. However, there were some exceptions. At Round Open, during Falls 2&3, I found that more females than males moved to a new zone between tagging and recapture. In addition, I found three cases in which there were differences in movement patterns in relation to lobster size: 1) more sub-legal than commercial sized lobsters moved to a new zone between tagging at Round Closed and recapture during Falls 2&3; 2) commercial sized lobsters tagged at Round Open and recaptured during Springs 1&2 moved farther than sub-legal sized individuals; and 3) more sub-legal than commercial sized lobsters were immigrants to Duck Closed during Falls 2&3. These results were somewhat difficult to interpret. Unfortunately, this is a rather common theme among studies of lobster movement patterns in coastal areas: other studies have generally found little variation in movement parameters in relation to sex or size but most also reported a few anomalous results that did not fit this pattern (e.g. Fogarty et al. 1980; Ennis et al. 1989, 1994; Comeau et al. 1998). Moreover, comparison of such anomalous results among studies also has shown few general trends.

My results suggested that local exploitation rates of lobsters were quite high, up to 87.2% for some population components, and well within the range reported by Canada's Fisheries Resource Conservation Council (FRCC 1995). Although, Karnofsky and Price (1989) indicated that some lobsters never enter into traps. Consequently, because all lobsters tagged in my study were initially captured using traps, my estimates of exploitation rates may have actually applied to trap-prone lobsters only rather than the whole population. Therefore, my estimates may have been excessively high. However, I found that many more lobsters tagged in the nearby control areas were harvested than lobsters that were tagged in the no-take reserves, likely a result of the low frequency of movement between these two areas. In addition, comparison of the frequency of mortality between the Duck Islands site and Round Island suggested that exploitation rates were much lower in the general area of the Duck Islands, probably a result of both high exposure (Figure 5.1) and poor weather conditions during Spring which often deterred commercial harvesting in this area.

Relative to males, female lobsters may be offered some additional protection from the fishery by the presence of eggs and/or a V-notch. Release of ovigerous females is one of the oldest conservation measures for lobsters and serves to preserve existing clutches of eggs to hatching (Miller 1995). However, because female lobsters typically bear eggs only every second year (Waddy et al. 1995), unless coupled with V-notching, this measure only protects mature females while ovigerous. V-notching is the process of cutting a shallow notch mark into the tail of an ovigerous female. When marked animals are recaptured later, after having released their eggs, they are returned to the water. Marks are retained for up to two molts and this measure has the effect of protecting known spawners for several additional years. Under current regulations in Newfoundland, V-notching by harvesters is voluntary but landing of V-notched animals is prohibited. Because of increased protection offered to females, it was suspected that more males than females would have been harvested. However, I found little evidence for a difference between females and males in their frequency of mortality related to the commercial fishery. This may not be unexpected because there is some evidence to suggest that female lobsters may be more susceptible to capture during Spring than males (Ennis 1983). Even though females receive additional protection, their increased catchability may result in similar exploitation rates for females and males. One exception was observed for lobsters tagged at Round Open during Fall 1997 and harvested during Spring 1998, where more females than males were harvested.

Although the no-take lobster reserves had only been closed for three annual lobster harvesting seasons, differences between the lobster populations in the no-take reserves and nearby control areas have been reported, although, the response of lobsters was variable both between sites and sexes (Chapter 4). At the Round Island site, lobsters seemed to have responded well to local protection: within the reserve, population density was high and apparently stable over time, and female and male size increased, as did the proportion of ovigerous female lobsters. However, at the Duck Islands reserve, the response was quite different: population density increased dramatically between 1997 and 1998, and male size increased over time, but there was no change in female size or the proportion of ovigerous females. In addition, spatial comparisons between the reserve and nearby control area at the Round Island site indicated that although population size was greater outside of the reserve (in a larger adjacent control area), density was greater within the reserve. Furthermore, females and males were larger within the reserve than the nearby control area and more of these females were ovigerous. Spatial comparisons between the reserve and nearby control area at the Duck Islands site indicated that although there were more lobsters inside the reserve, population densities in the two areas were quite similar. Also, although both females and males were larger within the reserve, there was no difference in the proportion of females that were ovigerous between the two areas. Taken together, these data were consistent with the notion that no-take reserves improved the lobster populations within them, particularly at the Round Island site. However, the lack of an increase in mean lobster size within the no-take reserves, independent of such an increase in the nearby control areas, among males at Round Island and females at Duck Islands, coupled with the lack of a difference in the proportion of ovigerous females at the Duck Island reserve relative to outside was difficult to interpret.

