# Assessing Marine Protected Areas as a conservation tool: a decade later, are we continuing to enhance lobster populations at Eastport, Newfoundland?

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# ASSESSING MARINE PROTECTED AREAS AS A CONSERVATION TOOL: A DECADE LATER, ARE WE CONTINUING TO ENHANCE LOBSTER POPULATIONS AT EASTPORT, NEWFOUNDLAND?

by

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## ABSTRACT

Marine Protected Areas (MPAs) have emerged as potential conservation tools for improving oceans management worldwide. As more MPAs with no-take marine reserves are established, the importance of evaluating their effectiveness is growing. Two MPAs, Round Island and Duck Islands, were established around the Eastport Peninsula, Bonavista Bay, Newfoundland in October 2005. It was expected that these MPAs would act as reserves for American lobster (*Homarus americanus*), where larger lobsters are allowed to grow, experience a higher reproductive potential and possibly seed the surrounding area through adult spillover. This paper focuses on a portion of an annual lobster monitoring program established in 2004, which consists of tagging lobsters inside the Eastport MPAs and the surrounding open areas and collecting data on size, sex, condition (ovigerous and/or v-notched) and movement. These data are compared to tagging data collected at Eastport in 1997, after the *Fisheries Act* closures to the Round and Duck Islands, following one fishing season. Changes to population structure ten years after closure include: a higher abundance of large lobsters, including ovigerous females, a broadening of population size structure and increases in average sizes of male and female lobsters. Some benefits, including the increased presences of large lobsters were detected in the adjacent commercially fished areas. Small numbers (2-3%) of lobsters are migrating across the MPA boundaries. The MPAs have contributed to conserving and enhancing this population of American lobsters.

## RÉSUMÉ

Il s'avère que les zones de protection marines (ZPM) peuvent être des outils de conservation, aptes à améliorer la gestion des océans dans le monde entier. Avec l'établissement d'un nombre croissant de ZPM comportant des réserves marines non exploitées, il devient de plus en plus important d'évaluer l'efficacité de ces zones. Deux ZPM, celle de l'île Round et celle des îles Duck, ont été créées alentour de la péninsule d'Eastport, dans la baie de Bonavista à Terre-Neuve, en octobre 2005. On pensait que ces zones feraient office de réserves pour le homard (*Homarus americanus*), parce que les grands homards pourraient y grandir et présenter un potentiel reproducteur supérieur, et que le surplus d'adultes s'y trouvant servirait à peupler les régions avoisinantes. Le présent document porte sur une partie d'un programme de surveillance annuel des homards lancé en 2004, qui consiste à marquer des homards à l'intérieur des ZPM d'Eastport et dans les eaux libres avoisinantes en vue de recueillir des données sur leur taille, leur sexe, leur condition (p. ex., homards ovifères ou marqués d'une encoche en V) et leurs déplacements. Cette information est ensuite comparée aux données de marquage obtenues en 1997 à Eastport après la fermeture, en vertu de la *Loi sur les pêches*, des secteurs de l'île Round et des îles Duck au terme d'une saison de pêche. Au nombre des changements observés dans la population dix ans après cette fermeture il faut signaler une plus forte abondance de grands homards, y compris de femelles ovifères, un élargissement de la structure de tailles au sein de la population et une hausse des tailles

moyennes des mâles et des femelles. Les avantages de la fermeture se sont aussi manifestés dans les zones de pêche commerciale adjacentes, notamment par la présence accrue de grands homards. Un petit nombre (de 2 à 3 %) de homards se déplacent hors des ZPM. Les zones de conservation marines ont effectivement contribué à conserver et accroître cette population de homards.

# INTRODUCTION

Precautionary management initiatives such as Marine Protected Areas (MPAs) with no-take reserves are being implemented at increasing rates and emerging as effective tools to protect various fish populations from commercial exploitation (Dugan and Davis 1993; Rowley 1994; Bohnsack 1998; Roberts *et al*. 2001). Russ and Alcala (1996) provide evidence of coral reef fishes being exported from marine reserves to the outside commercially fished area in Apo Island, Philippines. The use of MPA no-take reserves as a conservation tool for managing of reef fisheries has also been documented in Clarke *et al*. (1989). Harvestable size spiny lobsters (*Jasus edwardsii*) from a Marine Park in New Zealand were eleven times more abundant and experienced a higher biomass than the partially protected park and the unprotected areas (Shears *et al*. 2006). The current paper examines the effectiveness of two such MPAs on the Eastport Peninsula, Bonavista Bay, Newfoundland (Figure 1) ten years after the closures in 1997.

Management of the Newfoundland lobster fishery has historically been based on biological input controls such as laws against retention of ovigerous (berried) females and immature individuals, with emphasis on effort controls (licensing, seasons, trap limits, other gear restrictions and escape vents). A decline in local lobster landings, fear of encroachment from outside communities on traditional lobster fishing areas and poaching around the Eastport Peninsula led to self policing and implementing conservation initiatives such as the closure of Round and Duck Islands (2.1 $km^2$) in 1997. Also in that year, the 100 $km^2$ Eastport Peninsula Lobster Management Area (EPLMA) was implemented (Figure 1). Within the EPLMA boundary several other management initiatives were undertaken, including voluntary v-notching (apply v-shaped notch in tail of known reproductive females), reductions in traps and days fished (Davis *et al*. 2007; Collins and Lien 2002). No fishing is allowed within the Round and Duck Islands reserves and only fishers from the seven Eastport Peninsula communities have the right to fish within the EPLMA boundary. Official *Oceans Act* designation in 2005 meant regulatory prohibition of most activities inside the Round Island and Duck Islands MPAs with the exception of scientific monitoring and research. Since the “closed areas” were not officially MPAs until after 2005 both terms are used interchangeably. The main regulatory conservation objective, as laid out in the Eastport MPA Management Plan, is to produce a viable population of American lobsters through the conservation, protection, and sustainable use of resources and habitats (DFO Report 2007). Currently, there are twelve small areas in eight locations (including Eastport) across the province, including Trout River, Shoal Point, Leading Tickles, Summerford, Gander Bay, Random Island, Penguin Islands (southeast coast) and Ashes Island (St. Brendan’s, Bonavista Bay) closed to lobster fishing.

No-take reserves are being implemented at increasing rates in other parts of the world. These closures including demersal fish closures off the east coast of Iceland (Jaworski *et al*. 2006), haddock (*Melanogrammus aeglefinus*) closures off the coast of Nova Scotia (Fisher and Frank 2002) and American plaice (*Hippoglossoides platessoides*) closures in the North Sea (Piet and Rijnsdorp 1998) have shown benefits such as increased abundance and size.

The potential benefits of MPAs include the protection of populations through: increased individual size (Babcock *et al*. 2007; McClanahan and Kaunda-Arara 1996); increased abundance (Russ and Alcala 1996; Shears *et al*. 2006); improved habitat (Rodwell *et al*. 2003) and developing a completed community structure inside the reserves (McClanahan and Kuanda-Arara 1996). These benefits may be expected to increase egg production (Babcock *et al*. 2007), export larvae to outside commercially-harvested areas, and encourage adult spillover effects (McClanahan and Kuanda-Arara 1996; Russ and Alcala 1999; Abesamis *et al*. 2006). Studies on the coral reef fisheries indicated that mean size and spawning biomass was higher inside marine reserves compared to fished areas outside the reserve (Russ and Alcala 1999; Roberts *et al*. 2001). It is also anticipated that establishing a network of these small reserves will provide some added protection during times of environmental downturns and/or uncertainty in management (Trippel 1995; Stefansson and Rosenberg 2005).

This paper explores the potential utility of MPAs as a conservation tool to enhance the long term sustainability of lobster populations both inside the Eastport MPAs and in the adjacent commercially fished areas. The effectiveness of these MPAs were evaluated by: assessing differences in population structure inside versus outside the MPA and examining changes over the past decade, determining if there are differences in mean carapace length (CL) between MPAs and adjacent outside areas and identifying any changes over time, assessing differences between proportion of ovigerous females inside and outside the MPAs in recent years and changes over time and assessing movement patterns of lobsters in and around the MPAs over the past four years.

This research builds on findings of Rowe (2001, 2002) in which the first three years following protection from fishing pressure was explored at the Eastport sites. Although some changes have been shown to occur early on, continued changes in larger sizes and higher proportions of berried females inside the MPAs were expected, as well as, other changes that were not detected in the first three years of closure. A broadening of the population size structure inside the closed areas was also anticipated. Lastly, some changes to the outside areas including adult spillover, following a decade of protection were predicted.

## METHODS

Biological and tag-recapture data were collected on lobsters at Eastport from 2004 - 2007. Participants were trained in both a classroom setting and onboard fishing vessels prior to each field season. Two-person crews collected biological data from inside each of the MPAs and in the adjacent commercially fished areas. The same crews have collected data annually since 2004. In the first year, the research extended over five weeks in the summer (July 7 – August 16, 2004) and an additional five weeks in the fall (September 7 – October 13, 2004). Following 2004, data was collected for three to four weeks in September – early October after the majority of lobsters had molted. Tagging is usually conducted during this period in order to reduce tagging-induced mortality and tag loss (Comeau and Manon 2003).

Lobsters were caught using catch-and-release trapping consisting of 50 commercial wooden traps. Traps are made from wooden laths and are generally 1.5 - 2 feet long. Lobsters enter through rings (between five inches and six inches in diameter) and then become trapped in the parlor portion of the trap. A space is left between the bottom two laths so that small lobsters (< 65 mm) can escape. Twenty-five of the traps were located inside the MPAs and 25 in the adjacent commercially fished area (Figure 2a and 2b). These areas were subdivided into smaller areas of roughly equal size and separated by distinguishable landmarks (such as distinct rock outcrops or points on a headland). Each site was assigned a unique identification number in order to track the movement of lobsters. Traps were generally placed at depths between three and ten meters and distributed evenly over all the smaller subdivided areas.

The adjacent commercially fished sampling areas were similar to those described in Rowe (2001) and areas used in other tagging research at the Eastport sites (Collins and Lien 2002). The bottom bathymetry is similar inside the closed areas and in the outside commercially adjacent areas. A narrow band of rocky substrate from the coastline to 10 m characterizes lobster habitat inside the MPAs and in the adjacent commercially fished areas outside along the coast where lobsters were tagged and released.

The traps were hauled every day, weather permitting, all lobsters inside the traps were measured using vernier calipers and data on carapace length, zone of capture, sex and condition (ovigerous and/or v-notched) was recorded. In addition, each lobster caught was marked with a streamer-tag which had a unique number. Some lobsters have retained their tags from earlier studies (Ennis *et al*. 1998; Collins and Lien 2002; Rowe 2002) and new data was recorded on these lobsters.

During this research multiple captures of the same animal were common, which allowed examination of possible adult spillover effects from the MPAs to adjacent commercially harvested areas. Eastport tagging data from summer 2004 to fall 2007 was used for this portion of the analysis, although some lobsters tagged prior to 2004 remain in the dataset as recaptures. If a recaptured lobster moved across the MPA boundary, the number of days at large was calculated from the last time the lobster was captured to the day when it was caught again on the other side of the boundary.

In order to compare the mean carapace length of lobsters over several years only the fall data was used, since summer data was only collected in 2004. Males and females were analyzed separately. At both Round Island and Duck Islands the first occurrence of each male and each female lobster, in each year (1997, 2004-2007) was recorded. Information on recaptures was used to estimate population size and to assess movement. The 1997 data used in the study was comparable in timing, content and methodology.

