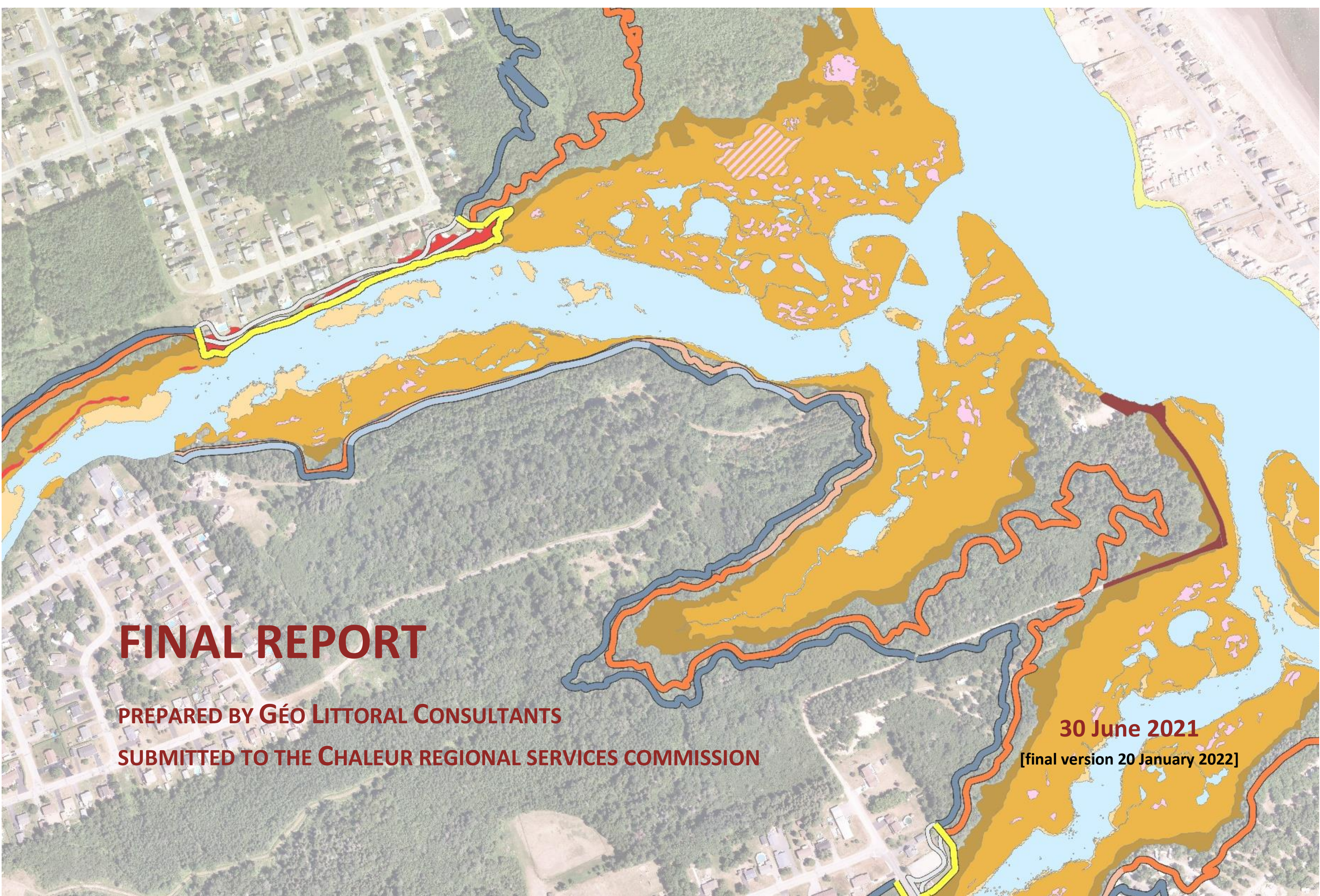
Géo Littoral Consultants
Services de SIG et de cartographie
Études environnementales
Programmes d'interprétation

Contract Identification: **PL2020-01_CSRChaleur**

Coastal Erosion Risk Analysis for Part of the Territory of the Chaleur Regional Service Commission



FINAL REPORT

PREPARED BY GÉO LITTORAL CONSULTANTS

SUBMITTED TO THE CHALEUR REGIONAL SERVICES COMMISSION

30 June 2021

[final version 20 January 2022]

This project is part of a process by the Chaleur Regional Services Commission towards the development of a regional climate change adaptation plan, to identify long-term objectives. Supervision of the implementation of this plan is the responsibility of the Regional Advisory Committee on Adaptation to Climate Change in the Chaleur Region (RACACCCR), which advises the RSC Board on this matter.

This project aimed specifically at producing geospatial data in order, on the one hand, to identify the infrastructures that will be at risk, between now and 2050 and 2100, due to erosion processes and the displacement of the coast, in the localities of Nigadoo, Salmon Beach and Janeville, and on the other hand to provide information on the recent evolution of the salt marshes present along the coasts of Beresford and part of Bathurst (associated with the estuarian part of the Peters River).

Géo Littoral Consultants would like to acknowledge the participation of: Marc BOUFFARD (former Director of Town Planning at the Chaleur RSC) and Dominique BÉRUBÉ (Coastal Geomorphologist at the Department of Natural Resources and Energy Development, Bathurst office) in the development and guidance of this study; Mariette HACHEY-BOUDREAU (former GSI Technician at the Chaleur RSC) for her technical support; and Serge JOLICOEUR (*GLC* and Université de Moncton) for his support in coastal geomorphology and the text revisions.

This project was possible with the financial support of the Provincial Government through the New Brunswick Environmental Trust Fund (NBETF).

Cover Page
Beresford coastal habitat map with projections of the marsh boundary in 2100
(2018 orthophotos in background)

Recommended citation:

O'CARROLL, S. and DIOUF, S. 2021. *Coastal Erosion Risk Analysis for Part of the Territory of the Chaleur Regional Service Commission: Final Report*. Study carried-out by Géo Littoral Consultants and submitted to the Chaleur RSC. 124 pages + GIS files.

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Executive Summary (study highlights)

The coastal evolution of the study area (Nigadoo, Beresford, Salmon Beach and Janeville) from 1944 to 2018/2020 highlights the dynamic nature of the coastal zone. This study is in consistent with the results of other studies made elsewhere in the northern parts, as well as in the southeastern parts of the Province, which shows an erosion-dominated evolution (and some localized sites where the coast has advanced). Two scenarios (to the years 2050 and 2100) were developed to model future coastline positions and to identify infrastructures that may be risk: "Conservative" and "Pessimistic".

Chaleur Bay-facing coasts

- The retreat rate of unconsolidated cliffs in the three sub-sectors was **greater during the period 1944-1985** than during the recent period 1985-2018/2020 and than the entire period 1944-2018/2020:

Nigadoo:	-0.24 ±0.14m/yr, against -0.18 (1985-2018) and **-0.15** (1944-2018)
Salmon Beach:	-0.38 ±0.15m/yr, against -0.33 (1985-2020) and **-0.34** (1944-2020)
Janeville:	-0.36 ±0.13m/yr, against -0.27 (1985-2020) and **-0.26** (1944-2020)

- The general exposure of the coast of Salmon Beach and Janeville (north and northwest quadrants) to the prevailing winds and waves combined to the absence of a rocky platform on the foreshore to mitigate the wave energy could explain **retreat rates up to 35% higher** than those measured at Nigadoo during the period 1944-1985. This difference undoubtedly corresponds to the "natural" conditions between these sectors because few or no protective structures were present there at the time.

- The recent trend towards the **hardening of the coast** through the installation of riprap and protective walls is clear in all three sub-sectors. The generalization of these structures along the base of the bluffs began at the end of the 1990s. In Nigadoo, more than 70% of the coast is today (2018) artificialized: the longest segment of natural coast (except for the Nigadoo sand spit) is little more than ~150 meters in length. At Salmon Beach, about 50% of the coast is artificial (2020): in the northwestern part of the sub-sector, riprap is being erected at the seaward edge of coastal dunes! At Janeville, about 90% of the coast is in its natural state in 2020: a few protection structures are found in the southwestern part of the sub-sector, in contact with Salmon Beach.

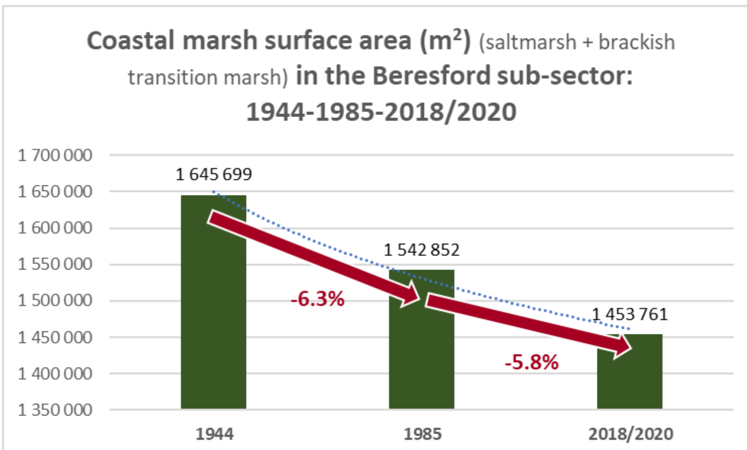
- The projected displacement of the coastline for the year 2050 based on a "Pessimistic" scenario (which considers historical erosion rates plus sea-level rise) is **~2 times greater** than the displacement of the coastline based on a "Conservative" scenario (which only considers historical erosion rates). The projected coastline displacement for the year 2100 based on a "Pessimistic" scenario is **~6 times greater** than the projected displacement based on a "Conservative" scenario.

- Between 2018/2020 and 2100, under "Conservative" and "Pessimistic" scenarios, the following amount of infrastructure would be at risk of erosion in the three (3) Bay-facing sub-sectors:

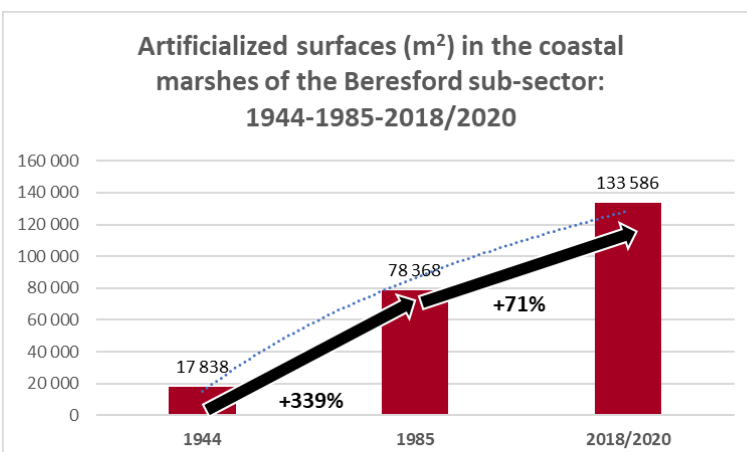
Infrastructure	Scenario Type	Sub-sector			*TOTAL*
		Nigadoo	Salmon Beach	Janeville	
Buildings	Conservative	20	81	36	***137***
	Pessimistic	**48**	**174**	**174**	***396***
Sanitary pipes	Conservative	30 m	-	-	***30 m***
	Pessimistic	**195 m**	**-**	**-**	***195 m***
Pumping stations	Conservative	-	-	-	-
	Pessimistic	**2**	**-**	**-**	***2***
Communication poles	Conservative	2	20	-	***22***
	Pessimistic	**35**	**94**	**86**	***215***
Roads	Conservative	5 m	207 m	106 m	***318 m***
	Pessimistic	**294 m**	**2,878 m**	**2,484 m**	***5,656 m***

The salt marshes of the Beresford sub-sector

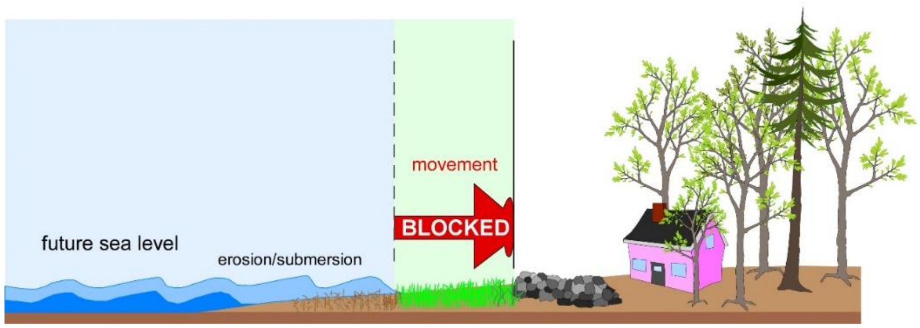
- The area occupied by coastal marshes has declined over the period 1944-2018/2020, dropping from 164.6ha to 145.4ha (decrease of 11.7%). The trend illustrates that it is the **brackish transitional marsh which is the marsh habitat undergoing the greatest anthropogenic pressure** (28.5% area loss since 1944); losses are lower between 1944 and 1985 (4.2ha or -12%) than between 1985 and 2018/2020 (6ha or -19%).



- Since 1944, developments covered 11.6ha of marshes, an increase of +649%. The post-1985 installment of laws, regulations and policies aimed at protecting wetlands appears to have had the effect of slowing down the artificialization of the marshes, but not to a complete halt.



- Currently (2018/2020), the coastal marshes directly abutting (0m) artificial surfaces represent a length of ~4km: this is a situation of **coastal squeeze**. Depending on the future evolution scenario considered, the length of the coast in a coastal squeeze situation would increase by 674.2m or 2,104.2m by 2100 (i.e. +14% or +34%).



Marsh movement type by 2100	Total length (m), "Conservative" scenario		Total length (m), "Pessimistic" scenario	
	m	%	m	%
Gradual (code 1)	15,346.05	62%	15,742.67	64%
Impeded (code 4)	4,772.93	19%	2,818.21	11%
Blocked (code 3)	4,737.11	19%	6,167.13	25%
Total for 2100 scenario	*24,856.09*	*100%*	*24,728.01*	*100%*
length currently blocked (2018/2020)	4,062.9	16%	4,062.9	16%
increase of blocked length in 2100 relative to total already blocked in 2018/2020	**+674.2**	**+14%**	**+2,104.2**	**+34%**

- The southern portion and estuary of the Peters River is where the movement of coastal marshes in response to the relative sea level rise by 2100 appears to be least constrained at present. Here, there are many **accommodation spaces** (portions of land that are large enough and free of development) necessary for their migration.

I. Timeline of this Project

On October 22, 2020, the Chaleur RSC informed *Géo Littoral Consultants* (*GLC*) that it had been awarded the mapping contract. This project specifically aims to produce geospatial data for the localities of Nigadoo, Beresford, part of Bathurst (associated with the estuarian part of the Peters River), Salmon Beach and Janeville to 1) identify the infrastructures that will be at risk, by 2050 and 2100, due to erosion processes and the shifting of the coastline or the shoreline, and 2) to provide information on the recent evolution of the salt marshes present along the coasts of these same localities.

On November 20, the contract drawn up by *GLC* and adjusted and improved by the Chaleur RSC was formalized by both parties.[1]

GLC received on November 20 the external hard drive and paper copies of historical aerial photographs (1944 and 1985) covering the study area. On November 23, the *GLC* team officially begins the work associated with this contract.

On June 30, 2021, *GLC* submitted to the CSR Chaleur, by mail, the hard copies of the Final Report (French and English), the electronic versions of all the documents, including the geospatial database (GIS layers), as well as all material support lent to *GLC* for the realization of the project (external hard drive containing the relevant digital files) (see *Annex E* for the complete list of deliverables). *GLC* hand-delivered to Dominique BÉRUBÉ (MRNDÉ) the paper copies of the aerial photographs of the 1944 and 1985 series lent for the project.

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[1] The contract is signed on November 17 by the representative of *GLC* and on November 18 by the representative of the Chaleur RSC. This document is named: *Contrat_CSR Chaleur et GéoLittoral Consultants_SIGNÉ_20 novembre 2020.pdf.*

II. Meetings Held

On October 28, a first meeting (kick-off meeting) takes place by videoconference (TEAMS software).[2] The people present were Marc BOUFFARD (Chaleur RSC), Dominique BÉRUBÉ (DNRDED), Simon DIOUF (*GLC*) and Stéphane O'CARROLL (*GLC*). Among the objectives of this meeting are[3]:

- to allow members (client and service provider) to get to know each other;
- to ensure that both parties (client and service provider) have the same understanding of the goals, objectives and deliverables of the project;
- to ensure that the documents necessary for carrying out the mapping project are made available to *GLC*;
- to identify the dates of the next meetings, the documents to be returned, and the public presentation of the results;
- to see to the signing of a contract between the Chaleur RSC and *GLC*.

On December 18, a second meeting was held by videoconference (TEAMS software). The people present were Marc BOUFFARD (Chaleur RSC), Mariette HACHEY-BOUDREAU (Chaleur RSC), Tanya PELLECIER (Chaleur RSC), Dominique BÉRUBÉ (DNRED), Simon DIOUF (*GLC*) and Stéphane O'CARROLL (*GLC*). The objectives of this second meeting were numerous and mainly concerned methodological aspects, including[4]:

- the delimitation of the zone of influence of the tide along the upstream part of an estuary;
- mapping cases deemed difficult, where input from RACACCCR members is necessary for the advancement of the project;

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2 In the Request for Proposal, this first meeting was scheduled "in person" (face-to-face), but due to the Covid-19 pandemic, we held a videoconference.

3 The minutes of the meeting of October 28 correspond to the following document: *PL2020-01_Réunion 1_ Démarrage-question et éclaircissements_28 octobre 2020.pdf.*

4 The minutes of the meeting of December 18 correspond to the following document: *PL2020-01_Réunion 2_Compte rendu_18 décembre 2020.pdf*.

- the identification of the altimetric level of the Higher high water large tide (HHWLT) and the Higher high water mean tide (HHWMT) in the vicinity of the Beresford salt marshes;
- the positioning of the baseline (reference line) for establishing transects;
- the inclusion (or not) of private protection structures in the projection of the 2050 and 2100 coastline positions;
- the date of availability of the 2020 digital orthophotographs.

On January 22, 2021, a third meeting was held by videoconference (TEAMS software). The people present were Marc BOUFFARD (Chaleur RSC), Tanya PELLECIER (Chaleur RSC), Dominique BÉRUBÉ (NREDNB), Simon DIOUF (*GLC*) and Stéphane O'CARROLL (*GLC*). The objectives of this meeting were[5]:

- status of the mapping of the Beresford salt marshes for 1985 and first results for 2018;
- date of availability of the 2020 digital orthophotographs.

On March 18, a fourth meeting was held by videoconference (TEAMS software). The people present were Marc BOUFFARD (Chaleur RSC), Dominique BÉRUBÉ (NREDNB), Simon DIOUF (*GLC*) and Stéphane O'CARROLL (*GLC*). The objectives of this meeting were[6]:

- status of the mapping of the Beresford salt marshes for 1944 and first results for 2018/2020 and 1985;
- discussions on the work schedule.

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5 The minutes of the meeting of January 22 correspond to the following document: *PL2020-01_Réunion 3_Compte rendu_25 janvier 2021.pdf*.

6 The minutes of the meeting of March 18 correspond to the following document: *PL2020-01_Réunion 4_Compte rendu_18 mars 2021.pdf*.

III. Georeferencing Aerial Photographs

On February 10, 2021, *Géo Littoral Consultants* accessed, via the ftp site of the Department of Natural Resources and Energy Development, the 2020 digital orthophotographs covering the eastern part of the Beresford sub-sector and the sub-sectors of Salmon Beach and Janeville (Figure 1).

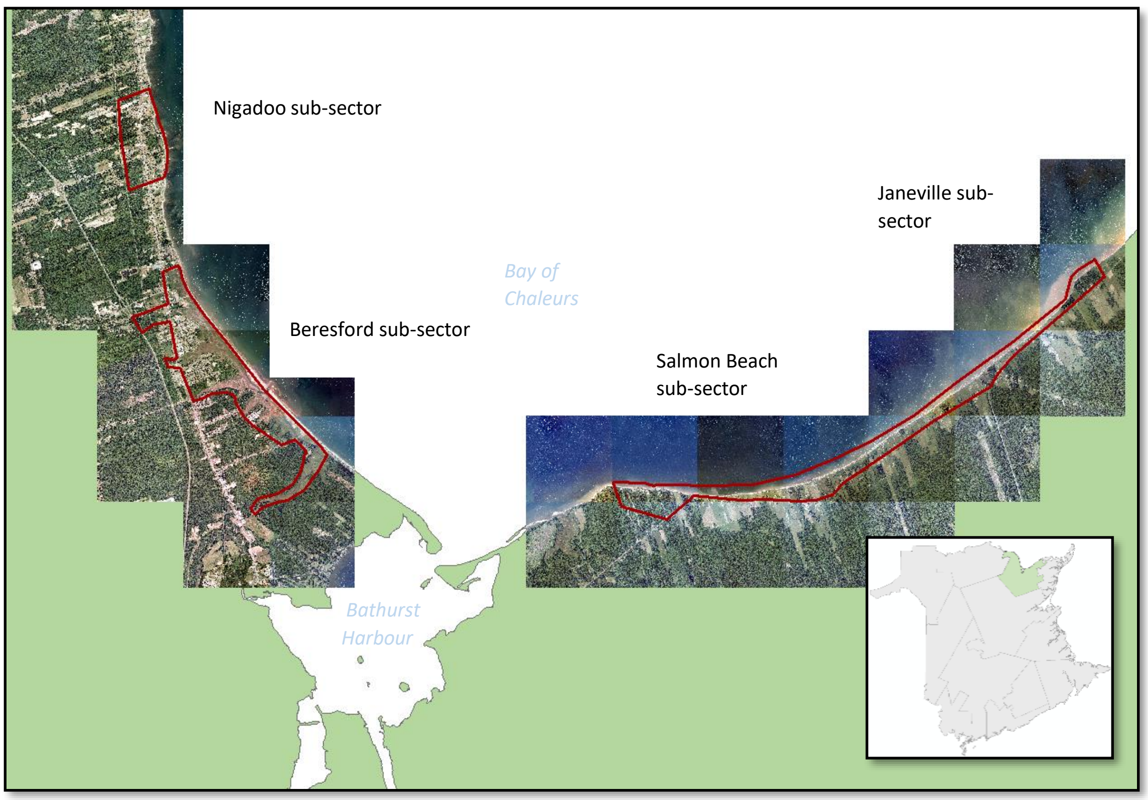


Figure 1. Study area and orthophoto coverage for 2018/2020 (west of Bathurst Harbour) and 2020 (east of Bathurst Harbour).

All historical aerial photographs used in this work (the 1944 and 1985 series) were digitized with the *ScanMaker Pro 1000XL* (*Microtek*). This device has a scanning area of 12 inches by 17 inches, which allows aerial photos to lie completely flat on the glass surface. The chosen photogrammetric approach provided for the digitization of aerial photos at a common resolution, i.e. 1200 dpi (dots per inch). This approach had to be modified slightly for the 1944 and 1985 series in the Beresford sub-sector (Table 1).[7]

The number of control points (elements of the landscape common to the aerial photos and orthophotography from 2018 or 2020) used for the georeferencing of the photos varies between 5 and 14 per photo. It is the "projective" type transformation that has been used when georeferencing aerial photos (a transformation commonly used in similar digital mapping projects). The margin of error associated with georeferencing an individual photograph, expressed as Root Mean Square Error (RMSE), ranges from 0.36m to 1.78m. The largest RMS error for a single control point is 2.78m (1944 photo A7391-7, near the Peters River). These values of the RMS error (at the level of a photograph or at the level of the individual control points) are considered very satisfactory by *GLC*. The pixel size of georeferenced aerial photos from 1944 varies between 0.24m and 0.46m, while that of photos from 1985 varies between 0.27m and 0.3m. These values are suitable for the mapping proposed within the framework of this project. Figure 2 shows the display of photos from 1944 and 1985 georeferenced as part of the project.

[7] For the Beresford sub-sector, some aerial photos of 1944 and 1985 were digitized in several parts, despite a good margin of error (low RMS); the positioning of the photo relative to the reference orthophotograph was not adequate. Such situations occur when the topography is irregular: low relief along the salt marshes and at the coast, and high relief (more than 6m) at the top of the slopes. Scanning a photo into smaller sectors improved the positioning of the 1944 and 1985 series, improving the reliability of vectors mapped in this sub-sector.

Table 1. Details of georeferencing aerial photos from 1944 and 1985.

Sub-sector	Name of georeferenced aerial images	# control points	Type of transformation	RMS error	Pixel size *(m)*	Orthophoto used for georeferencing
Nigadoo	CSR_1944_Nigadoo_R	10	Projective	**1.3**	0.37	2018
	CSR_1985_Nigadoo Centre_R	8	Projective	**0.91**	0.29	2018
	CSR_1985_Nigadoo Sud_R	9	Projective	**0.5**	0.27	2018
Beresford et rivière Peters	CSR_1944_A7366-32_N-nord_R	6	Projective	**0.74**	0.24	2018
	CSR_1944_A7366-32_N_R	7	Projective	**0.52**	0.24	2018
	CSR_1944_A7366-32_C-nord_R	6	Projective	**0.36**	0.23	2018
	CSR_1944_A7366-32_C-sud_R	7	Projective	**0.45**	0.24	2018
	CSR_1944_A7366-32_N_R	6	Projective	**0.74**	0.24	2018
	CSR_1944_A7366-30_S-se_R	13	Projective	**0.88**	0.4	2018;2020
	CSR_1944_A7366-32_S-n_R	10	Projective	**1.41**	0.24	2018
	CSR_1944_A7360-38_N_R	7	Projective	**0.78**	0.24	2020
	CSR_1944_A7360-37_E_R	5	Projective	**1.01**	0.3	2020
	CSR_1944_A7360-37_O_R	5	Projective	**0.68**	0.3	2020
	CSR_1985_BeresfordNord_R	10	Projective	**0.73**	0.27	2018
	CSR_85511-86_N_R	9	Projective	**0.37**	0.27	2018
	CSR_85511-64_N_R	12	Projective	**0.85**	0.27	2018
	CSR_85511-86_S_R	11	Projective	**1.40**	0.27	2018
	CSR_1985_85511-64_S_R	14	Projective	**1.34**	0.28	2018
	CSR_1985_85511-43_N_R	8	Projective	**0.58**	0.28	2018; 2020
	CSR_1985_85511-43_S_R	9	Projective	**0.56**	0.27	2018; 2020
	CSR_1985_85511-45_N_R	8	Projective	**0.53**	0.28	2020
	CSR_1985_85511-45_S_R	10	Projective	**0.99**	0.27	2020
	CSR_1985_85512-231_E_R	11	Projective	**1.52**	0.28	2020
	CSR_1985_85512-231_O_R	10	Projective	**0.86**	0.28	2020
Salmon Beach	CSR_1944_Salmon Beach Ouest_R	10	Projective	**1.58**	0.41	2020
	CSR_1944_Salmon Beach Centre_R	7	Projective	**1.31**	0.42	2020
	CSR_1944_Salmon Beach Est_R	8	Projective	**1.16**	0.42	2020
	CSR_1985_Salmon Beach Ouest_R	11	Projective	**0.98**	0.28	2020
	CSR_1985_Salmon Beach Centre_Ouest_R	7	Projective	**0.66**	0.27	2020
	CSR_1985_Salmon Beach Centre_Est_R	12	Projective	**0.89**	0.27	2020
	CSR_1985_Salmon Beach Est_R	10	Projective	**1.01**	0.27	2020
Janeville	CSR_1944_Janeville Ouest_R	6	Projective	**0.52**	0.38	2020
	CSR_1944_Janeville Centre_R	6	Projective	**1.05**	0.22	2020
	CSR_1944_Janeville Est_R	7	Projective	**1.11**	0.41	2020
	CSR_1985_Janeville Sud-ouest_R	9	Projective	**0.78**	0.26	2020
	CSR_1985_Janeville Centre-sud_R	7	Projective	**1.43**	0.26	2020
	CSR_1985_Janeville Centre-nord_R	6	Projective	**0.67**	0.28	2020
	CSR_1985_Janeville Nord-est_R	8	Projective	**0.70**	0.28	2020
		Average	*1944 :*	***0.92***	***0.31***	
			1985 :	***0.87***	***0.27***	

* The historical aerial photographs georeferenced here were provided to Géo Littoral Consultants by the DNRED of New Brunswick (Bathurst)

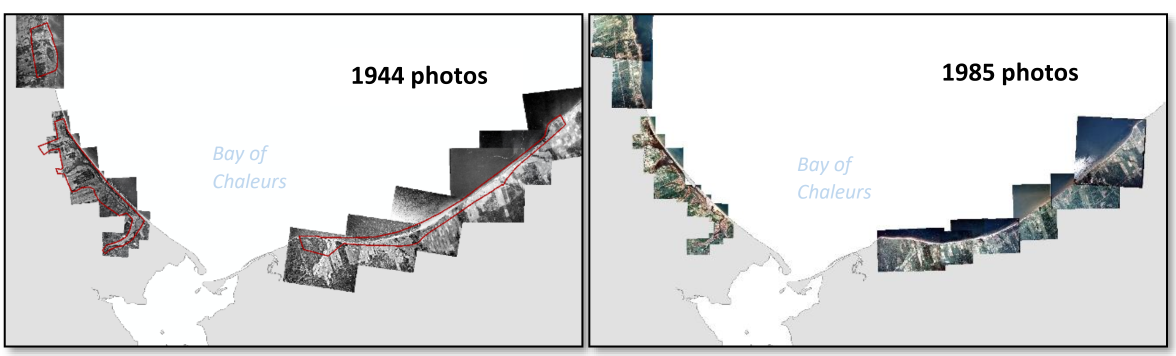


Figure 2. Location of georeferenced aerial photos from 1944 and 1985.

IV. Mapping the Bay-Facing Coasts

IV.I. Important landscape features: the coastline and the shoreline

To calculate the historical displacement of the coast, the coastline (CL) is the vector most commonly used by the New Brunswick Department of Natural Resources and Energy Development, because it corresponds to different elements of the landscape that are easy to identify by photointerpretation (O'CARROLL *et al*., 2006; JOLICOEUR and O'CARROLL, 2012; CHELBI *et al*., 2019; WSP, 2020).

Although it is often associated to a water level (Higher high water large tide - HHWLT), on aerial photos, the CL is positioned in the following places (Figure 3):

- *Sandy coast* (presence of coastal dunes): limit of the vegetation front (American beach grass - *Ammophila breviligulata*) when the dune has a regular profile; top of the dune cliff when the dune is scarped.
- *Unconsolidated coast* (till, unconsolidated sediments): break in slope, often the top of the scarp or the limit of perennial vegetation.
- *Rocky coast*: top of the cliff or limit of perennial vegetation.
- *Artificial coast*: in the presence of riprap, it is the base of the structure that is mapped; in the presence of a vertical wall (wooden or concrete), the top of the structure is mapped.
- *Marsh coast*: external limit (seaward) of the upper part of the marsh, corresponding to the limit of the distribution of the *Spartina Pectinata* and the *Spartina Patens* and/or a break in slope (see also subsection *V.I. - Main Marsh Characteristics*).

The shoreline (SL) is also often associated to a water level (Higher high water mean tide - HHWMT), it is positioned in the following places on the aerial photos (Figure 3):

- *Sandy beach*: it is the wet/dry sand boundary that is mapped. This contact is also discernible by the presence of scattered marine debris or wrack lines indicative of the mean high tide.[8]
- *Marsh coast*: it is the contact established by the outer limit of the saltgrass meadow (limit between the vegetated part of the marsh – *Spartina Alterniflora* and/or *Spartina Patens* – and the bare foreshore) (see also subsection *V.I. - Main Marsh Characteristics*).

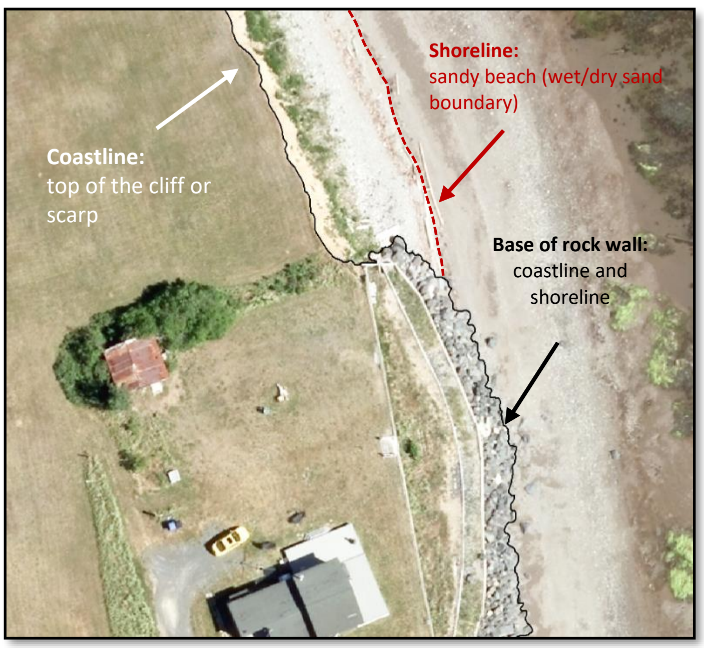


Figure 3. Mapping of the coastline and the shoreline on the 2018 orthophotograph.

8 In cases where the sandy beach is absent, such as in front of a protective structure, the base of the structure acts as the shoreline.

The main distortion for vertical aerial photos corresponds to the displacement of the relief relative to the center of the lens (i.e. at the *nadir* point): only the top of the object is visible, whereas for all the other objects in the photo, one side is visible in addition to the top, which gives the impression that these objects extend towards the edges of the image (Figure 4). Sometimes, the aerial photos were not taken in a perfectly vertical angle (due to a movement of the aircraft in flight) and this situation can result in a coastline obstructed by the presence of trees (Figure 4). In such situations, the vector was mapped by best estimating the likely location of the coastline or shoreline.[9]

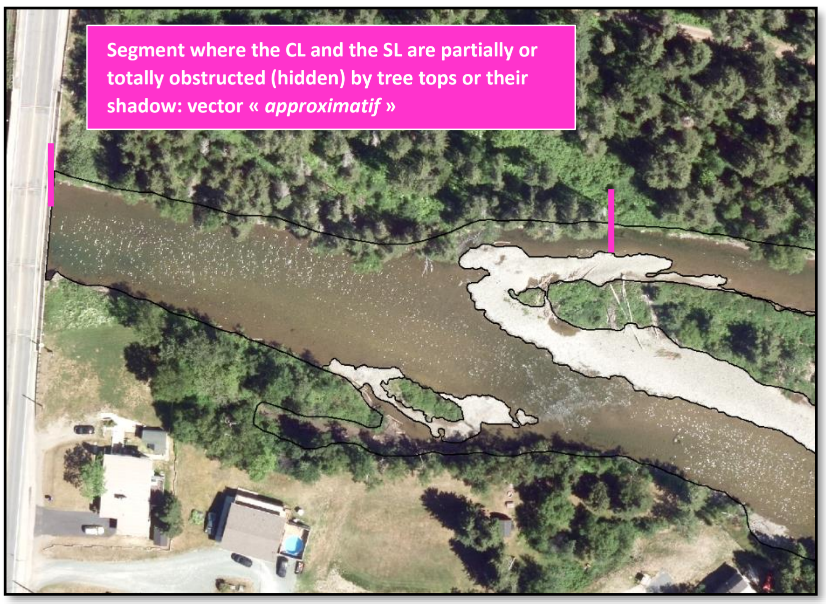


Figure 4. Example of an approximate positioning of the coastline and the shoreline.

[9] In the attribute table, these vectors are clearly identified by the suffix "_*Approx*" (meaning that the position of the vector is not certain, but rather estimated).

IV.II. Measuring coastline displacement

IV.II.I. Calculating annual rates

The mean annual shoreline displacement rates were calculated along 653 transects placed perpendicular to a baseline and 30m apart along the seafront of Chaleur Bay (Nigadoo, Salmon Beach and Janeville sub-sectors), all generated via the *DSAS* module (*Digital Shoreline Analysis Software*) of the United States Geological Survey (*ArcGIS* extension). This module measures, along each of the transects, the distance between two positions of the coastline in time and divides this distance by the number of years considered (see THIELER *et al*., 2009 for a detailed description of the operation of the *DSAS* module).[10] This procedure is consistent with the method used by the New Brunswick DNRED. The potential position of the coastline in 2050 and 2100 can then be projected (see subsection *IV.IV. - Scenarios for the future location of the coastline*).