Observations of differences among lobster population components in their response to small no-take reserves (Chapter 4) was much easier to explain in light of this investigation into local lobster movement and survival. Generally, because the frequency of lobster emigration from the reserves was relatively low and harvesting pressure outside of the reserves was intense, protection from exploitation likely resulted in higher mean lobster size observed within the reserves. Additionally, the exploitation rate of female lobsters at Round Open seemed especially high and this may have been the reason for the particularly strong differences observed between female lobsters inside and outside of the no-take reserves at the Round Island site. Although movement between the reserves and nearby harvested areas was less frequent at the Duck Islands site, differences in populations parameters between these two areas were less pronounced relative to the Round Island site. This was likely due to relatively low levels of exploitation that occurred in the Duck Islands area. If exploitation rates measured in this area during 1998 and 1999 reflected a general pattern for this site, then it is probable that the lobster population at the Duck Islands was in better condition at the onset of reserve establishment. If the lobster population was in better condition at the onset, then considering that older/larger lobsters molt less frequently (Waddy et al. 1995), increases in mean lobster size will be slower to appear, and considering the alternate year reproductive cycle (Waddy et al. 1995), the proportions of females that were ovigerous may have been approaching its upper limit.

Although these no-take reserves are still rather new, my results indicate that they can offer increased survival to the lobsters within them and therefore have the potential to provide direct benefits to the local lobster population and fishery. This may occur in two ways: through increased egg production by lobsters within the reserve or by emigration of juvenile or adult lobsters from reserves to harvested areas (Roberts and Polunin 1991; Rowley 1992, 1994). Female fecundity of the American lobster increases exponentially with increasing size (Ennis 1981). Because of the greater mean size of female lobsters within the no-take reserves (Chapter 4), their egg production would be high relative to females from adjacent harvested areas. However, considering that only 1.5% of lobsters within the Eastport Peninsula Lobster Management Area receive protection within no-take reserves (Chapter 4), their contribution to total local egg production may be modest, although even a modest contribution could be vital in view of the extremely low levels of egg production that currently predominate (FRCC 1995). To further increase local egg production, a greater proportion of the area should be closed to harvesting. Considering that lobsters move over a relatively small geographic range, this measure would likely reduce the frequency of emigration from the reserves and thereby provide further protection to individuals from exploitation.

Emigration of juvenile or adult lobsters from the no-take reserves to nearby harvested areas may benefit the local fishery. For this to occur, emigration from the no-take reserves must be higher than immigration to the no-take reserves and it must also compensate for the removal from exploitation of the now protected population (Roberts and Polunin 1991; Rowley 1992, 1994). In this study, it appeared that more tagged lobsters emigrated from the no-take reserves than immigrated to these areas (Round Closed: 16/256 or 6.3% were immigrants; Round Open: 51/347 or 14.7% were immigrants; Duck Closed: 4/154 or 2.6% were immigrants; Duck Open: 6/133 or 4.5% were immigrants). Although I was unable to quantify whether emigration of adult lobsters from the no-take reserves to nearby harvested areas improved the local fishery enough to compensate for the removal from exploitation of the now protected population, tagged lobsters that had emigrated from the reserves and were harvested in the fishery were generally much larger than most other lobsters harvested. If the formation of no-take reserves is sanctioned on the basis of benefits to local fisheries, it will be critical to quantify such effects.

Early study of these no-take American lobster reserves suggests that they may be a useful conservation tool for this species. Although, the response of lobsters in different areas to reserve protection will likely depend on the size of the reserve in relation to the extent of local lobster movement and the local exploitation rates in the nearby harvested areas. In Newfoundland waters, lobsters are heavily exploited and individuals appear to move very little (Templeman 1940; Ennis 1984a, 1984b; Ennis et al. 1989, 1994).

Consequently, even small no-take reserves may be effective. However, some American lobster populations undertake extensive inshore-offshore migrations and commonly disperse long distances (e.g. Cooper and Uzmann 1971; Dow 1974; Fogarty et al. 1980; Campbell 1986; Pezzack and Duggan 1986) so that no-take reserves would have to be very large in order to show similar results. Further study is needed to investigate the factors influencing adult lobster movement patterns.

Table 5.1. Proportion of lobsters that moved between geographic zones for 890 lobsters marked and recaptured. Recaptures occurred during five distinct periods: Fall 1 (1-13 days post-tagging), Spring 1 (209-282 days post-tagging), Fall 2 (324-379 days post-tagging), Spring 2 (580-644 days post-tagging), or Fall 3 (704-721 days post-tagging).

	n	% moved between zones
Fall 1	326	17.2
Spring 1	311	64.0
Fall 2	166	35.5
Spring 2	53	73.6
Fall 3	34	44.1

Table 5.2. Proportion of lobsters that moved between geographic zones in relation to sex and size for 890 lobsters marked and recaptured (separating different geographic areas of tagging and recapture periods). Recapture periods: Fall 1 (1-13 days post-tagging), Fall 2&3 (324-379 or 704-721 days post-tagging), Spring 1&2 (209-282 or 580-644 days post-tagging). Data analyzed using a Generalized Linear Model with a binary response variable using a logit link function. Models first run with an interaction term for sex by size but in all cases, it was non-significant and removed from final models.