The 'Univariate' procedure in Statistical Analysis System (SAS) version 9.1 was used to examine for outliers. The few outliers found were very large lobsters which were left in the analysis because they are known to occur in the area. A Kolmogorov-Smirnov test of distribution was used to examine changes in the shape of the population size structure. The continuous data on mean carapace length was analyzed using an unbalanced generalized linear model (GLM) with carapace length as the dependent variable to test for differences between inside and outside the closed areas and differences between years. In the early models I included 'side' (inside MPAs vs. adjacent commercially fished area), 'location' (Round Island or Duck Islands), 'year' (1997, 2004-2007) and the interactions of 'side*loc', 'side*year', 'loc*year' and 'side*loc*year' as independent variables. Only in cases where there was a significant effect were variables considered (in the final model). Least square means was used to test differences between each treatment and unequal sample sizes were adjusted using Tukey Kramer. In order to analyze the proportion of ovigerous females between inside and outside the MPAs a Maximum Likelihood Analysis using chi-squared comparisons was used (Freq procedure). All Statistical tests were two-tailed and the tolerance for accepting type III error was set as 0.05.

## RESULTS

In total, 3025 lobsters were tagged between summer 2004 and fall 2007 in the Eastport area. When analyzing the size structure of population and mean carapace length only the fall tagging data was assessed (n = 2431 tags). Information on an additional 405 lobsters, tagged prior to 2004 (retained tags) was also collected as part of this research. There were 2780 instances of recaptured lobsters used to examine movement of lobsters at the Eastport MPAs from 2004 to 2007. Data on 691 lobsters tagged in Eastport in 1997 was also used to assess temporal changes in population structure, mean sizes and proportion of ovigerous females. The number of lobsters sampled over all five years was higher inside the MPAs (n = 2530 lobsters) than in the adjacent commercially fished areas (n = 1548). The total number of females (n = 638) and males (n = 651) were similar inside Round Island MPA. Inside the Duck Islands MPA there were higher numbers of males (n = 755) than females (n = 486).

### Population Structure

The minimum legal size at which lobsters were harvestable in 1997 was 81mm carapace length (CL) but increased to 82.5 mm CL towards the end of the 1998 commercial fishing season. The undersize group (≤ 82 mm CL) represents those lobsters that were smaller than legal size and not eligible for catch.

<u>Population structure differences between inside and outside closed areas</u>
In 1997, after one year of protection from fishing, few differences were evident between inside the closed areas and the adjacent commercially fished areas (Figure 3, 4, 5 and 6). A Kolmogorov-Smirnov test of these distributions showed no significant differences (Table 1 and Table 2) between the size distribution patterns of male or female lobster carapace lengths at Round Island (p = 0.3460, p = 0.9990 for males and females

respectively) and Duck Islands ($p = 0.6530$, $p = 0.3240$ for males and females respectively).

In 2007, many changes were evident inside the closed areas compared to the adjacent commercially fished areas. There were a higher percentage of legal size lobsters, including large ovigerous females inside the Round Island (Figure 3) and Duck Islands (Figure 4) closed areas compared to the adjacent commercially fished areas. A higher percentage of large lobsters older than first year recruits to the fishery (male lobsters > 95 mm CL; female lobsters > 92 mm CL) occurred inside both the closed sites at Round Island and Duck Islands compared to the adjacent commercially fished areas (Figure 3, 4, 5 and 6). A higher percentage of male lobsters > 120 mm CL were present inside the closed areas at both Round Island and Duck Islands in 2007. Despite these apparent differences in population size structure, only the distribution patterns of Round Island females and Duck Islands males were significantly different in 2007 ($p = 0.018$ and $p = 0.006$ respectively).

In most cases, differences (described above) were detected between the size distributions inside and the adjacent commercially fished areas by 2004 (Table 1 and Table 2), except for the Duck Islands females ($p = 0.111$) which were significantly different by 2005 and in 2006, but not in 2007. At Round Island a significant ($p = 0.006$) difference in the shape of distribution of males was detected by 2004 but in all of the remaining years no difference was found between inside and the adjacent commercially fished areas.

In the adjacent commercially fished areas, lobsters larger than those first year recruits to the fishery are present in 2007 at both the Round Island and the Duck Islands sites. There were also ovigerous females surviving to these sizes. Also apparent was the presence of male and female lobsters ≥ 120 mm CL in the adjacent commercially fished areas of Round Island and Duck Islands. The only significant changes over time (between 1997 and 2007) in the adjacent commercially fished areas were at Duck Islands ($p = 0.019$).

<u>Temporal changes inside closed areas (1997 vs. 2004, and 1997 vs. 2007)</u>

In most instances significant changes to the population structures were found inside closed areas by 2004 (Table 1 and Table 2) and remained different in 2007, except for the Duck Islands females ($p = 0.203$). The shape of the size distribution of Duck Islands females inside the MPA was not significantly different from the distribution pattern in 1997 until 2006 ($p = 0.000$) and stayed different in 2007 ($p = 0.003$).

The size distribution pattern of females (Figure 3 and 4) inside Round Island closed area ($p = 0.027$) and Duck Islands closed area ($p = 0.001$) have changed significantly over the past decade. The relative abundance of ovigerous females of all sizes was higher inside the closed areas and especially true for lobsters > 92 mm CL. At Round Island, no significant difference was found between the distribution patterns of male lobsters between 1997 and 2007 ($p = 0.324$). However, in 2007 there were large male lobsters between 106 mm CL and >120 mm CL present which were not seen inside Round Island in 1997. At Duck Islands significant differences in the distribution patterns of male lobsters were found between 1997 and 2007 ($p = 0.003$).

Temporal changes inside closed areas (2004, 2005, and 2006 vs. 2007)
No significant changes in distribution patterns were detected between males inside the Round Island or Duck Islands closed areas in any recent year (Figure 7, 8, 9 and 10; Table 3) compared to 2007. Significant changes in female size distribution patterns at Round Island closed area were detected between 2004 and 2007 ($p = 0.0390$), 2005 and 2007 ($p = 0.0390$) and between 2006 and 2007 ($p = 0.000$). At Duck Islands, a significant change in the distribution pattern between 2006 and 2007 females was detected ($p = 0.0180$).

**Mean Carapace Lengths**

Mean carapace lengths (including 95% confidence limits) from 1997 and 2004 - 2007 at both Round Island and Duck Islands were analyzed (Figure 11). This included mean carapace lengths inside the MPAs and in the adjacent commercially fished areas.

Males
Model results for male lobsters are shown in Table 4 derived from the analysis of variance (ANOVA) table (GLM procedure in SAS). Since the three way interaction term was not significant ($p = 0.5286$) and location is a random factor ($p = 0.2654$), the data was separated by location and the Round Island and Duck Islands sites were examined separately. There were no interactive effects detected once data was separated by location ($p = 0.1122$ (Round Island) and $p = 0.1314$ (Duck Islands)).

The mean carapace length of male lobsters were significantly larger ($p \leq 0.0001$) inside the MPA at Round Island than the adjacent commercially fished area (Table 5). The mean carapace length of male lobsters were also significantly larger ($p \leq 0.0001$) inside the MPA at Duck Islands (Table 6). Year was also a significant factor in determining carapace length at both Round Island and Duck Islands sites ($p \leq 0.0001$).

Mean CL of male lobsters at Round Island increased significantly from 1997 to each of the recent years 2004-2007 ($p \leq 0.0001$). At Duck Islands the mean CL increased significantly ($p \leq 0.0001$) until 2007 when it experienced significant decline ($p = 0.0998$).

Females
Model results for female lobsters are shown in Table 7 derived from the ANOVA table. Three way interactive effects were not significant ($p = 0.2297$) as was the side and year interactive effect ($p = 0.4321$) so they were removed and the model was run again. Since the interaction between location and year ($p = 0.0009$), as well as, side and location ($p = 0.0165$) were significant, the data was split by location and the results examined separately.

At the Round Island site the interactive term of side and year was significant (Table 8, $p = 0.0434$). Confidence limits show that the carapace lengths are significantly higher inside the closed area in one of the five years examined (Figure 11). The only year with significant difference in carapace length between inside and outside the Round Island site was 2007.

At the Duck Islands site no significant interactive effect was found between side and year (Table 9, $p = 0.7499$). Carapace lengths of female lobsters inside the Duck Islands closed area are significantly larger than carapace lengths of lobsters in the adjacent commercially fished area ($p \leq 0.0001$). A significant difference between mean carapace lengths was found between years ($p \leq 0.0001$). The mean carapace length of female lobsters was significantly different between 1997 and 2004 ($p \leq 0.0001$), 2005 ($p \leq 0.0001$), 2006 ($p \leq 0.0001$) and 2007 ($p = 0.0357$).

**Proportion of ovigerous females**

Given the differences already found between locations, I conducted this portion of the analysis by separating Round Island and Duck Islands (Figure 12). A chi-squared test of all five years was conducted (Table 10), no interactive effects were detected between side and year at either the Round Island site ($p = 0.8167$) or the Duck Islands site ($p = 0.5167$). The data showed that the proportion of ovigerous females was higher inside compared to the adjacent commercially fished areas at both the Round Island ($p \leq 0.0001$) and Duck Islands ($p \leq 0.0001$) locations. At Round Island no significant differences were found between years ($p = 0.2638$). However, at Duck Islands there were significant differences between years ($p \leq 0.0001$).

**Movement**

Multiple captures were common which allowed examination of possible adult spillover effects from the MPAs to the adjacent commercially fished areas. No movement was detected between the Round Island and Duck Islands MPAs during the study period. Among lobsters recaptured, 2706 of 2780 (97%) were captured on the same side of the MPA that they were originally tagged. In total, 74 of 2780 (3 %) lobsters recaptured crossed the MPA boundary between 1 and 1150 days after release. The maximum distance moved at Duck Islands was 1246 m in 358 days and at Round Island the maximum distance moved was 1077 m in 716 days. The amount of exchange was similar between the two locations, Round Island (36 of 1471 = 2%) and Duck Islands (38 of 1309 = 3%).

At Round Island 26 of the 36 (72%) movers emigrated from the MPA, the remaining 10 of 36 (28%) lobsters moved into the MPA. Movement out of the Duck Islands MPA represented 33 of 38 (84%) of all exchanges detected and the remaining 5 of 38 (16%) lobsters moved into the MPA. Given that the numbers of lobsters tagged inside were twice as high as the number tagged outside there were no directional differences detected in movement. All lobsters that emigrated from both MPAs have remained outside. Most of the lobsters that moved were above minimum harvestable size at both locations. At Round Island, 25 of 36 movers were ≥ 92 mm CL, 34 of 38 of the movers at Duck

Islands were ≥ 92 mm CL. Nine lobsters were below minimum legal size at Round Islands and three lobsters were below minimum legal size at Duck Islands. Similar numbers of males and females were moving at Duck Islands (21 males: 18 females) and Round Island (21 males: 15 females).

## DISCUSSION

In the first three years of closure, Rowe (2002) found significant differences in mean size of male and female lobsters and the proportion of ovigerous females inside the Round Island closed area compared to adjacent commercially fished areas, as well as, increases in mean size and proportion ovigerous over time. At Duck Islands the mean size of males and females was greater inside the closed area compared to the adjacent commercially fished area, however, no difference was detected in the proportion of ovigerous females and no increases were found in mean female carapace length or in the proportion of ovigerous females. This paper builds upon Rowe's findings and offers additional insight into further changes ten years after the closures.

From this study, it was evident that there were benefits to having these MPAs, but differences in trends were observed at each of the MPAs. In most instances, an increased occurrence of large lobsters, including large ovigerous females, was found inside the closed areas compared to adjacent commercially fished areas by 2004 and in some cases continued differences were seen between inside versus outside up to 2007 (Round Island females and Duck Islands males). Mean sizes of male lobsters inside both the Round and Duck Islands closed areas were larger than mean sizes of male lobsters in the adjacent commercially fished area and it increased from 1997 to 2004, and in most cases remained higher. In 2007, the mean sizes of male lobsters inside the Duck Islands MPA and outside the Duck Islands MPA declined. In that year, there were higher numbers of lobsters (inside and outside) under minimum legal fishing size than in any other year while the numbers of larger lobsters remained stable. These factors combined may have lowered the mean carapace sizes for 2007.

