Health, population and environmental conditions of clam flats in the Bay of Fundy, Nova Scotia, Canada.

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by

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ABSTRACT

LeBlanc, A. R., M. Maillet, M. Ouellette, M. Stephensen and L. Hamilton. 2011. Health, population and environmental conditions of clam flats in the Bay of Fundy, Nova Scotia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3039: viii + 68 p.

Soft-shell clams (*Mya arenaria*) and quahogs (*Mercenaria mercenaria*) have long been species of interest for the diversification of aquaculture in Atlantic Canada. Most of the research and development has been on adapting known culture methods to the conditions in the area. One of the challenges faced was disease. In the late 1990's, soft-shell clam populations were severely reduced by haemic neoplasia. Issues with a quahog parasitic disease (QPX) were also encountered, especially in hatcheries. The primary objective of this project was to evaluate the prevalence of soft-shell and quahog diseases in the Bay of Fundy, Nova Scotia. A second objective was to relate diseases with environmental conditions. A third objective was to evaluate the population dynamics of soft-shell clams and quahogs in the Bay of Fundy. No diseases of interest were found in either species in the area surveyed therefore, the second objective was not attained. Maps of clam distributions and several environmental factors were created and are presented in this report.

RÉSUMÉ

LeBlanc, A. R., M. Maillet, M. Ouellette, M. Stephensen and L. Hamilton. 2011. Health, population and environmental conditions of clam flats in the Bay of Fundy, Nova Scotia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3039: viii + 68 p.

Depuis longtemps, les myes (*Mya arenaria*) et les palourdes américaines (*Mercenaria mercenaria*) sont des espèces d'intérêt pour la diversification de l'industrie aquacole dans les provinces de l'Atlantique, au Canada. La majorité de la recherche et du développement jusqu'à présent, porte sur l'adaptation de techniques de culture connues aux conditions rencontrées dans la région. Toutefois, l'un des défis dont les aquaculteurs doivent faire face sont les maladies. À la fin des années 1990, les populations de myes ont été réduites par la néoplasie hémique. Il y aussi eu des difficultés avec une maladie parasitaire de la palourde (QPX), notamment en écloserie. L'objectif primaire de ce projet fut d'évaluer la présence de maladie chez les myes et les palourdes dans la Baie de Fundy, Nouvelle-Écosse. Un second objectif fut de lier les maladies avec des facteurs environnementaux. Un troisième objectif fut d'évaluer la dynamique de population des myes et des palourdes dans la Baie de Fundy. Aucune maladie d'intérêt n'était présente dans les myes et les palourdes provenant des régions échantillonnées donc le deuxième objectif n'a pas été atteint. Des cartes de distribution de populations et de plusieurs facteurs environnementaux furent créées et sont présentées dans ce rapport.

INTRODUCTION

Interest in cultivating clams in eastern Canada, as an alternate species, has grown in the past decades. So far, the shellfish aquaculture industry is based mainly on the blue mussel (*Mytilus edulis*) and the American oyster (*Crassostrea virginica*). In the 1990's, research projects were initiated to develop clam aquaculture techniques. Species of interest were the soft-shell clam (*Mya arenaria*), the quahog (*Mercenaria mercenaria*) and the bar clam (*Spissula solidissima*) because of their high market value. The focus of the research was on adapting known culture techniques to the conditions encountered in the region (Carver and Mallet 1991, Niles 1996, Doucet 1998, Chevarie and Myrand 2003, MacNair 2003a, 2003b). Success was variable and site dependent. Issues such as slow growth and erratic mortalities have prevented the industry from reaching a viable level.

One of the major obstacles in developing the industry was clam disease. In the late 1990's, there was a large mortality of soft-shell clams which was later attributed to haemic neoplasia (McGladdery *et al*. 2001). This led the Department of Fisheries and Oceans (DFO) to re-examine archived soft-shell clam tissues and tissues collected by other agencies (for unrelated studies) for the presence of the disease. A monitoring program in Prince Edward Island (PEI) was also started by DFO in 1999 to determine the extent of the disease. Results from the archived tissues (1990-1997) showed low prevalences of haemic neoplasia (< 11%) in the Gulf of St Lawrence (McGladdery *et al*. 2001, MacCallum 2003). In 1997, prevalence on PEI increased (up to 55%), eventually leading to the mortalities in 1999. Hamemic neoplasia was also found in low prevalence (< 6%) in the Bay of Fundy, except for two sites at the head of the Bay where prevalence were between 22 and 31 % (Morrison *et al.* 1993). Haemic neoplasia is a disease that affects the blood cells of soft-shell clams, quahogs, mussels and oysters. The cells become non-functional. It may also lead to uncontrolled multiplication of the cells. The affected animal can recover by rejecting the affected cells or can die if most cells in the body are transformed by the disease (McGladdery 2001). There is also a gonadal neoplasia that affects the gonads and can reduce spawning levels. It is most commonly found in Maine (USA) but it has been found in low prevalence in the Gulf of St. Lawrence and in St. Andrews, NB (Barber *et al*. 2002).

Quahog Parasite X (QPX) is another disease that could limit the development of quahog aquaculture. It was first identified in Atlantic Canada in the late 1950's when a mass mortality of quahogs occurred in Neguac, NB (Drinnan and Henderson 1963). In 1989, it was associated with mortalities in a PEI hatchery (Whyte *et al*. 1994). A monitoring of quahogs in the 1990's indicated that QPX is present in Atlantic Canada (Gulf of St Lawrence and Bay of Fundy) however it has not been associated with mortalities of wild quahogs since the 1950's (MacCallum and McGladdery 2000). QPX is also present in the USA (reviewed in MacCallum and McGladdery 2000). QPX is a parasite that infects connective tissue and muscles of quahogs and induces a massive haemocyte infiltration response and necrosis of the affected tissue (Whyte *et al.* 1994). QPX infections occur in healthy quahogs but they can also be fatal (MacCallum 2001).

Innovative Fisheries Product (IFP), a shellfish processing and depuration company based in Nova Scotia, has obtained the right to fish a number of beaches that are closed to shellfish harvesting due to bacteriological pollution. The company fish clams on these beaches which they then depurate before selling them as food items. They are also interested in shipping clams overseas. To do this, animals have to be declared free of any OIE-listed disease so as to avoid introducing diseases in new areas (OIE is The World Organisation for Animal Health). The company also has the responsibility of managing these beaches in a sustainable manner. Therefore, DFO has entered a partnership with the company to do research and development of culture techniques to enhance and/or restore clam beds.

The objectives of this project were to survey the area for any OIE-listed disease and other diseases of interest to aquaculture (e.g. haemic neoplasia, QPX) and to link disease and distribution to environmental conditions in order to obtain an idea of the general health of the clam population in the Bay of Fundy.

MATERIALS AND METHODS

SITE SELECTION

The study areas are all located on Nova Scotia's western shore (Figure 1). All sites chosen are closed to recreational shellfish harvesting. St. Mary's Bay (Q1) is one of only two sites where quahogs are found in the Bay of Fundy. In addition, this site is managed by IFP by way of a lease. The lease has a surface area of 1682 ha with a maximum intertidal surface area of 628 ha or 6.28 km^2. The mean tidal range for St Mary's Bay is 4.6 m with a maximum of 6.4 m (Gregory *et al*. 1993). The mean tidal current is 0.14 m/s that can reach 0.23 m/s.

Five soft-shell clams sites were chosen with the help of IFP and the clam fishers. IFP leases a site in Yarmouth Bar (M1) that was chosen for the study. This area has a mean tidal range of 3.8 m with a maximum of 5.2 m. the mean tidal current in Yarmouth is 0.10 m/s with a peak of 0.16 m/s (Gregory *et al*. 1993). Three sites were chosen in the Annapolis Basin: The Joggins (M2), Moose River (M3) and Upper Clements Park (M4). All these sites are also leased and managed by IFP. The Annapolis Basin has a mean tidal range of 6.8 m with a maximum of 9.3 m. Mean tidal currents are 0.97 m/s with a peak of 1.52 m/s (Gregory *et al*. 1993).

The fifth site was located in the Minas Basin. In 2005, the site chosen was Parrsboro (M5). However, because of low clam densities, it was replaced by a site in Five Islands (M6), Sand Point Beach, in 2006. The area sampled on both these beaches was prohibited to shellfish harvesting for being within 125 m from a wharf. Neither of these sites is leased therefore there is no harvesting on these beaches. For these reasons, they were considered as control sites. Only data from Five Islands will be presented. The Minas Basin has a mean tidal range of 11.3 m with a maximum of 15.0 m and a mean tidal current of 2.17 m/s with a peak of 3.40 m/s (Gregory *et al*. 1993).

SAMPLING DESIGN

General

The detailed locations of the sampling stations are described in the sections below. All stations were located in the intertidal zone, on mud flats and were exposed to air at low tide. Exposure to air varied between 4-6 hours depending on the beach. All data (health and population surveys and environmental parameters) were collected at low tide, when the stations were exposed to air.

2005

A temperature logger (Vemco 8-bit Minilog TR) was installed in the sediment in a randomly chosen area of each soft-shell clam beach (M1-M6, Figure 1). Sampling stations were generated using GIS software (MapInfo Professional, Version 6). Eight stations were located in a circular fashion at a radius of 50 m from where the Vemco was installed. A second set of 8 stations were chosen at 100 m radius from the Vemco location and then a third set of 8 stations at 150 m from the Vemco for a total of 24 stations per beach. Stations that were in the subtidal zone, in marsh grass or otherwise inaccessible were not sampled. The numbers of stations that were sampled on each beach at each date are presented in Table 1.

In St. Mary's Bay, IFP conducts yearly population surveys so their data was used for this study. Those sampling stations are situated at the intersections of a 250 m x 250 m sampling grid over the entire intertidal area (6.82 km²). A smaller area of 375 000m² was chosen for the purpose of this study and quahogs from the stations within this area (10 stations) were used for condition indices and health analyses. The data reported here for the population survey in St Mary's Bay is also limited to those ten stations. A temperature logger (Vemco 8-bit Minilog TR) was installed in the sediment in this area.

Soft shell clams and quahogs were collected in the spring, summer and fall for the health survey and the condition indices (Table 1). The population surveys were conducted in the spring and fall in St. Mary's Bay (Q1) and in summer and fall for the soft-shell clam beaches (M1-M6). Environmental parameters were not investigated in 2005. The population survey in Moose River was not conducted in the fall of 2005 due to lack of time.

2006 and 2007

A different sampling design was used in 2006-2007 in order to cover a larger area of each beach. Sampling stations were again generated using GIS software (MapInfo Professional, Version 6). Stations were chosen at the intersections of a 150 m x 150 m grid for Yarmouth (M1), Upper Clements (M4) and Five Islands (M6). In Moose River (M3), the area to be covered was smaller therefore stations were located at every intersections of a 100 m x 100 m grid in order to have a similar number of stations as the other beaches. In The Joggins (M2) and St Mary's Bay (Q1), the stations were set at the intersections of a 250 m x 250 m grid but the grid was reduced to 150 m x 150 m in summer 2006 (and subsequent samplings) because too few stations could be covered in a tidal cycle. Stations that were in the subtidal zone, in marsh grass or otherwise inaccessible were not sampled. The numbers of stations sampled per beach varied between 8 to 12 stations (Table 1) depending on how many could be covered in one tidal cycle on each beach. Temperature loggers (Vemco 8-bit Minilog TR) were installed in the sediment on each beach in the area covered by the survey.

At each station, data was collected for the health survey, condition indices, sulfide concentrations, the depth of the oxic layer and organic matter in the spring, summer and fall. In spring and fall, data was also collected at each sampling station for the population survey and identification of other fauna and in the summer, sediment samples were collected. See Table 1 for details of the sampling schedule. The spring 2006 population survey in Moose River (M3) was not conducted due to lack of time. In spring 2007, the population survey in Moose River (M3) was done on two different days because of unfavorable weather conditions on 16 May 2007.

DATA COLLECTION

Disease samples and condition indices

Sixty (60) clams (soft-shell clams or quahogs) were collected from the intertidal zone on each beach on every sampling date (Table 1) for a total of 540 animals per beach during the study period. In 2005, all animals were collected in the same area of the beach, within a radius of approximately 10 m. In 2006 and 2007, 10 animals were collected from 6 of the stations used in the population survey (see description of stations in previous section).

Out of the 60 clams, 30 were used for histology and the other 30 were used for condition index analyses. For the condition index analyses, the shell length was measured from anterior to posterior then the meat was separated from the shell. The meat was dried at 70°C in a drying oven for 24 hours then weighed. The shells were air dried for 24 hours and weighed. The condition indices were calculated as follows:

*CI = Dry meat weight/dry shell weight * 100*

<u>Preparation for disease analysis</u>

The soft-shell clams/quahogs were measured from the anterior to posterior with a calliper. They were placed on a tray and numbered to make sure that the traceability of each animal was not compromised. The animals were shucked carefully to ensure that the organs were kept intact. Once shucked, the flesh part of the mollusc was placed on a cutting board covered with paper towel. Bleach was used to disinfect the cutting board and instruments between samples. A sample is 30 animals from one beach. A slice of tissue that included the mantle, gills, digestive gland and gonads was taken. The piece of tissue was then placed in a histology cassette and fixed in Davidson's solution. During the 2006-2007 sampling season, extra pieces of tissue were preserved in 95% alcohol for PCR analysis. This is used as a confirmatory tool in a situation where a disease of concern would be found. The fixed tissues were infiltrated with paraffin, put into moulds, cut and put onto slides. These were then stained using Harris' hematoxylin and eosin. All the histological techniques mentioned above are described in Howard *et al*. 2004. The slides were then ready to be read under a microscope.

Slide reading

The slides were quick scanned at 4X to capture the general physiological condition. A magnification of 10X was used to do a full scan and capture any diseases, parasites and pathological agents. Any abnormalities were recorded.

Statistical analyses

The condition indices of soft shell clams at each collection date were compared with a mixed linear regression. The date was included as a categorical fixed factor and a random intercept by beach was included. The residual spread differed per date therefore a model allowing for a different variance per date was a better fit to the data (Likelihood ratio test (LRT) = 49.1, df = 8, p<0.001). The lme procedure, with the varIdent variance structure from the nlme package of the R programming environment (version 2.14.2) was used to analyze the data. The significance of a factor was determined by comparing the AIC, BIC and log likelihood of models with and without that particular factor.

The condition indices of quahogs at each collection date were analyzed with a generalized least squares model to deal with heterogeneity in the data. The date was included as a categorical fixed factor. Quahogs were only sampled on one beach therefore there was no beach factor included in the analysis. The spread in the residuals differed per date therefore a model that allows different variances per date was a better fit to the data (LRT = 52.1, df = 8, p < 0.001). The gls function with the varIdent variance structure from the nlme package of the R programming environment was used for this analysis.

The significance of a factor was determined by comparing the AIC, BIC and log likelihood of models with and without that particular factor. The nlme package uses the likelihood ratio test to compare models. When applicable, dates were compared using the contrast function of the contrast package. The significance level for all analysis (soft-shell clams and quahogs) was p < 0.05.

Distribution of clams

At each sampling station, the top layer (2-3 cm) of sediment from a 0.25 m^2 quadrant was collected with a garden spade and sieved through a 2-mm mesh to collect small soft-shell clams or quahogs. The rest of the animals were collected manually to a depth of up to 30 cm for soft-shell clams and 15 cm for quahogs. All animals were measured to the nearest 1 mm using a digital caliper. Population surveys were conducted in the spring and fall of each year (Table 1).

Sulfur and depth of oxic layer

Three sediment cores were collected at each sampling station on each beach on every sampling date (3 cores/sampling station/date/beach, see Table 1 for number of sampling stations/beach/date). The cores (PVC; area = 78.5 cm^2) were pushed into the sediment manually. The depth of the core depended on the type of sediment but was always at least 10 cm. The depth of the sediment above the black sediment, termed the oxic layer was measured for each core. Then a 5 ml subsample of sediment was taken from the surface (first 5 mm) of the core with a spoon and placed in a 20 ml amber vial. Another 5 ml subsample was taken at a depth of about 6 cm from the top and placed in another 20 ml amber vial. As soon as all field work was completed, samples were taken to the lab and sulfide concentrations of the sediments in the amber vials were determined using the method described in Wildish *et al.* (1999).

Organic matter

Three surface sediment samples were collected from each station on each beach (3 samples/sampling station/beach/date; Table 1) by scraping the top 1 cm with a garden spade (equivalent to 20 g of sediment on average) and analyzed for organic matter. In the lab, the entire sample of sediment was weighed, dried at 70°C in a drying oven for 24 hours and weighed. It was then ashed at 600°C in a muffle furnace for 8 hours and weighed again (Buchanan 1984). The percent organic matter content of the surface sediment was calculated with the following formula

$$\%\ Organic\ matter = \frac{Ashed\ \ weight\ (g) -\ Dried\ weight\ (g)}{Dried\ weight\ (g)} * 100$$

Sediment analysis

In the summers of 2006 and 2007, one sediment core was collected from each sampling station (1 core/sampling station/beach/year; Table 1) for the analysis of the sediment. The cores (aluminum; area = 78.5 cm^2) were pushed into the sediment manually. The depth of the core depended on the type of sediment. The sediment in the core was placed in a bag and frozen for later analysis. At time of analysis, the core was divided in two and one of these halves (approximately 70 g of sediment) was placed in pre-weighed aluminum dishes, weighed, dried at 70°C for 24 hours and weighed again. The sediment was placed in a stack of sieves (4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125µm and 63 µm) and shaken for 15 minutes with a mechanical shaker (Analysette 3 Spartan). The content of each sieve was then weighed. The median grain size and the inclusive graphic standard deviation (IGSD), a measure of sorting, were calculated (Appendices B and C; Buchanan 1984, Gray and Elliot 2009).

Infauna

One core sample (aluminum; area = 78.5 cm^2) was taken at each sampling station on each beach to collect infauna (Table 1). The sediment was passed through a 2 mm sieve. All fauna was bagged and frozen. The infauna was separated, identified to the lowest taxonomic group possible and counted. Samples were collected in the spring and fall.

Statistical analyses

The effects of environmental parameters on the clam densities were tested using mixed generalized linear models. With count data, normality and equality of variances assumptions needed for ANOVA analysis are rarely met, even after transformation of the data. Therefore, a mixed generalized linear model (GLMM) with a Poisson distribution was used to compare densities. When a Poisson distribution was not appropriate due to overdispersion of the data, the negative binomial distribution was used. The Poisson distribution has an expected mean and variance of:

$$E(Y) = \mu \text{ and } var(Y) = \mu$$

The negative binomial distribution has an expected mean and variance of:

$$E(Y) = \mu \text{ and } var(Y) = \mu + \mu^2/k \text{ or } var(Y) = \varphi\mu$$

There were correlations between some of the environmental parameters therefore a subset was chosen to eliminate theses correlations. Correlations were tested with the Spearman test and any correlation above 0.5 was deemed significant. The environmental parameters that were finally included in the analysis were sulfide concentration at the sediment-water interface, organic matter and IGSD. Season (spring and fall) was also included as a fixed factor.

Soft-shell clam densities were regressed on the environmental parameters to determine which, if any, parameters influence the distribution of clams. Sampling stations were nested in beaches and included as a random factor in the analysis. Juvenile ($SL \leq 15$ mm) and adult ($SL > 15$ mm) densities were analyzed separately.

A similar analysis was done for the quahog densities. Juvenile ($SL \leq 5$ mm) and adult ($SL > 5$ mm) densities were analyzed separately. In this case, stations were not nested in beach because there was only one beach with quahogs. Stations were included as a random factor.

Statistical analyses were done with the R programming environment (R Development Core Team, version 2.14.2). The function glmmadmb of the glmmADMB package was used. The variance of the negative binomial distribution used in the analysis was $var(Y) = \varphi\mu$. To test the significance of a factor, models with and without the factor were compared with an F test, using the waldtest function of the lmtest package.

RESULTS

HEALTH

No OIE-listed diseases were found in either clam species collected in the Bay of Fundy between 2005 and 2007 (Table 2). QPX was not present in quahogs in St Mary's Bay. Haemic neoplasia was not present in the Bay of Fundy however gonadal neoplasia was found in 2 soft-shell clams in The Joggins in fall 2005 (Table 2). There were a few occurrences of metaplasia. Rickettsia-like organisms (RLO) and metacercaria (see

Appendix A for description) were found at all sites except in St. Mary's Bay where there were no metacercaria and few were found in Five Islands.

CONDITION INDICES

Mean condition indices for the soft-shell clams varied between 9.3 ± 0.5 to 28.2 ± 0.8 % (Figure 2). The lowest value occurred in spring 2006 in Moose River and the highest in fall 2007 in Yarmouth. Condition indices (CI) of soft-shell clams were different between dates (LRT = 417.0, df = 8, $p<0.001$). The estimated beach-to-beach variation corresponds to a standard deviation of $\sigma_{Beach} = 1.70$. On average, CI were similar in 2005 and the spring of 2006. They increased in summer and fall 2006 and were higher in 2007 than in previous years (Figure 2).

Condition indices of quahogs varied between 4.5 ± 0.1 and 5.5 ± 0.2 %. They were different between dates (LRT = 92.4, df = 8, $p < 0.001$). They were higher in the fall of 2006 and all of 2007 than the previous dates (Figure 2).

DISTRIBUTION AND ENVIRONMENTAL CONDITIONS

Distribution

The mean densities of soft-shell clam juveniles (SL ≤ 15 mm) varied between 1 and 250 individuals/m² depending on the beach and the date. In Yarmouth, juveniles were found at most stations sampled, except in the spring of 2006 (Figure 3). In fall 2006, most juveniles were found at one station only (Figure 3). However, not all stations were sampled because of foul weather. In The Joggins, in 2005, juveniles were more common towards the shore (Figure 4). In 2006 and 2007, most of the soft-shell clams collected were less than 15 mm SL. Larger individuals were found at a few stations only (Figure 4). In 2005, Moose River had the lowest juvenile density (0.9 ± 0.6 individuals/m²; table) of all beaches sampled. In 2006 and 2007, most individuals were less than 15 mm SL (Figure 5). In 2005, there were large densities of juvenile in Upper Clements (Table 3) and they were found at most stations (Figure 6). In the following years, juvenile densities were much lower, especially in the spring (Table 3, Figure 6). In fall 2007, juveniles were more common than larger individuals at 5 out of the 8 stations sampled (Figure 6). Juvenile density in Five Islands was consistently low (Table 3). They were found at most stations at one time or another during the two years of sampling (Figure 7).

The mean densities of adult soft-shell clams (SL > 15 mm) varied between beaches (Table 3). Within beaches, densities were similar between dates in most cases (Table 3). In some cases, densities were higher in 2005 but the stations were in different locations than in 2006-2007. In Yarmouth, adult densities were higher in fall 2006 and spring 2007 than at the other dates (Table 3). In The Joggins, adult densities were about 10 times higher in 2005 than in 2006-2007, when densities were quite low (Table 3). Adults were mostly found at the stations closer to the shore in The Joggins (Figure 4). In Moose River, adult densities were higher in spring 2007 than at the other dates (Table 3). Some adults were found at most sites (Figure 5). Upper Clements had the highest soft-shell clam adult densities of all beaches (Table 3). Most adult individuals were found at the stations closer to shore (Figure 6). In Five Islands, adult clam densities were similar until fall 2007 when they decreased by almost half (Table 3). The stations with the highest densities had the highest elevations and had muddy sediments (Figure 7). The stations with few clams were in the river, where the sediment was mostly gravel.

Mean densities of market size soft-shell clams (SL ≥ 45 mm) also varied between beaches and in some instances by dates (Table 1). At Moose River and Five Islands, densities were higher in the spring than in the fall. At the other beaches, the mean densities were similar in 2006 and 2007. In Upper Clements, densities of market sized soft-shell clams were highest in 2005.

Quahog juveniles (SL ≤5 mm) were found only once, in fall 2006, in St Mary's Bay (Table 3). They were all found at one station (Figure 8). Mean adult (SL > 5 mm) densities were highest in spring 2005 and lowest in fall 2007. In between these dates, densities were similar. Densities at each station varied during the sampling period (Figure 8). Market size quahog (SL ≥ 55 mm) densities were highest in spring 2005, decreased slightly in fall 2005 and 2006. In 2007, mean densities were about half of what they were previously (Table 3).

Sulfide and depth of oxic layer

Sulfide concentrations at the sediment-water interface varied mostly between 0 and 40 µM. In Yarmouth, concentrations were all below 10 µM except fall 2007, when they varied between 15 and 32 µM (Figure 9). In The Joggins, sulfide concentrations at the sediment-water interface were also below 10 µM except for a few stations in spring (maximum 25 µM) and fall (maximum 31 µM) 2007 when concentrations were higher (Figure 10). In spring and summer 2006, concentrations in Moose River (Figure 11) were below 10 µM. In fall 2006, they varied between 14-26 µM. In spring 2007, concentrations reached 64 µM at the stations near the railway bridge in Moose River. In summer 2007, concentrations at most stations were below 10 µM again. The station with the highest concentration in the spring still had a highest concentration in the summer (23 µM). In fall 2007, concentrations varied between 10 and 38 µM with no particular pattern on the sampled area. Sulfide concentrations in Upper Clements varied between 0 and 25 µM during the sampling period (Figure 12). In Five Islands (Figure 13), sulfides were below 10 µM in 2006. In spring 2007, concentrations increased and varied between 50 and 73 µM. Concentrations decreased and by fall 2007, they were below 10 µM again. Sulfides in St Mary's Bay were similar to Five Islands. Concentrations were below 10 µM in 2006, increased to 60-75 µM in spring 2007 and were below 20 µM by fall 2007 (Figure 14).

Sulfide concentrations at a depth of 6 cm were generally higher and more variable than at the sediment-water interface. In fall 2006, sulfide concentrations in the deeper sediment at Yarmouth were similar to the concentrations at the sediment-water interface (Figure 15). At the other sampling dates, they ranged from 0 to 200 µM; however these differences showed no particular pattern. At The Joggins, sulfide concentrations were lower in 2006 than in 2007 (Figure 16). In 2007, sulfide concentrations were lower near the shore and increased with the distance from shore, reaching concentrations of 80µM. At Moose River, sulfide concentrations at a depth of 6 cm ranged from 40 to 310 µM (Figure 17). The stations around the railway bridge pillars generally had higher sulfide concentrations. Sulfide concentrations at a depth of 6 cm in Upper Clements (Figure 18) were lowest in fall 2006 (0-40 µM) and highest in fall 2007 (100 -200 µM). In the spring and summer of both years, concentrations varied between 20 and 80 µM. Concentrations were consistently higher at a few stations, in the centre of the area surveyed. In Five Islands in 2006, sulfide concentrations at a depth of 6 cm varied between stations (Figure 19). They were higher at the upstream stations. Concentrations at these stations increased in 2007. The highest concentration in 2006 was around 60 µM whereas it reached 310 µM in 2007. At St. Mary's Bay, the only beach with quahogs, sulfide concentrations at a depth of 6 cm were below 40 µM in spring 2006 and subsequently increased, reaching a maximum concentration of 220 µM in spring 2007 (Figure 20).