	female sub-legal		female commercial		male sub-legal		male commercial		sex		size	
	n	% moved	*n*	% moved	*n*	% moved	*n*	% moved	χ^2_1	*P*	χ^2_1	*P*
Round Closed												
Fall 1	13	23.1	40	22.5	8	0.0	55	25.5	0.04	0.8352	1.10	0.2948
Falls 2&3	6	66.7	20	35.0	10	70.0	41	31.7	0.03	0.8701	6.70	0.0096
Springs 1&2	16	62.5	44	65.9	12	75.0	26	80.8	2.30	0.1292	0.19	0.6653
Round Open												
Fall 1	13	0.0	13	23.1	7	14.3	32	12.5	0.07	0.7855	1.70	0.1922
Falls 2&3	1	100.0	4	100.0	8	25.0	11	54.5	6.40	0.0114	1.71	0.1912
Springs 1&2	44	65.9	85	64.7	25	52.0	69	66.7	0.17	0.6763	0.50	0.4789
Duck Closed												
Fall 1	5	0.0	14	14.3	5	0.0	50	24.0	0.65	0.4202	3.90	0.0482
Falls 2&3	6	33.3	21	23.8	9	22.2	40	35.0	0.36	0.5480	0.10	0.7531
Springs 1&2	0	---	3	100.0	0	---	3	100.0	---	---	---	---
Duck Open												
Fall 1	3	0.0	19	10.5	19	5.3	30	16.7	0.49	0.4825	2.00	0.1569
Falls 2&3	6	33.3	5	40.0	8	37.5	4	0.0	0.48	0.4896	0.61	0.4347
Springs 1&2	5	80.0	11	45.5	4	25.0	17	58.8	0.05	0.8246	0.01	0.9428

Table 5.3. ANOVA of distance moved in relation to sex and size of 368 lobsters marked and recaptured in a different geographic zone from the one in which tagged (separating different geographic areas of tagging and recapture periods). Recapture periods: Fall 1 (1-13 days post-tagging), Fall 2&3 (324-379 or 704-721 days post-tagging), Spring 1&2 (209-282 or 580-644 days post-tagging). Models first run with an interaction term for sex by size but in all cases, it was non-significant and removed from final models.

	sex			size		
	F	df	*P*	*F*	df	*P*
Round Closed						
Fall 1	0.59	1, 23	0.4496	1.09	1, 23	0.3072
Falls 2&3	1.42	1, 28	0.2442	3.04	1, 28	0.0923
Springs 1&2	0.90	1, 66	0.3456	1.60	1, 66	0.2105
Round Open						
Fall 1	0.58	1, 5	0.4793	0.59	1, 5	0.4757
Falls 2&3	0.83	1, 10	0.3833	0.18	1, 10	0.6775
Springs 1&2	0.17	1, 140	0.6820	7.30	1, 140	0.0078
Duck Closed						
Fall 1	0.21	1, 12	0.6559	---	---	---
Falls 2&3	0.74	1, 20	0.3997	0.00	1, 20	0.9521
Springs 1&2	0.58	1, 4	0.4876	---	---	---
Duck Open						
Fall 1	0.17	1, 5	0.6943	0.84	1, 5	0.4018
Falls 2&3	0.20	1, 4	0.6799	0.00	1, 4	0.9882
Springs 1&2	0.98	1, 17	0.3368	2.53	1, 17	0.1300

Table 5.4. Proportion of immigrants occurring within geographic areas (i.e. no-take reserves or nearby harvested areas) for 890 lobsters marked and recaptured. Recaptures occurred during five distinct periods: Fall 1 (1-13 days post-tagging), Spring 1 (209-282 days post-tagging), Fall 2 (324-379 days post-tagging), Spring 2 (580-644 days post-tagging), or Fall 3 (704-721 days post-tagging).

	n	% immigrants to area
Fall 1	326	1.5
Spring 1	311	11.9
Fall 2	166	9.0
Spring 2	53	34.0
Fall 3	34	5.9

Table 5.5. Proportion of immigrants occurring within geographic areas (i.e. no-take reserves or nearby harvested areas) in relation to sex and size for 890 lobsters marked and recaptured (separating different geographic areas of recapture and recapture periods). Recapture periods: Fall 1 (1-13 days post-tagging), Fall 2&3 (324-379 or 704-721 days post-tagging), Spring 1&2 (209-282 or 580-644 days post-tagging). Data analyzed using a Generalized Linear Model with a binary response variable using a logit link function. Models first run with an interaction term for sex by size but in all cases, it was non-significant and removed from final models.

