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An assessment of the biological indicators for the Eastport Marine Protected Area (MPA): A case study in support of an ecosystem goods and services valuation of MPAs

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The Eastport Marine Protected Area (MPA) was designated in 2005 as part of Canada's overall MPA Network under the *Oceans Act*. Data have been collected continually since 1997, representing a rich data source related to the main conservation objective: protection of a viable lobster fishery. As such, it was selected as a case study in the determination of ecosystem goods and services (EGS) valuation for MPAs. Biological indicators are required to inform the process including: abundance, size structure, estimate of berried females and the catch per unit effort as compared to other areas without protection. This research document provides an analysis of the required data, as available, for the EGS study and ancillary information that can help to provide context and further scrutiny where applicable or required.

It was determined that overall there was no measurable effect on the lobster MPA when comparing lobster at the Lobster Fishing Area (LFA) level against four selected indicators. There were modest differences between the Eastport area (LFA 5) compared to LFA 4B (Northeast Coast), whereas no major differences could be detected between LFA 5 and LFA 10 (Placentia Bay). Effects of the protection measures are evident at the local level, with larger females being produced and retained within the population, but the effects may be the result of other conservation measures not associated with the MPA designation. However, due to the documented life cycle of a lobster, if any substantial changes are likely to occur, they will be realized within the next several years.

Évaluation des indicateurs biologiques pour la zone de protection marine (ZPM) d'Eastport : étude de cas à l'appui de l'évaluation des biens et services liés aux ZPM

RÉSUMÉ

La zone de protection marine (ZPM) d'Eastport a été désignée en 2005 dans le cadre du réseau global de ZPM du Canada, établi en vertu de la *Loi sur les océans*. Des données ont été recueillies de façon continue depuis 1997, ce qui constitue une excellente source de données pour le principal objectif de conservation : la protection d'une pêche au homard viable. À ce titre, elle a été choisie pour faire l'objet d'une étude de cas visant l'évaluation des biens et services liés aux ZPM. Des indicateurs biologiques sont nécessaires pour guider le processus, notamment : l'abondance, la structure par taille, l'estimation des femelles œuvées et la capture par unité d'effort par rapport aux autres zones sans protection. Ce document de recherche fournit une analyse des données requises disponibles pour l'évaluation des biens et des services, et des renseignements complémentaires qui peuvent contribuer à l'établissement du contexte et à la réalisation d'un examen approfondi, le cas échéant.

De manière générale, il a été déterminé qu'il n'y a pas d'effet mesurable sur la ZPM du homard lorsque l'on compare les homards à l'échelle de la zone de pêche du homard (ZPH) par rapport à quatre indicateurs choisis. Il y avait de légères différences entre la zone d'Easport (ZPH 5) et la ZPH 4B (côte nord-est), alors qu'aucune différence majeure n'a pu être détectée entre la ZPH 5 et la ZPH 10 (baie Placentia). Les effets des mesures de protection sont évidents à l'échelle locale : des femelles plus grosses sont produites et préservées au sein de la population. Toutefois, les effets pourraient être le résultat d'autres mesures de conservation qui ne sont pas liées à la désignation de la ZPM. Cependant, en raison du cycle de vie documenté d'un homard, si des changements importants devaient se produire, ils auraient lieu au cours des prochaines années.

INTRODUCTION

PURPOSE

In 2012, the Office of the Auditor General concluded a Performance Audit of Biodiversity - Marine Protected Areas (MPAs). One of two key recommendations for Fisheries and Oceans Canada (DFO) was that the Department “identify specific ecosystem services provided by existing and planned MPAs and assesses their values to better understand their benefits and costs”. In recognition of the complexity of this work and capacity/resource constraints, the Department committed to undertake a benefits valuation case study of an existing MPA by March 2014. The site selected was the Eastport MPA, located off the East Coast of Newfoundland. The Eastport MPA’s primary conservation objective is to maintain a viable population of lobster through the conservation, protection, and sustainable use of resources and habitats (DFO 2013).

The valuation study of ecosystem goods and services (EGS) in the Eastport MPA can be approached using two methods:

Estimating the incremental impacts “with” and “without” the MPA in the same geographical area, requiring data from 1995-2020; or

Using different geographical areas to compare the productivity for the time series 2005-20. Given data constraints and the need for a MPA assessment well before collection of 2020 data are possible, there are challenges using both approaches. This document presents a review and analysis of available data, based on the indicators identified as appropriate metrics for use in the EGS analysis, including:

a) Estimates of abundance;

b) Catch per unit effort (CPUE);

c) Estimates of berried females; and

d) Size distributions.

The study focused on Lobster Fishing Area (LFA) 5 in which the Eastport MPA is located, in relation to other LFAs without reserve status. Where appropriate, it assesses trends in the status of the Eastport lobster population against identified indicators. It also extends the analysis to include local effects of protected and unprotected areas within the Eastport Lobster Management Area (EPLMA) where possible.

AMERICAN LOBSTER

The American Lobster (*Homarus americanus*) is a relatively long-lived, cold water shellfish that occurs along the west coast of the Atlantic Ocean, from Newfoundland to Cape Hatteras. Adult lobsters prefer rocky substrates where they can find shelter, but also live on sandy and even muddy bottoms, with total lifespans of more than 30 years (Lawton and Lavalli 1995). Commercial concentrations generally occur at depths less than 50 m. Lobsters require 8 to 10 years to reach a carapace length (CL) of 82.5 mm, which is the minimum legal size limit for Newfoundland (Collins et al. 2009). Growth is achieved through molting. Molt frequency depends on the age of the animal and on water temperature, but lobster might molt 15 to 20 times before reaching reproductive maturity (Wilder 1953). The molting frequency decreases as lobsters age; with large lobsters molting once every few years. Mating occurs after they molt in July to September, and the female extrudes eggs that remain in the clutch for approximately 9-12 months subsequent to mating (Ennis 1995). The clutches are on the underside of the abdomen where the ovigerous (egg-bearing) animal protects and maintains the eggs. Fecundity of females increases on a logarithmic scale, with body size and eggs from larger lobsters tend to contain more energy per unit weight than those of smaller females indicating that eggs from larger females are more viable (Attard and Hudon 1987). First time spawners can produce nearly 8,000 eggs while larger, mature females measuring 127 mm CL have been found to produce up to 35,000 eggs (Currie and Schneider 2011). Some larger females can spawn for two consecutive years before molting (Aiken and Waddy 1986).

Hatching occurs during a four-month period extending from late May through most of September, and newly hatched prelarvae undergo an initial molt to Stage I before release by the ovigerous female (Ennis 1995). Following release, larvae swim upward and undergo a series of three molts during a 6-8 week planktonic phase, during which most mortality is thought to occur (Ennis 1995). Survival from the larval stage to the initial benthic stages is impacted by predation as well as by transport and advection which can retain the larvae near areas that are favourable to benthic settlement or disperse them into unsuitable habitats (Butler et al. 2006). During the third molt, a metamorphosis occurs and the newly developed post larvae (Stage IV) transition from pelagic to benthic. Lillis and Snelgrove (2011) demonstrated that water flow can significantly influence lobster postlarval settlement on complex habitat types (i.e. cobble).

Ennis (1984a) reported that lobsters can be both transient in nature and territorial throughout the winter months. It is common for individual lobsters to return to certain shelters. Ennis (1984b) also found that in St. Chad's (Bonavista Bay, Newfoundland and Labrador (NL)) lobsters appeared to be localized within 1 km of where they were tagged and released. Adult lobsters have few known natural predators with commercial harvesting accounting for most adult mortality. Lobster diet typically consists of rock crab, polychaetes, molluscs, echinoderms, and various finfish (Collins et al. 2009).

BACKGROUND OF EASTPORT MPA

The lobster fishery in Newfoundland has traditionally been based out of small open boats operating along the shore, and within a limited distance from home ports. Declining trends in landings for the Northeast Coast led a group of stakeholders in the Eastport, Bonavista Bay area to join together to form the Eastport Peninsula Lobster Protection Committee in 1995. Their efforts led to the voluntarily closure of two areas known to be productive lobster habitats: Duck Island and Round Island. Their preliminary goal was to prevent a collapse of the local lobster fishery. In 1997, a formal co-management agreement with DFO defined the Eastport MPA and it was officially designated under the *Oceans Act* in October 2005. There are two primary conservation objectives:

- To maintain a viable population of American Lobster through the conservation, protection and sustainable use of resources and habitats within the EPLMA;
- To ensure the conservation and protection of threatened or endangered species.

It should be noted that there are no known concentrations of threatened or endangered species within the EPLMA or Eastport MPA and no management measures have been undertaken to date. The greater EPLMA consists of 400 km^2 (Figure 1) while the specifically designated *Oceans Act* MPA is 2.1 km^2 consisting of the coastal area surrounding Round Island and Duck Island.

Within the MPA area, no fishing occurs without approved permits from the DFO Oceans Program. The management measures specifically designed for the EPLMA include:

- The fishing season (early May to early July) prohibits harvesting during peak molting and mating periods;

- Commercial lobster fishing within the inner zone of the EPLMA is restricted to the lobster harvesters from the Eastport Peninsula communities as a condition of license;
- Each harvester has a 150 trap limit (reduced from 200 in 2008);
- Mandatory trap tags, which aid in enforcement.

Management measures for all lobster harvesters throughout the NL Region:

- Traps must meet certain specifications: trap dimensions and opening size limit to prohibit the number/size of lobsters captured;
- Minimum legal size (MLS) of the CL is set at 82.5 mm to allow female lobsters an opportunity to reproduce before they reach commercial age (Note: minimum size was increased from 81 mm in 1998);
- Release of ovigerous (egg-bearing) females enhances the reproductive potential of the population.

Another voluntary conservation measure known as v-notching, has been implemented in the Eastport area and throughout the NL Region. A v-shaped notch is clipped in the second right tail fin of berried (egg-bearing) females. Although v-notching is voluntary in the NL Region, it is illegal to possess a v-notched lobster and harvesters can be fined for retaining them. The mark remains visible for several molts and protects the lobster in alternate years when it is not egg-bearing. The goal of v-notching female lobsters is to delay harvest of known reproductive females for additional molt cycles, thereby increasing its likelihood of contributing eggs to the population while remaining protected from harvest (DeAngelis et al. 2010).

There are 15 LFAs in the NL Region (Figure 2). The LFAs are sub-divided into statistical sections for reporting of landings and commercial fishery data. Overall, the Newfoundland fishery has remained relatively stable since the 1960s to present day, with reported landings ranging from 810 t to 3,080 t (Figure 3). Prior to the 1920s, the reported landings in the lobster fishery reached a high of 7,950 t.

This research document analyzes the existing data at two spatial scales: large scale which includes the LFA-wide effects using commercial at-sea sampling; and local scale of protected and unprotected areas within the EPLMA using tagging data. Both scales were deemed appropriate for this analysis because within LFA 5, all data stemming from the commercial at-sea sampling program is derived from within the EPLMA.

There is limited data available for an area without MPA protection within LFA 5, to make a viable comparison. Therefore, it was necessary to use an equivalent LFA, which requires a larger scale. The Eastport MPA is located in LFA 5 while Notre Dame Bay is located in LFA 4B and Placentia Bay in LFA 10. LFA 4B is located north of the MPA and would not likely be influenced by larval spillover effects of the MPA because the prevailing currents flow in a southerly direction (Pepin and Helbig 1997) and it is similar in geography, geology and bathymetry to the Eastport Area making it a viable comparison. The Placentia Bay lobster fishery, located on the opposite side of the Avalon Peninsula, has had a similar long-term trend to both Notre Dame Bay and Eastport Area in that it has steadily decreased since the early 1990s (DFO 2014a). It is also the next closest LFA to Eastport Area that has a sufficient quantity of data, with similar geographic features that would not likely be influenced by the MPA.

Existing information at the local level is primarily from the fall sampling program initiated by the DFO Oceans Program. The local analysis is useful in measuring population characteristics but is difficult to attribute an economic valuation to the data as there is no fishing within the MPA as a result of management measures.

DATA SOURCES

This evaluation utilized several data sources dependent on the indicator under study and the type of information required. The following section details the types of data employed.

Commercial at-sea sampling

The commercial at-sea sampling program employs observers to record daily catches aboard fishers' boats in specific locations around the province. Where possible, every trap is sampled and CLs of all lobster, both commercial and non-commercial, are recorded, to the nearest millimeter using Vernier calipers. Lobster measuring MLS = 82.5 mm CL are recorded as 83 mm CL for consistency in estimations. Animals are placed into one of seven categories based on sex, reproductive condition and, if female, presence or absence of a v-notch (Table 1).

From this data, average size CL was calculated for males and females as well as several biological indicators such as size range of males and females, sex ratio, and fecundity among other indices. With respect to LFA 5, this data has been collected annually since 1998 during the commercial fishing season from May-July and is divided into three areas within the EPLMA (Figure 4). The data has been collected since 2004 in LFA 4B and 2005 in LFA 10. It should be noted for clarity that in LFA 5, every third trap is recorded, however in other LFAs, every trap is recorded.

Logbooks

Catch data were analyzed from DFO and Index logbooks (i.e. logbook data from index fishers). Throughout the commercial lobster fishing season, index fishers collect daily information including the number of legal size lobster, traps hauled, ovigerous females caught, and undersize males and females caught. Logbook data provides information useful for estimation of the performance of the overall fishery, known as catch per unit effort (CPUE). The initial index logbook program was implemented during the development of the MPA from 1997-2003 overseen by DFO Science. Following MPA designation, the logbook program was maintained by the DFO Oceans Program from 2004-09. In 2010, mandatory logbooks were introduced by DFO for the lobster fishery throughout the NL Region and are maintained through DFO Fisheries Management. Index fishers return logbook data to DFO under authority of Section 61 of the *Fisheries Act* and are a condition of license. Index logbook data are available for LFA 4B and 10 since 2004.

Fall sampling

The fall tagging study within the EPLMA was implemented in 1997 to provide fishery-independent data to monitor the MPA. It includes 50 commercial traps for each MPA (i.e. 25 inside the protected area and 25 in the unprotected area for Round Island and Duck Island respectively for a total of 100 traps) that are sampled daily for three to five weeks with release of all caught lobsters. No data were collected in 2003 (Figure 5).

A review of the Eastport MPA monitoring program was conducted in 2011 to determine whether the indicators, protocols and strategies were sufficient to assess the impact of the MPA (DFO 2014b). As a result of the review, 80 modified traps (40 targeting sublegal, 40 targeting very large lobsters or jumbos) were introduced in 2011 and expanded in 2012 to target the sub-legal and jumbo lobster population as well as the commercial component of the catch (DFO 2014b). However, these modified traps were not taken into account during the present analysis as scale of the modified time series was inadequate for inferences based on two years. In addition, DFO (2014b) recommended expansion of the reference or unprotected areas to incorporate sites farther removed from the MPA to ensure the spillover effect of the protection measures would not confound results. As indicated in Table 2, modification of the unprotected areas has occurred throughout the entire monitoring program.

As part of the sampling protocol, a streamer tag is inserted with the aid of an attached embroidery needle into the thoracic-abdominal membrane and abdominal muscle on one side and threaded over the dorsal artery and through the abdominal muscle on the opposite side, as described by Moriyasu et al. (1995) and depicted in Figure 6. Animals greater than 100 mm CL are tagged through one muscle band. Fish harvesters tag and record information on CL, gender, berried status, v-notch status, tag numbers, trap number, and area caught or recaptured. Following tagging, the lobsters are immediately released. These lobsters are fished inside and outside the MPA boundaries in specified areas in concordance to predetermined locations as part of the management and monitoring plans.

Fall tagging data provides a basis to quantify the movement of lobster inside and outside the MPA and a better understanding of the immediate impacts of the MPAs on the adjacent habitats, or spillover effects. However, it should be noted that the shedding rate for streamer tags in the field have been found to reach 18% (40% for molted animals and 11% for non-molting animals) after 8−12 months based on double tagging with a secondary carapace marking (Ennis 1986; Rowe and Haedrich 2001). Streamer tag shedding was not related to sex or size, but these studies did not assess the level of tag-induced mortality. However, the fall tagging data remains a valuable data source as long as these caveats are included for estimates in abundance and survival would be biased which can be remedied by adjusting the estimates accordingly. The tagging data were used to generate estimates on abundance, survival and capture probabilities and population density within the MPA (see Analysis). These data were also used to determine any changes in the size of lobsters within the protected and unprotected areas.

Landings

The reported landings are provided by the DFO Statistics Division, Policy and Economics Branch and are utilized to determine trends in the fishery. These values can be useful in comparing areas and the fishery performance throughout the island. Statistical Sections are used to divide the LFAs for further comparisons when appropriate. The landings are derived from the receipts at the processing plants as well as sales purchase slips and vendor slips; however, reporting of lobster landings is not mandatory in NL nor do the values account for poaching or fishers who sell their catch privately resulting in the underestimated totals by an unknown amount. It should be noted that while other analyses were conducted to determine any local effects using the landings data based on Statistical Sections, DFO can no longer report landings and catch information if a data set has fewer than five fishers, vessels, or buyers to ensure that private information cannot be extracted from the data. Therefore, the results of the analysis based on Statistical Section cannot be published.

ANALYSIS

The request for science advice required the analysis of the Eastport MPA be compared with another area without protection and not influenced by MPA conservation measures, or spillover effects. To enable this request, the analysis is conducted on two spatial scales. Data are compared for LFA 5 with LFAs 4B and 10, and then where appropriate, the analysis is extended for the Eastport MPA, specifically, inside and outside the protected areas as described in Figure 5. The adjacent unprotected area does not provide sufficient distance to assess the incremental impacts without the potential for spillover from the MPA.

INDICATOR #1 – ESTIMATE OF ABUNDANCE

Management Areas

Exploitable Biomass Estimation

The EGS study requires an estimation of abundance of lobster in the protected area and another area, not impacted by MPA management measures. Abundance indicators typically include landings recorded from processing plant purchase slips, catch rates of commercial size lobsters from sampling surveys and logbooks and densities from trawl surveys. Fishery independent data such as trawl surveys are unavailable for the Newfoundland lobster fishery; therefore, an alternate method is required to provide a proxy for the abundance values for LFA 4B, 5 and 10. Tremblay et al. (2012) reported strong evidence that suggests landings can reflect the commercial biomass for lobster in the Maritimes Region based on the positive relationship between landings and trap catch rate (or CPUE) and correlation with the number of lobsters per trawl set in a trawl survey. However, there are uncertainties and caveats identified in using this biomass proxy which include (Tremblay et al. 2012):

a) Landings are affected by factors other than abundance such as management rules, number of trap hauls, soak days and fishing strategy;

b) Landings cannot reflect trends in abundance of prerecruits and ovigerous females;

c) Changes in fishing effort may bias interpretation if not taken into account;

d) Efficiency in fishing due to larger boats, improvements in technology, etc. may also bias interpretation;

e) Landings are responsive to regulation changes; and

f) Accurate landings are reflective of accurate records from industry.

