Jacques Whitford

FINAL REPORT

Background Report for the Fundy Tidal Energy Strategic Environmental Assessment

OFFSHORE ENERGY ENVIRONMENTAL RESEARCH ASSOCIATION

Project No. 1028476

Jacques Whitford

Environmental
Engineering
Scientific
Management
Consultants

3 Spectacle Lake Drive
Dartmouth NS
Canada B3B 1W8

Bus 902 468 7777
Fax 902 468 9009

www.jacqueswhitford.com

FINAL REPORT

Background Report for the Fundy Tidal Energy Strategic Environmental Assessment

OFFSHORE ENERGY ENVIRONMENTAL RESEARCH ASSOCIATION

PROJECT NO. 1028476

PROJECT NO. 1028476

PROJECT TO **Offshore Energy Environmental Research Association**
5151 George Street
Halifax, NS B3J 3P7

FOR **Background Report for the Fundy Tidal Energy Strategic Environmental Assessment**

ON **Bay of Fundy Tidal Power Development**

January 2008

Jacques Whitford
3 Spectacle Lake Drive
Dartmouth, Nova Scotia,
B3B 1W8

Phone: 902-468-7777
Fax: 902-468-9009

www.jacqueswhitford.com

in partnership with:

Acadia Centre for Estuarine Research

in association with:

Devine Tarbell & Associates Inc.

The Huntsman Marine Science Centre

W.F. Baird & Associates, Coastal Engineers Limited

Jim Calvesbert Consulting

PREFACE

This report was commissioned jointly by the Offshore Energy Environmental Research Association (OEER) Tidal Advisory Group (TAG) and the New Brunswick Department of Energy. Both Nova Scotia, through the OEER, and New Brunswick are carrying out strategic environmental assessments (SEA) of marine renewable energy in the Bay of Fundy, with particular focus on tidal instream turbines.

An SEA is an environmental assessment process carried out before decisions are to be made about specific projects. It involves the participation of a wide range of stakeholders and the general public, and will result in recommendations on whether, where and how to develop tidal energy in the Bay of Fundy.

This background report is intended to inform the SEA participants in both provinces by (a) drawing together existing information on the environment, the socioeconomic context, and marine renewable technologies, (b) addressing potential interactions, and (c) identifying information gaps. Any conclusions or recommendations contained in this report are the responsibility of Jacques Whitford, and have not been endorsed by either the OEER or NB Energy.

The next step in the process is to hear from all interested parties. We encourage you to make a written submission on any aspect of the report or any other issue pertinent to the SEA process, and to participate in forthcoming consultation meetings.

For more details visit www.bayoffundysea.ca. This website provides information and resources on the Nova Scotia process and a link to the New Brunswick process.

You may also directly contact:

Nova Scotia

Lesley Griffiths

SEA TAG Process Lead

oeer@offshoreenergyresearch.ca

New Brunswick

Heather Quinn

NB Department of Energy

heather.quinn@gnb.ca

EXECUTIVE SUMMARY

This report is a background study on ocean renewable energy which is intended to facilitate a Strategic Environmental Assessment (SEA) of potential tidal energy development projects in the Bay of Fundy. This study has been commissioned by the Offshore Energy Environmental Research Association (OEER) and co-funded by the New Brunswick Department of Energy.

Nova Scotia's current energy mix is primarily dominated by coal, which provides approximately 75% of the Province's electrical power. In Nova Scotia, Renewable Energy Standard Regulations, made under Section 5 of the *Electricity Act*, specify two main requirements. The *Renewable Energy Standard 2010* requires each load serving entity to provide customers with renewable low-impact electricity equivalent to at least 5% of its total annual sales for the calendar years 2010, 2011, and 2012. The R*enewable Energy Standard 2013* requires each load serving entity to provide its customers with renewable low impact electricity equal to at least 10% of its total annual sales. New Brunswick has a more diverse energy mix including; hydro, oil, coal, diesel, natural gas and nuclear generation. Pursuant to the *Electricity Act*, Regulation 2006-58 will require standard service suppliers to provide a minimum renewable energy component of 10% of kilowatts-hours sold by the year 2016 in the Province of New Brunswick. Price volatility of foreign energy supplies will affect both provinces, and the need to develop local energy resources will play an increasingly critical role in ensuring energy security for both the Provinces of New Brunswick and Nova Scotia.

In addition to regulated demand, there is also an increasing market demand for electricity generated by renewable sources such as tidal power, to reduce greenhouse gas (GHG) emissions and avoid the purchase of offset credits otherwise needed to meet reduction commitments. Tidal power generated in the Bay of Fundy is viewed as a potentially significant part of the renewable energy mix for Nova Scotia and New Brunswick.

Key study limitations in addition to those included in the terms of reference provided by OEER, include the following:

- The information provided in this report is at an overview level and based on readily available sources. There are information gaps in the description of existing environmental and socioeconomic conditions, ocean energy technologies, potential environmental interactions and management strategies.
- Development scenarios have been presented for illustrative purposes based on several factors including available tidal energy, and jurisdictional and ecological diversity. This report does not claim that these are "preferred" scenarios or that other locations would not be viable.
- It is assumed that all specific ocean energy projects, including demonstration projects, will be subject to project and site specific environmental assessment requirements as part of a regulatory environmental approvals process. This site specific evaluation, including consultation with potentially affected stakeholders, is considered vital for a complete evaluation of potential environmental effects and their significance as well as the development of specific mitigation and monitoring programs.
- Given the lack of specific knowledge on the nature, location and timing of potential tidal power development projects in the study area, potential interactions are described in general terms. Potential environmental issues are identified as well as an overview of general planning and

management considerations which may be implemented to avoid or reduce potential environmental interactions.

Based on the results of an issues scoping exercise, a list of Key Environmental Issues (KEIs) was prepared from which to focus this evaluation. The KEI's evaluated include: Critical Physical Processes; Fisheries; Fish and Fish Habitat; Marine Benthic Habitat and Communities; Pelagic Communities; Marine Mammals; Marine Birds; Species at Risk; Aquaculture; Marine Transportation; Tourism and Recreation; Marine and Coastal Archaeological and Heritage Resources; and Economic Development.

As requested by OEER, overview descriptions of several available marine-based energy conversion approaches are presented and discussed in the report; these include:

- Offshore Wind Energy Conversion;
- Tidal In-Stream Energy Conversion (TISEC);
- Tidal Lagoon Energy Conversion; and
- Wave Energy Conversion.

As requested by OEER, only TISEC is addressed in detail with respect to the Bay of Fundy; however, the other technologies may also be valid for certain applications subject to further evaluation and assessment.

Some aspects of a typical TISEC project construction and operation directly influence various biological and socioeconomic components, and some influence the physical processes, which could in turn influence the biological components. The following table outlines typical project components and potential physical, biological and socioeconomic interactions. The potential interactions and environmental management and planning considerations with respect to several development scenarios are outlined in more detail in this report.

TABLE E.1 Typical Environmental and Socioeconomic Interactions with TISEC Projects

Project/Construction Phase	Physical Process Interaction	Biological Component Interaction	Socioeconomic Component Interaction
Seabed Preparation	▪ Sediment transport ▪ Waves/currents through channel modification ▪ Noise and vibrations ▪ Introduction of additional hard-substrate	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Marine and Coastal Archaeological and Heritage Resources ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Pile Installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Noise and vibrations	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation

TABLE E.1 Typical Environmental and Socioeconomic Interactions with TISEC Projects

Project/Construction Phase	Physical Process Interaction	Biological Component Interaction	Socioeconomic Component Interaction
Gravity Foundation Installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Introduction of additional hard substrate	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Scour Protection Installation	▪ Sediment transport (sediment suspension) ▪ Introduction of additional hard-substrate (if traditional protection is used)	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
TISEC Installation	▪ Modified currents ▪ Reduction in total tidal energy	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals ▪ Marine Birds (especially if surface-piercing structures are involved)	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Cable Installation	▪ Sediment transport (sediment suspension, exposure of fines, scour)	▪ Marine Benthic Habitat and Communities ▪ Marine Mammals (temporary displacement) ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Project Operation	▪ Reduced currents ▪ Modified waves ▪ Degradation of anti-fouling coatings ▪ Electro-Magnetic Fields (EMF)	▪ Marine Benthic Habitat and Communities ▪ Marine Mammals ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Maintenance	▪ New anti-fouling agents ▪ Spills from maintenance vessels ▪ Re-introduction of lubricating oils	▪ Removal of marine life affixed to TISEC unit ▪ Spill impacts on Marine Mammals, Marine birds, and Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
De-commissioning	▪ Similar to construction	▪ Similar to construction	▪ Similar to construction

Reference: after Michel *et al.* 2007

Details on the specific nature and spatial and temporal distribution of potential tidal power projects in the Bay of Fundy and their environmental effects are not available at this time. For the purposes of this study it was necessary to develop several example development scenarios to further focus this evaluation.

Based on the existing environment of the region and the potential environmental interactions and issues identified, key environmental management considerations are identified in the report to help guide future planning for tidal power development projects in the Bay of Fundy.

One of the key components of this study is the identification of data gaps that make it difficult to accurately predict environmental consequences of potential interactions with project activities. The following table provides a summary of the data gaps and associated recommendations by KEI.

TABLE E.2 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
Critical Physical Processes	▪ Lack of detailed, site specific information on vertical and horizontal current structure and substrates for validation of models. ▪ Inadequate fine-scale hydrodynamic and sediment models relevant to selected sites of tidal energy development. ▪ Limited knowledge of the overall distribution and dynamics of sediments in the Bay of Fundy. ▪ Limited application of hydrodynamic models to assess the impacts of TISEC developments.	▪ Gather site specific information about substrates and sediment movement and currents for proposed development locations using in situ monitoring with ADCP and sediment sensors. ▪ Complete high density multibeam bathymetric studies of the Bay, and complete the analysis of existing data. ▪ Adapt or refine hydrodynamic models to provide adequate small-scale analyses of the potential and effects of energy extraction developments. ▪ Hydrodynamic modeling should be used to assist with the selection of sites for TISEC developments in order to optimize the extractable tidal energy potential and minimize cumulative effects on physical or biological processes.
Fisheries	▪ Absence of information on fish behaviour with respect to TISEC technologies. ▪ Inadequate knowledge on the effects of remobilized sediments on commercially important species of fish and shellfish. ▪ Questions about EMF from sub-sea cables and the effects on demersal fish and shellfish. ▪ More specific information is required regarding the number of fishing operations, vessels and products, and locations of fixed gear fisheries. Present data gathered for fisheries management purposes is insufficient for assessment of tidal power implications. ▪ Assumed existing infrastructure such as wharves would be used to support TISEC development projects—infrastructure status and availability or requirements for tidal power development is not well known. ▪ Lack of clarity on set-back requirements for marine energy developments.	▪ Conduct experimental and field-based monitoring studies of fish behavior and mortality, in the vicinity of tidal power devices. ▪ Conduct experimental studies of fish responses to vibrations or noise generated by TISEC devices. ▪ Conduct experimental studies of effects of high suspended sediments on migratory and commercial fish species. ▪ Work with fishing groups to obtain better fisheries data particularly with respect to activities near proposed development sites. ▪ Determine specific infrastructure requirements (e.g., wharves, supply bases) and necessary upgrades for each proposed project. ▪ Gather detailed information on potential adverse effects on local fisheries, and necessary mitigative measures (including project site selection). ▪ Establish consultative group including fishers and developers to create effective set-back guidelines.
Fish and Fish Habitat	▪ Data on distribution, seasonality and trophic relations of many non-commercial species of fish are not available. ▪ Absence of information on fish	▪ Conduct experimental and field-based monitoring studies of fish behavior and mortality, in the vicinity of tidal power devices. ▪ Conduct experimental studies of fish

TABLE E.2 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
	behaviour and/or mortality with respect to TISEC technologies, particularly with respect to noise and vibration. ▪ Questions about EMF from sub-sea cables and the effects on demersal fish.	responses to vibrations or noise generated by TISEC devices ▪ Establish an ongoing and updatable database of knowledge about local and migratory fish stocks. ▪ Identify potential mitigative measures for effects on fish populations based on experimental results.
Marine Habitat and Benthic Communities	▪ Available data on existing benthic communities are limited in the Outer Bay. ▪ Available data on existing benthic communities of the Upper Bay are limited, especially in view of some significant changes that have happened in the Bay since the data were obtained. ▪ Little existing data for many areas in the Bay.	▪ Replication of broad benthic surveys that were conducted in the 1970's. ▪ Establishment of long-term survey transects of benthic habitats and communities in priority areas for energy developments, including reference (*i.e.* non-impacted) sites. ▪ Creation of a coordinating agency to ensure consistency and quality of monitoring activities.
Pelagic Communities	▪ Similar to Fisheries and Fish and Fish Habitat issues noted above with respect to pelagic species.	▪ Similar to Fisheries and Fish and Fish Habitat issues noted above with respect to pelagic species.
Marine Mammals	▪ Lack of data on marine mammal behavioural responses to TISEC devices. ▪ Limited data available on the occurrence of marine mammals in the Upper Bay of Fundy.	▪ Study long term effects of health and behavior (*e.g.*, mortality, migration, avoidance, attraction) of tidal power development on marine mammals including monitoring of results from pilot and demonstration projects in the Bay of Fundy and elsewhere. ▪ Establish long term monitoring programs for marine mammals in the Upper Bay of Fundy, incorporating NGO resources. ▪ Identify and assess possible mitigative measures for effects of TISEC development on mammals.
Marine Birds	▪ Lack of data on marine seabird and shorebird activity in the area of priority sites. ▪ Lack of information on the trophic relationships of many marine birds, and their ability to adjust feeding preferences.	▪ Establish long term monitoring programs for marine birds in the Upper Bay of Fundy, incorporating NGO resources. ▪ Surveys to support project-specific environmental assessment prior to deployment. ▪ Identify and assess possible mitigative measures for effects of TISEC development on birds, including the secondary effects associated with changes in prey availability.

TABLE E.2 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
Species At Risk	▪ Requirement for better site -specific information on species presence (depending on species and location).	▪ Establish an ongoing and updatable database of knowledge about local and migratory species at risk in the Bay of Fundy. ▪ Identify and assess potential mitigative measures for different species at risk. ▪ Work with Species Recovery Teams to develop comprehensive strategies for species at risk that use areas of high priority for energy extraction. ▪ Where necessary, conduct species-specific surveys in high priority areas.
Aquaculture	▪ Similar to Fisheries above (including lack of knowledge concerning appropriate setback distance from TISEC devices).	▪ Similar to Fisheries above.
Marine Transportation	▪ Uncertainty regarding level of interaction with other marine transportation users in the study area.	▪ Stakeholder consultation (other marine users). ▪ Regulatory consultation (*e.g.*, *NWPA* process). ▪ Detailed navigation safety assessments and underkeel clearance surveys in the context of site specific project EA and project site selection.
Tourism and Recreation	▪ Lack of information on informal and unregulated recreational activities.	▪ Project-specific data gathering as part of site specific EA process (including shore-based facilities).
Marine and Coastal Archaeological and Heritage Resources	▪ Uncertainty regarding the location and condition of many potential archeological and heritage resources (marine and shore-based) in the study area.	▪ Detailed site specific bathymetric survey using side-scan sonar as part of project specific EA process. Follow up with ROV survey if sonar shows potential resources. ▪ Detailed archeological survey may be necessary as part of shore-based facility site selection and EA process.
Economic Development	▪ Uncertainty in identification of specific business opportunities for local business. ▪ Local capacity not clear.	▪ Local economic benefits study in context of project specific EA process. ▪ It is recommended that an Energy Sector Capability Study be commissioned for Atlantic Canada to address the barrier to supply-chain deficiencies within Atlantic Canada's Energy Sector, particularly within Nova Scotia and New Brunswick. ▪ Study potential benefit agreements. ▪ Project-specific job fairs.

TISEC technology is in a very early stage of development. Many potentially applicable devices are barely beyond the prototype stage, and few have been tested for prolonged periods in the marine environment. While the technology is developing rapidly in the case of the few that have been field tested, they all lack adequate examination for their potential environmental effects. Even where field testing has included some degree of environmental effects monitoring, it is not possible to transfer the limited information so far available on the environmental effects from those test sites to the Bay of Fundy. It is therefore necessary to establish facilities at one or more sites in the Bay of Fundy at which such technologies can be tested and thoroughly monitored; it is acknowledged that planning for the first of such facilities is currently under way.

It is recommended that a cautionary, staged approach be taken with respect to development of TISEC technology projects in the Bay of Fundy. Many unknowns exist and it is the recommendation of this study team that a small number of pilot scale projects proceed with significant monitoring and adaptive management plans. This would allow for future expansion into demonstration and commercial scale developments, provided environmental and socioeconomic components in the Bay of Fundy are not compromised, to the satisfaction of government and local stakeholders. This would be accomplished by gathering data to address the data gaps and allow for design considerations and development of appropriate mitigation measures. The end result would be confident predictions of potential environmental effects through project-specific environmental impact assessment.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 INTRODUCTION

The development of renewable energy sources in Nova Scotia and New Brunswick is a critical component of the future energy mixes of the two provinces. Previous studies of offshore resources have indicated substantial possibilities for ocean renewable energy in the Bay of Fundy. As with any other energy development prospect, planning for ocean renewable energy must take into account possible environmental and socio-economic effects.

This report is a background study on ocean renewable energy which is intended to facilitate an ongoing Strategic Environmental Assessment (SEA) of potential tidal development projects in the Bay of Fundy (Figure 1.1). This study has been commissioned by the Offshore Energy Environmental Research Association (OEER) and co-funded by the New Brunswick Department of Energy.

1.1 Study Objectives

The purpose of this document is to provide a consolidation of existing, readily available information on the environmental setting of the Bay of Fundy, and to identify potential environmental issues which may be associated with tidal energy development in the area. The report also describes several types of ocean energy technology with additional detail provided on Tidal In-Stream Energy Conversion (TISEC) technology. It outlines several representative tidal development scenarios, potential environmental and socioeconomic issues, and a number of planning considerations to reduce or avoid potential adverse interactions. This report is intended to serve primarily as a relatively “high level” document to facilitate the SEA process and an important component is the identification of data gaps and recommendations for follow-up activities to address gaps in data and existing knowledge.

1.2 Background

In 2006, the Electric Power Research Institute (EPRI) released a series of reports which identified the available energy resources created by the tidal regime within the Bay of Fundy and the potential for associated tidal energy development. With the development of current and emerging ocean energy technologies, including TISEC, industry has identified the tides within the Bay of Fundy as a world-class energy resource with the potential for economically feasible commercial development.

In 2007, the Province of Nova Scotia provided funding for a SEA, to be commissioned by OEER, to facilitate the potential development of tidal energy projects within the Bay of Fundy through an environmentally and socially responsible process.

The Province of Nova Scotia issued a request for proposals (RFP) in August, 2007 for the development of a Tidal Energy Demonstration Facility. This RFP invited TISEC technology developers to submit proposals to demonstrate their technology in the Bay of Fundy within jurisdiction of the Province of Nova Scotia. As part of this RFP, pending required permitting and approvals, developers will be permitted to demonstrate their technologies for a minimum of 12 months.

In October, 2007, the New Brunswick Department of Natural Resources released an *Interim Policy on Allocation of Crown Lands for Research in Support of In-Stream Tidal Power Generation*. The interim policy was designed to provide the public and the New Brunswick Department of Natural Resources with direction regarding the use of submerged Crown land to conduct research in support of potential in-stream tidal power generation development.

1.3 Energy Mix and Security

As carbon-based energy resources decline, prices will likely continue to increase. The predictability of potential tidal energy output creates an advantage over that of other less-predictable renewable energy resources, such as wind power. As utilities are responsible for ensuring a reliable supply to customers, it is necessary for the utilities to provide back-up sources to account for the grid's existing wind power generation capacity. As such, balancing the grid becomes more feasible as the generation becomes more predictable. While the initial cost of energy produced (cost per kw/h) associated with the production of tidal energy remains high, relative to that of other available energy sources, it is expected to become more feasible as TISEC technologies are refined, and as the costs of traditional carbon-based fuels continue to increase.

The Nova Scotia Utility and Review Board (NSUARB), under the *Public Utilities Act*, supervise all electric utilities operating as public utilities within the Province of Nova Scotia. Nova Scotia Power Inc. (NSPI) is the Province's largest public utility which is regulated by NSUARB. NSPI serves approximately 450,000 customers, generating almost 2300 megawatts.

In Nova Scotia, Renewable Energy Standard Regulations, made under Section 5 *of the Electricity Act*, specify two main requirements. The *Renewable Energy Standard 2010* requires each load serving entity to provide customers with renewable low-impact electricity equivalent to at least 5% of its total annual sales for the calendar years 2010, 2011, and 2012. The *Renewable Energy Standard 2013* requires each load serving entity to provide its customers with renewable low impact electricity equal to at least 10% of its total annual sales. Noncompliance with the Renewable Energy Standard Regulations could result in fines of up to $500,000 per day.

Nova Scotia's current energy mix is primarily dominated by coal, which provides approximately 75% of the Province's electrical power. Other sources include a mix of wind, hydro, tidal, oil, and natural gas. NSPI's generation capacity includes four combustion turbine sites, two wind turbine sites, five thermal plants, 33 hydro plants, and one tidal plant.

New Brunswick's largest utility, NB Power, generates electricity from 15 generating stations around the Province. These generating stations have a combined capacity of almost 3950 MW and serve approximately 370,000 customers. New Brunswick has a diverse energy mix including; hydro, oil, coal, diesel, natural gas and nuclear generation. Pursuant to the *Electricity Act*, Regulation 2006-58 will require standard service suppliers to provide a minimum renewable energy component of 10% of kilowatts-hours sold by the year 2016 in the Province of New Brunswick; increasing 1% per year for ten years. Similar to the Nova Scotia regulation, there is a monetary penalty for utilities that do not comply with the regulation. Price volatility of foreign energy supplies will affect both provinces and the need to develop local energy resources will play an increasingly critical role in ensuring energy security for both the Provinces of New Brunswick and Nova Scotia.

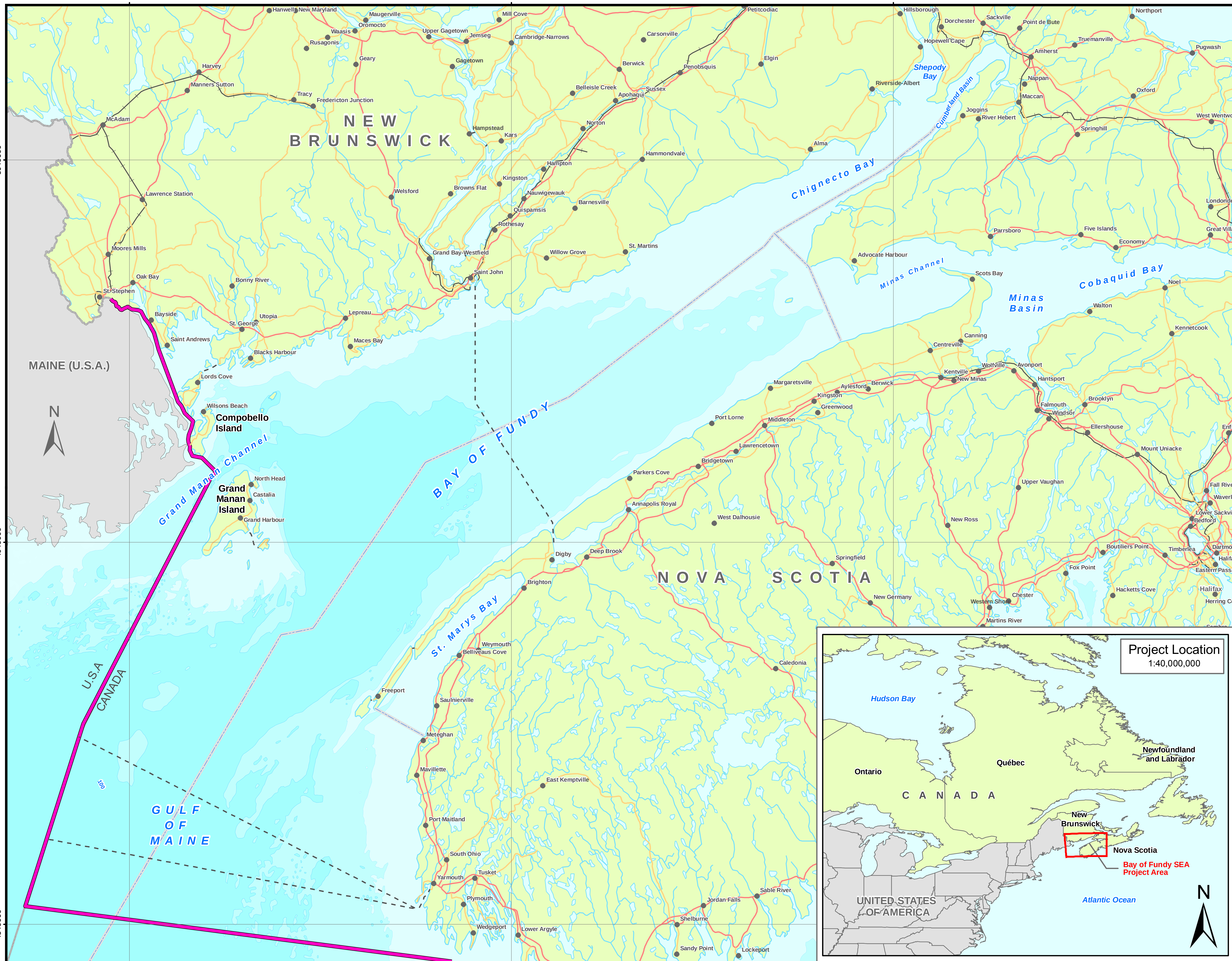


Figure 1.1

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Project Area

Base Map Features

- Community
- Project Limits
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- International Bounds
- Provincial Offshore Boundary
- Hydrology
- Open Water

Bathymetric Contours

- 50.00
- 50.01 - 100.0
- 100.1 - 200.0
- 200.1 - 400.0
- 400.1 - 500.0
- 500.1 - 1000
- 1001 - 2000
- 2001 - 3000
- 3001 - 3500
- 3501 - 4000
- 4001 - 4500
- 4501 - 5000
- 5001 - 5500

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-001

The generation of electricity by renewable resources produces fewer atmospheric emissions compared with conventional fossil fuel fired generation. In the case of generation using tidal resources, the electricity produced would reduce greenhouse gas (GHG) and air pollutant (AP) emissions otherwise produced by fossil fuels. With the progressive development of transmission facilities, open access transmission tariff systems, more open markets and requirements to significantly reduce GHG and AP emissions, sales of renewable electricity into the grid may also displace energy from generating facilities located deeper in the northeastern United States and even in Ontario.

There is an increasing market demand for electricity generated by renewable sources. This will provide opportunities for the sale of Bay of Fundy tidal power which in turn could potentially displace or avoid the production of an equal amount of electricity from conventional sources, usually fossil based generation. This market demand for cleaner energy will result in opportunities for Fundy tidal power producers to bid energy, capacity and ancillary services into an open market to meet peak daily or seasonal energy demands, and also to procure long term base load supply contracts.

In the longer term, as additional generation is required to satisfy increased system demand and to offset the retirement of aging generation plants, there is opportunity for renewable energy supplies to influence the selection of electricity supply type in each nearby market.

Electricity generation is the largest source of GHG and AP emissions in Nova Scotia and New Brunswick, and is the target of climate change-based regulations in many areas of the world. At the same time, many companies and institutions are recognizing the need to do their part to combat global climate change resulting from GHG emissions. As a result, they have calculated their “carbon footprint” and are taking steps to reduce it. Frequently, a large component of their “footprint” is caused by the electricity they purchase. While their first steps are to reduce consumption, these electricity customers then turn to opportunities to use other sources of energy or to purchase clean or renewable electricity to reduce GHG emissions and avoid the purchase of offset credits otherwise possibly needed to meet reduction commitments.

There will also be demand for renewable electricity to meet regulated demand (Renewable Portfolio Standards) already established in Nova Scotia and New Brunswick, and also in most nearby jurisdictions.

Finally, there will also be market demand for green power to meet the needs of customers looking to meet regulated emission reduction requirements. Governments are moving toward regulated systems to reduce GHG and AP emissions, usually from the larger emitters. Electricity generating companies will therefore be looking to develop a cleaner portfolio of facilities. Other large emitters may be looking to purchase cleaner electricity if they are required to address indirect emissions such as with the development of a new facility, or they may be looking for renewable energy projects as opportunities to secure GHG or AP offset credits.

Estimates for the quantity of GHG and AP emissions displaced or avoided in any market can be performed by simulating electricity system dispatch patterns. Such simulations can predict the output of individual generating units under a variety of scenarios. The differences in energy generated by each unit, and hence emissions, can be calculated.

There is, potentially, great complexity associated with the analysis of the interconnected systems. However it is estimated that there is potential to reduce both GHG and AP emissions from the introduction of renewable energy sources, and these reductions can be quantified. For example, the Government of Newfoundland and Labrador has examined the potential of the proposed Lower Churchill hydroelectric project to displace GHG and AP emissions. These were quantified and reported in the Province's Climate Change Action Plan. It is roughly estimated that emissions reductions will be greater in the short term with the quantities of emissions displaced decreasing over time as policies of continuous improvement and associated tighter emissions legislation take effect.

1.4 Study Limitations

The scope of this study was prescribed by the RFP issued by OEER. While the OEER scope intends to cover a wide range of issues, it is not intended to be exhaustive.

Key study limitations in addition to the terms of reference provided by OEER, include the following:

- This report is not intended to recommend or otherwise analyze the effectiveness or commercial viability of any particular ocean energy technology or development scenario or location, or provide an impact assessment with specific evaluation criteria or determination of significance.
- The information provided in this report is at an overview level and based on readily available sources. There are information gaps in the description of existing environmental and socioeconomic conditions, ocean energy technologies, potential environmental interactions and management strategies.
- Development scenarios have been presented for illustrative purposes based on several factors including available tidal energy, and jurisdictional and ecological diversity. This report does not claim that these are "preferred" scenarios or that other locations would not be viable.
- The study is based on readily available, current information on ocean energy technologies. As technology continues to advance, there may be a need to update the information and re-evaluate potential environmental issues.
- There is limited knowledge available on the cumulative interactions of more than one ocean renewable energy project in an area, or the "carrying capacity" of a particular development in terms of available extractable energy or environmental effects. This paucity of information is attributable, in part, to the general lack of commercial scale operating experience of tidal in stream developments at this time.
- It is assumed that all specific ocean energy projects, including demonstration projects, will be subject to project and site specific environmental assessment requirements as part of a regulatory environmental approvals process. This site specific evaluation, including consultation with potentially affected stakeholders, is considered vital for a complete evaluation of potential environmental effects and their significance as well as the development of specific mitigation and monitoring programs.
- This report focuses primarily on potential environmental and socio-economic interactions within the marine environment. It is understood that some land based components (*e.g.,* shore based, transmission corridors) would be required for commercial-scale developments. Potential terrestrial effects are highly site specific and evaluated more appropriately during project specific assessments, and are not the focus of this strategic evaluation.

1.5 Study Team

Jacques Whitford Limited (JW), in partnership with the Acadia Centre for Estuarine Research (ACER) have formed a consulting team with a broad range of expertise in environmental sciences and ocean energy engineering. JW and ACER have been supported by The Huntsman Marine Science Centre (Huntsman), Devine Tarbell & Associates, Inc. (DTA), Baird and Associates Coastal Engineering (Baird) and Jim Calvesbert Consulting.

The following team members are acknowledged for their contributions to this document:

Robert Federico, Jacques Whitford;

Angela Swaine, Jacques Whitford;

Shannan Murphy, Jacques Whitford;

Steven Fudge, Jacques Whitford;

Patrick Pearce, Jacques Whitford;

James Knight, Jacques Whitford;

Laird Niven, Jacques Whitford;

Tony Daye, Jacques Whitford;

Jim Calvesbert, Jim Calvesbert Consulting;

Dr. Graham Daborn, Acadia Centre for Estuarine Research;

Dr. Anna Redden, Acadia Centre for Estuarine Research;

Dr. Mike Brylinsky, Acadia Centre for Estuarine Research;

Dr. Mike Dadswell, Acadia Centre for Estuarine Research;

Dr. Gerhard Pohle, The Huntsman Marine Science Centre;

Lou Van Guelpin, The Huntsman Marine Science Centre;

Andre Casavant, Devine Tarbell & Associates, Inc.;

Peter Browne, Devine Tarbell & Associates, Inc.;

Peter Zuzek, W.F. Baird & Associates, Coastal Engineers Limited;

Dr. Robert Nairn, W.F. Baird & Associates, Coastal Engineers Limited; and

Andrew McGillis, W.F. Baird & Associates, Coastal Engineers Limited.

1.6 Document Organization

This report is organized as follows.

Section 1 provides an introduction and provides background information on the Project, as well as the purpose and context of the study, and the organization of the document.

Section 2 describes the study methods, including issues scoping and evaluation methods.

Section 3 provides a description of available ocean renewable energy technologies.

Section 4 outlines the in stream tidal technology scenarios developed to provide focused boundaries for this study.

Section 5 presents an overview description of the existing physical, biological and socio-economic conditions in the Bay of Fundy.

Section 6 provides an issues based discussion of potential environmental interactions, environmental planning and management considerations, data gaps and follow-up for each of the development scenarios identified in Section 4.

Section 7 presents an evaluation of cumulative interactions.

Section 8 provides a summary and conclusions of the study.

Section 9 presents references used in the preparation of this report.

2.0 STUDY METHODS AND ISSUES SCOPING

2.1 Approach

This document focuses on selected Key Environmental Issues (KEIs), which include environmental and socioeconomic issues of concern, potentially associated with tidal power development in the Bay of Fundy. The evaluation includes consideration of typical tidal power project components and activities and their potential interactions with the region's existing environmental conditions. This is not meant to provide an exhaustive or comprehensive review of the available literature regarding the effects of tidal power development, but rather to provide background information to support general planning purposes as well as future project-specific and site specific environmental assessments.

Given the lack of specific knowledge on the nature, location and timing of potential tidal power development projects in the study area, potential interactions are described in general terms. Potential environmental issues are identified as well as an overview of general planning and management considerations which may be implemented to avoid or reduce potential environmental interactions.

As noted in Section 3.0, the focus of this study is TISEC technology. However, the scope of this study did not allow for consideration of all potential scales of TISEC development at all potential development sites in the Bay of Fundy. Rather a high level summary of existing environmental conditions for the Bay of Fundy study area is presented with potential environmental and socioeconomic interactions considered for several example development scenarios, as discussed in Section 4.0 of this document.

2.2 Issues Scoping and Key Environmental Issue Selection

Assessing all of the potential environmental components associated with a proposed undertaking or strategic planning process is impractical, if not impossible. It is generally acknowledged that environmental assessment should focus on particular components of the environment that can serve as indicators of environmental change and/or are particularly valued by society. A list of issues for consideration in this study was provided in the RFP issued by OEER (2007). In addition, an issues scoping exercise was conducted by the study team which included consideration of the biophysical and socioeconomic environments of the region and existing knowledge regarding the potential for effects of marine development projects.

Other studies and environmental assessments related to tidal power projects were reviewed including:

- Scottish Marine Renewables Strategic Environmental Assessment (SEA) Environmental Report (Faber Maunsell and Metoc PLC 2007);
- Instream Tidal Power in North America Environmental and Permitting Issues (DTA 2006);
- New Brunswick Tidal In-Stream Energy Conversion (TISEC) Survey and Characterization of Potential Project Sites (EPRI 2006d); and
- Nova Scotia Tidal In-Stream Energy Conversion (TISEC) Survey and Characterization of Potential Project Sites (EPRI 2006e).

The results of these studies and assessments were considered as part of the scoping exercise, as appropriate, with consideration of the differences in respective study areas.

Based on the results of this issues scoping exercise, a list of KEIs was prepared (Table 2.1) from which to focus this evaluation. The KEI list is compared with the list of issues required to be discussed in the OEER RFP.

TABLE 2.1 Scoping of Key Environmental Issues

Environmental Component[1]	Scoping Considerations	Selected Key Environmental Issue
Bottom Morphology and Sediment Transport	These components are related to marine and estuarine hydrodynamics. Tides and currents are siting and operational factors but may also be components of the environment affected by the Project. Currents, tides, bottom morphology and sediment transport are assessed in the physical oceanography section.	▪ Critical Physical Processes (Section 6.1)
Noise and Vibration	Concern related to an increase in ambient noise levels and the potential effects on marine life. Potential effects on marine organisms are discussed in relevant sections.	▪ Fisheries (Section 6.2) ▪ Fish and Fish Habitat (Section 6.3) ▪ Marine Mammals (Section 6.6) ▪ Marine Birds (Section 6.7) ▪ Aquaculture (Section 6.9)
Benthic Ecology	Focus on direct and indirect physical effects on marine benthos. Scientific concern for marine habitat. Species of special concern are protected under the *Species at Risk Act*. Fish and fish habitat, are protected under the *Canada Fisheries Act*.	▪ Marine Benthic Habitat and Communities (Section 6.4)
Sediment and Water Quality	Marine sediment and water are pathways for potential ecosystem effects on benthic communities and fish. Fish habitat is protected under the *Fisheries Act.* Both sediment and marine water quality are inherently linked to habitat quality for aquatic species.	▪ Pelagic Communities (Section 6.5) ▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat
Protected Sites and Species	Species at risk are discussed within the context of their relevant environmental component (*e.g.*, fish, birds, mammals). Protection of species biodiversity is administered through the *Species at Risk Act*, Nova Scotia *Endangered Species Act*, Nova Scotia *Wildlife Act, Migratory Birds Convention Act,* New Brunswick *Endangered Species Act and* New Brunswick *Protected Natural Areas Act*. Protected Sites such as listed RAMSAR sites, marine protected areas, biosphere reserves and wildlife protection areas.	▪ Species at Risk (Section 6.8) ▪ Marine Birds ▪ Marine Mammals ▪ Fish and Fish Habitat
Shipping and Navigation	Marine transportation is a KEI in consideration of potential effects of Project related marine traffic, and Project marine infrastructure as a potential impediment to vessel movements and safety. These issues are regulated under the *Navigable Waters Protection Act*. Recreational boating is included.	▪ Marine Transportation (Section 6.10)

TABLE 2.1 Scoping of Key Environmental Issues

Environmental Component[1]	Scoping Considerations	Selected Key Environmental Issue
Recreation and Tourism	It is important to consider the compatibility of the Project with existing recreational uses and tourist attractions considering the importance of the Bay of Fundy to these social components (*e.g.*, aesthetics). Boating safety is addressed under Marine Transportation. Recreational fisheries are included under Fisheries and Aquaculture.	▪ Tourism and Recreation (Section 6.11)
Marine and Coastal Historic Resources	Concerns with the effective management of archaeological and heritage resources. Focus on marine historic resources (*i.e.*, shipwrecks, fossil sites) Administered under the Nova *Scotia Special Places Protection Act* and the New Brunswick *Historic Sites Protection Act.*	▪ Marine and Coastal Archaeological and Heritage Resources (Section 6.12)
Community Economic Development	Fundamental socio-economic determinant. Related to increased economic activity related to the Project including supporting services.	▪ Economic Development (Section 6.13)
Marine Birds and Marine Mammals	Protection of species biodiversity and critical habitat. Scientific and public concern. Regulatory protection under the *Species at Risk Act, Nova Scotia Endangered Species Act*, Nova Scotia *Wildlife Act* and *Canada Fisheries Act*, *Migratory Birds Convention Act* and Western Hemisphere Shorebird Reserve Network, and New Brunswick *Endangered Species Act*.	▪ Marine Birds ▪ Marine Mammals
Fish and Shellfish	Focus on marine commercial species. Public and scientific concern for fish and fish habitat and species of special status and their habitat that may occur in the area. Habitat support for commercial, recreational and aboriginal fisheries. Fish habitat is protected under the *Fisheries Act*. Species of special concern are protected under the *Species at Risk Act*. Fisheries and aquaculture are addressed separately.	▪ Fish and Fish Habitat ▪ Pelagic Communities
Commercial Fisheries	Fisheries and aquaculture are considered a KEI due to their importance to the regional economy and importance as a socio-cultural activity among maritime communities. Protected under the *Fisheries Act*, Nova Scotia *Environment Act* and New Brunswick *Clean Water Act*. Includes recreational fishing.	▪ Fisheries ▪ Aquaculture
Ice Activity	Ice conditions are discussed in terms of facility siting and operational constraints. A separate evaluation for Ice Activity is not included.	N/A
Other Marine and Coastal Resource Uses	None identified.	N/A
Onshore Grid Connections and Transmission Capacity	These components are briefly addressed as facility siting opportunities constraints. A separate KEI is not included.	N/A
Energy Mix Security and Pricing	These components are briefly addressed as factors relevant to overall project feasibility and public policy regarding ocean energy development. A separate KEI is not included.	N/A
Greenhouse Gas Emissions	Instream tidal power is a form of renewable energy with opportunities to displace fossil fuel use. A brief discussion of the potential displacement of greenhouse gas emissions will be discussed. A separate KEI is not included.	N/A
Supporting Services and Resources	These components are addressed in the context of opportunities and constraints for facility site selection. Relevant discussion is also included in the Economic Development VEC. A separate KEI is not warranted in this assessment.	▪ Economic Development

List incorporates all issues noted in Section 1.4 of OEER RFP.

2.3 Issues Evaluation

The following sections briefly describe the approach taken for the evaluation of the KEIs with respect to potential interactions, management opportunities and identification of data gaps.

Potential Interactions

Some aspects of a typical TISEC project construction and operation directly influence various biological and socioeconomic components, and some influence the physical processes, which could in turn influence the biological components. Table 2.2 outlines typical project components and potential physical, biological and socioeconomic interactions. The potential interactions and environmental management and planning considerations with respect to several development scenarios are outlined in more detail in Section 6.0 of this report.

TABLE 2.2 Potential Interactions

Project/Construction Phase	Physical Process Interaction	Biological Component Interaction	Socioeconomic Component Interaction
Seabed Preparation	▪ Sediment transport ▪ Waves/currents through channel modification ▪ Noise & Vibrations ▪ Introduction of additional hard-substrate	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Marine and Coastal Archaeological and Heritage Resources Resources ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Pile Installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Noise & Vibrations	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Gravity Foundation Installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Introduction of additional hard substrate	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Scour Protection Installation	▪ Sediment transport (sediment suspension) ▪ Introduction of additional hard-substrate (if traditional protection is used).	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
TISEC Installation	▪ Modified currents ▪ Reduction in total tidal energy	▪ Marine Benthic Habitat and Communities ▪ Fish and Fish Habitat ▪ Marine Mammals ▪ Marine Birds (especially if surface-piercing structures are involved)	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation

TABLE 2.2 Potential Interactions

Project/Construction Phase	Physical Process Interaction	Biological Component Interaction	Socioeconomic Component Interaction
Cable Installation	▪ Sediment transport (sediment suspension, exposure of fines, scour)	▪ Marine Benthic Habitat and Communities ▪ Marine Mammals (temporary displacement) ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Project Operation	▪ Reduced currents ▪ Modified waves ▪ Degradation of anti-fouling coatings ▪ Electro-Magnetic Fields (EMF)	▪ Marine Benthic Habitat and Communities ▪ Marine Mammals ▪ Fish and Fish Habitat	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
Maintenance	▪ New anti-fouling agents ▪ Spills from maintenance vessels ▪ Re-introduction of lubricating oils	▪ Removal of marine life affixed to TISEC unit. ▪ Spill impacts on Marine mammals, sea birds, and fish.	▪ Marine Transportation ▪ Economic Development ▪ Fisheries ▪ Aquaculture ▪ Tourism and Recreation
De-commissioning	▪ Similar to construction	▪ Similar to construction	▪ Similar to construction

Reference: after Michel *et al.* 2007

Study Boundaries

This study focuses on identifying potential environmental issues and interactions that may occur as a result of potential tidal power development projects within the Bay of Fundy. The spatial boundaries of the example development scenarios are presented in Section 4.0 where the scenarios are further discussed.

Details on the specific nature and spatial and temporal distribution of potential tidal power projects in the Bay of Fundy and their environmental effects are not available at this time. For the purposes of this study it was necessary to develop several example development scenarios to further focus this evaluation. Scenario development is discussed in Section 4.0. The specific number, size, location, timing and technology cannot be predicted at this time.

Environmental Planning and Management Considerations

Based on the existing environment of the region and the potential environmental interactions and issues identified, key environmental management considerations are provided to help guide future planning for tidal power development projects in the Bay of Fundy to reduce or eliminate adverse environmental effects.

Data Gaps and Follow-up

These sections provide an overview of the nature and adequacy of available information on the environmental issues in the study area, and identify any important data gaps and information requirements. Follow-up programs are also discussed where applicable.

Cumulative Environmental Interactions

Environmental interactions of individual projects and activities can overlap spatially and temporally to create cumulative interactions. Cumulative environmental interactions are difficult to predict in cases where environmental evaluations are conducted on hypothetical scenarios as they are done for this study. This is particularly difficult in the case where no commercial scale TISEC projects exist to provide the appropriate level of environmental effects monitoring data to assist with cumulative effects predictions. Nevertheless, for this study cumulative interactions have been considered conceptually from two perspectives. The first consideration is the case of several TISEC project developments within the Bay of Fundy and the predicted cumulative interactions with the environment. The second consideration is the potential for cumulative interactions with other types of projects and activities currently taking place or that are planned to take place in the Bay of Fundy. This study considers the potential for cumulative environmental interactions as applicable for each key environmental issue at a highly conceptual level.

3.0 OCEAN RENEWABLE ENERGY

3.1 Summary of Select Ocean Energy Technologies

As requested by OEER, overview descriptions of several available marine-based energy conversion approaches are presented and discussed in the following sections; these include:

- Offshore Wind Energy Conversion;
- Tidal In-Stream Energy Conversion (TISEC);
- Tidal Lagoon Energy Conversion; and
- Wave Energy Conversion.

As requested by OEER, only TISEC is addressed in further detail in subsequent sections of the report with respect to the Bay of Fundy; however, the other technologies may also be valid for certain applications subject to further evaluation and assessment.

3.1.1 Offshore Wind Energy Conversion

Technology Description

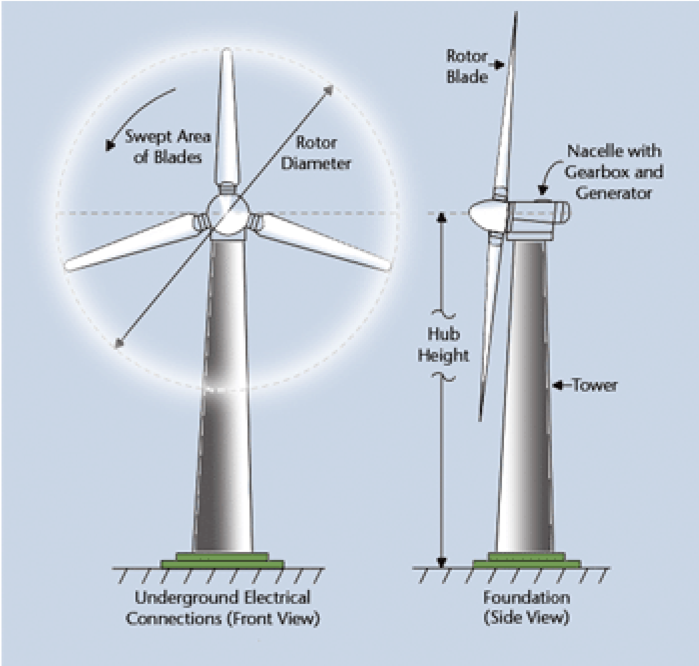
Although there have been many different types and designs of wind turbines over the years, modern commercial systems have been optimized towards a single configuration – the three-bladed horizontal-axis turbine on the top of a tower mast. Modern wind turbines consist of a foundation, a tower, a nacelle, and the rotor. Refer to Figure 3.1.

The rotor is made up of the blades, hub, and pitch systems. Most modern designs include three blades; however two blade devices have been installed. Traditional flat blades are not used anymore, rather modern blades are actually foils that are pitched to match the wind speed such that they generate lift and spin the rotor assembly as efficiently as possible for the given wind speed. The rotor and hub assembly are attached to the generator through a gearbox. Both the gearbox and the generator are normally contained within the nacelle. The unit pivots (or yaws) around the top of a tower. The towers are normally constructed of steel and provide rigidity and support for the system. The towers are connected to the foundation piece – in marine applications this is generally either a monopile or a gravity-based foundation.

Commercial applications of offshore wind turbines are typically now installed in large clusters, called wind farms or wind parks, where transmission lines and other infrastructure may be shared. The electricity is transferred onshore with a subsurface transmission cable; often small electrical substations are installed offshore to transform the energy prior to transmitting it onshore.

Although average wind energy is predictable over long periods of time, in the short-term the predictions are less consistent, making integration of wind energy into a mixed grid a continuous task for the utility companies.

FIGURE 3.1 Diagram Illustrating a Wind Turbine (courtesy ESN)



State of Technology

The development and installation of wind turbines is now quite common. Since the technology is virtually the same for onshore and offshore applications, offshore wind turbines are the most developed of the marine-based alternative energy alternatives. They have been commercially installed in several locations around Europe, and have proven their financial viability for the European electricity market. Refer to Figure 3.2 for an example from Denmark. The designs have been optimized, and at present, are in the 3 MW range; however, plans for 4-5 MW turbines are in the works and some prototypes have been constructed.

Foundation designs have generally been optimized as well, and there are several marine contractors available with the experience and capabilities to install offshore wind turbine foundations. Typically the European examples have shown that the installation costs are presently limiting offshore wind farms to water depths in the 20-30 meter range; newer turbines with greater electrical output are expected to make it financially viable to go into deeper water, but it has not yet been proven. Floating turbine foundations are under development but are presently not viable for commercial applications.

FIGURE 3.2 Photograph of Existing Offshore Wind Turbine in Denmark (courtesy www.windpower.org)

3.1.2 Tidal In-Stream Energy Conversion (TISEC)

Technology Description

The technology for TISEC conversion is similar to the technology used in wind energy conversion, only it is underwater. A fluid moves past a series of blades, causing them to spin a generator via a powertrain, resulting in electricity, which is fed back to the grid through a subsurface transmission line. Refer to the conceptual diagram in Figure 3.3. The difference is that the fluid is far more dense, and in the case of tidal, the currents are more predictable than winds.

Current designs consist of blades designed to rotate about either the vertical (perpendicular to the sea-surface) or horizontal (parallel to the sea-surface) axes. There are fewer of the designs that implement the vertical-axis approach than the horizontal-axis approach. The rotor blades themselves may be ducted or non-ducted. Ducting implies installing the turbine blades within a "tunnel" that is normally designed to accelerate the flow within the tunnel. Non-ducted usually employs variable-pitch blades. Refer to Figure 3.4 for an example of a ducted TISEC. A very different design approach is one that uses an oscillating hydrofoil. These devices consist of a blade, or wing, that is mounted on the end of a lever-arm. As the current rushes past the wing, the arm is forced either up or down, pumping fluid past a turbine, generating electricity. Refer to Figure 3.5.

FIGURE 3.3 Artist's Rendition of a Pile-supported Dual-turbine Device (courtesy Marine Current Technologies)

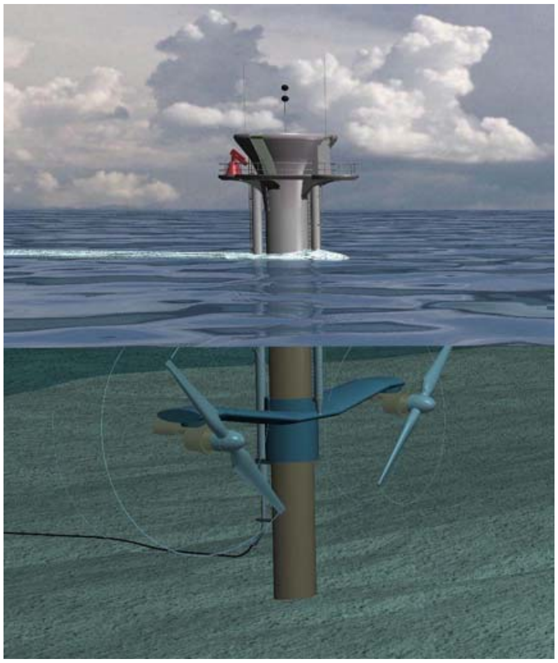
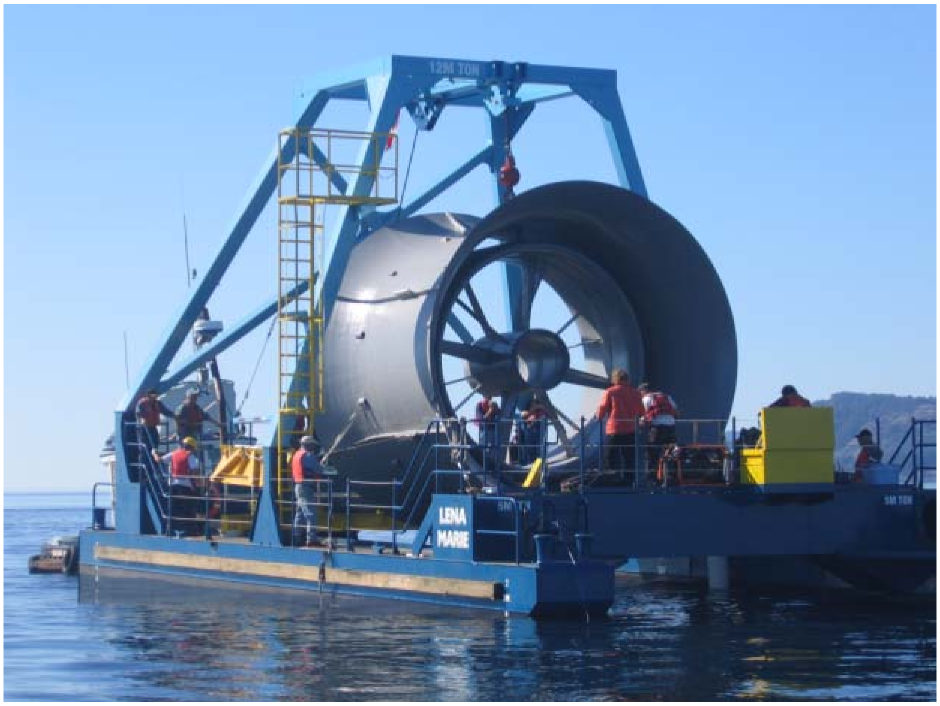


FIGURE 3.4 Installation Barge and a Ducted TISEC Device (courtesy Clean Current Power Systems)



TISEC technology may be secured in place using two different approaches: bottom-mounted and anchor-tethered. Bottom-mounted usually involve concrete caissons or marine piles. The bottom-mounted structures rest directly on or are driven into the sea bottom and the device is usually attached rigidly to the foundation. The structure may or may not be surface-piercing. Anchor-tethered devices are buoyant, or have some means of keeping them off the bottom, and are tethered to the sea-bottom using traditional offshore anchors (either mass-anchors, such as concrete blocks; pile-anchors; drilled anchors; suction-anchors, *etc*).

State of Technology

The technology involved with TISEC is generally still relatively immature when compared with wind energy conversion. No one device or type of device has yet proven to be dominant over other devices/types – and indeed there may not be one design-type that gains universal acceptance as has occurred with wind conversion technologies. There are approximately 20 different devices available on the market today, at various states of development, from concept through to in-situ prototype and pilot testing. Large-scale commercial TISEC applications have not yet been developed. Presently, pilot sites are in place in the UK and Race Rocks in British Columbia, and proposals are in place to put pilot units into the Gulf Stream off the east coast of Florida, and various locations in Asia.

FIGURE 3.5 Image of the Stingray Oscillating Hydrofoil Device (courtesy the Engineering Business)

A large proponent of these projects has been EMEC (The European Marine Energy Centre), a research group based in Orkney that is investing in research and development of various marine power devices, including TISEC devices and wave energy devices.

3.1.3 Tidal Lagoon Energy Conversion

Technology Description

The concept of a tidal lagoon is similar to that of a tidal barrage. Tidal barrages span natural gaps in a bay and retain the water on one side as the tide fluctuates. Refer to Figure 3.6. An example of a tidal barrage is the Annapolis Royal Generating Station in Nova Scotia. Once there is a maximized head on one side of the barrage, the water is released and allowed to flow through turbines in the barrage, thus converting some of the potential energy into electricity. A tidal lagoon is essentially the same thing, only the impoundment area is not a natural bay or river, rather it is an area contained by a constructed wall. Refer to Figure 3.7.

Current designs for tidal lagoons generally involve using rubblemound structures on large tidal shelves where the water is relatively shallow at low tide. These proposed lagoons are generally round; some of them have flow control structures within the lagoons to manage the flow and head in a more efficient fashion. The generation components will likely be made up of a series of low-head generators through which the water flows. These generators are placed in ducts designed to focus and transform the flow in such a way that the turbine blades operate at or near their peak efficiency (often above 90%).

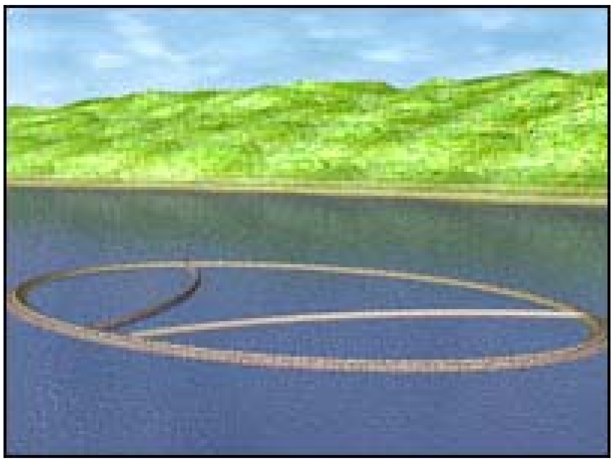
Modern applications of these devices are proposed to work on both rising and falling tides. Some existing barrage devices use surplus power from the grid at high tide to spin the turbines to pump water into the impoundment area to increase output through the falling tide cycle. Like TISEC technology, tidal lagoons allow for the reasonable prediction of energy output as the tides are predictable.

A rubblemound containment structure is a sloping structure with large stone or concrete armour units on the outside layers to absorb wave and current energies. For a tidal lagoon to be practical, the inner core of the structure would have to be made of an impermeable material, to operate in much the same way as an earth-dam. The end result would look similar to a stone or concrete-armoured breakwater.

The generated electricity could travel through the rubblemound containment structure a relatively short distance to land, thus requiring a shorter subsurface transmission line compared with other ocean energy technologies. However, these structures can also be expected to create a relatively large "footprint" within the marine environment, potentially causing important changes to local hydrodynamics, and potential alteration to the movement of migratory and transient marine life as the habitat becomes lost to them.

FIGURE 3.6 La Rance Tidal Barrage (240 MW) in France (courtesy Popular Mechanics)

FIGURE 3.7 Proposed Tidal lagoon in Wales (courtesy BBC)



State of Technology

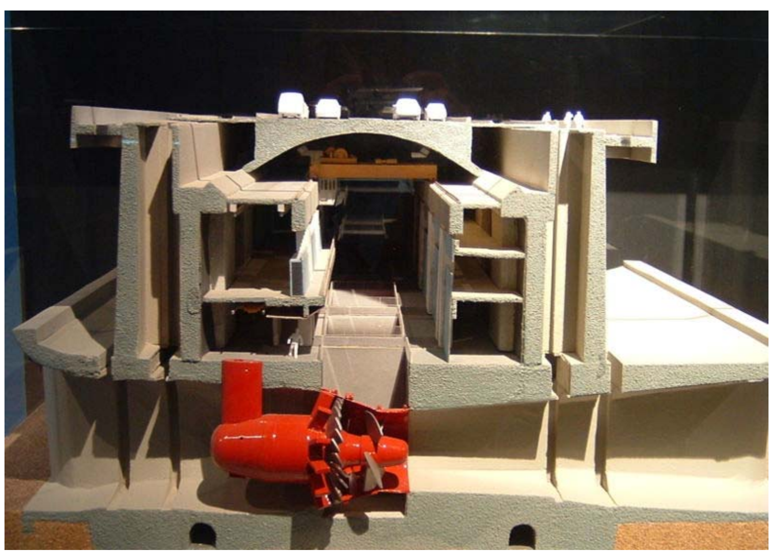
Although no full commercial tidal lagoons have been constructed, the technology to do so is well understood and has been applied in several locations in the form of a tidal barrage, hydroelectric power projects, breakwaters, and power projects.

The impoundment structures are very well understood. Most designs would likely use a rubblemound structure with an impermeable core, similar to a modern breakwater. Refer to Figure 3.8. These structures have been found to dissipate wave energy, preventing navigation troubles caused by reflected waves, as well as provide useful fish habitat in the armour-unit voids.

FIGURE 3.8 Breakwater Under Construction with Concrete Armour Units (courtesy Baird & Assoc.)

Low-head generators have been in use for over one hundred years in various hydroelectric and tidal lagoon projects around the world. The most applicable examples for a tidal lagoon are the ones installed at the Annapolis Royal Generating Station on the Bay of Fundy, and at the La Rance tidal barrage in France. A scale model cross-section of the generators at La Rance is provided in Figure 3.9. These turbines are installed in ducts and both have been used for decades generating electricity with each tidal cycle.

FIGURE 3.9 Scale Model Cross-Section of the La Rance Tidal Power Facility Showing Ducting and Turbine Layout



Nova Scotia Power has experience with load cycling and grid management issues associated with tidal flows at the Annapolis Royal generating station, which should be valuable for future proposed projects.

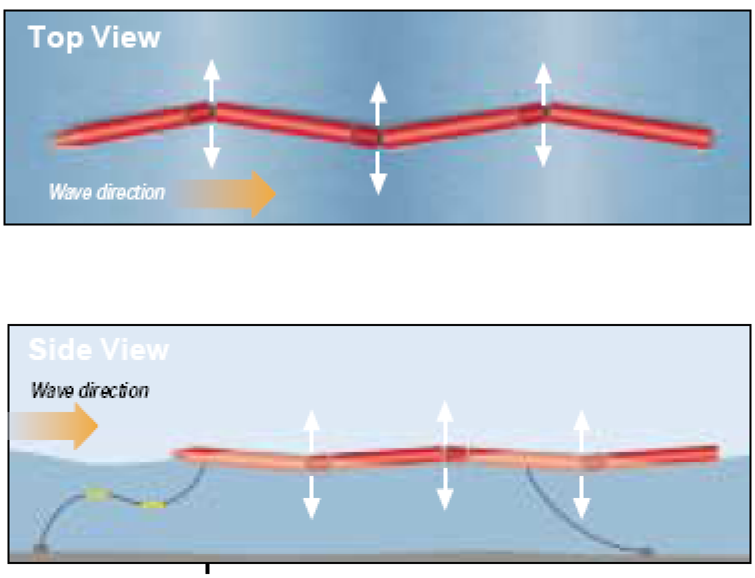
3.1.4 Wave Energy Conversion

Description of Technology

Wave energy conversion into electric power takes many forms due to the complex nature of waves and the potential to harness this energy in several different fashions. Wave energy conversion devices have not yet stabilized around one particular design, and they may never do so. Most of the devices, however, may be categorized into three types: floating, oscillating water-column, and overtopping. Each approach operates in a fundamentally different fashion.

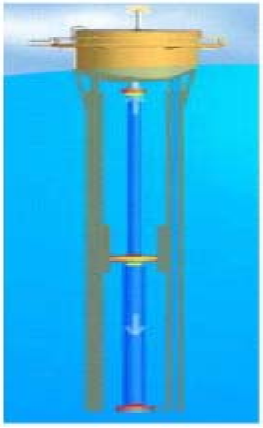
Floating wave energy conversion devices sit on top of the water, and as the wave moves underneath it kinetic energy is converted to electric energy. Essentially, waves lift the device up from the trough to the crest, and gravity pulls the device down from the crest through to the trough of the wave. There are two leading types of floating generators, point-absorbers and attenuating varieties. The attenuating varieties consist of several floating cylinders, linked together at the ends. It is arranged perpendicular to the incoming wave crests, and the wave bends each section of the device differently, and the joints contain pistons that compress a gas or fluid that is then used to spin a turbine, generating electricity. The main proponent of articulating technologies is Ocean Power Development Limited, which owns the Pelamis wave power device shown in Figure 3.10.

