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Characterization of the American lobster (*Homarus americanus*) habitat and fishery to inform marine spatial planning in Malpeque Bay, PEI

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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.

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ABSTRACT

Shellfish aquaculture has become an important economic activity of coastal communities in Atlantic Canada. However, several issues are still inducing significant strain on this industry, such as social acceptance and spatial usage conflicts. These are complex issues that are part of the challenges in coastal zone management. In 2013, the Department of Fisheries and Oceans identified the need to develop a detailed spatial plan to accommodate the potential increase in aquaculture acreage in Malpeque Bay, PEI. One of the considerations in this process is to evaluate how much expansion could occur without affecting the productivity of commercial, recreational or Aboriginal species, such as the American lobster (*Homarus americanus*). This project investigated the potential overlaps between proposed shellfish aquaculture sites with potential productive benthic habitats and the lobster fishing activities. Given that these areas are relatively large, a tiered approach strategy was used to collect information at various scales and spatial coverage, and to efficiently identify zones of interest. The first step was to analyze data from the at-sea sampling program to evaluate lobster catches and fishing efforts at a bay scale level. The second and third steps were to conduct multi-beam acoustic seabed surveys and SCUBA transects surveys for habitat characterization. Results from this study showed that, based on catch per unit effort and seabed characteristics, the south block and the northern portion of the west block of the proposed sites expansion scenario are considered poor habitat for lobster serving as a transitory zone. However, the southern portion of the west block is considered prime lobster ground serving as residence habitat for all benthic life stages and size groups of lobster. This study provides relevant information to the current marine spatial planning process in addressing some concerns from the lobster fishing industry. It provides objective observations and measurements, which should facilitate effective and transparent internal and external consultations.

Caractérisation de l'habitat et de la pêche du homard de l'Atlantique (*Homarus americanus*) pour documenter la planification de l'espace marin dans la baie Malpeque, à l'Île-du-Prince-Édouard

RÉSUMÉ

La conchyliculture est devenue une activité économique importante pour les collectivités côtières du Canada atlantique. Toutefois, plusieurs enjeux imposent encore des contraintes importantes sur cette industrie, comme l'acceptation sociale et les conflits liés à l'utilisation de l'espace. Il s'agit de problèmes complexes qui entrent dans la liste des défis relatifs à la gestion de la zone côtière. En 2013, le ministère des Pêches et des Océans a déterminé qu'il était nécessaire d'élaborer un plan spatial détaillé pour prendre en compte l'augmentation éventuelle de la surface consacrée aux activités aquacoles dans la baie Malpeque (Î.-P.-É). Au cours de ce processus, il faut évaluer à quel point ces activités peuvent prendre de l'expansion sans nuire à la productivité des espèces visées par la pêche récréative, commerciale et autochtone, comme le homard de l'Atlantique (*Homarus americanus*). Ce projet a étudié les possibles chevauchements entre les sites de conchyliculture proposés et les habitats benthiques productifs potentiels ainsi que les activités de pêche du homard. Puisque ces zones sont assez grandes, une approche à trois niveaux a été utilisée pour recueillir de l'information à différentes échelles et couvertures spatiales, et pour bien désigner les zones d'intérêt. La première étape visait à analyser les données du programme d'échantillonnage en mer afin d'évaluer les prises de homard et l'effort de pêche dans la baie. Les deuxième et troisième étapes consistaient à mener des relevés acoustiques multifaisceaux du fond marin et des relevés de transect en plongée aux fins de caractérisation de l'habitat. Cette étude démontre que, d'après les captures par unité d'effort et les caractéristiques du fond marin, le bloc sud et la portion nord du bloc ouest du scénario d'expansion des sites proposés sont considérés comme un habitat de mauvaise qualité pour le homard et servent donc surtout de zone transitoire. Cependant, la portion sud du bloc ouest est considérée comme étant un habitat de prédilection pour le homard et sert d'habitat de résidence pour tous les stades de vie benthique et tous les groupes de tailles de homard. Cette étude fournit de l'information pertinente au processus de planification de l'espace marin pour aborder certaines préoccupations exprimées par l'industrie de la pêche du homard. Elle fournit des mesures et des observations objectives, ce qui devrait faciliter la tenue de consultations internes et externes transparentes et efficaces.

INTRODUCTION

Shellfish aquaculture has become an important economic activity of coastal communities in Atlantic Canada. The blue mussel (*Mytilus edulis*: hereafter referred to as mussel) industry emerged on the east coast during the 1970s, expanded rapidly in Prince Edward Island (PEI) during the 1990s, and today is Canada's leading cultured shellfish species by weight and value. However, several issues are still inducing significant strain on this industry, such as social acceptance and spatial usage conflicts. These are complex issues that are part of the challenges in coastal zone management. In early 2000, a moratorium on further leasing for mussel aquaculture was initiated in PEI. In 2007, a request was made to review the moratorium and Malpeque Bay was identified as one of the areas in PEI for potential mussel aquaculture expansion. In 2013, the Department of Fisheries and Oceans (DFO) identified the need to develop a detailed spatial plan to accommodate the potential increase in aquaculture acreage in Malpeque Bay, currently at 7% coverage (DFO 2015). One of the considerations in this process is to evaluate how much expansion could occur without affecting the productivity of commercial, recreational or Aboriginal (CRA) species, such as the American lobster (*Homarus americanus*; hereafter referred to as lobster), a very important socio-economic driver in coastal communities of the southern Gulf of St. Lawrence (sGSL), including in Malpeque Bay (Fig. 1), and the Atlantic rock crab (*Cancer irroratus*; hereafter referred to as rock crab).

This document contributes to one of the terms of reference (TOR-4) of a regional science peer review meeting on the potential impacts of hydrated lime treatments associated with proposed expansion of mussel production in Malpeque Bay held in Moncton (New Brunswick), February 8-9, 2016 (DFO 2016). The focus of this document is on identifying ecosystem components, more specifically the larval phases of invertebrate species in the pelagic zone and seabed characteristics in the benthic zone, which could be sensitive to pressures from human activities (e.g., hydrated lime treatments). TOR-4 states: "based on field studies and literature, quantify the extent to which non-target organisms (specifically lobster) are present in areas being considered for the expanded leases in Malpeque Bay". Further description of TOR-4 lists five themes to be covered, from literature review of larvae phases of several invertebrate species (i.e., lobster, rock crab, mussel and Eastern oyster, *Crassostrea virginica*) to lobster fisheries effort, and seabed characteristics. Given this broad stroke, and to maintain cohesion, the working document was organized in two sections. The first section summarizes the information on the biology of lobster with consideration for Malpeque Bay. The second section presents the results of a research project that was conducted in 2015 on lobster habitat characterization and fishery's spatial use, in Malpeque Bay. The project was conducted within the Program for Aquaculture Regulatory Research (PARR) to inform a mussel aquaculture spatial planning process that is currently underway for Malpeque Bay.

SUMMARY OF LOBSTER LIFE HISTORY

The life history of the lobster consists of planktonic and benthic phases. The planktonic phase follows the hatching of the eggs attached under the female's abdomen. Hatching in the sGSL is normally observed in July and August. Lobster larvae go through three free-swimming larval stages (I to III) and one postlarval stage (IV) that are all highly concentrated at or near the surface (< 2 m) during the planktonic phase (Ennis 1995). Stages I to III are active but relatively weak swimmers, in terms of maintaining position or making headway in flowing water (Herrick 1895), compared to stage IV that display remarkable swimming ability and capacity for rapid and directed swimming (Ennis 1995). The planktonic phase lasts for 22 days at 22°C to as many as 103 days at 10°C (Templeman 1936; MacKenzie 1988). In general, as the temperature increases from 10°C to 22°C, the stage duration decreases from 14 to 2 days for stage I, from

15 to 4 days for stage II, from 25 to 5 days for stage III, and from 49 to 11 days for stage IV (Templeman 1936; MacKenzie 1988). At a constant 15°C, the planktonic phase last around 45 days (MacKenzie 1988). Stage I larvae could emerge as early as late-June with peak numbers in July and well into August (Scarratt 1964, 1973; Ennis 1995). Larval lobster undergo a metamorphosis during the molt to stage IV in which the anatomical characteristics of the larval stages are replaced by those of a juvenile lobster (Ennis 1995). Stage IV marks the transition from the planktonic to the benthic stage as lobster settling to the bottom is considered the first postlarval stage, i.e., first benthic stage (Ennis 1995).

The settling of stage IV to the bottom is mainly driven by temperature and habitat type. The presence of a sharp thermocline in the water column could delay settling as postlarvae are reluctant to pass through a thermal gradient of 4-5°C (Boudreau et al. 1991, 1992, 1993). In addition to a thermal gradient, there is a minimal temperature threshold where postlarvae remain in the water column in waters above 12°C (Annis 2005). Another strong environmental cue that influences the post settlement distribution of postlarvae is the type of habitat. Settled postlarvae are mostly observed in cobble substrates (Wahle and Steneck 1991). Hence, a rocky habitat in shallow (<10 m) water (≥12°C) is especially important during the transition from the pelagic to the benthic stage (stage IV) where postlarvae settle on a rocky habitat that offers shelter from predators (Wahle and Steneck 1991; Rondeau et al. 2014).

The distribution of shelter-restricted juveniles (around 33 mm of carapace length; CL) is influenced by the type of habitat. High abundances of shelter-restricted juveniles are observed in cobble and cobble/boulder substrates (Heck et al. 1989; Wahle and Steneck 1991) and rock on sand (Hudon 1987). Their abundances are very low in mud flats, in contrast to larger juveniles which are observed in these areas (MacKay 1929; Cooper and Uzmann 1980), and they are not found on exposed bedrock or sand substrates. Following the shelter-restricted phase, juvenile lobsters will enter a roaming phase. Hence, lobsters are habitat specific and will select a more complex habitat with an assemblage of rocks (boulders) on a softer and mobile substrate (cobbles and gravel that can be mixed with mud and/or sand) (Lawton and Lavalli 1995). Lobsters will take advantage of rocks to excavate a shelter where they spend most of their time.

Based on tagging studies, movements of lobsters >51 mm CL within the sGSL are characterized by small distances traveled, between release and recapture position, and generally along the shore (Comeau et al. 1999; Comeau and Savoie 2002a). The smallest average distance traveled recorded was observed in parts of Baie des Chaleurs and Western Cape Breton at 2 km and the longest in central Northumberland Strait at 19 km (Comeau et al. 1999; Comeau and Savoie 2002a). There was no correlation between size, sex or year at large in terms of the average distance traveled. In the Malpeque area, the average traveled distance is 10 km with exchange between the bay and the adjacent coastal waters of the Gulf (Comeau et al. 1999; Comeau and Savoie 2002a).

Similar to hatching, other important physiological traits for lobster are mostly observed in summer. The main molting period for lobster in sGSL is from early July to early September (Comeau and Savoie 2001). Mating occurs between July and early September mainly between a male and a soft-shell female (Atema et al. 1979; Karnofsky and Price 1989; Karnofsky et al. 1989; Cowan and Atema 1990), although mating is also reported for female in hard-shell condition (Waddy and Aiken 1990). Generally, the female reproductive cycle is 2 years with egg extrusion one year after mating and then carrying the eggs, attached under the abdomen, for nearly another year before hatching (Aiken and Waddy 1982; Comeau and Savoie 2002b). This two-year reproductive cycle may be shortened to one due to fluctuations of environment factors, mainly temperature (Templeman 1934, 1936; Waddy and Aiken 1992; Waddy et al. 1995; Comeau and Savoie 2002b). The size at the onset of 50% maturity for female lobsters (Comeau and Savoie 2002b) from Malpeque is around 72 mm CL (Comeau 2003). Male lobsters become sexually mature at around 50 mm CL (Conan et al. 2001).

The lobster fishery in Canada is based entirely on effort control (i.e., no quota) and measures to protect key components of the lobster population. Effort is controlled by a fixed number of fishing licenses per Lobster Fishing Area (LFA), an individual trap allocation, restrictions on gear characteristics, and a 2-month fishing season (Rondeau et al. 2014). In addition to effort controls, only harvested animals with a CL above the minimal legal size, and females not carrying eggs with sizes <115 mm and >130 mm CL can be retained (Rondeau et al. 2014).

Malpeque Bay is located within LFA 24 (Fig. 2) that encompasses the entire northern coast of PEI (Rondeau et al. 2014). This fishery operates from 1 May to 30 June each year and the minimal legal size in 2015 was 72 mm CL. Traditional Fishing Knowledge suggest that although there are fishing activities within the bay for the entire season, an increase of that activity is observed in June as harvesters move traps that were deployed outside into the bay coinciding with the increase of water temperature (Robert MacMillan, pers. comm., PEI provincial government). The total commercial lobster catches for LFA 24 showed a steady increase from 1947 (497 t) to 2014 (preliminary landings of 7,046 t from DFO Statistics Sector) with few minor fluctuations (Rondeau et al. 2014). Overall, a 15-fold increase was observed from the lowest landings recorded in 1947 to the peak in 2013 (7,493 t). There is no fine scale information collected on a regular basis by DFO on lobster fishing activities for Malpeque Bay. However, the DFO Aquaculture Leasing Division did a lobster fishing buoys survey in 2012, 2013 and 2014, to collect information for the spatial planning process underway, that provided indications of spatial coverage and fishing patterns (Fig. 3). Overlaid on a bathymetry chart, a pattern that follows mostly the channels at the mouth of the bay and the deepest depth contour edges (light blue-white), and also generally scattered fishing activities in the head of the bay is observed. The absence of fishing activities in the northwest, the east (e.g., March Water), and southwest (i.e., the Bentick Cove area) of the bay is probably due in part to the presence of shellfish aquaculture leases in those areas (Fig. 4).

Further information about planktonic life stages of rock crab and commercial bivalve species, mainly for mussel and Eastern oyster is summarized in Appendix A.

LOBSTER HABITAT CHARACTERIZATION

This project investigates the potential overlaps between proposed shellfish aquaculture sites, potentially productive benthic habitats, and the lobster fishing activities. The objectives of this project are to:

- Conduct a spatial analysis of existing data collected from the at-sea sampling program of the lobster fishery in Malpeque Bay;
- Conduct an acoustic seabed survey of area overlaps between the lobster fishery and proposed new mussel aquaculture activities;
- Conduct underwater transect surveys to characterize the seabed and qualitatively classify habitats in relation to lobster abundance and;
- Identify potential spatial and temporal overlaps with proposed shellfish aquaculture sites.

METHODOLOGY

The study sites for this project were delimitated by Scenario 6, used currently in the spatial planning process in Malpeque Bay, which identifies proposed potential areas for shellfish aquaculture sites development (Fig. 4; VisionQuest 2008[1]). Herein, we will refer to the group of sites in the Richmond Bay area as the 'west block' and the sites below Courtin Island as the 'south block' (for geographical location see Figure 3). Given that these areas have a large spatial coverage (approximately 10 km^2) and the relatively short window of the field season to conduct the work (i.e., 1 year funded project and coordination with other ongoing projects), a tiered approach strategy was used to efficiently identify zones of interest. The first step was to analyze the lobster catch and fishing efforts at the bay scale. The location of lobster fishing activities (fishing pressure indicator, i.e., human dimension) was used as a proxy for lobster abundance (i.e., lobster dimension). The second step was to conduct an acoustic seabed survey of the potential areas where development of more shellfish aquaculture sites have been proposed, with a particular focus in the zones of interest identified in step 1. The rationale for using this tool was that seabed hardness and roughness can indicate potentially important habitats for lobster (i.e., rocky habitats), and thus areas that contribute to lobster population abundance and productivity. The third step was to conduct SCUBA transect surveys to ground truth the acoustic seabed survey mapping and to assess lobster densities in various types of habitats. Finally, the information collected at various scales and spatial coverage was used to identify and assess the relative significance of potential overlaps between proposed shellfish aquaculture sites, and lobster population and fishery.

Database analysis of the lobster fishery activities

The Lobster Resource Monitoring Program began in 1998 as a joint venture between DFO and the PEI Department of Agriculture and Fisheries (accessed 31 May 2016). The information gathered through this program maintains a detailed profile of the harvestable lobster resource caught in PEI waters. Since 2000, it has been solely funded by the PEI provincial government although data is shared and archived within the DFO Lobster Section database. Data collection is conducted by technicians through at-sea sampling on-board commercial vessel during the lobster season. Information collected includes fishing location, trap type, depth, CL, sex, presence and staging of eggs, and missing appendages (Mallet et al. 2006).