At the time of this analysis, there were no published working population models for Canadian lobster that provide estimates of total biomass based on the available data that were applicable to the Newfoundland case study (Smith et al. 2012). However, landings are considered the most appropriate proxy for exploitable biomass in the three LFAs given data availability with the caveats in place. Therefore, the following analysis utilizes exploitable biomass as a proxy for abundance. It should be noted that the exploitable biomass, by definition, represents the legal size, non-ovigerous portion of the population.

A 2013 stock assessment for American Lobster in the Newfoundland Region (DFO 2014a) clustered LFAs into four areas to provide an analysis on a regional basis, enabling conclusions on a broader scale namely, Northeast (LFAs 3-6), Avalon (LFAs 7-10), South Coast (LFAs 11-12) and West Coast (LFAs 13-14), based on trends in landings and their magnitude (Figure 8). The Northeast and the Avalon areas have seen steady declines in landings since the late 1970’s whereas the South Coast and West Coast have continued to increase. DFO (2013) reported total landings increased by 70 % from 1,760 t in 2000 to 3,000 t in 2008 before declining by 28 % to 2,150 t in 2012 resulting from a decrease in the Northeast and Avalon regions and an increase in the South and West Coasts. The reported landings have become spatially concentrated. The contribution of the most productive LFA to the reported landings (i.e. LFA 11) has increased from less than 15 % in the early 1990s to around 45 % from 2010 to 2013.

A comparison of reported landings for LFAs 4B, 5 and 10 indicates there is variation prior to the late 1990s; however, the trend in the recent past is consistently downward across the region. Both LFA 4B and 10 had substantially higher landings than LFA 5 during 1974-94, a period of decline in the landings of the lobster fishery in eastern Newfoundland. Throughout the same period, LFA 5 remained relatively stable. From 1998-2012, there was no significant difference in landings by LFA and by year [Two-way ANOVA: Year F=1.801, p<0.05 | Area F=4.154, p<0.05]. The Tukey Honest Significant Difference (HSD) method comparing the means of the three groups showed that LFA 5 and LFA 10 are not significantly different (p=0.899), whereas LFA 4B differed from both the other LFAs (4B/5 p<0.05; 4B/10 p=0.057).

Eastport Lobster Management Area

Lobster Abundance

Data from the fall tagging study in the EPLMA provides a more comprehensive, localized perspective on changes in population abundance based on mark-recapture analysis using data from 1997-2012. Mark-recapture methods are used in a wide range of studies to quantify the spillover from marine reserves to fishery catches (Goni et al. 2010). Typical mark-recapture approaches can be categorized as closed or open population methods. The methods employed were first described in Jolly (1965), modified in Seber (1965), and are collectively referred to as the Jolly-Seber methods. These methods provide a technique for estimating abundance in a population where three or more samples of marked animals have been collected (Amstrup et al. 2005). The closed population method assumes, among other things, that the population remains constant with no emigration from the population. These assumptions would be violated in the case of the EPLMA as a result of the fishery, death and migration out of the area over the course of the 16-year study; therefore, an open population model was applied. The capture occasions are distinct in time and mortality occurs between them in open population models (Baillargeon and Rivest 2007). Also, by using the open population estimators, it is possible to calculate survival and capture probabilities and an estimate of the number of new arrivals which would be otherwise unavailable in closed methodologies.

Assumptions of the open population models include (Amstrup et al. 2005):

a) Every individual, marked or unmarked, has the same probability of being caught in the *i*th sample;

b) Every marked individual has the same probability of surviving from the *i*th to the (*i*+1)th sample (Note: if the survival rate estimates are to apply to all individuals of the population, not just the marked individuals, then the probability of survival must be assumed the same for both marked and unmarked fish);

c) Individuals do not lose their marks and marks are not overlooked at capture; and

d) Sampling time is negligible in relation to intervals between samples.

The mark recapture analysis was conducted using a method developed by Baillargeon and Rivest (2007) in R software; Rcapture uses Poisson regressions fitted with a generalized linear model (glm), where loglinear parameters are transformed into demographic parameters. The analyses generate estimates of survival which are used to derive capture probabilities, population size, the number of new units entering the population, and the total number of units inhabiting the survey area (Baillargeon and Rivest 2007). However, the current package does not account for trap effects. Trap effects can produce positive or negative bias in population estimates if animals avoid traps, or migrate towards them (Amstrup et al. 2005). It should also be noted that it is not possible to separate survival from emigration or recruitment from immigration without additional information.

The data requires transformation into a capture history data matrix of zeroes and ones to represent an animal was captured in a specific sampling event. For example, the capture history of 01011 represents an animal not captured during the first event, but subsequently caught during the second, fourth and fifth events. Differences in size and sex are not considered in this analysis as a result of the transformation. The estimates of abundance, new arrivals survival and capture probabilities were estimated using the fall tagging data which were available from 1997 to 2012, excluding 2003. To accomplish these analyses, each sampling event was assigned a distinct event number for each sampling day (Table 3).

It was necessary to consider the lobster both inside and outside the protected boundaries to compare the effect of the MPA protection measures. Abundance estimates using the tagging data can only be conducted for the immediate Eastport area because no comparable surveys have been conducted in other parts of the NL Region during the required time period. Collins (2010) performed an earlier analysis on the Eastport MPA based on data from 1997-2008. The analysis considered several aspects of the lobster population and included an analysis of the tagging data using the Schumacher-Eschmeyer method, a closed mark-recapture method which does not consider new arrivals or mortality that may take place over the course of sampling as each year is considered separately. Also, Collins (2010) considered each separate area within the MPA (i.e. Round Island and Duck Island). The present analysis pooled the data to evaluate the overall effects of the protected/unprotected areas rather than focusing on differences among sites within the EPLMA. Ennis (1984a) conducted a mark-recapture study in Comfort Cove, Notre Dame Bay, during the 1970s and 1980s using methods including the Petersen-Leslie closed method, but the time period and scale of study preclude comparison with the Eastport data.

Capture probabilities were estimated by tracking the lobsters over the course of sixteen years. The capture probability was higher inside the protected area over time [Two-way ANOVA: Year $F=4.157$, $p<0.01$; Area $F=22.416$, $p<0.001$] as demonstrated in Figure 9. This difference could be attributable to the much smaller size of the protected area than the unprotected area, but sampling efforts were similar for both areas.

The survival probability of the protected lobsters was also higher than the unprotected lobsters over time [Two-way ANOVA: Year $F=2.65$, $p<0.05$ | Area $F=30.55$, $p<0.001$) (Figure 10). Higher survival probabilities are consistent with the objectives of establishing an MPA because with no exploitation, the only losses should be attributable to emigration and natural mortality. It is noted that the survival probability could be slightly higher than values by an unknown number owing to tag loss as well. The overall effect of protection from commercial exploitation was modest, however, because the average survival probability in the protected area was 0.64 in contrast to 0.45 in the surrounding unprotected habitats.

The abundance of lobster within the protected area remained relatively stable over the study period (Figure 11). An apparent increase since 2009 suggests the start of a potential trend, but the change is very recent and further data are required to evaluate its strength. Abundance estimates for protected and unprotected areas were not significantly different ($p=0.291$) but they were differences in considering years as a factor [Two-way ANOVA: Year $F=4.35$, $p<0.01$ | Area $F=1.21$, $p=0.291$].

There was no significant difference in new arrivals between areas ($p=0.156$) but there was a difference among years [Two-way ANOVA: Year $F=4.67$, $p<0.01$ | Area $F=2.29$, $p=0.156$]. Also, Figure 11 indicates slight variation in the number of arrivals. We note that the abundance estimates and the number of new recruits in both protected and unprotected areas follow the same trends of an apparent increase in 2010 and 2011, but it is too early to determine if the trend will be sustained in this analysis. Also, the numbers of new recruits differed significantly among years, but protection status had no significant effect. The observations provided no evidence that protection from commercial exploitation resulted in overall changes in abundance that differed from areas subjected to exploitation, despite potentially greater survival rates in protected areas. Patterns of variation in parameters derived from mark-recapture analysis suggest that processes operating at the scale of the EPLMA, or beyond, may be influencing overall patterns in abundance. Also, application of other protection measures to the entire EPLMA, such as v-notching and the increase in MLS, may lead to an increase in overall abundance and new recruits.

The population density was calculated using abundance estimates with the dimensions of each area as indicated in Table 2. Densities differed significantly over time ($p<0.01$). The protected area consistently supported higher lobster density (Figure 13) since the inception of the MPA, with similar pattern in year-to-year variations in both protected and unprotected areas. However, given the smaller size of the protected area, the sampling effort would have been greater inside the protected area potentially biasing the estimate.

Movements

Information derived from the tagging data also provides an opportunity to examine how lobsters move within the MPA. Analysis of this information can provide insight on patterns of movement of lobster and whether protection measures provide some spillover benefits to adjacent unprotected areas.

As reported by Janes (2009), multiple recaptures were common within the protected and unprotected areas. Overall, 651 lobsters of the possible 9,906 were tagged in both the protected and unprotected areas indicating movement during the study.

Overall, we observed multiple captures both inside and outside the protected areas. During the course of the 16 capture periods, several lobsters were recaptured far more than other lobsters. For example, one lobster was recaptured 16 times and two lobsters were recaptured 14 times. A summary of the frequency of recaptures is provided in Table 4 which shows that 61% of the lobsters tagged were never recaptured.

To analyze the results of the tagging movements, we constructed a four-way contingency table and a mosaic plot in the statistical software, R, to represent the categorical data in a meaningful way. Mosaic plot is a graphical method for visualizing data from two or more qualitative variables. It gives an overview of the data and makes it possible to recognize relationships between different variables. For example, independence is shown when the boxes across categories all have the same areas. Similar to bar charts, the area of the tiles, also known as the bin size, is proportional to the number of observations within that category.

The data was categorized by the following factors:

- Movement out of the animals' original capture location, regardless of whether it was inside the protected area (i.e. move or no);
- Location of the lobster (i.e. in and out of the protected area). We did not further divide the data to include differences in Round Island and Duck Island;
- Sex of the lobster (i.e. male or female); and
- The size category of the lobster based on four categories: 1 - <83 mm CL, 2- between 83-92 mm CL, 3 – 93-102 mm CL and 4 - >103 mm CL.

A Chi square analysis revealed significant differences among the categories ($p <0.001$). The mosaic plot (Figure 14) indicates that among other results, more males are tagged than females. Movement (in/out of the protected area) occurs more frequently in smaller individuals from the protected area.

The analysis was further refined to determine whether there were significant differences among the lobsters that moved. Figure 15 represents the relative size classification for males and females that moved inside or outside the protected areas. There does not appear to be a large variation in the proportions of sizes, regardless of sex or location.

A three-way contingency table of the frequency of movements between the protected and unprotected areas shows a slightly larger proportion of large males that move between the areas relative to other size groupings (Table 6). The analysis revealed significant interaction effects except for protected status and sex of the lobster. Therefore, there is a significant difference in protected males and females in their tendency to move among the different areas.

INDICATOR #2 – CATCH PER UNIT EFFORT

The CPUE index is typically used in fisheries as an indicator of abundance. In general, changes in the CPUE are inferred to represent changes to true abundance based on a non-standardized sampling approach. A decreasing CPUE can indicate overexploitation, whereas a stable CPUE could be indicative of a stable population.

The use of CPUE as an indicator has several advantages over other methods of measuring abundance. It does not interfere with routine harvesting operations, and can be easily collected from harvesters' records. The ideal practice involves the standardization of the effort employed (e.g. number of traps, duration of searching), which controls for the reduction in catch size that often results from subsequent efforts. The main difficulty when using CPUE is to define the unit of effort. In this analysis, the calculation of CPUE is not standardized for variation in water temperatures, for differences in fishing practices among fishers or for seasonal changes in fishing activity. Inconsistent participation in the logbook program used to estimate the data could also affect analysis.

Available logbook data within LFAs 5, 4B, and 10 and within respective statistical sections of the index logbook information was combined and CPUE (number of commercial lobsters per trap haul) averages were calculated and compared based on annual and weekly trends. The mean CPUE is calculated by summing the mean catch (by day, fisher, and area) and dividing by the sum of the mean number of traps for the same period.

Management Areas

CPUE has changed little over the time period for which data are available in the LFAs (Figure 16). It does not appear that the CPUE has differed substantially between the areas. There is, however, a slight increase in the index overall for all LFAs in the study since 2004. Analysis revealed a significant difference in the CPUE over time, but no significant difference among the LFAs [Two-way ANOVA: Year $F=2.841$, $p<0.05$ | Area $F=0.519$, $p=0.605$]. There was a difference when considering years as a factor, suggesting a change in CPUE over time. No significant differences among the LFAs were found when comparing each LFA separately [Tukey HSD 4B/5 $p=0.819$, 4B/10 $p=0.587$, 5/10 $p=0.865$].

Further analysis of CPUE by week of the fishery (Figure 17) shows that CPUE generally begins the season at a higher rate and then decreases throughout the fishing season in LFA 4B and LFA 5. CPUE in LFA 10 appeared relatively consistent over the course of the season with no substantial variation in the overall trend among years. The season was shorter in LFA 4B compared to LFA 5 and shorter still compared to LFA 10 likely due to the length of the season regulated for each LFA respectively.

Eastport Lobster Management Area

Variations in CPUE using at-sea sampling data (Figure 18) were also considered within LFA 5: St. Chad's (Area 1), Salvage (Area 2) and Happy Adventure (Area 3). The data indicate no consistent trend. Analysis suggests that the areas within the EPLMA differ significantly based on years and areas [Two-way ANOVA Years F=5.094, p<0.001 | Area F=8.552, p<0.05]. To further the analysis, the Tukey HSD test showed no significant difference between the Duck Island and Round Island locations respectively (p=0.925).

INDICATOR #3 – ESTIMATE OF BERRIED FEMALES

An estimate of berried females was also included in the request for science advice for the EGS study. This value is not typically estimated in stock assessments in the NL Region for lobster; therefore, using commercial at-sea sampling data and landings, the potential proportion of berried females within the exploitable biomass was calculated.

Interpretation of these values requires extreme caution. Berried females and undersized lobsters are not components of the legal catch and are not used in calculations of the exploitable biomass as described in the caveats noted from Tremblay et al. (2012). Therefore, the estimates provided here represent a theoretical value. It was deemed more meaningful to use the proportion of berried females within the population to estimate productive females from the commercial at-sea sampling data using the percentage of legal sized (CL >82.5 mm) berried females/total number of exploitable lobster measured within each LFA on an annual basis from the commercial at-sea sampling data.

Management Areas

Proportions of berried females appear consistent throughout all the LFAs as described in Figure 19. Within LFA 5, an increase in the proportion of berried females appeared to plateau in 2006 with little change. The percentage of berried females in LFA 10 from commencement of at-sea sampling appeared to initially decrease and then increase over the past two years. LFA 4B also increased slightly since the beginning of the monitoring period (i.e. 2004). Figure 20 describes the proportions of males, non-berried and berried lobsters within the population for each LFA. The proportion of berried females appears larger in LFA 10 than in LFA 5. Also, for all areas combined, it appears that males represent a larger component of the population overall. The percentages were compared statistically as well.

ANOVA analysis of percentages revealed significant year and LFA effects [Two way ANOVA: Years: F=2.97, p<0.05 | Area: F=7.315, p<0.05]. However, further analysis using a Tukey's HSD, showed that only LFAs 5 and 10 differed significantly at p<0.05. The comparisons related to LFA 4B yielded no significant differences for either area [Tukey HSD 4B/5 p=0.528, 4B/10 p=0.179].

To extend the analysis, the resulting percentage of berried females was multiplied by the reported landings for each LFA to estimate the hypothetical biomass of berried females within the landings (Figure 21). Commercial at-sea sampling data were limited for all areas within the LFA; however, we compared them for consistency. It appears that berried females are decreasing in all areas of the study, which corresponds with results on the exploitable biomass. We propose that the scale of increase in larger females is insufficient as a proportion of females to impact the figures.

Reproductive potential relationships

Another measure that can be used to quantify perceived impacts of the MPA involves the estimation of the production of viable larvae contributing to the population. With respect to the American lobster, fecundity is defined as the rate of egg release per year in those females that show eggs on the abdomen (Currie and Schneider 2011). The reproductive potential of lobsters is directly related to the fecundity of the animal in that larger females have been shown to produce larger, more viable eggs as noted above. Therefore, larger females have greater reproductive potential than smaller females.

The relationship for this index is described by the equation: $Eggs=\alpha(CL)^{\beta}$. The parameter α represents a scaling factor, CL represents the carapace length and β is a power law exponent (Currie and Schneider 2010). Several studies (Ennis 1980; Rowe 2001, 2002; Collins 2010; Currie et al. 2010) have used various estimates of the parameters α and β to compare the reproductive potential based on latitudinal variation and varying methods of counting eggs for the calculations, among other factors. The parameters used in Currie and Schneider (2011) were accordingly in LFAs for which there are specific estimates available, as indicated in Table 6b.

The length frequency distribution for each LFA and year was applied to the fecundity equation on the commercial at-sea sampling data. Figure 23 indicates a consistent trend for most years in most LFAs except for LFA 5. It appears there was a large proportion of contributing large females, preceding a drastic decline in the number of eggs produced per individual.

Eastport Lobster Management Area

Similar analyses were also completed for the EPLMA to estimate berried females. The commercial at-sea sampling data was used to obtain the proportions of various categories for St. Chad's, Salvage, and Happy Adventure. The tagging data are inappropriate for this purpose because sampling occurred following the shedding of eggs for some lobsters and prior to the extrusion of eggs for others; therefore, tagging data underestimates berried females.

We found consistent percentages of berried females throughout the EPLMA area and across the study period. The range of the proportion within the sampled population did not vary substantially and on average, the percentage of berried females varied little between the start and end of the survey period.