The black anoxic sediment in Yarmouth was close to the sediment water interface as indicated by a depth of the oxic layer of less than 1 cm (Figure 21). The oxic layer reached 3 cm at a few stations in the spring of both years. At The Joggins (Figure 22), the limit of the oxic layer was not reached at one station located near the shore (<6 cm). In the spring of 2006, another station had a deep oxic layer; however this station consisted of very soft mud while the station near the shore was harder and had more gravel. At the rest of the stations, the oxic layer was near the sediment surface (0-3 cm). In Moose River, the oxic layer varied between 0 and 3 cm, except in fall 2007 when it was deeper than 6 cm near the railway bridge (Figure 23). The depth of the oxic layer in Upper Clements in the sampled area varied between 0 and 1 cm (Figure 24). In Five Islands (Figure 25), the limit of the oxic layer was not reached at most of the stations (over 6 cm). These stations consisted mostly of coarse sand. Where it was reached, in finer sediments, it was normally shallow, between 0 and 2 cm. The depth of the oxic layer in St. Mary's Bay was more variable than at the other beaches (Figure 26). It varied between 0 and over 6 cm but in no particular pattern.

Organic matter

Organic matter in Yarmouth varied between 1 and 3% and was fairly constant throughout the studied area during the study period (Figure 27). Organic matter was slightly higher in The Joggins, between 1 and 5% (Figure 28). Generally, organic matter content was higher further from shore. Organic matter content was higher at the upstream stations in Moose River (Figure 29). Here, organic matter content was as high as 8% at some stations. Similarly to The Joggings, higher organic matter content was further from the shore in Upper Clements (Figure 30). Organic matter was lower in the spring of both years than at other times. Maximum organic matter content in Five Islands was around 4% (Figure 31). Areas of higher organic content were consistent during the sampling period. Organic matter content was below 3% in St. Mary's Bay (Figure 32).

Sediment analysis

Sediment characteristics were not the same at all beaches. In Yarmouth, median grain size at most stations was very fine sand (0.0625 – 0.125 mm; Appendix B) with a few stations of fine sand (0.125-0.250 mm) in 2006 and in 2007, the sediment was mostly very fine sand except one station with fine sand (Figure 33). The IGSD values in 2006 were mostly between 0.71 and 2 (Figure 33). These values indicate that the sediments were moderately to poorly sorted. In 2007, the IGSD values decreased and varied from

0.50 to 1 (moderately well sorted to moderately sorted sediments). In The Joggins, median grain size varied from very fine sand to fine sand in 2006 while in 2007 all stations were very fine sand with two areas of silt/clay (< 0.0625 mm) sediment (Figure 34). In 2006, IGSD values were between 1 and 2 (Figure 34), indicating poorly sorted sediment usually found in low energy areas. However in 2007, the IGSD varied from <0.35 to 1, indicating that sediments were mostly well sorted, which usually indicates a high energy area. In Moose River, median grain size varied from very fine sands to medium sand (0.25-0.50 mm) in 2006 (Figure 35). In 2007, the median grain size was mostly very fine sand with some upstream areas of fine sand. The sediment was mostly poorly sorted (IGSD > 1) in 2006 (Figure 35). In 2007, the IGSD values were lower; indicating that the sediment was well sorted (Figure 35). In Upper Clements, in 2006, one station consisted of coarse sand (0.5-1.0 mm) while the others were composed of fine sand to very fine sand (Figure 36). In 2007, the sediment was composed mostly of silt/clay to very fine sand except for the same station composed of coarse sand. There were also large boulders (> 1 m) around that station. The sediment in Upper Clements was moderately sorted to poorly sorted in 2006 and 2007. The IGSD values varied between 1 and 3 in 2006 and between 0.71 and 2 in 2007 (Figure 36). Sediment composition in Five Islands was more heterogeneous than the other beaches (Figure 37). The stations at higher elevations had fine to very fine sand. The stations with granule (2-4 mm) and very coarse sand (1-2 mm) were at lower elevation and close to the river bed. In 2007 most stations had similar sediment composition than in 2006 except for the areas of coarse sand where median grain size decreased slightly. The IGSD varied from 0.40 to 2 (well sorted to poorly sorted) in 2006. The area with the highest IGSD in 2006 had the lowest in 2007 (Figure 37). In St Mary's Bay, most stations consisted of fine to very fine sand, with only 2 stations having larger median grain size (Figure 38). In 2007, median grain size increased at some stations, decreased at others and remained unchanged in still other stations. The IGSD values were between 1 and 4 for both years (Figure 38), indicating poorly sorted sediment found in low energy areas.

Relationship between distribution and environment

In all of the analyses, the negative binomial distribution was a better fit to the data because of overdispersion. For the soft-shell clam juvenile analysis, the negative binomial dispersion parameter was $\varphi = 25.143$ (± 5.06 SE). The only environmental parameter that significantly influenced the distribution of soft-shell clam juvenile was the IGSD (Table 4). In the spring, spat density decreased as the IGSD value increased ($\beta = -0.48 \pm 0.18$ SE, z-value = -2.70, $p = 0.007$), indicating more spat in poorly sorted sediment. The interaction between IGSD and season was significant (Table 4). In the fall, there is no relationship between IGSD and spat density ($\beta = 0.14 \pm 0.15$ SE, z-value = 0.96, $p = 0.338$). The variation due to different stations within beaches was very small ($\sigma^2_{Beach/Station} = 4.80 \times 10^{-9}$). The variation due to different beaches was $\sigma^2_{Beach} = 0.06$.

For the adult soft-shell clam, the model used was a negative binomial distribution ($\varphi = 11.39 \pm 2.16$ SE). None of the environmental parameters measured influenced the distribution of the adult soft-shell clams (Table 4). Most of the variation was due to the stations within beach ($\sigma^2_{Beach/Station} = 1.23$). The variation due to different beaches was $\sigma^2_{Beach} = 0.73$.

There were not enough quahog juveniles to analyze statistically therefore only the densities of adults were analyzed. None of the environmental parameters measured influenced the distribution of the adult quahogs (Table 4). The negative binomial parameter was $\varphi = 7.80$ (± 2.14 SE). The variation due to different stations was ($\sigma^2_{Station} =$ 0.17).

Temperature

The only sediment temperature data that was retrieved was the 2005 temperatures (Figure 39). The data from the other years were lost. St Mary's Bay had the highest sediment temperatures from May to the end of September. By October, temperatures were the same at all beaches. The maximum daily temperature in St Mary's Bay and Upper Clements were reached around 15 August with a second peak around 1 September. In Yarmouth and The Joggins, the maximum daily temperatures were reached around 1 September. The maximum daily temperature in St Mary's Bay was 22°C and 19°C in Upper Clements, for both peaks. The maximum daily temperature in Yarmouth was 18°C and in The Joggins, 15°C. By mid-October, the temperature decreases to 10°C and was similar for all beaches.

INFAUNA

The species present in the epifauna differed at each beach. The most common families found in the sediment along with soft-shell clams in Yarmouth (Table 5) were the gammarid amphipods (Gammaridae), threadworms (Capitellidae, mostly *Capitella* spp.) and bamboo worms (Maldanidae). Periwinkles (Littorinidae) were also common. In The Joggins (Table 5), the most common species other than the soft-shell clam was the swamp snails, *Hydrobia truncata* (Family Hydrobiidae). Other common families were the threadworms, bamboo worms and the shimmy worms (Capitellidae, Maldanidae and Nepthyidae, respectively). In Moose River (Table 5), the most common species found consistently were the *Macoma balthica* (family Tellinidae) and gammarid amphipods. Periwinkles and bamboo worms were also common in Moose River. Most of the *M. balthica* found were at the station next to the railway bridge, where sulfides and organic matter were higher. *M. balthica* was the most common species with the periwinkles as the second most common family in Upper Clements (Table 6). *M. balthica* was also the most common species in Five Islands (Table 6). Periwinkles were also fairly common. Whelks and snails, especially the dog whelk (Nassariidae), were common on the beach in St Mary's Bay (Table 6). There were also a few species of polychaete worms.

DISCUSSION

DISEASES

The objectives of this project were to gather baseline information on the types and prevalence of diseases present in the Bay of Fundy area and to link them to environmental conditions. The focus was on OIE-listed and endemic diseases such as neoplasia and QPX. The former diseases are present along the eastern coast of the USA and in the Atlantic Provinces and have been associated to mortalities in the past (McGladdery *et al*. 1993, Morrison *et al*. 1993, MacCallum and McGladdery 2000, McGladdery 2001, MacCallum 2001, MacCallum 2003). During the survey period, between 2005 and 2007, no diseases were found in either clam species in the Bay of Fundy. Some parasites were present such as rickettsia-like bacteria (RLO) and metacercaria. These parasites are ubiquitous in Atlantic Canadian waters and the USA and they are found in most bivalve species (MacCallum 2003). They do not cause disease or any deleterious effect to tissues.

Haemic neoplasia was not found during this survey, while gonadal neoplasia was found in only 2 clams in the Joggins. Both diseases have been present in the Bay of Fundy in low prevalence in the past (Morrison *et al*. 1993, Barber *et* al. 2002). They are also present on the US eastern coast (reviewed in MacCallum 2003) and haemic neoplasia was identified for the first time in 1999 in Prince Edward Island (McGladdery 2001, MacCallum 2003).

QPX is more common in clams from hatcheries and aquaculture sites. It has been found in some wild populations in the US and in St. Andrew's NB, more precisely in Sam Orr's Pond (MacCallum and McGladdery 2000, MacCallum 2003). In 1998, a histological examination of quahogs from St Mary's Bay (Bay of Fundy) was carried out and QPX was not present (MacCallum and McGladdery 2000). This survey shows that the site remains QPX-free.

Because no diseases were found, the linking of diseases to environmental conditions was not possible. However, we did get baseline information and observations on the environmental conditions and clam densities of these beaches.

DISTRIBUTION AND ENVIRONMENT

Another objective of the project was to relate soft-shell clam and quahog distributions to environmental conditions. Bivalves in general are well known for their aggregated distribution (Saila *et al.* 1967, Newell 1991, Dame 1996, Strasser *et al*. 1999, Fegley 2001, Mann *et al*. 2005); however the process is not well understood. Many factors, such as temperature, salinity, sediment type and currents, affect the distribution of clams (Malouf and Bricelj 1989, Grizzle *et al*. 2001). None of the environmental parameters measured explained the distribution of adults of either species of clams. Most of these parameters were homogeneous in the areas surveyed whereas the distribution of clams was not always homogeneous. Five Islands was the only beach were environmental parameters varied over the area surveyed. It is also the only beach where there is no fishing activity. Fishing is usually concentrated where clam densities are highest so some areas of the beaches do not get fished at all. Where fishing occurs, it is difficult to determine if densities are determined by natural processes such as recruitment or by fishing.

Many studies show that sediment and hydrodynamics may explain clam distribution and different growth rates (Pratt and Campbell 1956, Saila *et al*. 1967, Newell and Hidu 1982, Appledoorn 1983, Grizzle and Morin 1989, Menzel 1989) but this is not always the case. Clam patchiness does not always correspond to sediment patchiness (Strasser *et al.* 1999). Soft-shell clam abundances are often higher in mud (Newell and Hidu 1982, Appledoorn 1983, Gunther 1992, Strasser *et al*. 1999) while quahogs are more common in sand (Pratt and Campbell 1956, Grizzle and Morin 1989, Menzel 1989, Mann *et al*. 2005). There appears to be an upper limit to how much silt clams can live with. Too much silt may clog the siphon leading to reduced growth (Newcombe 1935, Pratt and Campbell 1956). Quahogs were shown to produce more pseudofaeces in mud which probably increases energy expenditure (Pratt and Campbell 1956). Erosion and bedload transport could also be factors in sediment preferences. St. Onge and Miron (2007) found that there is less bedload transport of mud and gravel than sand at all of current speeds tested. There was also less erosion of soft-shell clams in those sediments. Hunt (2004) found that quahogs burrow faster and are less likely to be eroded in coarse sediment. While most stations on the beaches in the Annapolis Basin were hard mud, a few stations consisted of very soft mud where no clams were ever found. In Five Islands, approximately 86% of clams were collected at the stations with higher mud content (5 stations). In a survey of Minas Basin clam flats, Witherspoon (1983) also found more clams in muddy sediments. She found few clams in gravel and none in soft mud or shifting sands. Newcombe (1935) found that clams transplanted in shifting sands did not survive. He attributed this mortality to smothering. The area surveyed in St. Mary's Bay was mostly sandy sediment, except for one station where we did not find quahogs. Quahogs have a shorter siphon and do not dig as deep as soft-shells therefore they need a harder substrate to prevent sinking (Menzel 1989). Quahog densities in St. Mary's Bay are relatively high. Typically, population densities range between 1 and 15 individuals/m² (Fegley 2001).

The abundance of juvenile soft-shell clams (< 15 mm) was variable with none in some years and very high in others. It was also different between beaches. In the spring, small soft-shell clams were more common in well sorted sediment typical of high energy areas (Gray and Elliott 2009) while in the fall, the homogeneity of the sediment had no impact on the number of juveniles. Because small clams (both soft-shell and quahogs) can be transported and redistributed during strong tides and storms (Roegner *et al*. 1995, Gunther 1992, Hunt & Mullineaux 2002, Hunt *et al*. 2003, St. Onge and Miron 2007), initial settlement does not necessarily predict later recruitment. Soft-shell clams < 15 mm in the Bay of Fundy are most likely 0 and 1 year old (Newcombe 1935, Witherspoon 1983) therefore they do not necessarily represent recruitment. Soft-shell clam and quahog recruitment varies from year to year and from one area to another (Kube 1996, Strasser *et al*. 1999, MacKenzie and McLaughlin 2000, Hunt *et al*. 2003, Vassiliev *et al*. 2010) and mortality is very high shortly after settlement (Brousseau 1978, Gunther 1992, Mann *et al*. 2005). Other than transportation, predation can also impact recruitment and alter size distribution of a population (Gunther 1992, Hunt and Mullineaux 2002, Hunt *et al*. 2003). The lack of small quahogs in this study may be due to the sampling method rather than the absence of animals. Another study on the beach in St. Mary's Bay revealed much larger numbers of small quahogs than this study (LeBlanc, unpublished data).

Sulfides are produced when sulfate-reducing bacteria reduce sulfates from the water column and from the decomposition of organic matter (Fenchel and Riedl 1970). A small part of this sulfide is reduced by iron present in the sediment and forms pyrite which we see as the black sub-surface sediment layer common in the Bay of Fundy. The rest of the sulfide remains in the pore water and eventually diffuses to the sediment-water interface, where it is oxidized by oxygen present in the surface water. Sulfide itself can be toxic to animals. Bivalves, especially soft-shell clams, are highly tolerant to sulfide (Theede *et al*. 1969, Theede 1973). Tolerance to sulfides is related to the habitat where species naturally occur (Theede *et al*. 1969, Lewitt and Arp 1991, Bagarinao 1992). Even within the same species, different populations are more or less tolerant of sulfides depending on the conditions where they live (Jahn and Theede 1997). Smaller individuals are less tolerant of sulfides than larger ones (Jahn *et al*. 1997, Laudien *et al*. 2002). In the presence of sulfides, smaller clams appear to switch to anaerobic metabolism therefore their survival will be related to their energy reserves (Jahn *et al*. 1997, Laudien *et al*. 2002). Juveniles of the surf clam, *Donax serra*, move out of the sediment in the presence of sulfide making them more susceptible to transport to a more favorable habitat (Laudien *et al*. 2002). Sulfide concentrations were higher in the deeper black layer than at the surface or in sand and gravel. Concentrations were always below 300µM, except on one occasion. Below 300µM, oxic conditions are considered normal (Wildish *et al*. 1999).

In summary, we were not able to conclusively explain the distribution of clams with the physical factors that we measured. Most of these factors are not independent of one another. For example, organic matter will probably lead to higher sulfide concentrations. This effect will be higher in mud than in sand or gravel where water can penetrate more easily and deeper which means oxygen reaches deeper in the sediment. Where currents are slower, deposition may be higher which means that new sediment is added at a faster rate than elsewhere. In this case, a deeper black sub-layer may not indicate better oxygenation but rather newer sediment. Most of these factors are driven by hydrodynamics. Small scale hydrodynamics may be the most important factor explaining the distribution of clams on a tidal flat (Gunther 1992, LeBlanc and Miron 2006).

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Table 1. Sampling information. Environmental conditions include sulfide concentrations, organic matter and depth of oxide layer. Samples for sediment analysis were only taken in the summer seasons. Infaunal samples were only taken in 2006 and 2007.

Year	Beach	Health & CI			Population survey & Infauna						Environmental conditions								
		Spring	Summer	Fall	Spring			Fall			Spring			Summer			Fall		
					Date	Stations	Area (he)	Date	Stations	Area (he)	Date	Stations	Area (he)	Date	Stations	Area (he)	Date	Stations	Area (he)
2005	Yarmouth	27/06	30/08	27/10	30/08	13	2.1	28/10	11	1.8									
	The Joggins	28/06	31/08	24/10	29/07, 31/08	23	5.4	24-25/10	18	3.3									
	Moose River	28/06	31/08	28/10[a]	28/07	8	0.9												
	Upper Clements	28/06	29/08	26/10	26-27/07	19	3.8	26-27/10	16	3.8									
	St. Mary's Bay	27/06	29/08	27/10	25/04	10	31.3	11/10	8										
2006	Yarmouth	24/05	17/08	11/10	26/06	12	14.9	12/10	4		6/07	11	14.5	17/08	11	13.3	11/10	9	10.3
	The Joggins	25/05	14/08	30/10[a]	14/06	6	10.9	17/10	8	8.2	13/06	6	10.9	14/08	6	5.6	30/10	6	8.3
	Moose River	25/05	18/08	1/11				18/10	8	3.4	7/07	8	4.5	18/08	8	4.5	1/11	8	4.5
	Upper Clements	25/05	15/08	31/10	15/06	9	10.3	16/10	9	9.2	15/06	9	10.3	15/08	10	11.4	31/10	9	10.2
	Five Islands	30/05	29/08	26/10	13/07	10	7.9	26/10	10	7.9	12/07	10	7.9	29/08	9	7.9	27/10	9	7.9
	St. Mary's Bay	29/05[b]	16/08	2/11	16/06	10	32.2	19/10	13	16.9	16/06	11	31.2	16/08	11	14.6	2/11	13	16.9
2007	Yarmouth	5/06	14/08[a]	24/10	5/06	8	8.0	24/10	7	7.1	5/06	8	8.0	14/08	9	10.4	24/10	9	7.1
	The Joggins	14/05	14/08	30/10	14/05	6	6.9	30/10	6	5.3	14/05	6	6.9	14/08	6	4.3	30/10	6	5.3
	Moose River	16/05	15/08	31/10	16/05, 6/06	8	4.5	31/10	8	4.5	16/05, 6/06	8	4.5	15/08	8	4.5	31/10	8	4.5
	Upper Clements	15/05	16/08	1/11	15/05	8	8.0	1/11	8	7.9	15/05	8	8.0	16/08	9	10.2	1/11	8	7.9
	Five Islands	24/05	30/08	15/11	24/06	9	7.9	15/11	9	7.9	24/05	9	7.9	30/08	9	7.9	15/11	9	7.9
	St. Mary's Bay	17/05	17/08	23/10	17/05	12	15.7	23/10	12	15.7	17/05	12	15.7	17/08	12	15.7	23/10	12	15.7

[a] No sample for condition indices.
[b] The samples for condition indices were taken on 06/06/06.

Table 2. **Average lengths and health diagnotics (number of individuals with the condition) of soft-shell clams and quahogs collected in the Bay of Fundy, Nova Scotia, Canada during the spring, summer and fall of the years 2005 to 2007.**

				Histology results[1]					
	n	**Average Length**	**Standard error**	**Metaplasia**	**Haemic Neoplasia**	**Gonadal neopladia**	**RLO**	**Metacercaria**	**QPX[2]**
Yarmouth (M1)									
Spring 05	30	54.7	0.66	3	0	0	0	12	n/a
Summer 05	30	52.4	1.03	0	0	0	4	8	n/a
Fall 05	30	58.4	1.15	0	0	0	3	10	n/a
Spring 06	30	58.4	1.57	4	0	0	12	10	n/a
Summer 06	30	47.8	1.19	0	0	0	6	9	n/a
Fall 06	30	50.6	1.05	0	0	0	5	6	n/a
Spring 07	29	45	1.09	0	0	0	6	3	n/a
Summer 07	30	53.3	1.69	0	0	0	13	0	n/a
Fall 07	30	45.8	1.47	0	0	0	6	0	n/a
The Joggins (M2)									
Spring 05	30	57.7	1.91	0	0	0	4	8	n/a
Summer 05	27	47.3	0.91	0	0	0	3	6	n/a
Fall 05	25	60.9	1.5	1	0	2	2	5	n/a
Spring 06	30	60.9	1.97	0	0	0	2	10	n/a
Summer 06	30	60.3	2.36	0	0	0	10	8	n/a
Fall 06	29	58.1	2.43	0	0	0	4	10	n/a
Spring 07	30	58.6	2.32	0	0	0	5	13	n/a
Summer 07	30	62.6	1.71	0	0	0	9	4	n/a
Fall 07	30	50.5	1.92	0	0	0	2	0	n/a
Moose River (M3)									
Spring 05	20	62.2	1.25	0	0	0	1	5	n/a
Summer 05	22	59.9	2.2	0	0	0	2	9	n/a
Fall 05	30	65.3	1.07	0	0	0	2	14	n/a
Spring 06	30	73.4	1.21	0	0	0	8	16	n/a
Summer 06	30	68.6	2.02	0	0	0	5	14	n/a
Fall 06	30	70.6	1.99	0	0	0	5	13	n/a
Spring 07	30	68.2	1.47	0	0	0	6	0	n/a
Summer 07	30	53.8	1.96	0	0	0	17	0	n/a
Fall 07	30	46	2.09	0	0	0	5	5	n/a

[1] See appendix for descriptions.
[2] QPX is not present in soft-shell clams.

Table 2. **Average lengths and health diagnotics (number of individuals with the condition) of soft-shell clams and quahogs collected in the Bay of Fundy, Nova Scotia, Canada during the spring, summer and fall of the years 2005 to 2007.continued**

				Histology results[1]					
	n	**Average Length**	**Standard error**	**Metaplasia**	**Haemic Neoplasia**	**Gonadal neopladia**	**RLO**	**Metacercaria**	**QPX[2]**
Upper Clements (M4)									
Spring 05	30	47.2	0.79	0	0	0	0	10	n/a
Summer 05	30	44.5	0.42	0	0	0	0	7	n/a
Fall 05	28	47	0.74		0	0	0	21	n/a
Spring 06	30	48.1	1.47	0	0	0	1	3	n/a
Summer 06	29	52.6	1.65	0	0	0	0	6	n/a
Fall 06	30	45.9	2.14	0	0	0	1	12	n/a
Spring 07	30	45.9	1.82	0	0	0	0	5	n/a
Summer 07	30	49	1.1	0	0	0	7	1	n/a
Fall 07	30	44	1.15	0	0	0	4	0	n/a
Five Islands (M6)									
Spring 06	30	56.2	2.06	0	0	0	5	0	n/a
Summer 06	30	54	1.92	0	0	0	5	2	n/a
Fall 06	30	46.3	1.76	0	0	0	2	0	n/a
Spring 07	30	54.2	2.07	0	0	0	4	0	n/a
Summer 07	30	49.4	1.59	0	0	0	1	0	n/a
Fall 07	30	53.4	1.47	0	0	0	1	0	n/a
St. Mary's Bay (Q1)									
Spring 05	30	55.6	0.79		0	0	1	0	0
Summer 05	30	52.2	0.54	0	0	0	4	0	0
Fall 05	30	53.5	0.99	n/a	n/a	n/a	n/a	n/a	0
Spring 06	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0
Summer 06	30	51.9	1.01	0	0	0	1	0	0
Fall 06	30	51.7	1.38	0	0	0	3	0	0
Spring 07	27	50.1	1.03	0	0	0	1	0	0
Summer 07	30	53.5	1.53	0	0	0	0	0	0
Fall 07	30	53.4	0.43	0	0	0	0	0	0

[1] See appendix for descriptions.
[1] QPX is not present in soft-shell clams.

Table 3. Mean soft-shell and quahog clam densities (individuals / m²) collected in the Bay of Fundy, Nova Scotia, Canada between 2005 and 2007.

		Juvenile[1] (SL ≤ 15 mm)		Total Adult (SL > 15 mm)		Market [1] (SL ≥ 45 mm)	
	N	X	se	X	se	X	se
Yarmouth (M1)							
Summer 05	13	17.8	5.1	63.1	21.9	13.2	3.3
Fall 05	13	20.0	5.6	51.4	11.4	12.0	4.1
Spring 06	12	5.3	3.7	47.0	13.4	8.7	2.1
Fall 06	4	163.0	132.1	154.0	81.7	8.0	2.8
Spring 07	8	90.0	34.5	126.0	55.8	19.0	7.1
Fall 07	9	14.7	5.5	44.0	13.8	8.9	3.6
The Joggins (M2)							
Summer 05	23	12.2	6.8	29.7	12.3	6.4	1.8
Fall 05	18	13.8	7.0	10.4	3.2	2.0	0.7
Spring 06	6	2.0	1.4	2.0	1.4	0.7	0.7
Fall 06	8	72.0	48.8	2.0	1.1	1.0	0.6
Spring 07	6	10.7	5.1	1.3	1.3	1.3	1.3
Fall 07	6	8.7	4.2	3.3	1.6	2.0	1.4
Moose River (M3)							
Summer 05	9	0.9	0.6	8.0	3.1	7.6	2.9
Fall 06	8	14.0	5.6	7.0	3.9	0.0	0.0
Spring 07	8	70.0	25.2	17.0	5.7	2.5	1.3
Fall 07	8	4.5	2.4	4.0	2.1	0.0	0.0
Upper Clements (M4)							
Summer 05	11	249.1	81.6	268.0	97.7	22.2	5.5
Fall 05	15	174.7	35.9	170.1	17.5	23.7	7.1
Spring 06	9	8.0	5.5	142.2	51.8	6.7	3.2
Fall 06	9	20.9	6.0	160.9	65.6	9.3	5.0
Spring 07	8	4.5	1.6	95.0	32.6	8.5	3.2
Fall 07	8	91.5	26.0	102.0	35.4	11.5	6.1
Five Islands (M6)							
Spring 06	10	4.0	1.6	54.8	29.7	10.0	3.6
Fall 06	9	1.8	0.7	56.0	35.4	5.3	3.5
Spring 07	9	10.7	6.2	48.4	20.5	9.8	2.9
Fall 07	9	5.8	2.7	29.3	13.6	5.8	2.3
St Mary's Bay (Q1)[1]							
Spring 05	10	0.0	0.0	70.4	31.7	24.0	14.1
Fall 05	8	0.0	0.0	46.5	21.6	14.5	8.1
Spring 06	10	0.0	0.0	51.2	19.0	16.4	10.5
Fall 06	12	3.3	3.3	58.0	15.2	14.3	5.0
Spring 07	11	0.0	0.0	46.2	11.9	5.4	1.7
Fall 07	11	0.0	0.0	34.7	9.2	7.0	2.2

[1] Juvenile size for quahogs are SL ≤ 5 mm and market size are SL ≥ 55 mm.