An analysis of fishing activities in Malpeque Bay was conducted by extracting data from the Lobster Section database. Since the sampling protocol was standardized in 2001, only data for the period of 2001 to 2014 was used in this study. The information in the Malpeque Bay dataset was than validated, corrected and transformed for statistical and spatial analysis. The data considered were: longitude-latitude coordinates, buoy id (identical to a line of traps), trap id, CL (mm), weight (in g from the weight-length relationship in Rondeau et al. 2014) and sex of every lobster collected in a trap, for all traps within a line. The number of traps attached to a buoy varied between 3 and 5. Lobsters were further categorized as undersize (<72 mm CL), legal size (≥72 mm CL; including berried and window-size females), and berried females of all sizes. The weight of all lobsters within a line was summed for total weight (TW). The catch (g) per unit effort (CPUE) was then calculated by dividing TW and the number of traps for each buoy. This was done for legal size lobsters and berried females separately. The longitude-latitude data were transformed into north and west distances (km) from a reference point. A generalized

[1] VisionQuest. 2008. Malpeque Bay Aquaculture - The Way Ahead. Consultant Report. (accessed May 31, 2016)

additive model (GAM) was used to fit the data, with distance from reference point of buoys as the predictor variables. More specifically, the model included an isotropic smooth function for the distance in the x and y axis. The functions for the smooth were calculated with thin plate regression splines. The GAM function from the 'mgcv' package (Wood 2011) in the R programming language (R Core Team 2015; Version 3.2.3) was used. The argument gamma = 1.4 was included in the function to avoid over fitting the data (Wood 2006). The model was used to predict legal size lobster CPUE contours in the Malpeque Bay area using regularly spaced coordinates. An image of the predicted CPUE contours was than created in QGIS (Version 2.12.3).

Acoustic seabed survey

The acoustic remote sensing seabed survey, of the proposed potential areas for shellfish aquaculture sites development, was conducted using a small research vessel equipped with a seabed mapping system. A multi-beam sonar (WASSP™ WMB-160F; 160 kHz frequency with an automatic ping rate, determined by depth, and a beam width of 112 beams at 1.07º over 120º port/starboard swath) that collects acoustic data from the seabed, a real-time kinematic GPS with motion-compensation (pitch and role) and tidal correction for navigation and positioning (x, y & z), and the OLEX™ system (version 8.4), which analyzes acoustic echo-sounder signals in real-time and classifies the seafloor according to various physical characteristics (e.g., bathymetry, hardness, and coarseness/roughness of the seabed) were used conjointly as the seabed mapping system (herein refer as the multi-beam OLEX™ system). Surveys were conducted at speeds of 8 to 10 knots. The survey strategy consisted in first covering the entire west and south block areas with spacing between tracks (as a compromise between area coverage and data point density, for accuracy and resolution) to narrow-down and identify zones of interest, that consisted of a combination of bathymetry (e.g., slopes), hardness (>65% and <90%), and roughness of seabed features. The parameters used were based on prior knowledge from surveys conducted by the Lobster Section which established a relationship between the acoustic seabed readings and seabed features that indicated relative potential in terms of lobster habitat (Gilles Paulin, pers. comm., DFO Moncton, NB). Additional survey tracks were conducted in the zones of interest, which includes the ones identified in the first step, to reduce spacing in coverage and to increase accuracy and resolution. The surveys were carried out on August 17-18 and August 24-26, 2015. They were typically conducted in the mornings, as weather conditions were more favorable for mapping and it enabled the planning and identification of sites to be validated and characterized by SCUBA transects, step 3 of the tiered approach.

SCUBA transect surveys

Visual line-transect surveys using SCUBA divers were performed between 19-26 August, 2015 to assess the lobster density and length-frequency characteristics (Rondeau et al. 2014) in Malpeque Bay. Transects within the survey area, i.e., proposed aquaculture leases, were selected based on seafloor information mapped by remote sensing using the multi-beam OLEX™ system. Small-scale topographic maps of bottom-type were generated in real time. Validation of maps produced by the multi-beam OLEX™ system was done by diver-held underwater camera and direct observation by SCUBA divers. The formal boundaries of the survey region were mainly defined using observed abiotic characteristics (e.g., mud, sand, gravel, cobble, boulders) and presence of lobsters. A transect consisted of a 100-m line marked at 5-m intervals spread-out parallel to the coastline in order to be aligned with the prevailing currents. Divers surveyed against the current to avoid decreased visibility from disturbed sediments. Start and finish positions of all line-transects were entered into the on-board GPS chart plotter. The number of line-transects was a function of the location of proposed aquaculture leases and the type of habitat observed from the multi-beam OLEX™ system. Two divers descended and each sampled two meters on either side of the line-transect, for a total potential swept area of 400 m^2. Divers attempted to capture every lobster observed within the line-transect. All captured lobsters were measured (CL) and the sex was determined. Divers also recorded the seafloor characteristics (i.e., size, type and aggregation of rocks and other features). Information from each diver was recorded on underwater sampling sheets at each 5-m interval. To standardize the information collected by divers, the sediment size classification scheme developed by Wentworth (1922) and later modified by Pettijohn (1949) was used.

Since lobsters are habitat specific and will select a more complex habitat with an assemblage of rocks (boulders) on a softer and mobile substrate (cobbles and gravel that can be mixed with mud and/or sand) (Lawton and Lavalli 1995), lobster habitat preferences could be characterized by collecting information on the size and type of material observed on the seafloor, its assemblage, and lobster densities.

For the purpose of this study, the following classification is proposed based on artificial lobster reef surveys carried-out between 2000 and 2005 in the sGSL (M. Comeau, DFO, pers. comm.):

- Type I: Prime lobster ground is characterized by a complex habitat composed of numerous small to mid-size boulders (diameter >25 cm) on a gravel or small cobble substrate, or a mixture of gravel-mud-sand, i.e., highest lobster densities.
- Type II: Good lobster ground is also characterized by small to mid-size boulders on a softer substrate, but the complex assemblage of small to mid-size boulders form reefs that are separated, but located at very close proximity, i.e., high lobster densities.
- Type III: Marginal lobster ground is characterized by small to mid-size boulders on a similar substrate as described for the good lobster ground, but the reef type formations are farther apart. Between these reef formations, simple habitat composed of soft (gravel, mud and/or sand) or hard bottom substrate, characteristic of a poor lobster ground, is observed, i.e., low lobster densities.
- Type IV: Poor lobster habitat is characterized by a simple habitat composed of soft material (such as gravel, sand and mud) or hard bottom (sandstone or granite bottom) with no boulder size rocks. Lobsters might be seen in this type of habitat but they are likely in transition between more suitable lobster grounds, and will not permanently use this type of habitat, i.e., very low lobster densities to nil. This type of habitat cannot sustain the lobster life cycle.

For each transect, counts of observed lobster by cohort, using size intervals based on Hudon (1987), Gendron and Sainte-Marie (2006), and Rondeau et al. (2014), were tabulated and analyzed. Since the SCUBA survey was carried-out close to the end of the 2015 stage IV settlement period, cohort 0 actually represent the annual young-of-the-year (only two animals were observed at 5 mm CL). The size classes related to the other cohorts are: cohort 1, 12-26 mm CL; cohort 2 , 27-46 mm CL; cohort 3, 47-59 mm CL; cohort 4, 60-69 mm CL; cohort 5, 70-80 mm CL; and cohort 6+, >80 mm CL. Densities for each cohort in each transect were estimated by dividing the observed count by the swept area.

RESULTS AND DISCUSSION

The spatial pattern and coverage of the data points for the combined years of the at-sea sampling database analysis (Fig. 5) are similar to the lobster fishing buoys survey that was conducted between 2012 and 2014 (Fig. 6) by the DFO Aquaculture Leasing Division. Direct spatial overlaps between proposed shellfish aquaculture sites and lobster fishing activity can be observed, specifically in the northern and southern portion of the west block and the northern portion, and along Courtin Island, of the south block (Figs. 5 and 6). At this stage, one could interpret a potential conflict between these activities by using simple spatial overlay. However, lobster trap locations is only a human dimension proxy for lobster abundance (in CPUE), and the ecosystem component has to be taken into account in a spatial analysis to consider transition versus residency areas. In the context of risk analysis, potential benthic effects from human activities would have higher consequences on residency compared to transitory areas. The at-sea sampling data analysis allows creating a spatial map of the fishing activities in terms of CPUE of legal sized lobsters. Based on the CPUE contours presented in Figure 7, the south block area is potentially a transitory zone because of low CPUE values, whereas the southern portion of the west block could be a residency zone (i.e., high CPUE values). Thus, area overlaps found in the southwest portion of Malpeque Bay (i.e., yellow and orange bands in Figure 7) became zones of particular interest for step 2 of the tiered approach. CPUE of berried females was plotted to identify possible source of larval emergence within Malpeque Bay. However, no concentration could be identified based on at-sea sampling data (Fig. 8). Furthermore, 94% of the traps sampled had a CPUE < 300 g (50% of them had no berried female) that prevented the estimation of a berried female CPUE contour map (see Figure 8). This is not surprising because harvesters are systematically avoiding areas of high berried female concentrations as they are of no commercial value.

As expected, the acoustic seabed survey (i.e., the multi-beam OLEX™ system) was an efficient tool to scale-down zones of interest (i.e., from km^2 to m^2). Figure 9 shows the total coverage (>10 km^2) that was surveyed in approximately 3 days. SCUBA transects conducted to ground truth the hardness acoustic classification confirmed that the soft bottoms (blue-green) were mainly a homogenous seabed with Type IV lobster habitat. Thus large areas could be ignored and sampling activities focused on seabed features of higher complexity (yellow-orange). Figure 10 shows the bathymetry of the south block. Softer bottoms are mostly located in the deeper section of the block which is consistent with typical sediment accumulation in aquatic basins. More complex seabeds (i.e., with slope, hardness and roughness) were identified which are mainly associated with land features that are extending into the bay (i.e., landscape bathymetric ecology). Interestingly, several mounts scattered throughout the area could be observed which are most likely shell accumulations (based on SCUBA transect observations). In fact, they were misleading during the acoustic remote sensing seabed survey by indicating hardness values that were usually associated with good seabed for lobster habitat, but were actually Type IV lobster habitat (Fig. 11). The hardness value anomaly came from the presence of many shells scattered on the seabed. Figure 12 shows the bathymetry of the west block. Similarly to the south block, the deeper parts correspond to softer grounds (Fig. 13). The seabed feature that became of high interest in our survey can be seen in the southern portion of the west block, which is a land feature that extends into the bay. Again, there was a bias with the hardness values because of the presence of shell mounts in the block. However, combined with roughness we were able to narrow-down significant seabed features to be validated using SCUBA transects, step 3 of our tiered approach.

Data analysis from the SCUBA transect surveys showed that all transects (see Figs. 11 and 13), except transects 6, 7 and 12, were characterized as simple habitat composed of soft material, primarily mud with large quantities of old shells, shell fragments covering the mud, and often Eastern oyster shells, i.e., Type IV - poor lobster habitat. In some transects, sand habitat was also observed with bowl-like feature and small patches of very small gravel. A rocky habitat was observed in transects 6 and 7 (Fig. 14), characterized with boulders and cobbles on top of a combination of hard sandstone, sand and mud, .i.e., Type I - prime lobster ground. Small reefs with a combination of boulders, cobbles, mud, sand and hard sandstone separated by simple soft habitat (mud and sand with fragment of old shell) was observed in transect 12 (Fig. 15), which is characteristic of a Type II - good lobster ground. Also, no commercial sized lobster were collected, i.e., two animals (71 mm CL) from cohorts 5 and none from 6+ (Table 1). Finally, only two young-of-year were observed. They measured 5 mm CL, with one sampled in transect 12 in a good lobster ground while the other was collected in a poor lobster ground at transect 15 (located in the northern portion of the south block; Fig. 11).

Lobster densities (lobster/100 m^2) correlate with the type of habitat. Lobster densities for all transects from the south block (transects 1-5, 15 and 16) of the survey area (i.e., poor lobster habitat) are low with a total average of 1.11 (Table 1). Total average densities of shelter-restricted juveniles (≤33 mm CL) were also low at 0.29, with 4 of the 7 transects at 0.00 (Table 1). Transects located in the west block of the survey area were done on a more heterogeneous seabed with a combination of prime, good and poor lobster habitat. Similar to the south block, the overall and shelter-restricted juvenile average densities were low for the poor lobster habitat (transects 8-11, 13 and 14) at 1.50 and 0.21 in the west block (Table 1). These densities contrast with those observed in transects 6, 7 and 12. The highest densities both for the overall and for the shelter-restricted juveniles were observed in transect 7 (70.00 and 34.00, respectively), followed by transect 6 (34.00 and 22.00, respectively) and finally transect 12 (11.00 and 8.00, respectively). In general, the overall and shelter-restricted juvenile average densities on the lobster reefs were estimated at 38.33 and 21.33, respectively (Table 1). Overall and shelter-restricted juveniles average densities in the prime/good lobster habitat were, respectively, 30- and 85-fold higher compared to all the average densities estimated from poor lobster habitat (Table 1). Figure 16 shows the size frequency distribution of lobsters measured during the SCUBA transects surveys. As mentioned earlier, all lobsters measured were below the minimum legal size of 72 mm CL. However, a wide range of sizes were found throughout the surveys. The difference between a poor (e.g., T1) and a prime (T6) lobster habitat can be observed by a scattered size distribution of lobsters compared to a much more consistent pattern for the latter (Fig. 16), an indicator of higher habitat complexity.

CONCLUSION

This study shows that considering elements both within the lobster dimension (i.e., seabed characteristics and lobster population dynamics) and the human dimension (e.g., lobster fishing activities and shellfish aquaculture leases) are paramount for comprehensive marine spatial planning. In other words, solely using the human dimension would be misleading in decision-making.

Based on the CPUE modeling and seabed characteristics, the area of the south block seems to be a transitory zone for lobsters. The ecosystem component that is valued, i.e., lobster habitat in this case, is considered to be of lower importance (Fig. 17). Based on what is known about the potential pathways of effects (PoE) from shellfish aquaculture (DFO 2010), it seems highly probable that both activities can sustainably coexist within this zone. Furthermore, it seems unlikely that CPUE will significantly change by relocating fishing buoys in other areas within this zone. However, the southern portion of the west block is showing indication of a residency zone for the lobster population, thus the seabed habitat is considered to be of higher importance (Fig. 17). Given that knowledge gaps still exist with PoE associated with shellfish aquaculture, such as benthic effects on hard versus soft bottoms, it would seem prudent to favor an avoidance strategy at this time, such as promulgated in the *Fisheries Act* and the new Aquaculture Activities Regulations. Although we didn’t observe any direct overlaps between proposed shellfish aquaculture sites and valued seabed features in the other portions of the west block, there are indications that the zone along the shoreline could be of interest. Given that knowledge gaps still exist with PoE associated with shellfish aquaculture, such as in far field effects, it would seem prudent to pursue investigations to evaluate effective mitigation measures in relation to this zone.

The purpose of this project was to provide relevant information to the current process in developing a marine spatial plan for current and future mussel aquaculture development in Malpeque Bay, PEI. Specifically, it should address some concerns from the lobster fishing industry in providing objective observations and measurements, based on scientific principles, in order to facilitate effective and transparent internal and external consultations.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Aiken, D.E., and Waddy, S.L. 1982. Cement gland development, ovary maturation, and reproductive cycles in the American lobster *Homarus americanus*. J. Crustacean Biol. 2: 315-327.

Annis, E.R. 2005. Temperature effects on the vertical distribution of lobster postlarvae (*Homarus americanus*). Limnol. Oceanogr. 50: 1972-1982.

Atema, J., Jacobson, S., Karnofsky, E., Oleszko-Szuts S., and Stein, L. 1979. Pair formation in the lobster, *Homarus americanus*: behavioral development, pheromones and mating. Mar. Behav. Physiol. 6: 277-296.

Boudreau, B., Simard, Y., and Bourget, E. 1991. Behavioural responses of the planktonic stages of the American lobster *Homarus americanus* to thermal gradients, and ecological implications. Mar. Ecol. Prog. Ser. 76: 13–23.

Boudreau, B., Simard, Y., and Bourget, E. 1992. Influence of a thermocline on vertical distribution and settlement of post-larvae of the American lobster *Homarus americanus* Milne-Edwards. J. Exp. Mar. Biol. Ecol. 162: 35–49.

Boudreau, B., Bourget. E., and Simard, Y. 1993. Behavioural responses of competent lobster postlarvae to odour plumes. Mar. Biol. 117: 63–69.

Comeau, M. (ed.). 2003. Workshop on lobster (*Homarus americanus* and *H. gammarus*) reference points for fishery management held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 2506: vii + 35 p.

Comeau, M., and Savoie, F. 2001. Growth increment and molt frequency of the American lobster (*Homarus americanus*) in the southwestern Gulf of St. Lawrence. J. Crustacean Biol. 21: 923-936.

Comeau, M., and Savoie, F. 2002a. Movement of American lobster (*Homarus americanus*) in the southwestern Gulf of St. Lawrence, Canada. Fish. Bull. 100: 181-192.

Comeau, M., and Savoie, F. 2002b. Maturity and reproduction cycle of the female American lobster, *Homarus americanus*, in the southwestern Gulf of St. Lawrence, Canada. J. Crustacean Biol. 22: 762-774.

Comeau, M., Lanteigne, M., Robichaud, G., and Savoie, F. 1999. Lobster (*Homarus americanus*) movement in the southern Gulf of St. Lawrence - Summary sheets of tagging projects conducted between 1980 and 1997. Can. Ind. Rep. Fish. Aquat. Sci. 249: 111.

Conan, G.Y., Comeau, M., and Moriyasu, M. 2001. Are morphometrical approaches appropriate to establish size at maturity for male American lobster, *Homarus americanus*? J. Crustacean Biol. 21: 937-947.