Comparison of proportions of reproductive groups across each individual sampling area indicated no substantial changes across the region for the proportions among the population over the study time

We estimated the reproductive potential using length frequency distributions for the areas within the EPLMA. As shown in the analysis presented for the broad management area level, the index increased over time. No particular area appears consistently higher than another, however, since the inception of the MPA management measures, results from the various areas trend consistently together.

INDICATOR #4 - POPULATION STRUCTURE/LENGTH FREQUENCY DISTRIBUTION

Management Areas

Size Distribution

Size distribution analysis can provide a perspective on change in a population over time. By studying the change in size distributions of the target species, it is possible to infer the consequences and effectiveness of management measures. Although they provide an indication of population size structure, careful use of the size-frequency distributions to determine relative abundance of undersized, ovigerous and v-notched animals is required. These components within the population can be overestimated as a result of potential bias in the sampling design. Unlike the commercial component of the catch, which is removed after the first capture, the non-commercial animals (undersized lobster, berried and v-notched female lobster) can be captured and recorded multiple times, particularly near the end of the season when the commercial component has been substantially depleted and removed from the fishery (Collins et al. 2009).

The relative size frequency distributions of all lobsters caught during commercial at-sea sampling were generated annually and expressed as percentages for both male and female components of the population (commercial males, commercial females, ovigerous females, and undersized) within LFAs 4B, 5, and 10.

There has been a general increase in larger females in LFA 5 compared to the other LFAs (Figures 33-36). Relative to animals in LFA 4B, the lobster population in LFA 5 include a sex ratio that appears skewed toward a higher proportion of females than other management areas. This pattern is evident in two aspects: the tail end of the distribution of the plots and the greater relative proportion of females captured during the at-sea sampling.

Most size frequency plots clearly show a sharp drop at legal size (CL=82.5 mm), with few lobsters achieving the second molt following this level. This pattern indicates that most of the exploitable biomass is caught in the year of recruitment to the fishery. However, at either end of the distribution for LFA 5, there appears to be more animals compared to the LFA 4B, and to a smaller extent compared to LFA 10. LFA 10 appears to support a larger second molt class through the years, especially for males. There appears to be a sporadic nature to the trends in frequencies in the size distribution for LFA 4B compared to other areas. It should be noted, however, that the amount of lobsters caught in each year directly affects the frequency plot representation.

Average Carapace Length

Average CL of males, females and berried females obtained from commercial at-sea sampling data for all three LFAs offers another indicator of change in size that can be analyzed with the available data (Figure 31). The average size of females in LFA 5 increased post-1998 with limited evidence of a plateau since 2004, whereas the limited data from other LFAs indicates that average size of females has remained relatively stable from 2004 to present in LFAs 4B and 10. The males have been relatively stable in the three LFAs. The trend for berried females follows the similar trend for females in all LFAs.

By comparing the same data for each category against all three LFAs, LFA 5 exhibited the most consistent incremental increase CL over time for non-berried females and berried females. The size of sampled males in LFA 4B and 10 appear to be more sporadic.

An ANOVA comparing year, LFA, and category (i.e. male, female, and berried) revealed significant differences in average CL for year and category [Year: $F=7.715$, $p<0.001$; LFA:

F=1.145, p=0.241; Category: F=9.274, p<0.01]. Using time as a factor, a difference was shown in overall average CL. A Tukey's HSD test found no significant difference in females and berried females; however, males were significantly smaller than both categories of females (p=0.402).

The average CL was also compared within each LFA by males, females and berried females and then between each LFA.

Sex Ratio

The sex ratio was calculated from commercial at-sea sampling data using the ratio of males to females, regardless of whether females were egg-bearing. Measures implemented in the MPA to protect ovigerous females such as v-notching and releasing berried females should increase the number of females in the population.

The sex ratio for each LFA suggests a slight decline in the ratio of males to females for all LFAs (Figure 33). A single factor ANOVA found no significant difference in the variation of sex ratio for the LFAs (F=0.481, p=0.623). A difference might be expected if more females are released after capture as a result of v-notching and other conservation measures. In recent years, it appears that the population is becoming evenly distributed, which can be help build the population given that larger males are required to mate with larger females in the population.

V-notching analysis

As previously mentioned, v-notching has been used as a conversation measure in areas through Newfoundland and has been found to help conserve females in the population.

Index logbook data were used to evaluate the rate of v-notching of ovigerous females (number of ovigerous females v-notched/total ovigerous females) annually within each LFA. The relative high rate of v-notching in the EPLMA demonstrates the overall conservation awareness from 1997 to 2006 in the fishery for that area, but since then has become variable (in recent years, rates in LFA 5 that were v-notched has been comparable to other regions within the province (Figure 34). Initially, fishers in the MPA had high participation prior to implementation. When contrasted with other LFAs, the percentage of v-notched lobsters in LFA 5 is comparable to that found in LFA 10, but is generally higher than in 4B. Interestingly, Fortune Bay has traditionally had a very low v-notching rate, yet has a very large active fishery which is increasing and producing the highest landings in the province (Figure 34).

Eastport Lobster Management Area

We compared average sizes of the males, females, and berried females between protected versus unprotected areas using the fall tagging data. There does not appear to be a significant trend in the average size of either sex, regardless of the location of the lobster. The standard deviation appears to increase over time, indicating variability in length.

An ANOVA analysis showed significant differences among the various factors of interest (Table 9): protection, sex and year. Interaction effects were also considered, and there were no significant differences effects associated with interactions of time-sex, protection-year, and protection-sex-year. There was however a significant interaction in the protection: year which could indicate that the longer the MPA is established, the greater benefit the lobster are being afforded.

A detailed comparison of the percentiles of the length-frequency data between sexes and protection revealed that the tail end of the distribution has increased since 1997 for both sexes and in the MPA as well as exploited areas (Figure 36). The 80th percentile has apparently remained relatively constant since roughly 2003 whereas the change in the 90th percentile since

2006 has been limited for three of the four categories with a corresponding decline in the larger size categories of males from unprotected areas.

The boxplots for protected and unprotected areas represent the mean, standard deviation and lower and upper quartiles from the tagging data. The mean has remained very constant since 1997 (Figure 37). However, the size of the whiskers have increased over time, indicating a potential shift in the outliers, but as a population, little change has occurred.

DISCUSSION

INDICATOR #1 – ESTIMATION OF ABUNDANCE

The exploitable biomass used in the abundance estimates indicates no substantial change in the overall relative abundance of lobster in LFA 5 compared to LFAs 4B or 10. The relative size of the MPA compared to the size of the LFA could reduce the perceived overall impact on the exploitable biomass in the LFA. For the Eastport MPA, there appears to be a modest increase over time in the size of the population, however, both populations (protected and unprotected) have increased. This increase could have resulted from an overall spillover effect or it may suggest the adjacent area is too close to separate distinct effects. The tagging data revealed that some lobsters tend to move between protected and unprotected areas, but there is no indication of mass migrations due to high density areas.

INDICATOR #2 – CPUE

The estimated CPUE was compared among each LFA and showed no significant difference among areas. The weekly CPUE showed no significant trend, however, the LFA 10 season appears slightly longer compared to LFA 5 and even longer than in LFA 4B. This difference may be attributable to latitude or water temperatures which are known to affect lobster fecundity and growth relationships (Currie et al. 2010). There were also no substantial changes in the CPUE at the EPLMA level.

INDICATOR #3 - ESTIMATE OF BERRIED FEMALES

Proportions of berried females were not significantly different among LFAs, and did not change significantly over time. An analysis of the reproductive potential for the three LFAs indicates increasing egg production over time, likely resulting from increased average CL in berried females. This increase in size could be attributable to the MPA but other conservation measures such as v-notching throughout the island could also contribute to increased numbers of protected berried females, and hence the potential to subsequently produce more eggs.

INDICATOR #4 - SIZE STRUCTURE AND DISTRIBUTION

The average size of both male and female lobsters in the EPLMA has trended upward since 1997, largely as a result of increased abundance of larger lobsters above the 70th percentile of the annual length frequency distribution, but large males from unprotected areas have declined since 2006. Although data from other LFAs are limited to post 2004, there is also evidence of a modest increase in average size, suggesting that processes operating at large spatial scales are affecting lobster populations across eastern Newfoundland. The implementation of v-notching may be a contributing factor, but this would not account for changes in the average size of males. This general size increase suggests that within the EPLMA, the effect of the MPA cannot be detected based on size-structure information.

DATA GAPS/ISSUES IN ANALYSIS

Data availability

The Eastport area provides the longest, most continuous source of lobster data for the island. As such, the data is rich and can provide insight into the lobster population and fishery. However, comparison of the MPA with other areas requires similar data for those regions, and data availability for other areas is poor. In LFA 4B commercial at-sea sampling data are available from 2004, 2007-present and LFA 10 at-sea sampling data were available since 2005. A longer history in the data set could result in detection of longer-term trends and provide a more thorough review if a study is required on a LFA wide basis.

Log book data

The index fishers and DFO logbook data is limited in its reliability as a data source. The returns of the logbooks, while contingent upon the renewal of a license, have not had a good return rate in the past because they were strictly voluntary until 2010 and that bias may introduce error into the information content.

Tagging Data

Assessment of the effectiveness of the MPA relied heavily on data obtained through the tagging study. While the tagging data provide a lengthy time series, there are active ongoing improvements for several aspects of the program based on recommendations from DFO (2014b). A sufficiently longer time series of the newly established monitoring protocols will improve this program. The adjacent areas that aim to serve as a basis for comparison close to the MPA areas are also subject to potential spillover effects, which make assessment of the broader-scale significance of the MPA difficult. New reference areas, at a greater distance from the MPA, should be monitored to determine whether the MPA has a regional scale. Several years (5-10) will be needed before a comprehensive assessment can be carried out based on the expanded program. Further, there are limited tags returned from the spring fishery which limits the program's ability to assess the overall impact of the fishery on the population. Final, georeferencing the fall tagging events would provide greater accuracy in the estimation of abundance and analysis of movement and mark-recapture analysis in the region.

Habitat

A comprehensive assessment of the production potential of the lobster fishery in the EPLMA was not feasible because of the lack of accurate knowledge of the extent of suitable habitats. Although the fishery may provide some indices of where lobsters have traditionally been harvested, the information is largely qualitative and difficult to apply in a predictive evaluation. A habitat map of the MPAs and reference areas would be useful in the assessment.

Long term projections

The biological indices in the 2013 request for science advice included the projection of trends until 2020. The trends in CPUE indicate a weak increase in the annual mean. The new recruit estimation trends demonstrated a short-term increase in the last two years of the series but the long-term trend was not significant. Quantile depiction of carapace size from protected and unprotected lobsters indicates marginal improvements in the size relative abundance of the larger lobsters (>100 mm CL). Therefore, we anticipate limited change from current population characteristics if environmental conditions and fishing pressure remain relatively similar to the current state of the EPLMA.

The request for EGS biological indicators spanned a time scale of 1995-2020 for Approach 1 and 2005-20 for Approach 2. Both methods pose challenges because future projections are not possible without a proper population model based on a more comprehensive monitoring program that provides a better perspective on the abundance to inform processes that influence growth and survival potential. A female lobster could take 8 to 10 years to reach maturity. Because the official implementation of the MPA occurred in 2005, we would anticipate that the effects of the protected area could become more apparent in 2012-14. Although there are signs of improved recruitment in the region in recent years, we note that the unofficial protection of Duck and Round Island MPAs was initiated in 1997, and that changes in production appear to be modest at best and likely reflect processes that operate at much larger scales than the limited 2.1 km^2 afforded by the MPA.

CONCLUSIONS

Marginal gains have been shown in the comparisons of LFA 5 to the two other LFAs. There has not been a significant improvement in most indicators to show that the Eastport MPA has enhanced the fishery. This lack of improvement could reflect the small scale of the MPA in relation to the scale of the entire LFA. An assessment at the regional level of the EPLMA found that small improvements have been made within the local area that could result in a spillover effect. Larger individuals are getting larger as expected, and lobsters move frequently to and from the protected/unprotected areas. The average CL of males is increasing slower than females.

FUTURE PRIORITIES

There are several areas of the monitoring program that could be undertaken by DFO Oceans Program that could improve the results of future requirements. A viable working population model for the Eastport lobster population would enable future predictions in the population and enable a better assessment of the changes within the MPA. Geo-referencing of logbooks and the fall sampling program would greatly enhance in the analysis of the mark recapture data. It is suggested that there is a continuation of the outside reference points are critical to understanding the potential spillover effects from the MPAs.

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TABLES

Table 1. Lobster categories.

Number	Sex	Ovigerous	V-Notch
1	Male	-	-
2	Female	No	No
3	Female	No	New
4	Female	No	Old
5	Female	Yes	No
6	Female	Yes	New
7	Female	Yes	Old

Table 2. Size of protected and unprotected areas (in hectares).

Years	Round Island - In	Round Island - Out	Duck Islands - In	Duck Islands - Out
1997-1999	28	114	87	45
2000-2002	28	102	87	51
2004-2011	28	89	87	62
2012	28	178	87	264

Table 3. Fall tagging sampling events.

Year	# of Sampling days	# of Observations
1997	10	692
1998	10	863
1999	10	1065
2000	11	1150
2001	12	947
2002	8	643
2003	-	-
2004-Spring	27	1065
2004-Fall	18	952
2005	12	828
2006	18	1423
2007	16	1565
2008	12	1033
2009	17	1473
2010	16	1377
2011	18	1279
2012	19	1351

Table 4. Summary of frequency of recaptured lobsters in the Eastport area (inside and outside the MPA).

Recaptures	Frequency	Relative Percentage
16	1	0.01
14	2	0.02
13	3	0.03
12	3	0.03
11	4	0.04
10	9	0.09
9	15	0.15
8	19	0.19
7	30	0.30
6	66	0.67
5	125	1.26
4	224	2.26
3	443	4.47
2	902	9.10
1	1982	20.00
0	6081	61.37

Table 5. Summary of the number of individual lobster movements by size, sex, and area.

MOVE	SIDE	SEX	<83	83-92	93-102	>103
move	**IN**	**F**	106	173	81	84
move	**IN**	**M**	149	228	154	244
move	**OUT**	**F**	69	138	105	115
move	**OUT**	**M**	116	166	128	173
no	**IN**	**F**	882	1292	875	781
no	**IN**	**M**	747	1544	1416	2178
no	**OUT**	**F**	1064	989	345	343
no	**OUT**	**M**	911	1214	564	317

Table 6a. Three way contingency table for analysis of movements - A: Protected area status, B: Size Category, C: Sex.

Sex	Status	<83	83-92	93-102	>103
Male	Protected	185	279	201	266
Male	Unprotected	134	198	167	220
Female	Protected	102	165	75	79
Female	Unprotected	76	88	59	108

Table 6b. Three way contingency table for analysis of movements - A: Protected area status, B: Size Category, C: Sex.

Source	G2	df	P
ABC	42.94	10	<0.0001
AB	13.82	3	0.0032
AC	*0.06*	*1*	*0.8065*
BC	17.44	3	0.0006
AB(C)	25.44	6	0.0003
AC(B)	11.68	4	0.0199
BC(A)	29.06	6	<0.0001

Table 7. Fecundity relationships.

Method	Region - LFA	α	β	Reference
LT1	Northeast – 4B	0.0094	3.17	Collins (2010)
LT2	Northeast – 4B	0.18	2.52	Collins (2010)
Paradise, Placentia Bay	Avalon - 10	0.013	3.1	Ennis (1980)
Northeast Coast	Northeast – 4B	0.40	2.32	Ennis (1980)
Currie	West Coast	0.049	2.18	Currie (2010)

Table 8. ANOVA Analysis of size differences for the average sizes of males, females and berried females in the protected and unprotected areas.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***
Protection	1173.2	1	1173.18	1078.01	< 0.0001
Year	22.2	1	22.21	20.4	<0.001 ***
Sex	395.1	1	395.11	363.1	< 0.001 ***
Protection: Year	3.6	1	3.60	3.3	0.067
Protection: Sex	110.3	1	110.32	101.4	< 0.001 ***
Year: Sex	1.0	1	1.03	0.95	0.33
Protection: Year: Sex	0.1	1	0.11	0.10	0.753
Residuals	19243.3	17683	1.09	-	-

FIGURES

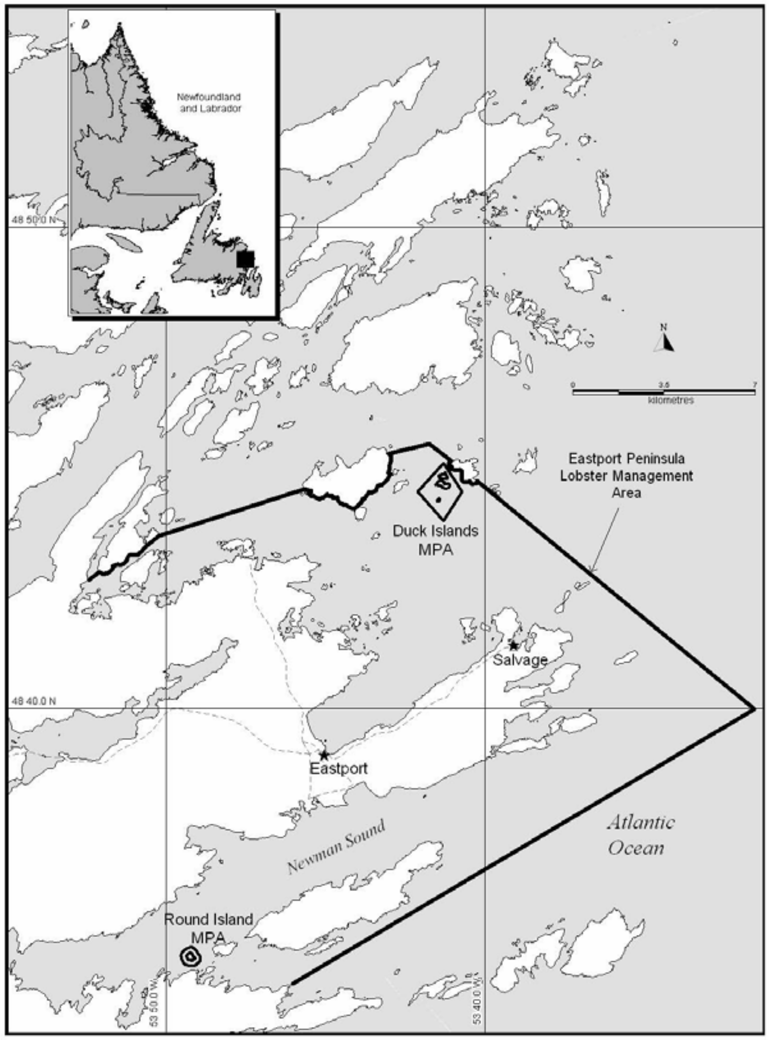

Figure 1. Eastport Peninsula Lobster Management Area, Bonavista Bay, NL (Canada).