Although Rowe (2002) did not detect increases in mean size of female lobsters inside Duck Islands closed area within the first three years of closure, this study found the mean CL of females had increased by 2004. No significant difference in mean CL of female lobsters between inside and outside Round Island closed area were found until 2007, however, Rowe found differences between sides and increases in the first three years of closure. Although significant differences were not detected until 2007, it does appear that mean size of female lobsters inside the closed areas at Round Island had increased since 1997 but since increases occurred inside as well as outside, no difference was found between sides until 2007 when an increase in mean size inside the MPA was accompanied by a decrease in mean size outside (Figure 11).

The proportion of ovigerous lobsters was significantly higher inside both MPAs compared to the outside areas. The proportion of ovigerous females at Round Island increased during the first three years of establishment (Rowe 2002) and results of this study indicate they have remained higher inside the MPAs and changed little over time. At Duck Islands, higher proportions of ovigerous lobsters inside the MPA represent changes that took longer to occur (since 1999). The ovigerous populations at Duck Islands also appear to have more year to year variability. Since the proportion of ovigerous females inside Duck Islands MPA has not exceeded levels from 1997, it is possible that the proportions may have already been approaching an upper limit as Rowe (2002) suggested. It is also possible that the berried females are more sensitive to the turbulent oceanic conditions known to occur at the Duck Islands site. Size frequency distributions also indicate higher occurrences of ovigerous females inside both the Round Island MPA and the Duck Islands MPA over all size groups.

Collectively the higher incidence of large lobsters, large ovigerous females and increased mean sizes indicated that after 10 years these MPAs are likely encouraging higher reproductive potential compared to the adjacent commercially fished areas. Results of a study on rock lobsters (*Panulirus cygnus*) inside a sanctuary in Western Australia were comparable (Babcock *et al*. 2007). Inside this sanctuary, a greater proportion of harvestable sized lobsters and higher egg production were found compared to the adjacent open areas. Davidson *et al*. (2002) found that large reproductive males were 10 times more abundant within the reserve compared to adjacent fished areas, suggesting that more eggs would be fertilized in the reserve than on the adjacent fished coast. The presence of large male and female lobsters inside the MPAs may encourage higher reproductive potential in several ways. Large females can extrude more than one batch of eggs from one fertilization event, which is important because they molt less frequently than smaller lobsters (Waddy *et al*. 1995). In these cases it might not be necessary for large females to mate every time they reproduce. Large females also produce exponentially higher numbers of eggs than smaller females and their eggs are often more robust (Aiken and Waddy 1980a; Ennis 1981) with a higher energy per unit of weight. They release their eggs earlier improving growth through the post larval stages and suggested improved survival (Attard and Hudon 1987). This enhanced reproductive potential would be an important factor in times of environmental uncertainty. Trippel (1995) suggested that networks of small closed areas may provide additional protection against environmentally ‘bad years’ and variability. These enhanced populations will likely increase potential egg production, possibly becoming a ‘source’ area of eggs and larvae.

It is apparent that the mean sizes increased within a few years of protection but significant changes in mean size of Duck Islands females (including proportion berried) took longer to occur, likely in the period between 1999 and 2004. Most changes in size structure were also detected by 2004, except for the Duck Islands females which also took longer to occur. Comparable results on timing of changes in marine reserves have been reported by other studies. A review of 80 marine reserves by Halpern and Warner (2002) suggest that changes in mean sizes of organisms are reached within 1-3 years. Nardi *et al*. (2004) showed that the closed areas improved the abundance of reef fish species but that the amount of time the area needs to be closed and the geographical scale required depends on the particular species. Cox and Hunt (2005) found that spiny lobsters in the Western Samba Ecological Reserve, Florida Keys showed steady increases in mean size of legal sized lobsters and an increased frequency of very large lobsters (especially males) within five years of the establishment in 1997.

The majority of lobster movements detected were small scale movements which is consistent with other studies of lobsters in the coastal waters of Newfoundland (Templeman 1940; Ennis 1984; Ennis *et al*. 1989) compared to some areas of western Nova Scotia and the Bay of Fundy (Tremblay 1998; Comeau and Savoie 2002). The majority of lobsters that moved did not cross the MPA boundary or move long distances, suggesting that there is strong site fidelity at both the Eastport closed areas. Although small numbers of lobsters were tracked moving from the MPAs to the adjacent commercially fished areas, twice as many lobsters were tagged inside the closed areas suggesting no directional differences in movement. Since the majority of lobsters moving out were larger than 92 mm, which is lower than the mean CL inside these closed areas, it is possible that these lobsters are being displaced by increasing numbers of lobsters > 92 mm known to occur inside the MPAs.

The exchange (3%) between MPAs and the commercially harvested adjacent area was lower than the exchange (8.7%) reported by Rowe (2001) during tagging conducted at Eastport between 1997 and 1999. Movement in the Eastport area may be impeded by bottom topography, especially the deep water (Rowe 2001) surrounding the MPAs, which lobsters have been shown to avoid (Ennis 1984). Ennis (1984) concluded that during the summer there is a thermocline between 5 m and 10 m, which in the fall is mixed into the water column by storm activity and this turbulence triggers small scale movements by lobsters. Evidence from tracking within subareas in this study indicates that the lobsters crossing the MPA boundaries followed a parallel path with the coastline and then followed corridors of shallower water stretching to the outside areas, thus avoiding the deeper water. It is also possible that because Eastport is located near the northern limit for the species that densities of lobsters may be low. Taken together with the lower water temperatures and the longer estimated time to reproductive maturity (8-10 years), it will likely take longer than 10 years for populations inside these MPAs to become dense enough to allow significant amounts of spillover to occur. In warmer climates spillover has been reported sooner. Goni *et al*. (2006) reported the export of spiny lobsters from Columbretes Islands Marine Reserve (Western Mediterranean) after a decade of protection. In the absence of evidence for a mass exodus from the Eastport MPAs, there were indications that some lobsters are moving to the adjacent commercially fished areas and may be providing benefits to the outside areas.

It is possible that higher egg production inside the MPAs and movement of some lobsters out of the MPAs may be enhancing local populations in the adjacent commercially fished areas. Some examples of this enhancement include a higher abundance of large lobsters not typical of commercially fished areas, higher mean sizes, and higher catch per unit effort (CPUE) in the adjacent commercially fished areas. Commercially fished populations from areas other than Eastport indicate that the majority of individuals caught are first year recruits to the fishery (Ennis *et al*. 1989; 1994) which is not the case in the adjacent commercially fished areas at Eastport. In addition, the average mean CL of male and female lobsters from adjacent commercially fished areas at both Round and

Duck Islands were higher than those calculated from the commercial spring sampling in the 100 $km^2$ EPLMA (Appendix 1) suggesting possible benefits closer to the MPA boundary. Goni *et al*. (2006) found that the export of spiny lobsters from a marine reserve in the Western Mediterranean maintained catch rates up to 1500 m from the reserve boundary. Logbooks collected as part of the broader MPA monitoring program show stable CPUE in the EPLMA in contrast to the lower CPUE from Lobster Fishing Area 4 (Statistical Section 7), Notre Dame Bay, approximately 200 km northwest of Eastport (Appendix 1). Reports from lobster harvesters also suggest stable catch rates and in some cases increasing individual landings.

This evidence does suggest benefits to the outside area; however, it cannot be said with certainty that MPAs alone are responsible for these changes given that other conservation initiatives such as v-notching have also been implemented. Since the MPAs were first established the numbers of v-notched lobsters inside the MPAs are smaller, however, evidence still suggests potential enhancement of egg production is occurring. There are fewer v-notched lobsters at Duck Islands compared to Round Island and it could be argued that v-notching is not responsible for these benefits because if they were solely responsible then reported changes in the population would only be seen at the Round Island closed area. This could also be another potential explanation as to why the Duck Islands females took longer to show significant differences in size structure and increases in female size and proportion of ovigerous females.

Although there was no 'baseline data' collected and it is difficult to determine the relative contribution of other conservation initiatives in the immediate area, the data suggests that MPAs are certainly contributing to the enhancement of lobster populations both inside the MPAs and in the adjacent commercially fished areas. The strength of this study lies in the significant insight regarding differences between inside the MPAs and the adjacent commercially fished areas as well as indications of changes to both the MPA population and the outside population a decade following closure. Although the carrying capacity within the MPAs did not appear to be at its limit a decade following protection, it is possible that given the local conditions it may take longer for this to occur. It is plausible that these MPAs will bring continued benefits to the outside areas through higher egg production and further adult spillover as the carrying capacity is reached in the years to come, although the amount of time it will take is difficult to predict.

## ACKNOWLEDGEMENTS

A special thanks to the crews that participated over the past four years. Without their hard work and dedication the monitoring of the MPAs would not be possible. I am grateful to P. Veitch of Science Branch, Fisheries and Oceans Canada (DFO) for technical support in processing the data and developing graphs, J. Lawson for collecting the 1997 data, R.K. Collins at DFO for use of the 1997 tagging data and for reviewing an earlier draft, K.S. Dwyer and R. Gregory who also reviewed drafts and provided helpful feedback on figures, and D. Stansbury for his assistance with the statistics programs. This research received financial support from the Oceans Division DFO, the Legacy Nature Trust and the Atlantic Canada Opportunities Agency (2004). The 1997 lobster tagging data was collected at Eastport as part of a project sponsored by Canadian Centre for Fisheries Innovation (CCFI). It was the result of a successful collaboration between DFO and members of the Eastport Peninsula Lobster Protection Committee. The data was donated to Science Branch at Fisheries and Oceans Canada in St. John's.

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Table 1. Kolmogorov-Smirnov test of distribution of male lobster carapace lengths, maximum deviation from expected (D) and associated p-value (0.05 tolerance).

| | **Round Island** | | **Duck Islands** | |
|---|---|---|---|---|
| | D | P | D | P |
| 1997 In vs. 1997 Out | 0.069 | 0.999 | 0.173 | 0.324 |
| 2004 In vs. 2004 Out | 0.310 | 0.006 | 0.293 | 0.011 |
| 2007 In vs. 2007 Out | 0.173 | 0.324 | 0.310 | 0.006 |
| 1997 In vs. 2007 In | 0.173 | 0.324 | 0.328 | 0.003 |
| 1997 In vs. 2004 In | 0.362 | 0.001 | 0.310 | 0.006 |
| 1997 Out vs. 2007 Out | 0.241 | 0.057 | 0.276 | 0.019 |

Table 2. Kolmogorov-Smirnov test of the distribution of female lobster carapace lengths, maximum deviation from expected (D) and associated p-value (0.05 tolerance).

| | **Round Island** | | **Duck Islands** | |
|---|---|---|---|---|
| | D | P | D | P |
| 1997 In vs. 1997 Out | 0.121 | 0.346 | 0.095 | 0.653 |
| 2004 In vs. 2004 Out | 0.301 | 0.000 | 0.155 | 0.111 |
| 2007 In vs. 2007 Out | 0.198 | 0.018 | 0.155 | 0.111 |
| 1997 In vs. 2007 In | 0.190 | 0.027 | 0.259 | 0.001 |
| 1997 In vs. 2004 In | 0.207 | 0.012 | 0.138 | 0.203 |
| 1997 Out vs. 2007 Out | 0.112 | 0.438 | 0.173 | 0.056 |

Table 3. Kolmogorov-Smirnov test of the distribution of male and female lobster carapace lengths inside the MPAs in 2004, 2005, 2006 and 2007, maximum deviation from expected (D) and associated p-value (0.05 tolerance).

