EVALUATION OF A SALT MARSH RESTORATION MONITORING PROTOCOL FOR USE BY COMMUNITY GROUPS IN THE BAY OF FUNDY, CANADA

by

Tony M. Bowron

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DALHOUSIE UNVIRSITY
SCHOOL FOR RESOURCE AND ENVIRONMENTAL STUDIES

The undersigned hereby certify that they have read and recommended to the Faculty of Graduate Studies for acceptance of a thesis entitled "Evaluation of a Salt Marsh Restoration Monitoring Protocol for use by Community Groups in the Bay of Fundy, Canada" by Tony M. Bowron in partial fulfillment of the requirements for the degree of Master of Environmental Studies.

DATED:______________________

Supervisor: ______________________________

Dr. Peter G. Wells

Committee Members: ______________________________

Dr. Alan R. Hanson

____

Dr. Graham R. Daborn

____

Dr. Jeff Ollerhead

____

Dr. Karen Beazley

External Reader: ______________________________

Dr. Martin Willison

DALHOUSIE UNIVERSITY

DATE: April 12, 2006

AUTHOR: Tony M. Bowron

TITLE: Evaluation of a Salt Marsh Restoration Monitoring Protocol for use by Community Groups in the Bay of Fundy, Canada

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For the Bay, may your rivers always flow…

…in both directions.

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ABSTRACT

The purpose of this study was to evaluate the Global Program of Action Coalition for the Gulf of Maine Monitoring Protocol (GPACMP) through assessment of the indicators and data collection methods against various technical, practical and program considerations, including a field test. Recommendations are made for a Bay of Fundy restoration monitoring program.

The GPACMP fails to give adequate consideration to invertebrates and winter conditions as indicators. Individually the indicators all tested well technically. From a practical and program standpoint, some aspects of the individual indicators, particularly data collection, handling and analysis, might not be practical currently, given the experience and operational limitations in Atlantic Canada.

The field test of the GPACMP exposed a number of challenges with respect to access to sampling equipment, expertise, and suitable physical conditions for data collection methods. The application of the GPACMP revealed several insights into the impacts of the Cheverie Creek tidal barrier and provided an adequate baseline against which to compare post-restoration conditions.

Recommendations for further development of the GPACMP include: (i) greater consideration given to salt marsh pannes, pools and drainage channels as geomorphological attributes; (ii) inclusion of winter conditions and invertebrates as indicator categories; (iii) individual indicator and program objectives; (iv) data handling, analysis, interpretation and reporting; and (v) integration of the monitoring program into a broader restoration and management strategy for Atlantic Canada.

The recommended monitoring program for the Bay of Fundy remains consistent with the GPACMP to facilitate comparisons with GPACMP sites, while being more responsive to Bay of Fundy site-specific conditions and existing monitoring activities.

LIST OF ABBREVIATIONS USED

BoFEP	Bay of Fundy Ecosystem Partnership
DEM	Digital Elevation Model
DFO	Department of Fisheries and Oceans Canada
DGPS	Differential Global Positioning System
EAC	Ecology Action Centre
GIS	Geographical Information System
GOMC	Gulf of Maine Council on the Marine Environment
GPAC	Global Programme of Action Coalition for the Gulf of Maine
GPS	Global Positioning System
HADD	Harmful Alteration, Damage or Destruction
MRHM	Marsh Response to Hydrologic Manipulation
NB	New Brunswick
NS	Nova Scotia
NSDOTPW	Nova Scotia Department of Transportation and Public Works
SMaRTS	Salt Marsh and Restricted Tidal Systems Working Group

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Finally, I would like thank my family and friends for their love and support throughout this long journey. Mom, it is spelled E-C-O-L-O-G-Y, and I am done now.

CHAPTER 1 - INTRODUCTION

> *Fundy's giant tides have been relentlessly blocked, diverted, and short-circuited, beginning with dikes built by Acadian settlers in the late 1600s to turn salt marsh into farmland and ending with the ill-conceived causeways and dams of the mid to late 1900s.*
> (Conservation Council of New Brunswick 1999)

1.1 Problem Definition and Background

The Bay of Fundy and its associated watersheds comprise a significant portion of the Gulf of Maine's terrestrial, coastal and marine ecosystem. Estuaries and their associated habitats provide important ecological functions, services and habitats for a wide range of marine and terrestrial species, including humans, and are a major source of food material for neighbouring marine and terrestrial ecosystems. The coastal estuaries, mudflats, salt marshes and tidal rivers in the Bay of Fundy are recognized as providing many ecosystem services that support the function and productivity of this larger system.

Over the last 400 years, human activities throughout the Bay of Fundy have reduced the amount of salt marsh and free-flowing tidal river habitat. Conservative estimates for the upper Bay of Fundy put the loss of salt marsh habitat at 80% (Gordon 1989; Percy 1997; Reed and Smith 1972). Many of these activities are of historical and social significance (agricultural dyking); however, the loss of habitat, primary productivity and species as a result of the construction of these and of modern tidal barriers (largely roads and causeways) and coastal development has had significant ecological implications and is preventable and repairable if tidal hydrology is appropriately restored (Sinicrope et al. 1990; Burdick et al. 1997).

Major barriers to the hydrology and movement of species and materials have been constructed on at least 25 of the 44 medium to large size rivers flowing into the Bay of Fundy (Wells 1999). The full range of ecological changes that these barriers have had on individual estuaries, or the impact they have had, individually and cumulatively, on the Bay of Fundy is currently unquantified.

Tidal wetlands are valued ecosystems and their restoration has become a common practice in the Gulf of Maine over the past two decades (Dionne et al. 1998). Interest and efforts to restore Bay of Fundy salt marshes has increased in New Brunswick (NB) and Nova Scotia (NS) during the last seven years. The driving force for this effort to return the tides to restricted salt marsh and tidal river systems in the Bay of Fundy has been largely the non-governmental environmental community. Since 1998, the Conservation Council of New Brunswick[1] (NB), the Ecology Action Centre[2] (EAC) (NS) and their partners have been engaged in efforts to identify and restore altered, degraded and lost coastal wetland systems (salt marshes and tidal rivers) on both sides of the Bay of Fundy.

Despite the length of time that restoration projects have been occurring in the Gulf of Maine, and efforts to identify and undertake restoration of salt marshes in the Bay of Fundy, there is a high level of uncertainty around the ecological benefits of restoration efforts. Contributing to this uncertainty is an overall lack of adequate baseline information on pristine tidal wetlands (their form, ecological function, and societal value), a lack of information on potential restoration sites, inconsistencies in research and monitoring data collection, a lack of agreement over scientifically defensible criteria for assessing restoration success, and unclear restoration goals (Neckles and Dionne 2000). The Global Programme of Action Coalition for the Gulf of Maine (GPAC) hosted a workshop in 1999 to develop a common protocol for monitoring and evaluating tidal wetland restoration projects, hereafter referred to as the GPAC Monitoring Protocol (Neckles and Dionne 2000; Neckles et al. 2002). The purpose was to improve knowledge of existing tidal wetlands systems, to explore the full range of tidal marsh restoration opportunities in the Gulf of Maine and Bay of Fundy, and to better evaluate restoration project success on a regional scale.

In 1999, the EAC began a project to identify opportunities for salt marsh restoration on the NS side of the Bay of Fundy and to undertake the restoration of a tidally restricted

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[1] An environmental non-governmental organization based in Fredricton, New Brunswick.

[2] A Halifax, Nova Scotia based environmental non-governmental organization.

salt marsh system (Appendix A). In 2002, the GPAC Monitoring Protocol was implemented on a restricted salt marsh and tidal river system, as well as an unrestricted reference site in Cheverie, Hants County, NS. The EAC's Cheverie Creek Salt Marsh and Tidal River Restoration Project (EAC Project) was the first intentional salt marsh restoration project to be undertaken in the Bay of Fundy and the first to utilize the GPAC Monitoring Protocol. However, since it was designed primarily based on experience with salt marsh restoration projects conducted in New England, there was some question as to suitability of indicators and data collection methods described in the GPAC Monitoring Protocol, for salt marsh restoration projects in the Bay of Fundy.

As a consequence, this study examines the effectiveness and suitability of the GPAC Monitoring Protocol for use by tidal wetland restoration practitioners to assess the ecological condition of tidal wetlands and success of tidal restoration projects in the Bay of Fundy. Particular consideration was given to environmental non-governmental organizations and community groups.

1.1.1 Estuaries

Estuaries are bodies of semi-enclosed water where fresh water from rivers and streams flow into and mix with salt water from the sea (Mann 2000). This mixing of fresh and salt water creates an environment where salinity is intermediate between fresh and salt water and where tidal action is an important biophysical regulator. Estuaries are a transition zone between land and sea.

Estuaries and near-shore marine waters are amongst the most biologically productive ecosystems in the world (Niering and Warren 1980). Research by Costanza et al (1997) valued the ecosystem services provided by estuaries to be the highest among all the biomes. Estuaries occur in all regions of the world, but their productivity varies with climate, hydrology, and coastal geomorphology. Each estuary, according to its specific characteristics and conditions, supports a range of different wetland habitats. In most temperate areas (Gulf of Maine and Bay of Fundy), estuaries tend to be comprised of inter-tidal mud and sand flats, eelgrass, rockweed and shellfish beds, salt marshes, scattered rocky outcrops, shores and beaches (Dionne, Bonebakker and Whiting-Grant 2004).

Estuaries and coastal wetlands provide essential habitat for over two-thirds of commercial finfish and shellfish landed in the United States (Gosselink et al. 1974). Estuaries are also valuable for their recreational, tourism, social and esthetic contributions to society.

1.1.2 Mudflats

Mudflats, or tidal flats, are comprised of sediments such as fine sands, silts and muds that are deposited in sheltered, low energy, intertidal (area between high and low tide) areas of estuaries in temperate latitudes (Hatcher and Patriquin 1981). A developing mudflat grows both vertically and horizontally as sediment is deposited along the leading edge of the flat and upon the flat surface. The salt marsh/mudflat intertidal system can be regarded as a single integrated unit whose physical processes are interdependent, where the development of the first may lead to the establishment of the second and together creating an intertidal transitional zone that is highly stable (Nordstrom and Roman 1996).

1.1.3 Salt Marshes

Salt marshes are grass dominated tidal wetlands that serve as a transition zone between the terrestrial and the marine environments. They are intertidal zones of moderate to low wave action along the shorelines of tidal rivers, estuaries and bays which are sheltered from all but the strongest (highest energy) wave and storm action and whose vegetation is daily inundated by salt water (tides). Salt marshes are highly dynamic ecosystems, responding to and reflecting the interactions between freshwater, saltwater and sediments.

Salt marshes can develop in a variety of settings, provided the hydrology, sediment and biological conditions are suitable. They usually form in coastal areas that are emerging or which are stable relative to sea level. Salt marshes develop on intertidal mudflats that have developed vertically to the point where the elevation of the mudflat surface equals or exceeds mean high water level and which has consolidated enough to allow for the colonization of the mudflat surface by salt-tolerant plants (Gonni and Thomas 2000; Hatcher and Patriquin 1981; and Nordstorm and Roman 1996).

The salt marshes of the Bay of Fundy are relatively recent inter-tidal land forms, having developed only in the last 3000 to 4000 years (Niering and Warren 1980; Shaw 2003). Salt marsh, or tidal marshes, can be found all along the eastern seaboard of North America. Johnson (1925) classified the marshes of this coast into three categories: coastal plain, New England and Fundy type marshes. The marshes in New England are predominantly a deposit of salt marsh peat with variable amounts of silt. As a result of the large tidal amplitude, strong tidal currents and high silt-carrying capacity of the waters, Bay of Fundy salt marshes tend to have a much higher mineral content. Frequency and depth of tidal flooding of the marsh surface is another significant difference between New England and Fundy marshes (Desplanque 2000). New England marshes experience much more frequent flooding with a significant depth of water as compared to Fundy marshes which only experience complete tidal flooding several times a month and to a significant depth of water only by extreme high water events. A commonality among all three types of marshes is the tendency to exhibit complex patterns of zonation with respect to plants and animals that reflect the daily, monthly and seasonal changes in water depth, salinity and temperature.

Salt marshes in the Bay of Fundy are typically divided two distinct zones (Figure 1). The seaward edge of the salt marsh, below mean high water and experiencing regular flooding by the twice daily tides, is the low marsh. Dominated almost exclusively by salt marsh cordgrass (*Spartina alterniflora)*, low marsh is typically found on the outer edges of larger salt marshes, along tidal creeks, and on the seaward side of agricultural dykes and may dominate young or smaller marshes.

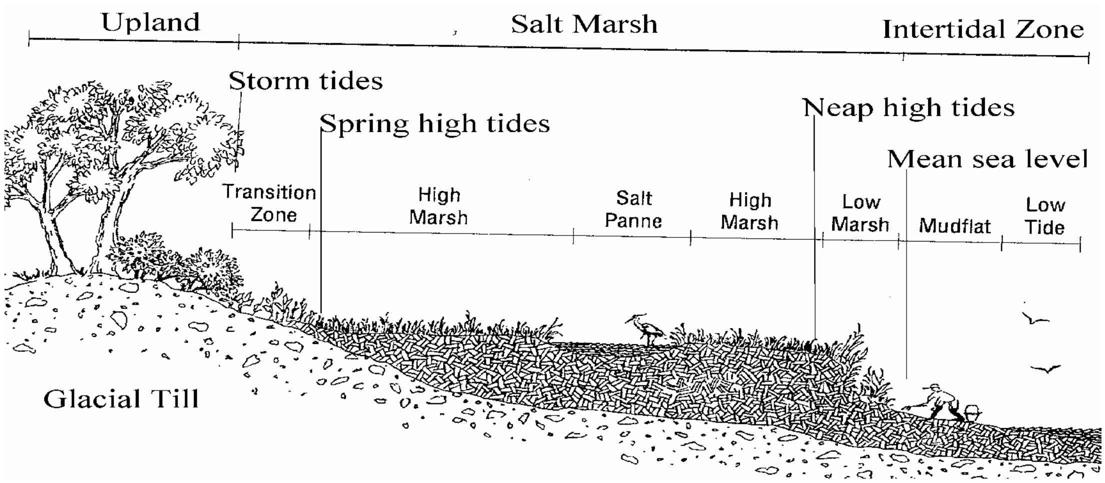

Figure 1Coastal salt marsh profile (modified from Purinton and Mountain 1998).

The high marsh, occurring above the mean high water line, experiences flooding only by the highest of tides (spring tides, storm or extreme tidal events). Species diversity is greater in the high marsh, with salt meadow cordgrass (*Spartina patens*) dominating the seaward edge of the high marsh and becoming interspersed with sea-side plantain (*Plantago maritima*), sea lavender (*Limonium nashii*), black grass (*Juncus gerardi*), rush grass (*Juncus balticus*) and sea-side goldenrod (*Solidago sempervirens*) as one moves towards the terrestrial edge of the high marsh. The terrestrial edge of the high marsh is typically characterized by a band of local shrub species set against a line of trees (upland buffer). Mature, or large, salt marshes are characterized by large expanses of high marsh. The high marsh areas in the upper Bay of Fundy have experienced extensive dyking over the past 350 to 400 years in order to secure these areas for agricultural use.

Salt marshes are an integral part of Bay of Fundy coastal estuaries – the prairies of NS. They are characterized by low lying, open plains of lush grasses, cut through by drainage channels and salt marsh pannes and pools of various sizes. Salt marsh pools are depressions that retain water throughout the growing season and do not dry as shallower pannes tend to (Chapman 1960). These features are more prevalent in the low marsh while the high marsh, save the few deep channels and salt marsh pools, is predominantly vegetated. The complexity of the low marsh provides for a wider range of habitats that support a greater diversity of wildlife. Research by Gordon et al. (1985) on productivity rates of salt marshes in the upper Bay of Fundy concluded that primary productivity in the low marsh exceeds that of the high marsh. Teal and Howes (Weinstein and Kreeger 2000), summarized their research findings on the value and function of salt marshes by saying "…that marshes import and export nutrients and marshes grow fish."

Recently considered wastelands with little economic value, salt marshes are now becoming recognized, valued and protected for the wide range of ecological services and products they provide. Services include: support of estuarine productivity, habitat for a broad range of animals (insects, molluscs, crustaceans, resident and migratory species of fish, birds and a host of smaller mammals), water purification, and coastal protection (Mitsch and Gosselink 1986). The contribution made by salt marshes to the ecosystem services provided by estuaries is second only to seagrass/algae beds (Costanza et al. 1997). There is considerable scientific evidence that fin and shellfish fisheries depend on the biological activities occurring in these tidal wetlands (Cruz 1973; Graff and Middleton 2002; Teal 1962). Salt marshes also play a crucial role in nutrient cycling within estuaries (Welsh 1980). Salt marshes are further valued for recreation, education, research, aesthetic and cultural significance.

The historic conversion of salt marshes to agricultural lands, combined with the loss and degradation of these areas as a result of modern development and resource extraction activities, has resulted in the loss of an estimated 80% of original salt marsh area in the upper Bay of Fundy (Gordon 1989; Percy 1997; Reed and Smith 1972).

An annotated bibliography of existing information/literature on salt marshes in the Bay of Fundy is included in Appendix B. This bibliography contains materials that are not referenced elsewhere in this document and is not an exhaustive list.

1.1.4 Ecological Restoration

Any single act of habitat destruction may not threaten the integrity of an entire estuary, but the cumulative impact of changes both over time and throughout the estuary can severely hinder the function and value of an estuary which in turn, when duplicated in multiple estuaries, can impact the productivity and health of the broader marine ecosystem. If the act of hydrological modification is severe enough, the entire hydrological, biological and ecological condition of the system can be rapidly and radically changed (Dionne 2002).

Ecological restoration is an activity that initiates or directs the recovery of an ecosystem with respect to its health, integrity and self-sustainability (SER 2002). An ecosystem requiring restoration is typically one that has undergone some degree of degradation, damage, alteration or which has been entirely destroyed as the direct or indirect result of human activities. Active intervention is necessary when the degradation or loss of ecosystem function or value is such that the ecosystem is unable to recover its pre-altered state or succession trajectory independent of such involvement.

Ecological restoration attempts to return an altered or lost ecosystem to its historical, pre-disturbed condition and natural developmental trajectory. Although it is not a possibility that restoration practitioners will be able to completely restore an ecosystem to its former pre-disturbed state, an understanding of the structure, form and function of the pre-disturbed ecosystem and the current condition of the ecosystem type can aid in guiding the system towards improved ecological health and integrity[3].

Put simply, restoration is the return of an altered or lost ecosystem to a state that closely resembles the historic condition and in which it possesses the necessary physical and biological resources to continue its development with little to no artificial assistance (modified from Gulf of Maine Council 2004). Once restored, a habitat should be able to take its place structurally and functionally within the larger ecosystem and change and adapt in response to the normal range of environmental stress. The Gulf of Maine Council on the Marine Environment's (2004) policy for intertidal habitats is:

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[3] Ecological Integrity – "…condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes." (Parks Canada 2000).
"Condition, ecological health and integrity refer to the current state of a system, how well it is composed and functioning" (Wells 2003).

> The Council's objective is to support restoration of natural tidal regimes – and thus the functions and values of tidal wetlands – to intertidal habitats through the removal of selected dikes, fill, water control structures, and inadequately sized culverts (7).

Salt marsh restoration not only improves natural systems, but promotes opportunities for sustainable economic development (e.g. enhanced fisheries) and provides social benefits resulting from having more functional habitats (e.g. ecotourism opportunities).

1.1.5 Ecological Monitoring

As efforts to restore altered, degraded and lost tidal wetland habitats increase, there is a need to assess, monitor and report on the impacts of restoration activities. Pre and post-restoration monitoring is an essential component of the restoration process. Restoration monitoring is intended to follow the recovery process of a restoration site against a reference condition (site), to provide information and improve understanding of how marsh systems function, how impacts from tidal restrictions affect marsh processes, and whether impacted systems can be restored (Burdick et al. 1999).

Monitoring involves the unbiased collection of data over time. Carlisle et al. (2002) defined monitoring as " Periodic or continuous survey or sampling to determine the status or condition of various media and systems, including water bodies, groups of plants and animals, or ecological systems." Much work has gone into the development of programs to monitor ecological integrity through the use of ecological indicators (hereafter referred to as indicators) and the development and use of guidelines to direct such processes (Dale and Beyeler 2001; Jackson et al. 2000; Kurtz et al. 2001; Ure 2003). Monitoring programs depend on the development and selection of indicators that measure characteristics of valued ecosystem components and those most responsive to stressors (Kurtz et al. 2001).

Indicators are measurable characteristics (biological, chemical or physical) related to the structure, composition, or functioning of ecological systems; they are measurable surrogates for ecosystem properties and components that cannot be measured in a more direct way (Jackson et al. 2000; Murtaugh 1996; USEPA 2005). The use of indicators as a measure of the condition or direction of change of an ecological system relies on the assumption that changes observed in the indicator(s) are reflections of changes occurring in the ecosystem (Dale and Beyeler 2001). Therefore, indicators identified for use as part of a monitoring program need to be ones that are important to ecosystem structure and function; that are responsive to external stressors; are relevant to the scientific and/or management question or goal; and which are measurable (Fisher 1998). In general indicators should be (Dale and Beyeler 2001; Noon et al. 1999; NPS 1999; USDA 1996):

- meaningful to the problem at hand;
- easy to measure and practical to use;
- able to be repeatedly measured with different personnel without introducing bias;
- socially acceptable and easily understood;
- low impact to measure;
- sensitive enough to provide an early warning of change;
- integrative: the full suite of indicators provides a measure of the larger environmental component or system of ultimate interest;
- responsive in a known way to natural disturbances, anthropogenic stresses, and changes over time;
- they can be accurately and precisely estimated (have low natural variability - high signal to noise ratio);
- affordable (i.e. the costs of measurement are not prohibitive); and,
- be interpreted and explained both statistically and non-statistically.

Since many indicators could be used as part of a monitoring program, selecting an appropriate and effective set of core of indicators is a critical component of any ecosystem monitoring program. The challenge, therefore, is to select indicators that fit within the constraints of cost, equipment, expertise, staff and budget and still obtain meaningful information (USDA 1996). Potential indicators should be evaluated against a series of criteria aimed at identifying those indicators that best capture some of the complexities of the ecosystem yet remain simple enough to be easily and routinely monitored (Dale and Beyeler 2001; Kurtz et al. 2001; Ure 2003; USDA 1996).

Parks Canada has developed a process for selecting indicators of ecological integrity in Canadian national parks that was developed (Ure 2003; Table 1). This process involved the identification and assessment of potential indicators through literature review, a series of expert consultations, and a focused workshop (Ure 2003). The GPAC Monitoring Protocol was developed in a similar manner. A critical next step in this process is the validation of potential indicators through field testing and adaptive management. The Gulf of Maine Council promoted the implementation of the GPAC Monitoring Protocol on a series of on-going and proposed salt marsh restoration projects within the Gulf of Maine and Bay of Fundy in an effort to test and refine the indicator categories, indicator variables and data collection methods outlined in the protocol. The EAC Project and this study were part of this regional effort to test, implement and improve the GPAC Monitoring Protocol.

Table 1 A process for the selection of indicators of ecological integrity in Canada's national parks (Ure 2003, 41)

Key elements in a process for selecting indicators
1. Identify monitoring goals and objectives
2. Identify significant stressors and ecosystem components
3. Select potential indicators of ecological integrity
4. Evaluate potential indicators with assessment criteria
5. Select a core suite of indicators
6. Research, field validate and pilot test core indicators
7. Develop and implement monitoring program
8. Feedback and adaptive management

1.1.6 Salt Marsh Restoration Monitoring in the Gulf of Maine and Bay of Fundy

The approach to monitoring both the impacts of tidal restrictions on salt marshes and habitat responses to restoration activities, adopted for use in the Gulf of Maine and Bay of Fundy, involved the selection and assessment of a comprehensive yet low-cost set of indicators, using a common set of methodologies, which are representative of key ecosystem components (Burdick et al. 1999; Carlisle et al. 2002; Neckles et al. 2002). The indicators and data collection methods for assessment that were identified by the GPAC Monitoring Protocol include: geospatial attributes, hydrology, soils and sediments, vegetation, nekton, and birds (see Chapter 3; Table 4) (Neckles and Dionne 2000; Neckles et al. 2002). For each of these indicators, a set of core variables and additional variables are identified along with one or more methods for sampling each variable. Indicators were selected through an evaluation and consensus process that considered critical information gained, feasibility, cost (in U.S. dollars), the skill level required for measurement, and spatial and temporal sampling frequency (Neckles and Dionne 2000).

This approach, involving the monitoring of wetland conditions and responses to restoration activities through the use of a set of core and selected project specific additional variables along with consistent sampling methods within each indicator type, is meant to allow for project or site specific modification and application of the GPAC Monitoring Protocol. The GPAC Monitoring Protocol was designed primarily to identify changes in habitat conditions and to follow salt marsh recovery following specific restoration activities (removal of tidal barrier(s), replacement of culvert(s), ditch plugging, removal of fill, creek or pond creation).

The use of the common suite of indicators, variables and data collection methods as part of on-going and future salt marsh restoration projects throughout the Gulf of Maine and Bay of Fundy is meant to facilitate a regional synthesis of salt marsh restoration results. "Ultimately, it will be possible to establish a range of reference conditions characterizing natural tidal wetlands in the region and to compare performance curves between populations of restored and reference marshes for assessing regional restoration effectiveness (Neckles et al. 2002, 556)." Monitoring in this manner serves as a feedback mechanism that supports further efforts to implement restoration projects and conservation plans to protect salt marshes.

1.2 Rationale for Study

With the loss of approximately 80% of salt marsh habitat in the upper Bay of Fundy, and the presence of barriers to waters and species on over 50% of the rivers in the Bay of Fundy (Bowron 2003; Gordon 1989; Percy 1997; Reed and Smith 1972; Wells 1999), there is a need to protect remaining habitats. However, protection alone is not sufficient. We must restore, where feasible, habitats that have been altered, damaged or destroyed.

With the growing focus of many federal, state, provincial and nongovernmental programs on restoration of the natural hydrology and functional values of macro-tidal wetland systems in the Bay of Fundy, it is important to learn from these early efforts. The GPAC Monitoring Protocol was developed to provide guidance and standards for conducting and monitoring restoration projects and to create a regional comparable database of ecological condition and ecosystem response. The development of the GPAC Monitoring Protocol was largely driven by Gulf of Maine interests and was based upon the knowledge of the ecology of New England salt marshes and the restoration experiences in that region.

As the interest in the conservation and restoration of salt marshes and related coastal habitats and species in the Bay of Fundy grows, there is a need for the development, acceptance and widespread application of a standard set of indicators, ecological variables and consistent data collection methods, such as the GPAC Monitoring Protocol, that are tailored to the ecological conditions of the Bay of Fundy. However, given the context in which the GPAC Monitoring Protocol was developed and the ecological differences between Bay of Fundy marshes and those in New England such as tidal range, sediments and winter conditions, there is a question as to the appropriateness and effectiveness of the indicators and sampling methods recommended for use on tidal wetland restoration projects in the Bay of Fundy.

The EAC Project is both the first intentional salt marsh restoration project to be undertaken in NS in the Bay of Fundy as well as the first to utilize the GPAC Monitoring Protocol (Appendix A). The EAC Project presented the dual opportunity to study a restricted site and a reference site and to evaluate the appropriateness of the indicators, variables and sampling methodologies recommended by the GPAC Monitoring Protocol (this thesis).

1.3 Objectives of the Study

Success of future salt marsh restoration projects in the Bay of Fundy depends upon understanding the range of natural forms and functions of these tidal systems and their responses to restoration activities, and the development of standard methods for monitoring restoration sites and evaluating restoration efforts. As part of this process, this study evaluated the appropriateness and effectiveness of the GPAC Monitoring Protocol for use on macro-tidal salt marsh systems in the Bay of Fundy. This was accomplished through the following objectives:

- To evaluate the GPAC Monitoring Protocol against a set of scientific, practical and programmatic considerations drawn from a review of the indicator literature;

- To field test the GPAC Monitoring Protocol as part of a proposed salt marsh restoration project to monitor a tidally restricted (restoration site) salt marsh and tidal river system (Cheverie Creek) and an unrestricted (reference site) salt marsh and tidal river system (Bass Creek); and

- To provide recommendations for the modification of the GPAC Monitoring Protocol for use in tidal wetland restoration projects in the Bay of Fundy, with potential applicability to other tidal restoration projects in Atlantic Canada.

This research, in addition to establishing a baseline against which to compare post-restoration conditions at the Cheverie Creek restoration site, will provide further understanding of the influence of tidal restrictions on the form and function of macro-tidal systems in the Bay of Fundy, and the appropriateness of the GPAC Monitoring Protocol as a tool for assessing tidal wetland restoration projects in the Maritime Region of the Gulf of Maine.

1.4 Organization of Thesis

Chapter 2 describes tidal barriers in the Bay of Fundy, the study sites and the GPAC Monitoring Protocol. The methods used to evaluate and field test the GPAC Monitoring Protocol and achieve the study's objectives are presented in Chapter 3. The evaluation of the GPAC Monitoring Protocol is presented and discussed in Chapter 4. This includes the gaps and weaknesses identified in the GPAC Monitoring Protocol as well as the strengths. Recommendations for the modification of the GPAC Monitoring Protocol for use as part of future salt marsh restoration projects in the Bay of Fundy are presented in Chapter 5. Finally, Chapter 6 is a synthesis of the results of this study, including recommendations for future salt marsh monitoring and research projects.

A series of appendices provide: (A) information on the EAC Project; (B) an inventory of literature relating to Bay of Fundy salt marshes; (C) the results and discussion of the field test; (D) the habitat maps for Cheverie Creek and Bass Creek; and (E) Dr. Konisky's hydrology report for Cheverie Creek.

CHAPTER 2 - DESCRIPTION OF STUDY SITE AND THE GPAC MONITORING PROTOCOL

The coast that we see today – its pattern of islands, inlets and headlands – represents merely a snapshot in time, a pause in the continuing changes in sea level. (Atlantic Geoscience 2001)

Introduction

This chapter introduces the Bay of Fundy and Minas Basin ecosystem broadly, and summarizes activities that have impacted coastal wetlands in the region. The chapter then provides a detailed description of the Cheverie Creek and Bass Creek ecosystems and the rationale for the selection of these two tidal river and salt marsh systems as restoration and reference sites, respectively. The chapter concludes with a brief description of the GPAC Monitoring Protocol.

2.1 Bay of Fundy

Located on the east coast of Canada, the Bay of Fundy separates the provinces of NS and NB and comprises the north-eastern part of the Gulf of Maine watershed. The Bay of Fundy is a funnel shaped macro-tidal system that is approximately 270 km long, 80 km wide at the mouth, or outer Bay, and narrows at the head or upper Bay (Figure 2). The upper Bay is divided into two smaller bays, Chignecto Bay bordering NS and NB, and Minas Basin in NS.

The Bay of Fundy experiences semi-diurnal tides (two highs and two lows in approximately 25 hours); a total of 100 km^3 of water moves into and out of the Bay on each tide (Burzynski and Marceau 1984). The difference between high and low tide varies from between four to five metres in the outer Bay to over 16 m at Burncoat Head in the Minas Basin (Altantic Geoscience Society 2001). The Bay of Fundy shares with Ungava Bay, Quebec the highest recorded tidal range in the world (17.0 m +/- 0.4 m at Burncoat Head, Minas Basin, Nova Scotia) (O'Reilly et al. 2005).

Figure 2 Satellite image of the Bay of Fundy showing the outer and inner Bay of Fundy. Modified from www.redtailcanyon.com/ (accessed March 2005).

The extreme tidal range of the Bay of Fundy was formed between 7,000 and 4,500 years ago as the sea-level rose and the land subsided following the retreat of the glaciers (Atlantic Geoscience Society 2001). The combination of the depth and shape of the Bay of Fundy produces a natural period of oscillation of the Fundy-Gulf of Maine system that almost matches the natural period of oscillation exhibited by the North Atlantic tidal cycle. This near match results in the amplification of the tidal range in the Bay and a dramatic increase in tidal range from the lower to upper Bay. The dramatic daily ebb and flow of the tide and the tremendous energy it creates drives many of the complex interactions among the chemical, physical, sedimentalogical and biological processes in the Bay of Fundy.

2.1.1 Minas Basin

The Minas Basin is a semi-enclosed embayment which is divided into the Minas Channel, Minas Basin, Cobequid Bay, Southern Bight and the Avon River (Figure 3). The Minas Basin is connected to the rest of the Bay of Fundy by the Minas Channel, which is 24 km at its widest and narrows to 5 km near Cape Split. The Minas Basin covers an area of 740 km^2, ranges in depth at low tide from 25 to 50 m in the central Basin and is 115 m at its deepest point. At low tide almost 400 km^2 of the inter-tidal zone in the Minas Basin is exposed (Burzynski and Marceau 1984). A number of medium to large rivers flow into the Minas Basin including the Salmon, Walton, Cogmagun, Kennetcook, St. Croix, Avon, and Cornwallis rivers, as well as a large number of smaller rivers like Cheverie Creek and Bass Creek.