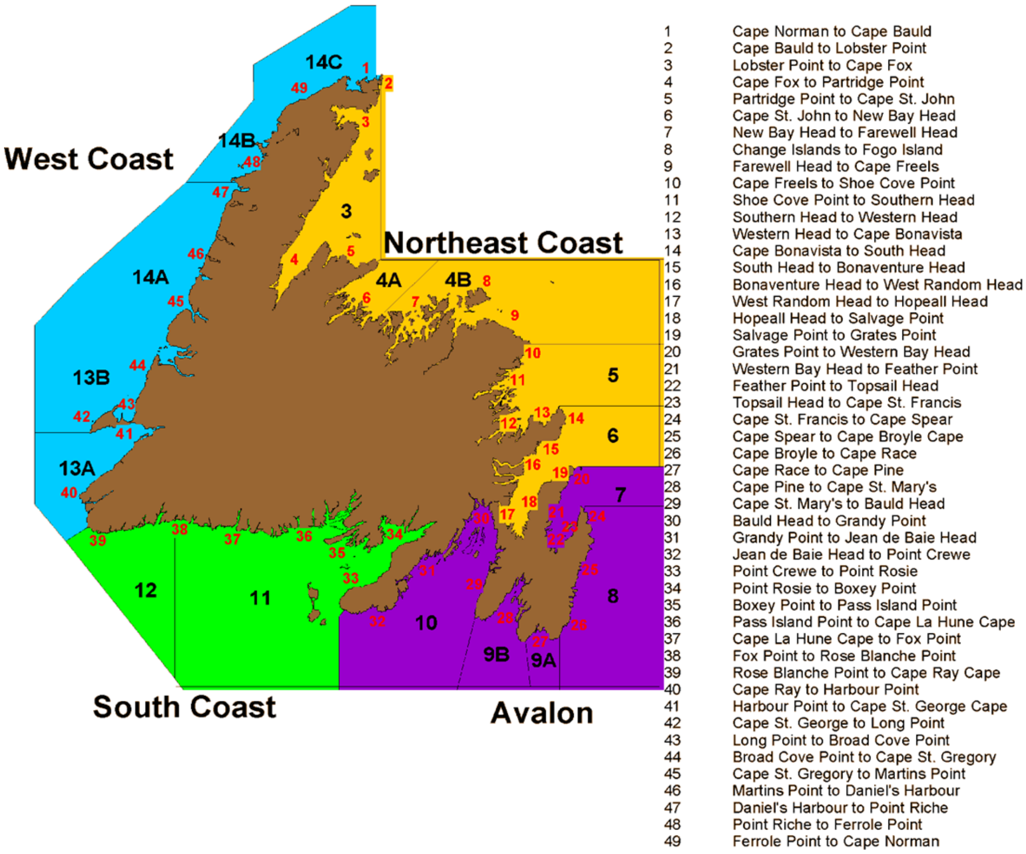

Figure 2. LFAs (black numbers/letters) and statistical sections (red numbers), NL Region.

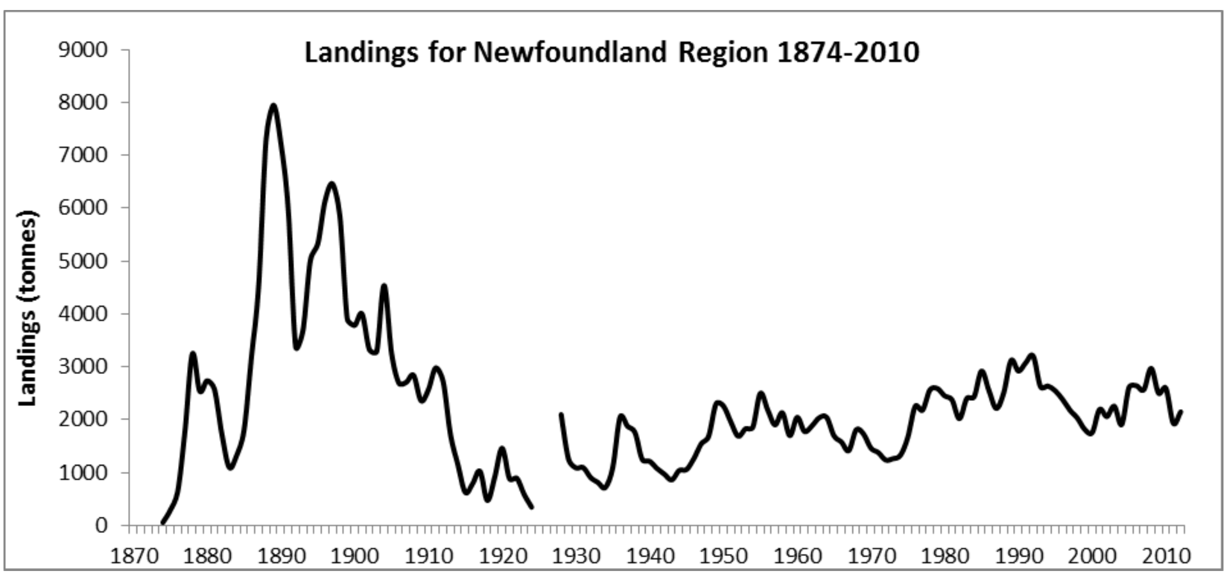

Figure 3. Total landings for the NL Region 1874-2010 (DFO 2013).

Figure 4. Map of commercial at-sea sampling locations in the EPLMA.

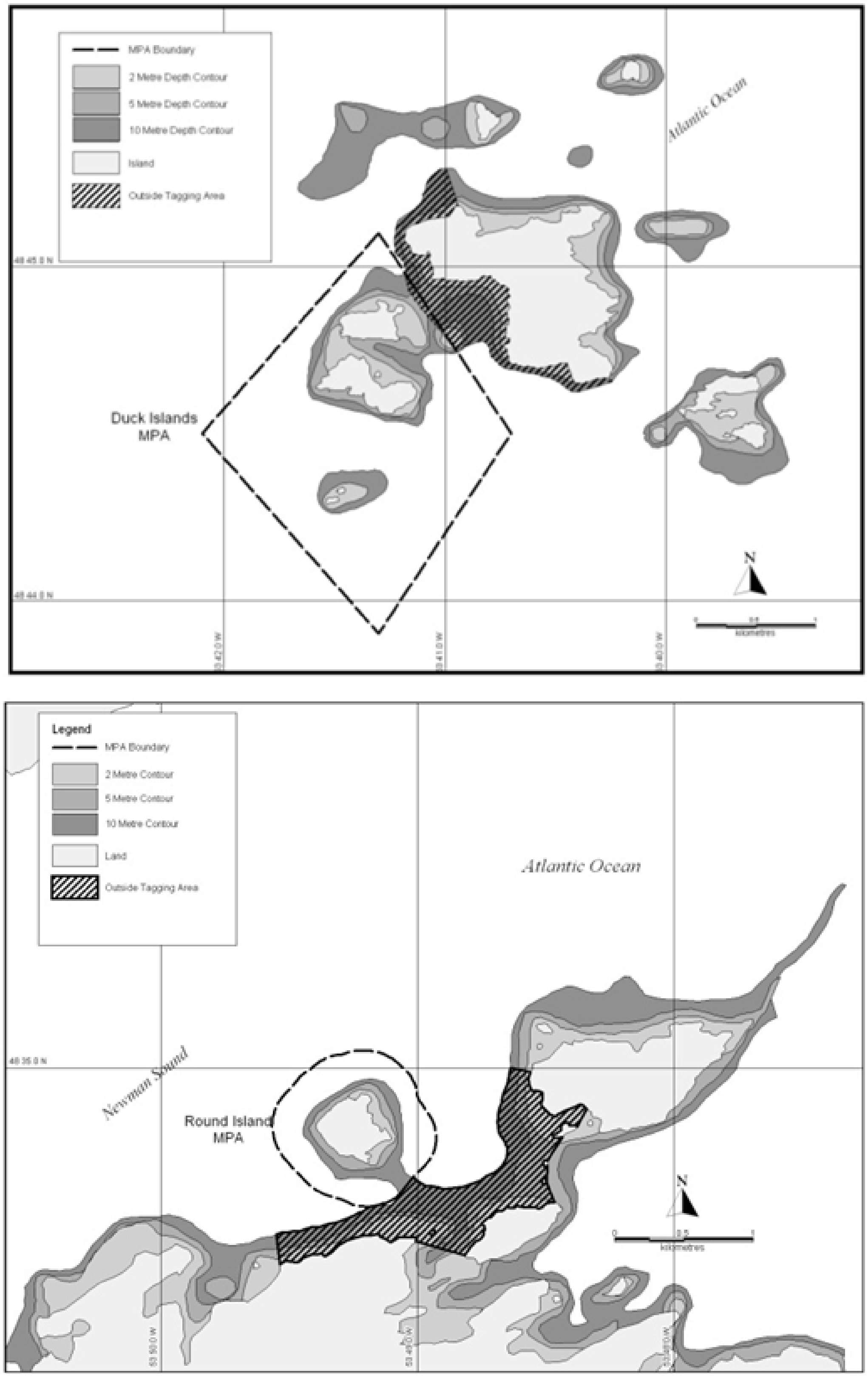

Figure 5. Fall tagging areas: (top) Duck Island and (bottom) Round Island protected and unprotected areas.

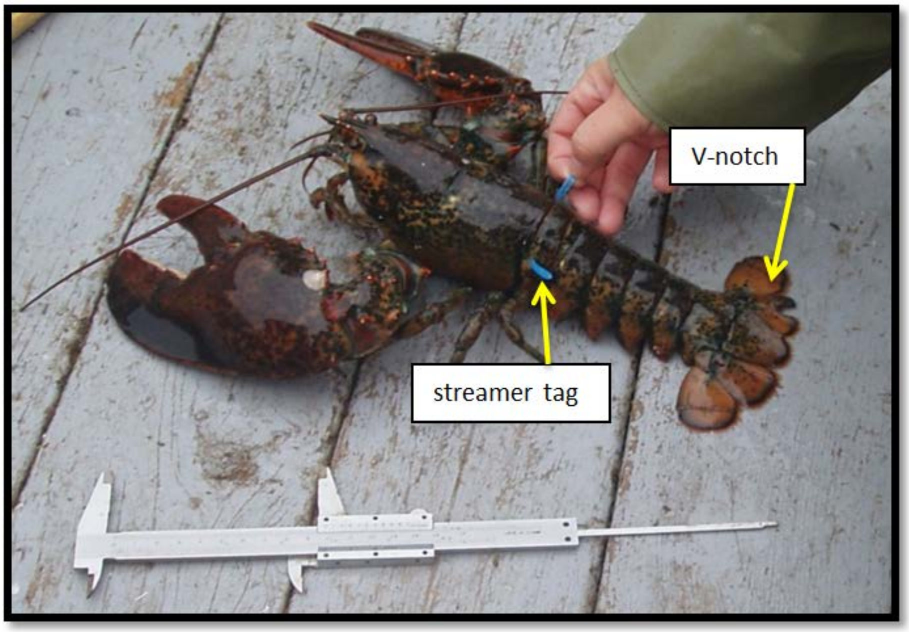

Figure 6. Female lobster with v-notch and DFO tag.

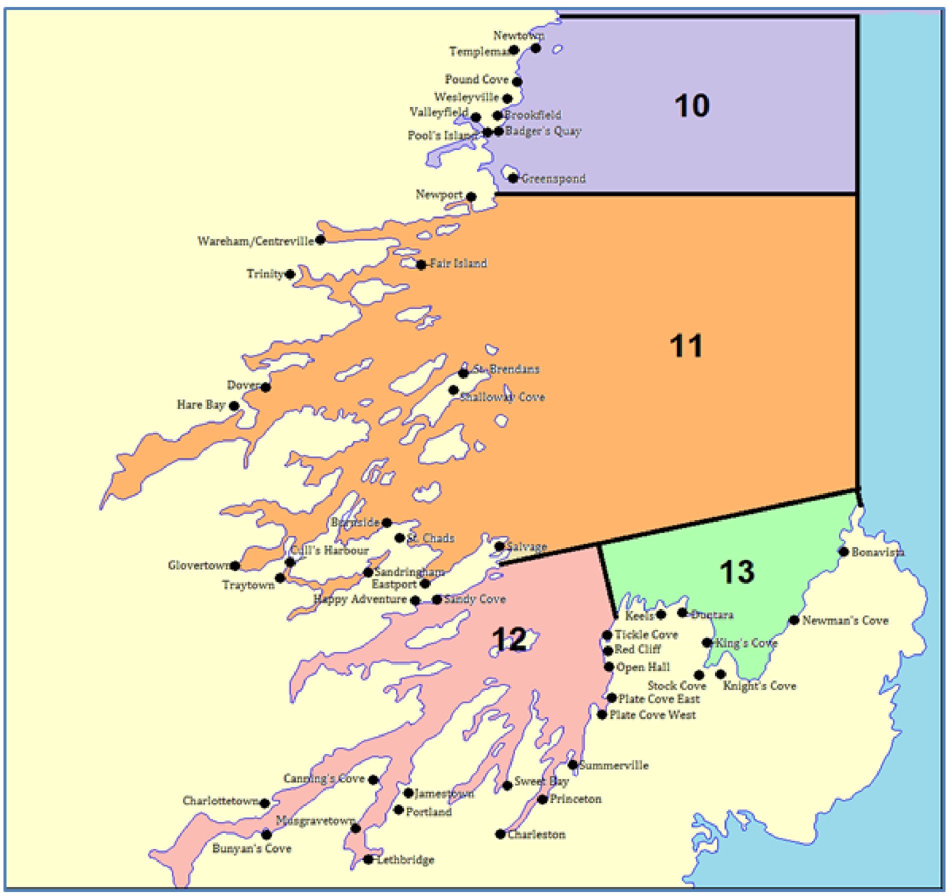

Figure 7. Map of Statistical Sections in the EPLMA.

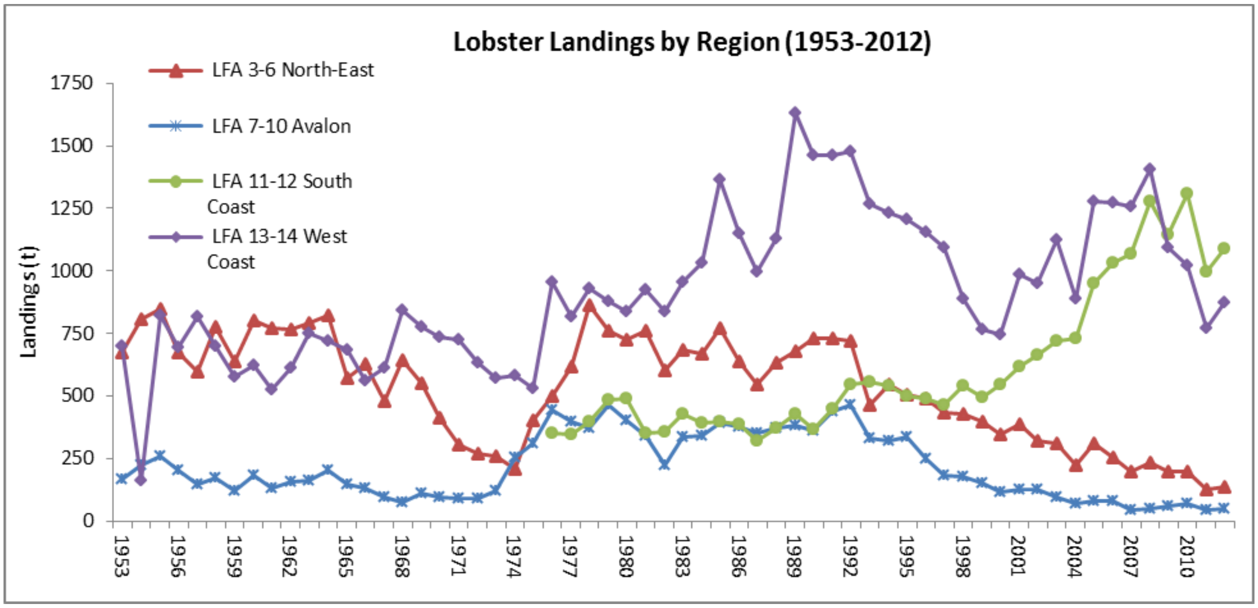

Figure 8. Landings for NL Region by LFA Regions (1953-2012).

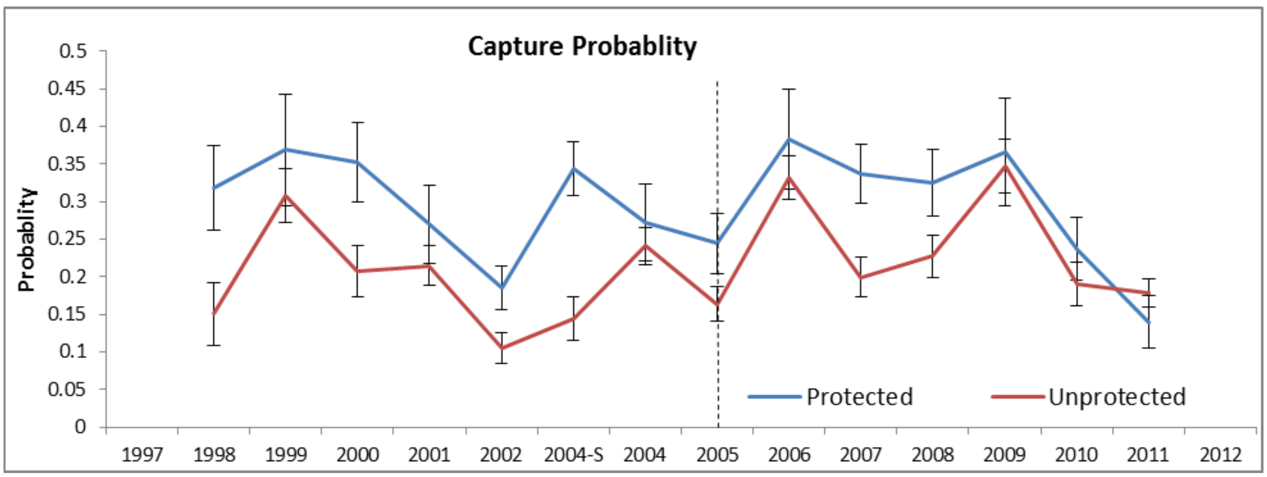

Figure 9. Capture probability for protected and unprotected areas (Bars indicate standard error, dashed line indicates MPA designation).