IV.II.II. Calculating the margin of error

Measuring a distance between two vectors in a geographic information system (GIS) has a quantifiable margin of error. The following three (3) variables are part of the calculation of the margin of error:

a) The difference in the positioning (**P**) of georeferenced aerial photos compared to recent orthophotographs (2018 or 2020): this error is expressed by the root mean square (RMS), calculated by the GIS from the differences in location of control points.

b) The size of the pixel (**TP**) of georeferenced aerial photos and recent orthophotographs (2018 or 2020): from 0.22m to 0.41m for photos from 1944 or 1985, and from 0.1m for the 2018 series and 0.2m for the 2020 series. It determines the minimum size of the details that can be reliably identified on the photographs.

[10] Two main outputs are generated by *DSAS* and used in this work: The **Net Shoreline Movement** (NSM), which corresponds to the distance between two shorelines, expressed in meters; the **End Point Rate** (EPR), which is the ratio between the distance measured and the period considered, expressed in m/year.

c) The quality of the identification (**QC**) of the mapped elements (cartographer error): 2m for the 1944 photos, 1m for the 1985 photos, and 0.5m for the recent orthophotographs (2018 and 2020). It is influenced by the size of the pixel on the ground, but also depends on the expertise of the cartographer and the visual quality of the photograph.

ME (margin of error) = **P** (*RMS*) + **TP** (size of the pixel) + **QC** (quality of the mapping)

For example, at transect 57 in the Nigadoo sub-sector, the maximum margin of error associated with the measurement of the distance between the position of the 1944 CL and that of the 2018 CL is 4.27m calculated as:

(1) 1.3m (georeferencing RMS of photo A7365-1) + (2) 0.37m + 0.1m (pixel size of photo A7365-1 and 2018 orthophoto) + (3) 2m + 0.5m (work of the photo-interpreter) = **4.27m**. So, at transect no 57 there is a total setback of -20.42 ±4.27m.[11]

Carried over to the period 1944 - 2018 (74 years), this margin of error is **± 0.06m/year**, so at transect no 57 there is an average annual decline of -0.28 ±0.06 m/yr.

[11] This result meets the precision of less than 5m indicated in the *RFP No: PL2020-01* for the positioning of the 1944 vectors: 0.92m (average RMS, 1944 photos) + 0.31m (average pixel size, 1944 photos) + 0.2m (pixel size, 2020 orthophoto) + 2m (work of the photo interpreter, 1944 photos) = **3.43m**. Less than 4 m for the 1985 vectors: 0.87m (average RMS, 1985 photos) + 0.27m (average pixel size, 1985 photos) + 0.2 m (pixel size, 2020 orthophoto) + 1m (work of the photo interpreter, 1985 photos) = **2.34m**. Less than 3 m for the vectors of 2018 or 2020: 0.1m or 0.2m (pixel size 2018 or 2020), 0.5m (work of the interpreter) = **0.6m** to **0.7m**.

Any distance (or rate) greater than the margin of error is considered significant (there is erosion and retreat of the CL or there is advance and progradation of the CL), while any distance (or rate) equal to or less than the margin of error is considered as apparent stability (non-"significant" displacement of the CL).

IV.III. Results

IV.III.I. Nigadoo sub-sector

The coast of the Nigadoo sub-sector (~2.2km) corresponds to unconsolidated cliffs less than 6 meters high; a narrow sandy beach (usually less than 10 meters in width) may be present at their base. Observation of the available aerial images, especially the most recent series (2018), shows that parts of the foreshore consist of a rock platform which is in places covered with a thin sand veneer. Many coastal protection structures, mainly riprap and concrete walls, are now built at the foot of unconsolidated cliffs. This trend towards the hardening of the coast is quite recent, starting in all probability in the late 1990s (DIOUF, 2019).[12] A low vegetated sand spit (~260m in length, ~30m in width and ~3.5m maximum elevation) is present at the mouth of the Nigadoo River; it partially closes a small estuary. The latter is marked by alluvium banks, sometimes vegetated.

The coastline (CL) was mapped for the three study years (1944, 1985, 2018) in the Nigadoo sub-sector. During the last 74 years (1944-2018), cliffs not protected by structures have retreated by -11.13 ±4.27m/yr, i.e. a rate of **-0.15 ±0.06m/yr** (Table 2). During the period 1944-1985, characterized by the absence of protection structures at the coast, the CL along the unconsolidated cliffs retreated on average by -9.8 ±5.8m, i.e. a rate of -0.24 ±0.14m/yr. During the period 1985-2018, marked by the development of numerous protection structures at the base of the cliffs, the CL in sectors that remained natural retreated on average by -5.93 ±2.73m, i.e. a rate of -0.18 ±0.08m/yr.[13] In 2018, ~70% of the coasts made

[12] An article on this subject has just been accepted in the journal *Vertigo* entitled: *Impacts des structures rigides de protection sur la côte néo-brunswickoise de la baie des Chaleurs au Canada* (DIOUF, BÉRUBÉ and ROBICHAUD - authors). Its publication is scheduled for 2022.

[13] See Map Plates 1A, 1B, 1C prepared by DIOUF *et al*. (2019a) for erosion rates over the 1934-2018 period, available at DNRED (http://dnr-mrn.gnb.ca/ParisWeb/PublicationSearch.aspx).

up of unconsolidated cliffs were hardened by protection structures in the Nigadoo sub-sector (Figure 5).

Table 2. Historical evolution (1944-2018) of the coastline of the Nigadoo sub-sector (including the trends of the intermediate periods of 1944-1985 and 1985-2018).

Unconsolidated Coast

	1944-2018 (74 years)			1944-1985 (41 years)			1985-2018 (33 years)		
Observed Trend	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Advance of the coastline	0	-	-	0	-	-	0	-	-
Apparent stability	3 (5%)	-3.60 ± 4.27	-0.05 ± 0.06	29 (45%)	-2.99 ± 5.80	-0.07 ± 0.14	3 (5%)	-0.54 ± 2.73	-0.02 ± 0.08
Retreat of the coastline	17 (26%)	-11.13 ± 4.27	-0.15 ± 0.06	**36 (55%)**	-9.80 ± 5.80	-0.24 ± 0.14	17 (26%)	-5.93 ± 2.73	-0.18 ± 0.08
Transects along protection structures	**45 (69%)**	-1.95 ± 4.27	n.a.	0	-	-	**45 (69%)**	+4.82 ± 2.73	n.a.

Sand Spit Coast

	1944-2018 (74 years)			1944-1985 (41 years)			1985-2018 (33 years)		
Exposition	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Bay-facing	10 (59%)	-1.72 ± 4.27	-0.02 ± 0.06	10 (59%)	+0.32 ± 5.80	+0.01 ± 0.14	10 (59%)	-1.42 ± 2.73	-0.04 ± 0.08
Estuary	7 (41%)	-0.85 ± 4.27	-0.01 ± 0.06	7 (41%)	-0.60 ± 5.80	-0.01 ± 0.14	7 (41%)	-0.32 ± 2.73	-0.01 ± 0.08

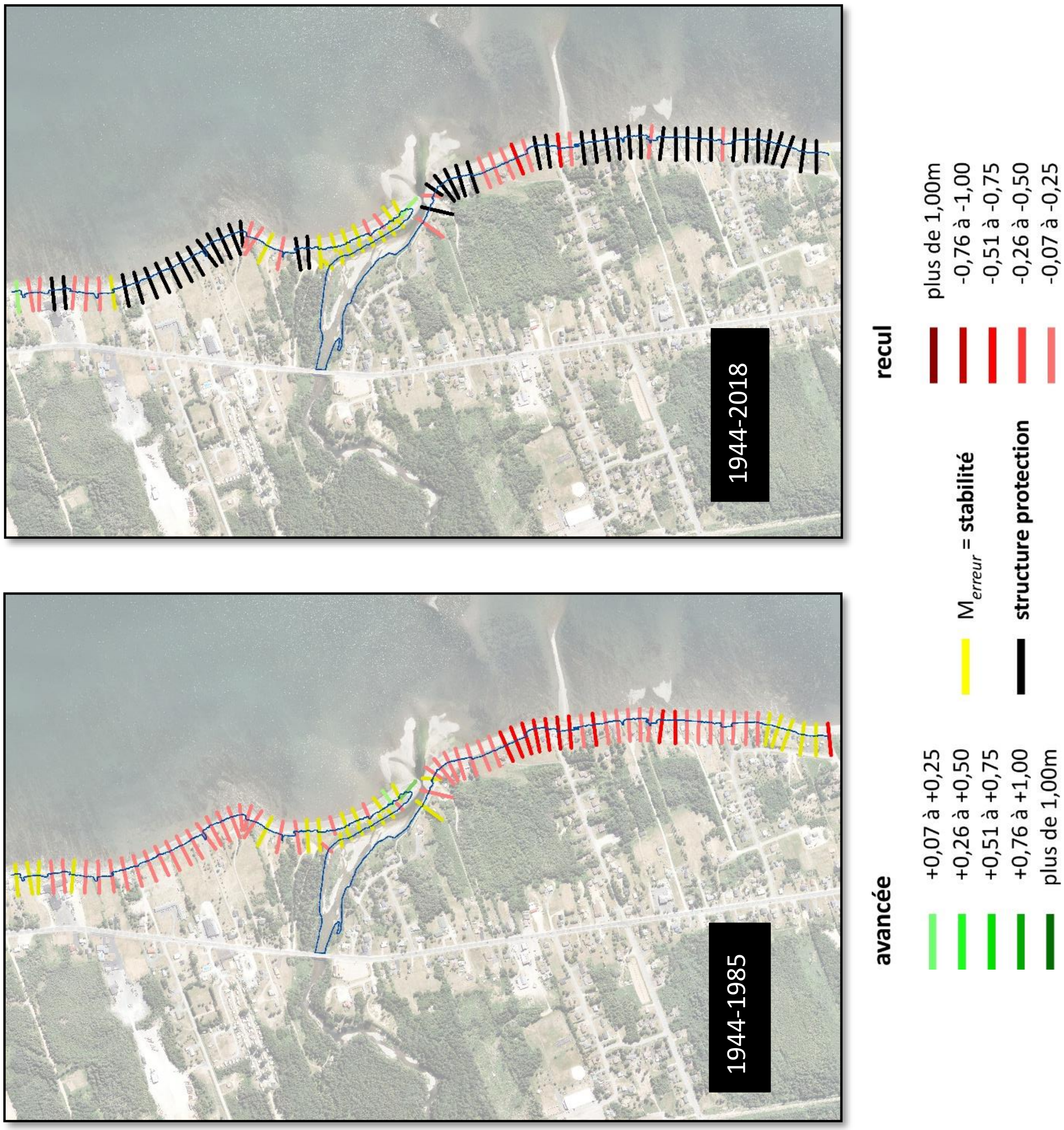


Figure 5. Coastline retreat rates in the Nigadoo sub-sector: 1944-1985 and 1944-2018.

IV.III.II. Salmon Beach sub-sector

The coast of the Salmon Beach sub-sector (~6.5km) corresponds to unconsolidated cliffs less than 6 meters high in its western part, and to low coastal dunes in its northeastern part. Three short and low sand spits are present on the coast and partially close the mouth of estuaries, where three watercourses in the sub-sector empty. Over the entire study period, we note the presence of a riprap protection structure along the main coastal road. In 1944, this structure was ~780m long, while in 2020, the riprap was increased and extended at both ends to a total length of ~1.1km. The almost natural coast of yesteryear (period 1944-1985) is characterized today by the development of protection structures, both at the base of the unconsolidated cliffs of the western part and in front of the coastal dunes of the northeastern part.

The CL was mapped for the three study years (1944, 1985, 2020) in the Salmon Beach sub-sector. During the last 76 years (1944-2020), unconsolidated cliffs not protected by structures have retreated by -25.39 ±4.50m/yr, or a rate of **-0.34 ±0.06m/yr** (Table 3).

During the period 1944-1985, characterized as "natural" (except for the protection structure in front of the road), the CL along the unconsolidated cliffs receded on average by -15.32 ±6.02m, i.e. a rate of -0.38 ±0.15m/yr. During the 1985-2020 period, marked by the development of numerous protection structures at the base of the cliffs, the CL in natural sectors retreated on average by -11.27 ±2.92m, i.e. a rate of -0.33 ±0.08m/yr. During the last 76 years (1944-2020), the areas of coastal dunes not protected by structures were mostly stable (-0.23 ±4.50m/yr, i.e. a rate of 0 ±0.06m/yr) (Table 3), which was also the case during the period 1944-1985. During the period most recent period 1985-2020, the dune CL retreated on average by -9.54 ±2.92m, i.e. a rate of -0.28 ±0.08m/yr.[14] In 2020, ~50% of the coastline of the Salmon Beach sub-sector is hardened by protection structures (Figure 6).

[14] See Map Plates 3A, 3B, 3C, 4A, 4B, 4C prepared by DIOUF *et al*. (2019b,c) for erosion rates over the 1934-2012 period.

Table 3. Historical evolution (1944-2020) of the coastline of the Salmon Beach sub-sector (including the trends of the intermediate periods of 1944-1985 and 1985-2020).

Unconsolidated Coast

	1944-2020 (76 years)			1944-1985 (41 years)			1985-2020 (35 years)		
Observed Trend	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Advance of the coastline	0	-	-	0	-	-	0	-	-
Apparent stability	1 (1%)	-1.78 ± 4.50	-0.02 ± 0.06	6 (5%)	-2.58 ± 6.02	-0.06 ± 0.15	0	-	-
Retreat of the coastline	48 (36%)	-25.39 ± 4.50	-0.34 ± 0.06	**96 (74%)**	-15.32 ± 6.02	-0.38 ± 0.15	45 (35%)	-11.27 ± 2.92	-0.33 ± 0.08
Transects along protection structures	**85 (63%)**	-5.62 ± 4.50	n.a.	28 (21%)	+9.22 ± 6.02	n.a.	**85 (65%)**	+1.31 ± 2.92	n.a.

Sand Spit Coast

	1944-2020 (76 years)			1944-1985 (41 years)			1985-2020 (35 years)		
Observed Trend	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Advance of the coastline	6 (7%)	+22.83 ± 4.50	+0.30 ± 0.06	21 (24%)	+8.04 ± 6.02	+0.20 ± 0.15	20 (23%)	+9.52 ± 2.92	+0.27 ± 0.08
Apparent stability	**42 (50%)**	-0.23 ± 4.50	-0.0 ± 0.06	**43 (48%)**	+0.02 ± 6.02	+0.0 ± 0.15	23 (26%)	+0.65 ± 2.92	+0.02 ± 0.08
Retreat of the coastline	22 (26%)	-22.53 ± 4.50	-0.30 ± 0.06	23 (26%)	-18.96 ± 6.02	-0.47 ± 0.15	**30 (34%)**	-9.54 ± 2.,92	-0.28 ± 0.08
Transects along protection structures	14 (17%)	-0.98 ± 4.50	n.a.	1 (1%)	+0.44 ± 6.02	n.a.	15 (17%)	+0.18 ± 2.92	n.a.

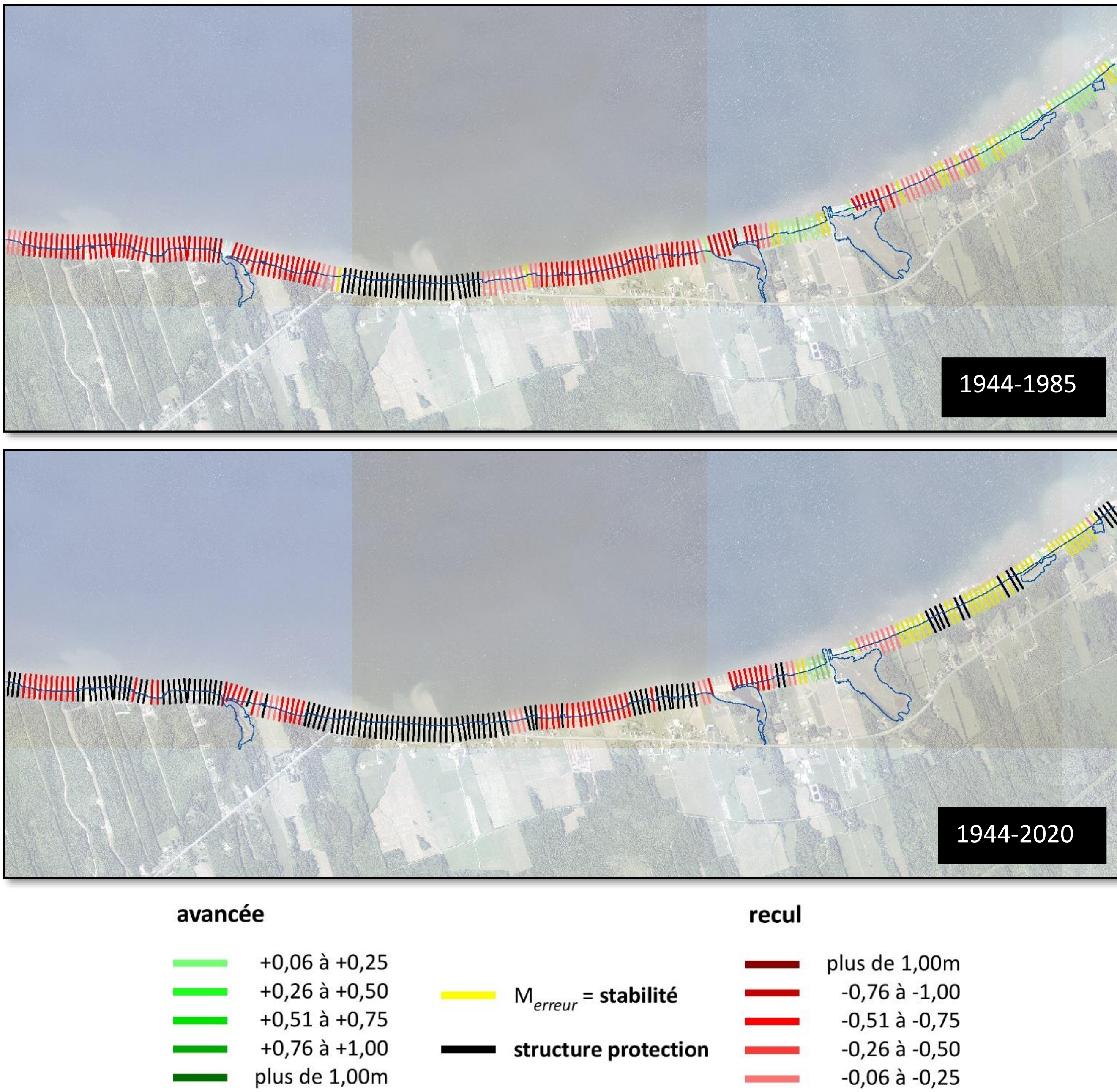


Figure 6. Coastline retreat rates in the Salmon Beach sub-sector: 1944-1985 and 1944-2020.

IV.III.III. Janeville sub-sector

The coast of the Janeville sub-sector (~8.6km) corresponds to unconsolidated cliffs less than 6 meters high in its southwestern part, and to high unconsolidated cliffs (more than 23 metres) in its northeastern part. Short and low sand spits are present on the coast and partially close the mouth of estuaries, where watercourses in the sub-sector empty. Interesting observations are to be underlined in this sub-sector, the first being the mainly natural character of the coast over the entire study period (1944-2020), except for a few riprap rock walls that appeared since 1985 in the southwestern part. The second observation, linked to the first, being that the riprap protection structures that appeared since 1985 were developed in the part of the Janeville sub-sector, where erosion rates were significantly lower (compared to the rates in the northeastern part).

The CL was mapped for the three study years (1944, 1985, 2020) in the Janeville sub-sector. During the last 76 years (1944-2020), areas not protected by structures have retreated by -19.69 ±4.08m/yr, or a rate of **-0.26 ±0.05m/yr** (Table 4).

During the period 1944-1985, where no protection structure was observed at the coast, the CL along the unconsolidated cliffs retreated an average of -14.67 ±5.48m, or at a rate of -0.36 ±0.13m/yr. During the 1985-2020 period, marked by the development of a few protection structures at the base of the unconsolidated cliffs in the southwestern part, the CL in natural areas retreated an average of -9.37 ±2.80m, i.e. a rate of -0.27 ±0.08m/yr. In 2020, more than ~92% of the coasts of the Janeville sub-sector are still evolving "naturally" (Figure 7).

Table 4. Historical evolution (1944-2020) of the coastline of the Janeville sub-sector (including the trends of the intermediate periods of 1944-1985 and 1985-2020).

Unconsolidated Coast

	1944-2020 (76 years)			1944-1985 (41 years)			1985-2020 (35 years)		
Observed Trend	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Advance of the coastline	1 (0,3%)	+9.28 ± 4.08	+0.12 ± 0.05	0	-	-	4 (1%)	+9.53 ± 2.80	+0.28 ± 0,08
Apparent stability	14 (5%)	-1.98 ± 4.08	-0.03 ± 0.05	84 (31%)	-1.79 ± 5.48	-0.04 ± 0.13	45 (17%)	-1.16 ± 2.80	-0.03 ± 0.,08
Retreat of the coastline	**226 (84%)**	-19.69 ± 4.08	-0.26 ± 0.05	**185 (69%)**	-14.67 ± 5.48	-0.36 ± 0.13	**191 (71%)**	-9.37 ± 2.80	-0.27 ± 0.08
Transects along protection structures	28 (10%)	-3.35 ± 4.08	n.a.	0	-	-	28 (10%)	+7.66 ± 2.80	n.a.

Sand Spit Coast

	1944-2020 (76 years)			1944-1985 (41 years)			1985-2020 (35 years)		
Observed Trend	**# of transects**	**Distance (m)**	**Rate (m/yr)**	# of transects	Distance (m)	Rate (m/yr)	# of transects	Distance (m)	Rate (m/yr)
Advance of the coastline	1 (6%)	+5.11 ± 4.08	+0.07 ± 0.05	2 (12%)	+9,35 ± 5.48	+0.23 ± 0.13	3 (18%)	+14.75 ± 2.80	+0.43 ± 0.08
Apparent stability	0	-	-	3 (19%)	-2.39 ± 5.48	-0.06 ± 0.13	3 (18%)	+0.83 ± 2.80	+0.02 ± 0.08
Retreat of the coastline	**14 (87%)**	-16,71 ± 4,08	-0.22 ± 0.05	**10 (62%)**	-10.57 ± 5.48	-0.26 ± 0.13	**10 (59%)**	-12.65 ± 2.80	-0.37 ± 0.08
Transects along protection structures	1 (6%)	-19,52 ± 4,08	n.a.	1 (6%)	+5.07 ± 5.48	n.a.	1 (6%)	-2.96 ± 2.80	n.a.

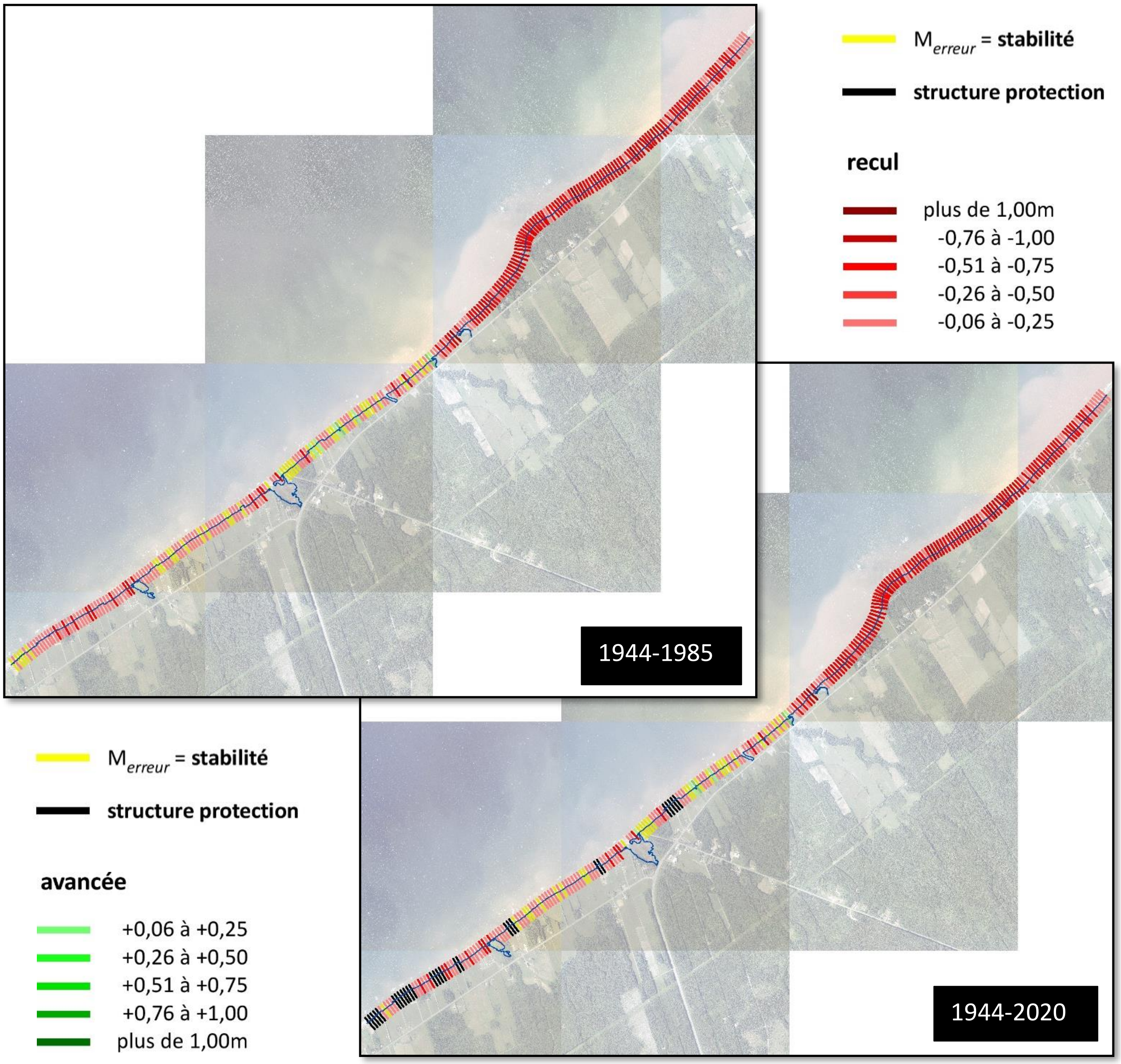


Figure 7. Coastline retreat rates in the Janeville sub-sector: 1944-1985 and 1944-2020.

IV.IV. Scenarios for the future location of the coastline

Due to the projected acceleration in relative sea-level rise for the next few decades, the rate of coastal erosion is also expected to accelerate (WONG *et al*., 2014; CROWELL, LEATHERMAN and DOUGLAS, 2018; MASSELINK *et a*l., 2020), and this is particularly the case for soft cliffs, sensitive to sea-level rise and highly erodible (BROOKS and SPENCER, 2012).

In general, it is not an easy task to predict the future position of the coastline, precisely because the future will only show its face until later (the verification of today's predictions can only be done in several decades). The other difficulty in predicting future rates of coastal displacement is that there are no immediate comparisons, as the rates of sea level rise predicted over the next century are unprecedented in the past historical periods (at least over the last two millenia), making it difficult to extrapolate historical measurements into the future. In addition, modeling the coastline retreat, particularly cliffs, requires extensive data on the physical characteristics of the coastline and marine conditions (e.g. the sediment composition of the cliffs; the volume of sand transit from littoral drift; the topography and depth of the foreshore; the significant height and direction of storm waves; etc.), the availability of which is often limited or absent. Nevertheless, approaches have been developed to illustrate the future position of the coastline, and this study borrows two of them.

IV.IV.I. "Conservative" and "Pessimistic" scenarios

To establish the scenarios for the position of the coast in the future, the 2018/2020 coastline was first redrawn, to remove the irregularities of detail (the tool "Smooth lines" in *ArcGIS*: PAEK method - Polynomial Approximation with Exponential Kernel, smoothing tolerance of 80).[15] It is this "smoothed" coastline which was subsequently moved forward (progradation) or rear (retreat) according to the calculated local displacement rates (see subsections *IV.III.I.* to *III*.). The coastal line of the three sub-sectors (Nigadoo, Salmon Beach, Janeville) was then divided into coastal segments showing a homogeneous

[15] The CL vectors initially traced at the base of the protective structures were deleted and then replaced by vectors which pass behind the structures. It was this new adjusted CL vector that was then smoothed out to remove any irregularities in detail.

evolution during the historical period 1944-2018/2020 (or 1944-1985 if the hardening of the coast was too important) (Figure 8).

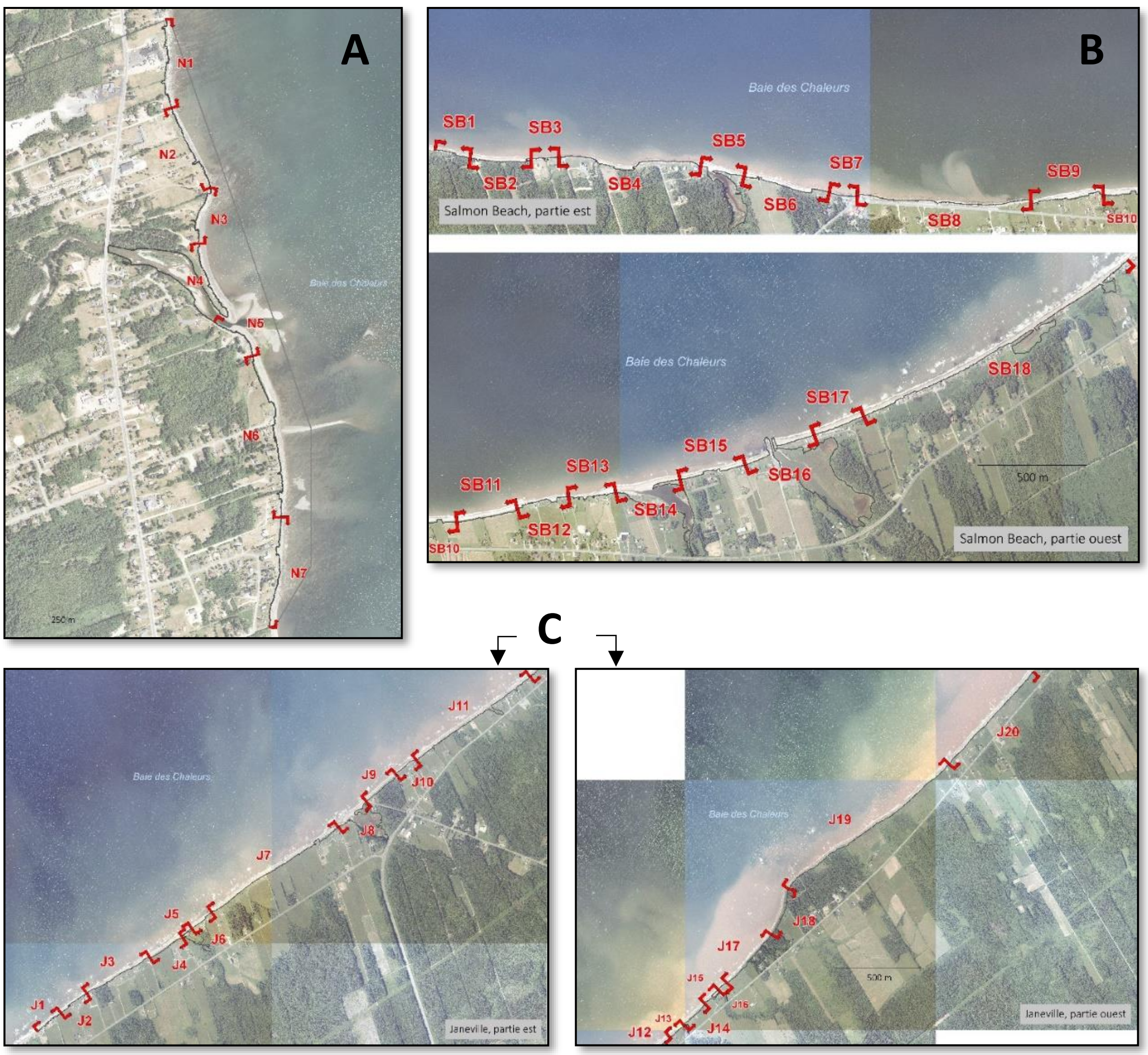


Figure 8. Sectors with homogeneous evolution in Nigadoo (A), Salmon Beach (B) and Janeville (C).

Two scenarios were prepared for the years 2050 and 2100 as part of this project: "Conservative" and "Pessimistic" (requirement included in the *Request for Proposals No: PL2020-01*). The "Conservative" scenarios are based on the average annual rates calculated from the displacement of the coast between 1944 and 2018/2020. They therefore correspond to the future (and linear) projection of the rates observed over the historical period (this approach is commonly used by the DNRED in similar projects since the 2010s). A second approach was adopted to prepare the so-called "Pessimistic" scenarios; it involves the average annual rates calculated and includes the rise in sea level (recent and future).[16]

Calculation of the projected displacement of the coastline

The "Pessimistic" scenarios are based on the interaction between the anticipated rise in sea level and the historical erosion of the coasts. Recent research in coastal erosion modeling has resulted in a simplified equation making it possible to predict or evaluate the response of the coast to the rise in sea level and therefore the possible positioning of the coastline in the future (ASHTON *et al*., 2011; MASSELINK *et al*., 2020). The future coastal retreat rate is expressed as:

$$R_{future} = R_{historical} * (NM_{future} / NM_{historical})$$

, where *R* is the rate of retreat of the coastline and *NM* is the rise in sea level for the period considered (future) and the longest period for which a rate is known (called "historical period"). Using data from the Charlottetown tide gauge (with an operating period of over 100 years) and DGPS data measuring the upward (uplift) or downward (subsidence)

[16] Other approaches are possible to develop scenarios that suggest an acceleration in the rates of displacement of the coast in response to the anticipated rise in sea level: identification of the maximum erosion rates measured during the analysis of the greatest number of aerial photograph series; project the maximum setback measured during a one-off major storm event; model shoreline response via hydrodynamic models, such as *SCAPE*. These various approaches were beyond the reach of *GLC* within the framework of this contract.

movement of the earth's crust contained in DAIGLE (2020), it is possible to estimate the relative sea-level rise in the study area.

For Zone 2 (from Belledune in the west to Grande-Anse in the east), there would have been a relative sea level rise of **10.6cm** over the last 76 years (period 1944-2020).[17] According to the projections contained in DAIGLE (2020) (based on the RCP8.5 scenario of the IPCC), the relative sea level of Zone 2 will be 18cm higher in 2050 and 60cm higher in 2100, compared to 2020.

As an example of the calculation of the projection distances of the coastline (2050 and 2100), compared to its 2020 position, according to a "Pessimistic" scenario, the homogeneous evolution sector SB6 of the Salmon Beach sub-sector is used. Between 1944 and 2020 (historical period), the unconsolidated cliffs eroded by -25.16 ± 4.69 m, i.e. a rate of retreat of **-0.33 ±0.06m/yr**.

$R_{2050} = R_{historical} \text{ x } (NM_{2050} / NM_{historical})$
$R_{2050} = -0.3m/yr \text{ x } (18cm^{18} / 10.6cm)$
$R_{2050} = -0.3m/yr \text{ x } 1.7$
$R_{2050} = -0.51m/yr$

Distance 2050: R_{2050} x 30 yrs
Distance 2050: -0.51m/yr x 30 yrs

Distance 2050: 15.3m

$R_{2100} = R_{historical} \text{ x } (NM_{2100} / NM_{historical})$
$R_{2100} = -0.3m/yr \text{ x } (60cm^{18} / 10.6cm)$
$R_{2100} = -0.3m/yr \text{ x } 5.7$
$R_{2100} = -1.71m/yr$

Distance 2100: R_{2100} x 80 yrs
Distance 2100: -1.71m/yr x 80 yrs

Distance 2100: 136.8m

By comparison, under a "Conservative" scenario, which is a linear transposition of historical rates, the 2050 coastline would be at -9 meters from its position in 2020, while it would be -24 meters in 2100. This example illustrates that the "Pessimistic" scenario projects more significant shifts in the coast than the simple transposition of historical rates

[17] Calculation of the relative sea-level rise (RSLR) for zone 2 during the 1944-2020 period: isostatic uplift = 8cm/100 years → 6.1cm/76 years. Sea level rise = 22cm/100 years → 16,7cm/76 years. **RSLR** = 16.7cm – 6.1cm **= 10.6cm/76 years**.