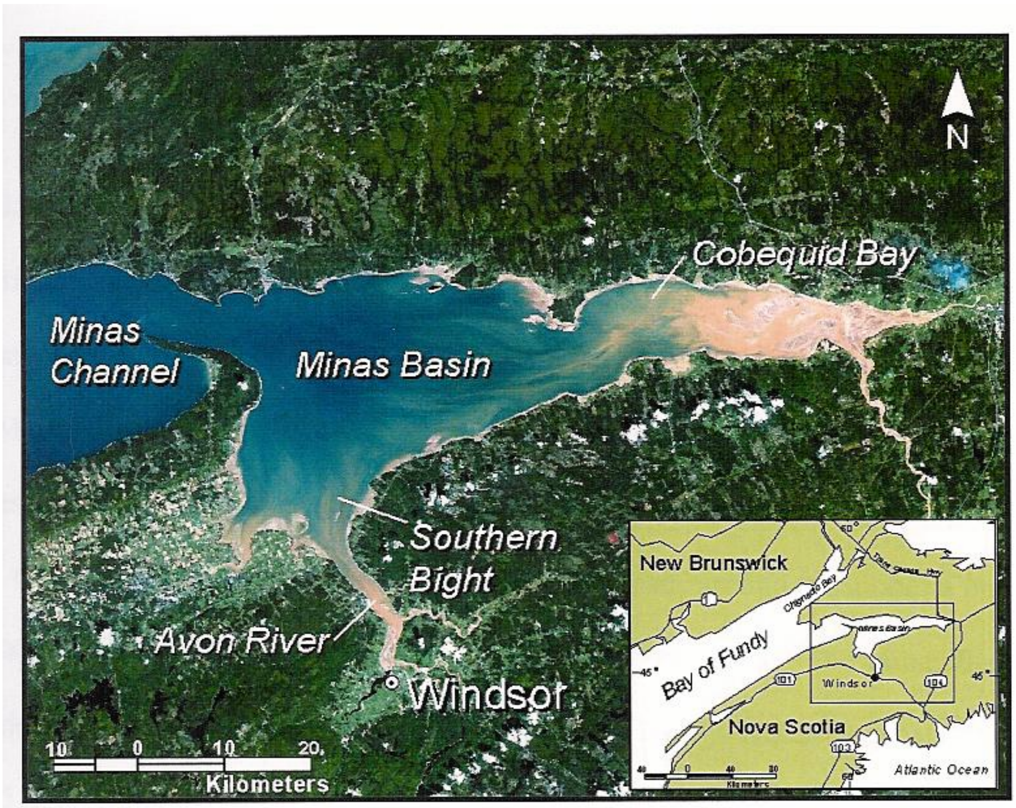

Figure 3 Satellite image and map of the Minas Basin (reprinted with permission, Townsend 2002).

2.1.2 Tidal Barriers

Tidal barriers are obstructions constructed in or across a tidal body (salt marsh, tidal river or estuary) that change the tidal flow in all or part of the water body, both above and below the obstruction (Wells 1999). Tidal barriers and activities that have led to the alteration and loss of salt marsh and tidal river habitat around the Bay of Fundy include dykes, dams, ditches, wharfs, breakwaters, railways, roads and causeways (with bridges, and culverts which are often improperly sized or placed in relation to the original river or marsh channels). A summary of the common types of tidal barriers present in the Bay of Fundy is given in Table 2.

Table 2 Examples of tidal barriers present in the Bay of Fundy (adapted from Wells 1999).

Dyke & Aboiteau/Aboiteaux(pl.)	A dyke is an earthen barrier appearing as an embankment or long ridge, constructed to prevent tidal flooding of low-lying coastal flood plains. An aboiteau is a small wooden tunnel with a hinged door inside, built into a dyke. The door swings open to let fresh water drain out and closes to keep out the tide. Modern versions in reconstructed dykes [and highway crossings] use square logs or concrete, long sluices with multiple (often three) waterways, and bronze or steel gates (modified from Wells 1999).
Causeway	A raised road across a low lying area, wet place or body of water. Causeways are often constructed with either a bridge, culvert or dam structure built into it. If improperly located or sized, both causeway-bridge and causeway-culvert structures may act as partial to complete restrictions to tidal flow. Causeway-dam structures with tide gates, if built in an estuary, are tidal barriers (Modified from Wells 1999).
Culvert	A wooden, metal or concrete drain or waterway under a road or railroad (Webster's Revised Unabridged Dictionary 1998).
Dam	A structure of rock, concrete or other material constructed to hold back water and raise its level to form a reservoir or to prevent flooding (Pickett 2000). Dams are generally built with a mechanism for releasing water in a controlled fashion.

Along much of the world's coastlines, structures that were designed to stabilize and protect property prevent the landward migration of coastal marshes as sea-level rises (Pilkey and Neal 1992). Acceleration in the rate of coastal development, namely transportation, and rural and urban development throughout Gulf of Maine and Bay of Fundy watersheds, has led to the reduction and obstruction of tidal flow in estuaries and coastal rivers and added to the significant loss of salt marsh area and function (Boumans et al. 2002). This squeezing of coastal wetlands between rising sea level and entrenched coastal infrastructure jeopardizes the abilities of coastal habitats to adapt to changes in environmental conditions and threatens to increase the loss of salt marsh habitat in the Bay of Fundy (Daborn 2003; Doody 2001).

The known or suspected range of ecological changes induced by tidal barriers include (Boumans et al. 2002; Neckles and Dionne 2000; Wells 1999):

- reduction in the length of tidal rivers and tidal prism;
- change in freshwater discharge;
- reduction or prevention of the movement of salt water upstream;
- change, often severe, in hydroperiod, sedimentation and erosion;

- alteration of flood pattern and potential increased flood risk;
- reduction of open salt marsh habitat;
- reduction of nutrient transfer (exchange) to the estuary;
- conversion of salt marsh ecosystem from a net exporter to a net importer of materials;
- restriction or prevention of the movement and migration of nekton, invertebrates and other wildlife;
- promotion of the spread of invasive and exotic species; and
- decoupling of the natural sedimentation process in wetlands from tracking sea level rise.

During the latter half of the last century, a large number of medium to large-sized barriers were constructed across tidal rivers and estuaries throughout the Bay of Fundy. Ranging from large causeways and dams for transportation and the protection of agricultural lands to hydro and tidal power generation, these barrages were often constructed with little or no consideration for river and estuarine ecology and conservation concerns for the wetland systems which they were crossing. For decades in the Maritime Provinces, transportation engineers constructed tidal crossings that were complete barriers to tidal flow or were installed with inadequately sized and improperly located culverts without sufficient consideration for ecosystem processes. The altered hydrology, which in most cases remains at present, has led to significant degradation and loss of tidal wetland habitat, species and function throughout the Gulf of Maine (Boumans et al. 2002; Percy and Harvey 2000; Wells 1999).

The years 1955 to 1971 saw the construction of the largest of the tidal barriers in the Bay of Fundy. Wells (1999) summarized the chronology of these barriers on the major tidal rivers in the Bay of Fundy:

- 1955: Shepody River – control structure, protection of agricultural land.
- 1958-60: Annapolis River, at Granville Ferry and Annapolis Royal – causeway with control structure to replace a former bridge, and provide farmland (reclaimed marshland) protection upstream.

- 1960: Tantramar River – control structure, farmland protection, roadway.
- 1964-66 – St. John River – Mactaquac Dam, above Fredericton, power station, roadway.
- 1968-70 – Petitcodiac River, at Moncton – causeway-dam, farmland protection.
- 1969 – Avon River, at Windsor – causeway-dam, farmland protection
- 1970 – Memramcook River – control structure, farmland protection
- 1984 – Annapolis River – reconstruction of causeway-dam and startup of completed tidal power generating station.

Of an estimated 44 medium to large-sized rivers flowing into the Bay of Fundy, major barriers to tidal flow exist on 25 (Wells 1999). Studies by the EAC examining tidal barriers on salt marshes and tidal rivers of all sizes in the Minas Basin have revealed that over 50% of the tidal crossings along coastal roads are causing significant hydrological modification to the affected systems (Bowron and Fitzpatrick 2001; Dalton and Mouland 2002; Bowron 2003)

2.1.3 Tidal Barriers in the Minas Basin

Historical and modern agricultural dykes, a railway, a section of the Trans Canada Highway, secondary roads, culverts, and bridges are all present in the Minas Basin. Wells (1999) identified 10 medium to large barriers in the Minas Basin (Figure 4). An audit of tidal barriers in Hants County and Colchester County during the summers of 2001 and 2002 found that over 50% of the tidal crossings in each County had partial to complete restrictions (Figure 5) (Bowron and Fitzpatrick 2001; Dalton and Mouland 2002). Neither of these studies addressed the location or extent of agricultural dyking in the watershed. Although the Nova Scotia Department of Agriculture and Fisheries has documentation on the actively maintained dykes and aboiteaux in the province, accurate information on the number, location and status of non-provincial dykes (dykes and aboiteau that are not maintained by the Nova Scotia Department of Agriculture and Fisheries) is not available.

Figure 4 Location of large-scale tidal barriers (not including dykes, aboiteaux, or dams) in the Upper Bay of Fundy (reprinted with permission, Percy and Harvey 2000).

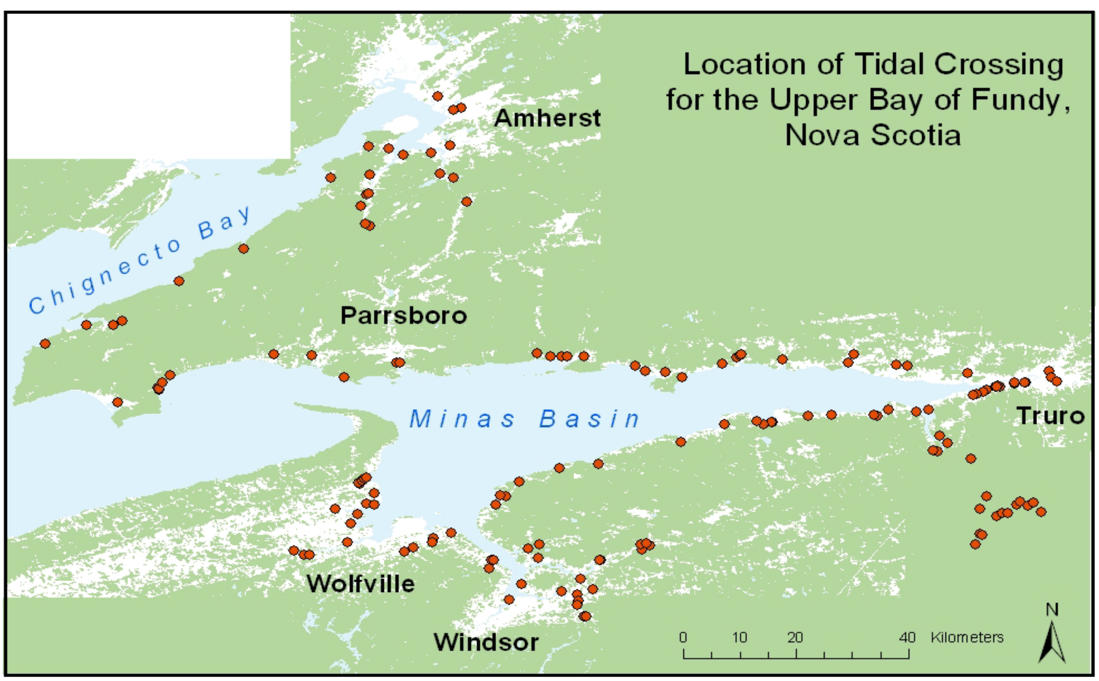

Figure 5 Location of all tidal crossings in the upper Bay of Fundy identified during the EAC's 2001 to 2004 Tidal Barrier Audit Project.

2.2 Study Area

2.2.1 Cheverie Creek – Tidally Restricted Study Site

Cheverie Creek is a small tidal river centrally located in the coastal village of Cheverie, Hants County, NS (Figure 6). Route 215, the main road in the area, crosses the mouth of Cheverie Creek as a two-lane, rock-filled causeway (Figure 7). Limited tidal exchange is allowed through a 1.5 m x 1 m double wooden box culvert set deep in the road bed on the south end of the causeway. A scour pool is present on both the upstream and downstream ends of the crossing and the downstream channel is diverted north part way along the base of the causeway by a rock berm that is clearly visible on the aerial photograph (Figure 7). A composite photograph of the upstream end of the culvert, scour pool, creek, marsh surface and dyke is provided by Figure 8.

Historically[4], the river was dyked and the area upstream used for agricultural purposes; however, it is evident by the current condition of the site (partially tidal) that it has not been used as farmland for many years. Aerial photography from the 1930's shows the road-causeway with a small bridge. At that time, the dyke was in decline and the aboiteau had been removed. In 1960 the bridge was replaced by a culvert equipped with a clapper gate that prevented tidal flow upstream. At this time, the river system was completely tidally restricted and freshwater vegetation including trees and shrubs became established on the marsh surface. It is unknown exactly when the gate was removed or how (most likely by a winter storm). However, since the early 1980s (approximate, based on anecdotal information from local residents) the crossing has allowed a limited amount of tidal flow. This re-establishment of limited tidal exchange has allowed some natural restoration of the system towards the conditions that likely existed prior to the construction of the original dyke nearly 200 years ago. This sequence of events is presented in Table 3.

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[4] Little documented information is available on historical land use at both study sites. The sequence of events presented here has been reconstructed based on anecdotal information from local residents.

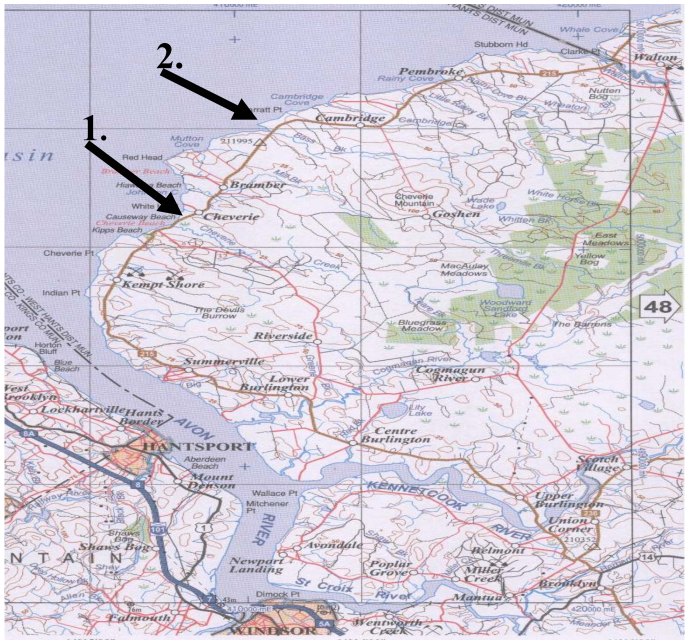

Figure 6 Location of the Cheverie Creek restoration site (#1) and the Bass Creek reference site (#2) (Service Nova Scotia and Municipal Relations 2001).

Table 3 Sequence of disturbance events at Cheverie Creek (based on anecdotal information from local residents).

Years (ca)	Activity	Component of system tidally influenced
Before 1700	Free flowing tidal river and salt marsh	Entire system tidal
1700 – 1750	Dyke and aboiteau constructed across marsh	Seaward of dyke
1800	Road, bridge and breakwater built in present location	Area between dyke and causeway-bridge and seaward of road
1880 – 1900	Aboiteau and section of dyke removed	Tidal flow restored to entire river/marsh system
1900 - 1950	Road and bridge maintained	Entire system
1960	Bridge replaced with a culvert equipped with a tide gate	Seaward of causeway
1975 - 1985	Tide gate removed	Partial restoration of tidal flow to entire system

Figure 7 1992 aerial photograph of Cheverie Creek Causeway-Culvert. (Modified from Nova Scotia Department of Natural Resources, 2003). Inserted image is of the two-lane rock-filled causeway and the square wooden box culvert almost completely submerged at low tide by freshwater flow; taken by T. Bowron, 2002.

Figure 8 View upstream at Cheverie Creek from the road surface above the culvert. Photo by T. Bowron, spring 2002.

2.2.2 Bass Creek: Unrestricted Reference Site

A reference marsh [site] is one that displays a characteristic "minimally disturbed" condition, or maximum functional capacity, and represents other marshes in a given region sharing a similar hydrological regime, topographic setting and climate zone (Carlisle et al. 2002). Important background information, identification of locally specific restoration targets, and tracking restoration trajectories can be gained and accomplished by duplicating the monitoring program on an existing local, undisturbed, wetland (Zedler 2001). Depending on land use history and current development pressures, locating natural river-estuarine system(s) that can serve as reference sites may be difficult because disturbances may have so reduced the area of wetlands and/or altered their condition.

Bass Creek is an unrestricted tidal river and salt marsh system located in Bramber, approximately 5 km north of Cheverie Creek along Highway 215 (Figure 6). Similar to Cheverie Creek, Highway 215 crosses the river near its mouth. However, unlike the crossing at Cheverie Creek, the Bass Creek crossing is a combination causeway-bridge structure (Figure 9), whereby the bridge section spans the width of the main river channel.

Smaller in spatial extent than the river and marsh system at Cheverie, it is likely that the geological and social history of this site has closely paralleled that of Cheverie Creek. Historically dyked for agricultural purposes and later used as a location for a sawmill, remains of both the old dyke and in-stream structures are evident in aerial photographs and during site visits. The evidence of a dyke and aboiteau across the mouth of the river suggests that the river was blocked at one time. However, the apparent age of the remnant structures, the status of the existing crossing and the distinct lack of evidence of agricultural use of the upstream system indicate that the system has been tidal for a considerable period of time.

Although markedly smaller in size than the Cheverie Creek system, and with a questionable classification as an unrestricted 'natural' tidal river and salt marsh system, Bass Creek was the only tidal river and salt marsh system in relatively close proximity to the study site that could serve as a suitable reference site. Other tidal systems in the area were either substantially different in size and structure and/or had one or more tidal barriers present.

Figure 9 1992 aerial photograph of Bass Creek Causeway-Bridge. (Modified from Nova Scotia Department of Natural Resources, 2003). Inserted image is of the Bass Creek bridge at low tide; taken by T. Bowron, 2001.

2.3 The GPAC Monitoring Protocol

The GPAC Monitoring Protocol identifies a standard set of salt marsh indicators and data collection methods to characterize salt marsh ecosystem components that, when applied pre- and post-restoration activities, provide information about ecosystem response to restoration (Neckles and Dionne 2000; Neckles et al. 2002). The resulting suite of indicators for monitoring impacted, restored and natural tidal wetlands was arrived at through consensus among the approximately fifty wetland scientists and restoration practitioners present at the workshop (Neckles and Dionne 2000; Neckles et al. 2002). Potential indicator variables were evaluated by participants in terms of information gained, feasibility, cost (in U.S. dollars), the skill level required for measurement, and spatial and temporal sampling frequency needed (Neckles and Dionne 2000; Neckles et al. 2002). These core indicators are measures of wetland structure that collectively provide basic information on ecosystem response to restoration. Within each of these core indicator categories, additional variables are also identified for application to individual monitoring projects as resources, expertise, or time allow or as required by project specific goals (Konisky et al. 2003). The additional variables are indicators of marsh functions that, if measured, will provide greater insight into overall ecosystem response.

Salt marsh monitoring data should be collected for a minimum of one year prior to restoration, annually for two to three years after restoration activities, and then every two years thereafter until long-term success criteria for the project are achieved (Neckles et al. 2002). It is recommended that monitoring be continued for a minimum of five years following restoration activities and ideally continued for between 10 to 15 years.

A complete list of the GPAC Monitoring Protocol indicators (core and additional) along with the sampling methodology and sampling frequency are provided in Table 4 (end of section) and a brief description of each general category of indicators (baseline habitat map, hydrology, soils and sediments, vegetation, nekton, birds) is provided below.

2.3.1 Baseline Habitat Map

A baseline habitat map should be prepared to document habitat conditions at both the restoration and reference sites prior to undertaking restoration actions. The map should include key geographical and social features relevant to the monitoring site as well as physical and biological habitat features such as the location of tidal creeks, pannes, vegetation patterns and potential stressors on the system. The map provides a foundation for the monitoring activities and a baseline against which changes in habitat conditions post-restoration may be described and compared.

2.3.2 Hydrology

The fundamental control on the structure and function of a salt marsh is flooding with salt water (Mitsch and Gosselink 1986). The frequency and duration of salt water flooding (hydroperiod) of a salt marsh is determined by the tidal signal (pattern of water level change with respect to a reference point) and marsh surface elevation. Alterations to the natural hydroperiod of a marsh by a tidal restriction may result in significant changes in the form and function of a marsh, changes which may be possible to reverse by restoring its original hydroperiod.

Additional variables for hydrological monitoring include: tidal creek cross-section; water table depth (distance between the marsh surface and the top of the water table); surface water physico-chemical and physical characteristics (salinity, temperature, pH, dissolved oxygen); current profiles in main channel; and extent of tidal flooding.

2.3.3 Soils and Sediments

Soil salinity (interstitial pore water salinity) determines, to a large degree, the distribution and abundance of plant species in salt marshes (Niering and Warren 1980). The re-establishment of natural marsh plant communities and the restriction or elimination of invasive or non-tidal wetland species are among the most common goals of restoration projects in New England (Neckles and Dionne 1999). The best indicator of changes in marsh conditions regulating plant growth, distribution and abundance would be measuring pore water salinity during the early to mid growing season (Neckles and Dionne 1999).

Additional soils and sediments indicators include: sediment accretion and organic matter (additional information provided below); sediment elevation; redox potential and sulphide concentrations.

Monitoring sediment accretion rates and determining the organic content of marsh soils prior to engaging in restoration activities can reveal insights regarding pre-restoration marsh conditions and the process of recovery following restoration. Deposition of inorganic and organic materials onto the marsh surface by tidal flooding and vegetation is one of the most important processes allowing marshes to grow vertically and horizontally, maturing over time, and allowing marshes to keep pace with sea level rise. The presence of a tidal restriction which reduces tidal exchange can reduce the sediment supply to the marsh surface, slowing the rate of marsh growth and increasing the significance of the organic depositional process to marsh growth (Burdick et al. 1989; Burdick et al. 1997). Experiences with tidal restrictions in the United States and agricultural dyking in NS illustrated the connection between tidal restrictions and the subsidence of the marsh surface as well as the inability of marsh areas behind such structures to build in elevation in step with rising sea levels (Burdick et al. 1997; Mitsch and Gosselink 1986; Nova Scotia Department of Agriculture and Marketing 1987). As well, both flooding and salinity control the decomposition rate of organic materials. Rapid sediment buildup (increased elevation) following restoration may be due to the increased supply of sediments to the marsh as well as changes in organic contributions as plant communities change in response to the new tidal regime.

2.3.4 Vegetation

Salt marsh plant species decline when tidal flushing is impaired (Zedler, 2001). Therefore, the re-establishment of natural tidal marsh vegetation communities and/or the control of invasive and non-salt marsh plant species has become a common focus for restoration projects in New England (Neckles et al. 2002). It is important to monitor abundance and species composition before and after restoration and assess changes due to restoration compared to annual variability. Monitoring efforts should focus on abundance, species composition, height (species of concern) and stem density (species of concern).

Additional salt marsh vegetation indicators include: aboveground biomass; stem density; and proportion of flowering stems.

2.3.5 Nekton

Salt marshes support a wide range and abundance of organisms that swim, collectively referred to as nekton, which include fish and many types of invertebrates. Fish and macrocrustaceans form an important ecological link between the primary producers of the marsh (plants) and near shore fisheries (Neckles and Dionne 2000). Their position in the upper levels of the coastal food webs and their dependence on a wide range of food and habitat resources serve to integrate ecosystem elements, processes and productivity (Kwak & Zedler 1997). Fish sampling is conducted within the tidal creeks and channels and in flooded vegetation. Core indicators include: composition; species richness; density; and length.

Additional measurements that provide greater understanding of the suitability of the habitat for fish and productivity include fish biomass, growth, diet, and numbers of larval mosquitoes. Although larval mosquitoes are not a traditional nektonic species, the GPAC Monitoring Protocol includes larval mosquitoes as an additional variable in the nekton category due to its link with fish in the marsh ecosystem. The distribution and abundance of mosquito larvae relative to the distribution and abundance of standing water on salt marsh can provide insight into patterns of tidal flooding on the marsh surface and the presence, absence, abundance and mobility of fish species on the marsh.

2.3.6 Birds

Highly visible and dynamic members of the salt marsh community, birds are an obvious indicator to include in a restoration monitoring program. Like fish, birds are higher trophic-level organisms with species that are strongly dependent on salt marsh habitats and provide insight into marsh habitat structure and function (Neckles and Dionne 2000).

Species abundance, richness and behavior provide information on the value of the habitat to birds.

Additional indicators which provide further information on the value of the restored habitat to birds include observations concerning small passerines and other cryptic birds of the salt marsh, birds in the buffer (upland edge of the wetland), and use of the habitat during the winter by waterfowl.

Table 4 GPAC Monitoring Protocol: core and additional indicators to be monitored on restoration and natural marshes (modified from Neckles and Dionne 2000; Neckles et al. 2002).

Core Indicators	Additional Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
Baseline Habitat Map				
Locator map		Location of salt marsh monitoring site		
Key features		Geographical and cultural features associated with monitoring site – roads, rivers, culverts, bridges		
Wetland/area/cover types/sediment condition		Delineated salt marsh, fresh/brackish marsh, forested wetland, shrub-dominated wetland, open water, invasive or species of interest; soil organic content at sampling stations		
Manipulations		Location of pre and post-restoration actions, such as culverts, dredging, removal or addition of fill, excavations, ditch plugging etc.		
Sample locations		Locations of pre and post-restoration monitoring stations (transects, plots, wells, survey points, etc.)		
Base map documentation		Sources of base map – scale of map and north arrow, latitude and longitude		
	Detailed, geo-referenced site information	Detailed cover-type mapping, ownership boundaries, elevation contours, 100 year floodplain boundary		
Hydrology				
Tidal signal		Pattern of water level change with respect to a reference point	Continuous water level recorders or Tide staff observations at 10 minute intervals	2 to 4 week period of operation 13hr observation periods during 3 spring & 3 neap tides
Elevation		Marsh surface elevation at contour intervals of 15 cm or less	Contour map or Hypsometric curve	Once
	Tidal creek cross-section	Cross-section profiles of major tidal creeks measured at permanent location		Once
	Water table depth	Groundwater depth below marsh surface	Permanent wells (groundwater wells) or Piezometers	Sampled at low tide, 6 times b/w early and mid-growing season, including neap and spring tides

Core Indicators	Additional Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
	Surface water characteristics	DO, salinity, temperature, pH		
	Current Profile	Tidal current in main channel		Measured over several tidal cycles
		Soils and Sediments		
Pore water salinity		Salinity of soil water	Groundwater wells or soil cores or sippers	6 times b/w early to mid-growing season, including neap and spring tides
	Organic matter	Organic content of marsh soils	20 cm soil cores	Once prior to restoration and post as required
	Sediment accretion	Accumulation of inorganic & organic material on marsh surface	Marker horizon	Marker horizon set prior to restoration and sampled at a known period of time post
	Sediment elevation	Short term changes in sediment elevation	Set Elevation Table	
	Redox potential	Redox potential at 1 cm and 15 cm depths		
	Sulfide concentrations	Concentrations of sulfide in pore water		
		Vegetation		
Composition		Identity of all plant species per m^2	Permanent plots positioned along transects at intervals necessary to maintain independence (>10-20 m)	Once at time of maximum standing biomass (mid-July through August)
Abundance		Percent cover per m^2 by species		
Height		Mean height of 3 tallest individuals of each species of concern per m^2	Permanent plots on transects	
Density (sp. of concern)		Number of shoots per m^2 in plots restricted to species of concern	Permanent plots established within distinct stands of species of concern	

Core Indicators	Additional Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
Photo stations		Photographs from permanent stations	Panoramic views of entire marsh from several compass bearings; close-ups of permanent plots	
	Above ground biomass	Biomass of living aboveground plant material collected from additional randomly positioned plots in vicinity of permanent plots		
	Stem density (all sp.)	Number of shoots per m^2, by species, within permanent plots		
	Proportion of stems in flower	Proportion of shoots of each species that are flowering within permanent plots		
		Nekton		
Composition		Identity of each animal sampled	Throw traps in creeks and channels (small fish) and Fyke nets in creeks >15m wide (large fish) and Fyke nets on marsh surface (fish catch data must be standardized by marsh area)	At mid-tide during 2 spring tides in August Installed at slack high tide: two spring tides during early season migration of diadromous fish; 2 spring tides in August Installed at low tide to sample ebb tide, 1 spring tide in Aug.
Species Richness		Total number of species represented		
Density		Number of animals per area (throw traps and marsh surface fyke nets)		
Length		Length (fish, shrimp) or width (craps) of individuals to the nearest 0.5 mm, by species		
	Biomass	Wet weight of animals in sample, by species, recorded from throw trap and fyke net samples		

Core Indicators	Additional Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
	Fish growth	Fish condition (length/biomass) within size classes for selected species collected in throw trap and fyke net samples		
	Fish diet	Gut contents of subsample of fish collected in throw trap and fyke net samples		
	Larval mosquitoes	Larval mosquitoes in salt pannes	Dipper	Collected weekly from April through August along transects that intersect standing water on marsh surface
Birds				
Abundance		Number of birds per ha, by species	20 minute observation periods in the morning from site-specific vantage points that provide an uninterrupted view of at least a portion of the salt marsh	High and low tides: 2 times during breeding season (May/June); once per week during waterfowl migration (March/April and October/November); once per week during shorebird migration (July-Sept)
Species richness		Total number of species represented		
Feeding/breeding behavior		Type of behaviour per observation interval, by species		
	Passerines & cryptic birds		20 minute observation periods from centre of 50 m radius counting circles established in the salt marsh	
	Birds in buffer		20 minute observation periods from centre of 50 m radius counting circles established in the habitat adjacent to the salt marsh	

Core Indicators	**Additional Indicators**	**Description**	**Sampling Method**	**Sampling Frequency** (Before & after restoration except as noted)
	Waterfowl in winter		20 minute observation periods from site-specific vantage points continued throughout the winter (as long as marsh is ice free)	

CHAPTER 3 – METHODS

Overview and Approach

The primary goal of this study was to evaluate the indicators and associated sampling techniques recommended by the GPAC Monitoring Protocol to assess tidal restoration of salt marshes on local and regional scales in the Gulf of Maine watershed. The methods involved four phases. First, a general process for evaluating indicators was developed based on a review of existing indicator literature and monitoring initiatives. The resulting indicator assessment criteria were used to evaluate the indicators recommended by the GPAC Monitoring Protocol in the key areas of scientific validity (technical considerations), practical considerations and programmatic considerations. The GPAC Monitoring Protocol was then used to develop and implement a monitoring program as part of a proposed salt marsh restoration project in the Bay of Fundy (the field test). Finally, on the basis of these assessments, recommendations were made for the modification of the GPAC Monitoring Protocol for use as part of future tidal wetland restoration projects in the Bay of Fundy, with potential applicability to other tidal restoration projects in Atlantic Canada.

3.1 Evaluation of the GPAC Monitoring Protocol

3.1.1 Selecting Indicator Assessment Criteria

The initial phase of this study involved a comprehensive literature review of salt marsh ecology, the impacts of tidal barriers on tidal wetlands, salt marsh monitoring and restoration, and the evaluation and use of indicators to monitor ecosystem conditions. Based on this review, a series of indicator assessment criteria was selected from existing indicator evaluation frameworks (Dale and Beyeler 2001; Jackson et al. 2000; Noon et al. 1999; Ure 2003). The resulting indicator assessment criteria were divided into three areas of consideration: (i) technical (scientific validity); (ii) practical; and (iii) programmatic (Table 5). The indicator assessment criteria were used to guide the evaluation of the indicators and variables of the GPAC Monitoring Protocol rather than a strict systematic assessment (for example, statistic power was not explored. Although discussed separately, the criteria within each of these categories are functionally related and when viewed as a whole, provide guidance to the indicator evaluation process.

Technical Considerations (scientific validity)

For any monitoring program, indicators should be measurable, provide data that are scientifically reliable, and allow for comparison with reference conditions. The measurements must be sensitive enough to detect changes in ecological condition and to be able to discern between natural variability and changes due to human activities. The sampling methods should be reliable and precise. For a monitoring program where it is not logistically feasible to monitor all possible parameters, selected indicators should be representative of a range of ecosystem scales, parameters/species. The data collection methods and data should be compatible with those used for similar monitoring initiatives in the region and a set of reference condition data should be available for comparison.

Practical Considerations

A successful monitoring program must be able to collect and analyze scientifically valid data over the long term. Since the application of a lengthy, complex monitoring protocol on a large scale is likely to be cost prohibitive, it is important that the monitoring program be manageable within the logistical constraints of the project. State-of-the-art technology is of little use or utility if personnel cannot operate it or if data cannot be collected at all locations. A monitoring program should produce a large amount of data and information in relation to the cost and effort involved. Also important from a practical standpoint is the level of environmental impact of sampling. Sampling should have a limited impact on the environment and sampling of a given variable or location should not affect subsequent measurements or concurrent sampling of other variables.

Programmatic Considerations

Considerations from a program or project management position are generally concerned with the overall monitoring program rather than individual indicators. In other words, how well does the monitoring program as a whole operate. The full suite of indicators to be used in a monitoring program should be relevant to its goals and objectives. It is typically not feasible to monitor every physical and biological parameter in order to make an estimate of ecological condition or to detect ecosystem change. It is important that an ecological-based monitoring program employ a specific suite of indicators that spans key environmental gradients, spatial scales and ecosystem components to ensure that the project goals are met once all the data are collected. As well, the monitoring program should produce information that is easily understood and accepted by scientists, managers, decision-makers and the public.

Table 5 Summary of criteria for assessing potential indicators (modified from Dale and Beyeler 2001; Jackson et al. 2000; Noon et al. 1999; Ure 2003).