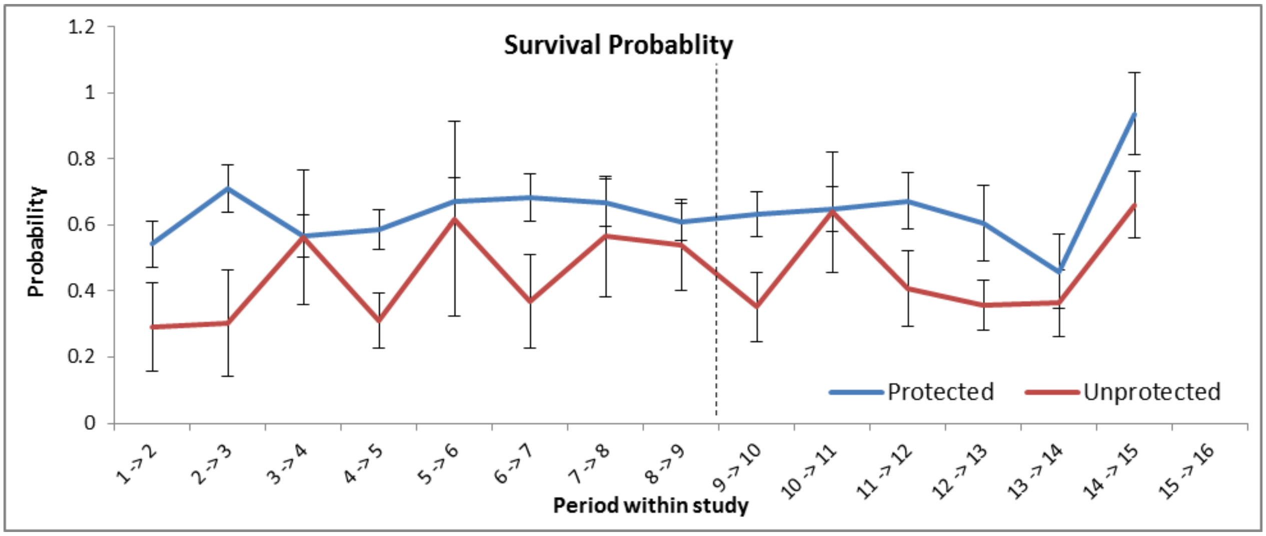

Figure 10. Survival probability of protected and unprotected lobsters (Bars indicate standard error, dashed line indicates MPA designation).

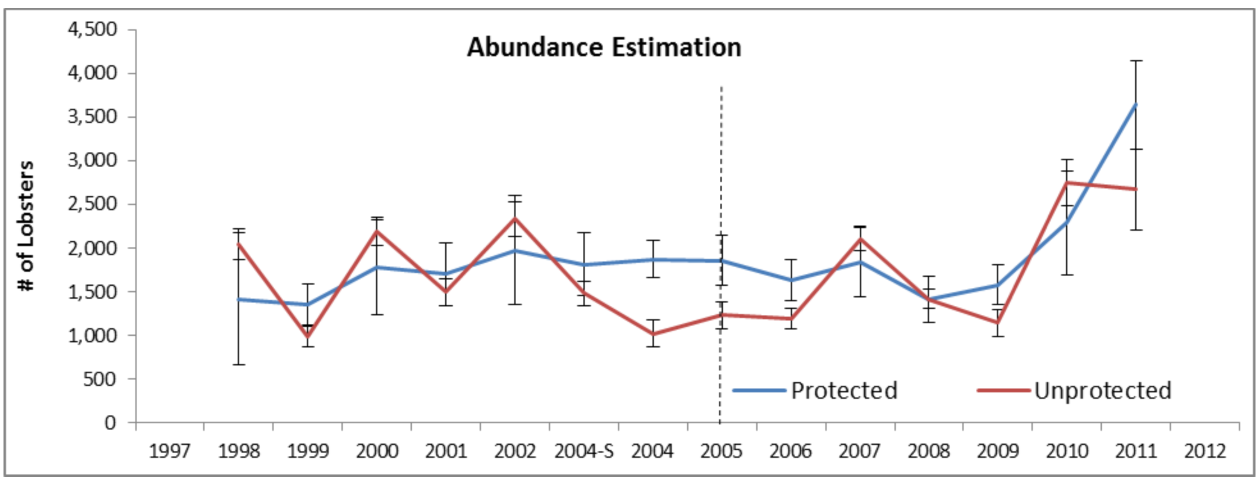

Figure 11. Estimated abundance including new recruits for protected and unprotected areas (Lines denote means, bars indicate standard error, dashed line indicates MPA designation).

Figure 12. Estimated new recruits for protected and unprotected areas (Lined denote means, bars indicate standard error, dashed line indicates MPA designation).

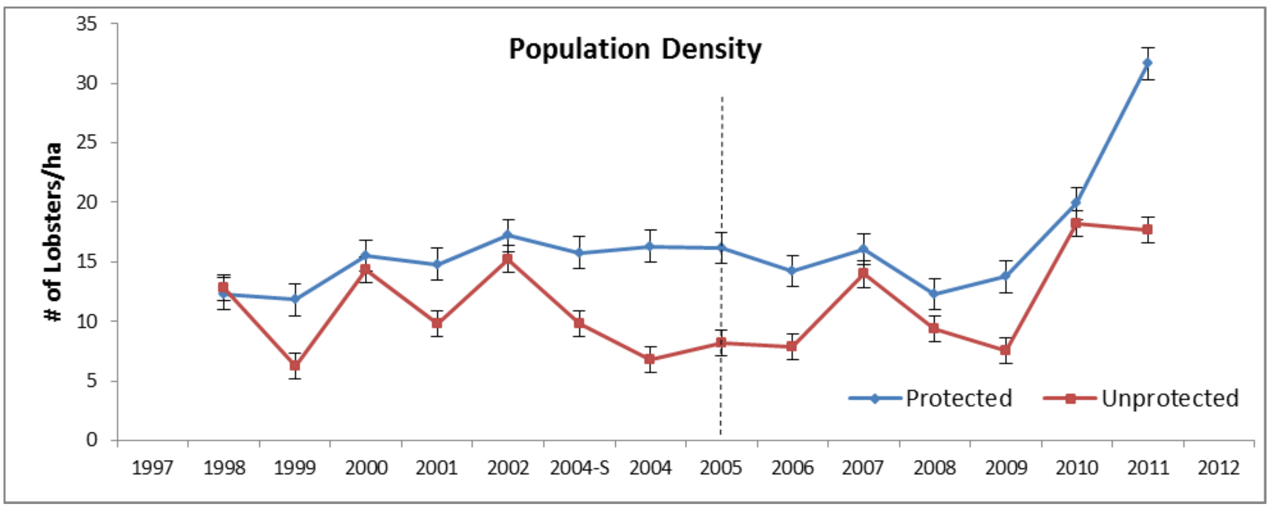

Figure 13. Density estimation of lobster in protected and unprotected areas (Lines denote means, bars indicate standard error, dashed line indicates MPA designation).

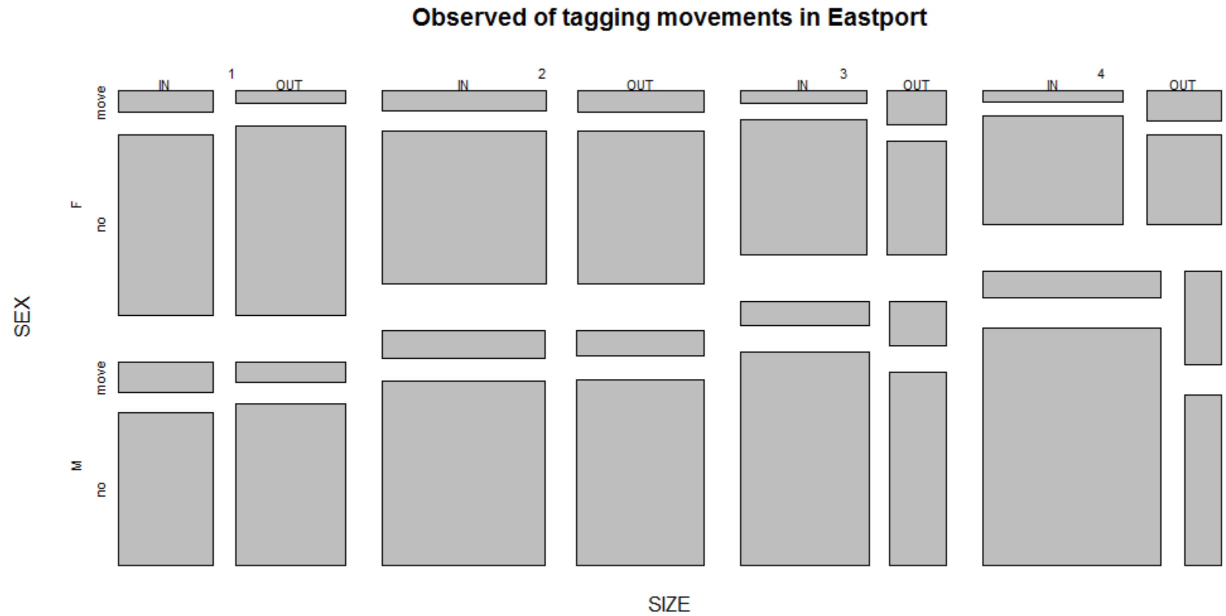

Figure 14. Mosaic plot for the observed tagging movements in the Eastport MPA. Categories=size classes (1=lobsters <82 mm CL; 2=lobsters 83-92 mm CL; 3=93-102 mm CL; 4=lobsters >103 mm CL), IN/OUT=presence inside or outside of the protected areas, move/no move=if an individual moved between the areas.

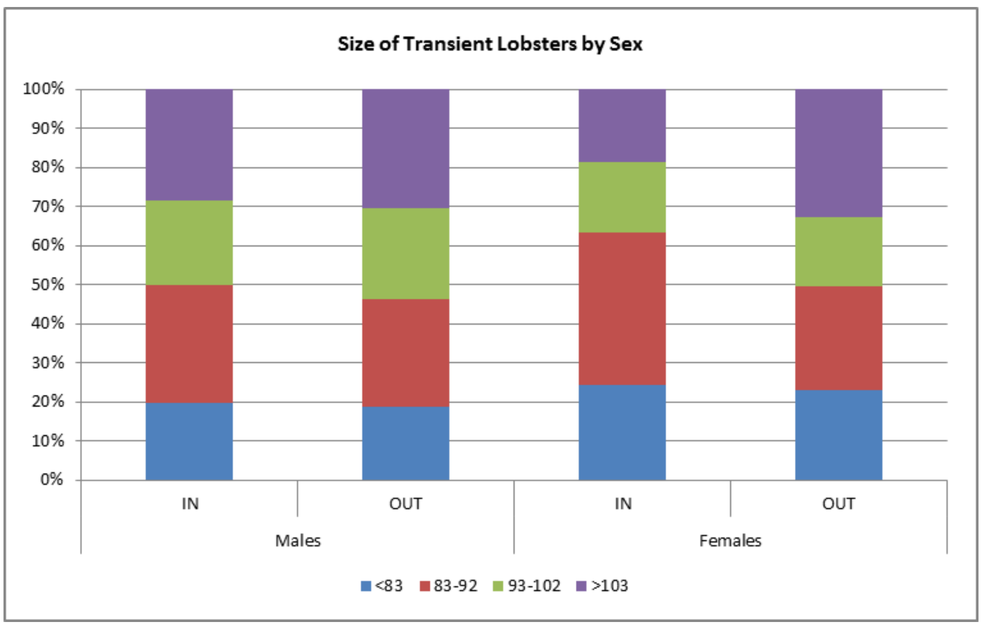

Figure 15. Movements of transient lobsters by sex (IN/OUT=presence inside or outside of the protected areas).

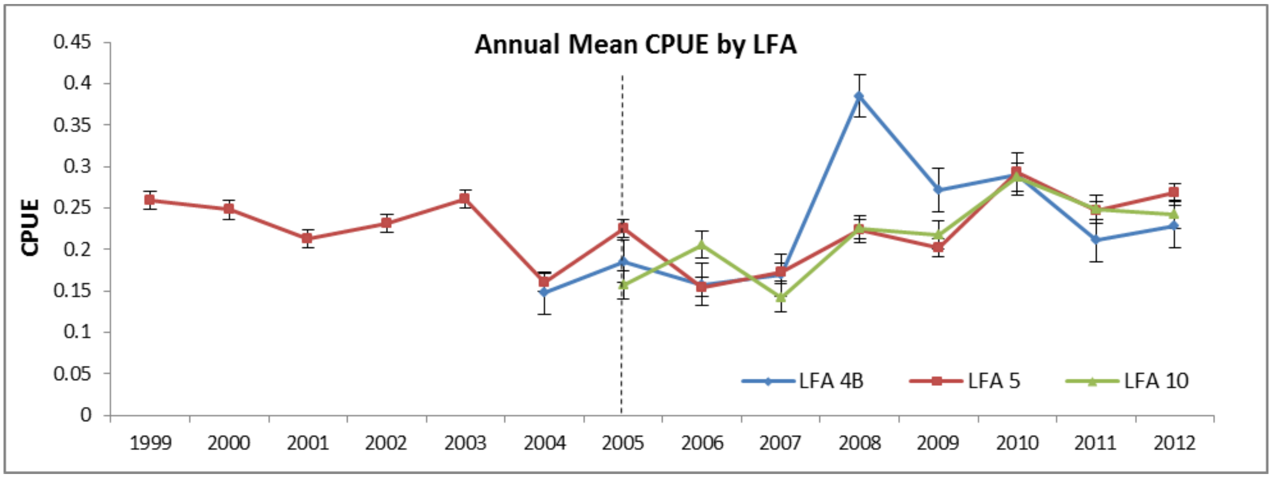

Figure 16. Annual Mean CPUE in 2004-12 by LFA (dashed line indicates MPA designation).

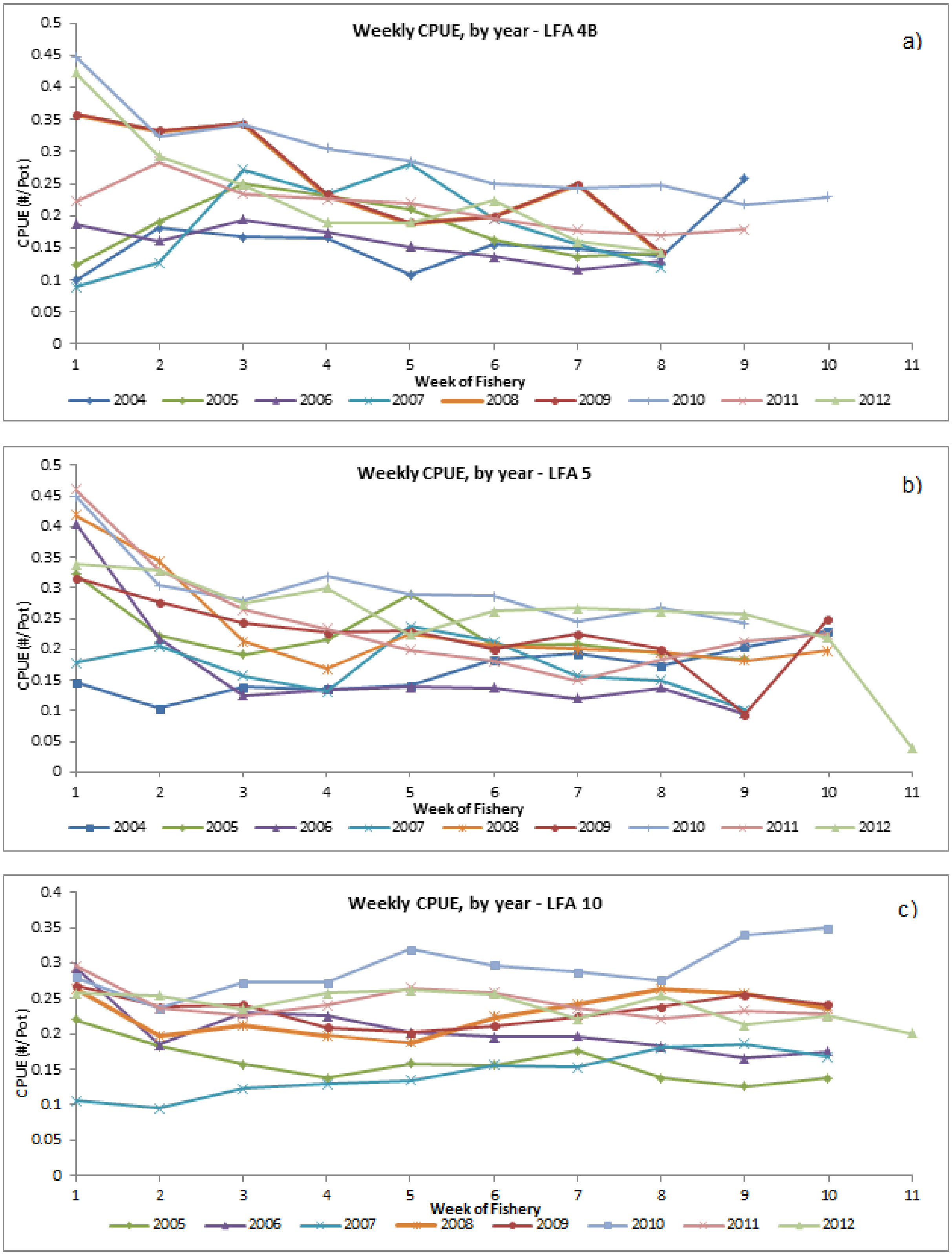

Figure 17. Weekly CPUE by year: a) LFA 4B, b) LFA 5, c) LFA 10.