[18] Projections de la hausse du niveau marin relatif de DAIGLE (2020) d'ici 2050 et 2100

into the future. Table 5 shows the projected distances calculated in each homogeneous evolution sector of the study area.

Table 5. Rate of retreat of homogeneous sectors and projection of the distance of displacement of the coastline in 2050 and 2100, according to the "Conservative" and "Pessimistic" scenarios.

	Homogeneous sector	Length (m)	Nr of transects used	Retreat rate (m/yr)	Margin of error (m/yr)	Period used	Distance of displacement (m)[1]			
							Conservative scenario		Pessimistic scenario	
							2050	2100	2050	2100
Nigadoo sub-sector	N1	317.4	5	-0.11	0.06	1944-2018	-4	-9	-6	-51
	N2	304.8	10	-0.19	0.14	1944-1985	-6	-16	-10	-88
	N3	209.2	4	-0.11	0.06	1944-2018	-4	-9	-6	-51
	N4 (dune)	338.4	9	stability	0.06	1944-2018	0	0	-3	-28
	N5	174.7	4	stability	0.06	1944-2018	0	0	-3	-28
	N6	575.5	7	-0.24	0.06	1944-2018	-8	-20	-13	-111
	N7	381.5	13	stability	0.06	1944-2018	0	0	-3	-28
Salmon Beach sub-sector	SB1	161.1	5	-0.22	0.15	1944-1985	-7	-18	-11	-100
	SB2	278.3	8	-0.43	0.06	1944-2020	-13	-34	-22	-195
	SB3	126.5	4	-0.31	0.15	1944-1985	-9	-25	-16	-140
	SB4	653.6	22	-0.51	0.15	1944-1985	-15	-41	-26	-231
	SB5 (dune)	165.6	5	-0.53	0.06	1944-2020	-16	-42	-27	-240
	SB6	389.3	9	-0.33	0.06	1944-2020	-10	-26	-17	-149
	SB7	132.0	4	-0.16	0.15	1944-1985	-5	-13	-8	-72
	SB8 (wall)	785.7	26	fixed	-	-	-	-	-	-
	SB9	331.8	11	-0.17	0.14	1944-1985	-5	-14	-9	-77
	SB10	184.5	4	-0.32	0.06	1944-2020	-10	-26	-16	-145
	SB11	283.5	8	-0.33	0.06	1944-2020	-10	-26	-17	-149
	SB12	242.8	7	-0.32	0.15	1944-1985	-10	-26	-16	-145
	SB13	215.4	7	-0.44	0.15	1944-1985	-13	-35	-22	-199
	SB14 (dune)	193.1	9	-0.40	0.06	1944-2020	-12	-32	-20	-181
	SB15	284.4	6	-0.21	0.06	1944-2020	-6	-17	-11	-95
	SB16	252.1	5	stability	0.06	1944-2020	0	0	-3	-27
	SB17	245.7	8	-0.07	0.06	1944-2020	-2	-6	-4	-32
	SB18	1428.2	34	stability	0.06	1944-2020	0	0	-3	-27
Janeville sub-sector	J1	213.6	7	stability	0.06	1944-2020	0	0	-3	-27
	J2	235.2	8	-0.13	0.12	1944-1985	-4	-10	-7	-59
	J3	541.6	10	-0.15	0.05	1944-2020	-5	-12	-8	-68
	J4	275.0	9	-0.23	0.05	1944-2020	-7	-18	-12	-104
	J5 (dune)	92.6	3	-0.13	0.05	1944-2020	-4	-10	-7	-59
	J6	180.4	4	-0.15	0.05	1944-2020	-5	-12	-8	-68
	J7	1113.4	34	-0.17	0.05	1944-2020	-5	-14	-9	-77
	J8-9 (dune)	232.6	8	-0.28	0.05	1944-2020	-8	-22	-14	-127
	J10	288.8	10	-0.12	0.05	1944-2020	-4	-10	-6	-54
	J11	186.6	6	stability	0.05	1944-2020	0	0	-3	-23
	J12	1025.6	33	-0.08	0.05	1944-2020	-2	-6	-4	-36
	J13	132.3	5	stability	0.05	1944-2020	0	0	-3	-23
	J14	240.3	8	-0.13	0.06	1944-2020	-4	-10	-7	-59
	J15	146.4	4	-0.11	0.06	1944-2020	0	0	-3	-27
	J16	89.4	3	-0.13	0.06	1944-2020	-4	-10	-7	-59
	J17	529.8	16	-0.25	0.06	1944-2020	-8	-20	-13	-113
	J18	395.9	13	-0.36	0.06	1944-2020	-11	-29	-18	-163
	J19	1645.6	55	-0.46	0.06	1944-2020	-14	-37	-23	-208
	J20	985.4	33	-0.29	0.06	1944-2020	-9	-23	-15	-131

[1]The projected distance of displacement is rounded.

Comments regarding the inclusion of the results of the two scenarios

Some elements must be highlighted: first, the "Conservative" scenario assumes that the rate of evolution of the coast will be the same in the future as it was before 2020. This situation is possible, but more and more experts expect different conditions over the next century (WONG *et al*., 2014). Second, the development of a "Pessimistic" scenario (which negatively accentuates the measured evolution) was a requirement specified in the *RFP No: PL2020-01*. Finally, the relative sea-level rise anticipated for Zone 2 (and supported by the Provincial Government through the work of DAIGLE, 2020), would be **5.7 times greater** over the next 80 years than it was over the course of the past 76 years. *Géo Littoral Consultants* believes that simply taking into account the "Conservative" scenario would undoubtedly be insufficient in the context of a sustainable development approach for the coastal zone.[19] Although modeling the response of the coast to climate change remains to be perfected, we believe that the future coastal positions obtained via the "Pessimistic" scenario, which incorporates sea-level rise (observed and projected), should be discussed by those responsible for land-use planning at the Chaleur RSC.

The ultimate objective of the scenarios ("Conservative" and "Pessimistic") is to obtain an order of magnitude of the possible displacement of the coast by 2050 and 2100. In the case of the "Conservative" scenario, the assumption is that the future evolution would continue at a pace like that observed between 1944 and 2018/2020. However, the conditions that prevailed during the historical period are not likely to be the same during the next decades: in particular, it is predicted an acceleration in sea-level rise, a reduction in the period of seasonal ice cover due to warmer temperatures, a modified storm regime (different frequency and intensity) and probably an increase in the number of seasonal freeze/thaw cycles affecting rocky shores (BERNATCHEZ *et al*., 2014). The processes of coastal erosion and the retreat of the coast should logically be enhanced. The "Pessimistic" scenario has been proposed to consider these future situations, which are different from those of the recent past. These two types of scenarios make it possible to identify certain places in the study areas where current or future infrastructure developments could be exposed to erosion risks.

[19] Due to the fact that sea-level rise is integrated, the homogeneous evolution sectors which were considered stable under the "Conservative" scenario are no longer so, and were therefore projected according to the historical margin of error (0.06m/yr) in the "Pessimistic" scenario.

IV.IV.II. Reservations and caveats

In the scenarios, adjacent coastal segments that were projected at different mean displacement rates were connected to each other by arbitrarily drawn lines (Figure 9). It is important to note that both lines (the coastal segments and the vectors connecting them) should not be interpreted as a prediction of the actual position of the coast in the future.

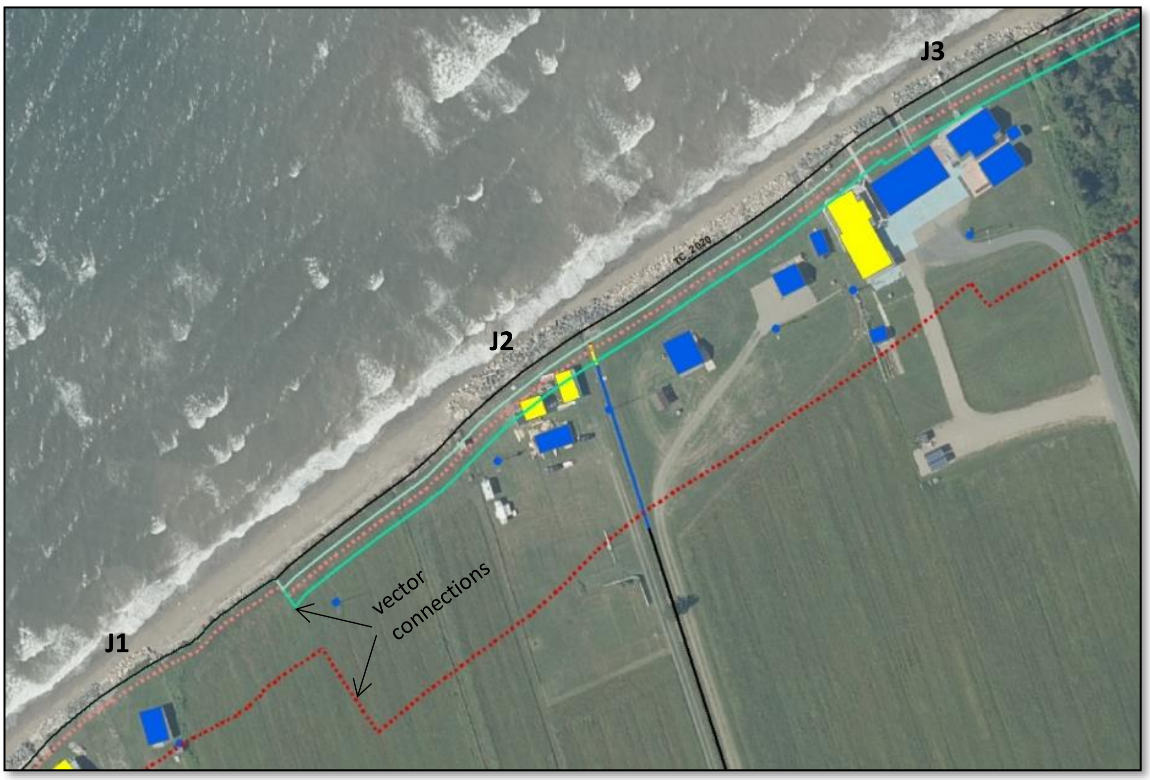


Figure 9. Examples of straight vector connection between sectors of homogeneous evolution.

IV.V. Identification of infrastructure at risk

As required in the *RFP No: PL2020-01*, *GLC* relied on the methodology used in similar projects along the north coast of New Brunswick to establish the level of risk to erosion of infrastructure located nearby the coast.[20]

The erosion risk index proposed by ROBICHAUD *et al*. (2011) makes it possible to estimate the potential for an infrastructure to be threatened by the retreat of the coast in the future (2050 and 2100 within the framework of this project). A 5-meter safety margin is added to the calculated projections. The method proposes three (3) levels of erosion risk: Rating 3, Rating 2, Rating 1.

Rating 3, which translates to an imminent risk of erosion, is defined as follows:

> "… *toute infrastructure se trouvant à 5 m ou moins du trait de côte ou de la ligne de rivage de 2018 [ou 2020]…*" (CHELBI *et al*., 2019, p. 16)

Rating 2, which translates to a risk of erosion by 2050, is defined as follows:

> "… *les infrastructures se trouvant à l'intérieur d'une zone débutant à 5m derrière le trait de côte de 2018 [ou 2020] et se terminant à 5m derrière le trait de côte projeté de 2050, se verront attribuer une cote 2. Ces infrastructures pourraient donc être en danger d'érosion d'ici 2050 et sont à surveiller prioritairement*…" (*ibid*, p. 16)

Rating 1, which translates to a risk of erosion by 2100, is defined as follows:

> "… *une infrastructure à risque de cote 1 se trouvera dans une zone définie par une ligne située à 5m derrière le trait de côte ou de la ligne de rivage de 2050 et une ligne située à 5m derrière le trait de côte ou la ligne de rivage de 2100, et sera*

[20] During the project meetings, the comparability of the results of studies carried out by the various consulting firms to determine the infrastructures at risk of erosion was a concern mentioned by the representative of the Chaleur RSC. *GLC* therefore used the same approach as CHELBI *et al*. (2019) and WSP (2020). For the details of this methodology, the reader is referred to ROBICHAUD *et al*. (2011).

> *donc considérée à risque d'érosion entre 2050 et 2100*." (*ibid*, p. 16)

All infrastructures that are beyond the projected vector of 2100 (+ the 5-meter safety setback) are considered not to be at risk of erosion before 2100, and are assigned the **Rating 0**:

> "*Les infrastructures étant situées à plus de 5m du trait de côte projeté en 2100 sont considérées comme sans risque (risque nul).*" (WSP, 2020, p. 11)

Tables 6, 7 and 8 bring together information on infrastructure at risk of erosion in the three sub-sectors studied. Note that the use of the geodatabase which is part of the deliverables will allow a better appreciation of the infrastructures at risk of erosion according to the different scenarios prepared ("Conservative" 2050 and 2100; "Pessimistic" 2050 and 2100).

Table 6. Number of infrastructures by risk index according to the type of scenario used, Nigadoo sub-sector.

Infrastructure	Total today (2018)	Type of scenario	Index 3 (current risk)	Index 2 (risk up to 2050)	Index 1 (risk between 2050-2100)	Index 0 (no risk to 2100)	*At Risk*
Buildings[1]	712	Conservative	**8**	**6**	**6**	692	*20*
		Pessimistic	**8**	**10**	**30**	664	*48*
Sanitary pipelines (m)	10058.0	Conservative	**5.5**	**10.7**	**13.5**	10028.3	*29.7*
		Pessimistic	**5.5**	**16.9**	**172.4**	9863.2	*194.7*
Pumping stations	4	Conservative	0	0	0	4	*0*
		Pessimistic	0	0	**2**	2	*2*
Communication posts[2]	336	Conservative	0	0	**2**	334	*2*
		Pessimistic	0	**4**	**31**	301	*35*
Roads (m)	21572.0	Conservative	0	0	**4.6**	21567.4	*4.6*
		Pessimistic	0	0	**293.6**	21278.3	*293.6*
Recreational trails (m)	631.85	Conservative	0	0	0	631.9	*0*
		Pessimistic	0	0	0	631.9	*0*

Table 7. Number of infrastructures by risk index according to the type of scenario used, Salmon Beach sub-sector.

Infrastructure	Total today (2020)	Type of scenario	Index 3 (current risk)	Index 2 (risk up to 2050)	Index 1 (risk between 2050-2100)	Index 0 (no risk to 2100)	*At Risk*
Buildings[1]	558	Conservative	**37**	**20**	**24**	477	*81*
		Pessimistic	**37**	**38**	**99**	384	*174*
Sanitary pipelines (m)	0	Conservative	0	0	0	0	*0*
		Pessimistic	0	0	0	0	*0*
Pumping stations	0	Conservative	0	0	0	0	*0*
		Pessimistic	0	0	0	0	*0*
Communication posts[2]	375	Conservative	0	**3**	**17**	355	*20*
		Pessimistic	0	**11**	**83**	281	*94*
Roads (m)	35463.8	Conservative	**17.5**	**89.5**	**100.4**	35135.5	*207.4*
		Pessimistic	**17.5**	**216.8**	**2643.5**	32586.0	*2877.8*
Recreational trails (m)	56156.69	Conservative	0	0	0	56156.7	*0*
		Pessimistic	0	0	0	56156.7	*0*

Table 8. Number of infrastructures by risk index according to the type of scenario used, Janeville sub-sector.

Infrastructure	Total today (2020)	Type of scenario	Index 3 (current risk)	Index 2 (risk up to 2050)	Index 1 (risk between 2050-2100)	Index 0 (no risk to 2100)	*At Risk*
Buildings[1]	659	Conservative	**5**	**12**	**19**	623	*36*
		Pessimistic	**5**	**18**	**151**	485	*174*
Sanitary pipelines (m)	0	Conservative	0	0	0	0	*0*
		Pessimistic	0	0	0	0	*0*
Pumping stations	0	Conservative	0	0	0	0	*0*
		Pessimistic	0	0	0	0	*0*
Communication posts[2]	378	Conservative	0	0	0	378	*0*
		Pessimistic	0	0	**86**	292	*86*
Roads (m)	47448.9	Conservative	**61.6**	**17.0**	**27.4**	47343.0	*106.0*
		Pessimistic	**61.6**	**28.5**	**2393.9**	44965.0	*2484.0*
Recreational trails (m)	52855.8	Conservative	0	0	0	52855.8	*0*
		Pessimistic	0	0	0	52855.8	*0*

V. Mapping the Beresford Marshes

Géo Littoral Consultants chose to retain the 2018 and 2020 orthophotographic series, as opposed to the 2016 orthophotographic series, for the "recent" mapping of the Beresford marshes for the following reasons:

- The 2018 and 2020 series were ordered for forest resource inventory purposes, while the 2016 series was ordered for property valuation purposes. The pictographic quality of the 2018/2020 series place the natural environment at the heart of its objectives (which is also the case for this study).
- The 2018 orthophotographs were taken between July 11 and August 11 and those of 2020 on July 21[21], during plant growth. The main plant species of the marshes (*Spartina alterniflora, Spartina patens, Spartina pectinata*) are more clearly identifiable because of their colors and their respective shades. In the 2016 orthophotographs (taken in two flights, on June 7 and October 4[21]), the beige color of the vegetation is predominant (periods of dormancy or outside the period of plant growth) (Figure 10).

Figure 10. Comparison of the rendering of the vegetation cover: 2016 and 2018 orthophotos.

[21] Mariette HACHEY-BOUDREAU, former GIS Technician at the Chaleur RSC (personal communication).

- The provincial coastal geomorphologist and member of RACACCCR, Dominique BÉRUBÉ, expressed reservations about the adequate positioning of the images of the 2016 series; a slight shift seems to be inherent in this series when compared to other digital orthophotographs covering this region, namely those of 2007, 2012 and those of 2018 (Figure 11).

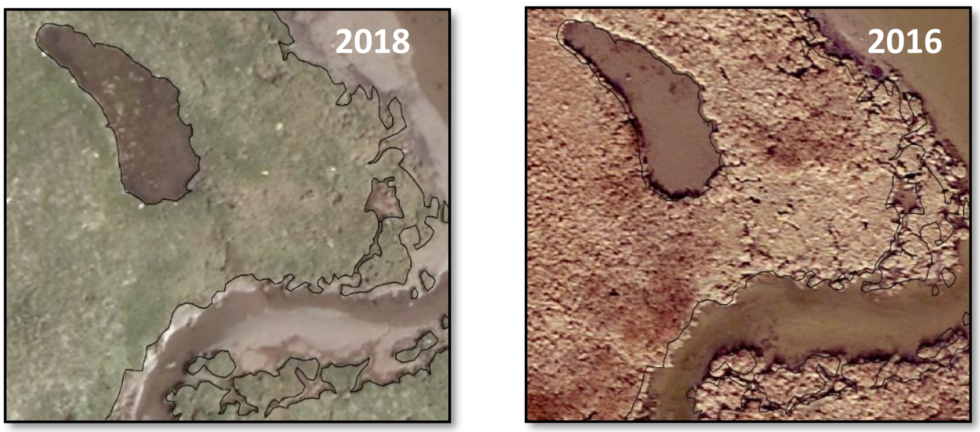


Figure 11. Slight shift of the 2016 digital orthophotography compared to the 2018.

The 2016 orthophotographic series is nevertheless useful in mapping work. Several tiles of this series were taken at high tide, which makes it possible to confirm, for example, the presence of dominant plant species (monospecific color tint) or the connection of semi-open ponds to the estuary, where the 2018 series is less categorical at this level (Figure 12). Other products were used to perform the marsh mapping, including aerial photos from 1985 and 1944 (as well as those from intervening years, when available), but also products derived from LiDAR data from 2016 and 2018 (a DEM and a shaded-relief DEM, in CGVD2013) (Figure 13).[22] The simultaneous use of several documents makes it possible to improve the interpretation of the landscape and the habitats of an environment where elevation is practically homogeneous, such as in the case of coastal marshes.

[22] These products were prepared by Mariette HACHEY-BOUDREAU, former GIS Technician at the Chaleur RSC.

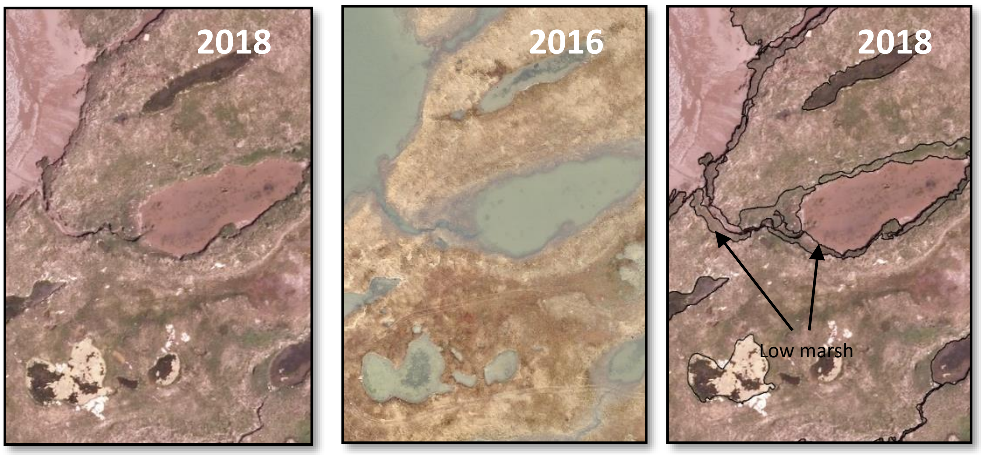


Figure 12. Use of the 2016 digital orthophoto to confirm and to adjust the boundaries of the low marsh observed on the 2018 orthophoto.

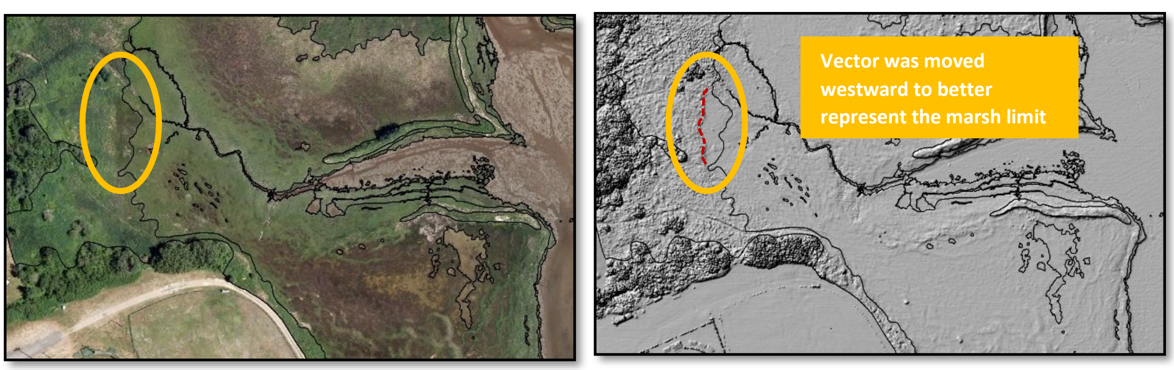


Figure 13. Use of a shaded-relief DEM to adjust the mapping of the coastline (limit of the high marsh and the brackish transitional marsh) observed on the 2018 orthophoto.

V.I. Main Marsh Characteristics

On a landscape scale (larger than the site and smaller than the region), coastal marshes thrive and are often found in places where the action of storms and energetic waves is attenuated, mainly along low energy coasts, in estuaries and shallow bays or behind barrier islands or sand spits, where these features offer protection against the energetic conditions found in the open sea. Coastal marsh development is enhanced when wind and wave conditions favor fine sediment build-up, and the substrate (underlying geology) is conducive to the development of flat surfaces within the intertidal zone.

In their 2014 publication, ROGERS and WOODROFFE propose a classification of temperate zone coastal marshes based on their physical context. Although the Beresford marshes only extend over ~6 kilometres of coastline, it is possible to recognize three of these marsh types: the "deltaic" type (b), the "estuarine" type (c) and the "back-barrier" type (d) (Figure 14). The deltaic type includes marshes that develop on small islands of alluvium deposited at the contact zone between the fluvial part and the estuarine part of a watercourse. The Millstream River and Grants Creek marshes are examples of deltaic marshes (see subsection *V.III.II.*). The estuarine type includes marshes that develop at the edge of estuaries thanks to inputs of fine sediments or along the banks of lagoons, the mouth of which is partially or intermittently closed by sandy spits. The central portion (which represents most of the Beresford marshes) corresponds to estuarine marshes. The back-barrier type corresponds to marshes developed in the concave part located between the terrestrial and the coastal environment, a portion of territory protected from the onslaught of the sea by a sandy spit or a barrier island. The northern part (behind the Beresford public beach and south of Chalets Street) and the southeast part (west of Jacques-Cartier Street, towards Youghall Beach) are examples of back-barrier marshes. Subsection *V.III. - Presentation of the results*, below, will allow us to recognize the different types of coastal marshes present in the Beresford sub-sector.

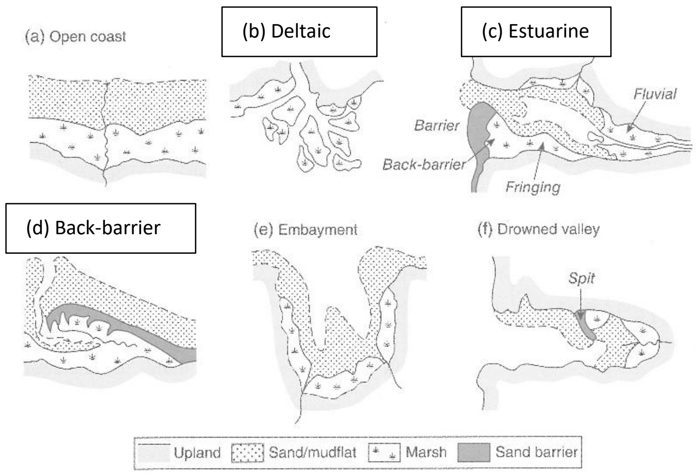


Figure 14. Classification of temperate marshes (ROGERS and WOODROFFE, 2014).

There are several names to describe the low, flat, humid lands near, and influenced by, the sea: salt marshes, tidal marshes, saline wetlands, coastal marshes. In this work, we use two terms to refer generally to coastal wetlands: 1) **salt marsh**, and 2) **coastal marsh** (Figure 15).

<u>The salt marsh is the vegetated portion of wetlands influenced by the monthly tide</u>. The plant species found there are called halophytes, they are adapted to live in a salty environment (soil and water). The salt marsh corresponds, on the "sea" side, to the edge of the vegetation, while on the "land" side, it stops at the limit reached by the monthly high tide, also called the *Higher high water, large tide* (HHWLT).[23] The salt marsh consists of two zones, defined according to the dominant plant species: the low marsh and the high marsh. The low marsh often forms a narrow strip along the seaward edge, inundated at each high tide. It is often made up of a single plant species, the saltwater cordgrass (*Spartina alterniflora*); sometimes we also find samphire green (*Salicornia europea*).[24] The larger and more extensive high marsh is at a slightly higher elevation, and is flooded

[23] According to the NB DNRED, here are the altimetric levels (CGVD2013) for the Beresford lagoon/estuary complex: +0.8m (HHWLT); +0.3m (HHWMT); -0.6m (MSL); -1.2m (LLWMT); -1.7m (LLWLT).

[24] As part of field campaigns in 2015 and 2016, KALACSKA *et al*. (2017) characterized the vegetation of the Beresford, Youghall and Pointe Carron marshes.

only a few times a month, at the time of the astronomical high tide. The high marsh is dominated by the saltmeadow cordgrass (*Spartina patens*), but the vegetation cover is nevertheless diversified: sea lavender (*Limonium sp*.), Maritime plantain (*Plantago maritima*), sea arrowgrass (*Triglochin maritima*), samphire green (*Salicornia europea*), puccinellia (*Puccinellia paupercula*), seepweed (*Suaeda maritima*), and goldenrod (*Solidago sempervirens*) can be found there.[24]

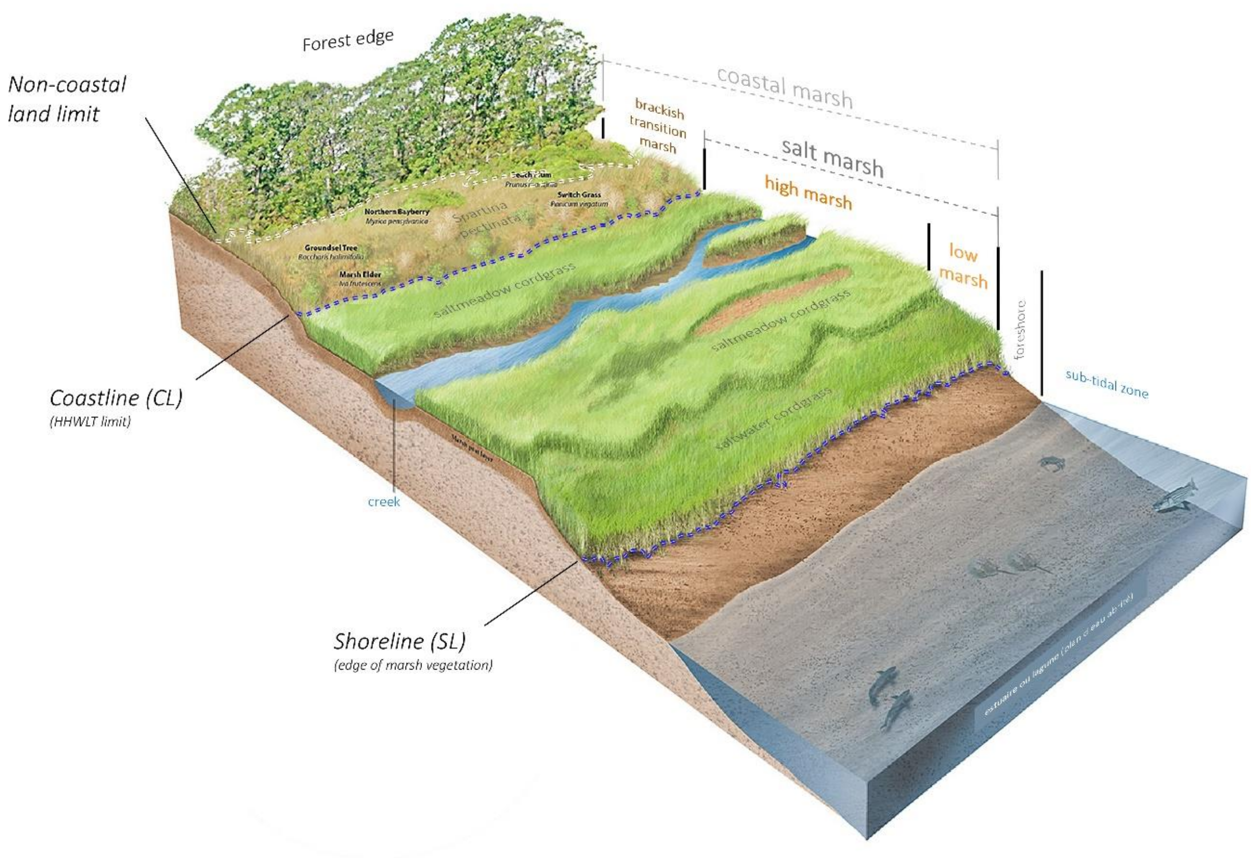


Figure 15. Main divisions and habitats of the coastal marsh (modified from P.J. Lynch, 2017).

Between the salt marsh and the non-coastal lands (often the forest edge) lies the brackish transition marsh. This wetland strip is slightly higher than the high marsh and its soil is less saline. The main plant found there is the prairie cordgrass (*Spartina pectinata*), to which can be added the Baltic rush (*Juncus balticus*), blackgrass (*Juncus gerardii*), cattail (*Typha latifolia*), common reed or phragmite (*Phragmites australis*), and sometimes low shrubs signaling the beginning of the non-coastal lands. <u>The combination of the salt marsh (low marsh and high marsh) and the brackish transition marsh constitutes the coastal marsh</u> (Figure 16).

Figure 16. Positioning of the main vectors of the coastal marsh (Peters River estuary).

V.II. Cartographic Legend

The different elements recognized and mapped in the Beresford coastal marshes for the three years studied (1944, 1985, 2018/2020) are presented in Appendix A – *Map Legend*. It is a key to the interpretation of polygons, including their representation - color and raster - in the prepared maps and the shape files delivered, and presented in the form of a summary explanatory note.

Once the coastal marsh mapping was completed and validated, the vector (polyline) shapefile was transformed into a polygonal (polygon) shapefile. It was from the latter that the habitats of the marsh were "created" and that surface area statistics were extracted for each of the years of mapping (1944, 1985 and 2018/2020). This made it possible to draw up an evolving portrait of the coastal marsh habitats of the Beresford sub-sector.

V.III. Presentation of the results

Results for the entire Beresford sub-sector

As part of the project, ~585km of vectors was mapped in the coastal marshes of the Beresford sub-sector for the years 1944, 1985 and 2018/2020 (Figure 17).

The recent portrait of the Beresford salt marshes (2018-2020) shows that there is a little over 52km of marsh front (edge of low marsh or high marsh) in contact with the lagoon or with the estuarine portions of the water (Table 9). The tidal creeks (natural streams that carry high tide and drain the marsh at low tide) of the Beresford marshes are meandering, often narrow, and of varying length. Their number totals 303 for an approximate shoreline length of ~25km; they cover 1.4ha. They constitute the connection between the sea and the semi-opened ponds of the high marsh: the latter are filled at high tide and drained at low tide thanks to the creeks. A total of 314 semi-opened ponds (covering 5.6ha) of different size and shape were counted on the 2018/2020 aerial images, the largest being 3,485m^2. The length of the coastline associated with these bodies of water represents ~18.6km.

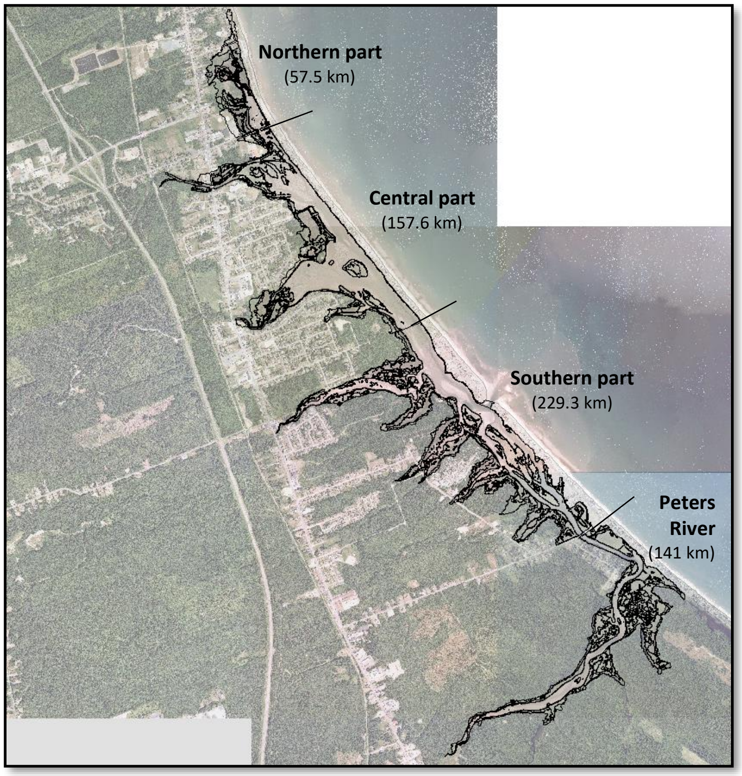


Figure 17. Extent of coastal marsh mapping, major divisions of the Beresford sub-sector, and total length mapped (1944, 1985 and 2018/2020).

Table 9. Length (m) of the main features of the Beresford salt marshes mapped for the year 2018/2020.