Criteria	Description
Technical Considerations	
Measurable	- The indicator should be easy to measure, practical to use, be measurable over time, have a defined numerical scale and be quantified simply - Sampling does not affect subsequent measurements or simultaneous sampling of other parameters
Sensitive	- The indicator responds, in a known manner, to stresses placed on the system by human actions as well as natural variation and does so in an appropriate time frame and spatial scale - Responds to restoration activity within a relatively short period of time
Valid/accurate	- Indicator is a true measure of some environmental conditions within constraints of existing science and is linked to an endpoint in an assessment process
Reproducible/Reliable	- Measurements and results should be reproducible within acceptable limits for data collection over time and space - Measurements are able to be made repeatedly with different personnel without introducing bias - Should have low natural variability (high signal to noise ratio)
Representative	- Changes in the individual indicator represent trends/changes in other ecosystem parameters/species they are selected to represent
Reference value	- Has reference or historical condition against which to measure progress
Data compatible	- Data are compatible with existing data sets/past conditions and are applicable to other areas/ecosystems
Practical Considerations	
Cost/cost effective	- Information is available or can be obtained with reasonable cost/effort - The costs of measurements are not prohibitive
Level of difficulty	- Access to expertise/training/equipment to monitor - Ability to find, identify, and interpret chemical parameters, biological species, or habitat parameter - Easily detected - Accepted sampling method available or development of new techniques feasible - Low impact to measure - Socially acceptable - Reasonable sampling frequency (sampling window)
Programmatic Considerations	
Relevant	- The indicator should be relevant to the desired goals and objectives of the monitoring program

Program Coverage	-	Program uses suite of indicators that encompass major components of the ecosystem over the range of environmental conditions to be expected and provides a measure of the larger environmental component or system of interest
Understandable	-	The monitoring results can be interpreted and explained in a format that the target audience can understand (statistically for scientists and non-technical for managers/public)

3.1.2 Evaluating the GPAC Monitoring Protocol

The GPAC Monitoring Protocol was evaluated against the selected indicator assessment criteria (Table 5) first on an individual indicator basis (hydrology, soils and sediments, vegetation, nekton, and birds) and then as a whole. The evaluation was aided by a review of the literature on the subject, consultation with wetland scientists working in the Bay of Fundy, and the actual application of the GPAC Monitoring Protocol as part of a salt marsh restoration project. It was through both the conceptual review and the field testing of the indicators and sampling methods that the individual indicators and the program as a whole were evaluated to find the strengths, weaknesses and gaps in the GPAC Monitoring Protocol.

3.2 Implementation of the GPAC Monitoring Protocol

This section describes the monitoring program (indicators, variables and data collection methods) that was developed using the GPAC Monitoring Protocol as part of a proposed salt marsh restoration project and as a means to field test the GPAC Monitoring Protocol in the Bay of Fundy. The indicators and data collection methods described are those of the GPAC Monitoring Protocol, unless otherwise specified. The indicators measured in this study were hydrology, soils and sediments, vegetation, nekton, and birds. A complete list of GPAC Monitoring Protocol indicators (core and additional), sampling methodology, and site-specific application is provided in Table 6. Not all the indicators were monitored at both sites due to resource constraints of the EAC Project. The results of the field test, along with a general discussion of what the monitoring program revealed about the pre-restoration condition of Cheverie Creek and the Bass Creek reference site, the expected changes due to planned restoration actions and some of the limitations associated with the field test are included in Appendix C.

3.2.1 Baseline Habitat Map

The baseline habitat map for Cheverie Creek was developed using the 1992 1:10,000 aerial photograph for the site, and a combination of differential global positioning system (DGPS) and geographical information system (GIS) (Figure 10). Detailed habitat sketches and field notes were also taken to complement the electronic mapping activities.

Sampling was conducted at Cheverie Creek using transects established in a non-biased, systematic sampling procedure. Twenty six transect lines were established at Cheverie Creek (Appendix D). In order to get a better representation of the area between the causeway and the dyke, the first two transect lines were set closer together than the other 24. The third line was then set up 10 m from the upstream side of the dyke and the remaining 23 lines set 50 m apart.

Standard survey equipment (survey tripod, level, and two range poles) were used to produce straight, reproducible lines. Transects were marked by placing a front and back stake at the beginning of each line, 10 m apart. Lines were measured 50 m and 90 degrees from the front stake of the previous line. Transects ran perpendicular to the main creek channel and extended from the terrestrial edge of the marsh on the north side of the creek to the terrestrial edge of the marsh on the south side (Appendix D). Sampling stations along each transect line were set 20 m apart with the first station set 0.5 m from the creek edge and marked using a two foot bamboo stake and flagging tape. The eight transects, 100 m apart, established at Bass Creek were set up in the same manner (Appendix D).

Transects at Cheverie Creek ranged in length from 106 m to 313 m, with an average length of 193 m. The longest transect established at Bass Creek was 107 m, the shortest 55 m, with an average length of 78 m.

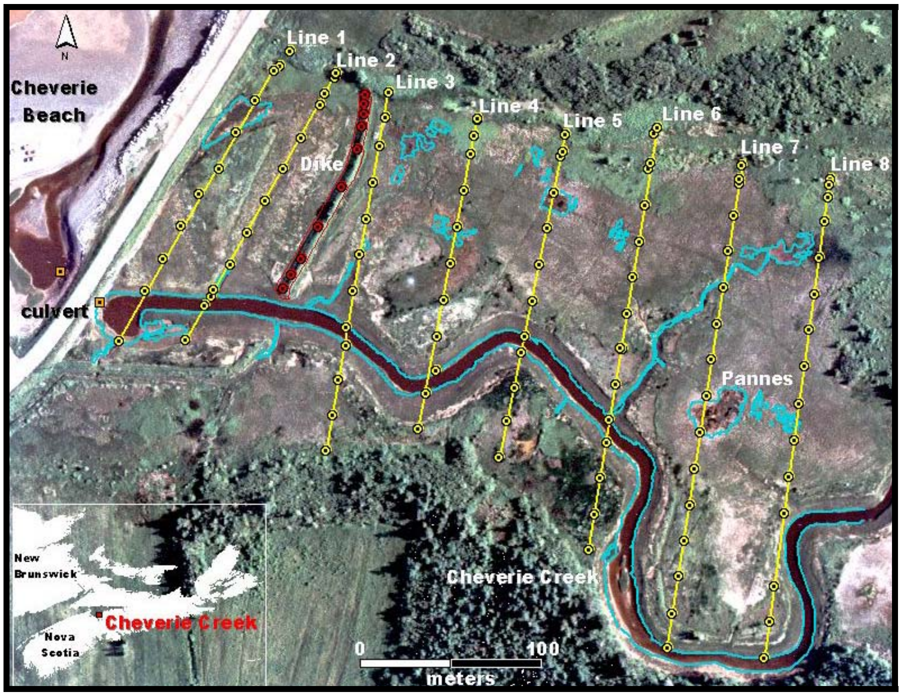

Figure 10 Rectified aerial photograph showing main marsh features, transect lines and sample locations for the front portion of the Cheverie Creek system. The vegetation and soils and sediment sampling locations are indicated by the circles containing dots (reprinted with permission of Townsend 2002).

Detailed, geo-referenced habitat and monitoring information was collected for Cheverie Creek using two GPS Trimble® Pathfinder Pro XR receivers with an accuracy of 0.8-1.5m. Trimble® PathFinder Software and GIS ArcView 3.2© Spatial Analyst, were used to collect, download and analyze line (creek edges and dyke), area (pannes) and point data (sampling locations, culvert ends, center of road and the road bridge) for the Cheverie Creek site. ArcView and related GIS software are available from the Environment Systems Research Institute (ESRI 2005). A detailed description of this data collection and analysis methodology is given in Townsend (2002) and Chiasson (2003).

3.2.2 Hydrology

Hydroperiod

To assess hydrology at Cheverie Creek, the maximum water levels were collected both upstream and downstream of the causeway-culvert over a two week period (September 18 and October 2, 2003). Elevation of water levels were recorded using manual tide level recorders (metal pole with a float and marker – float rises and falls with the tide leaving the marker suspended at the high tide level, height of marker above the marsh surface was measured with a metric field tape at low tide and reset with float at base of pole) installed on both the upstream and downstream sides of the causeway. Incremental tide levels (upstream and down) were measured simultaneously every 15 minutes over two individual high tide cycles, one on September 26, 2003 and a second on October 1, 2003, using a simple set of tide staffs.

Marsh surface elevations were measured at 92 locations along the first eight transects at Cheverie Creek during the summer of 2002 using the GPS and GIS equipment and the mapping technique described in Section 3.2.1. Additional elevation data were measured, using a rod and laser-level, to determine the culvert invert elevation and the peak elevation of the high tide (unrestricted bay side) on May 14, 2003. These site measurements, combined with Canadian Hydrographic Service web-based tide charts for Hantsport, Kings County (nearest available location) (http://www.lau.chs-shc.dfo-mpo.gc.ca/), provided the basis for the implementation of a simple calibrated model of Cheverie Creek tidal hydraulics (Konisky 2004). The model generated estimates of marsh tidal flooding for a complete tidal series, from neap to spring tides. When combined with marsh surface elevation measurements, projected tidal heights were used to estimate ecologically-important marsh flooding frequencies.

Modeling was conducted by Dr. Raymond A. Konisky at the Wells National Estuarine Research Reserve in Wells, Maine, United States. The model, Marsh Response to Hydrologic Manipulation Model (MRHM), is an enhanced version of software originally developed at the University of Maryland (Boumans et al. 2002; Konisky et al. 2003).

Table 6 GPAC Protocol Monitoring Indicator categories, variables, methodologies and site-specific application (x indicates site specific application) (modified from Neckles et al. 2002).

Core Indicators	Additional Indicators	GPAC Sampling Method	Sampling Method Used	Cheverie Creek (Restoration Site)	Bass Creek (Reference Site)
Baseline Habitat Map					
Locator map			Topographical map, Aerial photograph	X	X
Key features			Aerial photograph	X	X
Wetland/area/cover types/sediment condition			Aerial photograph, DGPS/GIS	X	X
Manipulations			DGPS/GIS	X	
Sample locations			Aerial photograph, DGPS/GIS	X	X
Base map documentation			DGPS/GIS	X	X
	Detailed, geo-referenced site information		Aerial photograph, DGPS/GIS	X	
Hydrology					
Tidal signal		Continuous water level recorders, or Tide staff observations at 10 minute intervals	Manual (maximum) water level recorders, and tide staffs	X	
Elevation		Contour map, or Hypsometric curve	Contour map (DEM), DGPS/GIS	X	
	Tidal creek cross-section				
	Water table depth	Permanent wells (groundwater wells), or Piezometers	Groundwater wells	X	X
	Surface water characteristics				
	Current Profile				
Soils and Sediments					

Core Indicators	Additional Indicators	GPAC Sampling Method	Sampling Method Used	Cheverie Creek (Restoration Site)	Bass Creek (Reference Site)
Pore water salinity		Groundwater wells, or soil cores, or sippers	Groundwater wells	**X**	**X**
	Organic matter	20 cm soil cores	Sediment cores (soil samples)	**X**	
	Sediment accretion	Marker horizon	Sediment plates	**X**	
	Sediment elevation	Set Elevation Table	Sediment plates	**X**	
	Redox potential				
	Sulphide concentrations				
Vegetation					
Composition		Permanent plots positioned along transects at intervals necessary to maintain independence (>10-20 m)	Permanent plots positioned along transects at 20 m to 40 m intervals, and Line intercept	**X**	**X**
Abundance				**X**	**X**
Height				**X**	**X**
Density (sp. of concern)		Permanent plots established within distinct stands of species of concern			
Photo stations		Panoramic views of entire marsh from several compass bearings; close-ups of permanent plots	Panoramic views of marsh from transect endpoints, close-ups of permanent plots	**X**	**X**
	Above ground biomass				
	Stem density (all sp.)		Permanent plots positioned along transects at 20 m to 40 m intervals	**X**	**X**
	Proportion of stems in flower				
Nekton					
Composition		Throw traps in creeks and channels (small fish) and Fyke nets in creeks >15m wide (large	Minnow traps in creeks, pannes and main tidal channel (small fish), and fyke net on marsh surface and in main tidal channel (large fish)	**X**	**X**
Species Richness				**X**	**X**
Density				**X**	**X**
Length				**X**	**X**

Core Indicators	Additional Indicators	GPAC Sampling Method	Sampling Method Used	Cheverie Creek (Restoration Site)	Bass Creek (Reference Site)
	Biomass	fish) and Fyke nets on marsh surface (fish catch data must be standardized by marsh area)			
	Fish growth				
	Fish diet				
	Larval mosquitoes	Dip sample (dipper)	Dip sample (Dipper)	**X**	**X**
		Birds			
Abundance		20 minute observation periods in the morning from site-specific vantage points that provide an uninterrupted view of at least a portion of the salt marsh	Series of 10 minute observation circles (100 m diameter)	**X**	**X**
Species richness				**X**	**X**
Feeding/breeding behavior					
	Passerines & cryptic birds	20 minute observation periods from centre of 50 m radius counting circles established in the salt marsh	Series of 10 minute observation circles (100 m diameter)	**X**	**X**
	Birds in buffer	20 minute observation periods from centre of 50 m radius counting circles established in the habitat adjacent to the salt marsh	Series of 10 minute observation circles (100 m diameter)	**X**	**X**
	Waterfowl in winter	20 minute observation periods from site-specific vantage points continued throughout the winter (as long as marsh is ice free)			

Konisky (2003) described this modeling exercise as follows (Figure 11).

> We will use a model known as MRHM (Boumans et al. 2002) to predict upstream water level and water volume flow through tidal culverts, based on measured records of downstream tidal signal and culvert dimensions, and calibrated parameters. In addition, the model will use a profile of surface elevations to estimate the area of a marsh flooded by each tide. The general approach for use of this model is to calibrate predictions of upstream tidal heights to observed conditions, and then to use the calibrated model as the basis for conducting hydrologic scenario analysis. In particular, marshes with current tidal restrictions are modeled with hypothetical new culvert designs to simulate hydrologic restoration. Results from this exercise will provide new information about the restoration capacity of restricted marshes.

Initially three hydrologic scenarios were analyzed: (1) the current culvert design (40 m in length, with side-by-side 1.74 m x 1.34 m box culverts); (2) a replacement crossing with a span of 4.27 m x 1.22 m; and (3) a replacement crossing with a span of 11.58 m x 3.05 m. At the request of the Nova Scotia Department of Transportation and Public Works (NSDOTPW), three intermediate model scenarios were run for replacement spans of the following dimensions: (1) 9 m x 3 m; (2) 8 m x 3 m; and (3) 7 m x 3 m to investigate system response. Konisky's (2004) report "Analysis of Tidal Hydrology at Cheverie Creek Marsh" is included in Appendix E.

The monitoring of hydrology for the EAC Project was conducted to determine the degree to which the Cheverie Creek system was tidally restricted. Given that Bass Creek is classified an unrestricted tidal river and marsh ecosystem, no hydrological data were collected for this site.

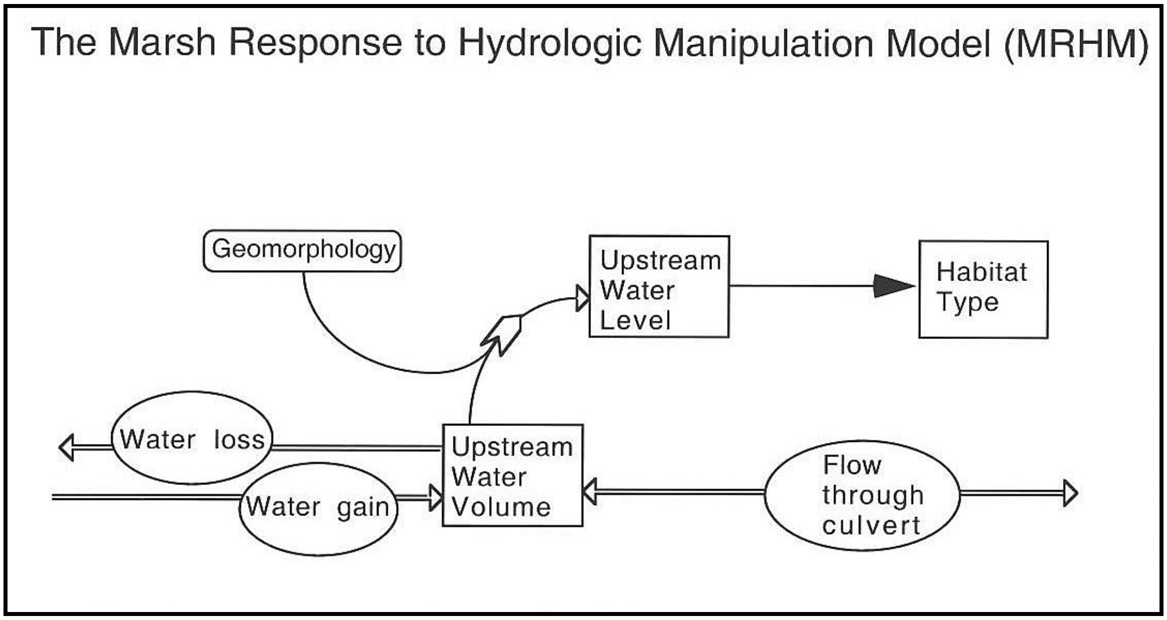

Figure 11 Conceptual model of water level change in salt marshes, including marshes with tidal restrictions (Boumans et al. 2002).

Water Table Depth

Depth to water table (groundwater) was sampled using groundwater wells constructed from 1 m long plastic pipe (1/2" diameter) with seven 3 mm holes drilled in alternating sides at 2.5 cm intervals, extending 5-25 cm from the base of the well. The bottom of each well was sealed using duct tape and the tops capped with two 45^0 plastic elbows to prevent the entrance of surface water and to allow venting. Groundwater wells were installed to a depth of 90 cm (Figure 12). Seven groundwater wells were installed at Cheverie Creek (Appendix D). Six groundwater wells were installed at Bass Creek (Appendix D). Water table depth sampling stations were coupled with soil salinity sampling sites at both study sites.

The depth of groundwater below the surface of the marsh was measured using a weighted string lowered into the groundwater well, removed and the portion of the string that is wet measured using a metre stick. A single measurement was taken at each station during low tide on a bi-weekly basis between July 2003 and November 2003. Measurements from the seven stations at Cheverie Creek occurred fourteen times and the six stations at Bass Creek were sampled twelve times.

Figure 12 Eric Hutchins (US National Oceanic and Atmospheric Administration: NOAA) demonstrates the proper technique for installing groundwater and salinity wells at Cheverie Creek. Photo by T. Bowron, spring 2003.

3.2.3 Soils and Sediments

Pore Water Salinity

Pore water salinity was measured using a pair of salinity wells, one shallow and one deep, installed at each sampling site for a total of two samples per station. Wells were constructed from plastic pipe (75 cm long, 1/2” diameter) with seven 3 mm holes drilled in alternating sides at 2.5 cm intervals, extending 5-25 cm (shallow) or 45-65 cm (deep) below the marsh surface. The bottom of each well was sealed using duct tape and the tops capped with two 45^0 plastic elbows to prevent the entrance of surface water and allow venting. Water samples were drawn into a 50 ml syringe fitted with a clear rubber tube that was lowered into the well and rinsed with saline water following each use. Salinity was measured on-site using a handheld temperature compensated optical refractometer (nearest 2ppt).

Between July 2003 and November 2003, 10 samples were collected and analyzed from the seven stations at Cheverie Creek (Appendix D). Sampling occurred on nine occasions during the same period from six stations at Bass Creek (Appendix D). Salinity differences between shallow and deep wells were compared using paired t-Tests and between the two sites using t-Tests with $\alpha = 0.05$.

Organic Matter and Bulk Density

Soil samples were collected during the 2002 field season at Cheverie Creek only. Soil cores to 10 cm depth were collected (two per station) using a stratified random sampling procedure paired with vegetation sampling plots. This is contrary to the GPAC Monitoring Protocol which recommends soil samples be paired with pore water salinity and groundwater water sampling stations. One sample was used to estimate the organic matter content (as % dry weight) and the other to measure bulk density (as a ratio of oven-dried mass of soil to its total volume). A total of twenty-five paired soil samples were collected. Sample processing and data analysis for this variable were conducted by EAC Project partners (Saint Mary's University, using the laboratory facilities at Mt. Allison University in Sackville, NB).

Sediment Accretion and Sediment Elevation

The GPAC Monitoring Protocol recommended the use of a series of horizon markers in combination with Sediment Elevation Tables to monitor accretion rates and changes in marsh surface elevation. A different sampling method was used for this study in order to remain consistent with sampling methodologies being used to monitor these parameters on marshes and mudflats elsewhere in the Bay of Fundy (van Proosdij 2002). Coupled with the soil sampling stations, twenty-five 10 cm x 20 cm aluminum plates were buried 10 cm below the marsh surface during the 2002 field season. A thin, metal rod was used to measure depth at three points along the axis of each buried plate. For each sampling period, the three measurements were averaged to give a single depth reading. The change in surface elevation between sampling intervals was determined by comparing the average depths. Measurements were taken once a month on a low tide during the neap cycle between June 2002 and December 2002, and again in 2003 for the months of June through November.

3.2.4 Vegetation

A detailed vegetation survey was conducted at Cheverie Creek over the first 400 m of the marsh (first eight transect lines). Sampling was conducted using a 1 m^2 quadrat having 25 grid squares at 92 stations (Figures 10 and 13). Sampling was conducted according to GPAC Monitoring Protocol (species diversity, density and distribution) as reported in Chiasson (2003).

Emergent plant communities over the entire marsh surface of Cheverie Creek and Bass Creek were assessed along 26 and 8 permanent transects respectively using a second methodology (Figure 14). A 50 m field tape was used to measure the distance covered by each dominant species identified along each transect (line-intercept). Measurement commenced along each transect at the back stake (upland north) which was considered zero and extending along the line, across the Creek to the upland edge on the south side. For each dominant plant type (most abundant) along a transect, the average height was estimated with a metre stick. In addition to these measurements, a written description was completed for each transect to include subordinate species and the presence of key marsh features, such as salt marsh pannes, on or near each line. In addition, the front stakes of each transect served as a permanent photograph station from which a landscape photograph along each transect was taken.

Figure 13 Density vegetation analysis (counting stems) using 1 m^2 quadrat on the South side of Cheverie Creek. Photo by T. Bowron, August 2002.

Figure 14 Field team measuring dominant plant communities along a transect line at Cheverie Creek (line intercept method). Photo by N. Chiasson, 2002.

3.2.5 Nekton

Fish

Fish were sampled at both sites using minnow traps (for small fish, <2.54 cm diameter) and a fyke net (for large fish, > 2.54 cm diameter). During the 2002 field season, fish sampling at Cheverie Creek was conducted over a two week period (August 16 to August 28) using four minnow traps. Traps were baited with macaroni, anchored to the Creek bank and set by tossing the trap into the middle of the channel (Figure 15). Traps were set for approximately 24 hours at a time. During the 2003 season, sampling was conducted at both Cheverie Creek and Bass Creek (12 samples each) between September 23 and October 1 for a total of 24 samples collected during the sampling period. Fish sampling locations are identified in Appendix D.

Larger fish using the main channel at both Cheverie Creek and Bass Creek were sampled using a fyke net, set across the channel at low tide to fish through a single high tide. To sample fish use of the marsh surface at the restoration site, the fyke net was set at low tide on the marsh surface (Line 2) to sample fish accessing the marsh surface during the high tide. Fyke net sampling was carried out over a two week period between September 23, 2003 and October 1, 2003.

Figure 15 Fish sampling using minnow traps. Photo by N. Chiasson 2002.

All captured fish were held in buckets, counted, identified to species using identification guides (Audubon Society 1993; Graff and Middleton 2002) and measured for length. All fish were then returned live to the site of capture.

Larval Mosquitoes

Larval mosquitoes were sampled using a "dipper" (350 ml white cup on a long handle) which was used to scoop water from the marsh surface (Figure 16). Sampling occurred for each salt marsh pool/panne complex (hereafter referred to as pannes) which intersected designated transect lines (Appendix D). For each panne, six samples were collected and the following information recorded:

1. visual presence/absence of mosquito larvae in the panne;
2. the number of mosquito larvae sampled;
3. presence/absence of fish;
4. water level (0=low, 1= medium, 2=high) (amount of water in the panne compared to the size of the panne); and

5. conspicuous aspects of the panne such as the presence of algae/submerged vegetation, clarity of water.

If a full cup of water was not possible, the amount of water in the dipper was estimated (e.g. ½ full, ¼ full). Pannes on both Cheverie Creek and Bass Creek were sampled bi-weekly from April to September.

Figure 16 Sampling for mosquito larvae at Cheverie Creek. Photo by P. Clement 2003.

3.2.6 Birds

The bird survey methodology used was a modified version of the GPAC Monitoring Protocol suggested by the Canadian Wildlife Service (Environment Canada), which in turn was based on the approach developed by Tom Hodgman (Maine Fish & Wildlife) and Greg Shriver (State University of New York) **(**Hanson 2001; Hanson and Shriver In press). This method was used so that the data collected would be compatible with other ongoing research in Atlantic Canada and New England.

Seven and five survey points were established at Cheverie Creek and Bass Creek respectively. Survey points were situated 200 m apart and marked with a flagged bamboo stick. The area surveyed extended to a 100 m radius from the marked survey point. This created a series of survey (observation) circles (no overlap) extending from the front of the marsh (causeway) to the back (freshwater system) that maximized the area of the marsh encompassed by the survey while minimizing the amount of upland habitat falling within individual survey circles. The location of survey points for both Cheverie Creek and Bass Creek identified in Appendix D.

Eight surveys were completed from July 31, 2003 to October 17, 2003 on both sites. Point counts were conducted between 0730 and 1100 hours. Surveys were not conducted during periods of high winds or heavy rain. All birds heard or seen within 50 m and 50 m to 100 m from the survey point, including flyovers, were identified and recorded during the ten minute period spent at each survey site. Upon arriving at an individual survey point, the ten minute survey was delayed for one minute of silence to allow for any disturbance caused by travel between points to fade to minimize effects on presence or behaviour. The ten minute survey period was divided into three time intervals (1-3, 3-6 and 6-10) and all observations were recorded based upon the subcategory in which they were made. Every effort was made to distinguish between the same bird observed/heard more than once and the presence of more than one bird within the same survey area. Incidental encounters made while walking to and between points during the survey period, as well those observed outside the survey period, were recorded separately.

Weather conditions (precipitation, sky clarity, wind) were recorded prior to performing the bird counts. Changes in weather conditions occurring during the survey period as well as noise that could affect observations (from road traffic or forest workers) were recorded.

3.3 Modifying the GPAC Monitoring Protocol for use as part of salt marsh restoration projects in the Bay of Fundy

The recommended monitoring program for use as part of salt marsh restoration projects in the Bay of Fundy (Chapter 6) was developed based on the evaluation and implementation of the indicators and data collection methods recommend by the GPAC Monitoring Protocol, and through consultation with Fisheries and Oceans Canada Habitat and Regulatory staff and researchers at Saint Mary's University and Acadia University. In keeping with the GPAC Monitoring Protocol, only the suite of indicators and recommended data collection methods are presented. Aspects of data entry, data analysis, comparison and presentation are not included.

3.4 Limitations of this approach

It is important to discuss several issues and considerations associated with the approach to evaluating and applying the indicators and methods used in this study. Limitations found with the GPAC Monitoring Protocol are addressed in Chapter 4 as part of the evaluation of the protocol. Limitations associated with specific individual indicators and data collection methods involved in the implementation of the monitoring programs are addressed in Chapter 5 in the appropriate indicator sections. The more general issues and considerations involved in the selection, assessment and implementation of the GPAC Monitoring Protocol are presented here.

With regard to the evaluation of the GPAC Monitoring Protocol, there is the potential for bias inherent in the subjective nature of the approach to selecting and applying the indicator assessment criteria. The selection of these criteria and application of the indicator assessment criteria were conducted in a qualitative manner based on the review of the literature and the experience of the researcher. A review of the same literature and the application of the resulting indicator assessment criteria by another researcher, and in the absence of site specific considerations may yield different results. The results of this study are at least in part, a reflection of the researcher's knowledge and experience with the GPAC Monitoring Protocol.

Some general limitations relating to the implementation of the GPAC Monitoring Protocol, in particular data collection, relate to data gaps resulting from the lack of resources or personnel to support sampling early in the field season. For example, bird surveys should start in May and carry on throughout the season into the fall migration period; however, the lack of funds and trained personnel meant that bird surveys were not started until July 2003. The reliance on summer students and volunteers to conduct sampling may have resulted in inconsistencies in the measurements and in sampling times. In an attempt to address this difficulty, training of all staff and volunteers in the sampling techniques was conducted in each year of the study and every attempt was made to ensure consistent supervision of seasonal staff and volunteers. Access to adequate sampling equipment was also an issue. For example, appropriate fish sampling equipment was not secured to adequately sample fish in the main tidal channels at Cheverie Creek or Bass Creek, and automatic data loggers for monitoring hydrology also could not be obtained.

CHAPTER 4 – RESULTS: EVALUATING THE GPAC MONITORING PROTOCOL

Overview and approach

The GPAC Monitoring Protocol was developed to provide a standard means to evaluate the impacts of salt marsh restoration projects that meets the needs of both local site-specific monitoring and restoration projects and regional assessments of restoration success (Neckles et al. 2002). The suite of core indicators, additional variables and sampling methods recommended were intended to ensure a minimum level of consistency in data collection throughout the region. By establishing consistency in the variables being studied and the methods employed, comparisons among study sites located throughout the Gulf of Maine and Bay of Fundy would be possible. The ability to conduct such a regional comparison will allow a greater understanding of the range of habitat conditions present in the region, the type and extent of ecological change that has occurred as a result of human activities, the opportunities for restoration, and the response of habitats in different parts of the region to restoration activities. Such information will allow greater understanding of the differences between habitats and conditions, their responses to restoration actions, and will serve to focus protection and restoration efforts and resources.

This chapter evaluates the GPAC Monitoring Protocol for use on salt marshes in the Bay of Fundy as part of salt marsh restoration projects. The GPAC Monitoring Protocol is evaluated both on an individual indicator basis and as the full suite of indicators to identify the weaknesses and gaps in the approach. Throughout this evaluation, consideration is given to the use of the GPAC Monitoring Protocol by non-governmental, community or environmental organizations. Evaluation was conducted using the indicator assessment criteria identified in Chapter 3 (Table 5), a review of the scientific literature and salt marsh monitoring initiatives occurring elsewhere in the Bay of Fundy, and through the application of the GPAC Monitoring Protocol as part of a proposed salt marsh restoration project, the results of which are included in Appendix C.

4.1 Evaluating the Individual Indicators of the GPAC Monitoring Protocol

A summary of the advantages and disadvantages for each of the indicators identified by the GPAC Monitoring Protocol is presented in Table 8.

4.1.1 Geospatial Attributes (Baseline Habitat Map)

Although not technically an indicator of ecological condition, the development of a baseline habitat map is an important component of both salt marsh restoration projects and monitoring programs. The information requirements and data collection/mapping approaches recommended by the GPAC Monitoring Protocol for developing a baseline habitat map met a majority of the technical, practical and programmatic considerations identified by the indicator assessment criteria. The challenges associated with this indicator are practical in nature and involve the options for data collection and the level of difficulty associated with these methods.

There are several options available for developing the baseline habitat map and aspects of each were employed in the field test. Topographical maps are easy and inexpensive to obtain as hard copies but the information they contain is limited, dated, and not very versatile. Aerial photographs (1:10,000) are also easy and inexpensive to obtain and are particularly useful for identifying key habitat features and for laying out sampling locations. The more current the aerial photograph the better, as coastal habitats may undergo considerable changes, abruptly or gradually, over time and what is shown in an image as recent as 5 to 10 years old can be very different from what is presently on the ground. Aerial photographs are very powerful visual tools for designing a monitoring program, identifying areas and features that are likely to experience change, and as an aid in describing the project to the general public. Current aerial photographs can reveal information about a marsh system that cannot be seen easily when on the marsh or gained from data analysis. Additionally, historical air photographs provide information about historical conditions and/or events.

Digitized aerial photography combined with digital maps and on-site GPS data collection (mapping) tends to be more challenging as the level of difficulty involved is greater, the costs higher, and the equipment and level of expertise required greater than using topographical maps or aerial photographs alone. The benefits of being able to develop detailed, geo-referenced baseline habitat maps make it by far the most scientifically valid and useful. However, given the relative newness of this technology, access to equipment and trained staff are likely to prove challenging for many smaller groups, communities or volunteer organizations attempting to establish a salt marsh monitoring program.

An example of a baseline habitat map developed using a combination of aerial photographs and GIS/GPS technologies is depicted in Figure 10 (Chapter 3, Section 3.2.1). Presenting a large amount of information with the baseline habitat map in an integrated and highly visual manner is a powerful tool for communicating monitoring results.

4.1.2 Hydrology

Core Variables:

- Hydroperiod (tidal signal[5] & marsh surface elevation)

Additional Variables:

- Water table depth

Technical Considerations

The core variables under the hydrology indicator category are scientifically valid. Tidal signal and marsh surface elevation are two components needed to determine the hydroperiod of a particular marsh. Both variables are easily measured given the data sampling options available and representative of ecological conditions. Tidal signal in particular can be highly sensitive to change, is easily measured pre- and post-restoration and is representative of changes in hydrology following restoration. Water table depth, tidal creek cross-section, current profiles and water quality characteristics are all useful variables, providing data on ecosystem conditions that are feasible to collect and analyze.

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[5] Tidal signal refers to the pattern of water level change with respect to a reference point.

Practical Considerations

Hydroperiod

The challenge with this indicator arises in regard to the two data collection options. The both of which require access to expertise, training and monitoring equipment. However, despite the expertise and technical requirements of these two variables, the significance of this indicator to the restoration goal (restoration of a more natural tidal regime) makes it mandatory.