Cooper, R.A., and Uzmann, J.R. 1980. Ecology of juvenile and adult *Homarus*. pp. 97–139. In: J.S. Cobb and B.F. Phillips (Eds.). The biology and management of lobsters, Vol. 2: Ecology and management. Academic Press, New York.

Cowan, D.F., and Atema, J. 1990. Moult staggering and serial monogamy in American lobsters, *Homarus americanus*. Anim. Behav. 39: 1199-1206.

DFO. 2010. Pathways of Effects for Finfish and Shellfish Aquaculture. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/071.

DFO. 2015. Carrying capacity for shellfish aquaculture with reference to mussel aquaculture in Malpeque Bay, Prince Edward Island. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/003.

DFO. 2016. Review of potential impacts of hydrated lime treatments associated with proposed expansion of mussel production in Malpeque Bay, PEI. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/014.

Ennis, G.P. 1995. Larval and postlarval ecology, pp. 23 - 46. In: J.R. Factor (Ed.). The Biology of the lobster *Homarus americanus.* Academic Press, London.

Gendron, L., and Sainte-Marie, B. 2006. Growth of juvenile lobster *Homarus americanus* off the Magdalen Islands (Quebec, Canada) and projection of instar and age at commercial size. Mar. Ecol. Prog. Ser. 326: 221-233.

Heck, K.L., Able, K.W., Fahay, M.P., and Roman, C.T. 1989. Fishes and decapod crustaceans of Cape Cod eelgrass meadows: Species composition, seasonal abundance patterns and comparison with unvegetated substrates. Estuaries 12: 59-65.

Herrick, F.H. 1895. The American lobster, a study of its habits and development. Bull. U.S. Fish. Comm. 15: 1-252.

Hudon, C. 1987. Ecology and growth of postlarval and juvenile lobster, *Homarus americanus*, off Îles de la Madeleine (Quebec). Can. J. Fish. Aquat. Sci. 44: 1855-1869.

Karnofsky, E.B., and Price, H.J. 1989. Dominance, territoriality and mating in the lobster, *Homarus americanus*: a mesocosm study. Mar. Behav. Physiol. 15: 101-121.

Karnofsky, E.B., Atema, J., and Elgin, R.H. 1989. Field observations of social behavior, shelter use and foraging in the lobster, *Homarus americanus*. Biol. Bull. 176: 239-246.

Lawton, P., and Lavalli, K.L. 1995. Postlarval, juvenile, adolescent, and adult ecology, pp. 47 - 88. In: J.R. Factor (ed.). Biology of the lobster, *Homarus americanus*. Academic Press, New York.

MacKay, D.A. 1929. Larval and postlarval lobsters. The American Naturalist 63: 160-170.

MacKenzie, B. 1988. Assessment of temperature effects on interrelationships between stage durations, mortality, and growth in laboratory-reared *Homarus americanus* Milne Edwards larvae. J. Exp. Marine Bio. Eco. 116: 87-98.

Mallet, M., Comeau, B., Gagnon, D., and Comeau, M. 2006. At-sea sampling data collection and fishery regulations for the southern Gulf of St. Lawrence lobster (*Homarus americanus*) fishery – 1982-2000. Can. Manus. Rep. Fish. Aquat. Sci. 2769: v + 105 p.

Pettijohn, F.J. (ed.). 1949. Sedimentary rocks. Harper & Row, New York, 718 p.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (accessed March 10, 2016).

Rondeau, A., Comeau, M., and Surette, T. 2014. Assessment of the American Lobster (*Homarus americanus*) Stock Status in the Southern Gulf of St. Lawrence (LFA 23, 24, 25, 26A and 26B). DFO Can. Sci. Advis. Sec. Res. Doc. 2014/036. xii + 92 p.

Scarratt, D.J. 1964. Abundance and Distribution of Lobster Larvae (*Homarus americanus*) in Northumberland Strait. J. Fish. Res. Board Can. 121: 661-680.

Scarratt, D.J. 1973. Claw loss and other wounds in commercially caught lobsters (*Homarus americanus*). J. Fish. Res. Board Can. 30: 1370-1373.

Templeman, W. 1934. Mating in the American lobster. Contrib. Can. Biol. Fish. 8: 423-432.

Templeman, W. 1936. Local differences in the life history of the American lobster (*Homarus americanus)* on the coast of the Maritime Provinces of Canada. J. Biol. Board Can. 2: 41–88.

Waddy, S.L., and Aiken, D.E. 1990. Intermolt insemination, an alternative mating strategy for the American lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. 47: 2402-2406.

Waddy, S.L., and Aiken, D.E. 1992. Seasonal variation in spawning by preovigerous American lobster (*Homarus americanus*) in response to temperature and photoperiod manipulation. Can. J. Fish. Aquat. Sci. 49: 1114-1117.

Waddy, S.L., Aiken, D.E., and De Kleijn, D.P.V. 1995. Control of growth and reproduction, pp. 217 - 266. In: J.R. Factor (Ed.). Biology of the lobster *Homarus americanus*. Academic Press, Toronto.

Wahle, R.A., and Steneck, R.S. 1991. Recruitment habitats and nursery grounds of the American lobster *Homarus americanus* - A demographic bottleneck. Mar. Ecol. Prog. Ser. 69: 231–243.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30: 377-392.

Wood, S.N. 2006. Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC

Wood, S.N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semi parametric generalized linear models. J. Roy. Stat. Soc. 73: 3-36.

TABLES

Table 1. Data analysis summary of lobsters (grouped as cohorts) measured during the SCUBA transect surveys in Malpeque Bay, PEI. Cohort 0 represents the young-of-the-year. Transects within the Richmond Bay area (West), below Courtin Island (South) and those with reefs located in the west block are grouped. Crypt refers to shelter-restricted juveniles (≤33 mm of carapace length).

			Number by cohort								Density by cohort (number per 100 m²)								
Location	Transect	Area	0	1	2	3	4	5	6+	Total	0	1	2	3	4	5	6+	Total	Crypt
South	1	400	0	3	5	1	0	0	0	9	0.00	0.75	1.25	0.25	0.00	0.00	0.00	2.25	1.00
	2	400	0	0	1	1	1	0	0	3	0.00	0.00	0.25	0.25	0.25	0.00	0.00	0.75	0.25
	3	400	0	0	2	0	0	0	0	2	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.50	0.00
	4	400	0	0	1	3	0	0	0	4	0.00	0.00	0.25	0.75	0.00	0.00	0.00	1.00	0.00
	5	400	0	0	1	1	1	0	0	3	0.00	0.00	0.25	0.25	0.25	0.00	0.00	0.75	0.00
	15	400	1	2	5	1	0	0	0	9	0.25	0.50	1.25	0.25	0.00	0.00	0.00	2.25	0.75
	16	400	0	0	1	0	0	0	0	1	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.25	0.00
	mean										0.04	0.18	0.57	0.25	0.07	0.00	0.00	1.11	0.29
West	8	400	0	0	8	3	1	0	0	12	0.00	0.00	2.00	0.75	0.25	0.00	0.00	3.00	0.25
	9	400	0	1	4	2	0	0	0	7	0.00	0.25	1.00	0.50	0.00	0.00	0.00	1.75	0.25
	10	400	0	0	5	4	1	1	0	11	0.00	0.00	1.25	1.00	0.25	0.25	0.00	2.75	0.50
	11	400	0	0	1	0	0	0	0	1	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.25	0.00
	13	400	0	1	2	0	1	0	0	4	0.00	0.25	0.50	0.00	0.25	0.00	0.00	1.00	0.25
	14	400	0	0	1	0	0	0	0	1	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.25	0.00
	mean										0.00	0.08	0.88	0.38	0.13	0.04	0.00	1.50	0.21
South + West					mean						0.02	0.13	0.71	0.31	0.10	0.02	0.00	1.29	0.25
Reef	6	200	0	26	35	5	1	1	0	68	0.00	13.00	17.50	2.50	0.50	0.50	0.00	34.00	22.00
	7	100	0	17	40	9	4	0	0	70	0.00	17.00	40.00	9.00	4.00	0.00	0.00	70.00	34.00
	12	200	1	8	11	1	1	0	0	22	0.50	4.00	5.50	0.50	0.50	0.00	0.00	11.00	8.00
					mean						0.17	11.33	21.00	4.00	1.67	0.17	0.00	38.33	21.33

FIGURES

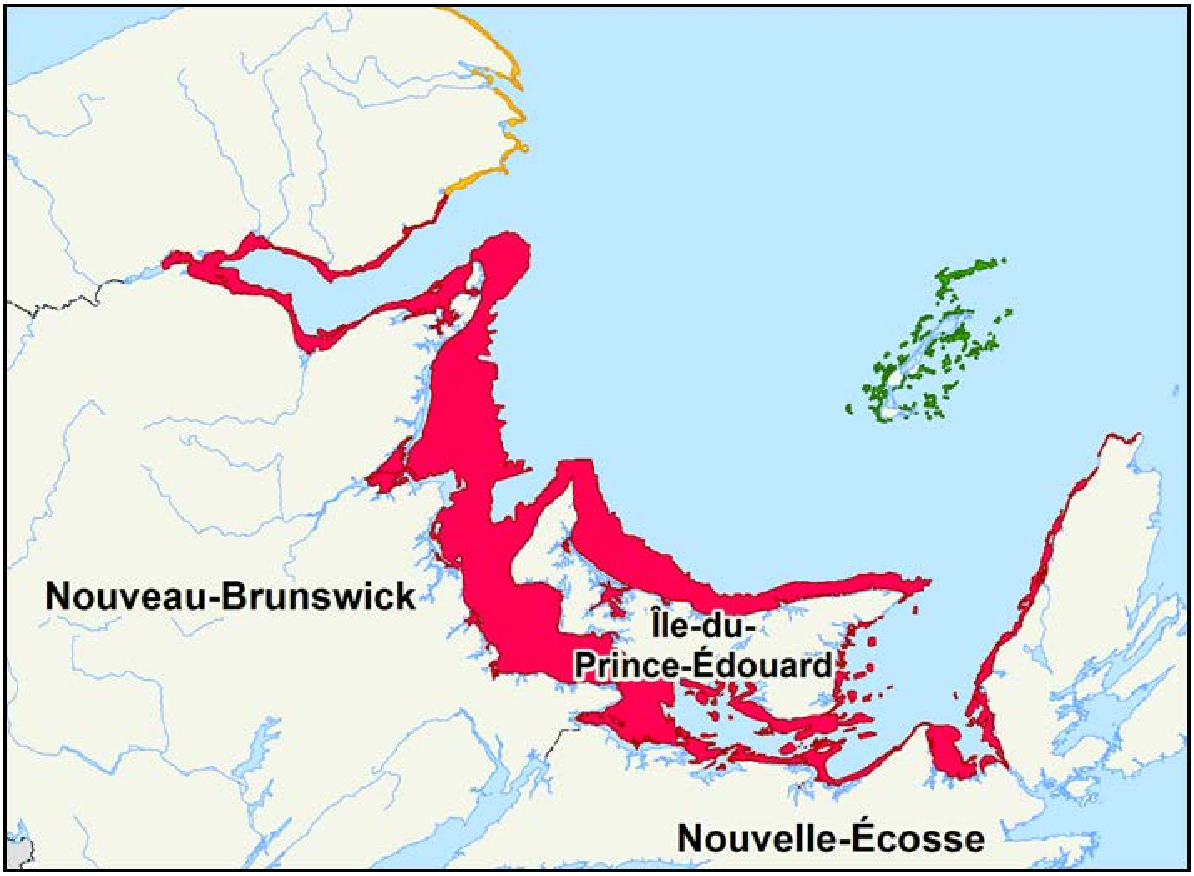


Figure 1. Estimated lobster distribution in the southern Gulf of St. Lawrence. Source: map generated by the DFO Policy and Economics Sector, using Traditional Fisheries Knowledge, landing statistics and environmental variables; unpublished.

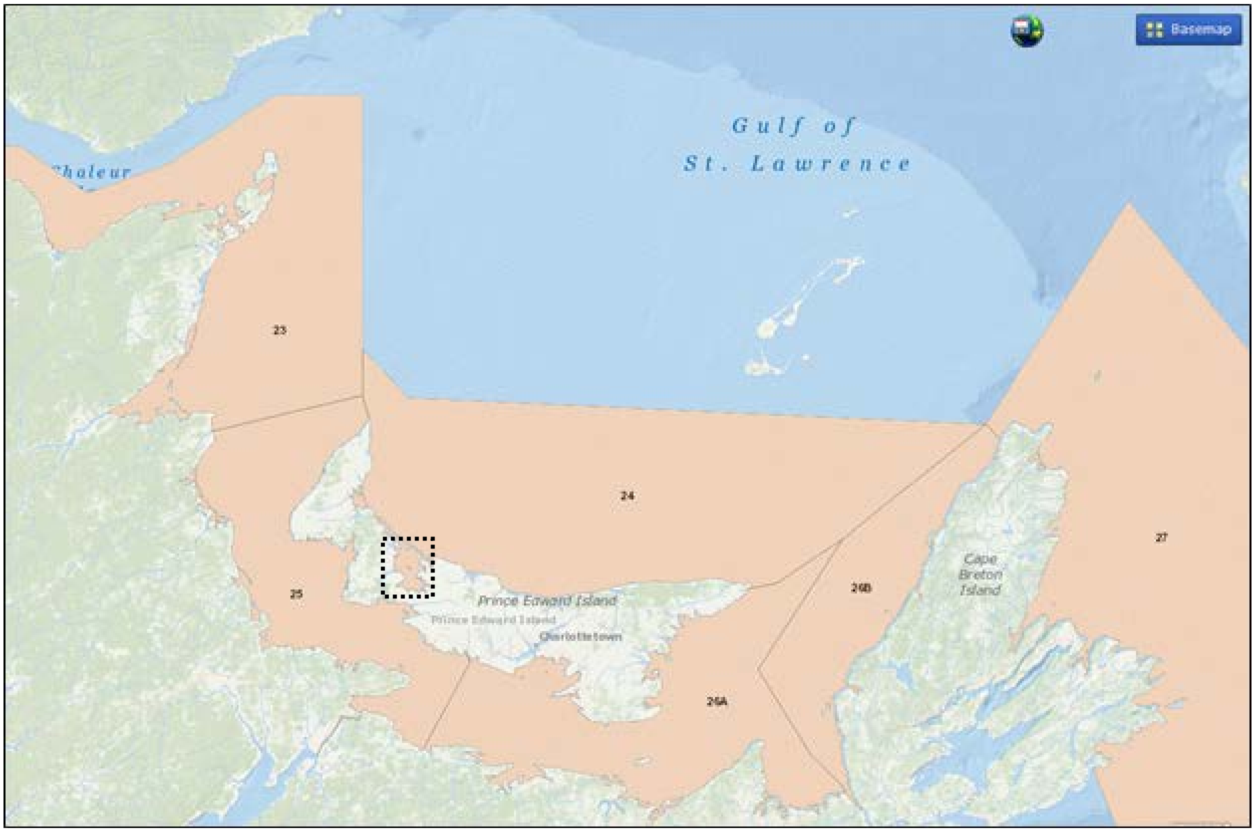


Figure 2. Lobster Fishing Areas of the southern Gulf of St. Lawrence, with the location of Malpeque Bay shown as the dashed rectangle.