Vector name	Description	Length (m)
LR_drain	Shoreline (HHWMT) along a drainage ditch, influenced by the tide	1,271.0
LR_étier	Shoreline (HHWMT) along a natural tidal creek, influenced by the tide	24,776.2
LR_marais	Shoreline (HHWMT) along the edge of the low or the high marsh, in contact with the sea	52,067.6
LR_ms-ouverte	Shoreline (HHWMT) along a pond in the marsh, influenced by the tide	18,645.6
	Length of the shoreline associated to a marsh in 2018 / 2020	***96,760.3***
TC_champ	Coastline (HHWLT) representing the contact between the high marsh and a field	486.0
TC_drain	Coastline (HHWLT) along a drainage ditch, influenced by the tide	571.9
TC_étier	Coastline (HHWLT) along a natural tidal creek, influenced by the tide	1,095.1
TC_friche	Coastline (HHWLT) representing the contact between the high marsh and a new growth forest	56.0
TC_marais	Coastline (HHWLT) representing the contact between the high marsh and the transition marsh	25,474.8
TC_remblai	Coastline (HHWLT) representing the contact between the infill zone and the high marsh	3,138.8
	Length of the coastline associated to a marsh in 2018 / 2020	***30,822.6***

As mentioned above, the coastline corresponds to the higher high water large tide (HHWLT), and in the context of a salt marsh it reflects the contact between the high marsh and the brackish transition marsh. In the study area, the coastline associated with the marsh is ~25.5km. Other types of coastlines have been identified in the marshes, in particular a coastline corresponding to the contact between a high marsh and an embankment zone (~3km linear). This situation is found especially in the northern and central parts, where, since 1985 (ironically, it corresponds to the start of enactments of provincial legislation to protect wetlands), portions of marshes have been backfilled to make way for real-estate or recreational developments: for example, the artificial surface area of the marshes in the central part of the Beresford sub-sector increased by 218% over the period 1985-2018 (Figure 18).

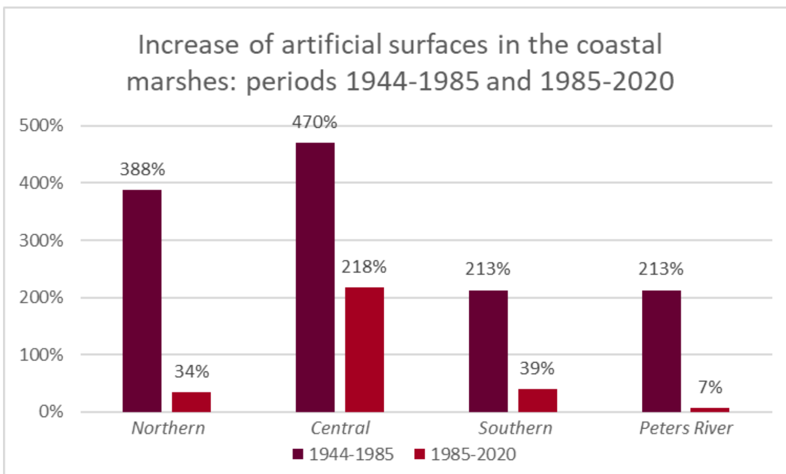


Figure 18. Percentage increase in artificialized surfaces in the coastal marshes of the Beresford sub-sector: periods 1944-1985 and 1985-2018/2020.

The coastal marshes of the sub-sector covered 164.6ha in 1944, and today they cover 145.4ha, **a decrease of 11.7%** (Figure 19).[25] In order to better understand how the decrease

[25] Our results differ from those of HACHEY, BÉRUBÉ and EVANS (2004), produced under a contract commissioned by the Town of Beresford in 2003. This study concluded that there was a loss of 2% in salt marsh surface area over the period 1934-2002 (150.7ha in 1934 compared to 147.9ha in 2002). Singular methodological approaches are at the origin of this notable difference in the results of the two studies.

in area of coastal marshes is distributed, the two main habitats of coastal marshes have been distinguished, namely the salt marshes (or tidal marshes, regularly subject to the influence of the tide) and the brackish transition marshes (wetlands located between salt marshes and non-coastal lands) reached irregularly by the sea, during high tides and storm surges. The salt marshes of the Beresford sub-sector dropped-off from an area of 128.9ha in 1944, to 122.8ha in 1985, to 119.9ha in 2018/2020, representing a decrease of 7% between 1944 and 2018/2020. The brackish transition marshes, for their part, dropped-off from 35.7ha in 1944, to 31.5ha in 1985, to 25.6ha in 2018/2020, representing a decrease of 28.5% between 1944 and 2018/2020.

The area occupied by all types of development identified in the coastal marshes increased from 1.8ha in 1944 (mainly dykes), to 7.8ha in 1985 (mainly embankments and roadways for vehicles), to 13.4ha in 2018/2020 (mainly embankments, roadways for vehicles and transformations from "salty" to "freshwater" environments), an area increase of 11.6 ha since 1944. The histogram of the figure 18 (above) shows that the older period (1944-1985) was marked by a greater proportion of increase in artificialized marshland surfaces than the recent period (1985-2018/2020). This change in trend is the result of two very different situations:

a) the small artificialized area in the starting year (1944) which resulted in huge percentages of change (213% to 470%) over the period 1944-1985.

b) the enaction in the following period (1985-2018/2020) of laws, regulations and policies aimed at the protection of wetlands (*Clean Water Act, 1989*; *Watercourse and Wetland Alteration Regulation, 90-80*; *Coastal Zone Protection Policy, 2002*; *Wetlands Conservation Policy, 2002*) seems to have had an effect of slowing down the artificialization of the marshes (relatively small increases for the Northern, Southern and the Peters River parts, and very strong increase in the Central part +218%).

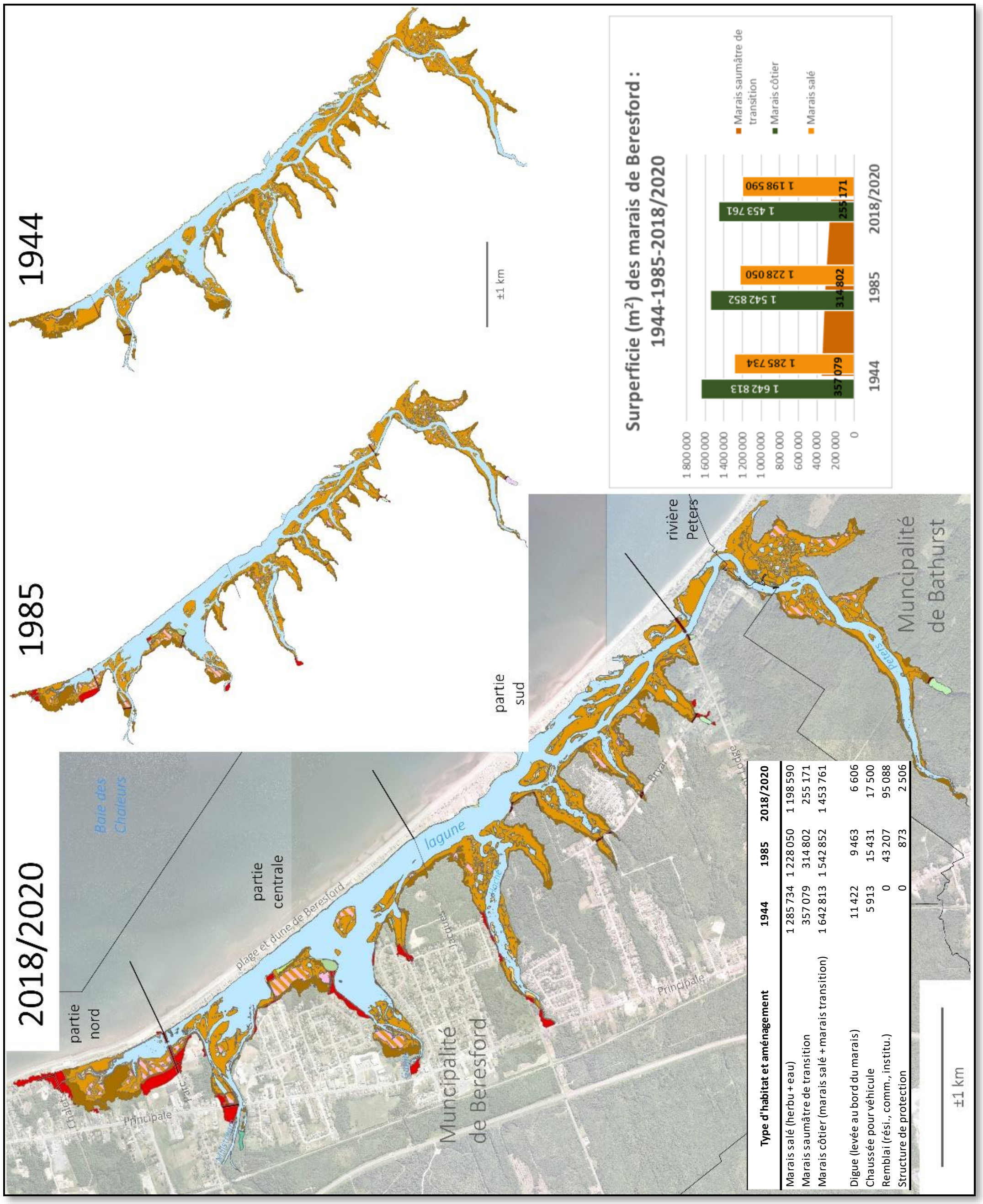


Figure 19. Mapping and area of coastal habitats in the Beresford sub-sector for the years 1944, 1985 and 2018/2020.

The results according to the four parts of the Beresford sub-sector

The decreases (surface area of coastal marshes) and increases (surface area of human intervention) documented show geographic variability. Indeed, the organization of the data according to the four (4) parts of the Beresford sub-sector shows that since 1944, the decline of the coastal marsh has mainly occurred in the Northern and Central parts (-23% and -20 %) and that it is in these same two sectors that the decrease in the brackish transition marsh, which naturally constitutes the accommodation space on which the high marsh can migrate with the rise in sea level, is the most significant over the last 74 years (-30% in the Northern part; -49% in the Central part) (Figure 20). In addition, the largest increases in artificialized areas have been recorded in the Northern and Central parts of the Beresford sub-sector.

In contrast, the Southern part and the Peters River estuary have experienced similar evolutionary trends, but much less significant. In the Southern part, the area occupied by the coastal marsh has decreased by 8% since 1944, and the brackish transition marsh has experienced the greatest decrease, with a loss of 15% (compared to a decrease of 7% for the salt marsh). Artificial surfaces in the Southern part have more than quadrupled since 1944, but they remain half as large as those in the Northern and Central parts (Figure 21). The Peters River Estuary is the part of the Beresford sub-sector where changes since 1944 have been least significant. The coastal marsh of the Peters River (including the salt marsh and the brackish transition marsh) has experienced a slight decrease over the past 76 years (1944-2020), i.e. an area loss of 4.7%. The "natural" character of the banks of the estuary and the remoteness of the marsh infrastructure undoubtedly play a role in the small loss of surface area of the coastal marshes: it is here that the artificial surface in the marsh is the least important compared to the three other parts of the Beresford sub-sector (5.35X smaller), and even seems to have leveled-off since 1985 (9,236m^2 vs 9,836m^2 in 2020).

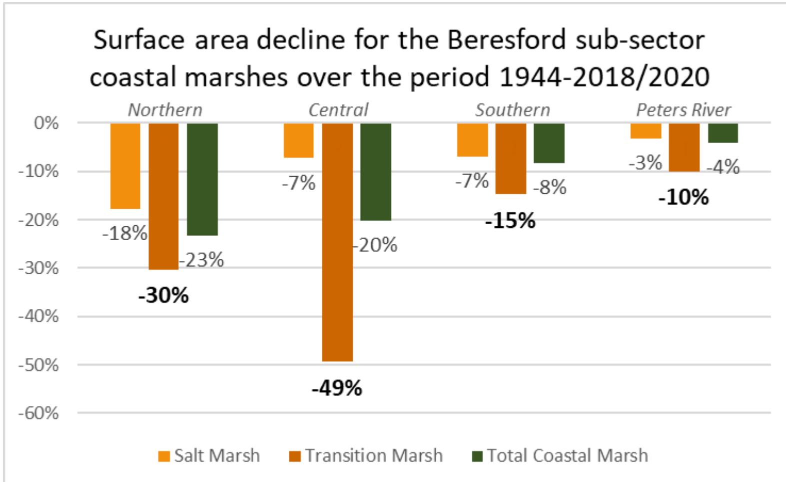
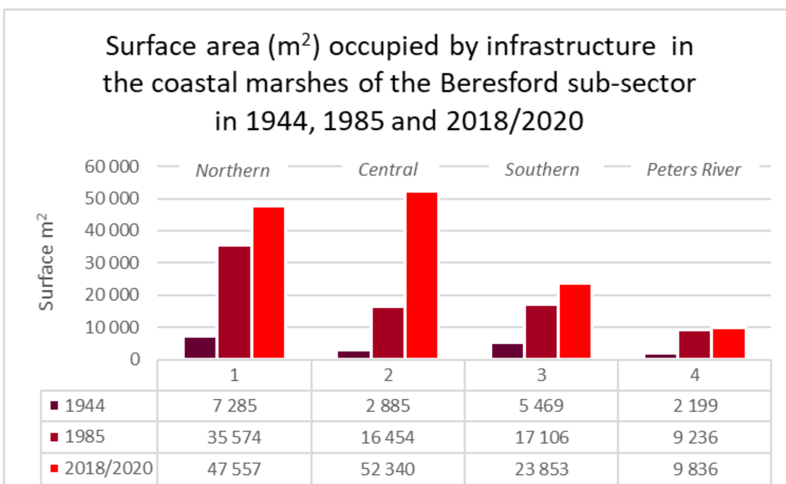


Figure 20. Percentage decrease in the area occupied by the marshes over the period 1944-2018/2020, in the four (4) parts of the Beresford sub-sector.



	1	2	3	4
1944	7 285	2 885	5 469	2 199
1985	35 574	16 454	17 106	9 236
2018/2020	47 557	52 340	23 853	9 836

Figure 21. Increase in artificialized surfaces (m^2) in the marshes in 1944, 1985 and 2018/2020, in the four (4) parts of the Beresford sub-sector.

V.III.I. The Northern part of the Beresford sub-sector

In the Northern part of the Beresford sub-area, there is 17.8% less salt marsh in 2018 than there was in 1944 (10.3ha versus 8.5ha) (Figure 22, Table 10).

The low marsh surface area increased by a factor of 2.55, from 0.3ha in 1944 to 0.9ha in 2018, while the area occupied by the high marsh decreased by 35% over the same period (9.7ha to 6.3ha). The reduction in the span of the bridge leading to the beach and the dune of Beresford, along Parc E Street, over the lagoon (103m in 1944 vs 20.7m in 2018) to make it a partial causeway somewhere before 1985, could have favored the development of the low marsh in the upper reaches of the lagoon (restricted propagation of the tidal wave) - a more in-depth study of the impacts of the new bridge would be required.

The presence of water on the surface of the salt marsh has more than quadrupled in 74 years, from 0.3ha to 1.3ha. This notable increase should be put in context as it could be attributable to the quality of the aerial photos used in relation to the type of landform mapped: 2018 excellent visual quality; 1985 good visual quality; 1944 lower visual quality. Images from 1985 and 2018 showed several sites of reticulated marshes, which were not visible on the 1944 aerial photos. The ditches (artificially dug drainage canals) appeared operational on the aerial photos of 1944 and covered an area of 984m^2; in 2018 most of them seemed abandoned (not maintained) and they only covered 303m^2.

In 1944, the brackish transition marsh occupied 43% (7.9ha) of the coastal marsh in the northern part, and in 2018 it represented 39% (5.5ha) - the reduction in area represents a decrease of 30.3%. The significant increase in artificialized surfaces in the coastal marsh since 1944 (6.5 times more) corresponds to filling (10.4% of roadways and 80% of backfill) to the detriment of the brackish transition marsh.[26] In the northeastern portion of the site, in the early 1980s, the backfilling of a brackish transition marsh began to accommodate a real-estate development. In 2018, this artificial surface covered the entire marsh, an area of 21,464m^2. In the southwestern portion of the site, 19,978m^2 of high marsh and brackish transition marsh were backfilled to develop the *Centre Réal-Boudreau* parking lot and to repair Parc E Street (leading to the beach and the dune). Dykes (earth levees with an average width of 5 meters) built on either side of the shores of the lagoon were identified

[26] Once again, the latter corresponds to the so-called "accommodation" (migration) space of the salt marsh as the sea level rises. By hampering this migration, the filling of the brackish transition marsh should also lead to future losses of the area of the salt marsh (in addition to those associated with its submersion on site).

in all the aerial photos series: in 2018, there were ~350m of dikes on the east shore and ~640m on the west shore - a field study would be required to confirm that these earthen elongated mounds are indeed dykes.

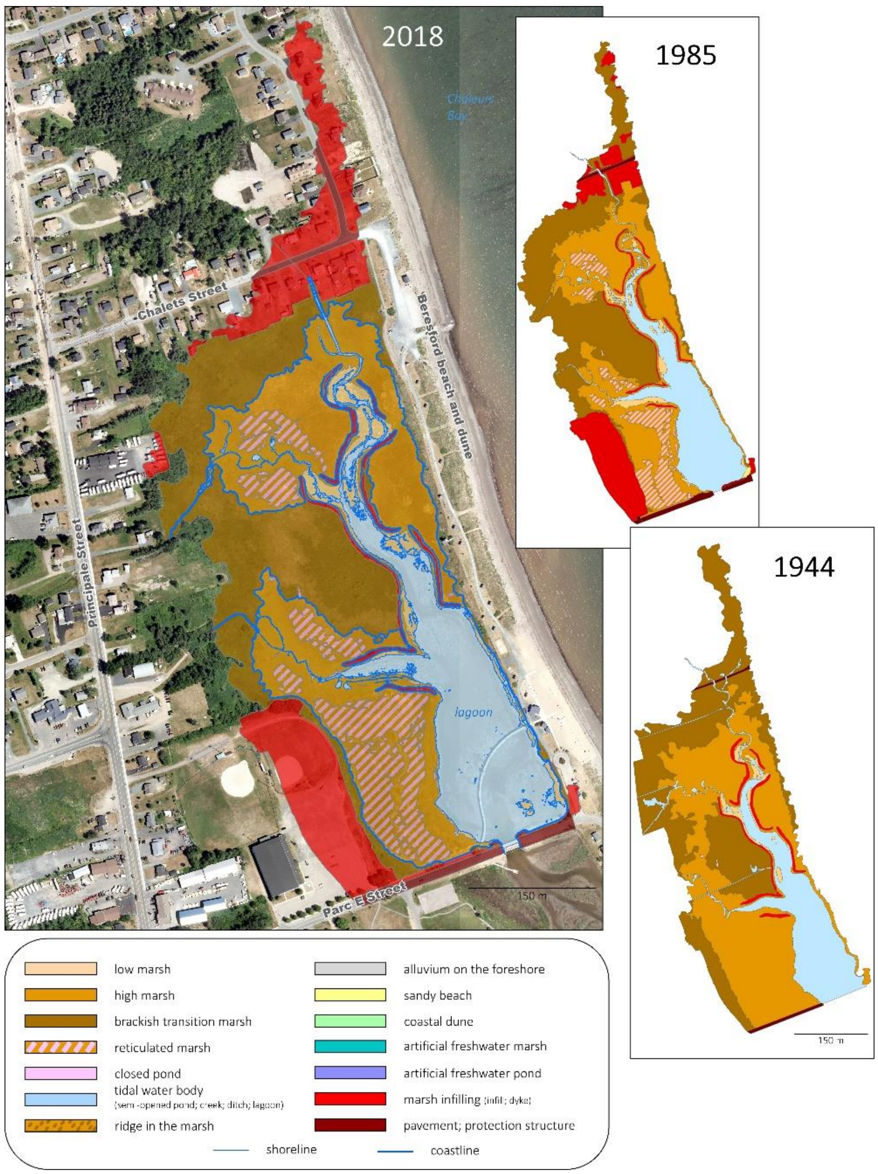


Figure 22. Mapping of coastal habitats in the Northern part: 1944, 1985 and 2018.

Table 10. Distribution of coastal habitats in the Northern part: 1944, 1985 and 2018.

	Habitat Type	Surface Area (m^2) 1944	1985	2018
	1 Salt Marsh	**103,208.8**	**85,235.8**	**84,876.5**
1.a	Vegetated salt marsh	100,188.0	74,237.8	71,592.8
1.a.1	Low marsh	3,473.2	4,987.9	8,857.3
1.a.2	High marsh	96,714.8	69,250.1	62,735.6
1.a.3	Reticulated marsh (50%)	0	8,257.5	11,165.3
1.b	Presence of water	3,020.8	10,997.8	13,283.7
1.b.1	Tidal creek	1,109.3	1,483.7	1,332.8
1.b.2	Semi-opened pond	848.3	275.8	274.9
1.b.3	Ditch (for drainage)	984.5	616.4	303.1
1.b.4	Closed pond	78.8	364.5	207.5
1.b.5	Reticulated marsh (50%)	0	8,257.5	11,165.3
1.c	Ridge in the marsh	0	0	0
	2 Brackish Transition Marsh	**78,574.6**	**66,269.6**	**54,782.4**
Note	Coastal Marsh total area (salt marsh + brackish transition marsh)	181,783.4	151,505.4	139,658.9
	3 Other Natural Habitats	**37,767.2**	**37,068.4**	**34,782.1**
3.a	Lagoonal foreshore	37,767.2	36,825.8	34,782.1
3.a.1	Lagoon (water body)	37,767.2	36,825.8	34,782.1
3.a.2	Alluvium (sediment banks)	0	0	0
3.a.3	Alluvium (vegetated banks)	0	0	0
3.c	Sandy beach	0	242.6	0
3.d	Coastal dune	0	0	0
3.e	Tidal inlet (in dune)	0	0	0
3.f	Non-coastal land (in marsh)	0	0	0
	4 Human Interventions	**7,284.8**	**35,573.7**	**47,556.7**
4.a	Dyke (levee along marsh border)	5,430.9	3,724.7	3,641.6
4.b	Pavement for vehicle	1,854.0	3,697.0	5,150.9
4.c	Infill (resid., commer., institu.)	0	27,938.6	38,644.1
4.d	Peat extraction	0	0	0
4.e	Protection structure	0	213.5	120.2
4.f	Pillar in lagoon (old bridge)	0	0	0
4.g	Artificial pond	0	0	0
4.h	Artificial marsh	0	0	0

*The high marsh surface area includes that of the reticulated marsh

V.III.II. The Central part of the Beresford sub-sector

In the Central part of the Beresford sub-sector, there is 7.3% less salt marsh in 2018 than there was in 1944 (26.1ha versus 24.2ha) (Figure 23, Table 11).

The area covered by low marsh increased by a factor of 1.3, from 0.8ha in 1944 to 1.1ha in 2018, while the area of the high marsh decreased by 18.2% over the same period (23.6ha to 19.3ha). A quarter of this loss of area is attributable to human activities, but the rest would be the result of natural erosion of the patches of marshes in the lagoon and the retreat of the marsh edge occupying the shores of the lagoon (Figure 24).

The presence of water on the surface of the salt marsh has more than doubled in 74 years, from 1.7ha to 3.8ha. As mentioned in the Northern part (subsection *V.III.I.*), this increase is partly linked to the visual quality of the aerial photographs of 1985 and 2018, allowing the identification of areas of reticulated marshes. Where the high number of depressions did not allow their individual mapping, it was estimated that 50% of these areas were occupied by the high marsh platform, and the other half by water surfaces (closed ponds). The area occupied by semi-open ponds increased over the period 1944-2018, which is corroborated by their number: 8 in 1944; 29 in 1985; 48 in 2018.

In 1944, the brackish transition marsh occupied 30.6% (11.5ha) of the coastal marsh of the central part, 28% in 1985 (9.6ha), and in 2018, it represented only 19.4 % (5.8ha) - this is a reduction of half (49%) over the period 1944-2018. Here too, the significant increase in artificial surfaces in the coastal marsh between 1944 and 2018 (18.1 times more) corresponds to filling (7.2% for pavements and 82% for backfill) and this often to the detriment of the brackish marsh of transition. The backfilled marsh area at the *Sportek Complex* is 7670m^2; the one on either side of Principale Street on the north bank of the Millstream River is 11,677m^2; the embankment south of Saint-Pierre Street 11,379m^2.

Table 11. Distribution of coastal habitats in the Central part: 1944, 1985 and 2018.

Habitat Type		Surface Area (m^2)		
		1944	1985	2018
	1 Salt Marsh	**260,615.2**	**246,434.9**	**241,694.4**
1.a	Vegetated salt marsh	243,990.4	213,003.5	203,472.1
1.a.1	Low marsh	8,147.2	13,739.4	10,599.5
1.a.2	High marsh	235,843.2	199,264.1	192,872.6
1.a.3	Reticulated marsh (50%)	0	17,067.7	24,271.8
1.b	Presence of water	16,539.9	33,400.1	38,126.7
1.b.1	Tidal creek	1,046.7	1,248.6	1,350.3
1.b.2	Semi-opened pond	3,276.8	5,103.3	5,134.4
1.b.3	Ditch (for drainage)	239.7	1,106.8	234.6
1.b.4	Closed pond	11,976.7	8,873.7	7,135.6
1.b.5	Reticulated marsh (50%)	0	17,067.7	24,271.8
1.c	Ridge in the marsh	84.9	31.3	95.6
	2 Brackish Transition Marsh	**115,073.7**	**96,105.1**	**58,249.6**
Note	Coastal Marsh total area (salt marsh + brackish transition marsh)	375,688.9	342,540.0	299.9
	3 Other Natural Habitats	**520,424.5**	**525,477.8**	**520,249.1**
3.a	Lagoonal foreshore	491,311.6	510,856.9	504,198.6
3.a.1	Lagoon (water body)	490,777.8	510,413.9	493,931.2
3.a.2	Alluvium (sediment banks)	533.7	443.0	9,602.0
3.a.3	Alluvium (vegetated banks)	0	0	665.4
3.c	Sandy beach	19,011.1	7,364.9	7,602.5
3.d	Coastal dune	5,484.8	1,862.0	1,989.1
3.e	Tidal inlet (in dune)	0	0	0
3.f	Non-coastal land (in marsh)	4,617.1	5,394.0	6,458.8
	4 Human Interventions	**2,885.1**	**16,453.5**	**52,339.6**
4.a	Dyke (levee along marsh border)	1,488.0	1,812.7	1,297.9
4.b	Pavement for vehicle	1,397.1	5,686.0	3,791.2
4.c	Infill (resid., commer., institu.)	0	8,662.4	42,915.8
4.d	Peat extraction	0	0	0
4.e	Protection structure	0	292.4	1,551.6
4.f	Pillar in lagoon (old bridge)	0	0	0
4.g	Artificial pond	0	0	0
4.h	Artificial marsh	0	0	2,783.1

*The high marsh surface area includes that of the reticulated marsh

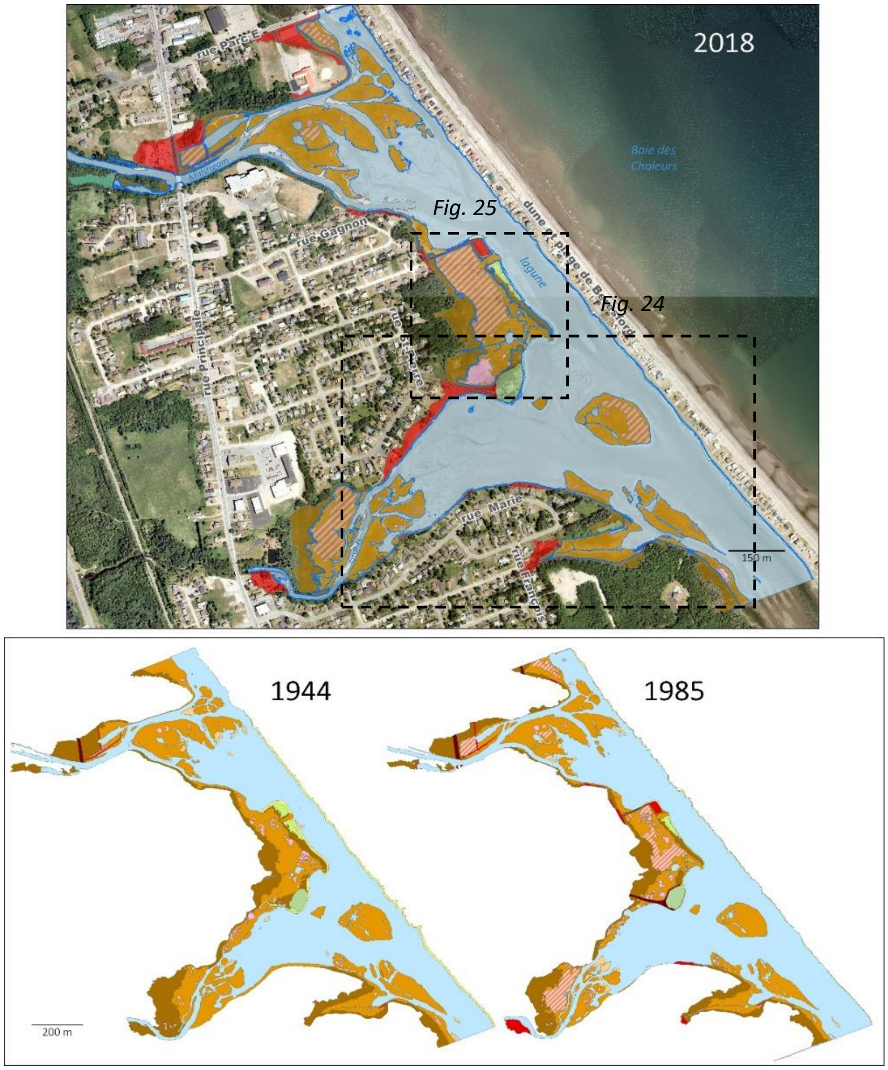


Figure 23. Mapping of coastal habitats in the Central part: 1944, 1985 and 2018. See Figure 22 for the legend.

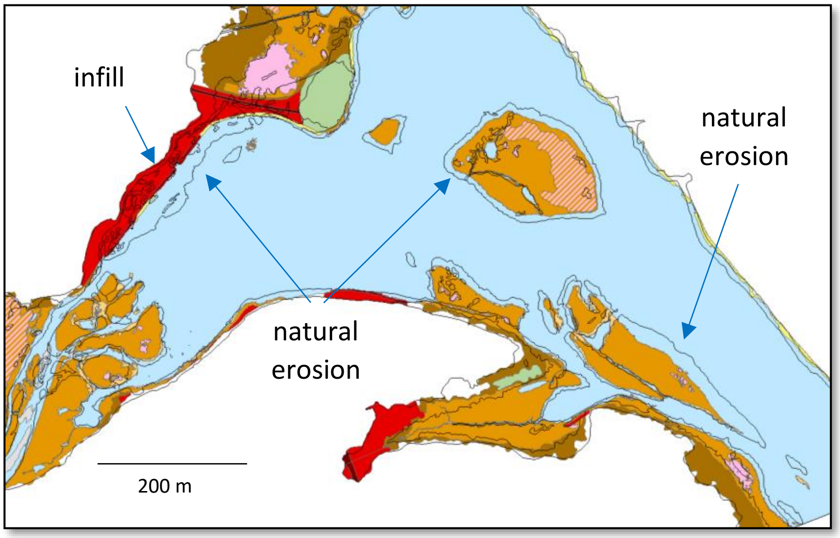


Figure 24. 1944 cartography (black lines) superimposed on 2018 habitats.

The hydrology of the coastal marsh located at the end of Saint-Pierre Street seems to have been modified due to human activities (Figure 25). This 78,160m^2 coastal marsh, which was once linked to the lagoon from the north, south-east and south, is today isolated from the tides on two of these three sides, following the construction of two causeways for vehicle access. In the 1944 aerial photo, this coastal marsh looks like most coastal marshes in the area: a high marsh punctuated by closed ponds; semi-open ponds connected to the lagoon by creeks; a band of brackish marsh making the transition between the high marsh and the non-coastal lands (forest or fields). On the east side, a beach and a dune isolate this marsh from the lagoon. The 1985 aerial photo shows the development of two causeways: one in the north leading to the coastal dune, and the other in the south leading to a wooded islet. The shape and size of some isolated ponds have changed since 1944. The semi-open pond in the southeastern portion is larger, and the creek that connects it to the lagoon is wider and expanding to the northeast in the high marsh, joining some isolated ponds to create semi-open ponds. Examination of the photos seems to indicate the presence of narrow strips of vegetation that separate depressions: a reticulated marsh landscape has clearly been in development since 1985. In the 2018 aerial photo, the presence of water on the surface of the high marsh is important: some isolated ponds of 1944 and 1985 have enlarged (different shape, different size). The southeastern creek, "emerging" in 1985, has developed further (northward progression, development of tributaries), transforming isolated ponds into semi-open ponds. Elsewhere, the reticulated marsh has spread. In several places, the strips that isolate the depressions between them are broken, and a vast network of interconnected ponds is present. In the southern part of the marsh, the causeway leading to the wooded islet was widened (backfilled), and a series of isolated ponds below (present in 1944 and 1985) merged to become a larger coalescing pond in 2018. In short, the presence of water on this marsh is increasing - further study would be required to determine if the marsh is in the process of submergence.

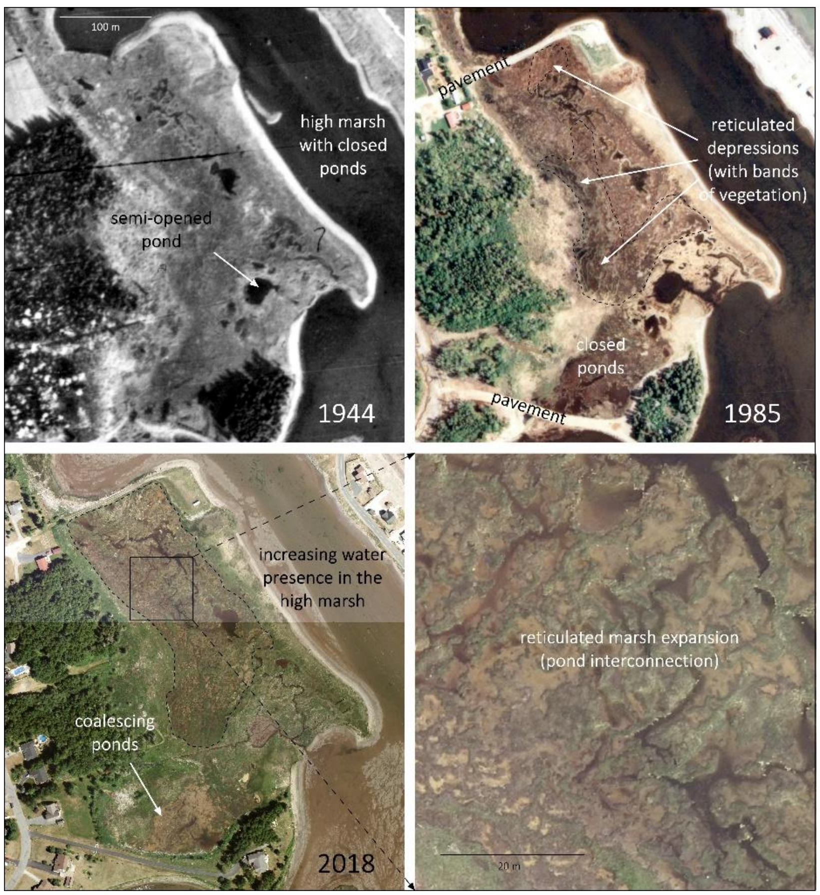


Figure 25. Evolution of the coastal marsh east of Saint-Pierre Street since 1944.

V.III.III. The Southern part of the Beresford sub-sector

In the southern part of the Beresford sub-sector, there is 6.9% less salt marsh in 2018/2020 than there was in 1944 (54.7ha versus 50.9ha) (Figure 26, Table 12).