The use of upstream and downstream water level recorders or tide staffs in isolation or in combination can produce suitable data for hydrologic modeling when combined with the marsh surface elevation (gained using DGPS or Total Station) data. Collecting the data and developing the hydrologic model for a site, regardless of which sampling approach is used, requires the assistance of experts. Once completed, this should provide a model of current flooding conditions (which can be ground-truthed) and used to predict post-restoration flooding conditions under different tidal scenarios.

Both tidal signal and marsh surface elevation are critical to a monitoring program but are demanding in terms of equipment, experience and resources (time and money).

The more technologically advanced sampling methods, although the least demanding in terms of personnel time onsite and yielding the highest quality and quantity of data, have the potential to be the less feasible option given access to equipment difficulties. The more labour intensive sampling approach, with easy to construct and use equipment, as illustrated by the field test, provided adequate data to allow for hydrology modeling. It is effective but requires people to spend long periods of time on-site and repeated visits to the site to take measurements. However, given the tidal range of the Bay of Fundy and the fact that the only movement of water through the majority of tidal crossings during low tide is fresh, there would be no tidally influenced change in water level experienced at a crossing for much of any given 13 hour period. Experience with the tidal barrier audit work indicates that accurate tide elevation data for a given site can be collected over a 4 to 6 hour period (Bowron and Fitzpatrick 2001).

An alternative to actual on-site monitoring of the tide staffs could be the use of programmable cameras, webcams or other types of imaging devices that could be installed in a secure location with a clear line of sight to the tide staffs that would take images at the required time intervals. This would reduce the time necessary for personnel to be on-site observing and recording the tide level while also providing visual documentation of tidal behaviour, in addition to the numerical data.

The modified version of the maximum water level method described above, when coupled with incremental measurements for one or more high tide cycles, provided reliable data. The equipment used was very simple in design, installation and monitoring.

The two data collection methods available for determining marsh surface elevation are similar to those available for determining tidal signals. The highest quality and versatile surface elevation data can be collected using a DGPS or Total Station (producing a DEM) but does require access to such equipment and expertise to operate. Developing a contour map using relative elevations collected over a series of points on the marsh to produce a hyposmetric curve is a cost effective option but does produce lower quality and less versatile data.

Water table depth

Monitoring water table depth using groundwater wells is an effective sampling approach because of the ease involved in the construction, installation and use of these inexpensive wells. Sampling requires little more than string, a nut and a metre stick. However, at a recommended minimum of six sampling dates per field season, pre and post-restoration, this is a time-consuming indicator to monitor, particularly if the restoration site is a large one and wells are dispersed over a broad area.

Alternative methods (e.g. using piezometers) are available for monitoring this parameter that may provide greater accuracy; however, the additional cost, level of experience, and installation requirements may outweigh the benefits.

Program Considerations

On the whole, the hydrology indicator is the most technically involved and resource dependent component of the monitoring protocol. Given that the primary goal of the majority of restoration projects is the restoration of a more natural hydrological regime to the wetland, it is understandable that considerable emphasis is placed on the need for reliable and reproducible data.

Regardless of which methods are used to measure tidal and surface elevations, recording and correlating the data and conducting the hydrological modeling require the involvement of project partners with the capability to perform this type of analysis.

4.1.3 Soils and Sediments

Core Variables:

- Pore water salinity

Additional Variables:

- Organic matter & organic carbon content / bulk density / soil texture
- Sediment accretion

Pore water salinity

Technical Considerations

Pore water salinity can be easily measured on-site using salinity wells (similar in construction, installation and sampling schedule to ground water wells) and a handheld refractometer. Locating salinity sample stations (and ground water well sampling stations) can be subjective and should be performed by an individual knowledgeable of salt marsh vegetation. Once installed, however, salinity sampling in this method is a straightforward exercise and can easily be performed following basic training in sampling procedures. Sampling does not affect subsequent measurements or simultaneous sampling of other parameters. Pore water salinity is sensitive to changes in hydrologic conditions; however, measurements at particular sampling locations can be highly variable and susceptible to influence by local conditions such as surface water or rain. As well, differences in salinity regimes observed at different study sites may occur naturally and not be due to the presence or absence of human stressors.

Practical Considerations

The costs and level of difficulty involved in sampling pore water salinity are low. Specialist's involvement, equipment needs and sampling frequency are all reasonable and the information that can be gained by monitoring this variable is useful for understanding the relationship between hydrology and vegetation.

Organic Matter & Organic Carbon Content / Bulk Density / Soil Texture

Technical Considerations

Measuring marsh soil characteristics is one of the most challenging methods in the GPAC Monitoring Protocol. Identifying soil sampling locations can be subjective and should be performed by a trained individual; even if sampling is matched with pore water salinity sampling stations. The sampling procedure is complex but the requirement to sample only once prior to restoration and again three to five years following restoration reduces the demand on the monitoring program. The processing of soil samples also requires expertise, access to equipment and the costs associated with processing can be high (as much as $140 per sample). The response rate of this variable to changes caused by restoration can be slow to occur, hence the infrequent sampling schedule is appropriate. Overall, given the potential to provide insight into the controls on vegetation type, cover and overall system productivity, the compatibility with existing data sets and the information on historical conditions that this variable can provide make it a desirable one to include in a monitoring program.

Practical Considerations

The potentially prohibitive factors associated with this variable are the result of the dependence on the participation of experts in sample site identification, sampling method, sample processing and data integration, and the cost of processing. The level of difficulty associated with this variable is high.

Sediment Accretion

Technical Considerations

The GPAC recommended method for monitoring accretion rates, although potentially more accurate than the approach used in the EAC Project, relies heavily on the participation of experts and access to specialized equipment. The sampling method tested in this study, which is consistent with research being conducted on macrotidal sites elsewhere in the Bay of Fundy, is more involved and invasive during the initial setup and installation stage compared to the marker horizon method. However, the low level of difficulty involved and the monthly sampling schedule, which can be matched with ground water depth and pore water salinity sampling and can be easily be performed with minimum training, and is simpler than the collection of core samples using either a cryogenic corer or cutting plugs (USGS 2005).

Measuring sediment accretion using sediment plates, similar to using the marker horizon, without also monitoring sediment elevation using a Sediment Elevation Table (SET), provides information only on surface processes (events happening above the plate or marker) such as sediment deposition or erosion. When monitored in combination with a series of SETs, information on both surface processes and subsurface processes can be gained (root growth, decomposition, compaction, porewater flux) (USGS 2005).

Practical Considerations

Both the marker horizon and the sediment plate methods are highly vulnerable to disturbance. A misplaced step or winter ice can affect the validity of measurements taken at an individual sampling site by compacting the soil above the plate or marker horizon. On restoration sites such as Cheverie Creek, which have low sediment reserves because of the presence of a tidal restriction, repeated measurements at individual plates by poking the metal rod into the ground and lowering the clamp can adversely affect subsequent measurements. Disturbance of the vegetation above the plate, failure of the measurement holes to fill in, and the presence of standing water at the sampling location can affect the reliability of subsequent measurements and reduce representativeness (personal observation).

Soils and Sediments Programmatic Considerations

As an indicator category, soils and sediments due to their correlation with hydrology and vegetation are highly relevant to the desired goals of most restoration projects. The monitoring of soils and sediments should be considered an integral part of a restoration monitoring program, as the variables are related to both vegetation type and cover and the growth or decline of a marsh. Although the level of difficulty associated with monitoring organic matter, sediment accretion and elevation is high; the information that can be gained by including these variables in a monitoring program, if project resources allow, highly desirable.

4.1.4 Vegetation

Core Variables:

- Composition of all plant species
- Abundance of all plant species
- Height of dominant plant species
- Photo stations

Additional Variables:

- Stem density of either all or key plant species

Technical Considerations

Species composition, abundance, height, and stem density

Salt marsh vegetation reflects a wide range of environmental and edaphic conditions such as hydrology, salinity and substrate. However, as a result of this close association with an array of physical and geological conditions, it can be difficult to isolate a specific stressor or control on this indicator. The use of permanent plots along established transects to monitor species composition, abundance, height and richness is an accepted sampling method for vegetation and offers much opportunity for comparison of conditions at an individual site over time and between study sites.

Practical Considerations

Salt marshes tend to have low biological diversity and high productivity, making the task of learning to correctly identify plants relatively easy. The GPAC Monitoring Protocol recommended procedures for measuring each variable are also relatively easy to learn and apply. The GPAC Monitoring Protocol recommends sampling during the height of the growing season (mid-July through August) which is the best time of the season to identify plants. Plant identification can be more difficult early and late in the season, and sampling during these periods can yield different results (types of plants and number of individuals) (Chmura 2005). Depending on monitoring/research goals, additional vegetation sampling may be recommended to describe this seasonal variation (particularly spring). The sampling frequency (once per season), low cost involved in sampling, potential for data integration and compatibility, and the highly visible nature of this indicator makes it a most desirable component of a monitoring program.

Photo Stations: Technical and Practical Considerations

Permanent photo stations, both landscape and close-up, provide qualitative information on changes in plant communities over time, and is a low cost, low effort method of capturing a baseline and tracking changes, post-restoration. Although this is becoming a commonly used monitoring technique, it should not be used as the sole means of gathering vegetation data as it can be difficult to differentiate species in the photographs. It is a complementary qualitative technique that can sometimes portray trends, patterns and information more readily than quantitative data and can be incorporated in baseline habitat map(s). The use of photo stations for gathering information and observing seasonal trends on the marsh beyond what is occurring with vegetation can be very useful for gaining insight into marsh functions or occurrences that are not captured by sampling other ecosystem variables. Such functions or occurrences may include: standing water, changes in plant community assemblages, winter ice conditions, deposition of materials on the marsh, or episodic disturbances caused by storms or human activities such as All-Terrain-Vehicle use.

Vegetation Programmatic Considerations

The productivity of salt marsh vegetation is one of the main contributors to coastal and marine food webs and salt marshes are physically dependent upon their plants. Although it can be difficult to trace changes in vegetation type and cover to a particular control, the potential for combining the condition of vegetation along with the physical and chemical parameters of other indicators to provide insight into the larger ecosystem makes vegetation a most versatile and useful biological indicator.

Considering both the technical and practical aspects of the methods used in the field test of this indicator, the intensity of transect and quadrat vegetation sampling conducted over the front part of the Cheverie Creek marsh was far greater than recommended by the GPAC Monitoring Protocol. If this sampling approach was to be used again at Cheverie Creek or another restoration site, far fewer transect lines would be recommended, while still covering the same extent of the area, and the number of sampling stations would be greatly restricted (n=20 to 40).

The line-intercept sampling method, recommended by Dr. Derek Davis (former curator of the Nova Scotia Museum of Natural History) and employed over the entire marsh surface at Cheverie Creek and Bass Creek, is also a useful approach to sampling vegetation that requires less time and provides a broader picture of overall plant community assemblages. Line-intercept identifies the dominant species and its height, with additional species only being noted qualitatively through observational notes taken during the survey. This method allows for comparison over time at the same location but is not as well suited for comparisons between restoration and reference sites. For this reason, if comparison between sites is a project objective, this sampling method should not be used in isolation to monitor vegetation.

The quadrat sampling approach identifies all species encountered in the sampling area and provides quantitative data for each species such as percent cover, richness and density. An advantage of the line-intercept method over the quadrat sampling approach is that it will immediately detect changes in the area(s) encompassed by species. If, following restoration, the low marsh zone (*S. alterniflora*) increases in extent, this growth will immediately be detected by line-intercept sampling while the permanent plots may go unchanged. Quadrat sampling provides more quantitative data but is also more involved, while the line-intercept method provides less quantitative data it does provide a broader overview of habitat conditions over the entire marsh surface. Neither approach is difficult or expensive to conduct, the main requirements being time and effort.

4.1.5 Nekton

Core Variables:

- Composition
- Density
- Species richness

Additional Variables:

- Larval mosquitoes

Technical Considerations

Composition, density, species richness

As one of the three biological indicators included in the GPAC Monitoring Protocol, nekton, particularly fish, represents a higher trophic level than plants and the presence or absence of nektonic species on the marsh may reflect environmental conditions not discernible from vegetation alone. The GPAC Monitoring Protocol identifies this category as nekton, but is in fact primarily focused on fish. Like plants, fish can be identified following basic training about the characteristics of the various species likely to be encountered and the use of identification guides. Fish can be difficult to sample due to their mobility, seasonal variability and the sampling method used (see discussion below concerning the sampling methods used at Cheverie Creek). The location, time of year, time of day, part of the tidal cycle and the type of sampling equipment can dictate which species are caught and may cause considerable variability in sampling results. Many samples (spatially and temporally) are required to accurately evaluate a population or community and if a change is observed, it can be difficult to identify a causal factor for the change if beyond not flooded versus flooded.

Sampling for smaller species in the main creek, channels and pannes through the use of minnow traps is an uncomplicated, highly replicable procedure that will collect common (small) marsh species.

Sampling for larger species can be more difficult, complicated by the fact that it can be difficult to obtain suitable sampling equipment (fyke nets, lift nets, beach seine) for use in the tidal conditions likely to be encountered in the Bay of Fundy. Over the course of the two years of attempting to sample nekton species at Cheverie Creek, appropriate equipment for sampling larger species in tidal conditions could not be located. The fyke net that was tested proved to be unsuitable (too small, not designed for two directional flow) for use in the tidal conditions of both Cheverie Creek and reference sites. A comparison of the advantages and disadvantages associated with each of the recommended sampling techniques is shown in Table 7.

Table 7 Advantages and disadvantages of fish sampling techniques.

Sampling Method	Advantage	Disadvantage
Minnow Traps	- Collect common marsh species - Easy to set and retrieve - Easy to collect multiple samples - Does not require a lot of people - Inexpensive - Easy to obtain	- Unknown sampling area - Data are qualitative - Only collect small species - Variable results to effort ratio
Fyke Net	- Collect many species - Collect from known area - Quantitative data	- Variable catch efficiency - Awkward to set in high current conditions - Difficult to retrieve nekton from trap - Labour intensive - Equipment difficult to obtain - Requires a number of people
Lift Net	- Collect many species - Collect from a known area - Quantitative data	- Variable catch efficiency - Awkward and labour intensive to set and operate - equipment difficult to obtain - Setup time & people needed
Beach Seine	- Collect many common marsh species - Collect from known area - Will collect many species	- Variable catch efficiency - Equipment difficult to obtain - Awkward and labour intensive to set and operate, especially in high flow conditions or in large/steep banked systems - Safety

Practical Considerations

As previously indicated, accessing equipment appropriate for sampling in the hydrological conditions, composition and scale of many of the marsh and river systems in the Bay of Fundy can be difficult (lack of resources) and costly (>$1,500 to purchase). The level of difficulty for this indicator is moderate due to the varied needs of the sampling techniques available, the mobility and variability of the indicator species, sampling frequency and the safety factor. Aside from sampling in the pannes on the marsh surface which can be conducted during low tide and sampling using the minnow traps, nekton sampling requires working on the marsh and in or near the tidal channels during the high tide cycle which can present significant safety risks. In some systems, it simply may not be feasible to work in and around the main tidal channel or marsh surface during the high tide cycle, due to safety concerns.

Of all the GPAC Monitoring Indicators, nekton is the one indicator that in Atlantic Canada requires a scientific license prior to sampling. The Federal Department of Fisheries and Oceans requires a permit for all fish sampling activities.

Larval mosquitoes: Technical and Practical Considerations

Monitoring larval mosquito densities in the high marsh pannes is included in the nekton indicator category of the GPAC Monitoring Protocol. Mosquitoes serve as an indicator of some aspects of hydrology and fish productivity and mosquito control is one of the leading project goals of restoration projects in New England (Neckles and Dionne 2000). The level of difficulty involved in monitoring larval mosquitoes is low and the equipment needs and costs are minimal. The once a week sampling frequency recommended by the GPAC Monitoring Protocol, and the number of samples needed to accurately evaluate the population is demanding.

Nekton Programmatic Considerations

As a higher trophic level and a highly mobile group, fish are a valuable indicator of ecosystem conditions. Fish have the potential to be a strong indicator of restoration success because, if the habitat conditions are unsuitable, fish will move from or not occupy sites. The lack of quantifiable historic information concerning the use and significance of tidal wetland systems in the Bay of Fundy by fish generally and individual species, and the challenges in obtaining current information makes this an important but difficult indicator to monitor. Despite this, the restoration of fish passage and fish habitat is likely to be a central goal of restoration projects in Atlantic Canada in the years to come. Therefore, the inclusion of fish as one of the key faunal indicators in a monitoring program, despite the challenges associated with sampling, is recommended. Fish are a dynamic and interesting indicator to sample and one that can be used to foster an appreciation for their habitat and interest and support for restoration projects.

4.1.6 Birds

Core Variables:

- Abundance
- Species richness

Additional Variables:

- Passerines & cryptic birds
- Birds in buffer zone

Technical Considerations

Abundance, species richness, passerines & cryptic birds, and birds in buffer

With training, practice and/or the assistance of amateur or professional birders, surveying birds can be relatively easy due to their highly visible and sonorous nature. Like fish, this indicator can be highly sensitive to habitat conditions and is able to respond rapidly to disturbance due to its mobility, which also means identifying a particular stressor can be challenging. This mobility makes birds a highly variable indicator. Birds present at a site will vary hourly, daily, seasonally, and annually and in random ways, requiring repeated surveys to obtain sufficient and accurate data on their habitat use.

Wetland birds are a much studied group and much is known about their life history, ecology and geographical distribution. The presence or absence of a particular bird on a site can indicate ecosystem integrity, similar to fish, as they can easily move to or from an area if conditions are unfavourable.

Practical Considerations

Birds are inexpensive but time consuming to survey. The level of difficulty involved in monitoring the core variables is moderate and complicated only by the requirement of surveyors to be able to identify species both by sight and sound and the need for repeated surveys throughout the season to capture habitat significance for migration, feeding or breeding. Both the GPAC Monitoring Protocol methodology and the revised method used in the field test are suitable for monitoring bird use of salt marshes in the region. Passerines and cryptic birds as well as birds in the buffer are captured with the sampling approach used. The GPAC Monitoring Protocol mentions behavioural observations as a useful additional factor to note during bird surveys; however, this adds an extra level of difficulty to the indicator due to the experience/skill required to make such observations and introduces a greater degree of subjectivity to the data.

Regarding the survey methodology, the number of survey points depends on the size of the marsh being studied. An advantage of the shorter observation periods used in the field test is that it allows for a greater number of sampling locations over the larger marshes that are likely to be encountered in the Bay of Fundy. The shorter observation period per point will allow for a larger percentage of the area to be sampled during the early morning hours, which is a prime time for bird activity. The time of day and recommended survey schedule make studying birds demanding, but the financial costs, associated with monitoring this indicator are negligible. Given the popularity of recreational birding, identifying and recruiting skilled amateur birders to assist with conducting bird surveys should not be too difficult.

The GPAC Monitoring Protocol also makes the recommendation to monitor waterfowl use of the marsh throughout the winter as long as it is ice free. Indeed this is valuable information and attempts should be made to monitor bird use of the marsh during the winter months. However, the point should be made that for much, if not all, of the winter, the majority of the marshes in the upper Bay of Fundy are covered by snow and ice, making access difficult and limiting the species likely to be encountered.

Table 8 Advantages and disadvantages of GPAC Monitoring Protocol indicators.

Advantages	Disadvantages
Geospatial Attributes	
- Requires only one survey prior to restoration and as needed following - Provides accurate information that can be used to integrate, compare and present data from other indicators - Powerful tool for communicating project results - Low impact to measure	- Depends heavily on involvement of skilled personnel - Equipment costs associated with digital mapping can be high and requires the participation of professionals to operate and conduct data analysis
Hydrology	
- Range of data collection methods available make sampling relatively easy - Impacts of tidal restrictions & responses to restoration activities easily observed and measured - Central indicator/control on ecosystem condition	- Time requirements for some variables and data collection methods demanding - Difficult to access equipment that yields highest quality data
Soils and Sediments	
- Core variable easy to measure - Equipment and professional assistance requirements for core variable low - Salinity is an important chemical parameter - Salinity sampling can be coupled with hydrology (water table depth) - Provides insights into the controls on vegetation type and cover - Provides insight in to marsh response over time to changes in hydrology conditions over time	- Requires sampling at multiple locations and over extending period of time - High cost, equipment needs and dependence on the participation of professionals for additional variables - Recommended sampling method for core variable can be affected by rainfall and season
Vegetation	
- Salt marsh plants relatively easy to identify - Low cost and reasonable sampling frequency - Plants integrate a range of ecosystem conditions - Central to restoration goals	- Requires sampling at multiple locations - Results can vary with season and early spring/late fall identification can be difficult - Can be difficult to isolate a specific stressor or control - Identification of invasive or non-salt marsh species can be difficult
Nekton	
- Higher trophic level species - Presence or absence of key species reflect ecosystem conditions - Relatively easy to identify - Fish passage and fish habitat central restoration goal	- Mobility of fish makes sampling challenging - Sampling method can dictate species collected - Equipment and costs for some sampling methods can be high - Multiple samples over space and time required - Species collected can vary greatly over location, time and with effort - Requires sampling permits prior to sampling

Birds	
- Higher trophic species - Popular with public and scientists and large number of proficient data collectors available - Highly sensitive to ecosystem conditions and respond rapidly to disturbance - Much is known about the life histories, ecology and distribution of wetland birds - Presence or absence of key species can indicate ecosystem integrity - Equipment needs and sampling costs negligible - Identification of common species relatively easy to learn	- Species observed can vary daily, seasonally and randomly - Large number of sampling locations and repeated surveys required to obtain sufficient information on wetland use - Can be difficult to distinguish between individuals – challenge to get absolute numbers - Requires ability to identify birds by sight and sound

4.2 GPAC Monitoring Protocol Programmatic Considerations

When considered as a whole, the indicator set recommended by the GPAC Monitoring Protocol spans the majority of the key environmental gradients, spatial scales and ecosystem components. However, two potentially important components are omitted: invertebrates, and winter conditions, with the exception of waterfowl use. Accordingly, I recommend that variables related to these indicator categories be incorporated into the protocol (specific measures and methods are described in Chapter 6).

Invertebrates

By converting living and dead salt marsh vegetation into a form more accessible for other organisms, invertebrates (snails, mussels, crabs, shrimp, insects, spiders, amphipods, isopods, worms etc.) are largely responsible for providing food resources for the broader coastal and marine ecosystem. Invertebrates are good indicators of changes in tidal flow, vegetation cover, and water and sediment quality conditions (salinity regime, nutrients, dissolved oxygen) (Carlisle et al. 2002). Monitoring the invertebrate community of a salt marsh may provide information as to how impacted a site may be and allow tracking of habitat recovery following restoration. For compensation restoration projects on fish habitat and overall ecosystem capacity (habitat availability and productivity), the inclusion of invertebrates (many of which are sedentary) in the monitoring program will reflect past and present environmental conditions in ways that highly mobile species (fish and birds) cannot.

Winter

The available literature dealing with the role of winter processes, particularly the role of winter storms and ice in the formation, maintenance and function of Bay of Fundy salt marshes is limited. Winter processes, particularly ice, have three general functions: erosion, transport and sedimentation (Dionne 2000; Drapeau 1992; Gordon and Desplanque 1983; Martini 1981; Partridge 2000). Research into variation in surface sediment deposition on salt marshes in the Bay of Fundy by Chmura et al. (2001) found that marsh morphology may play a role in sediment transport and deposition by affecting the degree to which marshes are subject to ice scour and ice rafting. Ice scour and ice rafting are two processes that make a significant contribution to surface sediment deposition (Wood et al. 1989).

In addition to the movement of sediment by ice, influenced by hydrology and marsh morphology, ice and winter storms play a role in the transport of organic materials (detritus – dead plant material) both locally and regionally. The frequency and extent of inundation of the marsh surface is greater during the winter months than the remainder of the year as a result of larger astronomical tides and storm events. This increased frequency and extent of tidal flooding, when combined with development and transport of ice, can result in transport and deposition both on the marsh system and out into the larger marine ecosystem.

The GPAC Monitoring Protocol does not consider monitoring winter conditions, aside from the recommendation to monitor bird usage of the marsh until the marsh is covered by snow and ice. Given the potentially significant role that winter processes play in both the physical and biological development and functioning of salt marshes in the Bay of Fundy, the development of a set of winter specific indicators and data collection methods for inclusion in GPAC Monitoring Protocol is warranted.

General Program Considerations

In the field test of the GPAC Monitoring Protocol every attempt was made to adhere to the full list of indicators and the methods recommended for each by the GPAC

Monitoring Protocol (Neckles and Dionne 2000). The failure to include all the variables within each category of indicators and the deviations or modifications to data collection methods and sampling frequencies made during the field test were the result of a combination of difficulties in securing equipment, a lack of resources and/or expertise, and the attempt to remain consistent with ongoing research efforts elsewhere in the Bay of Fundy. Being equally a restoration and research project, the level of detail and rigorous sampling that was conducted would not be necessary in every restoration project.

Every new restoration project will pose site specific challenges and require specific information and a monitoring program tailored to the conditions and information needs. The intensity and duration of monitoring undertaken will be directly related to the rationale for the restoration project (proactive habitat stewardship or compensatory mitigation). A monitoring program for a mitigation project will be designed to meet specific regulatory criteria: if the goal is fish passage restoration, monitoring will focus on the hydrological conditions (e.g. water levels, current speeds, surface water characteristics) and monitoring activities cease once the legal requirements are met. A habitat stewardship based project and/or research project will likely have more general project objectives and therefore a monitoring program that is broader in scope and continues over a longer period of time.

When designing a long-term monitoring program for a salt marsh restoration project, it is important to carefully consider the goal(s) of the project, the site-specific conditions of the site, and the short, intermediate and long-term anticipated/desired habitat changes likely to result from restoration activities. Whether it is a mitigation project or a more general habitat restoration/enhancement/creation project, the host of indicators, monitoring methods and sampling frequency will depend heavily on the information needs central to the project goal, the time frame involved and the resource, equipment and expertise constraints of the project. It will be important to focus on the indicators/variables that are central to project goals and will readily reflect changes in the system following restoration.

As already mentioned, the lack of consideration given to the role that winter processes play in the development, structure and function of salt marshes in the Bay of Fundy, and invertebrates as one of the faunal indicators are a definite omission of the GPAC Monitoring Protocol (Neckles and Dionne 2000; Neckles et al. 2002). In addition, an effective monitoring program should direct the processes of data analysis, interpretation, reporting, and feedback in order to facilitate adaptive management and long-term success of restoration projects (Wiersma and Campbell 2002). The lack of such information and direction in the GPAC Monitoring Protocol is a significant omission. If standardization of salt marsh restoration and monitoring programs is the goal of the GPAC Monitoring Protocol, then it is necessary to not only identify which indicators to measure and what methods to use, but also to indicate a standard method of data handling, analysis, interpretation and reporting.

The driving force in the Maritimes for salt marsh restoration in the coming years is likely to be compensatory mitigation in compliance with a Fisheries Act Section 35(2) Authorization (Fisheries and Oceans 1985, Fisheries and Oceans 1986) and the restoration of habitat for endangered species (notably, fish passage for the inner Bay of Fundy Atlantic Salmon). Projects will be conducted by a range of proponents in collaboration with NGOs and community groups and under the regulatory guidance of Fisheries and Oceans Canada. Monitoring activities involved in these projects are going to be dictated by the goal(s) of individual projects. Projects will primarily be concerned with fish passage and the availability of fish habitat (extent and duration of marsh surface flooding, and the presence of networks of pools and secondary stream systems). If regulators and proponents are expected to implement monitoring programs in accordance with the GPAC Monitoring Protocol, a stronger case will have to be made for the inclusion of all core indicators in the monitoring program and the rationale/links between each indicator more fully explained.

4.3 Discussion

The GPAC Monitoring Protocol presents each indicator in isolation and does not clearly make the link either in terms of sampling schedules, techniques, data integration, analysis, or comparison. The Protocol is presented in a manner that appears stepwise in nature (do A then B then C and so on) when in fact many of these indicators integrate with and/or build upon one another both in terms of where and how the measurements are made, the sampling schedule, and the resulting data analysis.

The GPAC Monitoring Protocol has an inherent New England (USA) bias. This is understandable given that the workshop that led to the development of the Monitoring Protocol was dominated by American researchers and restoration practitioners and that the only salt marsh restoration and associated monitoring occurring at the time that could be drawn upon was occurring in southern New England. As a result, the GPAC Monitoring Protocol is geared toward the New England ecological, management, social and economic system.

Pressure on coastal wetland habitats throughout New England has primarily been the result of social pressures such as transportation and intense urban and coastal development (Dionne 2002). Given the high level of coastal development that has been occurring throughout New England, the majority of opportunities for salt marsh restoration are in areas that have been heavily impacted by such development, and the restorable areas are restricted as a result. In contrast, the largest loss of salt marsh habitat in the Bay of Fundy to date has been due to the construction of agricultural dykes, causeways and coastal roads along rural stretches of coast, over a 350 year period.

The majority of potential restoration sites that have been identified in the upper Bay of Fundy to date range in size from 10 to 50 hectares upwards into the hundreds of hectares (Bowron 2003). Restoration sites of this scale will be a challenge to monitor and, thus, modification and streamlining of the GPAC Monitoring Protocol, particularly the data collection methods and sampling frequency, may be necessary.

The lack of provincial and federal support that currently exists in Nova Scotia (see below) is likely to mean that groups and agencies attempting to engage in tidal wetland restoration projects are not going to be able to fully implement the GPAC Monitoring Protocol. The monitoring activities undertaken will be limited to indicators and sampling periods required by the regulatory agency, particularly when it comes to legislatively required compensation projects[6]. Monitoring efforts will be more focused on meeting the regulatory objectives/requirements of projects which are not always going to be in line with the ecological requirements.

One of the main shortcomings of the GPAC Monitoring Protocol is its assumptions. It assumes that salt marsh restoration is already a Federal, State and Provincially supported practice and that government departments and community-based organizations are actively engaged in salt marsh restoration activities. It also assumes that government departments and staff with access to State and Provincial repositories of scientific expertise and equipment are partnering on restoration projects. Although this may be the case in New England, it is not yet the situation in Atlantic Canada. Government departments and/or individuals in the province and/or region who are sympathetic to the need for such partnerships and project support are curtailed by a lack of resources, equipment, staff, expertise, jurisdictional uncertainty, and the lack of policy and political support. As an example, at the Federal Department of Fisheries and Oceans Maritime Region, when approached for assistance with the nekton sampling at Cheverie Creek, departmental staff were unable to locate adequate scientific equipment with which to conduct the sampling.

There is little experience in this region with restoring tidal wetlands. In order for the GPAC Monitoring Protocol to be implemented effectively as part of salt marsh restoration projects in the Bay of Fundy, additional resources, information, support and guidance needs to accompany the GPAC Monitoring Protocol. When it comes to

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[6] The Canada Fisheries Act (S.35) makes it illegal to harmfully alter, disrupt, or destroy (HADD) fish habitat. Habitat compensation (restoration) is required when a HADD is authorized under S.35(2) of the Fisheries Act (Fisheries and Oceans 1985; Fisheries and Oceans 1986).

legislatively required salt marsh restoration projects (compensation projects), there needs to be greater understanding at the regulatory/policy and even project proponent level of the need for intensive monitoring (all core indicators and additional indicators directly associated with the project goal(s)), particularly on the first few restoration projects to be undertaken.

As a tool for guiding research-level monitoring projects to determine the ecological condition of salt marshes in the Gulf of Maine and Bay of Fundy, the GPAC Monitoring Protocol is a powerful tool. However, the intention of the GPAC Monitoring Protocol is not to determine ecological condition, but to follow/record ecosystem response to a particular restoration action(s) and determine restoration success. It is intended to be used as part of a larger effort to restore altered, degraded or destroyed salt marsh habitat back to a functioning tidal wetland system. It does not contain information on the preceding and subsequent restoration project/program steps. This information and experience exists in New England, but it is not currently present in Atlantic Canada. The GPAC Monitoring Protocol was designed with the intention of being adopted and implemented by pre-existing restoration campaigns and projects already conducting monitoring of one type or another. So, in a sense, it is not so much that the GPAC Monitoring Protocol is lacking or inadequate for use in the Bay of Fundy, but rather that the context or framework in which such a program is meant to be implemented is not yet present in Atlantic Canada. Monitoring is but one part of the restoration process, albeit an important part. It must be preceded by conceptual and installation planning and followed by post-installation tasks, evaluation and adaptive management, and overall project activities such as those outlined by Clewell et al. (2000). The GPAC Monitoring Protocol needs to better reflect and emphasize this larger context for application in the Bay of Fundy.

On the whole, the GPAC Monitoring Protocol, in the context of a restoration project, is a good starting point for designing a salt marsh restoration monitoring program. Adaptations and modifications to the indicators and methods, such as the inclusion of invertebrates as a category of indicators, will be dictated by available resources, access to equipment, level of involvement by experienced partners, and the objectives of individual projects. Overall, the GPAC Monitoring Protocol performed well on a macrotidal salt marsh system in the Upper Bay of Fundy.