FIGURE 3.10 Articulating-type Device for Wave Energy Conversion (courtesy Ocean Power Delivery Ltd.)



The point-absorber varieties consist of a floating object that rides the surface of the wave. This object converts the vertical motion into electricity via one of several different approaches: having one segment or portion of the float move relative to the other (*e.g.*, a floating object in a cylinder), or the up and down motion relative to the seafloor pumps water or hydraulic fluid through a turbine. See Figure 3.11 for a schematic of a point-absorber. It is expected that all floating types would be installed as part of an array.

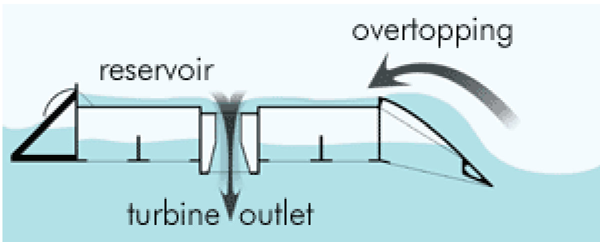
FIGURE 3.11 Buoy-style Point Absorber for Wave Energy Conversion (courtesy Finavera)



The second type of device is the oscillating water column. This type of energy extraction may be understood by thinking of a wave blow-hole on a shoreline. As wave energy enters into a submerged hole, the pressure gradient forces air or some other fluid up through a tube or opening. Attaching a turbine to this rushing gas or fluid allows one to generate electricity using it. These devices are ideally suited to installation along a shoreline, however there are several groups researching the potential for using them offshore as well.

The final type of wave energy conversion device reviewed for this report is the overtopping variety. The physical phenomenon behind these devices may be observed at any beach; the waves run-up the beach to an elevation that is higher than the water surface itself. These units sit at or near the surface, and have a leading edge that resembles a ramp. As the wave energy reaches the ramp, it slides up the ramp and into a reservoir. This reservoir is then drained past a turbine mounted in the drainage duct(s). A schematic of this type of device may be seen in Figure 3.12.

FIGURE 3.12 Schematic of Wave Overtopping Energy Conversion Device (courtesy Wave Dragon ApS)



All of the floating, or offshore devices must be anchored to the bottom and tethered in some way that allows for a certain degree of movement. This may prove challenging in an area with a large tidal range, such as the Bay of Fundy. They would most likely be anchored to the sea-bottom using traditional offshore anchors (either mass-anchors, such as concrete blocks; pile-anchors; drilled anchors; suction-anchors, etc). The electricity would be transmitted onshore using a sub-surface transmission cable.

These devices all rely upon a high wave energy location to be financially viable. Selection of a device will depend on the predominance of either swell waves (waves that have a longer period) or wind generated storm waves. Since waves change (in size, shape, direction, and kinematics) as they move towards shore, the water depth at which the devices are installed would be an important factor.

State of Technology

Although wave energy conversion devices are still immature and have not been applied in widespread commercial applications, many of the devices are undergoing demonstration or pilot projects. Some commercial applications have been permitted and construction has begun at a site off the coast of Portugal (*Aguçadora Wave Park*). It is quite likely that additional commercial wave farms will be constructed within five to ten years.

3.1.5 Applicability to the Bay of Fundy

When considering what type of renewable energy resource to apply in a given location, it is worthwhile to review which resources are plentiful in the available locations.

The physical geography and properties of the Bay of Fundy do not offer a regular or reliable high energy wave climate. The fetches across which the waves may be generated are generally too short for a significant wave climate to develop from all but two directions (the Southwest and Northeast). This means that the Bay of Fundy is not well suited to applying an existing wave energy conversion device at this time.

Offshore wind installations are mature and proven around the world; however they do not take advantage of the natural attributes of the Bay of Fundy – the extreme tidal range. They also cause more concern for the general visual aesthetics of the areas as the majority of the structure is above the surface. Since much of the load on the structure is above water, rigid surface-piercing bases are required. These rigid bases do not move with ice flows and ice cones on the structures will not work given the large tidal range. The requirement to be surface-piercing puts offshore wind parks at a distinct disadvantage from a constructability and engineering standpoint in any area with significant tidal variations and ice.

The large initial capital cost that must be spent for tidal lagoons prior to any economic return generally make them challenging to consider for phased development projects. Tidal lagoons also occupy a significant area of the seabed, largely cutting those sections off from marine life.

With the natural tidal range in the Bay of Fundy being so large, there is a very unique opportunity to utilize this resource. Therefore, TISEC lends itself quite naturally to an application in the Bay of Fundy. Other sections of this report will identify several locations that that are known to provide excellent tidal energy potential.

3.1.6 Environmental Considerations

The primary environmental considerations include alteration of benthic habitats, changes to physical processes (sediment transport, currents, *etc.*), potential interaction with fish and fish habitat, as well as possible interactions with marine mammals, birds, and their habitats. These potential interactions are discussed further in Section 6 of this report.

Although the specific magnitudes may vary, in general most of the environmental impacts are consistent between the various technologies. Foundations and site preparation impact benthic habitats and communities, cables are required for each of the options, *etc.* Notable exceptions include impacts to flying animals (birds, bats, *etc.*), hydrodynamics, and movement of migratory/transient marine animals.

All surface-piercing structures have the potential for impacts upon flying animals such as birds or bats, however the potential for impacts is significantly greater for wind energy conversion devices as they occupy a much greater area above the sea surface.

All foundations have some impact on local hydrodynamics; however the ability for TISEC devices to remove energy from the system will result in some far-field current impacts that are likely to be more significant than those of wind technologies. Although the artificial representation of this energy loss is a serious challenge for numerical modelers, three-dimensional numerical models are the best tool to assess the magnitudes and spatial limits of these impacts and have been identified as a data-gap in previous studies (Michel *et al.,* 2007). Tidal lagoons may result in important changes to local and far-field hydrodynamics. These hydrodynamic impacts would be site specific and would require modeling of the near and far-field regimes during the environmental assessment phase to determine physical response and environmental viability of the project.

Although there is some avoidance during construction, there is evidence that transient and migratory marine animals have returned to offshore wind park project areas post-construction (Michel *et al.* 2007). It is not yet known how TISEC devices will impact the movement of migratory and transient marine animals, however it is possible that the impacts with tidal lagoon installations may be somewhat greater as the impoundment area is generally lost to those species as habitat.

Other environmental and socioeconomic considerations include aesthetic concerns such as visible surface-piercing structures and potential space-use conflicts with commercial navigation, recreational boating, fishing, and marine archaeology.

3.2 Detailed Discussion of TISEC

3.2.1 Introduction

As discussed in Section 3.1.5, the Bay of Fundy naturally lends itself to TISEC devices and technologies. This section will not attempt to select a particular device, but rather will provide more information on some of the issues associated with specific aspects of the installation for TISEC devices in the Bay of Fundy.

Section 3.2.2 describes some of the varied TISEC devices, and gives the background to them.

3.2.2 Available Devices

A 2005 report by EPRI titled *EPRI Survey and Characterization – Tidal In Stream Energy Conversion Devices* summarizes many available TISEC devices, presenting the state of technology, planned testing, planned power output, installation and operations and maintenance notes (EPRI 2005). A more thorough listing of devices, although without any further information or evaluations, has been collected on the EMEC website (http://www.emec.org.uk/tidal_developers.asp).

A table with the listing of all the devices presented on the EMEC website, as well as their current development status (if known) is presented in TABLE 3.1.

The UK Department of Trade and Industry has developed a process to evaluate the performance of TISEC units (DTI 2007). The approach provides a unified method of comparing the results of various installations/devices using data obtained in pilot projects and studies. The application of this performance protocol is not within the scope of this document; however, given that it is the sole published approach for evaluating TISEC device performance, it is a useful reference for future proponents of pilot and commercial TISEC installations; the Table of Contents from the document has been included in Appendix A.

Environmental Loads

Throughout the following section, various components of the construction and operation of a TISEC development will be presented. It is important to recognize that some aspects of the project and construction directly influence various biological components, and some influence the physical processes, which could thus influence the biological components. Table 3.2 outlines the project components and potential physical and biological impacts. Potential interactions and mitigative measures in consideration of several development scenarios are outlined in more detail in later sections of the report.

TABLE 3.1 List of TISEC Device Developers and Current State of Project Development

Company	Device	Country	Type of Device	Foundation	State of development
Atlantis Resources Corp	Aquanator	Australia	Oscillating Hydrofoil	Pile-Supported	Unknown
BioPower Systems Pty Ltd	bioStream	Australia	Oscillating Hydrofoil	Gravity	Lab testing (2007), Full-scale in-situ testing planned for 2008.
Blue Energy	Blue Energy Ocean Turbine (Davis Hydro Turbine)	Canada	Vertical Axis Turbine	Float and Anchor	Lab testing underway (2007)
Clean Current Power Systems	Clean Current Tidal Turbine	Canada	Horizontal Axis Turbine	Gravity	Race Rocks demonstration project completed (2007)
Edinburgh Designs	Vertical-axs, variable pitch tidal turbine	UK	Vertical Axis Turbine	Float and Anchor	Unknown
Edinburgh University	Polo	UK	Vertical Axis Turbine	Unknown	Unknown
GCK Technology	Gorlov Turbine	USA	Vertical Axis Turbine	Float and Anchor	Small scale test units installed in various locations
Greenheat Systems Ltd	Gentec Venturi	UK	Venturi	Float and Anchor	Construction of demonstration unit to begin in 2008
Hammerfest Strom	Tidal Stream Turbine	Norway	Horizontal Axis Turbine	Pile-Supported	Demonstration unit installed in 2002.
Hydro-Gen	Hydro-gen	France	Horizontal Axis Turbine	Float and Anchor	10 kW unit sea-tested in 2005 and 2006. 50 kW testing to be started in 2007.
Hydrohelix Energies	hydro-helix	France	Horizontal Axis Turbine	Unknown	Unknown
Hydroventuri	Rochester Venturi	UK	Venturi	Unknown	Demonstration units in place in 2005
Ing Arvid Nesheim	Waterturbine	Norway	Vertical Axis Turbine	Float and Anchor	Unknown
Kinetic Energy Systems	Hydrokinetic Generator	USA	Horizontal Axis Turbine	Gravity	Unknown
Lunar Energy	Rotech Tidal Turbine	UK	Horizontal Axis Turbine	Gravity	Anticipated commercial plant in UK in 2010/2011
Marine Current Turbines	Seagen, Seaflow	UK	Horizontal Axis Turbine	Pile-Supported	Anticipated commercial plant installation by end of 2007.
Neptune Systems	Tide Current Converter	Netherlands	Venturi	Gravity	Unknown
Neptune Renewable Energy Ltd	Proteus	UK	Vertical Axis Turbine	Float and Anchor	Lab testing completed in 2005.
New Energy Crop.	EnCurrent Vertical Axis Hydro Turbine	Canada	Vertical Axis Turbine	Unknown	In-water testing of 3kW unit completed.
Ocean Renewable Power Company	OCGen	USA	Horizontal Axis Turbine	Float and Anchor	Demonstration unit to be installed in 2008.
Open Hydro	Open Centre Turbine	Ireland	Horizontal Axis Turbine	Gravity	Demonstration project installed at EMEC in 2006.
Overberg Limited	Evopod	UK	Horizontal Axis Turbine	Float and Anchor	1/10th scale prototypes tested in 2005-2007.
Ponte di Archimede	Kobold Turbine	Italy	Vertical Axis Turbine	Float and Anchor	Testing platform with Kobold installed in Straight of Messina
Pulse Generation	Pulse Generators	UK	Oscillating Hydrofoil	Gravity	Demonstration project at Humber planned for installation in 2007.
Realtime Technology Ventures Limited	Neptune	UK	Horizontal Axis Turbine	Gravity	Unknown
Robert Gordon University	Sea Snail	UK	Horizontal Axis Turbine	Hydrofoil-inducing downforce	Foundation technology, prototype testing at EMEC
Rugged Renewables	Savonius turbine	UK	Horizontal Axis Turbine	Gravity	Prototype testing at NaREC planned.
Scotrenewables	SRTT (Scotrenewables Tidal Turbine)	UK	Horizontal Axis Turbine	Float and Anchor	Prototype testing planned for EMEC.
SMD Hydrovision	TiDEL	UK	Horizontal Axis Turbine	Float and Anchor	Unknown
Statkraft	Tidevanndkraft	Norway	Oscillating Hydrofoil	Float and Anchor	Unknown
Swanturbines Ltd.	Swan Turbine	UK	Horizontal Axis Turbine	Float and Anchor	Working on design of demonstration unit.
Teamwork Tech.	Torcado	Netherlands	Horizontal Axis Turbine	Pile-Supported	Demonstration turbines installed in exhaust sluice.
The Engineering Buisiness	Stingray	UK	Oscillating Hydrofoil	Gravity	Full-scale demonstration unit tested. No longer in development.
Tidal Electric	Tidal Lagoons	UK/USA	Lagoon	Lagoon	Tidal lagoon based
Tidal Generation Limited	Deep-gen	UK	Horizontal Axis Turbine	Gravity	Working on conceptual designs for demonstration unit at EMEC
Tidal Hydraulic Generators Ltd	Tidal Hydraulic Generators	UK	Horizontal Axis Turbine	Unknown	Unknown
Tidal Sails	Tidal Sails AS	Norway	Oscillating Hydrofoil	Float and Anchor	Prototype deployed in 2007.
TidalStream	TidalStream	UK	Horizontal Axis Turbine	Float and Anchor	Scale model testing completed.
UEK Corporation	Underwater Electric Kite	USA	Horizontal Axis Turbine	Gravity	Device ready for commercial applications
University of Strathclyde	Contra-rotating marine current turbine	UK	Unknown	Unknown	Unknown
Verdant Power	Various	USA	Horizontal Axis Turbine	Pile-Supported	Demonstration project installed in New York River
Woodshed Technologies - CleanTechCom Ltd	Tidal Delay	Australia / UK	Unknown	Unknown	Unknown

Developer and device names from *http://www.emec.org.uk/tidal_developers.asp,*

TABLE 3.2 Project Phase and Potential Impacts (after Michel *et al.* 2007)

Project/Construction Phase	Affected Physical Process	Affected Biological components
Seabed preparation	▪ Sediment transport ▪ Waves/currents through channel modification ▪ Vibrations ▪ Introduction of additional hard-substrate	▪ Benthic communities ▪ Benthic habitat ▪ Fish habitat ▪ Marine mammals
Pile Installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Vibrations	▪ Benthic communities ▪ Benthic habitat ▪ Fish habitat ▪ Marine mammals
Gravity foundation installation	▪ Sediment transport (sediment suspension and initiation of scour) ▪ Introduction of additional hard substrate	▪ Benthic communities ▪ Benthic habitat ▪ Fish habitat ▪ Marine mammals
Scour protection installation	▪ Sediment transport (sediment suspension) ▪ Introduction of additional hard-substrate (if traditional protection is used).	▪ Benthic communities ▪ Benthic habitat ▪ Fish habitat
TISEC installation	▪ Modified currents ▪ Reduction in total tidal energy	▪ Benthic communities ▪ Benthic Habitat ▪ Fish ▪ Marine mammals ▪ Birds, if surface-piercing
Cable installation	▪ Sediment transport (sediment suspension, exposure of fines, scour)	▪ Benthic communities ▪ Marine mammals (temporarily displaced) ▪ Benthic habitat ▪ Fish ▪ Fish habitat
Project Operation	▪ Reduced currents ▪ Modified waves ▪ Degradation of anti-fouling coatings ▪ Electro-Magnetic Fields (EMF)	▪ Benthic communities ▪ Benthic habitat ▪ Marine mammals ▪ Fish
Maintenance	▪ New anti-fouling agents ▪ Spills from maintenance vessels ▪ Re-introduction of lubricating oils	▪ Removal of marine life affixed to TISEC unit. ▪ Spill impacts on Marine mammals, sea birds, and fish.
De-commissioning	▪ Similar to construction	▪ Similar to construction

Foundations

Regardless of what TISEC devices are selected, some form of anchor or foundation will be required. The selection of the appropriate foundation depends on the selected device and seabed conditions in the proposed locations.

The two types of foundations that exist and are proven in offshore applications are the marine pile and the gravity foundation. For example, the seabed conditions at Head Harbour Passage are listed as gravel/mud, bedrock, and rock/gravel (EPRI 2006a). The seabed conditions at Minas Passage are listed as gravel with exposed bedrock, and some erratics (EPRI 2006c).

Piles are generally used when soft seabed conditions are available, however piles may also be drilled into harder seabed or rock where conditions dictate that standard pile driving will not be possible; the cost for installation increases significantly when piles are drilled instead of driven. The offshore wind industry has advanced the design and installation of marine piles significantly – in particular they have advanced the use of monopiles – a large diameter pile that supports the full weight and moment of the structure in a single pile. Marine piles are a proven technology, having been used extensively in the offshore wind and oil energy industries. Offshore piles are normally installed with the use of a jack-up rig – essentially a barge that lifts itself off the water on legs, providing a stable platform for drilling or driving. A picture of a barge installing a monopile is provided in Figure 3.13.

FIGURE 3.13 Installation of a Monopile Using a Jack-up Rig (courtesy UK Seacore)

The second type of foundation considered here is a gravity foundation. Gravity foundations are typically large concrete chambers filled with some form of heavy ballast, (*e.g.* mine tailings, dense rock, *etc.*). Gravity structures require either a flat seabed or seabed preparation prior to installation.

Both pile and gravity foundations generally require subsurface soil investigations of the seabed; typically these soil investigations require boreholes. One borehole at each location is generally the minimum requirement to characterize the seabed conditions.

Floating devices that are tethered to the bottom with chains/cables will require permanent anchors, which are usually a variation of gravity or pile foundations, albeit smaller as the devices transmit much smaller moments to the seabed.

There are further alternative foundations, such as suction-buckets, and skirted gravity structures. Suction buckets have not yet been proven in single pile applications with a high moment (bending and overall rotational load - as may be required by a pile-supported TISEC device) and skirted gravity structures are still considered somewhat experimental.

The physical presence of the foundations, and the devices themselves will alter the currents; studies of the wake effects at the installation of previous devices, for example the Stingray tidal project, have not provided sufficient data to fully understand the wake effects of these foundations and devices (The Engineering Business, Ltd. 2005). Reducing these uncertainties will require in-situ testing at pilot projects, physical modeling, and three-dimensional hydrodynamic modeling (Baird & Associates 2007a). These modified currents have various physical and biological impacts, discussed later in

Section 5. Beyond affecting currents, the physical presence of the foundations will also affect benthic organisms, fish, and marine mammals. Each of these is also presented in Section 5.

Seabed Preparation

Seabed preparation is a particular requirement for gravity-based foundations; however some pile installations also require seabed preparations.

With gravity structures, a flat working surface is normally required. Seabed preparations can involve dredging to create a flat section on the seabed, or using fill materials to level out lower areas, or both. Regardless of what approach is used, seabed preparation usually includes the installation of scour-resistant materials as a bedding layer for the foundation.

The dredging process involves the removal of material from the seabed. There are several different types of dredges, each with technical or environmental advantages. The types of environmental effects, however, are generally the same: benthic habitat is completely removed or destroyed in the dredged area; suspended sediments can smother other habitat or organisms and carry contaminants great distances; and that an artificially modified bathymetry may cause changes to current patterns, potentially altering adjacent shoreline erosion rates or changing the stability of the nearby seabed itself. Researchers are only just now beginning to quantify the farfield impacts of modified currents and waves as a result of localized dredging. Benedet *et al.* measured and modeled the creation of erosion and accretion hot-spots on shorelines caused by localized dredging offshore in Florida (Benedet *et al.* 2006), and Baird & Associates has recently completed a study of the physical and biological impacts of dredging, including the stability of the ridges and shoals present in the nearby areas (Baird & Associates 2007b). Finally, there is the requirement for the disposal of the dredge spoil. There are two options for disposal of dredge spoil – land-based and offshore disposal. There is an approved offshore disposal area in the Bay of Fundy at Black Point (approximately 6 km from St. John, NB), and depending upon sediment quality, there are several different options for land-based disposal. The decision on where to dispose of the dredged material is generally evaluated when sediment quality and other factors have been determined.

One of the advantages with pile structures is that they can penetrate through weaker soils down to firmer soils, however occasionally problematic soil conditions may occur in the top layers that need to be removed prior to driving.

Very large erratic boulders are generally too expensive to move or remove. Fortunately, they are usually easy to avoid in the micro-siting process.

Scour Protection

With the exception of sound bedrock, exposed seabeds in the immediate vicinity of foundations must be protected against scour. Scour is a serious concern as it can result in the undermining of supporting soils if not mitigated with well engineered protection.

Scour is the erosion of the bed material that is due to the presence of the structure itself; as water flows past the foundation the currents are accelerated in certain locations, causing irreversible erosion of the native sea bed material. Driving forces for scour may be waves, currents, or both. Soils that had previously been stable may not be stable after the structure is installed.

Two types of scour exist: local and global. Global scour is the erosion that occurs within an array of structures, or structural elements present on or near the bottom. The combined group effect of these structures' presence causes this erosion in the near-field of the array. Local scour is erosion immediately adjacent to, or underneath a structural element (such as a pile, or caisson) that touches, or is close to, the seabed.

Global scour is highly dependant upon the development process that is followed, and the eventual layout of the TISEC foundations. Global scour is challenging to deal with in both physical and numerical models. In numerical models, the challenge of accurately representing the structures within the model exists (the large grid domain generally requires grid spacing larger than the size of the structure). With physical models there are scale and depth-limitation issues associated with representing many structures spread across the installation. In general, renewable energy projects have historically not quantified global scour, as the spacing required to allow the dissipation of turbulence is likely great enough that the scour caused by the presence of multiple structures (multi-structure group influence) is limited. That being said, it has been observed at least one offshore wind farm – Scroby Sands (CEFAS 2006). Within the framework of the proposed TISEC installations, it is recommended that a pre- and post-construction monitoring program be developed to identify global scour issues before significant problems arise.

The local scour process, particularly around piles, is well understood. Around piles, various approaches are used to predict scour depth; however modern designs are now typically used (Sumer and Fredsøe 2002). Around gravity-based structures, scour is still generally predicted using numerical and physical models tailored to the specific site and conditions being considered. For example, a comprehensive study was completed to design the scour protection for the 65 bridge piers supporting the Confederation Bridge, which was founded on weak sedimentary bedrock in the Northumberland Strait (Baird & Associates 2007c). A figure illustrating a physical model and then final installed protection against scour used for the Confederation Bridge piers is provided in Figure 3.14.

FIGURE 3.14 Physical Model (left) and Installed Scour Protection (right) for the Confederation Bridge (Courtesy Baird & Associates)

The time-scale of scour is dependant upon bed material; however in most cases it is significantly shorter than the projected life of the project (Sumer and Fredsøe 2002). Therefore, if problematic scour is anticipated, protection will be required immediately after the installation of each TISEC device. Scour protection typically exists in the form of stone material being placed around the foundation; some other approaches have been used – notably concrete armour units and artificial vegetation. The use of artificial vegetation however, is mostly considered experimental and requires additional monitoring.

The impacts caused by local scour vary based upon scour protection requirements; therefore the impacts and appropriate mitigation efforts must be determined on a site-specific basis. Typically, scour protection needs are determined on the basis of foundation geometry, current/wave environment, and physical properties of the local seabed. Should scour protection be necessary, it will cover benthic habitat over the protected area, introduce additional non-native hard-substrate and cause temporary construction-based impacts during installation (vibration and sediment suspension – Michel *et al.* 2007). Should scour protection not be necessary, temporary impacts associated with the initiation and continuation of scour (until equilibrium scour depth is reached) would include sediment suspension in the immediate area, and possibly the exposure of contaminated sediments.

Cabling

The installation of the transmission cable is an obvious necessity - the cable is used to transmit the generated electrical energy and to relay critical information from the TISEC units back to the operations and maintenance controllers. Sub-sea cabling is a well-established process, having been used extensively by the offshore energy and communications industries. There can, however, be challenges associated with the installation and operation of the cable, plus several different environmental consequences.

The cable capacity is highly dependant upon the selected development process (Section 4); however the impacts of cable installation remain the same. The cable itself must be strong and flexible enough to withstand the significant loads experienced during installation, as well as cable movement or accidental impacts during use. In areas with strong currents, vibration caused by vortex shedding (large turbulent eddies resulting from the presence of the cable or pipe) is a real concern. In order to minimize the likelihood of vibration problems and accidental strikes, it is likely that the final installation will be buried beneath the seabed, and covered with stone to protect it. It is this trenching and burying process that causes the majority of the environmental interaction.

Traditionally, submarine cables that are placed beneath the seabed are installed in one of four different ways: Jetting, Ploughing, Trenching, and Direction drilling. Jetting uses high-pressure water jets to push aside soils or sediments; the water jet is dragged across the sea-bed leaving a channel within which the cable can be placed. Ploughing is the pushing or pulling of a physical object that resembles a farmer’s plough, leaving the channel within which the cable may be placed. Trenching involves the physical digging (or cutting in the case of rock) of the seabed, leaving a channel for the cable. Once the channel is excavated and the cable installed, it must be backfilled. The backfilling will be done with a stable material, likely a coarse gravel or stone.

Directional drilling is usually done from shore; a large drilling rig drills a tunnel into the ground, going underneath the seafloor. Depending upon the geotechnical properties and the bathymetry of the final cable route, it may be possible to directional drill the entire cable-route for a Bay of Fundy installation (EPRI 2006a and 2006b). At a minimum, it may be possible to use directional drilling through the nearshore areas, minimizing the impact to sensitive shore habitat.

Most environmental interactions from the installation and operation of the cable occur during the installation process. Benthic habitat is most affected. As the trench is prepared, sediment suspension occurs, leading to clouding (which may influence fish, marine mammals, and seabed vegetation) as well as smothering of benthic habitats when the sediments eventually fall out of suspension. Furthermore, the presence of the trench may allow sensitive sediments to be exposed to waves and water-flow, further enhancing the sediment suspension. Finally, there is an eventual loss of the natural substrate as it is replaced with stone material during the backfilling process.

During operation the presence of electro magnetic fields (EMF) and increased localized temperatures due to the cable should be investigated. The scale of specific impacts caused by the presence of EMF in the marine environment is not known, however research is presently under way to ascertain the magnitude of the impacts. When cables are in operation, there is some heat generated. Adequate shielding and insulation is generally considered sufficient to minimize this effect. Some reports cite that trenching the cable does not reduce the presence of EMF (Gill *et al.* 2005); however most environmental impact assessments for alternative energy projects have recommended trenching the cable at least 1-3 metres below the sea bed to reduce the impacts of EMF and temperature fluctuations (Michel *et al.* 2007).

The specific effects associated with subsea cabling are discussed in more detail in Section 6.

Maintenance

The relative lack of operating experience with TISEC devices leads to some uncertainty with regard to maintenance frequency and approaches; however, some maintenance of the TISEC devices is a certainty. It is generally assumed that maintenance will be have to be done above the sea surface; there are two approaches to this, one being the installation of devices that can lift themselves out of the water by moving up surface-piercing piles, and the other involves devices that are brought to the surface using barge or ship-mounted crane mechanisms. Floating devices are obviously simpler to access for maintenance. Units that remain submerged for longer stretches of time will need to have greater reliability built into the designs.

Typical regular maintenance activities on a TISEC device would be the removal of bio-fouling organisms, the changing of gearbox oil and filters, replacement of sacrificial components and other consumables (backup batteries, warning lights, *etc.*), as well as the re-lubrication of seals and other moving parts. Inspections on other components would also be done at this point. More major repairs, such as the replacements of gear boxes or blades would likely be done by bringing the unit, or portions of it, back to the shore. Based on wind turbine experiences, the most critical major component for replacement is the gearbox, with an average mean time to failure of approximately 10 years (EPRI 2006b). Device manufacturers have various ranges for regular maintenance intervals. Lunar Energy for example, recommends major replacement of their central cassette every four years (EPRI 2005), and MCT is targeting annual maintenance with major overhauls every five years (EPRI 2005). Present day TISEC installations, by the nature of their pilot/demonstration deployments have all generally required more maintenance and inspections than commercial project targets. It should be anticipated that initial deployments of TISEC devices in the Bay of Fundy would require more frequent inspections and maintenance than the final large-scale commercial installations.

Undertaking maintenance activities generally increases the risk of certain environmental difficulties, most notably spills of drive train fluids and bearing lubricants. These potential spills could influence fish, marine mammals and sea birds in the near-field as well as a more extensive array of wildlife in the far-field if the spill is large and allowed to reach shorelines. However, it would be unlikely for the spill to be large, simply because the devices do not contain large volumes of these fluids and lubricants. Spills would not have any significant influence on physical processes. Mitigation measures for spills would include the use of non-toxic lubricants (such as vegetable based oils), the development of an adequate spill-response program, potentially including the purchase of specialized equipment and training of local emergency response personnel.

Bio-fouling is usually not a problem in areas with strong currents, such as those proposed in the Bay of Fundy. However, should it be a problem, bio-fouling agents such as anti-fouling paints and coatings may need to be applied on critical components. Depending upon the agents used, some of these products can have adverse environmental effects due to toxic compounds. Organisms that come into direct contact with the coated surface may be affected by the presence of these chemicals as well as other marine organisms. Presently, research is underway into finding improved compounds. These effects would be no more significant than those created by the anti-fouling coating on the bottom of a ship or boat. Initial mitigation approaches would be to avoid the use of antifouling agents and monitor for bio-fouling troubles. If bio-fouling cannot be avoided with the currents and maintenance programs, anti-fouling coatings may be necessary. In this case a primary mitigation approach would be the selection of modern low-toxicity antifouling compounds in accordance with the International Maritime Organization's *International Convention on The Control of Harmful Anti-Fouling Systems on Ships* (IMO 2005).

Exclusion Zones

The requirement for exclusion zones is generally site and device specific. There are also different types of exclusion zones: construction, commercial navigation, commercial fishing, recreational fishing and boating, dredge and anchor, security, *etc.*

Typically the entire site is specified as an exclusion zone during construction; this is common with marine construction projects, is typically lifted during extended periods of construction shut-downs, and only remains in place until the completion of the construction. Another typical exclusion is on anchoring and trawling, particularly in areas with cabling. The exclusions and limits on anchoring and trawling in the cable areas are normally left in place throughout the project's operational life.

Site-specific considerations for the development of exclusion zones would include proximity to commercial shipping routes, discussions with commercial fishery organizations, discussions with recreational fishing and boating organizations, as well as discussion with provincial and federal security agencies. The establishment of exclusion zones may require a risk-assessment study: the depth and scope for this study is site-specific and should be addressed within the environmental assessment.

There is some variability in how other international offshore renewable energy projects have handled exclusion zones: For the proposed Long Island Offshore Wind Park in the United States, it was decided not to apply for any exclusion zones (http://www.lipower.org/cei/offshore.html), whereas in Denmark a

200 m wide exclusion zone has been included around the Horns Rev offshore wind park (Noer *et al.*, 2000).

TISEC device selection and detailed design issues will have an influence on the requirements for exclusion zones. Some devices may be installed deep enough to avoid navigation issues (albeit potentially at a loss in power generation), and others will be nearer to the surface, making the necessity for an exclusion zone more likely. Furthermore, some devices may have greater tolerances to fouling from fishing equipment and debris than others.

4.0 BAY OF FUNDY DEVELOPMENT SCENARIOS

This section describes a number of potential tidal power development scenarios and technology options to be further evaluated in this strategic assessment.

Several studies (EPRI 2006 d, e; Triton 2006) have been recently conducted on the feasibility of Tidal In-Stream Energy Conversion (TISEC) projects which identified several potential sites within the strategic assessment study area as some of the largest potential resources for tidal energy in North America. The amount of tidal energy available for conversion to electricity requires in-depth knowledge of multiple, complex biophysical systems, and evolving turbine generating devices. Due to the information gaps with respect to the tidal resource area and conversion devices, it may be several years before the commercially available TISEC generated power within the strategic assessment study area can be accurately estimated and whether it represents a significant portion of the potential renewable energy.

There are several pilot and demonstration TISEC projects that have been deployed which provide a wide variety of valuable information related to the aspects of installation and anchoring techniques, the equipment used to survey the area, typical studies associated with evaluating demonstration projects, accessing the project components, potential environmental issues, and numerous other considerations. Given the early stages of the tidal energy industry however, commercial TISEC projects do not exist at this time.

The following discussions are intended to provide an overview of the Bay of Fundy and a better understanding of the techniques used to quantify available energy at a particular site and the portion of energy that can be extracted for conversion. A more focused discussion is provided to identify the different phases that a developer may undertake in anticipation of a commercial development, herein described as: *pilot, non-grid connected phase; demonstration phase*; and *commercial phase*. The pilot and demonstration subsections are based on readily available information, whereas the commercial subsection includes anticipated tasks and sites selected based on professional judgment of the study team and consultation with OEER.

Typically, the pilot phase evaluates a prototype tidal technology. The prototype evaluation often includes barge-type deployments or other short-term, readily accessible scenarios and does not necessarily have to take place in the resource area ultimately desired for commercial development.

The demonstration phase tends to involve one or several tidal devices deployed in a resource area that is considered favorable for longer-term evaluation and capable of generating power to an electrical grid. Many of the activities that have taken place for these types of deployments are well documented and have been incorporated herein as it provides an accurate context for environmental considerations to be addressed in subsequent sections of this document.

The commercial phase is intended for projects that are developed for long-term, economically viable power generation. Given that commercial TISEC projects do not currently exist, only planning activities and relatively short studies have been conducted to date. The subsection addressing commercial phase projects includes identification of sites for illustrative purposes within the strategic assessment study area. In consultation with OEER, a total of four sites which are potentially capable of commercial development have been identified for further study. The criteria used for selecting the four sites for further evaluation are discussed in Section 4.5.4.

4.1 Characterization of the Bay of Fundy

The Bay of Fundy, Gulf of Maine and Georges Bank constitute one of the world's most biologically productive ecosystems. The rich marine waters and shoreline habitat are supported from a deepwater conduit that brings dense, high-salinity, nutrient-rich deep water upwelled from the North Atlantic. Tides in the Gulf of Maine and Bay of Fundy are forced by the tides in the North Atlantic Ocean rather than from the direct influence of the sun and moon. The North Atlantic tide enters the Bay and increases dramatically toward the basins at the head of the Bay. This dramatic tidal range amplification is due to two phenomena. First, the natural period of the basin enclosing the Gulf of Maine and Bay of Fundy is a little over 13 hours, which is very close to the principal lunar semi-diurnal tidal period of 12.4 hours. Second, is the effect of the Bay of Fundy's natural shoaling and funneling. Together, these produce the highest tides in the world (EPRI 2006e).

A more in-depth description of each of the illustrative sites selected as part of this strategic assessment is provided in the subsections below. For a more detailed discussion of the Bay of Fundy, refer to Section 5.

4.2 Siting and Oceanographic Considerations

Several recent studies have addressed potential TISEC resources in the provinces of New Brunswick and Nova Scotia and cover the study area of this strategic assessment. The EPRI North American Tidal Instream Power Feasibility Demonstration Project (EPRI 2006 d, e) provides several reports which describe these site resources. As part of a contract for Natural Resources Canada, Triton Consultants Ltd. (Triton) prepared the Canada Ocean Energy Atlas (Phase 1) Potential Tidal Current Energy Resources (Triton 2006).

The resource characteristics to be evaluated as part of a commercial-scale TISEC project can be quite complex, especially when considering the lack of commercial scale study information. There are many variables related to marine life and the interaction with these facilities that can only be studied after the devices have been installed and operating for a certain amount of time. Therefore, this assessment focuses on the information that is either readily available or which can be conservatively estimated.

There are several key factors that have been reported as favorable for siting tidal energy conversion facilities. Presently the maximum practical depth for most tidal technology developers is about 70 meters. Most devices however, require depths of 10 to 40 meters (Black and Veatch 2005).

For locations in the headwaters of the Bay of Fundy, it can be reasonably assumed that developers will favor a submerged technology due to the amount of floating ice. The 30-year median of predominant ice type in the headwaters of the Bay of Fundy indicates the presence of ice up to 30 centimeters thick. In 2003, the Minas Passage, the Minas Channel, Cape Enrage, Shepody Bay and the Cumberland Basin experienced at least 30% cover of 15 cm ice in floes at least 100 meters in length. In 2007, the navigational buoy off Partridge Island Beach moved approximately one kilometer from its normal location as a result of pressure from the ice floes (Sanders and Baddour 2007).

There are several other siting considerations including: distance to the central power grid interconnecting point; environmental sensitivity; access to nearby ports; favorable bathymetry; and competing uses of sea space. Environmental considerations will be discussed in greater detail in other sections of this document. The siting considerations for the demonstration sites identified herein are addressed below in Section 4.5.4 Potential Commercial Sites.

4.3 Available Tidal Energy for Potential Conversion

There are many techniques to estimate the available tidal energy for potential conversion. Perhaps the most recent studies that provided estimates of available tidal energy were conducted by the Electric Power Research Institute (EPRI) and Triton.

To oversimplify the estimation technique used in the EPRI studies (EPRI 2006 b, c, e), the total available tidal stream resource is the product of the mean annual, depth-averaged power density multiplied by the mean channel cross-sectional area, which yields the mean annual kinetic tidal power. In some cases, Canadian Hydrographic Service (CHS) charts were used to identify existing tidal current velocities and other sources of bathymetric information were used to estimate the cross-sectional area. If current velocities in the study area were not available, then extrapolation techniques were used. For example, CHS chart #4010 was used to estimate a channel-wide average peak tidal current velocity of 3.1 m/s (6 knots) in Minas Passage, which corresponds to a power density of 15 kW/m^2. After compensating for time- and depth-averaging, the power density was calculated to be 4.9 kW/m^2. The area of interest was estimated to be 226,400 m^2, which yields an available total power resource of 1100 MW. This is an estimate of the resource area only and does not include efficiency losses due to power transmission and a project capacity factor (ratio of average generation to the capacity of an electric generating device).

Triton compiled a study report using a more rigorous approach to identify tidal resources, which included two dimensional tidal current modeling (Triton 2006). The objective of the Triton report was to provide a preliminary tidal current resource inventory, whereby the estimates identified, focused on the total potential resource available in the tidal flow as opposed to including any economic considerations. In addition to numerous other sites in the Bay of Fundy, Triton identified Minas Passage as a resource with great tidal power potential. (The report references Minas Basin, but coordinates indicate Minas Passage). To estimate the total potential resource available, data from numerical tidal models were used to provide additional information for the current power assessment. The Bedford Institute of Oceanography (BIO), provided model results which were incorporated into Triton's finite element harmonic tidal model Tide2D. This estimation technique yielded a mean potential power of 1903 MW, which is 73% higher than EPRI's estimate of the same resource and is probably a more accurate estimate of the actual available current given the source data used and technique applied. Until the resources undergo further studies, discrepancies of this magnitude should be anticipated when estimating the total potential resource available.

The resource areas identified in the EPRI (EPRI 2006 d, e) and Triton (Triton 2006) reports are outlined below and presented in Figure 4.1.

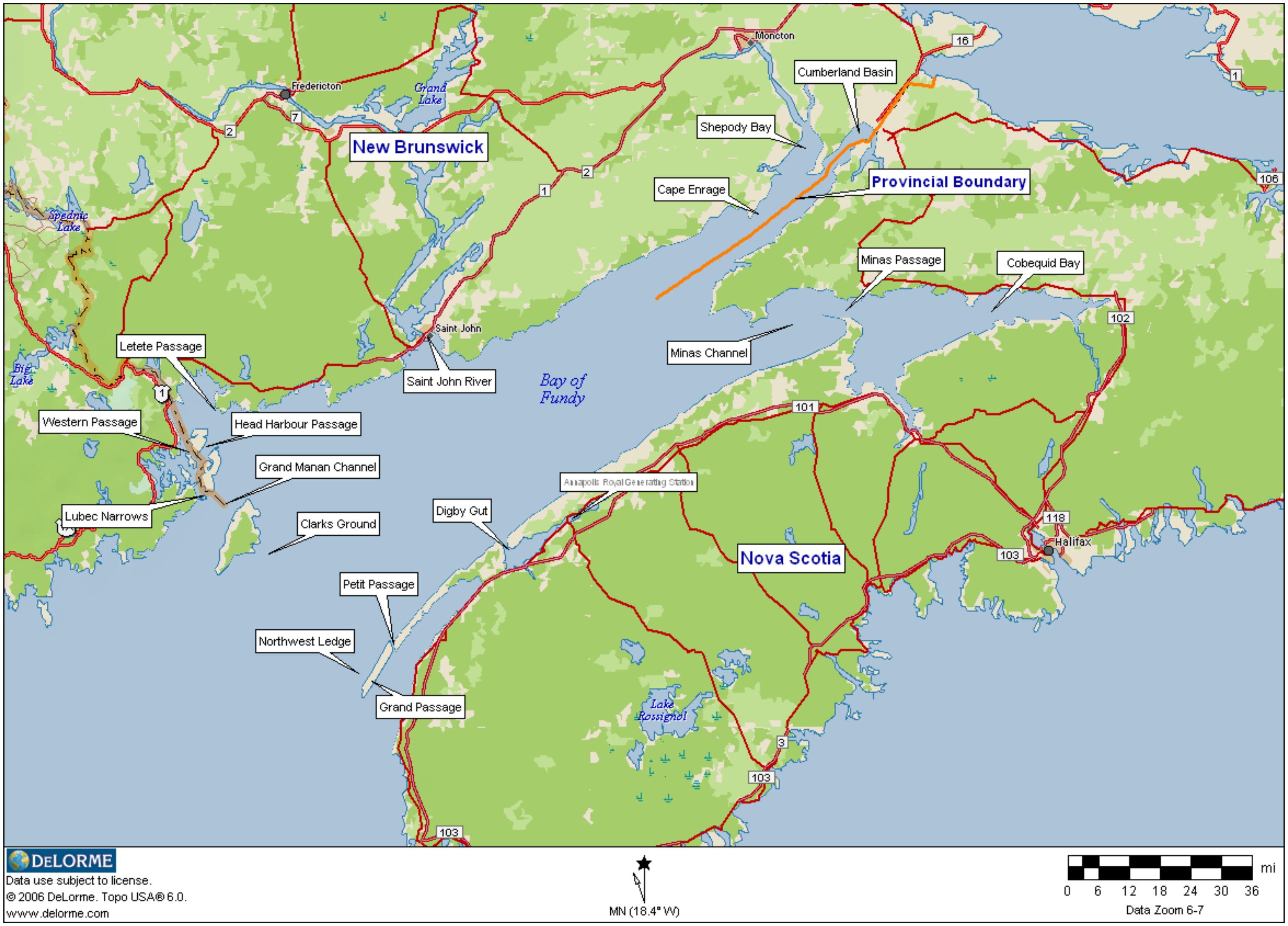
Location	Tidal Resource Power (MW)	
	EPRI	Triton
Minas Passage, NS	1100	1903
Minas Channel, NS		
Clarks Ground, NB	870	
Cape Enrage, NB		216
Northwest Ledge, NS	100	
Petit Passage, NS		73
Cumberland Basin, NB	61	24
Grand Manan Channel, NB	56	
Head Harbor Passage, NB	47	50
Grand Passage, NS	44	74
Shepody Bay, NB	43	
Cobequid Bay, NS	42	
Western Passage, NB	36	83
Digby Gut, NS	33	
Letete Passage, NB	14	
Lubec Narrows, NB	4	4
St. John River	TBD	

4.4 Extractable Energy

Several recent reports involving energy conversion of tidal resources and deployment of devices for commercial-scale application include discussions related to energy extraction. Recently, EPRI published a report (EPRI 2006a), wherein a 15% energy extraction was discussed. In essence the report identifies the spatial constraints associated with tidal stream energy, mentions that limited modeling has been conducted to date, and specifies that 15% was "selected" by EPRI as the level of extraction which will not result in significant alteration to the estuary circulation. EPRI reviewed previous modeling results that were conducted and summarized the reasoning for selecting 15% as the environmental extraction limit.

> *In reviewing these results, EPRI has used 15% as the environmental extraction limit. According to the open-ended channel model results reported in Reference 13 (Bryden and Melville 2004). Choosing and evaluating sites for tidal current development. Proc. Instn. Mech. Engrs., Part A: Journal of Power and Energy, Vol. 218 pp. 567-577], this would result in a tidal current speed reduction averaging 4% along the entire channel length. It is unknown whether or not such a change in flow speed would result in significant environmental consequences, such as slower transport of nutrients and oxygen or less turbulent mixing. However, it is worth noting that the above studies assume steady state conditions – and tidal flows are inherently unsteady. Extraction of energy and subsequent reduction in downstream flow rates will result in an increased head at the mouth of the estuary (since the tidal basin will be filling slower), giving rise to a partially restorative forcing. Extraction rates are likely to be a function of channel geometry and tidal regime and, therefore, specific to particular channels. Better understanding of these effects would require the development of ecosystem-level models, driven by site-specific hydrodynamic numerical models, reflecting actual site bathymetry and tidal changes in sea level, as well as turbine-specific interactions with the flow.*

FIGURE 4.1 Bay of Fundy Site Map



In 2004 the Carbon Trust of the United Kingdom, commissioned an assessment of the UK tidal energy resource. Black and Veatch (B&V) conducted a study - Phase I Report, 2005 (Black and Veatch 2005), to determine the fraction of the total tidal energy resource that could be extracted from a site before negative economic or environmental effects occur, called the Significant Impact Factor (SIF). The Phase I study initially assumed a SIF of 20% extraction of the potential energy at all sites assessed. The report also concluded that much of the UK tidal resource is concentrated predominantly at a depth greater than 40 meters.

The B&V Phase II study was conducted and refined to focus on the development of a more robust SIF for the ten most promising of the original sites analyzed in Phase I. The fact that B&V conducted a second report which is site specific and focused on an improved SIF analysis suggests that progress is being made with respect to the overall goal of determining what portion of tidal energy is extractable. It is also indicative of the degree of site specific assessment that will likely be required for TISEC projects in the Bay of Fundy.

However, upon searching for the definition of “significant economic or environmental effect”, B&V specifies that the understanding of the SIF is still in the developmental stage, but that the primary environmental effects of energy extraction that determine the SIF is site specific and includes changes to: regional tide propagation; pollution transport/dilution; sedimentation and other coastal processes; and marine life.

B&V identifies five different types of tidal stream sites and includes a range of likely SIF:

1) Inter-island channels with ‘fixed’ head differences, which may be caused by a tidal phase lag between the two ends of the channel. In these channels the flow is broadly governed by the head difference at either end of the channel and the flow does not greatly affect the tidal elevation in the bodies of water at either end (SIFs 10-20%).
2) Open Sea sites with ‘fixed’ head differences. These are effectively similar to very wide channels without any side boundaries and therefore water is able to flow in/out of the site through these boundaries (SIFs 10-20%).
3) Headlands with ‘fixed’ head differences. The flow around headlands is generally very complex with shifting maximum tidal stream velocity locations. These types of sites are similar to open-sea site
4) with a side boundary (SIFs 10-20%).
5) Sea lochs with head differences determined by the energy extraction. Initial work indicates that energy extraction has little effect on such sites. Reducing the tidal stream velocity through energy extraction has a positive feedback on the head difference in a similar fashion to that experienced with a traditional barrage (SIFs up to 50%).
6) Resonant estuaries where the head differences are a result of complex effects (SIFs <10%).

The results of the focused modeling for the ten UK tidal sites indicated an acceptable SIF ranging from a low of 8% to a high of 20%. It is also mentioned that future developments in the understanding of the factors affecting the SIF could change these results.

The scope of this strategic assessment does not include an in-depth analysis of a SIF or any type of modeling to determine the potential energy extraction at an individual site within the strategic assessment study area. Given the extent of the modeling that has been conducted to date and the site specific issues that need to be considered, the next phase of the assessment should include extensive modeling for each potential commercial development site. A more detailed discussion related to modeling for use in turbine spacing and other parameters of interest is provided below in Section 4.5 Tidal Development Scenarios.

Upon review of the studies conducted, it appears that an acceptable range of extractable energy could be up to 20%, with the understanding that the definition of "significant economic or environmental effect" is highly subjective. Verifying this limit of extractable energy would necessarily begin with quantification of the existing site-specific conditions and establishment of acceptable deviation from those physical and environmental norms. However, the task of establishing acceptable deviations from the existing conditions alone would involve experts from a variety of disciplines (computational fluid dynamics [CFD] modeler, hydrologist, biologist, *etc.*), coordination with the jurisdictional agencies and applicable regulatory processes.

The research and modeling efforts referenced by EPRI and B&V (EPRI 2006a; Black and Veatch 2005) and associated with extractable energy, have been for inventory purposes only. There have been limited studies conducted to date which can provide model input data for the potential effects on marine life. This is one of the primary data gaps for Bay of Fundy developments and perhaps one of the more complex issues to monitor and study. There have been several marine life studies that have been conducted by various developers at specific locations. Some of the studies relate to baseline data, while other studies involve device operation. However, at this time, there is limited study information that is publicly available. In order to move forward on any potential tidal development in the Bay of Fundy, potential effects on marine life may need to be studied.

4.5 Tidal Development Scenarios

The following sections provide an overview of the types of tidal projects that have been conducted, activities or studies related to commercial developments, and considerations for commercial developments in the strategic assessment study area.

4.5.1 Introduction

The development of TISEC devices in the Bay of Fundy can be categorized into three potential scenarios: pilot, non-grid connected; demonstration; and commercial. These three scenarios, although loosely defined, are typically classified by properties such as generation capacity, time period/term of electrical generation and operation, and by development strategy.

A pilot, non-grid connected project scenario is a short term development that is focused on the initial testing of a tidal energy device(s). Pilot device deployment costs are minimized as there likely is no electrical grid connection and no economic viability. The pilot is important to the advancement of tidal energy developments because it facilitates a quick evaluation of device performance and typically can be conducted in any tidal resource. There are some evaluations that do not require a tidal resource at all, whereby the device is pulled behind a barge.

A demonstration project is typically deployed in the tidal resource area of interest. This allows collection of site-specific data, turbine refinements in accordance with precise fluid dynamics, and a better understanding of what would be involved as part of the commercial phase of the project. This scenario is not a commercial development, but could be the first phase of such a development and include an energy-producing device or multiple devices. Based on this assessment, the demonstration development scenario would likely utilize a small number of kinetic devices (1-20), with a full range of generation capacity likely under ~5 MW. In the Province of New Brunswick, an environmental impact assessment is required; however, electric power generating facilities that do not impact rare/endangered resources and have a production rating less than 3 MW are exempt from the provincial environmental impact assessment. Developers that wish to pursue smaller scale commercial projects (*i.e.*, less than 5 MW) may realize lower costs associated with shorter distances to grid connections depending on the site location. Distribution lines which are more abundant in near shore locations within the provinces can typically accommodate an additional 3-5 MW of generating capacity (Knight 2007, pers. comm.). However, the development scenario may or may not be grid connected depending on the goals of the developer and the conditions of the power purchase agreement.

For the next several years, the number and configuration of devices deployed as part of the demonstration phase may change due to several variables including but not limited to: the power purchase agreements negotiated by the developer; tax incentives; and the permitting regulations. The provinces or federal government may be interested in streamlining the permitting process during the demonstration phase in an effort to provide incentives for the industry within the Bay of Fundy. For example, in a new order (FERC AD07-14-000 2007) from the United State's Federal Energy Regulatory Commission (FERC) a development scenario labeled as "pilot-scaled" project is defined as having four criteria: (1) a generation capacity equal to, or less than, 5 megawatts ; (2) removable or able to shut down on relatively short notice; (3) not located in waters with sensitive designations; and (4) for the purpose of testing new hydro technologies or determining appropriate sites for hydrokinetic projects. The primary goal of this proposed licensing process is to encourage the development of innovative hydrokinetic technology, without the need for the full licensing process required by the FERC regulations under Part I of the *Federal Power Act*.

Finally, a commercial development scenario is defined as a grid-connected project having a permanent, long-term deployment until future permit renewal or decommissioning. This project scenario would not be constructed to serve as a test or demonstration of technology, but instead as an energy producing power plant.

In the Scottish SEA it is assumed that commercial device arrays will be approximately 30 to 50 MW in generating capacity, and will contain approximately 30 to 100 conversion devices. Little information is available on the potential footprints of tidal device arrays. Based on current information, a 30-unit tidal array could typically be expected to occupy 0.5 km^2, arranged in an oblong shape, the short dimension of which would be dependent on the width of the high energy tidal stream (Faber Maunsell and Metoc PLC 2007).

Planning the spatial arrangement and number of TISEC devices for a commercial phase tidal energy project requires a detailed assessment of the site's hydrodynamics and device-specific characteristics. The spacing and placement of TISEC devices is analogous to the development of wind power farms; the fluid dynamics, performance characteristics, and economics are highly coupled and equally complex.

There are varying options and methodologies for the developer to determine the most economical device arrangement while minimizing potential effects to the environment. The key abiotic baseline components for the developer to study are a 3-dimensional profile of the current velocities over the tidal range, and a detailed site bathymetry. These data may be sufficient to determine where the tidal resource is strongest and most economical. To perform these studies a developer will likely use Acoustic Doppler Current Profiling (ADCP) technology to profile the 3-dimensional current over a range of tides. Detailed site bathymetry will likely be collected using a single or multi-beam echosounder.

Using these site specific data on 3-D current velocity and bathymetry, the developer will need to perform sensitivity analysis calculations to determine how the number and arrangement of TISEC devices will affect the environment. Effects to the abiotic environment which could be modeled include, but are not limited to:

- energy extraction,
- change in water level,
- increased hydraulic head,
- sedimentation regimes and resulting geomorphology,
- regional tide propagation, and
- changes in hydrodynamics.

There are varying degrees of complexity to calculate these effects. Typically, an analysis of this problem requires the development and calibration of a CFD model. This process involves numerical approximation of the governing 3D unsteady flow equations, calibration to an extensive set of field data and simulation using a high-end computer processor. The end product allows the developer to visualize the complex flow field, and through parametric sensitivity analyses, determine the most appropriate spatial distribution and number of TISEC devices for the site-specific commercial project.

Due to the lack of commercial-scale instream kinetic tidal energy projects in operation today, many of the tidal technologies installed in demonstration projects are scaled down models from the planned commercial size. Consequently, many of the commercial build-out scenarios that need to be modeled may vary considerably at this time as many tidal technologies are still unproven and untested in true long-term operation.

4.5.2 Pilot & Non-Grid Connected Projects

Pilot and non-grid connected project scenarios are limited to projects that are deployed for a short term period, or mobilized for a short term, with the intent to conduct preliminary device tests and feasibility studies. Typically, these projects are a first step in evaluating the potential of a particular device technology. The information gathered from the pilot project will likely aid in determining the feasibility and practicality of developing and deploying the technology into a demonstration project or a commercial application.

Many pilot projects begin with device deployment in a controlled environment or temporary deployment from a barge or existing structure(s). The projects' objectives are typically to confirm theoretical power generation calculations and additional studies on performance. As there is no electrical grid connection, the pilot projects are not economically viable in the short or long term.

Pilot project siting has fewer criteria than demonstration and commercial developments. The basic siting resource necessary for the pilot project's objectives is easy access, an adequate tidal resource or simulation of a tidal resource.

Verdant Power, LLC (Verdant) conducted a pilot study with a tidal turbine deployed from a barge into a river system as illustrated in Figure 4.2.

FIGURE 4.2 Verdant Power Initial Turbine Testing

4.5.3 Demonstration Projects

Demonstration projects are intended to evaluate the long-term operation and potential environmental effects of one or several ocean energy conversion devices. The majority of tidal devices are still in the early stages of development. The implication of this is that a large proportion of the developments that will occur in the near future may be test or demonstration, rather than commercial developments (Faber Maunsell and Metoc PLC 2007).

Demonstration scenarios are advantageous as they allow the developer(s), investors, regulators, and public to assess the feasibility and viability of the technology and monitor its effects on the marine environment before investing in commercial scale tidal energy plants. Electricity generated by demonstration projects does not often contribute significant amounts of power to the grid. Therefore the projects are not economically viable on a long term power generation basis (Faber Maunsell and Metoc PLC 2007). As such, they are an investment to assess the tidal technology and potential environmental effects.

The siting criteria of tidal demonstration projects are a critical aspect in the economic feasibility, potential environmental effects evaluation, and operational demonstration of tidal technologies. The physical siting of demonstration projects is important because the information and knowledge gained from the project may support commercial scale build out in the same area. The most basic siting criterion for a tidal energy project is the tidal current resource. In the EPRI feasibility studies for New Brunswick and Nova Scotia, initial tidal site screening was based on average peak ebb and flood tidal velocities. Only the sites with both peak ebb and flood tidal currents averaging at least 1.5 m/s (3 knots) were considered (EPRI 2006 d, e).

In a tidal resource study for the UK, conducted by B&V (Black and Veatch 2005), a more conservative tidal current resource is recommended for project siting. B&V states that although there is a reasonable tidal resource at low speed (mean spring peak velocity less than 2.6 m/s [5 knots]) sites, it may be more difficult for devices to extract this resource economically. The best site prospects for the extensive deployment of cost-competitive tidal stream energy devices have an average peak spring tide velocity greater than 2.6 m/s (5 knots). To compare this value to the 1.5 m/s (3 knot) minimum resource in the EPRI report, the Bay of Fundy neap tides are 30 to 50% lower than spring tides (EPRI 2006 d, e); therefore, average peak spring tides of 2.6 m/s (5 knots) would equate to approximately an average of 1.5 m/s (3 knots) for peak neap tides. The overall average of peak tidal currents should therefore be approximately 2.1 m/s (4 knots).

Due to the early stages of the tidal power industry, and the uncertainty of potential environmental effects, demonstration projects are likely to require substantial testing, monitoring, and servicing throughout the operational life. Information on site bathymetry, sediment composition and concentration, therefore plays a significant role in site selection to test, monitor, and service the devices. Some developers may seek to deploy demonstration projects in shallow waters, while still deep enough for the operation and safety of the selected tidal device(s). The benefit of shallow waters is that they are typically more cost-effective in device installation and retrieval, which will be more frequent at this phase due to the inspection and maintenance activities required. Environmental and operational monitoring generally has less logistical challenges in shallow water than deep water.

However, several developers have technologies that have been tested and no longer require a lengthy demonstration phase of the technology itself. Therefore, deployment of devices in shallow waters is not desired, and in some cases the depths of the tidal resources may not meet the operational requirements of the devices.

Any site that is being pursued for eventual commercial development will likely go through a demonstration phase so that baseline data can be efficiently collected. There may be several studies involved in this phase of the project to evaluate the interaction of various aquatic species, marine mammals or other potential environmental effects. The demonstration phase provides the developer with the best opportunity to optimize turbine performance for site-specific conditions which will likely require turbine modifications or component upgrades. Each turbine modification may require slightly different monitoring techniques or reconfiguration of the monitoring equipment. Although some TISEC technologies allow for turbine retrieval by design (*e.g.*, MCT's SeaFlow or SeaGen technologies), the monitoring studies involved may require equipment to be submerged at various depths and in areas which may not be as easy to access. Typically, demonstration projects will require more frequent access to the turbine components and involve monitoring studies that may be more practical in shallow water.

Depending on the long term goals of the demonstration project, and the device's capabilities of deployment depth, site locations having areas of deep water resources, greater than 30 meters, are attractive for additional project development. Deep water areas will generally allow deployment of more devices and larger scale device models capable of greater capacity and electrical generation. The best prospects for the extensive deployment of cost-competitive tidal stream energy devices could be in turbine devices that are suitable for deployment in sites of depth greater than 30 meters (Black and Veatch 2005).

Whether regional, national, or remote, the location and capacity of a coastal utility grid and possible substation interconnection is critical in project siting feasibility. The distance to adequate electrical transmission is a large determining factor in the project startup costs. Demonstration projects with the potential to be developed into larger demonstration or commercial projects should assess the additional electrical generation and the existing load capacity on the transmission lines and substation.

Additional installation criteria for site selection for demonstration projects include seafloor geology, navigation, nearby regional shipyard labor and infrastructure support, and minimal conflict with competing users (*e.g.*, fishers). Seafloor geology, or sedimentation, at a deployment site is an important consideration for foundation design and has an impact on the type of foundation or anchor device used, installation methods and scour protection, if required (EPRI 2006a).

For the past several years, there have been significant steps taken by developers and investors to put tidal energy demonstration projects into the water. There are existing demonstration projects in various phases which are discussed in the subsections below.

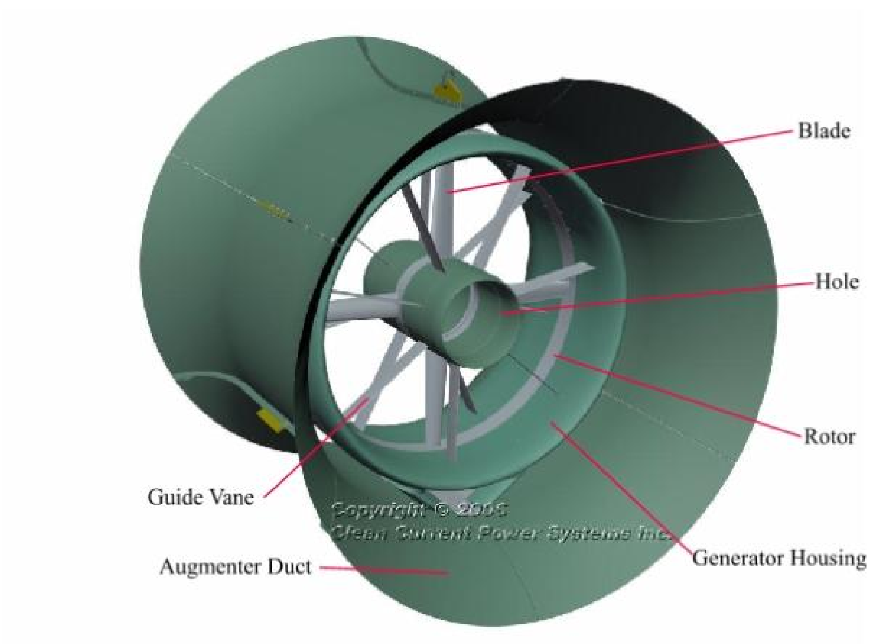
4.5.3.1 Clean Current Power Systems Inc.

In September 2006, Clean Current Power Systems, Inc. (Clean Current), a private British Columbia-based company, partnered with the Lester B. Pearson College of the Pacific, EnCana Corporation, and Sustainable Development Technology Canada, to install a tidal power demonstration project at the Race Rocks Ecological Reserve. The Race Rocks Tidal Energy Project is located offshore of Vancouver Island in the Strait of Juan de Fuca, British Columbia. It is Canada's first kinetic tidal power project. The demonstration involves the installation, operation, and monitoring of one 65kW tidal turbine generator.

The objectives of the Race Rocks Tidal Energy Demonstration Project are to: (1) provide electricity to replace 2 diesel generators; (2) demonstrate efficiency and reliability of the tidal turbine generators; (3) demonstrate power conditioning capabilities and support infrastructure; (4) study maintenance processes, (5) study behavior of sea mammals and fish in relation to turbine operation; and (6) contribute to the education experience of the partnering Pearson College (Archipelago Marine Research Ltd. 2006).

The 65kW Clean Current demonstration tidal turbine is a horizontal-axis ducted turbine with a direct-drive variable speed permanent magnet generator. The device is bi-directional with flow, equally efficient in both ebb and flood tide directions. The rotor assembly containing the blades is the one moving part. The turbine and housing structure, when deployed, is completely submerged in the water. The turbine has a design life of 10 years between major overhauls, and a service life of 25-30 years. The primary components of the turbine are illustrated in Figure 4.3 below (Archipelago Marine Research Ltd. 2006).

FIGURE 4.3 Turbine Design



The Race Rocks demonstration site is unique to other demonstration projects areas around the world. The demonstration project is sited in one of Canada's Marine Protected Areas and an Ecological Reserve designated in 1980. Canada's Ecological Reserves were created in order to preserve unique or representative ecosystems in the province that could serve for research and education and serve as baselines for monitoring ecological change with the encroachment of humans into natural areas. The site is managed by a group of interested parties including Pearson College and the Canadian Coast Guard.