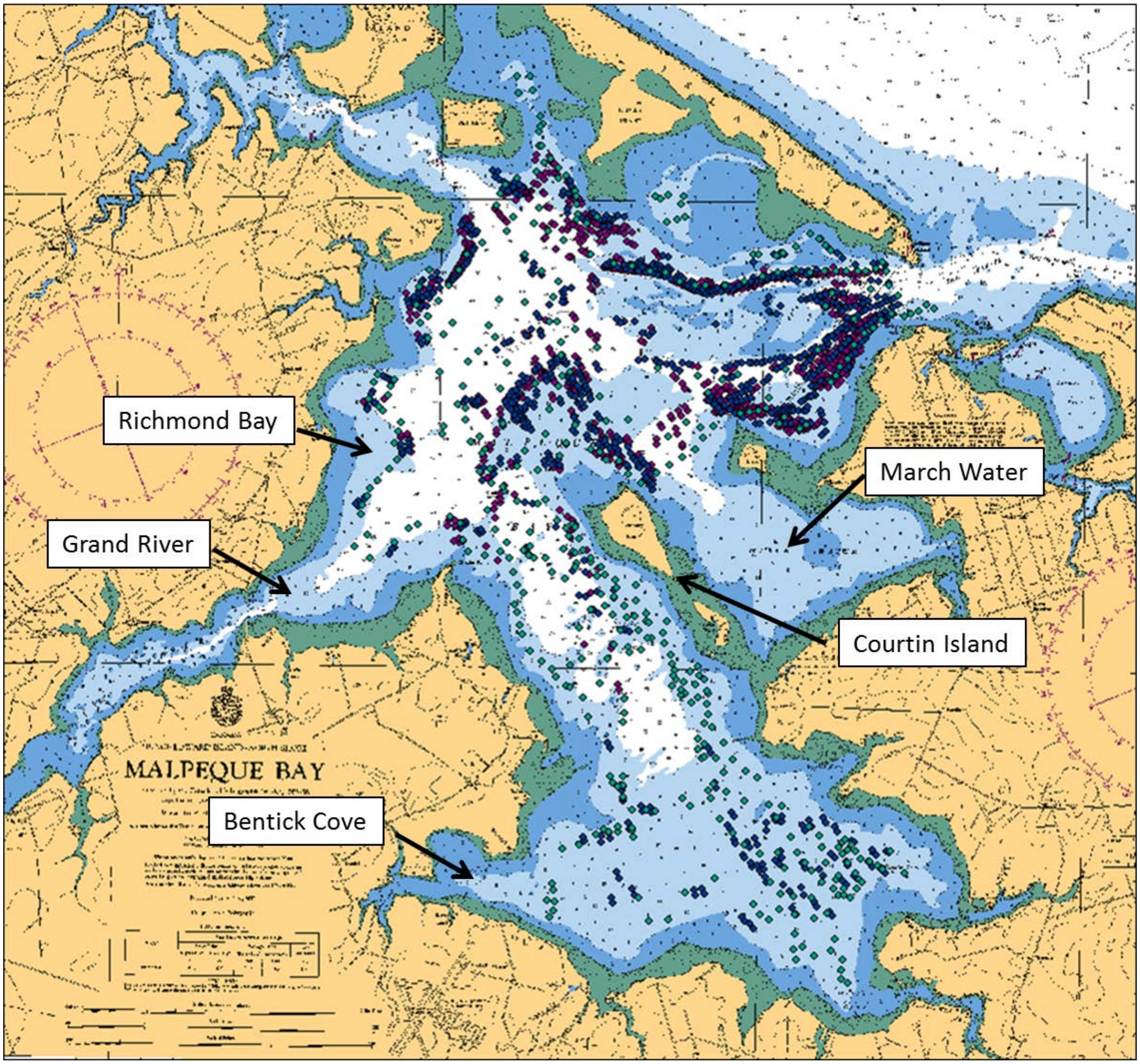


Figure 3. Spatial coverage of lobster buoys (1-2 days per year, at the end of June), in Malpeque Bay, PEI. This survey was conducted by the DFO Aquaculture Leasing Division, in 2012 (green), 2013 (blue) and 2014 (red). The map also includes geographical names and locations used in this document.

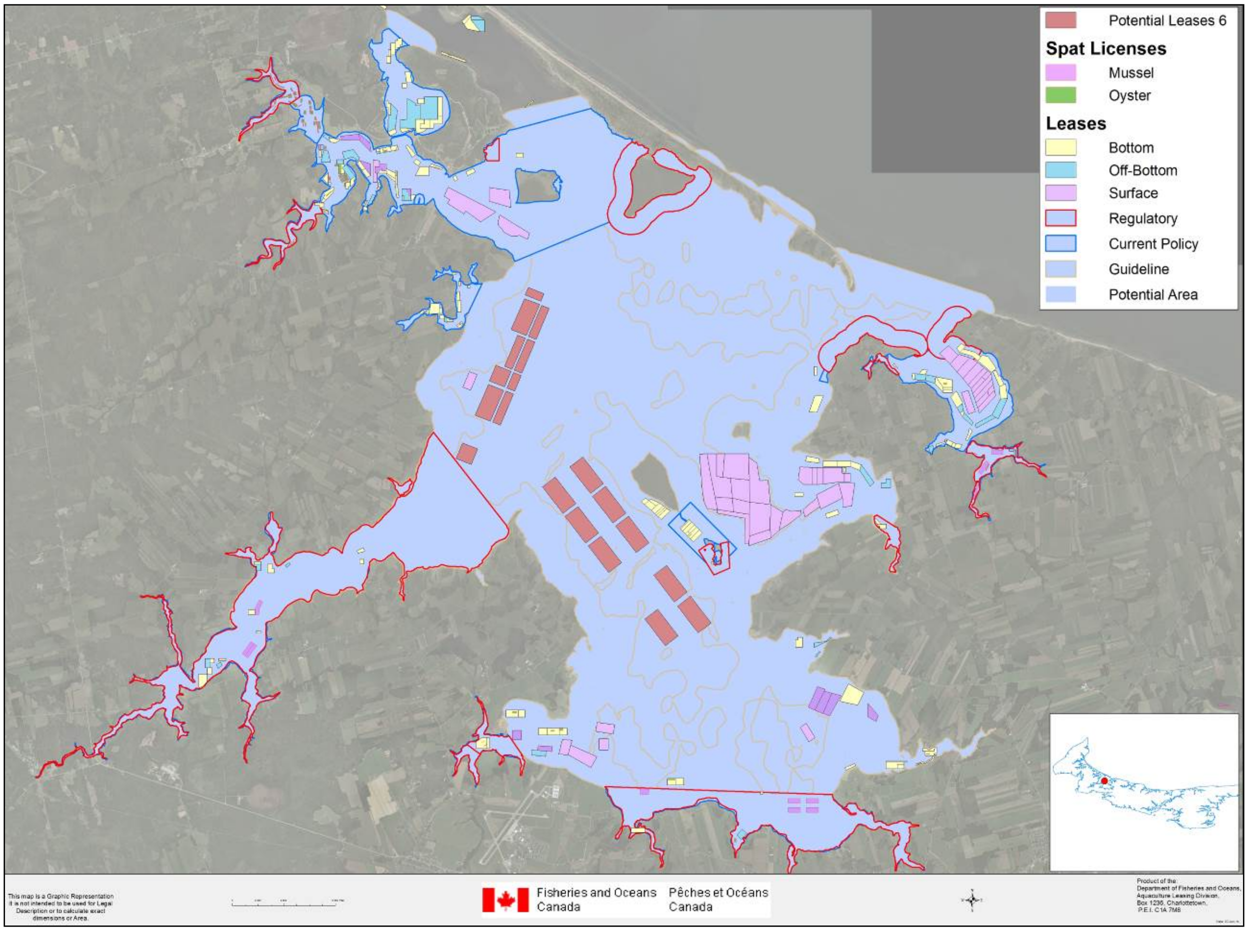


Figure 4. Proposed potential areas (Scenario 6) for shellfish aquaculture site development (red polygons) and current leases in Malpeque Bay, PEI. Source: DFO Aquaculture Leasing Division.

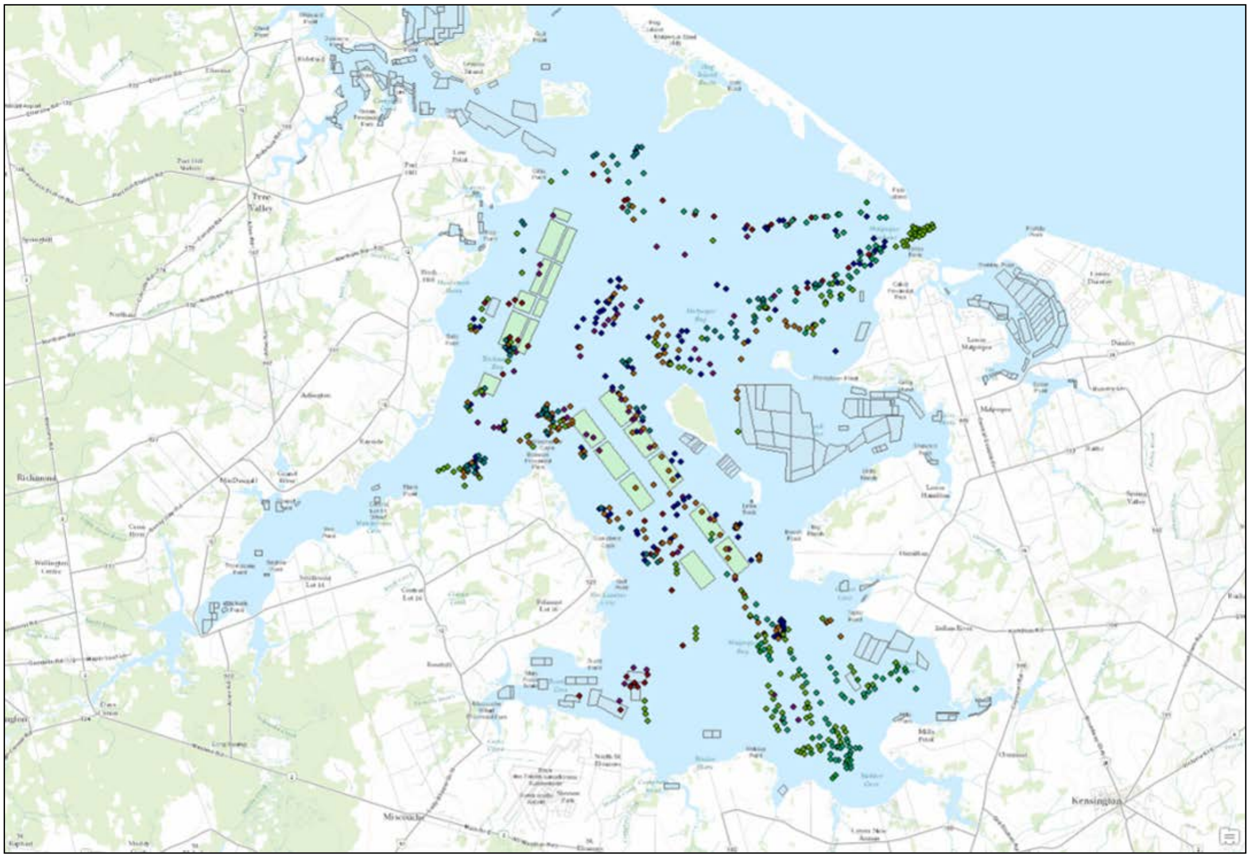


Figure 5. Total data points from the at-sea sampling program, for the combined years of 2001 to 2007 and 2012 in Malpeque Bay, PEI. Map includes the proposed (light green polygons) and current (grey polygons) shellfish aquaculture leases.

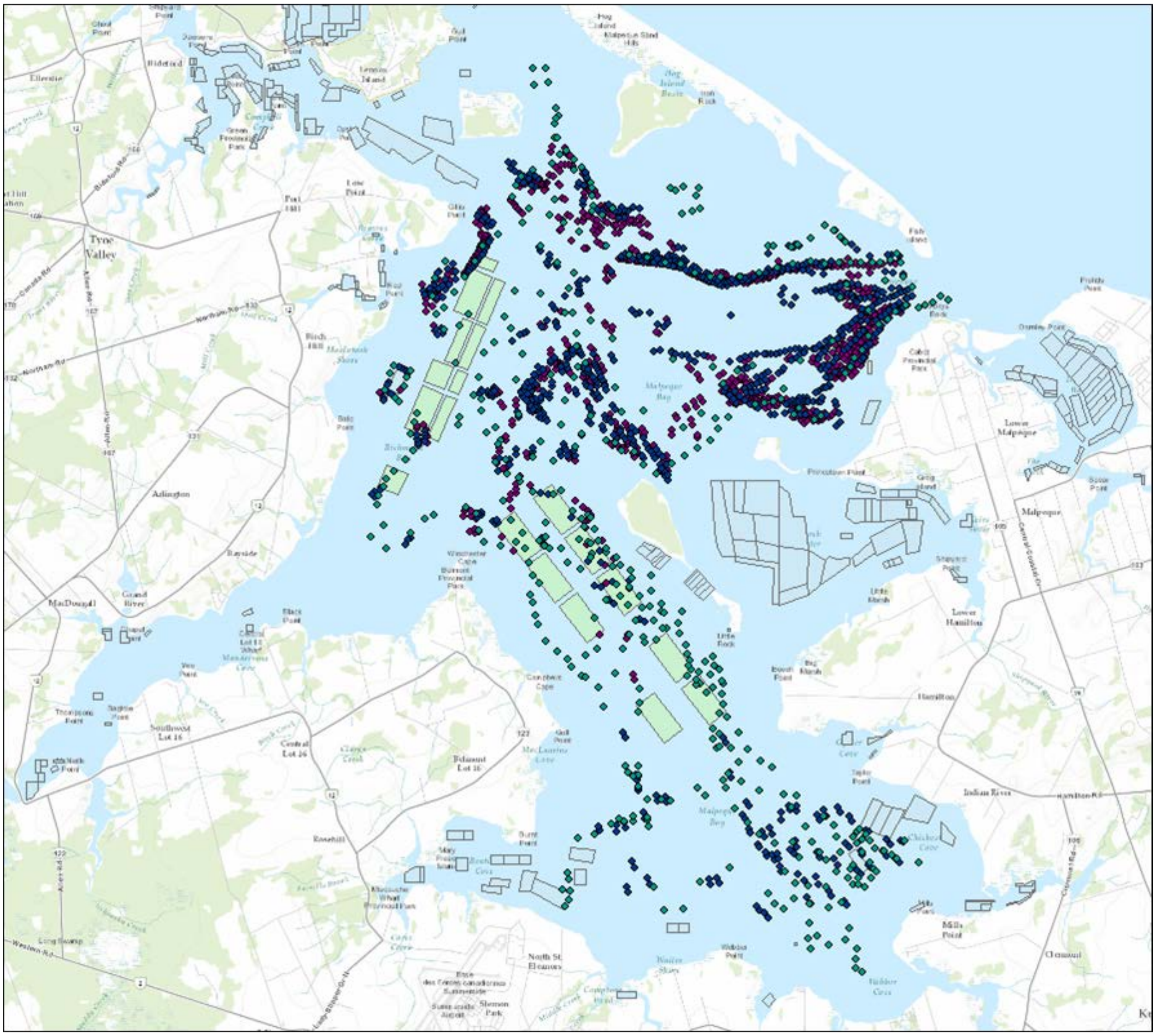


Figure 6. Spatial coverage of lobster buoys in Malpeque Bay, PEI based on a survey conducted by the DFO Aquaculture Leasing Division, in 2012 (green), 2013 (blue) and 2014 (red). Map includes the proposed (light green polygons) and current (grey polygons) shellfish aquaculture leases.

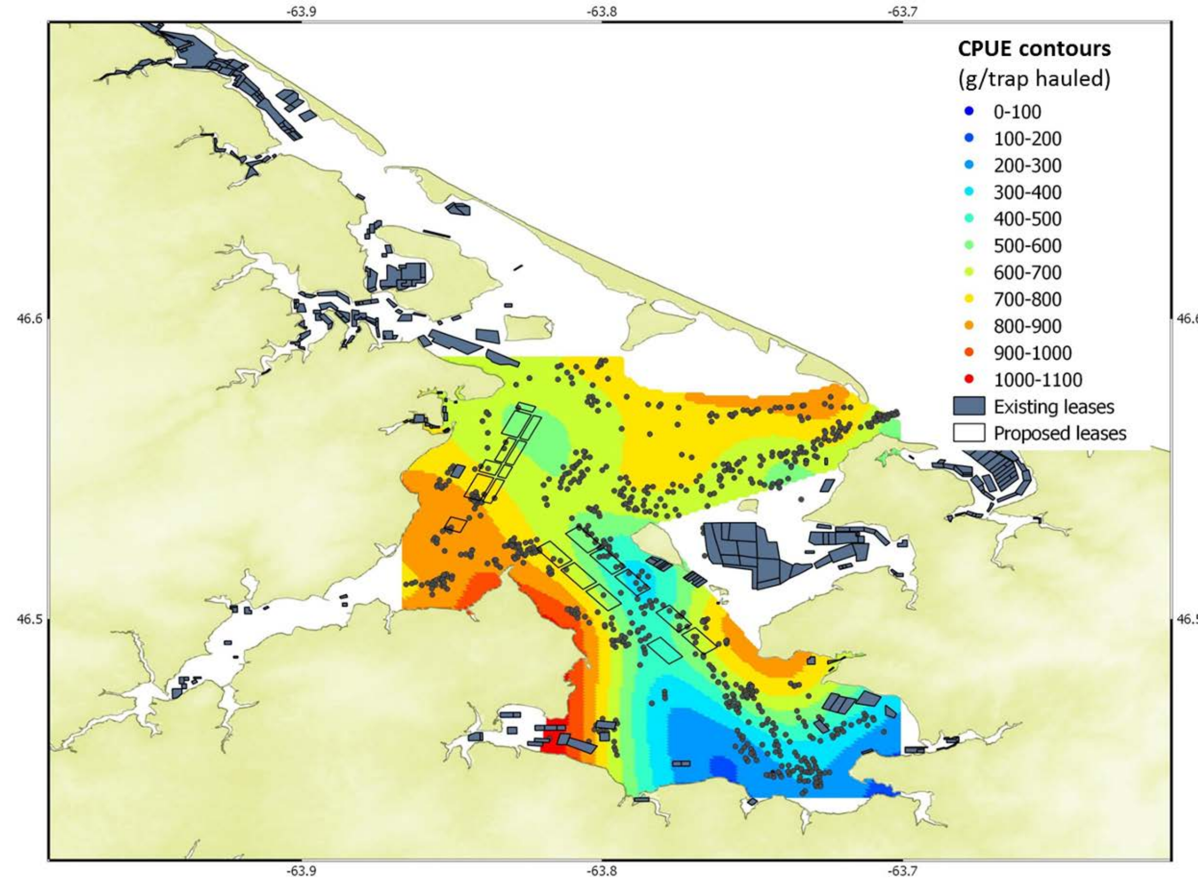


Figure 7. Catch per unit of effort (CPUE: g/trap hauled) contour map of legal size lobsters (>72 mm of carapace length including berried and window size females) observed during the at-sea sampling in Malpeque Bay, PEI. Map includes the proposed (open polygons) and current (dark-grey polygons) shellfish aquaculture sites. Masking was applied in the March Water area (east), along the sand dune (north) and in Bentick cove (southwest) to minimise the edge effect bias.