CHAPTER 5 – MODIFYING THE GPAC MONITORING PROTOCOL – A MONITORING PROGRAM FOR SALT MARSH RESTORATION IN THE BAY OF FUNDY

Introduction

At the present time, there is a need for a salt marsh monitoring program to fulfill the monitoring requirements associated with Fisheries Act-Section 35 Harmful Alteration Damage or Destruction (HADD) Authorizations (Fisheries and Oceans 1985) for salt marshes in Atlantic Canada. Whether as part of a compensation project or a proactive community-based restoration project, monitoring programs associated with restoration projects will be required to document the efficacy of the compensation being undertaken to restore a tidal wetland (salt marsh) habitat and to track restoration progress and determine project success (restored marsh exhibits similar physical, chemical and biological characteristics as the reference site). The following modifications and additions to the GPAC Monitoring Protocol are recommended on the basis of the evaluation and field test of the GPAC Monitoring Protocol's indicators and data collection methods, and consultation with provincial and federal government habitat and regulatory staff, and researchers at Saint Mary's University and Acadia University. These recommended modifications to the monitoring program for the evaluation of tidal wetland restoration in the Bay of Fundy retain all the GPAC Monitoring Protocol core indicators, as well as a number of the additional variables and activities. The main additions are the inclusion of invertebrates and winter conditions as indicator categories, while suggested revisions focus on the data collection methods. This proposed monitoring program also draws from the salt marsh monitoring protocols developed by Carlisle et al. (2002), James-Pirri et al. (2002), and Roman et al. (2001). It does not address data management or analysis techniques. It is recommended that the proposed monitoring program be implemented in its entirety as part of a salt marsh restoration project.

5.1 A Monitoring Program for Salt Marsh Restoration in the Bay of Fundy

The set of indicators, a brief description of each, the sampling method(s), and the sampling frequency are given in Table 9, located at the end of this section. Monitoring of all indicators should be conducted prior to undertaking any restoration activities, and continue for a minimum of five years following restoration or until such time as the project goals are met. The changes in physical, chemical and biological indicators over time following restoration should be monitored against the conditions exhibited by a neighbouring unrestricted un-impacted reference site to determine restoration success.

Transect Layout and Baseline Habitat Map

Transects serve to locate the sampling sites for each of the indicators being monitored. Transects, extending from the creek bank to the upland border and running perpendicular to the main tidal channel, should be stratified throughout the study site in order to cover a representative portion of the study area. The number of transects established will depend on the size of the study site and the variation in vegetation and habitat conditions over the entire marsh system and should be sufficient in number to allow for the establishment of an adequate number of sample stations (vegetation plots in particular). Roman et al. (2001) describe a recommended method for locating transects on larger, highly variable sites, that involves dividing the marsh into segments and randomly locating transects within each segment. For smaller sites displaying fairly uniform distribution of vegetation and habitat conditions, establishing evenly spaced transects (10 m to 50 m) across the study site is sufficient. Transects should be spaced at least 10 m apart in order to maintain the independence of replicate plots.

Each transect should be marked using two permanent stakes (wood, metal or plastic) labeled with the transect number. The first stake (front stake) should be located at the high marsh edge and the second stake (back stake) between five to ten metres into the upland buffer. All sampling locations along each transect should also be marked; 36” to 48” bamboo stakes tied with flagging tape are adequate. Since all permanent stakes and sampling plots are systematically placed, the position of lost markers due to ice or other disturbance is easy to relocate with the use of a metric field tape, Total Station or GPS.

A baseline habitat map for both the restoration site and reference site should be developed using a combination of remote sensing data, air photograph interpretation, ground observations and digital mapping technologies such as high accuracy GPS, Total Station and GIS. The main products will be a habitat map of the main physical and biological features and a digital elevation model (DEM) for both the restoration and reference sites that should include:

- delineated wetland area/cover types (both pre & post-compensation and both high to low tide range profiles);
- location of restoration activities (manipulations); and
- sampling locations (transects, hydrology, soils and sediments, vegetation, fish, birds, and invertebrates).

Hydrology

The fundamental control on the structure and function of salt marsh habitat is flooding with salt water (Neckles and Dionne 2000).

- *Hydroperiod*

The hydroperiod (frequency and duration that the area is flooded) for a site can be determined using tidal signal data (pattern of water level change with reference to a fixed point) for the site and marsh surface elevation (DEM).

- *Tidal Signal and Extent of tidal flooding*

Tidal signal can be measured using an automatic water level recorder, a series of tide staffs installed at key locations on the marsh (downstream and upstream of tidal restriction), or a manual tide level recorder depending on availability of equipment and suitability for use at the restoration site given hydrological conditions. Extent of tidal flooding (determining the area of marsh that floods on a given tide and is thus available for direct use by fish) can be mapped by marking the perimeter of the flooded area at high tide during both neap and spring tides and mapped using the same equipment used to develop the baseline habitat map and the DEM. Extent of tidal flooding is highly variable and mapping in this manner should be conducted in conjunction with other hydrological monitoring techniques.

- *Water table depth*

The GPAC Monitoring Protocol method for sampling water table depth using ground water wells is recommended. Sampling locations should be paired with pore water salinity and vegetation sampling stations. Sampling should be carried out by the same individual because of the subjective nature of this method (estimation of length of string that wet). For most monitoring programs, it will likely not be feasible to install a ground water well at each vegetation plot. Therefore, it is recommended that a limited number of wells, at least six per site, be installed in such a configuration that both the downstream to upstream and across the marsh surface (perpendicular to main tidal channel) profile can be captured.

- *Water quality*

Water quality (salinity, temperature, dissolved oxygen) should be sampled in conjunction with fish sampling efforts and locations. A number of instruments are available to quickly and easily measure these variables on site. Dissolved Oxygen Meters include, for example, the YSI 85 Multi-Function D.O. Meter used by Fisheries and Oceans' Community Aquatic Monitoring Program, and the YSI 550A DO Probe available through the Saint Mary's University's Community Based Environmental Monitoring Network. Equipment should be calibrated according to factory specifications prior to field sampling.

Soils and Sediments

Monitoring pore water salinity, sediment accretion rates, sediment elevation and soil organic content can provide insight into the processes controlling vegetation type, cover, and productivity and the vertical growth of the marsh following restoration.

- *Pore water salinity*

Measuring pore water salinity in conjunction with depth to water table throughout the growing season would provide the best indicator of changes in environmental conditions regulating plant growth, distribution and abundance. Given the potential for salinity wells to be influenced by surface and rain water and the tendency for well water to stratify over-time (high salinity water near the bottom of the well and fresher near the surface), if wells are to be used, they should be pumped dry and allowed to refill before each sampling event. Depending on soil porosity of the study site, the process of refilling could take a long time.

A soil probe (sipper) is an alternative sampling method that avoids the potential difficulties involved with the use of salinity wells and is logistically feasible to deploy in association with each vegetation plot (Figure 17). Methods to construct and sample using a sipper and a refractometer are outlined in Roman et al. (2001).

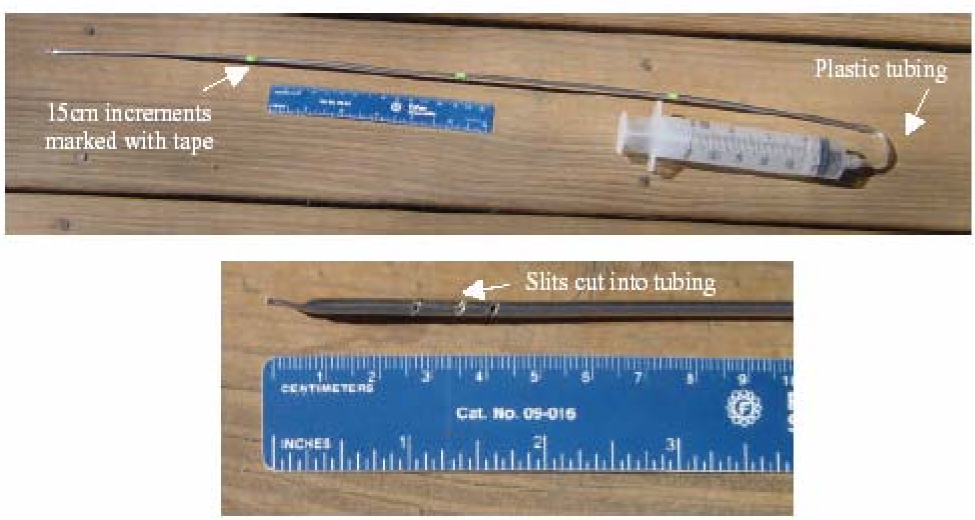

Figure 17 Photograph of a soil probe (sipper) used to sample pore water salinity (Roman et al 2001).

- *Sediment accretion & elevation*

Accretion of inorganic and organic material deposited onto the marsh surface by flood waters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding.   Failure to keep pace with increased flooding could result in the loss of key salt marsh features and functions (reduced productivity and loss of habitat). The recommended methods for monitoring sediment accretion and surface elevation changes involve the use of marker horizons (accretion) installed in association with a series of Sediment Elevation Tables (SET) (sediment elevation) as described by Dr. Cahoon and J. Lynch in Sediment Elevation Table (SET) (USGS 2005).

- *Organic Matter & Organic Carbon Content / Bulk Density / Soil Texture Bulk*

Monitoring of substrate qualities is important to identify controls on plant growth pre- and post restoration. A sediment corer can be used to collect bulk soil samples. Soil samples (5 cm diameter and 40 cm deep) should be taken in association with water table depth sampling locations and analyzed for bulk density, organic content and soil texture. The analysis of soil samples requires the participation of specialists with appropriately equipped laboratory facilities.

Vegetation

Salt marshes are dependent upon their plants – plant roots and stems trap and anchor marsh soils allowing for the vertical growth of the marsh over time. It is the plants of the salt marsh along with the physical conditions (hydrology, geology and chemical) that create the template for self-sustaining salt marshes and provide habitats to invertebrates, fish, birds and other animals.

Vegetation should be sampled over the study area and reference site in 1 m^2 plots systematically located along transects. For each transect, the first vegetation plot should be located within the low marsh area (ideally 0.5 m from the creek edge) and all subsequent plots placed along the transect at equal intervals from the first (20 m to 40 m depending on the size of the study area and no closer than 10 m). In order to detect subtle changes in vegetation, the minimum number of plots required in both the restoration and reference sites is n=20; however more is better (Roman et al. 2001). If dramatic changes are anticipated, it is suggested that a smaller number of replicates may be justified

(Roman et al. 2001). The number of transects, number of plots and spacing of plots will vary depending on the size of the marsh.

Vegetation sampling within each plot is conducted using the point intercept method (Roman et al. 2001). Plots consist of a 1 m^2 quadrat, consistently offset 1 m to either the left or right side of the transect (facing main tidal channel) and oriented towards the upland end of the transect. The 1 m^2 quadrat is divided into a grid of 25 squares (20 cm x 20 cm) and 25 of the intercept points used as sampling points (Figure 18). Once all plant species present in the quadrat are identified, a thin metal rod or wooden dowel is held vertical to the first sampling point and lowered through the vegetation to the ground below. All species that touch the rod are recorded as a hit for that point and the process is repeated for all 25 points. Categories other than plants, such as water, bare ground, rock or debris should also be recorded if hit by rod. Romans et al. (2001) recommend 50 sampling points per quadrat; however, 25 points per quadrat should be sufficient to capture vegetation changes following restoration (Lundholm 2005).

Photographs should be taken of the marsh along each transect, taken from the permanent markers at the upland end, as well as close-ups of vegetation plots.

Variables for this indicator category include:

- Species Composition,
- Species Abundance,
- Photographs of along each transect and close-up of each plot.

A schematic of the vegetation plot, groundwater well, pore water salinity and soil sample locations with respect to the sampling station stake is provided in Figure 19.

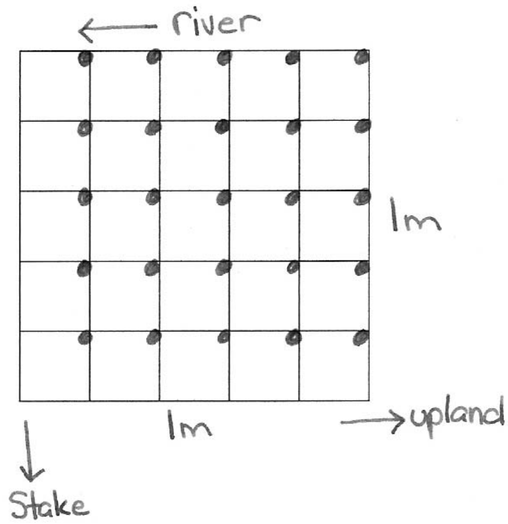

Figure 18 Location of sampling points within 1 m^2 quadrat used by point intercept method of sampling vegetation.

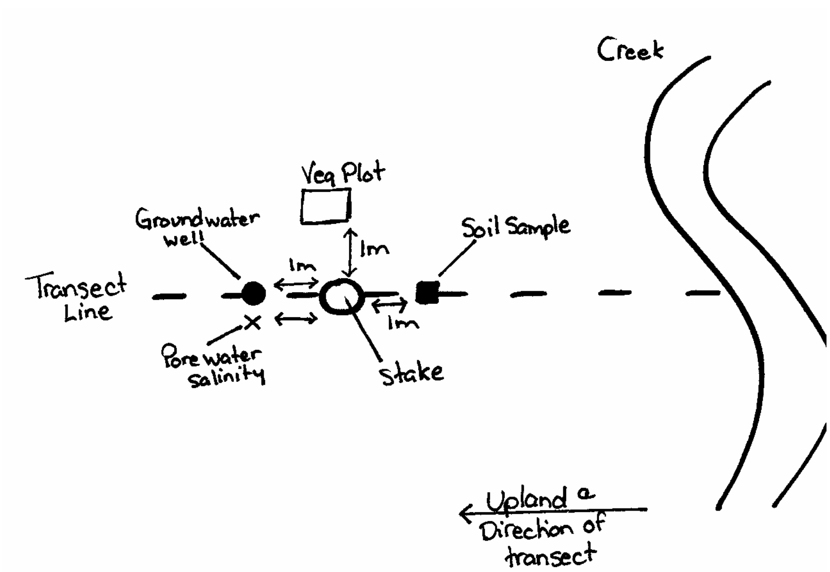

Figure 19 Schematic showing the location of soil sample, groundwater well, pore water salinity and vegetation plot relative to sampling station stake.

Nekton

Depending on habitat features and hydrology conditions, nekton sampling should be conducted in the tidal creeks, salt marsh pannes, and marsh surface (during high tide) using a combination of a throw trap, minnow traps and either a beach seine or fyke net (depending on availability of equipment). Smaller tidal creeks and salt marsh pannes can be sampled using baited minnow traps. Larger tidal channels and the marsh surface should be sampled using the GPAC Monitoring Protocol recommended method for the throw trap and fyke net. A beach seine (30 m x 2 m; 6 mm mesh size) can also be used to sample on the marsh surface during spring tides. An area of approximately 225 m^2 can be sampled by walking the beach seine out 15 m perpendicular to the shore, then 15 m parallel to the shore and returning the entire seine to the shore. Fisheries and Oceans Canada Gulf Region has developed a nekton sampling methodology (Community Aquatic Monitoring Program) that provides greater detail and troubleshoots this sampling method (EMAN 2005).

All individuals captured should be identified by species, counted and a representative number (up to 15 individuals) of each species collected and measured for length (fish and shrimp – total lengths, crabs – carapace width).

Variables for this indicator category include:

- Composition,
- Species richness,
- Density,
- Length.

Birds

The modified GPAC Monitoring Protocol method used by the EAC Project to survey birds is recommended. Surveys should be conducted using a series of observation circles encompassing the majority of the marsh area, with all individuals observed (seen or heard) recorded along with notes regarding behaviour. Surveys should take place early in the day (between 6 am and 11 am) and be scheduled throughout the year to capture the early spring, mid-summer and fall migration periods, and the spring breeding period. Surveys should be more frequent (weekly if possible) during the migration periods and less so during the breeding period (bi-weekly).

Variables for this indicator category include:

- Abundance.
- Species richness.
- Feeding/breeding behaviour.

Other Invertebrates

Invertebrates provide food resources that help fuel coastal and marine ecosystems. In addition to directly being fish food, invertebrates perform the important task of converting the rich productivity of salt marsh plants into a form (detritus) that is more accessible to other species such as fish. Invertebrates are good indicators of changes in hydrology, chemical characteristics and productivity.

The Reference Condition Approach methodology, originally developed for use in freshwater systems and modified and tested for use in the Bay of Fundy by Westhead (2005), is recommended for sampling invertebrates in the intertidal zones adjacent to salt marsh restoration and reference sites. Sampling should be conduct using the equipment and methods presented by Westhead (2005). Sampling is conducted using a 25 cm^2 quadrat and the collection of top 15 cm of soil within the quadrat. All species within the sample should be processed by specialists for species identity and density over the isolated sampling areas. Within the samples collected, molluscs are to be identified to the genus level and worms to at least family (genus or species if/when possible).

In addition to sampling for invertebrates on adjacent intertidal mudflats, invertebrates in the pannes, small tidal creeks and marsh surface should be sampled using a combination of a dipper (a scoop on the end of long handle) and/or invertebrate activity traps (pop bottle with the top third removed, inverted and reattached and suspended within the water column). Again, samples should be processed by specialists for species identity and density.

Density of larval mosquitoes can be sampled in the high marsh pannes using the GPAC methodology (dipper).

Variables for this indicator category include:

- Species composition,
- Species richness,
- Density.

Winter Conditions – A Structured Walk

It is recommended that winter conditions on the marsh be assessed using a structured walk with stops occurring at pre-selected observation points on the study site (marsh access point(s), upland end of transects, sampling locations along marsh if accessible). Site visits should be conducted bi-monthly to capture both neap and spring tide conditions; throughout the winter (December through March) and observations made concerning winter conditions such as the presence or absence of snow cover, ice, exposed marsh surface/vegetation, evidence of changed hydrology as a result of winter/ice conditions, use of site by waterfowl, and timing of melt out. More quantitative data concerning snow and ice conditions such as the depth of snow/ice and the size and nature of ice blocks should be measured (using standard metric field tape and/or meter stick) within pre-determined sampling areas. The location, size and nature of sediment blobs (ice rafts[7]) on the marsh surface after melt out should also be recorded. Panoramic photographs of the marsh area should be taken from the upland ends of transects as well as close-ups of any unique winter features, conditions or disturbances.

[7] Ice rafts - clumps (blobs) of sediment & other materials deposited on marsh surface in the spring by melting ice.

Table 9 Recommended Bay of Fundy Salt Marsh Restoration Monitoring Protocol (modified by the author from Neckles et al. 2002; and Roman et al. 2001). The components of the monitoring program that differ significantly from the GPAC Monitoring Protocol are presented in italics.

Core Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
Hydrology			
Tidal signal	Pattern of water level change with respect to a fixed point	Continuous water level recorders or *manual water level (maximum tide height) recorder* or Tide staff observations at 10 minute intervals	2 to 4 week period of operation measured daily following high tide for a period of at least 2 weeks 5 to 6 hr observation periods during 3 spring & 3 neap tides *As noted prior to restoration and again 1, 3 and 5 years post*
Elevation	*Digital Elevation Model*	*Total Station*	*Once prior to restoration and following as required (year 3)*
Extent of tidal flooding	*Area of marsh flooded by tide*	*Hypsometric curve* *or* *Flagging high tide line and mapping using Total Station*	*3 spring & 3 neap tides prior to restoration and again 1, 3, and 5 years post.*
Water table depth	*Groundwater depth below marsh surface*	*Permanent wells (groundwater wells)*	*Sampled at low tide, 6 times annually b/w early and mid-growing season, including neap and spring tides*
Water quality	*DO, salinity, temperature, pH of marsh surface flood waters & representative salt pannes*	*DO Meter*	*Sampled annually in associated with fish and invertebrate sampling*
Soils and Sediments			
Pore water salinity	*Salinity of soil water from depths of 15 cm to 45 cm*	Soil probe (sippers) & refractometer	6 times annually b/w early to late-growing season, including neap and spring tides
Sediment accretion	*Accumulation of inorganic & organic material on marsh surface*	*Marker horizon (Feldspar clay) & cryogenic coring* *3 to 4 marker plots in association with each SET*	*Established prior to restoration and sampled once per year following restoration – sample should be taken approximately same time each year*
Sediment elevation	*Short term changes in sediment elevation*	*Set Elevation Table (SET)*	*Once per year; coupled with sediment accretion sampling*

Core Indicators	**Description**	**Sampling Method**	**Sampling Frequency** (Before & after restoration except as noted)
Organic matter & organic carbon content / bulk density / soil texture bulk	*Characteristics of marsh soils*	*5 cm by 40 cm soil cores*	*Once prior to restoration and post as required (at least year 5)*
Vegetation			
Composition	Identity of all plant species per m^2	*Point intercept method using permanent plots positioned along transects at intervals necessary to maintain independence (>10 m)*	Once per year at time of maximum standing biomass (mid-July through August)
Abundance	Percent cover per m^2 by species		
Photo stations	*Photographs from permanent stations and close-ups of vegetation plots*	*Photo of marsh along transect taken from upland end; close-ups of permanent plots*	
Nekton			
Composition	Identity of each animal sampled	*Minnow traps in pannes/pools and small tidal creeks* and Throw traps in creeks and channels and Fyke net and/or beach seine in main tidal channel and/marsh surface	*Sampling with each method should be conducted 3 times per year (early, mid and late season) during a spring tide event*
Species Richness	Total number of species represented		
Density	Number of animals per area (throw traps and beach seine)		
Length	Length (fish, shrimp) or width (craps) of 15 individuals per species		
Birds			
Abundance	Number of birds by species	*10 minute observation periods in the morning from site-specific vantage points that provide an uninterrupted view of at least a portion of the salt marsh (200 m diameter observation circles)*	High and low tides: 2 times during breeding season (May/June); once per week during waterfowl migration (March/April and October/November); once per week during shorebird migration (July-Sept)
Species richness	Total number of species		
Feeding/breeding behavior	Type of behaviour per observation interval, by species		
Invertebrates			
Composition	*Identity of each animal sampled*	*(1) RCA – soil sample to 15 cm depth within 25 cm^2 quadrat on intertidal flats* *(2) Invertebrate Activity Traps in pannes*	*(1) Once per year (same time each year)* *(2) Annually – min 6 samples, bi-weekly early to mid season (June, July, Aug)*
Species richness	*Total number of species represented*		
Density	*Number of animals per sample*		

Core Indicators	Description	Sampling Method	Sampling Frequency (Before & after restoration except as noted)
Larval mosquitoes	Presence/absence and number of larval mosquitoes in salt marsh pannes	Dipper	Collected weekly from April through August along transects that intersect standing water (pannes/pools) on marsh surface
Winter Conditions			
Winter conditions	*Ice and snow cover,* *exposed marsh vegetation,* *use by waterfowl,* *changes in hydrology as a result of winter conditions*	*Structured walk (photography, field tape, estimation of area)*	*Once per month (December through March). Recommend twice per month to capture both spring tide and neap tide conditions.*
Snow and ice	*Depth of snow/ice on marsh surface* *Size and nature of ice blocks* *Location, size, nature of ice rafts (sediment blobs)*	*Pre-determined sampling areas (5 m^2 plots) (n=will depend on size of study site). Field tape, meter stick.*	

5.2 Adaptive Management

The concept of adaptive management, in which experience with and results of monitoring activities in previous years are used to modify the monitoring program for subsequent years, should be integrated into the monitoring framework. For instance, if the ecosystem is recovering as expected (exhibiting conditions similar to reference site), the sampling frequency of individual indicators (or indicator variables) may be reduced. Alternatively, if the ecosystem is not recovering as expected, an increase in sampling frequency or a change in sampling method of relevant indicators, and/or the inclusion of additional indicators may be required. When modifying any aspect of the monitoring program, care must be taken to ensure continued compatibility with previous year(s) monitoring activities. This monitoring will also contribute to the overall management of the restoration site by identifying whether the project is reaching the expected outcome. Subsequently, adjustments can be made to rectify the situation potentially leading to additional monitoring or restoration activities during the post-restoration phase of a project.

CHAPTER 6 – CONCLUSIONS

Monitoring is an essential component of any habitat restoration project. Pre- and post-restoration monitoring measures the effectiveness of restoration efforts and provides valuable information on ecological condition to guide future management and restoration efforts at the local and regional scale. Efforts to restore tidal wetlands have been underway in parts of New England since the early 1980s (Warren et al. 2002). Since the mid-1990s, efforts have been underway to develop a standardized monitoring protocol to assess habitat restoration efforts. A number of restoration and monitoring programs have been developed for use in the Gulf of Maine (Carlisle et al. 2002; James-Pirri et al. 2002; Roman 2001; and Zedler 2001). In particular, the GPAC Monitoring Protocol (Neckles and Dionne 2000) was developed in association with the Gulf of Maine Council on the Marine Environment to provide the basis for a regional (Gulf of Maine and Bay of Fundy) monitoring network. The GPAC Monitoring Protocol includes prioritized ecological indicators and data collection methods to characterize geomorphological attributes, hydrology, soils, plants and animal use.

As efforts to conserve and restore coastal wetland habitats and species in the Bay of Fundy increase, there is a need for the adoption or development of a standard approach to each kind of monitoring and its application on a regional scale. The success of future salt marsh restoration projects depends upon understanding the range of natural forms and functions of these habitats and their response to restoration activities.

This study has addressed the need for the development of a standard approach to monitoring the success of salt marsh restoration projects in the Bay of Fundy. The primary goal was to evaluate the GPAC Monitoring Protocol for use on macro-tidal salt marsh systems in the Bay of Fundy. This was accomplished by: (i) evaluating the ecological indicators and data collection methods identified by the GPAC Monitoring Protocol against a series of scientific, practical and programmatic considerations; (ii) applying the GPAC Monitoring Protocol as part of a proposed salt marsh restoration project; and (iii) providing recommendations for the modification of GPAC Monitoring

Protocol for use as part of tidal wetland restoration projects in the Bay of Fundy, with potential applicability to other tidal restoration projects in Atlantic Canada.

In order to evaluate the suite of indicators and data collection methods recommended by the GPAC Monitoring Protocol, a series of indicator assessment criteria were selected and arranged in three categories: (i) technical (scientific validity); (ii) practical; and (iii) programmatic (refer to Section 3.1.1, Table 5). Individually and as a whole, the indicators and corresponding data collection methods of the GPAC Monitoring Protocol were evaluated using the identified indicator assessment criteria (refer to Chapter 4).

When taken individually, the indicators (geospatial attributes; hydrology; soils and sediments; vegetation; nekton; and birds) all test well technically. When considered as a whole, the GPAC Monitoring Protocol fails to give adequate consideration to invertebrates and winter conditions as indicator categories. From a practical and programmatic standpoint, some aspects of the individual indicators, particularly data collection, handling and analysis might not be practical currently, given the experience and operational limitations in Atlantic Canada (see Table 8).

An effective monitoring program should direct the processes of data analysis, interpretation, reporting, and feedback in order to facilitate adaptive management and long-term success of restoration projects (Wiersma and Campbell 2002). The GPAC Monitoring Protocol should go beyond identifying the indicators and data collection methods, and provide guidance in the areas of data handling, analysis, interpretation and reporting.

Key recommendations for further development of the GPAC Monitoring Protocol include: (i) greater consideration given to salt marsh pannes, pools and drainage channels (natural and anthropogenic) as a geospatial attribute; (ii) inclusion of winter conditions and invertebrates as indicator categories; (iii) inclusion of individual indicator objectives; (iv) greater emphasis on data handling, analysis, interpretation and reporting; and (v) integration of the salt marsh restoration monitoring program into a broader salt marsh restoration and management strategy for Atlantic Canada.

A key element in the process of selecting indicators and the development of a monitoring program is the field test (Ure 2003; refer to Table 1). The application of the GPAC Monitoring Protocol as part of the EAC Project emphasized a number of the practical and program weaknesses and gaps in the Protocol that were identified in the evaluation phase of this study. Challenges in the areas of access to recommended/required sampling equipment, expertise, suitable physical conditions for recommended data collection methods, and the presence of the broader support network for restoration and monitoring were exposed by the field test.

With the necessary modifications made to the GPAC Monitoring Protocol to allow for the field test (refer to Section 3.2), its application to Cheverie Creek and Bass Creek revealed a number of insights about the impacts of the Cheverie Creek tidal barrier and provided an adequate baseline against which to compare post-restoration conditions (refer to Appendix C). The existing tidal crossing at Cheverie Creek is a significant tidal restriction to tidal flow and the movement of species and materials into and out of the system. Monitoring using the GPAC Monitoring Protocol indicators revealed that Cheverie Creek, following two decades of limited unmanaged restoration of tidal flow, possesses a range of physical and biological conditions similar to those observed at the reference site (Bass Creek). Removal of the existing restrictive tidal crossing would re-introduce natural tidal flooding to much of the historical tidal system and improve ecological conditions for native plant, fish and wildlife communities.

The development of a comprehensive monitoring program is an evolving process that involves collaboration, capacity, research, trial and error and an ability to adapt as experience with restoration techniques grows. Standard protocols for monitoring allow for consistent evaluation of habitat restoration efforts and outcomes overtime. As habitat restoration in the Bay of Fundy increases, so does the need for a consistent monitoring program.

Based on the evaluation and field test of the GPAC Monitoring Protocol's indicators and data collection methods, a monitoring program for salt marsh habitats in the Bay of Fundy was presented. The recommended monitoring program for the Bay of Fundy builds on the GPAC Monitoring Protocol's core indicators (invertebrates and winter conditions), reduces the additional variables (stem density of invasive species, bird behaviour, fish diet), and modifies some of the data collection methods (point-intercept method for vegetation) (refer to Section 5.1, Table 9). This modified monitoring program remains consistent enough with the GPAC Monitoring Protocol to facilitate comparisons with GPAC monitored sites, while being more responsive to Bay of Fundy and other local site-specific conditions.

This study illustrates the effectiveness and applicability of the GPAC Monitoring Protocol, previously untested as a key component of tidal wetland restoration projects in the Bay of Fundy. The recommended modifications and additions to the GPAC Monitoring Protocol made by this study, based on the evaluation and implementation of the protocol, provide a strong starting point for the development of project specific monitoring programs and a regional monitoring protocol. Further refinement of the monitoring program will come about through hands-on experience with the program and increasing regional capacity for project development, management, and technical resources. What is necessary to make a monitoring program, such as the GPAC Monitoring Protocol, effective for use on macrotidal salt marsh systems in the Bay of Fundy is the elimination of the jurisdictional, political, financial and regulatory constraints; a greater understanding of the ecology of Fundy marshes; and the creation of a regional salt marsh restoration strategy within which the monitoring program can be nested and sustained over the long-term.

Post Script

As a result of efforts by the EAC, a number of local residents and community organizations along the Hants Shore, the restrictive culvert at Cheverie Creek was replaced by a much larger crossing in December 2005 (Figure 20). Restoration of a more natural tidal regime to the Cheverie Creek tidal river and salt marsh ecosystem was made possible through the participation and financial support of the NSDOTPW and Fisheries and Oceans Canada. A NSDOTPW press release highlighting this collaborative project, as well as a second salt marsh restoration project undertaken by NSDOTPW and Ducks Unlimited Canada in 2005, is included in Appendix A.

Additional pre-restoration monitoring at Cheverie Creek and Bass Creek was conducted by the EAC during the 2004 field season and by CB Wetlands & Environmental Specialists in 2005. The 2005 monitoring along with the 2006 through 2010 post-restoration monitoring is being financially supported by DOTPW and Fisheries and Oceans Canada and conducted by CB Wetlands & Environmental Specialists.

Figure 20 The new Cheverie Creek tidal crossing installed by NSDOTPW and Fisheries and Oceans Canada in November/December 2005 (left – downstream end, right – upstream end).

APPENDIX A – THE ECOLOGY ACTION CENTRE'S CHEVERIE CREEK SALT MARSH AND TIDAL RIVER RESTORATION PROJECT

a). EAC's Salt Marsh & Tidal River Restoration in Nova Scotia brochure
b). Cheverie Creek Proposed Project Description (January 2004)
c). Nova Scotia Department of Transportation and Public Works press release on Cheverie Creek (November 2005)

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Ecology Action Centre

- Nova Scotia's oldest and most active environmental organization
- For over three decades the EAC has been a strong advocate for environmental change
- Our mission is to encourage a society in Nova Scotia which respects and protects nature and also provides environmentally and economically sustainable jobs for its citizens
- We have seven active issue committees: Coastal, Energy, Food Action, Marine, Urban, Transportation and Wilderness

If you are interested in becoming a member or getting involved, please contact us:

Ecology Action Centre
1568 Argyle Street, Suite 31
Halifax, NS
B3J 2B3
Ph: (902) 429-2202
Fax: (902) 422-6410
eac@ecologyaction.ca
www.ecologyaction.ca

Salt Marsh and Tidal River Restoration Project

Contact Information

Tony M. Bowron
Project Coordinator
1568 Argyle St., Suite 31
Halifax, NS, B3J 2B3
Ph: (902) 442-0199
Fax: (902) 422-6410
E-mail: **coastal@ecologyaction.ca**

For more information on this and other projects at the EAC please check out our website at: **www.ecologyaction.ca**

Project Funders

Fisheries and Oceans Canada
Unilever-Evergreen
Kendall Foundation
Saltwater Network
Gulf of Maine Council on the Marine Environment
NS Department of Transportation and Public Works
Environment Canada
Wildlife Habitat Canada
NS Department of Natural Resources – Habitat Conservation Fund
Human Resources Development Canada
Bay of Fundy Ecosystem Partnership
North American Fund for Environmental Cooperation
Global Program of Action Coalition
St. Mary's University
NS Museum of Natural History
Dalhousie University

Ecology Action Centre

Salt Marsh & Tidal River Restoration In Nova Scotia

The Ecology Action Centre's Salt Marsh and Tidal River Restoration Project

***Project Focus*:** *Protect, restore and raise awareness about the beauty and significance of Nova Scotia's coastal wetlands*

Salt Marshes

- Transition zone between land & sea
- Protect against erosion, flooding and storm surges
- Help control mosquito populations
- Improve water quality
- Provide habitat for birds, fish and wildlife. Important part of marine and terrestrial foodwebs

Threats include human activities such as ditching, dyking, road construction, in-filling and coastal development.

Activities such as these have resulted in an estimated **80% loss of salt marshes** in the upper Bay of Fundy. This EAC project was created in 1997 as a response to this loss of coastal wetlands.