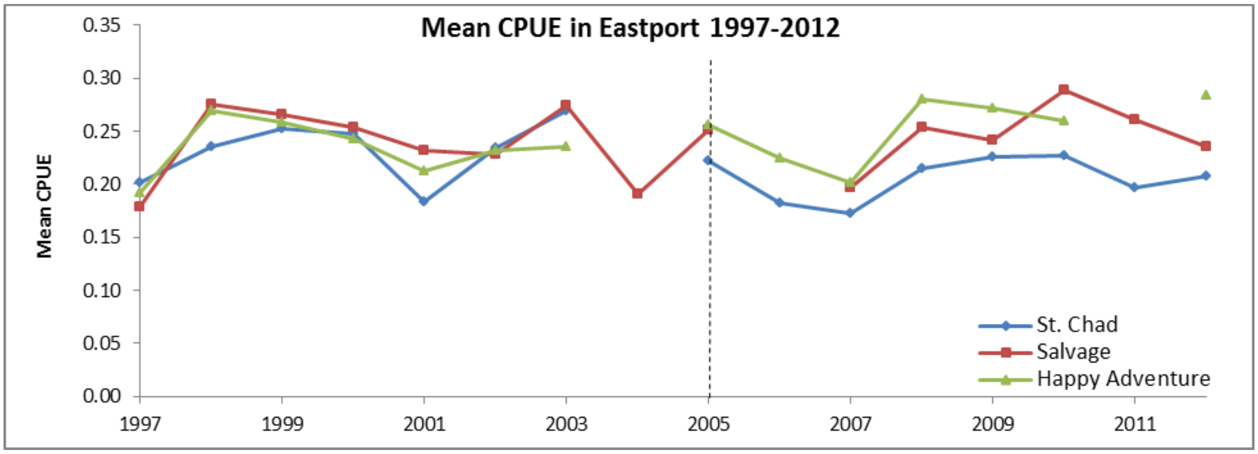

Figure 18. Annual mean CPUE for the Eastport MPA (dashed line indicates MPA designation).

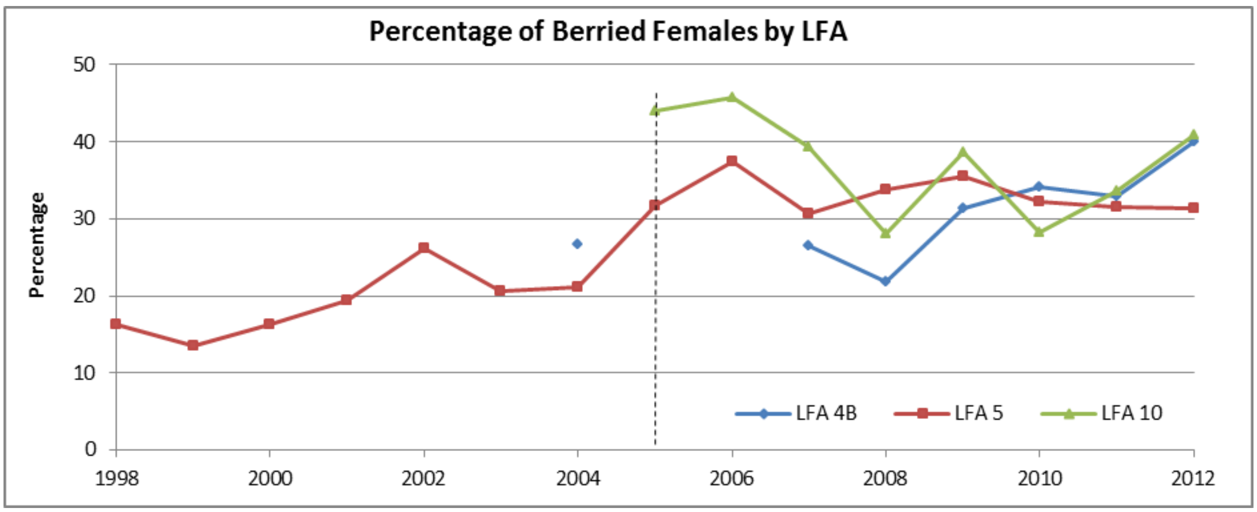

Figure 19. Percentage of berried females within commercial at-sea sampling data (dashed line indicates MPA designation).

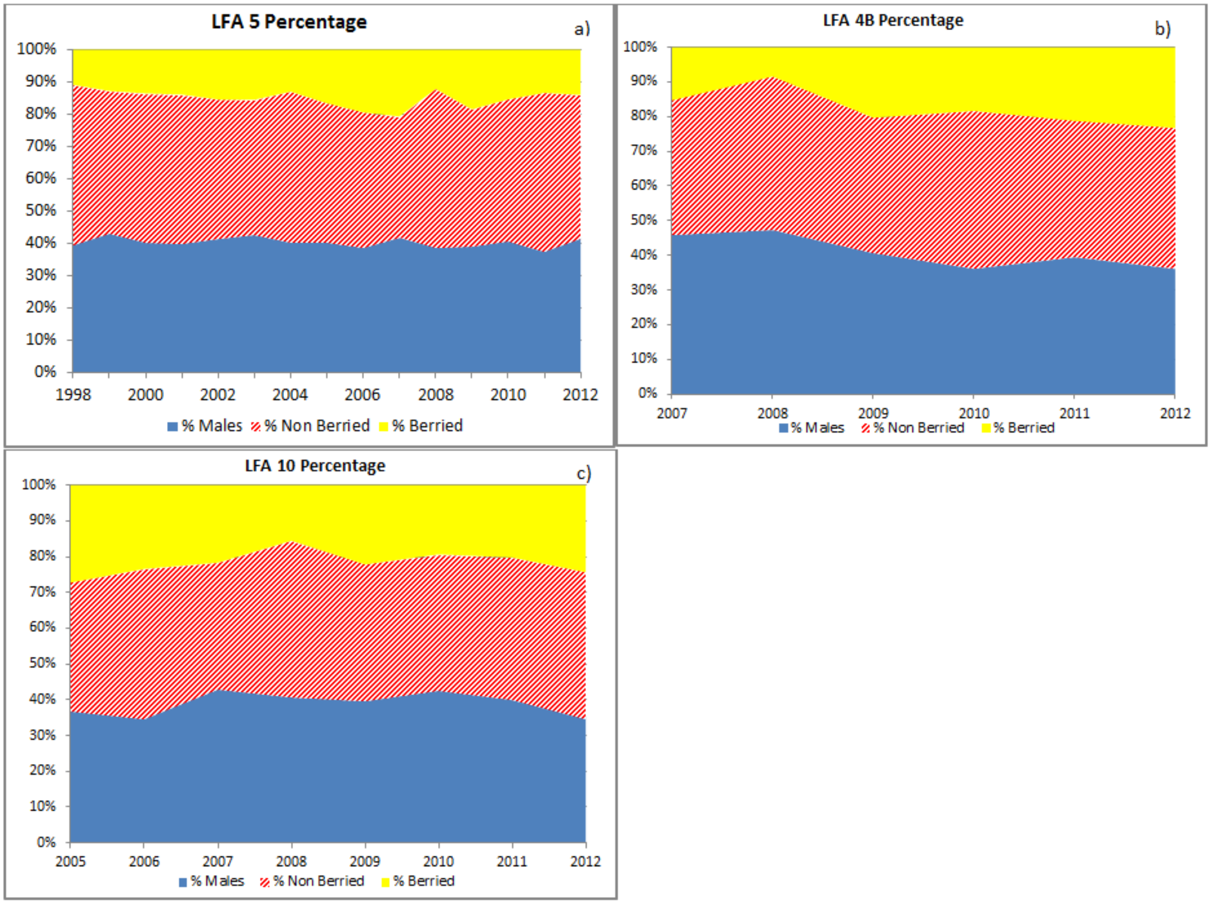

Figure 20. Proportions of lobster population for: a) LFA 5, b) LFA 4B, c) LFA 10.

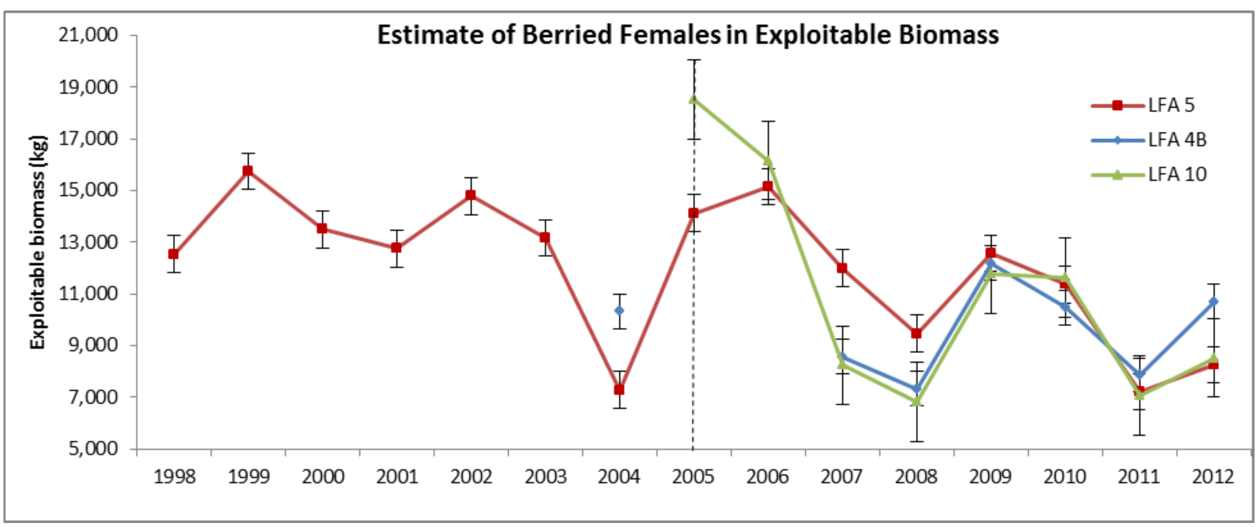

Figure 21. Estimate of berried female lobster in LFA comparison (dashed line indicates MPA designation).

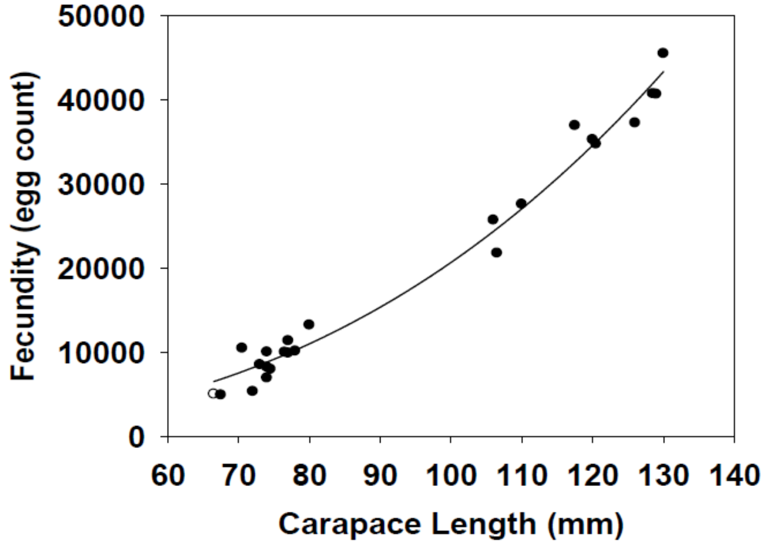

Figure 22. Fecundity-size relationship Barr'd Harbour and Lark Harbour on the west coast of Newfoundland. R2=0.98, S.E. on slope ± 0.1092. (Currie et al. 2010).

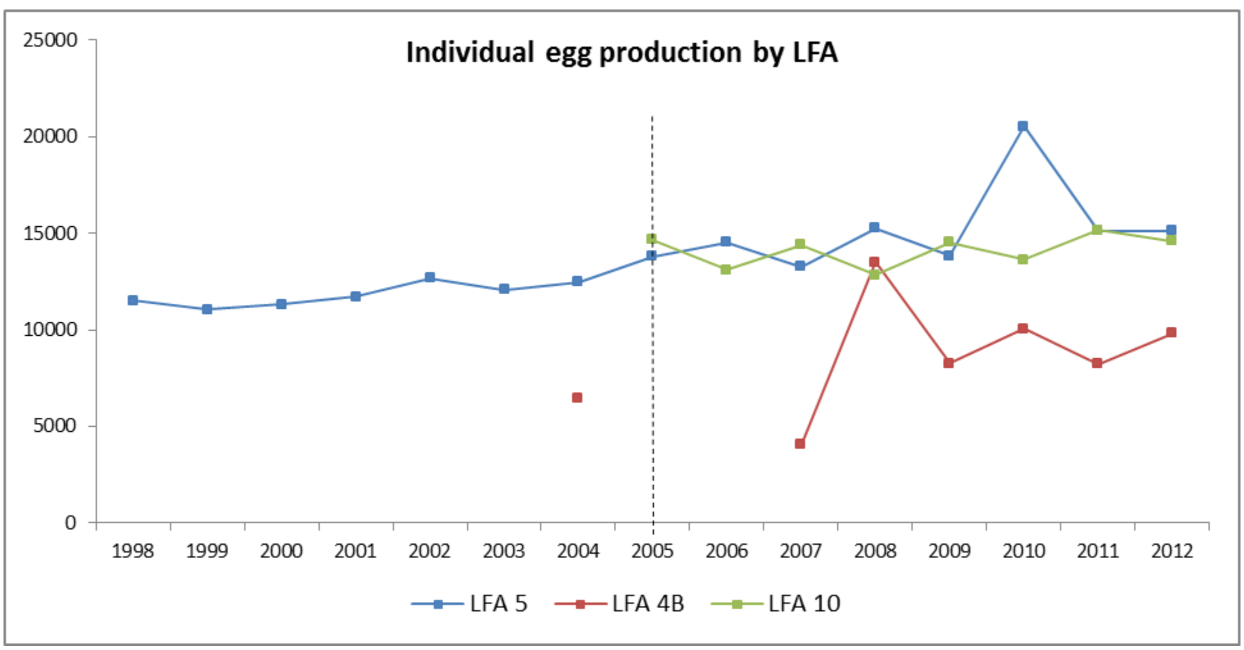

Figure 23. Individual egg production by LFA based on fecundity equations and size distributions.

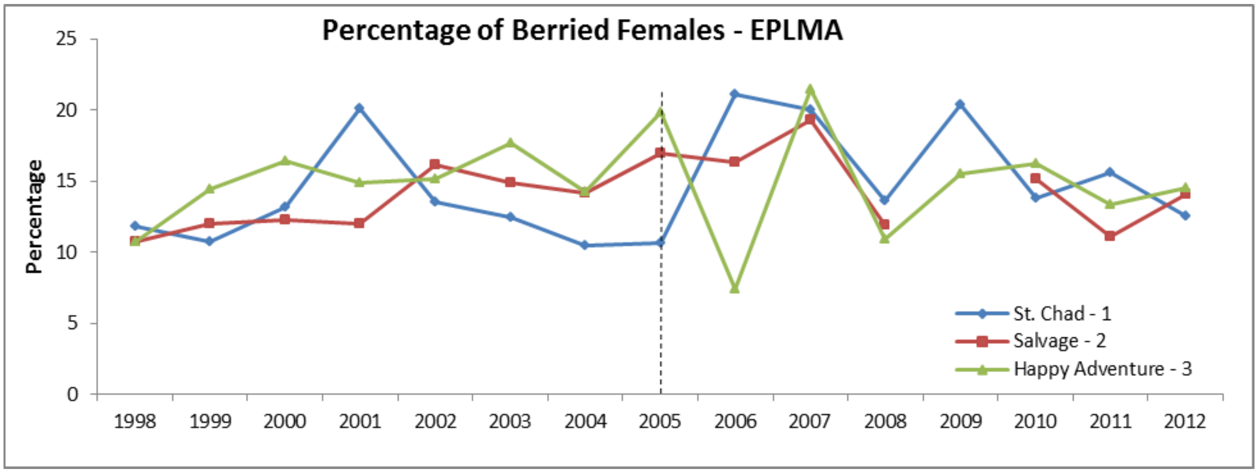

Figure 24. Percentage of berried females in the EPLMA based of length frequency estimation from at sea sampling data.

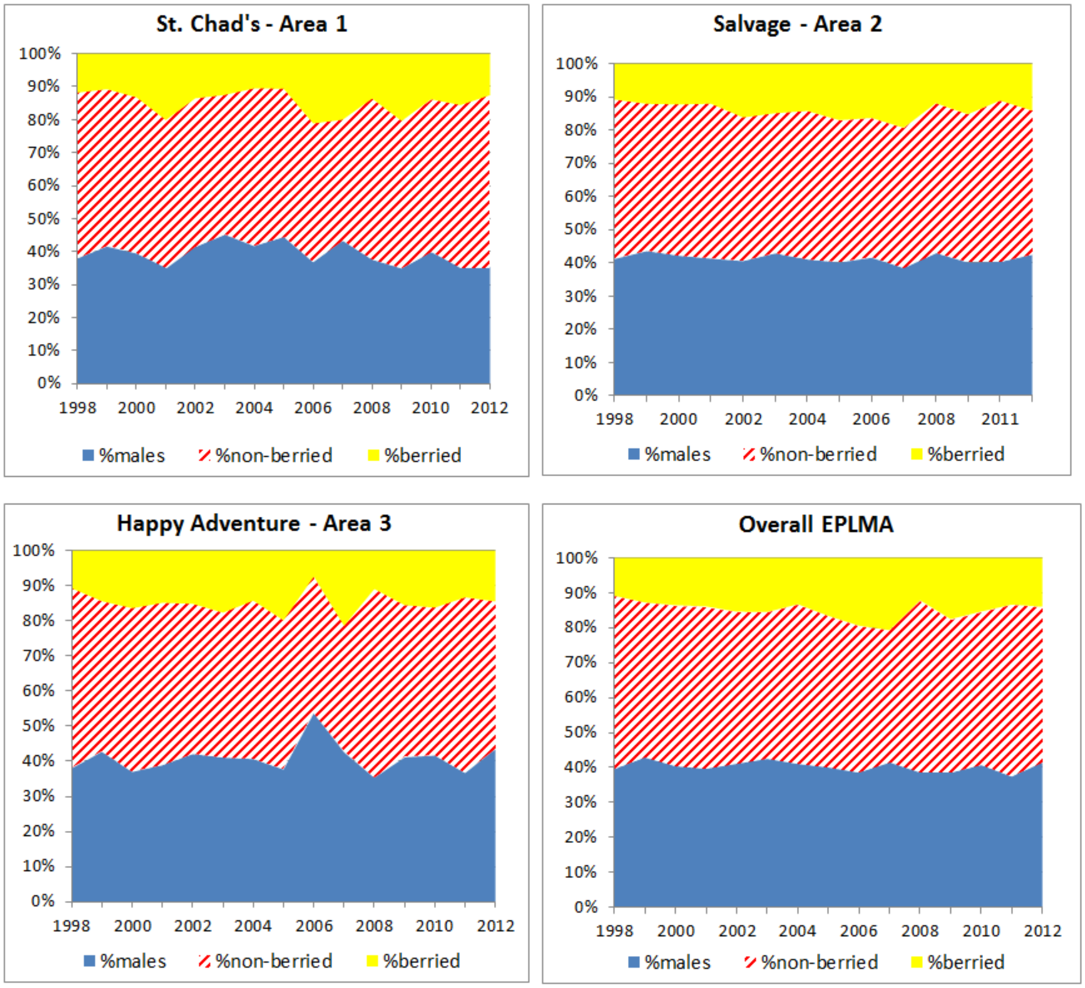

Figure 25. Proportions of lobster in commercial at-sea sampling for St. Chad's, Salvage, Happy Adventure and overall EPLMA.