Table 4. Results of generalized linear mixed models evaluating the relationship between soft-shell and quahog clam densities and environmental parameters measured in the Bay of Fundy, Nova Scotia, Canada, in 2006 and 2007.

Factor	AIC	Df	Res.Df	Df	F	Pr
Juvenile Mya arenaria						
Full model	755.8	11	130			
Organic matter x Season	755.0	10	131	1	1.142	0.287
H_2S x Season	753.1	9	132	1	0.083	0.774
IGSD x Season	**758.5**	**8**	**133**	**1**	**7.093**	**0.009**
H_2S sediment-water interface	751.1	8	133	1	0.048	0.828
Organic matter	749.4	7	134	1	0.248	0.619
Adult Mya arenaria						
Full model	863.8	11	130			
IGSD x Season	862.6	10	131	1	0.730	0.394
Organic matter x Season	861.1	9	132	1	0.578	0.449
H_2S x Season	862.1	8	133	1	2.971	0.081
IGSD	860.2	7	134	1	0.071	0.791
Season	858.5	6	135	1	0.329	0.567
H_2S sediment-water interface	858.3	5	136	1	1.816	0.180
Organic matter	858.9	4	137	1	2.689	0.103
Adult Mercenaria mercenaria						
Full model	320.7	10	34			
IGSD x Season	318.9	9	35	1	0.229	0.635
Organic matter x Season	317.8	8	36	1	0.932	0.341
H_2S x Season	319.2	7	37	1	3.752	0.061
Season	317.2	6	38	1	0.0006	0.981
IGSD	315.2	5	39	1	0.065	0.800
H_2S sediment-water interface	313.3	4	40	1	0.092	0.763
Organic matter	311.5	3	41	1	0.212	0.647

Table 5. Other species collected in the sediment (total number of individuals in 78.5 cm² core sample) on beaches in the Bay of Fundy, Nova Scotia, Canada in 2006 and 2007.

	Yarmouth				*The Joggins*				*Moose River*			
	Spring 2006	*Fall 2006*	*Spring 2007*	*Fall 2007*	*Spring 2006*	*Fall 2006*	*Spring 2007*	*Fall 2007*	*Spring 2006*	*Fall 2006*	*Spring 2007*	*Fall 2007*
Annelida												
Oligochaeta												
Tubificidae (sludge worms)	-	2	-	-	-	-	-	-	-	-	-	-
Polychaeta												
Capitellidae (threadworms)	-	29	-	-	-	27	-	-	-	-	-	-
Glyceridae (bloodworms)	-	-	-	-	1	-	-	-	-	-	-	-
Lumbrineriidae (threadworms)	-	3	-	-	-	11	-	-	-	6	-	-
Maldanidae (bambooworms)	-	-	11	17	-	-	21	7	-	-	17	9
Nepthyidae (shimmyworms)	-	-	3	2	5	-	7	13	8	-	3	3
Nereidae (clamworms)	-	-	1	-	-	1	-	-	-	-	1	11
Opheliidae (sandbar worms)	-	1	-	-	-	-	-	-	-	1	-	-
Orbiniidae	-	-	-	-	-	-	-	-	-	4	-	2
Phyllodocidae (paddleworms)	-	-	-	2	-	-	-	-	-	-	-	2
Arthropoda												
Crustacea												
Cancridae (crabs)	-	-	-	-	-	-	-	-	-	-	1	-
Gammaridae (amphipods)	-	37	-	2	-	-	2	1	-	25	27	33
Mollusca												
Bivalvia												
Tellinidae (macomas)	2	1	-	1	-	-	-	-	9	14	25	4
Gastropoda												
Buccinidae (whelks)	-	-	-	-	-	-	-	-	-	1	-	-
Calyptraeidae (slipper shells)	-	-	-	-	1	-	-	-	-	-	-	-
Hydrobiidae (swamp snails)	-	1	-	-	-	-	-	60	-	-	-	-
Littorinidae (periwinkles)	-	15	2	4	8	4	-	-	-	29	1	2
Naticidae (moon snails)	-	3	-	-	-	-	-	-	-	-	-	-

Table 6. Other species collected in the sediment (total number of individuals in 78.5 cm² core sample) on beaches in the Bay of Fundy, Nova Scotia, Canada in 2006 and 2007.

	Upper Clements				*Five Islands*				*St. Mary's Bay*			
	Spring 2006	*Fall 2006*	*Spring 2007*	*Fall 2006*	*Spring 2006*	*Fall 2006*	*Spring 2007*	*Fall 2007*	*Spring 2006*	*Fall 2006*	*Spring 2007*	*Fall 2007*
Annelida												
Polychaeta												
Capitellidae (threadworms)	-	2	-	-	-	-	-	-	-	23	-	-
Glyceridae (bloodworms)	-	-	-	-	-	-	-	-	1	-	-	-
Lumbrineriidae (threadworms)	-	4	-	-	1	1	-	-	-	2	-	-
Maldanidae (bambooworms)	-	-	3	5	-	-	-	1	3	-	2	-
Nepthyidae (shimmyworms)	1	-	3	4	-	-	1	2	5	-	-	-
Nereidae (clamworms)	-	-	-	-	-	-	-	2	-	-	-	-
Orbiniidae	-	-	-	-	-	-	-	1	-	-	-	2
Phyllodocidae (paddleworms)	-	-	-	1	-	-	1	1	-	-	-	-
Pectinariidae (trumpetworm)	-	-	-	-	-	-	-	-	-	-	-	1
Arthropoda												
Crustacea												
Cancridae (crabs)	-	-	-	-	-	-	-	-	-	2	-	-
Crangonidae (crangon shrimps)	-	-	-	6	-	-	-	-	-		-	-
Gammaridae (amphipods)	-	-	-	-	-	-	-	55	-	-	4	8
Portunidae (green crab)	-	-	-		-	-	-	-	-	12	-	-
Xanthidae (mud crab)	-	-	-	-	-	1	-	-	-	-	-	-
Mollusca												
Bivalvia												
Tellinidae (macoma)	10	44	19	18	252	83	61	85	-	1	-	-
Gastropoda												
Buccinidae (whelks)	-	-	-	-	-	-	-	-	-	-	-	1
Columbellidae (dovesnails)	-	-	-	-	-	-	-	-	-	1	2	3
Hydrobiidae (swamp snails)	-	7	-	-	-	-	-	-	-	2	2	3
Lepetidae (limpets)	-	1	-	-	-	-	-	-	-	-	-	-
Littorina (periwinkles)	7	81	2	1	8	4	1	-	-	16	-	-
Nassariidae (dog whelks)	-	5	-	-	1	-	-	-	3	128	-	-
Pyramidellidae (pyramid snails)	-	-	-	-	-	-	-	-	-	1	-	-
Nemertea												
Anopla												
Lineidae (ribbon worms)	-	-	-	-	-	-	-	-	1	3	-	-

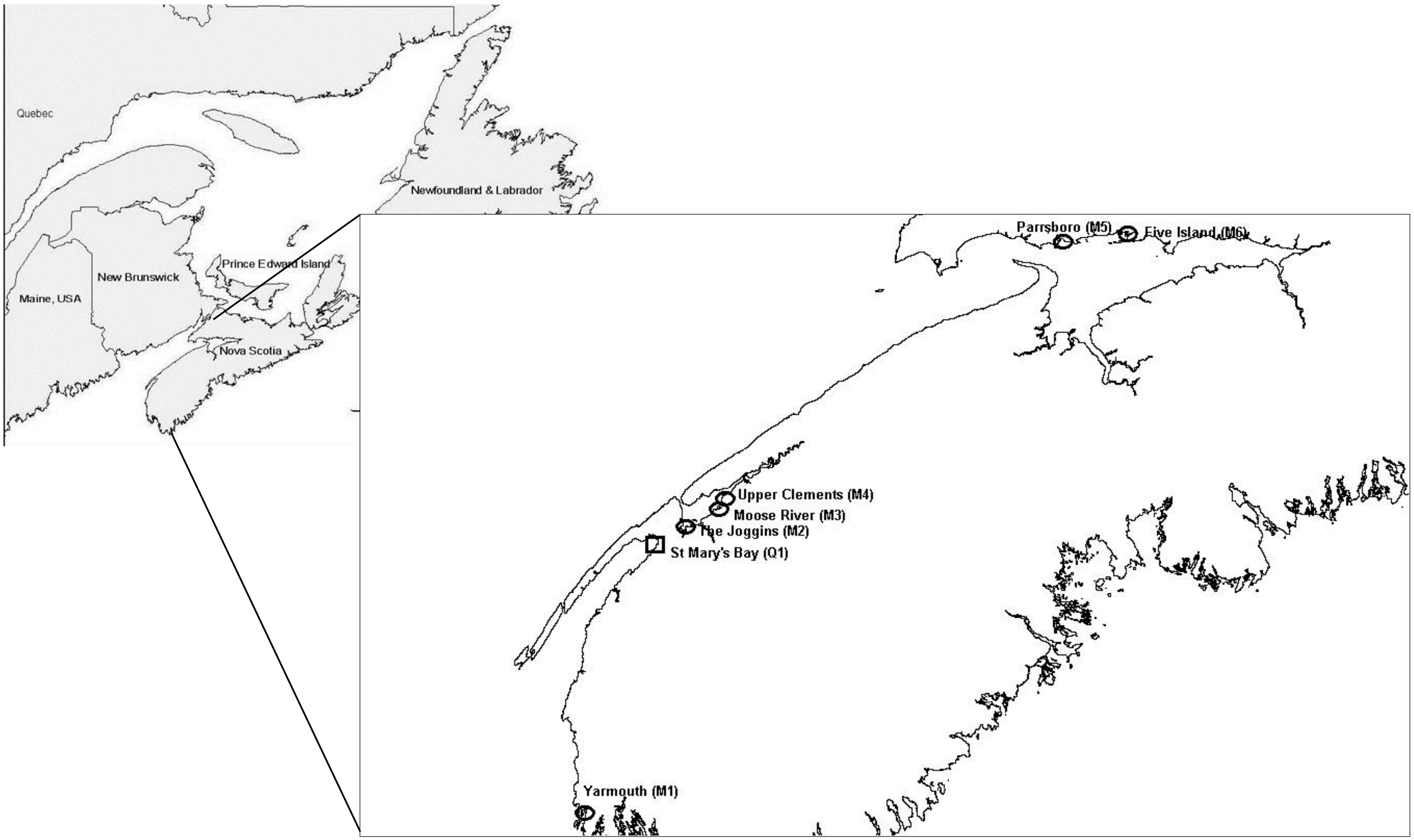

Figure 1. Location of beaches sampled in the Bay of Fundy, Nova Scotia, Canada from 2005 to 2007

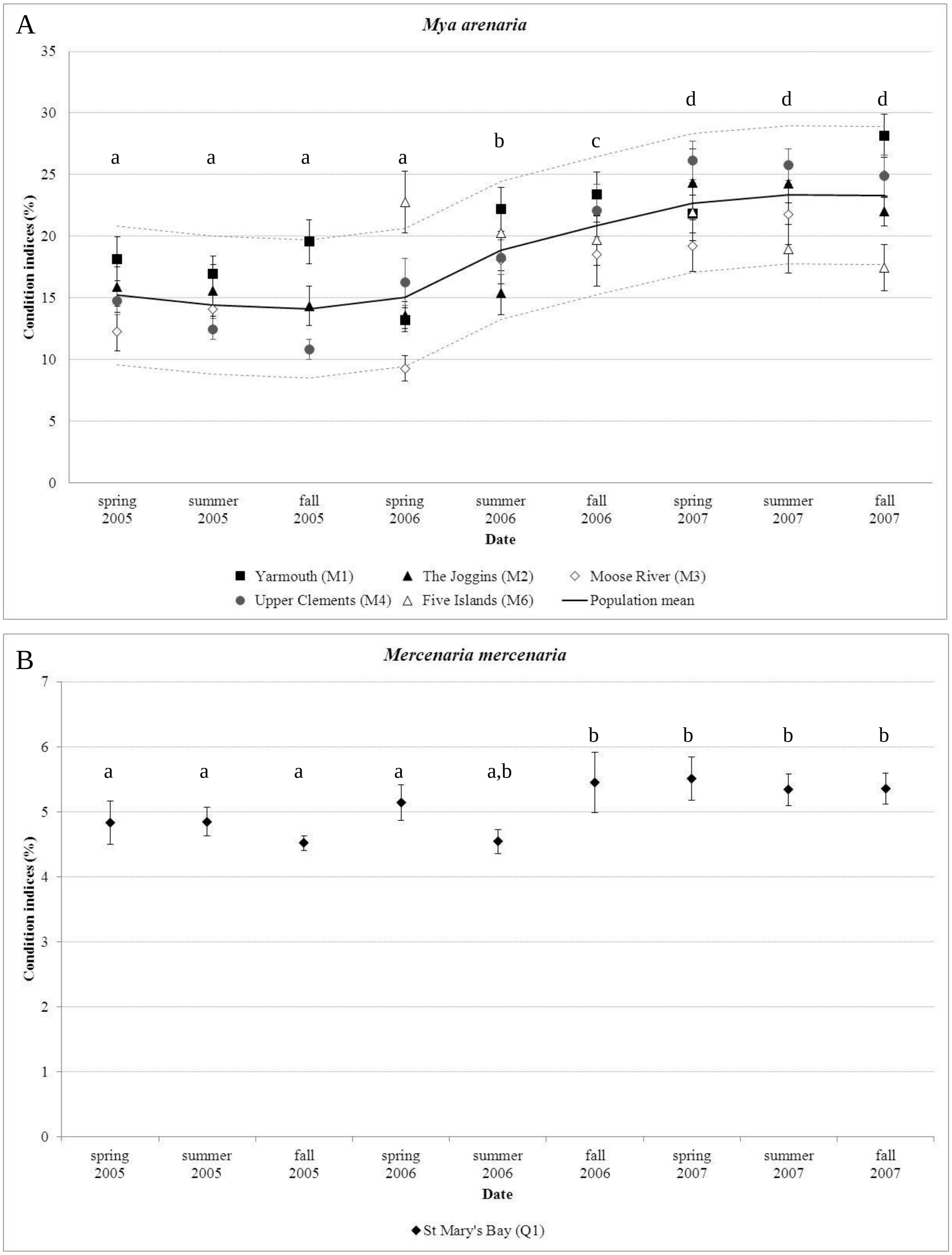

Figure 2. Mean condition indices (%) of soft-shell clams (A) and quahogs (B) collected in Nova Scotia between 2005 and 2007 (n=30). Error bars represent 95% confidence intervals. The dark line in A is the mean of all beaches while the dotted lines represent the 95% confidence intervals of the mean of all beaches. Small letters indicate which dates are similar.

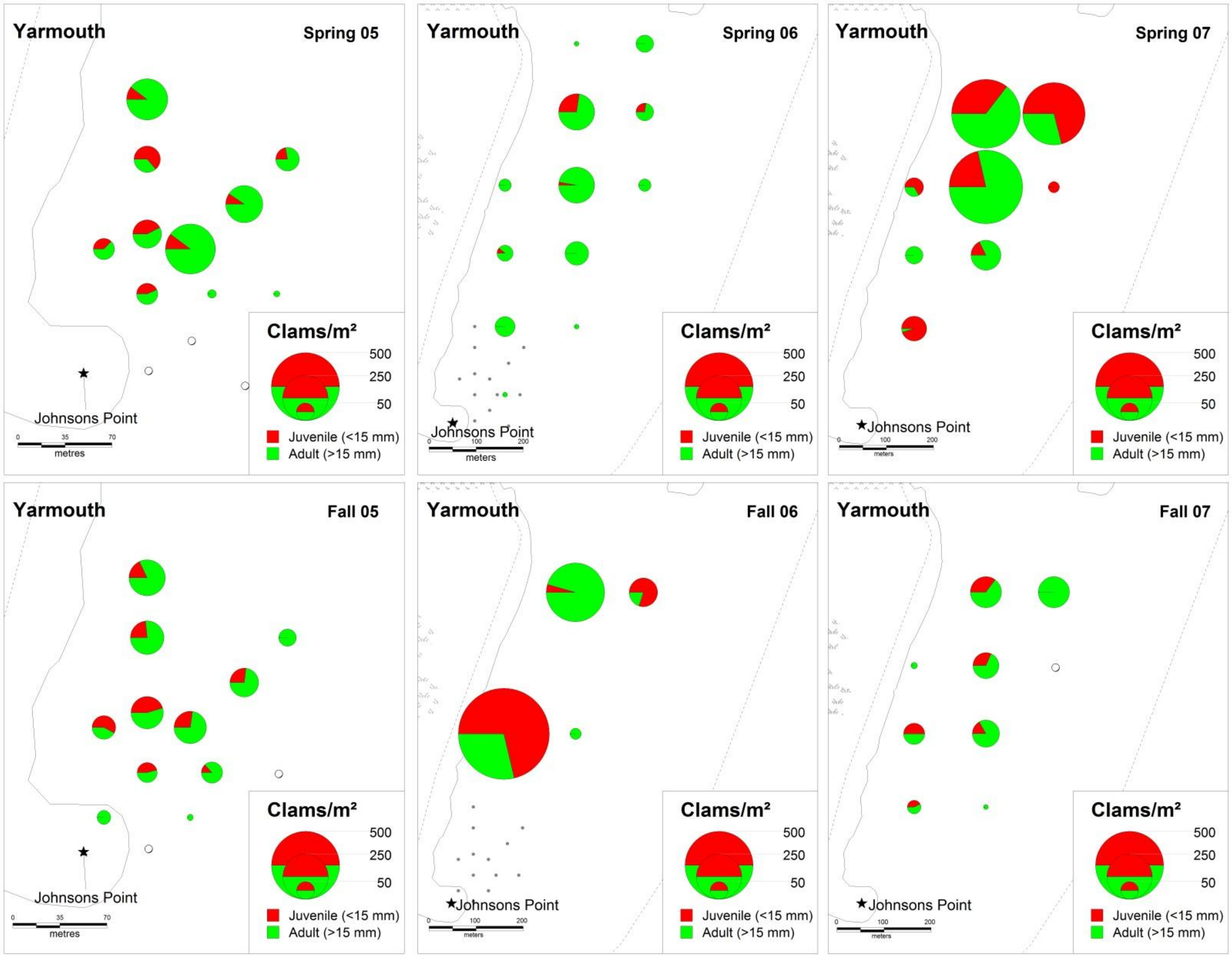

Figure 3. Distribution of soft-shell clams collected in Yarmouth (M1), Nova Scotia, Canada, between 2005 and 2007. The open circles indicate stations where no clams were found. The grey circles in the 2006 figures are the locations of the sampling stations in 2005.

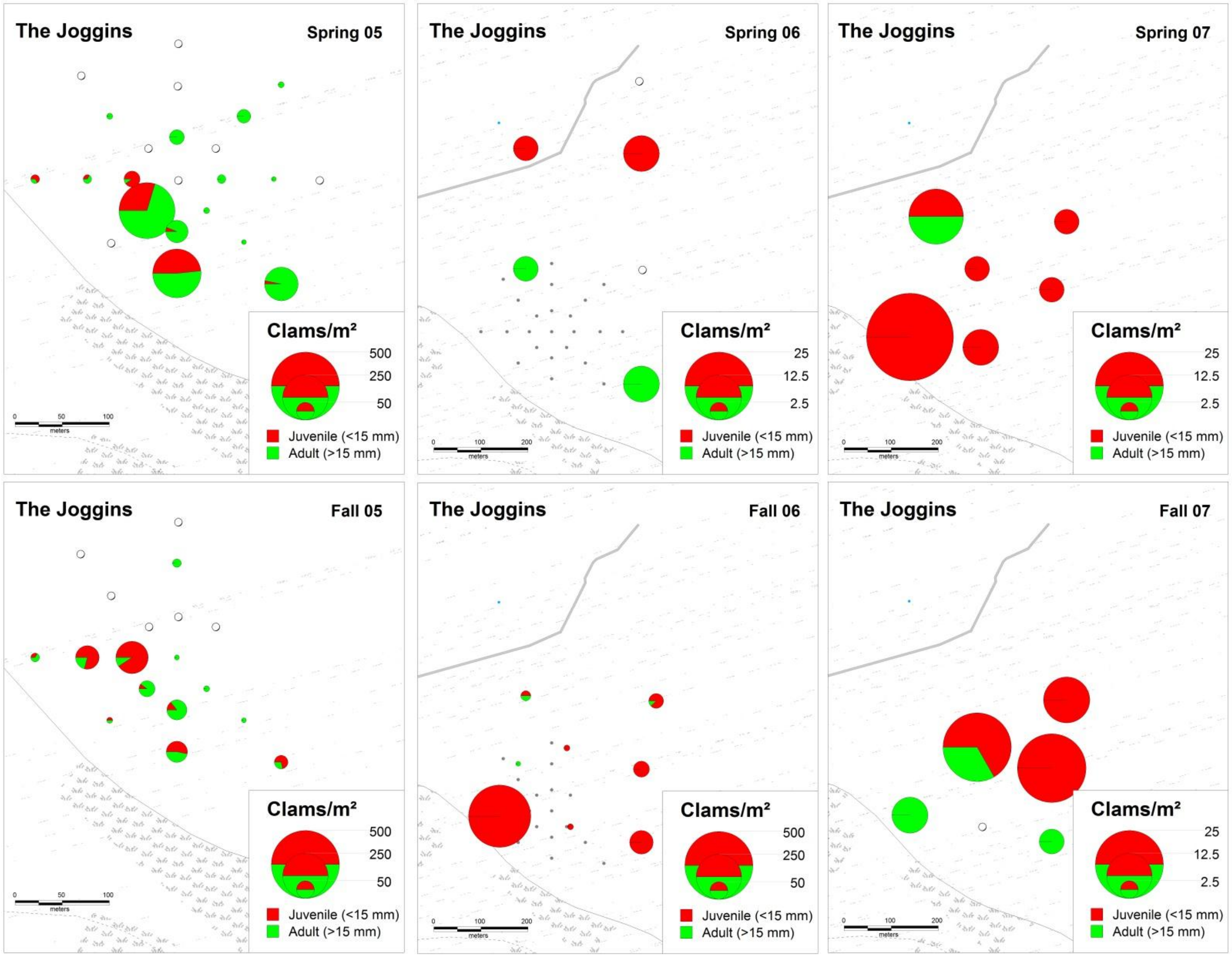

Figure 4. Distribution of soft-shell clams collected in The Joggins (M2), Nova Scotia, Canada, between 2005 and 2007. The open circles indicate stations where no clams were found. The grey circles in the 2006 figures are the locations of the sampling stations in 2005.

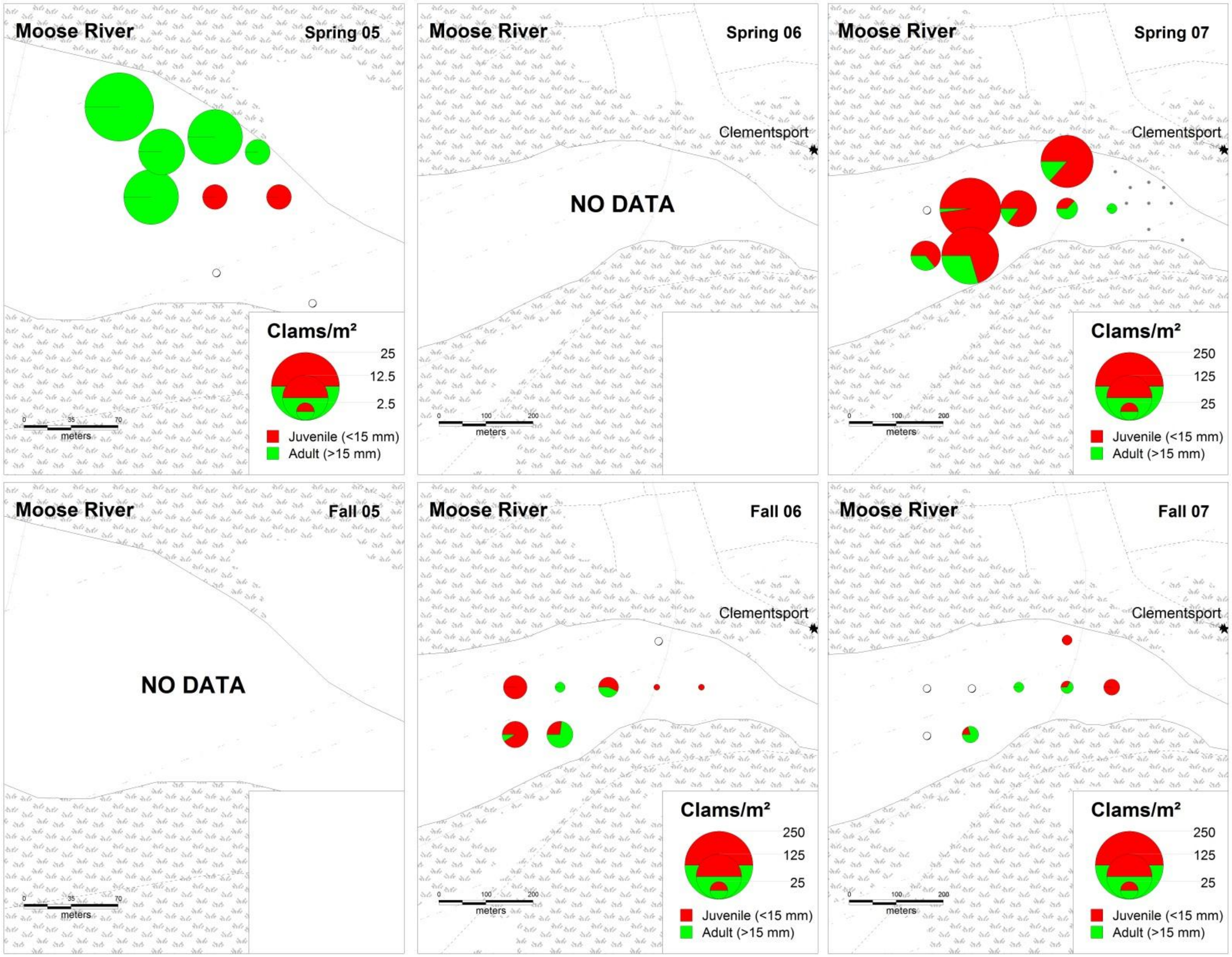

Figure 5. Distribution of soft-shell clams collected in Moose River (M3), Nova Scotia, Canada between 2005 and 2007. The open circles indicate stations where no clams were found. The grey circles in the 2007 figure are the locations of the sampling stations in 2005.