Restoration is the long term process of reversing this 400 year legacy of loss.
The projects goal has been to identify altered, degraded or destroyed salt marshes and to explore opportunities for habitat restoration and stewardship throughout the NS side of the Bay of Fundy.

Cheverie Creek

Our pilot salt marsh restoration site is a tidal river and salt marsh system located in Cheverie, West Hants County, NS, crossed by a causeway containing a culvert that partially restricts tidal flow to the upstream habitats.

Over the past several years the EAC has been promoting this site for restoration and has conducted field research at the site to collect baseline ecological data about the marsh and explore the potential for restoration through culvert replacement.

GPAC Regional Protocol was used to monitor hydrology, vegetation, soils and sediments, fish, birds, and other wildlife in order to develop a restoration plan and to track post restoration changes.

Education and community outreach programs are key aspects of the project.

Collaboration with project partners, community groups and government agencies resulted in the planning and design of a new crossing aimed at maximizing tidal flow and the restoration of salt marsh habitat and fish passage at Cheverie Creek.

Tidal Barriers

- Structures that prevent the natural movement of tidal water and species into low-lying coastal areas

Tidal barrier audits have been conducted for the NS side of the upper Bay of Fundy. Audits examined mainly road crossings to determine the degree to which they were restricting tidal flow and fish passage, and to identify potential restoration sites.

A natural tidal regime is essential to the health and productivity of salt marshes and tidal rivers. **Over 50% of the 156 tidal crossings assessed** were found to be either partially or completely restricting.

Causeways, dams, dykes, aboiteaux can form complete restrictions. Culverts and bridges that are too small or improperly located can significantly reduce tidal flow and fish passage. Both can result in dramatic ecological change to the upstream and downstream habitats.

Proposed Project Description (January 2004)

NAME: Cheverie Creek Salt Marsh and Tidal River Restoration Project

LOCATION: Cheverie Creek Cheverie, Hants Co.

PROJECT CONTACT: Tony M. Bowron, Project Coordinator, Ecology Action Centre, 1568 Argyle St. Suite 31, Halifax, N.S. B3H 2B3 Tel: 902-429-2202 Email: tbowron@dal.ca

UNDERTAKING: The project is designed to restore a more natural tidal regime to the tidally restricted Cheverie Creek salt marsh tidal river system. The project will involve the replacement of an inadequately sized and placed highway culvert with a larger, more strategically positioned crossing in order to improve tidal flow and fish passage to the system and enhance the tidal wetland habitat.

SCHEDULE: Property owner and public consultation, baseline monitoring, habitat profiling and hydrological modelling were carried during the 2002/2003 field seasons. A timeline for construction will be developed during the winter of 2004 with a summer 2004 construction date in mind.

DESCRIPTION:

Aerial Photo 92317-22 1992

Cheverie Creek is a small tidally restricted river located in the community of Cheverie. Highway 215 crosses the mouth of the river as a small causeway. Limited tidal exchange is allowed through a one and a half metre wide double wooden block culvert. The culvert is in disrepair on both ends, most likely due to ice and other debris striking the structure. Saltwater does pass through the culvert to flood an area of approximately 4-5 hectares. An old dyke system is visible running parallel to the causeway; however, it does not appear to be maintained. Consultation with the Department of Agriculture and Fisheries has revealed that the area is no longer of any value or interest to the Department. From the aerial photographs, an estimated 30 hectares would benefit from culvert replacement and habitat restoration work.

Downstream, water pools at the mouth of the culvert with a small fringe marsh forming on the sides of the pool. A rocky, barrier beach is forming on the approach to the scour pool and is subsequently diverting water flowing away from the system. Due to the size and position of the existing culvert, dangerous currents (whirlpools) are created in both the upstream and downstream scour pools during the rising and falling tide.

The area upstream of the crossing is privately owned by a series of both local and absentee landowners. The property on the north side of the river, immediately upstream of the highway is owned by Ducks Unlimited Canada, a strong supporter of this project. Property owner and boarder community consultations began during the winter of 2002 and continue through the present. Through a series of telephone, postal, on site and community hall meetings, the support and participation of owners and community members in the project has been fostered.

Enlargement of the culvert is necessary to increase tidal flow upstream and to eliminate the lag between the upstream and downstream ends. Placement of the culvert is also of concern as the barrier beach that is forming may eventually cut off all flow to the culvert and cause water to flood the road. We are aware that the causeway is a popular stopping spot for tourists as it faces Cape Blomidon so replacement of the entire causeway with a bridge is not a viable solution. The replacement of the existing culvert with a larger culvert, or even a small bridge, would increase tidal flow significantly, reduce the dangerous currents currently being created by the existing culvert and would not require replacement of the entire causeway.

Future restoration and habitat enhancement work at the site may include the modification of the remnant dyke on the north side of the river to allow for more even horizontal flow over the marsh surface, construction of a network of pannes and creeks to better facilitate the movement of fish species on the marsh, and the construction of boardwalk, birding stations and information stations.

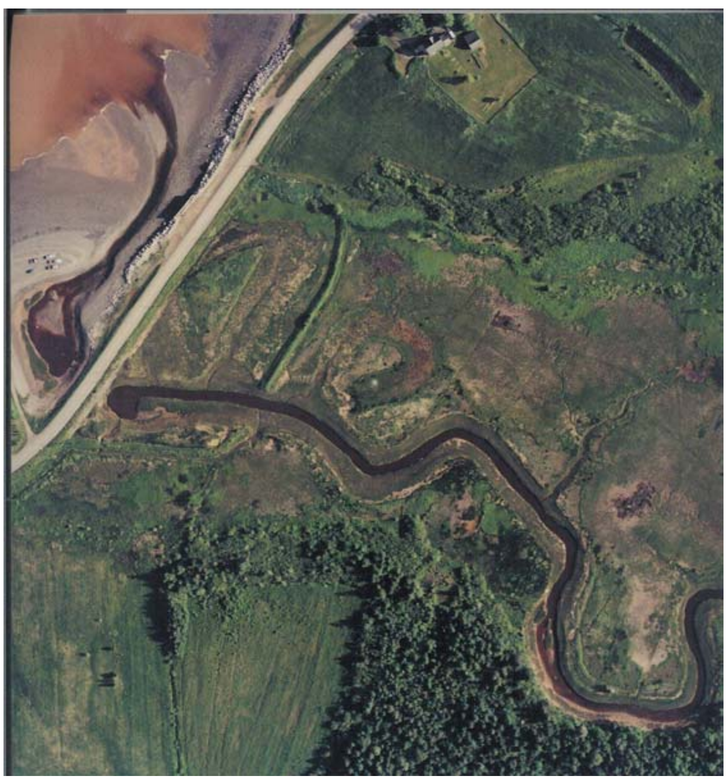
CONSTRUCTION: The replacement of the culvert will be carried out by the DOTPW. Information concerning the timing and the method of construction involved with replacing of the culvert has yet to be organized.

FUNDING: Project is currently being funded by the Gulf of Maine Council for the Marine Environment, Wildlife Habitat Canada, Nova Scotia Habitat Conservation Fund (DNR), Environment Canada and Fisheries and Oceans Canada.

PROJECT PARTNERS: Wildlife Habitat Canada, Hants County Rural Development Authority, Action to Protect the Environment (CAPE), Hants Shore Concerned Citizens Association (HSCCA), Fisheries and Oceans Canada – Habitat Management Division (DFO), NS Dept. of Natural Resources (DNR), Environment Canada, St. Mary's University, Dalhousie University, Mt. Allison University, NS Museum of Natural History, Bay of Fundy Ecosystem Partnership, Ducks Unlimited Canada (DUC), Eastern Habitat Joint Venture (EHJV), Atlantic Salmon Association (ASA).

Figure 1. Air photograph of Cheverie Creek (1:10000) (1992)

Figure 2. Downstream end of Cheverie culvert at low tide.



Government and Community Restore Minas Basin Salt Marshes

Nova Scotia Department of Transportation and Public Works

November 24, 2005

Two salt marshes off the Minas Basin will once again teem with life thanks to co-operative restoration projects undertaken by the provincial and federal governments and a variety of partners.

The Nova Scotia Department of Transportation and Public Works, Fisheries and Oceans Canada, the Ecology Action Centre, Ducks Unlimited Canada, and a number of local residents and community organizations are working together on two projects to restore 37 hectares (91 acres) of salt marsh in Hants County.

These, along with a similar project in New Brunswick, are the first such restorations attempted in the Maritimes and, as such, are attracting national and international interest from groups such as Wildlife Habitat Canada, the Gulf of Maine Council on the Marine Environment, and the North American Commission for Environmental Cooperation.

"This work will re-create complex marsh environments," said Ron Russell, Minister of Transportation and Public Works. "A wide variety of wildlife, both above and beneath the water, should thrive in the two areas we are restoring."

Geoff Regan, Minister of Fisheries and Oceans, remarked on the win-win nature of the initiative. "Too often, human progress carries a high environmental price tag. But I'm happy to say that, with this project, the environment comes out a big winner."

Work has begun on one project which will replace an existing small culvert on Route 215 at Cheverie Creek with a larger one. This will restore full tidal flooding to a 30-hectare salt marsh that, for the last half century, has been only a five-hectare salt marsh. The $1,075,000 contract for this job was awarded to Dexter Construction and the cost will be split equally between the provincial and federal governments.

The other project, which was completed in September, involved opening a dyke on a portion of the Walton River marsh. This returned a 12-hectare freshwater pond back to its original form as a salt marsh.

Both projects will be closely studied during the next five years to document how marshes and adjacent coastal ecosystems evolve.

"Co-operation and partnerships are keys to this project," said Mr. Russell. "In addition to the funding the project has received from the small craft harbours branch of Fisheries and Oceans Canada we've received considerable support from local residents along Route 215, students and teachers of the Dr. Arthur Hines Elementary School, Saint Mary's University, the Nova Scotia Department of Natural Resources, CB Wetlands and

Environmental Specialists, the Unilever-Evergreen Foundation, and the Henry P. Kendall Foundation."

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APPENDIX C – RESULTS: IMPLEMENTING THE GPAC MONITORING PROTOCOL

Introduction

This section presents the results of the field test of the GPAC Monitoring Protocol at the Cheverie Creek restoration site and Bass Creek reference site. The indicators measured include hydrology, soils and sediments, vegetation, nekton, and birds. The section includes a general discussion of what the monitoring program revealed about the pre-restoration condition of Cheverie Creek and the Bass Creek reference site, and the expected changes due to planned restoration actions. Limitations associated with this component of the study are also given.

1.1 Baseline Habitat Map

The baseline habitat maps for Cheverie Creek and Bass Creek upon which the monitoring program was based are in Appendix D.

1.2 Ecological Indicators

1.2.1 Hydrology

Hydroperiod (Tidal Signal)

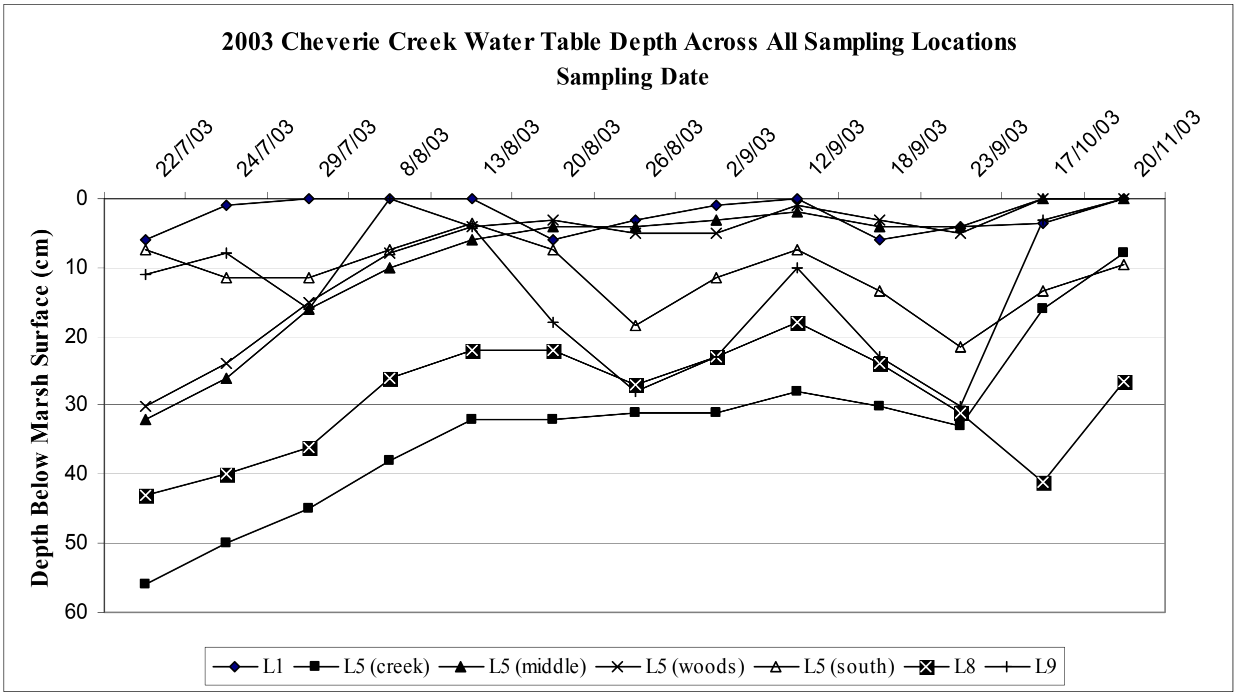
The hydrological modeling performed by Konisky (2004) showed that the existing tidal crossing condition results in a significant (1 m vertical) tidal restriction for spring tides which prevents frequent tidal flooding for approximately 75% of the marsh area (Appendix E). By testing an initial series of additional hydrologic scenarios, it was found that the restriction would be eliminated by replacing the existing culvert with an 11.58 m x 3.05 m opening in the form of a bridge span system (Appendix E).

At the request of NSDOTPW, in an attempt to balance economics and ecological gain, additional bridge span dimensions were tested in order to identify the minimum span dimensions that yielded the desired hydrologic conditions. The additional analysis determined that under current tidal conditions, an 8 m x 3 m bridge span system significantly reduced the restriction.

Water Table Depth

Distance below the marsh surface of the water table at all sampling locations for all sampling dates was graphed for both Cheverie Creek and Bass Creek (Figure 1). Both locations displayed a seasonal trend of decreasing depth from the summer into the fall. On an individual sampling location basis, all but two locations shared this trend. The ground water well located at Cheverie Creek L1 experienced a constant depth throughout the sampling season, which was to be expected given its close proximity to the tidal inlet and position on the slope of a small tidal creek (<5 m wide). The one other sampling station that did not experience this seasonal trend of depth to water table was Cheverie Creek L5 (south), which experienced an increase in depth into the fall.

A greater distance to the water table below the marsh surface during July and August compared to depths during the fall, over much of the marsh surface, was to be expected. The decreasing depth during the fall months corresponds with increasing tidal inundation (as also seen with increasing soil salinities – see next section) and the increase in rain events in the fall that is typical for this region. Using as much data as possible (common dates and comparable sampling locations), a comparison of average depth to water table between the two sites by date was conducted (Figure 2). Water table depths between the two sites were significantly different on only one occasion, July 29, 2003 ($P<0.05$, $P = 0.0453$). For all other sampling dates, there was no significant difference between depth to water table levels per sampling location between the two sites.



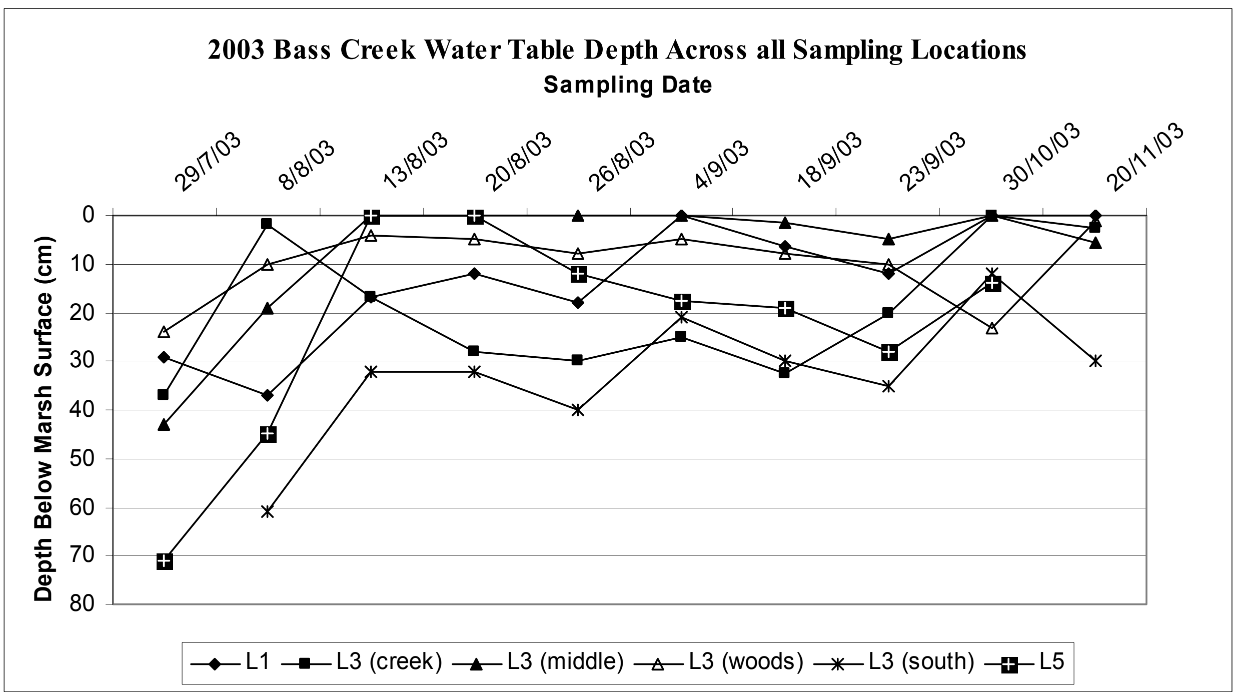


Figure 1 Water table depth below marsh surface for all locations and sampling dates at Cheverie Creek and Bass Creek.

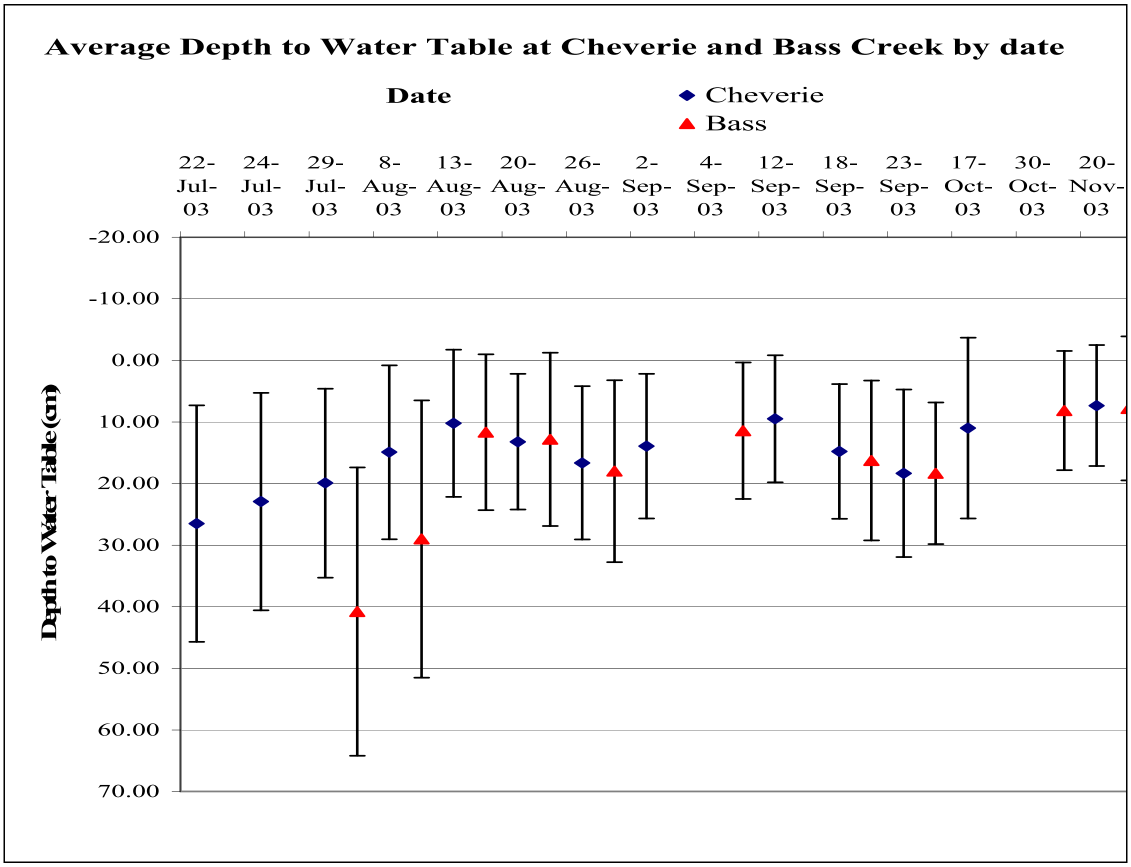


Figure 2 Average depth (and range) to water table at Cheverie Creek and Bass Creek by date.

1.2.2 Soils and Sediments

Pore Water Salinity

Soil pore water salinities from all sampling stations from July to November 2003 were averaged and examined to determine seasonal trends for both study sites (Figure 3). No significant difference was found between shallow and deep wells at either site (paired t-test, Cheverie Creek $P<0.526$; Bass Creek $P<0.147$). Average salinities ranged from 9 ppt to 36 ppt (Cheverie) and 1 ppt to 31 ppt (Bass). A comparison of average salinities between the two study areas revealed a difference of only marginal significance ($P>=0.05$) (Figure 4).

Salinity variation due to sampling station location was expected. As seen in Eberhardt and Burdick (2003), the lowest salinities would be expected in the wells found at the upper reaches of the main channel (L8&9 at Cheverie, L5 at Bass) and at the sampling stations along the marsh surface perpendicular to the main channel (L5woods at Cheverie, L3woods at Bass), and the highest at the wells nearest the tidal inlet (L1 at both locations). Only the wells located along L3 at Bass Creek clearly displayed this trend of decreasing salinities across the marsh surface away from the main channel. That the trend of decreasing salinities upstream from the main tidal inlet was not observed at either location is most certainly the result of the placement of the sampling stations. The location of the uppermost sampling stations at both sites was not far enough upstream to adequately capture the transition from salt water to fresh and the reduction in the extent and frequency flooding. The uppermost set of wells at both locations should have been placed further upstream at or beyond the head of tide. The considerable amount of standing water on the mid- to high marsh area along transect L5 at Cheverie Creek that persisted throughout the majority of the 2003 sampling season influenced the salinity readings along that transect, masking the expected decline in salinity away from the main channel.

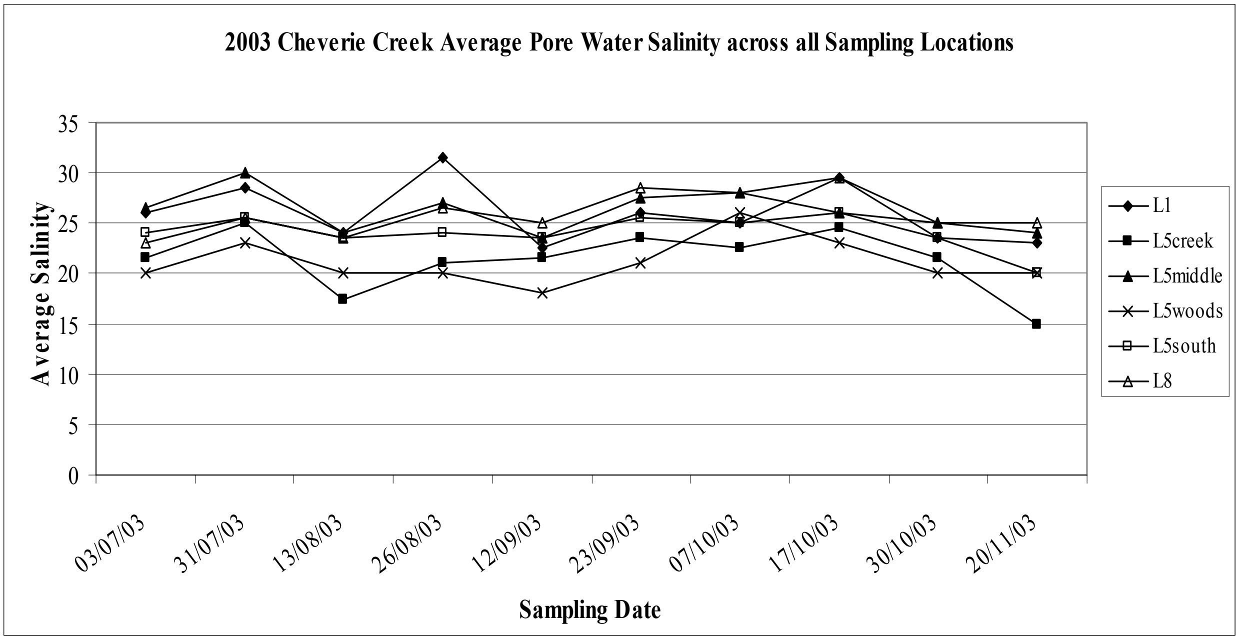
The majority of wells at both locations experienced declining salinity levels from summer into the fall. Five (L1, L3creek, L3middle, L3south and L5) out of six locations at Bass Creek and three (L1, L5creek, L5middle) out of six locations considered in the comparison at Cheverie Creek produced average salinities that were higher in summer than in the fall. At Cheverie Creek L5woods and L8 experienced increasing salinities into the fall, while L5south remained constant. Only the sampling station at L3woods at Bass Creek showed a similar increase into the fall. Again, the wet conditions along transect L5 at Cheverie Creek and the failure to adequately distribute wells throughout the system influenced these results. This trend is opposite to that observed during the Awcomin Marsh restoration project (Eberhardt and Burdick 2003) where salinities at both the restoration and reference sites were found to be lower in the spring and increased throughout the season into the fall. The difference in salinity trends could be the result of the two factors already described, less freshwater influence, or a fundamental difference in climatic or tidal conditions (greater tidal regime) that exists between Bay of Fundy salt marshes and those found in New England.

Additional salinity monitoring over one or more seasons will reveal whether or not these temporal and spatial trends persist. As well, research into the seasonal trends of additional salt marsh sites in both New England and Bay of Fundy would provide insight as to whether or not the trends observed at these sites (Bass Creek, Cheverie Creek and Awcomin Marsh) are typical of salt marshes in their respective regions. Given the single season of pore water salinity data with which to conduct a comparison and considering that only the front portion of Cheverie Creek was monitored for salinity, the two marshes do appear to be functioning similarly in terms of tidal inundation and water retention.

Organic Matter, Bulk Density and Sediment Accretion

Soil characteristics (bulk density, organic matter) and sediment accretion monitoring are being conducted to contribute to a long term study at a series of tidal wetland sites around the upper Bay of Fundy. This work is being conducted by researchers at Saint Mary's University, Acadia University, McGill University and Mt. Allison University.

Preliminary analysis of sediment characteristics at Cheverie Creek found that soils farthest from the main tidal channel are lower in density and higher in organic matter compared to soils closest to the channel (Chiasson 2003). This is a trend that has also been observed on New England salt marshes (DeLaune et al. 1979, and Ward et al. 1998). Soil texture of marsh soils consisted mainly of silt and sand with a very low percentage of clay (Chiasson 2003). The percentages observed, particularly for silt, for Cheverie Creek were much lower than the observed percentages for an unrestricted salt marsh located in Cumberland Basin (van Proosdij et al. 1999). This could reflect sediment availability in the different locations in the Bay of Fundy or to the presence of a significant restriction to tidal flow on the Cheverie Creek system.



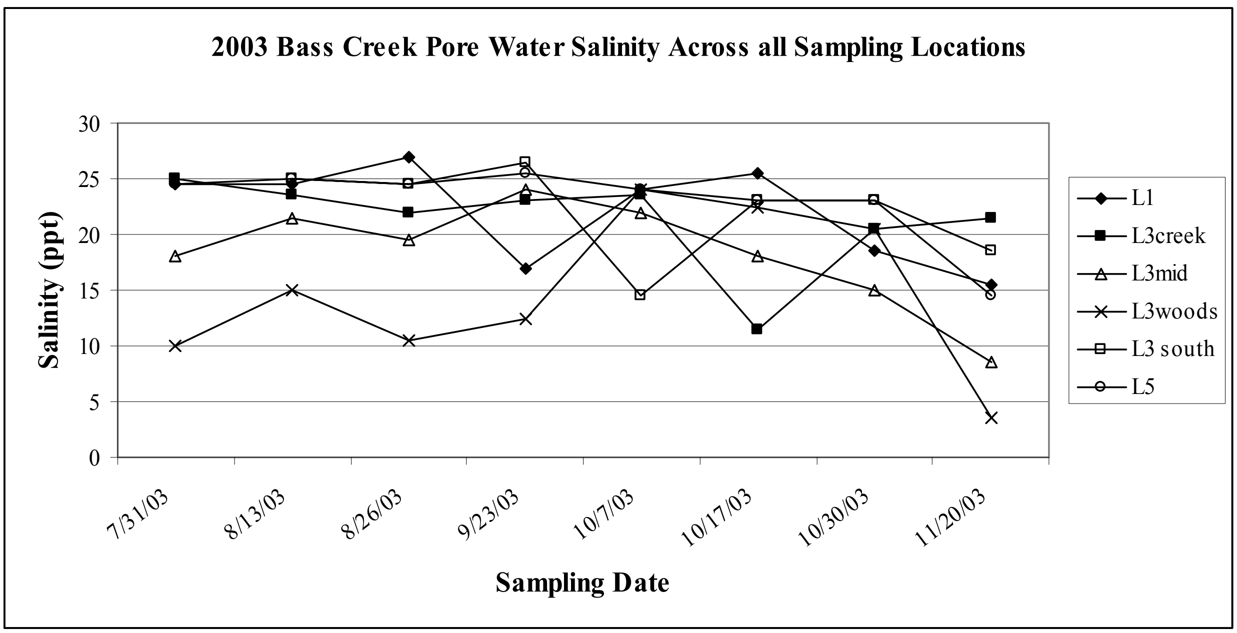


Figure 3 Pore water salinities averaged over all sites and depths for Cheverie Creek and Bass Creek.

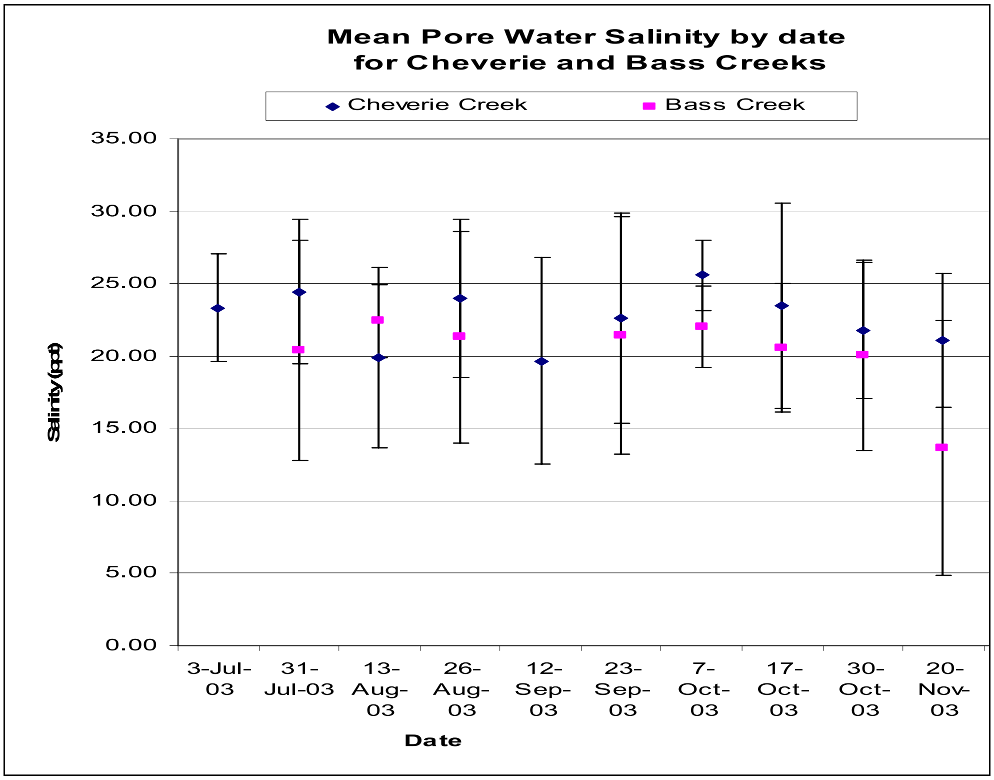


Figure 4 Comparison of average pore water salinities by date between Cheverie Creek and Bass Creek (2003).

Two years of sediment accretion data collected from the twenty-five sediment plates placed throughout Cheverie Creek were averaged (Table 1). Eleven stations exhibited an increase in elevation, eight experienced a decrease, one remained constant and five plates were unable to be located in 2003 (lost). When averaged over all sampling stations, the marsh experienced an average increase in elevation of 0.33 cm. When looked at on an individual transect basis, L2 and L7 were the only transects that experienced a decrease in elevation. All other transects experienced an increase in elevation when all stations along each transect were averaged. However, for this method of elevation monitoring, two years of data is not really sufficient to make any real statements about marsh surface elevation changes.