| | **Round Island** | | **Duck Islands** | |
|---|---|---|---|---|
| | D | P | D | P |
| **Males** | | | | |
| 2004 In vs. 2007 In | 0.224 | 0.093 | 0.138 | 0.607 |
| 2005 In vs. 2007 In | 0.172 | 0.324 | 0.224 | 0.930 |
| 2006 In vs. 2007 In | 0.224 | 0.093 | 0.190 | 0.222 |
| **Females** | | | | |
| 2004 In vs. 2007 In | 0.181 | 0.039 | 0.164 | 0.080 |
| 2005 In vs. 2007 In | 0.181 | 0.039 | 0.155 | 0.111 |
| 2006 In vs. 2007 In | 0.267 | 0.000 | 0.198 | 0.018 |

Table 4. Analysis of differences (ANOVA output) between mean carapace lengths of male lobsters as a function of side, location and year (tolerance = 0.05, $R^2$ = 0.1365, n = 2244).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 118.93 | <0.0001 |
| Location | 1 | 1.24 | 0.2654 |
| Year | 4 | 24.94 | <0.0001 |
| Side*location | 1 | 8.00 | 0.0047 |
| Side*year | 4 | 2.82 | 0.0240 |
| Location*year | 4 | 3.71 | 0.0052 |
| Side*location*year | 4 | 0.79 | 0.5286 |

Table 5. Analysis of differences (ANOVA output) between mean carapace lengths of male lobsters as a function of side and year at the Round Island site (tolerance = 0.05, $R^2$ = 0.1330, n =1090).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 30.96 | <0.0001 |
| Year | 4 | 33.21 | <0.0001 |
| Side*year | 4 | 0.95 | 0.1122 |

Table 6. Analysis of differences (ANOVA output) between mean carapace lengths of male lobsters as a function of side and year at the Duck Islands site (tolerance = 0.05, $R^2$ = 0.1307, n =1154).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 30.96 | <0.0001 |
| Year | 4 | 33.21 | <0.0001 |
| Side*year | 4 | 0.95 | 0.1314 |

Table 7. Analysis of differences (ANOVA output) between mean carapace lengths of female lobsters as a function of side, location and year (tolerance = 0.05, $R^2 = 0.1308$, n =1834).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 30.96 | <0.0001 |
| Location | 1 | 24.08 | <0.0001 |
| Year | 4 | 33.21 | <0.0001 |
| Side*location | 1 | 4.08 | 0.0435 |
| Side*year | 4 | 0.95 | 0.4321 |
| Location*year | 4 | 3.83 | 0.0041 |
| Side*location*year | 4 | 1.41 | 0.2297 |

Table 8. Analysis of differences (ANOVA output) between mean carapace lengths of female lobsters as a function of side and year at the Round Island site (tolerance = 0.05, $R^2 = 0.1373$, n = 1034).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 30.96 | <0.0001 |
| Year | 4 | 33.21 | <0.0001 |
| Side*year | 4 | 0.95 | 0.0434 |

Table 9. Analysis of differences (ANOVA output) between mean carapace lengths of female lobsters as a function of side and year at the Duck Islands site (tolerance = 0.05, $R^2 = 0.09666$, n = 800).

| Source | df | F | P |
|---|---|---|---|
| Side | 1 | 30.96 | <0.0001 |
| Year | 4 | 33.21 | <0.0001 |
| Side*year | 4 | 0.95 | 0.7499 |

Table 10. Maximum likelihood analysis using chi-square (**$\chi 2$**) comparisons of the proportions of ovigerous females inside and outside the MPAs in 1997 and all recent years (2004-2007).

| **Source** | **df** | $\chi^2$ | **P** |
|---|---|---|---|
| Round Island | | | |
| Side | 1 | 60.45 | <0.0001 |
| Year | 4 | 5.24 | 0.2638 |
| Side*year | 4 | 1.56 | 0.8167 |
| Duck Islands | | | |
| Side | 1 | 19.23 | <0.0001 |
| Year | 4 | 24.40 | <0.0001 |
| Side*year | 4 | 3.25 | 0.5167 |

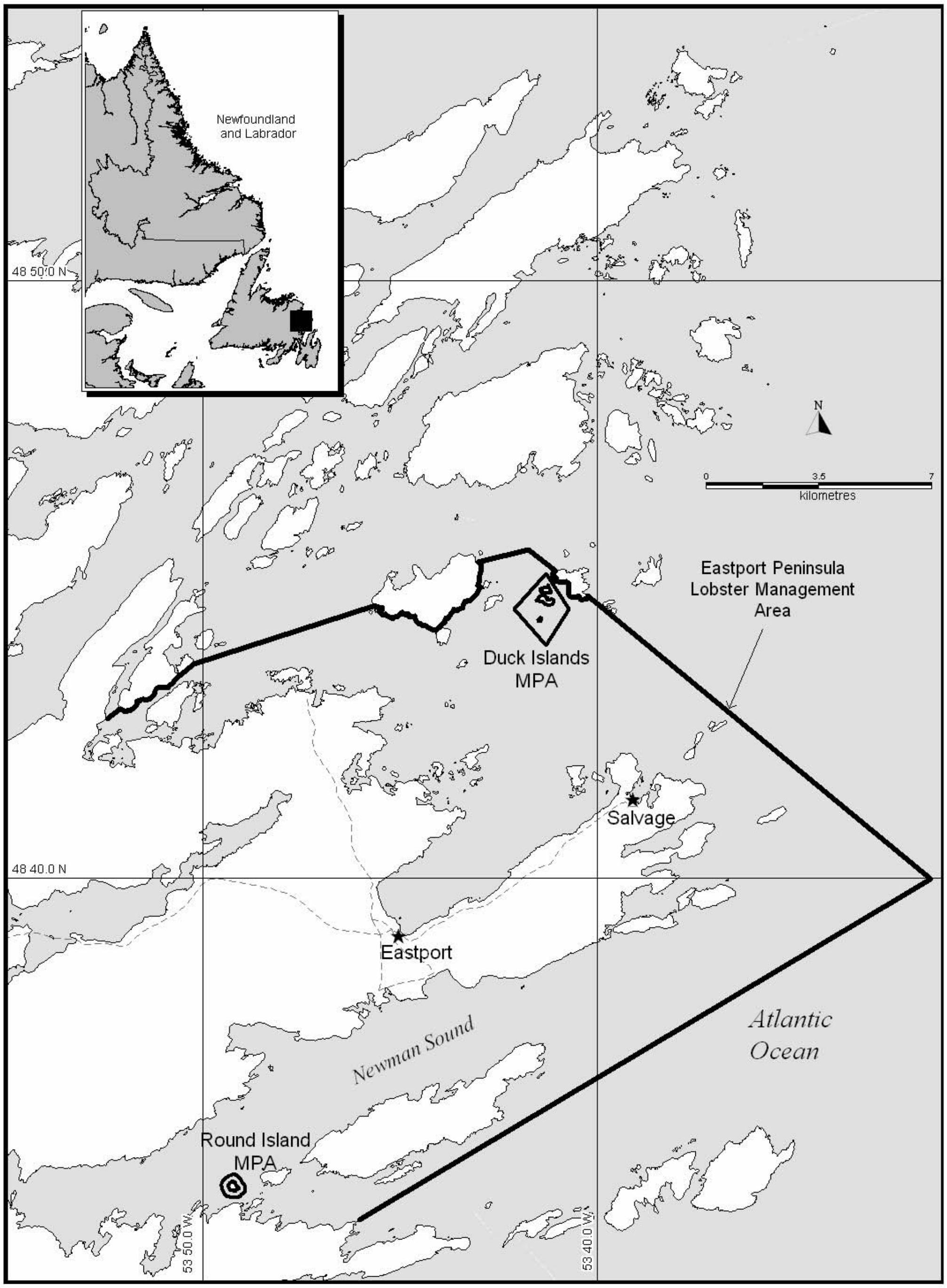



Figure 1. Eastport, Bonavista Bay, Newfoundland (Canada) showing Round Island and Duck Islands MPA boundaries and Eastport Peninsula Lobster Management Area boundary.

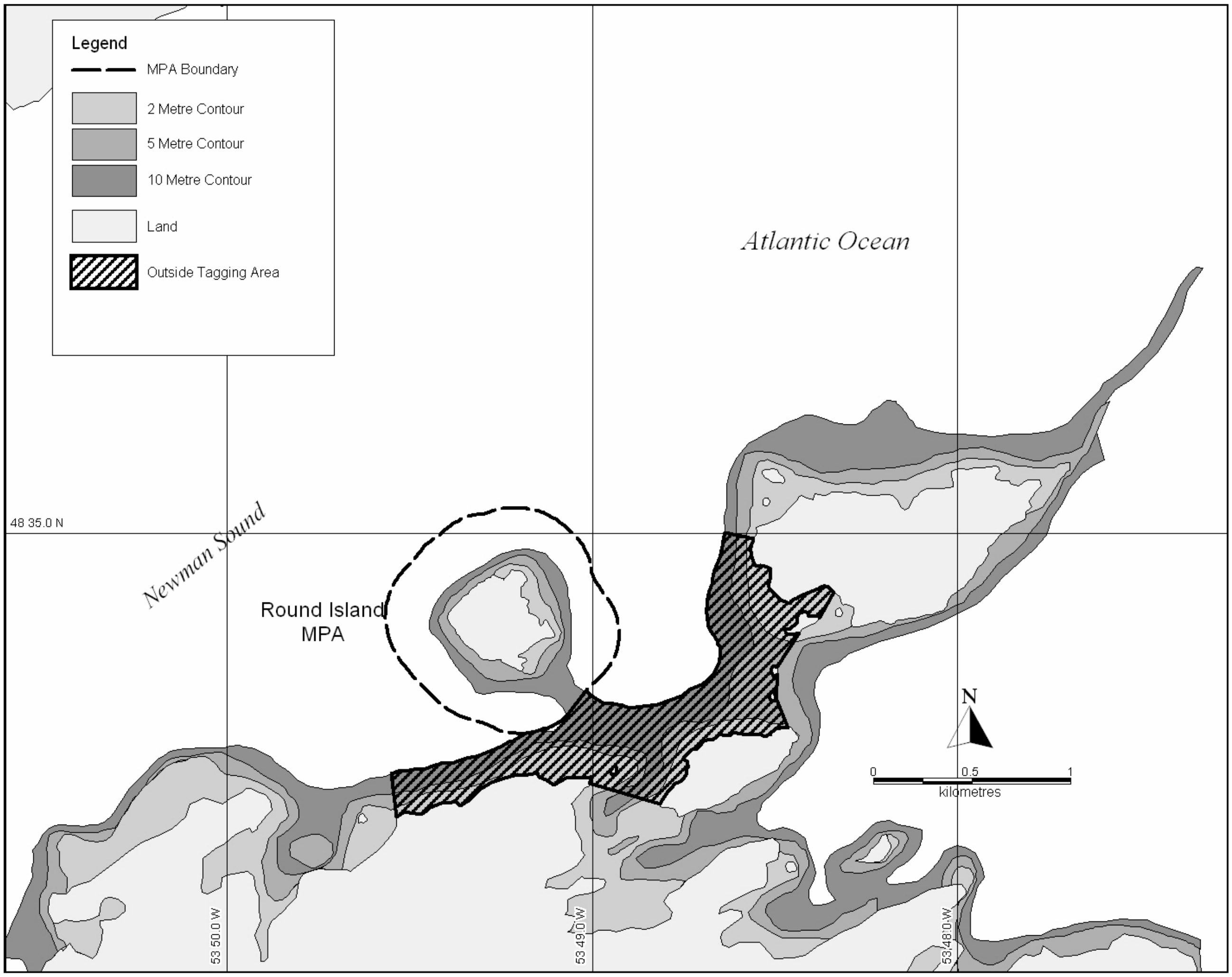



Figure 2a. Round Island tagging area.