	female sub-legal		female commercial		male sub-legal		male commercial		sex		size	
	n	% immigrant	*n*	% immigrant	*n*	% immigrant	*n*	% immigrant	χ^2_1	*P*	χ^2_1	*P*
Round Closed												
Fall 1	13	0.0	41	2.4	8	0.0	56	3.6	0.10	0.7474	1.10	0.2943
Falls 2&3	6	0.0	22	13.6	8	12.5	43	9.3	0.02	0.8746	0.19	0.6641
Springs 1&2	13	7.7	29	6.9	8	12.5	9	11.1	0.29	0.5931	0.02	0.8985
Round Open												
Fall 1	13	0.0	12	0.0	7	0.0	31	3.2	0.66	0.4153	0.41	0.5203
Falls 2&3	1	0.0	2	50.0	10	30.0	9	22.2	0.06	0.8014	0.00	0.9729
Springs 1&2	47	8.5	100	17.0	29	17.2	86	20.9	1.27	0.2592	1.76	0.1843
Duck Closed												
Fall 1	5	0.0	14	0.0	5	0.0	51	2.0	0.49	0.4842	0.19	0.6639
Falls 2&3	7	14.3	21	0.0	11	18.2	40	0.0	0.05	0.8275	9.33	0.0023
Springs 1&2	0	---	0	---	0	---	0	---	---	---	---	---
Duck Open												
Fall 1	3	0.0	19	0.0	19	0.0	29	0.0	---	---	---	---
Falls 2&3	5	0.0	5	0.0	6	0.0	4	0.0	---	---	---	---
Springs 1&2	5	0.0	14	21.4	4	0.0	20	15.0	---	---	---	---

Table 5.6. Number of female and male lobsters tagged inside no-take reserves and nearby control areas (open to harvesting) during Fall eligible for commercial harvest (i.e. ≥ 82.5 mm CL, not ovigerous or V-notched) and proportion reported harvested during following Spring commercial lobstering season.

	no-take reserve				control area			
	females		males		females		males	
	n	% harvested	*n*	% harvested	*n*	% harvested	*n*	% harvested
Round Island								
Fall 1997 - Spring 1998	27	18.5	101	12.9	57	71.9	76	52.6
Fall 1998 - Spring 1999	45	6.7	67	6.0	49	65.3	54	48.1
Duck Islands								
Fall 1997 - Spring 1998	28	3.6	66	1.5	16	31.3	26	11.5
Fall 1998 - Spring 1999	35	0.0	78	2.6	26	30.8	44	40.9

Table 5.7. *G*-test results for comparisons of proportions of lobsters harvested during Spring commercial harvesting between lobsters tagged inside and outside no-take lobster reserves (separating sexes) and between tagged females and males (separating locations of tagging: inside and outside no-take lobster reserves) at Round Island and Duck Islands sites during Fall of previous year.

	no-take reserve versus control area				females versus males			
	females		males		no-take reserve		control area	
	G_1	P	G_1	P	G_1	P	G_1	P
Round Island								
Fall 1997 - Spring 1998	22.14	< 0.0001	33.37	< 0.0001	0.53	0.4660	5.18	0.0228
Fall 1998 - Spring 1999	38.81	< 0.0001	30.44	< 0.0001	0.02	0.8817	3.10	0.0785
Duck Islands								
Fall 1997 - Spring 1998	6.55	0.0105	3.95	0.0470	0.37	0.5455	2.43	0.1191
Fall 1998 - Spring 1999	---	0.0005*	30.72	< 0.0001	---	1.0000*	0.73	0.3933

* P calculated using Fisher's Exact test because one cell contained a value of 0.

Table 5.8. Number of female and male lobsters tagged inside no-take reserves and nearby control areas (open to harvesting) during Fall eligible for commercial harvest (i.e. ≥ 82.5 mm CL, not ovigerous or V-notched), and retained tags until Spring, as well as related proportion harvested during following Spring commercial lobstering season.

	no-take reserve				control area			
	females		males		females		males	
	n	% harvested	*n*	% harvested	*n*	% harvested	*n*	% harvested
Round Island								
Fall 1997 - Spring 1998	22	22.7	83	15.7	47	87.2	62	64.5
Fall 1998 - Spring 1999	37	8.1	55	7.3	40	80.0	44	59.1
Duck Islands								
Fall 1997 - Spring 1998	23	4.3	54	1.9	13	38.5	21	14.3
Fall 1998 - Spring 1999	29	0.0	64	3.1	21	38.1	36	50.0

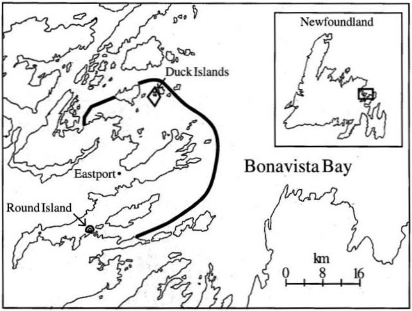

Figure 5.1. Eastport Peninsula Lobster Management Area with no-take lobster reserves at Round Island and Duck Islands indicated.

Figure 5.2. Lobster habitat available at Round Island site. Each zone of lobster habitat and its mid-point (blue cross) shown, as well as regions which compose no-take lobster reserve area (red), nearby control area (open to harvesting; green), and other nearby areas open to harvesting but not covered during Fall research trapping (yellow).