As a result of the site's designated status, there have been a significant amount of environmental baseline studies conducted long before the tidal demonstration project. Tidal velocity data were obtained from the Institute of Ocean Sciences from a current meter installed at Race Rocks from 1980 to 1981 for the purpose of obtaining data that would form the basis of the Race Passage Tables in the Canadian Tides and Currents Book. The peak current velocity from 1980 to 1981 was 3.1 m/s (6.0 knots) (Archipelago Marine Research Ltd. 2006). In addition, baseline underwater noise studies were conducted by Simon Fraser University at 14 different locations around the main Race Rocks Island. Extensive research has also been conducted on the resident hydroids, marine algae, macro invertebrates, marine mammals, and fish.

Environmental studies were also conducted specifically for the Race Rocks Tidal Power Demonstration Project. During the pre-construction phase a baseline record of terrestrial and marine species and habitat in the project area was developed. During the construction phase, the effects from construction on marine birds, marine mammals, and benthic habitat were monitored via observation and underwater camera. After construction and installation the potential effects from the construction phase on the benthic environment at the tidal turbine site were monitored by recording observations on biophysical features and collecting underwater video imagery along the submarine cable route and at other areas of potential impact identified during the construction phase.

To determine the optimal location for the turbine, an 11 transect ADCP survey was conducted on March 30, 2005 to capture the 3-dimensional profile of the tidal currents. Based on the ADCP results, dive teams surveyed the two most promising areas of interest for the turbine placement in April of 2005. To confirm the current velocity results, an ADCP was deployed in the second of the two potential turbine locations for a period of one month. Additional testing included a study of biofouling on different structural materials and anti-fouling coatings that would be potentially used on the turbine and related infrastructure. The samples used to test the various coatings are illustrated in Figure 4.4 below.

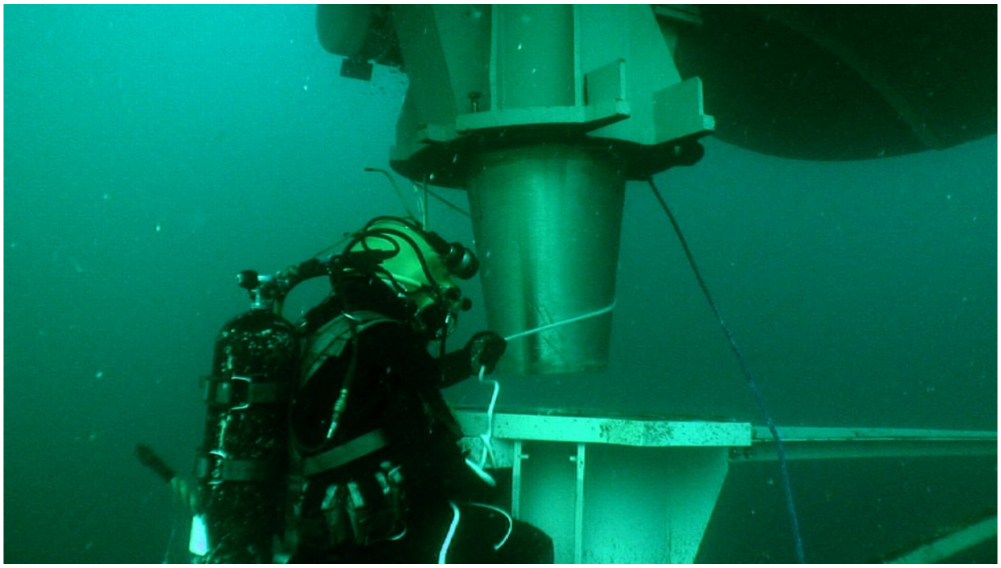
FIGURE 4.4 Biofouling on Materials and Coatings at Race Rocks

Pre-turbine deployment work and construction included an electrical cable connection from the turbine generator to an isolated control system that feeds electricity into the battery storage system at the Race Rocks Ecological Reserve Center. The electrical cable spans about 0.3 miles from the turbine generator to the Race Rocks Island dock. Intertidal construction was conducted where there was already extensive infrastructure, also enabling repairs to be made to the island dock structures. On the turbine deployment site, an area was dredged to remove overburden to prepare for drilling and installation of a monopile to secure the turbine to the seabed. A 1 meter wide, 8 meter deep hole was drilled and the lower pile was installed.

In the first week of September of 2006, before the turbine was installed on the monopile, the turbine was field tested in nearby Pedder Bay. A barge was constructed specifically for the purpose of cradling the turbine for field testing and for final deployment and retrieval. The field testing was conducted for the purpose of electrical tests and other turbine operational logistics. This particular deployment required a diver as illustrated in Figure 4.5. In the headwaters of the Bay of Fundy this technique may not be optimal given the high sedimentation concentration and reduced visibility. The wave action on the friable shorelines of the Upper Bay results in water that is increasingly turbid and diminishes light penetration in the water (Huntsman 1952; Daborn 1986; Brylinsky and Daborn 1987).

Installation of the demonstration turbine was completed on September 27 of 2006. The turbine was deployed in water 21 meters in depth and is 3.5 meters in diameter (Archipelago Marine Research Ltd. 2006).

FIGURE 4.5 Turbine Installation on Monopile



The testing of the Race Rocks demonstration project has validated the turbine's performance estimates. The generator has successfully extracted power in current velocities up to 3.4 m/s (6.6 knots). The turbine remained operational in the water for a period of 6 months. On May 24, 2007 the turbine was extracted from the water to be thoroughly inspected. Figure 4.6 below illustrates the retrieval technique and condition of the turbine after 6 months of operation.

FIGURE 4.6 Turbine Removed After 6 Months of Operation

4.5.3.2 Verdant Power, Inc.

In the United States, Verdant Power, LLC (Verdant) has been the first developer to deploy and operate a demonstration tidal energy project, the Roosevelt Island Tidal Energy (RITE) Project. The project is located in the East River, New York City, where Verdant has deployed 6 kinetic tidal turbines.

The Verdant turbines have a rotor diameter of 5 meters and a rated generation capacity of 35 KW each. The deployment technique and turbine design are illustrated in Figure 4.7. The turbines are deployed in approximately 30-35 feet of water where tidal current velocities reach 2.6 m/s (5 knots). A navigation exclusion zone has been placed around the turbine field array. At mean low water the tips of the turbines remain approximately 4 feet below the water surface. Electricity produced from the turbines is routed to a grocery store and depot bus garage.

The RITE demonstration project was permitted to operate for a testing period of 18 months while studies are conducted to evaluate environmental effects of the turbines on the river system.

FIGURE 4.7 Verdant RITE Turbine Deployment

Several studies have been conducted to date, some of which have been quite complex, time consuming, and costly. A list of the study activities is outlined below:

- Benthic Habitat Characterization
- Water Quality Assessment
- Mobile Hydroacoustic Fish Survey
- Fixed Hydroacoustic Fish Survey
- Hydrodynamic Survey
- Underwater Noise Survey

- Rare, Threatened and Endangered Species
- Bird Observation Survey
- Recreational Resources Assessment
- Navigation and Security Assessment
- Historical Resources Assessment

One of the more involved studies is the fish monitoring study. The Mobile and Fixed Hydroacoustic Fish Monitoring Studies were designed to collect baseline data and evaluate fish movement and behavior through a field of tidal energy turbines in the East River in New York City. The split-beam acoustic technique was selected as the best methodology to meet study objectives of obtaining fish spatial distributions and abundance, as well as provide fish behavior information by tracking a fish's swimming speed and direction, and estimates of individual fish target size, and provide continuous monitoring around operating turbines (Verdant Power 2006).

Baseline surveys consist of multiple pre- and post-deployment mobile acoustic surveys. Each survey event consisted of sampling multiple cross-channel transects throughout the study area during daylight and nighttime hours. Information on fish distribution, densities, and estimated size ranges has been evaluated for spatial and temporal trends and distributional data were evaluated for potential migration routes. Fish collection efforts included otter trawls during pre-deployment surveys to provide species information. Available historical fish collection data has also been analyzed to assist in species evaluation (Verdant Power 2006).

Fixed hydroacoustic techniques were used to monitor fish distribution and movement through the tidal turbine array. The study design consisted of a total of 24 split-beam hydroacoustic transducers deployed to monitor fish movement as they approach and move through the turbine field. Automatic Monitoring Control Software was developed to continually monitor the fish counts coming from the arrays and compare to multiple pre-defined acoustic events. If target numbers, types, and behaviors surpass threshold values, the acoustic system was set to notify on-site or remote project managers (Verdant Power 2006).

The split-beam acoustic technology was supplemented with an innovative but still experimental DIDSON system which uses high definition sonar to produce a near video quality graphic display.

4.5.3.3 Marine Current Turbines, Ltd

In the southern United Kingdom, Marine Current Turbines, Ltd (MCT) has been operating a demonstration tidal turbine at Lynmouth, Devon since May 2003. The SeaFlow, a first phase R&D project, consists of a single commercial-scale 300 KW tidal turbine prototype with a single 11 meter rotor. The turbine is designed for deployment in water depths of 20 to 30 meters with a resource of 2.3 - 2.6 m/s (4.5 to 5 knots) during peak spring tides.

In the next year MCT plans to install the next generation tidal turbine, a 1.2 MW device called SeaGen, in Strangford Lough, Ireland. The SeaGen turbine has twin 16 meter, bi-directional rotors. The system will be connected to an existing grid adjacent to the sewerage substation south of Strangford. To connect the transmission cable from the turbine to the grid, a 450 meter long horizontal directional drill (HDD) bore hole, 300 mm diameter, will be drilled 20 meters below the seabed for the 11 kV cable.

The SeaGen project has been granted a Food and Environmental Protection Act (FEPA) license for a period of 5 years following installation. Pre-installation environmental monitoring commenced in May 2004. A baseline report has been completed and was submitted to the Environment and Heritage Service (EHS) in August 2006. The environmental impact of SeaGen will be continuously monitored by an independent science team throughout the licensed 5 year installation period.

MCT has already conducted several on-site surveys. The geophysical survey of the area used high-technology instrumentation to determine the bathymetry, seabed features and sub-bottom geological profile. Echosounder data, sidescan sonar data, magnetometer and sub-bottom profiler data were required from all survey main lines spaced at 50 m, and specific main lines spaced at 10 m. Regional cross-lines were also surveyed, spaced at 500 m, and specific area cross-lines spaced at 25 m. The ADCP survey design required a moving vessel to record the current speed and direction over a complete tidal cycle (12.5 hours) on both spring and neap tides. An additional goal of the survey was to collect a video record of the seabed in the specific areas of the proposed development (Titan Environmental Surveys 2004).

A hydrodynamic modeling effort was also conducted by MCT. In order to determine the likely impacts of changes to the hydrodynamic regime, assessments were carried out as part of the EIA process. The downstream vertical current profile was modeled up to 1000 m away from the turbine in order to determine any likely changes near the seabed (Haskoning UK Ltd. 2005).

Other studies and surveys that are either being conducted or planned include the following:

- Potential impacts to marine mammals, cetaceans and basking sharks
- The presence, species and behavior of diving sea birds
- Diver surveys to detect change in biotope presence and structure
- Consultation with community and lough user groups

4.5.3.4 European Marine Energy Centre

In Scotland, the European Marine Energy Centre (EMEC) in Stromness, Orkney officially opened in August of 2004 and provides an open sea testing center for wave and tidal marine energy converters established to aid the advancement of the devices from prototype to commercial development. EMEC offers a range of services including, power performance verification, availability and reliability verification, electrical system testing, safety system testing, noise measurements, structural load measurements and verification, subsystem testing, and basic tests (Faber Maunsell and Metoc PLC 2007). Operations are spread over three sites specifically tailored for wave or tidal development. The sites experience waves up to 15 meters and tidal currents as fast as 4.1 m/s (8 knots). To evaluate electrical capabilities, EMEC has a full infrastructure of transmission lines, substation, and connection to the National Grid.

The tidal power site at EMEC is located on the western side of Eday Island. The site has recorded current velocities up to 4.0 m/s (7.8 knots). Five sub-sea cables have been deployed into the site. Each cable connects to the national grid and is capable of conducting about 5 MW of electricity (Faber Maunsell and Metoc PLC 2007).

OpenHydro was the first developer to deploy a tidal turbine at the EMEC tidal site in November of 2006. The 250 KW turbine was installed between a twin monopile structure that allows the unit to be raised and lowered for the purpose of operation, servicing, and inspection as illustrated in Figure 4.8. OpenHydro was awarded €1.8 million euros from the Scottish Executive in 2007 to install a second tidal turbine at the EMEC tidal site. The second turbine is planned to use a gravity base to mount the turbine to the seabed. Presently testing of the first OpenHydro turbine continues at EMEC.

FIGURE 4.8 Open Hydro at EMEC

Other developers planning to install tidal devices at EMEC include Lunar Energy, which is building its first full scale turbine, a 1 MW tidal device to be deployed at EMEC in 2008 (Faber Maunsell and Metoc PLC 2007).

4.5.3.5 Demonstration Findings and the Applicability to the Bay of Fundy

A lot has been learned from the existing pilot projects. For a demonstration-scale sized TISEC project, it is fair to argue that it's a proven technology from an energy conversion perspective. Collectively, there have been several studies that have been conducted for the tidal demonstration projects previously discussed. At this time, a majority of the recent environmental study information relating to the tidal energy demonstration projects is not publicly available, so it is difficult to identify what study information exists from these projects and how much of it is applicable to the Bay of Fundy. One of the lessons learned from the demonstration projects is the extensive efforts involved in scoping and designing appropriate studies that will address the concerns of regulators and resource agencies while also understanding the limitations imposed in working in a difficult environment. Furthermore, the potential effects to be studied are typically site and TISEC device specific. For example, the blade spacing and tip speeds can vary considerably among the different TISEC device designs. Therefore, the ability of fish or marine mammals to avoid one particular TISEC design may not necessarily be the case for another design. Further, it is uncertain how data collected for a small demonstration project can be scaled up to evaluate larger developments. Considering other factors involved, the study scoping process may be influenced by:

- the constraints and logistics of working in a difficult tidal environment,
- political or economic pressures to advance the alternative technology that needs to be studied,
- lack of information necessary to evaluate potential impacts,
- the number of issues associated with a particular site and/or technology,
- the resources available to compile the necessary data and study information,
- the technology available to obtain the study information desired, and
- the authorization process to enable collection of study information.

All demonstration projects will require site-specific data relating to tidal current flows in order to optimize the turbine design and ensure the devices can be properly secured to the seabed and accessed for routine maintenance. Additional site-specific data that will likely be required includes: bathymetry, sub-bottom profiles, seabed composition, biota, and several other water quality and environmental characteristics.

Given the studies that have been conducted for fish and marine mammal interaction, it's reasonable to assume that some developers have data and study information that can be applied to the Bay of Fundy. However, the scoping process will likely dictate that similar studies will be needed to assess for different TISEC devices and species present.

4.5.4 Potential Commercial Sites

Upon review of the available energy for conversion within the study area, there are many sites that could be selected for potential commercial development. Table 4.1 summarizes some of the readily available information regarding these potential commercial sites.

TABLE 4.1 Bay of Fundy Tidal Sites

	Location	Available Energy	Distance to Grid: Commercial (>2MW) Plant	Distance to Grid: Demonstration (<2 MW) Plant	Potential Conflicts or Issues	Selection for Commercial Use	Channel Depth
New Brunswick	**Cape Enrage**	100 MW	16 km to 69 kV	Unknown	**Minimal, but requires siting consultation with Alma Fishermen's Association	Yes	15 - 21 m
	Cumberland Basin	56 MW	16 km to 69 kV	Unknown	Minimal; few other uses	Potential	36 -80 m
	Head Harbour Passage	46.8 MW	5 km to 69 kV	Unknown	May be minimal in channel against Campobello Island shoreline due to high currents. Oceangoing vessel navigation passage to Eastport, ME and Bayside, NB	Yes	60 - 100 m
	Shepody Bay	43 MW	11 km to 69 kV	Unknown	Location of important RAMSAR sites in Western Hemisphere Shorebird Sanctuary	No	12 - 25 m
	Western Passage	35.8 MW	4 km to 69 kV	Unknown	May be minimal in central channel due to high currents, depth. Oceangoing vessel navigation passage to Bayside, NB	No	54 - 73 m
	Letete Passage	13.9 MW	11 km to 69 kV	Unknown	One of the few undisturbed bottom habitats in Bay of Fundy; popular with underwater photographers	No	21 - 42 m
	Lubec Narrows	4.1 MW	8 km to 69 kV	Unknown	Shallow depths, minimal conflict with other users	No	5 - 6 m
	Saint John River	TBD	Unknown	1 km to 12.5 kV	Minimal; surrounding urban area heavily developed	No	21 m
	Grand Manan	50 MW*	15-20 to 69 kV	Unknown	High concentration of North Atlantic right whales, right whale sanctuary	No	80 m
	Clarks Ground	216 MW*	10-20 km to 69 kV	Unknown	High concentration of North Atlantic right whales, right whale sanctuary	No	10 - 35 m
Nova Scotia	**Minas Passage**	1100 MW	13 km to 69 kV	10 km to 25 kV	Minimal; lobstering and scallop dragging precluded in deep and fast currents	Yes	36 - 110 m
	Minas Channel	873 MW	45 km to 69 kV	25 km to 12 kV	Minimal; lobstering and scallop dragging precluded in deep and fast currents	No	46 - 70 m
	Petit Passage	61 MW	60 km to 69 kV	1 km to 25 kV	Local ferry and recreational boat activity	No	21 - 46 m
	Grand Passage	44 MW	75 km to 69 kV	1 km to 12 kV	Local ferry and recreational boat activity	No	9 - 21 m
	Cumberland Basin	43 MW	20 km to 69 kV	6 km to 24 kV	Minimal; few other uses	Potential	36 - 80 m
	Cobequid Bay	42 MW	30 km to 69 kV	6 km to 12 kV	Minimal; few other uses	No	9 - 18 m
	Dibgy Gut	33 MW	10 km to 69 kV	7 km to 12 kV	Busy channel with multiple users, including Saint John ferry, commercial fishing fleet, salmon farming, and lobstering	Yes	9 - 61 m
	Northwest Ledge	73 MW*	80 km to 69 kV	5 km to 12 kV	Recreational boat activity	No	23 - 180 m

* Mean power potential from Triton "Canada Ocean Energy Atlas (Phase I) Potential Tidal Current Energy Resources Analysis Background, 2006

Note: The column titled “Selection for Commercial Use” summarizes the likelihood of sites being pursued for commercial development before other sites within the Bay of Fundy. The criteria and reasoning that these sites are anticipated to be pursued prior to other sites is discussed below.

The following discussion includes a process to narrow the field of the potential sites outlined above so that a more focused and illustrative environmental discussion can be provided for a select number of sites within the limits of this evaluation. For the most part the illustrative sites are believed to have a higher probability for eventual development, or developed prior to other sites within specific regions. The following site criteria are listed starting with the most significant:

1) Total available tidal energy.
2) Equal jurisdictional representation (*i.e.*, Nova Scotia and New Brunswick).

3) Coastal utility grid and substation loads and capacities, and availability of a suitable onshore grid interconnection point with a capability of handling a demonstration facility and with potential for growth to a commercial-scale plant.
4) Avoiding or minimizing adverse environmental effects.
5) Ecological diversity – developments within the study area that provide diversity in ecosystems and settings.
6) Favorable bathymetry and seafloor geology, for device and submarine cable installation, and long term stability.

Many sites in Nova Scotia and New Brunswick may be suitable for tidal power development, particularly smaller, "off grid" developments. This strategic evaluation focuses on those sites with the greatest potential for initial commercialization; however, it does not suggest that these other sites and developments are not viable.

Sites Selected for Further Evaluation

Nova Scotia

Minas Passage, Minas Channel, and Cobequid Bay

Due to the overall capacity of available energy, it is believed that Minas Passage has the highest probability of development and is worthy of further evaluation. Many of the environmental considerations and issues discussed for Minas Passage will also be applicable to Minas Channel due to the close proximity.

Northwest Ledge, Petit Passage, Grand Passage, Digby Gut

While Digby Gut has the smallest capacity of available energy among these sites, it was selected on the basis that it provides a unique area within the study region and is closest to a 69 kV transmission line (10 km compared to 60 km). There also may be a higher incidence of endangered North Atlantic right whales at the other sites compared to in the immediate vicinity of Digby Gut.

New Brunswick

Clarks Ground, Grand Manan Channel, Head Harbor Passage, Western Passage, Letete Passage, Lubec Narrows, St. Johns River

Head Harbor Passage was selected for further evaluation primarily due to the capacity of available energy and lower potential incidence of endangered North Atlantic right whales (compared to Clarks Ground and Grand Manan). This site is also located relatively close (5 km) to a 69 kV transmission line.

Cape Enrage, Cumberland Basin, Shepody Bay, NB

While Cumberland Basin and Shepody Bay are very good sites, due to the overall capacity of available energy at Cape Enrage, this site will have a higher probability of being developed prior to the other sites. It has almost double the capacity of Cumberland Basin and is essentially the same distance to a 69 kV transmission line.

4.5.4.1 Nova Scotia Sites

Minas Passage

Minas Passage is the resource site with the greatest power generation potential for Nova Scotia based on preliminary site resource assessments. Minas Passage is located near the entrance to the northeastern head of the Bay of Fundy (see Figure 4.1). The Passage connects Minas Channel to Minas Basin and Cobequid Bay. The fastest currents of 3.6 m/s (7 knots) to 4.1 m/s (8 knots) are located in the southern part of the Passage, with lesser currents of 2.6 m/s (5 knots) to 3.1 m/s (6 knots) located on the northern side (EPRI 2006c).

Transmission cable interconnection from Minas Passage to the Nova Scotia Power grid is accessible for demonstration and commercial scale developments. For a demonstration scale project with a capacity of approximately 500 kW, a 9.5 km upgrade is required to connect to the 25 kV line located in Parrsboro. However, it should be noted that generally, a 25kV line can accommodate up to a maximum of 5MW, should a demonstration project with a greater power generation capacity be deployed. Connection to a 69 kV line for a commercial scale project requires a 12.5 km extension (EPRI 2006c).

The bathymetry of Minas Passage shows a long linear depression in the middle of the Passage, reaching depths of 100 meters while shallow areas lessen to 36 meters. The range of depth offers great diversity in opportunities for a range of tidal technologies. The majority of the seafloor of Minas Passage is exposed bedrock with gravel deposits close to the northern and southern shores. Because of the tremendous tidal currents flowing through Minas Passage, coarse material (sand) is suspended in the water column with a concentration of up to 100 mg/L (Milligan 2006, pers. comm.). A potential result of the large volumes and movement of suspended sediment is significant abrasion on the project's components (DTA 2006).

Regional shipyard and maritime support for Minas Passage is available from nearby Parrsboro. Parrsboro is the best candidate for maritime support based on its location. According to the Nova Scotia EPRI report (EPRI 2006c), the Parrsboro Harbour Commission has been briefed on the study and is able to provide local support for TISEC projects in the upper Bay of Fundy. The Harbor also has significant funding from the Atlantic Canada Opportunity Agency to improve their harbor facilities and build a gantry crane support structure next to the public wharf.

The Committee on the Status on Endangered Wildlife in Canada (COSEWIC) identifies the harbour porpoise (*Phocoena phocoena*), and inner Bay of Fundy (iBoF) and Atlantic salmon (*Salmo salar*), as species being at risk that may occur in the Minas Passage project area.

The harbor porpoise is listed as special concern by COSEWIC and listed under the same designation by the *Species at Risk Act* (SARA). Harbor porpoises inhabiting the Bay of Fundy and Gulf of Maine appear to be a discrete population numbering between 50,000 and 90,000 individuals (Department of Fisheries and Oceans Canada 2006).

The iBoF Atlantic salmon refers to salmon populations originating in watersheds between the Saint John River, New Brunswick and the Annapolis River, Nova Scotia. COSEWIC and SARA designated the iBoF salmon as endangered in 2001. This assemblage appears to be geographically further separated with one group returning to Minas Basin/Passage and rivers draining into Chignecto Bay (Department of Fisheries and Oceans Canada 2006).

Right whales congregate in the southern part of the Bay of Fundy to mate, nurse young, and feed. Because they do not migrate into the upper Bay of Fundy, they are not a concern at Minas Passage. Cetaceans are not common in Minas Basin, though small pods of harbor porpoises can be seen and common and Atlantic white-sided dolphins (*Lagenorhynchus acutus*) periodically visit in summer (Bay of Fundy Ecosystem Partnership 2005).

It is highly likely that if a demonstration project is implemented in Minas Passage, that additional units may be deployed in Minas Channel given the tidal energy available and close proximity to Minas Passage. Many of the aquatic characteristics associated with Minas Channel will be very similar to those of Minas Passage.

<u>Potential Commercial Scenario for Minas Passage</u>

A limited survey of potential developers was conducted to determine what a commercial development may involve in Minas Passage. Based on readily available information and information that was provided by four developers, a commercial development may have the following characteristics:

From the preliminary research that has been performed, an in-stream tidal commercial development may include turbine spacing normal to the flow of at least 3 diameters (based on duct diameter) and the spacing downstream is 7 diameters. The subsequent downstream row is staggered so that the first turbine begins with an offset of 1.5 diameters (normal to the flow) from the upstream turbine. This staggering scheme increases the effective separation distance in the downstream direction. A full buildout commercial development in this area may include approximately 100 units or more and require an area of 750 m normal to the flow and 1.75 km in the flow direction. The total farm area would be 1.3125 km^2 (131.25 Ha). This is based on the assumption of a 15 m diameter turbine, which would result in a project capacity of ~120 MW.

However, the actual commercial development characteristics can only be determined after detailed measurements (bathymetry and ADCP current profiles) are obtained and then combined with numerical modeling. Final siting would be based on this analysis and experimentation.

Another developer did not elaborate on the specific spacing or configuration of the turbines, however indicated that 200 units, each with a 1 MW capacity, would fit in a square kilometer.

A third developer suggested the following information relating to a potential commercial development for the Minas Passage area: 2000 turbines, each rated at 325 kW (@ 2.83 m/s), 10m rotor diameter, overall array area of 30 km^2, bottom contact area 8000 m^2, and a total project capacity of 600 MWe. The developer clarified that there are many factors and variables that need to be considered to arrive at a commercial development scenario and that this information is being provided as general tidal energy generation device information intended to contribute to the assessment. The information is only generally, and not specifically, applicable to the several different sites within the Bay of Fundy that may be suitable for the commercial development of tidal energy conversion. The information is being provided for the sole purpose of assisting to provide background for developing potential commercial development scenarios. The superficial estimates of tidal current turbines that could be deployed as part of a multi-year phased build out scenario for the Minas Passage area are based on extremely limited available information and the developer has not performed its own resource assessment and detailed analysis program on the potential site.

John F. Wightman, Managing Director of ATEC Power Inc., and a spokesperson for the Atlantic Tidal Energy Consortium, had announced in late November 2006 that the consortium's business plan projects an installed capacity of about 600 megawatts of tidal power within 10 years. Of this total the average output would be in the range of 400 megawatts with a constant base load, from renewable sources, of 200 megawatts available 24/7. He indicated that tidal power holds the promise of not only meeting the government renewable energy targets but also stabilizing long term electrical rates for Nova Scotians (Minas Basin Press Release June 2007). A majority of the 600 megawatts of installed capacity (~90 percent) is anticipated to come from Minas Passage. There is limited information provided in the announcement, so many of the project specifics (*e.g.* spacing, configuration, number of turbines, area required) are unknown.

Based on these two scenarios it is clear that there is a wide range of perspectives for this resource (~120-600 MW). Although this is an extremely limited survey, the information provided indicates that the anticipated area of the commercial development per MW of installed capacity varies greatly. Specifically, it ranges from a low of 20 MW/km^2 (600 MW/30 km^2) to a high of 200 MW/km^2.

Digby Gut

For the purposes of identifying a more biologically diverse system within the study area, an alternative location was selected, even though it has significantly less tidal energy available. Digby Gut is the name of the passage that separates Annapolis Basin from the Bay of Fundy. The passage is approximately 4 km long and at the narrowest point 0.75 km wide. Although Digby Gut has the lowest initial power generation potential for Nova Scotia sites outlined in the EPRI report, the site offers significant biological diversity from Minas Passage compared to other nearby sites such as Minas Channel and Cobequid Bay. In addition Digby Gut offers shorter transmission cable distances than other candidate Nova Scotia tidal sites such as Petite Passage and Grand Passage. The only operating tidal power plant in North America, the Annapolis Royal Generating Station, is located at Annapolis Royal, which provides significant environmental information for the Annapolis Basin/Digby Gut area. The Generating Station is illustrated in Figure 4.9.

In the narrowest section of the passage tidal velocities of 2.6 m/s (5 knots) are attained during spring tides, and average a peak speed of approximately 2.2 m/s (4.3 knots) (EPRI 2006e).

Transmission cable interconnection from Digby Gut to the Nova Scotia Power grid is accessible for demonstration and commercial scale developments. Connection to the 12 kV line at Victoria Beach is suitable for up to 200 kW of power and requires a 7 km transmission cable from the project. The connection to a 69 kV line for a commercial scale project requires a 10 km cable from the project to the line.

The depth of Digby Gut is predominantly around 30 meters, but there are multiple deep depressions in the southern area of the channel that reach 94 meters. Tidal technology will be limited to those that are able to operate in 30 meters of water or less. The seabed in the southern channel is mainly composed of gravel waves with no fine grained mud. Exposed bedrock is expected to dominate the seabed at the northern section of the channel.

Maritime and infrastructure support for a project development at Digby Gut would be available from Saint John, New Brunswick. Saint John which is located across the Bay approximately 68 km away may be the best location for support because there are extensive support services from fabrication to installation and extraction. However, there may be other smaller fabrication services which are in the immediate vicinity of Digby Gut.

The most important environmental issues at Digby Gut will likely be similar to potential issues found at Head Harbour Passage, the other Outer Bay of Fundy project. These issues include potential effects on marine mammals and salmon. Digby Gut is also home to a large fishing fleet and a ferry terminus between Digby and Saint John.

FIGURE 4.9 Annapolis Royal Generating Station

4.5.4.2 New Brunswick Sites

Head Harbour Passage

Head Harbour Passage is located between Deer Island and Campobello Island in the Outer Bay, and is the main shipping entrance channel into Passamaquoddy Bay. The tidal resource is strong with spring tide current velocities up to 2.6 m/s (5 knots) and an average peak tidal velocity around 2.1 m/s (4 knots). The location provides a more biologically diverse tidal resource when compared to the characteristics of the Cape Enrage and Minas Passage sites which are located in the Upper Bay.

New Brunswick Power Company recommends that any project, demonstration or commercial, in Head Harbour Passage be connected to the Campobello substation. The connection to the substation is 4.5 km from landfall.

Head Harbour Passage is naturally deep. The bathymetry ranges from 60 to 100 meters. The seabed of the Passage is composed of bedrock overlain by poorly sorted till. In high current channels, mud and fine sands are swept away leaving a thin armoring layer of gravels, cobbles, and boulders.

Eastport, Maine is the best candidate for maritime support for basing inspection, maintenance and repair services. Eastport is the easternmost deepwater port in the US. In New Brunswick, St. Andrews, Blacks Harbour, and Bayside Marine Terminal do not provide as extensive services as Eastport.

The Quoddy Region and Head Harbour Passage are rich in marine mammal biodiversity, hosting 19 species. Notable species are the North Atlantic right whale, finback whale, humpback whale, minke whale, harbor porpoise, and harbor seal. Although marine mammals are seen in the project area, they do not usually occur in great numbers (DTA 2006). The most important potential environmental issues for Head Harbour Passage are effects on marine mammals, migrating wild Atlantic salmon and herring (DTA 2006). Head Harbour Passage is a major migration route for herring (Hooper, Conners Brothers, pers. comm.), and for Atlantic salmon from Passmaquoddy Bay and Cobscook Bay (Whoriskey *et al.* 2006).

Cape Enrage

In the New Brunswick EPRI report (EPRI 2006d), the resource site with the greatest power generation potential is Cape Enrage with 100 MW. Cape Enrage is located in the Upper Bay of Fundy, half way up Chignecto Bay. Cape Enrage has the development advantage over other nearby sites, such as Cumberland Basin, because of its favorable seabed composition. The site seabed is composed of a thin layer of sediment over bedrock between Cape Enrage and the Sand River, Nova Scotia. Water depths in the Cape Enrage area range from 15 to 21 meters.

Electrical connection to the New Brunswick grid would require approximately 16 km of transmission cable from landfall to the interconnect of a 69 kV line. On the Nova Scotia side, grid connection to a 69 kV line would require approximately 20 to 25 km of transmission cable.

Nearest shipyards and maritime infrastructure support is located at St. John, 110 km southwest, and Parrsboro, Nova Scotia, 65 km southeast. The Cape Enrage site is close enough to Nova Scotia for opportunities for the two provinces to collaborate on the siting and permitting process.

Cape Enrage is a popular tourist destination. The Cape Enrage Project attracts visitors to partake in rappelling, climbing, caving, kayaking, and adventure camps. The site is also unique with its lighthouse atop a 50 meter cliff, which remains the only lighthouse in the Bay of Fundy that is staffed for operation. Figure 4.10, illustrates the lighthouse and the dramatic cliffs that surround the cape.

Cape Enrage will likely have similar environmental issues to those outlined in Minas Passage, with the exception of sediment concentration, which is lower at Cape Enrage (DTA 2006). Potential issues include a sizable commercial fishing fleet from Alma, New Brunswick, adjacent to the project site. Additionally, the depth of 15 to 21 meters may not be adequate for certain technologies. Given the size of the commercial fishing fleet there may be concerns if an exclusion zone is established for a certain portion of this resource.

FIGURE 4.10 Cape Enrage Lighthouse

5.0 EXISTING ENVIRONMENT

The Bay of Fundy has been under study for more than a century, and there are now more than 2,000 publications dealing with various aspects of its natural environment. Much effort was focused upon the Bay as a result of tidal power proposals in the 1920s, 1930s, and 1970s (Daborn 2007), and the state of knowledge has been summarized several times (*e.g*. Huntsman 1938; Thomas 1983a; Daborn 1977; Gordon and Dadswell 1984; Percy *et al.* 1997). Since 1996, the Bay of Fundy Ecosystem Partnership has held biennial conferences to summarize ongoing research and issues about the Bay. Recently, an ecosystem assessment was completed for Minas Basin (Parker *et al*. 2007).

The Bay of Fundy is an integral part of a complex coastal oceanographic system (sometimes referred to as the Fundy—Gulf of Maine—Georges Bank or FMG system) that also includes the Gulf of Maine, Georges and Browns Banks, and the various channels between them. In many ways, this system responds as a unit to the tidal forcing of the Atlantic Ocean. However, specific responses vary among the different regions of the FMG system as a result of past geological factors that shaped local morphology, and of more recent dynamic and anthropogenic forces. Many dynamic oceanographic processes result in continuing change to the physical characteristics of the Bay of Fundy. In describing the existing environment, therefore, it must be recognized that the Bay of Fundy is constantly in a process of transition towards a future, somewhat different state, and the biophysical features that characterize it now are also subject to change.

There are substantially different physical (and hence biological) features in different regions of the Bay. For this reason, it is useful to recognize several sub-areas (Durbin 1996; Percy *et al.* 1997): the Outer Bay, extending up to a line between Digby and Saint John; the Inner Bay, extending from there to Cape Chignecto; and the Upper Bay, which includes Minas and Cumberland Basins, and Chignecto, Shepody and Cobequid Bays (Figure 5.1). In addition, there are important embayments connected to the Outer and Inner Bay regions—Passamaquoddy Bay, St. Mary's Bay and the Annapolis Basin—that are relatively shallow, greatly influenced by surrounding land and by input from river systems, and exhibit significantly different biophysical properties from those of the main Bay. (N.B. The "Quoddy Region" is a term that applies to Passamaquoddy Bay, the Deer Island archipelago, Campobello Island, the Wolves and all coastal waters from Point Lepreau (NB) to West Quoddy Head (Maine) and Grand Manan Island: *i.e.* a significant portion of the Outer Bay of Fundy as defined here (Thomas 1983a). Its use underscores the extensive connections between these lateral embayments and the main Bay of Fundy).

The Bay of Fundy is fundamentally a physically driven system. Strong tidal currents, associated with the near-resonance of the Bay with the natural forcing of the Atlantic tide, result in extensive vertical mixing throughout the Bay, but mixing is especially pronounced in or near narrow channels and passages; only in spring and summer does a central part of the Outer Bay tend to stratify (Watson 1936; Garrett 1977). Vigorous vertical mixing has important effects on biological productivity, especially through return of nutrients to surface waters, where they support primary production. Vertical mixing also brings deeper-lying zooplankton to surface waters where they may become a concentrated food source for fish, birds and baleen whales, and moves surface waters down to the bottom where their contents (phytoplankton and other particles) may be accessed by benthic organisms (Daborn 1986; Wildish and Fader 1998). The extent of vertical mixing varies over time with fluctuations in tidal range,

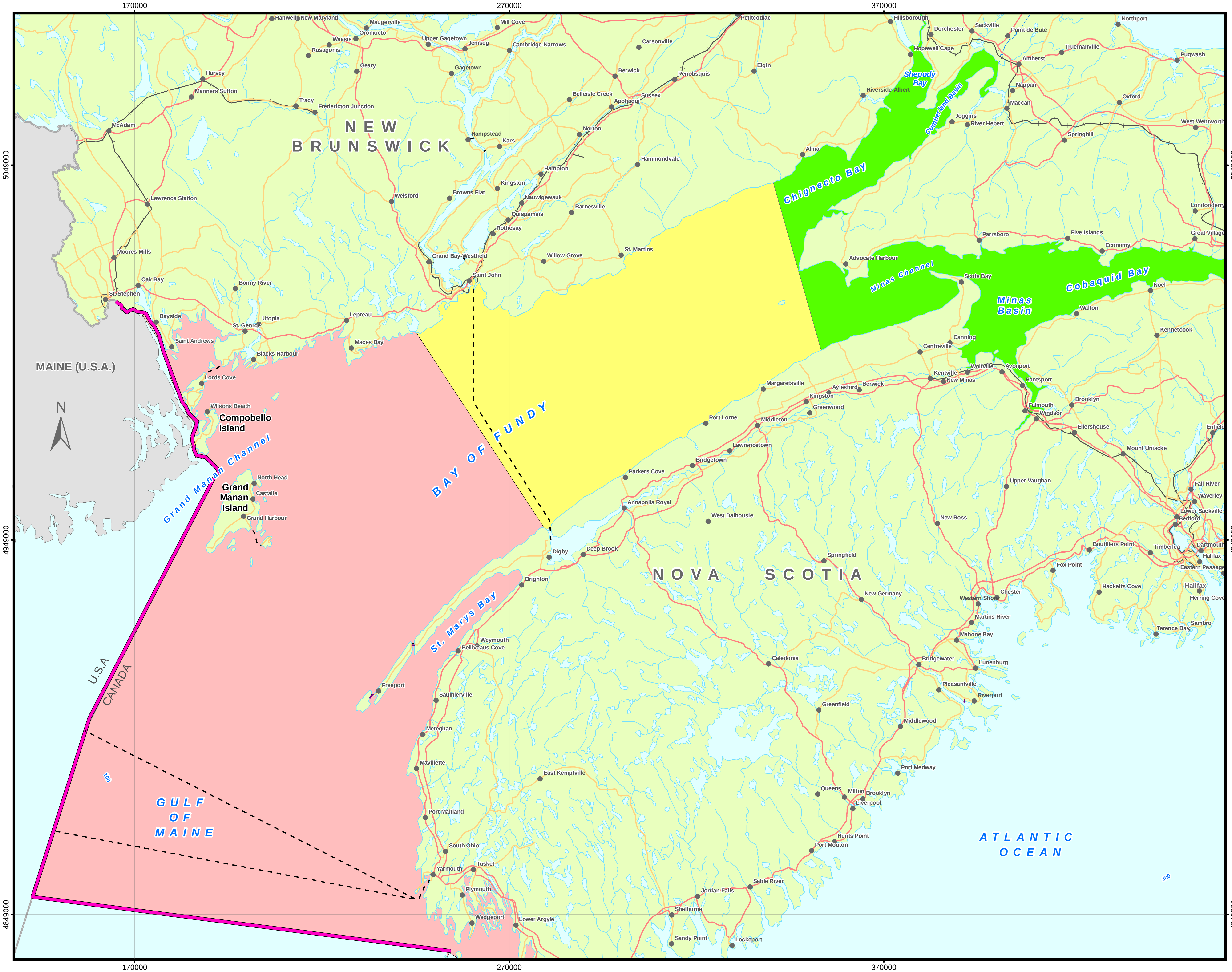


Figure 5.1

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Areas of the Bay of Fundy

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Oct 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-005

producing cyclical changes in sea surface temperature (see Page 2007), and affecting rates of biological production (*e.g.,* Cabilio *et al.* 1988).

The combination of Coriolis Force and the seasonally variable inflow of fresh water from the Saint John River, creates a residual circulation in which water tends to move toward the head of the Bay along the Nova Scotia shore, and outward to the Gulf of Maine along the New Brunswick shore, creating a gyre and region of transient stratification in the Outer Bay (Garrett 1977) (Figure 5.2). The water begins to move across the Bay about the Digby—Saint John line (Page 2000), which is the approximate boundary between the Outer and Inner Bays. These residual water movements may act as guides for migratory fish (Dadswell et al. 1984b), influence productivity, and determine settling patterns of fish and shellfish larvae (Wildish and Kristmanson 1979, 1997; Wildish and Peer 1983). Wave and ice action on the friable shorelines of the Upper Bay result in water that is increasingly turbid as one moves headward: high turbidity diminishes light penetration in the water, and significantly restricts phytoplankton growth in the Inner and Upper Bay (Huntsman 1952; Daborn 1986; Brylinsky and Daborn 1987).

As a result of its northern location, the Upper Bay of Fundy experiences more ice formation and activity than most other macrotidal estuaries that have been studied around the world. Ice armors channel sides in winter (Knight and Dalrymple 1976; Middleton 1977; Gordon and Desplanque 1983), but also reworks much of the surface sediment of the intertidal zone, and its flora and fauna (Daborn *et al.* 1991; Wilson 1991; Partridge 2000; Daborn 2007). Ice is probably a major factor in the export of primary production from saltmarshes in the Bay of Fundy (Gordon and Cranford 1994; Gordon *et al.* 1985; Daborn *et al.* 2003).

These physical forces have created a complex ecosystem that is biologically connected to the Arctic, the Caribbean, South America and even Europe through the movements of migratory fish, birds and whales. Consequently environmental assessments related to extraction of energy from offshore wind, waves or tidal currents, must consider how the conversion of energy affects the underlying properties of a system that is biophysically highly interconnected, and globally important.

5.1 Physical Components.

Many of the physical features of the Bay of Fundy are related to the geological events leading to its formation more than 200 million years ago. Others, including the characteristic tides, currents and sediment distributions, reflect more recent processes, particularly since retreat of the glaciers at the end of the last ice age. Biological features are largely dependent upon the latter phase of evolution of the Bay of Fundy system. Detailed accounts of the physical oceanography, with particular focus on the tides of the Bay, are to be found in Thomas (1983), Greenberg (1984) and Desplanque and Mossman (2004). A summary of characteristics of the Minas Basin has recently been prepared by Fisheries and Oceans Canada (Parker *et al.* 2007).

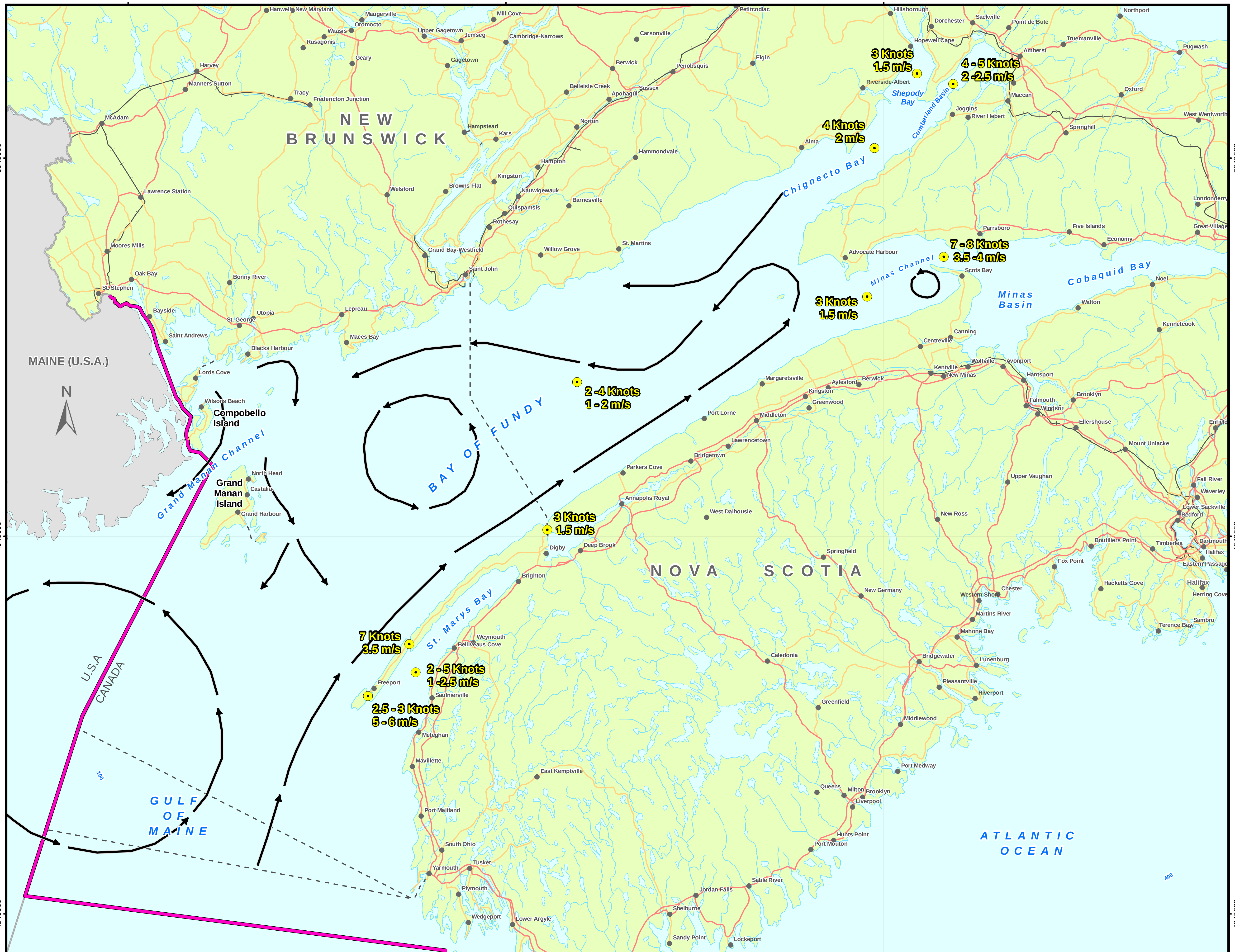


Figure 5.2

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Surface Currents and Velocities in the Bay of Fundy

Surface Currents

- Current Velocity Measurment
- SurfaceCurrent Flow Direction

Bas Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-017

5.1.1 Geological Setting

The Bay of Fundy is a fault-bounded half graben that began to form during the Triassic Period, 206-248 MYA (Stevens 1977). During the Triassic, an early Fundy Basin began to fill with lacustrine sediments (clays, silts and sands) derived from erosion of the Appalachian mountain chain to the west. The coarser sediments were subsequently folded and uplifted, giving rise to the red sandstone cliffs that are visible in the Upper Bay, and whose erosion provides much of the sediment suspended in and deposited from tidal waters at the present day (Amos 1984a; Nova Scotia Museum 1996; AGS 2001). Elsewhere, enclosed saline evaporation basins gave rise to gypsum deposits such as those now found south of Minas Basin. Subsequently, during the Jurassic, volcanic activity resulted in flows of black basalt that now underlie most of the Bay of Fundy, and outcropped to form the resistant shorelines of the North Mountain of Nova Scotia, Digby Neck, Grand Manan Island, parts of the north shore of Minas Basin and of the New Brunswick shore (AGS 2001). On the New Brunswick side of the Bay, basalt dominates the Saint John and Passamaquoddy Bay areas, but other parts of the shoreline represent old pre-Triassic metamorphic rocks, that are tightly folded and periodically intruded by granite and other igneous rocks. As visible along the North Mountain, the basalt flowed out over the Triassic sandstones to form a relatively resistant cap (Roland 1982). These Triassic and Jurassic sediments retain some of the world's most important fossil evidence of early life in the region (Thurston 1994; AGS 2001).

The varied rock exposures (Figure 5.3) explain many of the differences between the Outer, Inner and Upper Bay of Fundy. Most of the Outer and Inner Bay shores are relatively resistant igneous or metamorphic rocks. Waters tend to be relatively clear, and the rocky shoreline provides attachment for extensive seaweed communities. This shoreline coating of seaweeds diminishes as one proceeds up through the Inner Bay, because of increasing prevalence of ice in winter, the tidal exposure of more extensive cobble and boulder beaches (Stephenson and Stephenson 1972), and the water becomes more turbid. High turbidity is a striking feature of the Upper Bay embayments: Minas Basin is principally a sandy estuary associated with exposed sandstone cliffs, with silts and clays accumulating in more sheltered embayments; while Chignecto Bay is bordered by siltstones and shales originally deposited in shallow freshwater lakes, which yield finer sediments that are maintained in suspension by tidal and wave action (Amos 1984b).

During much of the Cretaceous and Tertiary periods (65-142, 18-65 MYA, respectively) sea level was much lower, and the upraised land was eroded by winds and water. It is thought that river drainage through the sediments deposited in what is now the Bay removed some of the more erodible sedimentary materials in river outflows of the Outer and Inner Bays, but that the Minas Basin may have received only smaller rivers that generally flowed northward (Roland 1982; AGS 2001), leaving most of the sandstones, silts and shales intact. Global cooling over the last 50 million years eventually led to the major Pleistocene ice ages, during which glacial advances and retreats scoured off and reformed much of the land surface of the region, and created the present topography in the watershed of the Bay of Fundy. Glaciers deposited a mixed till over the older freshwater deposits of the Bay itself that has somewhat protected these deposits as the tidal range and associated currents have increased (Amos and Joice 1977; Fader *et al.* 1977).

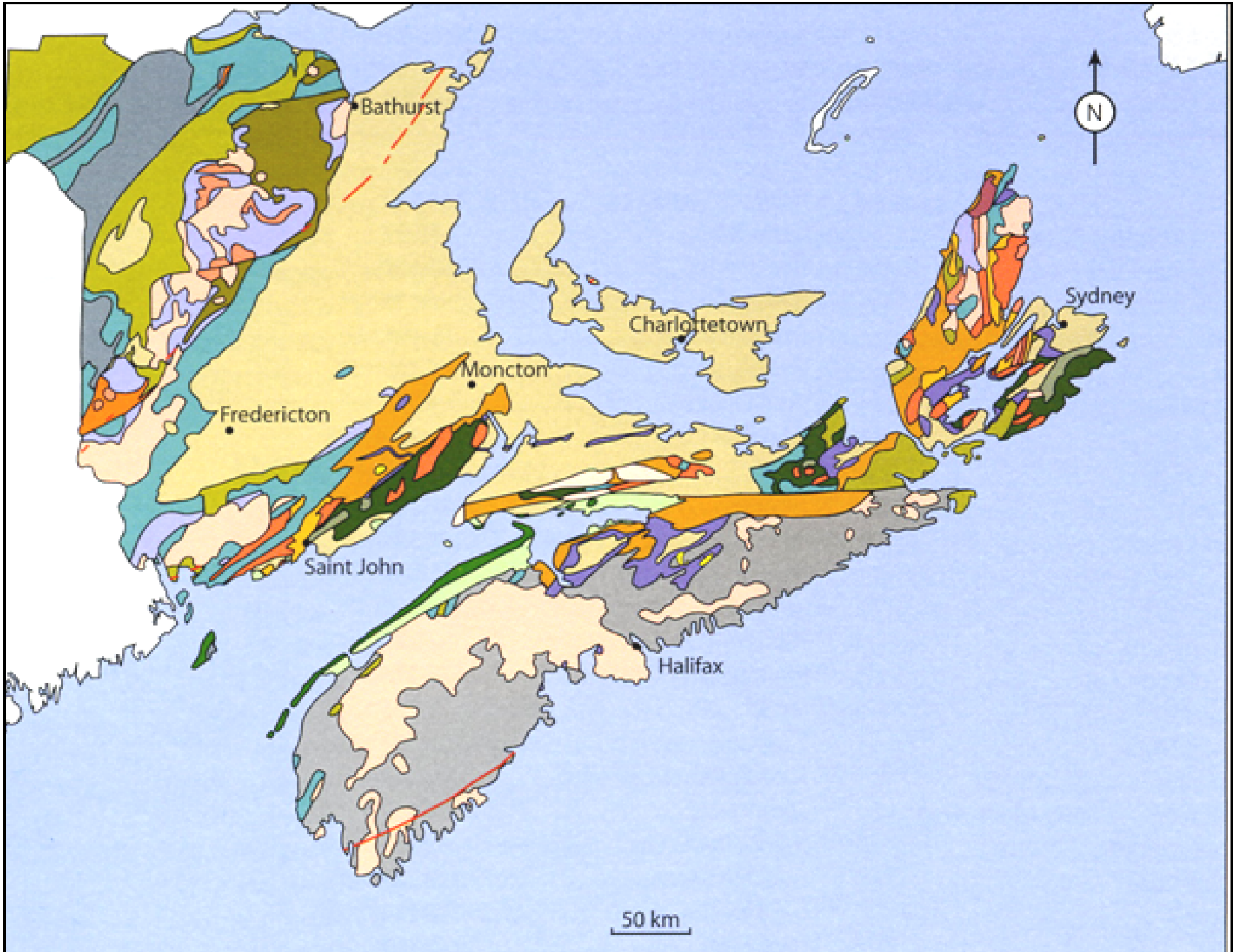


Figure 5.3

BAY OF FUNDY TIDAL POWER
STRATEGIC ENVIRONMENTAL
ASSESSMENT

Geological Setting of the Bay of Fundy

Mesozoic
- Cretaceous sedimentary rocks
- Early Jurassic rocks
- Early Jurassic volcanic rocks
- Triassic-Jurassic sedimentary rocks

Carboniferous and Permian
- Late Carboniferous-Permian terrestrial sedimentary rocks
- Early Carboniferous marine sedimentary rocks
- Early Carboniferous terrestrial sedimentary rocks
- Early Carboniferous plutonic rocks

Silurian and Devonian
- Silurian and Devonian plutonic rocks
- Devonian volcanic and sedimentary rocks
- Silurian volcanic and sedimentary rocks

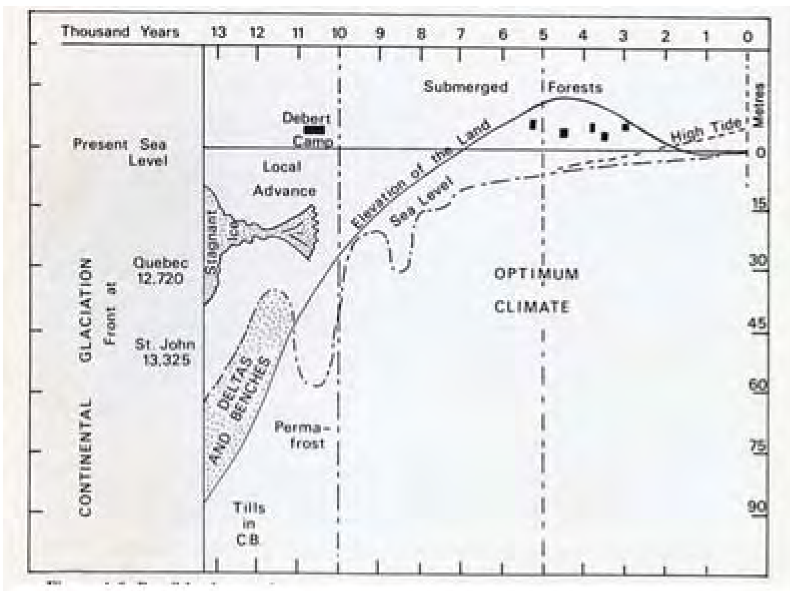
Cambrian and Ordovician
- Late Ordovician sedimentary rocks
- Cambrian-Ordovician plutonic rocks
- Ordovician Tetagouche volcanic rocks
- Ordovician Popelogan volcanic rocks
- Cambrian-Ordovician Miramichi sedimentary rocks
- Cambrian-Ordovician Avalon sedimentary and volcanic
- Cambrian-Ordovician Meguma sedimentary rocks

Precambrian
- Precambrian plutonic rocks
- Precambrian Bras d'Or volcanic and sedimentary rocks
- Precambrian Avalonian volcanic and sedimentary rocks
- Precambrian Grenville metamorphic and plutonic rocks

Map Parameters
Projection: UTM-Nad83-Z20
Scale Not To Scale
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-028

The depth of the Bay has changed extensively since the last ice sheets receded some 14,000 years ago. During that time, the sea level rose, but the land also rebounded as part of the isostatic adjustment to release from the weight of the glaciers, reaching its highest relative elevation about 4,000 years ago (Figure 5.4). At this time, the Upper Bay was a microtidal estuary or embayment, with a tidal range of only about 1 m, and an entirely different ecology from today (Bleakney 1982). At present Nova Scotia land is sinking again (because its original post-glacial rebound overshot its equilibrium position), so that relative sea level rise in the Bay exceeds that affecting other parts of the Atlantic coastline. Estimates of sea-level rise along the Gulf of Maine coast suggest that in the past century, sea level has risen more rapidly than at any other time in the Holocene (Kelley *et al.* 1995; Desplanque and Mossman 2004).

FIGURE 5.4 Post-glacial Sea and Land Level Changes in the Maritimes (Source: Roland, A 1982)



A principal factor in the evolution of the existing Bay of Fundy has been the depth of water over Georges Bank (Scott and Greenberg 1983). At 13,000 ybp (years before present), both Georges and Browns Banks were above sea level, and enclosed a shallow sea referred to as the DeGeer Sea (Kelley *et al.* 1995). As the ice sheets receded, sea level rose, and Georges Bank submerged, the Bay became invaded by sea water and progressively more influenced by tidal forces. Erosion of the bottom sediments combined with the increasing sea level to deepen the Bay of Fundy, progressively leading to greater tidal range (Amos 1987; Amos and Zaitlin 1985; Godin 1992).

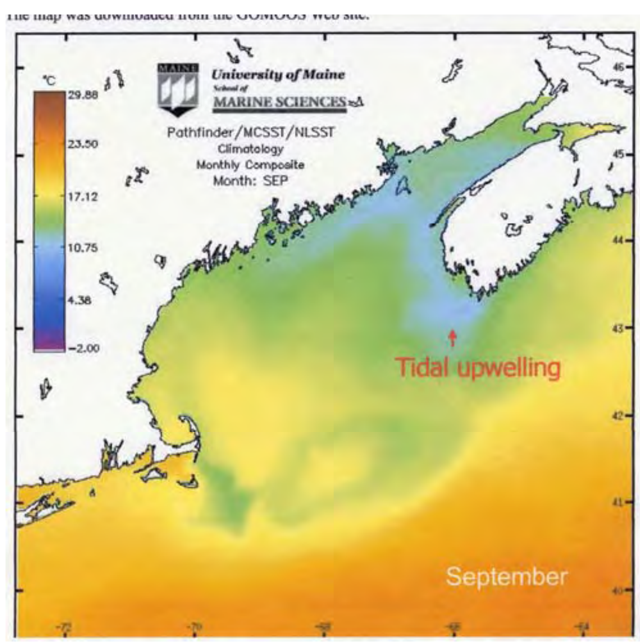
The Quoddy Region does not possess high-energy shores or soft bedrock that lead to rapid erosion, however unconsolidated glacial and fluvioglacial deposits abound in the region providing ample sedimentary shore material. The St. Andrews area and western Passamaquoddy Bay have substrates mainly of sand and mud from weathering and erosion of sedimentary rock and sediments, and due to low-energy wave conditions in the lee of Deer Island and sediment discharge from rivers. Deer, Campobello, and Grand Manan islands have hard rocky substrates (Logan *et al.* 1983).

5.1.2 Bathymetry

Water depth in the Bay of Fundy has changed considerably during the last 4,000 years, with rising sea level, increasing tidal range and erosion of glacio-fluvial deposits. Recent surveys with multibeam bathymetry and precise global positioning provide a greatly improved knowledge of the variable bathymetry, and indications that rates of change in water depth are occurring more rapidly in some locations such as Chignecto Bay.

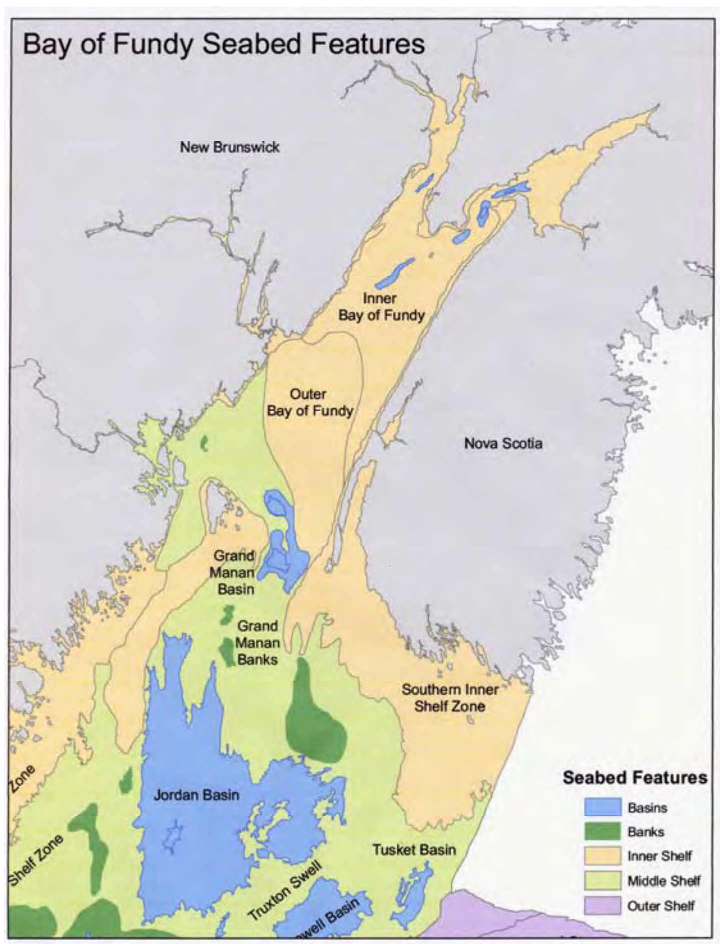
Water depth in the Jordan Basin, (Gulf of Maine) just outside the Bay of Fundy ranges to >300m, but this quickly declines to <160 m near the entrance to the Bay, where a sill runs southeast from Jonesport (Maine) to Lurcher Shoal at the end of Digby Neck (Desplanque and Mossman 2004). This sill creates a major zone of upwelling, by which cold, deep Atlantic water is brought to the surface by tidal forces, as flooding waters enter the Bay (cf. Section 5.1.5 below, and Figure 5.5). The narrow (55 km) channel between Grand Manan and Briar Island is c. 200 m deep in places, but in general, depths decline progressively as one moves up the Bay: 100-120 m on the Digby—Saint John line; 40-85 m between Quaco (NB) and Port Lorne (NS); and 40-60 m between Martin Head (NB) and Harbourville (NS). In general, depths in the Inner and Outer Bay regions tend to be a little greater on the Nova Scotia side of the Bay than off the New Brunswick shore, reflecting the erosional effects of the stronger Coriolis-driven inflowing tide on the south, and the smaller bottom currents and freshwater influence of the Saint John River outflow on the north. As a consequence, bottom sediments tend to be coarser to the south and finer toward the New Brunswick shore (Fader and Miller 1994).