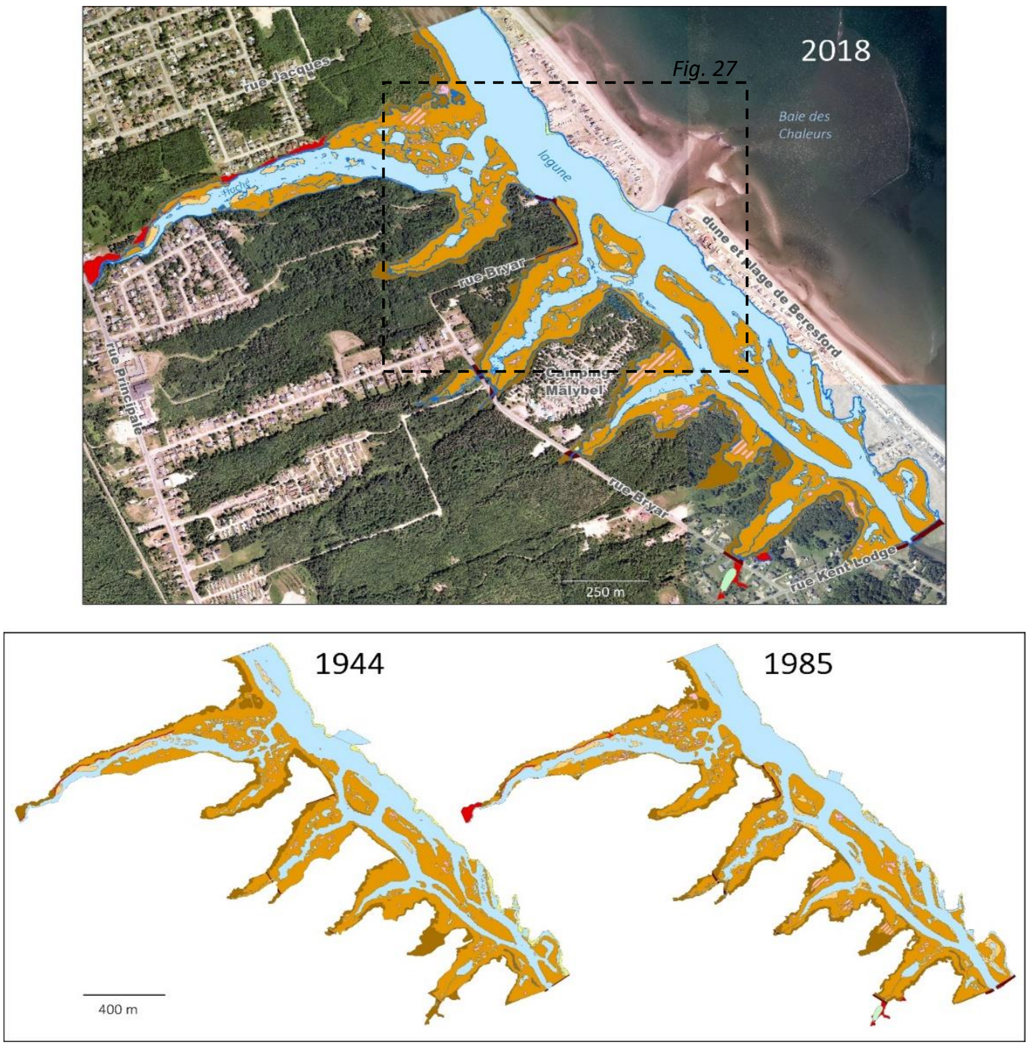


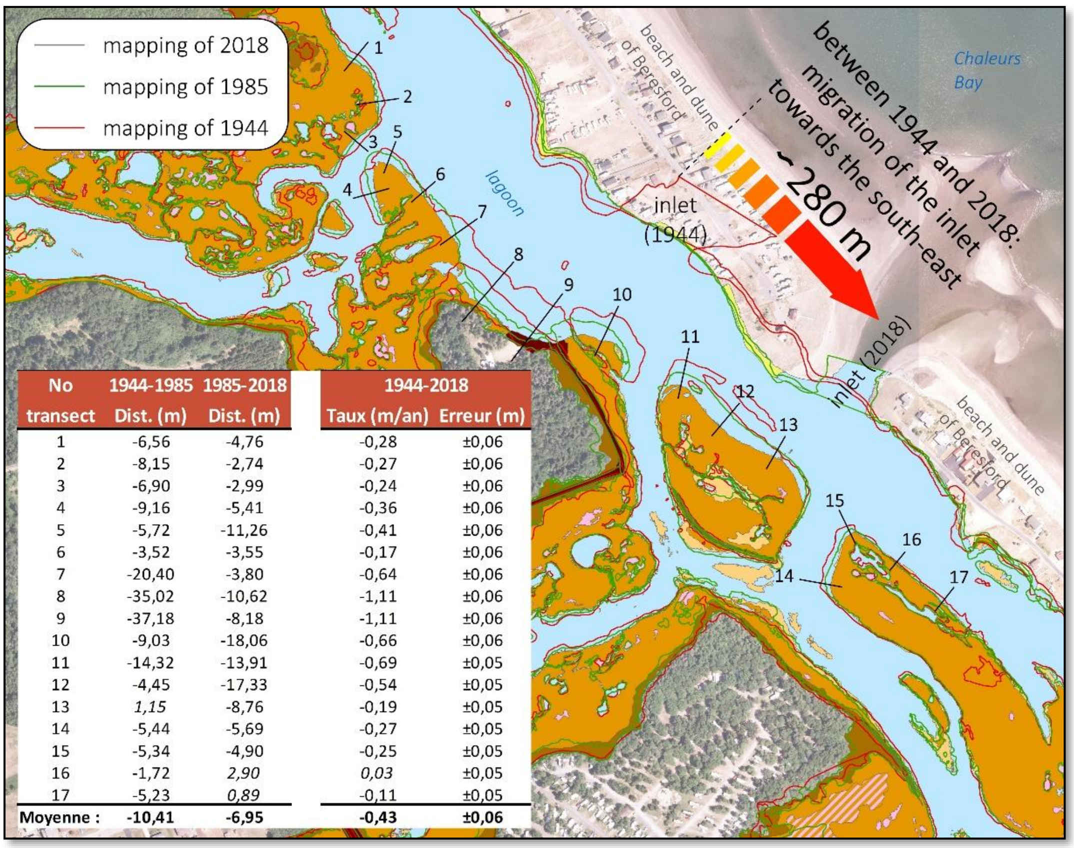
Figure 26. Mapping of coastal habitats in the Southern part: 1944, 1985 and 2018/2020. See Figure 22 for the legend.

Table 12. Distribution of coastal habitats in the Southern part: 1944, 1985 and 2018/2020.

Habitat Type		Surface Area (m^2) 1944	1985	2018
	1 Salt Marsh	**547,238.0**	**528,396.5**	**509,261.0**
1.a	Vegetated salt marsh	508,303.0	475,612.4	455,193.3
1.a.1	Low marsh	14,653.2	36,773.6	39,420.1
1.a.2	High marsh	493,650.0	438,838.8	415,773.2
1.a.3	Reticulated marsh (50%)	0	4,568.5	5,577.6
1.b	Presence of water	36,200.9	50,175.5	50,699.9
1.b.1	Tidal creek	6,396.9	5,897.4	4,182.7
1.b.2	Semi-opened pond	19,487.9	24,343.6	24,868.5
1.b.3	Ditch (for drainage)	0	347.3	94.6
1.b.4	Closed pond	10,316.1	15,018.6	15,976.5
1.b.5	Reticulated marsh (50%)	0	4,568.5	5,577.6
1.c	Ridge in the marsh	2,733.9	2,608.6	3,367.8
	2 Brackish Transition Marsh	**105,879.7**	**96,288.5**	**90,320.4**
Note	Coastal Marsh total area (salt marsh + brackish transition marsh)	653,117.7	624,685.0	599,581.4
	3 Other Natural Habitats	**398,102.1**	**402,851.6**	**417,255.0**
3.a	Lagoonal foreshore	370,709.4	393,583.3	408,008.2
3.a.1	Lagoon (water body)	369,616.4	392,333.4	408,008.2
3.a.2	Alluvium (sediment banks)	1,093.0	1,249.9	0
3.a.3	Alluvium (vegetated banks)	0	0	0
3.c	Sandy beach	20,123.8	6,107.9	6,014.6
3.d	Coastal dune	0	0	14.4
3.e	Tidal inlet (in dune)	7,268.8	3,101.0	3,069.5
3.f	Non-coastal land (in marsh)	0	59.5	148.3
	4 Human Interventions	**5,468.9**	**17,105.6**	**23,853.0**
4.a	Dyke (levee along marsh border)	3,360.0	2,863.2	608.0
4.b	Pavement for vehicle	1,908.6	5,268.8	7,769.5
4.c	Infill (resid., commer., institu.)	0	6,606.4	12,723.4
4.d	Peat extraction	0	0	0
4.e	Protection structure	0	367.4	752.3
4.f	Pillar in lagoon (old bridge)	200.4	0	0
4.g	Artificial pond	0	1,999.9	1,999.9
4.h	Artificial marsh	0	0	0

*The high marsh surface area includes that of the reticulated marsh

The low marsh surface area increased by 2.69X, from 1.5ha in 1944 to 3.9ha in 2018/2020, while the area occupied by the high marsh decreased by 15.8% over the same period (49.4ha to 41.6ha). This loss of area of the high marsh is largely due to natural erosion of the front of the high marsh in contact with the lagoon and on either side of the tidal inlet location since 1944 (see Figure 27).



No transect	1944-1985 Dist. (m)	1985-2018 Dist. (m)	1944-2018 Taux (m/an)	1944-2018 Erreur (m)
1	-6,56	-4,76	-0,28	±0,06
2	-8,15	-2,74	-0,27	±0,06
3	-6,90	-2,99	-0,24	±0,06
4	-9,16	-5,41	-0,36	±0,06
5	-5,72	-11,26	-0,41	±0,06
6	-3,52	-3,55	-0,17	±0,06
7	-20,40	-3,80	-0,64	±0,06
8	-35,02	-10,62	-1,11	±0,06
9	-37,18	-8,18	-1,11	±0,06
10	-9,03	-18,06	-0,66	±0,06
11	-14,32	-13,91	-0,69	±0,05
12	-4,45	-17,33	-0,54	±0,05
13	*1,15*	-8,76	-0,19	±0,05
14	-5,44	-5,69	-0,27	±0,05
15	-5,34	-4,90	-0,25	±0,05
16	-1,72	*2,90*	*0,03*	±0,05
17	-5,23	*0,89*	-0,11	±0,05
Moyenne :	**-10,41**	**-6,95**	**-0,43**	**±0,06**

Figure 27. Migration of the inlet and erosion of the marsh edge: 1944-1985-2018.

The maximum erosion of the high marsh edge occurred between transects 7 and 12, which corresponds to the general trajectory of the tidal inlet displacement between 1944 and 2018. The maximum erosion occurred at transect 8: a total retreat of 45.6m over the last 74 years (-35m between 1944-1985 and -10.6m between 1985-2018), i.e. an annual erosion rate of

-1.11 ± 0.06m/yr. For all the transects measured (nos. 1 to 17, Figure 27), the historical erosion rate is -0.43m/yr. For comparison purposes, the global average (compilation of available measurements) of the historical erosion rate of the salt marsh edge in the Chaleur region is -0.15m/yr, and that for all the salt marshes in New Brunswick is -0.28m/yr (*New Brunswick Coastal Erosion Database*, 2020). The opening onto Chaleurs Bay provided by the presence of the inlet has undoubtedly favored an accentuated erosion and retreat of the edge of the high marsh. The surface area of high marsh lost (eroded) since 1944 between transects 1 to 17 totals 19,081m^2 (1.9ha).

According to the examination of the available photographs, there is 1.4X more water in the salt marsh in 2018/2020 than there was in 1944: 5.1ha in 2018/2020 against 3.6ha in 1944 (an increase of 40%). The area occupied by closed ponds (more than 10 m in diameter) increased from 1ha in 1944, to 1.5ha in 1985, to 1.6ha in 2018/2020 (the number of closed ponds is also increasing for these three years: 86, 110 and 193, respectively). The area occupied by semi-opened ponds is also increasing, going from 1.9ha in 1944, to 2.4ha in 1985, to 2.6ha in 2018/2020 (the number of semi-open ponds is also increasing for these three years: 45, 62 and 133, respectively). The area occupied by creeks decreased by 35% between 1944 and 2018/2020, although the number of creeks identified has gradually increased (46 in 1944, 57 in 1985 and 134 in 2018/2020).

The area occupied by the brackish transition marsh fell from 10.6ha in 1944, to 9.6ha in 1985, to 9ha in 2018, a decrease of 14.7%. However, despite this decrease, the proportion occupied by the brackish transition marsh within the coastal marsh of the Southern part remained relatively stable (16.2% in 1944, 15.4% in 1985 and 15.1% in 2018/2020). The artificialized area in the coastal marsh has multiplied by a factor of 4.35 since 1944 (0.5ha, mainly dikes and causeways to 2.4ha, mainly embankments for real-estate developments and landscaping needs and roadways for vehicles). The loss of 1.6ha of brackish transition marsh since 1944 could be linked to the increase of 1.9ha of artificial surfaces over the same period. Regardless, the salt marsh landscape of the southern part of the Beresford sub-sector nonetheless remains relatively "natural" (Figure 26).

V.III.IV. The Estuary part of the Peters River

In the Estuary part of the Peters River, there is 4% less salt marsh in 2020 than there was in 1944 (37.8ha versus 36.3ha) (Figure 28, Table 13).

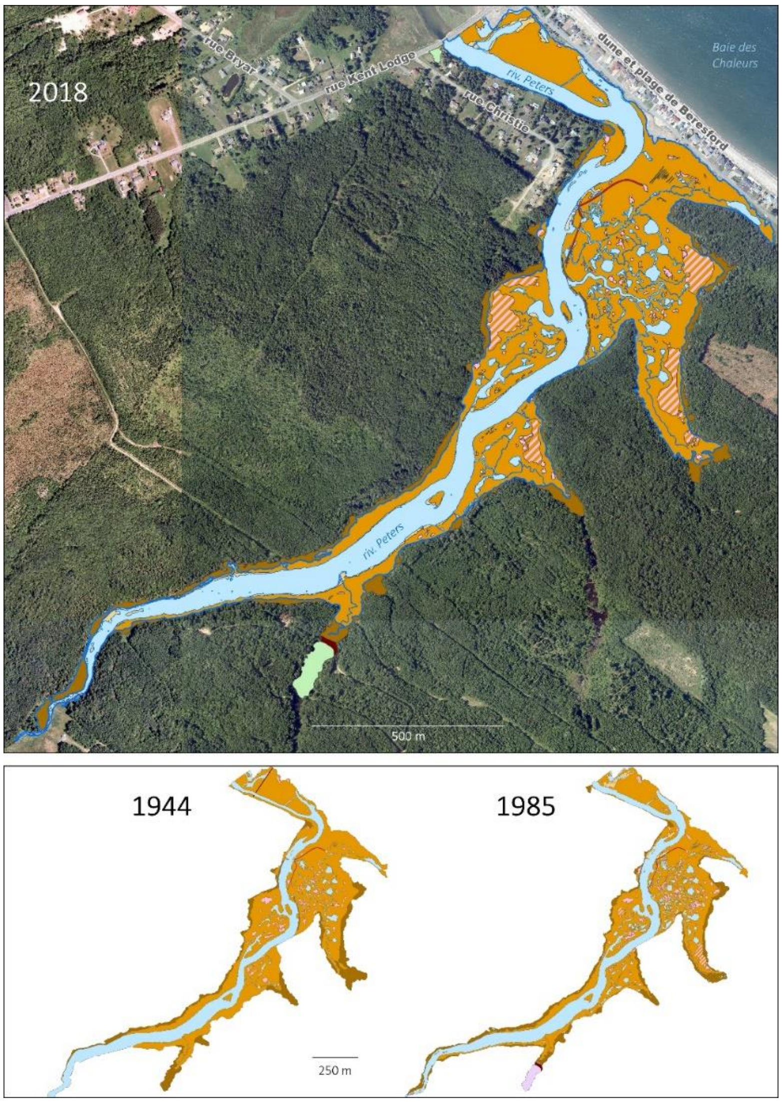


Figure 28. Mapping of coastal habitats of the Peters River estuary: 1944, 1985 and 2020. See Figure 22 for legend.

Table 13. Distribution of coastal habitats in the Peters River estuary: 1944, 1985 and 2020.

Habitat Type		Surface Area (m^2)		
		1944	1985	2018
	1 Salt Marsh	**377,558.0**	**367,983.3**	**362,758.1**
1.a	Vegetated salt marsh	341,189.0	313,97.3	308,985.4
1.a.1	Low marsh	281.3	8,596.0	10,639.8
1.a.2	High marsh	340,907.7	305,380.3	298,345.7
1.a.3	Reticulated marsh (50%)	0	2,948.0	12,603.0
1.b	Presence of water	34,379.5	52,803.8	52,993.2
1.b.1	Tidal creek	6,132.6	8,182.2	7,567.0
1.b.2	Semi-opened pond	12,734.1	24,299.7	25,334.6
1.b.3	Ditch (for drainage)	364.4	366.4	150.9
1.b.4	Closed pond	15,148.4	17,007.5	7,337.8
1.b.5	Reticulated marsh (50%)	0	2,948.0	12,603.0
1.c	Ridge in the marsh	1,989.6	1,203.3	779.4
	2 Brackish Transition Marsh	**57,550.7**	**56,138.5**	**51,818.7**
Note	Coastal Marsh total area (salt marsh + brackish transition marsh)	435,108.7	424,121.8	414,576.8
	3 Other Natural Habitats	**129,298.1**	**146,615.9**	**154,268.7**
3.a	Lagoonal foreshore	128,994.3	146,615.9	153,957.2
3.a.1	Lagoon (water body)	128,994.3	146,151.8	152,549.4
3.a.2	Alluvium (sediment banks)	0	464.0	1,407.9
3.a.3	Alluvium (vegetated banks)	0	0	0
3.c	Sandy beach	303.8	0	112.1
3.d	Coastal dune	0	0	0
3.e	Tidal inlet (in dune)	0	0	0
3.f	Non-coastal land (in marsh)	0	0	199.5
	4 Human Interventions	**2,198.9**	**9,235.6**	**9,836.3**
4.a	Dyke (levee along marsh border)	1,143.2	1,062.0	1,059.0
4.b	Pavement for vehicle	753.3	779.1,	788.1
4.c	Infill (resid., commer., institu.)	0	0	804.7
4.d	Peat extraction	302.4	526.0	234.3
4.e	Protection structure	0	0	81.6
4.f	Pillar in lagoon (old bridge)	0	0	0
4.g	Artificial pond	0	6,868.6	6,868.62
4.h	Artificial marsh	0	0	0

*The high marsh surface area includes that of the reticulated marsh

The area occupied by the low marsh has increased since 1985, going from 8,596m^2 to 10,640m^2 in 2020. The area covered by the high marsh has decreased by 12.5% over the period 1944-2020 (34.1ha to 29.8ha). The widening of the Peters River estuary (12.9ha in 1944 to 15.4ha in 2020: an increase of 19.4%) leading to erosion and retreat of the marsh edge as well as increase in the area occupied by water on the salt marsh (3.4ha in 1944 to 5.3ha in 2020: an increase of 54.1%) are responsible for the decrease in the area occupied by the high marsh since 1944.

According to the examination of the available aerial photographs, the presence of water on the surface of the salt marsh of the Peters River estuary increased by a factor of 1.54 between 1944 and 2020. The area occupied by the creeks, semi-opened ponds, ditches, closed ponds, and reticulated marsh experienced a 53.6% increase between 1944 and 1985, followed by a slight increase between 1985 and 2020 (0.4%). The area occupied by closed ponds decreased by 9,673m^2 between 1985 and 2020, while that occupied by the reticulated marsh increased by 9,655m^2 over the same period; the inclusion of individual closed ponds in 1985 within the area of the reticulated marsh in 2020 partly explains this situation, the other part corresponding to the transformation of closed ponds into semi-open ponds via development or expansion of tidal creeks. The area occupied by the ditches (artificially dug drainage channels) has more than halved over the period 1944-2020 (364m^2 to 151m^2), which shows that the ditches are not maintained. A dyke (levee) of more than 360m in length built on the high marsh of the east bank of the Peters River is observable in all the series of aerial photographs, as well as about ten trenches occupied by water (where peat extraction may have been attempted?) - further study would be required to determine the exact nature of these dykes and trenches.

In 1944, the brackish transition marsh occupied 13.2% (5.8ha) of the coastal marsh of the Peters River estuary, and in 2020 it represented 12.5% (5.2ha) - the reduction of the area represents a 10% decrease in the brackish transition marsh. The construction of a causeway across a brackish transition marsh led to the creation of an artificial freshwater pond of 6,869m^2 on the upstream side. Part of the losses of the brackish transition marsh corresponds to natural losses, mainly following migration from the high marsh to the brackish transition marsh, as seems to indicate the horizontal difference between the vectors of the coastline between the years. Similar situations, though less extensive, were observed in the Southern and Central parts.

V.IV. Coastal land boundary displacement scenarios for 2100

V.IV.I. The coastal marsh and forest boundary: factors at play

For several years, the numerical modeling of the response of coastal marshes to sea level rise has been under development. Numerical models, based on empirical observations or even on mathematical equations, involve several important parameters in the evolution of marshes, such as the rate of the rise in relative sea level, tidal levels, marsh vertical accretion rate, soil salinity, topography, sediment dynamics and elevation of certain indicator plant species (FAGHERAZZI *et al*., 2012).[27] The best known digital models are: Dynamic Interactive Vulnerability Assessment Wetland Change Model (*DIVA-WCM*); Salt Marsh Assessment & Restoration Tool (*SMART*); Polygon-Based Spatial Model (*PBS*); Hydro Marsh Equilibrium Model (*HydroMEM*); Sea Level Affecting Marshes Model (*SLAMM*). These marsh migration modelling softwares are valuable and important tools to support decision-making by managers.

It is possible to model the future evolution of certain marsh parameters using commonly available tools, such as digital terrain models or DEM (developed from altimetric data obtained from field surveys, but most often obtained by LiDAR missions) and field data acquired by DGPS associated with the elevation of certain plants representative of habitats or marsh areas (FEAGIN *et al*., 2010; FULLER *et al*., 2011; KIRWAN *et al*., 2016; SMITH, 2020). The most important aspect in developing a model is that the modeling results are interpreted considering the assumptions, simplifications and uncertainties included as inputs into the model (FULLER *et al*., 2011).

The decline of coastal forests in response to sea level rise and their replacement by marshes is well documented (KIRWAN *et al*., 2016; CARR *et al*., 2020). According to FAGHERAZZI *et al*. (2019), two main factors influence the variation of the upper position of the marsh and the forest edge: sea level rise and storms. Storms are occasional disturbances that affect coastal forests in the short term, damaging trees (strong winds which, among other effects, shatter crowns, break branches, or even uproot trees; flooding by seawater which increases soil salinity; in northern latitudes, spring offshore winds combined with high water levels that can push ice at the foot of trees, causing scraping which can damage bark and weaken trees) and triggering dieback which provides ecological space for the establishment of new plant species (Figure 29). The rise in sea

[27] In relation to the frequency and duration of submersion by the tide (hydroperiod).

level, on the other hand, is a background disturbance, which in the long term alters the salinity of the soil and the flooding regime, favoring the growth of halophyte grasses. Both disturbances are determinant in the dynamics of the boundary between marsh and non-coastal lands, and in a study of three coastal forest sites along the Northumberland Strait, ROBICHAUD and BÉGIN (1997) documented their combined effect in the terrestrial migration from an area where the forest is disturbed, causing the progressive retreat of the forest edge.

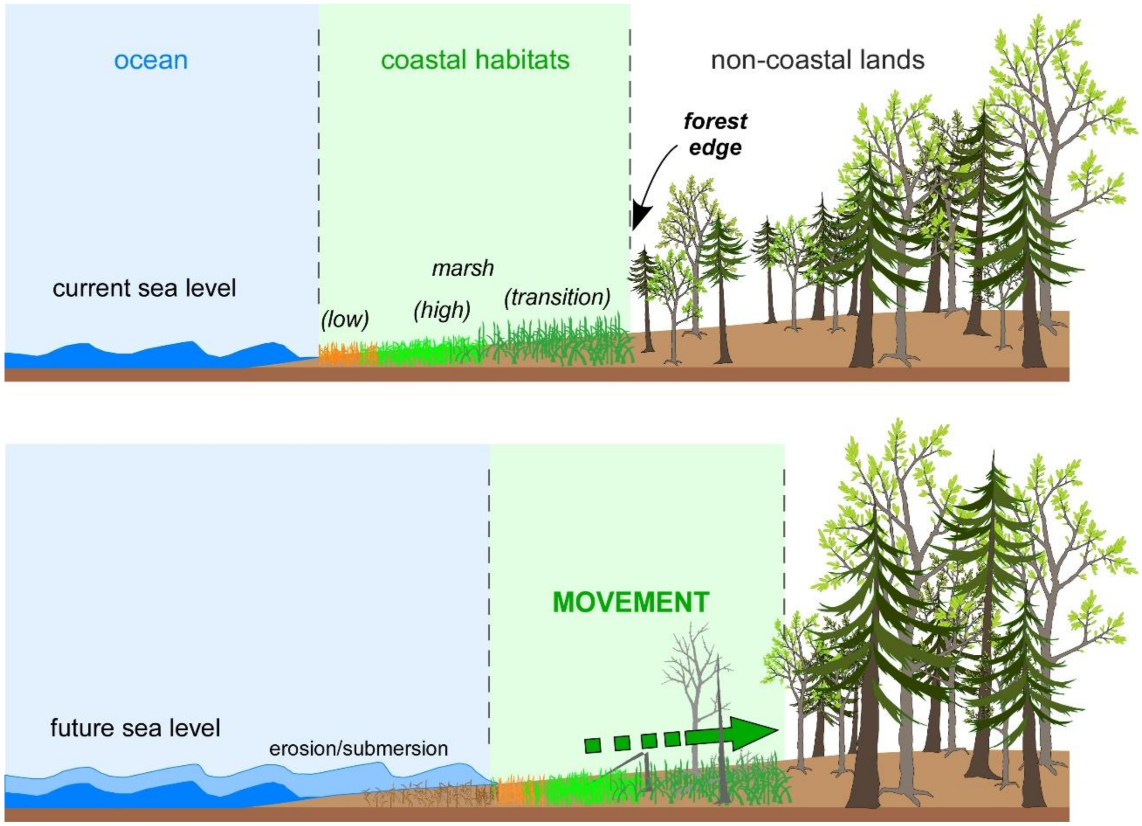


Figure 29. Diagram of the gradual migration of the forest edge (and salt marsh habitats) in response to the rise in sea level.

V.IV.II. Methodology used: determination of the altitude of the forest/coastal marsh contact

In this study, *GLC* proposes to use the elevation of the forest edge (in contact with the marsh) to design the projection scenarios of the coastal land limit in 2100, i.e. the potential position of the forest's contact with the coastal marsh in the future.[28]

Once the 2018-2020 coastal habitats mapping was completed, the vectors corresponding to the contact between the upper limit of the marsh (mainly the brackish transition marsh, but also some segments of high marsh) and the forest edge were extracted. In the attribute table of the mapping shapefiles, these vectors bear the identification "*Interface_Marais brackâtre transition-Forêt*" or "*Interface_Haut marais-Forêt*". We have excluded from the selection all the vectors making the marsh/forest contact and which we have qualified as being approximate positions of this limit (in the attribute table, these are all the vectors ending in "*..._Forêt_Approx*").

The mean elevation, as well as the mean of the minimum and maximum elevations were calculated for each of the vectors retained (because they were considered reliable), by extracting the altimetric data of the DEM along these vectors (Table 14).[29],[30] The statistics produced by this operation relate to the individual total length of each of the vectors. To ensure that the average elevation of the forest edge was as realistic as possible, all vectors selected were split into a length of one meter (1m), so that they were at the same resolution

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28 Although the forest edge is easy to identify by photointerpretation, our experience elsewhere in the province has shown that the non-coastal land boundary can be in front (seaward), especially in cases where there is the presence of shrub species difficult to separate from the upper part of the brackish transition marsh by photointerpretation.

29 The altimetric data of the Beresford DEM are presented in CGVD2013. The LiDAR data from which the DEM was prepared comes from two series: 2016 LiDAR data collected between 2016-06-07 and 2016-10-04; those for 2018 collected between 2018-07-11 and 2018-08-11 (Mariette HACHEY-BOUDREAU, former GIS Technician at the Chaleur RSC - personal communication).

30 The difference between the values of a DEM and the effective elevation of the soil, caused by the height of the vegetation, can be several tens of centimeters in these shrub areas (SCHMID *et al*., 2011). Along the north and east coasts of New Brunswick, spot checks carried out by the DNRED with high precision GPS indicate that LiDAR products do include a vertical error; the data collected and compiled indicate that the real ground elevation in salt marshes would be underestimated by about twenty centimeters by the various LiDAR products (Dominique BÉRUBÉ - personal communication). *GLC* included this margin of error in the scenarios developed.

than the DEM (1m X 1m). This step allowed us to exclude from the calculation of the means the vectors having elevations considered extremes (much too high or much too low), which would otherwise have been considered in the statistics, influencing the calculated means. To determine the range of extreme elevations to be excluded from the calculation of the means, four (4) contour lines (isolines) were generated from the DEM: 0.9m, 1.0m, 1.5m, and 2.0m. By displaying the 2018/2020 orthophotographs in the background, the positioning of the contour lines was compared to the mapping (by photointerpretation) of the forest edge considered reliable. The 1.0m elevation contour line intersected the mapped marsh/forest vectors in several places, while the 0.9m contour line was almost always "lower" (more marshward) than the visual position of the forest edge, while still being positioned very close to the mapped vectors. The 2.0m elevation contour line was systematically positioned within the forest (clearly away from the mapped vectors), while the 1.5m contour line was "higher" (more landward) than the position of the forest edge, while matching the mapped vectors a little better (Figure 30).

Based on these results, *GLC* chose to exclude from the calculation all 1m vectors whose mean elevation values were strictly less than 0.9m and greater than or equal to 1.5m. Thus, the average elevation of the forest edge of 2018/2020 in contact with the marsh in the Beresford sub-sector, according to the mapping and the calculations carried out, is **1.17m** (±0.2m). The delay in awarding the work contract to *GLC* (end-November) effectively wiped out any field trips aimed at clarifying the actual altitude of the forest edge. In the absence of such field data to validate the position of this limit (which would have made it possible to determine its elevation according to the DEM), it is therefore the calculated average value of the elevation of the forest edge (1.17m) which was used to design the scenarios of the limit of the coastal marshes in 2100.[31]

[31] The contours generated to develop the scenarios were smoothed in *ArcGIS* using the Polynomial approximation option with exponential kernel (*PAEK*) and a smoothing tolerance of 25 meters.

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Table 14. Elevations of the forest edge in 2016-2018 according to altimetric data from the Beresford DEM: vectors making contact between brackish transition marshes (BTM) and the forest edge; vectors making contact between the high marsh (HM) and the forest edge.

	Forest edge elevation (m): BTM*				Forest edge elevation (m): BTM*				Forest edge elevation (m): BTM*			
	Lenght (m)	µ MIN	µ MAX	Mean	No. Vect. 1 m[1]	µ MIN	µ MAX	Mean	No. Vect. 1 m[2]	µ MIN	µ MAX	Mean
Northern part	246.8	1.27	1.87	1.5	245.0	1.46	1.51	1.48	106.0	1.27	1.31	1.29
Central part	3,364.9	0.75	2.02	1.32	3,351.0	1.21	1.26	1.23	2,506.0	1.14	1.18	1.16
Southern part	5,835.0	0.87	1.57	1.16	5,813.0	1.18	1.24	1.21	5,127.0	1.15	1.21	1.18
Peters River	3,602.1	0.76	1.93	1.12	3,593.0	1.03	1.09	1.06	2,572.0	1.04	1.10	1.07
				1.28				*1.25*	***Forest edge mean elevation:***			***1.17***

	Forest edge elevation (m): HM**				Forest edge elevation (m): HM**				Forest edge elevation (m): HM**			
	Lenght (m)	µ MIN	µ MAX	Mean	No. Vect. 1 m[1]	µ MIN	µ MAX	Mean	No. Vect. 1 m[2]	µ MIN	µ MAX	Mean
Northern part	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Central part	9.9	0.82	1.27	0.99	9.0	0.95	1.04	0.99	5.0	1.04	1.19	1.12
Southern part	51.6	0.47	1,00	0.74	50.0	0.91	1.0	0.96	31.0	1.1	1.19	1.14
Peters River	45.6	0.41	1.11	0.72	45.0	0.68	0.77	0.72	6.0	0.94	1.06	1.0
				0.82				*0.89*				*1.09*

The elevation contained in this Table are in CGVD2013.
1 = vectors were cut into ~1 m lenght to match the DEM resolution.
*BTM = contact forest - brackish transition marsh **HM = contact forest - high marsh
2 = 1 m vectors having a mean elevation < 0.9 m and > 1.5 m were removed.

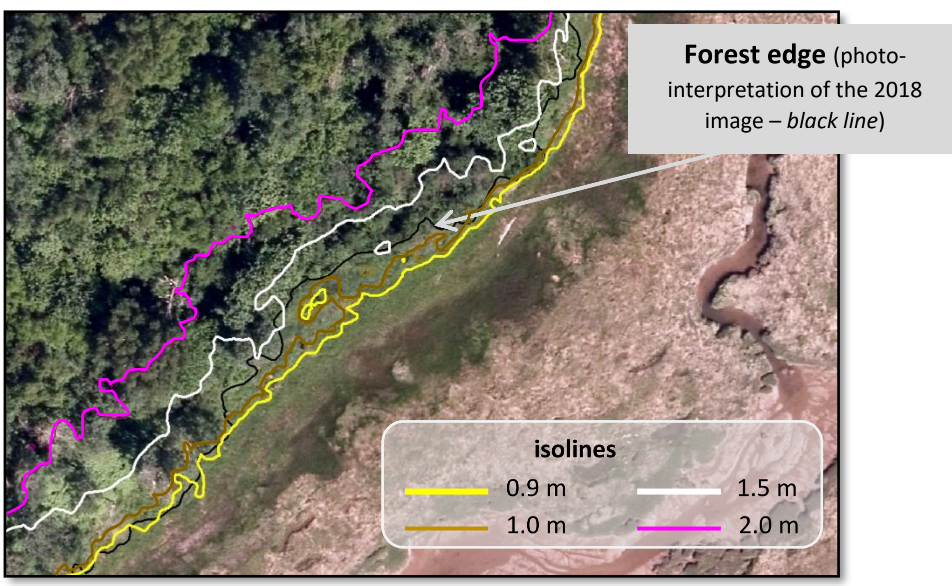


Figure 30. Example of positioning of the isolines to determine the elevation range to be used to establish the average elevation of the forest edge in 2018/2020.

V.IV.III. The scenarios used

Two scenarios of the 2100 coastal land boundary position were prepared by integrating the projection data of the relative sea level rise contained in DAIGLE (2020): a so-called "Conservative" scenario and a so-called "Pessimistic" scenario.[32] In the "Conservative" scenario, the elevation of the forest edge in contact with the marsh in 2100 would be 1.77 ±0.2m, while in the "Pessimistic" scenario, its elevation would be 2.42 ±0.2m.

The location of one or the other of these two isolines relative to the current position of the marshes of the Beresford sub-sector makes it possible to grasp (to illustrate) the accommodation space (space required for marsh migration, which should be free of development) that will be necessary to provide to allow the marshes to migrate landward as the relative sea-level rises. In general, three scenarios illustrate the possible evolutions of the contact between the coastal marsh and the non-coastal lands in the Beresford sub-sector by the year 2100 - these are indicative evolution scenarios and not evolution predictions:

A. A **Gradual Movement** (natural accommodation space *potentially sufficient* to allow the marsh to migrate to non-coastal lands in response to HNMR) (Figure 29, above).

B. A **Blocked Movement** (accommodation space *potentially absent* due to the presence of infrastructure - public, commercial, residential, institutional - adjacent to the marsh and where the future installation of the marsh will undoubtedly be deemed unacceptable by the owners. It is under this evolutionary scenario that the concept of coastal squeeze was developed in Great Britain) (Figure 31).

C. An **Impeded Movement** (natural accommodation space *potentially insufficient* due to the steep landward slope adjacent to the marsh. Marsh migration will be possible, but it will be small - distance of less than 10 meters between the current limit of the marsh and the position of either the "Conservative" or the "Pessimistic" scenarios.