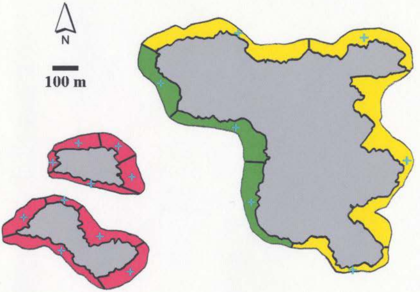

Figure 5.3. Lobster habitat available at Duck Islands site. Each zone of lobster habitat and its mid-point (blue cross) shown, as well as regions which compose no-take lobster reserve area (red), nearby control area (open to harvesting; green), and other nearby areas open to harvesting but not covered during Fall research trapping (yellow).

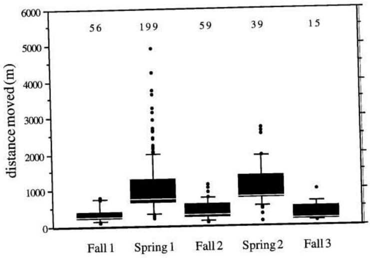

Figure 5.4. Box plots indicating distance moved by 368 lobsters marked and recaptured in a different geographic zone from the one in which tagged. Recaptures occurred during five distinct periods: Fall 1 (1-13 days post-tagging), Spring 1 (209-282 days post-tagging), Fall 2 (324-379 days post-tagging), Spring 2 (580-644 days post-tagging), or Fall 3 (704-721 days post-tagging). Box plots indicate outliers (points) and 10th, 25th, 50th, 75th, and 90th percentiles. Sample sizes given above estimates.

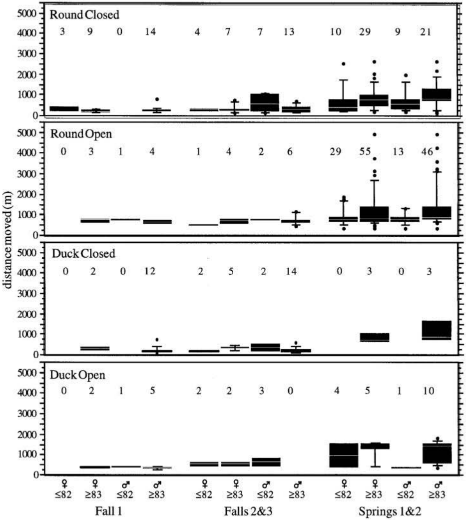

Figure 5.5. Box plots indicating distance moved in relation to sex and size of 368 lobsters marked and recaptured in a different geographic zone from the one in which tagged (separating different geographic areas of tagging and recapture periods). Recapture periods: Fall 1 (1-13 days post-tagging), Fall 2&3 (324-379 or 704-721 days post-tagging), Spring 1&2 (209-282 or 580-644 days post-tagging). Box plots indicate outliers (points) and 10th, 25th, 50th, 75th, and 90th percentiles. Sample sizes given above estimates.

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CHAPTER 6:

SUMMARY

THE IMPORTANCE OF LOBSTER TO THE EASTPORT PENINSULA

The American lobster fishery on the Eastport Peninsula involves approximately 50 harvesters from seven small communities (Burnside, Eastport, Happy Adventure, Salvage, Sandringham, Sandy Cove, and St. Chad's). In 1994, these harvesters recognized that a substantial decline in their lobster stocks had occurred over the preceding decade, and that it had accelerated by increased harvesting effort directed towards the local lobster resource as a result of groundfish closures. Historically, lobster harvesting was a secondary fishery in this area; harvesters took lobsters for only the first few weeks of the season before pursuing groundfish. With the collapse of local cod stocks due to overfishing (Hutchings and Myers 1995; Sinclair and Murawski 1997), a moratorium on groundfish harvesting off the northeast coast of Newfoundland was announced in 1992. Since the moratorium, lobstering has become an important source of income for many individuals (Hamilton and Haedrich 1999), particularly inshore, small-boat harvesters. Previously inactive licences have been reactivated and active licences are being more fully utilized as lobsters are harvested during the entire season because there are few alternative fisheries. During 1989-1998, 209 metric tons of lobster was landed on the Eastport Peninsula with a total landed value of $1,664,296 or 14.3% of the combined landed value of all species harvested in the area during this period (Statistics Branch of Canada's Department of Fisheries and Oceans, unpublished data). This represents a substantial proportion of the total revenue in the local fishery, the most important economic activity in the region.

THE EASTPORT PENINSULA LOBSTER FISHERY: A NEED FOR CONCERN?

Canada's Fisheries Resource Conservation Council (FRCC 1995) has raised concerns about the future of American lobster stocks in Atlantic Canada. Female maturation occurs after several years of growth and egg production increases exponentially with increasing size (Prudden 1962; Aiken and Waddy 1980a, 1980b; Ennis 1981). In many areas, current exploitation rates are high (harvesters take up to 85% of the animals present that are eligible for legal harvest each year) and primarily immature animals are harvested (FRCC 1995). This is a problem because intense harvesting results in extremely low levels of egg production and risks recruitment failure during periods when conditions that influence survival to recruitment are unfavorable.