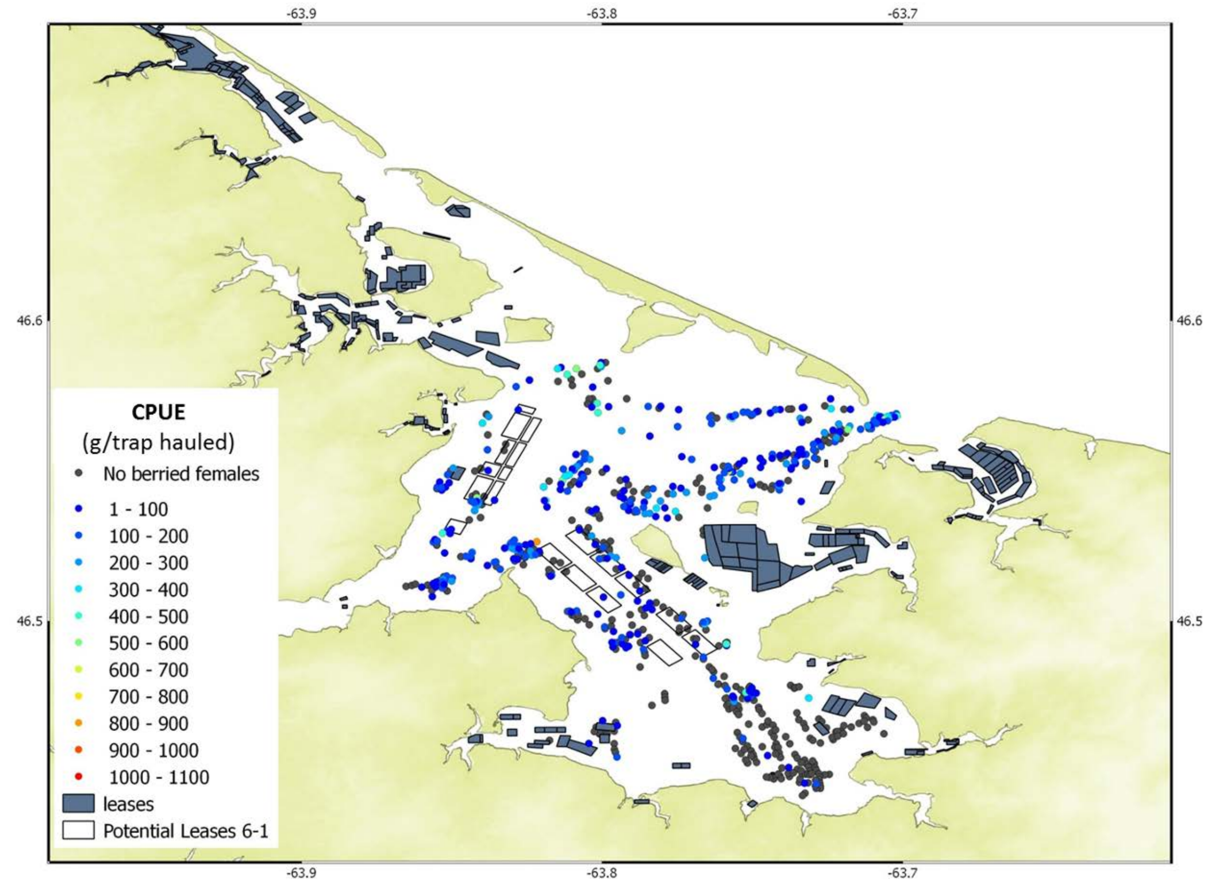


Figure 8. Catch per unit of effort (CPUE: g/trap hauled) map of total data points for berried female lobsters observed during the at-sea sampling in Malpeque Bay, PEI. Map includes the proposed (open polygons) and current (dark-grey polygons) shellfish aquaculture sites.

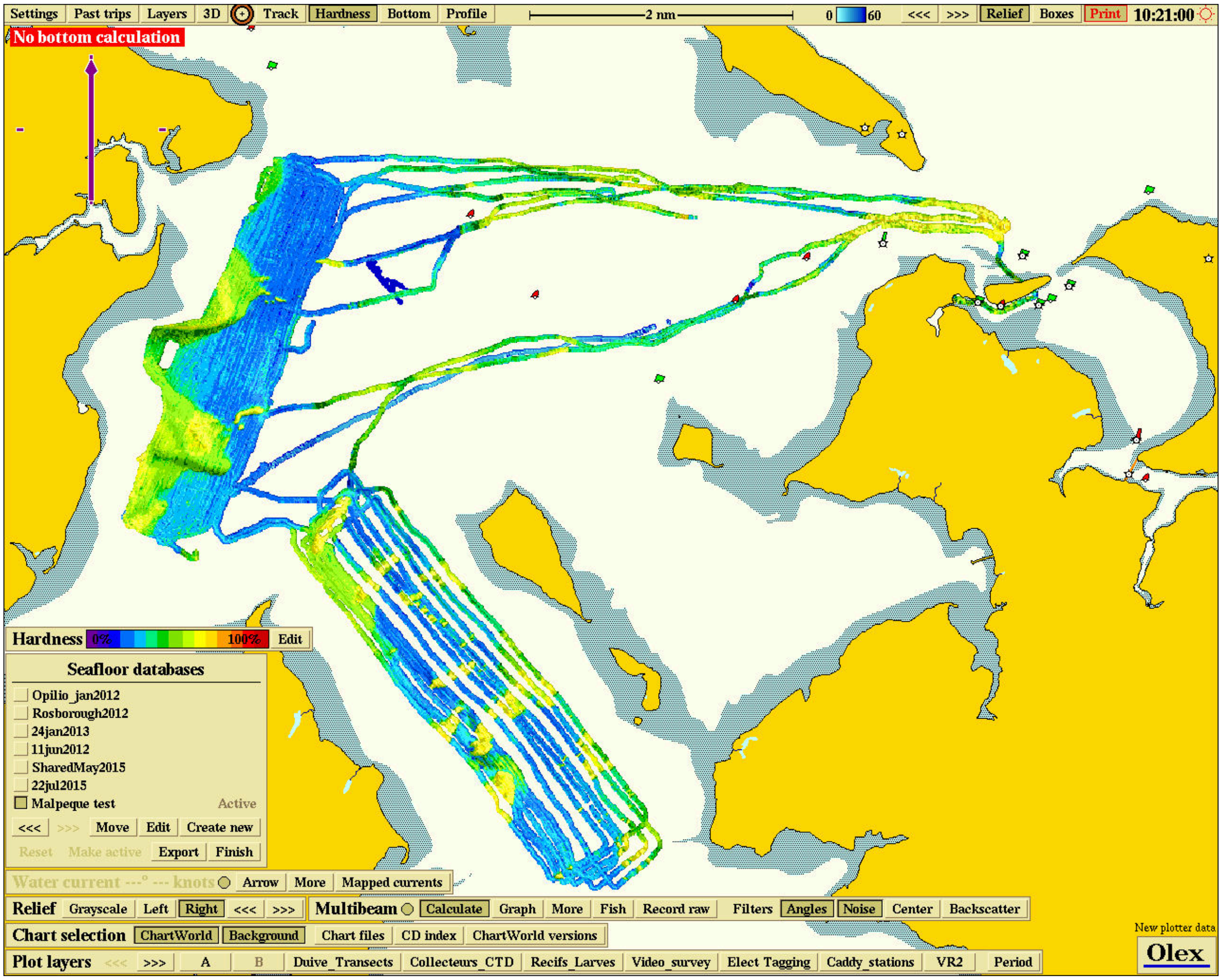


Figure 9. Total coverage of the acoustic seabed survey conducted in Malpeque Bay, PEI in August 2015 with the yellow-orange hardness variable classification identifying zones of interest.

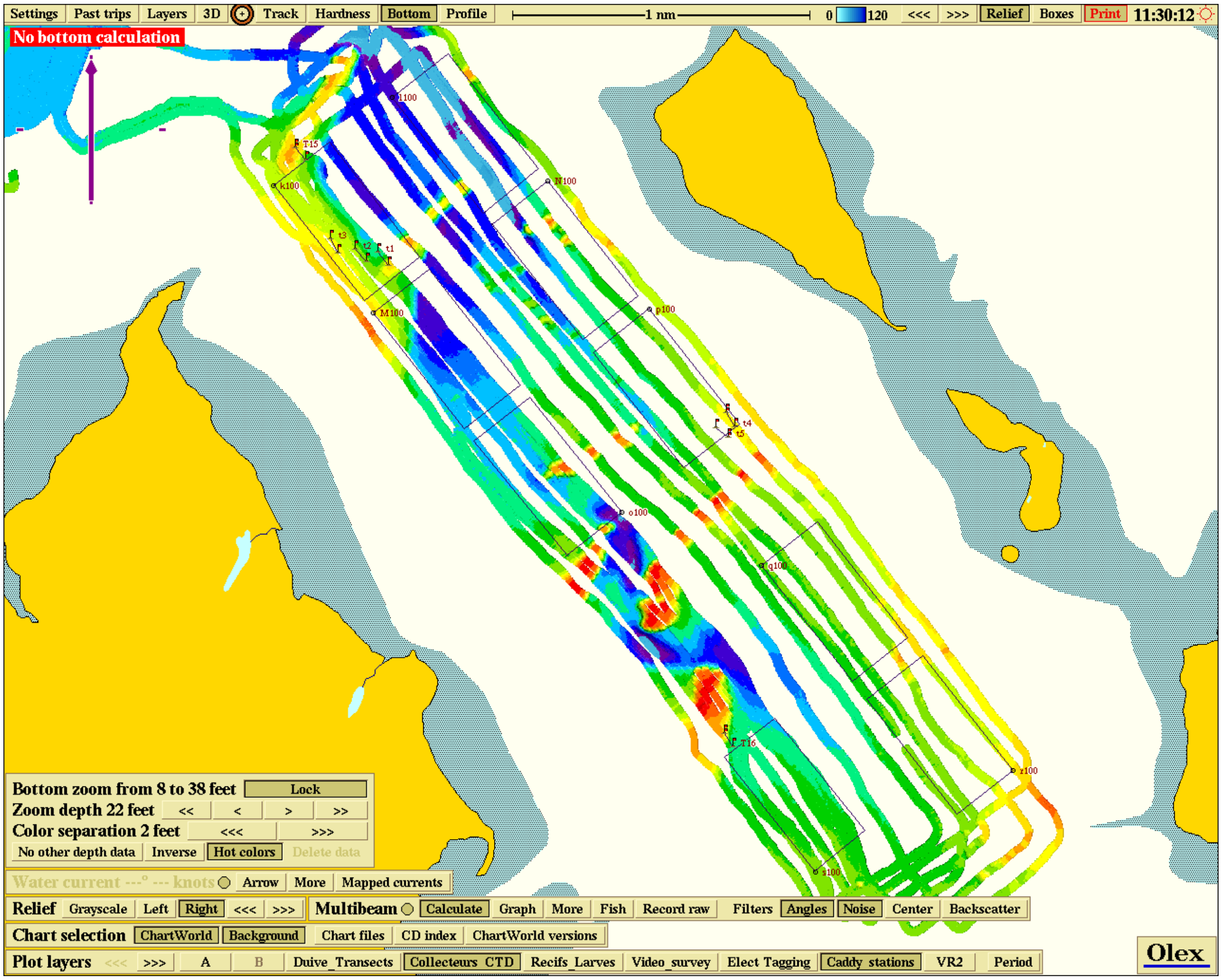


Figure 10. Bathymetry of the sites below Courtin Island (south block) from the acoustic seabed survey conducted in Malpeque Bay, PEI in August, 2015. The depth classification color scale is from shallow (red; 2.4 m) to deep (purple-dark blue; 11.6 m). Map includes the proposed shellfish aquaculture sites (open polygons) and location of SCUBA transects (red flags: T1-5, 15 & 16).

Figure 11. Hardness coefficients of the sites below Courtin Island (south block) from the acoustic seabed survey conducted in Malpeque Bay, PEI. The hardness classification is from hard (>90%; red) to soft (<25 %; dark blue). Map includes the proposed shellfish aquaculture sites (open polygons) and location of SCUBA transects (red flags: T1-5, 15 and 16).

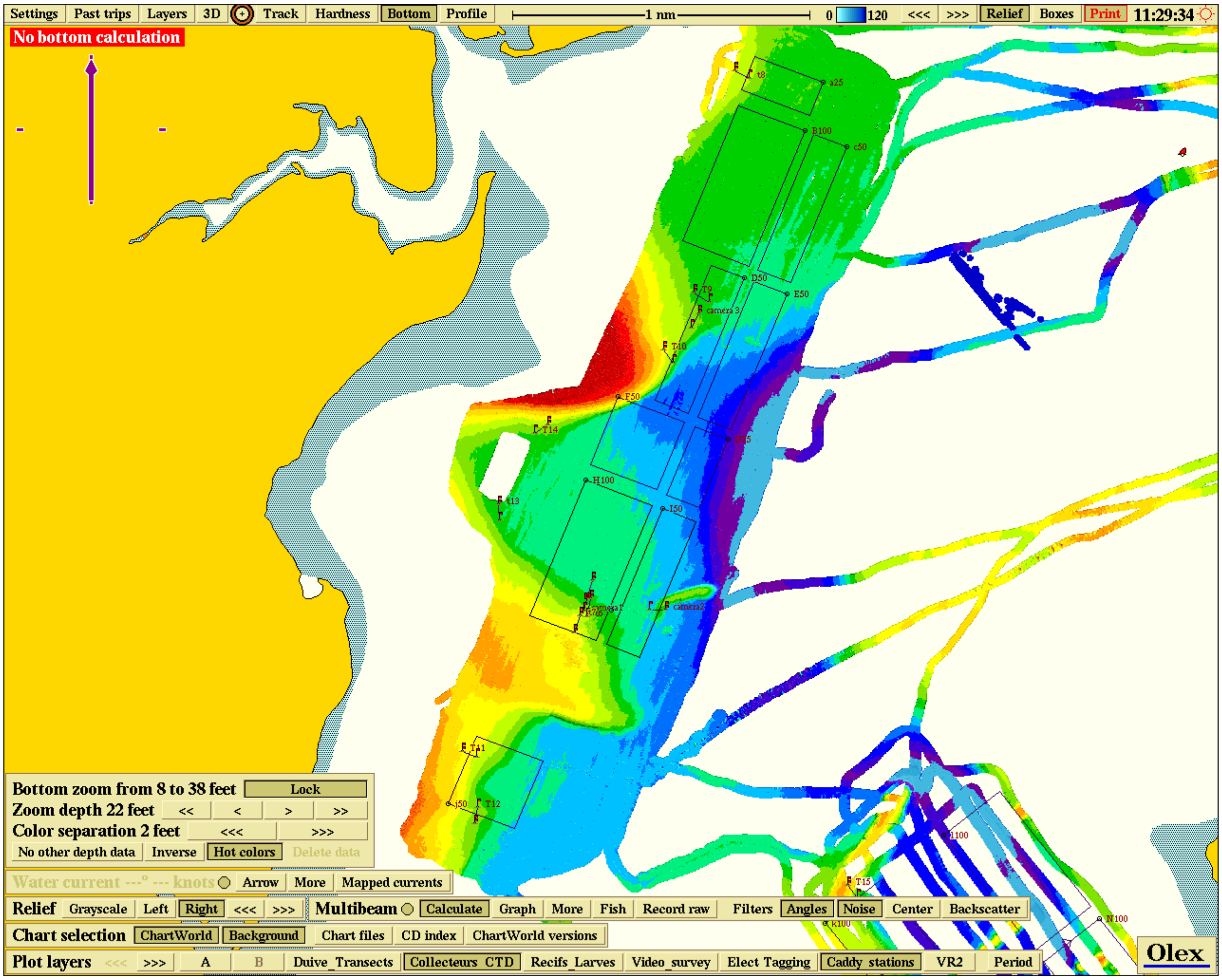


Figure 12. Bathymetry of the sites in the Richmond Bay area (west block) from the acoustic seabed survey conducted in Malpeque Bay, PEI. The depth classification color scale is from shallow (red; 2.4 m) to deep (purple-dark blue; 11.6 m). Map includes the proposed shellfish aquaculture sites (open polygons) and location of SCUBA transects (red flags: T6-T14; T8 is at the northern tip and T12 is at the southern tip). The white area (middle-left) surrounded by acoustic tracks is the only existing mussel lease in the area, SCUBA transects T13 and T14 are on both sides.