[32] Based on the RPC8.5 emissions scenario, DAIGLE (2020) projected for Zone 2 (which includes the study area) total increases in the RSL of 0.12 ±0.07m over the period 2010-2030 and 0.66 ±0.38m over the period 2010-2100. In order to take into account the 10 years that have elapsed since 2010, *GLC* subtracted 0.06m from the total RSLR forecast by DAIGLE (2020) until 2100 to thus establish the "Conservative" scenario at **1.77m** (1.17m + 0.60m). In the case of the "Pessimistic" scenario, there is an addition of 65cm more to the HNMR due to the acceleration of the melting of the ice caps to establish the future elevation of the forest edge at **2.42m** (1.17m + 0.60m + 0.65m).

Marsh segments falling into this category could see the brackish transition marsh, or even part of the low and high marshes, disappear by the year 2100 (Figure 31).[33]

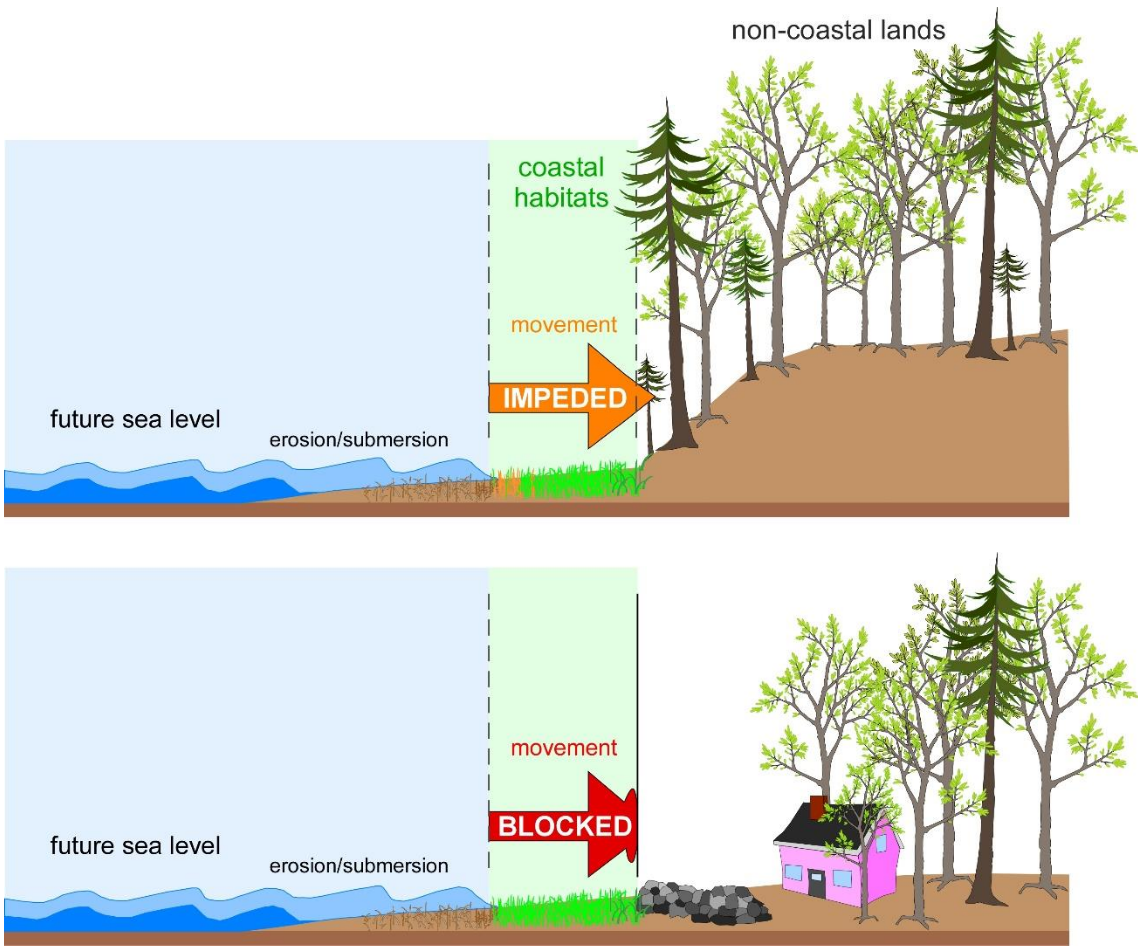


Figure 31. Schematization of migrations of the forest edge in response to sea level rise: Impeded and Blocked (coastal squeeze).

33 The situation of Impeded Movement is particular, and the future evolution of the marshes will depend on other parameters, in particular the rate of vertical accretion at the surface of the salt marsh (by sedimentation or by production of organic matter), determining its maintenance or its submergence.

V.IV.IV. The Northern part of the Beresford sub-sector

In the Northern part of the Beresford sub-sector, the marsh could migrate to two accommodation spaces, one in the northwest and the other in the central west (Figure 32). According to the "Conservative" scenario (elevation 1.77m), except for two short segments, the position of the marsh in 2100 would be largely located within the buffer zone of 30 meters, established by the New Brunswick Department of Environment and Climate Change (ECC).

Figure 32. Scenarios of the 2100 marsh position in the Northern part.

Under the "Pessimistic" scenario (elevation 2.42m), the migration of the marsh in these two accommodation spaces could have reached its maximum movement towards the west, because the marsh limit would be practically "at the doorstep" of the dwellings and other infrastructure. Elsewhere in the Northern part, the accommodation space would be insufficient for the marsh's migration because its movement would be blocked by the presence of developments: coastal squeeze situations along a good part of Chalets Street, to the north, a parking lot in the center-west, and close to recreational infrastructure along Parc E Street, to the south (blockage over a length of ~1.2km, or 56%). *GLC* considers that the marshes developed behind the Beresford dune will not migrate onto the latter; on the contrary, the most plausible evolutionary scenario to the year 2100 would be that the Beresford dune migrates over the marshes in response to the rise in sea level. In short, the future migration of the salt marshes of the northern part is precarious given the multiple constraints (physical and human) that *literally surround them*.

V.IV.V. The Central part of the Beresford sub-sector

In the Central part of the Beresford sub-sector, four (4) sites have natural accommodation spaces large enough to allow future marsh migration: the north bank of the Millstream River (between Principale Street and the *Sportek* complex); the forest east of Saint-Pierre Street; the downstream part of Grants Creek (east of Principale Street); the forest between the end of Jacques Street and the lagoon. The width of these spaces would vary between 15 to 150 meters under the "Conservative" scenario, and up to 300m under the "Pessimistic" scenario. Constraints to marsh migration in the form of coastal squeeze may develop in several places in the Central part, over a total length of ~2.6km (or 48%): along the embankment of the *Sportek* complex (which coincides with the southern end of the Northern part); very close to Gagnon Street; not far from Saint-Pierre Street along a roadway laid out in the marsh to access an islet; as well as at a few specific places along the southern shore of the lagoon. Another type of migration constraint is present in the Central part: it is the estuarine portion of the Grants stream (east of Principale Street) where a marsh with an area of 63,820m^2 has developed on both sides of the main watercourse as well as on deltaic shoals or alluvium (Figure 33). In this portion of the Grants Creek estuary, the high, steep slopes form a "cauldron" profile. This steep context is a natural physical constraint which should result only in a weak migration of the marsh: here, the vectors associated with the two scenarios ("Conservative" and "Pessimistic") are found practically one above the other, and are located only a few meters from the landward limit of the present marsh. Obviously, the provincial buffer zone along the northern and southern shores of this estuarine portion of Grants Creek is located well beyond scenarios of the future position of non-coastal lands.

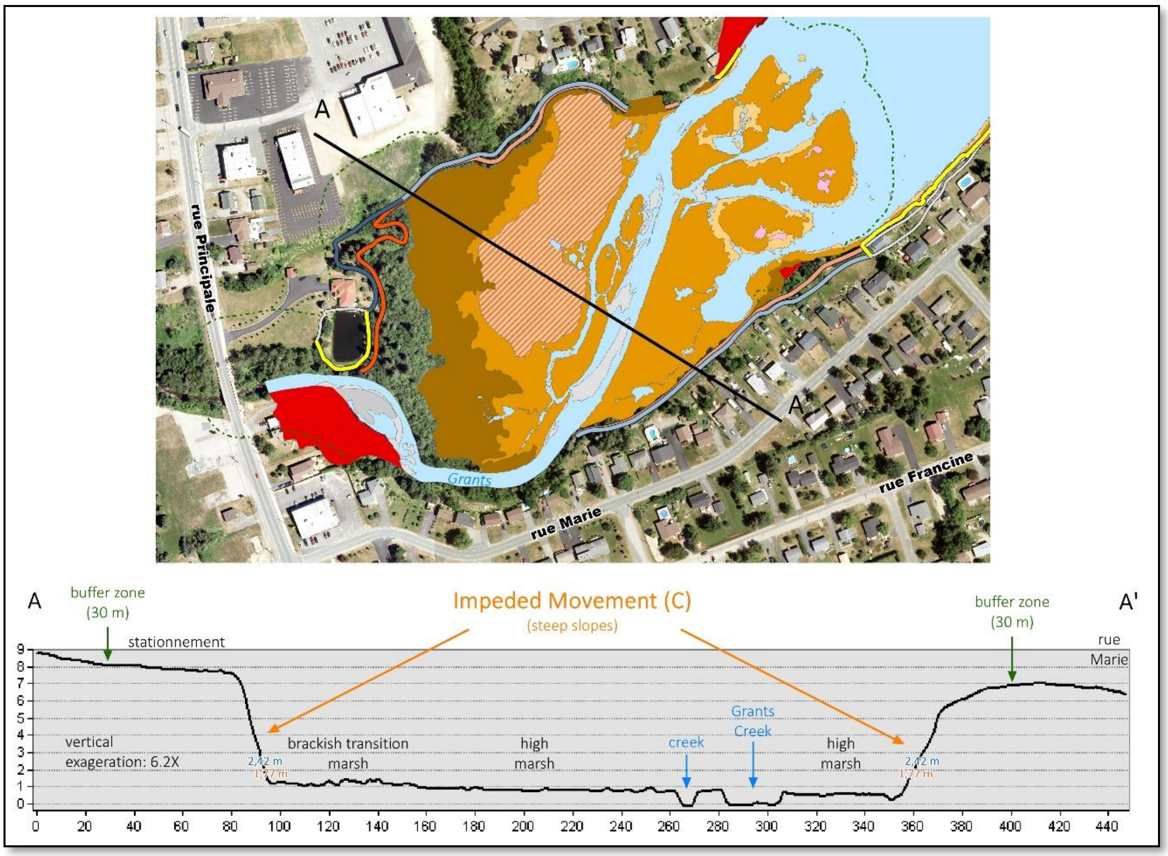


Figure 33. Illustration of an impeded movement of the marsh by 2100 (estuary, Grants Brook).

V.IV.VI. The Southern part of the Beresford sub-sector

In the Southern part of the Beresford sub-sector, six (6) sites have natural accommodation spaces large enough to allow future migration of the marsh (see small black stars in Figure 34). It is the forest between the end of Jacques Street and the lagoon (which coincides with the southern end of the Central part) and the five (5) points of land oriented north-east/south-west in the central and south portions. The site at the end of Jacques Street is the one with the largest accommodation space (see transect B-B', Figure 34). According to the "Conservative" scenario, the position of the forest edge in 2100 could be between ~150m and ~200m from its current position; according to the "Pessimistic" scenario, it could be more than 300m from its current position. In this site, the buffer zone (30m wide) associated with the wetlands is clearly insufficient to protect the space that would be necessary for the migration of the marsh in response to the rise in sea level by 2100. Very close to the *Camping Malybel*, the "Conservative" scenario identifies some portions of the territory that would be likely to be occupied by the marsh in 2100. On the other hand, under a "Pessimistic" scenario, practically half of the campground could be occupied by marsh. These natural land points (that of *Camping Malybel* and the others further south) and the upstream part of their watercourse are sites to be protected to ensure the future migration of the marshes.

A particular situation of constrained migration is identified in the Southern part of the Beresford sub-sector: this is the Outardes Street real-estate site (see transect A-A', Figure 34). Here, the north shore of the Haché Creek estuary depicts a situation where the movement of the marsh located below would be blocked (coastal squeeze) due to backfilling and real-estate development, and the south shore depicts a situation where the movement of the marsh would be impeded due to the high, steep slopes (for the year 2018, no brackish transition marsh was observed below the slope - the contact here is between the high marsh and the forest). The survival of the marshes located on both sides of the site's shores is compromised by 2100.

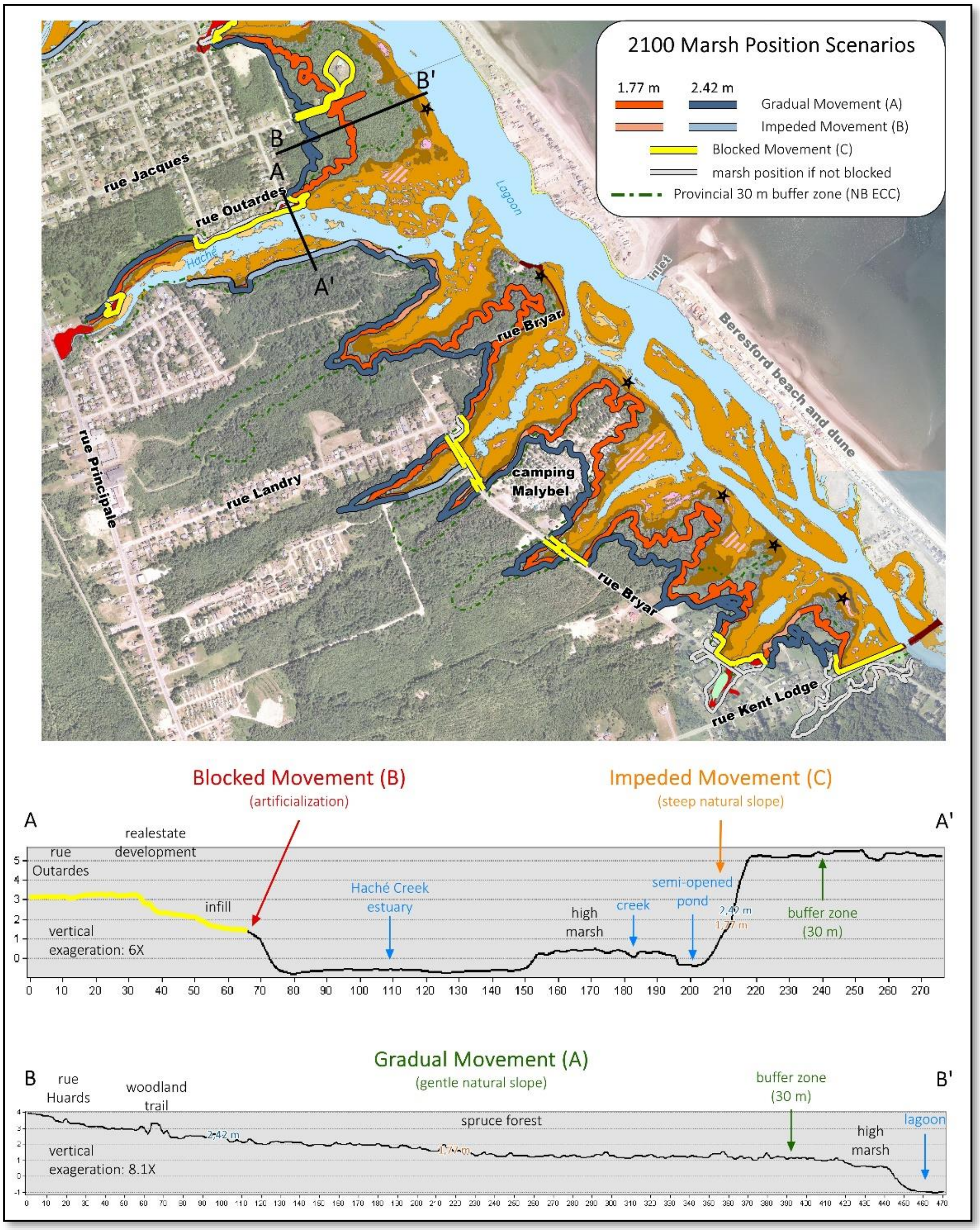


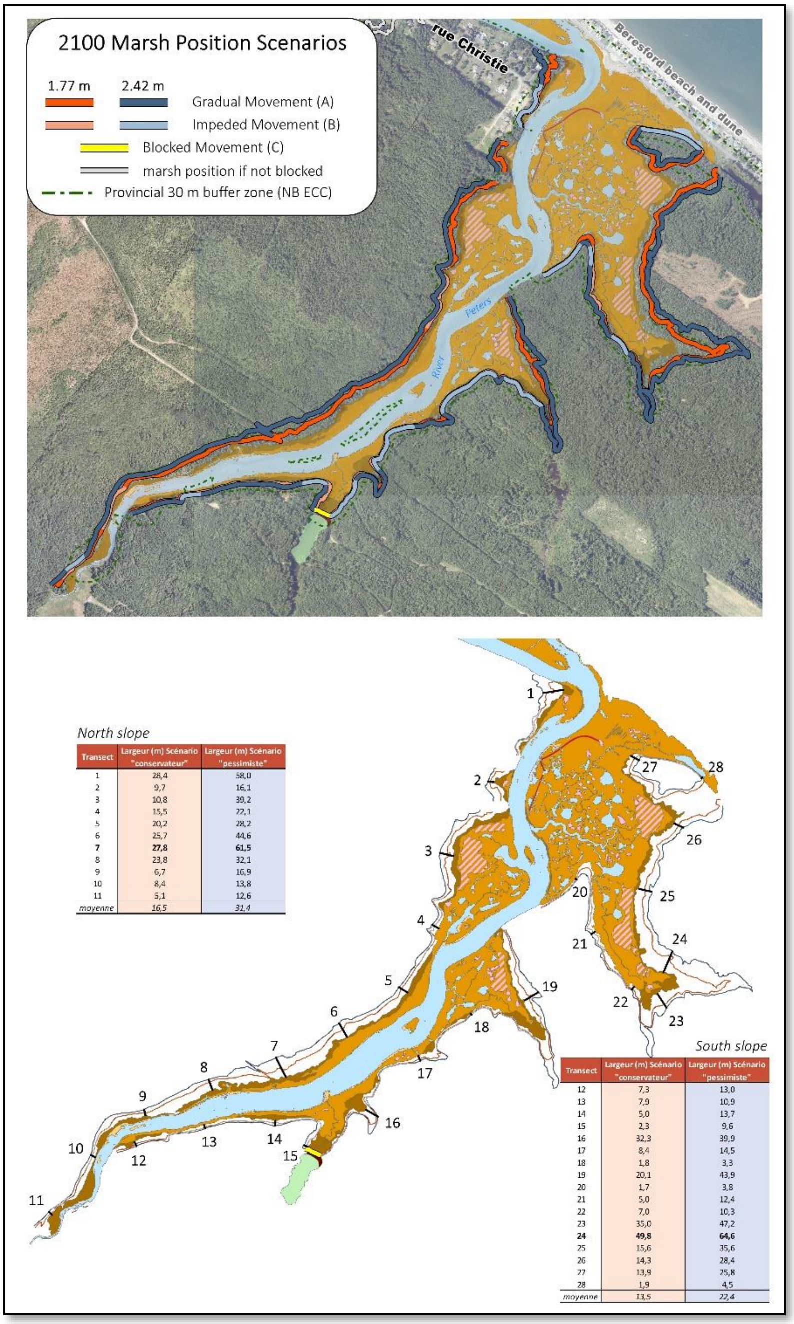
Figure 34. Scenarios of the position of the marsh in the Southern part in 2100 and illustration of Gradual, Blocked, and Impeded movements of the marsh.

V.IV.VII. The Estuary part of the Peters River

In the part of Peters River estuary, some land alterations are present: in the southern portion, a causeway has been built through a creek (creating a freshwater pond where a brackish transition marsh existed in 1944), and a real-estate development of 16 residences (Christie Street) is present on the top of the north shore of the estuary. Except for these two sites, the banks of the Peters River estuary are relatively natural (some logging and access roads have been noted in the "hinterland" on the various series of aerial photos, but no recent residential, industrial, recreational, or institutional development has been identified near the shores - although the extension of Christie Street to the southwest seems to be underway) (Figure 35).

According to the two scenarios developed by *GLC*, the northwest shore of the Peters River estuary seems to present a topography more favorable to the migration of the marsh by 2100. Two portions of the shore (total length ~210m) have steep slopes that can impede the movement of the marsh, but otherwise the remainder of the northwest shore (~90%) would be favorable to the gradual movement of the marsh. The average width of the necessary accommodation space along the north shore under a "Conservative" scenario would be 17m, and under a "Pessimistic" scenario it would be 31m. The generally higher relief and generally steeper slopes along the southeast shore of the Peters River estuary reflect a situation where the accommodation space required for future marsh migration is narrower than that of the north shore (average width of 14m under a "Conservative" scenario and 22m under a "Pessimistic" scenario). [34] In general, the sites where the future migration of the Peters River marshes would not be impeded and where a gradual movement would be possible, correspond to the slopes of the secondary valleys and their upstream sections, where the relief is low and gently sloping.

[34] The steep relief of the south shore of the estuary results in the absence of coastal marshes over an approximate length of 400m.



North slope

Transect	Largeur (m) Scénario "conservateur"	Largeur (m) Scénario "pessimiste"
1	28,4	58,0
2	9,7	16,1
3	10,8	39,2
4	15,5	22,1
5	20,2	28,2
6	25,7	44,6
7	**27,8**	**61,5**
8	23,8	32,1
9	6,7	16,9
10	8,4	13,8
11	5,1	12,6
moyenne	*16,5*	*31,4*

South slope

Transect	Largeur (m) Scénario "conservateur"	Largeur (m) Scénario "pessimiste"
12	7,3	13,0
13	7,9	10,9
14	5,0	13,7
15	2,3	9,6
16	32,3	39,9
17	8,4	14,5
18	1,8	3,3
19	20,1	43,9
20	1,7	3,8
21	5,0	12,4
22	7,0	10,3
23	35,0	47,2
24	**49,8**	**64,6**
25	15,6	35,6
26	14,3	28,4
27	13,9	25,8
28	1,9	4,5
moyenne	*13,5*	*22,4*

Figure 35. Scenarios of the marsh position of the Peters River estuary in 2100.

In the Beresford sub-sector in general, due to the type of human intervention (mainly embankments, real estate development and alterations for roadway development) and their location in coastal marshes (infill, especially brackish transition marshes), there are in 2018/2020, more than 4 km of coastal marshes whose movement is already "blocked" (coastal squeeze), precisely because of the encroachment of developments (Table 15).

Table 15. Length (m) of the coastline describing the types of movements possible for the coastal marshes of the Beresford sub-sector by 2100.

Marsh movement type by 2100	Total length (m), "Conservative" scenario		Total length (m), "Pessimistic" scenario	
	m	%	m	%
Gradual (A)	15,346.1	62%	15,742.7	64%
Impeded (C)	4,772.9	19%	2,818.2	11%
Blocked (B)	4,737.1	19%	6,167.1	25%
Total for 2100 scenario	**24,856.1**	**100%**	**24,728.0**	**100%**
length currently blocked (2018/2020)	4,062.9	16%	4,062.9	16%
increase of blocked length in 2100 relative to total already blocked in 2018/2020	+674.2	+14%	+2,104.2	+34%

Under a "Conservative" scenario projecting the limit of the coastal marshes in the year 2100, an additional 674.2m of linear coastal marshes would be blocked in their movement in response to the rise in relative sea-level, representing an increase of 14%. However, under a "Pessimistic" scenario, an additional 2,104.2m of marshland would be blocked in their movement, representing an increase of 34% compared to the current situation. In detail, this increase in coastal squeeze would occur mainly in the Southern part of the sub-sector, where an additional 1,003.5m of coastal marshes would be blocked in their migration to higher lands. The Northern part would see its total blocked line increase by 247.3m and that of the Central part would increase by 853.5m. As mentioned above, only the Peters River estuary would not experience an increase in coastal squeeze by 2100, precisely because of its "natural" character. But it remains difficult to project into the future what the shores of the Peters River estuary should look like; the projections developed as part of this study do not depict how land use will unfold over the next 79 years.

As is the case with several salt marshes along the coast of the Atlantic provinces, the rate of vertical accretion (by sedimentation and on-site production of organic matter) could prove to be a determining factor for the future of certain marshes in the Beresford sub-sector: survival and maintenance of marshes if the vertical accretion rate is sufficient, or submergence and gradual disappearance of marshes if the vertical accretion rate of the marsh is insufficient.

VI. Potential Evolution and Land-Use Planning

As discussed above, it must be recognized that the most common shoreline response to sea level rise is recession, necessary for the coast's natural adjustment to new conditions. Adapting to rising sea levels is first accepting this fact and remembering that in the absence of coastal developments, the high rates of retreat of the coast are generally not considered problematic.

Sustainable management of the coast, and of the coastal zone in general, must take place over the long term, having a multi-decade vision of spatial planning. The strategies below could be considered individually or in combination to sustainably manage the challenges associated with coastal erosion and coastal habitat migration in response to sea-level rise.

Chaleurs Bay facing coasts

- Avoidance is a strategy that relies on action upstream, before a problem arises, to not allow the development of infrastructures that would end up in areas at risk of erosion before the end of their life cycle. Avoidance can be achieved through zoning (or land-use planning) measures to establish a margin of non-constructibility along the coast.[35] Here, management takes place in the optic of long term, and in this sense the sectors where the rates of coastal retreat are the strongest and where the erosion is chronic should be prioritized to establish setback boundaries (or non-constructibility) that are positioned far enough in space and time.

  Avoidance can also take other forms of action, for example granting *protection status* to coastal areas that have remained natural (without developments); the establishment of a *coastal land buy-back programme* would make it possible to remove plots of land from the risk of erosion; *conservation clauses* could be discussed with coastal landowners[36] and incorporated into title deeds if a coastal

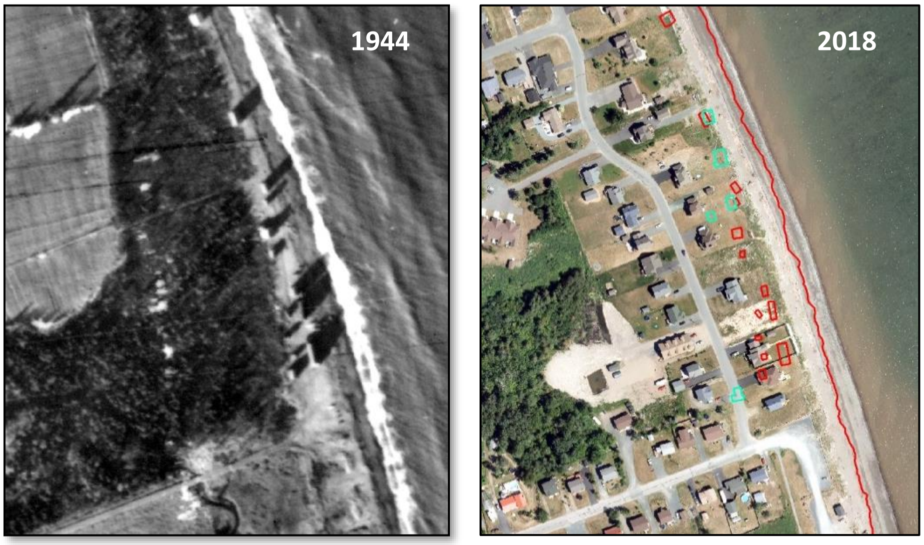
[35] We must understand this concept with all the flexibility it allows: we can occupy the space as long as the setback boundary is still far, but we must avoid constructions or developments that involve longer periods than what the pace of coastal retreat allows in a given area.

[36] For example, citizens sensitized to the protection, the integrity of the coastal zone and of nature.

land purchase program is not possible; could one even imagine *land incentives* put in place by the responsible authorities - in the same way that there are tax breaks to stimulate the establishment of businesses in certain regions - where a "rebate" (credit) would be given to landowners who neither develop nor harden (through the placement of protection structures) the coastal portion of their property (GRANNIS, 2011, p. 54)?

- The strategic withdrawal, which consists in removing the stakes (infrastructure) from the area at risk of erosion instead of choosing to fight against erosion by hardening the coast, could be considered in developed sectors. The general objective of this strategy is to move out goods and activities in order to restore a accommodation space for coastal ecosystems, and to reduce risks in the long term. The methods of implementing the strategic withdrawal vary due to regional or local characteristics (critical distances, thresholds, safety margins or setbacks, etc.), but the socio-economic aspects can no longer be excluded from the process (protection of people, fair compensation).[37] The implementation of such a strategy would make it possible to achieve a few objectives: first of all to avoid the proliferation of protection structures on the coast (riprap, walls, embankments, gabions, etc.), which have negative effects on the beaches located in front (thinning and narrowing) and often on the coasts located downstream (locally, an acceleration of erosion via the "end effect"; over a longer distance, disturbance, or even rupture, of sediment exchanges); then to protect residents and property from major storm events (precautionary principle); and finally, to promote the maintenance of coastal ecosystems and "natural" landscapes (for local populations, recreational potential and tourist attraction).

[37] After tropical storm Xynthia, several French coastal owners were evicted from their homes. A "progressive" strategic withdrawal has since emerged in the discourse of coastal management in France. LAMBERT (2013) summarizes the approach envisaged: *"[...] to avoid the shock and pain of sudden loss and help develop a culture of risk. The proposal consists in organizing a gradual abandonment of the properties over three periods of 30 years […]. Thus, we could envisage that until 2040, the sited property can be occupied or rented, but becomes non-transferable (no inheritance, no sale). In a second period, until 2070: the property could be occupied, but could no longer be rented. And finally, until 2100: the property could only be occupied by its owner, before being incorporated into the public maritime domain*." (text translated by *GLC*)



Example of **building withdrawl** from the coastal zone:

Northern part of the Beresford sub-sector (in the vicinity of Chalets Street and Bay Street)

RED 1944

GREEN 1985

- The establishment of participatory management of coastal issues involving the citizens of the communities of the Chaleur RSC would certainly raise awareness of the problem of coastal erosion.[38] Policies that have originated from within (locally) would undoubtedly have a better chance of success. For example, the portions of land left vacant (wasteland) could be used for "light" uses: campgrounds, public access to the sea, lookouts, multi-use ecotourism trails (nature interpretation, walking, bicycle paths, picnic areas, etc.), agriculture. The development of such policies should aim above all at discouraging "hard" constructions (houses, industries, buildings with concrete foundations, asphalt paving, etc.) in order to avoid the creation of a risk and possible artificialization of the coastland in the near future.

[38] The organization of workshops and the steps undertaken and accompanied by researchers allow local communities to grasp the challenges because they participate in the identification of solutions (CHOUINARD, PLANTE and MARTIN, 2006). See also the publication GUILLEMOT *et al*. (2014).

Coasts associated to the Beresford salt marshes

- An accommodation space management strategy should be developed in conjunction with all stakeholders to identify the best options for using these lands that will eventually accommodate the marshes in the future.[39]

  We must see the management of these spaces over the short, medium, and long term: light facilities (sports fields, parks, recreational and tourist areas taking advantage of the presence of natural spaces and the marsh) are to be favored, but we can also install campsites, barns or storage buildings, structures without cement foundations, easy to remove when the time is right. It is undoubtedly necessary to innovate and think of title deeds or leases providing for the prohibition of permanent infrastructure and the fact that the space will have to be sold or bought back at maturity. In short, there are 79 years to 2100 and we can occupy and enjoy these spaces for a good part of that period, which retains their value.

- Opportunities to restore existing coastal marshes could be assessed, especially on municipal lands. Not only do these coastal environments have recreational tourism potential and natural protection against flooding and wave action, but it is well documented that salt marshes are good atmospheric carbon "sink", and that as such, they participate in the reduction of greenhouse gases responsible for climate change. The rate of burial or carbon sequestration by salt marshes is ~240gC/m^2/year, which makes salt marshes one of the most productive coastal ecosystems in this area (ORTIZ, 2019).[40] A recent study aimed at estimating the stock of carbon contained in the coastal marsh of Pointe Carron concluded that its salt marsh (with an area of 43.8ha) would contain 17.1 kilograms of carbon per square meter, or ~7,500 tonnes of carbon for this whole salt marsh. Based on the monetary market value of carbon in 2013, the study estimates that the carbon stored

[39] These options could include: the creation or designation of protected natural areas; the development of riverside parks; changing zoning to exclude development; adding protection clauses to title deeds; the purchase of land by conservation organizations.

[40] By comparison, mangroves bury carbon at a rate of ~163gC/m^2/yr and eelgrass beds or "sea grass" on the foreshore, at ~138gC/m^2/yr (ORTIZ, 2019).

in the Pointe Carron salt marsh would represent a total of US$139,000 (VAN ARDENNE *et al*., 2018).

Any action to restore coastal marshes previously backfilled or otherwise altered could turn into an economic lever for the Municipality of Beresford, like a property tax. Support (financial and logistical) for restoration can come from the federal government (Environment and Climate Change Canada - *North American Waterfowl Management Plan*), the provincial government (Environment and Climate Change) and non-profit organizations (Wildlife Habitats Canada; Ducks Unlimited; New Brunswick Natural Sites Foundation; Nature Conservancy of Canada).

Géo Littoral Consultants hopes that the data contained in this report will enable those in charge at the Chaleur RSC to continue their reflection on the issues of erosion, the retreat of the coast and the preservation of the territory's "salt" marshes, the choices to be made and the actions to be taken. The Chaleur RSC has the opportunity here to develop and implement innovative measures at the regional and provincial levels, in accordance with its privy situation being one of the only two Canadian bays that are members of the *Most Beautiful Bays in the World* club (https://world-bays.com/).

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Appendix A – Map legend

Sea and Foreshore

Lagoon (key: LAGUNE) (colour: Sodalite blue)

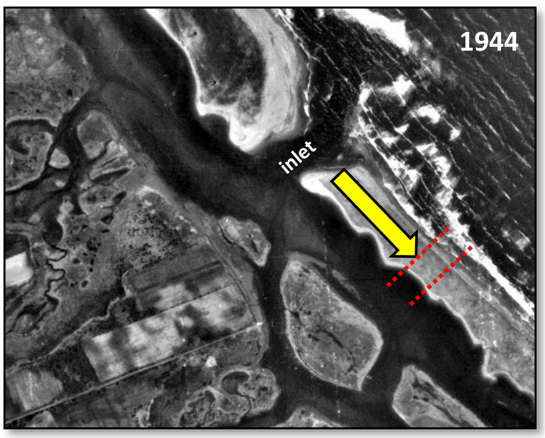
A saline body of water, including the estuaries of the main rivers flowing into it, located behind the Beresford coastal dune system, and connected to Chaleur Bay by an inlet. The lagoon is influenced by the tide.

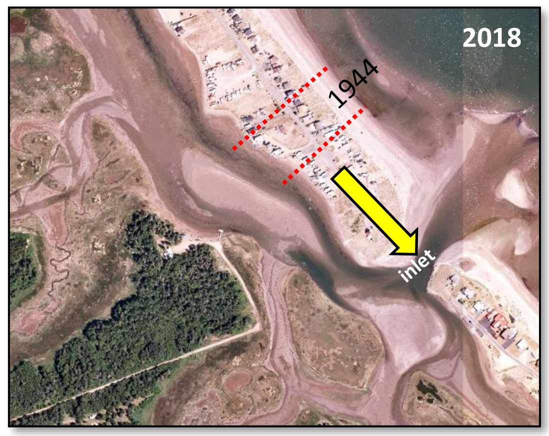
Alluvium (key: ALLUVIONS) (colour: grey 10%)

Deposit of materials on the bed of a watercourse or on the foreshore of the lagoon. Made up of sediments the size of sands and gravels, alluvium often takes an elongated shape in the direction of the current. These sediment banks can be vegetated.

Inlet (key: GOULET) (colour: Sodalite blue)

More or less deep opening in the coastal dune of Beresford allowing the tidal wave to penetrate (making the connection between the Bay and the lagoon). The Beresford inlet (or gully) has moved ~280 meters southeast since 1944. *The area of this body of water has not been included in the calculations*.