FIGURE 5.5 Sea Surface Temperatures in the Gulf of Maine and Bay of Fundy (from Page 2007 GOMOOS website)



The Upper Bay regions of Minas Basin and Chignecto Bay are generally <40 m in depth, except for specific localities where strong tidal currents created by the larger tides and narrowing of passages have scoured out the bottom in flute-like depressions that may extend to bedrock (Fader and Miller 1994). There are notably deep holes in Minas Passage (<120 m), near Cape D'Or (<110 m), and off Cape Enrage (<70 m), where the glacial till and underlying sediments have been removed (Cf. Figure 5.6). There is some evidence from recent bathymetric surveys that the channel off Cape Enrage in Chignecto Bay in particular has deepened by several metres during the last three decades (Parrott, pers. comm.). Whether this is connected to the construction of the Petitcodiac Causeway is not yet clear, but such observations reinforce the view of continuing processes of change in the Bay of Fundy system.

FIGURE 5.6 Bathymetric Features of the FMG System



(Source: "A Classification of Bathymetric Features - Gulf of Maine" by Gordon Fader, unpublished report commissioned by WWF-Canada)

5.1.3 Sediments and Sedimentology

The complex variations in tides, currents and morphology of the Bay of Fundy are reflected in the diversity of bottom substrates found throughout the Bay. Prior to the 1990s, knowledge of the sedimentary regime of the Outer and Inner Bay was based upon intermittent and sparsely distributed grab samples, benthic trawl surveys and sidescan sonar (Fader *et al.* 1977; Greenberg *et al.* 1997). Pelletier and McMullen (1972) described the overall pattern of sediment distribution in the Bay: more than half of the Bay is floored by a postglacial gravel lag derived from the reworking of Pleistocene deposits and bedrock. Sand and mud each dominated over about one quarter of the Bay. Extensive surveys using sidescan sonar to assess the aggregate potential of the Bay were carried out in the 1980s and early 1990s (Fader *et al.* 1977; Fader and Miller 1994), providing a much more complete picture of the substrates of the Bay, and a somewhat clearer indication of how currents and biological properties interact. From these surveys, Wildish and Fader (1998) identified 14 different geological provinces in the Bay of Fundy, with substrates ranging from glacio-marine mud to coarse gravel.

While these early studies identified areas of sand and gravel, sand wave fields, and exposed bedrock, they could not provide a full understanding of the physical processes at work on the bottom of the Bay. With the development of high definition multibeam bathymetry in the 1990s, however, it has become possible to map the bottom of the Bay with high precision (resolution 1 to 2 m horizontally and 0.1 to 0.2 m vertically). The images provide such fine detail that it is now possible to link many of the biological features to the physical processes that determine them (Greenberg *et al.* 1997; Parrott *et al.* 2007). Much of the floor of the Outer Bay is dominated by gravel or exposed bedrock; there are patches of coarse sand with the surface winnowed into megaripples by strong tidal currents. Seaward of Yarmouth, however, sand is more extensive, with large sand ridges topped by megaripples (Fader and Miller 1994). In 1994, areas of the Inner Bay that had been previously identified as consisting of sand and gravel were re-examined using multibeam bathymetry, and over the last decade most of the Outer and Inner Bay have been resurveyed (Figure 5.7; Parrott *et al.* 2007). In the Inner Bay, large wave fields, consisting of sand waves 4-12 m in height and 0.75 km in length (Greenberg *et al.* 1997) oriented perpendicular to the current have been found to extend through much of the Bay, but especially on the south side, where the sediments are coarser sands, reflecting stronger tidal currents. In addition, in the Outer and Inner Bays, long linear features that run parallel with the current direction for many kilometers have proved to be sand ridges that are topped with colonies of the horse mussel, *Modiolus modiolus* (Wildish 1983; Wildish and Kristmanson 1997; Wildish *et al.* 1999). Wildish *et al.* (1998) showed that the mussels growing on the sand ridges grew more rapidly than those on other substrates. These long features have been termed *bioherms*, which means a reef-building system, and one interpretation is that the surface colony of mussels plays a significant role in the resistance of the sand ridge to the winnowing effects of tidal currents. An alternative explanation is that these features form along areas of convergent flows near the bottom, resulting from the three dimensional movement of tidal waters above.

High precision surveying has been under way in the Bay of Fundy for several years, and has largely been completed for deeper waters of the Bay (Figure 5.7); however, many shallow waters that could be critical for the development of tidal stream generators, remain to be surveyed.

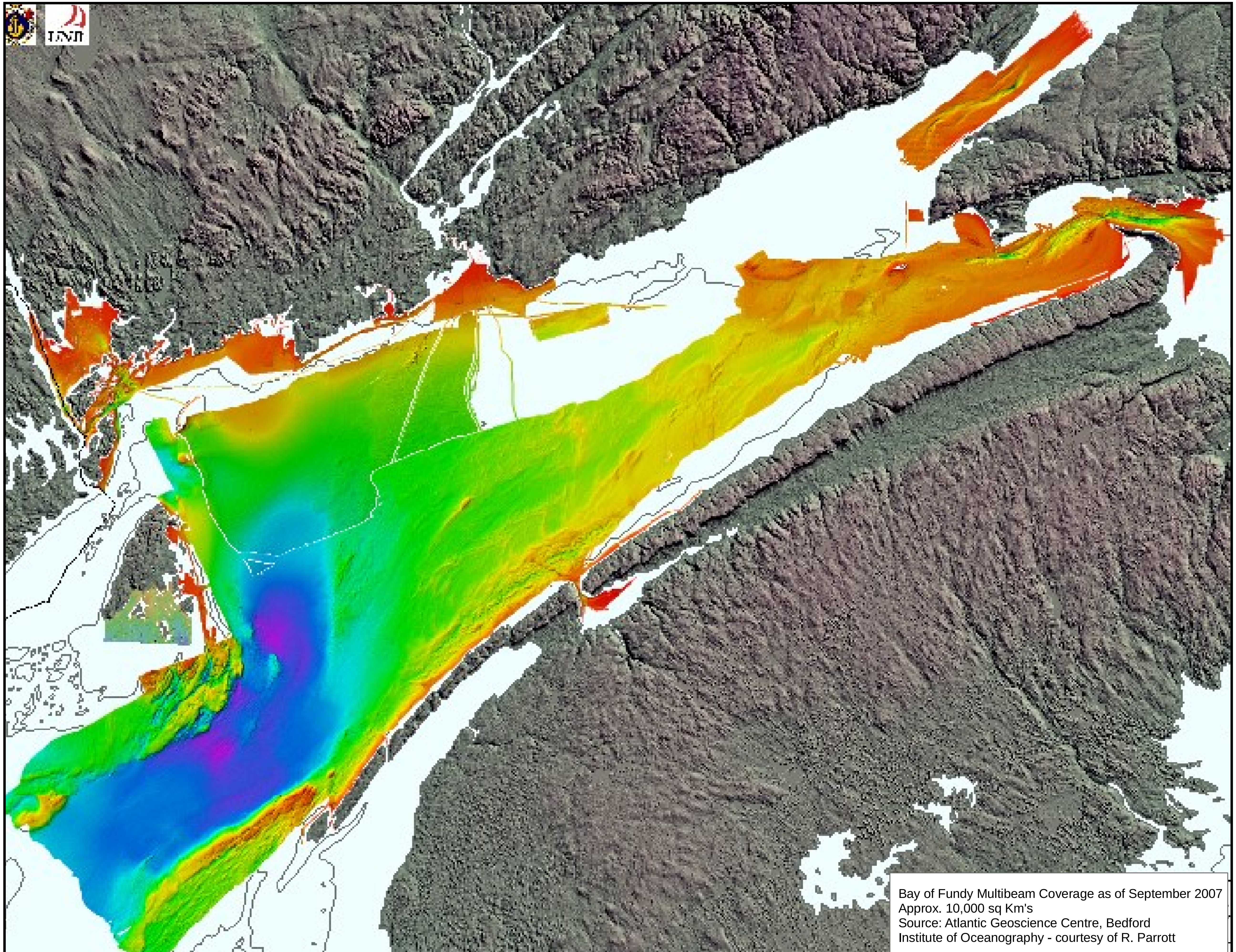


Figure 5.7

BAY OF FUNDY TIDAL POWER
STRATEGIC ENVIRONMENTAL
ASSESSMENT

Multibeam Survey Coverage in the Bay of Fundy - Completed by 2007

Depth (metres)

0.0
-25.0
-50.0
-75.0
-100.0
-125.0
-150.0
-175.0
-200.0
-225.0

Map Parameters
Projection: UTM-Nad83-Z20
Scale Not To Scale
Date: Nov 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-029

Multibeam surveys have also identified areas in Passamaquoddy Bay and parts of the Outer Bay in which the surface sediments have been disturbed, leaving circular or sub-circular depressions ('pockmarks') that are attributed to explosive outgassing of natural gas derived from organic decay within the sediments. These pockmarks exhibit distinctive ecological properties, including low biological diversity and evidence of continuing bacterial decomposition (Wildish *et al.* 2007).

The main part of the Outer and Inner Bay is underlain by basalt of Jurassic times, which is contiguous with the outcroppings on the Nova Scotia shore. On the southern side of the Bay, adjacent to the Nova Scotia shore, overlying sediments are thin or non-existent, but about 7 km from the shore the bedrock basalt is overlain by sedimentary bedrock, on top of which lie marine muds, in turn overlain by sands or glacial till (Anon 2007). Outside (*i.e.* north) of the scoured near-shore zone, the principal surficial sediments that extend from north of Digby to Ile Haute, are a coarse deposit known as the Sambro Sand Formation. This is a modified glacial till that has been and is being eroded by tidal currents, and exhibits a diverse array of active bedforms, including sand ribbons, waves and megaripples. It covers most of the southern half of the Inner Bay, the eastern portion of the Outer Bay, and extends up toward the New Brunswick shore east of Grand Manan Island (cf. Figure 5.7). North again of this sand body, towards the New Brunswick shore, sediments become finer, although there are active sand bedforms especially along the shore that exhibit erosional features.

The sedimentology of the Upper Bay is significantly different from the Outer and Inner regions (Middleton 1977), and varies also between Chignecto Bay and Minas Basin. Amos and his colleagues have investigated the characteristics, budgets, and dynamic processes influencing erosion and deposition of sediments in Minas Basin and Chignecto Bay (Amos 1987, 1984a, 1987, 1995; Amos and Mosher 1985; Amos and Tee 1989; Amos and Zaitlin 1985; Daborn *et al.* 1991). In an attempt to examine the potential effects of tidal power development on sediments, Greenberg and Amos (1983) found that existing numerical models could not describe the observed behaviour of sediments in the Upper Bay. Subsequent studies determined that, whereas Minas Basin was a 'sand particle' estuary, Chignecto Bay was predominantly a 'muddy estuary' (Amos 1987). The inner part of Minas Basin (Cobequid Bay) is characterized by coarse sandy deposits derived from erosion of exposed Triassic sandstones, exhibiting bedforms ranging from ripples to large dunes (Middleton 1977; Zaitlin 1987; Dalrymple and Rhodes 1995). Strong currents on the flood tide tend to move these sediments in a headward direction, so that much of the material is stored in the innermost regions. Finer sediments settle out only in areas sheltered from tidal currents and wind-driven waves (*e.g.* the Southern Bight of Minas Basin – Amos *et al.* 1988; Daborn *et al.* 1991), but are otherwise maintained in suspension by turbulence, leading to high suspended sediment concentrations in the water (*Ibid.*, Amos and Alfoldi 1979). In contrast, Chignecto Bay is bordered by shales and mudstones; these finer sediments are dispersed seawards toward the Bay of Fundy, especially as a response to storm activity, rather than being stored in the Upper Bay (Amos 1987; Amos and Tee 1989).

In spite of the high tidal range, strong currents and occasional wind effects, the behaviour and fate of sediments in Minas Basin are determined substantially by ice effects in winter (Gordon and Desplanque 1983; Desplanque and Mossman 1998; Crewe *et al.* 2005) and biological processes during the warmer months (Daborn *et al.*1993). Finer sediments accumulate extensively in sheltered areas during the summer months primarily as a result of the cohesive effects of benthic diatoms and bacteria (Hargrave *et al.* 1983; Daborn *et al.* 1993); such sediments have proved remarkably resistant to erosion by waves during the summer (Amos and Mosher 1985; Daborn *et al.* 1991, 1993; Schell and Daborn 1994). In winter, on the other hand, shore-fast ice freezes into the substrate during low tide, and is then fragmented and redistributed during the flood. This process completely reworks the sediment surface, leading to a relatively new habitat to be recolonized by invertebrate animals each spring (Daborn 2007).

While the complex interactions between tides, currents, sediments and biology have become clearer as a result of research during the last two decades, there are indications that the sediments of the Minas Basin and Chignecto Bay have undergone significant changes over this period. This is indicated by changes in the populations of important intertidal fauna (Shepherd *et al.* 1995; Greenberg *et al.* 1997). It is not clear whether these changes in water content, grain size and distribution are the result of recent events, such as the construction of causeways on the Petitcodiac River and the Avon River, or the disturbance caused by worm- or clam-harvesting, or whether they reflect long term cycles or progressive changes in the dynamic processes in the Upper Bay of Fundy. What these changes do indicate, however, is that it may be extremely difficult to identify effects that could be attributed unequivocally to future demonstration or commercial scale energy conversion projects in the Upper Bay of Fundy.

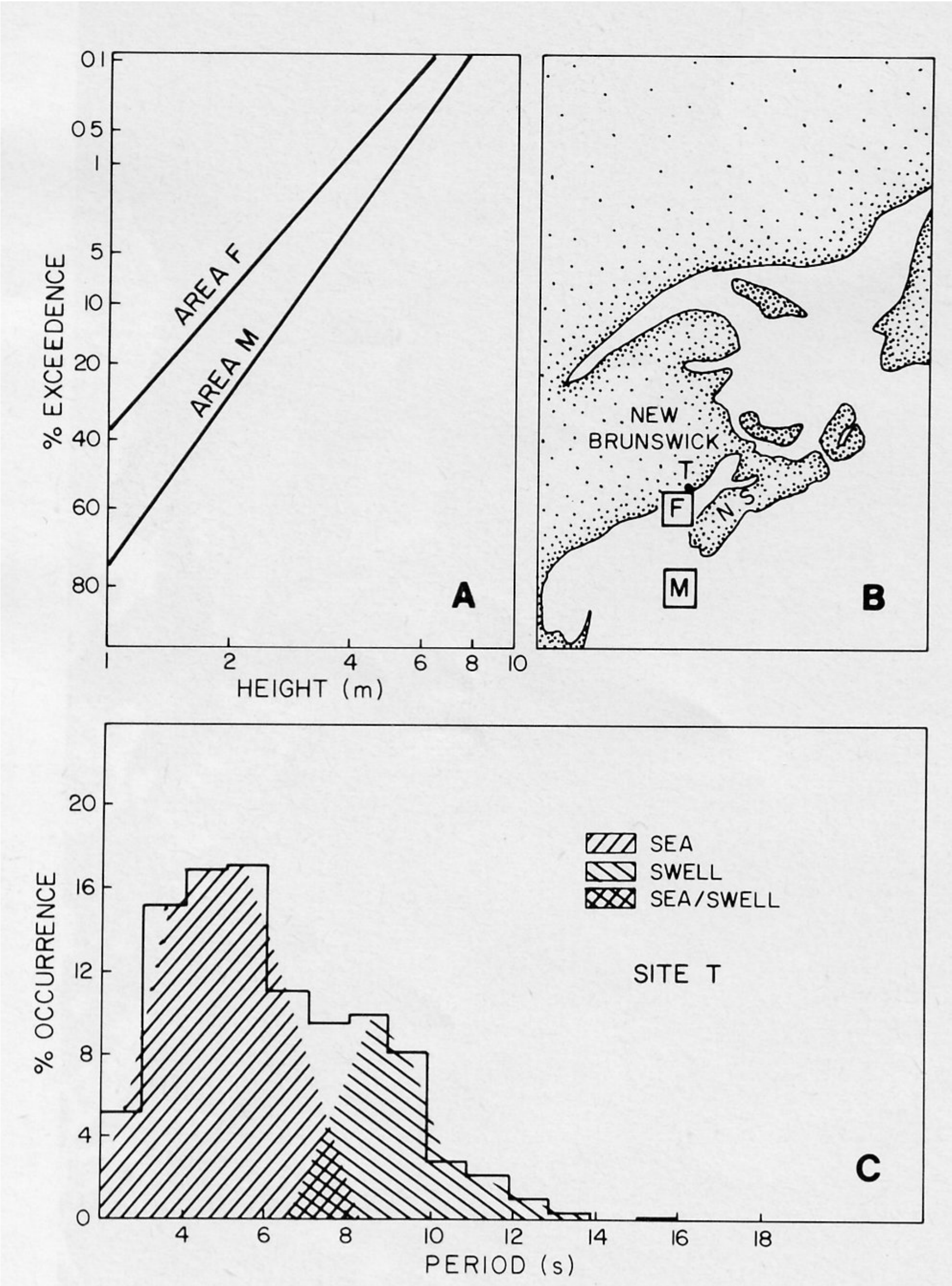
5.1.4 Wind and Waves

The wave climate of the Bay of Fundy is highly variable because of the relatively short fetch available over which the wind can act, and the variability in wind direction. Gates and O'Neill (1977) reported that within the Bay of Fundy, winds blow from the NW to SW quadrants more than 50% of the time, whereas at Saint John, N.B., there are stronger Northerly and Southerly components.

Wave climate studies in the Outer Bay and Gulf of Maine indicate that wave height generally diminishes from the Gulf of Maine into the Bay of Fundy: the largest waves in the region occur outside the Bay, and waves of any given height occur twice as often in the Gulf of Maine than in the Bay (Trites and Garrett 1983). Wave measurements, however, include both wind-generated waves, with periods of 4-8 seconds and heights of up to 1m, and ocean swells having periods of 7-14 seconds (Figure 5.8), although the sea swell is modest because of attenuation by the Scotian Shelf (Johnson 2007). In the Upper Bay, wave studies were reported by Amos and Joice (1977) for Minas Basin. Because of the narrow entrance into Minas Basin, and the orientation of Minas Channel, swells do not propagate effectively into the Basin, and the relatively small fetch limits local wave production to less than 2.5 m; in fact, during 1975, less than 0.5% of observations on a wave rider buoy in Minas Basin recorded wind-induced waves above 1 m in height, although longer period (swell) waves constituted almost 10% of measurements (Greenberg 1977). The wave energy available for generation therefore diminishes significantly as one moves up the Bay.

The Canadian Wind Energy Atlas suggests that the offshore wind resource in the Bay of Fundy could be substantial. Recently the Université de Moncton produced wind resource maps for three heights over land (30, 50 and 80 m) for Nova Scotia and New Brunswick (and for distances up to 10 km offshore, of Nova Scotia), showing that a significant wind resource exists along the shoreline of the Bay (see Appendix B). Mean wind speeds in excess of 7.5 m/sec were found along the North Mountain, the Yarmouth shore, over Grand Manan and Deer Island. Mean wind velocities over much of the Bay at a height of 80 m exceed 9 m/sec, representing an energy level of more than 700 W/m^2. The wind climate in the Outer Bay is thus in the range that might make offshore wind energy conversion viable, but the absence of sufficiently high and regular ocean waves anywhere in the Bay means that wave-energy conversion is unlikely to be fruitful.

FIGURE 5.8 Wave Climate in the Outer Bay of Fundy (From Trites and Garrett 1983)

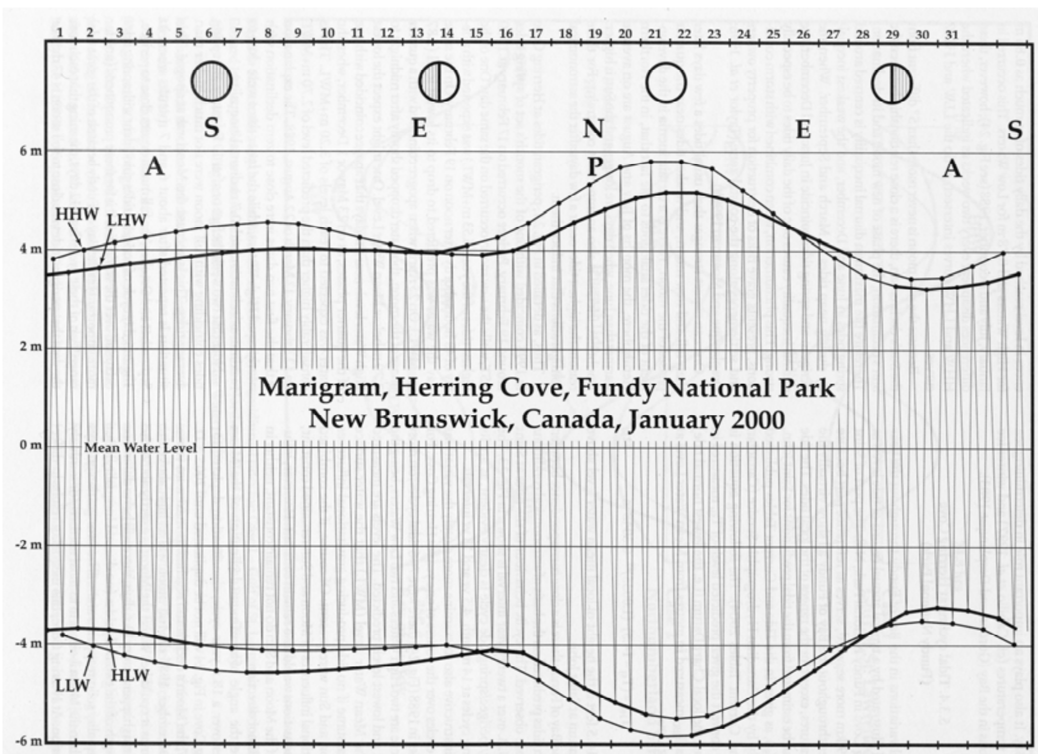


5.1.5 Tides, Currents and Mixing

The tides of the Bay of Fundy have been the subject of major investigations for more than a century, particularly at times when tidal power generation has been under consideration. A single average tide brings into the Bay a volume of water (~104 km^3) equal to the daily outflow of all the world's rivers; extreme tides can introduce up 146 km^3 every 6.2 h (Desplanque and Mossman 2004). Because the natural resonant period of the combined Bay of Fundy and Gulf of Maine system is about 13.3 h (Garrett 1972; Greenberg 1977), and the period of the Atlantic tide is 12.42 h, the FMG system is very close to resonance. As a result, the tidal range of the Atlantic Ocean (< 2 m) is amplified to more than 16 m in Minas Basin, and >15 m in Chignecto Bay (see Figure 5.11).

The tides are largely lunar driven, and thus predominately semidiurnal, with two tides per 24.8 hours. However, because the sun also exerts a gravitational effect, diurnal inequalities occur as a result of the changing declinations of the Moon and Sun with respect to the plane of the Earth's equator (Desplanque and Mossman 2004). Consequently, superimposed on the normal 14-day spring-neap cycle of the tides is a variable diurnal influence in which nighttime tides may differ from successive daytime tides (cf. Figure 5.9). In addition, the elliptical paths of the Moon and Earth produce variations in tidal forces associated with periods of 27.55 days (perigee-apogee cycle) and 182.5 days (perihelion-aphelion cycle).

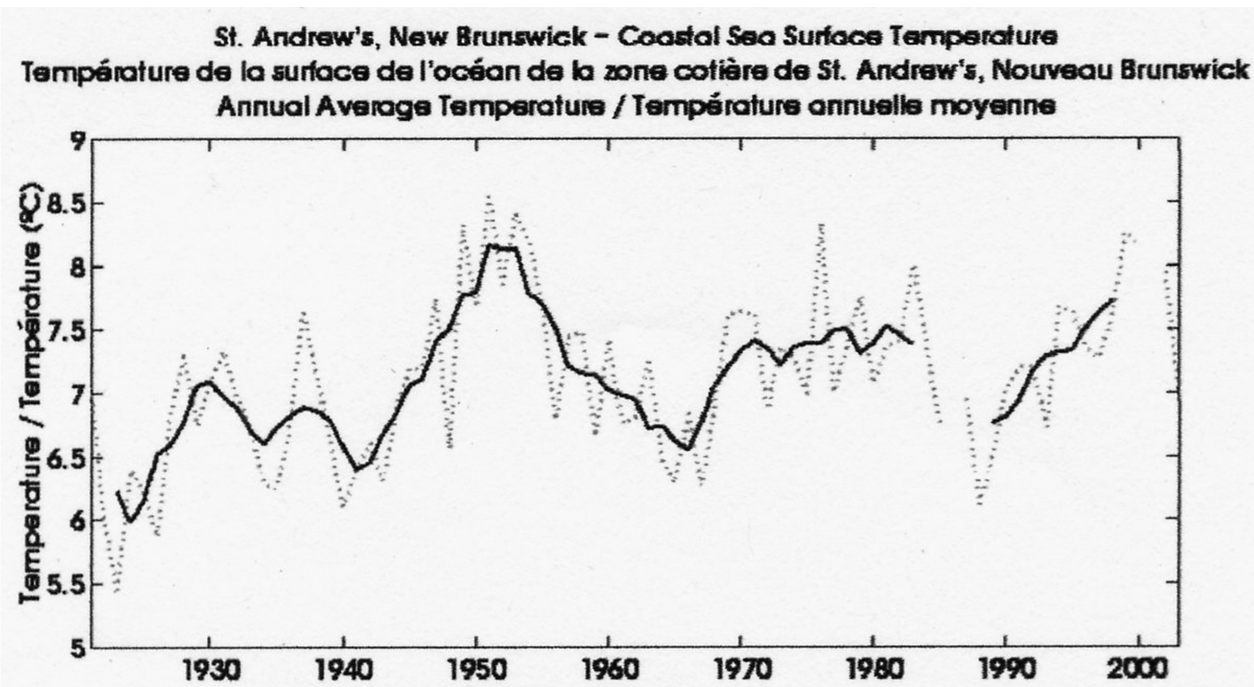
FIGURE 5.9 Monthly Tidal Cycle at Herring Cove, NB January 2000 (from Desplanque and Mossman 2004 P. 48)



There are numerous other extra-terrestrial influences upon tidal movements, but two in particular exert a significant influence upon the dynamics and biology of the Bay of Fundy. These are the 18.61 year *nodal cycle* caused by the rotation of the Moon's orbit about the normal to the plane of the Earth's orbit around the sun (*i.e.* the ecliptic), and the 18.03 year *Saros cycle* associated with repeated solar and lunar eclipses, when the Earth, Moon and Sun are in alignment. In theory the nodal cycle produces a modulation of +/- 3.7% of the major constituent (M_2) of the tide (Godin 1972), but in practice, non-linear frictional forces in the FMG system reduce this to +/- 2.6% (Garrett 1977). Although seemingly a small variation, the nodal cycle is detectable in sea surface temperature records at St. Andrews (Figure 5.10): sea surface temperatures during the peak years of the cycle are lower than those during years of lower tidal range (Loder and Garrett 1978).

The outcome results from the fact that a small variation in M_2 (and therefore tidal range) produces a larger variation in current velocities, which in turn produces an even larger variation in the degree of vertical mixing. This exerts an important effect on the ecology of the Bay of Fundy. From an analysis of more than a century of record, Cabilio *et al.* (1987) discovered that there were highly significant correlations between fish landings around the Gulf of Maine and Bay of Fundy, and an 18-year cycle of the tides. Positive correlations were found with northern species such as cod, haddock, alewife and herring, and a negative correlation with the warm water menhaden. The significance of the correlation varies if data on landings are offset relative to the nodal cycle, with the highest correlations occurring for a lag of years that corresponds to the time between hatching and recruitment into the fishery. Either the colder water temperatures, or enhanced primary productivity resulting from increased nutrient recirculation during the peak years of the cycle seem to favour survival of northern fish species, whereas the warmer waters nine or so years later benefit other more southern stocks.

FIGURE 5.10 Variations in Sea Surface Temperature at St. Andrews, NB (From Page 2007)



The velocity of flood and ebb waters is directly affected by the cross-sectional area of the passage through which the water passes. Maximum velocities between Grand Manan and Briar Island are 1.5 to 2 $m.sec^{-1}$, and between Grand Manan and the Maine shore nearly 2.5 $m.sec^{-1}$ (Figure 5.2). Through the Outer and Inner Bay, average maximum velocities are generally between 1.5 and 2.0 $m.sec^{-1}$, but increase at the entrances to Passamaquoddy Bay (<2 $m.sec^{-1}$), Cumberland Basin (<2.5 $m.sec^{-1}$) and Minas Basin (<5 $m.sec^{-1}$). Velocities do not vary much at different depths below the surface at any point, except for the boundary zone 1-2 m above the bottom sediments, in which currents sharply decline to values in the 10-50 $cm.sec^{-1}$ range (Trites and Garrett 1983; Page 2007). It is these velocities that winnow and mobilize the sediments, leading to the formation of dunes (Wildish and Peer 1983).

The banks in the eastern Gulf of Maine (Figure 5.6), and the sill on the north and eastern side of the Jordan Basin, force tidal water to the surface, creating major upwelling zones just outside the entrance to the Bay. Thus, as the water enters the Bay, it is vertically well mixed, nutrient-rich, and relatively cold. This is shown in Figure 5.5. The combined influence of Coriolis force, and the restrictive presence of Grand Manan Island, however, results in these well-mixed tidal waters adhering primarily to the Nova Scotia (*i.e.* southern) shore; the strong influence of the Saint John River, which is the largest freshwater source in the Fundy system, enhances the outward flow of water along the New Brunswick shore. Water begins to move across the Bay from south to north about the Digby—Saint John line. The result is a Bay-wide counterclockwise residual circulation pattern (Figure 5.2), in which passively-floating organisms (seaweed mats, plankton, particulates *etc.*) tend to drift along predictable paths in the Outer and Inner Bay. Typical residual drift velocities are 5-9 km per day, so that it takes about 5-6 days for water to travel the 50 km from Saint John to beyond Grand Manan (Page 2001), and 30+ days to travel around the Bay from Brier Island to Grand Manan.

The circulation pattern results in a gyre that occupies a large part of the northern Outer Bay. Towards the centre of the gyre, turbulence and vertical mixing are suppressed, and, with the added influence of freshwater input from the Saint John River, this region is susceptible to stratification, in contrast to the extensive vertical mixing that prevails throughout the rest of the Bay (Garrett 1977; Trites and Garrett 1983). Stratification occurs throughout the summer over the northern side of the Outer Bay (Figure 5.12), but tends to be strongest in the spring and early summer, when river outflow is greatest. Compared with the Nova Scotia side of the Bay, the lack of vertical mixing in this portion of the Outer Bay leads to warmer surface water temperatures (cf. Figure 5.5), and higher phytoplankton productivity.

5.1.6 Ice

An important feature of the Upper Bay of Fundy, compared with other tidal estuaries in which tidal power development is being considered, is the presence and variability of ice during the winter months. Except in severe winters, ice in the Outer Bay of Fundy is relatively thinner, associated with the shoreline or small embayments, and rarely builds into large floating masses. There is generally some ice cover in Passamaquoddy Bay in winter, although often not sufficient to inhibit even small vessels; occasionally, as in 1922-23 Passamaquoddy Bay may be completely ice covered (Trites and Garrett 1983). In the Upper Bay of Fundy, however, ice frequently forms over very large areas during low tide when the intertidal zone is exposed. This shore ice may then be refloated on the flood, broken up, or piled up to form large, multi-layered ice blocks several metres in height, which often become grounded in the intertidal zone, causing a scouring of the surface sediments in the process. In extremely cold periods, the sea surface itself may freeze, forming large floes that may move in and out with the tide.

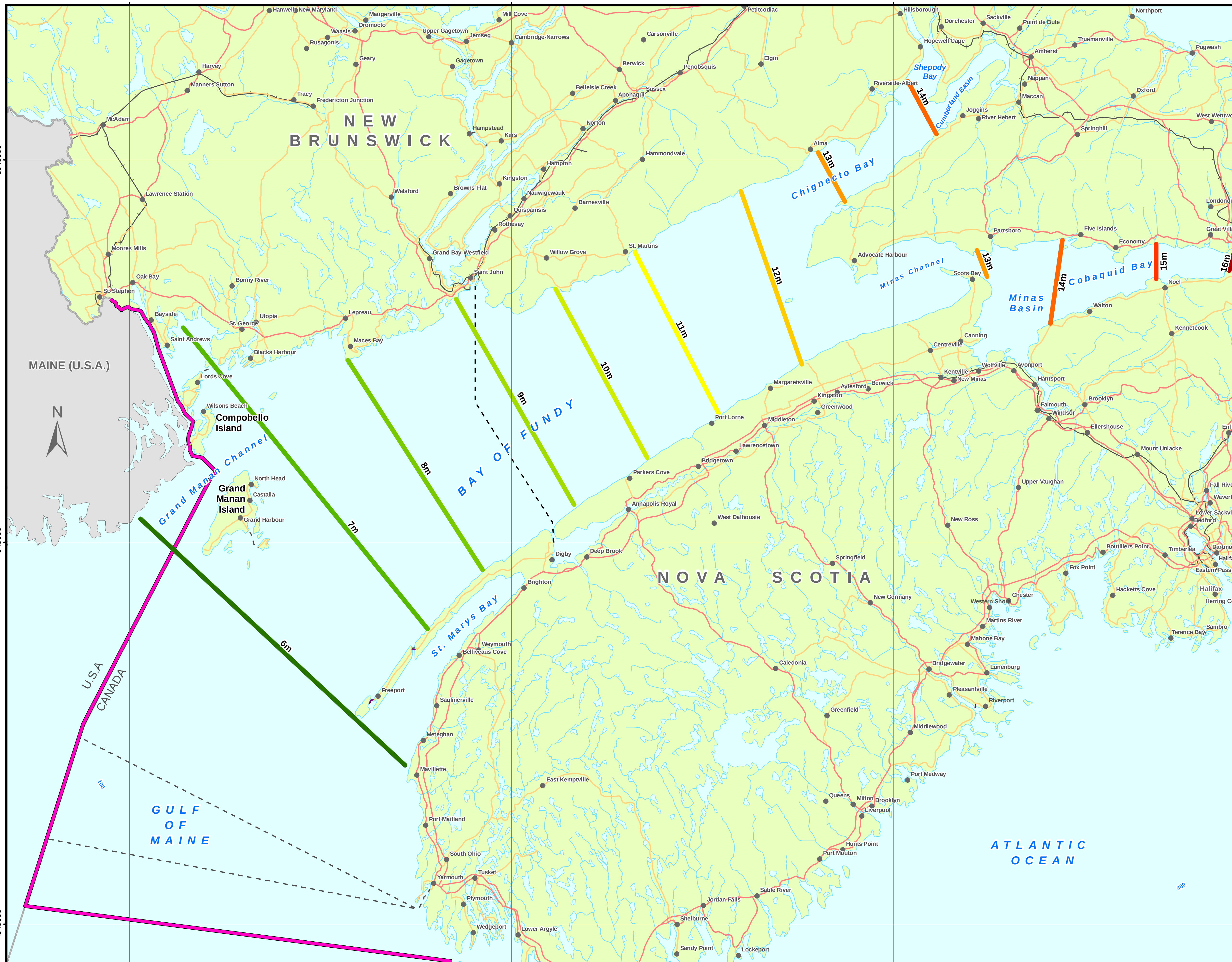


Figure 5.11

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Tidal Range in the Bay of Fundy

Tide Level (metres)

6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16

Base Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Oct 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-008

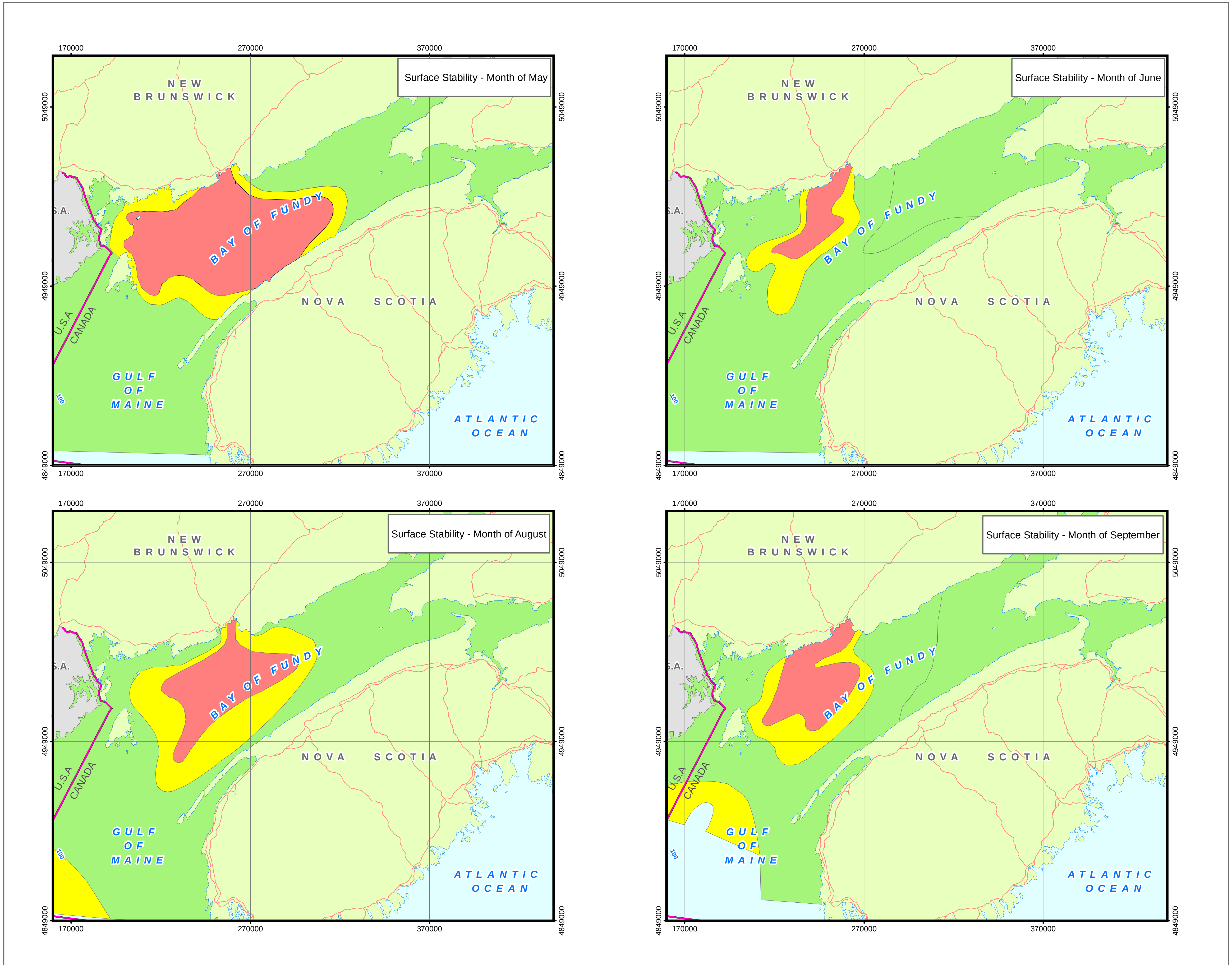


Figure 5.12

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Surface Stability in the Bay of Fundy

Surface Stability (Stratification)

- Well Mixed
- Frontal
- Stratified

Base Map Features

- Major Access Route
- Project Limits
- International Bounds

0 25 50 75 100 125

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-021

The Atlantic Tidal Power Engineering and Management Committee (ATPEMC 1969) examined the various types of ice, the extent of ice cover, the sediment load, and the fate of ice between January and March 1968. This was a severe winter, during which night-time and most daytime temperatures were below the freezing point of sea water (-2.5 C) from January 1 to March 15. Shore-fast ice up to 5 m was common and widespread, and occasional blocks up to 13 m in thickness were observed. During February 1968, ice covered the whole of Minas Basin, Minas Channel and Minas Passage, Chignecto Bay, Shepody Bay, Cumberland Basin, and in the Inner Bay of Fundy extended to Margaretsville, N.S.

Recently, Sanders and Baddour (2006) reviewed the prevalence and variability of ice formation, movement and persistence in relation to in-stream tidal energy harvesting. They reviewed ice records from 1967 to 2005 held by the Canadian Ice Service, and interviewed a local ship's captain who had operated year-round in Minas Basin for more than 30 years. "Significant ice", defined as ice floes at least 15 cm thick, > 100 m in length, and cumulatively covering >30% of the total water surface, had been present in Minas Basin in 3 of the previous 5 years.

The ecological implications of ice have been examined by Knight and Dalrymple (1976), Gordon and Desplanque (1983), Desplanque and Mossman (1998, 2004), Partridge (2000) and Daborn (2007). Ice has the effect of armouring the sides of rivers and drainage channels, effectively converting the channel into a hydraulic sluice that minimizes the further narrowing of the channel during the winter (Desplanque and Mossman 2004). In the intertidal zone ice freezes into the surface sediment at low tide, and, if refloated by the flood, will strip the surface of the sediment away, with significant effects on the fauna (Daborn and Dadswell 1988; Partridge 2000); in areas of salt marsh, this commonly will remove all of the above-ground vegetation remaining from the previous season (Daborn *et al.* 2002). Because of the high sediment load that may become trapped within (estimated at least 18% -- ATPEMC 1969), the ice may lose its buoyancy, and float at depths well below the surface.

5.1.7 Water Quality

The quality of estuaries and coastal waters is often primarily determined by the important role of inflowing rivers, which deliver dissolved and particulate matter that may be trapped in sediments or taken up by organisms. Whether these inputs result in enrichment or degradation of the coastal environment very much depends upon their concentration, and the extent to which they are diluted by and flushed out of the estuary. In the case of the Bay of Fundy, the huge volume of water that is imported on each tide completely dwarfs the total freshwater contribution from all of the rivers. Although some of these rivers carry effluents from urban or industrial areas (*e.g.* the Saint John River, the Petitcodiac River), or drain agricultural land (*e.g.* the Annapolis, Cornwallis and Salmon Rivers), the overall levels of contamination or enrichment are low, and are commonly retained within the estuary by the sequestering action of sediments or the filtering activities of benthic organisms. Consequently, water quality issues are associated almost exclusively with local circumstances, particularly in specific embayments or estuaries, or in association with industrial or aquaculture sites.

Salinity varies from 32+ psu at the entrance to the Bay to 0 psu in the rivers. Because of the very small freshwater component, and the extensive vertical mixing by the tides, salinity declines only slightly (to ~ 30 psu) through the Outer and Inner Bays. As a result of Coriolis' Force and the predominant inflow from the Saint John River, there is some lateral variation in surface salinities, with the New Brunswick side of the Bay being about 1-2 psu lower than the Nova Scotia side. In the Upper Bay, salinities tend to remain fairly high (<28 psu) wherever tidal waters are able to flow; brackish water conditions are encountered only for very short distances in the rivers themselves, where channel restrictions limit tidal flows. Consequently, brackish estuarine areas < 5 psu, in which sedimentation/suspension properties and fauna change significantly, are restricted to very short zones in the river itself. As indicated above, vertical mixing is sufficiently intense that conditions of stratification are limited to a region of the Outer Bay during the warm months (where it is associated with temperature differences and the freshwater brought down by the Saint John River), and to some unique circumstances in the estuaries, such as the sill at the mouth of the Kennebecasis River and behind the causeways constructed on the Annapolis and Petitcodiac Rivers.

Through most of the Bay, bottom sediments are constantly flushed and winnowed by tidal water that is more or less saturated with oxygen. Even in areas with high suspended sediment loads that are enriched with organic matter, and the biological oxygen demand is high, vigorous mixing is usually sufficient to maintain a high level of oxygen throughout the water column. Behind the Annapolis and Petitcodiac dams, however, the water is commonly stratified, with river water flowing out over the underlying salt water. In such circumstances, water quality of the deeper water may become degraded because of introduced organic matter and the depletion of oxygen. Another exceptional circumstance occurs in portions of the Quoddy region, where pockmarks attributed to outgassing of natural gas are sometimes associated with anaerobic bacteria, indicating depleted oxygen conditions (Wildish *et al.* 2007).

In spite of the large watershed of the Bay of Fundy, nutrient concentrations in water and sediments are primarily determined by tidal processes. In the Outer Bay, nutrient concentrations are generally high as a result of tidal upwelling at the entrance, and the circulation of cold, nutrient-rich deep ocean water into the Bay. These nutrients are what sustain the high productivity of phytoplankton and seaweeds. They may become depleted in surface waters of the Outer Bay, however, when this region stratifies in spring and summer, bringing an end to the seasonal production of phytoplankton.

Nutrients are even more abundant in the various embayments of the Bay of Fundy, however, and have been more extensively studied (Keizer and Gordon 1985; Wells *et al.* 1996). Nutrient concentrations in the embayments are the result of dynamic interactions between the water column, salt marshes, and underlying sediments, and are strongly affected by anthropogenic activities such as agriculture and aquaculture. In general, the embayments are enriched and exhibit higher nutrient concentrations. Although in most cases this does not cause blooms of phytoplankton or the depletion of oxygen, in some instances it has led to blooms of dinoflagellates, some of which are responsible for outbreaks of paralytic shellfish poisoning (PSP). Keizer and Gordon (1985) concluded that there was a net influx of nitrogen and silicate into Cumberland Basin from Chignecto Bay during the early summer, which stimulated growth of benthic diatoms and marsh plants, but for the rest of the year there was a net export. Sediments of the upper embayments commonly take up excess nutrients when available, releasing them when concentrations in the ambient water begin to fall; this sustains primary production for much of the growing season.

Excessive nutrient enrichment does occur, however, in areas of Passamaquoddy Bay and L'Etang Inlet, largely as a result of finfish aquaculture (Hargrave *et al.* 1993, Wildish and Pohle 2005).

Sediments below aquaculture cages where tidal flushing is limited have high oxygen demand, ammonium and sulphides, and consequently an impoverished fauna. Similar but less severe benthic impacts have been detected beyond cage-operations on an embayment scale (Wildish and Pohle 2005).

5.1.8 Contaminants

There are considerable data available on contaminants within the FMG system. A broad survey of metal concentrations in sediments from the Bay of Fundy was conducted by Loring (1979, 1982), and much of this information has been summarized by Wells *et al.* (1996) and by Horsley & Witten Inc. (1998). There are also a number of summaries dealing with the results of the Gulfwatch Mussel Monitoring Program developed and organized by the Gulf of Maine Council on the Marine Environment which began in the early 1990s and continues to this day (*e.g.* Fried 1999). Most contaminant studies have focused on the levels and distributions of heavy metals (also referred to as trace metals), Persistent Organic Pollutants (POPs), PCBs (polychlorinated biphenyls) and PAHs (polychlorinated hydrocarbons).

The heavy metals of concern include arsenic (Ar), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), silver (Ag) and zinc (Zn), and in the Bay of Fundy are derived mostly from industrial outflows. Since they are elements, they do not degrade and can accumulate in the environment, and some are subject to bioaccumulation in food webs. Even though several heavy metals (*e.g.*, copper, chromium. nickel and zinc) are essential cofactors of enzyme-mediated metabolism, they can be quite toxic when present in high concentrations.

POPs include a wide diversity of chlorinated compounds, many of which are used as pesticides: insecticides, fungicides and herbicides are widely applied in the agricultural and forestry industries. POPs originating from pesticide use include the chlorinated pesticides (DDT, DDD, DDE, lindane, aldrin, chlordane, toxaphene and heptachlor) and the organophosphate pesticides (parathion, malathion, systox, chlorthion, disyston, dicapthon and metasystox). POPs may enter the environment through point and non-point sources and do not readily degrade. This persistence makes them subject to bioaccumulation in food chains and, because they are lipid soluble, their concentrations can become excessively high in organisms, especially those at the top of the food chain that store fats, such as marine mammals. At high concentrations they can lead to neurological and reproductive problems and some are known to be endocrine disruptors and carcinogens.

PCBs were once used in the electrical industry as an insulator in electrical transformers and capacitors. Their use is now banned in both Canada and the US. They are released into the environment largely through leakage from damaged components and improper storage at disposal sites. They have a great affinity for attachment to sediment particles and can be transported to the marine environment by surface run-off or atmospheric deposition. They have many of the same toxic characteristics as pesticides.

PAHs are oil based hydrocarbons that originate from raw petroleum products and the burning of wood, coal and oils. They degrade slowly and are known to be both carcinogenic and teratogenic.

5.1.8.1 Heavy Metals

In most of the Bay of Fundy, heavy metals in the sediments are at or near natural levels for unpolluted coastal sediments (Horsley and Witten, Inc. 1998). A noted anomaly includes in an area near Grand Manan, where higher concentrations of some metals (Cr, V and Ni) result naturally from their occurrence in rock formations in the area.

Loring (1979) carried out an extensive survey of the distribution and abundance of 13 heavy metals in bottom sediments of the Bay of Fundy as part of studies to determine the potential environmental impacts of tidal barrages. In general, the results revealed a strong negative correlation between sediment particle size and heavy metal concentration: highest concentrations were found in the muds and lowest concentrations in the sands. With the exception of high cadmium concentrations at one site near Digby Neck, heavy metal concentrations were either average or below the average found in the Bay of Fundy and Gulf of Maine. In general, heavy metal concentrations decrease from south to north through the Gulf of Maine and Bay of Fundy (Fried 1999).

Nonetheless, high levels of some metals have been detected in the tissues of invertebrate animals from the Inner Bay of Fundy. Chou *et al.* (2000, 2004) found elevated levels of Ag, Cu, Cd, and Zn in tissues of lobsters and crabs collected from the several sites in the Inner Bay. Lobsters with Cu concentrations 10-80 times higher than those in lobsters from other non-industrial sites were collected from Cobequid Bay, Shepody Bay, Minas Basin, Minas Channel and Saint John Harbour, although the concentrations in the sediments were typical of other parts of the Bay of Fundy (Parker *et al.* 2007). The implication is that the animals were not deriving their metal burdens from the sediments, but probably from their food. Anomalous values occasionally have been encountered in other parts of the Bay, which also are not always explained by proximity to industrial inputs. For example, Chou *et al.* (2003) examined the levels of Ag, Cu, Cd and Zn in blue mussels (*Mytilus edulis*) collected at Broad Cove just south of Digby; Ag was undetectable and Cu and Cd were among the lowest of all sites examined, but the levels of Zn were among the highest of all sites studied.

Ray and Jerome (1987) examined heavy metal concentrations (copper, cadmium, zinc and lead) in the giant sea scallop (*Placopecten magellanicus*) from 19 sites in the Maritimes because of concern that this species was accumulating cadmium. A study by Uthe and Chou (1987) concluded that the high levels were entirely attributable to accumulation from natural, background levels, and were not caused by industrial inputs.

Copper, cadmium, zinc, and total mercury concentrations were determined for liver, kidney, and muscle tissues sampled from Bay of Fundy harbor porpoises in 1989 (Johnston 1995). Copper and zinc in Bay of Fundy porpoises were similar to values previously published from other locations and to other cetaceans in Canadian waters (Falconer *et al.* 1983).

5.1.8.2 Organic Contaminants

The Gulfwatch Mussel Monitoring Program is a chemical-contaminants monitoring program administered by the Gulf of Maine Council on the Marine Environment. Since 1993, it has been monitoring contaminants in tissues of the blue mussel (*Mytilus edulis*) at 38 sites located within the Gulf of Maine/Bay of Fundy region. Nine of these sites are located within the Bay of Fundy. The contaminants being monitored include nine trace metals, 24 polychlorinated biphenyl's (PCBs), 24 polycyclic aromatic hydrocarbons (PAHs), and 16 chlorinated pesticides).

Gaskin (1985) documented the levels of organochlorine residues in the Bay of Fundy/Gulf of Maine population of harbour porpoises (*Phocoena phocoena*) as being some of the highest in the world. More recently Westgate and Tolley (1999) examined the levels of organochlorine contaminants in harbour porpoises for three populations in the western North Atlantic. The geographic areas studied included the Avalon Peninsula in Newfoundland, the Gulf of St. Lawrence along the Gaspe Peninsula in Quebec and Grand Manan Island in the lower Bay of Fundy. The contaminants measured included PCBs, CHBs (chlorinated boranes), DDTs, chlordanes, HCHs (hexachlorocyclohexanes) and CBZs (chlorobenzenes). They found PCBs to be the most prominent contaminant and, together with DDT, higher in Gulf of Maine/Bay of Fundy harbour porpoises than in Gulf of St. Lawrence and Newfoundland harbour porpoises. The levels, however, were much lower than those found in porpoises collected ten years earlier reported by Gaskin *et al.* (1983). The results indicated that Grand Manan male porpoises had significantly higher levels of chlordanes, PCBs and DDT than males from the other areas. Trace metal contaminants in porpoises were also measured in this study and it was found that the mean concentrations of copper, zinc and mercury were similar to values reported for harbour porpoises in other regions of the world.

Chou *et al.* (2003) measured PCB and PAH concentrations in blue mussels collected for Broad Cove, Digby. PCBs were undetectable, but PAH concentrations were relatively high compared to seven other sites sampled within the Bay of Fundy.

5.1.8.3 Radionuclides

Anthropogenic sources of radioactivity within the Bay of Fundy include atmospheric fallout from nuclear weapons tests, fallout from the Chernobyl reactor accident in 1986, and effluent from the Point Lepreau, N.B. Nuclear Generating Station. Monitoring studies of radionuclide concentrations in seawater, sediments, atmosphere and marine biota studies by the Bedford Institute of Oceanography of the Department of Fisheries and Oceans began in 1978 at the startup of the Lepreau generating station. Levels of ^{137}Cs, $^{239, 240}Pu$ and ^{90}Sr in the lower Bay of Fundy do not differ from those of the open Atlantic Ocean, and generally reflect the declines associated with decay from material released during nuclear testing in the 1950s and 1960s. The only radionuclide attributable to the Point Lepreau Nuclear Generating Station is tritium, and elevated levels of this have only been found within 1 km of the reactor outfall, and then only during tritium releases (Wells *et al.* 1996).

At a monitoring site located at Digby, N.S, levels of radionuclides in a wide range of marine organisms showed levels to be similar to those present prior to operation of the Lepreau reactor (Nelson *et al.* 1985).

5.1.9 Biophysical Processes.

Although the Bay of Fundy is in many ways 'ruled by the tides' (Greenberg *et al.* 1996), there are several instances in which either the geological history or biological processes are seen to play strongly modifying and even overwhelming effects on the biological properties of the Bay system.

The heterogeneity resulting from variations in physical conditions throughout the Bay of Fundy has led to attempts to subdivide the Bay into a set of more or less distinctive subregions (*seascapes*), in expectation that such divisions would provide the basis for management and conservation. *Seascapes* are defined as: 'broad, oceanographic and biophysical areas characterized by particular water-mass characteristics and sea-ice conditions' (Bredin *et al.* 2004). Day and Roff (2000) classified regions of the Scotian Shelf and Bay of Fundy according to seven physical attributes: water temperature, bottom temperature, depth, stratification, exposure, slope, and sediment type. They identified 62 seascapes in the Scotia—Fundy area, of which 32 occurred in the Bay of Fundy (Bredin *et al.* 2004). Figure 5.13 shows the distribution of some of these seascapes in the Bay of Fundy. Each of the areas represents a specific combination of water depth, temperature, sediment type (*etc.*) that seems to be correlated with particular assemblages of organisms as determined by fisheries and ecological surveys. At a broad scale, the pattern of these seascapes more or less reflects the variation in tidal and sedimentological features in the Inner and Outer Bay. The greatest number of distinctive seascapes is found in the Outer Bay. (Details of the characteristics of each of the numbered areas could not be obtained for this report; the map is included to indicate that a comprehensive analysis that links physical and biological features together is in preparation, and could provide a useful basis for future management decisions in the Bay of Fundy).

When abundance data from fish surveys (or catch data from fisheries) are compared with the seascapes it is apparent that Atlantic cod, haddock, winter flounder, pollock and spiny dogfish are most abundant in seascapes 21 and 23, but these groundfish are notably uncommon in the neighbouring seascape (no. 19). Seascape 19 is a distinctive frontal zone, in which there is either convergence of surface waters (*i.e.*, downwelling), or upwelling associated with sudden changes in temperature or salinity (Bredin *et al.* 2004). Herring, on the other hand, are almost always found in greatest abundance in seascape 11, which represents the shallow coastal habitat.

This seascape classification helps to tie together the physical environmental characteristics and the biological characteristics of the Bay. It distinguishes between the shallow near-shore habitats in the Outer and Inner Bay (represented by Seascape #11) from deeper regions (*e.g.* #52), reflects the differences between the northern or New Brunswick portions of the Outer Bay and the Nova Scotia side (*e.g.* seascapes 19, 27 & 29 vs. 21), and the well-mixed region of the Inner Bay, and clearly shows that habitat differences occur over short distances around the islands and banks in the Gulf of Maine near the mouth of the Bay. It is partly this great diversity of habitat that gives rise to the great biodiversity found in the Outer Bay and Gulf of Maine. However, the data and properties chosen for the seascape classification were unable to discriminate between regions of the Upper Bay, even though there are notable differences in the environments and communities of Chignecto and Minas Basin.

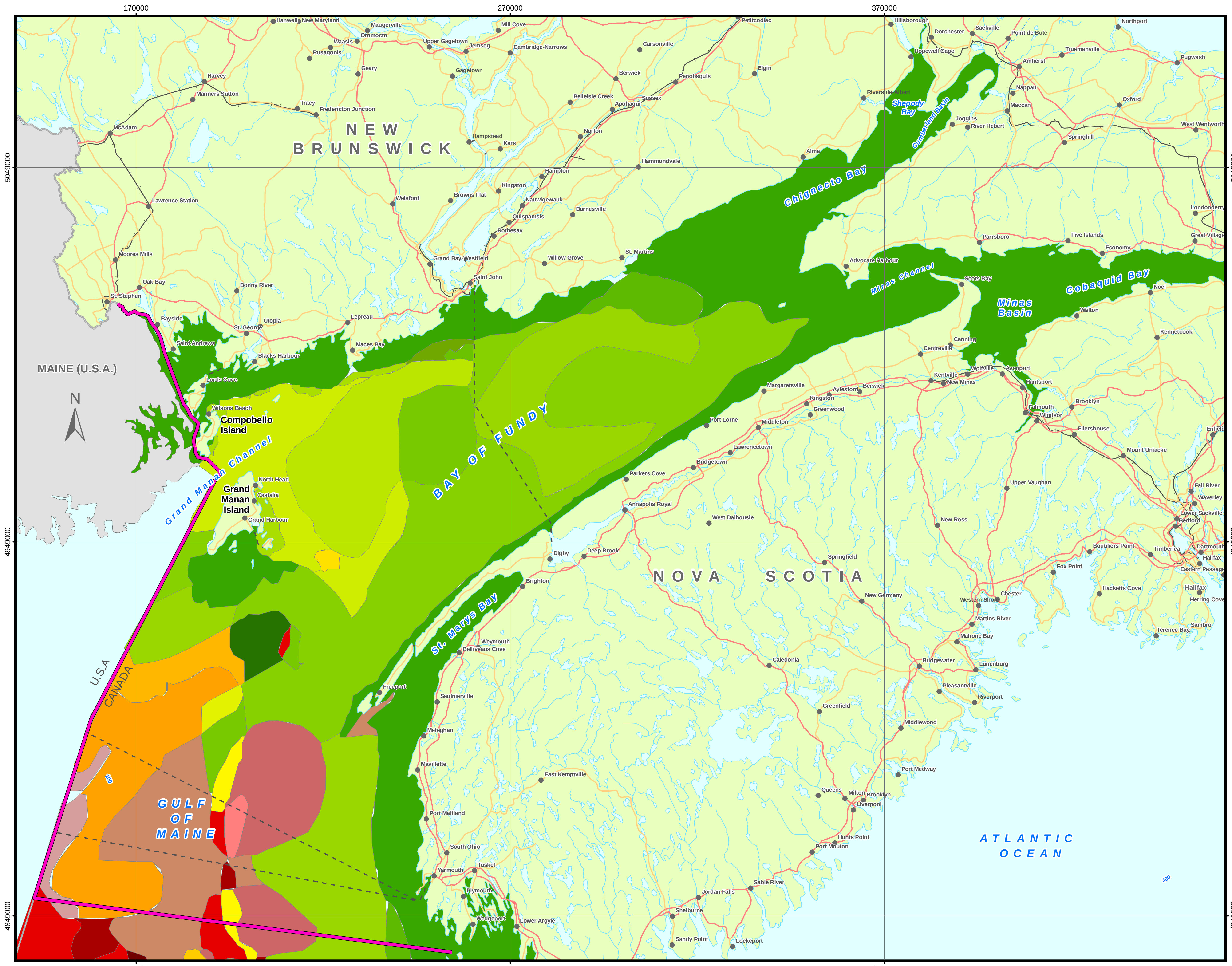


Figure 5.13

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Seascapes in the Bay of Fundy

Seascapes are defined as: broad, oceanographic and biophysical areas characterized by particular water-mass characteristics and sea-ice conditions' (Bredin et al. 2004). Day and Roff (2000) classified regions of the Scotian Shelf and Bay of Fundy according to seven physical attributes: water temperature, bottom temperature, depth, stratification, exposure, slope, and sediment type.

Seascapes Value

0	23	51	75
5	25	54	76
11	27	59	79
17	29	67	80
18	33	72	83
19	38	73	
21	39	74	

Bas Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-018

ACADIA ESTUARINE CENTRE FOR RESEARCH
New Nouveau Brunswick
Jacques Whitford
OEER FUNDY TIDAL ENERGY

One distinguishing feature of the Upper Bay is the extent to which biological processes modulate or interact with seasonal variations in physical properties. Studies of sediment dynamics, for example, have shown that in summer the behaviour of sediments is very much influenced by productivity of benthic microalgae and invertebrates (Faas *et al.* 1992; Daborn *et al.* 1993; Amos *et al.* 1994), whereas in winter the surficial sediments are completely reworked by ice, resulting in a new process of ecological succession each year. Significant changes in benthic organisms, and in the properties of intertidal sediments, have been recorded in recent decades (*e.g.* Shepherd *et al.* 1995; Daborn 2007), that may reflect currently unrecognized long term changes in biophysical processes, either of a cyclical nature, as with some fisheries (*e.g.* Cabilio *et al.* 1988), or progressive changes that might result from large scale modifications to tidal environments, as in the construction of tidal barriers (Wells 1999; Percy and Harvey 2000). These continuing changes may well limit success of attempts to identify the environmental effects of new energy extraction developments.

5.2 Biological Components

The significant differences in physical attributes (tides and sediments) between the major regions of the Bay of Fundy result in equally different biological communities and processes. To an extent this is regional: Upper Bay of Fundy biological communities are associated with shallow, turbid waters and fine, mobile sediments, whereas Outer Bay communities experience clearer waters and harder or coarser substrates. Within the Outer and Inner Bays, however, there is also a distinction between the communities of deeper and those of shallower waters, which becomes particularly relevant in considering the environmental effects of energy extraction. General summaries of knowledge of the Outer Bay of Fundy are to be found in Thomas (1983), and for the whole Bay of Fundy in Percy *et al*. 1997. Parker *et al.* (2007) provide a detailed summary of biophysical characteristics of the Minas Basin.

5.2.1 Primary Production

The major primary producers within the Bay of Fundy include phytoplankton, seaweeds, benthic algae and salt marsh grasses. The high diversity of physical habitats within different regions of the Bay results in a high degree of variability in the relative importance of different primary producers. Within the Outer and Inner Bay, where nutrient concentrations are high due to upwelling of deep nutrient-rich oceanic water that enters through the Gulf of Maine, and where suspended sediment concentrations are low, phytoplankton contribute upwards of 90% of the primary production. Seaweeds, mostly inter- and subtidal fucoids, are significant contributors to primary production within the Inner Bay, accounting for about 10 % of the total production. In the Upper Bay, the relative proportion of phytoplankton production decreases due to lower nutrient concentrations and higher suspended sediment concentrations; salt marsh and benthic algae production assume a greater importance, accounting for as much as 13 and 30 % of primary production, respectively.

Prouse *et al.* (1984) summarized the proportion of primary production provided by each producer group for each of the major regions of the Bay (Table 5.1).