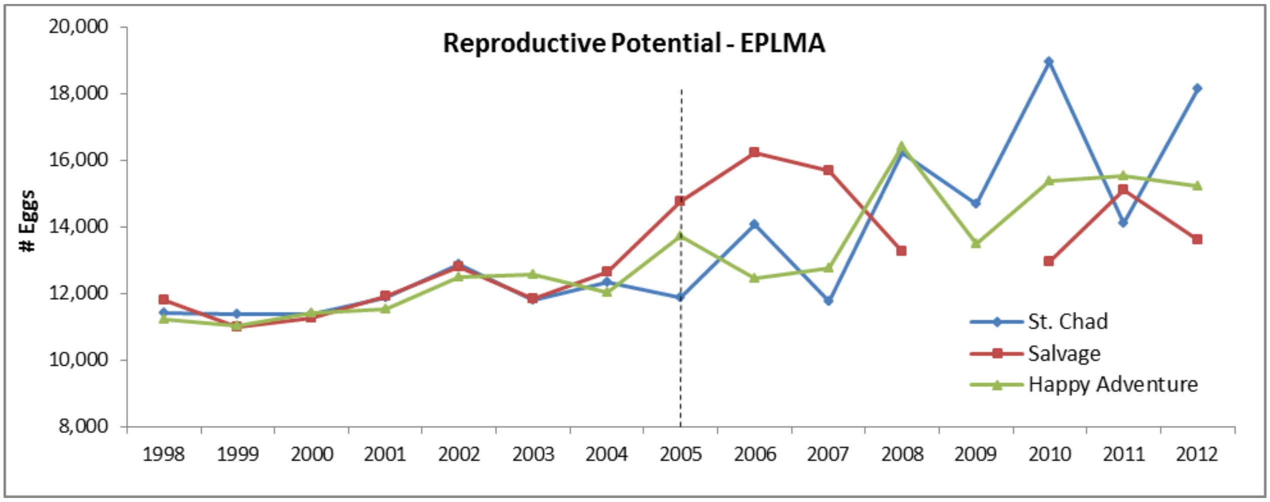

Figure 26. Reproductive potential – EPLMA (dashed line indicates MPA designation).

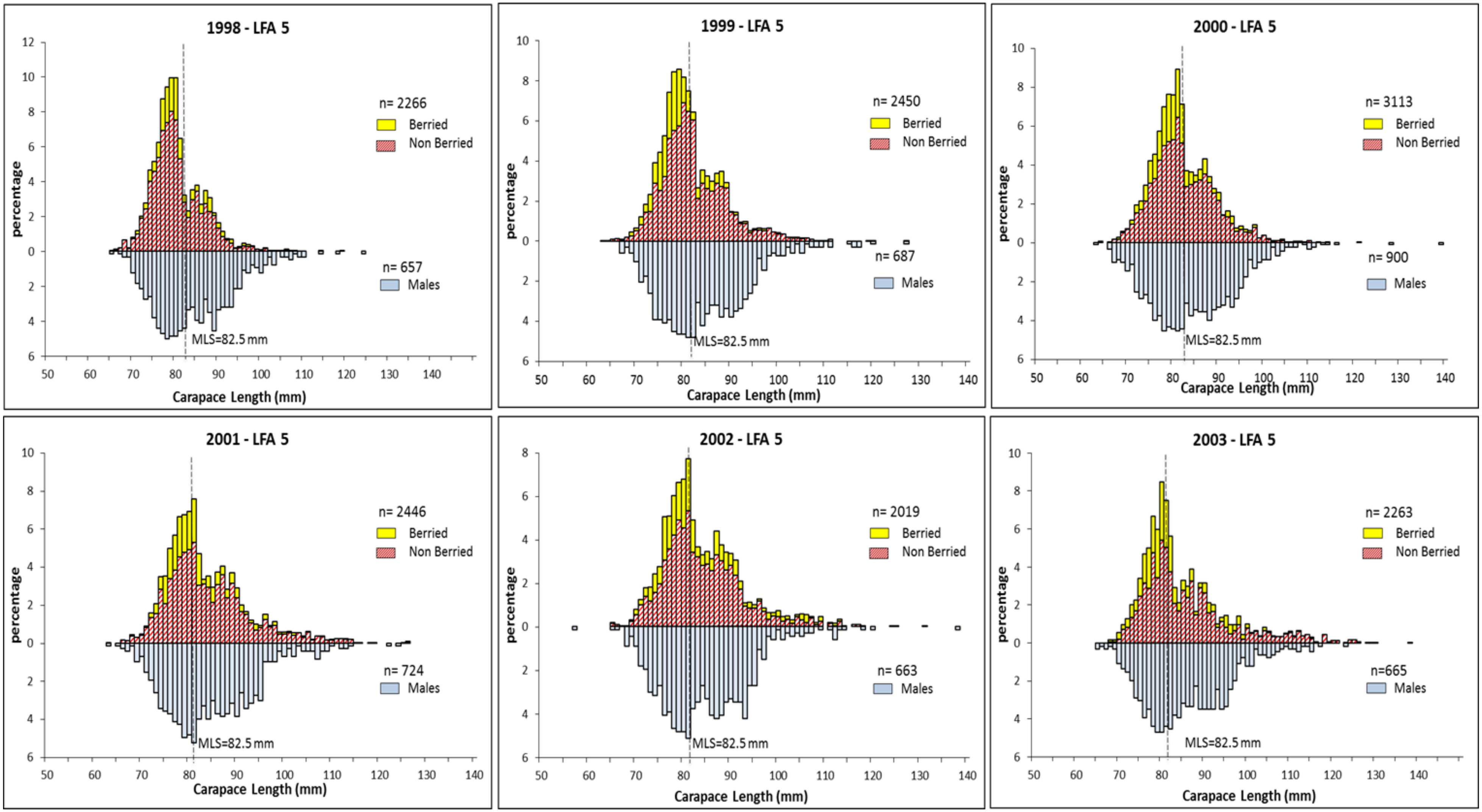

Figure 27. Size frequency distribution for LFA 5 for 1997-2003.

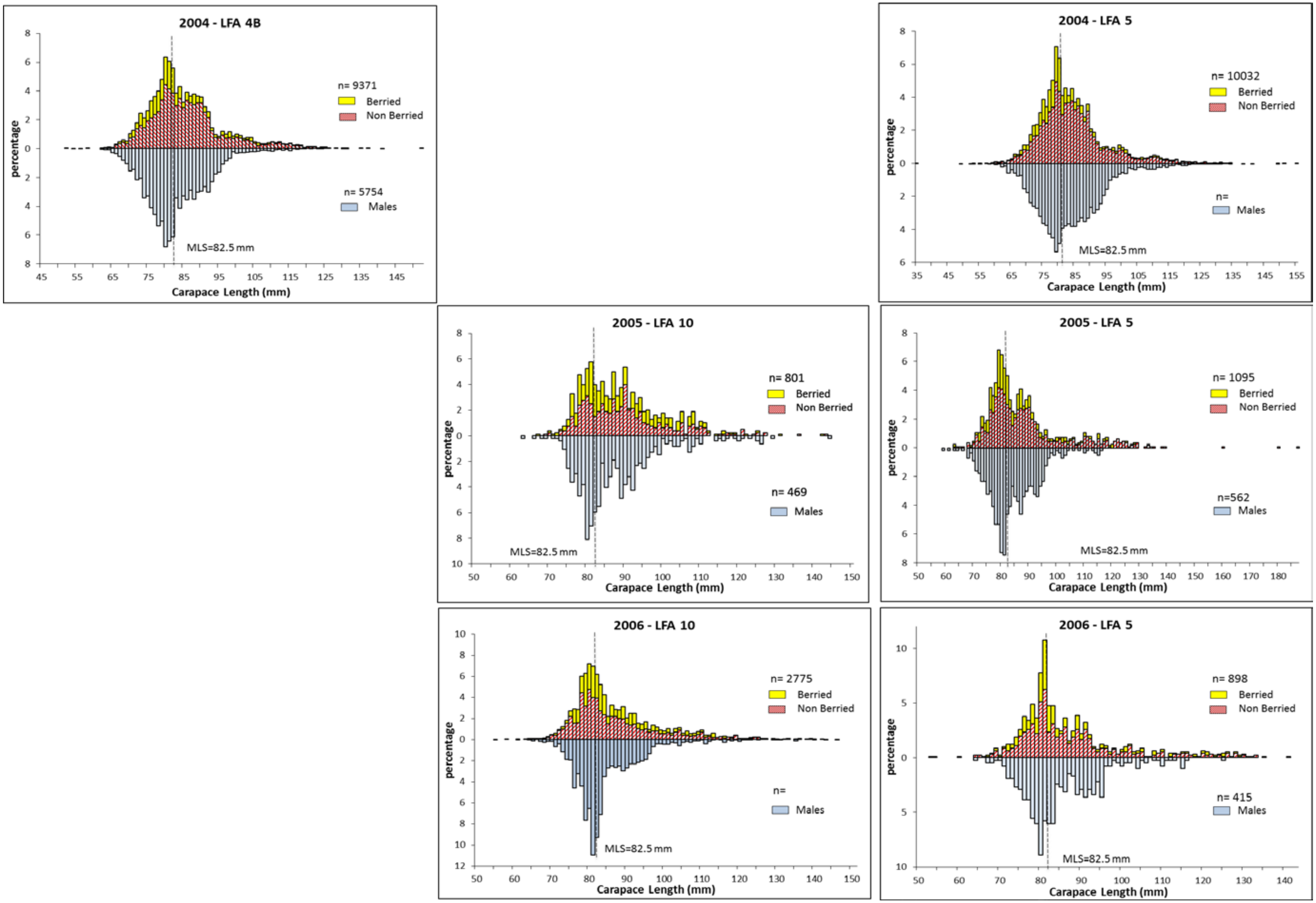

Figure 28. Size frequency distribution for LFA 4B, 5 and 10 for 2004-06.

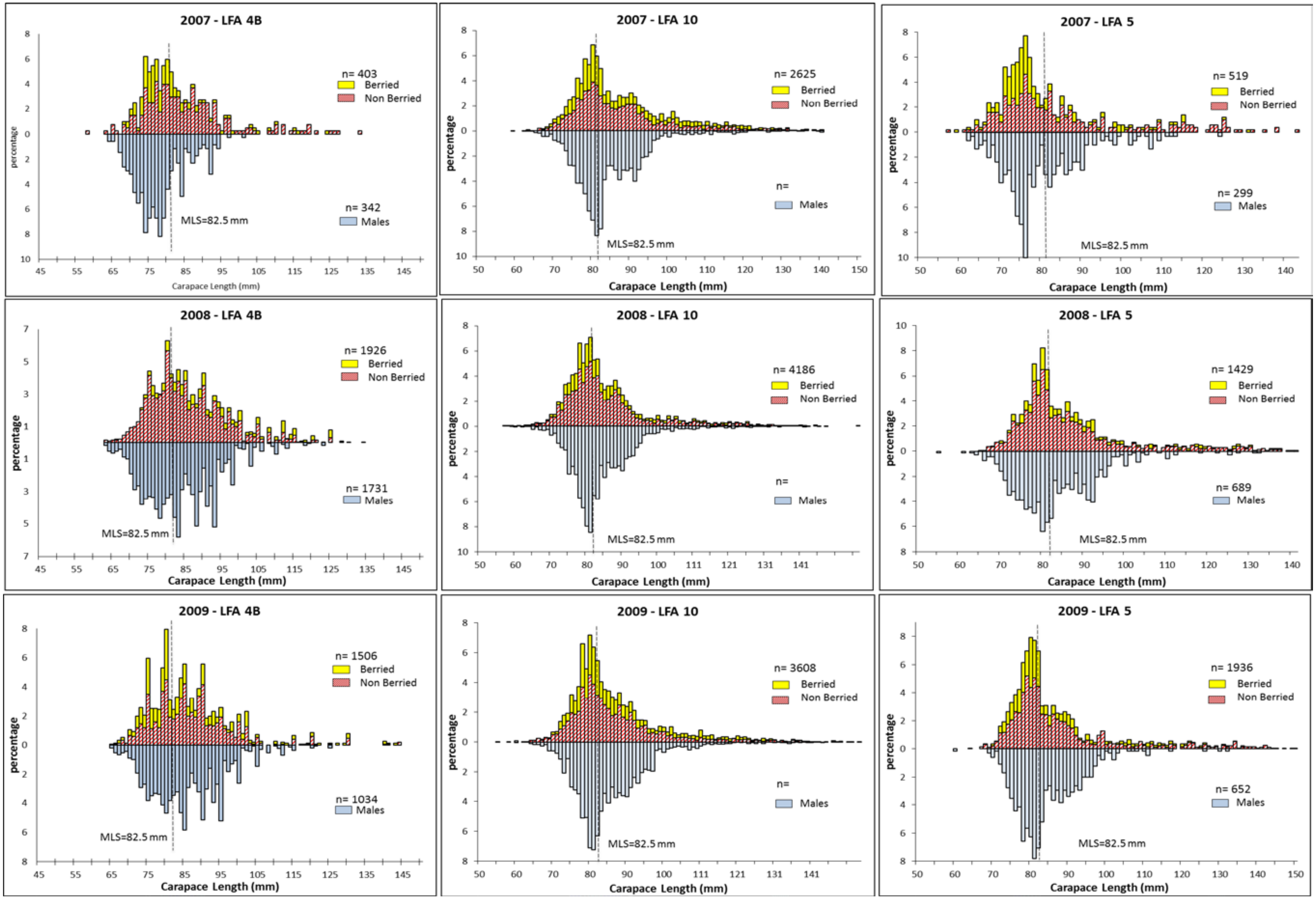

Figure 29. Size frequency distribution for LFA 4B, 5 and 10 for 2007-09.

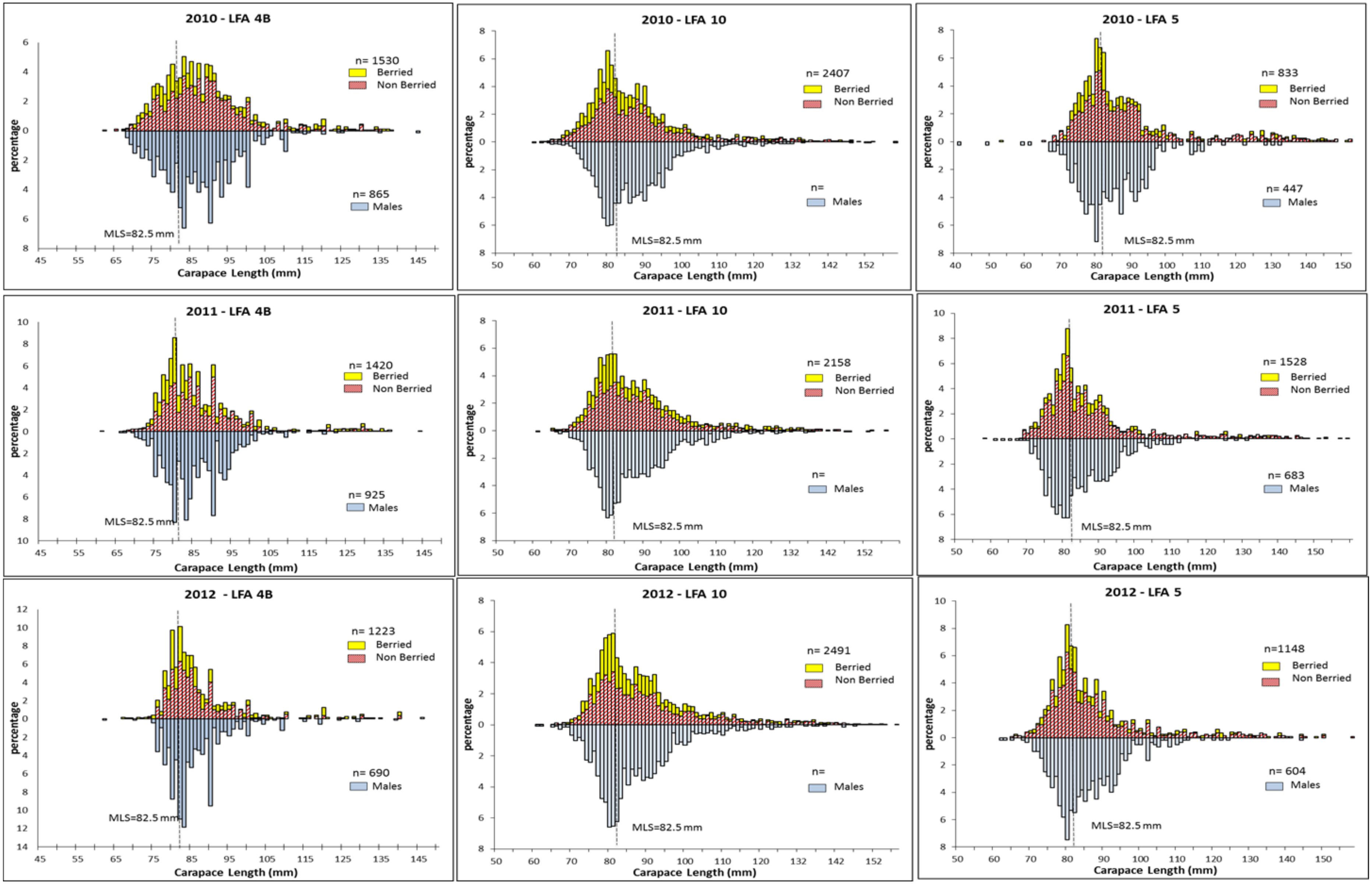

Figure 30. Size frequency distributions for LFAs 4B, 5 and 10 for 2010-12.