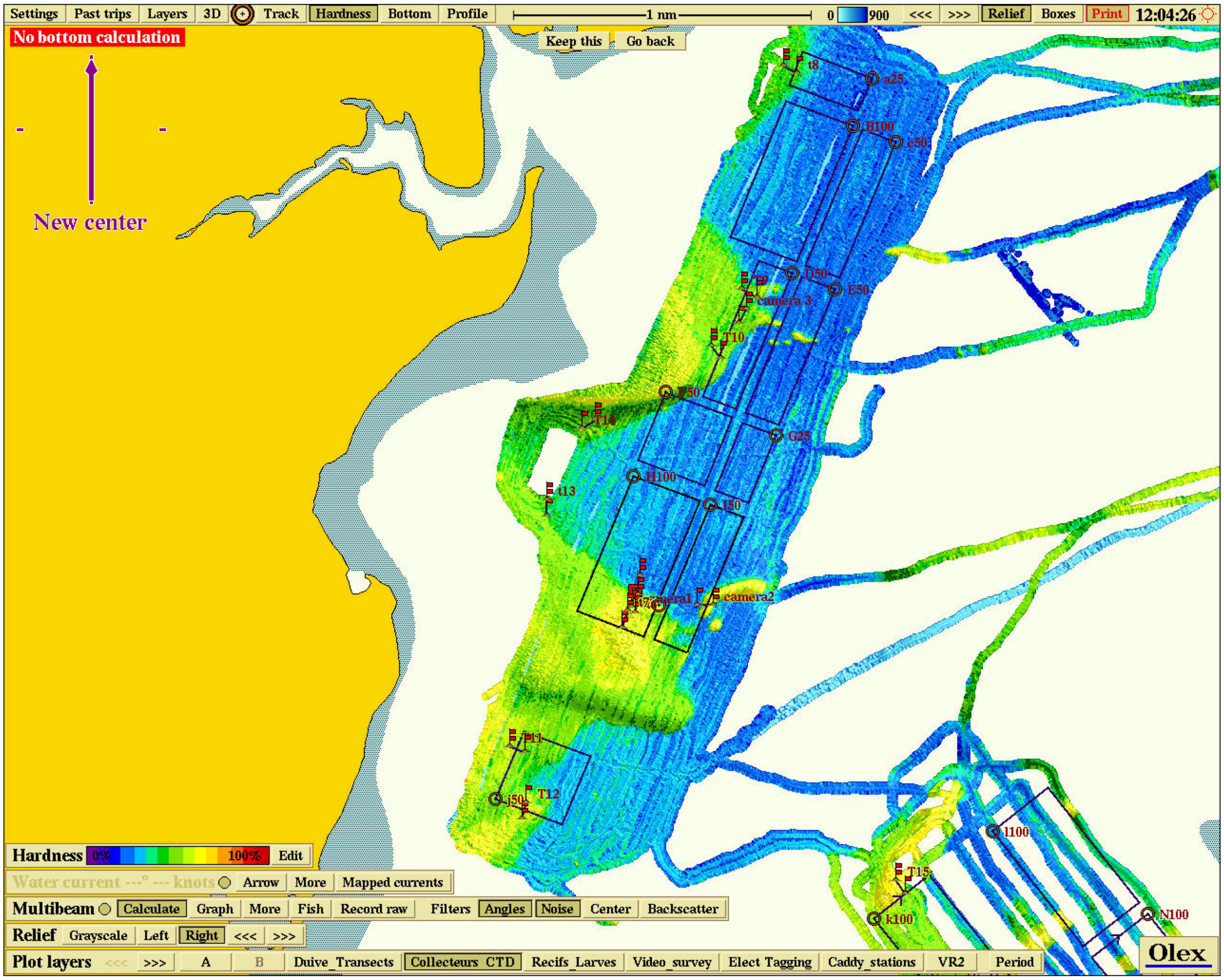


Figure 13. Hardness coefficients of the sites in the Richmond Bay area (west block) from the acoustic seabed survey conducted in Malpeque Bay, PEI. The hardness classification is from hard (>90%; red) to soft (<25 %; dark blue). Map includes the proposed shellfish aquaculture sites (open polygons) and location of SCUBA transects (red flags: T6-T14; T8 is at the northern tip and T12 is at the southern tip). The white area (middle-left) surrounded by acoustic tracks is the only existing mussel lease in the area, SCUBA transects T13 and T14 are on both sides.

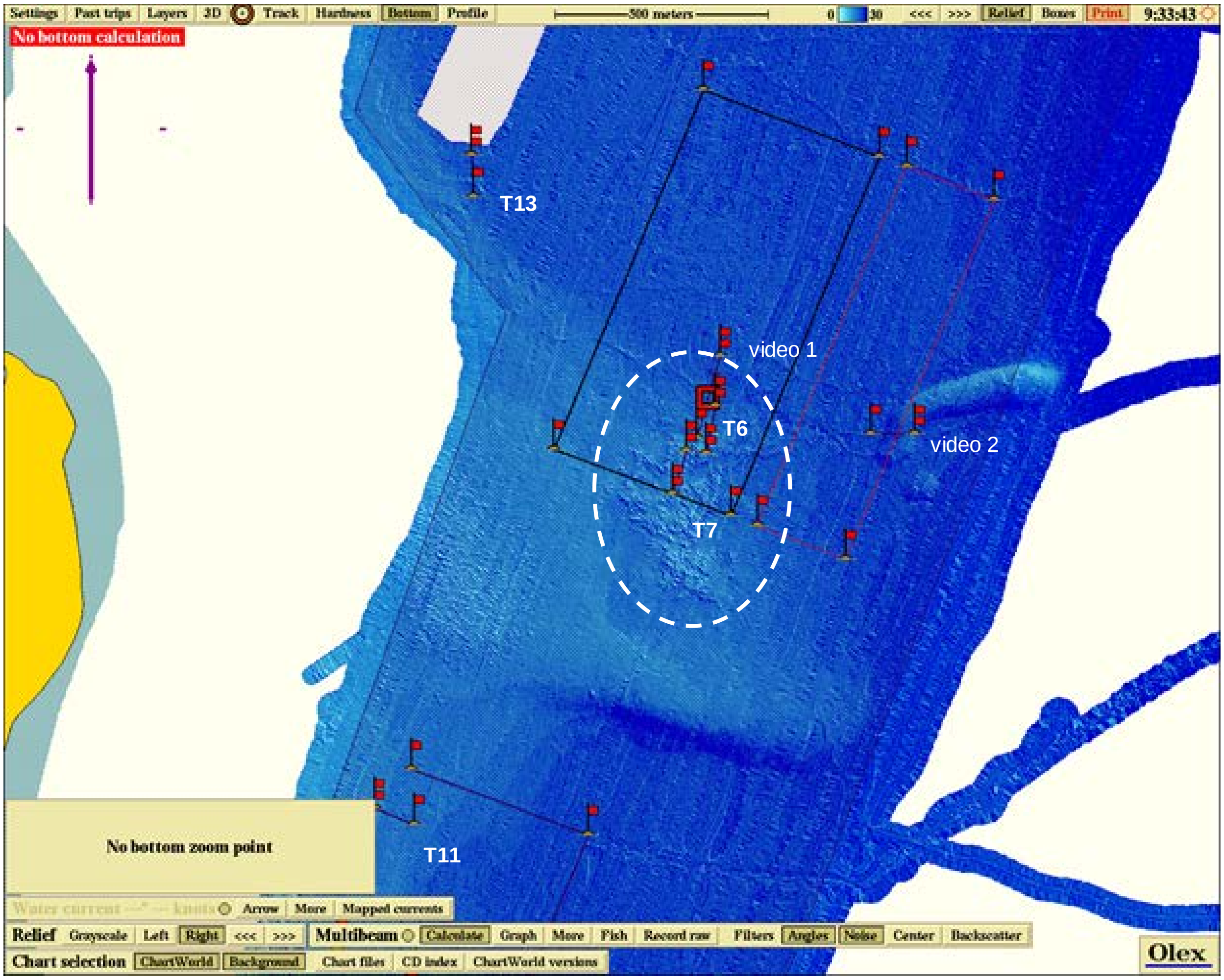


Figure 14. Roughness coefficients map that shows a lobster reef (dash circle) located in the southern portion of the sites in the Richmond Bay area (west block). Map includes the proposed shellfish aquaculture sites (open polygons) and location of SCUBA transects (double red flags). The seabed feature north of 'video 2' is a mound of shells.

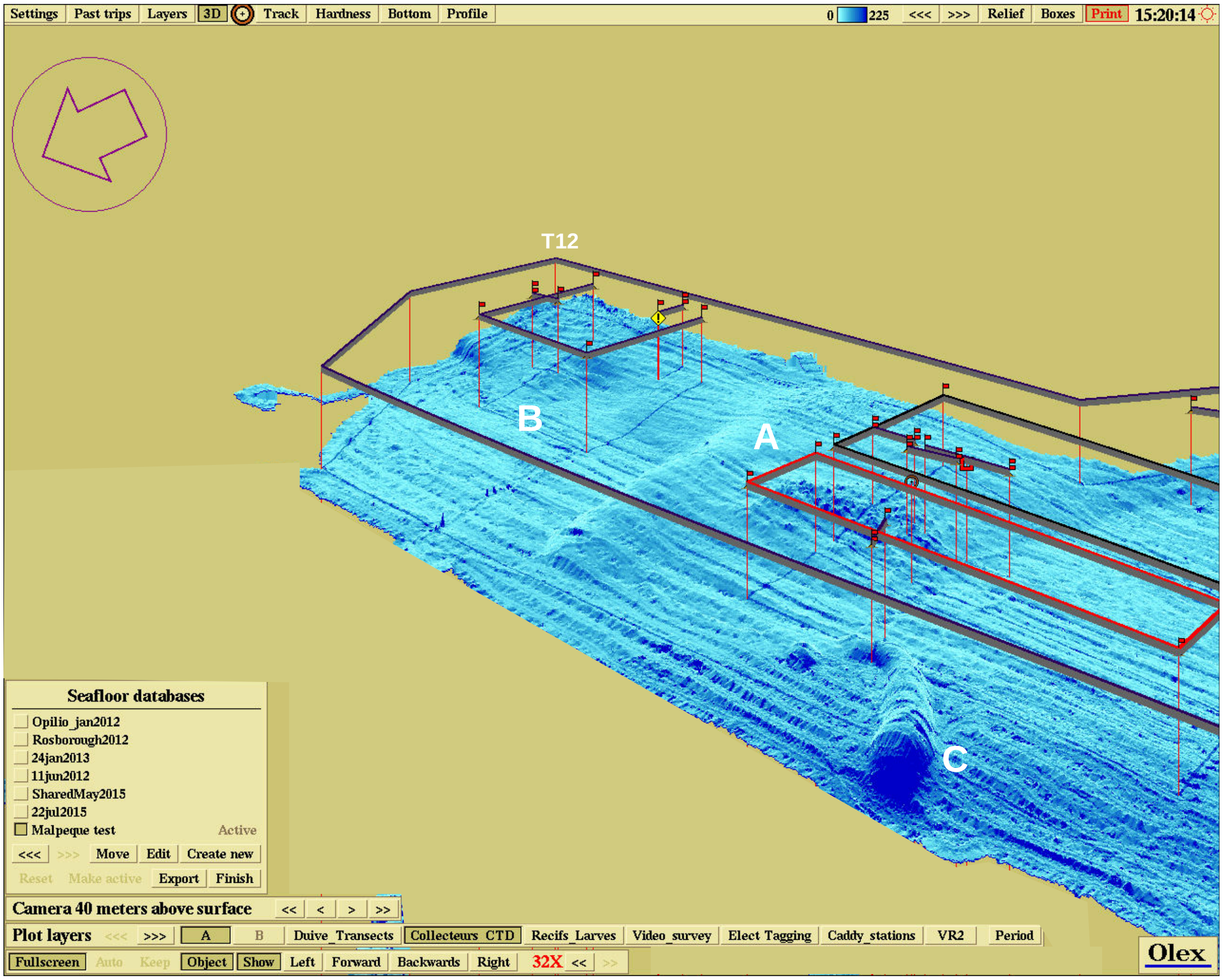


Figure 15. 3D rendering of the roughness map of the sites in the Richmond Bay area (west block; with a southwest heading), that shows a lobster reef (A: prime lobster ground) located in the southern portion and the most southern site (B), where good lobster habitat was found (T12). Map includes the proposed shellfish aquaculture sites (inner-open polygons) and location of SCUBA transects (double red flags). The seabed feature (C) was identified by SCUBA as a mound of shells.

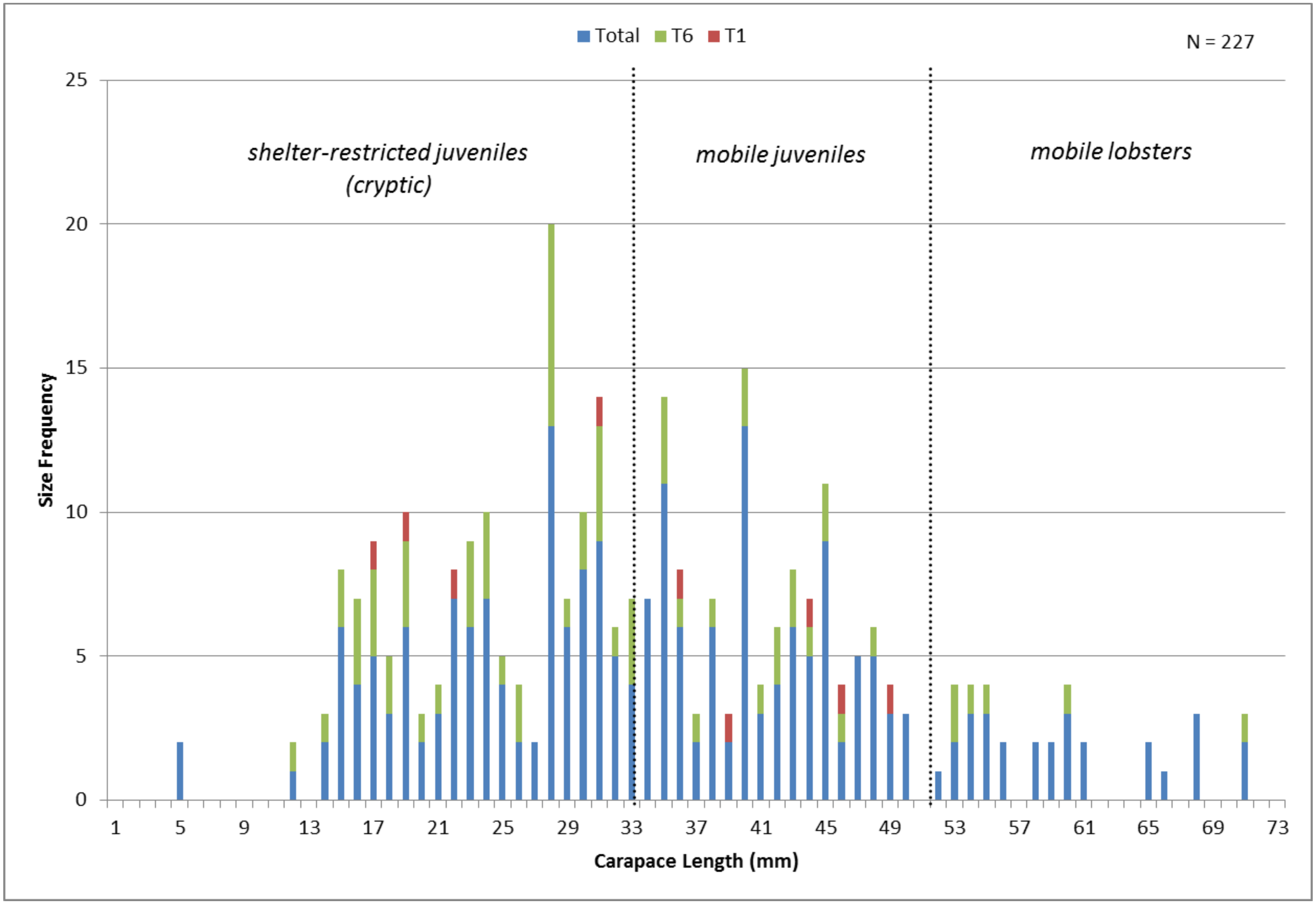


Figure 16. Size frequency distribution of lobsters measured during the SCUBA transect surveys in Malpeque Bay, PEI.