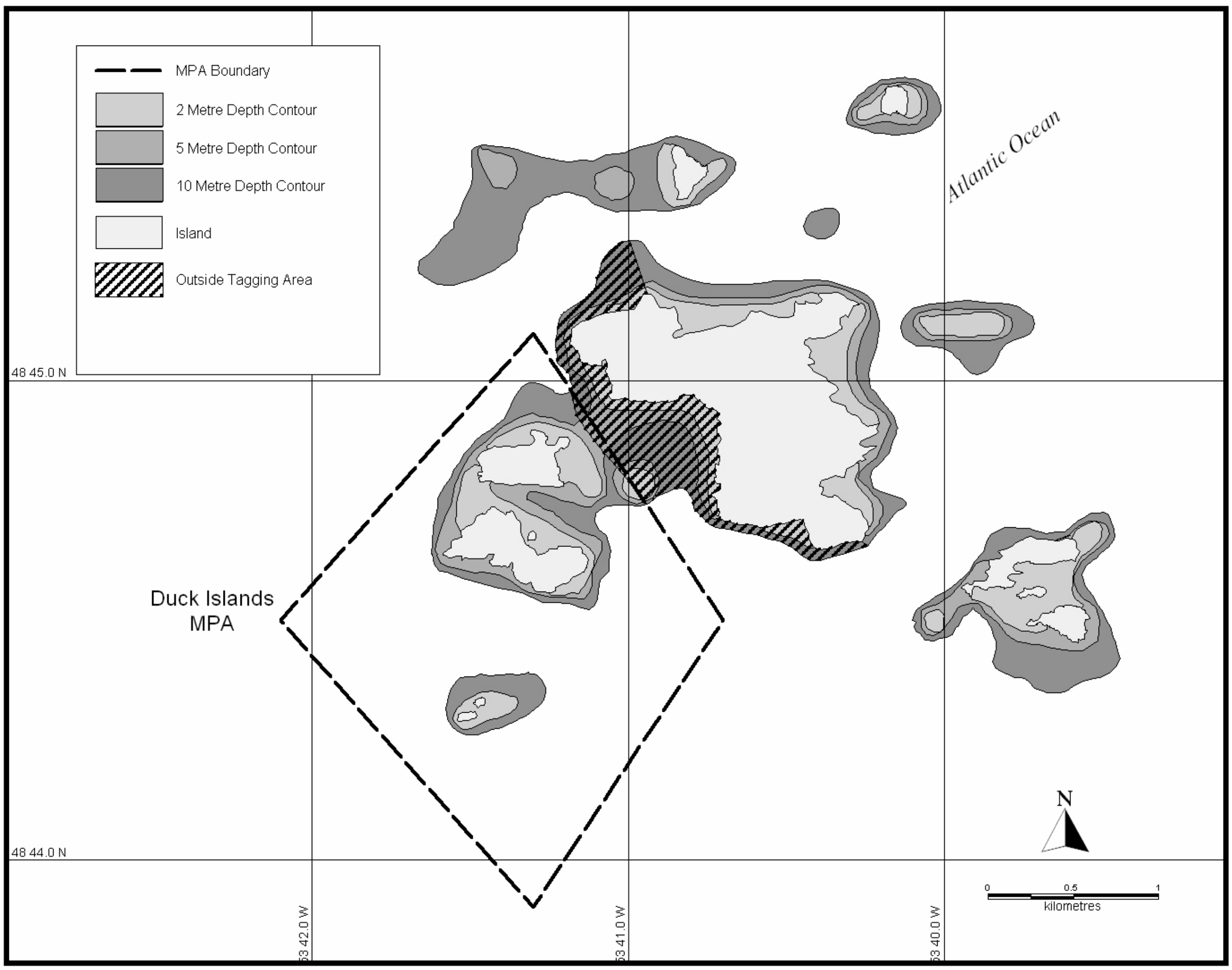



Figure 2b. Duck Islands tagging area.

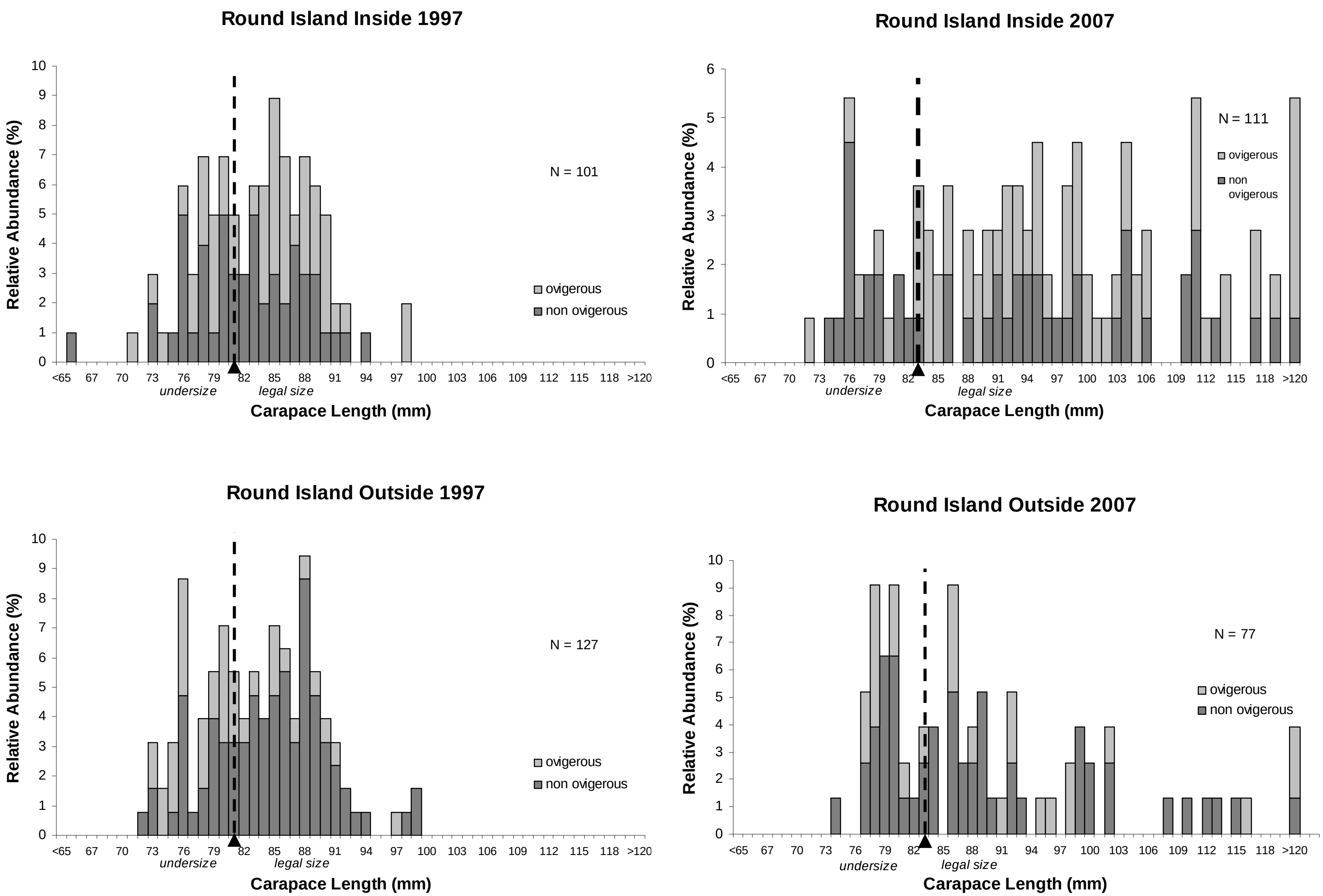



Figure 3. Carapace length frequency distributions of female lobsters inside and outside the Round Island Closed Area in 1997 and 2007; minimum legal carapace length (---).

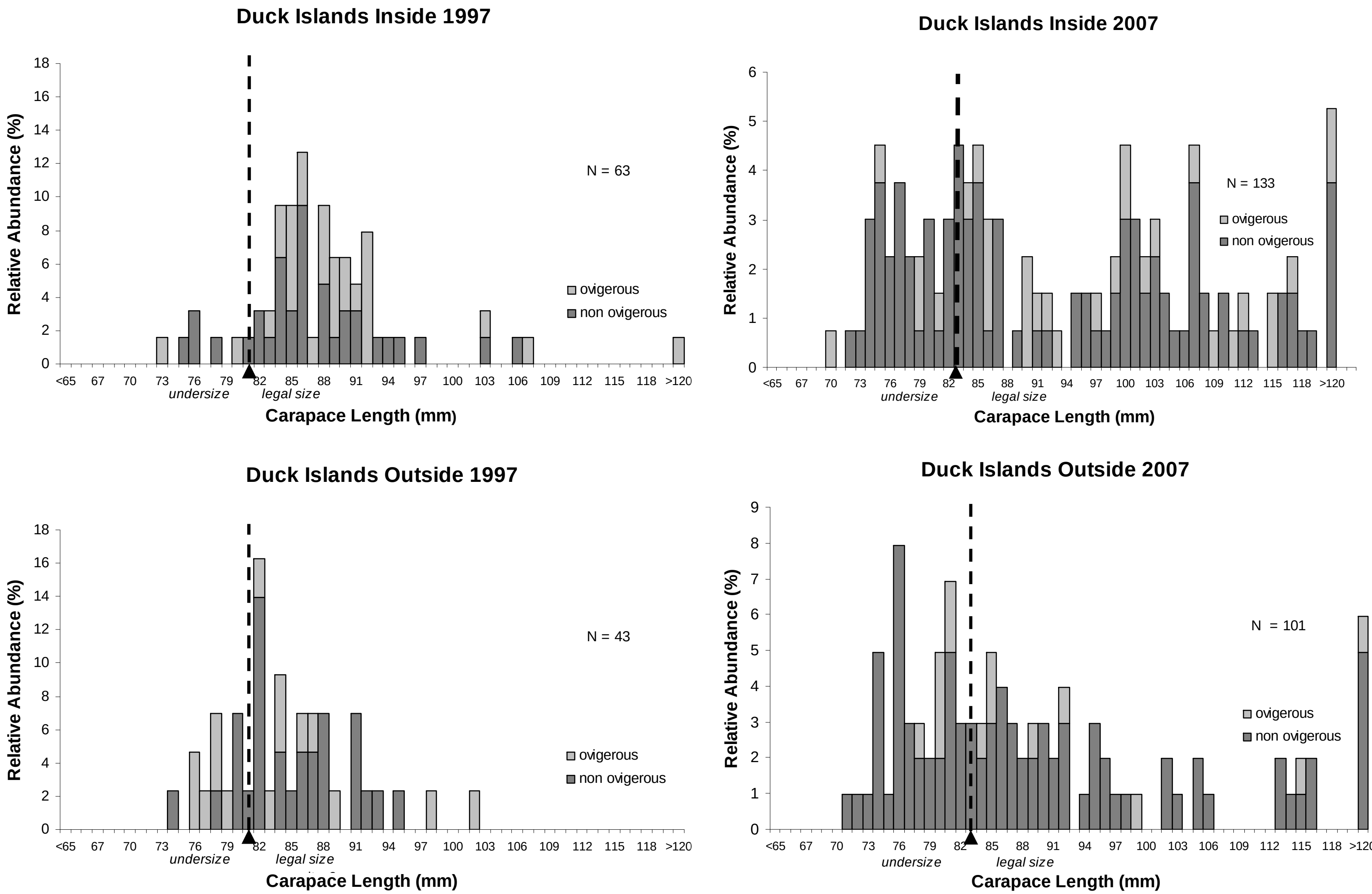



Figure 4. Carapace length frequency distributions of female lobsters inside and outside the Duck Islands Closed Area in 1997 and 2007; minimum legal carapace length (---).