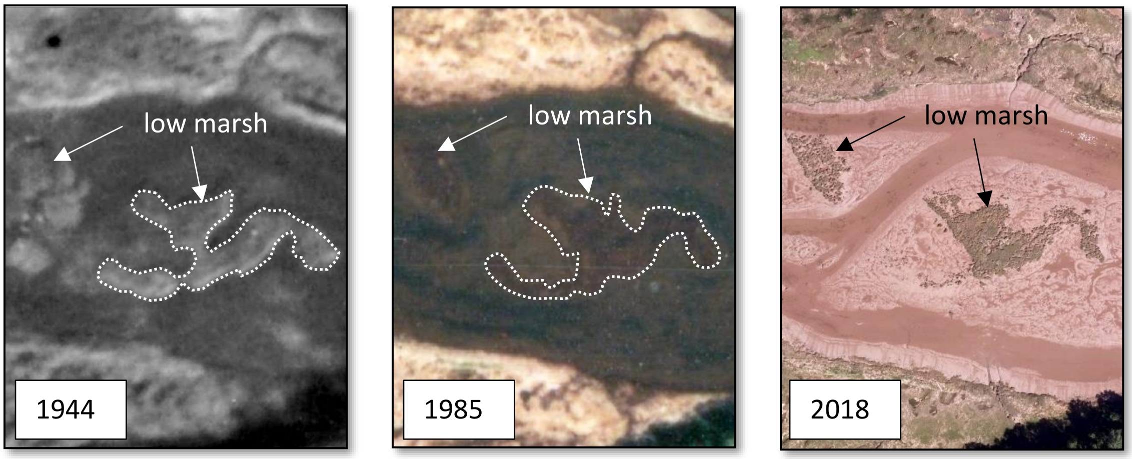




Coastal Marsh Habitats

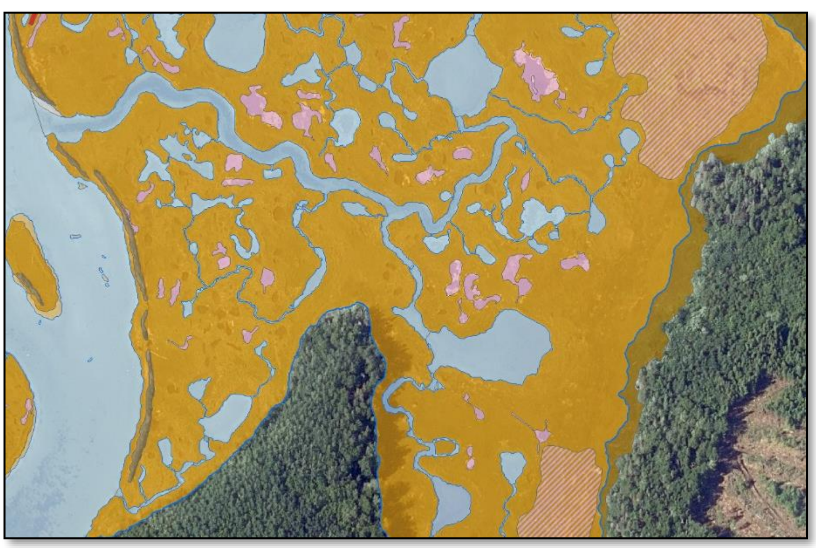
Low marsh (key: B_MARAIS) (colour: Mango)

Vegetated surface on the edge of a lagoon or a body of water influenced by the tide. The low marsh typically develops slightly below mean sea level and high tide - so it is flooded daily. It often forms a ribbon on either side of tidal creeks or ditches or a band on the edge of the lagoon or a semi-open pond. The low marsh is dominated by the seawater cordgrass, *Spartina alterniflora*, with occurrences of other osmotic halophyte plants, such as the samphire green. It has a dark gray tint in aerial photos from 1944; a dark brownish tint on those of 1985; and a khaki green tint on the 2018/2020 orthophotos (examples on the next page).



High marsh (key: H_MARAIS) (colour: Seville orange)

The high marsh is located a little higher in the salt marsh, of which it often represents the major part (see illustration below). It lies between the higher high water mean tide and the higher high water large tide - the high marsh is inundated during monthly astronomical high tides. The dominant plant species in the high marsh is the saltmeadow cordgrass, *Spartina patens*; other species accompany it because the high marsh is less frequently inundated by sea water, and therefore more diverse. The landscape of the high marsh is punctuated by numerous closed ponds, and it is crossed by tidal creeks which brings in and drains the tide to semi-open ponds (bodies of water influenced by the tide) or towards the upstream course of streams. The high marsh is limited inland by the brackish transition marsh (see also Figures 14 and 15).



Tidal creek (key: ÉTIER) (colour: Sodalite blue)

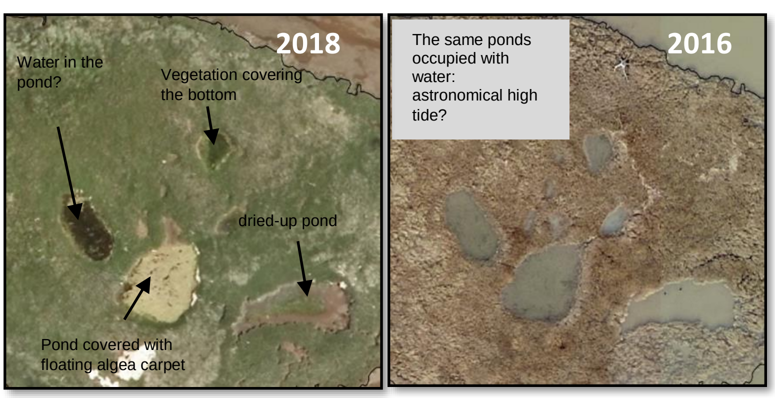
Small stream influenced by the tide. The tidal creek is in contact with the lagoon and the marsh's water bodies, such as semi-open ponds, or corresponds to the downstream portion of non-coastal watercourses.

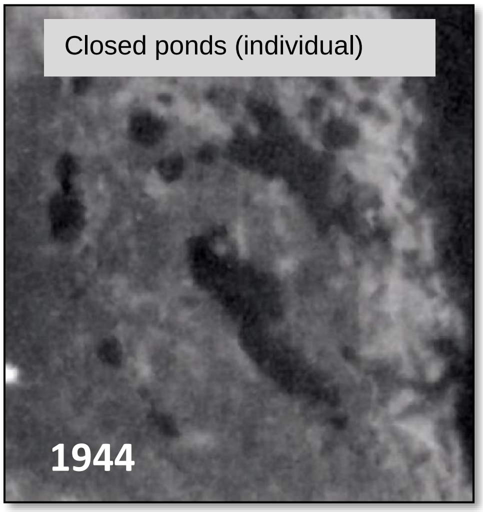
Semi-opened pond (key: MS_OUVERTE) (colour: Sodalite blue)

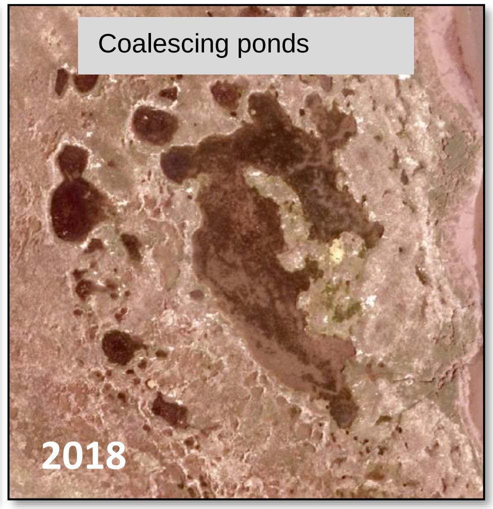
Body of water in the salt marsh which is influenced by the tide. The semi-open pond is connected to the lagoon by a tidal creek or a drainage ditch. A band of low marsh may be present on the banks of semi-open ponds.

Pond (key: MARE) (colour: Rhodolite rose)

Isolated body of water in the salt marsh. The high marsh is often punctuated by ponds of various sizes and shapes. These closed depressions in the salt marsh may or may not be occupied by water - this depends on several factors at work when the aerial photographs were taken (spring thaw, equinox tide, recent storm, drought period, local hydrology, etc.). Some depressions may be occupied by water, while others located a few meters away have dried up. Other depressions may be occupied by a mat of floating algae (a layer of enteromorphic algae and blue-green bacteria) (example below), while at other times of the year the ponds are covered with emergent vegetation. While the size of some closed ponds may persist for several decades, other ponds may enlarge and merge with adjacent ponds to form a single entity (coalescing ponds, next page).





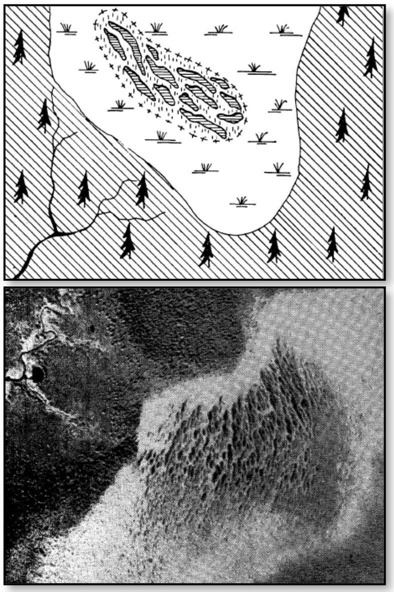


Ditch (key: DRAIN) (colour: Sodalite blue)

Drainage ditch built in the marsh. Like the tidal creek, the ditch is in contact with the lagoon and interior water bodies, such as semi-open ponds. The ditch can be distinguished from the tidal creeks by its very rectilinear layout.

Reticulated marsh (key: M_RÉTICULÉ) (colour: Seville orange 50%)
(colour: Rhodolite rose 50%)

Large surface in the high marsh with a hummucky relief, formed of individual ponds or depressions (often elongated), separated by strips or ribbons of marshes. These lentil-shaped depressions may or may not be occupied by water. The density of the ponds and their probable connection (between them) via gaps in the marsh strips separating them could mean the presence of a single large depression. In our calculations, 50% of the total area of the polygon is counted as "high marsh" and 50% is counted as "water". The term "reticulated marsh" was inspired by the reticulated bog of subarctic Quebec, described by Louis-Edmond HAMELIN (1957) (illustration on next page).

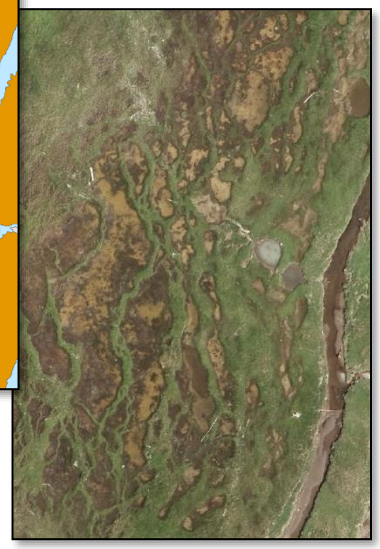


reticulated peatland
(HAMELIN, 1957)

near Grants Creek

reticulated marsh, central part (Beresford)

2018



Brackish transition marsh (key: MS_TRANSITION)

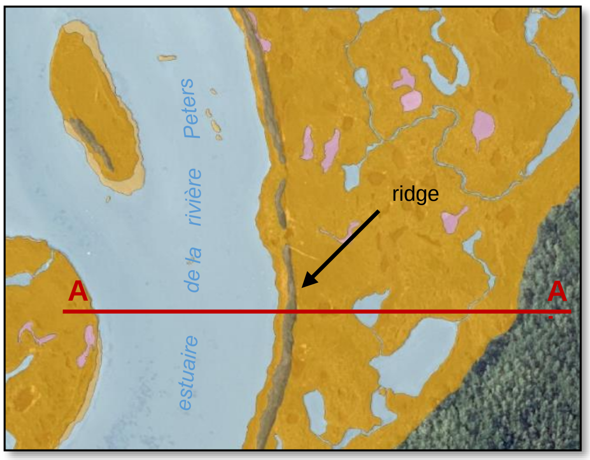
(colour: Raw umber)

Wetland located between the high marsh and non-coastal lands, often occurring in a more or less wide band or ribbon. The brackish transition marsh is only occasionally inundated by sea water (during strong storms, during astronomical equinox tides); it receives runoff (source of fresh water) from higher ground.[41] In general, the soils and water found there are of lower salinity, and this situation results in greater plant diversity than in the salt marsh; the brackish transition marsh remains dominated by the *Spartina pectinata*.

41 As part of a study of the Grande-Digue "Dune" system (beach, dune, and back-barrier marsh), local farmers referred to the brackish transition marsh as the "blotter".

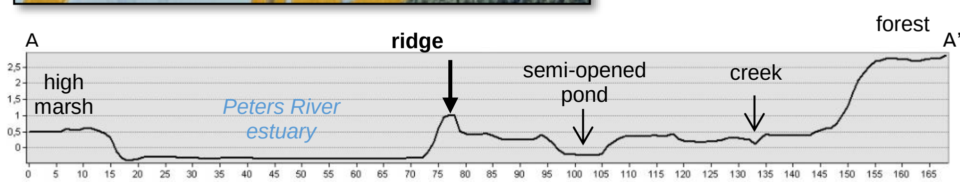
Ridge (key: BOURRELET) (colour: Light sienna)

Long, sinuous, and low relief (of the order of half a meter) found on the edge of marshes, often along the shore of an estuary. It possibly corresponds to a storm deposit (debris and sediment) or to a high level of river water. The ridges identified are all covered with marsh vegetation.



Example of a lateral ridge along the Peters River estuary

(2020 mapping)



Other Coastal Habitats

Beach (key: PLAGE) (colour: Medium yellow)

Accumulation of sediment, often the size of sands. A beach has been recognized on the edge of the lagoon and backing onto a salt marsh (at the end of Saint-Pierre Street); otherwise, most of the mapped beaches are found along the backshore of the Beresford coastal dune system. These beaches are often very narrow (a few meters wide).

Dune (key: DUNE) (colour: Medium key lime)

Wind-blown sand accumulation, covered by halophytic vegetation (American beach grass). With the exception of the Beresford dune (which was not mapped as part of this work), a narrow dune was recognized on the edge of a marsh, behind a beach (along the salt marsh at the end of Saint-Pierre Street).

Non-coastal land (key: TN_CÔTIÈRE) (colour: Sage dust)

Plot of land that is only occasionally inundated during extreme water levels (severe storms). As part of this work, only a few patches of forest within the coastal marsh have been mapped.

Human Alterations

Dyke (key: DIGUE) (colour: Mars red)

Earth levee built in the marsh to contain sea water. Elongated-shaped mound of about 2m in height (relative to the adjacent marsh surface) and built near the banks of the marsh. The dyke shape roughly follows the outline of the lagoon or the adjacent estuary. Dykes (parts thereof) were observed in some marshes of the Beresford sub-sector, but those in the northern part are most evident. A field campaign should be considered to confirm this hypothesis.

Pavement (key: CHAUSSÉE) (colour: Dark umber)

Earth embankment designed for vehicular traffic. It can be a roadway built up slightly higher than the surrounding marsh or a roadway significantly higher than the surface of the marsh (in the case of maintained provincial or municipal roads).

Infill (key: REMBLAI) (colour: Poinsettia red)

Any artificial surface intended to fill the marsh, raise it or obliterate it. Often backfilled surfaces accommodate buildings or correspond to raised grass plots (private or public, such as playgrounds).

Protection structure (key: S_PROTECTION) (colour: Toscan red)

Structure built on the shore to counter erosion and shoreline recession. Often, they correspond to riprap (hard rock boulder mounds placed at the foot of the cliffs), gabions (metal baskets filled with rock) or concrete walls (sometimes wooden walls) of varying height, length and width; occasionally, backfills are built with rocks or concrete blocks of varying size.

Trench (key: S_TRANCHÉE) (colour: Tudor rose dust)

Depression mostly elongated and narrow dugout in the high marsh. The trenches observed in the study area are in the salt marshes of the Peters River estuary and in the central part (marsh at the end of Saint-Pierre Street). Other trenches have been recognized but are rather rectangular in shape (see also Appendix B – *Evidence of human uses of the marsh*). All these examples could be peat extraction sites or even marsh silt extraction sites (as documented in some Prince Edward Island marshes). A field campaign should be considered to confirm these hypotheses.

Pillar (key: PILIER_ROCHE) (colour: Fuchsia pink)

Piles (about 5m X 5m) of rocks of varying sizes on the foreshore of the lagoon, possibly having been used for the construction of a bridge. In a first site, there are 6 pillars located in front of Jacques Street. Clearly visible on the aerial photos of 1944, some remnants can be observed on the more recent images. In a second site, two pillars are visible in the images from 1985 and 2020 in the vicinity of Christie Street - in 1944, this site had a bridge spanning the Peters River behind a large building, which could have been the "Kent Lodge" - hypothesis to be confirmed.

Freshwater pond (key: ÉTANG_ART) (colour: Lilac dust)

Body of water created artificially by the construction of a causeway in the upstream section of a creek, Peters River estuary sector. The previous brackish transition marsh is replaced by a freshwater body.

Freshwater marsh (key: M_DULCICOLE) (colour: Jadeite)

Freshwater marsh artificially created by the construction of a causeway in the upstream section of a creek (central part, along the Millstream River). The previous brackish transition marsh is replaced by a freshwater marsh.

Appendix B - List of recognized and mapped interfaces

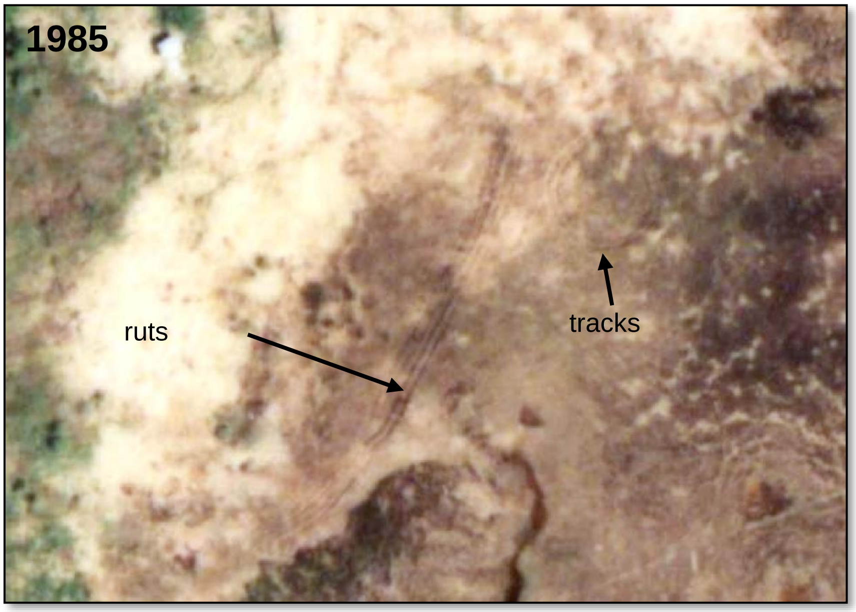
The "interface" mapping was proposed by Dominique BÉRUBÉ (New Brunswick Department of Natural Resources and Energy Development) during his supervision of the control work for the Grande-Digue spit site (KÂ, 2017). The process consists in naming, in the GIS attribute table, the environment, the form of land or the human infrastructure located on either side (on each side) of the digitized vector. For example, the vector representing the contact between the high marsh and the brackish transition marsh is named: "*Interface_Haut marais-Marais saumâtre transition*". By offering descriptive and complete terms, it is possible to know and represent, with a "click" of the mouse, the nature of the environment in question. Other attributes are added to these vectors to specify their characterization: coastline, shoreline, level of artificialization, etc. These additional attributes correspond to fields (columns) in the attribute table.

Interface_Alluvions-Bas marais	Interface_Haut marais-Friche
Interface_Alluvions-Forêt	Interface_Haut marais-Marais réticulé
Interface_Alluvions-Marais saumâtre transition	Interface_Haut marais-Marais saumâtre transition
Interface_Bas marais-Alluvions	Interface_Haut marais-Mur de béton
Interface_Bas marais-Bourrelet	Interface_Haut marais-Mur de bois
Interface_Bas marais-Digue	Interface_Haut marais-Plage
Interface_Bas marais-Dune littorale	Interface_Haut marais-Remblai (Chaussée)
Interface_Bas marais-Enrochement	Interface_Haut marais-Remblai (Digue)
Interface_Bas marais-Haut marais	Interface_Haut marais-Remblai (Récréatif)
Interface_Bas marais-Marais saumâtre transition	Interface_Haut marais-Remblai (Résidentiel)
Interface_Bas marais-Mur de béton	Interface_Haut marais-Terre non côtière
Interface_Bas marais-Plage	Interface_Marais réticulé-Forêt
Interface_Bas marais-Remblai (Chaussée)	Interface_Marais réticulé-Haut marais
Interface_Bas marais-Remblai (Digue)	Interface_Marais réticulé-Marais saumâtre transition
Interface_Bourrelet-Forêt	Interface_Marais réticulé-Remblai (Chaussée)
Interface_Bourrelet-Haut marais	Interface_Marais réticulé-Remblai (Digue)
Interface_Drain-Bas marais	Interface_Marais réticulé-Remblai (Récréatif)
Interface_Drain-Forêt	Interface_Marais saumâtre transition-Bourrelet
Interface_Drain-Haut marais	Interface_Marais saumâtre transition-Champ
Interface_Drain-Marais saumâtre transition	Interface_Marais saumâtre transition-Drain
Interface_Drain-Ponceau	Interface_Marais saumâtre transition-Dune littorale
Interface_Drain-Remblai (Chaussée)	Interface_Marais saumâtre transition-Enrochement
Interface_Drain-Terre non côtière	Interface_Marais saumâtre transition-Forêt
Interface_Dune littorale-Remblai (Chaussée)	Interface_Marais saumâtre transition-Friche
Interface_Enrochement-Champ	Interface_Marais saumâtre transition-Mur de béton
Interface_Enrochement-Marais saumâtre transition	Interface_Marais saumâtre transition-Remblai (Chaussée)
Interface_Enrochement-Remblai (Chaussée)	Interface_Marais saumâtre transition-Remblai (Digue)
Interface_Estuaire-Accès	Interface_Marais saumâtre transition-Remblai (Récréatif)
Interface_Estuaire-Alluvions	Interface_Marais saumâtre transition-Remblai (Résidentiel)
Interface_Estuaire-Bas marais	Interface_Marais saumâtre transition-Terre non côtière
Interface_Estuaire-Bourrelet	Interface_Mare semi-ouverte-Bas marais
Interface_Estuaire-Champ	Interface_Mare semi-ouverte-Bourrelet
Interface_Estuaire-Digue	Interface_Mare semi-ouverte-Haut marais
Interface_Estuaire-Dune littorale	Interface_Mare semi-ouverte-Marais réticulé
Interface_Estuaire-Enrochement	Interface_Mare semi-ouverte-Marais saumâtre transition
Interface_Estuaire-Forêt	Interface_Mare semi-ouverte-Remblai (Chaussée)
Interface_Estuaire-Friche	Interface_Mare semi-ouverte-Remblai (Digue)
Interface_Estuaire-Haut marais	Interface_Mare-Bas marais
Interface_Estuaire-Marais réticulé	Interface_Mare-Bourrelet
Interface_Estuaire-Marais saumâtre transition	Interface_Mare-Haut marais
Interface_Estuaire-Mur de béton	Interface_Mare-Marais saumâtre transition
Interface_Estuaire-Mur de bois	Interface_Mare-Remblai (Chaussée)
Interface_Estuaire-Mur de soutènement	Interface_Mare-Remblai (Digue)
Interface_Estuaire-Plage	Interface_Mur de béton-Remblai (Chaussée)
Interface_Estuaire-Remblai (Chaussée)	Interface_Plage-Accès

Interface_Estuaire-Remblai (Digue)	Interface_Plage-Bas marais
Interface_Estuaire-Remblai (Résidentiel)	Interface_Plage-Dune littorale
Interface_Estuaire-Résidu pilier rocheux	Interface_Plage-Enrochement
Interface_Estuaire-Rive	Interface_Plage-Forêt
Interface_Étang-Remblai (Chaussée)	Interface_Plage-Friche
Interface_Étier-Alluvions	Interface_Plage-Haut marais
Interface_Étier-Bas marais	Interface_Plage-Marais saumâtre transition
Interface_Étier-Haut marais	Interface_Plage-Mur de béton
Interface_Étier-Marais réticulé	Interface_Plage-Mur de bois
Interface_Étier-Marais saumâtre transition	Interface_Plage-Remblai (Chaussée)
Interface_Étier-Plage	Interface_Plage-Remblai (Digue)
Interface_Étier-Ponceau enrochement	Interface_Plage-Remblai (Résidentiel)
Interface_Étier-Remblai (Chaussée)	Interface_Ponceau-Remblai (Chaussée)
Interface_Étier-Remblai (Digue)	Interface_Remblai (Chaussée)-Champ
Interface_Forêt-Remblai (Chaussée)	Interface_Remblai (Chaussée)-Forêt
Interface_Forêt-Remblai (Digue)	Interface_Remblai (Digue)-Champ
Interface_Goulet-Plage	Interface_Remblai (Digue)-Forêt
Interface_Haut marais-Bourrelet	Interface_Remblai (Digue)-Remblai (Chaussée)
Interface_Haut marais-Champ	Interface_Sommet du mur de béton-Remblai (Chaussée)
Interface_Haut marais-Drain	Interface_Sommet enrochement-Remblai (Chaussée)
Interface_Haut marais-Dune littorale	Limite_44_Importée_85_pour_créer_polygone_Étang
Interface_Haut marais-Effluent urbain	Limite_44_Importée_85_pour_créer_polygone_Remblai
Interface_Haut marais-Enrochement	Limite_44_Importée_85_pour_créer_polygone_Remblai (Chaussée)
Interface_Haut marais-Excavation tourbe	Limite_44_Importée_20_pour_créer_polygone_Étang
Interface_Haut marais-Forêt	Limite_44_Importée_20_pour_créer_polygone_Remblai (Chaussée)

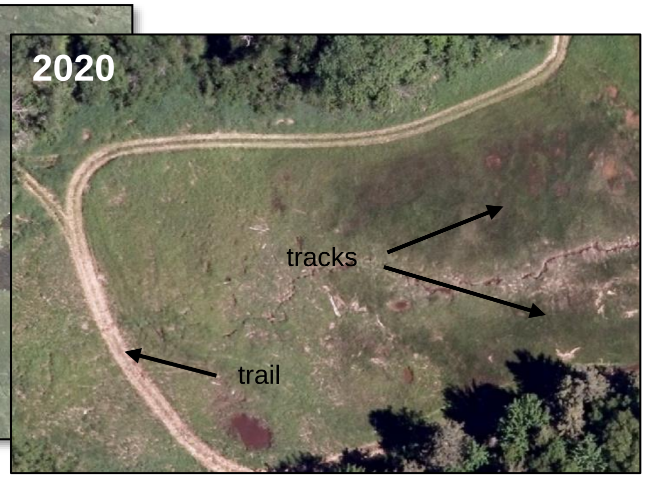
Appendix C – Evidence of human uses of the marsh

The figures included in Appendix B have been prepared in order to document and to inventory the various evidence of uses of the coastal marshes which could not be integrated within the framework of this project, but which were nevertheless observed during the mapping work. These are, for example, ruts following the passage of ORVs (off-road vehicles), cattle fence posts, etc.

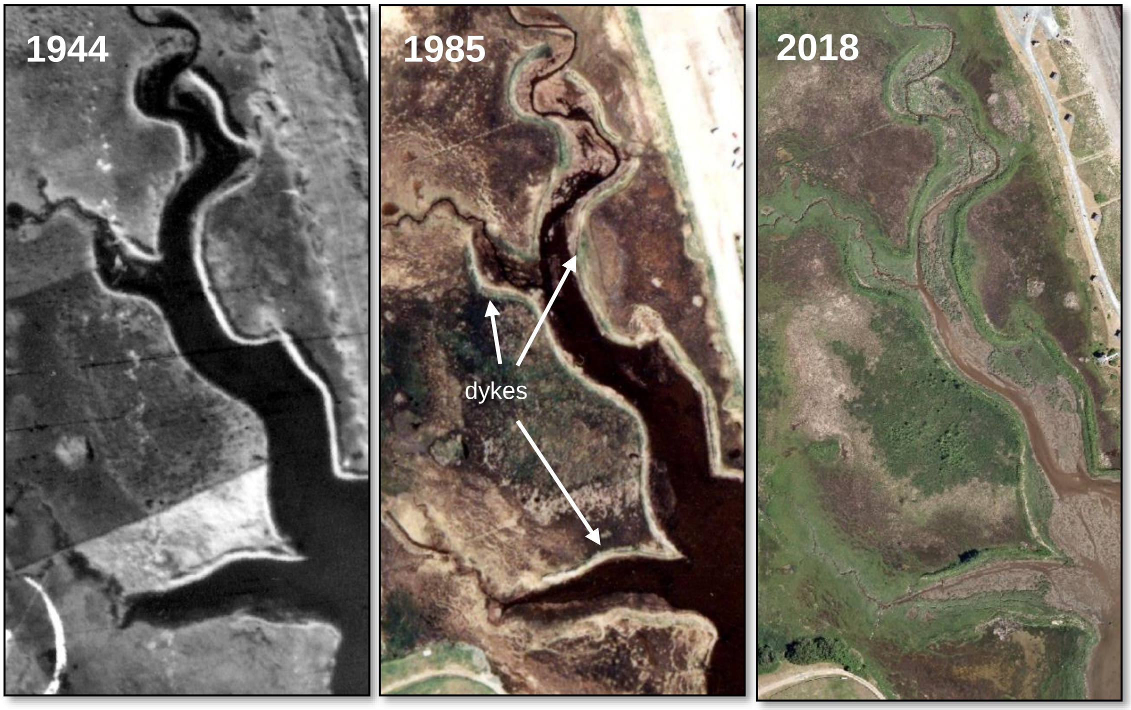


Ruts and tracks of motorized vehicular traffic in the high marsh and the brackish transition marsh of the Northern part, 1985 photos.

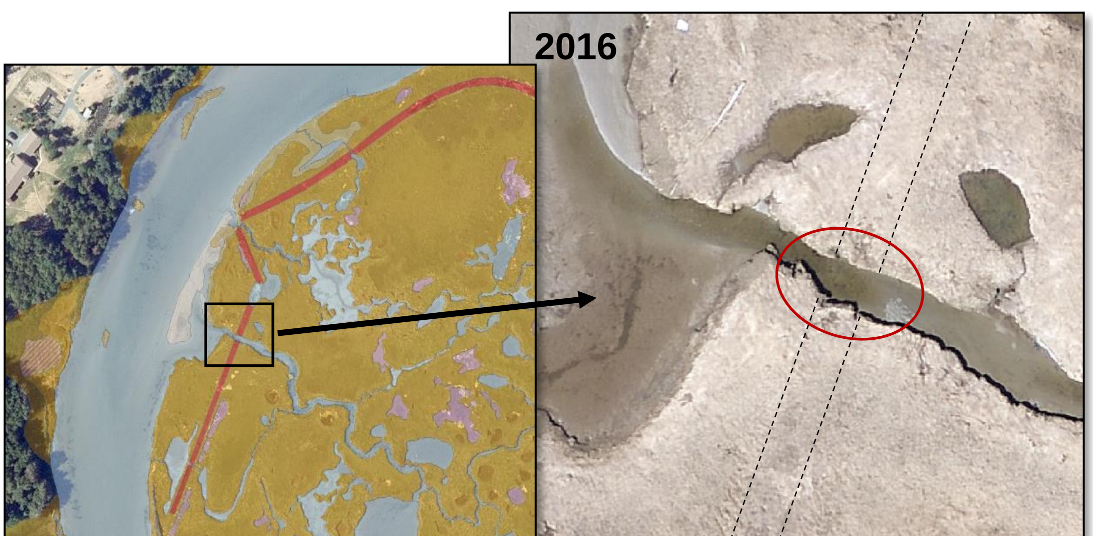
Vehicle traffic tracks in the brackish transition marsh of the Southern part, 2020 orthophotos.



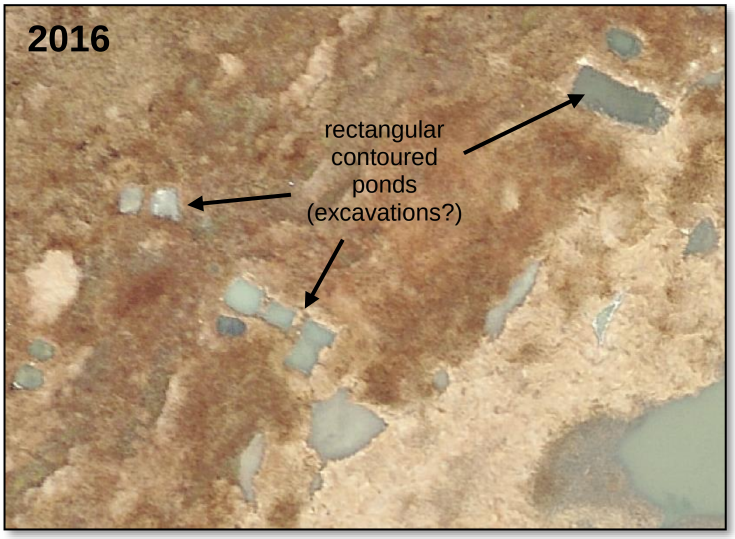
Regular trail in the brackish transition marsh and **vehicle traffic tracks** in the high marsh of the Southern part, 2020 orthophotos.



Dykes (levees, ridgess or infill) constructed along the shores of the lagoon/estuary of the Northern part, photos of 1944, 1985, 2018.



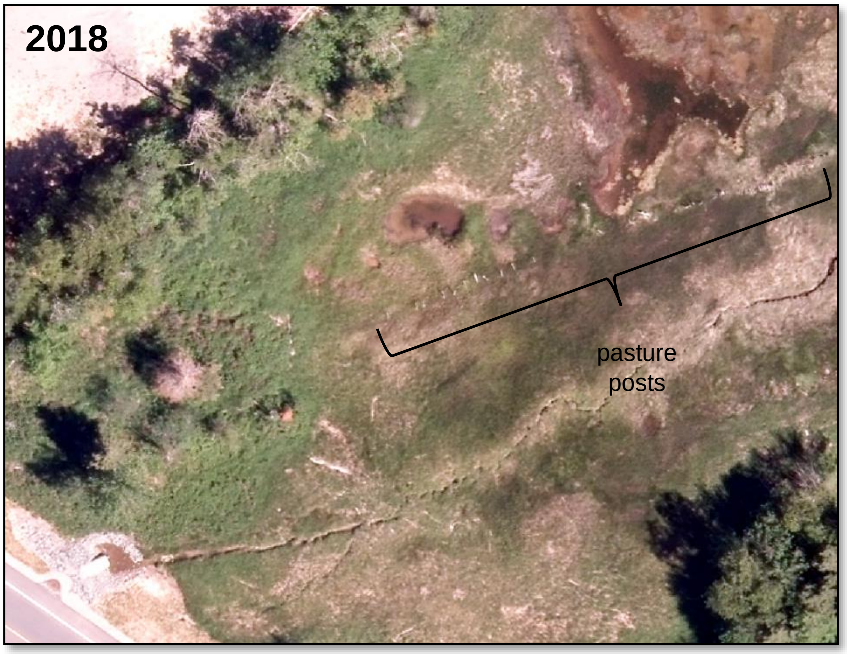
Dykes in the Peters River marsh; possible site of an Acadian **aboiteau** (2016 orthophoto)?



Excavations in the high marsh of the Southern part: peat extraction or marsh mud extraction? Evidences observed on all aerial photograph series (1944 to 2018), 2016 orthophoto.

Excavations (a dozen linear ditches in the marsh) in the high marsh of the Peters River estuary: peat extraction or marsh mud extraction? Evidences observed on all aerial photograph series (1944 to 2018), 2016 orthophoto.