The lobster fishery on the Eastport Peninsula has shown symptoms of the problems identified by the FRCC (1995). My results suggested that local exploitation rates of lobsters were quite high: annual harvesting mortality amounted up to 87.2% for lobsters eligible for commercial harvest. Moreover, because of these high exploitation rates, the fishery was based almost exclusively upon new lobsters recruiting to the size ranges eligible for commercial harvest each year (S. Rowe, personal observation; Ennis et al. 1989). Assessments of American lobster fisheries with such characteristics have clearly demonstrated that with the existing minimum legal size limits, yield per recruit is substantially less than maximum (Anthony and Caddy 1980). In addition, existing size limits are generally below the size at which many females lay eggs for the first time and, with the excessively high exploitation rates that prevail in most areas, egg production may be limiting recruitment.

WILL NO-TAKE RESERVES HELP CONSERVE LOBSTER?

My data suggests that the no-take reserves support approximately 1.5% of the lobster population within Eastport Peninsula Lobster Management Area within their boundaries, 0.6% at Round Island and 0.9% at the Duck Islands. Although the no-take lobster reserves had only been closed for three annual lobster harvesting seasons, there were obvious differences between the lobster populations in the no-take reserves and nearby control areas. However, my results suggested that over this three year period, the response of American lobsters to small no-take reserves was variable both between sites and sexes. At the Round Island site, lobsters seemed to have responded well to local protection: within the reserve, population density was high and apparently stable over time, and female and male size increased, as did the proportion of ovigerous female lobsters. However, at the Duck Islands reserve, the response was quite different: population density increased dramatically between 1997 and 1998, and male size increased over time, but there was no change in female size or the proportion of ovigerous females. Spatial comparisons between the reserve and nearby control area at the Round Island site indicated that although population size was greater outside of the reserve (in a larger adjacent control area), density was greater within the reserve. Furthermore, females and males were larger within the reserve than the nearby control area and more of these females were ovigerous. Spatial comparisons between the reserve and nearby control area at the Duck Islands site indicated that although there were more lobsters inside the reserve, population densities in the two areas were quite similar. Also, although both females and males were larger within the reserve, I found no difference in the proportion of females that were ovigerous between the two areas. Taken together, these data were consistent with the notion that no-take reserves improved the lobster populations within them, particularly at the Round Island site. However, the lack of an increase in mean lobster size within the no-take reserves, independent of such an increase in the nearby control areas, among males at Round Island and females at Duck Islands, coupled with the lack of a difference in the proportion of ovigerous females at the Duck Island reserve relative to outside was difficult to interpret.

This study showed that most (58.7%) tagged lobsters were recaptured in the same zone in which they were marked. In a previous study of lobsters near the Eastport Peninsula, Ennis et al. (1989) reported comparable results indicating that 53% of lobsters recaptured after 335-395 days at large were in the immediate vicinity of where they were initially caught and tagged. Among lobsters that moved, 77.1% had traveled less than 1000 m and the maximum distance traveled by any individual was 4942 m (after about 8 months at large). The observed lobster movement patterns resulted in exchange of adult lobsters between no-take reserves and nearby harvested areas, however, the amount of exchange was relatively low (8.7% of lobsters recaptured were in an area different from their location of tagging). Moreover, it seemed that more lobster exchange occurred at the Round Island site than at Duck Islands.

My results corroborate other findings which indicate that American lobster movement patterns in Newfoundland waters are restricted to small geographic areas (Templeman 1940; Ennis 1984a, 1984b; Ennis et al. 1989, 1994). Around the Eastport Peninsula, many islands, inlets and smaller bays provide extensive shoreline with extensive lobster habitat in adjacent subtidal areas. The local lobster grounds are a relatively narrow band of rocky substrate that extend from the mainly 5-10 m high cliff shoreline to depths generally less than 25 m at approximately 25-100 m offshore. Such features of the coastal physiography and bottom topography may impede or restrict the movement of lobsters. For instance, during my study period, no lobsters were observed to leave the lobster grounds surrounding the islands that compose the Duck Islands site. Moreover, at the Round Island site, no lobsters were observed to move from the study area, on the south side of Newman Sound, to the north side of Newman Sound. In this study, all minimum path distances extending from zones of origin to zones of termination resulted in lobster movements that were oriented parallel to the coast and/or maintained the lobster in relatively shallow water (i.e. generally less than 20 m deep). Therefore, it is possible that lobster movement was inhibited by excessively deep water or the presence of thermoclines (see Ennis 1984b). These observations are consistent with some other studies of lobsters in coastal areas (e.g. Ennis et al. 1994; Comeau et al. 1998).

My results suggested that local exploitation rates of lobsters were very high. However, many more lobsters tagged in the nearby control areas were harvested than lobsters that were tagged in the no-take reserves, likely a result of the low frequency of movement between these two areas. In addition, comparison of the frequency of mortality between the Duck Islands site and Round Island suggested that exploitation rates were much lower in the general area of the Duck Islands, probably a result of both high exposure and poor weather conditions during Spring which often deterred commercial harvesting there.