Table 1 Change in marsh surface elevation (cm) at Cheverie Creek

Cheverie Creek			
Line and Station	**2002**	**2003**	**Accretion rate**
L1 1S	11.8	N/A	lost
L1 2S	10.4	10.58	0.18
L1 4S	9.8	N/A	lost
L1 6S	5	5.3	0.3
L1 8S	11.4	11.7	0.3
L2 3S	10.95	9.28	-1.67
L2 6S	9.1	8.98	-0.12
L3 1S	13.75	14.3	0.55
L3 2S	12	11.13	-0.87
L3 4S	13.4	14.3	0.9
L3 C2 (south)	8.73	15.6	6.87
L5 1S	9.1	N/A	lost
L5 2S	12.05	10.88	-1.17
L5 4S	11.7	12.93	1.23
L5 6S	11	11.2	0.2
L5 C2 (south)	8.85	10	1.15
L7 1S	13.05	N/A	lost
L7 2S	10.65	10.1	-0.55
L7 5S	11.25	11.15	-0.1
L7 8S	10.57	10.5	-0.07
L7 11S	11	N/A	lost
L7 14S	12.57	11.2	-1.37
L8 3S	8.97	9.25	0.28
L8 5S	10.83	10.83	0
L8 7S	10.45	11.05	0.6
Average accretion rate (cm/year)			**0.332**

1.2.3 Vegetation

The vegetation species found at both Bass Creek and Cheverie Creek along with the total percent coverage for each species per site derived from the line-intercept data are given in Table 2. A zero value indicates a recorded presence of the specific species during vegetation survey but in negligible amounts. Those species marked with an i/o are species that were not recorded during the line-intercept survey but were recorded during quadrat sampling at Cheverie Creek or recorded as an incidental observation. Where no value is indicated, the species was not encountered during formal survey work or recorded as an incidental observation.

Table 2 Identification of vegetation species found at both Bass Creek and Cheverie Creek, including percent coverage of vegetation species sampled, and habitat features.

Species/Feature			% Coverage Per Species	
Scientific Name	Common Name	Grouping	Cheverie C.	Bass C.
Ammophila breviligulata	American Beach Grass	Brackish	6	8
Atriplex patula	Marsh Orach	Halophyte	0	i/o
Carex paleacea	Salt Marsh Sedge	Brackish	6	1
Distichlis spicata	Seashore Salt Grass	Halophyte	0	0
Glaux maritime	Sea Milkwort	Halophyte	0	i/o
Juncus gerardii	Black Grass	Halophyte	7	18
Limonium carolinianum	Sea Lavender	Halophyte	0	i/o
Plantago maritima	Seaside Plantain	Halophyte	0	0
Potentilla anserine	Silver Weed	Halophyte	i/o	i/o
Salicornia europaea	Common Glasswort	Halophyte	0	i/o
Scirpus maritimus	Bulrush	Brackish	i/o	i/o
Solidago sempervirens	Seaside Golden Rod	Halophyte	2	i/o
Spartina alterniflora	Smooth Cordgrass	Halophyte	18	5
Spartina patens	Salt Meadow Grass	Halophyte	47	52
Sueada martima	Sea-blite	Halophyte	i/o	i/o
Tpyhaceae sp.	Cattail Family	Brackish	3	0
Triglochin maritime	Arrow-grass	Halophyte	i/o	i/o
Upland vegetation (unidentified)			3	7
Unidentified species			0	0
Unidentified species AA			0	0
Salt panne			3	0
Debris (ice rafted rock)			0	1
Main creek channel			5	9
Secondary creek channel(s)			0	0

Both marsh systems are predominantly high marsh, with the dominant species being *Spartina patens* (52% at Bass Creek and 47% at Cheverie Creek). Low marsh habitats in both areas were dominated by *S. alterniflora.* Also present on both marshes is a range of high marsh and upland edge species including *Juncus gerardii, Carex paleacea, Solidago sempervirens* and *Ammophila breviligulata* common to Fundy marshes. A number of brackish, freshwater and terrestrial plant species (*Tpyhaceae sp., Scirpus maritimus* and *Rubus strigosus*) were observed at Cheverie Creek that were either not present at Bass Creek or were present in very small numbers and in isolated patches.

The presence of a broad range of native (salt marsh) plant species at Cheverie Creek, is the result of successful re-establishment of elements of a tidal marsh community following the removal of the tide gate twenty years ago. This supports the hypothesis that tidal river and salt marsh habitat recovery through the removal of tidal barriers and the restoration of a more natural hydrological regime to former tidal systems in the Bay of Fundy is possible. It provides an indication of the time period involved in such a recovery process, which is similar to the time periods predicted by restorationists in the US and which is being tested by a number of projects (Warren et al. 2002; Weinstein 1998; Zedler 2001). As well, it holds well with the hypothesis that with further enlargement of the tidal opening, completely eliminating the restriction, further development and enhancement of marsh habitat and functions and the realization of the full habitat and productivity potential and self-sustainability of the system will occur.

1.2.4 Nekton

Fish

Fish were sampled from the main creek at both Cheverie Creek and Bass Creek to examine the fish assemblage using the marsh and the potential for secondary production. The mummichog (*Fundulus heteroclitus*) was the dominant fish species captured at both sites. Over both years at Cheverie Creek, the mummichog occupied 60% of the total catch, while threespine stickleback (*Gasterosteus aculeatus*), American eel (*Anquilla rostrat*a), banded killifish (*Fundulus diaphanus*), Atlantic tomcod (*Microgadus tomcod*) and brook trout (*Salvelinus fontinalis*) comprised 13%, 12%, 8%, 3%, and 3% of the total catch, respectively. For Bass Creek, the mummichog occupied 95% of the total catch, while threespine stickleback and American eel made up 3% and 1% of the total catch, respectively. Table 3 presents the species, number of individuals and percentage of total catch for all sampling techniques over both years at both sites.

Table 3 Species and numbers of individuals captured during 2002 and 2003 fish survey at Cheverie Creek and Bass Creek, using both minnow traps and a fyke net.

Species Scientific Name	Common name	2002 Cheverie	2003 Cheverie	2003 Cheverie (Fyke net)	Total Individuals
Anquilla rostrata	American eel	5	2	0	7
Fundulus diaphanus	Banded killifish	5	0	0	5
Gasterosteus aculeatus	Threespined stickleback	4	4	0	8
Fundulus heteroclitus	Mummichog	29	7	0	36
Carcinus maenus	Green crab	1	0	0	1
Crangon septemspinosa	Sand shrimp	2	3	0	5
Salvelinus fontinalis	Brook trout	2	0	0	2

Littorina sp.	Periwinkle	416	418	0	834
Microgadus tomcod	Tomcod		2	0	2
Family Talorchestia	Sandhopper		2	0	2
Total individuals		464	438	0	902
Total fish species		6	4	0	6
Total fish		45	15	0	60
Total crustaceans		3	3	0	3
Total molluscs		416	418	0	834
	Species		**2003 Bass**	**2003 Bass (Fyke net)**	**Total Individuals**
Anquilla rostrata	American eel		1	0	1
Fundulus diaphanus	Banded killifish		0	0	0
Gasterosteus aculeatus	Threespined stickleback		3	0	3
Fundulus heteroclitus	Mummichog		80	3	83
Carcinus maenus	Green crab		0	0	0
Crangon septemspinosa	Sand shrimp		4	0	4
Salvelinus fontinalis	Brook trout		0	0	0
Littorina sp.	Periwinkle		0	0	0
Microgadus tomcod	Tomcod		0	0	0
Family Talorchestia	Sandhopper		0	0	0
Total individuals			88	3	91
Total fish species			3	1	3
Total fish			84	3	87
Total crustaceans			4	0	4

Also captured in the minnow traps set at Cheverie Creek were a significant number of molluscs. All 834 individuals collected were periwinkles (*Littorina sp.*). Of the crustaceans collected, the presence of the green crab (*Carcinus maenus*), which is an invasive species to this region, is noteworthy. During the 2002 vegetation survey, a number of green crabs were observed in the low marsh areas of Cheverie Creek during the leading edge of the rising tide. No individuals were captured during the fish survey.

Comparing same year samples (no sampling took place at Bass Creek in 2002), the number of species of fish and crustaceans sampled at Cheverie Creek and Bass Creek were similar (Figure 5). Aside from mummichogs, the number of individuals for each species was similar. The number of mummichog collected at Bass Creek (80) was greater than the number of individuals collected at Cheverie Creek (7). Even with the 2002 data included, the number of mummichog collected at Cheverie Creek still only totaled 36 individuals. *L. littorea* were routinely observed at Bass Creek; however, no individuals were captured during the fish survey.

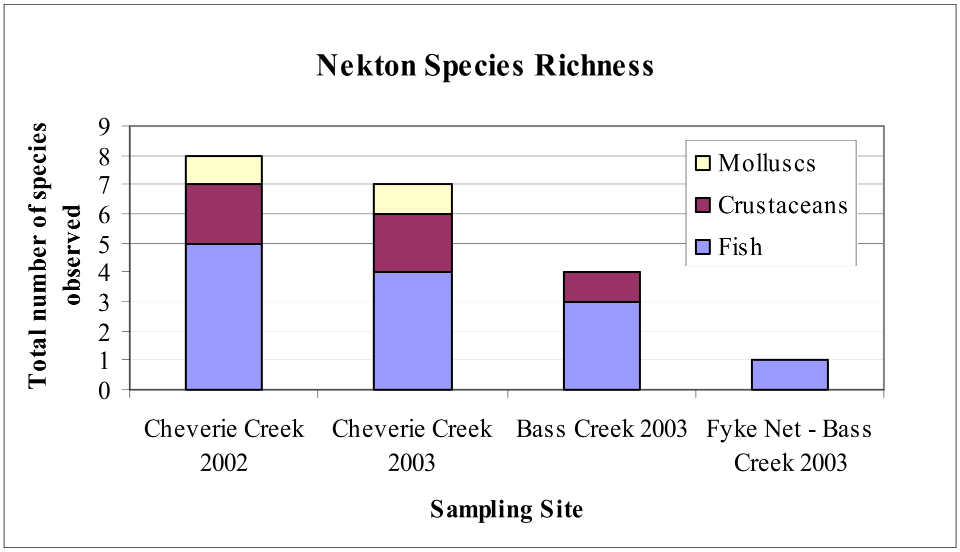


Figure 5 Number of fish, crustacean and mollusc species captured in minnow traps and fyke net.

Given that Cheverie Creek does receive regular, limited tidal exchange, the presence of similar species to those found at Bass Creek was to be expected. The differences in species and number of individuals is more likely influenced by structural factors such as the differences in the size of the main rivers, the amount of freshwater flow through the systems during low tide, and the overall size (length and width) of the systems rather than the frequency of marsh surface flooding. Cheverie Creek is larger in terms of channel width, depth, length and water volume. Through a combination of larger watershed, the damming effect of the causeway-culvert and elevation of the downstream system, the main river channel at Cheverie Creek retains a considerable amount of water at all times. In contrast, Bass Creek almost completely drains during low tide to the point where most of the creek, except for a limited number of deeper pools, is no deeper than 40 cm for much of the summer. The retention of water throughout the entire tidal cycle at Cheverie Creek combined with the larger percentage of *S. alterniflora* dominated low marsh habitat and the more complex network of pools, pannes and secondary drainage channels, potentially contribute to the slightly greater number of species and individuals.

It is likely that a number of larger fish species frequent both systems. However, due to difficulties with the fyke net and the lack of more appropriate sampling equipment (lift nets or beach seine), it was not possible to sample effectively for larger species. In addition, sampling using all techniques should be carried out during spring, summer and fall.

Although a focused fish survey was not conducted in the pannes on either marsh, observations of fish presence and absence were made during the 2003 mosquito larvae survey. Fish were observed to be present in a number of the pannes on both sites, although typically only in those pannes that received regular tidal flushing (those situated close to the high/low marsh interface) and which contained larger volumes of water (and therefore – did not dry up during the mid summer months). In addition to observations of the presence or absence of fish during the mosquito larvae survey, random samples were taken throughout both years of the study using a basic dip net. This was qualitative sampling; it was intended to gain insight into the species of fish present in the pannes. Over the course of the two years, *F. heteoclitus, G. aculeatus, Pungitius pungitius*, *F. diaphanus, Menidia menidia* and several unidentified species (potentially juveniles of the above) were identified. Of particular note, individuals captured in the pannes were smaller in size than those caught in the creek. This trend of smaller individuals in the pannes reflects observations made by research projects conducted on restoration and reference marshes in New Hampshire where it was hypothesized that pannes may be utilized by smaller fish as refuge habitat (Eberhardt and Burdick 2003).

An additional observation made at the restoration site relating to panne usage by fish is the presence of a large number of dead juveniles in a number of the shallow pannes early to mid July 2003, particularly *G. aculeatus*. This is likely the result of increased water temperature and reduced levels of dissolved oxygen caused by the presence of extensive algal mats. Metaphytic algae may function as a barrier to gas exchange and increase oxygen consumption at night.

Mosquitoes

The total number of mosquito larvae sampled over all stations at Bass Creek and Cheverie Creek is presented in Figure 6. At both locations, the largest number of larvae was collected on July 17, 2003. Fish, particularly *F. heteroclitus,* are voracious predators of mosquito larvae and are the main biological control predators used in mosquito control on Open Marsh Water Management marshes in the US (Garcia 1983; Hruby et al. 1985). Our field observations and measurements that saw low numbers of mosquito larvae in pannes possessing resident fish populations supports research identifying fish as the limiting factor for mosquito breeding (Lowry 1929). This held true for pannes at both study sites as those pannes that were observed to contain fish at the time of sampling yielded the lowest number of mosquito larvae observed and sampled. At Cheverie Creek, the pannes located along Lines 3, 5, 7, 11, and 25 contained the highest number of larvae. At Bass Creek pannes 4, 5 and 7 contained the highest numbers of larvae. In both cases, these were the shallow pannes located near the terrestrial edge of the high marsh, which did not receive regular tidal recharge, contained large algae mats, were mainly rain fed and did not contain fish.

Those pannes containing fewer numbers of larvae at both sites were those which were located nearer the high/low marsh interface, experienced more regular tidal flooding, were deeper and contained fish. The depth of these pannes, in addition to flooding frequency, may have an influence on the number of larvae observed, as the greater depth maybe an indication of greater permanency of these pannes as a part of the marsh landscape. As well, the greater depth may result in more favourable conditions for fish (lower water temperatures, stable salinity levels, available cover).

Both the salt marsh mosquito (*Aedes sollicitans*) and the freshwater species (*Aedes cantator*) were present in the pannes sampled; however, due to the large number of individuals encountered, identification and division between species during sampling was not conducted. The high population numbers during mid-July and the subsequent decline to zero by early September is consistent with the population dynamics of the mosquito which sees a shift from feeding and reproduction around the end of July to early August in preparation for the coming winter.

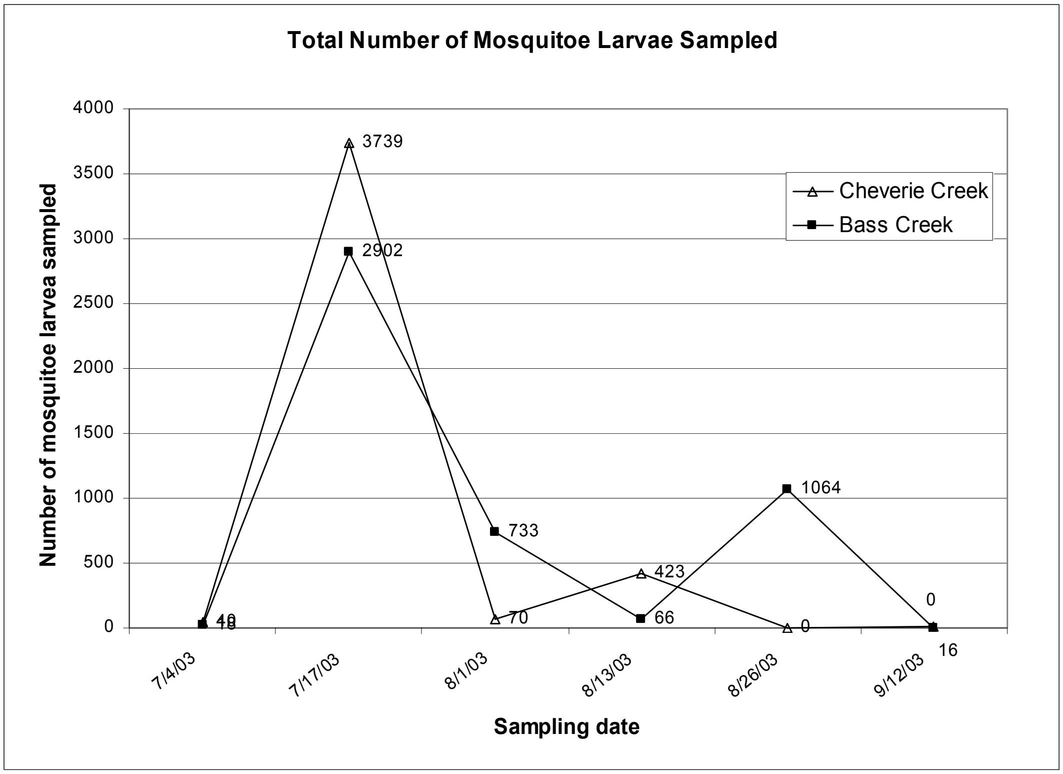


Figure 6 Total number of mosquito larvae sampled over all dates at Cheverie Creek and Bass Creek.

1.2.5 Birds

A list of the bird species and total numbers of individuals of each species observed during the 2003 bird survey at both Cheverie Creek and Bass Creek is given in Table 4. As discussed, Cheverie Creek, at approximately 60 acres, is a considerably larger wetland system than Bass Creek, at only 13 acres. The greater range and extent of wetland habitat types present at Cheverie Creek (salt marsh, brackish, tidal fresh, fresh and upland edge) results in greater range of ecological niches for a larger number of species and individuals. Even with the tidal restriction in place at Cheverie Creek, the tidal component of that system is larger than that present at Bass Creek and therefore it has more habitat available for salt marsh dependent bird species such as Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*), and Willet (*Catoptrophorus semipalmatus*).

Twenty-six bird taxa were observed on the Cheverie Creek system during the 2003 surveys. Twenty species were observed at Bass Creek. During our surveys, a total of 707 birds were observed (heard and sighted) at Cheverie Creek, while only a 138 were observed at Bass Creek. The birds most often observed during surveys at Cheverie Creek were Semi-Palminated Sandpipers (127), Tree Swallows (124), and Nelson's Sharp-tailed Sparrows (112). Bird counts were highest during the month of August (August 19, 2003). As an example, Figure 7 presents the abundance of Nelson's Sharp-tailed Sparrow, a rare salt marsh dependent species, observed at Cheverie Creek. The American Goldfinch (50) and an unidentified species referred to as "Little Brown Bird" (26) were the most common birds observed on Bass Creek, with all other species being observed in the single digit range. If resources and access to experienced birders had been available and surveys conducted during the spring migration and breeding season, the species richness and diversity numbers recorded would potentially have been higher.

Although not observed during the bird survey at Cheverie Creek, Great Blue Heron's were routinely observed during both field seasons fishing in the salt pannes along transects 1, 3 and 7. Further, local residents have reported seeing Short-eared Owls at Cheverie Creek.

Table 4 Bird species and number of individuals observed during the 2003 bird survey at Cheverie Creek and Bass Creek.

Species	Number of Individuals Observed	
	Cheverie Creek	Bass Creek
American Black Duck	22	0
American Crow	25	7
American Goldfinch	27	50
American Robin	5	5
Bald Eagle	5	0
Black Capped Chickadee	5	12
Cedar Waxwing	18	0
Double-crested Cormorant	4	0
Blue Jay	47	0
European Starlings	13	0
Great Blue Heron	0	2
Hummingbird	0	3
Kingfisher	2	4
Least Sandpipers	17	0
Merlin	6	0
Mourning Dove	0	1
Nelson Sharp-tailed Sparrow	112	0
Northern Flicker	20	6
Northern Harrier Hawk	8	0
Pileated Woodpecker	3	0
Red Winged Blackbird	1	1
Rusty Blackbird	0	2

Herring Gull	67	5
Sanderling	0	1
Semi-palmated Sandpiper	127	0
Solitary Sandpiper	3	5
Sparrow, unknown species	15	1
Tree Swallow	124	1
Warbler (yellow/black)	0	1
Willet	4	4
Wren	1	0
Unidentified species "A"	0	1
Unidentified species "little brown bird"	26	26
Total Individuals	**707**	**138**

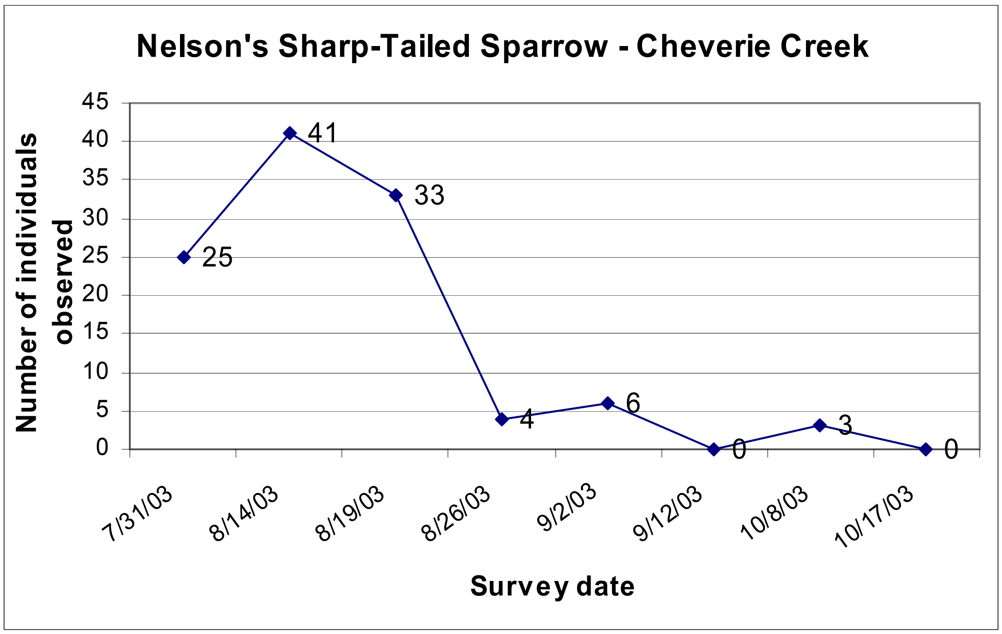


Figure 7 Nelson's Sharp-tailed Sparrow abundance at Cheverie Creek (post-breeding season).

1.2.6 Incidental Observations

In addition to the plant, fish and bird species identified during formal sampling/survey work, a range of other wildlife species were observed on both systems. Observations are obviously biased towards Cheverie Creek due to the considerably greater period of time spent at that location due to the additional year of monitoring work, size and research focus. Notable species observed (excluding those already mentioned) include: white-tailed deer, coyote, bald eagles, striped bass, red-backed vole, common wood nymph, rainbow trout, a variety of spiders, and individuals and a family of ruffed grouse.

1.3 General Discussion

A number of salt marsh plant, fish and bird species and easily identifiable salt marsh habitat zones have developed at Cheverie Creek in the twenty years since the removal of the tide gate. Prior to the natural removal of the Cheverie Creek tide gate, this system would have been predominately a terrestrial/freshwater system. The reintroduction of salt marsh species and the reestablishment of salt marsh habitat areas (low marsh, high marsh, pannes, upland edge) is evidence for the argument that removing tidal barriers favours restoration of salt marsh and tidal marsh habitat in the Bay.

The continued presence of freshwater and terrestrial species along the upland edge and extending out over the marsh surface in a number of locations, and completely dominating the entire marsh surface towards the back of the marsh (>line 26) at Cheverie Creek, is the result of the restrictive nature of the current causeway-culvert. It is anticipated that, with the replacement of the current culvert with a significantly larger opening (>8 m x 3 m), an expansion of the more salt tolerant plant species (halophytes), particularly *S. alterniflora* and *S. patens*, will occur (Konisky 2004).

With increased tidal flooding and frequency, the quality of salt panne and pond habitat for fish is anticipated to improve which should result in increased fish usage of these areas and subsequently a reduction in mosquito larvae numbers. Research on natural and restored salt marshes in New England has shown the significance of these coastal wetlands, and in particular salt marsh pannes, as habitat and food sources for fish, wildlife and avian species (Clarke et al. 1984; Daiber 1982; Erwin 1996; Warren et al. 2002; Weinstein 1998; and Zedler 2001). Similar research and level of understanding, particularly with regard to salt marsh restoration and the importance of salt marshes to fish, is currently not present for Bay of Fundy salt marshes.

The science of salt marsh restoration is, however, far from being able to predict the outcome of many restoration actions. It is only by engaging in restoration demonstration projects and coupling such projects with detailed pre- and post-restoration monitoring programs that contain a high degree of compatibility with similar work occurring throughout the region that the predictability of restoration outcomes can be improved. The ability to make informed decisions concerning the necessary actions needed to bring about desired habitat restoration results depends upon learning from each restoration project undertaken.

1.3.1 Marsh vs. Marsh

Based on similarities observed between Cheverie Creek and Bass Creek, it was demonstrated that Cheverie Creek is proceeding naturally along a restoration trajectory that not only is bringing it into parity with the unrestricted Bass Creek marsh but which is exceeding the unrestricted site in some aspects of habitat diversity and function. Future habitat management activities at Cheverie Creek, which will include the further restoration of a more natural hydrological regime to the system, will serve to enhance the recovery process that has been occurring over the past two decades. Such management actions will, as shown by Konisky (2004), result in an increase in flooding frequency and spatial extent of the Cheverie Creek marsh surface.

With increased flooding frequency and extent of tidal flooding, an increase in accretion rates in low lying areas of the marsh is likely to occur. It was observed during the study period that a larger amount of the Cheverie Creek marsh surface was covered by water than that of Bass Creek, both in terms of the number of well developed pannes and in the number of secondary creek channels, drainage ditches (dales) and depressions on the marsh surface that retain rain and run off water. Over time, with increased tidal flooding and a potential increase in sediment supply, the secondary channels, ditches and depressions may experience infilling or further development into permanent pools. Little is known about the development process of pannes and pools and the role that they play in the form and function of Bay of Fundy salt marshes; hence, it is difficult to draw conclusions about the impacts of their development, loss or conversion. The continued monitoring of the Cheverie Creek system, and research efforts post-restoration, have the potential to provide valuable information on the development and role of open-water areas in Bay of Fundy salt marshes.

Over the longer term post-restoration, changes in organic content, soil composition and bulk density are likely to occur. The supply of inorganic materials to the marsh surface should increase with increased tidal flooding following restoration. Despite the increased sediment supply and inorganic contributions to marsh surface elevations, the trend of increasing organic content at locations further from the main creek is likely to be retained but to a lesser degree. With increased sediment supply, the percentages of sands, silts and clays are likely to also increase, bringing the soils of the Cheverie Creek system closer in composition to those observed on tidal systems elsewhere in the Bay, given the location of the system and continued residual influence of the causeway and remnant dyke system. Monitoring accretion rates, elevation and sediment characteristics post restoration should reveal this shift away from a largely biologically dominated system.

The occurrence of a range of well established salt tolerant species following two decades of salt marsh reactivation (unmanaged restoration of tidal flow) is consistent with research and restoration monitoring work being conducted on New England marshes (Warren et al. 2002). The diversity of species is greater at Cheverie Creek than at Bass Creek, likely due to the greater area established as high marsh habitat and the presence of freshwater and terrestrial plant species. It is expected that an expansion of primary salt marsh species (*S. alterniflora, S. patens* and *Juncus gerardi*) and a reduction in freshwater and terrestrial species (*Typhaceae sp., Scirpus maritimus,* and *Ammophila breviligulata*) is likely to be observed following restoration.

An expansion of the detailed vegetation research conducted by Chiasson (2003) to encompass the entire marsh area at Cheverie Creek combined with replication at the reference site would provide greater insight into the relationship between current hydrological, soil, sediment and vegetation conditions. This would allow for greater comparison between restricted and reference site conditions.

Research has shown that fish species, particularly characteristic species such as *F. heteroclitus*, are likely to return to restored marshes soon after restoration of tidal flow (Warren et al. 2002). The species observed and sampled at Cheverie Creek would certainly appear to support the theory that small to medium sized marshes with well developed secondary channels, pannes and drainage systems support a significant number and richness of fish species, including a range of other macrovertebrates and invertebrates. However, in this study, the failure to secure effective sampling equipment significantly hindered the ability to sample fish species' use of creek and marsh surface at both locations. The differences observed between the two sites were likely the result of sampling intensity, habitat size, and habitat features.

With respect to fish, installation of a larger tidal crossing at Cheverie Creek will result in: improved fish passage to the system (elimination of velocity barriers created by the small culvert); improved access to a larger percentage of the marsh surface and the network of salt pannes (increased frequency, extent, duration and depth of tidal flooding of the marsh surface); and increased productivity potential of the system due to the greater percentage of the system available for use by fish, and the mobilization and transport of a larger amount of carbon-based materials into and out of the system.

Similar to fish, birds are a highly visible group that frequents marsh habitats, which can be difficult to sample. Salt marsh specialists (Willet and Nelson's Sharp-tailed Sparrow) are likely to be the most directly affected by changes in hydrology and plant community composition. Both species require extensive, well developed high marsh habitats to be successful. This is likely the reason so few individuals of these species were observed at Bass Creek which hosted a well developed but small high marsh zone in 2003. The generalists are less likely to be significantly affected by restoration activities, since changes will result in habitat enhancement rather then in significant changes to habitat type. Warren et al. (2002) observed that in the short term following restoration (4 -5 years), recolonization of recovering salt marsh habitat by salt marsh generalists is high. It is only in the longer term (10 – 15 years) that the specialists become established, which would appear to be the case with Cheverie Creek.

1.3.2 Limitations

In terms of area, habitat diversity, and species diversity and richness, the Cheverie Creek system has the appearance of being a more productive salt marsh system than Bass Creek. However, possessing a greater number of species or individuals (vegetation, fish or birds) is not necessarily a good indicator of greater function. This seems counter intuitive to the hypothesis that a tidally restricted system would less resemble a functioning tidal marsh system then an unrestricted system. However, this becomes understandable when you take into account the size difference between the two sites of this study and the recent history of the Cheverie Creek system.

Comparison of the Cheverie Creek system to a similarly sized and structured marsh system would undoubtedly provide greater insight into the ecological differences between restricted and unrestricted systems in the Bay of Fundy. Such a comparison would also allow for better monitoring of the natural recovery process that has occurred at this site over the past two decades.

The comparison to Bass Creek is not without merit, however. Each marsh regardless of size and/or structure is going to be host to physical and biological conditions, functions and species that are unique to that specific marsh, just as similarities will exist between all marshes within a region.

It can be expected that due to the close proximity of the two sites that such influences as tidal regime, sediment loading, and weather conditions would be similar. These are among the primary driving factors in marsh ecology whose influence would change with distance. A more suitable reference site was not available within a reasonable distance. All other river and salt marsh systems in the area were either substantially larger or were under the influence of one or more restrictions to tidal flow and species.

Limited financial resources did not allow for replication of hydrological, soil and sediment sampling at Bass Creek which would have enabled a more precise comparison of the physical features of the two systems. For example, had it been possible to collect surface elevation and tidal elevation data for Bass Creek, modeling of flooding frequency for that site would have been possible using Dr. Konisky's computer model. This would have enabled a comparison of flooding frequencies of the marsh surface between the two sites.

Limitations involved with the indicators and methods that were employed at both sites mainly revolve around access to equipment and sampling frequency. Particularly for fish and birds, sampling during the spring migration and breeding season would potentially have yielded species and numbers of individuals that were not present during the summer and fall periods when sampling did occur. Populations of fish, in particular, experience considerable spatial and temporal changes; a single tidal cycle can significantly change the number of individuals, species, and distribution of fish within a marsh system (Zedler 2001).

Failure to account for winter conditions (as discussed in Chapter 4) at both study locations is also potentially a significant limitation of this study.

1.4 Summary

There were several limitations to the field test of the GPAC Monitoring Protocol. The lack of access to appropriate sampling equipment and the presence of hazardous conditions (hydrology) contributed to the inability to effectively sample several of the indicators at both Cheverie Creek and Bass Creek. Commencement of sampling earlier in the season (spring) would have provided a greater range of samples with which to conduct analysis and would have revealed conditions and species that were not present later in the season. For example, the lack of capacity to conduct bird surveys during the breeding season (early spring) is a considerable shortcoming of the study.

Bass Creek, although an unrestricted tidal river and marsh system in close proximity to Cheverie Creek, is not an ideal reference site due to the historical alterations to tidal flow (previously dyked and farmed) and more specifically, the size difference between the two sites.

Winter processes (tides, storms, ice scour, ice rafting) may play a significant role in the geomorphic development and productivity of Bay of Fundy salt marshes, potentially more so than they do in more southerly marshes. Failure to address (quantify) this role is a shortcoming of both this study and the GPAC Monitoring Protocol.

Nonetheless, the application of the GPAC Monitoring Protocol to the Cheverie Creek and Bass Creek tidal river and salt marsh systems did reveal a number of insights into the impacts of the existing tidal crossing on the upstream system and the similarities and differences in form and function of the two systems. It was found that the existing tidal crossing tidal crossing (causeway and undersized wooden culvert) at the mouth of the Cheverie Creek system is a significant restriction to tidal flow, freshwater drainage and the movement of species and materials into and out of the system.

The presence of a range of physical and biological conditions and species at Cheverie Creek following two decades of unmanaged restoration of limited tidal flow was similar to those observed at Bass Creek and on marshes being studied elsewhere in the Bay of Fundy and Gulf of Maine. However, Cheverie Creek is tidally restricted and removal of the tidal restriction would re-introduce natural tidal flooding to a large percentage of the system and improve ecological conditions for native plant, fish and wildlife communities.