TABLE 5.1 Distribution of Primary Production in the Bay of Fundy (From Prouse *et al.* 1984)

Carbon fixation (in thousands of tons per year)					
Region	**Phytoplankton**	**Seaweeds**	**Benthic Algae**	**Salt Marsh**	**Total**
Upper Bay	**23.4** (56.3%)	-	**12.7** (30.6%)	**5.4** (13.0%)	**41.5** (3.7%)
Inner Bay	**125.7** (89.8%)	**13.5** (9.6%)	**0.4** (0.3%)	**0.4** (0.3%)	**140.0** (12.5%)
Outer Bay	**927.8** (98.5%)	**13.5** (1.4 %)	**0.4** (0.04%)	**0.4** (0.04%)	**942.1** (83.8%)
Total	**1076.9** (95.8%)	**27.0** (2.4%)	**13.5** (1.2%)	**6.2** (0.6%)	**1123.6**

5.2.1.1 Phytoplankton

Diatoms, of which there are more than 100 species, dominate most of the phytoplankton community in all regions of the Bay (Lakshminarayana 1983). Within the Outer Bay, there are more than 10 species of dinoflagellates, several of which are responsible for harmful algal blooms that occur often enough to limit the potential for shellfish aquaculture in the Bay and frequently result in the closure of clam flats for recreational and commercial harvesting of shellfish.

The Bay of Fundy has long been known as an area in which a number of harmful algal species are common. The most common species are the dinoflagellate *Alexandrium sp*. and the diatom *Pseudo-nitzschia sp*. Blooms of *Alexandrium sp*., which produces a paralytic shellfish poison (PSP), are common, and on numerous occasions blooms of this species have reached concentrations as high as 10,000 cells per litre (Martin *et al.* 2001). The dinoflagellate *Mesodinium rubrum* is a common species in the Bay of Fundy that produces red tides; these result in depletion of dissolved oxygen in areas where tidal mixing is weak and flushing rates are low. This has occurred in areas within Passamaquoddy Bay and resulted in mortality of cage-reared salmon.

5.2.1.2 Seaweeds

The seaweed community, which is best developed in the Outer and Inner regions of the Bay where there is little sediment and a stable substrate suitable for attachment, consists mainly of fucoids, predominantly rockweeds (*e.g. Ascophyllum nodosum*) within the intertidal zone, and kelps within the lower littoral and sublittoral zones. Although few animals, with the notable exception of sea urchins and some isopods (Strong and Daborn 1979, 1980), are thought to graze directly on seaweeds, the export of both dissolved and particulate organic matter from seaweed communities is thought to be an important source of nutrients to offshore waters (Bradford 1989). In addition, the loss of live seaweeds during storm events results in 'rafts' of seaweeds being exported to the pelagic zone where they constitute an important habitat and feeding area for seabirds, various marine animals and fish (Parsons 1986). Some of this material also accumulates along beaches where it forms beach wrack that is slowly degraded by microbes and invertebrates and provides both habitat and a food source for various organisms, especially seabirds, feeding along the shoreline. In addition to their importance as an energy source, the large size and structural characteristics of seaweed communities makes them an important habitat for many organisms. Numerous invertebrate species live within and attached to the fronds, and seaweed communities are considered important nursery grounds and refuge for many fish species (Rangeley 1994).

A number of species occurring in the Bay have commercial importance. Irish moss (*Chondrus crispus*), rockweed or bladder wrack (*Ascophyllum nodosum*) and other seaweeds are harvested for alginates, and dulse (*Palmata palmata*) is harvested as a food source. Some rockweeds are also harvested for use as garden and agricultural fertilizer and mulch.

5.2.1.3 Benthic Algae

Benthic algae communities are most prominent within intertidal areas composed largely of fine sediments. Within the Bay of Fundy, they are best developed in the Upper Bay where the large tidal range results in extensive mud and sand flats. In this area, benthic algal production accounts for about 30 % of the total primary production. These communities are composed almost exclusively of benthic diatoms (Kazmirska and Trites 2004; Trites *et al.* 2004).

Benthic diatoms are a high quality food source and are subject to considerable grazing pressure. They form the major food source for many intertidal benthic invertebrates which are in turn an important food source for fish and various waterfowl that feed on the numerous deposit-feeding polychaetes and crustaceans that graze mainly on benthic diatoms. This intertidal community is especially important in supporting the major staging area for migratory shorebirds which feed mainly on mud shrimp (*Corophium volutator*) during the late summer before flying south for the winter.

5.2.1.4 Salt Marshes

Although salt marshes occur in all regions of the Bay, like benthic diatoms they are most extensive in the Upper Bay where they account for about 13 % of the primary production. Salt marshes are typically composed of high marsh plants (*e.g.* marsh hay or *Spartina patens*), which occur above mean high water, and low marsh plants (mainly marsh cordgrass or *Spartina alterniflora*), which occur below mean high water. Many Fundy marshes have been dyked for agricultural purposes and it has been estimated that as much as 80 % of the original marshland has been lost in this process (Gordon and Cranford 1994).

Unlike many southern marshes, the high tidal energy, open coastline and winter ice results in most of the low salt marsh production being exported offshore where it then becomes part of the detrital food chain (Gordon and Cranford 1994).

Salt marshes provide habitat for both terrestrial and marine organisms. Terrestrial species include numerous insects and spiders, and various species of waterfowl use salt marshes as breeding and over-wintering habitat. Snails and shellfish are often found within the substrate of marshes and small fish are common to the tidal creeks associated with marshes. Recent studies (Conner *et al.* 2001) have indicated that salt marshes, like other wetlands, accumulate carbon and may be important sites of carbon sequestration.

5.2.2 Secondary Production

The notable differences in primary production processes in different regions of the Bay of Fundy, which are determined by the physical conditions, are reflected in the organisms that depend upon them. Consequently, secondary production processes, and the species of zooplankton, benthos and nekton, also vary in the different regions of the Bay.

5.2.2.1 Zooplankton

Early studies of zooplankton abundance and distribution in the Outer Bay of Fundy were carried out by Fish and Johnson (1937) as part of the International Passamaquoddy Fisheries Investigations (Huntsman 1938). Roff (1983) and Corey (1983) summarized the state of knowledge about the Quoddy Region (more or less equivalent to the Outer Bay region as used in this document). A number of zooplankton surveys in the Inner Bay were carried out as part of larger surveys that focused on larval fish or larval lobsters (Legaré and MacLellan 1960; Corey and Milne 1987; Brown and Gaskin 1989; Daborn 1996). Other than the Minas Basin, the Upper Bay of Fundy zooplankton is poorly known.

According to Roff (1983) the smaller zooplankton association of the Quoddy Region is comprised of meroplankton, which are organisms that occupy the plankton for only part of their life cycle (*e.g.* larvae of polychaetes, molluscs, echinoderms, crustaceans and several minor phyla), and holoplankton, which occupy the plankton for their complete life cycle (predominantly crustaceans: cladocerans, a few ostracods, and most importantly copepods, but also single-celled protozoans and a few other groups of lesser ecological importance). These smaller zooplankton species are seasonally variable and are more diverse in the Bay of Fundy in general compared to within Passamaquoddy Bay. However, the few species that are present may occur in great abundance. The copepods feed on phytoplankton, detritus, protozoans, and other zooplankton. They are important secondary producers in the Outer Bay, contributing greatly to the trophic complexity of these waters.

The principal group of smaller zooplankton consists of copepods. More than 50 species have been recorded in the Outer Bay, many of which are common to the Gulf of Maine and Scotian Shelf (Roff 1983), and drift in from the Gulf of Maine (Corey and Milne 1987). They are a mix of boreal species (*i.e.* having a northern distribution in marine and coastal environments), and some that are specifically associated with shallow waters, with distributions that extend both north and south of the Bay. The shallow water species, including *Eurytemora herdmani,* and species of *Acartia*, are extremely abundant and dominate the more turbid waters of the Inner and Upper Bay (Jermolajev 1958; Daborn 1984).

The most important species of copepod, *Calanus finmarchicus*, dominates the plankton of the Outer Bay during the fall and winter, but is much less abundant in the Inner Bay and is rarely encountered in the Upper Bay (Figure 5.14). This species is a fundamental food source for many species of fish (Legaré and MacLellan 1960), birds (Mercier and Gaskin 1985; Chardine 2005), and baleen whales (Woodley and Gaskin 1996). It is thought that the availability of *Calanus* to surface-feeding birds is dependent upon upwelling of deeper water at the entrance of the Bay of Fundy, which brings these relatively large copepods to the surface. Chardine (2005) suggests that the decline of the Red-necked phalarope in the Bay is associated with the absence of *Calanus,* either because they are not being brought to the surface at the appropriate time when the birds are migrating through the Bay, or because they are consumed by planktivorous fish (such as the herring -- Legaré and MacLellan 1960). Baleen whales, particularly the Northern Right whale, are believed to congregate in areas of large concentrations of the immature *Calanus* (CSAS 2007b).

Zooplankton numbers and diversity decline sharply with the increased mixing and turbidity of the Inner Bay (Figure 5.15). The absence of both phytoplankton and zooplankton in the Inner Bay led Huntsman (1952) to conclude that the Inner Bay was very unproductive, and predicted that as waters became even more shallow and turbid in the Upper Bay, the productivity would decline even further. Daborn (1986) suggested that the decline in both chlorophyll and zooplankton in the Inner Bay is caused by the increased vertical mixing as the tide moves into steadily shoaling waters, which allows large, filter-feeding benthic species, such as the horse mussel *Modiolus*, access to food in the whole water column. The pelagic-benthic coupling model is based on the concept that in vertically well-mixed waters the long-lived benthic filter-feeders will out-compete planktonic species, whereas in stratified or less well mixed situations, the plankton will dominate because of their access to higher temperatures and more food. This may explain both the prevalence of filter-feeding benthos such as scallops, mussels and clams in the Inner Bay, and the much greater abundance of plankton-feeding pelagic fish such as herring in the Outer Bay.

Corey (1983) summarized the literature on the larger zooplankton in the Quoddy Region. Within this larger component are numerous animals that migrate vertically from deeper water into the zooplankton at night. This group includes ‘krill’, amphipods, mysids and cumaceans, representing the most common crustaceans of the larger zooplankton. Diversity and abundance of larger zooplankton are lower within Passamaquoddy Bay and its marginal island passages, and are very low in the innermost areas, compared to outer waters. Community structure and relative abundances of the larger zooplankton vary greatly both temporally and spatially within the Quoddy Region. Diversity and abundance in Passamaquoddy Bay and its outer passages are greatest in summer and least in spring.

Gelatinous zooplankton, particularly the ctenophore *Pleurobrachia pileus*, and the jellyfish *Aurelia aurita*, are common in the Outer Bay of Fundy, mostly drifting in from stocks in the Gulf of Maine. Milne and Corey (1986), in a survey of ctenophore distribution carried out over an 8-year period, found that the centre of abundance for ctenophores in this region is located over the southwest Nova Scotia shelf, and that an area of secondary abundance, maintained by immigration from the shelf region, occurs in the region of Grand Manan Island. In the Outer Bay, large gelatinous zooplankton occasionally occur in large swarms during the summer, and represent an important group of predators on smaller zooplankton such as the copepods, which they may completely clear from surface waters. These larger zooplanktors thus may act as important competitors for planktivorous fish, and for the larval stages of many other fish species. But in turn, they are food for a number of other species, including leatherback turtles and lumpfish. Although these gelatinous forms are also captured in the Inner Bay, their small size there indicates that they are unable to feed effectively because of the relative scarcity of copepods.

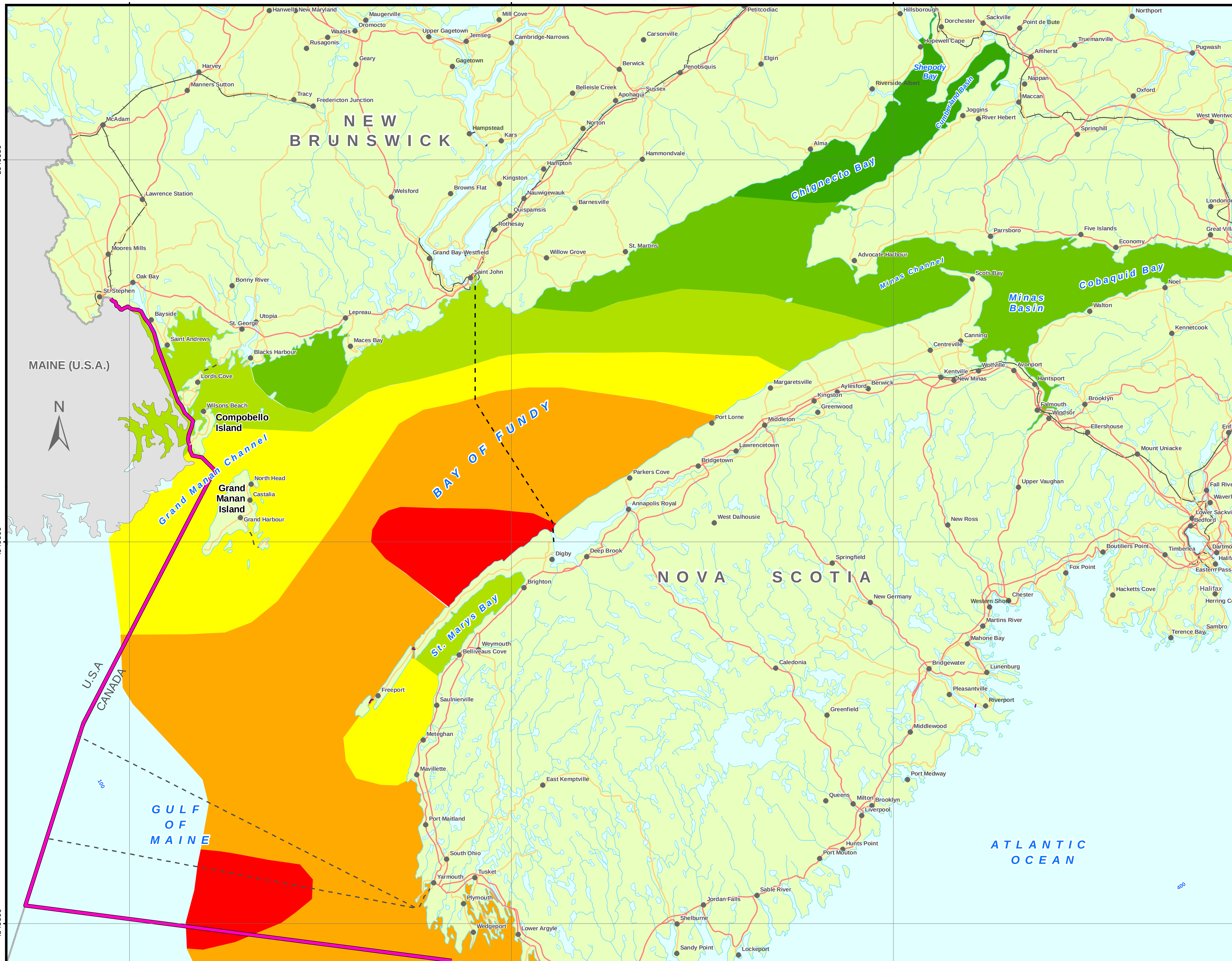


Figure 5.14

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Distribution of Planktonic Copepod *Calanus finmarchicus*

Abundance per cubic metre

- 0
- 10^2
- $10^2 - 10^3$
- $10^3 - 10^4$
- $10^4 - 10^5$
- 10^3
- $>10^5$

Base Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Oct 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-006

ACADIA ESTUARINE CENTRE FOR RESEARCH · New Brunswick Nouveau · Jacques Whitford · OEER FUNDY TIDAL ENERGY

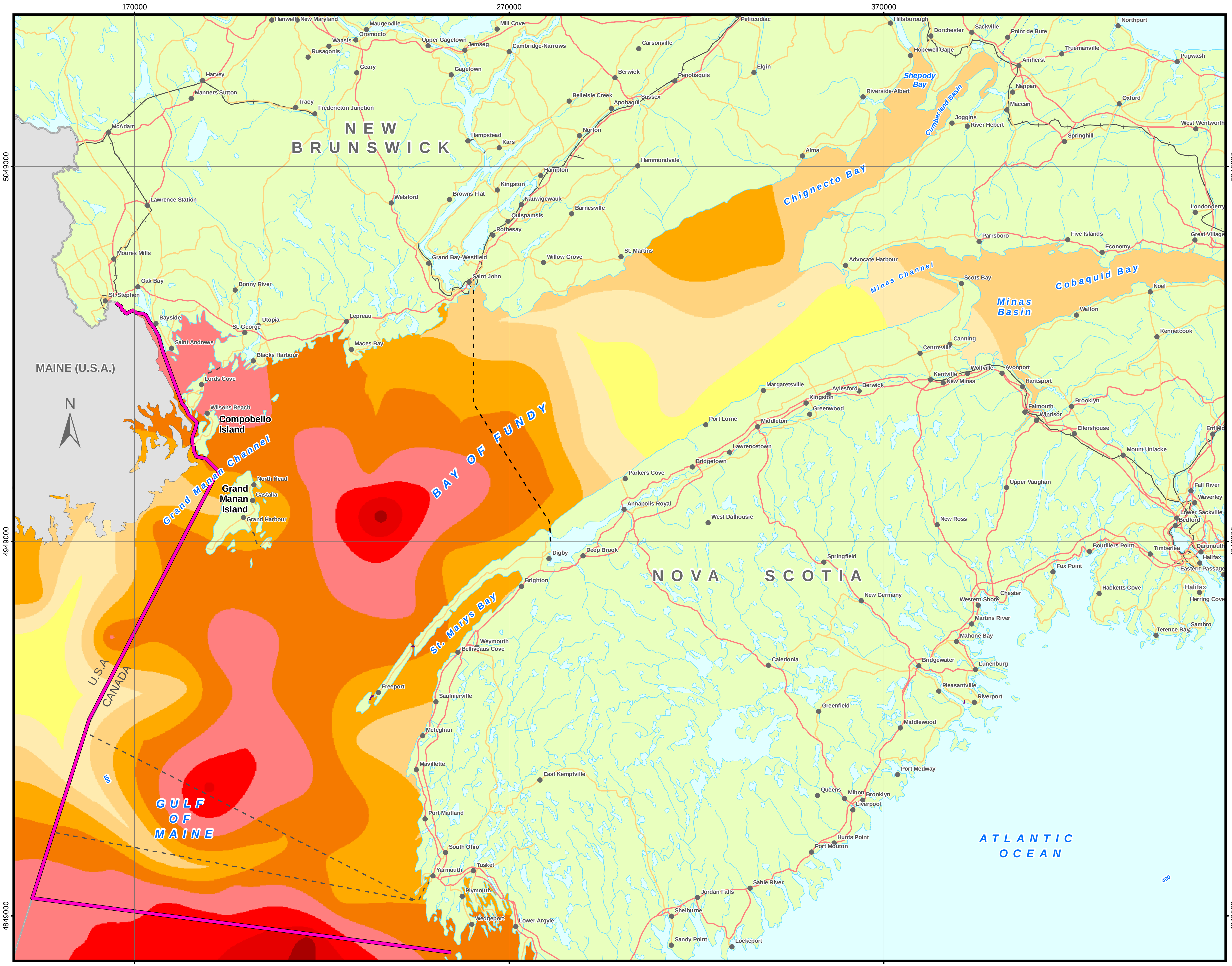


Figure 5.15

BAY OF FUNDY TIDAL POWER
STRATEGIC ENVIRONMENTAL
ASSESSMENT

Diversity of *Copepods* in the Bay of Fundy

Number of *Copepod* Species per Tow

- 6.0 - 7.5
- 7.5 - 9.0
- 9.0 - 10.5
- 10.5 - 12.0
- 12.0 - 13.5
- 13.5- 15.0
- 15.0 - 16.5
- 16.5 - 18.0
- 18.0 - 19.0

Base Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50
Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Oct 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-009

Planktonic populations in the Upper Bay are in fact distinctly different from those dominant in the Outer Bay regions. Most of the dominant species in the Upper Bay are small, readily passing through the coarse collecting nets that are normally used in clearer waters, which gave rise to the earlier perception that the Upper Bay was unproductive (*e.g.* Hunstman 1952). In fact, as turbidity levels increase in the Upper Bay, numbers of small zooplankton, such as *Eurytemora* and *Acartia*, become extremely abundant (Figure 5.16), especially in the most turbid estuaries (Jermolajev 1958; Daborn 1984), and play a major role in nutrition of many estuarine fish (Redden and Daborn 1991; Daborn 1996, 2007). Whether their abundance is due to the high turbidity, which limits predation by visually-feeding fish, or because these populations are sustained by the warmer temperatures and/or the abundance of microbial food on suspended sediments, has not been determined. It is, however, a potential uncertainty with regard to the effects of energy extraction in the Upper Bay.

5.2.2.2 Benthos

The *benthos* is the general term for those organisms that are associated with bottom substrates. They may be sessile, attached more or less permanently to hard, usually rocky surfaces, or may be buried in softer sediments such as sands or muds, in which case they may be called the *infauna*. Another group of animals, such as scallops, crabs, lobsters and shrimp, may spend much of their time moving around on the surface of the substrate, rather than buried or burrowed within it; these are called the *epibenthos* or *epifauna*.

The pattern of distribution of benthic organisms is determined primarily by the nature of the substrate, and secondarily by such factors as salinity, exposure to the atmosphere, or to predation by other animals. Wildish and Peer (1983) suggest that the strength of tidal currents determines which species of benthos will be dominant in subtidal areas, because of the influence on sediment stability, larval settlement, or feeding ability. Areas with low current speeds (*e.g.* < 20 cm/sec), and a deposition of organic matter tend to be dominated by deposit feeders that ingest and sort food from the substrate itself. Areas with high current velocities, where organic matter tends not to settle out, are dominated by suspension feeders: animals that take their food directly from the water flowing over them. If current velocities are not sufficient to scour the bottom, there is a strong relationship between the production of the benthos and the supply of particulate material brought to the benthos by turbulence in the water (Wildish and Kristmanson 1979), and in some circumstances this may lead to competition between the suspension-feeding benthos and the plankton in the water column above (Daborn 1986).

Because the dominant substrates of the Bay of Fundy vary substantially between the Outer, Inner and Upper Bays, the benthic communities of these regions are in many ways quite different; but substrates, and therefore the biota, also vary considerably within each region. Since substrate characteristics are the most important factor determining the benthic community, the fauna of any given substrate is likely to be similar, whether that substrate is found in the Outer Bay, the Inner Bay, or the Upper Bay.

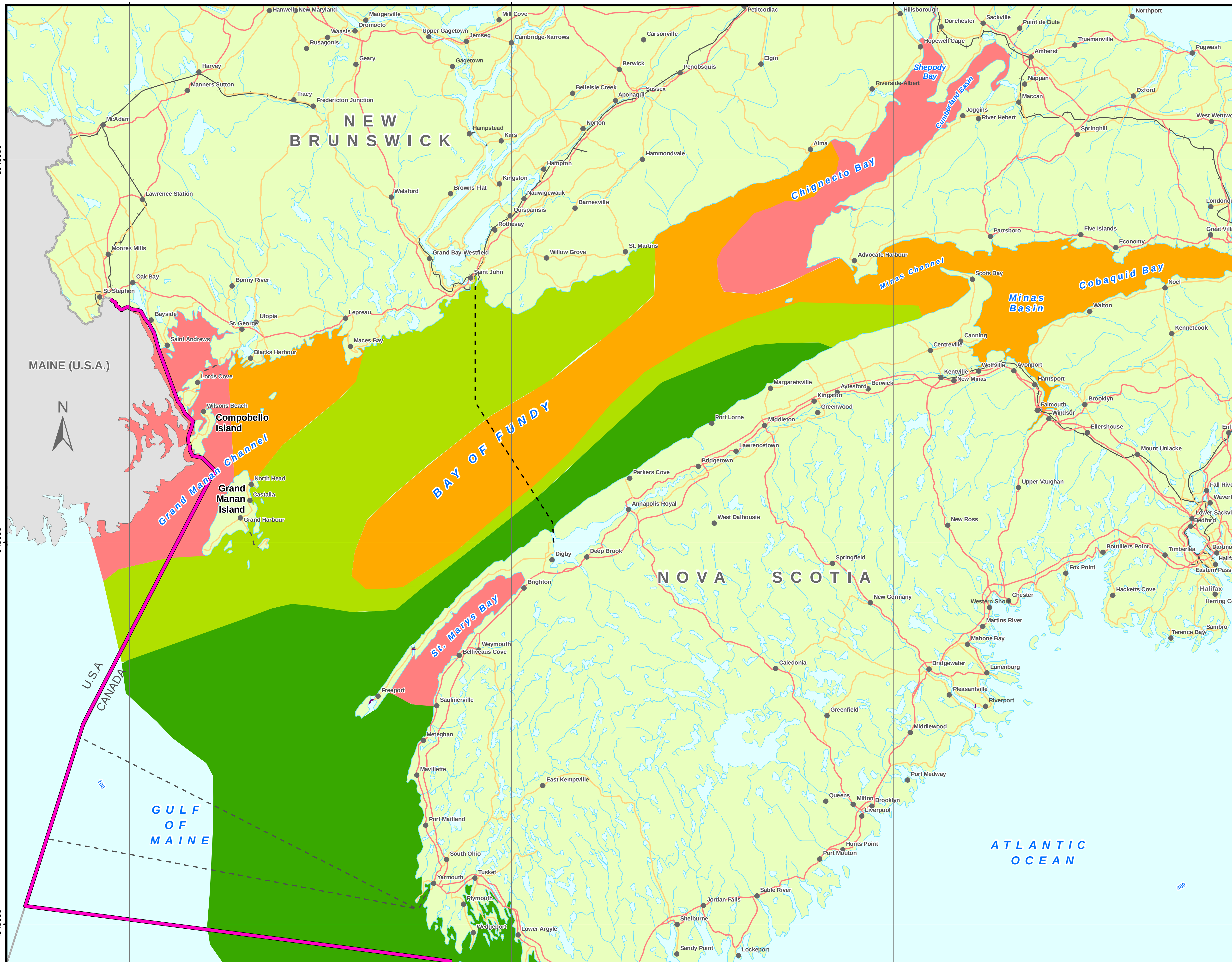


Figure 5.16

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Distribution of Planktonic Copepod *Eurytemora herdmani*

Abundance per cubic metre

- 0
- 10^2 - 10^3
- 10^3 - 10^4
- $>10^4$

Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Oct 30, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-007

ACADIA CENTRE FOR ESTUARINE RESEARCH
New Brunswick Nouveau
Jacques Whitford
OEER FUNDY TIDAL ENERGY

Benthos of the Outer Bay

The Quoddy Region of the Outer Bay of Fundy is a unique ecosystem supporting the highest biodiversity in the Bay of Fundy: over 2000 species of marine plants and animals (MacKay 2005). Environmental conditions in the Outer Bay have been detailed elsewhere (*e.g.* above, and in Buzeta *et al.* 2003, MacKay *et al.* 1979). In addition, several important estuaries empty into the Outer Bay, including the Saint John River Estuary, and are a major contributor of nutrients and thus biological productivity. The varied conditions support several major marine habitats of diverse and important biological communities which are discussed here as two principal ecological groupings: intertidal/nearshore and deeper channels/open waters.

Intertidal/Nearshore

In nearshore waters the very large tidal range creates a wide intertidal zone. About half of the Quoddy shoreline is rocky intertidal (Thomas *et al.* 1983). The biotic community of the rocky intertidal zone shows a strong vertical zonation, which is controlled by many factors such as slope, exposure, light, temperature, and biological interactions. The large tidal range concentrates wave action at the high and low tide levels and reduces wave effects in the midlittoral zone. In general, rocky shore zonation consists of the following. The uppermost (supralittoral) zone contains lichens and vascular plants, biota principally of terrestrial origin. The supralittoral fringe, from just above to just below extreme high water, is dominated by periwinkles, lichens, and blue-green algae, with a rockweed at the lowest level. The midlittoral zone extends to just above the extreme low water level, and is populated by barnacles, blue mussels, periwinkles, limpets, dog whelks, and amphipod crustaceans, as well as many other animal species among the large amounts of (mostly) knotted wrack, rockweed, other seaweeds and lichens. The infralittoral fringe, extending down to extreme low water, is the home of kelps as well as diverse red (including dulse and irish moss), green, and coralline algae. This diverse plant community houses a correspondingly diverse animal community dominated by green sea urchins, seastars, and northern rough whelks. Beneath extreme low water is the even more diverse infralittoral zone.

The rocky intertidal is interspersed with tide pools, which have been described in detail by Thomas (1983a). Tide pools experience extreme environmental variability and individually express low biological diversity and simple trophic structure, especially higher up the shore. Collectively, however, the varied – conditions found in different pools maintain a considerable biological diversity. Tide pools allow intertidal plants and animals to extend higher on the shore compared to open rock substrate. Pool plants and animals are used by transient herbivores and carnivores such as fishes, birds, and terrestrial mammals.

Steele (1983) discussed the coarse sedimentary shores of the Quoddy Region where erosive forces of waves reduce bedrock to this type of shore. The Quoddy Region does not possess high-energy shores or soft bedrock that leads to rapid erosion. However, unconsolidated glacial and fluvioglacial deposits abound in the region, providing ample sedimentary shore material. The size of rocks on which macroalgae can attach depends on wave exposure. In sheltered habitats quite small rocks can support large macroalgae; knotted wrack or rockweed (*Ascophyllum nodosum*) may even live unattached but resting on sand or gravel. Diatoms live on the macroalgae, on rocks, gravel, and sand or in their interstitial spaces. Epifaunal species living on the sediment surface are the same as those on bedrock, and exhibit similar intertidal zonation and abrasional effects. Beneath rocks lives a diverse fauna –

hydroids, sponges, anemones, barnacles, flatworms, amphipods, isopods, rock gunnels, rock crabs, green crabs, as well as periwinkles and dogwhelks during winter. Low-tide epifauna in fine-grained sediments is sparse – sand shrimp, sand dollars, green sea urchins, and whelks. But the infauna is more diverse with a macrofauna (≥500 µm) of gastropod and bivalve molluscs, annelid worms, isopods, and amphipods, as well as a diverse meiofauna (50 – 500 µm), and microfauna (≤50 µm).

Sublittoral substrates in the Outer Bay are either sedimentary or hard. Wildish (1983) listed a diverse fauna of polychaetes, molluscs, amphipods, echinoderms, sipunculids, ascheliminths, and ascidiaceans as characteristic of sedimentary substrates. He noted that tidal energy controls both sediment grain size and sorting, as well as animal distribution; strong tide and/or wave action can cause impoverishment of benthic populations.

Hard bottom sublittoral substrate, as characterized by Logan *et al.* (1983), is extensive and often bordered by rocky shore with rock rubble forming a steep zone of submerged rock debris, grading into sand and mud beyond about 30 m depth. Some deeper waters also have hard bottom where currents prevent mud from settling. Hard bottom may consist of ledge or rocks down to pebble size, as well as living and dead shells and man-made structures. Eastern Passamaquoddy Bay and the southern waters of the Outer Bay around Deer Island, Campobello Island, and Grand Manan exhibit hard rocky substrates. These provide a firm attachment for a diverse biota. Deer Island may show a higher diversity and abundance of species than Passamaquoddy Bay/Letete and Campobello Island due to varied bottom topography, narrow channels between islands, and vigorous tidal exchange distributing nutrients and food to all levels. Logan *et al.* (1983) described the biota: “Sessile encrusting forms include coelenterates, sponges, bryozoans, brachiopods, barnacles, annelids, bivalves and tunicates; motile forms include echinoderms, gastropods, amphineurans, and arthropods. In shallow water, where sufficient illumination reaches the bottom, encrusting calcareous red algae are common on exposed surfaces, together with occasional stands of seaweeds”. Western Passamaquoddy Bay has mainly sand and mud substrates. There are several species of common, non-commercial, demersal fishes inhabiting hard bottom substrates. Community distribution, species diversity, and composition on hard substrate may be controlled by many factors of which light, water energy, and sedimentation are important. Where tides and currents create strong water movement near the bottom, such as around the outer islands of the Outer Bay, there is low sedimentation in the upper 30 m except in the lee of outcrops or under boulders. Epifauna on the upper surfaces of rocks are dominated by passive suspension feeders, while animals in the low energy fine sediments beneath the rocks are active suspension feeders. This difference illustrates the importance of water energy in influencing hard substrate community structure.

Benthos of the Inner and Upper Bays

Until recently, knowledge of the benthic community of the Inner Bay was largely derived from records obtained through fishing activities, where species in addition to those being sought (*i.e.* lobsters, scallops and groundfish) have occasionally been recorded. Scientific sampling has traditionally been with small grabs or bottom trawls, which provide limited information about the array of bottom conditions or the fauna associated with specific substrates. With the advent of high precision multibeam bathymetry, however, knowledge of the substrates and the fauna of this region is rapidly expanding. Much of the Inner Bay is floored by sand (cf. Figure 5.7), exhibiting a variety of bedforms including extensive sand wave or dune fields, or gravel, with only occasional exposure of bedrock through the glacial till. The distribution of sand versus gravel substrates is presumed to reflect the strength of bottom currents on the flood and ebb, and directly affects the fauna present.

As in the Outer Bay, sandy substrates in the Inner Bay are commonly occupied by a relatively small number of species, particularly polychaetes, molluscs, echinoderms and amphipods. Because of the Coriolis effect, this is typically the condition on the southern side of the Bay; the major scallop bed that lies off Digby extends into the Inner Bay along the Nova Scotia shore, but scallops are less abundant on the New Brunswick side. As current velocity increases, and the sandy substrate becomes more mobile, the diversity of the epifauna and the shallow-burrowed infauna generally declines. Sand dune fields provide little opportunity for attachment, and the infauna tends to be a variety of specialized deposit-feeding polychaetes, amphipods and molluscs that are capable of burrowing deeply and rapidly, and thus tolerating a regularly shifting environment (Wildish and Kristmanson 1997). The exception appears to be the long ridge-like features known as *bioherms* described by Wildish and his colleagues (Wildish *et al.* 1998, 1999). These long ridges are capped by the suspension-feeding horse mussel (*Modiolus modiolus*), which may serve to stabilize the surface of the ridge against the scouring effects of the tidal current.

On the New Brunswick side of the Bay, lower current velocities combined with the tendency for stratification, lead to finer sediments on the bottom, often a mixture of sand and clay. In these environments, which are moderately stable, a variety of deposit-feeding polychaetes and molluscs are found. Coarser sediments, such as gravel, however, exhibit greater diversity, providing habitats for a wider array of species of all the above groups, together with lobster, crabs, ascidians, sipunculids and fish.

Except for the entrance passages, where high velocity currents have scoured to the glacial till or even to bedrock, the substrates of the Upper Bay are sedimentary in nature, ranging from sands to muds. Minas Basin is predominately a sandy estuary, because of the high tidal currents and the exposed sandstone shoreline (Amos and Joice 1977), whereas Chignecto Bay is more inclined to be muddy (Amos 1987). There are few bedrock outcrops in either system, and therefore species typical of hard substrates as found in the Outer Bay are uncommon. In the deeper passages, where the sediment is coarse gravel or boulders, habitat is found for organisms such as lobsters, and these areas may be relatively productive in a fisheries sense. Areas in the passages with the highest current velocities, however, may have a bottom composed of larger boulders or be scoured to bedrock. These are the places of most interest for tidal current energy extraction, but they are also among the most poorly known of habitats.

Because of the large tidal range, about one fifth of the area of Minas Basin is intertidal (Parker *et al.* 2007), with sandy substrates towards the low and high water marks, where wave action tends to be concentrated, but dominated by finer sediments such as silts and clays in the mid-tide zone. In Cobequid Bay, coarse sand deposits are inhabited by a relatively sparse group including soft-shell clams (*Mya arenaria*), burrowing isopods (*e.g. Chiridotea*) and various polychaetes (*Nephtys, Neanthes, Nereis* spp.). Sometimes the sand is stabilized by tube-dwelling polychaetes that secrete a mud and sand-grain tube that resists wave scour. In calmer locations, the sediment tends to have a higher clay content, and the infauna is dominated by a few species of polychaete worms (*Heteromastis*, *Nereis*, *Glycera*), and the burrowing amphipod *Corophium volutator*. In some places, especially near to the peripheral salt marsh, large numbers of the small clam *Macoma* occur, and in other locations, numerous mud snails such as *Ilianassa*.

As is common in nature, if the diversity of the fauna is low, generally because few species can withstand the physical conditions, the numbers of resident animals can be extremely high. This is the case with the polychaetes and *Corophium*. Populations in the many thousands of individuals per square meter have been recorded over large areas of muddy substrates in Minas Basin, Cumberland Basin and Shepody Bay, which are consumed extensively by resident and migratory fish, and migratory shorebirds (Hicklin and Smith 1979; Daborn *et al.* 1993; Brylinsky *et al.* 1996; Hamilton and Diamond 2000; Shepherd and Boates 1999). Recently, there have been indications that the distribution patterns of these abundant benthic animals may be changing, for reasons that are as yet unclear (Shepherd *et al.* 1995), but the implications for foraging shorebirds and fish is of some concern.

5.2.2.3 Fish

The Bay of Fundy provides habitat for a great variety of fish species, including those that spawn in Canadian waters, and others that migrate into the Bay for feeding (see Tables 3.2 and 3.6). Several species are or have been the basis for extremely important fisheries (cf. Section 5.2.3), although populations of a number of these have declined in recent years. Other species play significant roles as forage fish. There are a number of fish species that spawn in fresh waters of the Bay, but enter the coastal environment for much of their growth phase; these utilize the marine and estuarine resources of the Bay to varying degrees, some passing quickly through to offshore waters, while others spend longer foraging in different regions of the Bay. The diversity of habitats existing in the Bay of Fundy is a critical feature that supports this diverse and productive group of animals.

Fish are classified into functional groups that reflect their predominant habitat: *pelagic fish,* such as herring and sharks, are those that swim and feed primarily in the water column; they may be planktivorous or piscivorous (*i.e.* fish-eating); *groundfish,* such as cod, halibut and haddock, are associated with the bottom, feeding on benthic organisms or other fish. Their susceptibility to energy extraction devices will vary according to the location and characteristics of the device, and the habitual depth of movement of the fish. In addition, several important species in each of these groups are *diadromous*, *i.e.* they spend part of their life cycle in freshwater and another part in the marine environment. For these, the Bay of Fundy may represent a feeding and growing area, or merely a pathway between fresh and salt water habitats. Several of the *anadromous* species (*i.e.* those that spawn in freshwater and move to the sea to grow) are encountered in the Upper Bay during summers even when they are not returning from the sea to spawn. Dadswell *et al.* (1984a) have shown that American shad captured in Minas or Cumberland Basins represent all of the breeding stocks from rivers on the eastern seaboard of the United States as well as eastern Canada. They undergo a feeding migration within the Bay, following the residual circulation, over the course of the summer, before returning to their 'home' rivers to spawn in the next season. The possibility exists that other species, such as alewife, blueback herring, and sharks, may undertake similar feeding migrations, which would bring them into areas where tidal energy might be exploited. There is some evidence suggesting that many fish move in relatively large groups following tidal or residual currents as they approach their home river for spawning, or move around the Bay on feeding migrations (Dadswell *et al.* 1984a).

Pelagic Fish

Pelagic fish are a major component of the Bay of Fundy fish community. High primary productivity in the water column of the Outer Bay supports large numbers of pelagic fishes (Emerson and Wildish 1986) and its geographical configuration results in a cul-de-sac concentrating migrating fishes in the Bay during summer (Dadswell and Rulifson 1994). In addition, pelagic, anadromous species returning to spawn in Bay of Fundy tributaries are captured in fishing gear set to capture them or other species.

Probably the most important and characteristic pelagic species in the Bay of Fundy is the Atlantic herring (*Clupea harengus*). Herring are planktivorous fishes, dependent upon copepods and cladocerans that are found in abundance in the passages and Passamaquoddy Bay. It is believed that their previous abundance in the Outer Bay was associated with tidal circulation patterns that retained larvae and juveniles in the productive waters of the Quoddy region (Iles 1979), however exploitation has been heavy for more than a century and a half (see Perley 1852), and stocks are now considerably lower. Herring spawn in numerous areas of the Gulf of Maine, Georges Bank and Bay of Fundy, and migrate extensively around the FMG system (Coon 1999). However, a number of major spawning areas, including the largest along the southwest shore of Grand Manan island, appear to be no longer used. Significant spawning stocks persist in Scots Bay in the Inner Bay of Fundy, and small locations in the Quoddy region.

Porbeagle or mackerel sharks (*Lamna nasus*) commonly occur in the Bay of Fundy and its upper reaches (Dadswell *et al.* 1984a). They feed on other pelagic species such as salmon, herring, species of *Alosa,* and squid (Joyce *et al.* 2002), and would be expected where prey populations are dense, such as in Minas Basin and Passamaquoddy Bay. Several other pelagic sharks, including basking, thresher and great white sharks, also occur in the Bay of Fundy; although not abundant, they appear often, and have been captured as by-catch, observed or washed up dead on beaches on a regular basis during the last 150 years (Dadswell *et al.* 1984b).

Mackerel (*Scomber scombrus*) occur in the Bay of Fundy as adult spawners from a small spawning stock in Minas Basin (Dadswell *et al.* 1984a) and as migrating juveniles and adults from the large spawning stock south of Cape Cod (MacKay 1967). The mackerel is a highly migratory, pelagic fish that moves in and out of Canadian waters each summer between May and October from their wintering grounds off Long Island, USA.

Other large pelagic fish include bluefin tuna (*Thunnus thynnus*) and swordfish (*Xiphias gladius*), which are primarily open ocean species that periodically enter the Gulf of Maine and Bay of Fundy. Several species that are pelagic when in the Bay of Fundy environment, such as Atlantic salmon, the *Alosa* spp. (shad and gaspereau), and striped bass, are dealt with under Section 5.2.2.3.3.

Groundfish

Approximately fourteen fish species constitute the ground or demersal fish community of the Bay of Fundy that is exploited by commercial fisheries or by angling. Ground fish have never been a major component of the Bay of Fundy landings because almost all species only occur in the Bay during summer while migrating to and from the Scotian Shelf (Mahone *et al.* 1984; MacDonald *et al.* 1984). Some research suggests there is cod spawning on the western side of the Outer Bay (Hunt and Neilson

1993), but other studies suggest that traditional spawning areas for cod, haddock and pollock in the Bay of Fundy are no longer used (Buzetta *et al.* 2003).

The spiny dogfish (*Squalus acanthias*) is a small, slow-growing shark. Female dogfish attain a maximum size of about 1m and do not begin to reproduce until they are about 12 years old. Production of pups, which are born alive, requires 22-24 months gestation and numbers of pups/female seldom exceeds 10-20 (Scott and Scott 1988). Dogfish form sex-specific schools which migrate in and out of the Bay of Fundy. Mostly females occur in the Upper Bay where they arrive in May and remain until October (Moore 1998). While in the warm water of the Upper Bay the females release their pups (Moore 1998).

Cod constitute one of the oldest and most consistent fisheries in the Maritimes. They have been fished in the Bay of Fundy (Division 4X) since the 1700s (Anon 2006a). Cod are a demersal (*i.e.* near bottom) species that preys on many different food sources both from the bottom and in the water column. Young cod feed on invertebrates, but by age 3 they begin switching to a diet of fish. Growth is rapid and they mature by age 3 at a length of 50+ cm. This rapid growth and early maturity have maintained cod stocks even with years of overexploitation. Most spawning of the 4X cod stock takes place on Browns Bank and many of these fish migrate through the Bay of Fundy in summer (Frank *et al.* 1994). Recently a spawning concentration has been discovered to the west of Grand Manan and these cod probably also contribute to the Bay of Fundy fishery (Hunt and Neilson 1993).

Haddock is a bottom dwelling gadoid that feeds almost exclusively on small invertebrates (Scott and Scott 1988). They remain in depths of 50-200 m where water temperatures are above 2oC. Compared to cod, growth is slow, requiring 4 years to attain 38 cm and 10 years to attain 48 cm. The 50% maturity point of haddock is considered to be 3 yrs but spawning stock biomass is estimated for 4 yr old haddock and the stock is managed on this basis (Anon 2006b). The major spawning site for 4X haddock is Browns Bank and Jeffreys Ledge in the southern Gulf of Maine; adult haddock migrate annually from there into the Bay of Fundy to feed (Scott and Scott 1988; Frank 1992; Begg 1998).

Pollock are semi-pelagic gadoids which are nevertheless included among the groundfish. They apparently select regions with strong currents and upwelling and are abundant in the Bay of Fundy at locations like Minas Channel, the Passamaquoddy Bay Passages and off Brier Island (Perley 1852; Leim and Scott 1966). The Bay of Fundy pollock population is part of a trans-boundary stock that spawns in the southern Gulf of Maine during winter (Trippel and Brown 1993). The stock is highly migratory and migrates from Massachusetts Bay and Stellwagon Bank after spawning to the Bay of Fundy, Browns Bank and the coast of Maine. The Gulf of Maine pollock stock migrates south in fall and spawns in Massachusetts Bay (Scott and Scott 1988). Following the larval stage, juvenile pollock come inshore all around the Bay of Fundy and are abundant along beaches (Rangeley and Kramer 1995). At this stage they are commonly called ‘harbor pollock’. Growth is rapid and after their first year juveniles move offshore to feed on krill and fishes. Pollock attain 50-70 cm in length and maturity between 4-6 yrs of age.

Two species of hake are common in the Bay of Fundy: the white hake (*Urophycis tenuis*) and the silver hake (*Merluccius bilinearis*). White hake is a benthic fish which feeds on other fishes (75% of diet) and crustaceans (25%; Scott and Scott 1988). Silver hake are voracious consumers of fishes, particularly other gadoids and their own young (Scott and Scott 1988). Both species are summer spawners (unlike other gadoids) and move onshore for the purpose. Juvenile white hake are common in the shallows all around the Bay of Fundy (Dadswell *et al.* 1984a; MacDonald *et al.* 1984) but silver hake juveniles remain in deep water (Scott and Scott 1988). Growth and attainment of sexual maturity is rapid and both reach 40-50 cm in length and sexual maturity by 3-4 years of age.

Atlantic wolffish (*Anarhichas lupus)* is a solitary species that usually lives over hard bottom around large boulders or in holes. Wolffish appear to be non-migratory, and marked individuals are often recaptured within 10 km of their tagging site even after 5 years (Scott and Scott 1988). Atlantic wolffish are slow growing fish that require 10 years to reach a commercial size of 50 cm in length. They reach maturity at about 40 cm in length (Scott and Scott 1988). Wolffish feed on benthic organisms, such as echinoderms (sea urchins), molluscs (scallops), and crustaceans (lobsters and crabs), which they can crush with pavement-like teeth in their mouth. Because of their preference for scallops they are often a by-catch in the scallop fishery.

Monkfish (*Lophius americanus*) is another solitary species that is bottom dwelling and relatively sluggish. They are ‘anglerfish’ that lie partially buried and motionless on the bottom except for a ‘fishing lure’ which they twitch to attract prey (Scott and Scott 1988). They have an extremely large mouth with long in-curved teeth. Monkfish feed on all sorts of fishes but are especially well adapted to feed on flounders. There is a summer migration of monkfish into the Bay of Fundy which follows the annual flounder migration. They tolerate a wide range of temperature and move inshore into shallow water during summer (Scott and Scott 1988). Monkfish are often stranded on the tide flats of the Upper Bay by the rapidly receding tide (Bleakney and McAllister 1973; Dadswell, pers. obs.). Compared to other ground fish they are slow growing and long-lived.

Atlantic halibut (*Hippoglossus hippoglossus*) are large flatfish that grow relatively quickly and can reach a very large size. Female halibut attain about 100 cm in length and 12 kg in weight by 10 years of age; the species lives to ages of 30-35 yrs old and can weigh up to 700 lbs (Scott and Scott 1988). Female halibut attain 50% maturity around 115 cm in length. Halibut grow to a large size because, unlike other flatfish, they feed extensively on fish. There is an annual migration from deep water in winter to shallow water in summer and back and an annual migration of juveniles and a few adults into the Bay of Fundy from the Scotian Shelf. Young halibut penetrate Minas Basin in spring where there is an angling fishery for them (Wehrell 2005). Adults remain in deeper water but are captured regularly in the Inner Bay of Fundy.

Four species of ‘flounders’ are grouped under ‘flatfish’ in DFO landing statistics. These include the winter flounder (*Pseudopleuronectes americanus)*, the smooth flounder (*Liopsetta putnami*), witch flounder (*Glyptocephalus cynoglossus*) and American plaice (*Hippoglossoides platessoides*). Witch flounder and American plaice are species of soft bottoms and deeper, cold water habitats and are mainly found in the Outer Bay (Scott and Scott 1988). Winter flounder usually occur over sand and gravel and are seasonally abundant in all parts of the Bay. There is an annual migration that brings the main run up the Nova Scotia side of the Bay in spring, into Minas Basin in summer and down the New Brunswick shore in fall (MacDonald *et al.* 1984; Wehrell 2005). Smooth flounder are found only in warm, sheltered bays like Passamaquoddy and Minas Basin. They occur close inshore and move over the tide flats at high tide (Scott and Scott 1988).

Lumpfish (*Cyclopterus lumpus*) are relatively common everywhere in the Bay of Fundy and live over hard, rocky bottom. There is an onshore migration in spring for spawning and the males remain with the eggs to guard them until they hatch (Scott and Scott 1988). The young are semi-pelagic and are abundant among floating seaweed on the surface in the Bay of Fundy during summer and fall (Gregory and Daborn 1982). Lumpfish have never supported a fishery in the Bay of Fundy but they are the basis of a caviar fishery in Newfoundland.

Diadromous Fish

In the Maritimes there are eleven species that have a regular migration between the ocean and freshwater for the purposes of reproduction and growth. Of these, ten species are *anadromous* and spawn in freshwater, and one, the American eel (*Anguilla rostrata*), is *catadromous* and spawns in the sea. Diadromous species have always been important in the Maritimes because they were a source of food in early spring before the migrations of marine fishes arrived and because they were easy to catch with simple gear such as weirs, scoop nets, spears and by angling. Seven of these species are important to commercial and/or recreational fisheries.

American shad (*Alosa sapidissima*) are abundant in the Bay of Fundy because the region serves as one of the summer nurseries for the species and is a northern terminus for their coastal migration (Figure 5.17). Spawning populations exist in most of the major rivers of the Bay of Fundy, including the Saint John, Petitcodiac, Salmon, Avon, Gaspereau, and Annapolis. Eggs are laid above the head of tide, and drift downstream into estuarine waters (Williams and Daborn 1984), where juveniles may feed before moving out to sea. Spawning runs begin in April in most Bay of Fundy rivers; spawning occurs during June and spent adults migrate downstream in July. Juveniles migrate seaward during September and October at a size of 80- 110 mm (Stokesbury and Dadswell 1989) and the adults return to their natal river in 4-5 yrs at a size of 40-50 cm (Melvin *et al.* 1986). Adults in Canadian populations may return in future years to spawn again. Approximately 90% of over 3000 tag returns from shad tagged in marine waters of the Upper Bay of Fundy, however, were returned from fishers on shad spawning rivers in the United States (Dadswell 1986; Dadswell *et al.* 1987). Because of the complexities of their coastal migration and the current systems in the Bay of Fundy, abundance in the Inner Bay reaches high levels during summer (June-October). The adult population of migrating shad in this region during summer was estimated at 6 million during 1981-82 (Dadswell *et al.* 1984b). The total juvenile population in the region is probably several times higher (Dadswell, unpub. data).

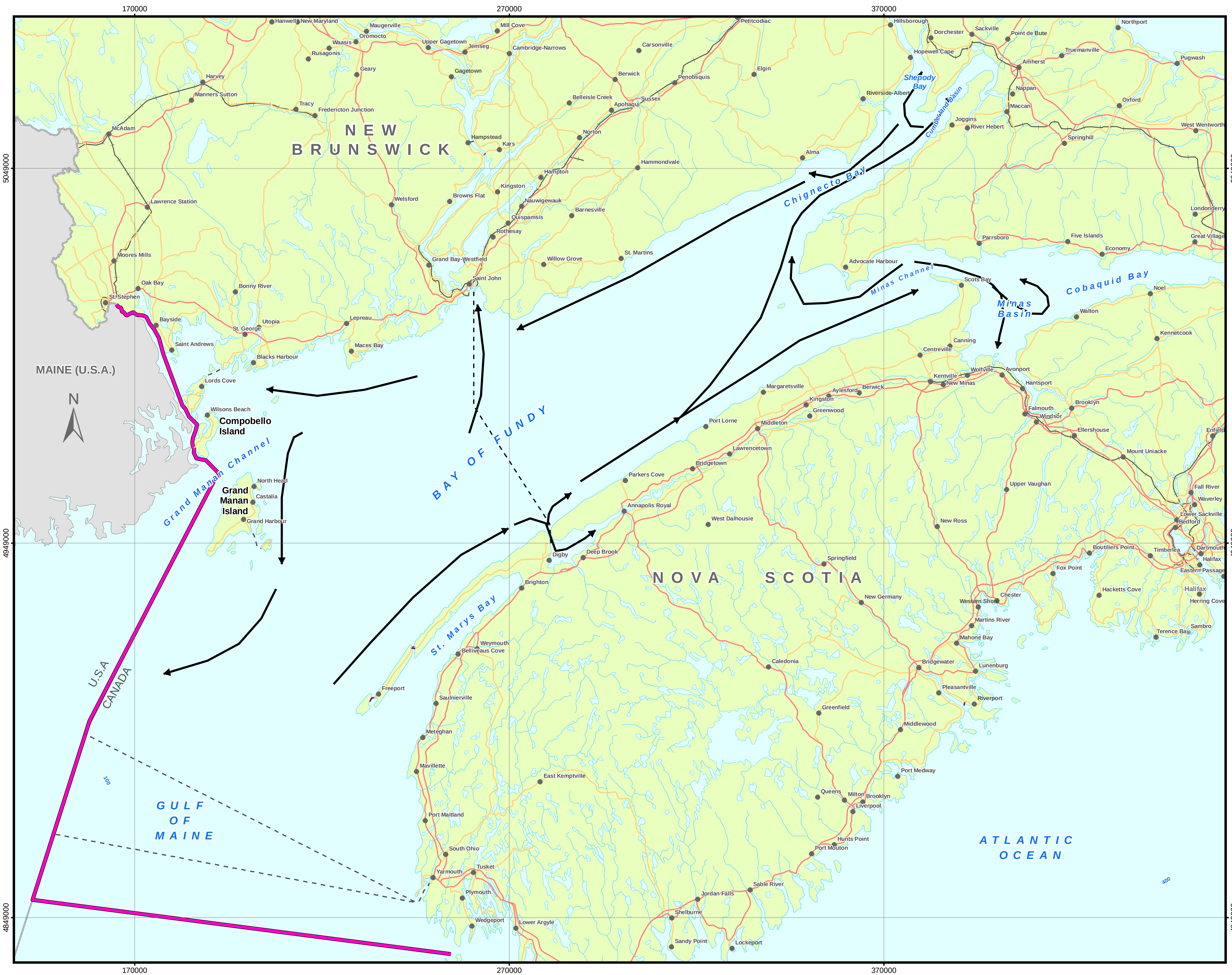


Figure 5.17

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Movement of American Shad in the Bay of Fundy

Movement of American Shad

Base Map Features

- Community
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-011

ACADIA CENTRE FOR ESTUARINE RESEARCH
New Nouveau Brunswick
Jacques Whitford
OEER FUNDY TIDAL ENERGY

Gaspereau or river herring is the collective name given to two *Alosa* species – the alewife (*Alosa pseudoharengus*) and the blueback herring (*Alosa aestivalis*) – which are difficult to distinguish from each other and which are often found together as mixed catches. Many tributaries of the Bay of Fundy have gaspereau populations, although construction of dams has resulted in significant declines in abundance by restricting access to spawning grounds, or because of mortality in hydro turbines during the downstream migration. They are now listed in DFO fisheries statistics as Alewife. Like American shad, these fishes migrate upstream in the Maritimes during spring (April-July) and spawn in lakes (alewife) or around rapids (blueback herring; Scott and Scott 1988; Dadswell 1985). Juveniles migrate seaward in the fall and remain in the sea until maturity before returning to fresh water to spawn at 4 or 5 yrs old. The gaspereau in the marine portions of the Bay of Fundy, like American shad, consist of mixed stocks from the entire east coast of North America (Rulifson 1994). Gaspereau tagged in Minas Basin have been recaptured from river fisheries as far south as North Carolina. During summer there are dense concentrations of juvenile and adult gaspereau in the turbid waters of the Upper Bay of Fundy (Stone and Daborn 1987; Dadswell and Rulifson 1994).

Atlantic salmon (*Salmo salar*) are and have been one of the premier pelagic fishes of the Bay of Fundy. Atlantic salmon spawn in freshwater streams where they bury their eggs in gravel during the fall (Scott and Scott 1988). The eggs hatch in April and the alevins remain in the gravel for six weeks feeding off their yolk sac. When the yolk sac is depleted they emerge as parr during May. The parr remain in fresh water for one to three years before migrating to sea as smolts at a size of 13-16 cm (Scott and Scott 1988). Atlantic salmon grow and mature while migrating around the North Atlantic (Spares *et al.* 2007) and then return to their natal rivers to spawn and complete their life cycle (Huntsman 1931). After feeding at sea they return to their natal rivers as grilse (1 sea winter (SW)) at a size of 45-60 cm, or as salmon (2SW) at a size of 70-80 cm. Unlike Pacific salmon, Atlantic salmon often survive spawning and may return numerous times to freshwater after feeding excursions of 1-2 years at sea. The Bay of Fundy has 59 tributaries that have or had salmon stocks (Amiro 2003) and these make up two major groupings: the Upper Bay stocks (iBoF) and the Outer Bay stocks (Amiro 2003). The iBoF stocks usually returned as grilse (60-100%) the Outer Bay stocks as salmon (60-80% 2SW fish). The 59 Bay of Fundy tributaries, once supported large populations of Atlantic salmon (Dadswell *et al.* 1984a; Amiro 2003), but the species is now rare or extinct in many of these.

Two species of sturgeon are found in tidal waters of the Bay of Fundy: Atlantic sturgeon (*Acipenser oxyrinchus*) and shortnose sturgeon (*Acipenser brevirostrum*). Atlantic sturgeon are found throughout the Bay and spawn in numerous tributaries, whereas shortnose sturgeon are only known from the Saint John estuary (Dadswell 1979; Dadswell 2006).

Atlantic sturgeon are anadromous fish that are slow growing but reach large size. Spawning is in fresh water during June-July. The young require 3-5 years in warm estuarine waters (10-25 psu salinity) before they attain about 100 cm and migrate to sea (Dadswell 2006). At sea they feed on various benthic infauna along the Continental Shelf (Scott and Scott 1988; Stein *et al.* 2004). They attain maturity at 15-20 yrs of age and 150-200 cm in length when they return to freshwater to reproduce (Scott and Scott 1988). They can grow to 480 cm in length and a weight of 350 kg. The largest population in the Bay of Fundy region is in the Saint John River but populations also exist in other tributaries (Dadswell 2006). While at sea, mixed stocks of Atlantic sturgeon migrate north and south along the continental shelf of eastern North America depending on season (Stein *et al.* 2004; Laney 2007). There is an annual migration of Atlantic sturgeon through the Bay of Fundy that utilizes the extensive tidal flats of the Upper Bay inside Minas and Cumberland Basins as feeding habitat (Armitage and Gingras 2003). They were the 5th most common fish encountered in trawl surveys in Minas Basin during 2004 (Wehrell 2005).

The shortnose sturgeon is an estuarine species that is confined to the Saint John estuary except during periods of peak flood conditions when they are known to occur in the Saint John Harbour area (Dadswell 1979). They prefer estuarine waters of 1-20 psu Shortnose are a small species that mature between 50 to70 cm and seldom grow larger than 120 cm and 10 kg (Dadswell 1979). They spawn during April-May in the tributaries of the Saint John estuary. Growth is extremely slow and they require 10-15 years to reach maturity. Adults are common in the mid-estuary of the Saint John and during the 1970s their population was estimated at 100,000 (Dadswell 1979).

The American eel (*Anguilla rostrata*) is a catadromous fish that lives and grows in estuarine or fresh water but returns to the ocean to spawn. All North American eels spawn in the Sargasso Sea off the eastern side of the Bahamas (McCleave *et al.* 1987). The larvae drift north in the Gulf Stream and arrive onshore all around the Bay of Fundy as glass eels in early May. Upstream migration as elvers is rapid and they are capable of climbing high water falls and migrating over land at night. Eels live in almost every sort of freshwater and estuarine habitat in the Maritimes from small streams to beaver ponds, large lakes and estuaries (Scott and Scott 1988). They feed on almost any fish or invertebrate they can capture but grow at a relatively slow rate. Silver eels returning to the sea to reproduce are about 80-100 cm in length and 8-10 yrs old (Jessop 1996).

Rainbow smelt (*Osmerus mordax*) are one of the most abundant anadromous fishes in the Bay of Fundy. Virtually every brook, stream and river has a smelt stock that migrates up from tidal waters to spawn in early spring (April-May) and provides local, recreational fisheries. Smelt are a small fish. They grow quickly and mature at 2-3 yrs old and 13-20 cm of length (Scott and Scott 1988). Spawning takes place close to tide head in freshwater streams. Development of the adhesive eggs is rapid (1-2 weeks) and larvae descend downstream to live in estuarine areas for the first 2-3 months. Pelagic larvae are extremely abundant in the Upper Bay of Fundy. Bradford and Iles (1993) found concentrations of 1-4 larvae/10m^2 in the Minas Basin.

Tomcod (*Microgadus tomcod*) is a small member of the cod family that is anadromous or may become land-locked in fresh water (Scott and Scott 1988). They spawn during winter, usually in December and January, which has led to their other name 'frostfish'. Adhesive eggs are laid on a gravel substrate in estuaries or just above tide head and the eggs hatch in late winter. The larvae immediately drift downstream and commence life as pelagic larvae. Growth is rapid and they settle along the fringe of the intertidal zone by late summer (Dadswell *et al.* 1984a). They attain 6-9 cm by age 1, 15-25 cm and maturity by age 2 and seldom live longer than 4 years (Scott and Scott 1988). Tomcod are exceedingly abundant in the turbid waters of the Upper Bay of Fundy (Dadswell *et al*. 1984a) and their spawning runs attract large numbers of bald eagles that overwinter around the Bay of Fundy (Reid 1982).

Striped bass (*Morone saxatilis*) are found all around the Bay of Fundy but are most common in Minas Basin, various estuaries (Saint John, Annapolis, and Shubenacadie) and in lakes connected to the Bay (Leim and Scott 1966; Rulifson and Dadswell 1995). There are two distinct groups of bass found in the

Bay of Fundy (Wirgin *et al.* 1995). One of these consists of local stocks that spawn in Bay of Fundy tributaries (Rulifson *et al.* in press) and the other represents migrant bass from United States spawning stocks (Rulifson and Dadswell 1995). Bass spawn in the upper, tidal reaches of larger rivers and in fresh water; the eggs are pelagic and are retained in the estuary until they hatch (Rulifson and Tull 1998). Juveniles remain in the estuary for their first year and then move progressively seaward with age (Rulifson *et al.* in press). By age 3 they begin migrating long distances up and down the east coast of North America in summer. They feed on invertebrates and fishes and grow rapidly. Maturity is attained at a size of 35-50 cm and 4-6 yrs of age (Scott and Scott 1988). Striped bass commonly reach a size of 80-130 cm and weights of 20-40 kg.

White perch (*Morone americana*) is a small species of anadromous fish closely related to striped bass. They live as isolated populations in various estuaries around the Bay of Fundy. They are semi-pelagic and feed on plankton, insects and small fishes (Scott and Scott 1988). White perch are slow growing and long lived. They seldom exceed 30 cm in length and 1 kg in weight. White perch have never supported a commercial fishery but are commonly caught by anglers. They sustain large populations in estuaries and contribute to large angling catches. There are no angling restrictions.

Fishes of the Outer Bay

Fishes in the Quoddy Region as a whole were reviewed by Scott (1983) who listed 104 species in 47 families ranging from primitive hagfishes to advanced flounders and ocean sunfishes. MacDonald *et al.* (1984) examined the fish community throughout the Quoddy Region, sampling intensively both temporally and spatially and catching 62 species. Along the beaches MacDonald *et al.* (1984) reported that clupeids and American smelt were the most important. Alewives, Atlantic herring, and smelt were common inshore in late summer. In estuaries herring were abundant in summer and replaced by smelt in winter. Juvenile pollock dominated beach catches in early summer. Juvenile red and white hakes were common along shore in summer. Atlantic tomcod were taken year round but were particularly abundant in early summer and in estuaries in early winter. Juvenile sculpins of most species were common at shore stations in summer. Threespine stickleback occurred year round along the shore, with other sticklebacks occupying estuaries. Mummichogs (*Fundulus* spp.) and Atlantic silversides were found in estuaries in summer and along shores in winter. For the blenny-like rock gunnels were predominant along the shore.