Because the frequency of lobster emigration from the reserves was relatively low and harvesting pressure outside of the reserves was intense, protection from exploitation likely resulted in the higher mean lobster size that was observed within the reserves. Additionally, the exploitation rate of female lobsters at Round Open seemed especially high and this may have been the reason for the particularly strong differences observed between female lobsters inside and outside of the no-take reserves at the Round Island site. Although movement between the reserves and nearby harvested areas was less frequent at the Duck Islands site, differences in populations parameters between these two areas were less pronounced relative to Round Island. This was likely due to the relatively low levels of exploitation that occurred in the Duck Islands area. If exploitation rates measured in this area during 1998 and 1999 reflected a general pattern for this site, then it is probable that the lobster population at the Duck Islands was in better condition at the onset of reserve establishment. If the lobster population was in better condition at the onset, then considering that older/larger lobsters molt less frequently (Waddy et al. 1995), increase in mean lobster size will be manifested more slowly, and considering the alternate year reproductive cycle (Waddy et al. 1995), the proportion of ovigerous females may approach an upper limit.

LIMITATIONS OF MY STUDY

Together, the time series data and the spatial comparisons provide strong, albeit circumstantial, evidence that protection from harvesting has led to improvements in the American lobster population within the reserves. This was not unexpected, given the high harvesting mortality experienced by this species throughout its range (FRCC 1995). However, the lack of replicate reserves in my study makes it difficult to assign specific effects to protection. The "experiment" of protecting American lobster populations needs to be repeated and monitored at similar sites before firm conclusions can be drawn.

In addition, my conclusions could have been stronger if this study had begun several years before the reserves were established, in order to quantify any pre-existing differences between the selected reserve areas and nearby control areas. This would have provided an experimental design with complete before and after comparisons of populations in and outside the reserves. Without data on the status of lobster populations at sites inside and outside of the reserves prior to reserve implementation, I cannot conclude with certainty that differences between the reserves and nearby control areas were due to protection from harvesting within the reserves. However, because the proportion of ovigerous female lobsters and lobster size was observed to increase over time within reserves and remain stable outside the reserves, I believe that these differences were attributable to the protection of lobsters within the reserves from the influences of harvesting. It will be interesting to monitor the development of American lobster populations within the no-take reserves and the nearby control areas over longer time periods. In the case of spiny lobster, density and mean size of some population components were observed to still be increasing after 16 years of reserve protection (MacDiarmid and Breen 1992). To better our ability to assess marine no-take reserves, quantitative population monitoring before and after reserve establishment should be a feature of any future reserve planning and implementation (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994).

CAPACITY OF RESERVES TO OFFER DIRECT BENEFITS TO THE FISHERY

Although these no-take reserves are still rather new, my results suggest that they can offer increased survival to the lobsters within them and thereby have the potential to provide direct benefits to the local lobster population and fishery. This could occur in two ways: through increased egg production by lobsters within the reserve or by emigration of juvenile or adult lobsters from reserves to harvested areas (Roberts and Polunin 1991; Rowley 1992, 1994). Female fecundity of the American lobster increases exponentially with increasing size (Ennis 1981). Because of the greater mean size of female lobsters within the no-take reserves (Chapter 4), their egg production would be high relative to females from adjacent harvested areas. Moreover, large lobsters produce eggs with a higher energy content per gram of egg, which should increase the ability of the larvae to survive adverse conditions (Attard and Hudon 1987). Consequently, large individuals within the reserves may make a greater contribution to egg production and recruitment within a population than is immediately apparent in comparisons of fecundity alone. Considering the relatively small proportion of lobsters within the Eastport Peninsula Lobster Management Area that receive protection within no-take reserves (Chapter 4), their contribution to total local egg production may be modest. However, even a small contribution could be vital in view of the extremely low levels of egg production that currently predominate (FRCC 1995).

To increase local egg production substantially, a greater proportion of the area should be protected from harvesting. Considering the relatively small geographic range over which lobsters move, this measure would likely reduce the frequency of emigration from the reserves and thereby provide further protection to individuals from exploitation. This would not necessarily lead to greater settlement of larvae and improved recruitment to the fishery. The relationship between American lobster parent stock size (i.e. egg production) and later recruitment to the fishery is not well understood (Caddy 1986; Fogarty and Idoine 1986; Ennis and Fogarty 1997). Both density-dependent and stochastic processes may lead to levels of larval settlement, and juvenile growth and survival, that bear no relationship to levels of egg production. However, considering that recent analyses for a number of populations in Canadian waters indicate egg per recruit levels under present conditions at only 1-2% that of an unexploited population (FRCC 1995), it seems only prudent to increase egg production.