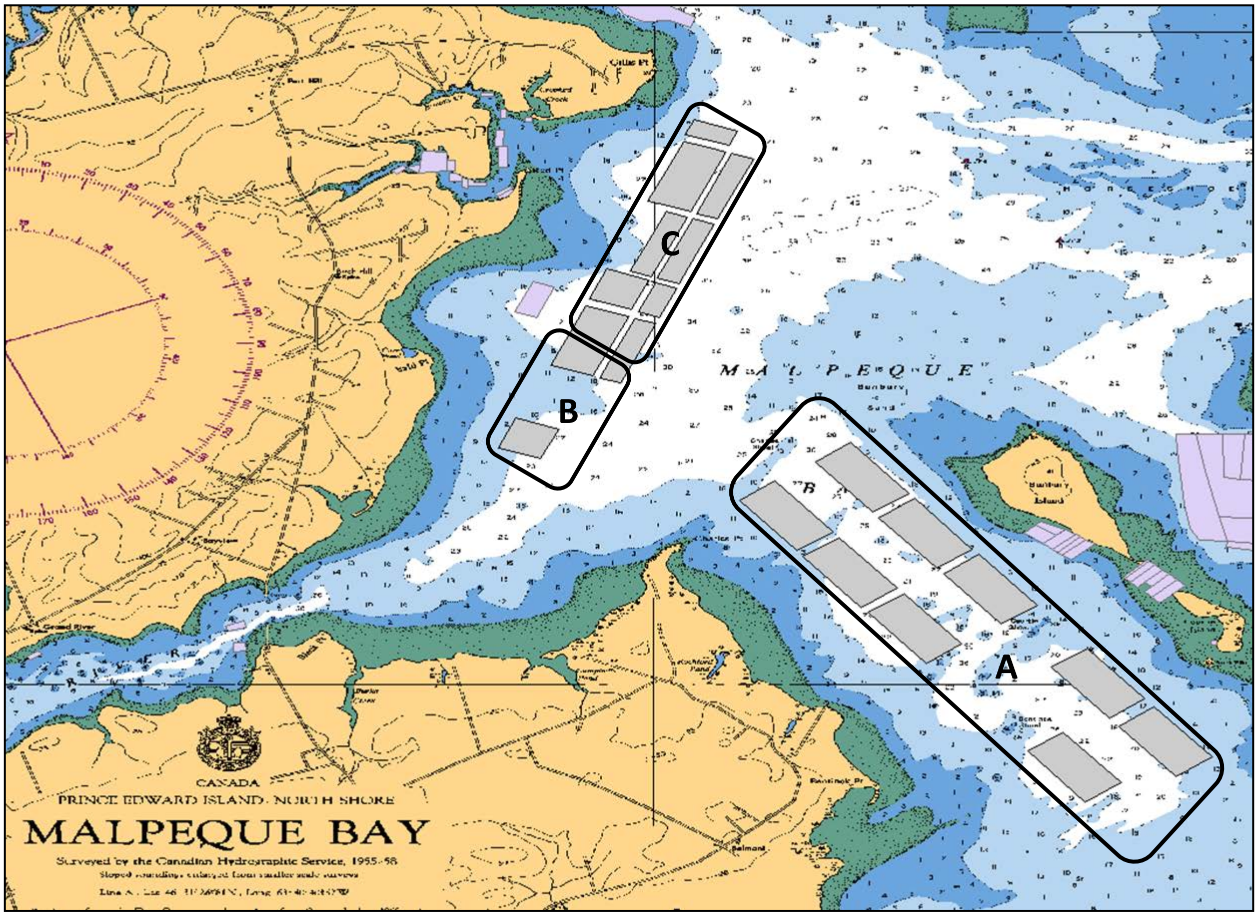


Figure 17. Summary of the spatial assessment of lobster habitat in the proposed scenario for lease expansion in Malpeque Bay, PEI. The habitat within the polygons marked (A) and (C) is considered poor habitat for lobster serving as a transitory zone. The habitat within the polygon marked (B) is considered prime lobster ground serving as residence habitat for all benthic life stages and size groups of lobster.

APPENDIX A. SUMMARY OF LIFE HISTORY INFORMATION FOR ROCK CRAB AND BIVALVES

This section considers information on biology of Atlantic rock crab (*Cancer irroratus*) and two commercial bivalve species, specifically the blue mussel (*Mytilus edulis*) and Eastern oyster (*Crassostrea virginica*). The information was compiled by M. Comeau, R. Sonier, and M. Ouellette, DFO Science Branch, Gulf Region.

ATLANTIC ROCK CRAB

The rock crab life history consists of planktonic and benthic phases. The planktonic phase (five zoeal stages and one megalopa stage) follows the hatching of the eggs attached under the female's abdomen. The hatching in the southern Gulf of St. Lawrence (sGSL) starts as early as mid-June with a peak larval abundance observed in August and September (Scarratt and Lowe 1972) (Fig. 1). Settlement of megalopa to the bottom (transitional stage from planktonic to benthic, i.e., first benthic stage) could be observed until mid-September (Fig. 1). Rock crab of all sizes occurred over a wide range of depths and habitat types in sGSL (Scarratt and Lowe 1972; Caddy and Chandler 1976). Rock crabs (mostly larger animals) are abundant on both mud-dominated and sandy substrates (Hanson 2009, Rondeau et al. 2014), and also common on rock and cobble substrates (Hudon and Lamarche 1989; Ojeda and Dearborn 1991; Wells et al. 2010). Higher abundances of smaller animals (<65 mm carapace width; CW) are mostly observed in rocky areas (Scarratt and Lowe 1972). Rock crab also occurs well up into small, very warm, estuaries where pronounced seasonal migrations in and out of these small estuaries were observed (Comeau et al. 2012).

They grow through the process of molting where the hard outer shell is periodically shed; the molting frequency slows once rock crabs become sexually mature. On average, female and male rock crabs mature at 57 and 75 mm CW, respectively (Scarratt and Lowe 1972). Mating occurs in late summer and fall (well into October), while the female carapace is still soft after molting. Generally, female rock crabs extrude eggs soon after mating and carry them under their abdomen for about 10 months (Bigford 1979). Male rock crabs take about six years to reach commercial-size (≥102 mm CW).

The rock crab fishery in the sGSL is comprised of three distinct components: the bycatch fishery, the bait fishery, and the directed fishery (Rondeau et al. 2014). The bycatch and the bait fisheries are conducted during the lobster fishery by lobster licence holders. The directed fishery is conducted at a different time, by rock crab licence holders. The management of the directed rock crab fishery in Malpeque Bay (located in fishing area 24; fishing areas for lobster and rock crab are similar) is based on effort control (150 traps per harvester), individual catch allocations (20 t), and a minimum legal size of 105 mm CW. This fishery operates from early July to late October each year. The individual allocations are not based on stock status and females cannot be landed. All rock crab landings from the directed fishery are verified through a dockside monitoring program (Table 1), and logbooks (daily record of catch, effort, and general fishing locations) are mandatory. In 2011, the total rock crab landings for fishing area 24 only represent 4% of the landings from the directed fishery for the entire sGSL (Rondeau et al. 2014). From the 10 permanent licenses issue in the fishing area 24, two are located at Malpeque wharf and two (with the possibility of an extra 2 from First Nation communal licenses) at the Lennox Island First Nation Wharf.

There is no fine scale information on rock crab fishing activities specifically for Malpeque Bay that is collected on a regular basis by DFO. However, the DFO Aquaculture Leasing Division from the Charlottetown office did a rock crab fishing buoys survey in 2012 and 2013 that provided spatial coverage and fishing patterns. Similar patterns were observed in both 2012 and

2013 with a continuous fishing effort mostly concentrated in the deeper channels that start at the mouth of the bay heading southeast and then southwest (Fig. 2).

BIVALVES

Figure 3 summarizes the life cycle of molluscan bivalves and their pelagic and benthic stages. A trocophore larva will develop rapidly (1-18 hours) following the external fecundation of gametes released in the water column. Within 1.5 days the trocophore larva will grow into a veliger larva characterized by a ciliated velum. Both stages are planktonic and free-swimming stages. The veliger larvae will then metamorphose into a competent benthic pediveliger larva by reabsorbing its velum and producing a foot, which will be utilized for locating an optimal substrate for recruitment. The benthic pediveliger stage may extend over 14-20 days. The larva is considered a juvenile bivalve following successful recruitment onto a substrate.

Figures 4 and 5 shows the abundance of oyster and mussel larvae in the Malpeque Bay system (2015 Dataset is from the Mussel Spat Survey of the Prince Edward Island Department of Agriculture and Fisheries accessed 26 February, 2016). Elevated oyster planktonic abundance was found in late July and early August. These spikes were followed by successfully recruited (benthic) larvae in late August (Fig. 1). Aucoin et al. (2005) also reported oyster larvae presence in Malpeque Bay in the mid-1950s (from Sullivan 1948) from early July to late August. The pattern for blue mussels was similar although advanced by approximately one-month with elevated planktonic larvae abundance from the end of May until the end of July, followed by high levels of set size larvae. The presence of low abundance planktonic mussel larvae from mid- August to the end of September indicates secondary spawning events (Fig. 1).

Bivalve spawning events are triggered by a combination of factors (e.g., temperature, food quality, gametes quality). Inter-annual variation in larval phenology remains undocumented for Malpeque Bay and other Prince Edward Island coastal systems.

Figure 6 shows and overlay between the proposed shellfish aquaculture sites and distribution of several commercial bivalve species, based on the Traditional Fisheries Knowledge Atlas (Legault 1998). It is a good indication of historical areas where we can expect larvae settlement. The only direct spatial overlap can be observed in the southern portion of the south block, below Courtin Island, with the oyster.

REFERENCES CITED

Aucoin, F., Doiron, S., and Nadeau, M. 2005. Guide d'échantillonnage et d'identification des larves d'espèces à intérêt maricole. Ministère de l'Agriculture, Pêcheries et Alimentation. ISBN : 2-550-40-178-6, 02-0163. 73pp.

Bigford, T.E. 1979. Synopsis of the biological data on the rock crab, *Cancer irroratus* Say. NOAA Tech. Rep. NMFS 426, 26p.

Caddy, J.F., and Chandler, R.A. 1976. Historical statistics of landings of inshore species in the Maritime provinces 1947-73. DFO Tech. Rep. 639. 240 p.

Comeau, L.A., Sonier, R., and Hanson, J.M. 2012. Seasonal movements of Atlantic Rock Crab (*Cancer irroratus* Say) transplanted into a mussel aquaculture site. Aquac. Res. 43: 509-517.

Hanson, J.M. 2009. Predator-prey interactions of American lobster (*Homarus americanus*) in the southern Gulf of St. Lawrence, Canada. N. Z. J. Mar. Freshw. Res. 43: 69-88.

Hudon, C., and Lamarche, G. 1989. Niche segregation between American lobster *Homarus americanus* and rock crab *Cancer irroratus*. Mar. Ecol. Prog. Ser. 52: 155-168.

Legault, J.A. (Ed). 1998. Traditional fisheries knowledge for the southern Gulf of St. Lawrence: provisional atlas. J. Lee MacNeill & Associates consultant report. (Available from DFO Bedford Institute of Oceanography Library Cat # FS23-350/1998).

Ojeda, P.F., and Dearborn, J.H. 1991. Feeding ecology of benthic mobile predators: experimental analysis of their influence in rocky subtidal communities of the Gulf of Maine. J. Exp. Mar. Biol. Ecol. 149: 13-44.

Rondeau, A., Hanson, J.M., and Comeau, M. 2014. Rock crab, *Cancer irroratus*, fishery and stock status in the southern Gulf of St. Lawrence: LFA 23, 24, 25, 26A and 26B. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/032. vi + 55 p.

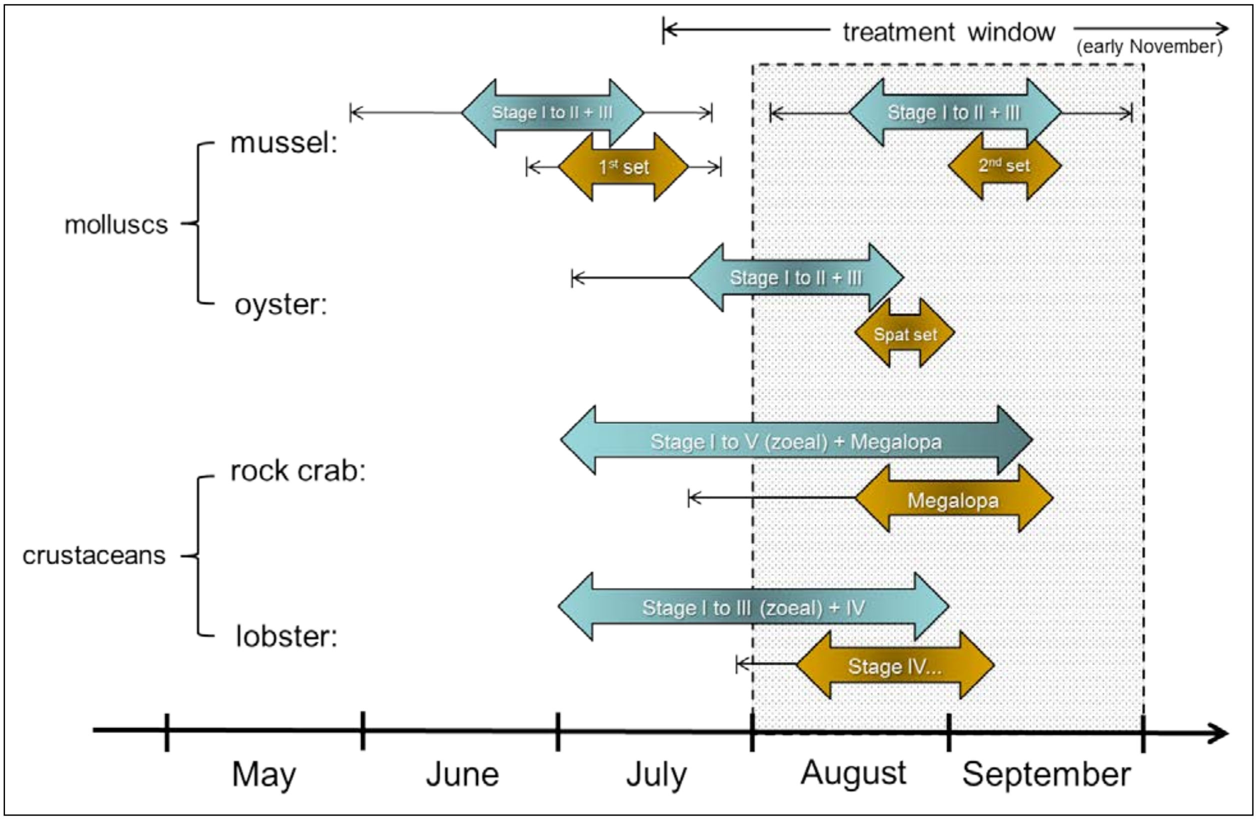
Scarratt, D.J., and Lowe, R. 1972. Biology of the rock crab (*Cancer irroratus*) in Northumberland Strait. J. Fish. Res. Board Can. 29: 161-166.

Sullivan, C.M. 1948. Bivalve larvae of Malpeque Bay, P.E.I. Fish. Res. Board Can. n°77, 36pp. + annexe.

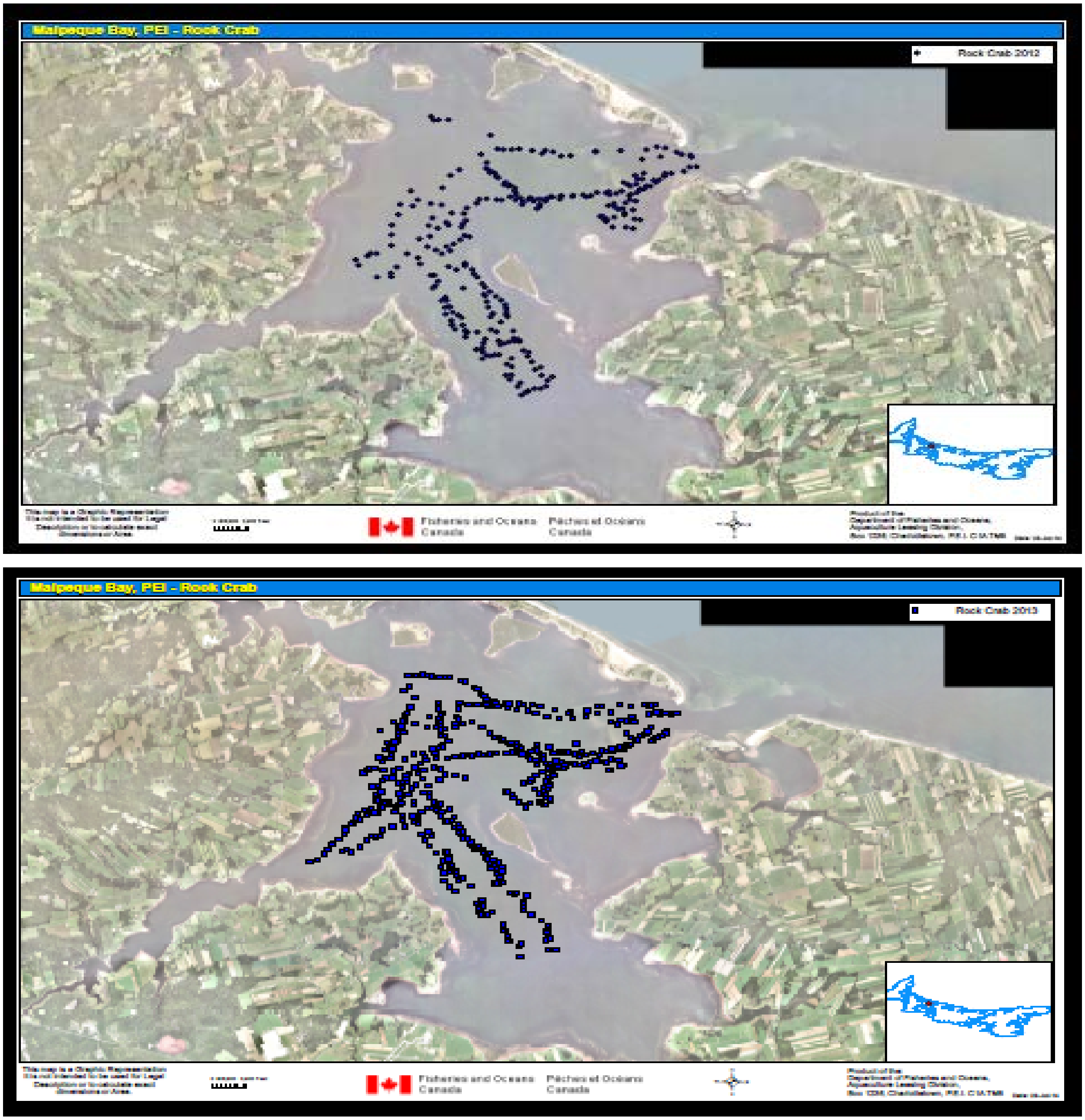
Wells, R., Steneck, R.S., and Palma, A.T. 2010. Three-dimensional resource partitioning between American lobster (*Homarus americanus*) and rock crab (*Cancer irroratus*) in a subtidal kelp forest. J. Exp. Mar. Biol. Ecol. 384: 1-6.