In deeper waters of the Quoddy Region MacDonald *et al.* (1984) recorded five skate species. Thorny and smooth skates were common year round outside of Passamaquoddy Bay; little and winter skates were present year round inside the bay in deeper water. Large smelt were found in deeper water in Passamaquoddy Bay in summer. Juvenile herring were abundant in winter in Passamaquoddy Bay at intermediate depths (~20 m). Eight gadoid (cod-like) species were recorded, dominated by cod. Juvenile cod were more common at intermediate depths of approximately 30 m in summer, but in winter moved to deeper water. Juvenile pollock were found in deeper waters of Passamaquoddy Bay in winter; no adults were caught. Adult red and white hakes were common in summer in deeper water inside and outside Passamaquoddy Bay. Fourbeard rocklings were common year round in deeper water outside Passamaquoddy Bay near the Wolves. Silver hake was an important gadoid in waters inside and outside Passamaquoddy Bay in summer and fall, with juveniles occupying the outer waters year round. Six species of sculpins were common away from shore with longhorn sculpins and sea ravens recorded as abundant year round. Juvenile sculpins of most species were common in deeper water within Passamaquoddy Bay in winter. Seven species of blenny-like fishes were caught of which ocean pout predominated away from shore. Eight flatfish species were taken with winter flounder being the dominant species. They tended to concentrate in shallower water in summer and deeper water in winter.

At one time the Quoddy Region had the most productive fishery in the Bay of Fundy (Huntsman 1922), particularly for cod and herring. However, traditional spawning areas for cod, haddock, and pollock in coastal areas of Nova Scotia (Scots Bay to Lurcher Shoal) and New Brunswick (Passamaquoddy Bay to Chignecto Bay and off southeast Grand Manan) are largely no longer active (Graham 2002, in Buzeta *et al.* 2003). Extant herring spawning grounds include waters off southwest Grand Manan (and occasionally in Whale Cove) and southwest Nova Scotia (Trinity Ledge, Lurcher Shoal, and German Bank) (M. Power, pers. comm.).

Fishes of the Inner and Upper Bay of Fundy

By comparison, knowledge of the fish species occurring in the Inner and Upper Bays was relatively limited until investigations during the 1970s and 1980s in relation to tidal power developments. Dadswell *et al.* (1984) reported on the first extensive studies of fish in Minas Basin, Cobequid Bay, Cumberland Basin and Chignecto Bay since the preliminary work of A.H. Leim in the 1920s (Leim 1924). More than 40 species of fish occur regularly in the Upper Bay (Table 5.2), of which almost half (16) have commercial value, although most of these species are primarily captured commercially in the lower parts of the Bay.

In spite of the severe conditions in winter and the high tidal currents and turbidities, there is nonetheless a diverse group of species encountered in the Upper Bay. Some of these are thought to be year-round residents (*e.g.* silversides, sticklebacks, tomcod, mummichogs *etc.*), while others probably migrate into the Upper Bay from further seaward during the ice-free months (*e.g.* lumpfish, dogfish, skates, sculpins). In general, the ecology of many of these species is poorly known.

TABLE 5.2 Fish of the Upper Bay of Fundy. (After Dadswell *et al.* 1984).

Common name	Frequency	Life Cycle	Common name	Frequency	Life Cycle
Little skate	C	M	Silver hake	C	M
Winter skate	R	M	White hake	C	M
Barndoor skate	R	M	Pollock	C	M
Thorny skate	C	M	Atlantic silverside	C	E
Dogfish	C	M	Mummichog	C	E
Atlantic sturgeon	U	A	Banded killifish	C	E
Alewife	C	A	Northern pipefish	R	M
Blueback herring	C	A	Smooth flounder	C	M
American shad	C	A	Winter flounder	C	M
Atlantic herring	C	M	Windowpane	C	M
Atlantic menhaden	R	M	Atlantic halibut	R	M
Atlantic salmon	R*	A	Striped bass	C	D
American smelt	C	A	Sea raven	C	M
American eel	C	Cat	Shorthorn sculpin	C	M
Threespine stickleback	C	E	Longhorn sculpin	R	M
Blackspotted stickleback	C	E	Grubby	R	M
Fourspine stickleback	C	E	Lumpfish	C	M

TABLE 5.2 Fish of the Upper Bay of Fundy. (After Dadswell *et al.* 1984).

Common name	Frequency	Life Cycle	Common name	Frequency	Life Cycle
Ninespine stickleback	C	E	Atlantic seasnail	C	M
Fourbeard rockling	C	M	Ocean pout	R	M
Atlantic cod	C	M	Rock gunnell	C	M
Atlantic tomcod	C	E	Goosefish	R	M
Butterfish	R	M	Mackerel	C	M
Key: (C= common; R= uncommon or rare; R*= Endangered; M= marine; A= anadromous; E= estuarine; Cat= catadromous)					

5.2.2.4 Birds

The Bay of Fundy is well known for the abundance and diversity of birds that reside there or visit during seasonal migrations (Brylinsky *et al.* 1997). Waterfowl and shorebirds are distinctive components of the Bay of Fundy ecosystem, and reflect the considerable biophysical differences that occur between the Upper and Outer regions. By contrast, the Inner Bay of Fundy is relatively poor in bird life (Hughson 1977). Many of them, through their migrations, link the Bay of Fundy with other coastal ecosystems of the Americas.

Christie (1983) dealt with the seabirds of the Outer Bay (Quoddy region) in detail, listing 300+ species, with 220 occurring regularly or in abundance (of these, approximately 40% were present mainly in summer, 15% mainly in winter, 19% year round, and 25% were transient visitors during migration). Because of their movements, seabirds transport energy and nutrients among ecosystems. Many thousands of great black-backed gulls, herring gulls, double-crested cormorants, common eiders, great blue herons, gannets, and black guillemots breed on islands in the Quoddy Region in addition to Head Harbour Passage where common eiders commonly breed. Rising numbers of herring and great black-backed gulls have caused serious loss of common eider eggs and young, as well as for those of other nesting seabirds. In offshore waters are shearwaters, razorbills, murres, dovekies, common puffins, and gannets rarely seen near land except during nesting. These move readily in response to tides and food availability. Other species found offshore are the black-legged kittiwake, various terns, great black-backed gulls, herring gulls, Iceland gulls, glaucous gulls, jaegers, storm petrels, and phalaropes. This seabird community feeds on small fishes, crustaceans, and squid and perhaps nocturnally migrating large zooplankton. Some birds follow whales to feed on animals they force to the surface. The passages among Quoddy islands are home to more than 27 seabird species. Many others are found there, especially close to shore and in shallow waters. Phalaropes, gulls, and terns frequent the passages from summer to early winter, but numbers are low otherwise. The tidal currents and upwelling through Western, Letete, and Head Harbour passages and Friar Roads with their swarms of zooplankton, especially euphausiids, herring schools, and squid provide high quality feeding for the surface-feeding and diving birds in the warmer months. Distribution of flocks in the passages changes during the tidal cycle. Razorbills and dovekies can be numerous in winter. Migrating northern phalaropes in the passages form the highest concentrations in eastern North America; those of Bonaparte's gull are the largest in eastern Canada. Inshore waters support a large number of birds with more diversity in winter than in summer. In winter there is greater diversity and numbers at the mouth of Passamaquoddy Bay, especially gulls and oldsquaws, than toward its head; near St. Andrews are greater abundances of eiders and scoters. Summer inshore species are mainly herring and black-backed gulls, common eiders, double-crested cormorants, black guillemots, ospreys, and common loons.

The intertidal zones of the Outer Bay and Passamaquoddy Bay are also important to seabirds, both divers and dabblers such as eiders, black ducks, and loons, and to birds feeding in exposed substrate such as gulls, great blue herons, belted kingfishers, sandpipers, plovers, some waterfowl, raptors, passerines, and others.

By comparison, the larger seabirds are less prevalent in the Upper Bay of Fundy. Prior to 1975, Canada geese were common in Cumberland Basin during the spring migration, but their numbers have recently declined, apparently because they have moved to estuaries of Prince Edward Island (Brylinsky *et al.* 1997). Scoters and eider ducks visit Minas Basin during the spring and fall migrations, respectively, but their numbers are much less than the concentrations in the Outer Bay. The Upper Bay, especially Cumberland Basin and the southern bight of Minas Basin, is, however, an important overwintering and staging area for black ducks, which forage in tidal channels draining salt marshes. Breeding colonies of cormorants, blue herons, herring gulls and greater blackbacked gulls are found on the islands in Minas Basin. In addition, Minas Basin and to a lesser extent Chignecto Bay, are important areas in the recovery of both the bald eagle and the peregrine falcon: the former associated with fish resources, and the latter with waterfowl and shorebirds.

The Upper Bay is really the domain of migratory shorebirds. Thirty years of research have demonstrated a critical role played by intertidal mudflats of the Upper Bay in the ecology of several species of small wading birds, including semipalmated sandpipers, short-billed dowitchers, and semipalmated and black-bellied plovers, that breed in the Canadian Arctic and winter in the Caribbean and South America. These species feed on the invertebrates of the mudflats, particularly the mud shrimp, *Corophium volutator,* and polychaetes such as *Neanthes* and the baitworm, *Glycera dibranchiata* (Hicklin 1987; Hicklin and Smith 1979; Sprague *et al.* 2005). The intertidal flats and their fauna provide a critical feeding habitat for millions of shorebirds, representing more than 90% of the world population of semipalmated sandpipers. Arrival of the shorebirds in July and August, when related individuals may be traveling together over successive years (Hicklin 2005), has impacts upon the intertidal fauna, and thence on the dynamics of the sediments (Daborn *et al.* 1993).

Recent changes observed in sediment properties have been associated with changes in the distribution and abundance of the invertebrate fauna, with declines in the abundance of shorebirds (Morrison *et al.*1994), and with changes in the foraging behaviour of shorebirds (Ginn and Hamilton 2007). Suggested causes include the increase in baitworm harvesting (Shepherd and Boates 1999), the cumulative effects of dams on rivers and estuaries of the Bay, and long term changes in the dynamics of the Bay of Fundy system (Daborn 2007). There is concern that continued changes in the distribution and behaviour of sediments in the Upper Bay of Fundy will have unpredictable implications for migratory shorebirds in the future; consequently, the sedimentary effects of energy extraction need to be assessed.

5.2.2.5 Mammals

Twenty-two species of marine mammals are known to occur within the Bay of Fundy (Table 5.3). Seven species are considered as commonly occurring within the Bay, five as occasional visitors and the remaining ten species only occur rarely. Two other species, the Atlantic walrus (*Odobenus rosmaruc*) and the Grey whale (*Eschrichtius robustus*) once occurred in the Bay but are now considered extirpated. Because of their low population numbers and low rate of reproduction, together with their susceptibility to mortality resulting from shipping and commercial fishing activities, most of the marine mammals present within the Bay have been assessed by COSEWIC (the Committee on the Status of Endangered Wildlife in Canada). Three species are considered Endangered, one species is Threatened, two are of Special Concern and eleven are assessed as Not at Risk.

All of the marine mammals are found primarily in the Outer and Inner region of the Bay, especially those areas of high productivity associated with major upwelling regions and oceanic fronts (Gaskin and Smith 1979; Watts and Gaskin 1985), and in island wake systems such as occur in the region of Grand Manan Island (Johnston *et al.* 2005). Gaskin (1983) reported on marine mammals in the Quoddy Region, listing six species of large baleen whales, 11 species of toothed whales, and two seal species. The concentrations of zooplankton in the Quoddy Region produced by tidal currents and upwelling attract large baleen whales in the summer and early fall. The plankton also attracts an abundance of herring and mackerel from late spring onward which are fed upon by various species of small toothed cetaceans, particularly the harbour porpoise. Harbour seals are found in the inner Quoddy Region and the shore of eastern Grand Manan, and grey seals are seen around Grand Manan in small numbers. Abundances of marine mammals in the Quoddy Region vary considerably from year to year, perhaps due to annual variations in the seasonality of prey.

The region is an important summer feeding and nursery ground for the North Atlantic right whale, with sightings from the inner Quoddy Region to Grand Manan and open Bay of Fundy waters. Humpback whales are found in the Digby Neck region in the eastern Outer Bay; in the western Outer Bay they frequent Letete Passage, Head Harbour Passage, and waters of Campobello Island, Deer Island, and the Maine shore. The finback whale is the most common species of large whale in the Bay of Fundy, observed off Deer Island, Campobello Island, Grand Manan, Brier Island, and the very outermost waters of the bay. The minke whale is a regular migrant throughout the Quoddy Region. The harbour porpoise is the most abundant cetacean in the Bay of Fundy and very important in the upper trophic levels in the coastal marine food web. Its prey consists of herring, mackerel, small cod-type fishes, and squid. Though most migrate to the region for the warmer months some have been observed in almost every month. Most congregate in the Quoddy islands and their passages out to the Wolves, and off upper Grand Manan.

A few species of marine mammals, such as harbour seals and harbour porpoises, occur commonly in the Upper region of the Bay and, occasionally other species of marine mammals, including whales, also enter the Upper Bay as well. These are often recorded from strandings (Hooker *et al.* 1997).

Only three species of marine mammals, the Harbour seal, Grey Seal and Harbour porpoise, are resident throughout the year. Most of the commonly occurring species begin arriving in the Bay during late May to exploit the more biologically productive areas within the Bay, and then leave during

October, although some stay into the winter. The only species known to breed regularly in the Bay are the Harbour and Grey seal.

TABLE 5.3 Species of Marine Mammals Present in the Bay of Fundy

	Species	Occurrence	Time In Bay	COSEWIC Status
Seals	Harbour Seal *(Phoca vitulina)*	Common	All year	Data Deficient
	Grey Seal (*Halichoerus grypus)*	Occasional	All year	Not at Risk
	Harp Seal *(Phoca groenlandicus)*	Rare		Not Assessed-
	Hooded Seal *(Cystophora cristata)*	Rare		Not at Risk
Dolphins and Porpoises	Atlantic Harbour Porpoise *(Phocoena phocoena)*	Common	All Year	Special Concern
	Atlantic White-sided Dolphin *(Lagenorhynchus acutus)*	Common	Jun-Oct	Not at Risk
	White-beaked Dolphin *(Lagenorhynchus albirostris)*	Occasional		Not at Risk
	Common Dolphin *(Delphinus delphis)*	Rare		Not at Risk
	Bottlenose Dolphin *(Tursiops truncates)*	Rare		Not at Risk
Toothed Whales	Long-finned Pilot Whale *(Globicephala melaena*	Occasional		Not at Risk
	Sperm Whale *(Physeter macrocephalus)*	Occasional		Not at Risk
	Killer Whale *(Orcinus orca)*	Rare		Data Deficient
	Beluga Whale *Delphinapterus leucas)*	Rare		Threatened
	Pygmy Sperm Whale *Kogia breviceps)*	Rare		Not at Risk
	Northern Bottlenose Whale *(Hyperoodon ampullatus)*	Rare		Endangered
	North Atlantic Beaked Whale *(Mesoplodon bidens)*	Rare		Special Concern
Baleen Whales	North Atlantic Right Whale *(Eubalaena glacialis)*	Common	Jun-Dec	Endangered
	Minke Whale *(Balaenoptera acuterostrata)*	Common	May-Nov.	Not at Risk
	Finback Whale *(Balaenoptera physalus)*	Common	May-Dec	Special Concern
	Humpback Whale *(Megaptera novaeangliae)*	Common	May-Dec	Not at Risk
	Sei Whale *(Balaenoptera borealis)*	Occasional		Data Deficient
	Blue Whale *(Balaenoptera musculus)*	Rare		Endangered

Food Sources

All of the marine mammals found within the Bay of Fundy are carnivorous and, with the exception of some of the baleen whales, are at the very top of the food chain. Most feed on fish, especially herring, but squid are also an important food source for many (Table 5.4). Seals tend to be more opportunistic feeders and will often feed on crustaceans, especially crabs, but also mollusks and polychaetes. Although small fish make up the diet of some of the baleen whales, most feed on euphausiids. The Northern Right whale, however, feeds mainly on copepod zooplankton.

TABLE 5.4 Food preferences of Bay of Fundy marine mammals (adapted from Nova Scotia Museum 1996).

	Species	Food Sources
Seals	Harbour Seal *(Phoca vitulina)*	herring/squid/flounder/alewife/hake/invertebrates
	Grey Seal (*Halichoerus grypus)*	herring/cod/mackerel/squid/invertebrates
	Harp Seal *(Phoca groenlandicus)*	
	Hooded Seal *(Cystophora cristata)*	
Dolphins and Porpoises	Atlantic Harbour Porpoise *(Phocoena phocoena)*	herring/mackerel/cod/smelt/pollock/redfish
	Atlantic White-sided Dolphin *(Lagenorhynchus acutus)*	herring/smelt/silver hake/squid
	White-beaked Dolphin *(Lagenorhynchus albirostris)*	fish/mollusks/crustaceans
	Common Dolphin *(Delphinus delphis)*	fish/squid
	Bottlenose Dolphin *(Tursiops truncates)*	fish/mollusks/crustaceans
Toothed Whales	Long-finned Pilot Whale *(Globicephala melaena*	squid/cod/mackerel/groundfish
	Sperm Whale *(Physeter macrocephalus)*	squid/cod/redfish/octopus/skates
	Killer Whale *(Orcinus orca)*	squid/cod/herring/groundfish/whales/seals/birds
	Beluga Whale *Delphinapterus leucas)*	fish/ squid/benthic crustaceans
	Pygmy Sperm Whale *Kogia breviceps)*	squid/fish
	Northern Bottlenose Whale *(Hyperoodon ampullatus)*	squid/herring/benthic invertebrates
	North Atlantic Beaked Whale *(Mesoplodon bidens)*	squid/fish
Baleen Whales	North Atlantic Right Whale *(Eubalaena glacialis)*	copepods/euphausiids
	Minke Whale *(Balaenoptera acuterostrata)*	squid/fish
	Finback Whale *(Balaenoptera physalus)*	euphausiids
	Humpback Whale *(Megaptera novaeangliae)*	sand lance/herring/euphausiids
	Sei Whale *(Balaenoptera borealis)*	euphausiids/copepods/fish/squid
	Blue Whale *(Balaenoptera musculus)*	euphausiids/mackerel/squid/herring/copepods

Seals

Of the four species of seals reported from the Bay of Fundy, only the Harbour and Grey seal occur on a common basis. The Harp and Hooded seal only occur rarely.

Harbour seals are one of the most abundant species of seals along the Nova Scotia coastline and are present in the Bay at all times of the year. Unlike other species of seals along the Atlantic coast, they do not congregate into large groups for pupping, but instead are found along the coastline in small isolated breeding groups from May to June (Boulva and McLaren 1979) and often remain in the vicinity of their breeding sites for the entire year. It has been suggested that this restricted range may make local harbour seal populations particularly at risk (Kovacs *et al.* 1990).

Grey seals are the most commonly observed seals along the coast of Nova Scotia. In the past, breeding colonies were largely restricted to the Gulf of St. Lawrence and Sable Island, but there is some evidence that the population has been increasing since the early 1960s, and adults and immature animals are now seen throughout eastern Canada including the Bay of Fundy (Stobo et. al. 1990).

Stobo and Fowler (1994) carried out one of the most intensive surveys of harbour and grey seals in the Bay of Fundy. The survey was carried out during 1985-87 and 1991-92. The region surveyed included the area between Quaco Head and Machias Seal Island along the New Brunswick coast, and the area between Parkers Cove and the southwestern shore in Nova Scotia. They found that both harbour and grey seals tended to haul out on small offshore islands and shoals rather than along the coastline, and that harbour seals were more often found on or nearer to the coastline. Harbour seals also tended to be more abundant than grey seals along the New Brunswick side of the Bay. The greatest concentration of seals was in the area of Grand Manan Island and in the region of southwest Nova Scotia. Their survey results also suggested that an increase in the harbour seal population had occurred between 1986 and 1991. In this same survey, during 1991, 51 harbour and 27 grey seals were observed in the Inner Bay at Ile Haute.

Harp seals whelp on the North Atlantic pack ice during early spring and then migrate as far south as Nova Scotia. Although there are some records of this species occurring in the Bay of Fundy (McAlpine and Walker 1999), its appearance there is considered rare. There is, however, some evidence that this stock is increasing in number, and that its habitat may also be increasing towards U.S. coastal waters (Rubenstein 1994; DFO 2005).

There is also some evidence that the presence of Hooded seals is also increasing in the Bay of Fundy region. McAlpine and Walker (1999) documented 31 sightings of Hooded seals in the Bay of Fundy between 1994 and 1998, a dramatic increase over previous sightings. Most of these sighting were from Penobscot Bay, but one sighting was for the Minas Basin in the Upper Bay.

Dolphins and Porpoises

Five species of dolphins and porpoises have been reported from the Bay of Fundy. Of these, only the Atlantic Harbour porpoise and the Atlantic White-sided Dolphin commonly occur within the Bay, mainly in the region of the Outer Bay and Gulf of Maine, but are also found within the Inner and Upper Bay as well. Of the remaining three species, the White-beaked dolphin occurs occasionally and the Common and Bottlenose dolphin only rarely.

Harbour porpoises in the Bay of Fundy are thought to form a single population (Wang *et al.* 1996; Read and Hohn 1995), separate from the Gulf of St. Lawrence, Newfoundland and Greenland stocks (Gaskin 1992) Although resident within the Bay all year, they are most abundant in the Outer Bay during the summer (July to September), shortly after the period in which they calve (May-June). In the autumn most migrate south and become widely dispersed within the coastal and offshore waters along New England and areas further south where they remain during winter and spring. While in the Bay of Fundy they are most abundant in areas conducive to concentrations of herring, their main food source (Gaskin *et al.* 1985).

Despite its abundance in the Bay of Fundy/Gulf of Maine, COSEWIC lists the Harbour porpoise as a species of Special Concern. This is largely due to their susceptibility to by-catch mortality in fishing gear, especially gill nets, and concerns that they are being excluded from a portion of their natural habitat by acoustic devices used in aquaculture operations.

The Atlantic White-sided dolphin occurs within the Bay of Fundy mainly during the summer months (June-September) and is thought to arrive from more offshore waters where they spend the winter. They often travel in groups ranging in size from 10 to more than 500 individuals and actively seek moving vessels. Its COSEWIC status is Not at Risk. Calving occurs during June and July.

The White-beaked dolphin is found throughout the North Atlantic. Although this species is common along the Atlantic coast of Nova Scotia, it is only occasionally seen within the Bay of Fundy. Its COSEWIC status is listed as Not at Risk.

The Common dolphin is found world-wide in temperate, tropical and subtropical seas. Although it sometimes enters the Gulf of Maine (Seltzer and Payne 1988), it is rarely present in the Bay of Fundy. The Bottlenosed dolphin is mostly found in offshore waters along the continental shelf and its occurrence in the Bay of Fundy is also rare.

Toothed Whales

Seven species of toothed whales have been reported as occurring in the Bay of Fundy, none of which are considered to occur commonly. Two species, the Long-finned pilot whale and the Sperm whale are occasionally found in the Bay and the remaining five species, the Killer whale, Beluga whale, Pigmy sperm whale, Northern Bottlenose whale and North Atlantic beaked whale only occur rarely. Of these species, the Northern Bottlenose whale is considered Endangered, the Beluga whale as Threatened and the North Atlantic beaked whale as of Special Concern by COSEWIC. The remaining species are considered as Not as Risk except for the Killer whale for which there are insufficient data to determine its status.

Part of the range of the long-finned pilot whale includes the inshore and coastal waters of Nova Scotia where it is thought to follow the movements of its major prey, the northern shortfin squid (Abend and Smith 1999) which normally move into inshore waters during mid-July and leave in the autumn. Occasionally this species is observed in the Gulf of Maine and lower Bay of Fundy. Sperm whales are also occasional visitors to this region. Although normally present in more offshore water, there is some evidence that their movement into the Gulf of Maine and Bay of Fundy may be influenced by warm-core rings that separate from the Gulf Stream near Georges Bank and move into this region (Griffin 1999).

The Killer whale is generally considered as uncommon or rare within eastern Canadian waters (NOAA), but they also occasionally enter the Bay of Fundy. On 21 August 1999, a pod of 12-15 Killer whales were observed in the Bay of Fundy just northwest of Digby.

The Beluga whale is found mainly in Artic and sub-Artic seas. The Gulf of St. Lawrence is the usual southern limit of its range, but on rare occasions it is observed in the Bay of Fundy. Its Threatened status under COSEWIC is partly due to high historical hunting mortality, to its potential susceptibility to bioaccumulation of numerous toxins as a result of its habitat, which includes industrialized areas such as the St. Lawrence watershed, and its chief prey, the American eel, which contains high levels of toxins.

The Pygmy sperm whale is distributed worldwide in temperate and tropical waters. Little is known about the population status of the Pygmy sperm whale in the Bay of Fundy.

The Northern bottlenose whale is only found in the North Atlantic Ocean. Along the Scotian shelf it is found mainly in the Gully, a submarine canyon located off the southeast coast. They are generally found in waters having a depth greater than 800 m and are rarely seen in the Bay of Fundy. There is, however, one report of a stranding in the Upper Bay of Fundy at Noel Head (Mitchell and Kozicki 1975). The Northern bottlenose whale is listed as Endangered by COSEWIC due to its Scotian shelf population being located in an area of high shipping activity and activities associated with oil and gas exploration and extraction.

Baleen Whales

Six species of baleen whales are known to occur within the Bay of Fundy. Four species, the North Atlantic Right, Minke, Finback and Humpback whales are common inhabitants of the Bay; one species, the Sei whale is an occasional visitor; and one species, the Blue whale only occurs very rarely. The North Atlantic Right and the Blue whale are listed by COSEWIC as Endangered; the Finback is listed as of Special Concern; and the Minke and Humpback whales are listed as Not at Risk. There are inadequate data to evaluate the status of the Sei whale.

Baleen whales feed primarily on zooplankton and small fish and are found mainly in the Outer and Inner regions of the Bay of Fundy, especially in those areas characterized by nutrient upwelling systems and high biological productivity such as occurs in the region around Grand Manan Island. Those species that occur commonly are usually present only between June and November of each year.

The Bay of Fundy is a major feeding and nursery area for the endangered North Atlantic right whale. It is believed that as many as two-thirds of the existing population, which is estimated to number as few as 350 individuals, migrates to the Bay from southern waters off the coast Georgia and Florida where they calve, and spend the summer and fall within the Bay (Brown 2005). They feed primarily on *Calanus finmarchicus* (Woodley and Gaskin 1996), a planktonic copepod which is abundant in the waters between Grand Manan Island and Nova Scotia. They are seldom seen from shore, preferring areas with water depths in excess of 100 meters which, in the Outer Bay of Fundy, may represent areas in which ocean circulation patterns entrap zooplankton (Baumgartner *et al.* 2003). Recent studies (Baumgartner and Mate 2005) suggest that high concentrations of zooplankton alone do not explain the distribution of right whales, and that low bottom water temperature, high surface salinity and high surface stratification are also important habitat characteristics.

Because right whales spend so much time in surface waters, they are especially susceptible to mortality by ship strikes (Brown 2005). As a result, a special conservation area has been established within the area of the Bay they frequent the most, and shipping lanes have been altered in attempts to reduce the incidence of ship strikes. Other threats to right whales include entanglements in fishing gear, marine contaminants and biotoxins, inadequate prey as a result of changes in ocean climate, circulation and productivity, and disturbances caused by tourism (COSEWIC 2003).

Minke whales are found world wide. The population inhabiting the eastern coast of the U.S. and Canada is believed to be part of the Canadian East Coast stock which ranges from the eastern half of the Davis Straight to the Gulf of Mexico (NOAA 2007c). Minke whales are common inhabitants of the Bay of Fundy between June and October. They feed primarily on small schooling fish such as herring and their distribution within the Bay of Fundy is determined largely by the distribution of their prey. They are often found trapped in herring weirs and there are records of their being stranded in the Upper region of the Bay within the Minas Basin (NOAA 2007c). Their North Atlantic population is not considered to be at risk and they are the only species of baleen whales that is still hunted commercially.

Finback whales are common inhabitants along the entire east coast of North America during all times of the year and are likely the most dominant large whale in the Bay of Fundy (Gaskin 1983) where they are most abundant between June and October. The adults feed primarily on juvenile herring and euphausiids and their distribution is correlated with that of their prey. They appear to feed mainly in convergent zones and frontal areas, turning into the tide as they feed, and favor areas having large variations in topography (Woodley and Gaskin 1996). Although Finback whales do not currently appear to be under any serious threat, they have been designated as a species of Special Concern by COSEWIC as a result of their susceptibility to ship strikes, entanglement in fishing gear, and human generated underwater noise that may degrade finback whale habitat by impairing their ability to communicate.

The Sei whale *(Balaenoptera borealis)* is a recent newcomer to the Bay of Fundy on a regular basis. They feed by skimming small plankton such as copepods and krill, despite being able expand their mouth by inflating the throat pleats. A whaling station operated at Blanford, NS, until 1970, hunting Sei whales but the population is not considered threatened.

The Blue whale is found in all oceans of the world. Within Canadian waters it is most common in the Gulf of St. Lawrence, but it is rarely seen in the Bay of Fundy. Blue whales feed mainly on euphausiids, but also take copepods, other crustaceans and squid. The Atlantic population has been designated as Endangered by COSEWIC. Threats to the population include ship strikes, entanglement in fishing gear, pollution and increased whale watching activity,

5.2.3 Fisheries

The fisheries of the Bay of Fundy (NAFO or ICNAF 4X) have been summarized in numerous reports over the last 30 years (Hare 1977, Dadswell *et al.* 1984a, Percy 1997; Dyer *et al.* 2005). The largest and most productive commercial fin fisheries are located in the Outer Bay and exploit fishes that either utilize the Bay as a feeding ground during summer (MacDonald *et al.* 1984) or concentrate in the region for spawning (Sinclair and Tremblay 1984). On the other hand, commercial shellfish fisheries exploit local populations mainly centered in the Bay (Caddy 1979; Campbell and Stasko 1986; Campbell 1992; Robinson 1993). The Inner Bay supports smaller volume commercial fisheries which are nevertheless important for the mainstay of the local coastal communities (Dadswell *et al.* 1984a; Percy 1997; Dyer *et al.* 2005). As well there is a component of fishes that occur in the Bay during summer but are exploited mainly in distant fisheries along the east coast of the United States (Dadswell *et al.* 1987; Dadswell and Rulifson 1994; Dadswell 2006). Recreational fishing is important throughout the Bay but is largely confined to the tributaries, protected embayments and tidal passages (Table 5.5; Percy 1997; Rulifson *et al.*, in press).

The commercial fisheries in the Outer Bay consist of high volume, high value species such as herring, cod, haddock, lobster and scallops (Table 5.5; Percy 1997). Herring, flounder, shad, dogfish, lobsters and clams are the main species exploited in the Inner Bay (Robinson 1993; Wehrell 2005; Dyer *et al.* 2005). During the last 20 years the commercial fishery in the Bay of Fundy has expanded into less traditional species partly because of some stock declines but also because of product demand caused by the globalization of Canadian fisheries exports (Robinson 1994, Botsford *et al.* 2004). Fisheries for sea urchin, marine worms and seaweed have either been initiated or greatly expanded (Table 5.5). The diversification has created a much improved and more robust commercial fishing industry, and fisheries in the Scotia-Fundy region are the most valuable in Canada.

Stock declines have also resulted in some fishes becoming listed as species at risk and their commercial fisheries closed. Porbeagle shark, Atlantic salmon and striped bass are the species occurring in the Bay of Fundy which have been listed under the Species At Risk Act (SARA). All have been assessed for Allowable Harm (CSAS 2004a and 2005).

Commercial fishing activities in Minas Basin have historically been limited to intertidal weirs, with a few vessels driftnetting for sea and river herrings, or dragging for flounder. Consequently, historical records are biased towards species that move onto the intertidal zone during the flooding tide; species of deeper water are less well represented.

Recreational fishing is an important local part of the Maritime economy as well as for tourism. Although there is no licensing of recreational fishers in tidal waters, in 2002, for the first time, the Department of Fisheries and Oceans (DFO) made amendments to the Maritime Provinces Fishing regulations that controlled the catches allowed in recreational fisheries. Some recreational fishes have also suffered stock declines which resulted in their listing under SARA. Atlantic salmon and striped bass are the species affected (Douglas *et al.* 2003; Amiro 2003). Inner Bay of Fundy (iBoF) Atlantic salmon and striped bass now have Allowable Harm Assessments (CSAS 2004b).

The Bay of Fundy commercial fisheries are valuable. Bay of Fundy landings are included in the Scotia-Fundy Region of DFO and commercial landings are recorded by Statistical District. Bay of Fundy districts are 24, 34-44, 48-56, 79, and 81 (Figure 5.18). Overall lobsters, scallops and herring have been and continue to be the most valuable exploited species. During 2004 lobster contributed $340 million, scallops, $110 million and herring, $21 million of the landed value of fisheries in the Scotia-Fundy region of which approximately $96 million came from DFO Production Areas in the Bay of Fundy. The landed value of all species of ground fish from the Bay of Fundy during 2004 was $1.5 million and sea urchin, marine plants and clams contributed approximately $10 million. The fisheries and aquaculture activities in the Bay of Fundy are together estimated to be worth $1B (Robinson, pers. comm.).

Pelagic Fishes

The pelagic fish stocks are assessed annually by the Department of Fisheries and Oceans and these assessments result in an annual Total Allowable Catch (TAC) by the fleet for most species. Fisheries statistics detailing total landings and value of catches are maintained annually by DFO. Seven species constitute the major pelagic fish landings in Bay of Fundy statistical districts (Table 5.5) and these are discussed individually below.

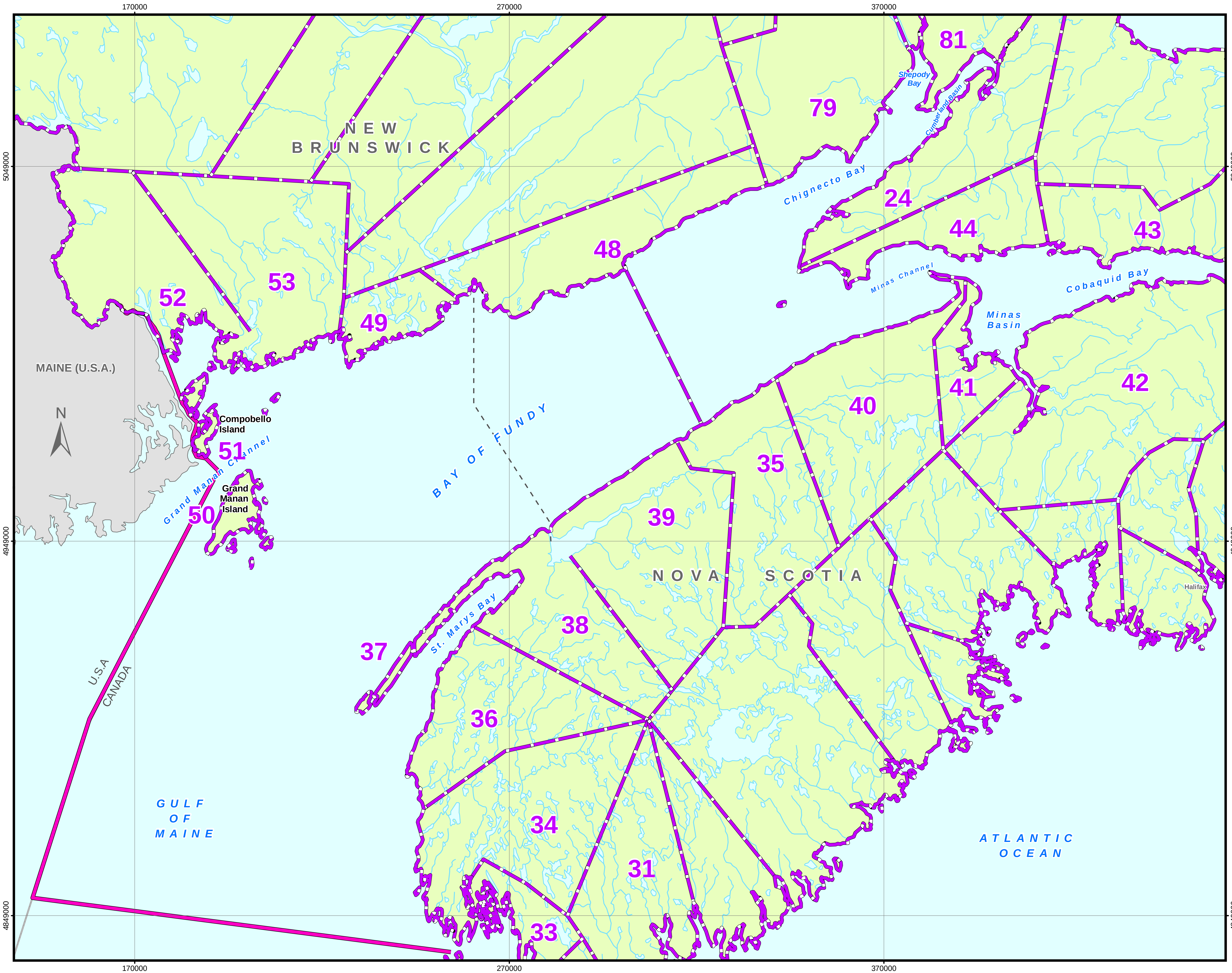


Figure 5.18

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Fisheries Management Areas for the Bay of Fundy

Fisheries Management Zone Boundary

Base Map Features

- Project Limits
- International Bounds
- Open Water
- Hydrology

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-027

Source: Small craft harbour locations provided by Fisheries and Oceans Canada - Maritimes Region

ACADIA CENTRE FOR ESTUARINE RESEARCH

New Nouveau Brunswick

Jacques Whitford

OEER FUNDY TIDAL ENERGY

TABLE 5.5 Fisheries Resources of the Bay of Fundy Region: Their Status and Comments on Fishing Gear

Group	Common Name	Scientific Name	Commer. Fishery?	Recrnl. Fishery?	Aqua-culture?	Stock Status	Comments on Fishery
Pelagic Fishes	Porbeagle	*Lamna nasus*	X, closed			+	gill net;
							COSEWIC status: Endangered
	American shad*	*Alosa sapidissima*	X	X		+++	commercial drift gillnet and weirs;
							Upper Bay
	Gaspereau*	*Alosa pseudoharengus*	X			+++	weirs; Upper Bay
		Alosa aestivalis					
	Atlantic herring	*Clupea harengus*	X	X		++++	purse seine, gillnet all BOF;
							weirs, Upper Bay
	Atlantic salmon*	*Salmo salar*	X, closed	X, closed	X	+_	drift, gill net, angling; COSEWIC status: Endangered
							large aquaculture production
	Mackerel	*Scomber scombrus*	X			+++	weir fishery, Outer Bay
	Bluefin tuna	*Thunnus thynnus*	X			+	taken offshore, landed in BOF ports;
							occasional in weirs in Outer Bay
	Swordfish	*Xiphius gladius*	X			+	offshore longline fishery, landed in
							BOF ports
Ground Fishes	Spiny dogfish	*Squalus acanthias*	X			++	drags, longline and handline; all Bay
	Atlantic cod	*Gadus morhua*	X			+++	drags mainly Outer Bay, some Upper Bay
							gillnet
	Silver hake	*Merluccius bilinearis*	X			++++	drags Outer Bay;
	Haddock	*Melanogrammus*	X			++++	drags Outer and Upper bay
		aeglefinus					
	Pollock	*Pollachius virens*	X	X		+++	gillnet, handline, drags, Upper and Outer Bay
							angling Upper and Outer bay
	White hake	*Urophycis tenuis*	X			+++	drags, Outer Bay
	Wolffish	*Anarhichas lupus*	X, closed			+	drags, Outer Bay
							COSEWIC status: Threatened
	Monkfish	*Lophius americanus*	X			++	drags, Outer and Upper Bay
	Witch flounder	*Glyptocephalus cynoglossus*	X			++	drags, Outer Bay

TABLE 5.5 Fisheries Resources of the Bay of Fundy Region: Their Status and Comments on Fishing Gear

Group	Common Name	Scientific Name	Commer. Fishery?	Recrnl. Fishery?	Aqua-culture?	Stock Status	Comments on Fishery
	Winter flounder	*Pseudopleuronectes*	X	X		+++	drags entire Bay;
		americanus					Upper Bay: weirs and angling
	Smooth flounder	*Liopsetta putnami*	X			+++	caught with winter flounder in Minas Basin
	American plaice	*Hippoglossoides platessoides*	X			+++	drags, Outer Bay
	Halibut	*Hippoglossus*	X	X		++	drags and longline, entire Bay
		hippoglossus					angling in Minas Basin
	Lumpfish	*Cyclopterus lumpus*	X			++	drags Outer Ba
Diadromous Fishes	Atlantic sturgeon	*Acipenser oxyrhinchus*	X	X		+++	gillnet and angling Saint John River;
							closed to other fishing in rest of Bay
	Shortnose sturgeon	*Acipenser brevirostrum*		X		+++	angling in the Saint John River; COSEWIC status:Endangered
	American eel	*Anguilla rostrata*	X			+++	trap and fykenet fishery, all Bay tributaries
	American shad*	*Alosa sapidissima*	X	X		+++	weirs Upper Bay; angling most Bay
							tributaries; gillnet Saint John estuary
	Gaspereau*	*Alosa pseudoharengus*	X			++++	weirs entire Bay; gillnet and
		Alosa aestivalis					traps Bay tributaries
	Atlantic salmon*	*Salmo salar*	X closed	X, closed	X	+	inner BOF stocks: COSEWIC status: Endangered
							COSEWIC status: Endangered
	Rainbow smelt	*Osmerus mordax*	X	X		+++	small recreational fishery
	Tomcod	*Microgadus tomcod*		X		++++	small recreational fishery
	Striped bass	*Morone saxatilis*	X, closed	X		+++	COSEWIC status: Threatened;
							angling restricted
	White perch	*Morone americana*		X		++++	angling most estuaries
Crustaceans	American lobster	*Homarus americana*	X			++++	trap fishery, stocks at 100 year high
	Rock/Jonah Crab	*Cancer sp*	X			++++	taken from lobster traps, small fishery
Molluscs	Sea scallop	*Placopecten*	X	X	X	+++	drags Outer and Inner Bay; divers.
		magellanicus					

TABLE 5.5 Fisheries Resources of the Bay of Fundy Region: Their Status and Comments on Fishing Gear

Group	Common Name	Scientific Name	Commer. Fishery?	Recrnl. Fishery?	Aqua-culture?	Stock Status	Comments on Fishery
	Soft-shell clam	*Mya arenaria*	X	X		++++	Intertidal rake fishery,
							Outer Bay and Minas Basin
	Blue mussel	*Mytilus edulis*	X	X	X	++++	permanent closure in BoF because of PSP
	Periwinkle	*Littorina littorea*	X	X		++++	intertidal and sub tidal collection, Outer Bay
	Squid	*Illex sp., Loligo sp.*	X	X		++++	weirs and drags, some jigging;
							angling Passamaquoddy Bay
Echinoderms	Green sea urchin	*Strongylocentrotus droebachiensis*	X			+++	Commercial scuba diving fishery
	Sea cucumber	*Cucumaria frondosa*	X				drag fishery in Outer Bay
Polychaetes	Bloodworm	*Glycera dibranchiata*	X			+++	intertidal rake
	Sandworm	*Arenicola sp*	X			+++	intertidal rake
	Clamworm	*Nereis sp*	X			+++	Intertidal rake
Marine Plants	Dulse	*Palmeria palmata*	X			+++	collected at low tide
	Irish moss	*Chondrus crispus*	X			+++	rake collection
	Rockweed	*Ascophyllum*	X			++++	collected from intertidal zone
		nodosum					

* some species listed in two categories because they are taken in different fisheries.
Key: ++++ = abundant, healthy stock and sustainable exploitation rates
+++ = stock is abundant, but exploitation rate is at a maximum
++ = low abundance or overexploited
+ = stock depleted; required rebuilding

Until recently, Porbeagle shark were exploited by a directed, gillnet fishery in the Outer Bay of Fundy (Campana *et al.* 2002). Catches in the Bay of Fundy were about 10MT/yr (Percy 1997). The fishery is now closed because Porbeagle was listed as Endangered by COSEWIC (Anon 2005).

American shad: The embayments of the Upper Bay of Fundy (Chignecto Bay and Minas Basin) have been the location of commercial shad fisheries for three centuries (Dadswell *et al.* 1984a). The fishery was pursued with intertidal weirs, fixed gillnets and drift gillnets. The fishery was one of the largest in the Bay of Fundy during the late 1880s with landings between 550-1400 MT, but catches declined steeply during the 1920s because of pollution and damming of shad spawning rivers along the east coast of North America (Leim 1924; Dadswell *et al.* 1987). Abundance and catches increased during the 1980s because of increased spawning stocks along the USA coast as a result of pollution abatement and stock enhancement (Dadswell *et al.* 1984). After 1990, however, lower catches were the result of restrictive management to protect the endangered iBoF Atlantic salmon, market access and demand. The fixed and drift gillnet fisheries have been restricted by season length and many licenses were bought back because of the by-catch of Atlantic salmon in that particular fishery. The weir fishery has been forced to decrease weir height because of the threat to Atlantic salmon, which has further reduced catches. Because fishing effort has been greatly reduced, recent catches are not a reflection of stock abundance or comparable to the past. Since 2000 catches have ranged from 4-10 MT. The reliability of these statistics is low.

Gaspereau, like American shad, have been fished commercially in the Bay of Fundy for three centuries (Dadswell *et al.* 1984). The fishery is exploited with intertidal weirs, trap nets, lift nets, scoop nets, fixed and drift gillnets. Large catches are taken in the Saint John River Harbour and estuary and the Upper Bay and its tributaries (Statistical Districts 41-43). Catches in the Saint John River averaged about 2300 MT during 1960-1980 and between 60-1200 MT in the Upper Bay during 1979-1981 (Dadswell *et al.* 1984a). Catches of 1400 MT in Nova Scotia and 1700 MT in the Saint John River were taken as late as 2000, but catches abruptly declined after 2002 when new fish processing regulations were introduced by DFO. Many fishers were unable or unwilling to comply with the regulations and closed their fisheries. Catches in 2004 for the entire Scotia-Fundy region were only 800 MT.

The landed value of the gaspereau fishery has lagged behind other sea fisheries in the region because few gaspereau are used as human food in Canada. Gaspereau are used for lobster bait, cat food, and fish meal or are smoked or salted and shipped to markets in the Caribbean. Average landed value in 2000 was $0.31/kg.

Atlantic herring (*Clupea harengus*) are one of the mainstays of the Bay of Fundy fisheries. The herring fishery is exploited by weirs, gillnets and purse seines. The weir fishery is concentrated in the Outer Bay where sardine-size herring have been captured, canned and exported to the world from Blacks Harbour for the last 120 years (Huntsman 1918; Ahrens 1990). The weir fishery in the Inner Bay lands sizeable catches (920 MT annually) but these are intermittent and seasonal, and cannot support a canning industry (Bradford and Iles 1993). The gillnet fisheries are concentrated along the Nova Scotia shore in the Outer Bay and in Minas Basin (Dyer *et al.* 2005), but catches are low (440 MT) compared to the mobile, purse seine fishery which lands the majority (about 98%) of the annual 110,000 MT catches (CSAS 2004b). The purse seine fishery exploits the adult spawning concentrations off Yarmouth, in Scots Bay and west of Grand Manan (Sinclair and Tremblay 1984) and feeding concentrations around Brier Island and Grand Manan (Dyer *et al.* 2005). The fishery which yielded

$21M in 2004 is partitioned between sardines and adults. The adults are now exploited for their high value herring roe, which is shipped to Japan, and the carcasses are used for aquaculture feed and fish meal production (CSAS 2004b).

The Scotia-Fundy herring stock has been managed by DFO based on annual assessments using herring larval abundance (Stephenson 1993), commercial landings sampling (CSAS 2004b), and acoustic surveys (Buerkle 1990). The TAC is conservative and is set annually at about 20% of the estimated adult spawning biomass, which was about 500,000 MT between 1999 and 2001 (CSAS 2004b). It is estimated that the Scots Bay herring stock contributes between 10-20% of the landings for the mobile purse seine fishery (Dyer *et al.* 2005).

Atlantic salmon (*Salmo salar*) were once the premier commercial and recreational fish of the Bay of Fundy. Commercial salmon landings in the Saint John River region (Statistical Districts 48, 49. 55, 56) during 1892-1965 averaged 150 MT/yr (Rodgers 1936; Dadswell *et al.* 1984a). Salmon were captured in weirs and drift gillnets in the Upper Bay and these fisheries usually landed about 20 MT annually during 1870-1950. Because of their desirability, salmon were the highest valued commercial species in Atlantic Canada before 1970 (Caddy and Chandler 1976).

Salmon populations in the Bay of Fundy began to decline during the 1960s and in 1972 the commercial fishery was closed for 10 years. It was reopened in 1981, then closed permanently in 1984 (Dadswell 2004). Since then populations have continued to decline, resulting in the closure of the angling fishery in 1992 and the almost complete demise of populations in the Upper Bay by 2000 (Amiro 2003). In 2001 the Inner Bay of Fundy (iBoF) stocks were declared Endangered by COSEWC and the species is now managed under an Allowable Harm Assessment with zero take of all life stages (CSAS 2004b). Atlantic salmon aquaculture in the Bay of Fundy has now replaced the commercial fishery and annual production is much higher than the former fishery on wild stocks.

Mackerel are caught using weirs, trap nets and gillnets. They used to support a large purse seine fishery but it has not operated for over 100 years. Mackerel are used as lobster bait and a small portion are consumed fresh in the Maritimes. Large numbers of mackerel occur primarily in the Outer Bay during summer and fall but the fishery has always been small because of low market demand and shipping difficulties. The 2004 Scotia-Fundy catch was only 6000 MT of which very little was from the Bay. The mackerel TAC has been set at 100,000 MT for the last 20 years but the catch has seldom exceeded 20% of the TAC during this period (Anon 2000). DFO and other Canadian agencies have encouraged fishers to increase their take of mackerel but the fishery remains underexploited.

Bluefin tuna and swordfish are landed in Bay of Fundy ports but very little of these catches come from the Bay of Fundy. Tuna have become a highly valued catch since air shipments to Japan began during the 1980s (Percy 1997). There is a fishery for tuna on the Scotian Shelf and many of these are landed in Yarmouth (Statistical District 34). Swordfish are only captured around the edges of the Scotian Shelf mostly over great depth (Scott and Scott 1988) and some of these are landed in Fundy ports.

Groundfishes

Ground fish stocks in the Bay of Fundy are assessed each year by a random, stratified trawl survey (Simon and Comeau 1994) and port sampling where commercial landings are monitored and additional information is collected for stock assessment (Percy 1997). Assessment takes into account information from the entire Scotia-Fundy region (over which most of these stocks are dispersed seasonally) and annual TACs are released for most species and geographical units. The following discussion is largely confined to the 4X Division (Browns Bank/Bay of Fundy).

Spiny dogfish were never a desired species in Canada until stocks of other ground fish declined during the 1980s. A Canadian fishery began in 1987 and expanded sharply during the 1990s (Percy 1997). Dogfish were first captured with fixed gear such as gill nets but as fishers became familiar with the gear-destroying ability of dogfish the fishery switched to drags. The drag or otter trawl fishery targets the dogfish in whatever region of the Bay of Fundy their migratory behavior is taking them. Since females are larger and more desired, the fishery is mainly exploited in the Upper Bay of Fundy. The fishery was unregulated in Scotia-Fundy until 2002 when a TAC of 2500 MT was set. Landings of about 2400 MT have been made each year up to 2006 (Anon 2007). Landings of dogfish in Minas Basin (SD 40) were approximately 700 MT in both 2001 and 2002 (Dyer *et al.* 2005).

The cod fishery in the Bay of Fundy is largely concentrated in the Outer Bay. There is a drag fishery off the western shore of Nova Scotia between Yarmouth and Digby and a gillnet fishery around Grand Manan. Cod, however, will pursue food resources wherever available and they can be captured inside the Saint John estuary and in Minas Basin during the spring (Wehrell 2005).

Cod landings from the Bay have been declining since the early 1990s. Before 1990 annual landings were around 24,000 MT. The TAC was dropped during the 1990s to 15,400 MT and annual landings were in this range until late in the decade. However, annual survey cruises in the late 1990s and port landings assessments indicated recruitment was rapidly declining and juvenile mortality was increasing (Bundy and Fanning 2005) and in 2000 the TAC was lowered to 5,900 MT. Apparently this step was taken too late and landings have continued to decline (Anon 2006a). The TAC was lowered to 5,500 MT in 2005 but in 2006 only 3,800 MT was landed. DFO lowered the TAC again in 2006 and they hope these measures will help the stock recover, although it appears large scale ecosystem changes may be the root cause of the lack of cod stock recovery on the Scotian Shelf (Bundy and Fanning 2005).

Haddock are captured mainly in the drag fishery along southwestern Nova Scotia and by gillnets around Grand Manan. Until 1965, before the Scotia-Fundy haddock stock collapsed from foreign fleet overexploitation, there was a large directed drag fishery in the Upper Bay (McCracken 1960). Most of the catch is exported to the United States.

Haddock are one of the most desired ground fish species in Atlantic Canada and after a 40 year period of depressed abundance some stocks have finally rebounded. The 2003 year class on Georges Bank was the largest on record (Anon 2006a) and the estimated spawning stock biomass in 2006 was 120,000 MT. Unfortunately so far, Bay of Fundy stock abundance has not rebuilt to levels prior to 1965, even with a closure of Browns Bank to fishing between February and June and 40 years of restricted landings (Anon 2006b). After a partial recovery during 1970-1989 when landings averaged 19-20 MT/yr the stock declined once more. Between 1990 and 2002 the TAC was reduced to 8 MT annually with landings of 7.2-7.6 MT (Anon 2006b). Although there were strong year classes produced from 1998 to 2000, landings continue to decline. Landings in 2005 were only 5.9 MT even with a TAC of 10 MT and in 2006 landings declined further to 5.1 MT. Low landings in 4X haddock could be from redirection of the fleet effort to Georges Bank since total haddock landings in Scotia-Fundy from 2004-2006 averaged 17,000 MT.

Pollock are fished commercially with drags, longline, handline and weirs. They are also a sought-after game fish either as juvenile 'harbor pollock' or as adults. Similar to other gadoids they are assessed annually for Division 4X by DFO for management of the stock. Pollock are less desirable as food fish than either cod or haddock and until the latter populations declined in abundance their fishery was secondary to commercial interests. After 1975, however, when haddock and cod stocks declined, landings in Scotia-Fundy increased from 24,000 to 41,000 MT annually and were 37,000 MT in 1990. About 2,000 MT of this total were landed at Bay of Fundy ports (Dadswell *et al.* 1984). Since 1993 landings have decreased, possibly because the stock was over exploited and possibly because of the effects of large-scale ecosystem changes on their prey resources. A decline in the abundance of their euphausiid prey has led to slower growth rates and poorer condition factors among pollock during 1995-2003 compared to these factors during 1965-1975 (Carruthers *et al.* 2005). In 2004 the TAC was set at 10,000 MT but landings were only 8,500 MT. The 2006 the TAC was set at 4,600 MT of which 4,100 MT were landed (Anon 2006a). Pollock are one of few ground fish that are abundant in the Upper Bay. The Minas Channel region has supported a large pollock fishery since the 1800s (Perley 1852).

There are two species of hake that are common in the Bay of Fundy; the white hake (*Urophycis tenuis*) and the silver hake (*Merluccius bilinearis*). While both are found in the Bay of Fundy only the white hake is captured to any extent and then only as by-catch in the general ground fish drag fishery. The silver hake is largely taken offshore in Emerald and LaHave Basins (Anon 2005). Silver hake occasionally occur in weir catches along the Nova Scotia shore of the Bay of Fundy but never in abundance (Dadswell *et al.* 1984a). Unfortunately both species are listed together as "hake" in Canadian fisheries landings. Landings of white hake are much less than silver hake in the Scotia Fundy region. White hake landings were 8,700 MT in Division 4VWX during the late 1980s but declined to 1,600 MT in 2004 (Anon 2005). Even when white hake landings were comparatively high only about 500 to 1,700 MT/yr were landed in Fundy ports (Dadswell *et al.* 1984a). Silver hake landings are almost exclusively made up of hake from offshore on the Scotian Shelf. Until 2000 the TAC was 90,000+ MT annually of which foreign vessels under agreements with Canada were allowed to take about 30% (Anon 2005). After 2000 the fishery was restricted to Canadian vessels and the TAC reduced to 15,000 MT/yr. Scotian Fundy landings of 'hake' in 2004 were 16,000 MT of which 90% were silver hake.

Atlantic Wolffish: Because of their solitary nature wolffish (listed as 'catfish' in DFO statistics) have never constituted a large portion of Canadian ground fish landings and directed fisheries for them are usually with long line. They are considered a by-catch in the drag fishery and are not regulated by a TAC (Anon 2002a), however, they have a 20% by-catch regulation. On the other hand, wolffish find the habitat of the Bay of Fundy and nearby Scotian Shelf suitable and most of the Canadian landings are from Division 4X. During the period 1970 to 1995 Canadian landings averaged between 50 to 106 MT (Anon 2002a). Landings in recent years in the Scotian Fundy region have been slightly higher at 191 MT in 2000, 177 MT in 2002 and 111 MT in 2005. The catch inside the Bay of Fundy averaged about 61 MT during the period 1998-2001 (Anon 2002a).

Monkfish: Because they are solitary and a top predator which has a low abundance, monkfish have seldom been the target of a directed fishery in Canada. In fact they were seldom landed before 1986 when they were 'discovered' by the restaurant trade and new markets developed (Beanlands 2000).

They are captured by gill net, long line or drag and are generally taken as a by-catch in the drag fishery and the scallop fishery. Landings from by-catch in the scallop fishery in the lower Bay of Fundy totaled 322 MT in 1997 and 150 MT in 2001 (Anon 2002b).

Monkfish are generally considered a by-catch and no annual TAC is set except the ground fishery is regulated by a 20% by-catch regulation. During 1996-1999 there was a special directed fishery with a TAC of 310 MT but it was discontinued. There is no category for them in DFO landing statistics but they make up about 40-50% of the annual ground fish ‘other’ category. Almost all Canadian landings are from Division 4X and especially the Outer Bay of Fundy. Landings from 1970-1986 averaged about 300-500 MT annually and increased sharply after 1986 to an average of 700 MT from 1990-1996, 1250 MT in 1997 and about 800-900 MT since then (Anon 2002b). Since 1986 the fishing mortality has been high but stable. Recruitment of younger monkfish was good during the early 2000s.

Halibut are a valuable fish. Their landed value in recent years has been around $10.00 /kg, about the same as lobster and scallop. The fishery is exploited exclusively with long lines. The halibut fishery has been monitored since 1883 and the annual long term average for Atlantic Canada landings is 1,900 MT (Anon 2006a). Because halibut are highly migratory, the fishery is managed as a unit including the Scotian Shelf and the Grand Banks. After landings peaked at 4,000 MT in 1986 the fishery was placed under a TAC of 3,200 MT in 1988. The TAC was lowered to 1,000 MT in 2000 and was raised slightly to 1,375 MT in 2005. The Atlantic Canada landings have more or less mirrored the TAC since 2000 and landings in 4VWX have ranged from 540 MT to 807 MT. The major fishery is concentrated on the Scotian Shelf and landings in the Bay of Fundy seldom exceed 10 MT. Small halibut landings are made in SDs 35, 40 and 44 along the Nova Scotia shore of the Inner Bay (Dyer *et al.* 2005).

Winter flounder are the most important commercial and recreational flatfish in the Bay of Fundy. They spawn inshore during spring (May) all around the Bay of Fundy but the main stock is concentrated in St. Mary’s Bay and Minas Basin in summer where they support a dragger fishery (Percy 1997). There is a relatively long larval stage and settlement takes place along the edge of the intertidal zone during September. Growth is relatively rapid and females mature at 3 yr and 20-30 cm in length (Scott and Scott 1988).

The flatfish fishery in the Maritimes is concentrated in the Bay of Fundy and Division 4X and is based largely on a single stock of winter flounder with a by-catch of plaice and witch flounder (Anon 1997). Landings during 1968-1981 in the Bay of Fundy averaged about 2,000 MT/yr (Dadswell *et al.* 1984a) but increased during the 1980s and 1990s. In 1994 the flatfish fishery was brought under a TAC of 4,500 MT/yr which was reduced to 3,000 MT by 1997. The entire Scotia Fundy region had a TAC of 7,900 MT in 2000 but this was reduced to only 2,000 MT in 2006 (CSAS 2007a). Flounder landings in the Upper Bay of Fundy (mainly SD 40, 41, 44) peaked at about 200 MT in 1992-93 and then declined in the late 1990s to approximately 100 MT during 2001-02 (Dyer *et al.* 2005). About half of the annual landings in Scotia-Fundy come from the Bay of Fundy/4X winter flounder stock. This stock has been declining for the last 15 years.

Diadromous Fishes

Diadromous species are an important part of the recreational angling fishery and therefore a component of the tourist business. They are jointly managed by DFO and the provinces and are assessed for commercial TAC's and angling regulations.

Sturgeons have long been utilized as a supply of meat and caviar. They were an important catch for aboriginals in the Maritimes before the arrival of Europeans because they are easy to capture in rivers by spearing and can remain alive out of water for a long period. A commercial fishery for Atlantic sturgeon has existed in the Maritimes since 1882 (Rodgers 1936; Dadswell 2006). They are captured in drags and intertidal weirs in the Bay of Fundy and by gillnet in the rivers and estuaries (Leim and Scott 1966). Annual catches in Minas Basin can amount to 100 sturgeon a year in some weirs and daily trawler catches may reach 20-30 individuals (Dadswell, pers. obs.). Shortnose sturgeon rarely attain the 120 cm minimum total length required for the take of sturgeon in the Maritimes and they are seldom taken commercially except as by-catch in the American shad fishery (Dadswell 1979). Additional regulations on the sturgeon fishery in the Maritimes include a closure during the month of June and a minimum gill net stretched mesh size of 32.5 cm (Dadswell 2006). The sturgeon fishery has never been large. Between 1882 and 1935 annual landings fluctuated between 212 MT and 10 MT/yr in the Saint John River (Rodgers 1936). There was a peak in landings between 1980 and 1994 when 20-80 MT/yr were taken but this exploitation appears to have depleted the adult stock, since landings were only 1-10 MT between 1995 and 2002 (Dadswell 2006). After 2002 Saint John license holders agreed to a moratorium to allow the stock to rebuild (Bradford, pers. comm.). Take in the rest of the Bay of Fundy has never exceeded a few MT/yr (Dadswell 2006). Since 2002 DFO has prohibited the take of sturgeon in the Maritimes in coastal weirs and as by-catch in the trawler fishery. There was also a 10 year moratorium placed on Atlantic sturgeon commercial fishing on the east coast of the United States in 1998 and in the USA EEZ in 1999 (Spear 2007).

There is a small recreational, rod and line fishery for sturgeon in the Saint John estuary. The fishery takes mostly shortnose sturgeon and a few Atlantic sturgeon. Take in the fishery is unknown but most fishers prefer to catch and release (Dadswell, pers. obs.). Shortnose sturgeon were assessed by COSEWIC and are listed as a species of concern (Dadswell 1984). Shortnose are listed as endangered in the United States.

Eels have been fished in the Maritimes by aboriginals for thousands of years and by European settlers since the 1600s (Scott and Scott 1988). They hibernate under the mud in winter and can be taken through the ice by spears. They are also captured by traps and eel pots and are taken in large weirs during their downstream migration in fall as silver eels. Since the 1989 there has been a glass eel fishery centered on the mouths of streams flowing into the Bay of Fundy and the rest of the Maritimes. The glass eel fishery is not allowed on streams that have an adult fishery. The elver fishery employs scoop nets and lights at night. It is difficult to sort out eel landings for the Bay of Fundy region because they are partitioned between marine and fish water. Marine landings are reported by region (Scotia-Fundy) and the freshwater landings by province. For the Bay of Fundy statistical districts in New Brunswick SD 48 and 49 are considered 'marine' and SD 55 and 56 are 'fresh water' although all the eels are actually caught in the Saint John River estuary and its tributaries. The commercial, Scotia-Fundy eel landings are predominately from the Saint John and other Bay of Fundy tributaries (Jessop 1996). There is no TAC for this fishery (except for elvers) and management is primarily by area restrictions for each fisher. Landings of adult eels in the Scotia-Fundy region rose from 60 MT in 1985 to 231 MT in 1994. During the period 1998 to 2004 landings declined from a high of 220 MT in 2000 to a low of about 120 MT in 2004.