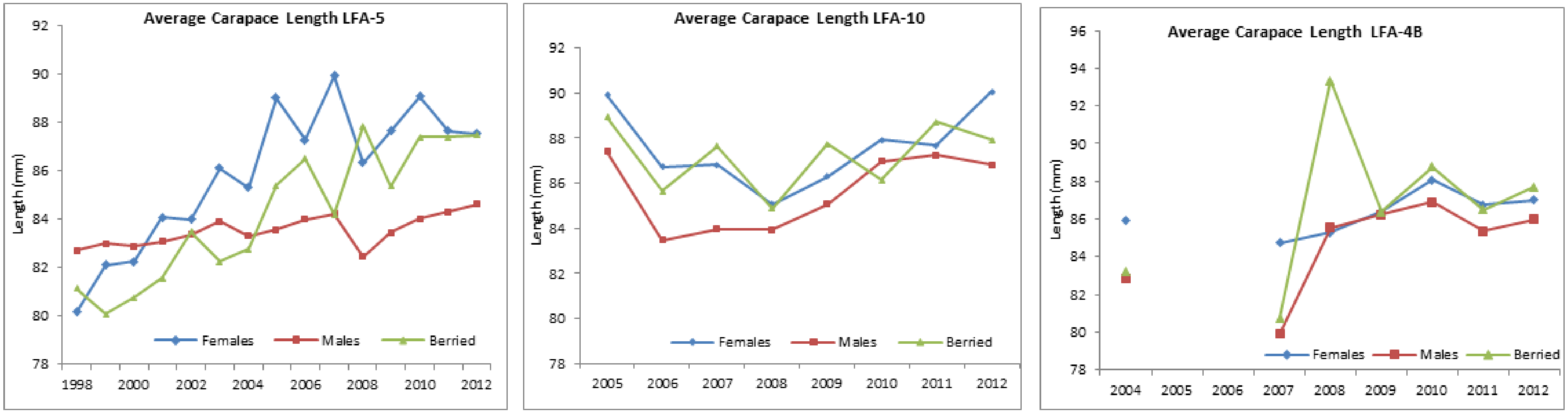

Figure 31. Average CL for each LFA.

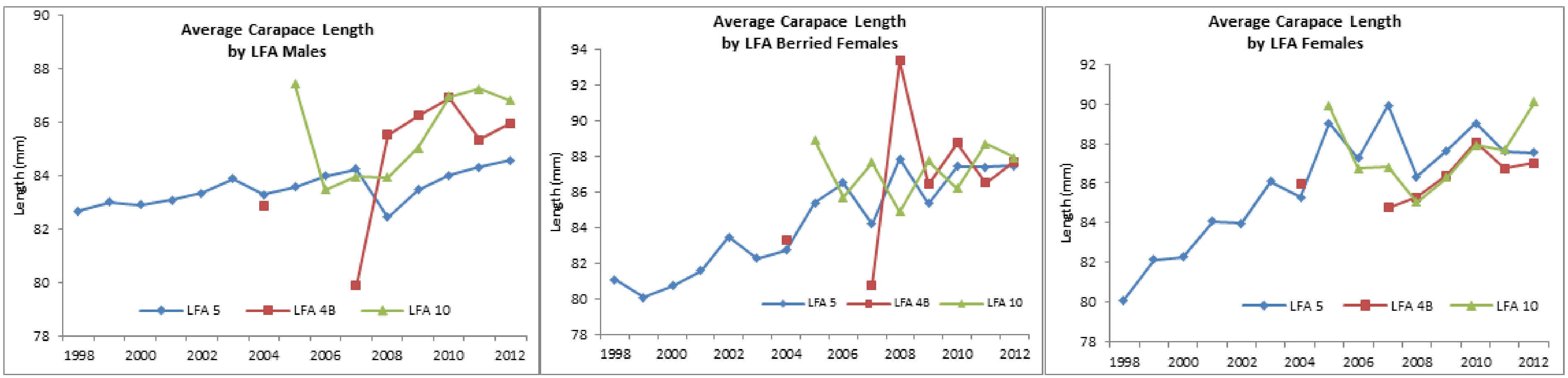

Figure 32. Average CL by sex.

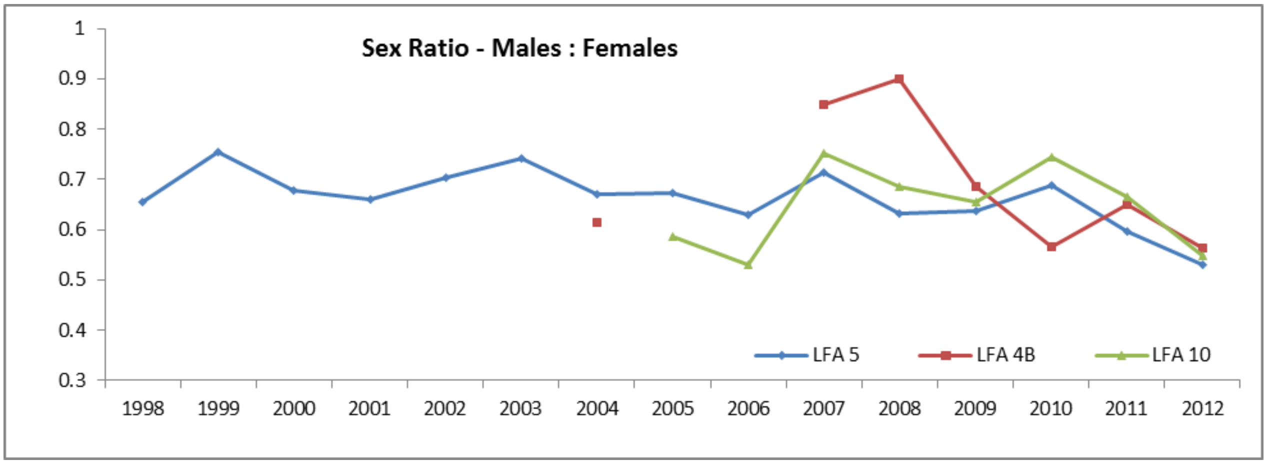

Figure 33. Sex Ratio Males:Females by LFA.

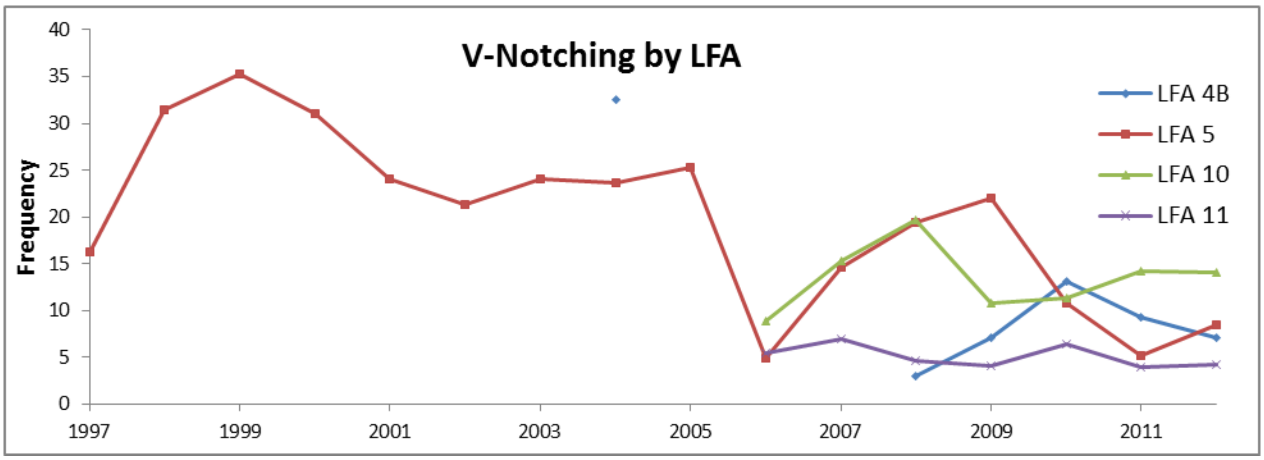

Figure 34. V-notching by LFA.

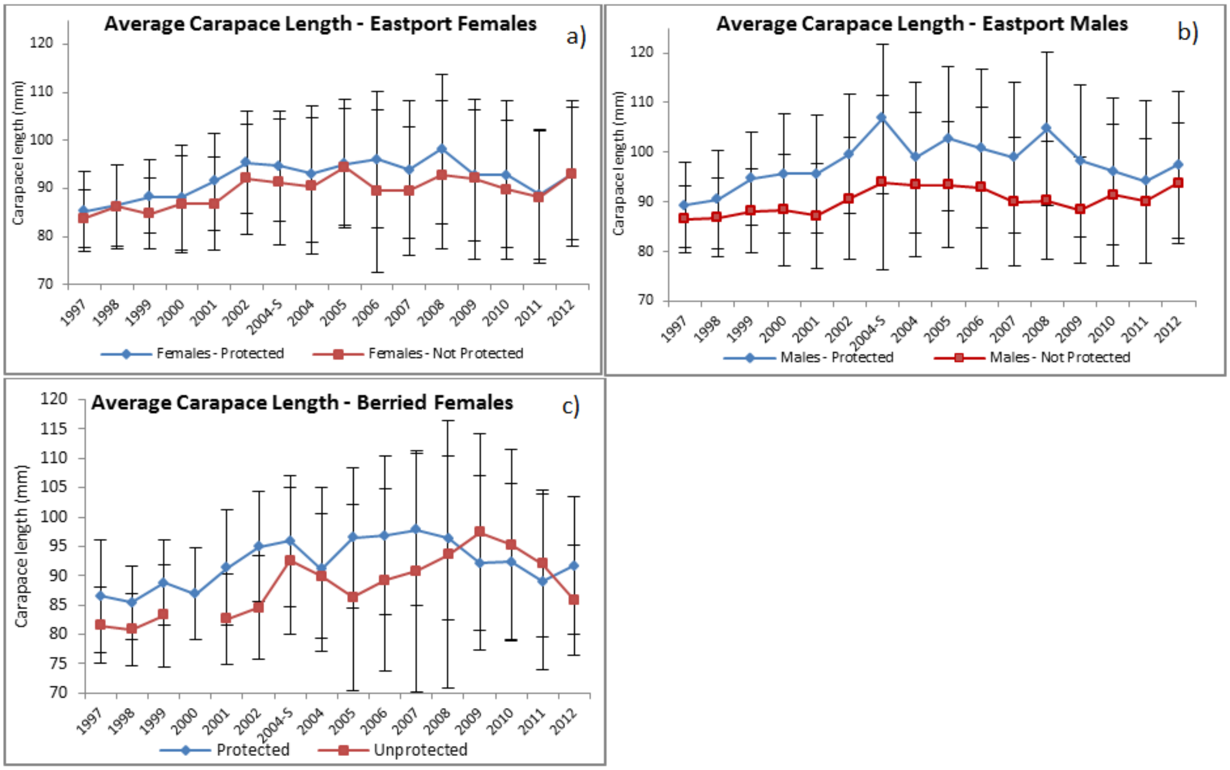

Figure 35. Average CL of Eastport lobsters: a) Males; b) Females; c) Berried females (Error bars represent standard deviation).

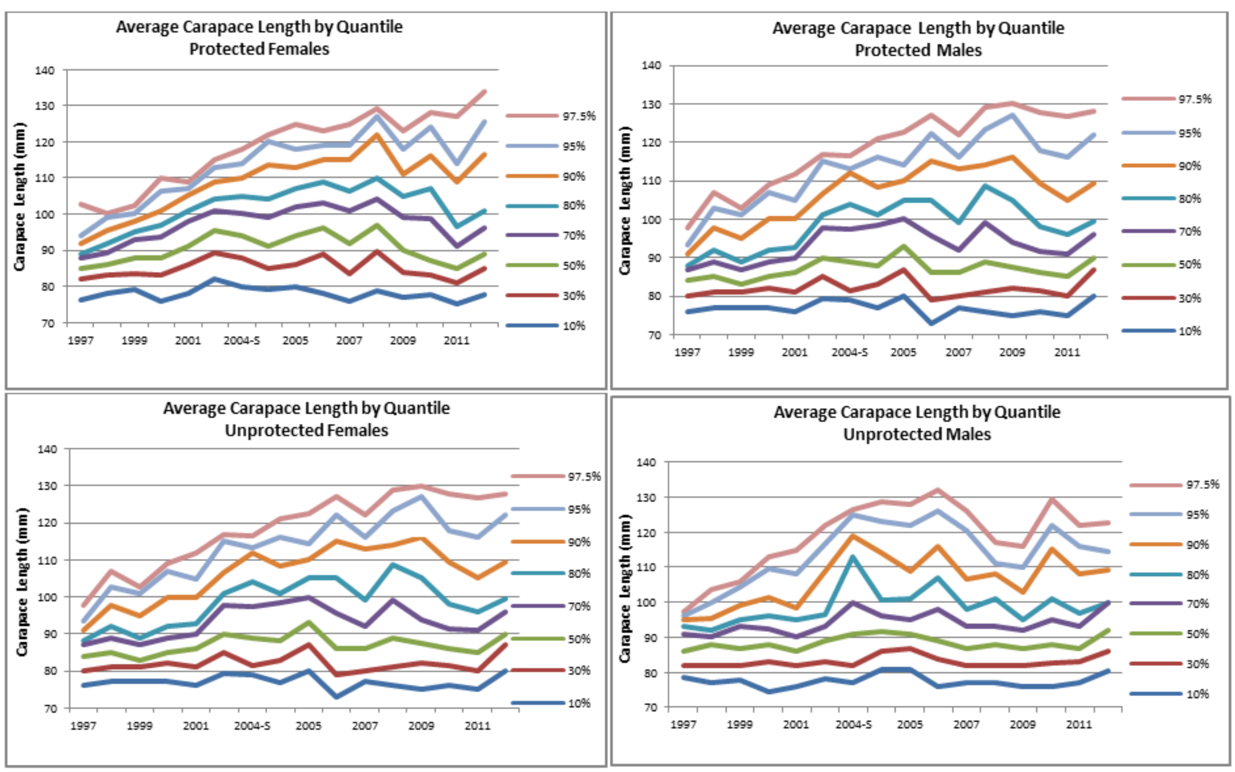

Figure 36. Average CL of protected and unprotected lobsters by quantiles.

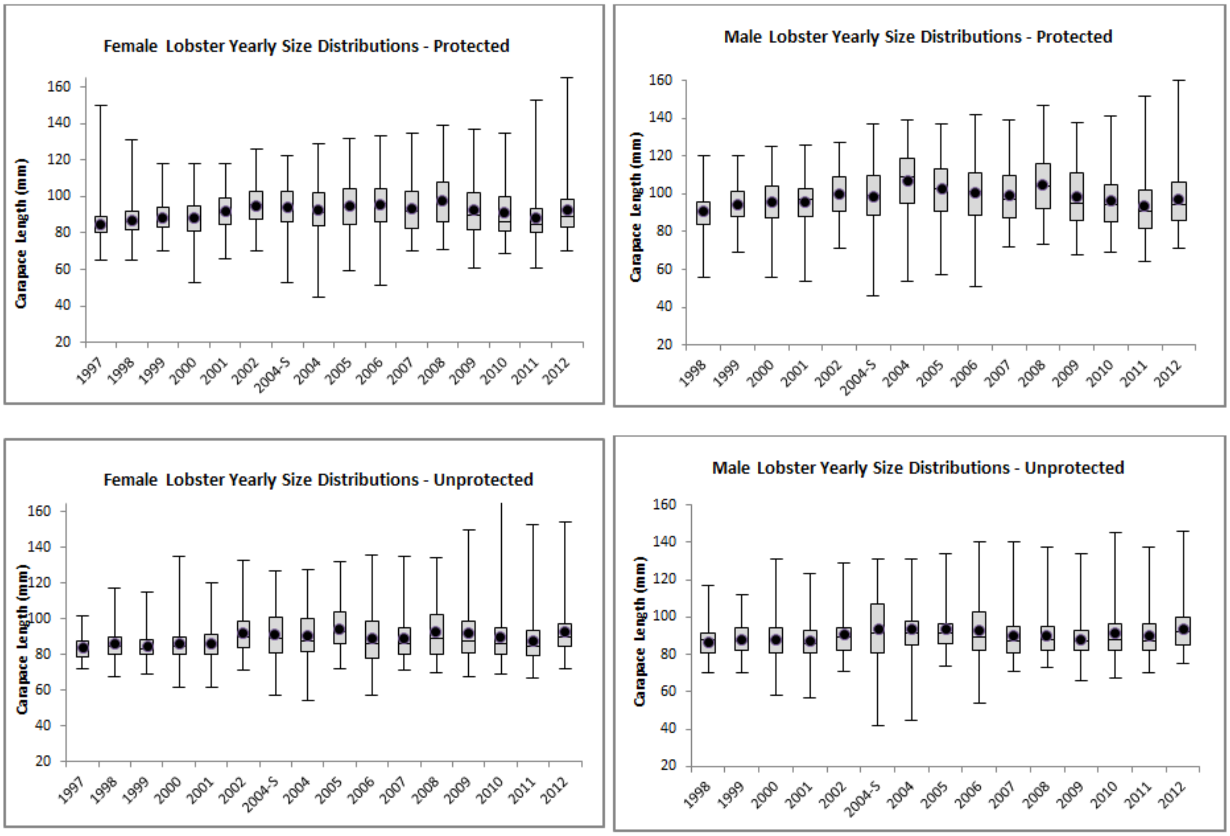

Figure 37. Boxplots for protected and unprotected areas represent the mean, standard deviation and lower and upper quartiles from the tagging data.