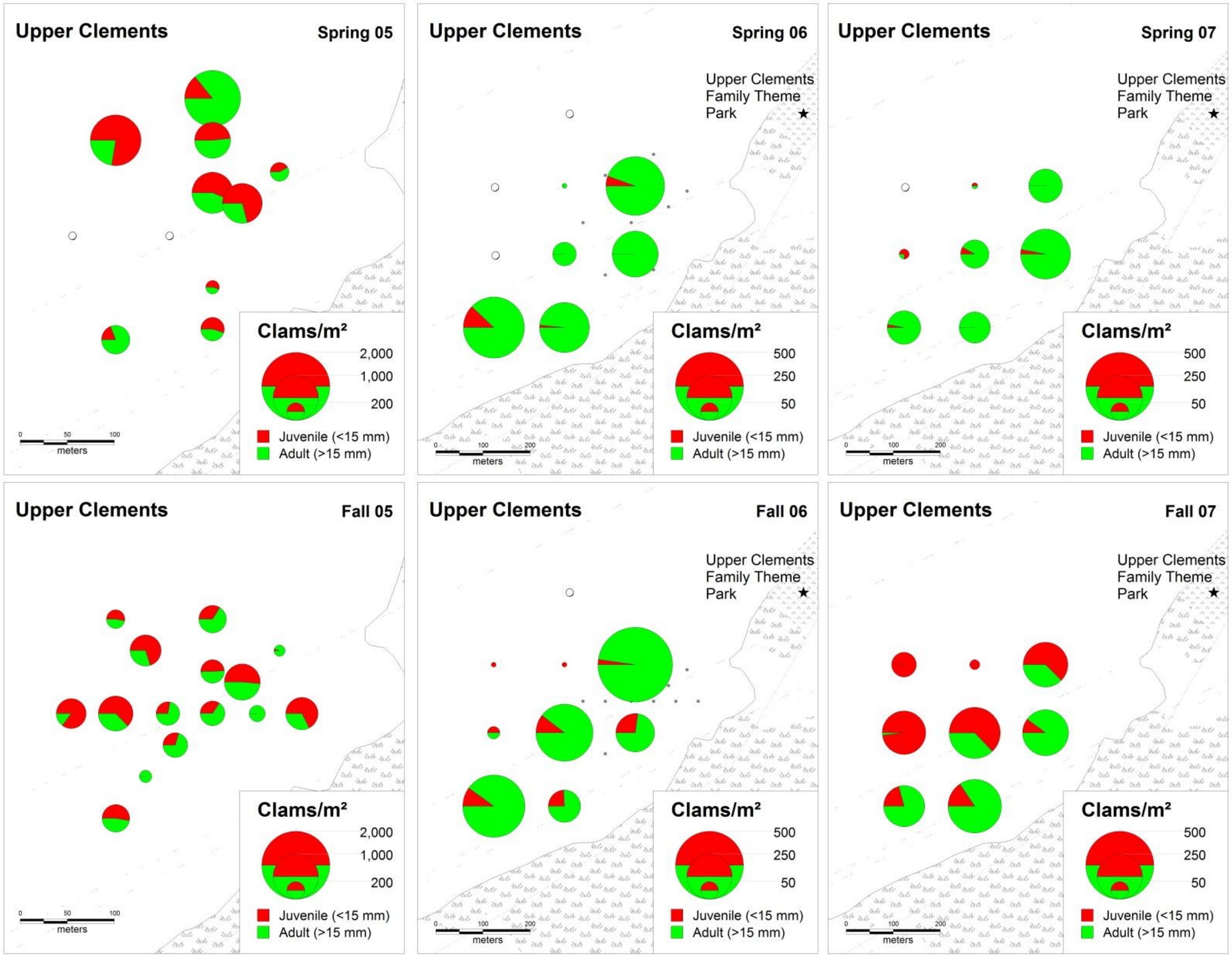

Figure 6. Distribution of soft-shell clams collected in Upper Clements (M4), Nova Scotia, Canada, between 2005 and 2007. The open circles indicate stations where no clams were found. The grey circles in the 2006 figures are the locations of the sampling stations in 2005.

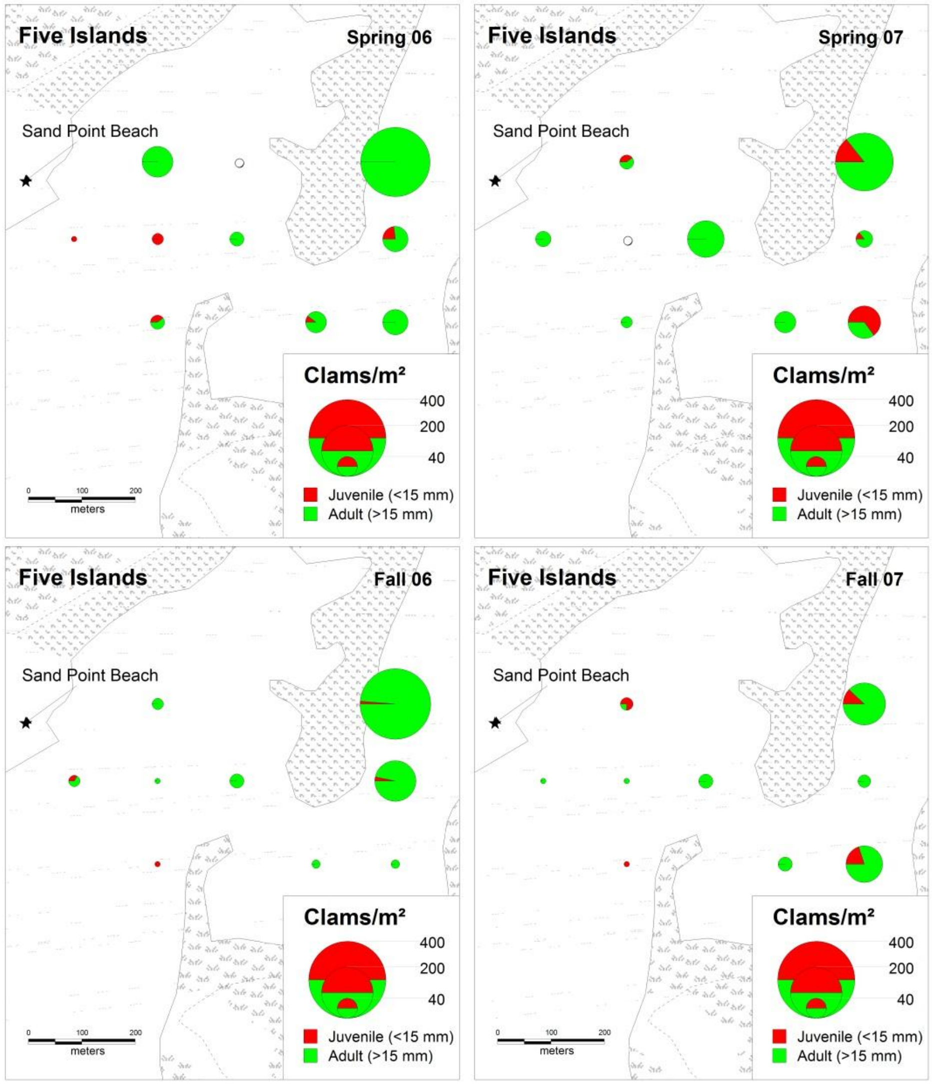

Figure 7. Distribution of soft-shell clams collected in Five Islands, Nova Scotia, Canada, between 2006 and 2007. The open circles indicate stations were no clams were found.

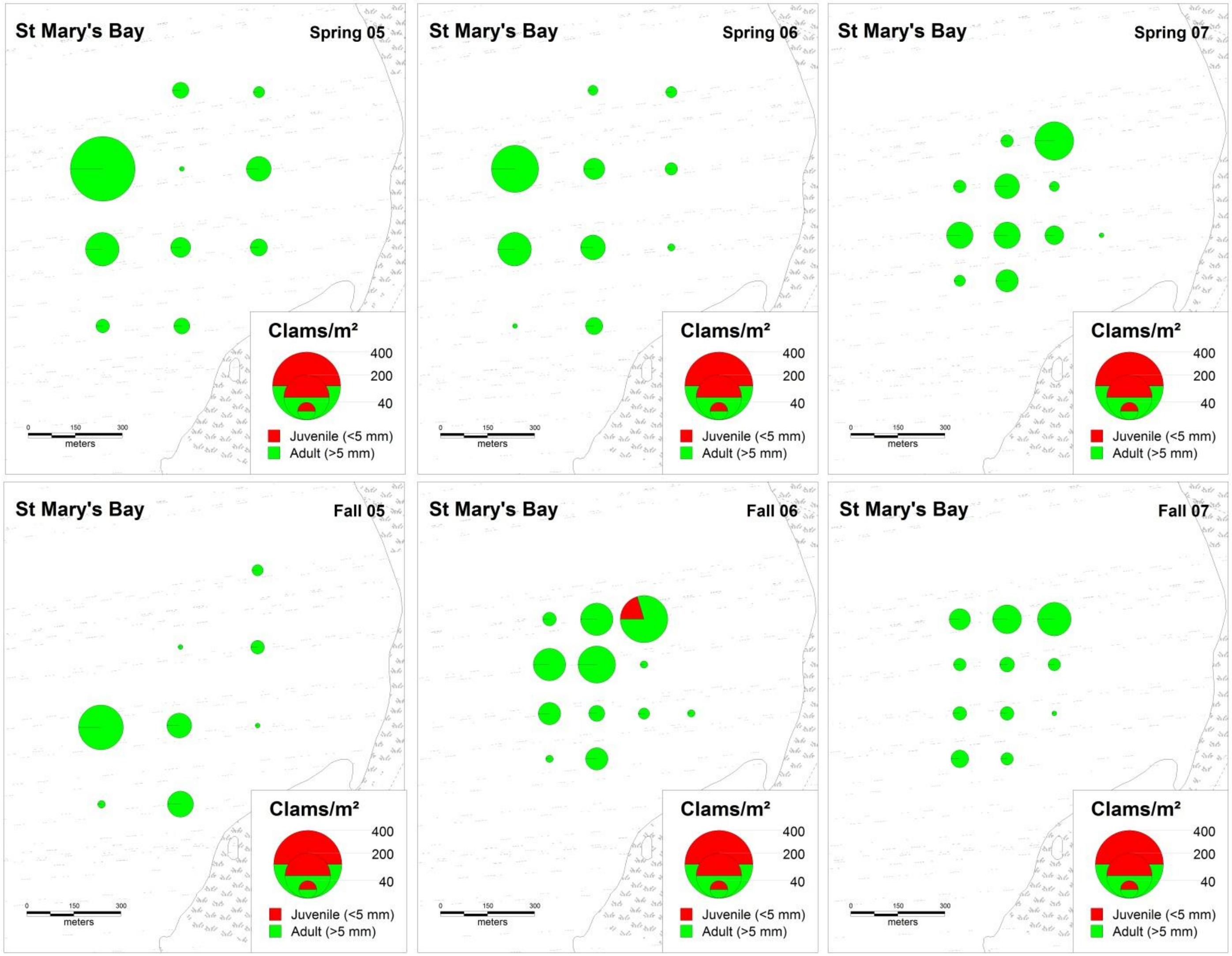

Figure 8. Distribution of quahog clams collected in St Mary's Bay (Q1), Nova Scotia, Canada, between 2005 and 2007. The open circles indicate stations where no clams were found.

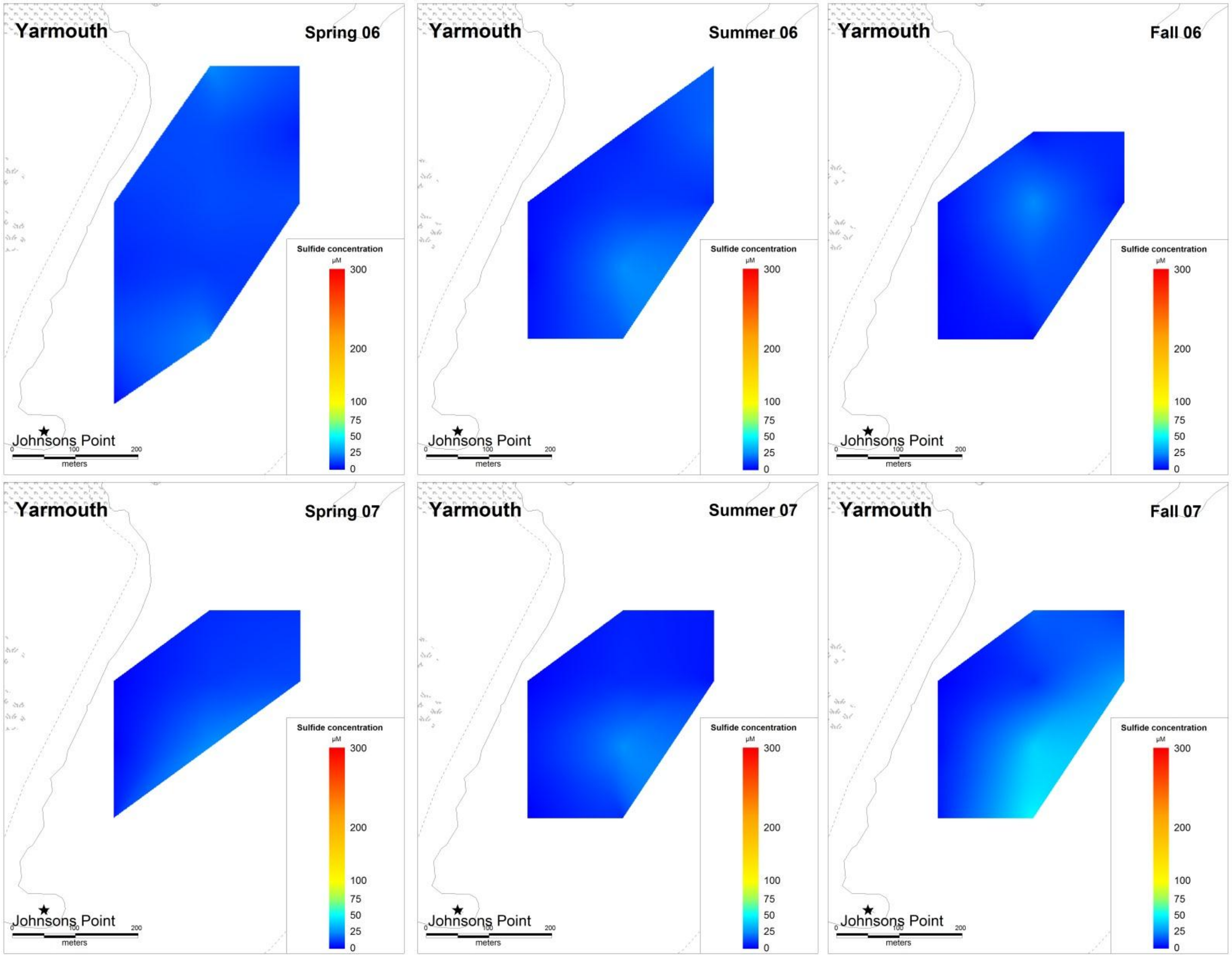

Figure 9. Sediment sulfide concentrations at the sediment-water interface in Yarmouth (M1), Nova Scotia, Canada, in 2006 and 2007.

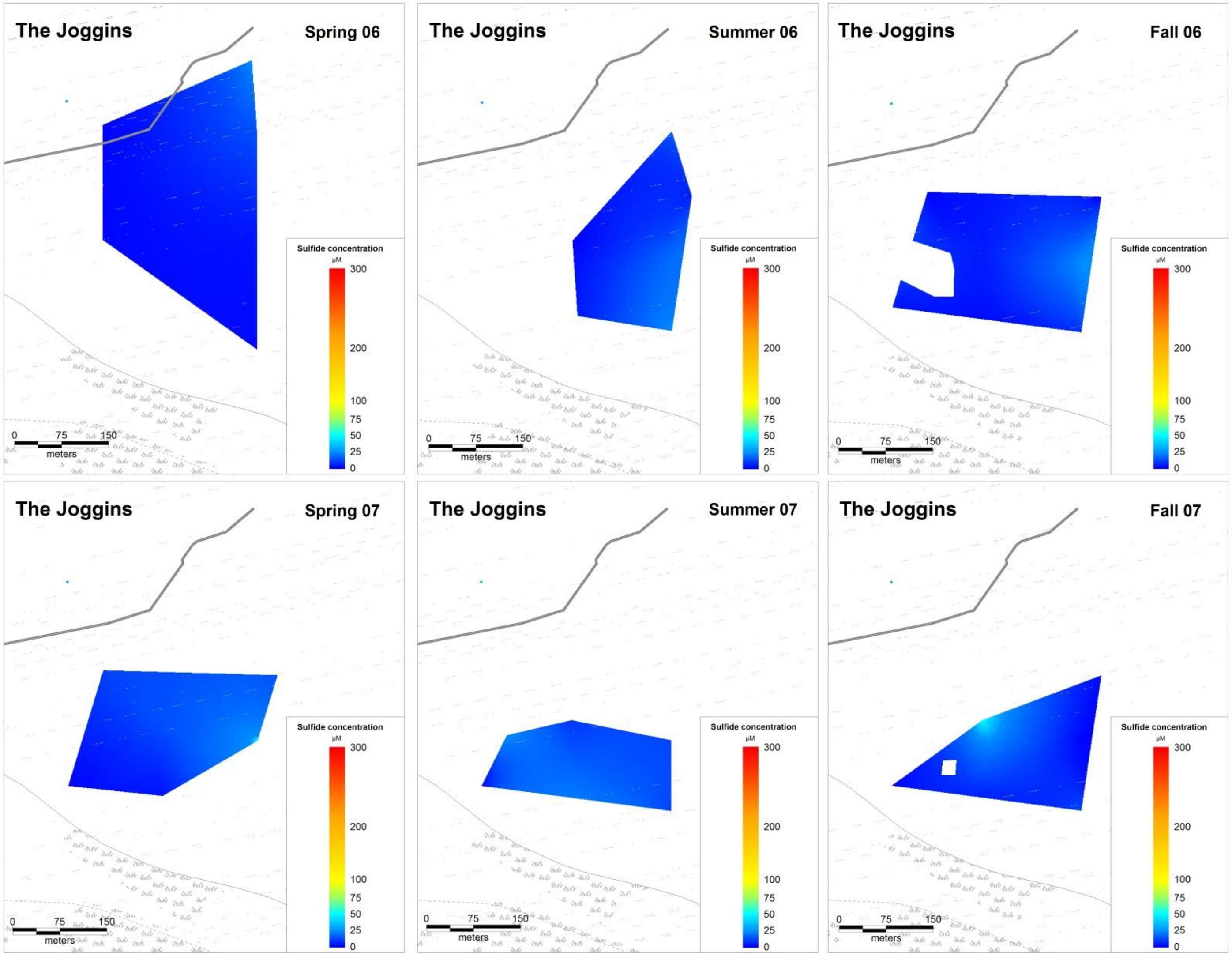

Figure 10. Sediment sulfide concentrations at the sediment-water interface in The Joggins (M2), Nova Scotia, Canada, in 2006 and 2007.

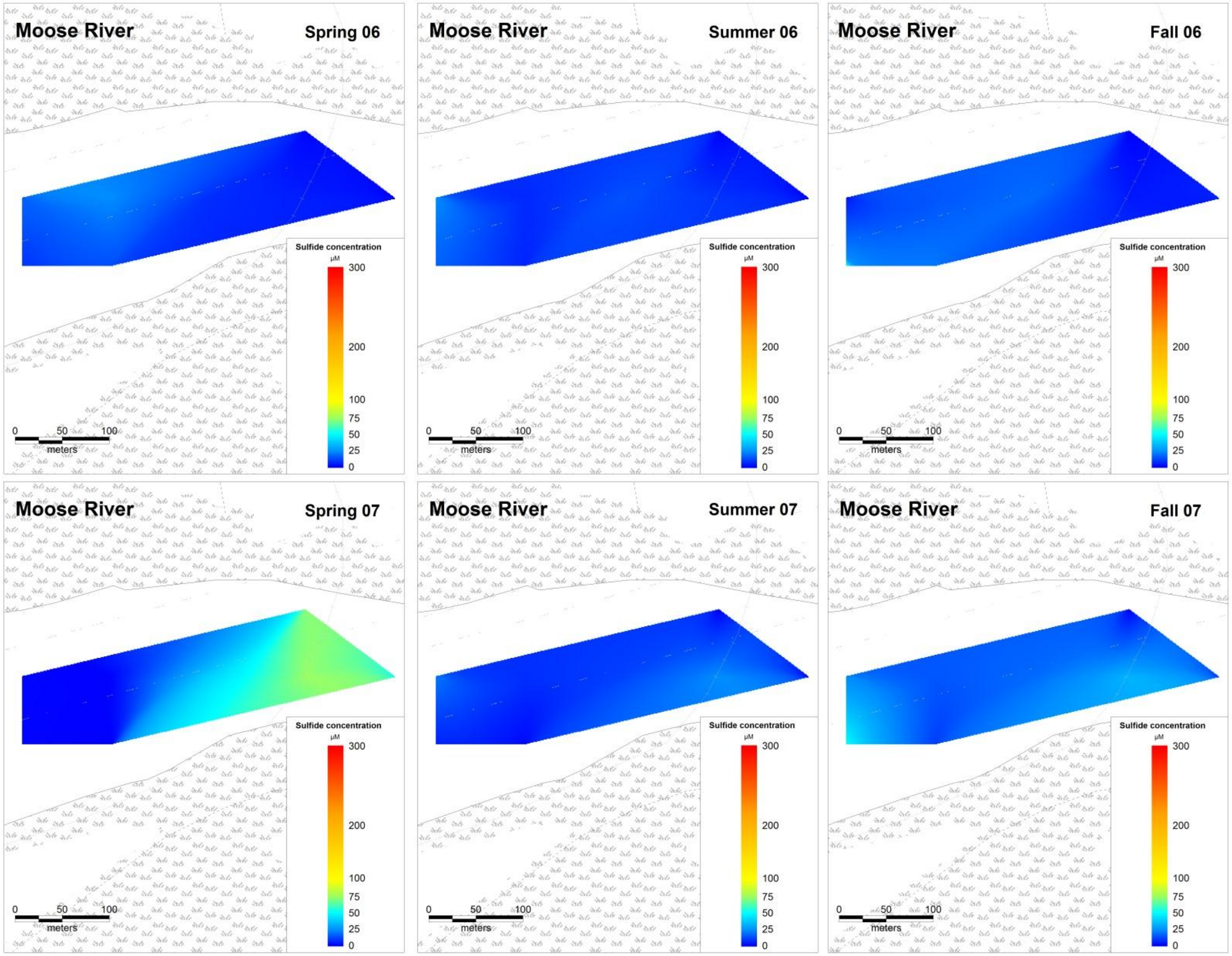

Figure 11. Sediment sulfide concentrations at the sediment-water interface in Moose River (M3), Nova Scotia, Canada, in 2006 and 2007.

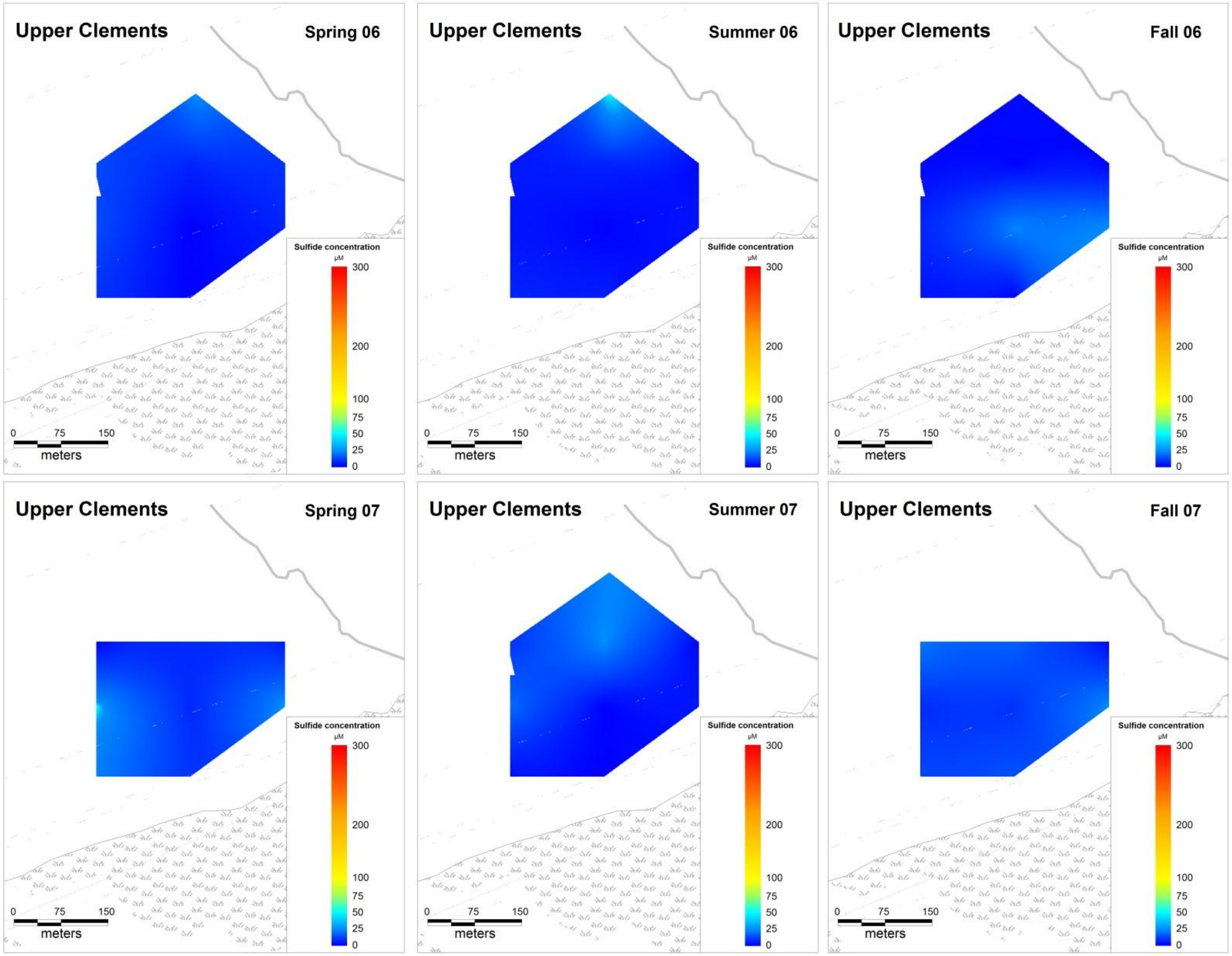

Figure 12. Sediment sulfide concentrations at the sediment-water interface in Upper Clements (M4), Nova Scotia, Canada, in 2006 and 2007.