Because of the characteristics of the eel fishing industry and eel life history, regional landings are difficult to interpret. Eels, after they are caught, are usually bought by brokers who concentrate the landings from a wide region into a small area and when these are sold (usually exported to Europe or Asia), it inflates the eel fishery value from that statistical district. Furthermore, fishers will deplete one area over a period of years then move their fishing to another area in another statistical district. This is exhibited as rapid increases and then rapid declines in landings in a statistical district (Dyer *et al.* 2005).

Except in major river systems such as the Saint John, eel landings are generally low. Three statistical districts in the Inner Bay of Fundy (SD 24, 42, 44) produced only 12.5 MT in 2000 and this was nearly 100% of the landings in the region (Dyer *et al.* 2005). Elver landings in 1989 were only 29 kg but this rose to 3,238 kg in 1995. The license limit for each elver fisher is 1000 kg with no more than 300 kg coming from any one river (Jessop 1996). Recent statistics are unavailable. There is a small recreational fishery for eels as by-catch during other angling pursuits. The angling daily bag limit is 10.

American shad (*Alosa sapidissima*) are caught in Maritime estuaries and rivers during their migration upstream in spring to spawn. Estuarine and river fisheries for shad are both commercial and recreational (Chaput and Bradford 2003). Shad are taken with weirs, traps, gillnets, scoop nets and by rod and line. The largest commercial fisheries in the Bay of Fundy are in the Saint John (Dadswell 1986) and Shubenacadie Rivers (Dyer *et al.* 2005). Shad are marketed fresh and locally but during the last 10 years a demand for shad roe has resulted in exports of this product from the Shubenacadie River to the United States. Recreational fisheries are well established on the Annapolis and Shubenacadie Rivers (Melvin *et al.* 1986). In 2002 a daily bag limit of 5/day was placed on the recreational shad fishery (Dyer *et al.* 2005). Annual landings for the Shubenacadie shad fishery varied from 10-60 MT during 1990 to 2001 (Dyer *et al.* 2005). Although the Annapolis River has a large shad run no large-scale commercial shad fishery has been allowed on the river since the 1880s (Melvin *et al.* 1986). Commercial fishing is limited to a scoop net fishery for two days a week.

Recent DFO commercial landings data for river fisheries in New Brunswick reflect the situation in the Saint John River. Landings in the Saint John seem to be cyclic in nature with each cycle of abundance lasting approximately 30 years, however construction of dams on the Saint John River has limited spawning habitat and this may have led to a reduction in shad landings after 1970. The cyclic nature in shad population dynamics has been shown to be environmental (Crecco and Savoy 1987). Shad landings in the Saint John averaged 100-200 MT/yr during 1880-1910 and 1930-1960 but declined to around 50 MT/yr or less after 1970 (Dadswell et al 1984a). Recently landings have only been 5-7 MT/yr (1996-2002; CSAS 2004a).

The gaspereau fishery exploits two species of river herring; the alewife and the blueback herring (Table 5.5). The gaspereau resource is exploited in freshwater using trap nets, scoop nets, gill nets and by angling. The major commercial fisheries around the Bay of Fundy are in the Saint John, the Shubenacadie, the Gaspereau, and rivers along southwest Nova Scotia around Yarmouth. DFO processing regulations introduced during 2002 have caused gaspereau landings around the Maritimes to decline to about 50% of their former levels. Total gaspereau landings during 2000 in the Saint John

River were 1,700 MT and in Nova Scotia, 1,400 MT were taken mainly in the Gaspereau, Shubenacadie and Tusket Rivers. The Gaspereau River in Nova Scotia alone produced 180 MT during 2000, which was estimated to be about 88% of the total spawning stock (Gibson and Myers 2001). Average annual Gaspereau River landings between 1964 and 2000 were 208 MT (Dyer *et al.* 2005). During this same period the Shubenacadie River produced between 50-363 MT annually.

There are small, recreational fisheries in many Bay of Fundy rivers. Most angled gaspereau are taken by jigging. The daily bag limit was set at 20 in 2002 and the season is from March to May.

Atlantic salmon: While the fishery was extant all commercial salmon catches for the Upper Bay of Fundy were made in the sea or the estuaries. Once the salmon entered a river they could only be taken legally by angling. Most salmon rivers were scheduled for fly fishing only and the recreational fishery attracted many tourists to the Bay of Fundy region. Angling catches in iBoF rivers averaged about 3000-5000 salmon until 1980 and then declined drastically until they were all closed in 1992 (Dyer *et al.* 2005). Some rivers such as the Petitcodiac and the Avon were lost to salmon at an earlier date in part because of causeway construction (Isaacman 2005).

The Outer Bay salmon rivers were concentrated in three regions: the Saint John River estuary, around Passamaquoddy Bay and in Annapolis Basin (Saunders 1981). The Saint John estuary populations declined after dams were built on the mainstem of the river but many tributaries had good sport fishing catches until the 1990s. The commercial fishery in the estuary was closed with those in the rest of the Maritimes in 1982. The Annapolis Basin populations declined to virtual extinction after dams were constructed for hydroelectric purposes on all of its tributary streams between 1935 and 1970 (Wildsmith 1981). Passamaquoddy rivers were open for sports fishing until all were closed in 2001 (CSAS 2004a). The decline of these runs has been variously blamed on acid rain and the impacts of escapees from the aquaculture industry in the area (Stokesbury *et al.* 2001).

Bay of Fundy rainbow smelt are harvested by recreational fishers during their spawning runs by dip netting and angling (Percy 1997). In 2002 the fishery was limited for the first time by a daily bag limit of 60 of which only 30 could be taken by dip netting (Dyer *et al.* 2005). The commercial smelt fishery in the Maritimes is largest in the Saint John and Tusket Rivers (Jessop 1996), but the Shubenacadie and Gaspereau Rivers also have large runs (Caddy and Chandler 1976). There has not been a directed commercial fishery for smelt in the Bay of Fundy in recent years (2005-2006) and landings in Scotia-Fundy between 2000 and 2004 were only 6-9 MT. Smelt could probably support a viable commercial fishery in the Bay of Fundy since landings in the Gulf of Saint Lawrence have been 300-800 MT between 2000 and 2005 and obviously a market exists. The smelt resource appears to be underutilized in the Bay of Fundy but this may be because of other recent fisheries management decisions made by DFO.

Tomcod: There are small recreational and commercial fisheries for tomcod in other parts of Canada (Quebec, Miramichi River, NB) but none in the Bay of Fundy (Scott and Scott 1988). A few are probably captured and retained by anglers fishing for smelt.

Striped Bass: There may be at least three stocks of striped bass in the Bay of Fundy, one in each of the Shubenacadie, Saint John and Annapolis Rivers (Rulifson and Dadswell 1995). The Shubenacadie stock is well studied and in 2002 the adult population size was estimated at 15,000 fish (Bradford, pers.

comm.). The Saint John population is less well known and was even assumed extirpated (Douglas *et al.* 2003) but recent findings indicate there is a large component of bass in the Saint John that cannot be assigned to any other east coast river using DNA analysis (Bradford, pers. comm.). The status of the Annapolis stock which had a spawning run as late as 1976 is unknown (Williams *et al.* 1984). Because of their large size and meat quality, bass are sought after as commercial and recreational fish. Commercial landings of striped bass during 1960 to 1980 in the United States was from 4,000-7,000 MT (Field 1997) and in the Bay of Fundy from 4-44 MT during the same period (Dadswell *et al.*1984a). The commercial fishery for bass in the Bay of Fundy has been subject to numerous restrictions and closures since the 1980s and was closed completely in 2002 (Douglas *et al.* 2003). The take of bass in commercial intertidal weirs was closed in 1996 except for the retention of one /day, minimum length of 68 cm, for personal consumption (Dyer *et al.* 2005).

The recreational fishery in the United States had a record catch of 8.5 million bass in 1994 worth billions of dollars to the angling industry (Field 1997). Angling for striped bass in the Bay of Fundy is on a much smaller scale and is concentrated in the Saint John estuary, Minas Basin and tributaries, Annapolis Basin and tributaries and estuaries around Yarmouth (Leim and Scott 1966; Rulifson and Dadswell 1995, Dyer *et. al*. 2005). Recreational catches in the Bay of Fundy region are restricted due to new recreational fishing regulations established in 2002 and because Canadian populations of striped bass were declared threatened by COSEWIC in 2004 and listed by SARA (Bradford, pers. comm.). Anglers may take only one fish/day and it must be larger than 62.5 cm. There is no fishing season in Nova Scotia but in New Brunswick angling is restricted to July to October (Dyer *et al.* 2005).

Invertebrate Fisheries

Fifteen species of invertebrates contribute to Bay of Fundy fisheries (Table 5.5). Invertebrate fisheries are the most valuable in Atlantic Canada and in the Bay of Fundy. Most fisheries are managed by seasons and allowable catches and are assessed annually by DFO. Others are controlled by licensing and restricted access and others are uncontrolled. Unlike many of the commercial fish species, the invertebrate fisheries are mostly based on populations that reside and reproduce in the Bay of Fundy.

Crustaceans

American lobster: American lobster is fished commercially in all parts of the Bay of Fundy except the extremely turbid waters of Cobequid Bay and inner Cumberland Basin. The American lobster is a relatively fast growing crustacean that attains maturity at a size of 80-100 mm carapace length (CL) and an age of 5-10 years (Cobb 1976), but lobster from the Bay of Fundy are slower growing than those found in other regions of the Maritimes because of the relatively cold water in most of the Bay (Campbell and Robinson 1983). They are voracious predators, scavengers and cannibals and live on whatever benthic organisms they can capture including other lobsters, crabs, scallops, other bivalves, sea urchins and dead and living fish.

The lobster fishery is exploited with small to medium sized vessels (10-20 m) because much of the fishery is in relatively shallow water (3-20 m). Lobsters are caught using baited traps (DFO 2001a). Bait is usually salted or fresh fish and the demand for bait sustains numerous other fisheries in the Bay (gaspereau, mackerel, and flounder). Regulatory controls include a limit on trap number/fisher (usually around 300-375), size of trap opening, minimum size limits (carapace length), and seasons. Most of the Bay of Fundy is limited to a season from late November to July with some winter restrictions. Carapace length limits are set for different lobster districts and minimum retention size in the Bay of Fundy is 82.5 mm CL (DFO 2001a).

Landings increased sharply during the 1980s reaching the highest levels during the 1990s since the fishery began in the 1880s (Williamson 1992; Lawton *et al.* 1998). These levels of production have continued to increase to the present. Landings from the Nova Scotia shore of the Outer Bay of Fundy, which produces approximately 90% of the catch, increased 36% between 1990 and 2006 and landings along the New Brunswick shore of the Bay increased by 300% from about 800 MT to 2,600 MT during the same period (CSAS 2007a). Lobster landings on the Nova Scotia shore of the Bay increased to 180 MT in SD 44, 100 Mt in SD 40 and 80 MT by 2001 (Dyer *et al.* 2005). Combined landings in these fishing regions seldom exceeded 70 MT before 1994. Lobster landings for the 2005-2006 season were 3,997 MT, the greatest on record for lobster fishing areas 35, 36 and 38 (CSAS 2007a). At the same time, the value of lobster has increased from about $6.70/kg in 1990 to $13.00/kg in 2006 making lobster by far the most valuable fishery in the Maritimes and in the Bay of Fundy (43.6% of total Maritime landings; DFO 2005).

The increase in landings has been attributed to more effective management policies, favorable environmental conditions and fisheries-induced changes to the coastal ecosystem (Steneck 1997). Monitoring of larval lobster settlement patterns (Steneck and Wilson 2001; Wahle 2007), indicated that settlement along the western shore of the Bay of Fundy reached record levels during 2005 and 2006. It would appear that the period of record lobster landings in the Bay of Fundy will continue at least for the near future.

Jonah (*Cancer borealis*) and rock (*Cancer irroratus*) crab are medium-sized crustaceans that occur over rocky/gravel bottom substrates along with American lobster. They have a life history similar to lobster (Robichaud and Frail 2006). Jonah crabs are the larger species, maturing at a size of 80-100 mm Carapace Width (CW). Rock crabs mature at a size of 50-80 mm CW. After maturity males and females copulate, sperm is stored by the female and when conditions are right she extrudes eggs, fertilizes them with the stored sperm and they are attached under her abdomen. When the eggs hatch larvae migrate to the surface and drift as part of the near-surface pelagic community. Settlement takes place after about 30-60 days depending on water temperature. Juveniles seek shelter under rocks and in crevices until they are large enough (>30 mmCW) to begin foraging on the open bottom. When smaller, both species are a preferred food of lobster (Cobb 1976).

Jonah and rock crabs have been landed as a by-catch of the lobster fishery since the 1960s but were never developed as a directed fishery because of processing difficulties (Robichaud and Frail 2006). During the 1990s, because of the large scale development of red and snow crab fisheries, processing capacity became available. The directed Jonah and rock crab fisheries were developed as exploratory fisheries in the Bay of Fundy region starting in 1995 (Robichaud and Lawton 1996). After 10 years as an exploratory fishery sufficient commercial resources were found and the fishery was declared commercial in 2004 (Robichaud and Frail 2006).

The fishery for Jonah crab is located in 50-300 m depths south of Grand Manan and on the Middle Ground off Yarmouth (Robichaud and Frail 2006). Rock crab is mainly caught in St. Mary's Bay, Annapolis Basin and Passamaquoddy Bay in depths less than 50 m. Both fisheries are managed with license limits (4-10 in each lobster fishing district), trap limits (100-300), seasons (period when no lobster fishery), and size limits (Jonah, 130 mm CW minimum; rock, 102 mm CW). Since most females of either species seldom attain the respective minimum size limit for their species, the fisheries are concentrated almost exclusively on males. Both species are also landed as a by-catch in portions of the lobster fishing areas of the Bay (Robichaud and Frail 2006). Landings during the period 1996 to 2004 rose from 45 MT to 400-500 MT for Jonah and around 150 MT for rock crab depending mainly on effort and market conditions (Robichaud and Frail 2006). The CPUE in all regions of the fishery remained relatively stable at 4-7 kg/haul during the exploratory period. Landed value for crab was about $2.00/kg during 2006 and the fishery produced about $1 million in the Bay of Fundy region.

Molluscs

Sea scallop (*Placopecten magellanicus*) are fished commercially in all regions of the Bay of Fundy except the extremely turbid Cobequid Bay and Cumberland Basin. Scallop fishing began in the Bay of Fundy in the 1920s off Digby and this area remains one of the most productive. Scallops are in high demand and command one of the highest market values of any fisheries product. During 2006 landings in the Scotia-Fundy region were valued at $79 million and the average landed value was $14.00/kg.

Sea scallops are a large bivalve mollusc that occurs in large concentrations or ‘beds’ in historically, discrete locations in the Bay of Fundy. The largest concentration is immediately off Digby with lesser beds in Scott’s Bay, around Ile Haute and off Lurcher Shoal (Anon 2002c). In the Bay of Fundy scallops mature at 3-4 yrs old and recruit to the fishery at 4-5 years old and 80 mm Shell Height (SH; Smith *et al.* 2005). Scallops are fished by heavy drags that are pulled along the bottom. In the Bay of Fundy all scallops are shucked at sea and only ‘meats’ landed.

The scallop fishery in the Bay of Fundy is complex. There are 3 fleets: the All-Bay fleet, the Upper-Bay fleet and the Mid-Bay fleet. The All-Bay fleet has access to the entire Bay, the Upper-Bay fleet may not fish seaward of a line from across the Bay through Ile Haute and the Mid-Bay fleet may not fish south of a mid-Bay line running down the Bay from Advocate Head. The Bay of Fundy is divided into Scallop Production Areas (SPAs) and each Area has a quota which is divided among the various fleets. The fishery is also managed by gear restrictions including maximum drag width (5.5 m), ring size (82 mm inside diameter) and a minimum body size (80 mm SH). DFO carries out annual assessment cruises to determine scallop recruitment and set annual quota levels (Smith *et al.* 2005).

Depending on the recruitment of dominant year classes brought on by favorable environmental conditions (Caddy 1979), scallop production in the Bay of Fundy exhibits cyclic peaks with landings ranging from lows of 300-500 MT and highs of 1,500-2,500 MT of meats. Peaks occurred in the early 1950s (Dickie 1955), the 1970s (Caddy 1979), 1988-1991 and 2003-2005 (Smith *et al.* 2005). Since 2001 the TAC has ranged from 1,075 MT in 2001 with landings of 993 MT to 1,755 MT in 2005 with landings of 1,595 MT. The All-Bay fleet generally takes about 50-70% of the landings. Because of changes in management schemes with the introduction of individual transferable quotas the number of vessels in the All-Bay fleet has declined from 99 in 2001 to 30-40 in 2006 (Smith *et al.* 2005).

There is also a recreational, scuba diving fishery for scallop in the Bay of Fundy (Table 5.5). The fishery is restricted by season, possession limit and minimum size. The diving season is from January

1 to April 30, maximum possession is fifty scallops and minimum size is 100 mm SH. There are no statistics on the annual landings from this fishery.

Soft-shell Clam (*Mya arenaria*): The soft-shell clam occurs in soft sediment intertidal flats of mud, sand, or gravel. It is a bivalve mollusc with a life history somewhat similar to the sea scallop except that the juveniles settle on the tidal flats and are not migratory. Soft-shell clams bury themselves in the tide flats to a depth of 10-20 cm and feed at high tide by extending a siphon to the sediment surface and drawing in water and food. Growth is relatively rapid and they mature in 2-3 years at a size of 45-55 mm SH (DFO 1996).

Clams are harvested commercially and recreationally by digging the intertidal flats with a shovel or clam hack (rake) (Robinson 1995). Licensed commercial diggers average 25-50 kg per tidal cycle. Recreational fishers are restricted to 100 clams/day (DFO 1996). There is a minimum size limit of 44-51mm SH in both fisheries depending on region.

There are four regions in the Bay of Fundy that support commercial clam fisheries: Charlotte Co. in SW New Brunswick; the north shore of Minas Basin; Annapolis Basin; and around Yarmouth Nova Scotia (DFO 1996). Commercial landings have been monitored for more than 100 years and exhibit cyclic peaks which are related to both environmental and social factors (Robinson 1995). Peak landings occurred in the periods 1901-1910, 1941-1952, 1970-74, 1982-88, 1995-1998 but overall landings have been declining since 1950. Average annual landings during cycle peaks were 5,700 MT for the period 1945-55, 2,906 MT for 1981-90 and 1,443 MT for 1992-1998 (DFO 1996). The clam fishery in SD 43 along the northern shore of Minas Basin mirrors these long term changes (Dyer *et al.* 2005). There was a peak production of 946 MT in 1946. Production then declined until stocks and production increased to 710 MT in 1982 with a further increase to 952 MT in 1991. Production then declined to 223 MT in 1995, 153 MT in 1999 and only 9.5 MT in 2002.

The causes of the long-term decline are numerous and include: overexploitation (Robinson 1995), pollution of tide flats from municipal and industrial pollution, which are then closed to digging (Robinson 1995); the invasion of the green crab in the Bay of Fundy during the 1950's, which eats large amounts of juvenile clams (Elner 1981; Floyd and Williams 2004); phytoplankton shellfish poisoning events, which are seasonal and cyclic, but close the fishery for periods of months (Martin *et al.* 1990) and the effects of ecosystem changes (Bourque *et al.* 2001). There are numerous ongoing efforts to improve the resource (DFO 1996).

Blue Mussels (*Mytilus edulis*): Blue mussels are a common bivalve found attached on hard substrate, intertidal flats. They are extremely abundant in the Outer Bay of Fundy. Mussels grow rapidly and are harvestable after two years of age. Unfortunately they are extremely susceptible to shellfish contamination either from pollution or phytoplankton toxins and all beds in the Bay of Fundy are under permanent closure. The closure also extends to any attempts to develop mussel aquaculture in the region.

Periwinkle (*Littorina littorea*): The periwinkle is a small gastropod that has been harvested by humans for centuries. Periwinkles live in rocky, lower intertidal zone and down to depths of 40 m (Gardner and Thomas 1987). They feed on the thin layer of algae and recently settled fauna in the surface film of rocks and on dead macroalgae washing up in the intertidal zone. They are a relatively slow-growing snail requiring 2-3 years to reach maturity at 10-15 mm SH and 4-5 years to reach commercial size of 19-30 mm SH. Populations of *Littorina liittorea* that support the commercial fishery are an introduced species from Europe. They became abundant in the Bay of Fundy after 1840 (Anon 1998).

The periwinkle fishery is unlicensed and open. Most periwinkles are taken by hand picking at low tide in the lower intertidal zone. Some diver harvesting also occurs in the sub-tidal zone using suction collecting. The fishery is unregulated by quotas or size restrictions (Anon 1998). The market will not accept periwinkles smaller than 19 mm SH which leaves a large, reproductive biomass available to provide recruitment. The fishery, which began in 1984, is restricted to the lower Bay of Fundy and concentrated mostly around Grand Manan in New Brunswick and Digby Co. in Nova Scotia (Anon 1998). Landings averaged between 200-250 MT between 1987 and 1997 (Anon 1998). Large periwinkles (25+ mm SH) are worth about $2.00/kg. Landed value of the fishery has remained stable at approximately $400K/yr since 1990.

Squid: There are two species of large squid found in the Bay of Fundy, the short-fin squid (*Illex illecebrosus*) and the long-fin squid (*Loligo pealei*). Both are pelagic and grow very quickly to a maximum length of 40-60 cm (Summers 1971; Perez and O'Dor 2000). Squid feed on fishes and other pelagic organisms (mainly herring) which they capture using their tentacles. Squid life spans are only one year long (Summers 1971; Perez and O'Dor 2000). The young are born in the fall of one year and the adults breed and die the next fall. Other than these common characteristics the two species have very different life histories.

Short-fin squid come inshore from the Gulf Stream to the Bay of Fundy during spring as juveniles (Perez and O'Dor 2000), grow rapidly to adult size by late summer, then migrate south to the Sargasso Sea east of the Bahamas where they breed and die (Rodhouse *et al.* 1998). Eggs and young are pelagic. The young drift north in the Gulf Stream and finally arrive back in Bay of Fundy (Perez and O'Dor 2000). Short-fin squid are a cold water species and are most abundant in the Outer Bay.

Long-fin squid migrate north from the eastern USA in spring and arrive in Bay of Fundy during early summer. Long-fin squid are a warm-water species and are most abundant in the Upper Bay especially Minas Basin (Bousfield and Leim 1958). They grow rapidly to adult size by late summer, breed, and females lay their eggs in cases near the low tide zone attached to the substrate, then die (Summers 1971; Bleakney and McAllister 1973). Development is rapid and the eggs hatch in 1-2 weeks. The young grow rapidly as they migrate south along the coast of the eastern USA, where they overwinter off the continental shelf of southern New England.

Squid have long been a sought after commercial resource along the coast of Canada and in the Bay of Fundy. They are mostly used for bait in the long line fishery but some are consumed locally. There was a large commercial fishery based on exports to Japan but it has been discontinued because of the role of squid in fisheries food chains (Dawe and Colbourne 1997). The peak landings for squid were 36,500 MT in 1973.

Squid are taken by hand line (jigging), mid-water trawls and in weirs. The fishery was taking 1,000-3,000 MT in the Scotia-Fundy region during the period 1990-1998 but after 1998 the TAC was severely reduced to assist the recovery of ground fish stocks (Dawe and Colbourne 1997). Landings in the Bay of Fundy were 500-1,000 MT during the 1990s but have been reduced to 20-40 MT since 2000.

Echinoderms

Green sea urchin (*Strongylocentrotus droebachiensis*): The green sea urchin is a spiny, egg-shaped echinoderm that feeds on benthic algae and macro-algae in relatively shallow water (0-30 m; Robinson *et al.* 2001). They grow quickly to maturity if sufficient food resources are available and can mature in 2-3 years at 25 mm diameter. Urchins spawn during early spring and after a 30-60 day larval period settle on the bottom. Growth is best when feeding on kelp and feeding fronts form on the edges of kelp beds (Miller and Nolan 2000). Urchins have a natural pathogen, *Paramoeba invadens*, which causes mass mortalities when water temperature rises above 18C (Miller and Nolan 2000). Fortunately urchin populations in the Bay of Fundy are not impacted by the pathogen because of lower average sea temperatures.

Urchins are fished for their roe (eggs) and a world-wide fishery is based on the import of 110,000-130,000 MT of urchin roe into Japan annually (Botsford *et al.* 2004). The product is unacceptable unless roe content is greater than 12% total body weight which restricts most fisheries to the winter period in the Bay of Fundy (Robinson *et al.* 2001). Urchins are caught using scallop drags or by hand using scuba diving. The fishery in the Bay of Fundy was not established until 1987 when scallop draggers in the Outer Bay around Grand Manan began fishing for them (Robinson *et al.* 2001). Landings grew rapidly, climbing from less than 100 MT in 1990 to 1,530 MT in 1994.

In 1996 the Bay of Fundy urchin fishery was brought under management (Anon 2000b, c). The fishery on the New Brunswick side of the Bay of Fundy is managed using limited entry, a season (October-April), a 50 mm diameter size limit and a TAC. The TAC in Grand Manan was set at 979 MT in 1996 and reduced to 778 MT in 2001 (Anon 2000b). There is also a fishery inside Passamaquoddy Bay. It has the same management regime as the Grand Manan fishery and a TAC of 900 MT. Total landings peaked at 1,900 MT in 1996 but have declined to 916 MT in 2006. The fishery on the Nova Scotia side of the Bay of Fundy is managed under a different regime (Anon 2000c, Miller and Nolan 2000). The fishery is by diver only with a limit of 4 divers per vessel. There is a 50 mm size limit but no TAC. Entry is limited annually by the amount of surveyed kelp edge available (Miller and Nolan 2000). The Nova Scotia fishery extends from Digby County into Minas Channel. Landings were low on the Nova Scotia shore until 1999 when they rose to 245 MT, mostly from Digby Co. (Anon 2000c). Since 2002 landings have remained between 250-320 MT.

Orange-foot Sea Cucumber (*Cucumaria frondosa*): Orange-foot sea cucumber is another benthic echinoderm that occurs on hard substrate bottoms of the Bay of Fundy at depths of 5-100 m (Singh *et al.* 1999). Sexes are separate and both reach sexual maturity at about 3 yrs. Spawning occurs in summer and larvae are pelagic for 1-2 months (Lundy 1996). Preferential settlement occurs over hard substrate. The cucumbers feed by capturing drifting particles with their oral tentacles and inserting the tentacles into their month to lick off the food. They are usually concentrated in dense beds. Cucumbers are very abundant in the outer portions of the Bay of Fundy but as yet still do not contribute to the commercial fishery although they are a product in high demand in China (Lundy 1996). The problem stems from a poor quality product produced from our stocks and the lack of processing capability.

Marine worms

Three species of marine worms are harvested in the Bay of Fundy (Table 5.5): bloodworm (*Glycera dibranchiata*), sandworm (*Nereis virens*), and clamworm (*Nereis sp*). All occur as infauna burrowing in intertidal mud and sand flats around the Bay of Fundy (Appy *et al.* 1980). Bay of Fundy marine worm resources are large because the intertidal flats are so extensive.

Marine worms are harvested for export to the United States and Europe for sport fishing bait (Shepard and Boates 1999). They are collected by digging the flats at low tide using traditional clam rakes. Although marine worms have been harvested in Yarmouth County since the 1950s (Klawe and Dickie 1957) the fishery only expanded to the tide flats in Minas Basin during the 1990s. The fishery was open and unregulated until 2002 when DFO began issuing exploratory licenses. The resource has not been assessed for landings or sustainability and DFO does not publish landing records. Other than licenses the fishery is unregulated. Licenses in the Parrsboro district (44) have risen from 8 in 2002 to 61 in 2004. Total licenses for 2004 in the Upper Bay of Fundy (SD 40-44, 24, 79 and 81) were 183 (Dyer *et al.* 2005).

Marine Plants

Three species of seaweed (Table 5.5) are exploited in the Bay of Fundy, almost all from the Outer Bay. These include dulse, which is harvested for human consumption, and Irish moss and rockweed which are harvested for industrial extracts such as carageenan.

Dulse (*Palmeria palmata*) is a red alga that grows subtidally and in the very low tide zone. It is collected by hand during spring tide periods, dried and marketed in this form (Dyer *et al.* 2005). Considerable recreational dulse collecting occurs and total landings are unknown. The main fishery is around Grand Manan and along the Nova Scotia Fundy shore from Yarmouth to Minas Basin.

Irish moss (*Chondrus crispus*), a red alga, and rockweed (*Ascophyllum nodosusm*), a brown alga, support a commercial fishery from Yarmouth to Digby on the Nova Scotia side of the Bay of Fundy and in Charlotte Co. on the New Brunswick side. Both are collected by hand using rakes or sickles. The rockweed rake has a cutting edge to cut off the plants at 12-20 cm above the holdfast (Ugarte *et al.* 2006). Irish moss is collected in the subtidal zone from 0 to 3 m deep. Rockweed is collected from the intertidal zone (Thomas 1994) using boats at high tide or by hand sickle on the flats at low tide (Sharp 1981). Both products are dried before sale to processors but landings are compiled by DFO as wet weight (DFO 1998). The fishery is driven by demand from processors. Irish moss is collected by individual fishers, rockweed by individuals or teams of harvesters that work for processing companies. Irish moss yields the chemical carageenan, and rockweed yields sodium alginate (Sharp and Semple 1997). Both materials are used as industrial emulsifiers in toothpaste, milk products and other processed foods.

Dulse has been collected for centuries. The fishery survives as a recreational, cottage industry. There are no licenses, no assessments and no regulations.

The industrial fishery has existed since the early 1960s in Nova Scotia. At first it was focused on Irish moss but international competition reduced the market for carageenan and most production is now from rockweed. Rockweed landings remained around 5,000 MT wet weight/yr until 1986 when they expanded rapidly to over 20,000 MT annually. Early, high levels of harvesting overexploited some flats and DFO became involved in assessment and regulating. The tide flats were surveyed, harvesters were licensed and some areas were assigned to processors and given exclusive harvesting rights (Ugarte and Sharp 2001). In 1995 the New Brunswick Fundy shore was opened to harvesting (DFO 1998). Rockweed collecting in the Bay of Fundy is concentrated in St. Mary's Bay and Annapolis Basin in Nova Scotia and in Charlotte co. in New Brunswick (SD 50-53). The Inner and Upper Bay of Fundy lack an industrial resource because of ice scour during winter which reduces the extent of intertidal seaweed cover in this region (Dyer *et al.* 2005).

The rockweed resource exploitation has been set at 17% of the standing biomass (DFO 1998). A TAC of 10,000 MT was set for the New Brunswick shore. Nova Scotia landings are not regulated by a TAC (DFO 1998). Landings on the Fundy shore of Nova Scotia have ranged from 579-1,626 MT annually in Annapolis Basin and 565-2,277 MT annually in St. Mary's Bay. Both regions have been estimated to have an annual sustainable yield of 1,000-1,200 MT (DFO 1998). Landings since 2000 in NB have ranged from 7,834 MT in 2000 to 12,088 in 2004. Landings in Southwest Nova Scotia have ranged from 19,767 MT in 2000 to 23,216 MT in 2004. About 20% of these landings are from the Yarmouth to Digby shore of the Outer Bay.

5.2.4 Mariculture

Worldwide there is a vast demand for seafood. Production has roughly doubled over the last 25 years to about 120 million tons annually. Throughout the world, some wild stocks of fish have recovered while others have been overexploited. As a result, the fisheries component experienced little or no increase during the last decade. In many areas, such as the northeast continental shelf, groundfish abundance and capture have declined dramatically under intensive harvest pressure (Link *et al.* 2002). Overall, globally the capture fishery is seen as having levelled off, as most main fishing areas have reached their maximum potential. It is apparent that levelling off of production from traditional sources means that wild fish supplies cannot meet the growing demand for aquatic food (FAO 2006).

Farming aquatic species is widely seen as the compensating means to meet future market demand for seafood. Considered the fastest growing food-producing sector, it now accounts for almost 30 percent of the world's food fish, and while production has increased from 6 to about 40 million tons in the new millennium, global aquaculture production will need to increase even more dramatically to meet consumer demand based on current per capita consumption. Given projected population growth over the next two decades production is expected to soar in the near future, doubling to at least 80 million tons by 2030 (FAO 2006). This means that worldwide aggregated country productions from aquaculture are expected to grow at an average annual growth rate of 4.5 percent over the period 2010–2030 (Brugère and Ridler 2004).

Seafood production from the marine aquaculture component (*i.e.* mariculture), where ocean energy sites will be located, is a major contributor in meeting this world demand. Globally, mariculture production in 2004 was 30.2 million tonnes, representing 51 percent of the world total aquaculture production (FAO 2006). Within Canada there is a correspondingly strong industry, where mariculture farms have become a mainstay in coastal communities (Alain 2005).

Atlantic Canada, where this industry has been active for about three decades (Anderson 2007) is a major region for aquaculture. Production has increased from less than 20,000 tons in the early 1990s to about 70,000 tons beginning in 2001. Accounting for 50% of the latter figure, salmon is by far the most prevalent species, with mussels (22%) and oysters (5%) being the only two other larger volume mariculture species (Statistics Canada 2005, DFO 2005).

Within Atlantic Canada the Bay of Fundy is a primary region for finfish aquaculture, with production in Nova Scotia, New Brunswick and adjacent northern Maine, USA. In Nova Scotia, most of the production occurs outside the Bay of Fundy with the exception of a few mariculture sites in the Outer Bay Digby-Weymouth area. There are presently no sites in the vicinity of the preferred ocean energy sectors within the Upper Bay Minas Basin area (Hagerman *et al.* 2006a).

The situation differs considerably in New Brunswick, where salmon mariculture is predominant in the Bay of Fundy (NBDAA 2007). There are approximately 100 finfish leases, located primarily in the inshore areas surrounding the Fundy Isles within the Outer Bay area (Figure 5.19). These sites produce about 35,000 metric tons of dressed fish annually, with a farm-gate value of $225 Million in 2005. Thus the industry has a major presence within the general vicinity of potential sites for ocean energy development. Based on criteria such as total energy from fast flowing waters, the interesting areas for tidal in-stream energy (Hagerman *et al.* 2006b) are located within the Letete, Western and Head Harbour Passages within the Outer Bay of Fundy. These areas also include a number of fish farm sites (Figure 5.21). Thus consideration must be given to possible interactions and potential overlap between these two industries within these areas.

One primary shared need between these two industries relates to siting requirements, *i.e.* the need for sites to establish and operate facilities. In terms of general trends for aquaculture, there appears to be a global shortage of aquaculture sites (FAO 2006) as the strong demand for seafood drives continued expansion of the industry. For example, it is predicted that an additional 66 salmon production sites, totalling about 800 hectares, will be put into operation within Canada by 2015 (Brugère and Ridler 2004). While there is no indication on regional allocation, and no apparent immediate plan for increasing sites in NB, there have been recent developments along the south shore of Newfoundland. Market demand will likely continue to exert pressure for more output of product and hence more sites in the long term. World demand for energy, and particularly renewable energy as contemplated here, is and will be no less intense. Thus, as tidal in-stream energy generating facilities come on-line and operate reliably, increased demand for the development of more sites is sure to follow.

Aquaculture issues related to environmental impacts and the conservation of marine life, including fish stocks, are presently the top concerns of the public within the New Brunswick Outer Bay area (SNBMRP 2006). These concerns are likely similar elsewhere in the Bay and will also pertain to ocean energy development. In terms of environmental impacts, both industries have environmental effects on the sea bottom, particularly on the benthic fauna. However, these effects differ. While mariculture effects include sensory, physical and biological components, it is primarily those relating to organic enrichment from operating activities (Wallace 1993) that affect the benthos. In contrast, primary benthic effects from in-stream power will likely be in terms of construction of facilities on the sea bed rather than during their operation (Casavant 2006), although changes in current velocities resulting in different sediment dynamics could have indirect effects.

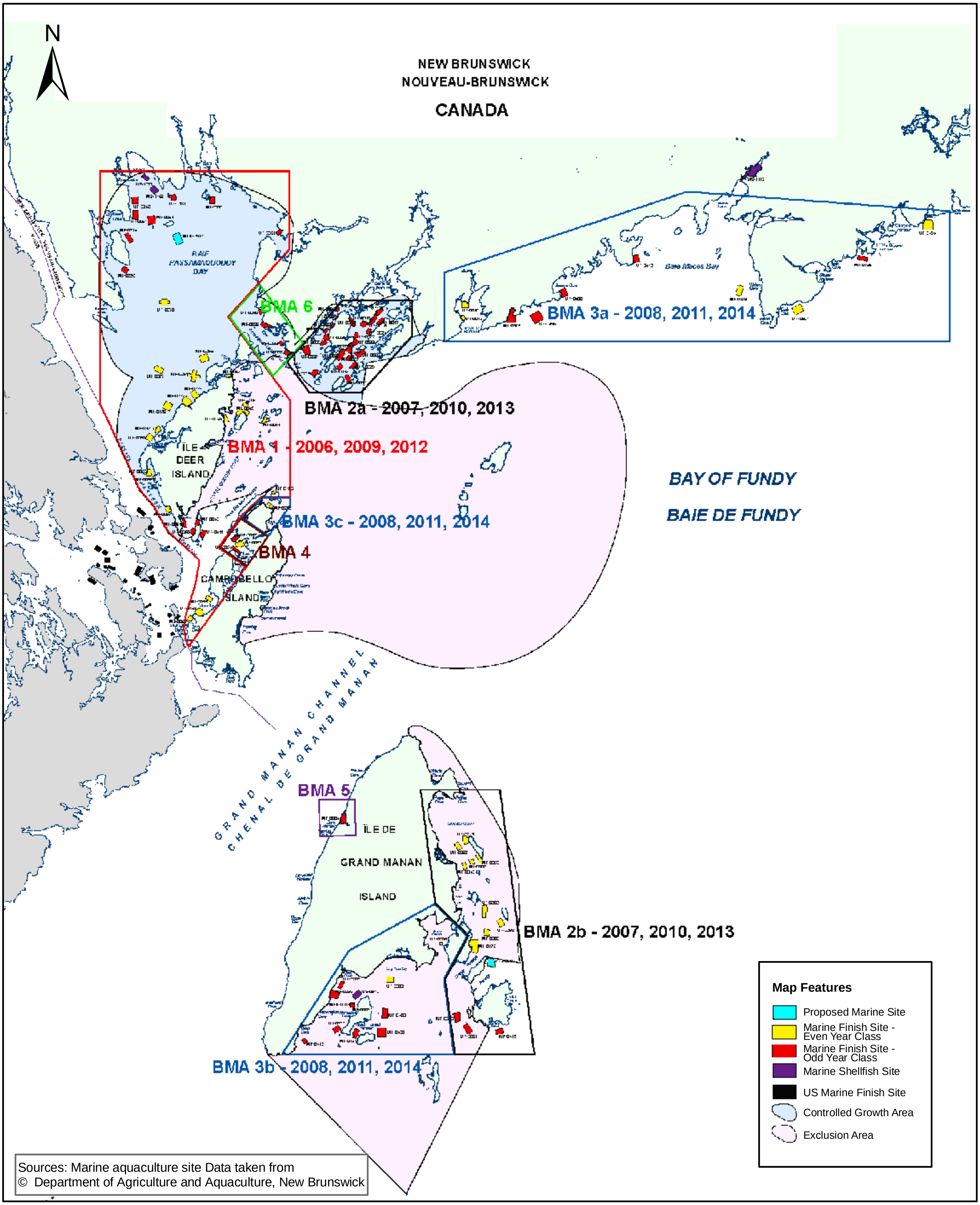


Figure 5.19

Marine Aquaculture Sites in New Brunswick and Cobscook Bay, Maine

Map Parameters
Projection: UTM-Nad83-Z20
Scale Not To Scale
Date: Dec, 20, 2007
Project No.: 1028476
Figure Tracking: 1028476-ACER-030

5.2.5 Species at Risk

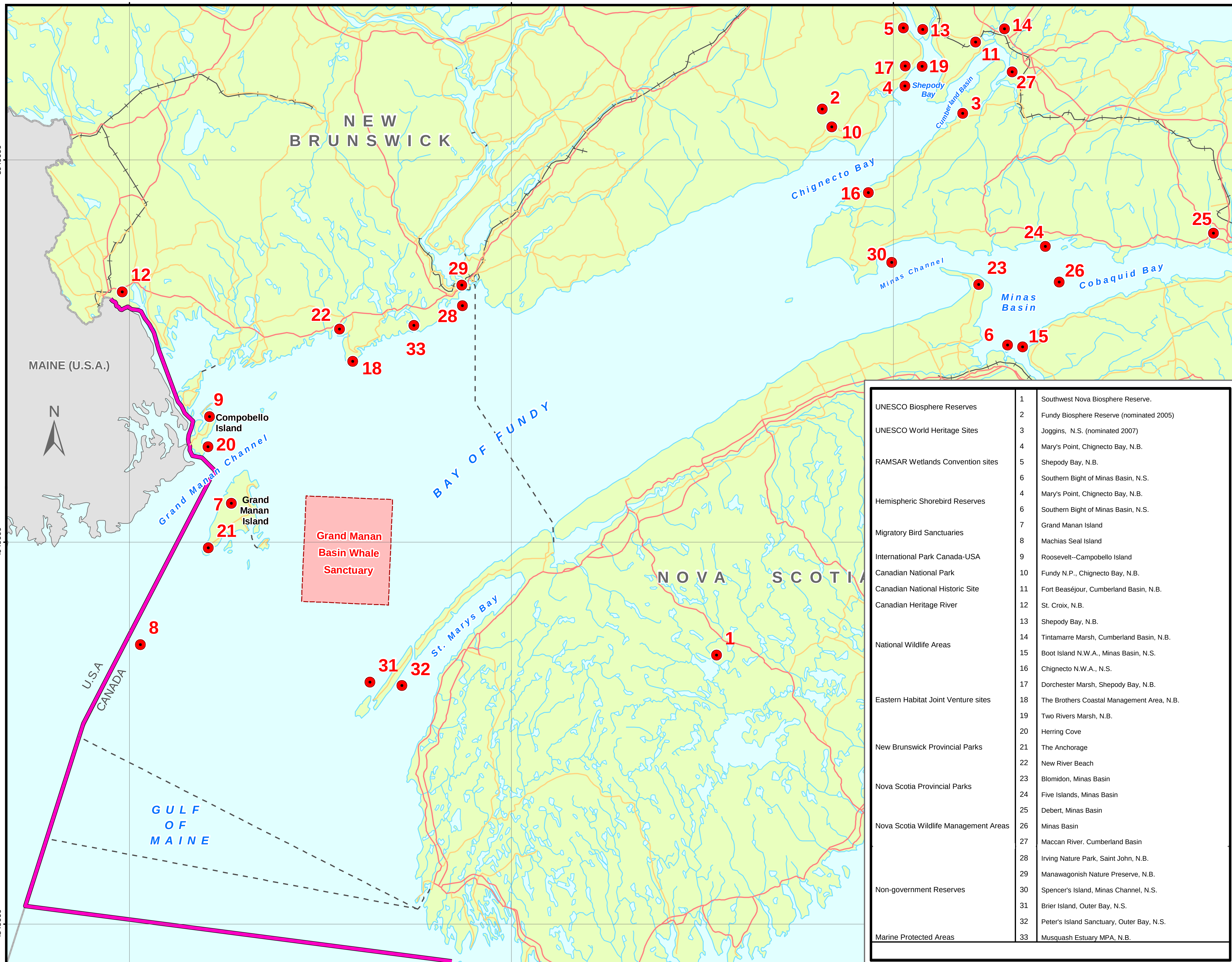
Species inhabiting the Outer Bay of Fundy which are considered to be at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (http://www.cosewic.gc.ca/) are listed in Table 5.6.

TABLE 5.6 COSEWIC Species at Risk in the Bay of Fundy.

Status	Common name	Scientific name
Endangered	North Atlantic right whale	*Eubalaena glacialis*
	northern bottlenose whale	*Hyperoodon ampullatus*
	piping plover (subspecies)	*Charadrius melodus melodus*
	roseate tern	*Sterna dougallii*
	porbeagle shark	*Lamna nasus*
	Atlantic salmon	*Salmo salar*
Threatened	least bittern	*Ixobrychus exilis*
	peregrine falcon subspecies	*Falco peregrinus anatum*
	striped bass	*Morone saxatilis*
	cusk	*Brosme brosme*
	spotted wolffish	*Anarhichas minor*
Special concern	harbour porpoise	*Phocoena phocoena*
	fin whale	*Balaenoptera physalus*
	Sowerby's beaked whale	*Mesoplodon bidens*
	harlequin duck	*Histrionicus histrionicus*
	Barrow's goldeneye	*Bucephala islandica*
	red-shouldered hawk	*Buteo lineatus*
	yellow rail	*Coturnicops noveboracensis*
	Atlantic cod	*Gadus morhua*
	winter skate	*Leucoraja ocellata*
	shortnose sturgeon	*Acipenser brevirostrum*
	Atlantic wolffish	*Anarhichas lupus*

5.2.6 Ecological Reserves.

The Bay of Fundy is replete with environmentally sensitive areas, some of which have been designated for conservation or special management under international, national and provincial programmes, or reserved by non-government organizations (Table 5.7). In addition to these, a Conservation Zone has been established in the Outer Bay of Fundy, and the IMO shipping lanes moved for the conservation of the North Atlantic right whale population. Locations are shown in Figure 5.20.



UNESCO Biosphere Reserves	1	Southwest Nova Biosphere Reserve.
	2	Fundy Biosphere Reserve (nominated 2005)
UNESCO World Heritage Sites	3	Joggins, N.S. (nominated 2007)
RAMSAR Wetlands Convention sites	4	Mary's Point, Chignecto Bay, N.B.
	5	Shepody Bay, N.B.
	6	Southern Bight of Minas Basin, N.S.
Hemispheric Shorebird Reserves	4	Mary's Point, Chignecto Bay, N.B.
	6	Southern Bight of Minas Basin, N.S.
Migratory Bird Sanctuaries	7	Grand Manan Island
	8	Machias Seal Island
International Park Canada-USA	9	Roosevelt--Campobello Island
Canadian National Park	10	Fundy N.P., Chignecto Bay, N.B.
Canadian National Historic Site	11	Fort Beaséjour, Cumberland Basin, N.B.
Canadian Heritage River	12	St. Croix, N.B.
National Wildlife Areas	13	Shepody Bay, N.B.
	14	Tintamarre Marsh, Cumberland Basin, N.B.
	15	Boot Island N.W.A., Minas Basin, N.S.
	16	Chignecto N.W.A., N.S.
	17	Dorchester Marsh, Shepody Bay, N.B.
Eastern Habitat Joint Venture sites	18	The Brothers Coastal Management Area, N.B.
	19	Two Rivers Marsh, N.B.
New Brunswick Provincial Parks	20	Herring Cove
	21	The Anchorage
	22	New River Beach
Nova Scotia Provincial Parks	23	Blomidon, Minas Basin
	24	Five Islands, Minas Basin
	25	Debert, Minas Basin
Nova Scotia Wildlife Management Areas	26	Minas Basin
	27	Maccan River. Cumberland Basin
Non-government Reserves	28	Irving Nature Park, Saint John, N.B.
	29	Manawagonish Nature Preserve, N.B.
	30	Spencer's Island, Minas Channel, N.S.
	31	Brier Island, Outer Bay, N.S.
	32	Peter's Island Sanctuary, Outer Bay, N.S.
Marine Protected Areas	33	Musquash Estuary MPA, N.B.

Figure 5.20

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Conservation Areas/ Ecological Reserves of the Bay of Fundy

Conservation Area
Right Whale Conservation Area

Base Map Features

Major Access Route
Minor Access Route
Ferry Route
Rail Line
Project Limits
International Bounds
Open Water
Hydrology

0 10 20 30 40 50
Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-002

ACADIA CENTRE FOR ESTUARINE RESEARCH
New Brunswick Nouveau
Jacques Whitford
OEER FUNDY TIDAL ENERGY

Although few of these sites are subject to stringent regulations, or national or international commitments, they reflect the special status of habitats in the Bay of Fundy, and therefore may have implications for the development of energy extraction initiatives. Consideration of other areas in the Bay of Fundy for conservation or special management is on-going. The World Wildlife Fund has been conducting an analysis of biophysical characteristics (as in seascapes – see Section 5.1.9 above) for all of Canada's ocean waters in an attempt to develop a comprehensive, ecosystem-based approach to the development of marine protected areas (Day and Roff 2000; Bredin et al. 2004). Because the Bay of Fundy has so many unique features, species and economically important resources, there have been numerous suggestions for other regions that should be accorded special status. For example, there are tentative proposals for other protected areas (e.g., a marine protected area for the Digby Neck region promoted by the Canadian Parks and Wilderness Society) and for an extension of the Fundy Biosphere Reserve to include Minas Basin. Such proposals will continue to arise, and, if implemented, will represent possible constraints on the expansion of energy extraction developments in the future.

TABLE 5.7 Ecological Reserves in the Bay of Fundy

UNESCO Biosphere Reserves	1	Southwest Nova Biosphere Reserve.
	2	Fundy Biosphere Reserve (nominated 2005)
UNESCO World Heritage Sites	3	Joggins, N.S. (nominated 2007)
RAMSAR Wetlands Convention sites	4	Mary's Point, Chignecto Bay, N.B.
	5	Shepody Bay, N.B.
	6	Southern Bight of Minas Basin, N.S.
Hemispheric Shorebird Reserves	4	Mary's Point, Chignecto Bay, N.B.
	6	Southern Bight of Minas Basin, N.S.
Migratory Bird Sanctuaries	7	Grand Manan Island
	8	Machias Seal Island
International Park Canada-USA	9	Roosevelt--Campobello Island
Canadian National Park	10	Fundy N.P., Chignecto Bay, N.B.
Canadian National Historic Site	11	Fort Beaséjour, Cumberland Basin, N.B.
Canadian Heritage River	12	St. Croix, N.B.
National Wildlife Areas	13	Shepody Bay, N.B.
	14	Tintamarre Marsh, Cumberland Basin, N.B.
	15	Boot Island N.W.A., Minas Basin, N.S.

TABLE 5.7 Ecological Reserves in the Bay of Fundy

	16	Chignecto N.W.A., N.S.
Eastern Habitat Joint Venture sites	17	Dorchester Marsh, Shepody Bay, N.B.
	18	The Brothers Coastal Management Area, N.B.
	19	Two Rivers Marsh, N.B.
New Brunswick Provincial Parks	20	Herring Cove
	21	The Anchorage
	22	New River Beach
Nova Scotia Provincial Parks	23	Blomidon, Minas Basin
	24	Five Islands, Minas Basin
Nova Scotia Wildlife Management Areas	25	Debert, Minas Basin
	26	Minas Basin
	27	Maccan River, Cumberland Basin
Non-government Reserves	28	Irving Nature Park, Saint John, N.B.
	29	Manawagonish Nature Preserve, N.B.
	30	Spencer's Island, Minas Channel, N.S.
	31	Brier Island, Outer Bay, N.S.
	32	Peter's Island Sanctuary, Outer Bay, N.S.
Marine Protected Areas	33	Musquash Estuary MPA, N.B.

5.3 Socio-economic Components

5.3.1 Tourism and Recreation

In 2005, tourism revenues in New Brunswick totalled approximately $1.2 billion (New Brunswick Government, 2006). In Nova Scotia, tourism revenues totalled approximately $1.3 billon in 2004 (Nova Scotia Government, 2005). For both provinces, the Bay of Fundy and its coastline play an invaluable role in attracting tourists and recreational users to the area through the provision of stunning scenery, wildlife, cultural assets, and a wide range of recreational opportunities. Tourism is promoted by both provincial governments, as well as the Bay of Fundy Tourism Partnership, an alliance of Fundy-based businesses, regional and provincial tourism organizations, and development agencies from New Brunswick and Nova Scotia.

Tourism and recreational activities that directly or indirectly rely on the Bay of Fundy include:

- bird watching;
- boating;
- hiking;
- kayaking;
- marine wildlife viewing;
- rafting;
- sailing;
- sight seeing; and
- swimming.

A brief overview of activities that may interact with tidal devices is provided below. A detailed summary of all activities and facilities related to tourism and recreation in and around the Bay of Fundy is not intended.

Direct Uses of the Bay of Fundy

Marine Wildlife Viewing

On the Bay of Fundy, marine wildlife viewing is one of the most popular tourist activities. It is perennially rated among the top ten activities to do in New Brunswick (New Brunswick Government, 2003). The nutrient-rich waters of the Bay of Fundy attract numerous marine mammals, including 12 species of whales. Most whale species come primarily to feed; however, some reside year round. The endangered North Atlantic right whale lives in the Bay from June through late October/November in most years.

A number of species of seals, whales, dolphins, and porpoises are commonly seen, some only occasionally, others rarely. Other aquatic and semi-aquatic species may also be seen such as river otters, muskrat, and beavers.

Marine mammals can be viewed anywhere in the Bay; however, one of the most popular locations is the Fundy Aquarium Zone (Bay of Fundy Tourism, 2007), which is situated where the mouth of the Bay of Fundy meets the Gulf of Maine in the Atlantic Ocean. Upwelling deep ocean water generated from the shifting tides creates an ideal environment for marine life. Numerous marine wildlife watching tours operate in both New Brunswick and Nova Scotia in this area; indeed, the tours offered by operators in Brier Island and Grand Manan Island are renowned for the number of species viewed.

Sea Kayaking, Boating, Sailing, and Rafting

The Bay of Fundy offers boaters ample opportunities to explore the sea cliffs and fossils surrounding the coast line. Located in the area where the Bay of Fundy meets the mouth of Chignecto Bay, this eco-zone is characterized by spectacular coastal landforms and unique geology. Over thousands of years, the tides have sculpted the Fundy coast in sea cliffs and rock formations. Sea kayaking is another popular means through which tourists and recreationists experience these natural attractions.

The Bay of Fundy is renowned for its tidal movement, and tidal bore rafting is another popular tourist activity, particularly in the Shubenacadie Estuary in Minas Basin, creating an exhilarating water rafting experience.

Recreational users can access the Bay from numerous small craft harbours and wharves. For instance, there are over 50 small craft harbours on the Bay of Fundy (Figure 5.21). For the most part, the harbours are concentrated near the mouth of the Bay of Fundy, in communities along Digby Neck, on the Nova Scotia coast, and on Grand Manan and Campobello Islands, on the New Brunswick side of the bay.

Commercial kayaking operators are located in numerous locations along the Fundy coast. The vast majority of trips are single day with groups of two or more, that travel along the coast, exploring the rugged and unique geology. Popular locations include Cape Enrage and Hopewell Cape.

Swimming

There are approximately 15 registered beaches along both provincial coasts of the Bay of Fundy. On the Nova Scotia side, these beaches are, generally, part of the provincial park system. For example, beaches are located at Cape Blomidon Provincial Park, Five Islands Provincial Park, and Cape Chignecto. On the New Brunswick side, beaches can be found in New River Provincial Park, Fundy National Park, Cape Enrage, and in the town of St. Andrew's.

It is highly likely that recreational swimming occurs at numerous locations along both provincial coasts. However, due to the informal nature of these locations, it is not possible to accurately determine their level of use. Nonetheless, a more detailed assessment of the degree of informal marine uses would be required for any specific Project.

Indirect Uses of the Bay of Fundy

In addition to the above activities that occur directly on the Bay of Fundy, other notable tourism and recreation activities occur in the vicinity of the Bay, and these may interact with tidal power developments.

For example, coastal scenic vistas are a much promoted attraction along the Bay of Fundy. Locations including Hopewell Cape and Cape Enrage, NB offer remarkable views of the Bay of Fundy. At many of these locations, other activities are available, including rock climbing and beach combing. Ultimately, the popularity of these attractions is directly related to the scenery provided by their proximity to the Bay of Fundy.

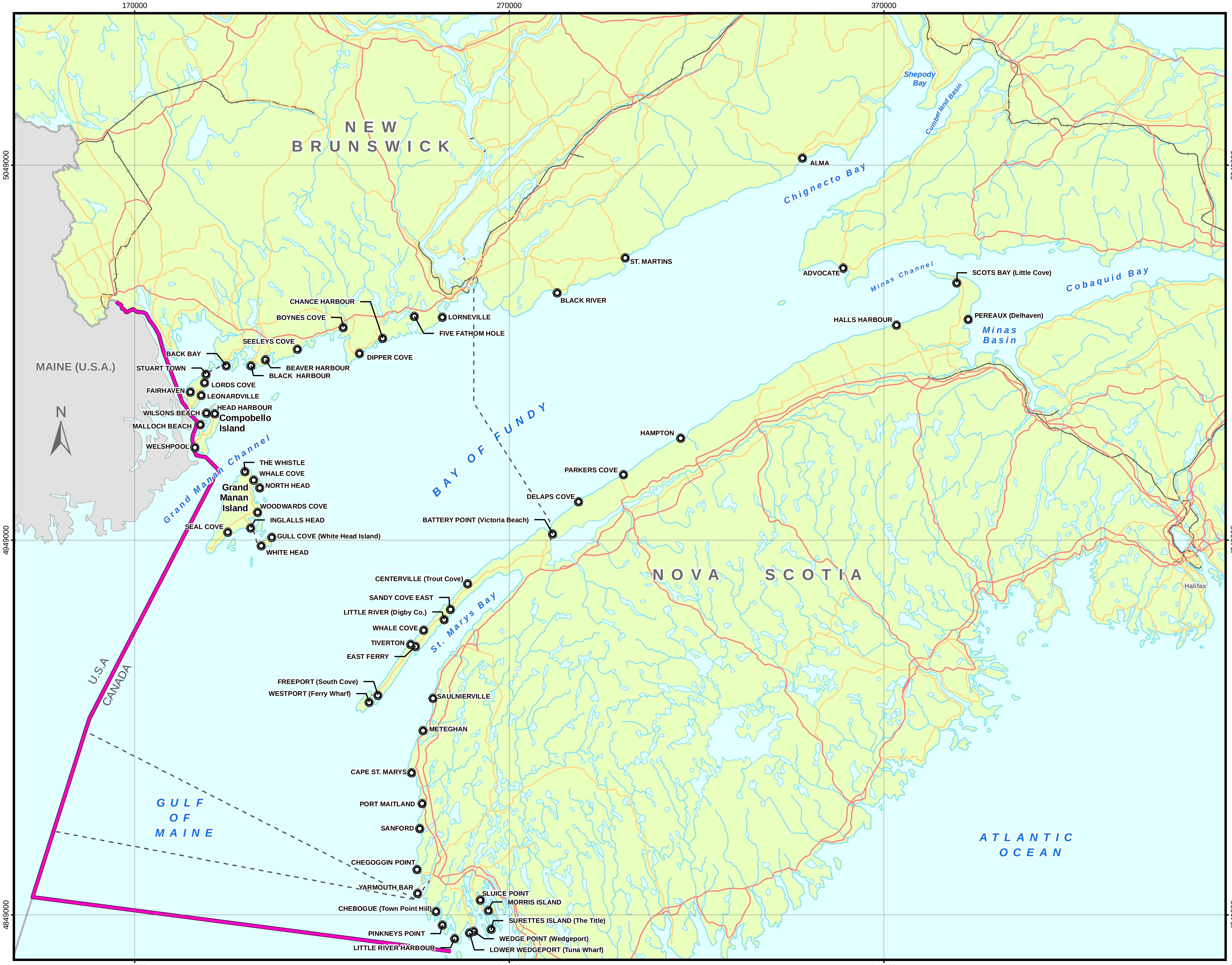


Figure 5.21

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Small Craft Harbour in the Bay of Fundy

Small Craft Harbour

Base Map Features

- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- Project Limits
- International Bounds
- Hydrology
- Open Water

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Sept. 25, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-002

Source: Small craft harbour locations provided by Fisheries and Oceans Canada

ACADIA CENTRE FOR ESTUARINE RESEARCH
New Brunswick Nouveau Brunswick
Jacques Whitford
OEER FUNDY TIDAL ENERGY

Hiking is another popular coastal activity that attracts numerous visitors to the area. Coastal trails offer panoramic views of the Bay and opportunities to see coastal wildlife. These types of trails are located along both provincial coasts; however, the most notable location to engage in this activity is in Fundy National Park, slightly west of Alma, NB.

Another notable attraction is the Fundy Trail, a series of auto-parkways, bicycle, and hiking paths that hug the New Brunswick Fundy coastline. Much like the Cabot Trial in Cape Breton, NS, the Fundy Trail opens up previously unreachable coastal areas of outstanding natural beauty to visitors.

5.3.2 Marine and Coastal Historic Resources

Existing Conditions

The Bay of Fundy has been the site of human activity for over 10,000 years, when the glaciers had begun to recede and sea level was about 100 m below present levels, leaving exposed tundra-covered margins around the Bay. By the beginning of the Palaeo-Indian Period in Nova Scotia, approximately 12,500 years before present (ybp), the first people were following the large herds of large terrestrial mammals that were after the rich flora that grew in the wake of the melting glaciers.

Pre-Contact Period (10,600 to 500 ybp)

The earliest evidence of human activity in the Maritimes comes from Debert, Nova Scotia, where excavations from 1964 confirmed its age as 10,600 ybp. Surveys from 1989 to 2007 have resulted in the discovery of more Palaeo-Indian sites in the Debert-Belmont area, which make up a total of more than 20 hectares. This is one of the most important archaeological sites in Canada.

The Palaeo-Indians in Debert were there to hunt the herds of caribou as they passed through on their yearly migrations. The artifacts recovered included fluted spear points for killing and hide scrapers and knives for processing. These artifacts were made from rhyolites and chalcedonies that were not local and it is speculated that their quarry sites were actually on the shores of Minas Basin and were inundated as the sea levels rose. A fluted point has also been found at Upper Pereaux, Kings County, on the western shore of Minas Basin, but this has not been confirmed as a Paleo-Indian site.

The period around 11,000 ybp saw a dramatic swing in the climate where temperatures cooled rapidly and local glaciers re-advanced in Nova Scotia (see Figure 5.4). Known as the Younger Dryas, this climactic change lasted for between 200 and 400 years and it is speculated that it was harsh enough to drive the Palaeo-Indian peoples from Debert and other areas.

The period after 10,000 ybp is one typified by a lack of archaeological evidence for human activity in Nova Scotia and is known as the Great Hiatus. In fact, archaeologists now feel that the people did not abandon the province but simply moved to the coast of the Bay of Fundy, altering their way of life from one based on terrestrial resources to one of marine resources. By 9500 ybp all of the ice was gone from the province and, while temperatures were similar to what we have today and a boreal forest of spruce, fir and birch had replaced the tundra, the sea levels remained approximately 50 m below present levels. Landforms that are now submerged were above the waters of the Bay of Fundy and, in one case, a ridge running from Digby Neck would have been an ideal place to hunt the large marine mammals that were abundant at that time. The discovery of ulus (semi-lunar shaped stone knives similar to those used by the Inuit to butcher marine mammals) and other artifacts from the waters off Digby Neck are strong evidence of a marine-based culture and such discoveries have also come from the west side of the Bay as well. One such site in Nova Scotia is BdDl-3, located roughly seven kilometers north of Gullivers Cove on Digby Neck, where two large slate ulus were found by a scallop dragger. The fishermen also claimed to have found walrus tusks in the past.

By 5000 ybp the sea levels were only about 15 m below present levels, the temperatures were somewhat cooler, and the forest was dominated by hemlock and oak. This is a period known to archaeologists as the Maritime Archaic and, although it isn't an extremely well known one due to a relative lack of artifacts, it is thought that these people exploited marine and coastal resources and that much of the physical evidence of their presence is now under water.