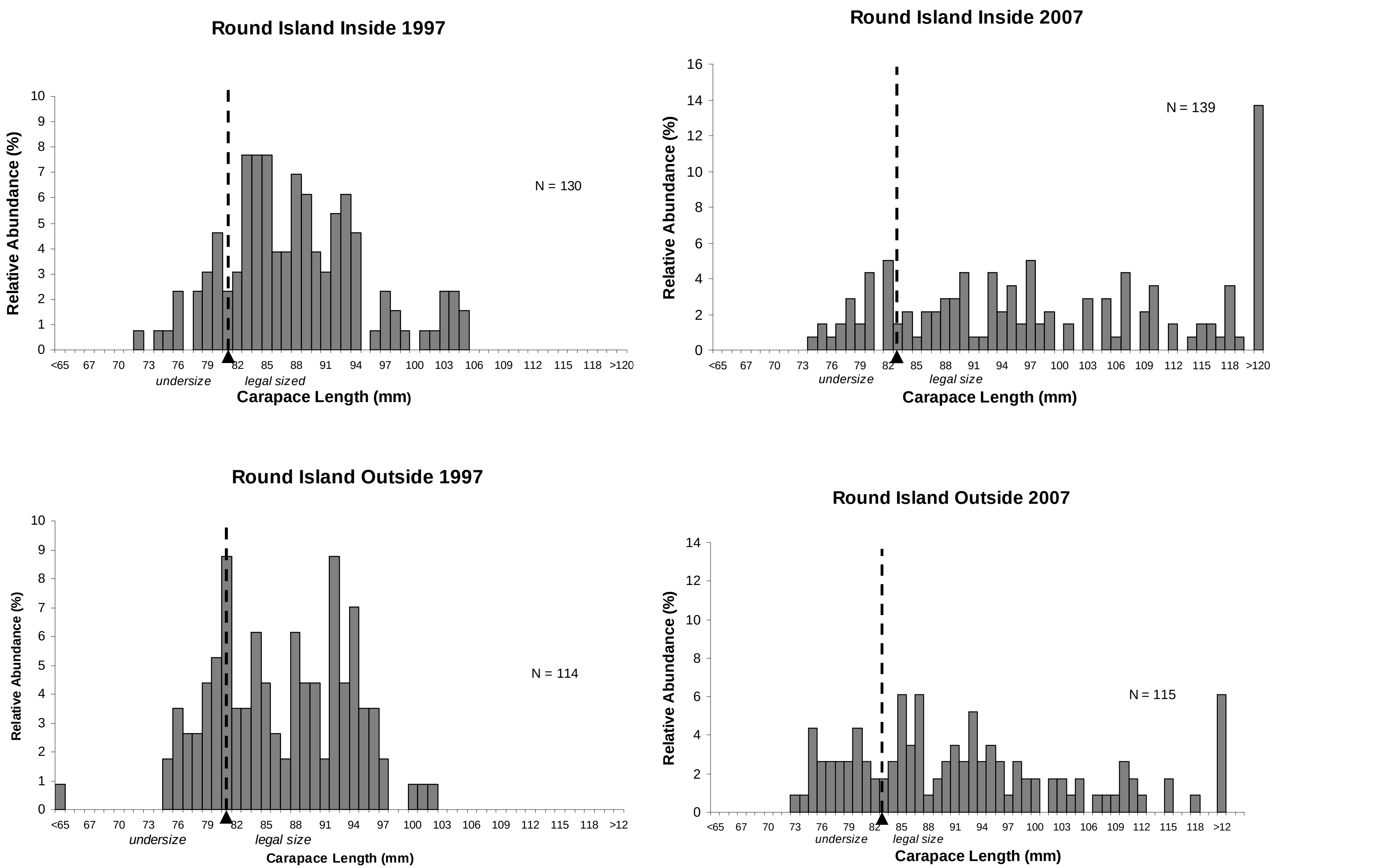



Figure 5. Carapace length frequency distributions of male lobsters inside and outside the Round Island Closed Area in 1997 and 2007; minimum legal carapace length (---).

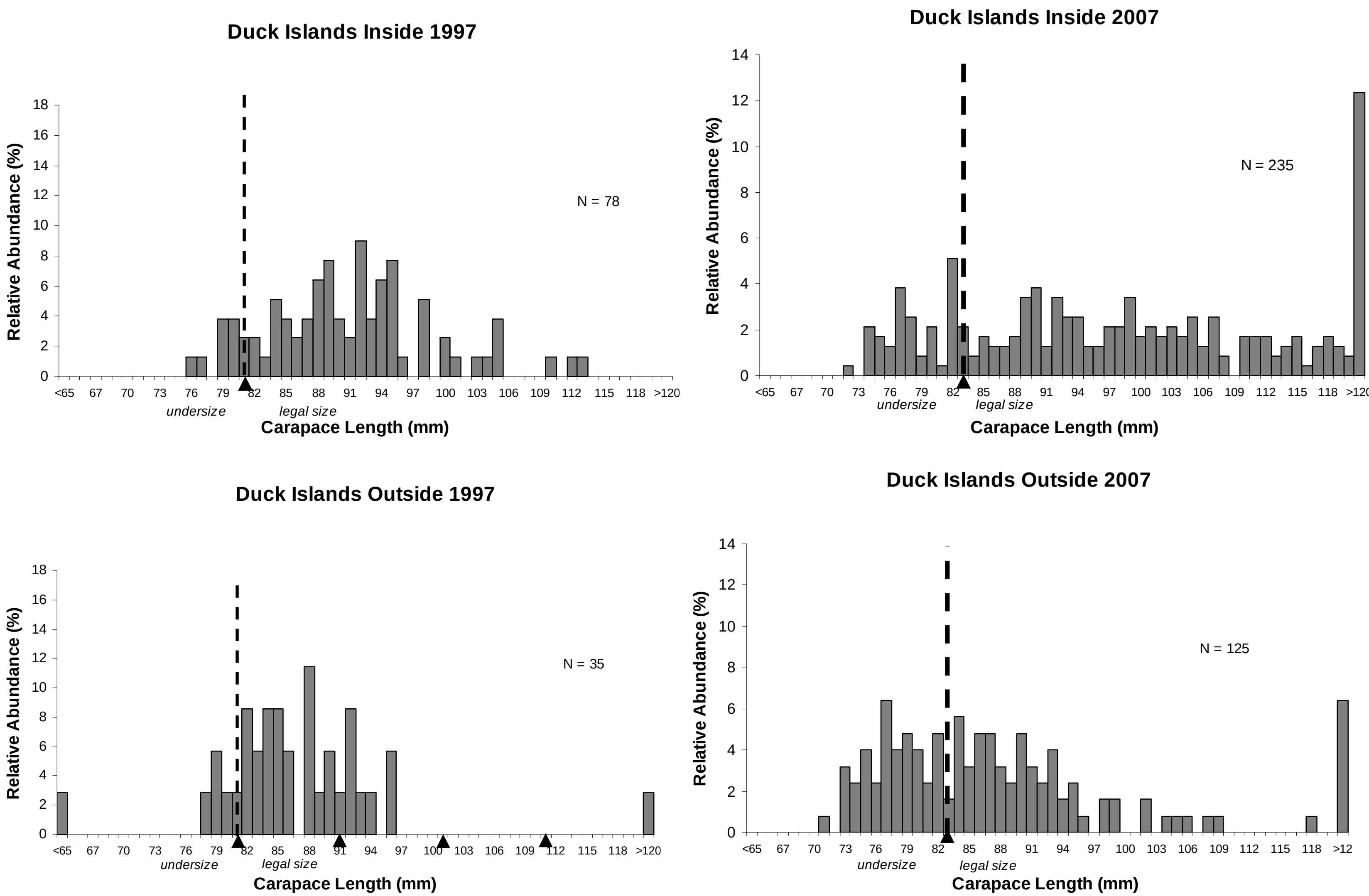



Figure 6. Carapace length frequency distributions of male lobsters inside and outside the Duck Islands Closed Area in 1997 and 2007; minimum legal carapace length (---).

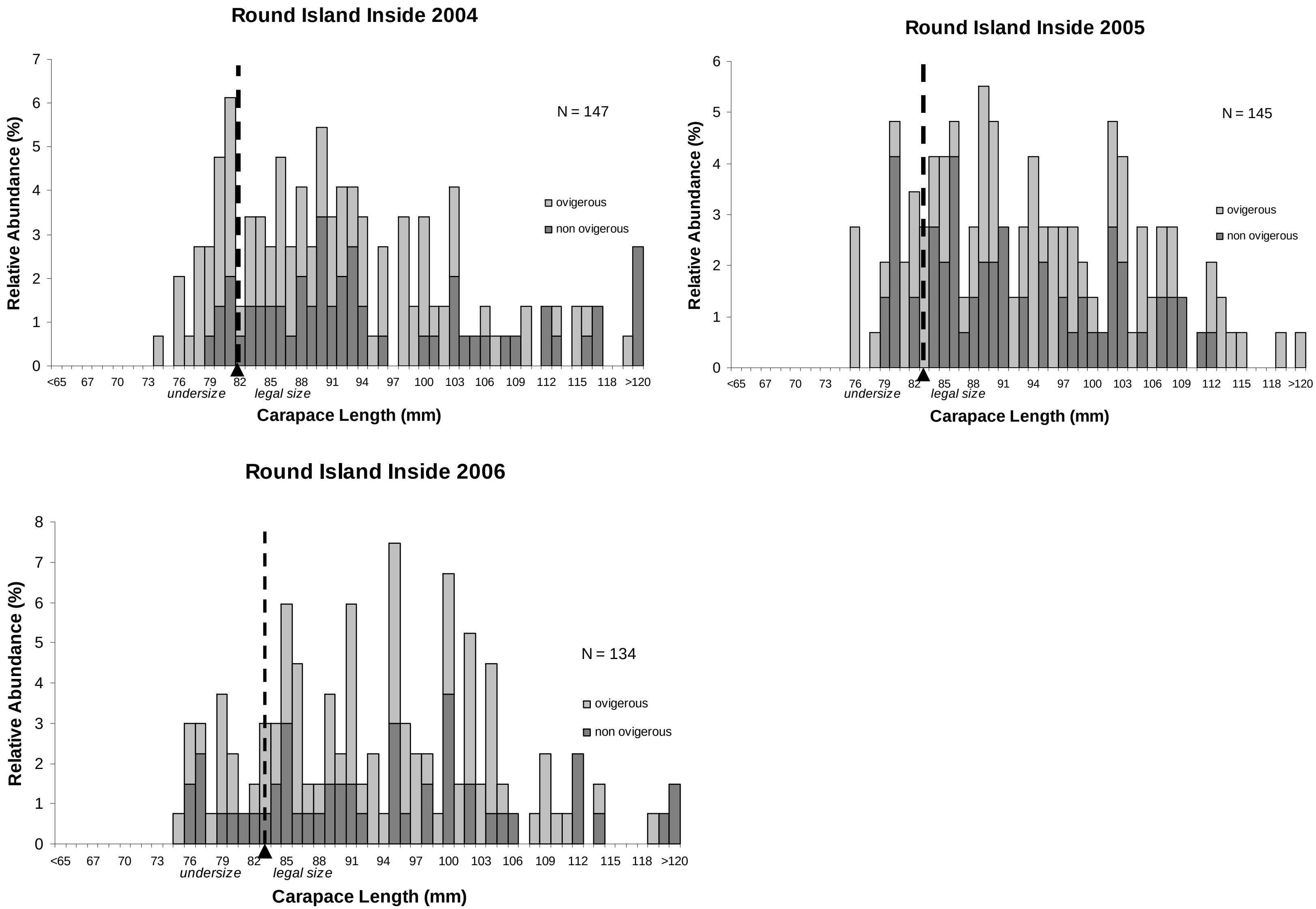



Figure 7. Carapace length frequency distributions of female lobsters inside the Round Island Closed Area in 2004, 2005 and 2006; minimum legal carapace length (---).