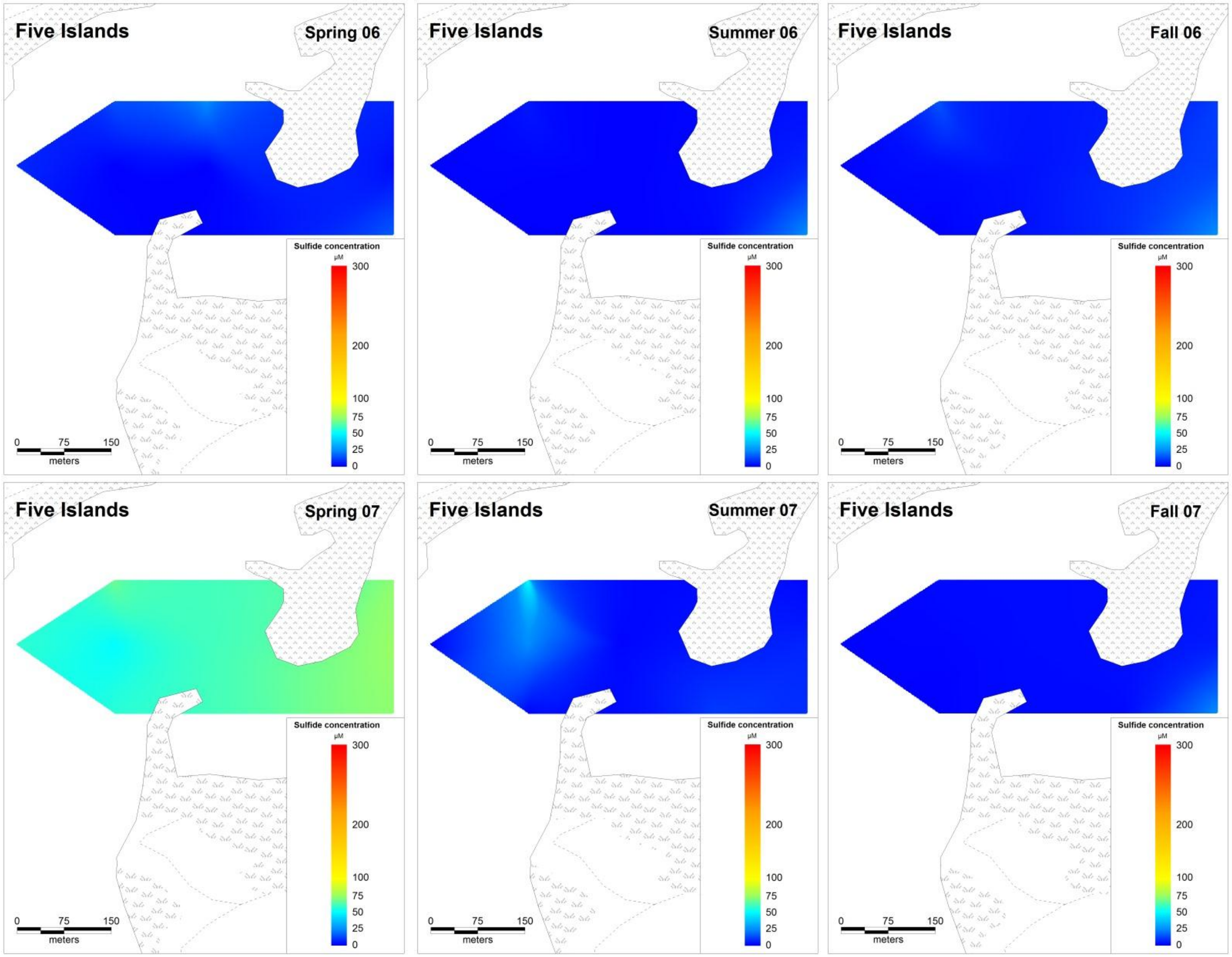

Figure 13. Sediment sulfide concentrations at the sediment-water interface in Five Islands (M6), Nova Scotia, Canada, in 2006 and 2007.

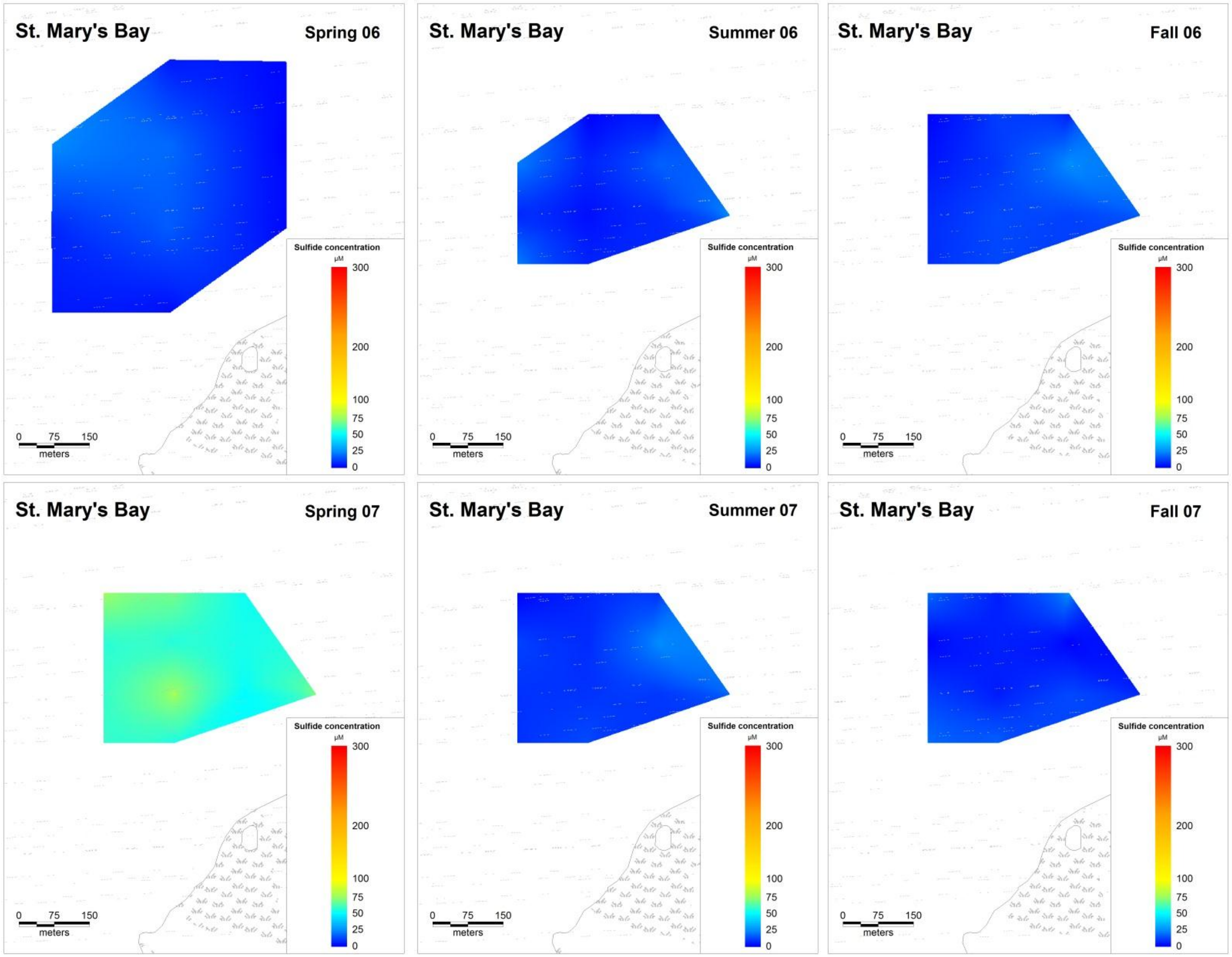

Figure 14. Sediment sulfide concentrations at the sediment-water interface in St. Mary’s Bay (Q1), Nova Scotia, Canada, in 2006 and 2007.

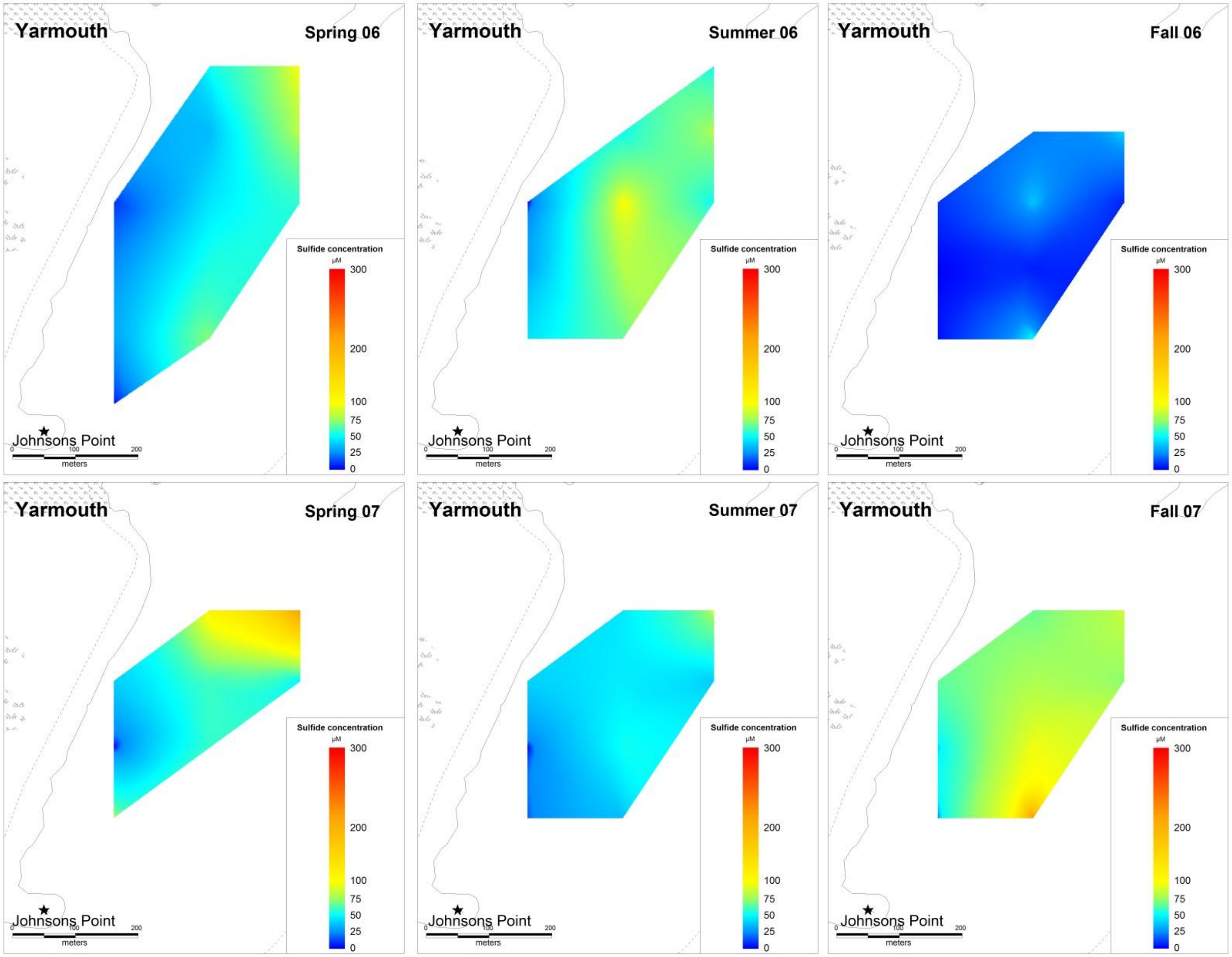

Figure 15. Sediment sulfide concentrations at a depth of 6-cm in Yarmouth (M1), Nova Scotia, Canada, in 2006 and 2007.

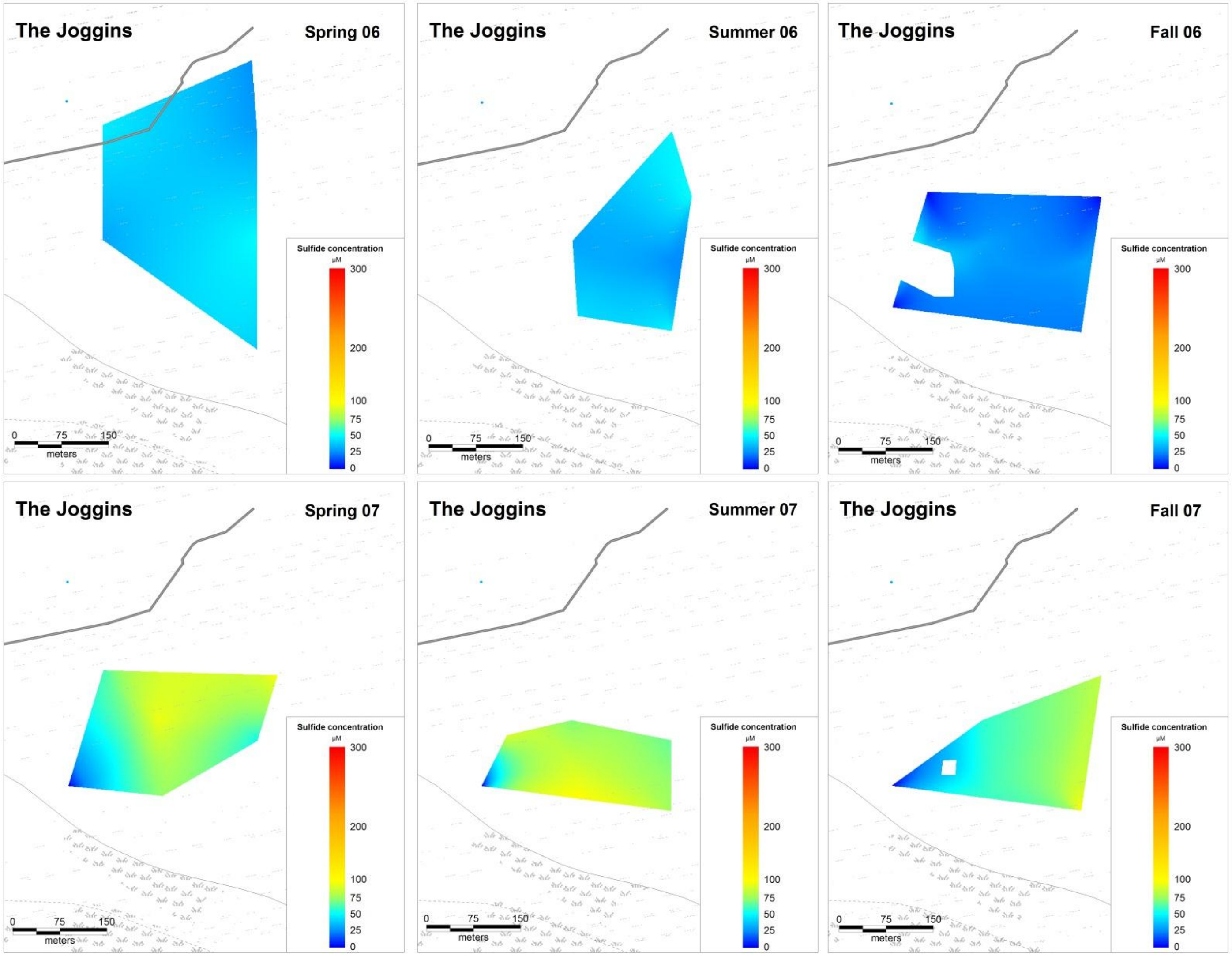

Figure 16. Sediment sulfide concentrations at a depth of 6-cm in The Joggins (M2), Nova Scotia, Canada, in 2006 and 2007.

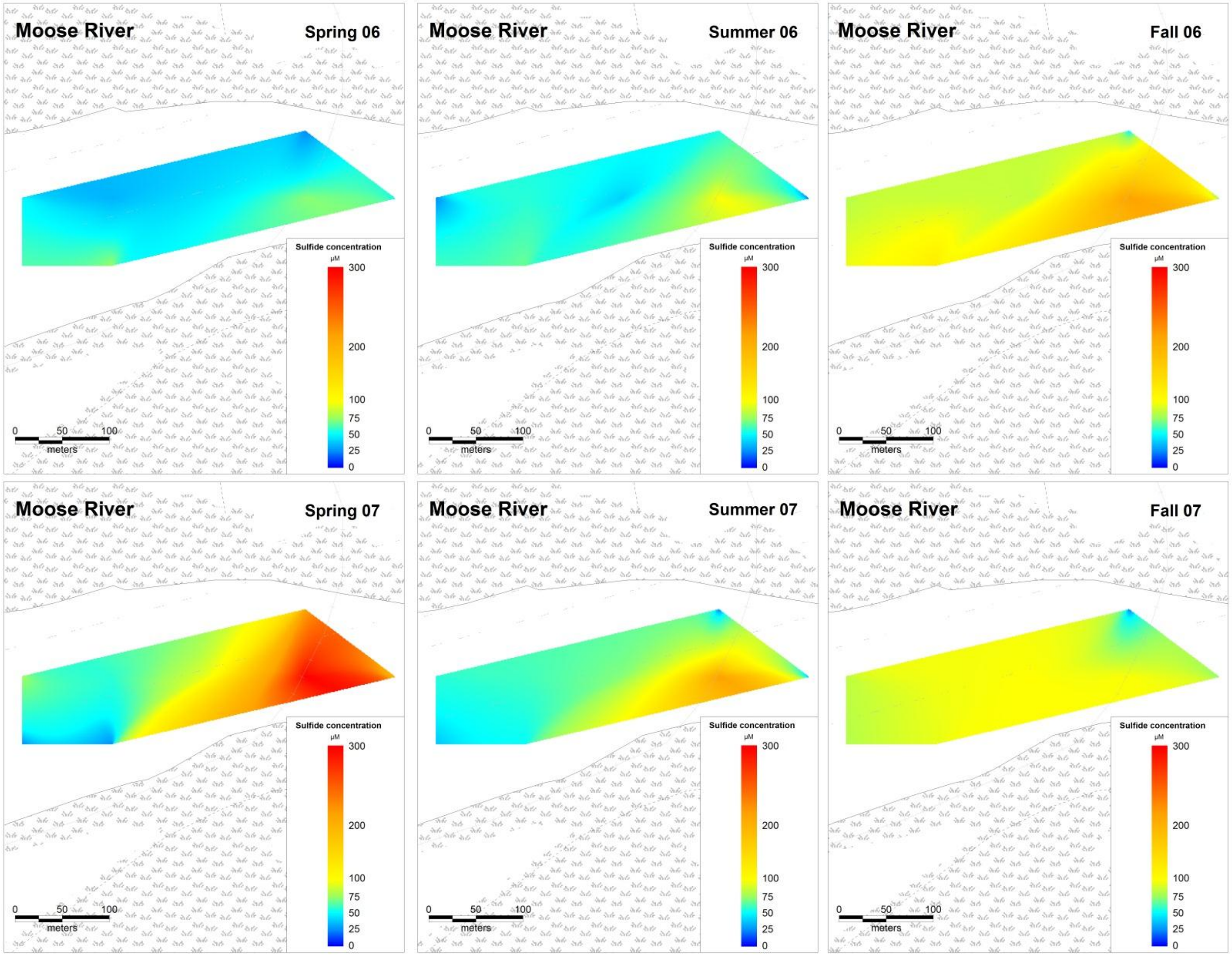

Figure 17. Sediment sulfide concentrations at a depth of 6-cm in Moose River (M3), Nova Scotia, Canada, in 2006 and 2007.

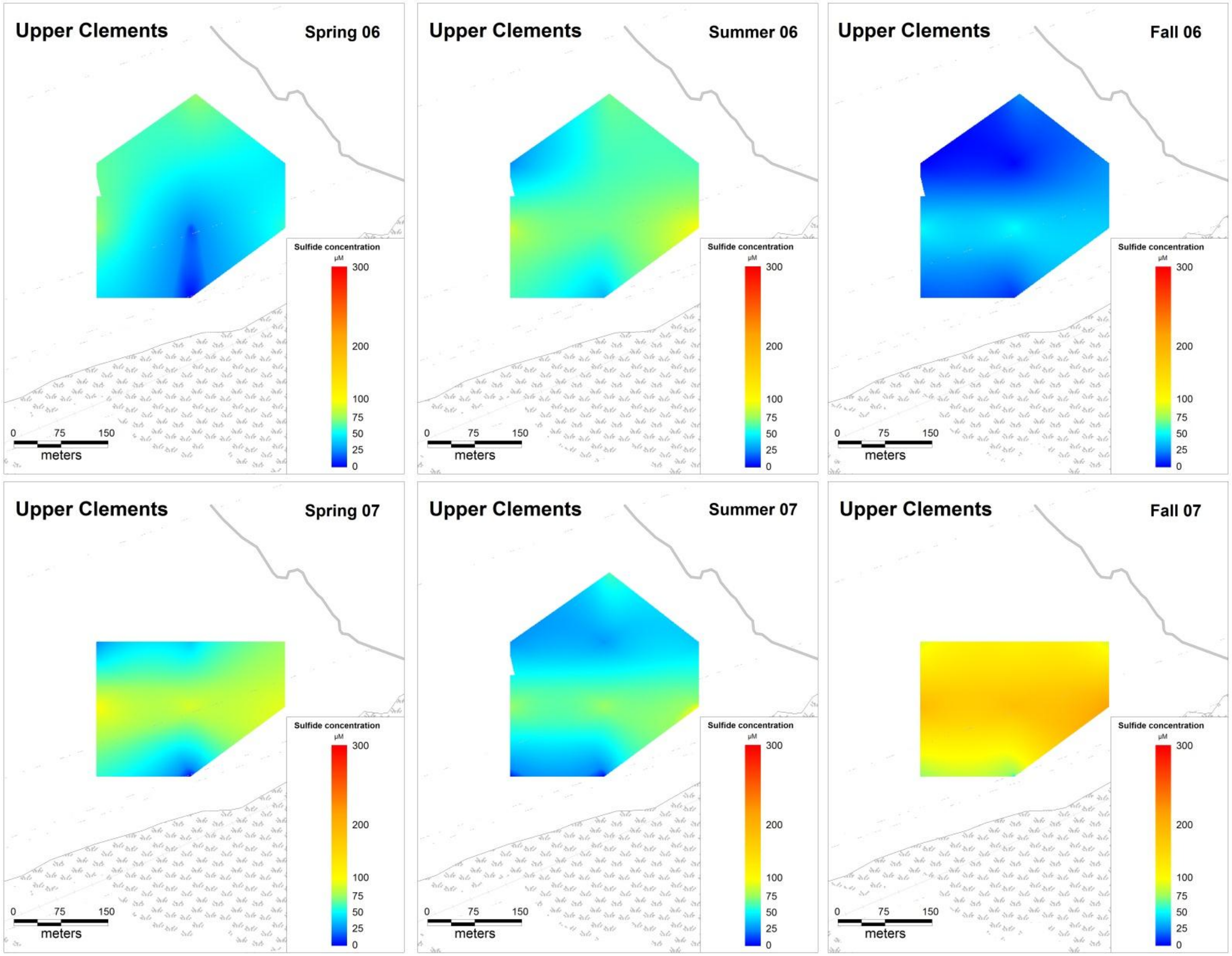

Figure 18. Sediment sulfide concentrations at a depth of 6-cm in Upper Clements (M4), Nova Scotia, Canada, in 2006 and 2007.