Monitoring of plants, fish and birds at both systems has shown that Cheverie Creek, as a result of limited restoration of tidal flooding, has progressed along a restoration trajectory so that it resembles a functioning salt marsh system. However, the presence of a large number of less salt tolerant plant species over a large area of the marsh, and the ratio of salt marsh generalists to specialist (birds), when combined with the examination of the hydrological conditions, soils and sediments (organic content, bulk density), indicates that the system has not yet achieved, and is unlikely to achieve without active intervention, full recovery to a self-sustaining tidal wetland system similar in form and function to unrestricted marsh systems in the region.

APPENDIX D – LOCATION OF TRANSECT LINES AND SAMPLING LOCATIONS

Transect lines and sampling locations at Cheverie Creek.

Lines – Transect lines (vegetation survey lines)
Arrow – Locations of tide level recorders
Dot – Bird sampling stations
Square – Water table depth and soil salinity sampling stations
Polygons – Mosquito sampling stations (pannes)

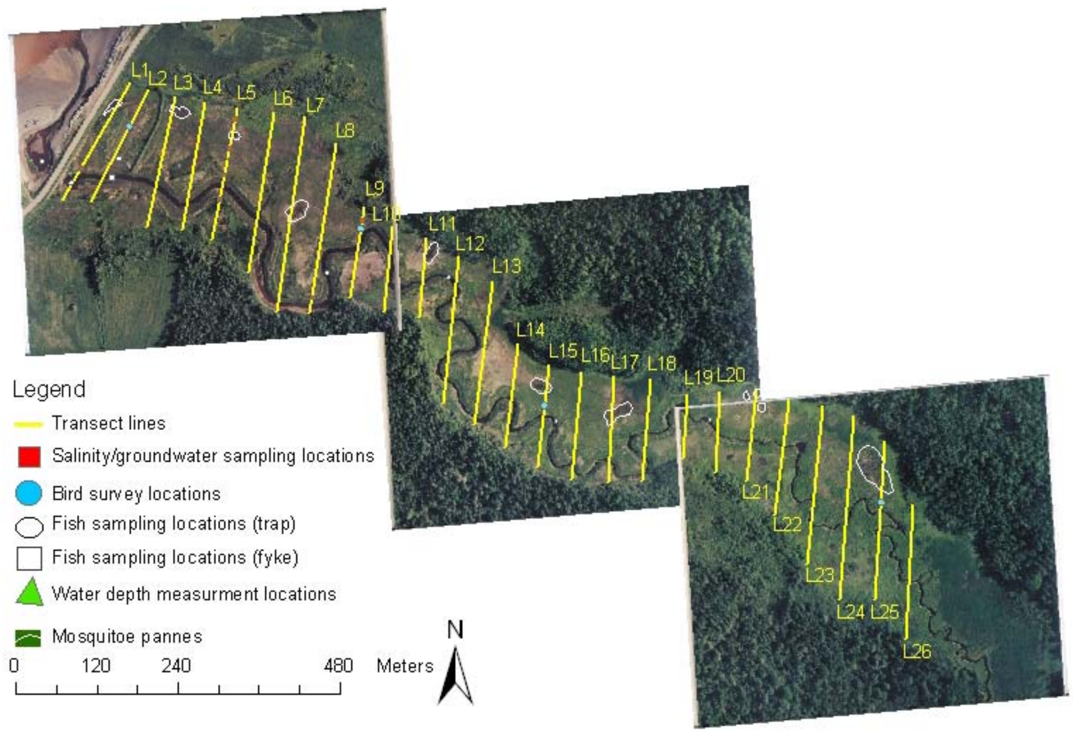


Figure 1. Cheverie Creek - complete study area, 1:10,000 scale.

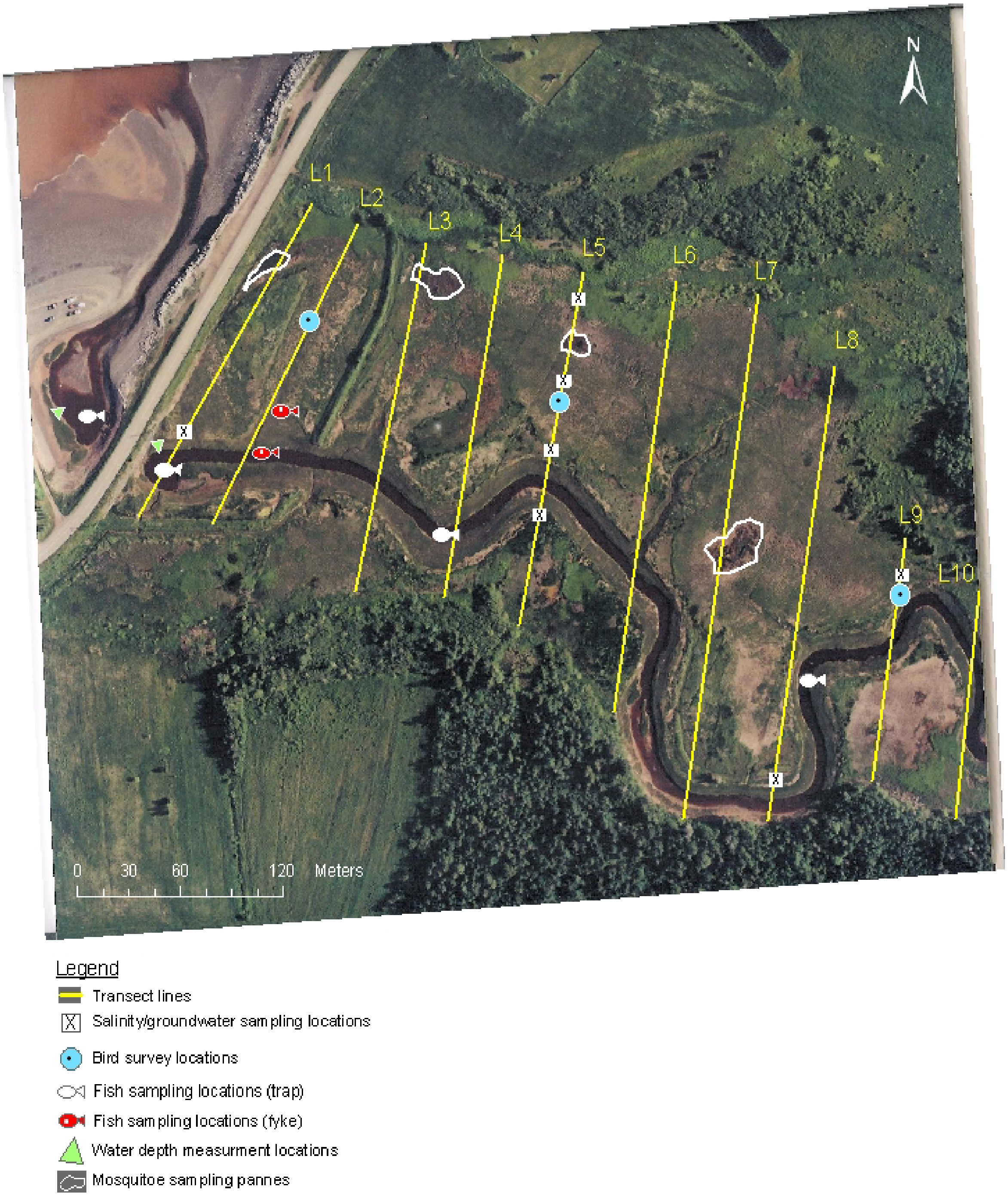


Figure 2. Front part of marsh, 1:10,000 scale at 5x zoom.

Figure 3. Mid marsh, 1:10,000 scale at 5x zoom.

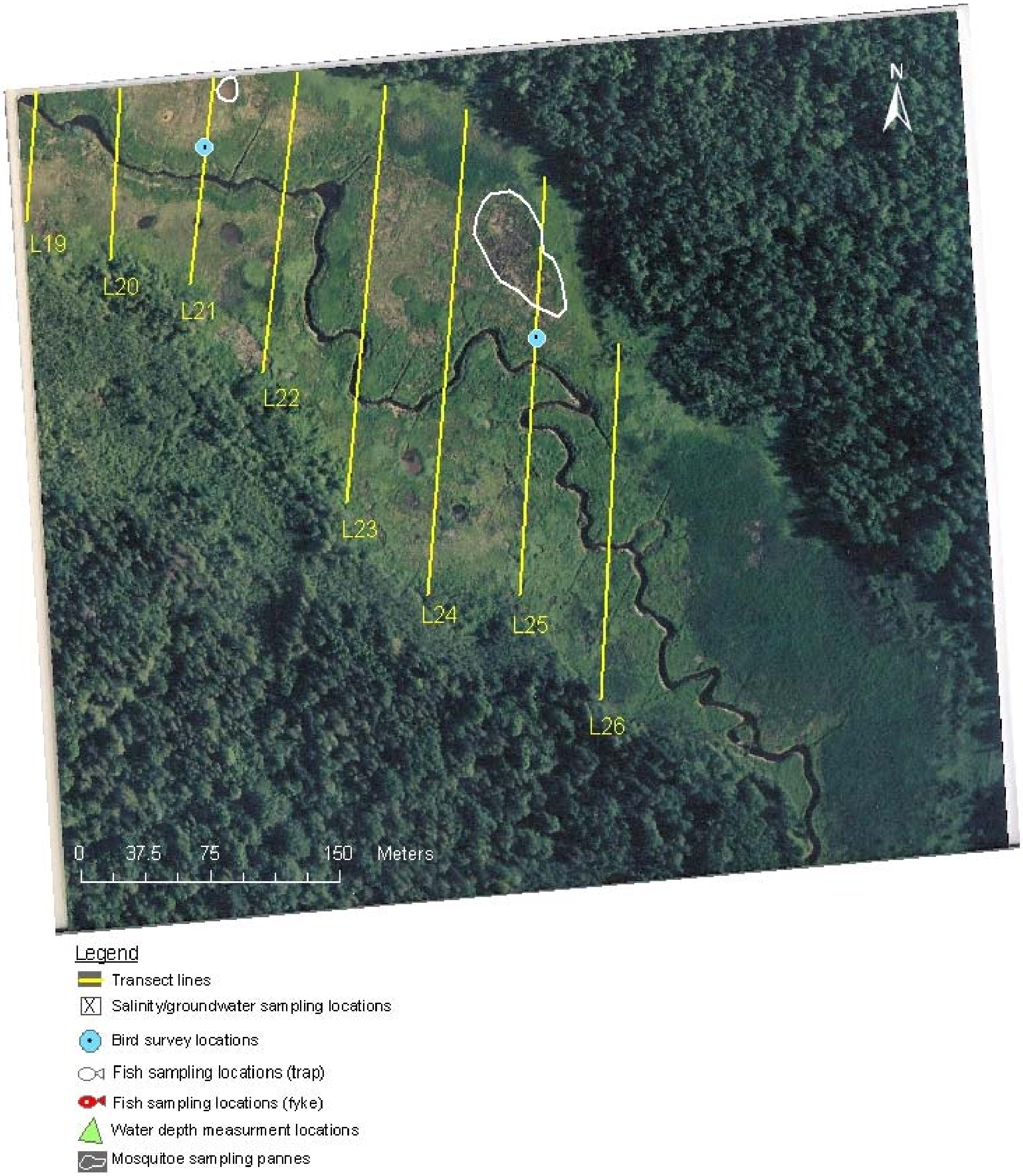


Figure 4. Back part of Cheverie Creek.

Transect Lines and Sampling Locations at Bass Creek.

Figure 5. Bass Creek salt marsh system.

Figure 6. Front part of Bass Creek.

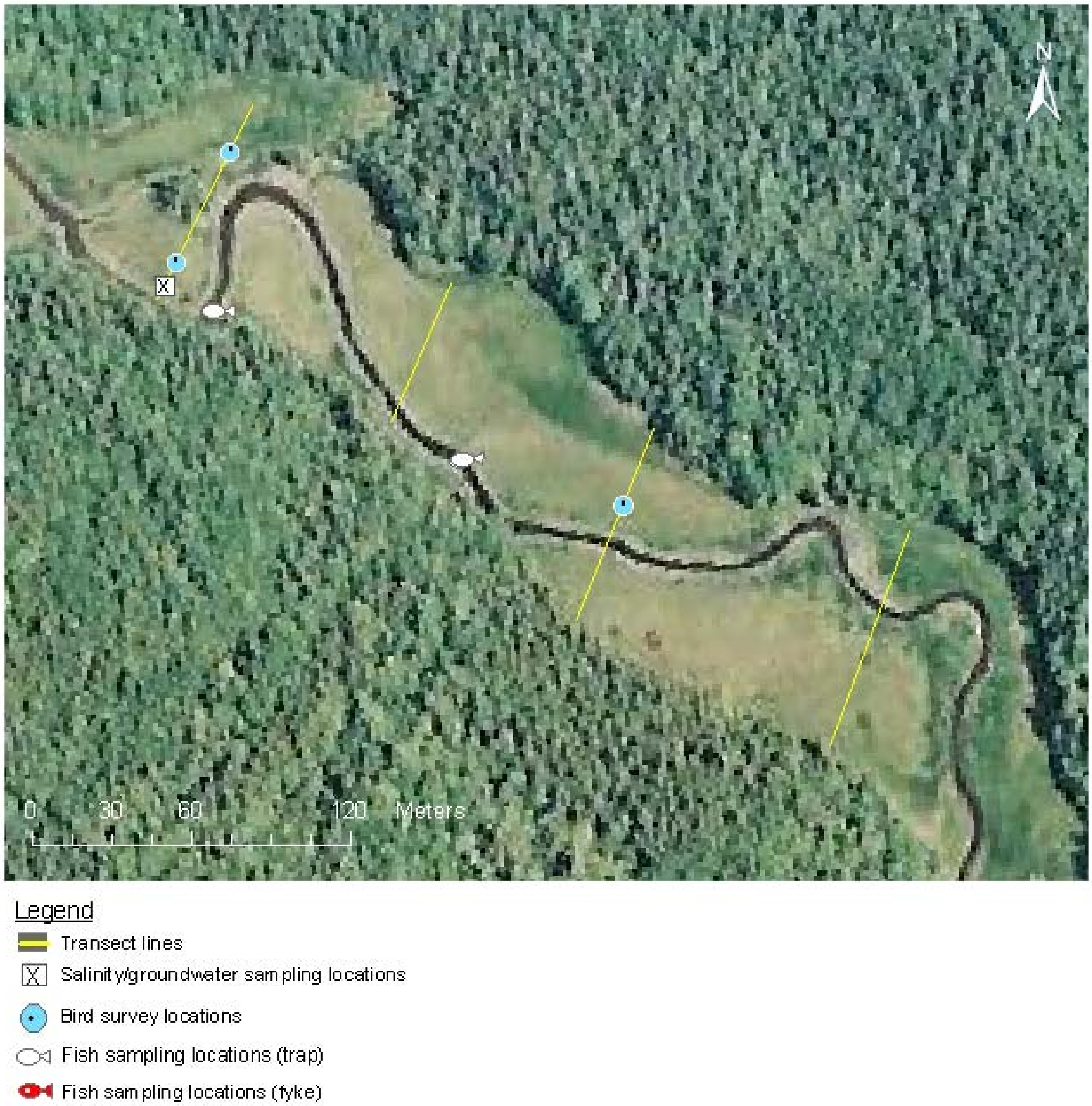


Figure 7. Back part of Bass Creek.

APPENDIX E – HYDROLOGIC MODELING REPORT

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ANALYSIS OF TIDAL HYDROLOGY AT CHEVERIE CREEK MARSH

February 12, 2004
Revised June 1, 2004

Raymond A. Konisky, Ph.D.
Wells National Estuarine Research Reserve, Wells, ME, USA

Executive Summary

Cheverie Creek Marsh is a 30-hectare marsh connected to the Minas Basin by a wooden culvert under Route 215. Poor condition and negative ecological impacts of the undersized wooden structure have led to consideration of culvert replacement. Field measures and tidal charts were used to configure a model to investigate current and potential tidal flooding at the site. Model analysis shows that existing conditions result in a significant (1 m) tidal restriction for spring tides. The undersized culvert eliminates frequent tidal flooding for about 75% of the marsh area. Model scenario analysis predicts that the restriction would be removed by replacement of the wooden culvert with a bridge span no smaller than 8 m wide x 3 m high. Removal of the tidal restriction would re-introduce natural tidal flooding to about 25 hectare of marsh, and therefore improve ecological conditions for native plant, fish, and wildlife communities. It is therefore recommended that an engineering study be commenced to investigate flood control, highway impacts, and site construction designs for culvert replacement at the site.

Introduction

Cheverie Creek Marsh is a 30-hectare coastal wetland along the Minas Basin in Cheverie, Nova Scotia. The marsh is fed by Cheverie Creek, a tidal creek channeled through an old wooden double-culvert under Route 215. The poor condition of the culvert and the recognition that the culvert is undersized for tidal flows has led to an investigation of replacement options at the site. To assess the tidal hydrology of the marsh and culvert, field measurements were made in September and October of 2003 of simultaneous water levels on the bay (downstream) and marsh (upstream) over several high tides. These measures provided the basis for implementation of a simple calibrated model of Cheverie Creek tidal hydraulics. The model generated estimates of marsh tidal flooding for a complete tidal series, from neap to spring tides. When combined with elevation measures, projected tidal heights were used to estimate ecologically-important marsh flood frequencies. Lastly, the calibrated hydraulic model was reconfigured for new proposed structures (i.e., bridge spans or larger culverts) to assess changes in flood regime associated with potential improvements.

Methods and Model Calibration Procedures

The hydraulic model combined site tidal measures, local tide charts, and elevation survey data to simulate tidal conditions at Cheverie Creek. Model software was originally developed at the University of Maryland (Boumans et al. 2002), and further enhanced at the Jackson Estuarine Laboratory (Konisky et al. 2003). Computations of water flow through tidal structures (i.e., culverts) are based on standard engineering equations (Chanson 1999). The model used field measures and tidal chart data to configure the model for the Cheverie Site.

Field Measures. Culvert dimensions for the model were collected at Cheverie Creek on May 14, 2003. Dimensions are 40 m in length, with side-by-side 1.74 m x 1.34 m box culverts. Elevations were measured, using a rod and laser-level, to determine the culvert invert elevation and the peak elevation of the high tide (unrestricted bay side) on that date. Marsh elevations were also measured along 9 randomly assigned transects across the marsh, at 90 total locations. Elevation data were temporarily benchmarked to the elevation of the bottom of the culvert on the upstream side. On September 26 and October 1, tidal heights were measured simultaneously upstream and downstream of the culvert every 15 minutes for a high tide cycle, using a simple set of tide staffs.

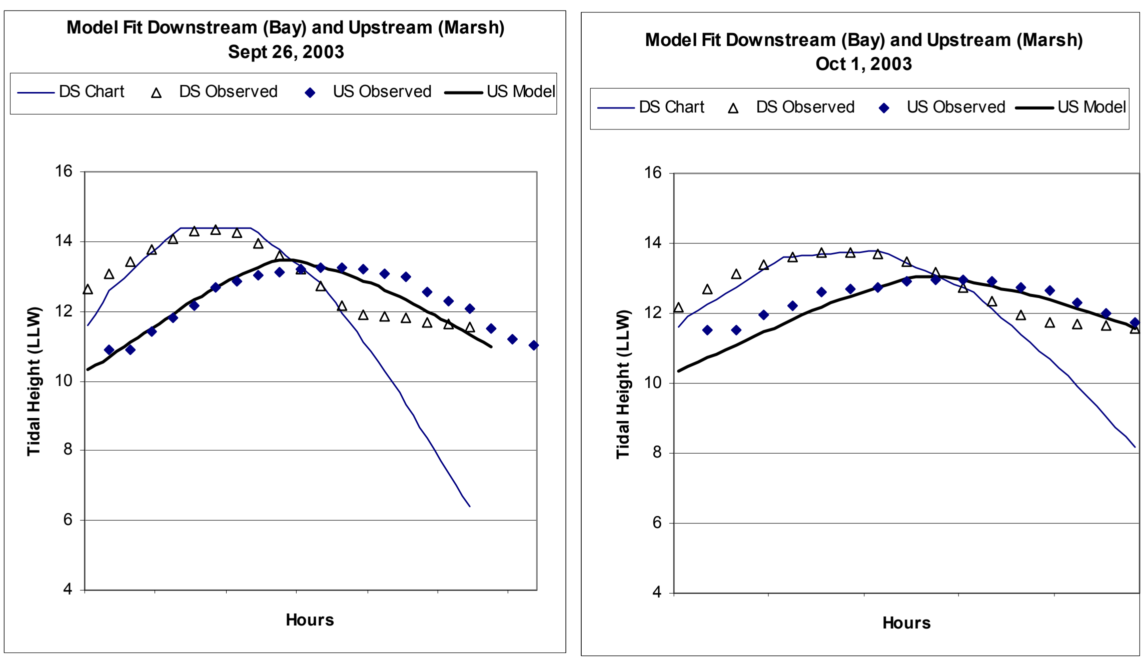

Figure 1. Model fit diagrams for Sep 26 and Oct 1 high tide with field measures.

Tidal Chart Data. The model requires a complete two-week, neap and spring tide record of tidal heights at 6-minute intervals to simulate the natural tidal signal at the site. To generate this record, the Canadian Hydrologic Services (CHS) web-based tide charts were accessed (http://www.lau.chs-shc.dfo-mpo.gc.ca/). The nearest available location, at Hantsport, was used as a proxy for Cheverie. A two-week set of hourly tidal heights were downloaded from September 19 to October 2, 2003, and converted to 6-minute intervals with linear interpolation. The CHS datum of Lower Low Water (LLW) was used for all elevation estimates in this analysis.

Model Calibration and Scenarios. Actual measures of downstream (unrestricted) tidal heights from Sep 11 and Oct 1 were plotted alongside tidal chart data from the same time to determine the datum correction to LLW (Figure 1). Peak-fitting exercises identified a datum correction to adjust tidal height measures to the LLW datum (Figure 1, upper lines). Predictions of upstream tidal heights were generated in an iterative set of calibration runs to match observed upstream heights with modeled estimated (Figure 1, lower lines). Model calibration was determined by visual analysis of the best fit for peak curves on both measurement days. Datum correction for the marsh elevation survey was also determined, by matching the observed peak of unrestricted high tide on the survey date (May 14) with the corresponding tidal height on the CHS website. Model scenarios were also developed to test the potential impacts of culvert expansion at the site.

Results and Discussion

The marsh elevation survey quantified the amount of Cheverie Creek marshland by elevation, resulting in a summary hypsometric curve. Figure 2 shows the curve, indicating that the marsh is dominated by a large flood plain at 13.0 m to 13.5 m of elevation (LLW), with little low marsh and creek (< 10%). Highest elevation areas are mostly associated with old agricultural dykes, although these features account for < 5% of marsh area. This hypsometry is typical of Gulf of Maine salt marsh, with the vast majority of the area classified as high marsh habitat.

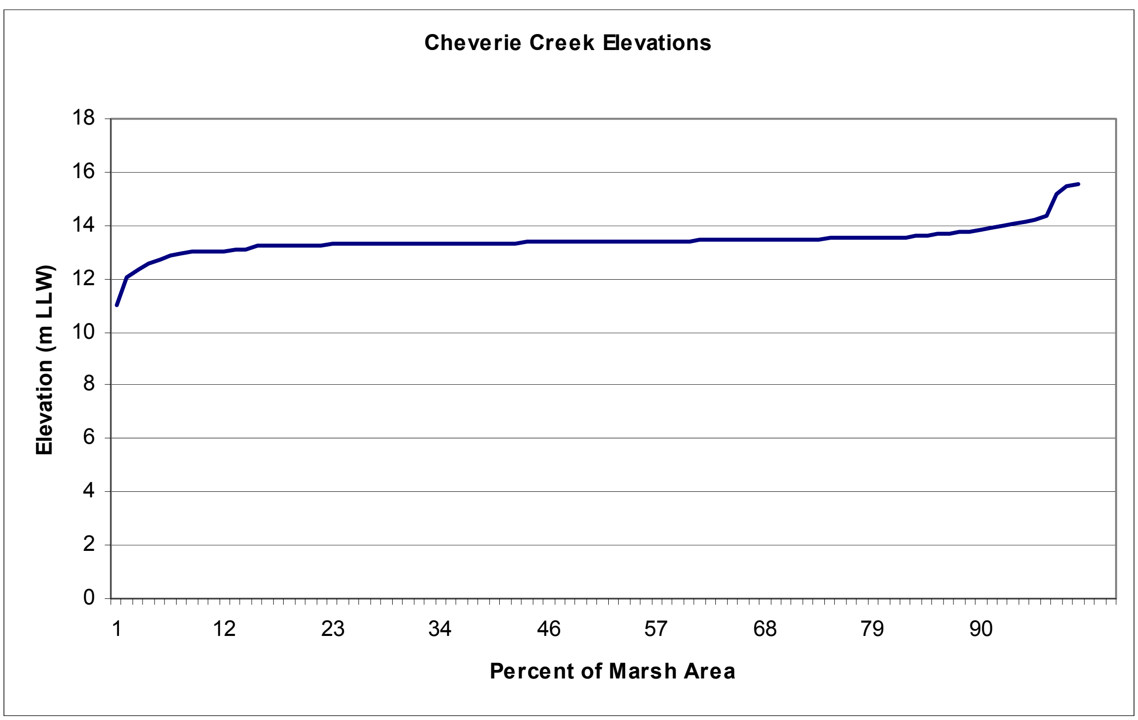

Figure 2. Hypsometric curve of Cheverie Creek showing amount of marsh area by elevation.

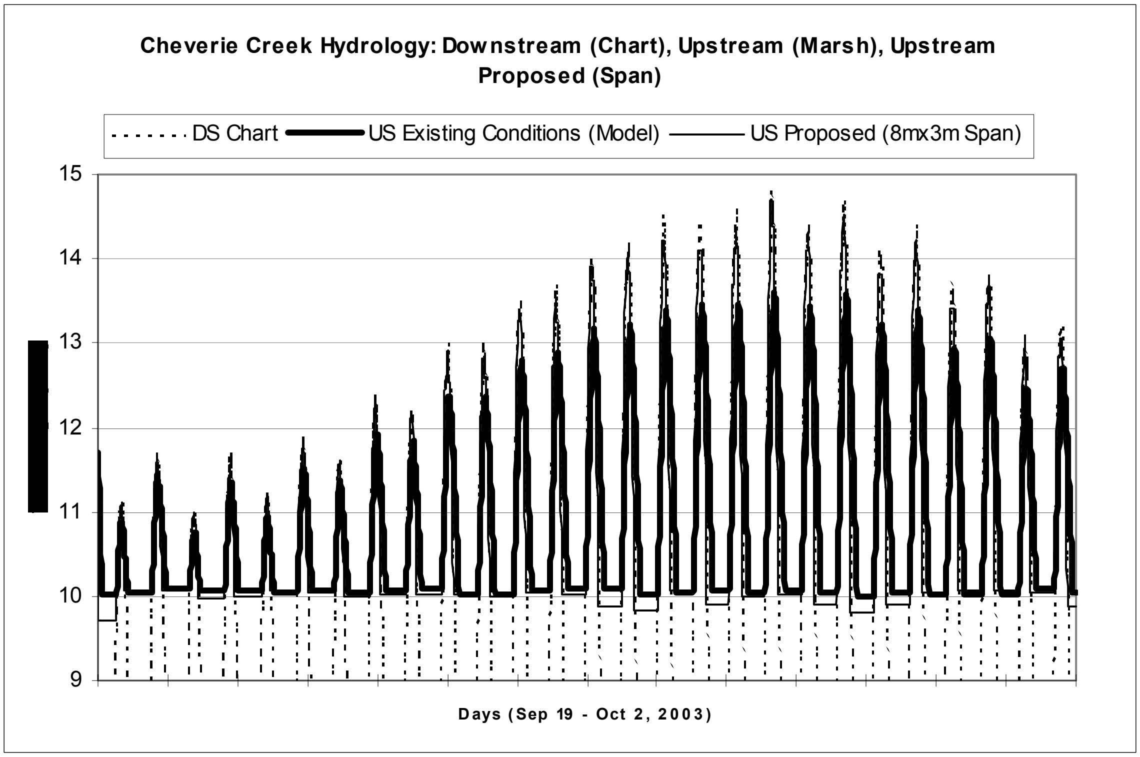

Figure 3. Tidal hydrographs for Cheverie Creek showing downstream (unrestricted) heights, upstream heights under existing conditions, and predicted heights following replacement of the culvert with a proposed 8 m by 3 m bridge span.

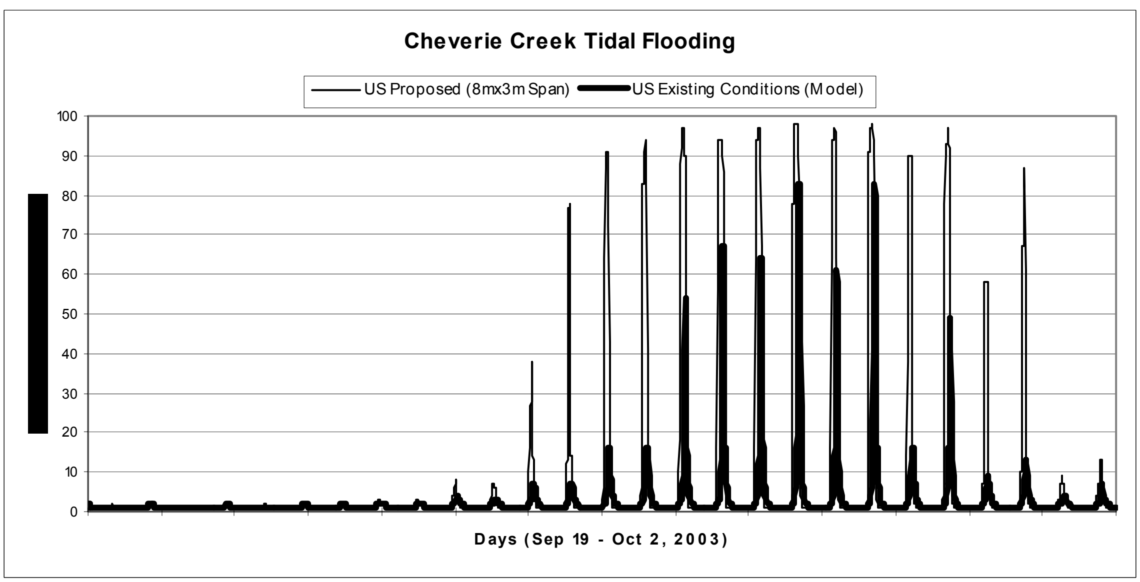

Figure 4. Tidal flooding for Cheverie Creek Marsh under existing culvert conditions and for a proposed 8 m by 3 m bridge span replacement.

Tidal hydrographs for Cheverie Creek are presented in Figure 3, showing the unrestricted downstream signal (based on tidal chart data) and the altered upstream signal (based on the calibrated model). The figure clearly demonstrates the restricted nature of tidal flows into the marsh, with reduced upstream heights for all but the smallest neap tides. Spring tide reductions are on the order of about 1 m. Figure 4 combines upstream tidal heights with marsh elevation to identify the flood regime of Cheverie Creek Marsh. Under existing conditions of tidal restriction, about 75% of high tides are insufficient to flood the expansive high marsh (elevations over 13 m LLW). These predictions are consistent with the observation that only about 5 of the 30-hectare marsh are routinely flooded (Bowron and Fitzpatrick 2001). While the current level of seawater inundation should be adequate to support most native plant communities (Konisky et al. 2003), the higher elevations of the marsh appear vulnerable to invasion by brackish plants. Further, the 1 m tidal restriction from the existing culvert may limit sediment and nutrient nourishment of the marsh, and reduce fish habitat, safe passage, and wildlife interactions.

To investigate the potential of culvert expansion, the model was reconfigured with an expanded inlet design at the same elevation as the existing culvert. Specifically, a bridge span system from the Shaw Group (www.shawgroupltd.com) was recommended for study by local highway authorities. The spans come in variable sizes from 4.27 m x 1.22 m (14 ft x 4 ft) to 11.58 m x 3.05 m (40 ft x 10 ft). The model was configured with both the minimum and maximum span sizes, and approximated as box culverts. Results indicate that replacement of the culvert with the large span would virtually eliminate the tidal restriction, with peak tidal heights at or near the unrestricted downstream heights. The small size span did not change the restriction, with upstream tidal heights the same as existing conditions. Three intermediate model scenarios were also run for replacement spans of the following dimensions: 1) 9 m x 3 m (29.53 ft x 9.84 ft), 2) 8 m x 3 m (26.25 ft x 9.84 ft), and 3) 7 m x 3 m (22.97 ft x 9.84 ft). Intermediate scenario runs predicted that the 9 m x 3 m size would completely remove the restriction, with 52% of all tides flooding the majority of the marsh surface. The 8 m x 3 m size also eliminated almost all of the restriction, with 48% of tides flooding the high marsh. However, the effects of restriction were more noticeable at the 7 m x 3 m size, with 44% of tides reaching high marsh. Based on this analysis, it is proposed that the minimum size for culvert replacement span at Cheverie Creek should be no smaller than 8 m x 3 m.

Potential impacts of the proposed 8 m x 3 m span on tidal flooding are shown in Figure 3 (tidal heights) and Figure 4 (marsh area flooded). Results show that removal of the restriction with an 8 m by 3 m span would double the number of tides that flood the majority of the marsh (Figure 4). A natural tidal cycle would be expected to provide wide-scale ecological benefits to the entire Cheverie Creek Marsh. Next steps should be an engineering review of flood control and structural design options for the proposed replacement project.

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