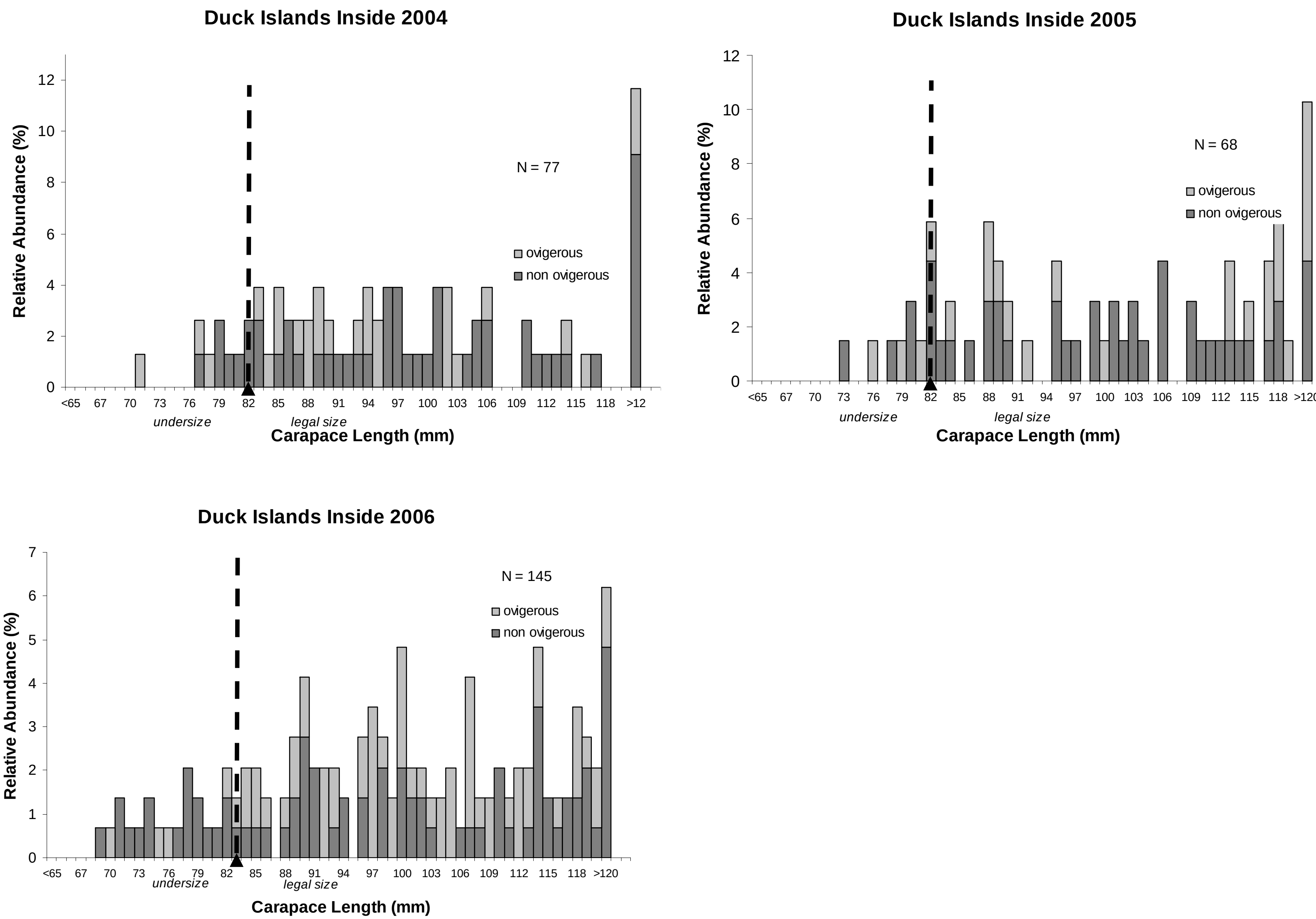



Figure 8. Carapace length frequency distributions of female lobsters inside the Duck Islands Closed Area in 2004, 2005 and 2006; minimum legal carapace length (---).

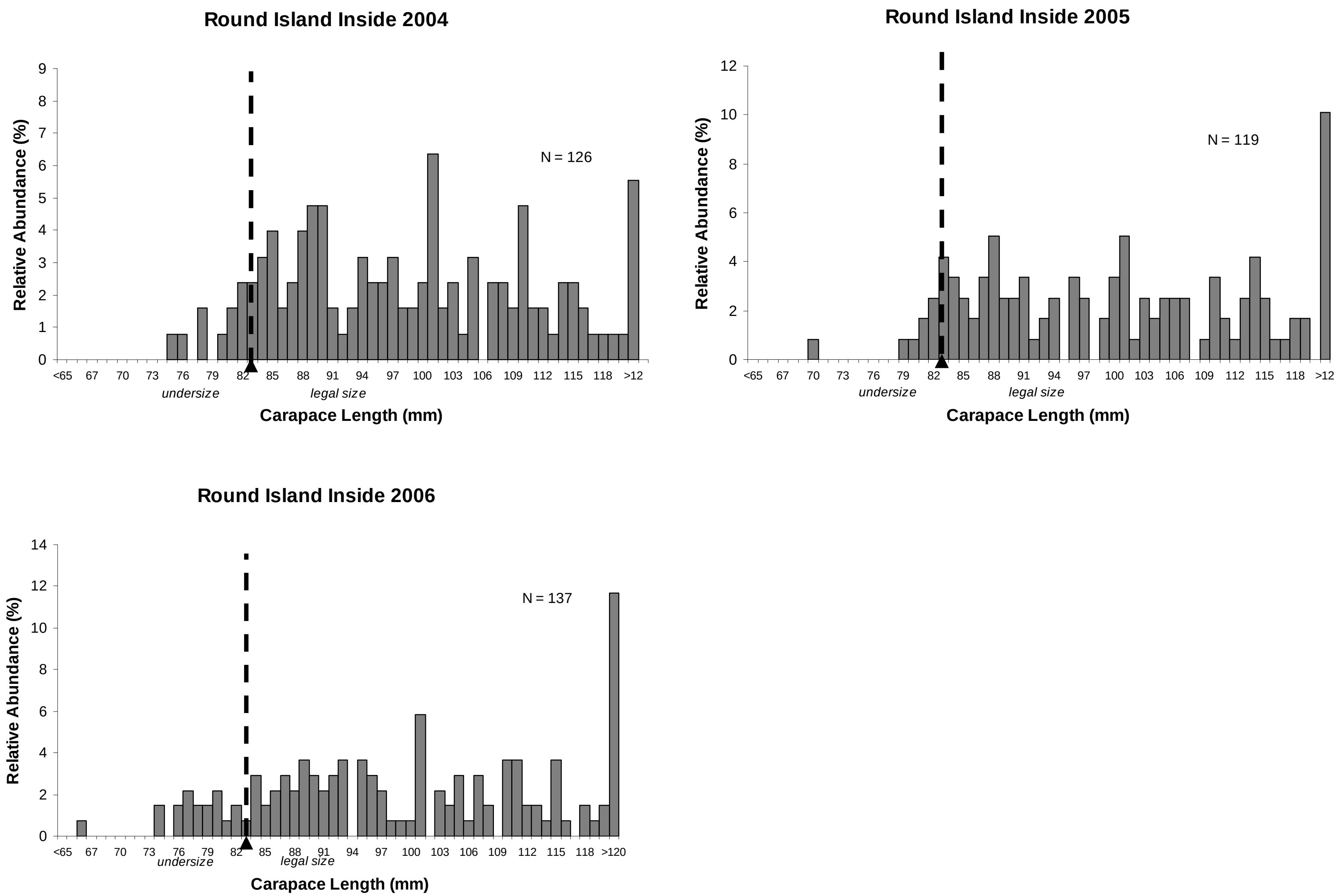



Figure 9. Carapace length frequency distributions of male lobsters inside the Round Island Closed Area in 2004, 2005 and 2006; minimum legal carapace length (---).

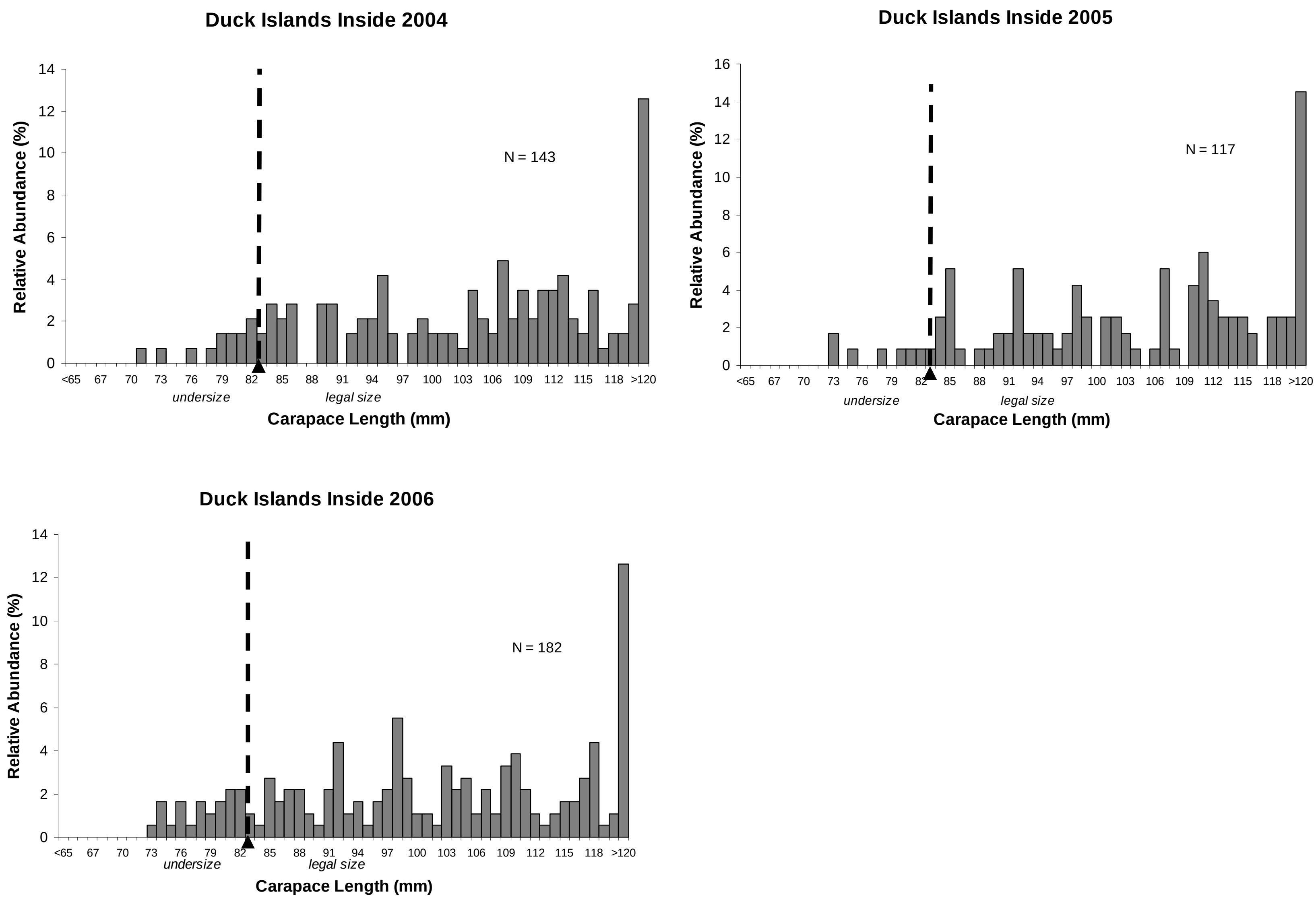



Figure 10. Carapace length frequency distributions of male lobsters inside the Duck Islands Closed Area in 2004, 2005 and 2006; minimum legal carapace length (---).