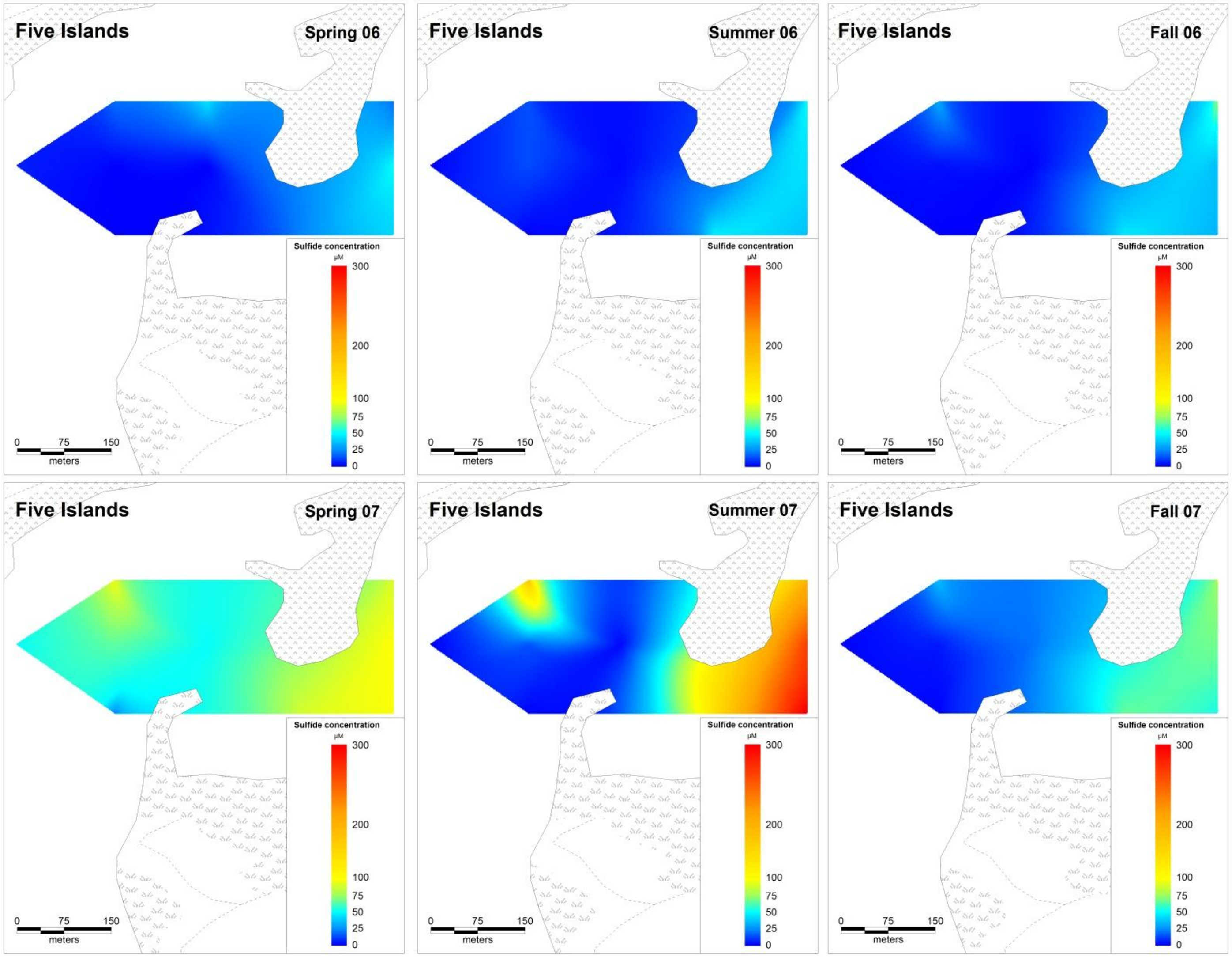

Figure 19. Sediment sulfide concentrations at a depth of 6-cm in Five Islands (M6), Nova Scotia, Canada, in 2006 and 2007.

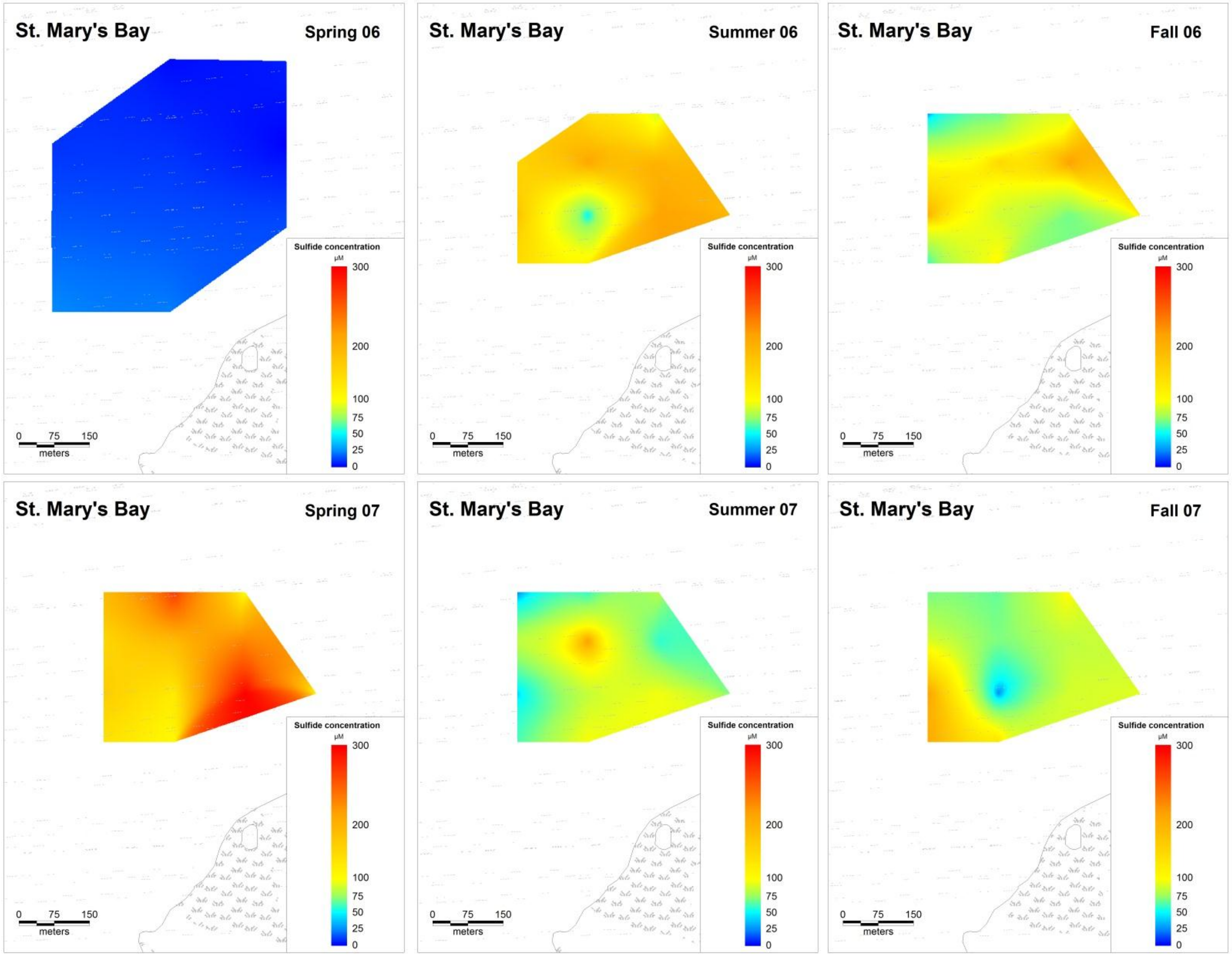

Figure 20. Sediment sulfide concentrations at a depth of 6-cm in St. Mary's Bay (Q1), Nova Scotia, Canada, in 2006 and 2007.

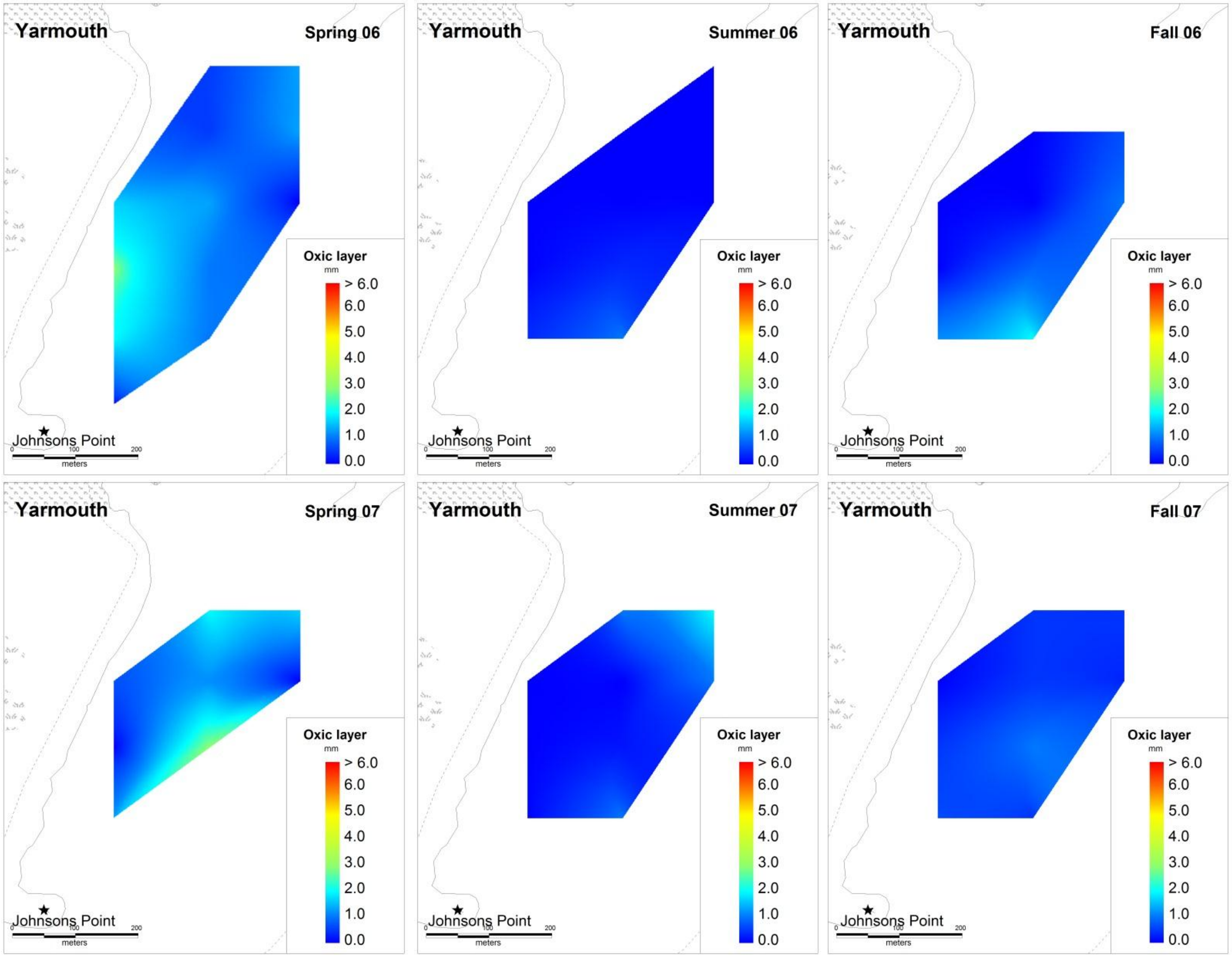

Figure 21. Depth of the oxic layer in Yarmouth (M1), Nova Scotia, Canada, in 2006 and 2007.

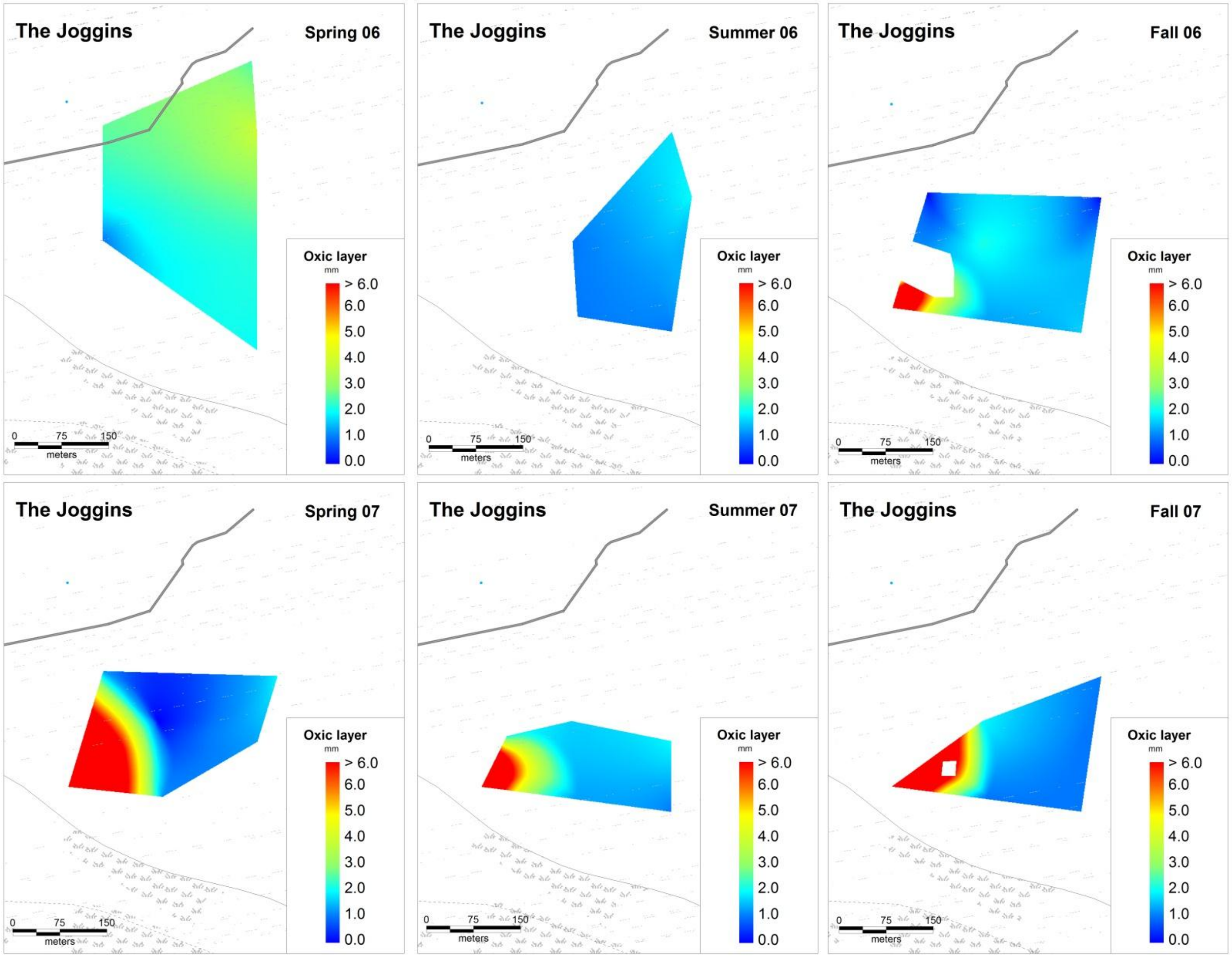

Figure 22. Depth of the oxic layer in The Joggins (M2), Nova Scotia, Canada, in 2006 and 2007.

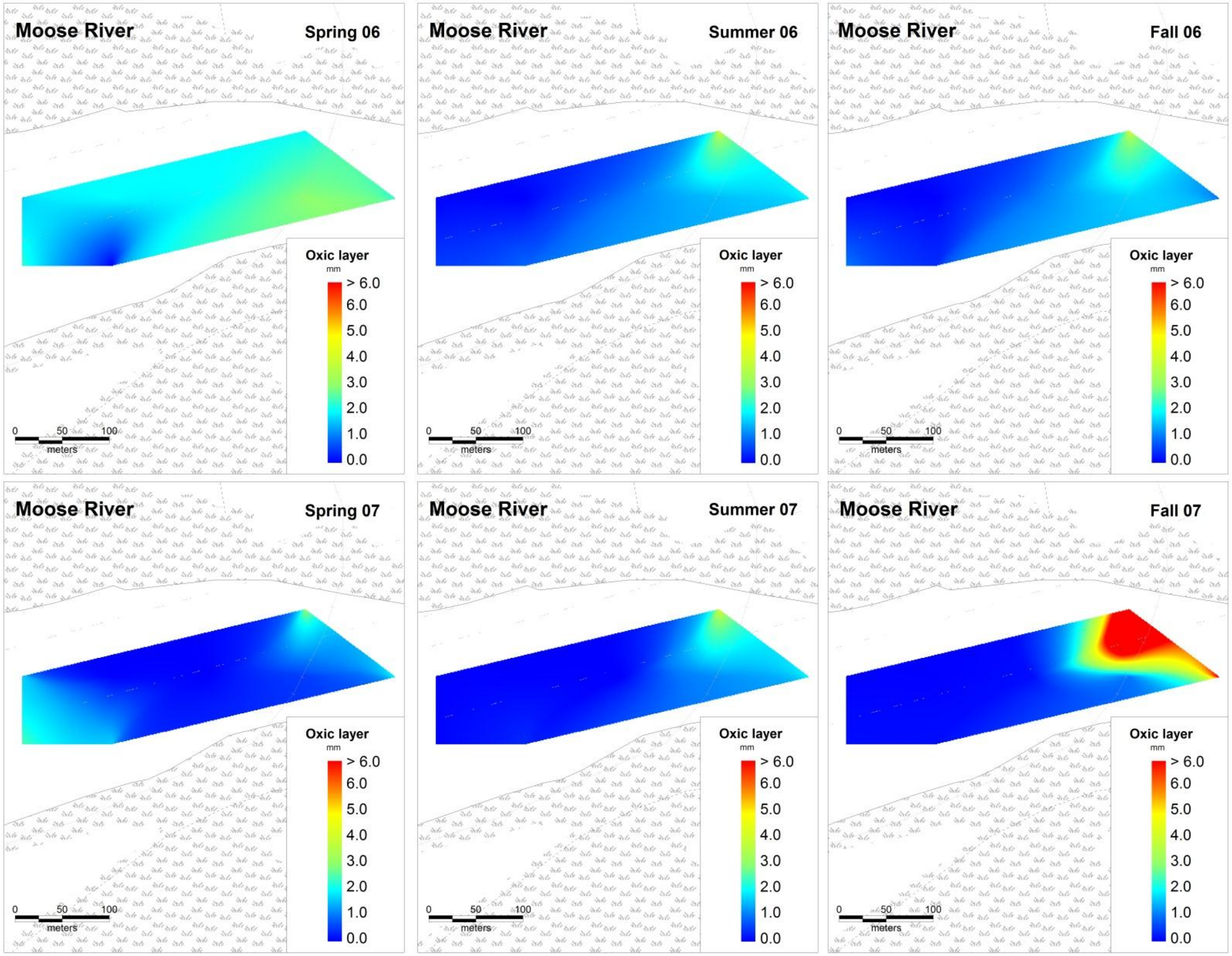

Figure 23. Depth of the oxic layer in Moose River (M3), Nova Scotia, Canada, in 2006 and 2007.

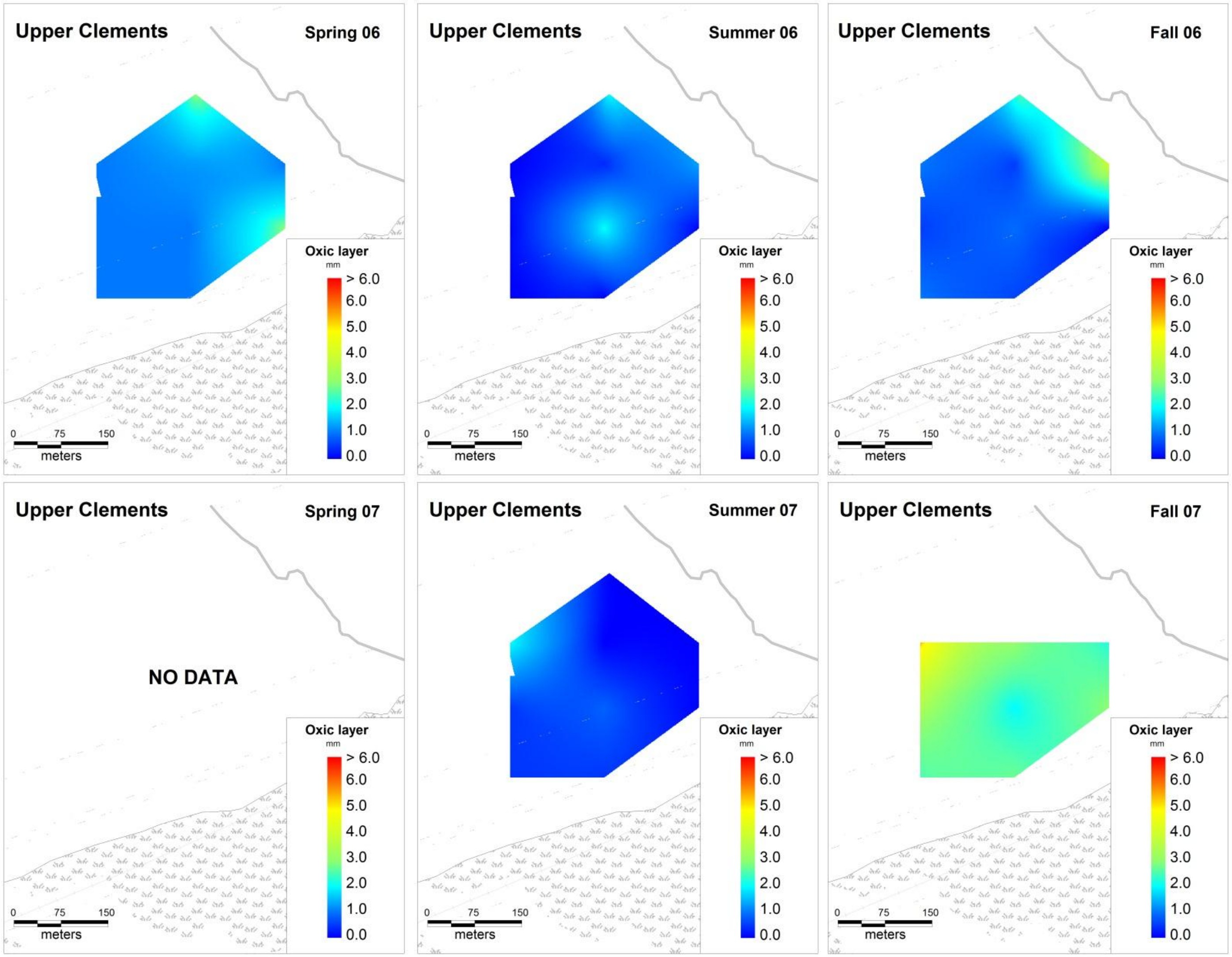

Figure 24. Depth of the oxic layer in Upper Clements (M4), Nova Scotia, Canada, in 2006 and 2007.

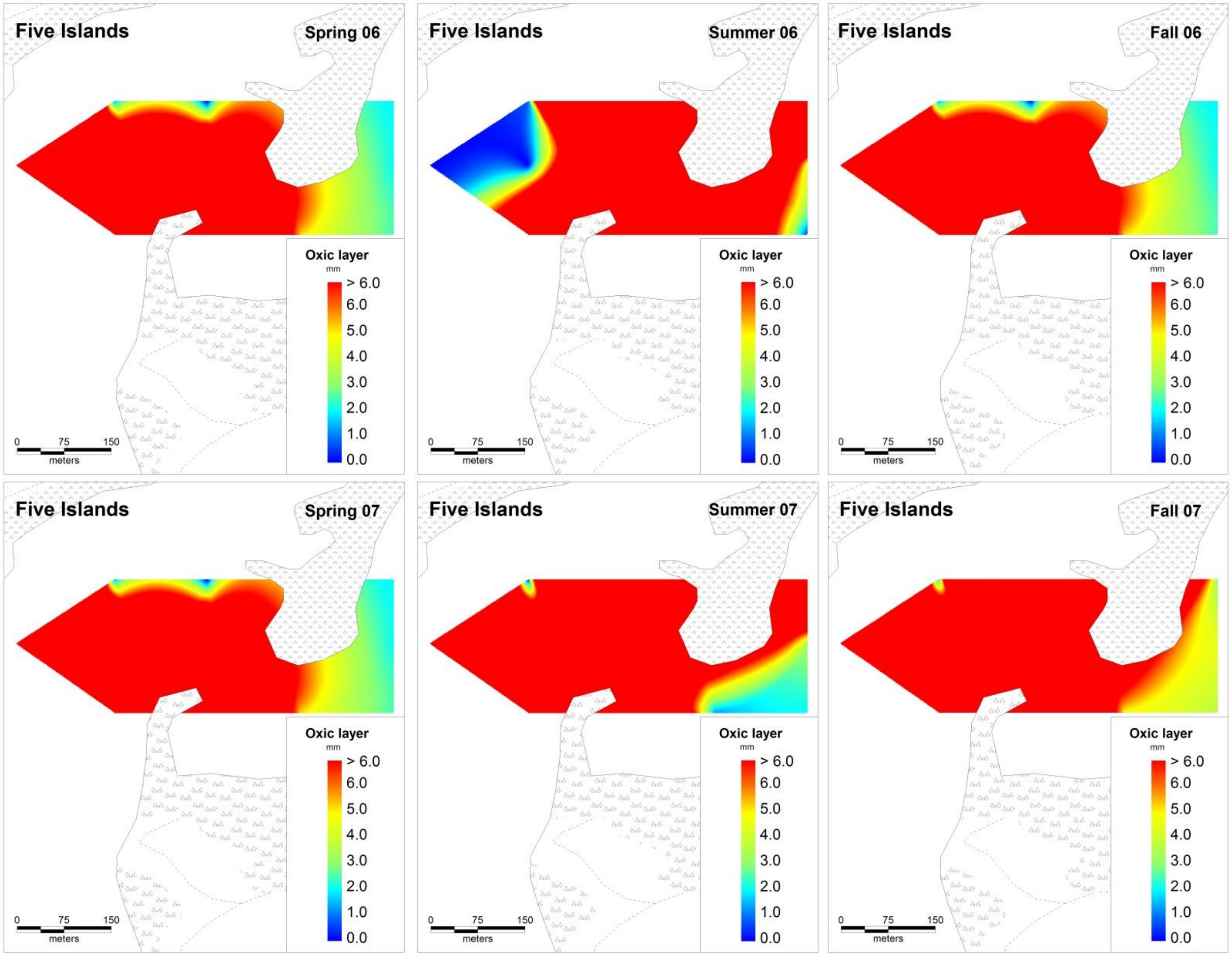

Figure 25. Depth of the oxic layer in Five Islands (M6), Nova Scotia, Canada, in 2006 and 2007.