Appendix Table 1. Rock crab (Cancer irroratus) landings (kg) and active licenses in Lennox Island and Malpeque between 2004 and 2015 reported during the dockside monitoring program.

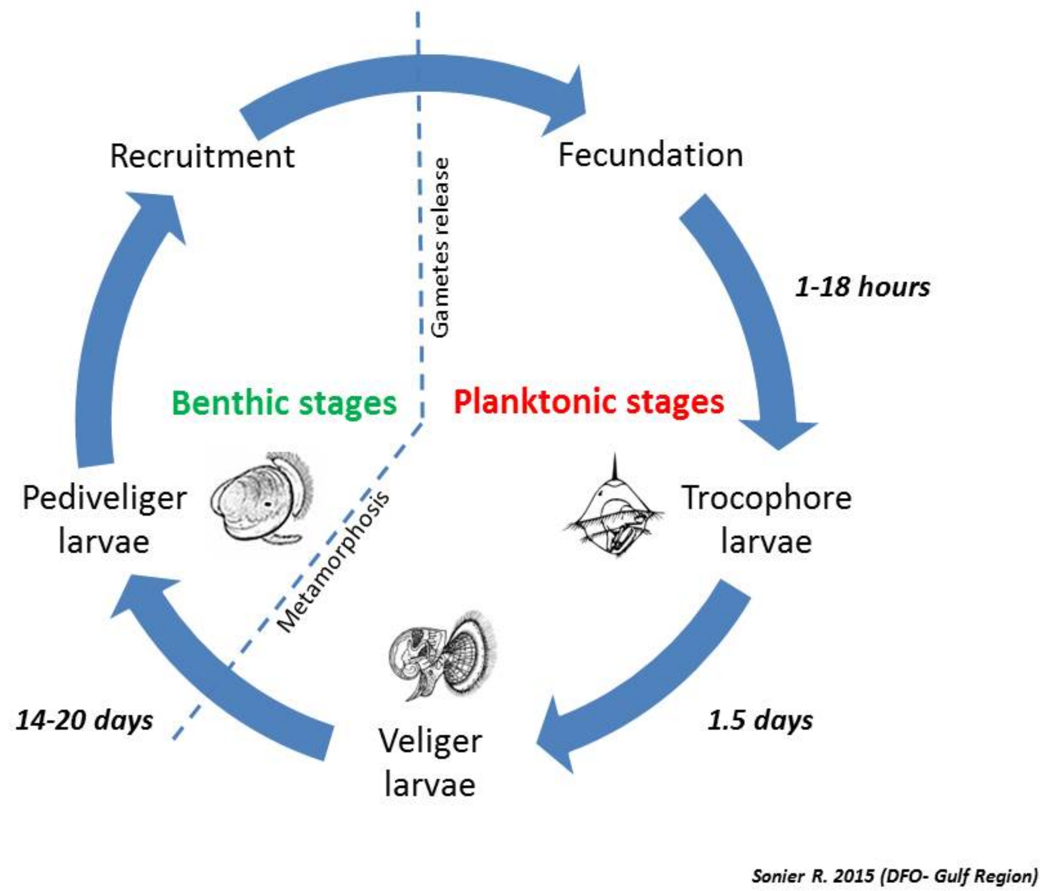
Year	Wharf	Landings (kg)	Active licences	Wharf	Landings (kg)	Active licences
2004	Lennox Island	5,369	1	Malpeque	61,869	2
2005	Lennox Island	2,999	2	Malpeque	36,383	2
2006	Lennox Island	102,010	2	Malpeque	21,214	2
2007	Lennox Island	0	Na	Malpeque	12,031	1
2008	Lennox Island	28,793	4	Malpeque	10,858	1
2009	Lennox Island	57,911	4	Malpeque	37,493	2
2010	Lennox Island	35,977	3	Malpeque	57,875	2
2011	Lennox Island	0	Na	Malpeque	65,557	2
2012	Lennox Island	38,248	2	Malpeque	40,564	2
2013	Lennox Island	59,454	2	Malpeque	25,273	2
2014	Lennox Island	35,095	2	Malpeque	29,518	2
2015	Lennox Island	20,445	2	Malpeque	33,738	1



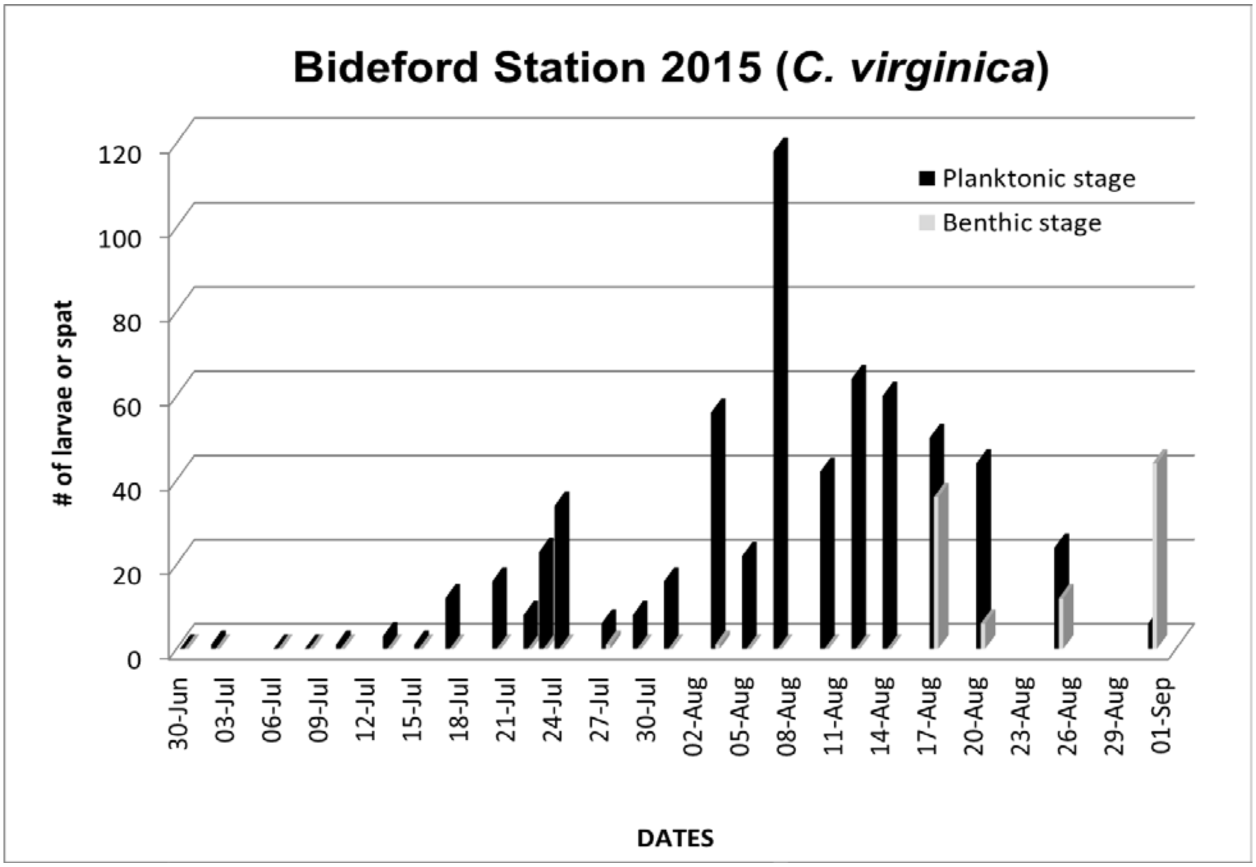
Appendix Figure 1. Summary of approximate temporal distribution of pelagic (green) and the first benthic (orange) life stages for shellfish species in the southern Gulf of St. Lawrence. Peak abundance periods are shown in broad arrows with shading indicating highest abundances, and ranges as narrow arrows. The timing of pelagic stages is mainly affected by water temperature and egg quality, whereas habitat type becomes an additional factor in the benthic stages. Also included is the general window (grey shaded rectangle and arrow showing range over season) of liming treatments from seed collectors and grow-out operations in Malpeque Bay.



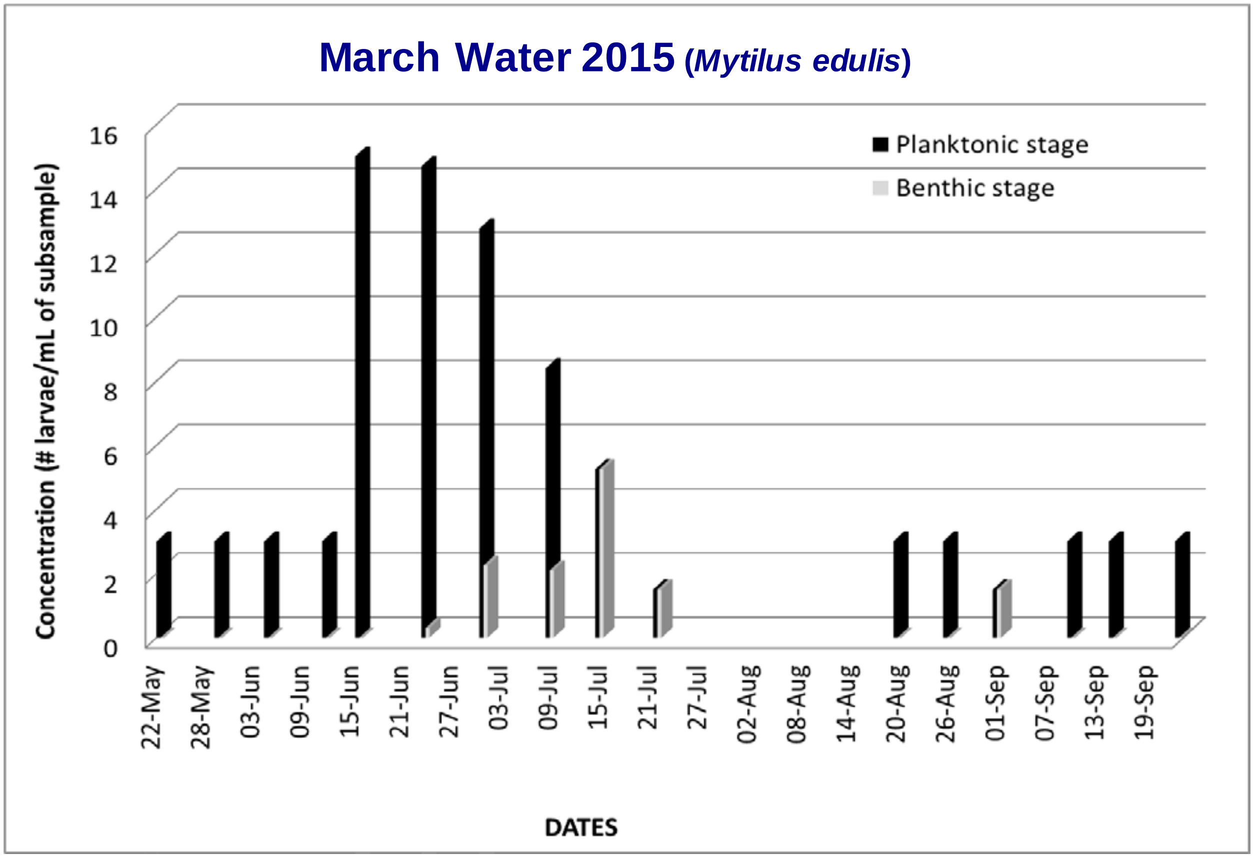
Appendix Figure 2. Spatial coverage of buoys during the directed rock crab fishing season in Malpeque Bay, Prince Edward Island. This survey was conducted by the DFO Aquaculture Leasing Division in 2012 (top panel), and 2013 (lower panel).



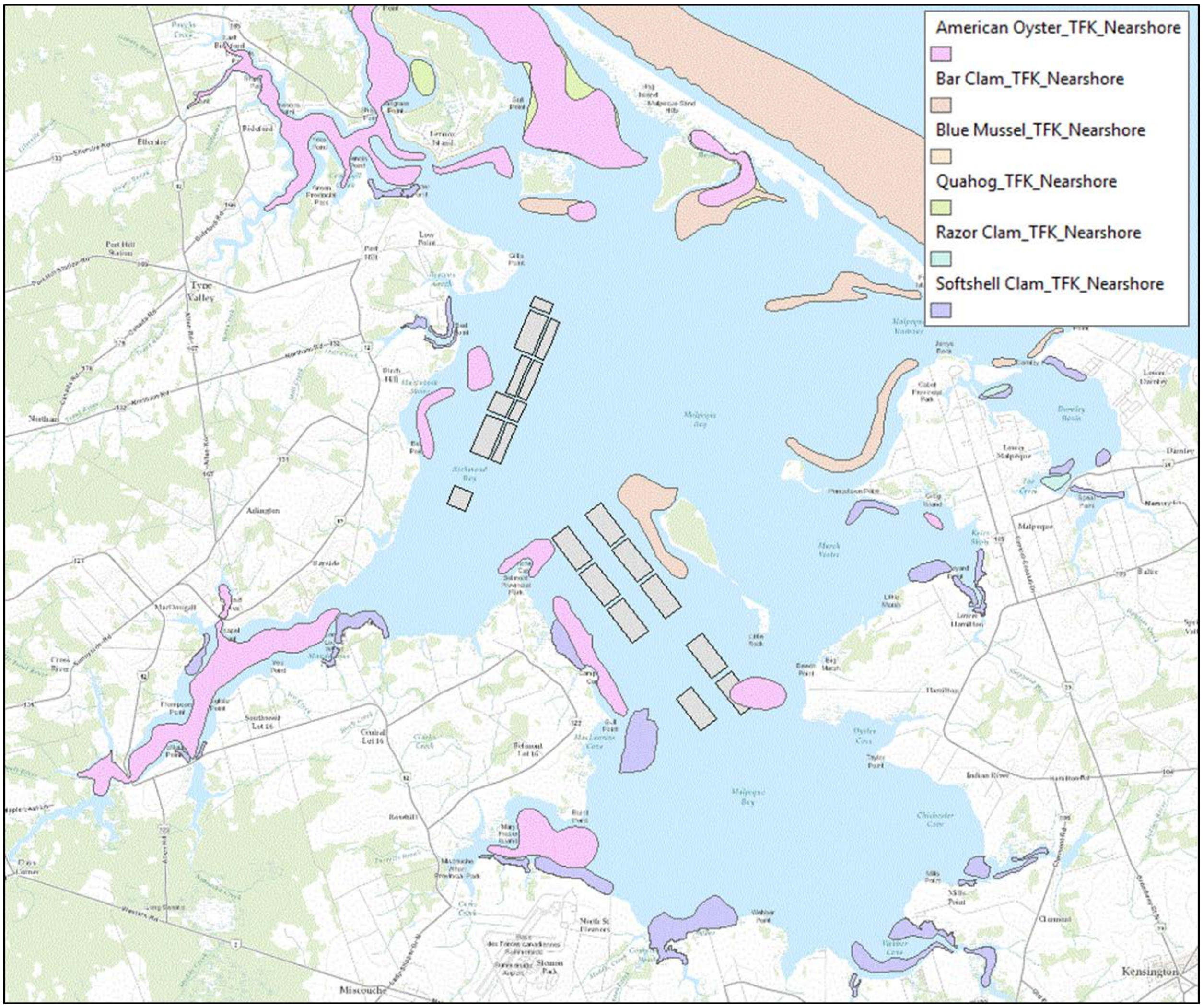
Appendix Figure 3. Illustration of the life cycle of a bivalve.



Appendix Figure 4. Eastern oyster (Crassostrea virginica) larval and recruitment monitoring data for 2015 in Bideford Station, Prince Edward Island.



Appendix Figure 5. Blue mussel (Mytilus edulis) larval monitoring data for 2015 in March Water, Prince Edward Island. Initial sampling used three different density classes; Low (1-5 larvae), Medium (6-15 larvae) and High (>15 larvae). Thus corrections have been made using the median of classes corrected with the percentage of pre-set size (<250µm) and set-size larvae (>250µm).



Appendix Figure 6. Traditional Fisheries Knowledge of commercial bivalve species in Malpeque Bay, Prince Edward Island. Map includes proposed potential areas for shellfish aquaculture sites development (grey polygons), Scenario 6 (source: DFO Aquaculture Leasing Division).