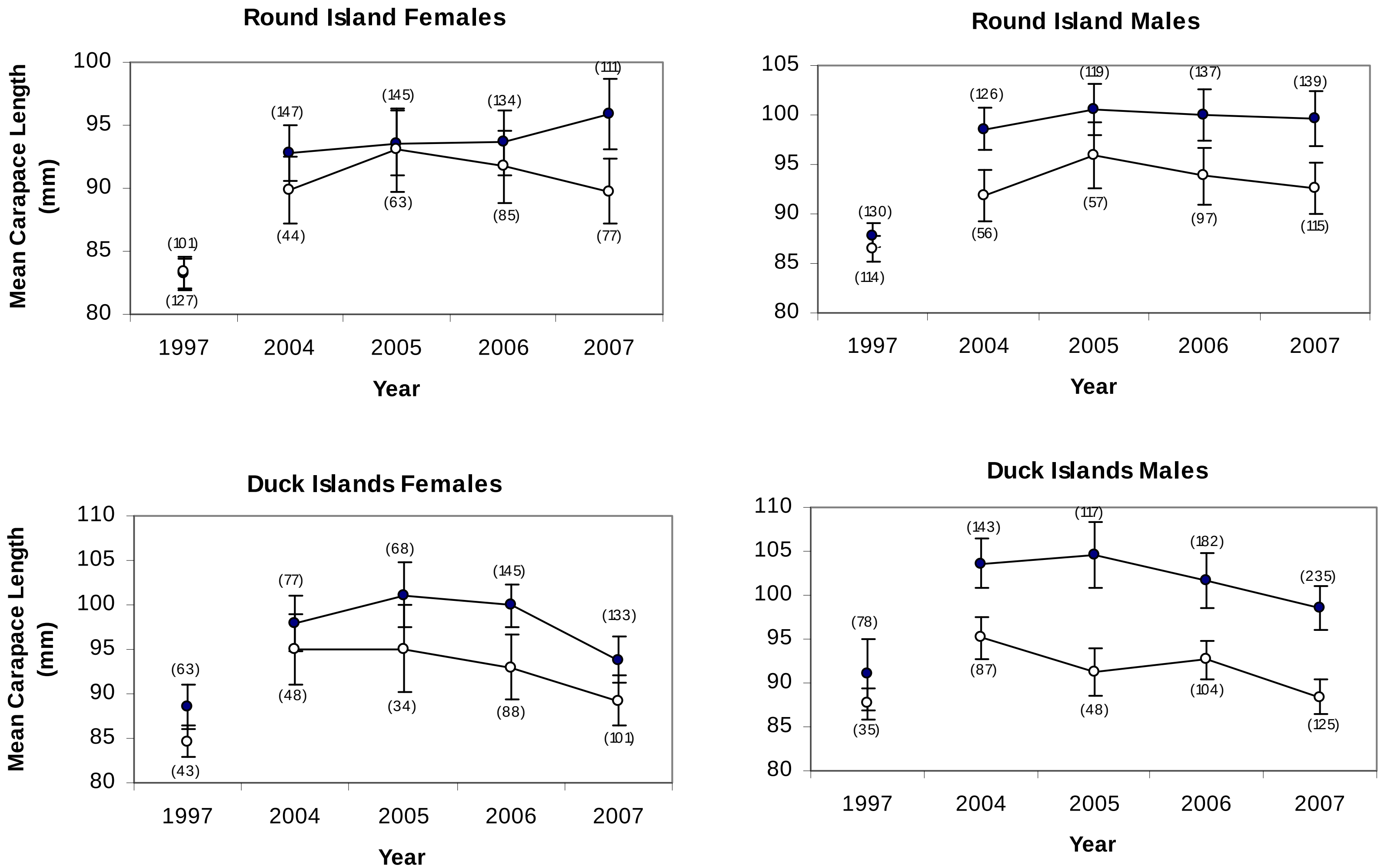



Figure 11. Mean carapace lengths of male and female lobsters with 95% confidence levels for Round Island and Duck Islands MPAs (●) and adjacent open areas (○) in 1997 and 2004-2007.

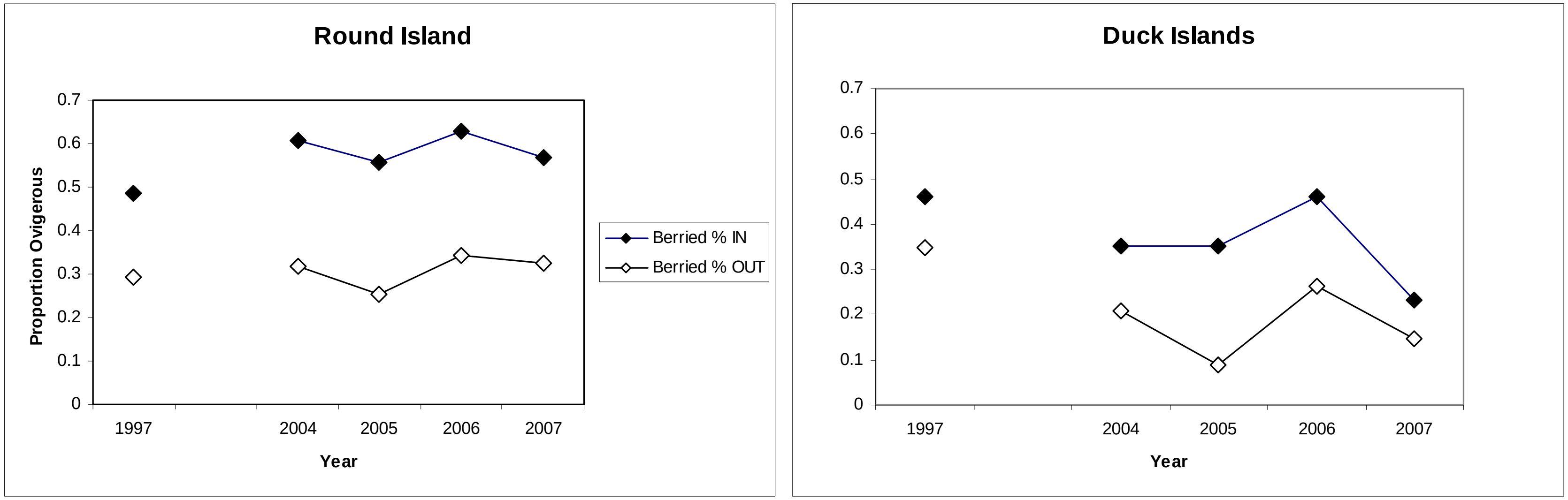
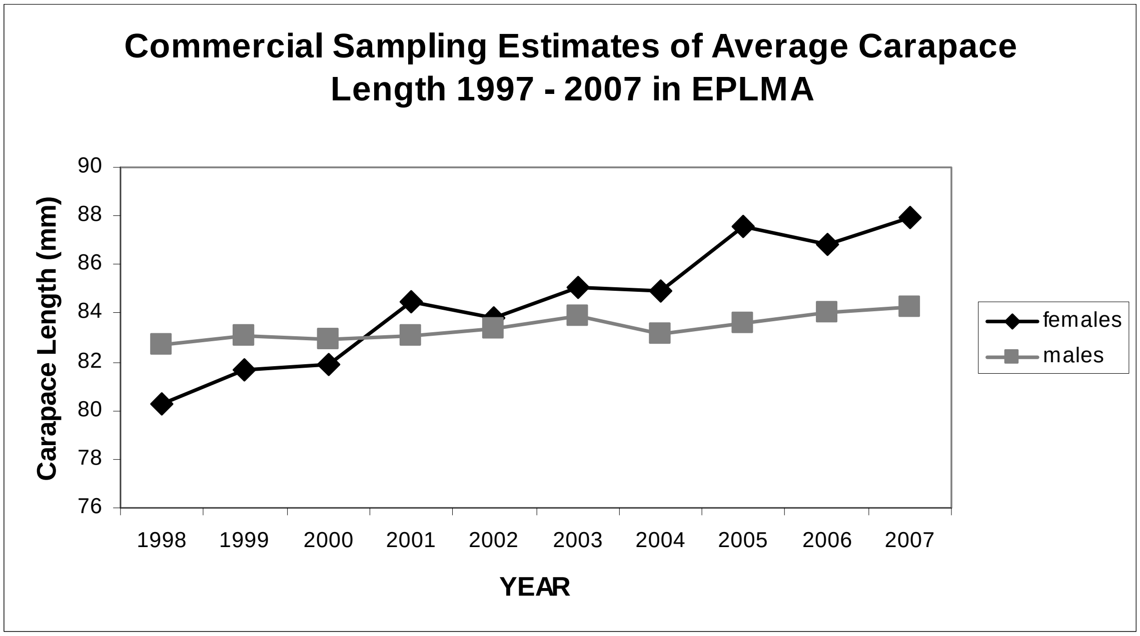
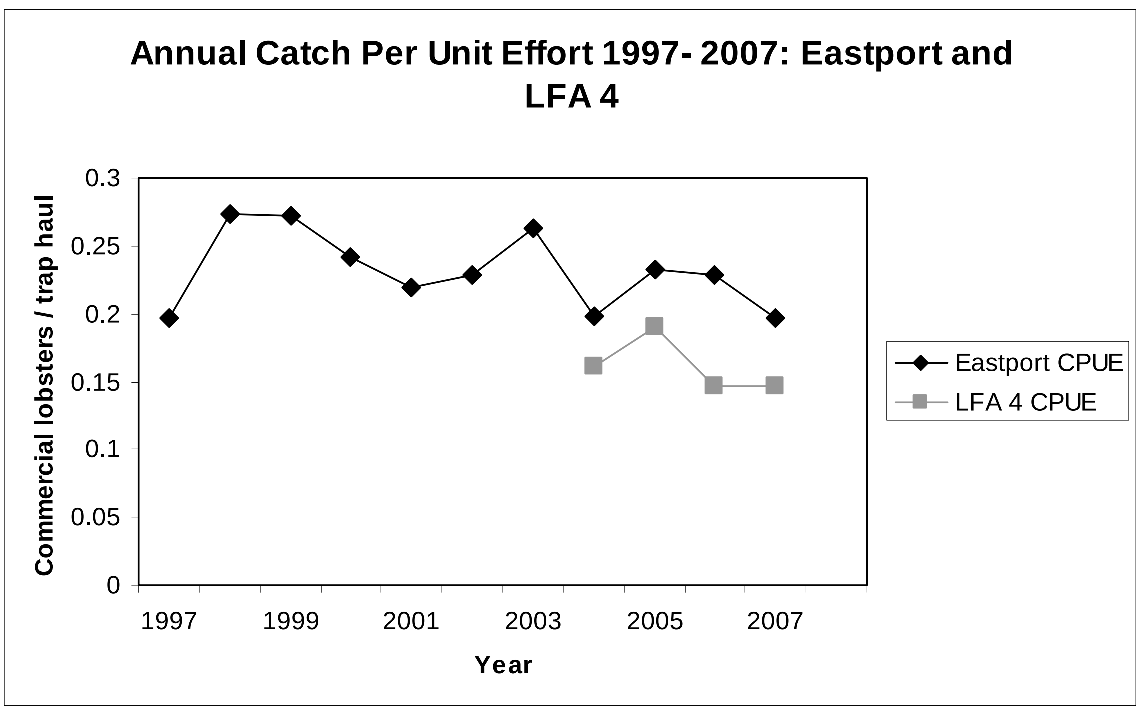



Figure 12. Proportion of ovigerous females inside (●) and outside (○) Round Island MPA and Duck Islands MPA in 1997 and between 2004 and 2007.

# APPENDIX 1


Commercial Sampling Estimates of Average Carapace Length 1997 - 2007 in EPLMA
Carapace Length (mm)
90
88
86
84
82
80
78
76
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
YEAR
females
males


Annual Catch Per Unit Effort 1997- 2007: Eastport and LFA 4
Commercial lobsters / trap haul
0.3
0.25
0.2
0.15
0.1
0.05
0
1997
1999
2001
2003
2005
2007
Year
Eastport CPUE
LFA 4 CPUE