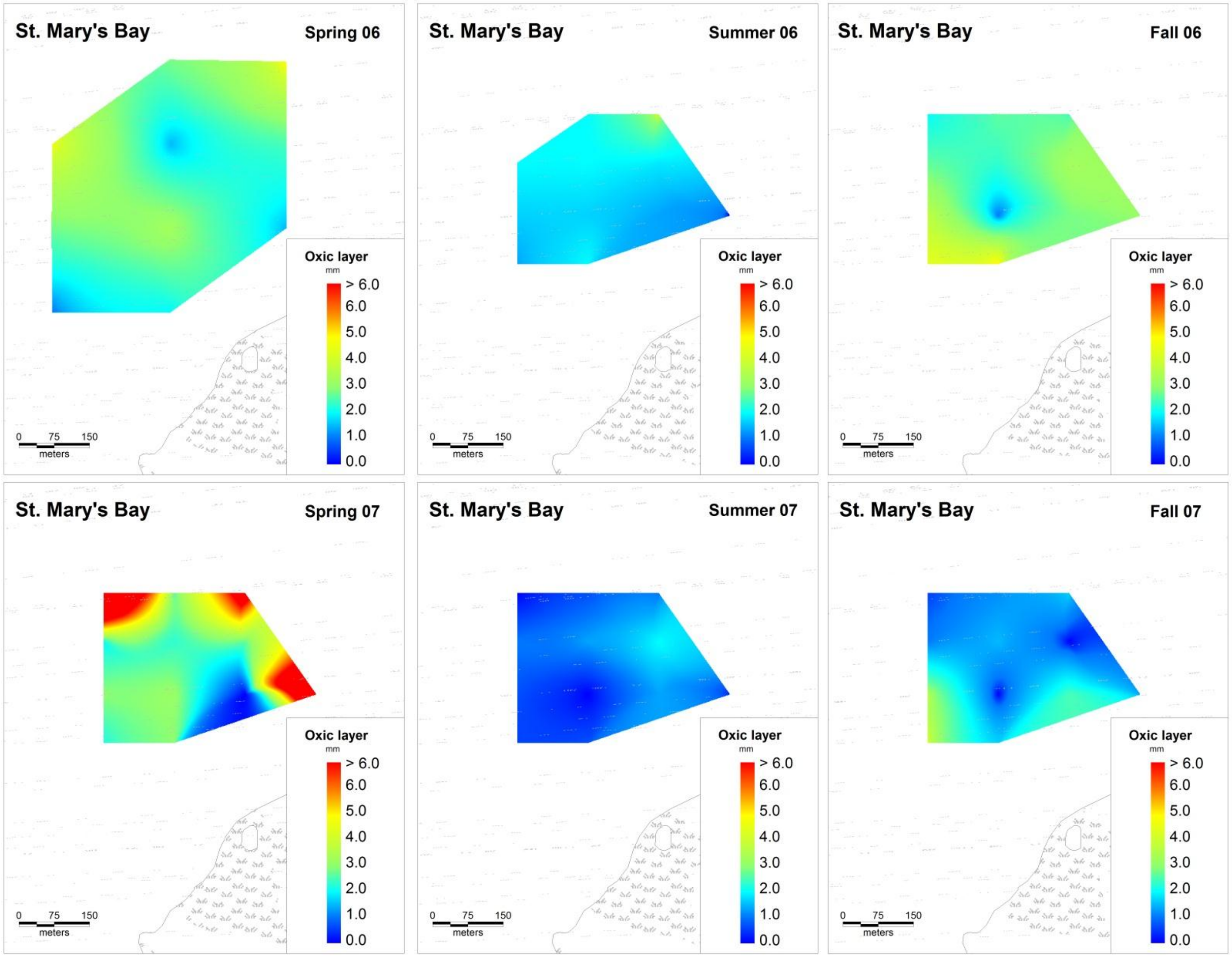

Figure 26. Depth of the oxic layer in St. Mary's Bay (Q1), Nova Scotia, Canada, in 2006 and 2007.

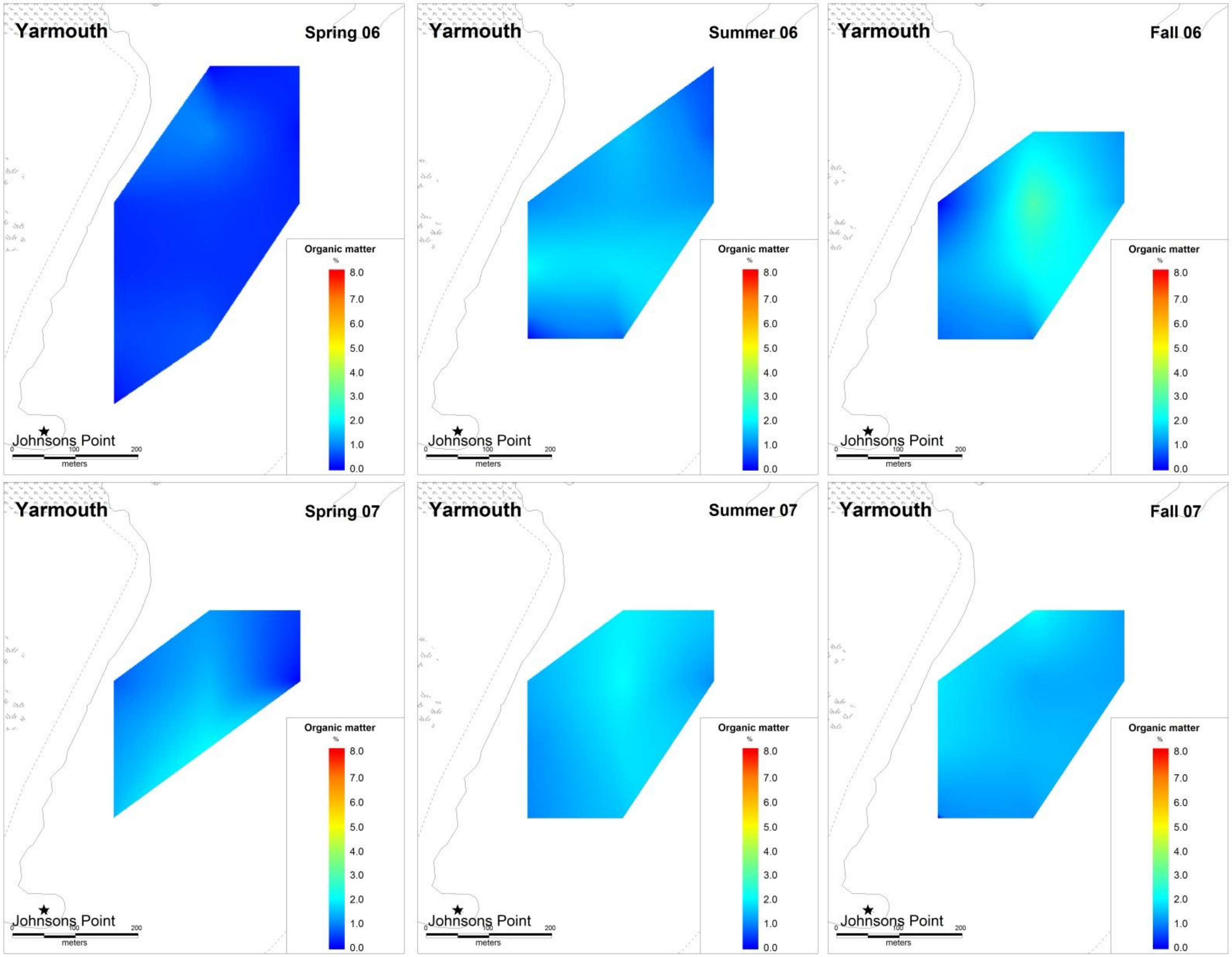

Figure 27. Organic matter content at the sediment surface in Yarmouth (M1), Nova Scotia, Canada, in 2006 and 2007.

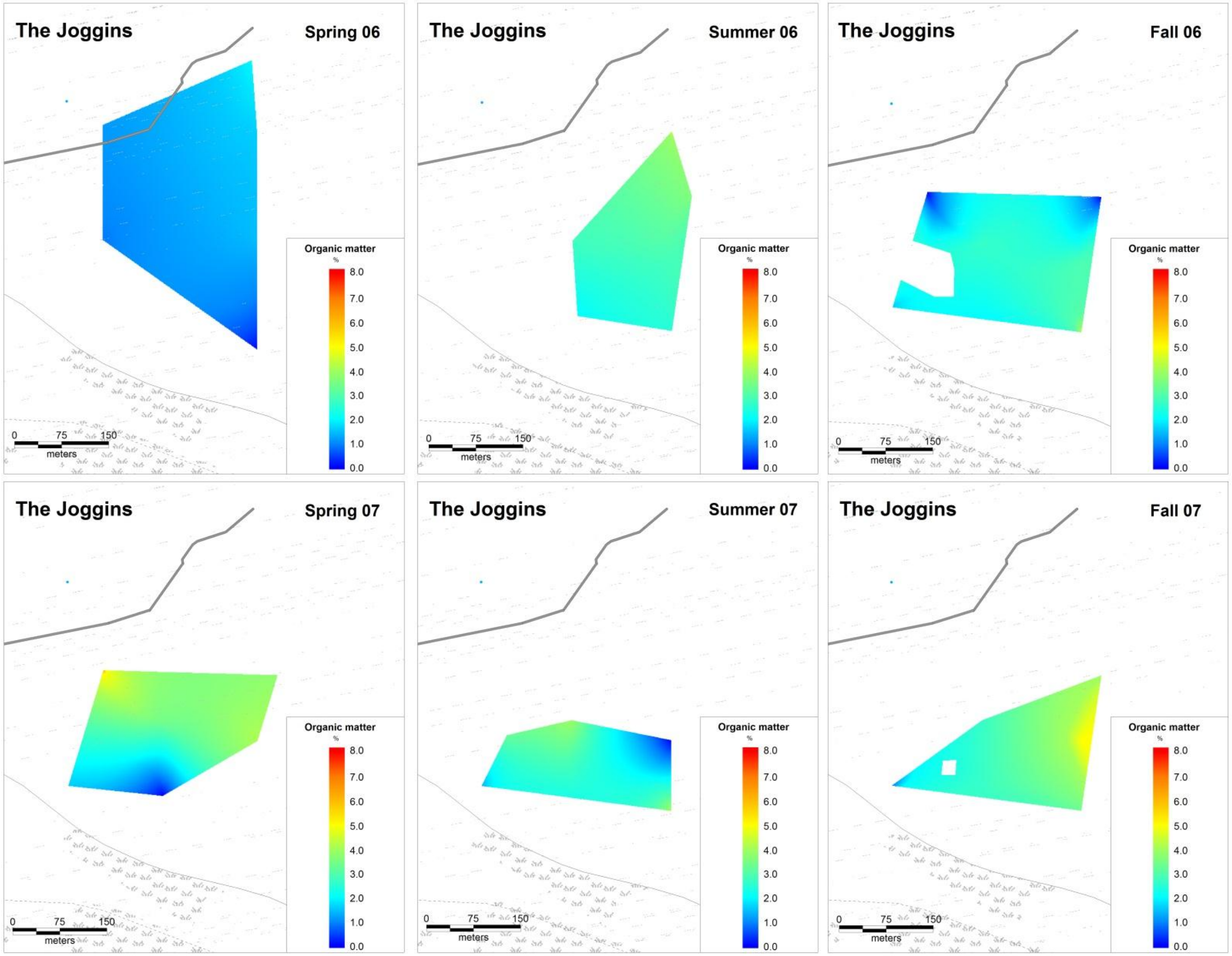

Figure 28. Organic matter content at the sediment surface in The Joggins (M2), Nova Scotia, Canada, in 2006 and 2007.

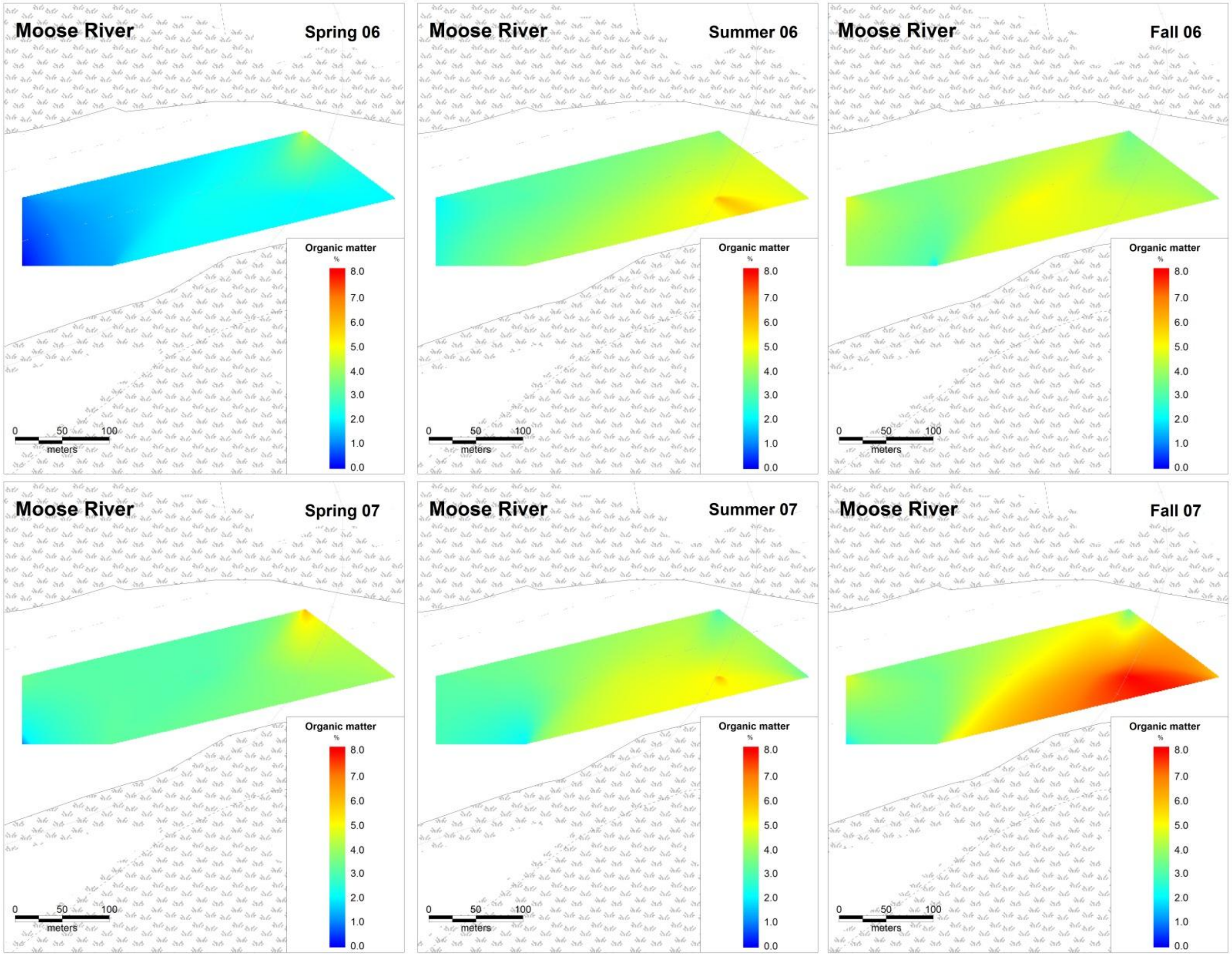

Figure 29. Organic matter content at the sediment surface in Moose River (M3), Nova Scotia, Canada, in 2006 and 2007.

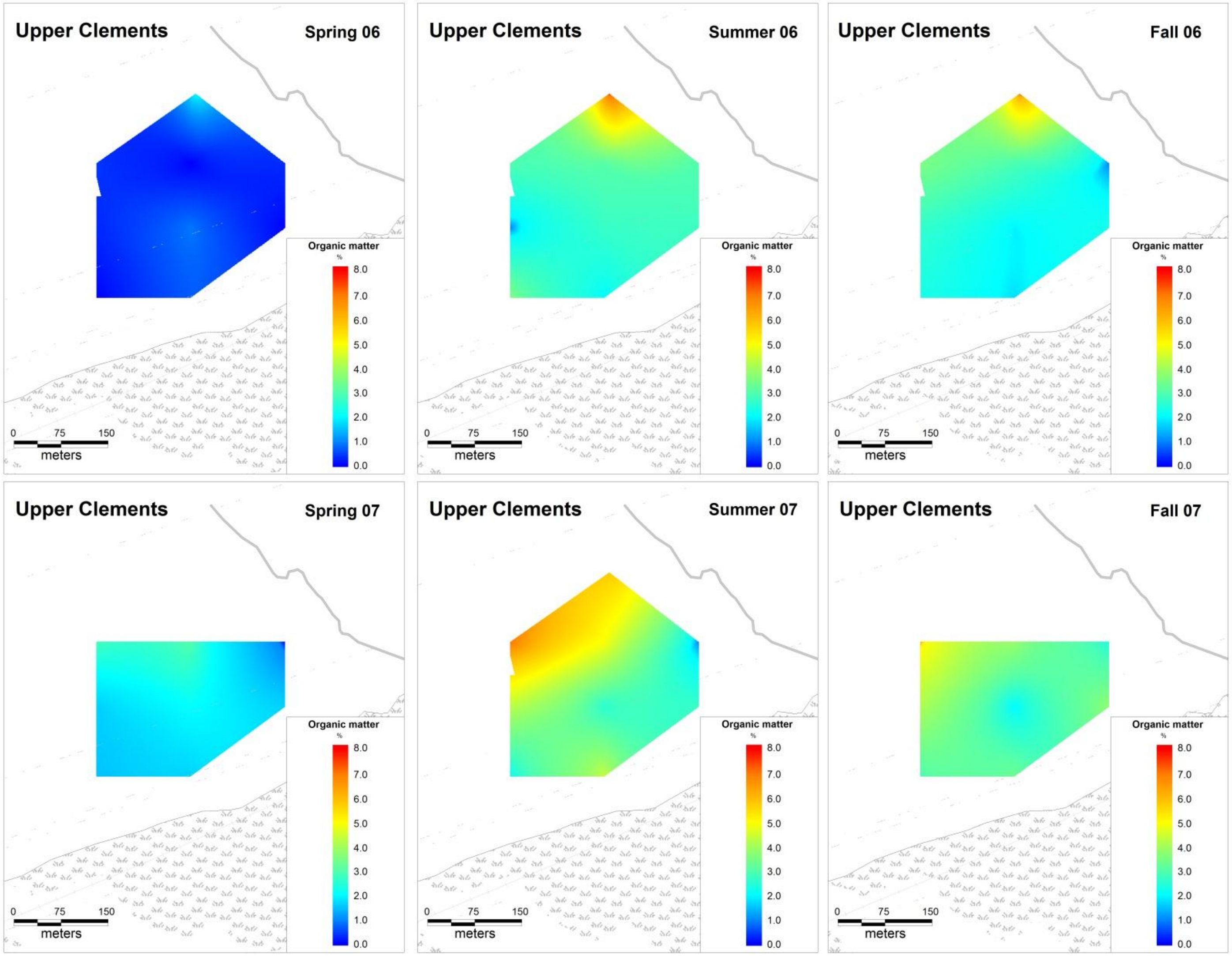

Figure 30. Organic matter content at the sediment surface in Upper Clements (M4), Nova Scotia, Canada, in 2006 and 2007.

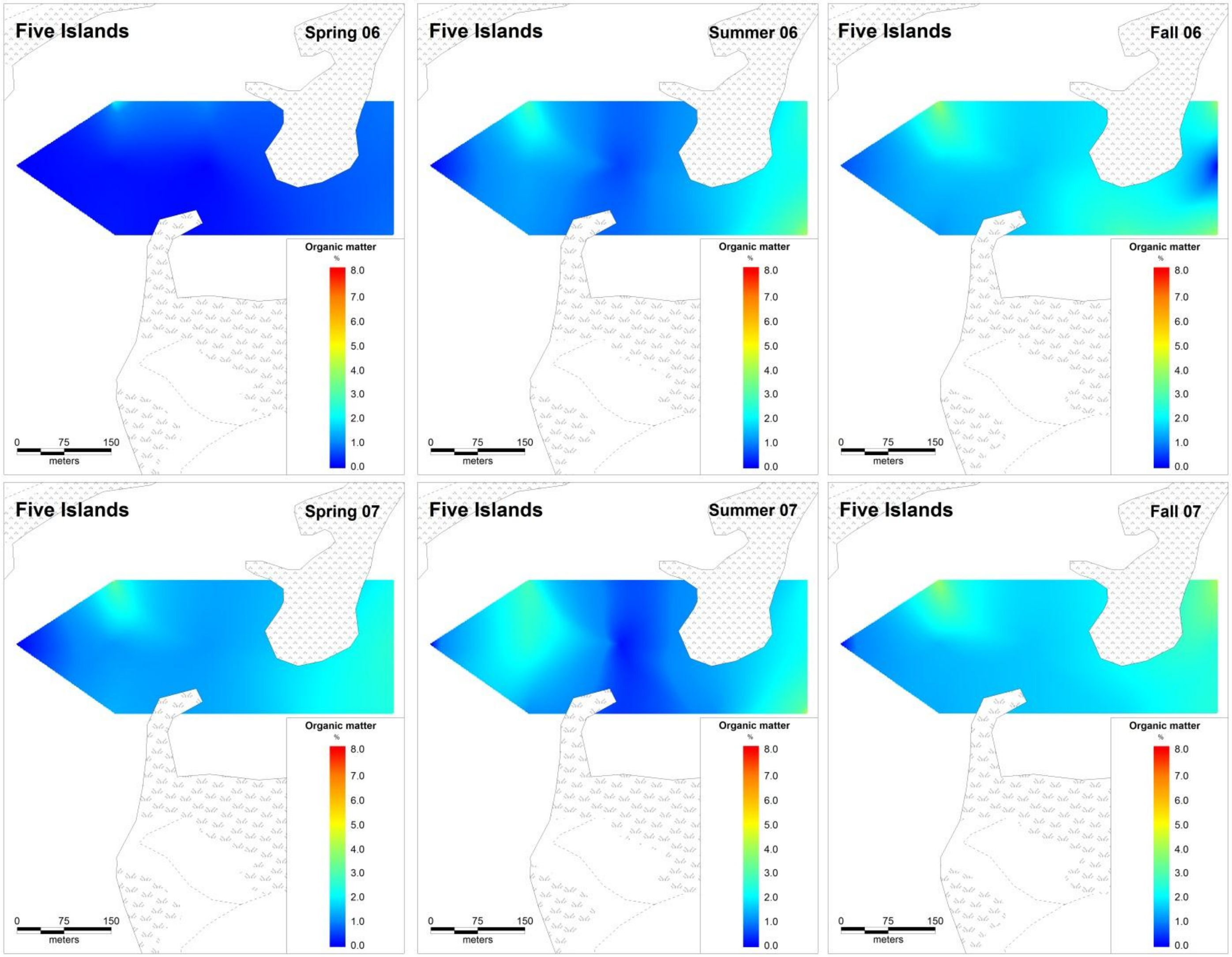

Figure 31. Organic matter content at the sediment surface in Five Islands (M6), Nova Scotia, Canada, in 2006 and 2007.

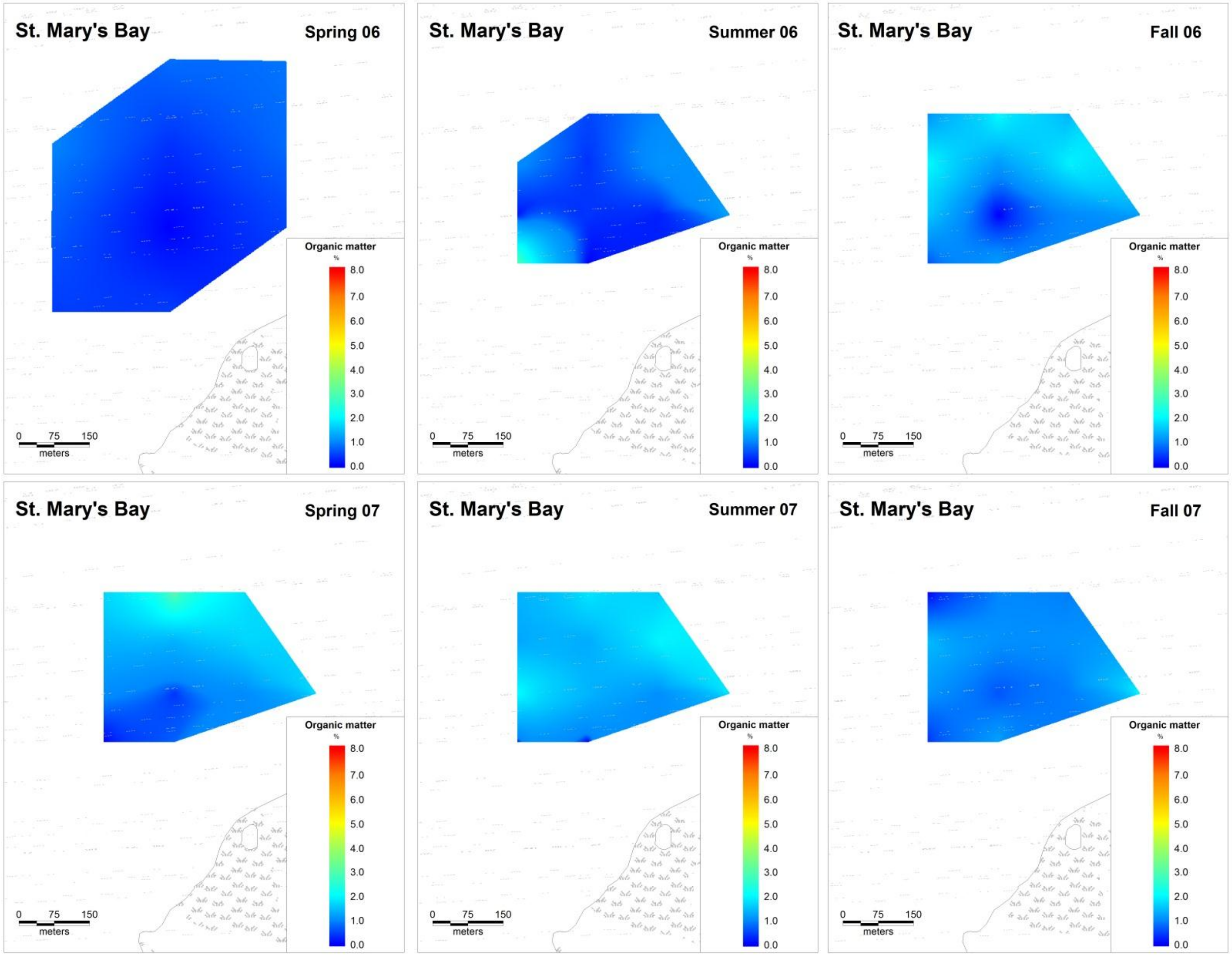

Figure 32. Organic matter content at the sediment surface in St Mary's Bay (Q1), Nova Scotia, Canada, in 2006 and 2007.