Another related issue is whether or not larvae will be exported from the reserves to replenish nearby harvesting grounds. Mechanisms that determine where American lobster larvae that originate in a given area eventually settle are uncertain. Most considerations of recruitment processes for lobster are based on the assumption that larvae are more or less passive current drifters and are transported downstream by surface currents, the distance depending on current velocity and the time required for development to the settling stage as determined primarily by temperature. Therefore, larvae that settle and recruit to the population in a given area would originate somewhere upstream. In Newfoundland waters, the time required for larval development to the settling stage is greater than one month (Ennis 1995) which could result in displacement to very distant areas. However, American lobster larvae have well-developed behavioural responses to a variety of environmental stimuli such as gravity, light, temperature, and hydrostatic pressure, that play a role in depth distribution and vertical movements (reviewed by Ennis 1995). Such behavioural responses may be involved in retaining larvae in the vicinity of natal areas. Self-recruitment in coral reef fish populations has recently been documented (Jones et al. 1999; Swearer et al. 1999) thus challenging the notion that long-distance dispersal is the norm for marine larvae. This has tremendous implications for marine reserve design because rates of dispersal between marine populations and thus recruitment to exploited populations, could be much lower than is currently assumed.

Emigration of juvenile or adult lobsters from the no-take reserves to nearby exploited areas may boost the local fishery. For this to occur, emigration from the no-take reserves must be higher than immigration to the reserves and it must also compensate for the removal from exploitation of the now protected population (Roberts and Polunin 1991;

Rowley 1992, 1994). In my study, it appeared that more tagged lobsters emigrated from the no-take reserves than immigrated to these areas. Although I was unable to quantify whether emigration of adult lobsters from the no-take reserves to nearby exploited areas improved the local fishery enough to compensate for the removal from exploitation of the now protected population, tagged lobsters that had emigrated from the reserves and were harvested in the fishery were generally much larger than most other lobsters harvested. If the creation of no-take reserves is sanctioned on the basis of benefits to local fisheries, it will be critical to quantify such effects.

In assessing the potential of reserves to provide direct benefits to local lobster populations and fisheries, it is important to realize that there is a trade-off between retaining adults to increase local egg production and hence later recruitment and exporting large adults to improve catches immediately. If either occurs in excess, it will jeopardize the effects of the other. In the case of American lobsters, the reserves examined in my study seemed to have a good combination of each factor. However, considering the extremely low levels of egg production that currently predominate (FRCC 1995), I believe that reserve design for this species should focus upon retaining adult lobsters as a source of egg production.

CAPACITY OF RESERVES TO OFFER INDIRECT BENEFITS TO THE FISHERY

No-take reserves can offer numerous indirect benefits to exploited populations and fisheries by protecting portions of exploited stocks from genetic changes, altered sex ratios, and other disruptions caused by selective harvesting mortality (Ricker 1981; Bohnsack 1992, 1998). Because of the severe intensity of harvesting pressure and its selection for larger animals (i.e. those above the minimum legal size limit), there is possibly strong selection acting in favour of smaller, slow growing individuals that mature early. In addition, I found some evidence to suggest that females may be more susceptible to capture in the commercial harvest than males, potentially creating a selective force against females. However, female lobsters are offered some additional protection from harvesting mortality by the presence of eggs and/or a V-notch which prevents them from being retained (Miller 1995). Therefore, even though females may be more susceptible to capture than males, the additional protection that they receive may result in similar exploitation rates for both sexes. Consequently, I found no evidence for a difference in sex ratio between reserves and nearby areas exposed to harvesting. No-take reserves, such as those near the Eastport Peninsula, that offer improved survival to a component of the population may help guard against any negative impacts due to selective harvesting mortality.

THE FUTURE

Early assessment of these no-take American lobster reserves suggests that they may be a useful conservation tool for this species. Nonetheless, the response of lobsters in different areas to reserve protection will likely depend on the size of the reserve in relation to the extent of local lobster movement and the local exploitation rates in nearby harvested areas. In Newfoundland waters, lobsters are heavily harvested and individuals appear to move very little (Templeman 1940; Ennis 1984a, 1984b; Ennis et al. 1989, 1994). Consequently, even small no-take reserves may be effective. However, some American lobster populations undertake extensive inshore-offshore migrations and commonly disperse long distances (e.g. Cooper and Uzmann 1971; Dow 1974; Fogarty et al. 1980; Campbell 1986; Pezzack and Duggan 1986) so that no-take reserves under those conditions would have to be very large in order to show similar results.

Effective fisheries management must consider the effects of changing environmental conditions and uncertainty or inaccuracies in stock assessment and projected sustainable catch levels (Roberts 1997; Dayton 1998; Lauck et al. 1998). Due to limited financial resources for research, the common lack of social or political will to establish no-take reserves, and the difficulties associated with studying and understanding recruitment processes in many marine fishes and invertebrates, it may require many years to provide scientific proof of the effectiveness of marine no-take reserves as a fisheries conservation tool. However, preliminary work using a number of different species, including this study of the American lobster, provides strong, albeit circumstantial, evidence that protection from harvesting can lead to improvements in harvested populations within reserves (reviewed by Roberts and Polunin 1991; Rowley 1992, 1994). Moreover, although no-take reserves have yet to be proven effective, it is unlikely that they will have any adverse effect on populations and I believe that they are a necessary and useful component of fisheries management. In the short-term, reserves should be established as a prudent and precautionary approach to fisheries management.

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