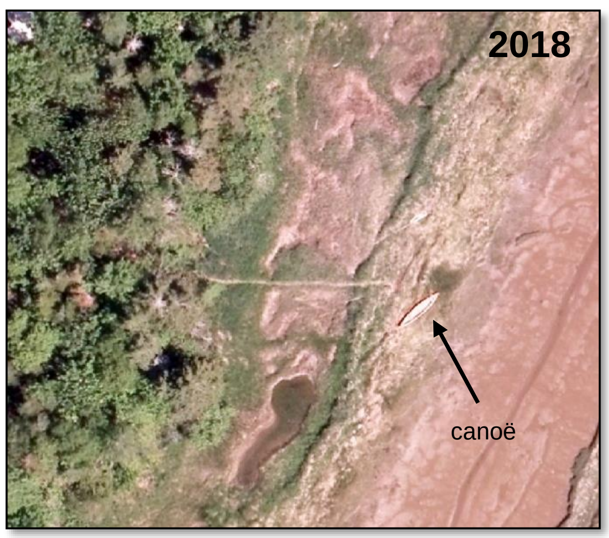
Excavations (4 linear features) in the high marsh of the Central part. Evidences observed on all aerial photograph series (1944 to 2018), 2018 orthophoto.



Remnants of pasture posts for cattle in the marsh of the Southern part, 2018 orthophoto.

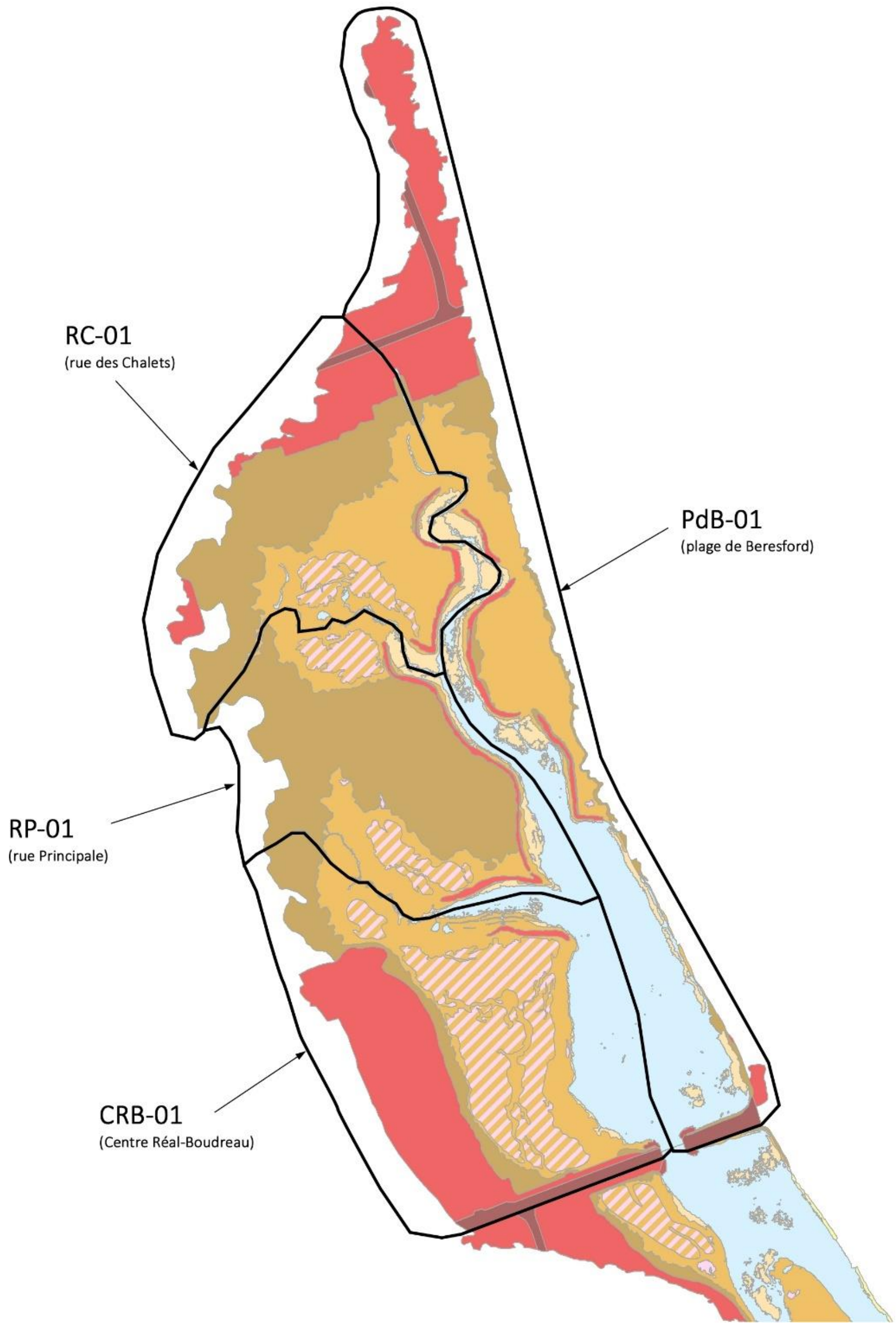
Boat remnants in the high marsh of the Central part, 2018 orthophoto.

Leisurly activity via the marsh of the Southern part, 2018 orthophoto.

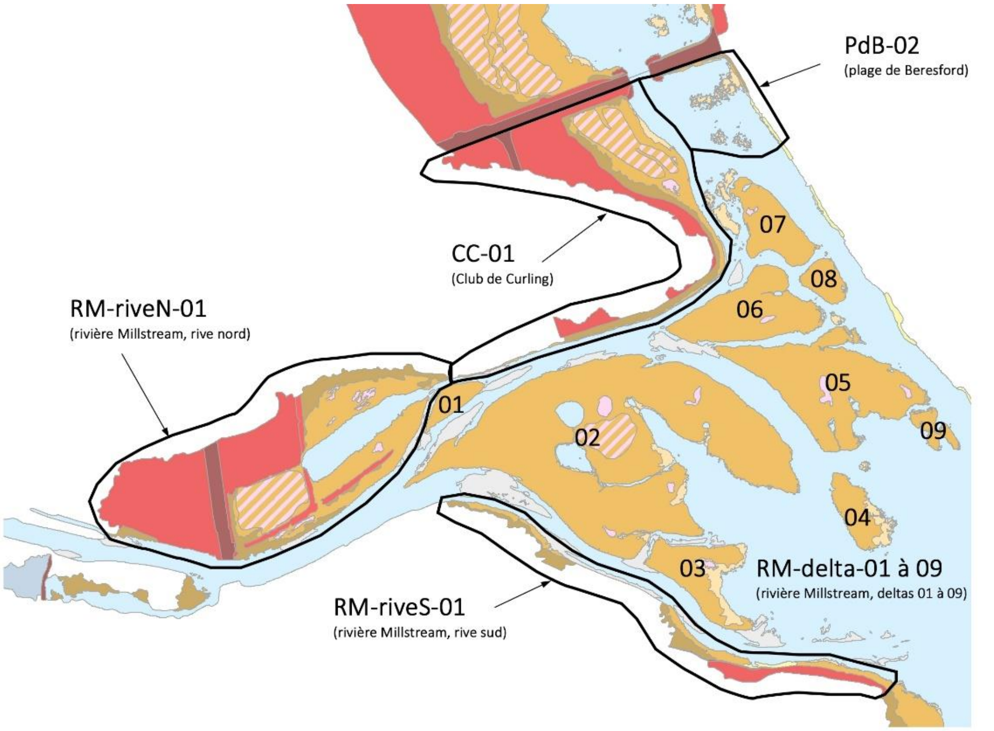


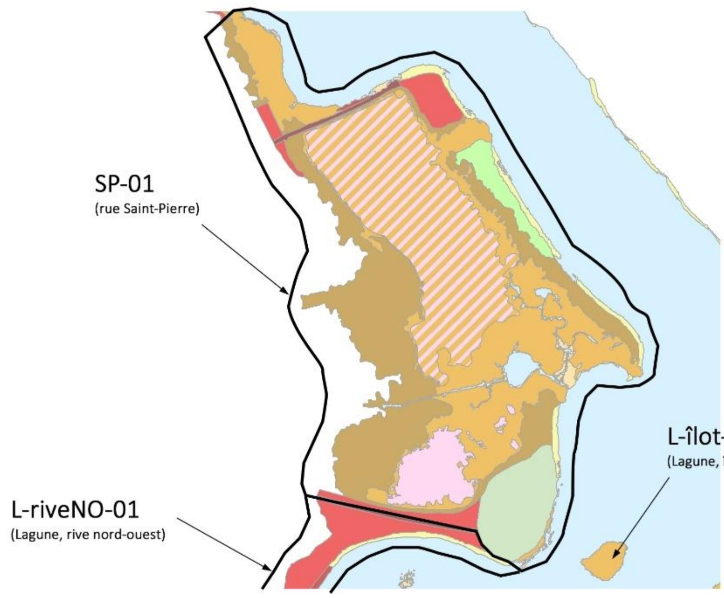
Appendix D – Individual names of marshes

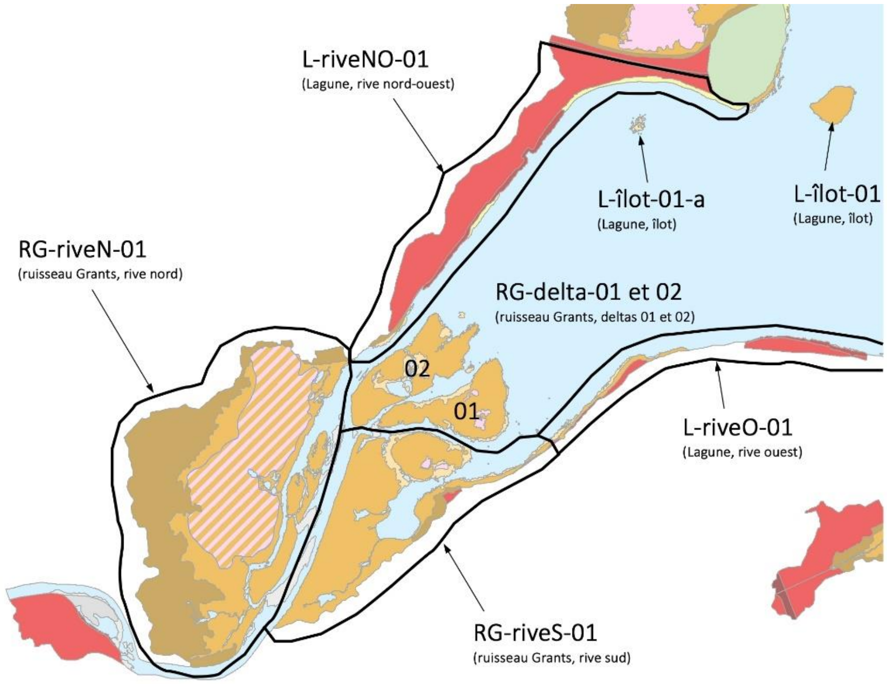
Each of the marsh portions of the Beresford sub-sector has been identified by an alphanumeric code. This identification allows for more detailed comparisons of recent developments (since 1944) in coastal marshes.

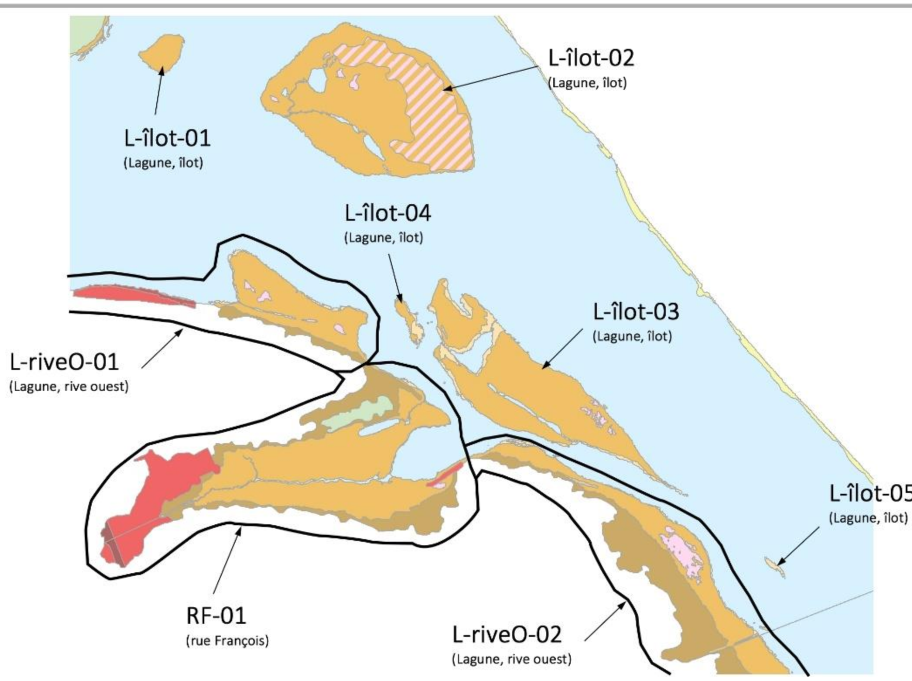

RC-01
(rue des Chalets)
PdB-01
(plage de Beresford)
RP-01
(rue Principale)
CRB-01
(Centre Réal-Boudreau)

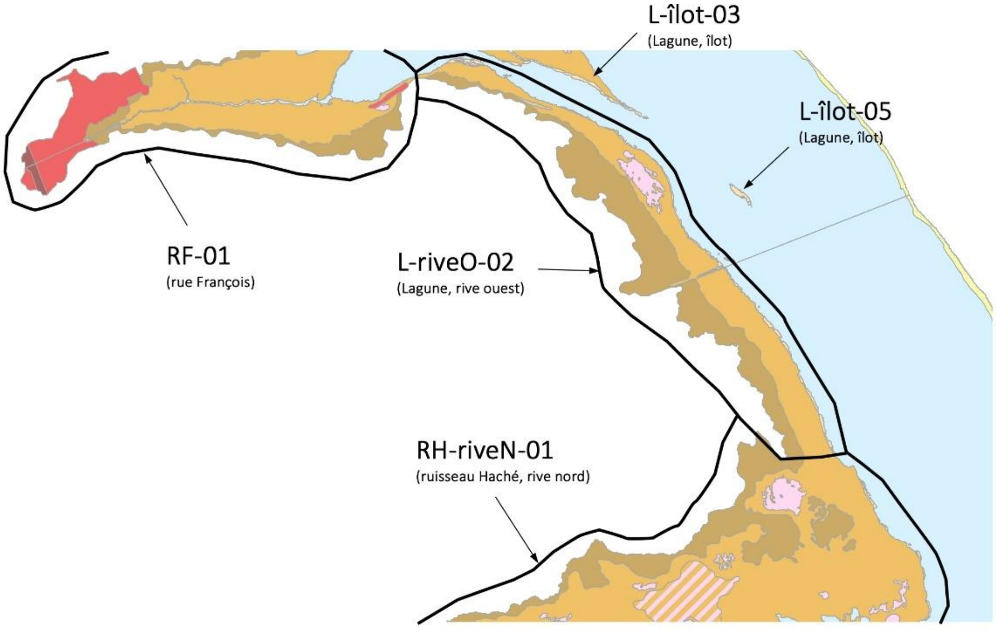
Géo Littoral Consultants
Services de SIG et de cartographie
Études environnementales
Programmes d'interprétation

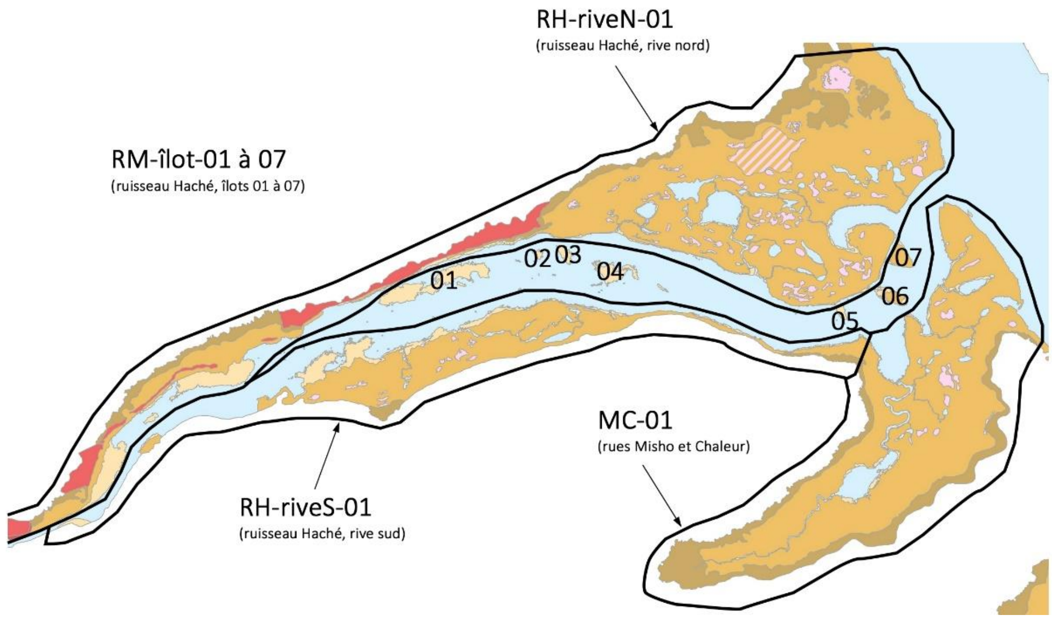


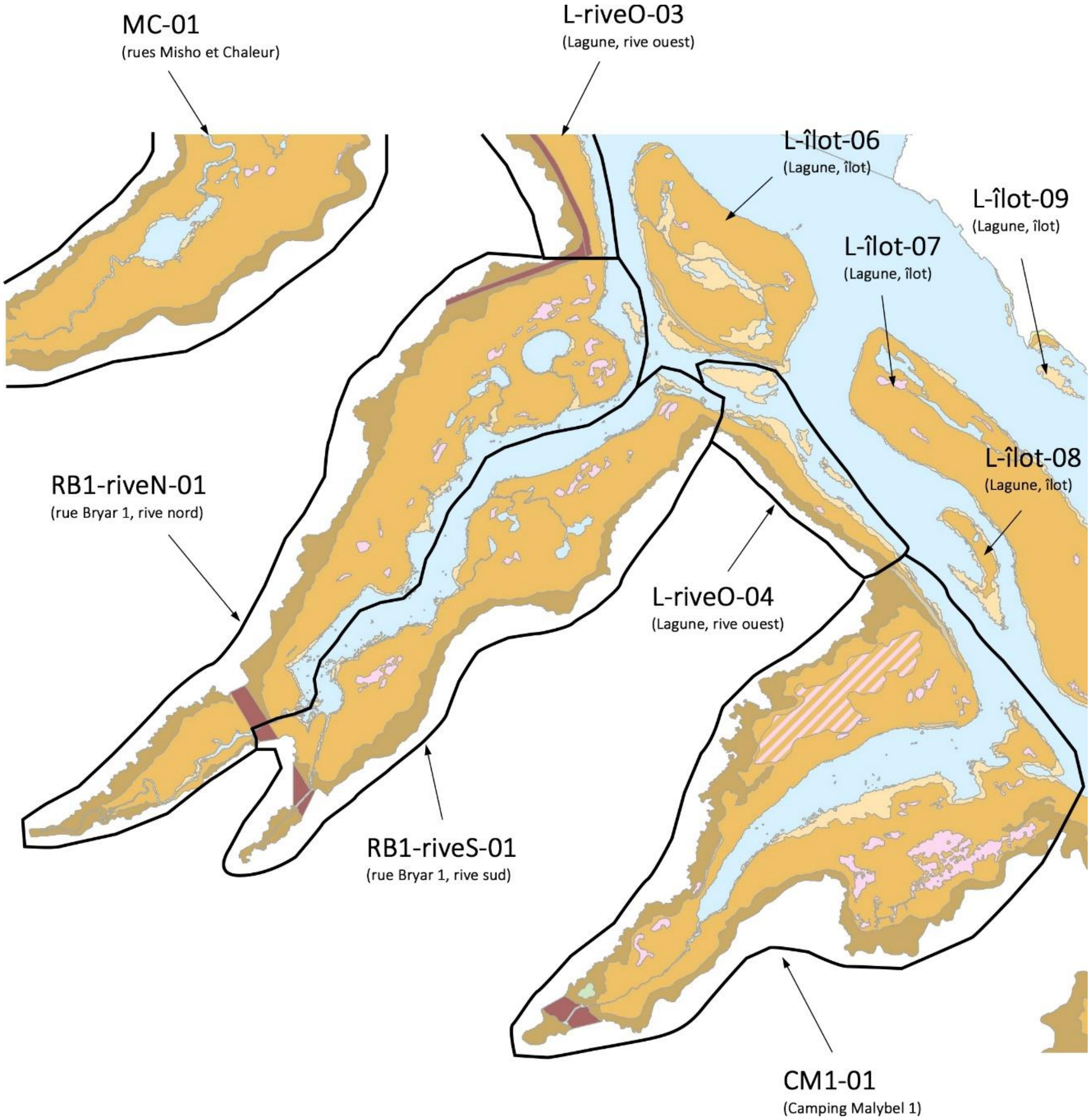


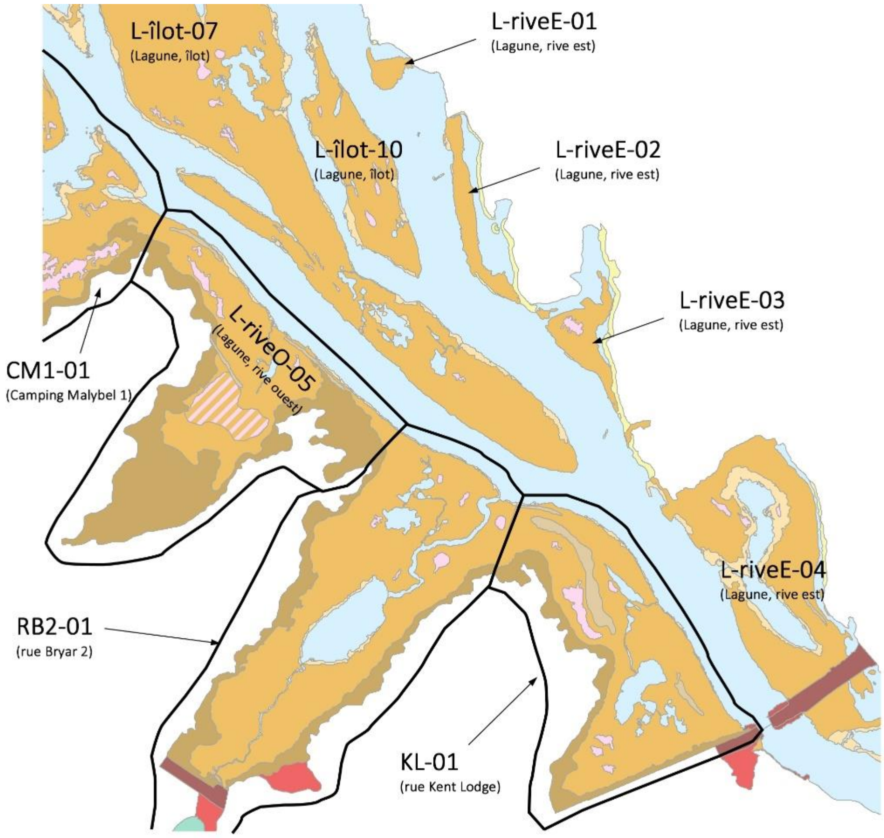

L-riveNO-01
(Lagune, rive nord-ouest)
L-îlot-01-a
(Lagune, îlot)
L-îlot-01
(Lagune, îlot)
RG-riveN-01
(ruisseau Grants, rive nord)
RG-delta-01 et 02
(ruisseau Grants, deltas 01 et 02)
02
01
L-riveO-01
(Lagune, rive ouest)
RG-riveS-01
(ruisseau Grants, rive sud)

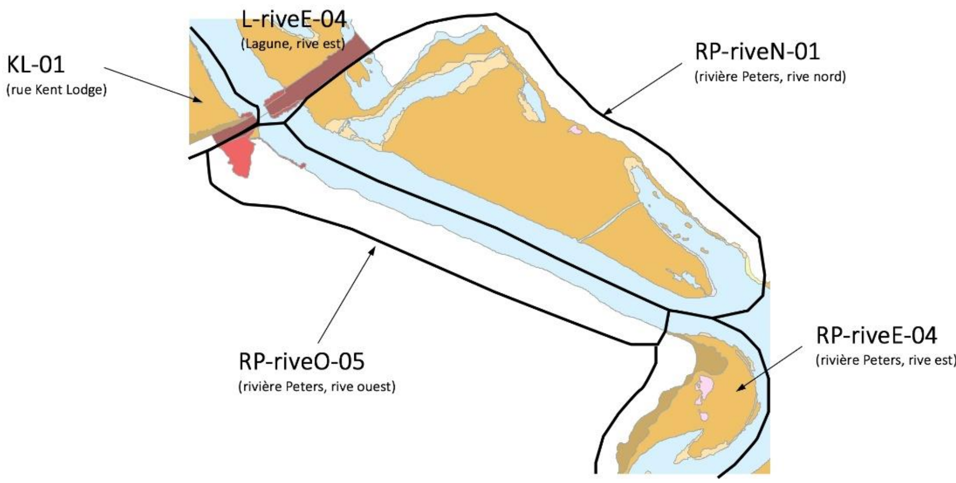

L-îlot-02
(Lagune, îlot)
L-îlot-01
(Lagune, îlot)
L-îlot-04
(Lagune, îlot)
L-îlot-03
(Lagune, îlot)
L-riveO-01
(Lagune, rive ouest)
L-îlot-05
(Lagune, îlot)
RF-01
(rue François)
L-riveO-02
(Lagune, rive ouest)

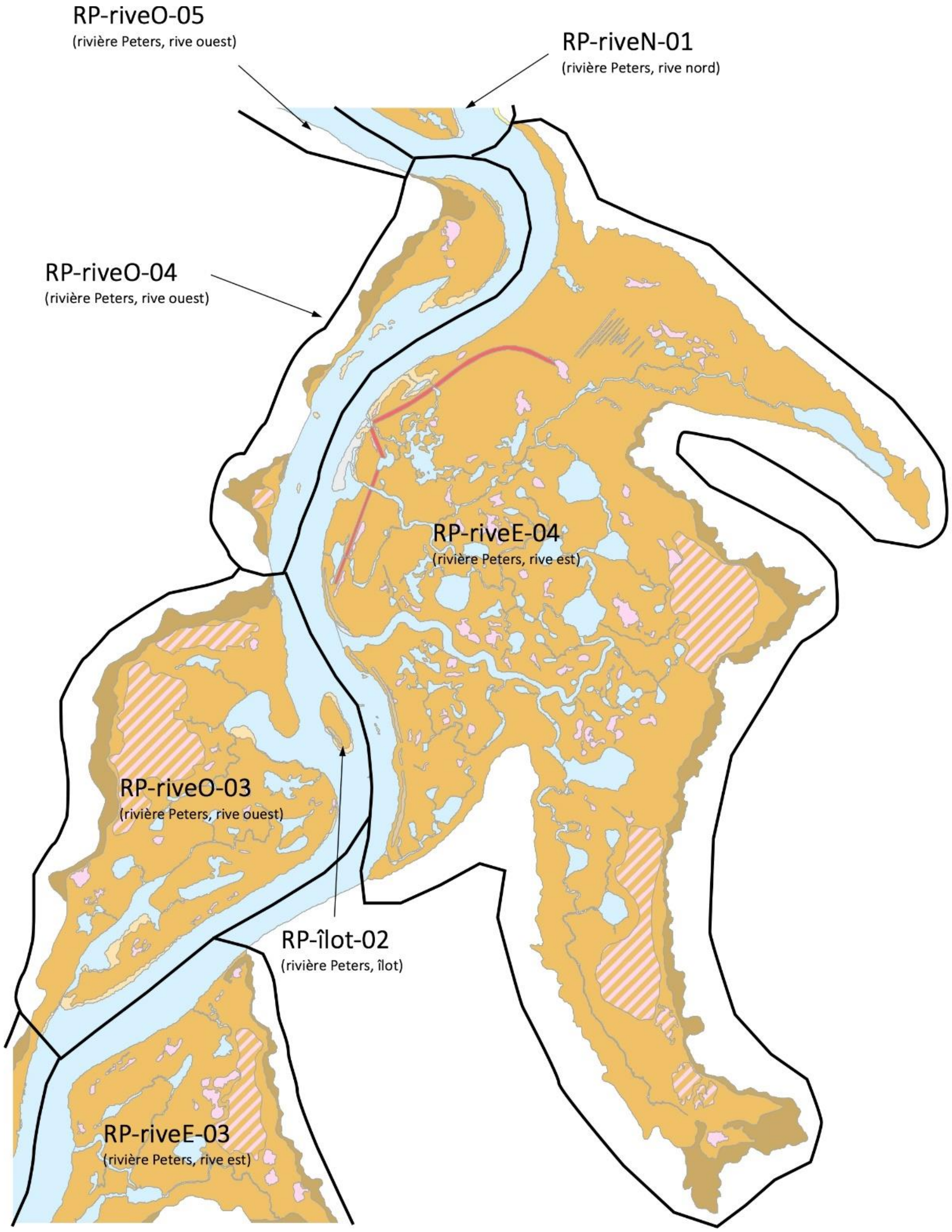

L-îlot-03
(Lagune, îlot)
L-îlot-05
(Lagune, îlot)
RF-01
(rue François)
L-riveO-02
(Lagune, rive ouest)
RH-riveN-01
(ruisseau Haché, rive nord)


RH-riveN-01
(ruisseau Haché, rive nord)
RM-îlot-01 à 07
(ruisseau Haché, îlots 01 à 07)
01
02
03
04
05
06
07
MC-01
(rues Misho et Chaleur)
RH-riveS-01
(ruisseau Haché, rive sud)

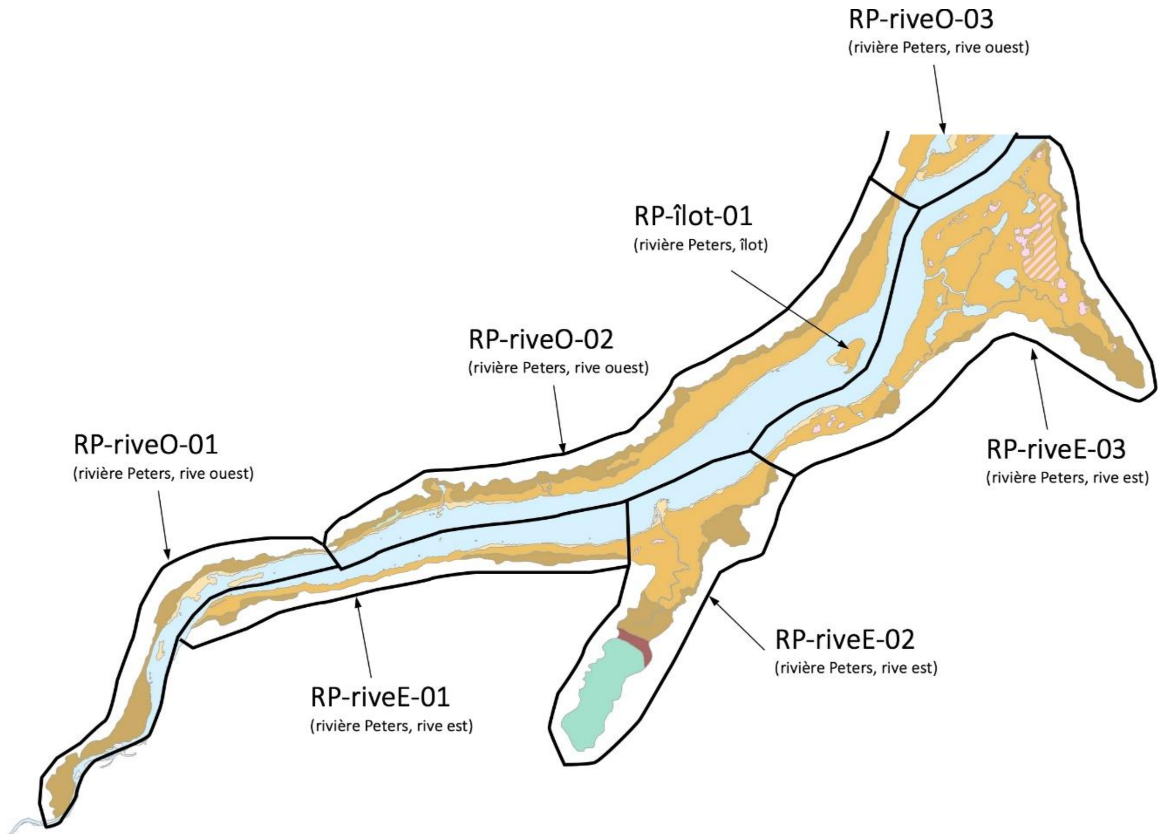

MC-01
(rues Misho et Chaleur)
L-riveO-03
(Lagune, rive ouest)
L-îlot-06
(Lagune, îlot)
L-îlot-09
(Lagune, îlot)
L-îlot-07
(Lagune, îlot)
L-îlot-08
(Lagune, îlot)
RB1-riveN-01
(rue Bryar 1, rive nord)
L-riveO-04
(Lagune, rive ouest)
RB1-riveS-01
(rue Bryar 1, rive sud)
CM1-01
(Camping Malybel 1)


L-îlot-07
(Lagune, îlot)
L-riveE-01
(Lagune, rive est)
L-îlot-10
(Lagune, îlot)
L-riveE-02
(Lagune, rive est)
L-riveE-03
(Lagune, rive est)
CM1-01
(Camping Malybel 1)
L-riveO-05
(Lagune, rive ouest)
L-riveE-04
(Lagune, rive est)
RB2-01
(rue Bryar 2)
KL-01
(rue Kent Lodge)


L-riveE-04
(Lagune, rive est)
KL-01
(rue Kent Lodge)
RP-riveN-01
(rivière Peters, rive nord)
RP-riveO-05
(rivière Peters, rive ouest)
RP-riveE-04
(rivière Peters, rive est)



RP-riveO-05
(rivière Peters, rive ouest)
RP-riveN-01
(rivière Peters, rive nord)
RP-riveO-04
(rivière Peters, rive ouest)
RP-riveE-04
(rivière Peters, rive est)
RP-riveO-03
(rivière Peters, rive ouest)
RP-îlot-02
(rivière Peters, îlot)
RP-riveE-03
(rivière Peters, rive est)


RP-riveO-03
(rivière Peters, rive ouest)
RP-îlot-01
(rivière Peters, îlot)
RP-riveO-02
(rivière Peters, rive ouest)
RP-riveO-01
(rivière Peters, rive ouest)
RP-riveE-03
(rivière Peters, rive est)
RP-riveE-02
(rivière Peters, rive est)
RP-riveE-01
(rivière Peters, rive est)

Appendix E – List of deliverables

The items listed in this appendix correspond to the deliverables sent to CSR Chaleur. These are folders containing GIS files (shapefiles, geodatabases, georeferenced old aerial photos) and other types of files (Excel tables, Word processing, PDF files) produced under the contract. The list also includes documents submitted in paper format.

NB: If you need a copy of the *ArcGIS* project, please copy the entire folder named "CSR_PL2020-01_Géolittoral consultants". It is very important to keep the final organization of the project to avoid breaking the links between the different files that make it up.

Documents submitted in paper format

Rapport final : Analyse de risque d'érosion côtière pour une partie du territoire de la Commission de services régionaux Chaleur (5 copies)

Final Report: Coastal Erosion Risk Analysis for a Portion of the Territory of the Chaleur Regional Services Commission (5 copies)

Document submitted in electronic format (on USB key)

Contrat PL2020-01_CSR Chaleur_Rapport FINAL_GéoLittoral Consultants_30 juin 2021.doc
Contract PL2020-01_Chaleur RSC_FINAL Report_GéoLittoral Consultants_30 June 2021.doc

Contrat PL2020-01_CSR Chaleur_Rapport FINAL_GéoLittoral Consultants_30 juin 2021.pdf
Contract PL2020-01_Chaleur RSC_FINAL Report_GéoLittoral Consultants_30 June 2021.pdf

Contrat PL2020-01_CSR Chaleur_Taux érosion_Nigadoo_30 juin 2021.xlsx
Contrat PL2020-01_CSR Chaleur_Taux érosion_Salmon Beach_30 juin 2021.xlsx
Contrat PL2020-01_CSR Chaleur_Taux érosion_Janeville_30 juin 2021.xlsx
Contrat PL2020-01_CSR Chaleur_Superficie habitats côtiers_Beresford_30 juin 2021.xlsx

Example of GIS database contents (on External Hard-Drive)