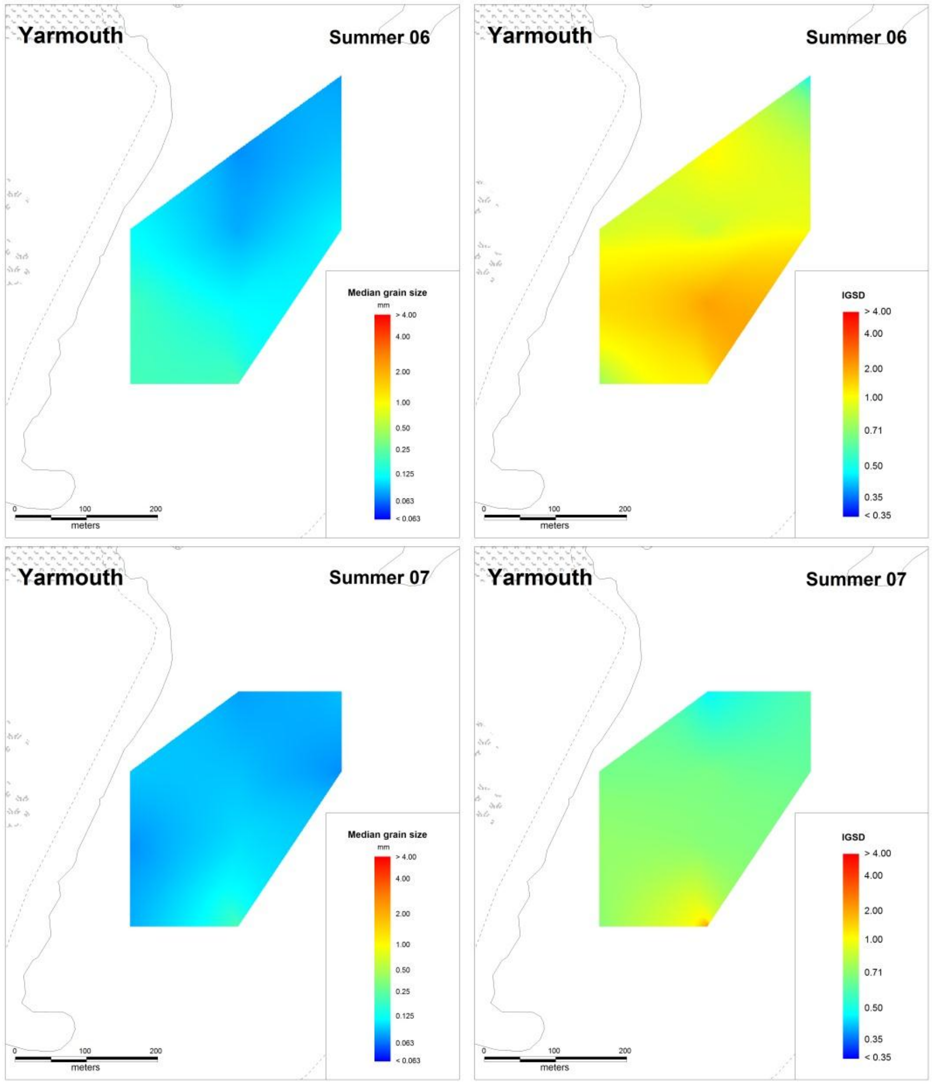

Figure 33. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in Yarmouth (M1), Nova Scotia, Canada, in 2006 and 2007.

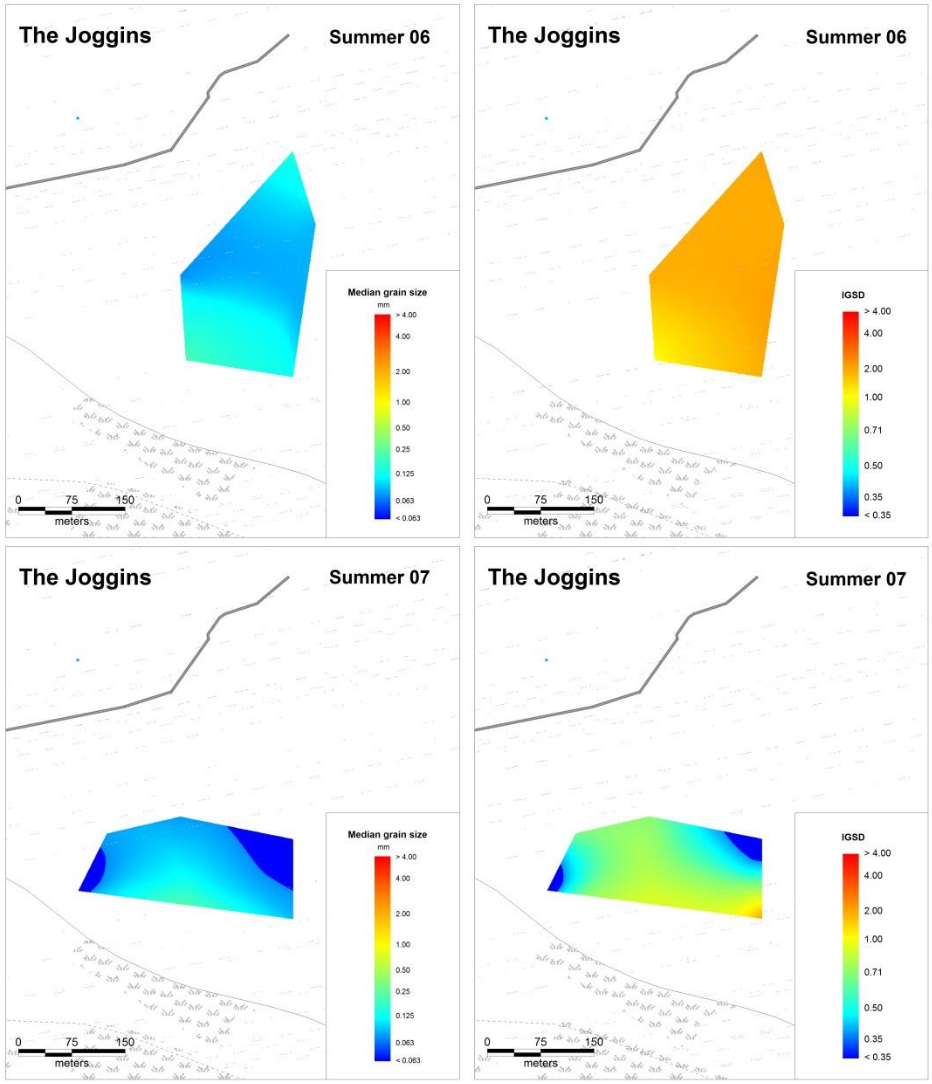

Figure 34. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in The Joggins (M2), Nova Scotia, Canada, in 2006 and 2007.

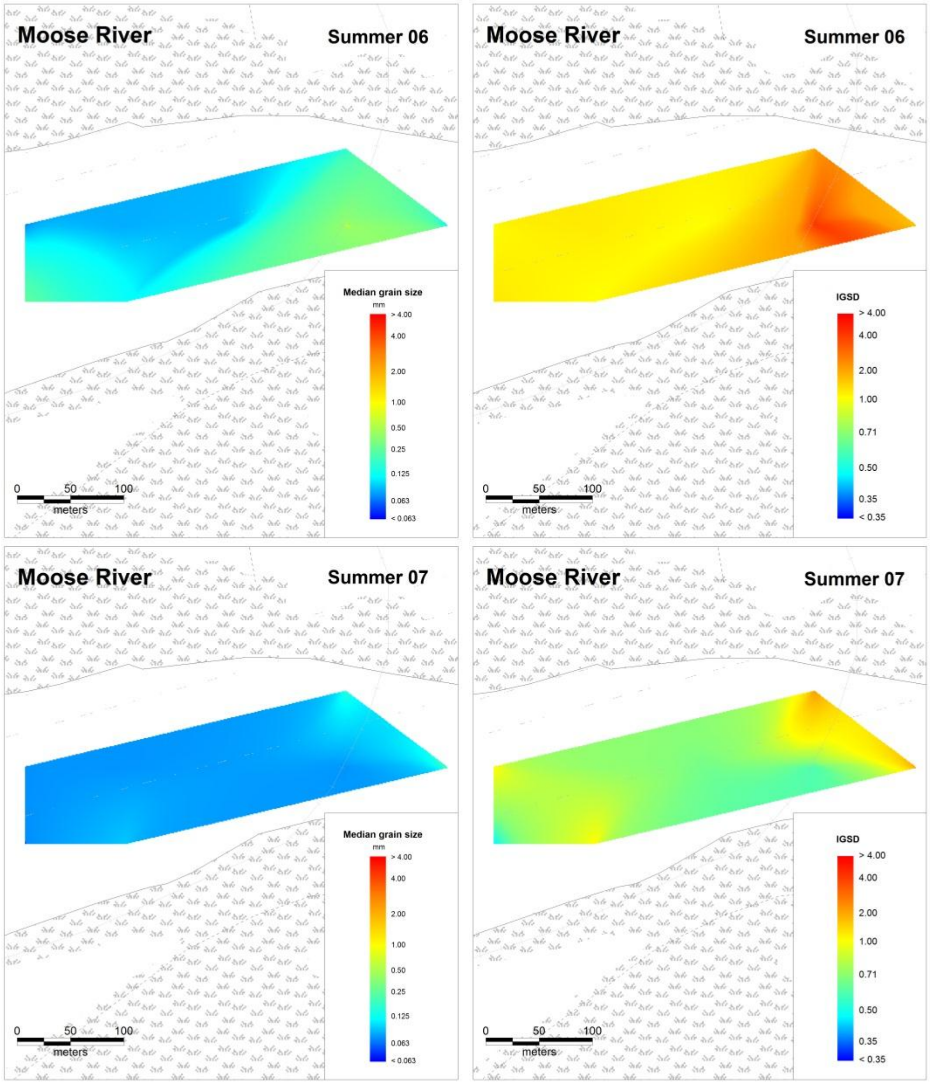

Figure 35. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in Moose River (M3), Nova Scotia, Canada, in 2006 and 2007.

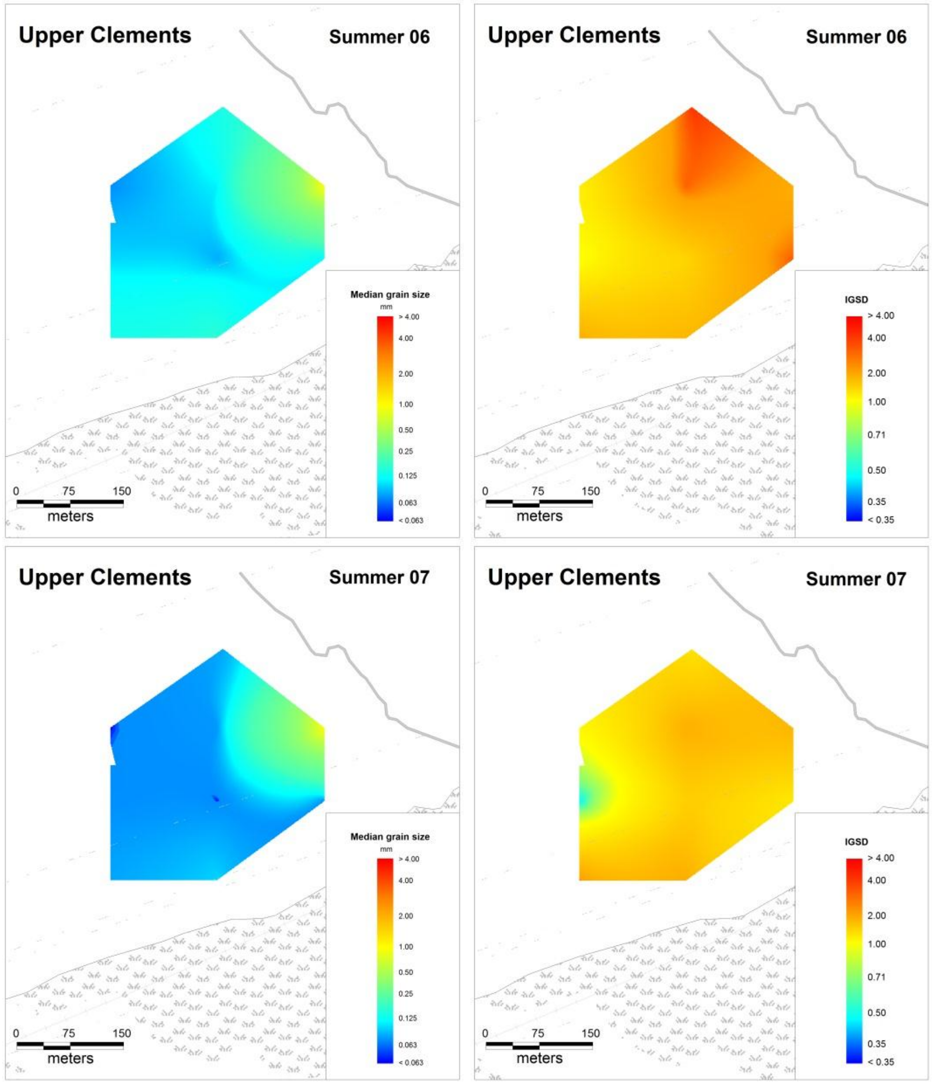

Figure 36. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in Upper Clements (M4), Nova Scotia, Canada, in 2006 and 2007.

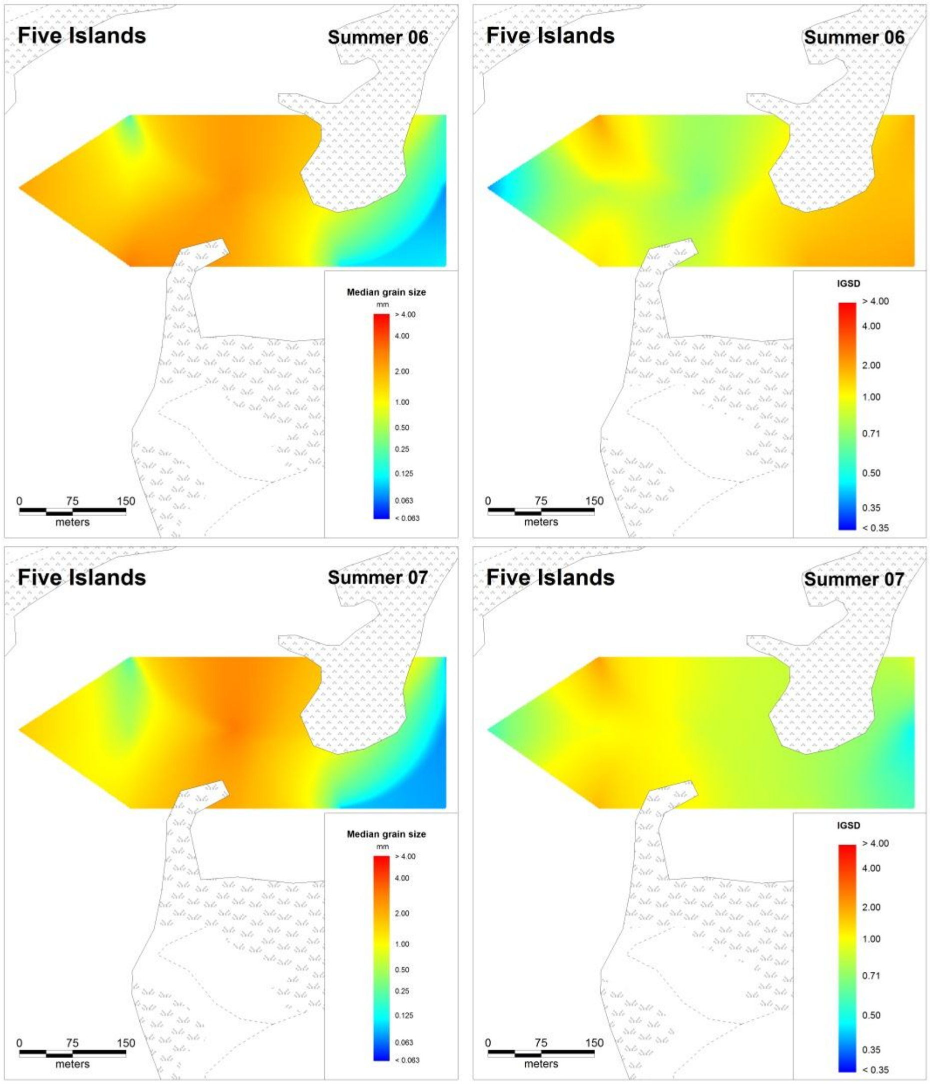

Figure 37. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in Five Islands (M6), Nova Scotia, Canada, in 2006 and 2007.

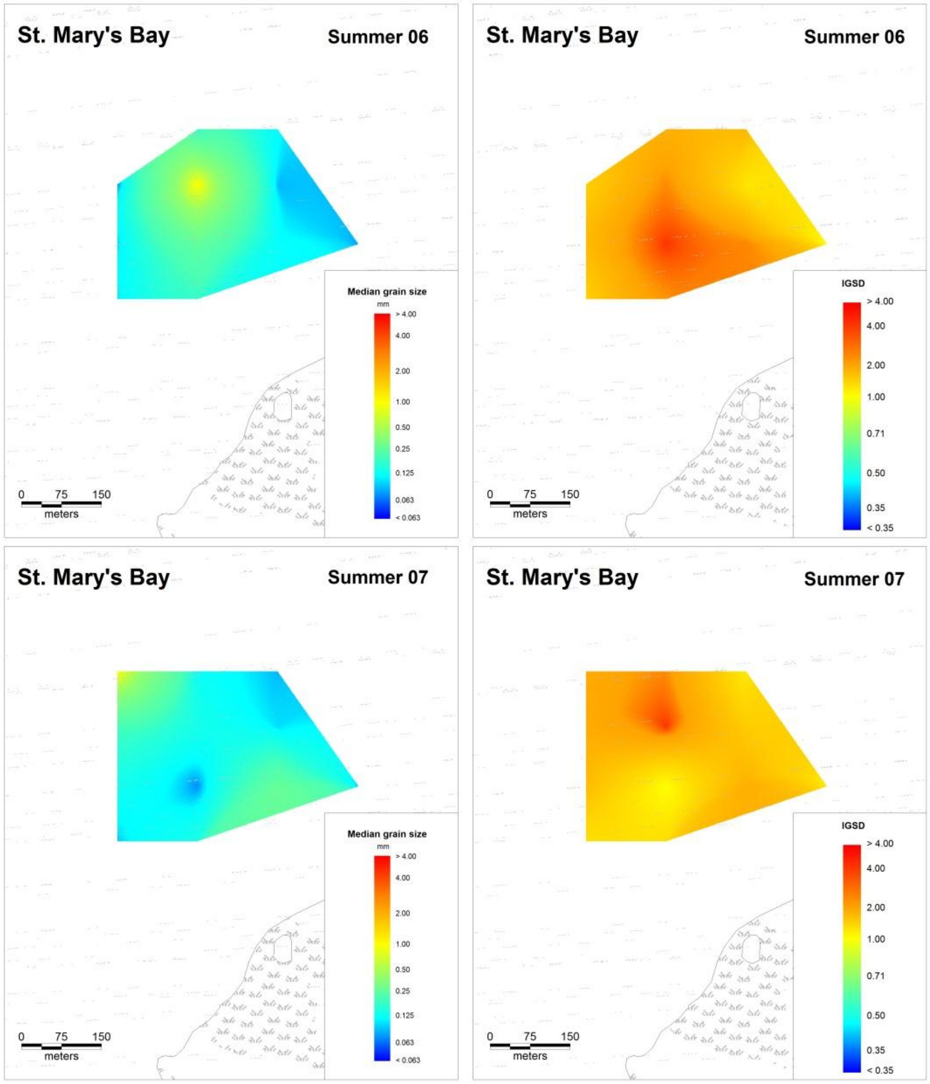

Figure 38. Median grain size and inclusive graphic standard deviation (IGSD) of sediment in St. Mary’s Bay (Q1), Nova Scotia, Canada, in 2006 and 2007.

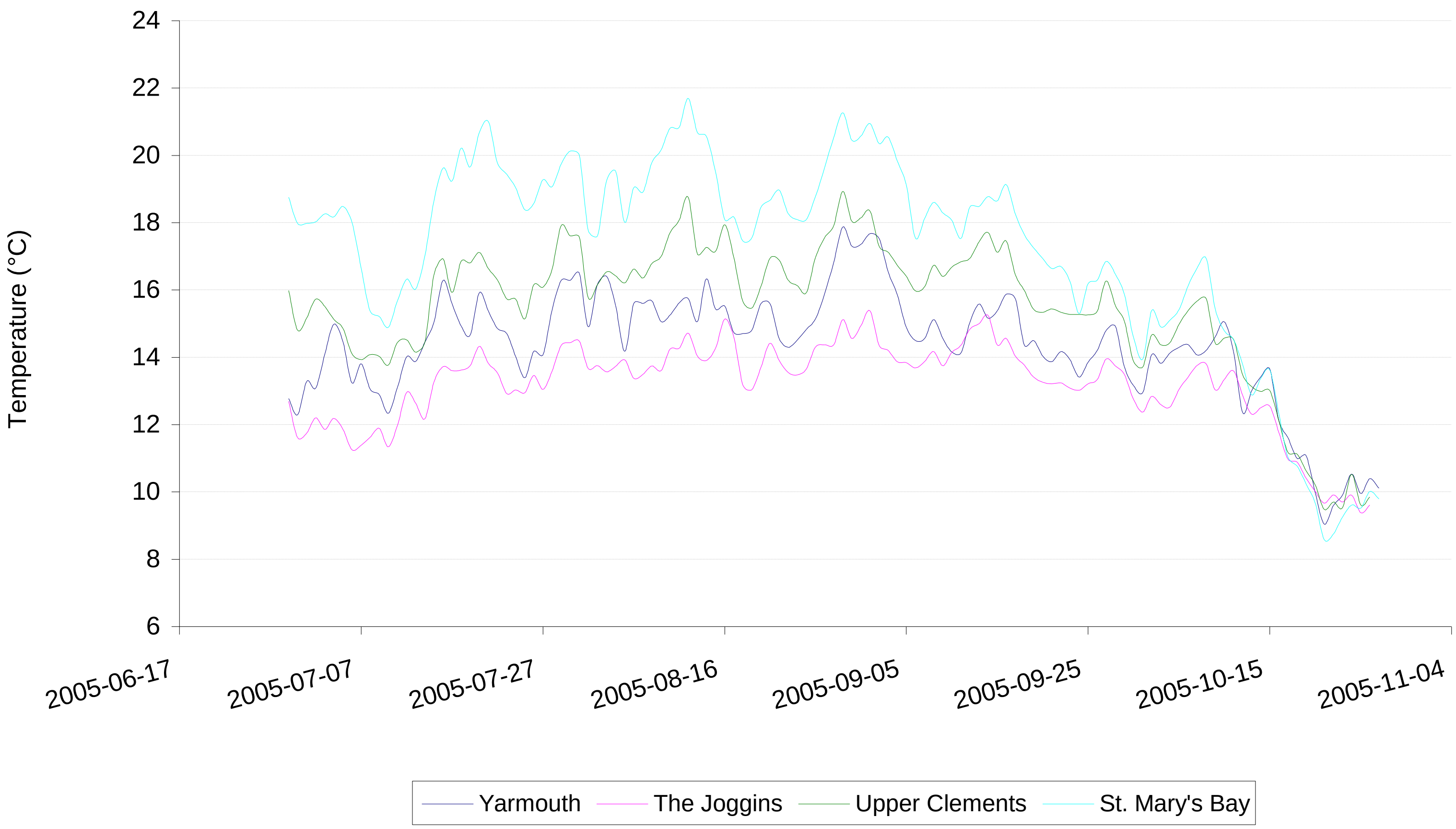

Figure 39. Sediment temperature taken at a depth of 5 cm on clam flats in the Bay of Fundy, Nova Scotia, Canada, in 2005.

APPENDIX A : DESCRIPTION OF DISEASES, PARASITES AND PESTS FOUND

Gonadal Neoplasia[1,2] – Neoplasia is defined as an abnormal proliferation of cells producing a lesion with no physiological function. Gonalda neoplasia affects the gonads causing the inability of the organism to reproduce.

Haemic Neoplasia[1,2] – This is defined same as above however haemic neoplasia affects the blood cells. Depending on the level of neoplasia, the clam may reject the affected cells and recover, or the neoplasia takes over the whole body and the clam eventually dies.

Metacercaria[1] **–** Unidentified Echinostomatid and Gymnophallid metacercariae (larvae). They encyst in the connective tissues of the mantle, foot and digestive gland or more rarely, in the gills. The cyst may develop into a pearl which makes it difficult to identify. The surrounding tissues appear unaffected and the effect on the host is localised. No pathology has been associated with the various species that occur in Canada.

Metaplasia[1] – The term to describe a change in shape of any epithelial cell. Waste products are disposed of by sloughing off the apical portion of the epithelial cells. The cells then regenerate for the next feeding cycle. During winter, when active feeding decreases stops or starvation is prolonged, all the tubule cells may become flattened.

QPX (Quahog Parasite X) disease[1,3] **-** Characterized as a Thraustochytrid, a spherical protist. The parasite induces a massive haemocytic infiltration response. Aggregations of "spore-like" stages are surrounded by necrotic haemocytes in the connective tissue of the digestive gland, mantle, gills, kdney and foot. In severe infections, mortalities are believed to be due to the proliferation of QPX throughout the tissues.

Rickettsia-like organisms (RLO)[1] **–** Intracellular prokaryote micro-organisms belonging to the bacterial groups Rickettsias. They are found world-wide in a wide range of bivalve species and occur most frequently in the cells lining the digestive tracts or gills. They have not been associated with disease in Canadian Atlantic waters.

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[1] McGladdery, S.E., R.E. Drinnan and M.F. Stephenson. 1993. A manual of parasites, pests and diseases of Canadian Atlantic bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 1931.
[2] McGladdery, S.E. 2001. Soft-shell clam neoplasias. Aquaculture Info notes. AIN 06.2001. Prince Edward Island Fisheries, Aquaculture and Environment.
[3] Lyons, M.M., R. Smolowitz, M. Gomez-Chiarri and J.E. Ward. 2007. Epizootiology of quahog parasite unknown (QPX) disease in Northern quahogs (= hard clams) *Mercenaria mercenaria*. J. Shellfish Res. 26:371-381.

APPENDIX B: CLASSIFICATION OF SEDIMENT GRAIN SIZE

Description of sediments in mm and phi scale based on the Wentworth scale (1922).

Broad description	Sediment description	Grain size (mm)	Φ (phi)
Gravel	Pebbles	>4	<-2
	Granule	4	-2
Sand	Very coarse sand	2	-1
	Coarse sand	1	0
	Medium sand	0.5	1
	Fine sand	0.25	2
	Very fine sand	0.125	3
Silt/clay or mud	Silt	0.0625	4
	Clay	<0.0625	>4

APPENDIX C: CLASSIFICATION OF SEDIMENT BASED ON SORTING

Description of the measure of sorting and sorting classes based on Gray (2009).

Inclusive graphic standard deviation (IGSD)	Sorting class
< 0.35 φ	Very well sorted
0.35-0.50 φ	Well sorted
0.50-0.71 φ	Moderately well sorted
0.71-1.00 φ	Moderately sorted
1.00-2.00 φ	Poorly sorted
2.00-4.00 φ	Very poorly sorted
> 4.00 φ	Extremely poorly sorted