By 3500 ybp sea levels were almost at present levels, as were temperatures and the forest was dominated by spruce, birch, and beech. Little is known about the transition from the end of the Archaic period to the beginning of what is now called the Maritime Woodland period (formerly known as the Ceramic), which began approximately 2500 years ago. This period is defined by the use of clay pottery, which would have been introduced from what is now the southern United States and New Brunswick, and it also included the development of the traditional hunting cycle of coastal exploitation in the summer and inland migration in the winter, which sustained what appears to have been a rapidly growing population. As a result, the majority of recorded archaeological sites within the Nova Scotia study area represent the Maritime Woodland period. The shell midden, or shell 'heap', is typical of this period and is evidence that the people at the time had bivalves as a major part of their summer diet. These shell middens are found near Freeport on Digby Neck (BbDn-1), in the Annapolis Basin near Bear River (BdDk-1 to 3), near Margaretsville (BgDg-1), near Clam Cove in Scots Bay (BhDc-5), and near Kingsport in Minas Basin (BgDc-7).

Contact or Protohistoric Period (AD1500 to 1604)

While there is evidence that the Norse were the first Europeans to contact the native populations in our region, it wasn't until the fishermen of Portugal and Spain established seasonal settlements on the coast that active contact and trade began. By the 1560s the development of the fur trade had permanently established the Europeans in North America and changed the lives of the native peoples of the Maritimes forever. By 1550, native groups had changed their yearly migration and were spending more time in the interior with the fur trade and returned to the coast to trade. One of the most distinctive sites of this time period is the copper pot burial, which dates to between 1500 and the late 1600s. One such site was found along the coast near Avonport, on the Minas Basin (BgDb-6).

Post Contact and Colonial Periods (AD1604 to present)

The European presence in Nova Scotia was firmly established with the French settlement/fort at Port Royal in the Annapolis Basin in 1604. This settlement was followed by the Acadians who used dykes to reclaim farmland from saltmarshes along the Annapolis River and along the shores of the Minas Basin and Cobequid Bay. As time went on and the British gained control of Nova Scotia, they expelled the Acadians and brought New England 'Planters' to take over the Acadian farmland. The growing population saw a growth in industry along the coast, particularly in forestry (saw-mills) and the shipping (ship builders) and the historic archaeological sites recorded along the shores on the Bay of Fundy and the Minas Basin are reflective of that. The economies of Nova Scotia and coastal New Brunswick depended on the sea both for the fishing industry and maritime trade. This dependence meant the region saw a great deal of ship traffic, which resulted in a correspondingly large number of shipwrecks in the time before lighthouses and electronic navigation equipment became common.

Shipwrecks

A high-level desktop study of shipwrecks within the Bay of Fundy was conducted mainly using the records contained within the Northern Shipwrecks Database. This type of study is severely limited because it is based on very general, and sometimes tenuous, records of wrecks for which there may be no remaining physical evidence. For the purpose of this study an arbitrary cut-off date of pre-1900 was established and only wrecks with a definite probability of havng sunk were recorded, mainly those listed as ‘wrecked’ or ‘total loss’. The search was also limited to those records with relatively specific location for the wrecks (some just indicate ‘Bay of Fundy’, for example). These records were then plotted by hand onto a marine chart with the Maritimes Backroads Atlas used as a supplement for those geographic locations not shown on the charts. These points were then plotted on a large-scale digital map of the study area. The results of this study are presented on Figure 5.22 and in Section 6.12.

5.3.3 Economic Development

Development of tidal energy projects within the Bay of Fundy would have beneficial direct and indirect economic effects on local communities and regional businesses. Direct benefits may include community development such as the use of existing equipment, local labour, infrastructure, and other support services. Other direct benefits may include construction activity, the addition of new infrastructure (*e.g.*, utilities), and increased capacity of local industry. Indirect benefits could result in increased local activity such as tourism, retail, housing starts and rentals, commercial and industrial real-estate, and operational and seasonal project associated support services.

EPRI (2006) identified various local and regional maritime support infrastructure for potential Bay of Fundy tidal energy projects. In New Brunswick, there is existing infrastructure and established support services that could provide industrial marine services, fabrication, and assembly of TISEC devices. Prospective service communities may include port cities such as Saint John which have existing fabrication, docking, and shipping facilities, in addition to maintaining an established industrial workforce. Atlantic Canada has played a major role in Canada’s shipbuilding industry. As such, industrial fabrication capacity also exists in other areas of New Brunswick including Moncton, Caraquet, and Miramichi. Caraquet has various fabrication facilities that are capable of producing conveyors and tanks that may be required by TISEC technology developers during deployment. Precision metalworks and other fabrication services are widely available in the Greater Moncton Area.

Engineering services will be required throughout the development of tidal energy projects and can be sourced throughout New Brunswick, with significant engineering capacity located in Fredericton, Saint John, and Moncton. New Brunswick’s post-secondary academic institutions provide world-class researchers which could facilitate technology development and conduct research services required by tidal energy project developers.

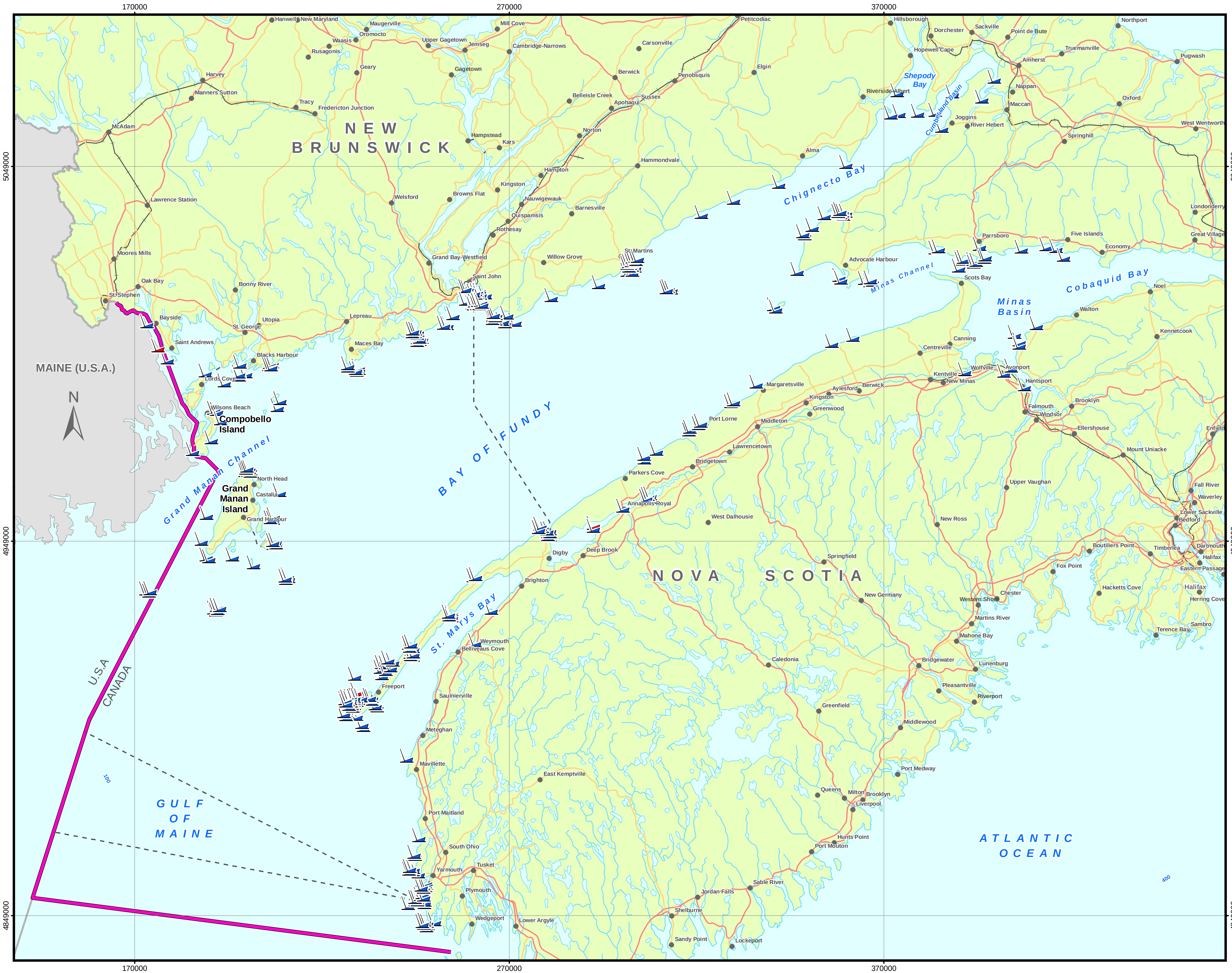


Figure 5.22

BAY OF FUNDY TIDAL POWER STRATEGIC ENVIRONMENTAL ASSESSMENT

Known Shipwreck Location

Known Shipwreck Locations

- Eighteenth Century
- Nineteenth Century

Base Map Features

- Community
- Project Limits
- Major Access Route
- Minor Access Route
- Ferry Route
- Rail Line
- International Bounds
- Hydrology
- Open Water

Source: Shipwreck data extracted from Northern Shipwrecks Database - Northern Maritime Rsearch

0 10 20 30 40 50

Distance in Kilometres

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:950,000
Date: Nov 28th, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-011

ACADIA CENTRE FOR ESTUARINE RESEARCH

New Brunswick / Nouveau Brunswick

Jacques Whitford

OEER FUNDY TIDAL ENERGY

Shipbuilding and fabrication continues to be a major industry in Nova Scotia. The Town of Shelburne has existing 2000 ton capacity shipyards which could be utilized for TISEC device construction and assembly. Similarly, the Town of Lunenburg has an existing 1600 ton capacity shipyard with two facilities which could accommodate TISEC device construction and assembly. Both Lunenburg and Shelburne are located on the south east tip of Nova Scotia, just outside of the Bay of Fundy which would require transportation to potential tidal energy project sites within the Bay of Fundy.

Halifax, as the largest city east of Quebec, has significant engineering capacity which could facilitate tidal energy projects within the Bay of Fundy. Provincially, Nova Scotia has many post-secondary institutions which could assist with research projects required by tidal energy project developers.

The Town of Parrsboro, located within close proximity to the Minas Passage, could service potential tidal energy developments within the Minas Passage and surrounding areas. Potential tidal energy projects that may be located in New Brunswick, such as Cape Enrage or Head Harbour, could be serviced from Saint John, New Brunswick.

5.3.4 Marine Transportation

The Bay of Fundy is a 276 Km long arm of the Atlantic Ocean wedged between the Maritime Provinces of New Brunswick and Nova Scotia and is accessed through the Gulf of Maine. The Bay features a narrowing width 118 Km between Yarmouth, N.S. and Cutler, Maine, to 43 Km at Cape Chignecto (Thurston, 1998).

The diminishing width gives the Fundy a "funnel" shape, and has a remarkable amplifying effect on the tidal patterns. The enormous tides of the Bay of Fundy can reach 16 metres at the head of the Bay.

The volume of water ebbing & flowing is estimated to be 2000 times greater than the daily discharge of the Gulf of St. Lawrence (Thurston, 1994).

Shipping in the Bay of Fundy includes international tanker and container traffic, coastal shipping, ferries, and cruise vessels. While commercial traffic is generally light in the Bay of Fundy, there is a great deal of shipping activity concentrated at the mouth of the Bay, with Saint John, New Brunswick being the major focal point. Saint John Harbour is a working Port and some of the largest ships in the world unload cargo at the port terminus. Shipping into Saint John, which is a year-round ice-free port, averaged (in 2006) 500 movements per month from December to April, 600 in each of the months of May and June, an average 1500 in July, September and October and a maximum number of 2321 in August (MCTS 2007). The majority of this traffic is commercial shipping and tug activity.

Aside from water depth restrictions due to tidal fluctuations, there are additional risks resulting from: navigation channel restrictions due to narrow passages for prospective sites; the possibly of mechanical failure of propulsion or steering gear; non-compliance with Collision Regulations; the density of traffic within navigable waterways restricting room to manoeuvre; environmental factors such as visibility, currents, wind; and, human error.

Two North Atlantic right whale conservation areas have been designated by DFO in the Grand Manan Basin area of the Bay of Fundy and in the Roseway Basin area of the Scotian Shelf. These areas are known to support feeding aggregations of North Atlantic right whales during the summer and fall months. In 2003, the shipping lanes into Saint John, New Brunswick were shifted in order to reduce the possibility of ship strikes of right whales in the Bay of Fundy Conservation Area. However, Transport Canada cannot regulate ships moving into or out of the Bay of Fundy traffic lanes, through areas where right whales may also occur in smaller densities (CSAS 2004a). While this will not directly affect any of the example tidal development sites discussed in Section 6, it does serve to indicate the increased concern being placed on environmental issues and the need for consultation with many non-governmental organizations with interests in these fields.

In addition to commercial shipping, and commercial fishing, there is also a growing recreational boating component which will have potential interactions with tidal energy development projects.

Although few of these sites are subject to stringent regulations, or national or international commitments, they reflect the special status of habitats in the Bay of Fundy, and therefore may have implications for the development of energy extraction initiatives.

6.0 ENVIRONMENTAL ISSUES

This background document is concerned primarily with the assessment of tidal in-stream devices (TISEC), but also includes reference to other potential marine energy options, including tidal lagoon, wave and offshore wind technologies. Each option presents somewhat different environmental issues which would be addressed in the course of normal environmental assessments. The following section is primarily concerned with tidal energy with a principal focus on the issues surrounding TISEC technologies.

In evaluating the environmental and socio-economic implications of tidal in-stream energy conversion in the Bay of Fundy, it is evident that there are many ways in which this development might interact with other existing or potential activities in the Bay, and have implications for communities around the Bay. Some of the concerns include effects on physical processes, some on biological phenomena, and others on activities such as fishing and transportation (*etc.*). Each of the following subsections presents an evaluation of interactions between the defined development scenarios and each of the KEIs identified.

6.1 Critical Physical Processes

6.1.1 Definition and Rationale for Selection

The major physical processes that define the Bay of Fundy and determine its ecological characteristics involve water movements, ice formation and sediment dynamics. Any significant modification of these processes is likely to have ramifying effects upon both the ecology of the Bay and the economic activities that are associated with it. For example: reductions in current velocity affect the transport and deposition of sediments; sediment properties (especially grain size, cohesiveness, organic and contaminant contents, weathering of surfaces, *etc*.) affect the benthic organisms that inhabit them, and consequently the fish and other species that feed upon them. For this reason, the potential effects of energy extraction devices on physical processes constitute a key environmental issue.

Water movements of concern include:

- tidal currents that effect the exchange of materials (nutrients, contaminants, oxygen *etc.*) in estuaries, determine the erosion, resuspension and deposition of sediments, and are the principal reason for interest in tidal energy extraction; and
- vertical mixing processes, especially areas of stratification or upwelling that are important in determining the nature of biological production both in the water column and on the bottom.

Sediments become an issue in four ways:

- when settled on the bottom, they are a major factor determining the community of animals and plants that inhabit them;
- both in suspension and when deposited they may carry contaminants that are available for uptake by pelagic and benthic organisms;

- in suspended and deposited mode, fine sediments are potentially the ‘food’ for many invertebrate suspension feeders that strip the bacteria and organic matter present on the particles;
- and in suspension, they may affect the behaviour and/or health of animals by their effects on gills or visibility of the water column.

Sediments vary widely throughout the Bay of Fundy, being distributed primarily in relation to prevailing current velocities, and are affected by episodic phenomena such as waves, storms and ice.

Ice has important physical effects on currents, waves, sediments and biota, particularly in the Upper Bay and bays. However, except in the case of a tidal lagoon, the presence and quantity of ice are primarily determined by external factors, particularly temperature and the salinity of the water, and these are not likely to be affected by energy extraction developments. Tidal lagoons, by retaining water while the sea level drops, may have some effects on increasing the formation of ice in winter months within the impoundment, with implications for the efficiency of operation of the tidal generating station; however, it is unlikely that such increases will be significant enough to affect regions outside the lagoon. The presence, formation and movements of ice need to be monitored, especially to assess its potential effects on TISEC structures.

6.1.2 Potential Environmental Interactions

A key issue relates to the effects of TISEC devices on the patterns and velocities of tidal currents. Essentially the TISEC device will reduce the overall energy density of the system from which it is extracting energy, and thus tend to modify all of the other processes that are dependent upon water movements. The energy density of flowing water is a cubic function of the current velocity; consequently, higher velocities represent vastly higher kinetic energy potential, which is why selection of sites tends to favour the passages with highest current flows. Similarly, the relationships between current velocity, mixing or stratification, and sediment dynamics, tend to be non-linear: a small increase in current velocity commonly results in proportionately larger increases in the phenomena determined by it. From the perspective of development, it is important to forecast the continuing energy output of the installation, and for that reason, a mean value for maximum current velocity, averaged over time and space, is used in assessing the potential of a site (see section 4.4). However, it is usually the maximum (or in some cases the minimum) velocity that is of most significance for ecosystem processes. Consequently, reductions in current flows resulting from a TISEC installation need to be carefully assessed prior to development.

Any structure established in a free-flowing channel will tend to resist flow, causing the water to accelerate around it, and hence inducing local scour effects, and this will happen with any TISEC device. Because of its conversion of kinetic energy to electricity, however, the net effect of a TISEC device would be a reduction of the energy density of the water downstream. It has been suggested that where the water is entering an enclosed embayment, such as the bays in the Upper Bay of Fundy, there is some compensatory increase in energy level because, by impeding the flow and slowing the filling of the basin, the hydrographic head between the sea and the basin will also be slightly increased (Black and Veatch 2005).

Reducing the current velocity downstream of the tidal power development is expected to have the following effects:

- decrease the resuspension of sediments or increase the rates of sediment deposition;
- modify the circumstances that lead to settlement of marine larvae;
- diminish the food supply brought to benthic filter feeders;
- decrease the extent of upwelling, or increase the tendency toward stratification;
- by affecting light and nutrient levels, influence the process of primary production; and,
- by affecting the benthic community, have indirect effects on the fish and birds (*etc*.) that feed upon them.

It is not likely that one TISEC device installed as part of a demonstration project will have measurable effects on any of these processes beyond the immediate area. However the cumulative effect of many such devices arrayed as part of commercial scale projects could modify these processes sufficiently to induce unacceptable changes in other properties.

Introduction of TISEC devices may have the potential for remobilizing deposited sediments (as a result of scour), creating changed sediment distributions, or having direct effects on organisms that are sensitive to particulates in the water column. Site preparation will tend to remobilize sediments that are present on site, creating plumes that will travel away from the site for varying distances. Although most TISEC devices are expected to contain only small quantities of toxic materials (*e.g.* oils, dispersants, biocides *etc.*), if these are released into the environment, they are likely to become preferentially associated with the finer sediments, and be distributed with them. Finally, sediment particulates derived from drilling in bedrock may have more deleterious effects on biological life than similar-sized sediments that are naturally present in the environment, because they often are more angular and have sharper edges than natural 'weathered' sediments.

Because the TISEC devices will convert kinetic energy into electricity, changes in current velocity will affect the dispersion and distribution of water-borne sediments, which may affect populations at some distance. High suspensions may be a significant problem for filter-feeding species, especially those living in relatively clear water, and may also affect the behaviour of foraging predators such as fish. These effects will vary, depending upon the nature of the substrate at the site, and the susceptibility of the fauna. It is likely that species living at sites in the Outer Bay are more susceptible to the effects of suspended sediments than those that inhabit the turbid Upper Bay. Drilling wastes will likely have negative effects arising both from the nature of the particles released, and also of contaminants (oils *etc.*) that may be released with them. During operation, the principal consequence may be the patterns of redistribution of sediments resulting from reductions in the kinetic energy of the water that has passed through the development.

6.1.3 Environmental Planning and Management Considerations

Effects on current velocity of any given size and type of development will be similar no matter which site is selected. Nonetheless, the effects will vary according to how narrow or constrained the location is: deployments in the open Bay, for example, would have much smaller effects than those in the narrower passages that are considered to have the highest potential for development. Similarly, the sediment issue will vary considerably depending upon the site. In the Outer Bay, waters are generally low in suspended solids, and the fauna is less adapted to high suspensions. In the Upper Bay, on the other hand, high turbidities are the norm, and concerns over the effects of mobilized sediments are related more to the changed distributions of deposited sediments, which will have consequences for the distribution and productivity of benthic organisms, and indirect effects on all of the species dependent upon them.

Minas Passage (Nova Scotia)

It is not expected that demonstration projects in Minas Passage will have sufficiently large effects on current velocity through the Passage to be detectable in any of the critical processes in the Minas Basin. Large scale commercial developments, however, might do so if they effectively reduce the kinetic energy of water entering Minas Basin by more than a few per cent. At present there is a great deal of uncertainty about what level of energy reduction is likely to be acceptable. This is the foundation of the need for much more comprehensive and effective modeling and field studies of the hydrodynamics of each of these sites.

Although located in the Upper Bay, which is generally more turbid than the rest of the Bay, water flowing through the Minas Passage is relatively low in suspended matter (<15 mg/L – Amos and Joice 1977) most of the time. Occasionally, following storms, or as a result of ice movements, plumes of suspended sediments may travel as far as the Passage on the ebb tide before settling out. Currents are sufficiently strong that most of the bottom is swept clear of fine sediment, leaving a bottom that is coarse (sand waves in some areas, cobble to boulder sized rocks in others) or scoured bedrock. In shallow waters and the intertidal zone, however, where current velocities are lower, coarse sediments drop out of suspension, leaving the high turbidity due to fine silt- and clay-sized particles. Natural sediments in Minas Basin are both highly weathered, and have relatively low contaminant loads (compared with many estuaries), and the fauna is somewhat adapted to higher sediment levels in the water. The primary direct effect on the ecosystem will be possible sediment releases associated with drilling or other site preparation activities. Information on suspended sediment concentrations in the area of potential TISEC development is, however, extremely limited; such information, identifying concentrations and grain size, needs to be collected at different levels in the water column over several tidal periods that represent the range of variation in tidal amplitude, seasonality, ice conditions and severe weather events.

There is also a concern, however, regarding the indirect effects on sediment dispersion and distribution as a result of reductions in the flow regime from commercial scale development. The whole dynamic character of the Minas Basin sediment regime hinges upon the velocity, circulation and mixing properties of the water moving into and out of the Basin. Reducing the velocity to any extent will likely change the dynamics for at least the central region of the Basin. A significant reduction in turbulence over portions of the basin would result in a drop in turbidity, increasing light levels, and therefore effects on both productivity in the water column (which is light-limited – Brylinsky and Daborn 1987) and foraging behaviour of fish. Whether such effects would result in significant changes to the food web or the fauna will need to be determined by modeling exercises.

Cape Enrage (New Brunswick)

Similar concerns apply to the Chignecto Bay sites. Maximum velocities at Cape Enrage are considerably lower than in Minas Passage, and peripheral sedimentary deposits are more extensive, and tend to be more fine-grained, than in Minas Basin (see Section 5.1.3). The most likely location for a TISEC site is near Cape Enrage; however, if other sites are developed, such as in Shepody Bay or Cumberland Basin, concerns over the effects on sedimentary dynamics will be magnified, because of the closer proximity of these sites to intertidal zones of high biological significance.

It should be noted in this context, that the sediment regime in Chignecto Bay would be dramatically changed for some time if plans for opening of the Petitcodiac Causeway are carried out. The remobilization of a large volume of sediment that is currently stored at the head of the Petitcodiac Estuary may well change the sediment character through Shepody Bay and the inner portions of Chignecto Bay (AMEC 2005).

Digby Gut (Nova Scotia)

Sedimentary issues in the Digby Gut and similar passages along Digby Neck are associated primarily with activities during construction and site preparation. The substrate is generally hard, ranging from gravel to bedrock, and the resistant shoreline of this part of the Bay does not leave much fine material to be distributed. Along the Fundy shore, outside of Digby Gut, the strong flood currents also generally keep the sediments coarse, and this area exhibits large sand waves of the Sambro Sand formation. During site preparation, the same concerns exist regarding generation of sediments from excavating processes, since benthic forms may be particularly vulnerable to non-weathered particulates. During operation, sediment remobilization is unlikely.

Head Harbour Passage (New Brunswick)

Head Harbour Passage substrate is principally rock outcrop or boulders. Sediments grade from gravel to sand and mud where current speeds are reduced, especially near some shores (Anon 2006b; Buzeta *et al.* 2003). The seabed in open waters of Head Harbour Passage has been interpreted from backscatter imagery to be hard bottom, probably gravel and sand (Anon 2006b). TISEC construction may cause resuspension of fine materials where the substrate is soft, in addition to those produced by drilling, the amounts increasing with the size of the installation. This may have local impact on benthic filter-feeders but should be temporary and not a concern during device operation. Since a large commercial installation could conceivably remove sufficient kinetic energy from water currents to increase sedimentation in parts of the Passage, with negative impacts on the biotic community, the scale of development would need to be limited to minimize that effect.

Management Opportunities

Providing answers to the challenging questions about the effects of TISEC development on the critical processes of the Bay of Fundy requires an holistic, cooperative and multi-disciplinary approach. The scientific community in the Maritime provinces is well experienced in such complex projects, having collaborated on the last major investigation into tidal power development in the 1970s and 1980s through an organization known as the Fundy Environmental Studies Committee (FESC) (Gordon and Dadswell 1984; Daborn 1977, 2007). All of the skills necessary exist at universities, colleges, and government agencies in Nova Scotia and New Brunswick. Participation of the fishing community and First Nations is also essential. In addition, there are several community organizations such as the Bay of Fundy Ecosystem Partnership, the Ecology Action Centre, the Conservation Council of New Brunswick, and the Fundy Marine Resource Centre, that both collaborate on scientific studies and act as contacts with the non-science communities around the Bay of Fundy. Involving these community groups will not only expand the capacity for field studies and monitoring, but will greatly enhance the transfer of that knowledge to the general public through the extensive outreach programmes the NGOs provide. Operating in this way, it is much more likely that the public will embrace environmentally-sound marine energy developments than otherwise. In the past, the coordinating FESC was hosted by the Atlantic Provinces Interuniversity Council on the Sciences; this might be a suitable host again, however there is another potential host in the form of the Atlantic Environmental Sciences Network (AESN), which already links university and government scientists together. In addition, the Centre for Offshore Oil, Gas and Energy Research (COOGER) or the Ocean Energy Environmental Research Association (OEER) could provide a coordinating role. This initiative should also be seen as moving the Atlantic region more effectively to satisfy the requirements for ecosystem- and community-based management as outlined in Canada's Ocean Plan.

6.1.4 Data Gaps and Follow-up

Knowledge about the excavation and construction activities required for both demonstration and commercial scale TISEC development can be derived from other marine constructions such as harbours, wharves, drilling rigs and offshore wind farms. However, the environmental effects are very site-specific, and require good information about substrates and current movements in the immediate area. Much of this required information is not presently available with sufficient detail or precision to assess the environmental effects of development. Some recent bathymetric surveys by the Bedford Institute of Oceanography will provide important information; it should be a priority to ensure that their analysis is completed. Very precise surveys of some of the areas selected for TISEC installation still need to be carried out. A high priority should be assigned to obtaining accurate and long term data on water movements and sediment distributions in the high priority areas for TISEC or lagoon developments in order to apply and validate hydrodynamic models that need to be used to forecast environmental effects.

Hydrodynamic models that would be suitable for forecasting the effects of TISEC developments on current velocities exist, and need to be applied in conjunction with sediment dynamics models. However, present information about the physical conditions in the four representative sites is insufficient to provide the validation for these models, and so a site-specific study of current flows and sediment properties is needed at any location that is considered for development. Monitoring of sediment concentrations, grain size, and organic content in the water column will be needed both prior to deployment of demonstration TISEC devices, and during testing. In addition, developing an adequate model of the dispersion and settlement of sediments during TISEC operation will require investigations of sediment distributions over areas that might be influenced by reductions in current velocity. If commercial development proceeds, ongoing monitoring will also be needed to ensure that any subtle, long-term modifications to ecosystem processes resulting from the development are detected.

The concern about sediment dynamics is most acute in the Upper Bay region. Because the sediments there are primary determinants of biological activities in Minas Basin and Chignecto Bay, being able to forecast their behaviour is a high priority. The dominance of hard substrates in potential development areas in the Outer and Inner Bay means that this would be less imperative in those locations.

6.2 Fisheries

6.2.1 Definition and Rationale for Selection

Fisheries activities are pursued throughout the Bay of Fundy. Consequently, installation of structures for energy conversion, whether from tidal currents, waves or offshore wind, would very likely take place in or near areas that are currently in use by the fishing sector. Effects on fisheries may be both direct (as in the case of exclusion zones, effects on fish behaviour, *etc*.), and indirect by affecting organisms (e.g. plankton and benthos) upon which the targets of the fisheries depend. Because of the varied physical conditions and habitats throughout the Bay, target species and fishing activities vary from region to region, and therefore the precise nature of the interaction with energy conversion installations will vary. These fishing activities are of major economic and social importance to communities around the Bay, which means that the extent to which existing fishing activities are displaced or decreased by energy development is a key environmental and socio-economic consideration.

6.2.2 Potential Environmental Interactions

A common feature of demonstration and commercial scale energy developments, during both construction and operation, is the need for an exclusion zone around the site of operation, including the deployment areas and the transmission cable(s), to avoid interference between fishing and energy conversion operations. The area of exclusion will probably have to be greater during the construction phase than during operation (except, perhaps, for a tidal lagoon), because of increased traffic of vessels associated with the installation, some of which may be considerably larger than normal traffic in the area. While the site is being prepared and the device(s) installed, use of fixed or mobile gear would have to be restricted within a zone that is sufficient to minimize the potential interference with drilling, substrate preparation, cable-laying, service vessel movements and device installation (*etc.*), and to ensure safety of fishers and construction personnel. Because the probable areas of deployment are those with higher current velocities and shorter intervals of calm water around high and low tides, anchoring and positioning of construction-related vessels will be more complex, emphasizing the needs for larger exclusion areas. During the operation phase, the size of the exclusion zone may be reduced, depending upon the nature of the fisheries involved, which in turn depends upon the site of development. A consideration will also be the potential hazard to the structure represented by lost fishing gear: traps, gill-nets, trawls and associated ropes or cables represent a threat to submersed TISEC devices.

In the case of a tidal lagoon, its construction will permanently remove the enclosed area from access by fisheries operations. There may be compensatory effects associated with the embankment enclosing the lagoon, where new benthic habitat may be created by the surface protection provided, and it may be possible to mitigate the effects of fisheries exclusion by utilizing the lagoon for mariculture purposes. The potential for mitigation will vary with the location, sediment and water column properties (*etc*.).

Noise and vibrational effects of construction may have varied implications for different species targeted by fisheries. It is very likely that schooling fish, and any fish possessing a swim bladder or using acoustic signals, will be affected by pile-driving activities during construction, but it is less clear to what extent this will apply also to benthic or pelagic invertebrates. The effects may be directly related to health of the individual animal (*e.g.*, by damaging sensory or sensitive tissues), or be indirect through effects on behaviour. Research at the Annapolis Tidal Generating Station has shown that deployment of underwater acoustic devices have proved effective at driving fish away from the turbine entrance if turned on just before the turbine gates are opened. If target species seek to avoid the area of the construction, this displacement may be of short term significance to local fishing activities. During the operational phase, the acute effects of pile-driving and construction will be absent, but noise and other vibrations produced by the turbine may continually affect behaviour of target species.

Excavation and site preparation activities during the construction phase will have a variety of effects, depending upon the location, and particularly the nature of the substrate. In areas with finer materials, remobilization or resuspension of sediments such as sand or silt may have short term deleterious effects on target fish species, but possibly longer-term residual effects on benthic organisms. While this may be a lesser problem in areas of bedrock, drilling operations could release drill fragments that are more angular, and potentially more damaging to tissues, compared with natural 'weathered' particles, with important implications for filter-feeding fish and shellfish.

Development of offshore energy generation sites will require similar shore-based infrastructure that currently supports the fisheries and aquaculture sectors, leading to a potential conflict. Many wharves and storage facilities are currently fully committed. It is expected that new energy-related developments will require upgrading of old or creation of new shore-based facilities, but there remains the possibility that investments in energy may displace traditional fisheries that are economically marginal.

6.2.3 Environmental Planning and Management Considerations

The potential for demonstration or commercial scale developments involving TISEC devices to displace established fisheries varies according both to the geographic location of the site, and the type of fishery currently pursued, which are functionally linked. The four scenarios are based upon representative areas chosen to illustrate the diversity of scale, location and implications of tidal current development.

Minas Passage (Nova Scotia)

The Minas Passage location exhibits the highest current velocities available in the Bay of Fundy (< 5 m/sec on spring tides), and a relatively large area in which TISEC devices may be installed, and therefore offers the largest scale potential for commercial development. Water depth exceeds 40 m over much of the Passage, with greatest depth of >100 m at low tide (see section 5.1.2). Because of the high current velocities, the substrate over much of the Passage is coarse, ranging from exposed bedrock to boulder, cobble and, sand waves, overlain with finer materials in shallower waters. Detailed information about substrate distribution will become available when recent multibeam bathymetric survey data have been analysed (Parrott, pers. comm.). It is expected that either demonstration or commercial TISEC deployment in this area would be in depths greater than 40 m, but with cable connections that must traverse shallow waters and the intertidal zone.

The principal, and most valuable fishery in the immediate area is for lobster. Traps are heavily weighted to resist the effects of strong currents, and set in lines. A dozen license holders operating out of Parrsboro, four from Delhaven, and another eight from Halls Harbour, are involved in this fishery during the open seasons, which extend from 14 October to 31 December, and 1 March to 31 July (Dyer *et al*.

2005). Landings rose from ~50,000 kg in the early 1990s to more than 150,000 kg by 2002, and value from c. $300,000 to more than $2.5 M. Records do not provide sufficient detail to ascertain the fraction of these landings that were derived from the Minas Passage specifically, as opposed to other lobster grounds inside and outside Minas Basin that were landed in the same districts (FMA 40, 41 and 44). Fishermen maintain that their fishery in Minas Passage not only captures lobster that are resident on gravel and cobble substrates, but also during a supposed migration of larger lobsters through the Passage into the warmer waters of Minas Basin (Taylor, pers. comm.). Although TISEC installations on scoured bedrock may not directly displace lobster fishing, there would be concern where the original substrate was cobble and gravel. Apart from direct displacement of lobster trap setting activities, there may be indirect effects on migrating lobsters during construction as a result of noise, vibrations, or sediments. Research is needed to assess the effects of these changes on lobster populations.

Excavation and construction will have direct impacts on the substrate in the Minas Passage site, and may initially remove some habitat that is important for lobster stocks. Depending upon the design, this may be compensated for in the longer term by increased habitat represented by rip-rap or other scour protection provided for the structure, as has been found in the case of the Confederation Bridge (Baird and Associates 2007c) and offshore wind farms (Dong Energy *et al*. 2006).

Operation of a demonstration-scale plant may have localized effects on substrate characteristics upstream and downstream of the device(s), and hence affect productivity or distribution of lobsters. In addition, electrical fields associated with the transmission cable may affect both behaviour of resident lobsters and the movements of migratory lobsters. In Danish offshore wind farms, electrical fields of transmission cables have been shown to affect movements of many benthic animals, especially fish, but the effects are variable between species. There appears to be little or no information about electrical effects of undersea cables on lobsters, indicating a need for further research. The effects of commercial-scale operations would be expected to be similar to that of a demonstration, only magnified proportionately.

Other relevant fisheries in the Minas Basin include dragging or handlining for pollock, haddock and spiny dogfish, and drift or gillnetting for Atlantic herring and American shad. While these activities occur less frequently in the narrow portions of Minas Passage, and therefore may not be directly displaced by construction activities, they are pursued in the neighbouring areas of the Minas Channel and Minas Basin. The purse seine fleet pursues herring extensively in Scots Bay just outside Minas Passage, and may well venture into the Passage when conditions permit. Much of the purse seine operations occur at night, and the vessels are not closely monitored, so the extent of this activity in the site area is unknown (Dadswell, pers. comm.). The secondary effects of noise, vibrations, and sediment dispersions on these stocks, in affecting their movement between the Minas Basin and Inner Bay of Fundy, need to be determined. Similarly, assessment of the long term effects of operations of a demonstration or commercial scale TISEC development on commercially important pelagic fishes requires further research.

Direct mortality on fish caused by turbines is a substantial concern. Although much experience on assessing mortality rates has been gained through investigation of hydroelectric installations, and locally at the Annapolis Tidal Generating Station (BEAK Consultants 1991; Dadswell and Rulifson 1994; Solomon 1988; Stokesbury *et al.* 2001), there is no information currently available in relation to the new TISEC technologies. Fish mortality in hydroelectrical systems generating electricity from the potential energy of stored water occurs by: a) being struck by rotating vanes or blades; b) by contacting the housing or fixed parts of the structures; c) by shear forces; and d) by sudden pressure drops as the fish proceed through the device. TISEC devices by definition function by extracting some of the kinetic energy of flowing water, whereas tidal barrage systems such as at Annapolis, and tidal lagoons, depend upon potential energy. The forces and factors affecting fish that are induced to pass through a TISEC device are different, but are generally unknown; in addition, the design of some TISEC devices permits fish to avoid the structure, provided the fish is able to detect it in time. This will be both technology- and site-specific, and requires further research.

In addition to the pelagic fishes, demersal fishes that traverse Minas Passage include smooth and winter flounder, and Atlantic sturgeon. These may be affected similarly by noise, vibrations and sediment effects of construction and operation, but may be particularly susceptible to the electrical field effects of the subsea cable(s). Research is required to assess this potential effect.

Shellfish fisheries in the region are represented by scallops and soft-shell clams. Nine scallop license holders land their catch, most of which is taken from beds in the Inner Bay of Fundy, Scots Bay and the outer Minas Channel, in FMA 44 (Parrsboro). Landings have been highly variable, from almost 0 in 1996 to more than 600,000 kg in 2002, representing a landed value of $750,000. Direct displacement of these activities is not expected from either construction or operation, however there may be indirect consequences arising from noise and sediment dispersion through effects on planktonic larvae. There appears to be no current research that would address this issue.

Cape Enrage (New Brunswick)

The Cape Enrage site is chosen to represent the potential issues to be found in Chignecto Bay and the entrances to Cumberland Basin and Shepody Bay. For logistical reasons, it offers the best energy potential in this portion of the Bay of Fundy (See Section 3), although water depths of < 30 m may be limiting for some technologies. The possibility that maximum depth off Cape Enrage has increased significantly over recent decades (Parrott, pers. comm.) suggests that hydrodynamic forces may be actively changing the depth profile in this area. This will need to be evaluated if the site is chosen for TISEC deployment in the future. Substrates range from exposed bedrock, to glacial till, and to areas overlain with finer sediments. Sediments in suspension and deposited in shallower areas of Chignecto Bay tend to be finer than the coarser sands that predominate in Minas Basin (See section 5.1.3).

The principal fishery in this area is for lobster, pursued by vessels from the harbour at Alma, NB. Landings and value of this fishery have increased significantly in recent years, from ~$550,000 and 50,000 kg in the early 1990s to > $3M and 150,000 kg in 2002. Eighteen license holders operated out of Alma in 2004 (Dyer *et al*. 2005). Concerns about the interaction between energy development and the lobster fishery in Chignecto parallel those for Minas Passage (see Section 6.1.3.1 above).

Scallop fishing is the second most important catch landed in FMA 79, but it has declined significantly since the early 1990s, when more than 500,000 kg were recorded. Unlike the Minas Basin landings, there has not been a significant recovery in recent years. Scallop surveys indicate that the principal beds are in the outer portion of Chignecto Bay and the nearby Inner Bay on the New Brunswick shore, and thus not near any of the sites so far considered. Direct impact of TISEC development therefore seems unlikely, although there may be conflict for land-based facilities.

Net fisheries include that for American shad, and beach seines set for herring. Drift nets are commonly set to shallow depth in the Upper Bay, because shad swim nearer the surface in the turbid waters of the Upper Bay (Dadswell *et al.* 1983, 1984a), so this fishery may be less susceptible to direct impacts of construction or operation of a TISEC station, depending on the clearance above the turbine. Many of the drift vessels are small, and operate out of unregistered harbours, so there may also be little competition for shore-based facilities.

Digby Gut (Nova Scotia)

TISEC locations in the Outer Bay of Fundy will intersect with a greater variety of fishing activities than in the Upper Bay. The Digby Gut site is similar to other alternatives along Digby Neck in that the passage is narrow, rocky, relatively shallow in places, and used by a number of other sectors including fishing, transportation, and aquaculture. The waters are also home to a greater variety of animals of concern, including cetaceans and fish.

Principal fixed gear fisheries at or near this site target lobster and crab; mobile gear includes drags for scallop, trawls for flounder, handlines for haddock and pollock, and gillnets for other pelagics. Within the Annapolis Basin, which is accessed by target species only through the Gut, are important dragging, trawling and gillnetting fisheries involving scallop, haddock, pollock, herring, shad, and gaspereau. The interactions for these activities would be similar to those described in 6.1.3.1. In addition to these, scallops, urchins and sea cucumbers are taken by divers for food and pharmaceutical interests.

Much of the substrate in the Digby Gut area is bedrock, so that excavation requirements may be less extensive than elsewhere, but the implications of noise and vibrations remain, both during construction and operation. Similar conditions and considerations would apply for the other Digby Neck sites (Grand Passage, Petit Passage, *etc.*), but in Digby Gut the vessel traffic not only includes numerous boats of the scallop dragging, longlining and trawling fleets that operate in the Outer Bay and Georges Bank, but also larger service and research vessels, and the large Digby—Saint John ferry. These will present particular challenges during the construction phase because of the narrowness of the passage.

Head Harbour Passage (New Brunswick)

Head Harbour Passage is a major migration route for herring (Hopper, Connors Brothers, pers. comm.), and for Atlantic salmon from Passamaquoddy Bay and Cobscook Bay (Whoriskey *et al*. 2006). Thus the potential impacts resulting from noise and/or vibrations during construction and/or operation of either a demonstration or commercial scale TISEC development in Head Harbour Passage requires investigation (Anon 2006b). The main fishing activities in the vicinity of Head Harbour Passage and its vicinity are the many herring weirs and several aquaculture sites for Atlantic salmon (Buzeta *et al.* 2003). The weir fishery in the passage is important to Deer Island and Campobello (Hooper, Connors Brothers, pers. comm.). The salmon aquaculture sites are few and relatively small, given the suboptimal high current conditions. Other fisheries include lobsters along the shores but not in the deeper channels, sea urchins, scallops, and groundfish handlining and trawling, and rockweed harvesting (Anon 2006b, Casavant 2006, MacKay 2005). Because of the hard substrates in the passage construction effects of sediment re-suspension and scour should be minimal (Anon 2006b). Competition with weir and aquaculture users for infrastructure likely will become an issue with TISEC development. The fishing industry has access to approximately 15 wharves all of which require new investment. This issue is currently being assessed by the Small Craft Harbours Branch of Fisheries and Oceans Canada.

Management Opportunities

Because the Bay of Fundy as a whole is a complex integrated ecosystem, modifications to any part may have effects on other regions. It is therefore essential that much of the research and monitoring needed to address these environmental effects be planned and integrated for the Bay of Fundy as a whole, and not just left to independent, site- and technology-specific environmental impact assessments.

Providing answers to the challenging questions about the effects of TISEC or tidal lagoon development on the critical processes of the Bay of Fundy requires an holistic, cooperative and multi-disciplinary approach. As outlined above, creating a collaborative, integrating research initiative like the early Fundy Environmental Studies Committee, is the most effective management approach, but would require extensive involvement of First Nations and the fishing sector, both to assist with, and to advise on the research. The NGO community should also be encouraged to participate.

6.2.4 Data Gaps and Follow-up

The response of fish to these new TISEC devices is currently unknown, and this is a critical gap in knowledge. Experiments at the Race Rocks in British Columbia, the East River in New York, and the EMEC site in Scotland have so far provided no indication that fish come close to the turbines during operation, however, only the Verdant experiment in the East River was designed to monitor the behavioural responses of fish. It is essential to know how fish and mobile invertebrates behave in the vicinity of each device in order to forecast the effects of development. This is a key requirement for research and monitoring at any demonstration site. Because of the varied TISEC designs, such research will be needed for each case.

There is very little information about the effects of electrical fields on the behaviour of organisms associated with the bottom substrate, such as groundfish and mobile invertebrates. Evidence from offshore marine wind farms in Europe shows that the behaviour of many species is modified by the presence of underwater electrical cables (Dong Energy et al. 2006). There is a clear need for experimental investigation of the effects of electrical fields on the health and behaviour of such species, especially those that are components of important fisheries, or upon which significant fish species depend.

Existing data on the economic value of the fisheries in the immediate areas of development are inadequate to assess the significance of displacement, largely because the data are often confounded by combining landings from several areas. The direct value of these activities to communities surrounding the site, therefore, cannot currently be determined. Research is needed into the number of fishing operations, vessels, and products, and the precise locations where fixed gear fisheries (*e.g.* lobster) are currently operated. The present reporting mechanisms used in management of the fisheries cannot be easily modified to provide the information needed to assess TISEC development. This needs to be a separate initiative involving the fishers themselves.

The research should also assess the adequacy of existing infrastructure to accommodate the activities of a demonstration project, and of larger scale commercial development. Many of the harbours from which fishing activities are operated are old, and congested, and would need to be upgraded to additional provide services for construction, maintenance and operation of TISEC developments of any size.

6.3 Fish and Fish Habitat

In addition to those species that are the targets of the Bay of Fundy fishing sector, there are other species of interest and concern that occupy or traverse sites that have been identified as of high potential for TISEC developments. Some of these are the object of commercial or recreational fisheries at other locations than the Bay itself, or are of special concern because they are rare or play significant roles in ecosystem dynamics and processes.

6.3.1 Definition and Rationale for Selection

An obvious group includes migratory species (see Section 5.2.2.3.3), both the diadromous stocks that move between Canadian fresh waters and the sea, and stocks such as shad, alewife, blueback herring, and striped bass, that come from non-Canadian spawning grounds and move through these passages on feeding migrations. Species that are listed as Endangered, Threatened, or of Special Concern (see Section 5.2.5) constitute another category of fish whose presence or movement through these passages may bring them into conflict with energy developments.

6.3.2 Potential Environmental Interactions

For all these stocks, the issues will be similar for all potential development sites and phases: *i.e.*, concerns over destruction or modifications of habitat; direct mortality caused by interacting with the device(s); effects of noise and vibration; and secondary or indirect effects on trophic (*e.g.*, predator-prey) relationships.

Destruction or elimination of some habitat is an inevitable consequence of energy development, for at the very least the structures will cover pre-existing habitat. This may be a minor loss where construction is on scoured bedrock with very limited habitat potential, or a much larger ‘footprint’ as in the case of a tidal lagoon. In many areas of the Outer Bay, bedrock is colonized by a great diversity of benthic organisms that are of importance to fish as food or cover, and thus elimination of this habitat may be of significance. More mobile substrates, such as gravel and sand, harbour a variety of organisms of direct importance to fish, and provide cover or nesting habitat (*etc.*). As in the case of offshore wind farms, the scour protection provided to underwater structures is likely to provide alternate, new habitat that may compensate for that which is lost (Dong Energy *et al*. 2006). Unlike the case of a tidal lagoon or a barrage, most TISEC installations have a small individual footprint, but arrays of such devices established in passages of limited expanse may have proportionately larger cumulative effects.

Noise and vibrations during excavation, installation and operation may have important deterrent effects on fish that are currently unknown. Such effects may be particularly important with regard to migratory stocks. Most migrations occur over relatively restricted time periods during the year for any single species, but the large number of species that undergo landward and seaward migrations means that collectively there will be little time during the year when there are no movements of fish through the energy generating site. Forecasting these events, and investigating mitigating actions requires research.

Effects on fish habitat may come from a variety of sources, including changes in current velocities, patterns of mixing and dispersion, erosion and deposition of sediments (*etc.*). These may be obvious, as during excavation and construction or more subtle during operation phases.

6.3.3 Environmental Planning and Management Considerations

As indicated above, some aspects of the concern over fish species will be the same at any site within the Bay of Fundy, depending primarily upon the technology and the scale involved. Examples include deterrence by noise and vibrations (*etc.*) and some aspects of habitat change. What will vary somewhat from site to site is the array of fish species that is found at each site.

Minas Passage (Nova Scotia)

More than 30 species of fish utilize Minas Basin, many of which need to pass through the Minas Passage once or more during their life time. Many of these are outlined in Section 5.2.2.3. Important diadromous fish include Atlantic salmon, striped bass, American shad, alewife, blueback herring, Atlantic sturgeon, rainbow smelt. Marine fishes that traverse the passage include the commercial species outlined above, and others such as porbeagle, spiny dogfish, butterfish, lumpfish, menhaden, three species of flounder and a number of forage fishes. Those fish on feeding migrations, as exemplified by the American shad, often move in and out with the tide in Minas Basin over a period of days or weeks; if this behaviour occurs when they are in the Passage, then it may be that such schools would pass by or through a TISEC development repeatedly during each season.

Construction activities will represent the same challenges as outlined in Section 6.1: noise and vibration, and resuspension of sedimentary material increasing turbidity or causing tissue damage. Because of the narrow time 'window' of low velocities in the Passage, it is probable that construction activities will occur at any time of the day or night, in which case effects of artificial lighting may become an environmental factor affecting fish behaviour. (Several species of fish such as shad are adapted to low light, and run at shallow depths only where turbidity is high as it is in the Upper Bay.)

Cape Enrage (New Brunswick)

Many of the same species that utilize Minas Basin are found in Chignecto Bay, although numbers of cod, halibut and haddock are lower. Spiny dogfish females move into Chignecto from Minas Basin following release of their pups in summer to feed on pelagic fish there. In the outer part of Chignecto Bay, Atlantic wolffish are found in coarse sediment areas associated with scallops, but it is not yet known if they inhabit gravel beds up near Cape Enrage. As a demersal species, they would be primarily impacted by changes to bottom habitat, but might also be affected by electrical fields of the cable.

In general, the same conditions apply to the Cape Enrage site as described for Minas Basin.

Digby Gut (Nova Scotia)

The known fish fauna of the Outer Bay of Fundy exceeds 100 species, including all of those that also occur in the Upper Bay. Migratory species of great interest include Atlantic salmon, sea trout, striped bass, shad and gaspereau, as well as herring, cod, halibut and haddock. In addition, however, are a variety of species that, have only been recorded from the Outer Bay, largely because they enter from the Gulf of Maine and Scotian Shelf. These include swordfish, menhaden, great white shark, and exotics such as ocean sunfish and sea horses. Considerations of the effects of TISEC deployment on fish populations in the Digby Gut area generally mirror those described above. In addition, fish of the Digby and Annapolis Basin are susceptible to a number of predators, including seals, porpoises and whales. Because of the relatively restricted area of the Gut, both construction and operation activities of energy development may result in greater interaction with local and transient fish species.

Head Harbour Passage (New Brunswick)

Head Harbour Passage is home at some time to most of the fishes detailed in Sections 5.2. and 5.3 above, both for nearshore locations and deeper channels. In general, potential impacts on fishes detailed above hold true for Head Harbour fishes. Species in the passage of particular concern which may be disrupted by TISEC construction or operation are: herring because of its ecological and commercial importance; Atlantic mackerel (which follows the herring); and Atlantic salmon, for which this is the major route between Cobequid and Passamaqoddy Bays and the sea (Whoriskey *et al.* 2006).

Management Opportunities

Providing answers to the challenging questions about the effects of TISEC development on the critical processes of the Bay of Fundy requires an holistic, cooperative and multi-disciplinary approach. As outlined above, creating a collaborative, integrating research initiative like the early Fundy Environmental Studies Committee, is the most effective management approach, but would require extensive involvement of First Nations and the fishing sector, both to assist with, and to advise on the research. The NGO community should also be encouraged to participate.

6.3.4 Data Gaps and Follow-up

There is a real shortage of information about the distribution, seasonality and trophic relations of many non-commercial species of fish, especially in Chignecto Bay. In all potential sites, the changes in fish stock abundance in the Bay of Fundy in recent decades leads to uncertainty about the present status of many components of the ichthyofauna. Prior to any installation, surveys of local and migratory stocks will need to be carried out. Following installation, the occurrence and behaviour of commercial and non-commercial fish will need to be monitored in the vicinity of the installation in order to build up a more comprehensive knowledge of their reactions and the implications for different fish species.

The potential for direct damage to or mortality of fish from interacting with TISEC devices is expected to vary both with the site of deployment and with the technology involved. Other than the preliminary, and relatively short-term experiment by Verdant Technologies in the East River, New York, there appear to be no current studies of fish mortality that could be translated to assess the implications in the Bay of

Fundy. This is an area requiring new research. The response of fish to these new TISEC devices is currently unknown. This is a key requirement for research and monitoring at any demonstration sites.

Potential mortality of fish that pass through the turbine is a concern for all species of fish, both commercial and non-commercial. As indicated above, it is not clear whether in operation TISEC devices will emit vibrations or noise that will affect the behaviour of fish in the vicinity. If fish do not avoid the turbine(s), then their vulnerability to damage on passage through a TISEC device will vary according to the design of the device, its dimensions, rotational speed, precise location, and depth in the water, as well as the size, mobility and robustness of the fish. Consequently, this is very much a technology-, site- and species-specific interaction. Many of the technologies are envisaged as sitting on the sea bed, so that the generator and moving parts are several meters above the bottom and several meters below the surface. Therefore, species that move in the mid-water zone are more likely to interact with the device than those which move close to the bottom (*e.g.* flounder, sculpins, sturgeon), or the few (like menhaden and halfbeaks) that primarily move just below the surface. Furthermore, tightly schooling fish may be more vulnerable than solitary ones, and if one or more turbines transects the route and depth of a school, any mortality effects will be magnified. Future environmental assessments will have to consider these variables. In operation, a large array of several devices will magnify the concerns about direct effects on fish.

Because of the varied TISEC designs, such research will be needed for each case. Mitigation of any direct turbine mortality may be possible. Research at the Annapolis Tidal Generating Station has shown that fish can be driven away from the turbine entrance by acoustic devices set nearby (McKinley and Kowlyk 1989). It may be necessary to consider such strategies during the design, testing and development phase, if it appears that fish do not avoid the structure. The intention to conduct demonstration studies offers the opportunity for that research to be carried out before commitments to large scale arrays are made.

As with fisheries of commercial interest, there is a clear need for experimental investigation of the effects of electrical fields on the health and behaviour of fish that live near or travel through the sites selected for TISEC development.

The fundamental knowledge described above does not exist anywhere else; consequently, building the research knowledge base among the scientific community of the Bay of Fundy represents a valuable asset that will amplify the potential for the Maritime region to become a global centre of excellence in marine energy developments.

6.4 Marine Benthic Habitat and Communities

6.4.1 Definition and Rationale for Selection

Benthic organisms include all of those organisms associated with substrates – either the sea bed, or solid structures sitting upon the sea floor, such as wharves, pilings, and energy conversion devices. The benthic fauna is comprised of a large number of animal and plant phyla, and commonly represents a major fraction of the biological diversity of the marine and estuarine community. It is also a critical foundation for many of the important fisheries of the Bay of Fundy. Any effects of marine energy devices that diminish the productivity or diversity of the benthic community will exert indirect effects upon the fisheries that depend upon the existing benthic community.

The benthic community varies widely in diversity and abundance in the Bay of Fundy, reflecting the great variety of substrates and physical conditions that occur in different regions. Excavation and site preparation will directly affect this community by eliminating organisms from the area of construction, but may also have more distant effects as a result of sediment remobilization. Although not usually mobile as adults, and therefore not likely to be directly affected by the operation of TISEC devices, benthic organisms are adapted to and critically dependent upon particular substrates, the distribution and properties of which might be altered by energy conversion developments. Provision of scour-protection around TISEC developments may replace some lost habitat, and even enhance the benthic community by providing habitat that did not previously exist.

The organisms that colonize human constructions in the marine environment are collectively referred to as the **biofouling community**. This consists of some of the plant and animal species that normally inhabit firm bottom substrates, which invade the new surface either by settling as larvae or spores from the plankton, or migrating in from surrounding areas.

The benthic fauna category also includes numerous species that are mobile, but stay very close to the surface of the substrate, rather than moving in the water column. This group of **epibenthic** animals includes a number of invertebrates, notably scallops, lobster, crab and a variety of shrimp-like crustaceans, as well as demersal fish.

6.4.2 Potential Environmental Interactions

Benthic organisms in the area of construction will be directly affected by removal or modification of habitat, and in the footprint of the development this is likely to be an adverse effect. Depending upon the original nature of the substrate, however, the effects may be beneficial, if the variety of habitat is increased as a result of the construction, as found with wind farm installations on sandy bottoms (Dong Energy *et al*. 2006). Benthic organisms, particularly filter-feeders, are especially sensitive to suspended sediments in the water column; plumes of sediment arising from site clearance or preparation activities may have extensive effects when carried offsite by currents. In the Outer Bay, the areas of most interest for TISEC development include many of the passages that exhibit the highest biodiversity, in which the fauna is not usually exposed to large quantities of suspended sediments, and therefore might be more susceptible. The nature of the particles is important: sediments derived from drilling operations have different effects than more weathered materials such as those that are frequently mobilized by currents and waves in the Inner and Upper Bay of Fundy.

The significance of the biofouling community in this context lies in the ability of the organisms to settle upon new surfaces of a wide variety of materials, to grow abundantly there, increasing the mass of the structure, and modifying important physical processes, such as the patterns of water flow over the surface. All estuarine and coastal waters tend to exhibit a high biofouling capacity, but in very high velocity flows, such as the passages of greatest interest for TISEC development, the short periods of low velocity when settlement may occur, coupled with the scouring effect of high current velocities during the flood and ebb in the Bay of Fundy, may minimize this risk. If, however, TISEC devices were to be deployed in lower velocity areas such as the open Bay, the significance of the biofouling community would be enhanced.

6.4.3 Environmental Planning and Management Considerations

The benthic and epibenthic communities vary markedly throughout the Bay of Fundy. In the Outer Bay, substrate types range from fine sands and muds, to mobile sand waves, gravel, and bedrock (see Section 5.1.3). Each of these has its unique combination of species. The greatest diversity is found on rocky substrates, particularly in the passages between islands and the mainland. The Upper Bay, with its large intertidal zones, is dominated by sedimentary substrates except in the regions of highest velocity, and the associated fauna, while being less diverse, is characterized by species that may be extremely abundant, adapted to strong physical forcing, and critical elements in biological interactions involving migratory birds and fish. The implications of TISEC development obviously vary between these regions.

Minas Passage (Nova Scotia)

Very little is known about the benthos occupying the Minas Passage itself. Large areas of the Passage are covered with gravel, cobble or boulder, overlain in shallower regions with finer sediments, particularly sand waves. Compared with many other coastal estuaries, the sediments are relatively uncontaminated (see Section 5.1.8; Chou *et al.* 2004). Excavation and site preparation will exclude some forms directly, and have indirect effects on benthic fauna upstream and downstream as a result of sediment remobilization. Creation of new habitat in the form of scour protection around the turbines may increase the benthic diversity in the long term.

An important indirect effect is identified with the changing current patterns that might be created by a commercial-scale development. TISEC devices convert some of the kinetic energy of tidal waters, which is the principal factor affecting sediment mobilization and distribution. If a significant fraction of the kinetic energy is removed, the overall effect in Minas Basin would be some reduction in turbulent mixing, changed patterns of current movement within the Basin, and hence changed patterns of sediment distribution. Some of the most important benthic species, such as the mud shrimp *Corophium*, the worms *Nephtys, Glycera* and *Nereis,* the bivalves *Macoma* and *Mya,* and the mud snail *Ilyanassa,* are each associated with sediments having distinct grain sizes. Over time, coarser deposits have given way to finer ones, and *vice versa*, and the pattern is one that varies seasonally and from year to year (Daborn 2006). Modeling of the water flow consequences of energy conversion is a critical need for assessing whether such changes associated with energy conversion will have measurable or significant effects on the benthic community of the Basin. The importance of understanding the effects of a commercial scale TISEC development on the patterns of water flow is in the critical role that these species play in the food web that sustains both migratory fish and migratory birds in Minas Basin.

Reductions in tidal mixing might also have implications for the extent and persistence of ice formation in the Minas Basin. In general, the freshwater input into the Basin is very small compared with the tidal inflow, and turbulent mixing leads to generally uniform salinities throughout the water column (see Section 5.1.7). In winter, tidal mixing is reduced because of smaller tidal range and currents, and any further reduction in mixing will tend to favour more persistent ice formation. Whether this is significant will only be determined through modeling.

Cape Enrage (New Brunswick)

Similar issues apply to Chignecto Bay sites, although the sediments tend to be finer than in Minas Basin, so that turbidities are higher, and deposits are often more muddy. Forecasting the effects of energy conversion, especially in terms of flow patterns and sediment behaviour, will be an important challenge.

Digby Gut (Nova Scotia)

The benthic and epibenthic fauna of Digby Gut is much more diverse than the Upper Bay sites, and includes a number of species such as lobster and scallop with important commercial significance. The substrate ranges from exposed bedrock to gravel and cobble, providing habitat for an array of cnidarians (*e.g.* sea anemones), molluscs (mussels, snails, scallop), echinoderms and arthropods. These species are less exposed to high suspended sediment concentrations than those in the Upper Bay, and hence are likely to be more sensitive to sediment plumes generated during site preparation. Reductions in current velocity by a commercial scale development may also have subtle effects in modifying the physical and trophic phenomena that generally determine the nature of the benthic community. It is likely, however, that these effects would be hard to detect in relation to the wide range of conditions that currently occur over the seasons.

Head Harbour Passage (New Brunswick)

Head Harbour Passage has an incredibly diverse benthic fauna carpeting the rocky substrate (Pohle, pers. obs.), particularly in the deeper channels with high currents. These high diversity zones are, to a large extent, within the shipping channel for traffic into Passamaqoddy Bay, and include areas with the greatest tidal in-stream power density. TISEC development will displace the benthic community in the immediate vicinity of the installation, but new habitat development from scour protection may mitigate that impact. Many of the sessile fauna are filter feeders and those downstream may be impacted during construction from increased sediments in suspension. Whether changes in circulation from equipment operation will impact the benthic fauna is unresolved, however, effects from a pilot installation should be minimal. Lobsters are not expected to be impacted negatively (Anon 2006b). Some of the technologies being considered, including a floating rotating buoy system (Pohle, pers. obs.), may mitigate some of the potential benthic impacts better than others.

6.4.4 Data Gaps and Follow-up

As a result of almost a century of investigation in the Outer Bay of Fundy, in relation to fisheries and aquaculture issues, the benthic community of the Quoddy region is fairly well known. The same cannot be said of the other representative sites, particularly in Chignecto Bay. In addition, significant changes have taken place in the Upper Bay over recent decades, for example as a result of causeway construction and changes in fishery stocks; consequences of these changes for the benthic community often take decades to be revealed (*e.g.* Daborn *et al.* 1995).

Repeats of the broad surveys of benthic organisms that were conducted in connection with the 1970s exploration of tidal power development are a necessity both to evaluate the rates of change that occur, and to provide a contemporary baseline for monitoring in the future.

In all locations in which marine energy developments are contemplated, a programme of monitoring of the benthic community and habitat characteristics needs to be established, and repeatedly surveyed for a number years following installation of any devices. Standard monitoring transects should be laid out in areas that are thought to be within the area of influence of the development, together with reference transects that are well outside that zone in order that effects on the benthic community associated with long-term natural cycles or other ecosystem changes can be distinguished from those resulting from the energy development itself. Because continuity and consistency in monitoring is critical, such a program should not be solely dependent upon short-term monitoring assignments or contracts, but designed and managed as part of a comprehensive monitoring strategy.

6.5 Pelagic Communities

6.5.1 Definition and Rationale for Selection

In addition to fish and mammal species that move within the water column, there are several planktonic and nektonic forms of importance to the dynamics of the Bay of Fundy ecosystem. Although most of the planktonic forms are small, and unlikely to be directly affected by the large scale TISEC devices being considered, there are a number of larger species that play significant roles in the food web that might be affected as they drift through the structure. These include the larger crustaceans such as euphausiids, jellyfish and ctenophores, squids, and larval and juvenile fish. Euphausiids are an important food source for planktivorous fish and baleen whales; jellyfish are food for lumpfish, leatherback turtles and ocean sunfish (*Mola mola*); and jellyfish, ctenophores and squid are either important plankton predators or prey upon juvenile fish. Since these all form important links in the food web, they are a necessary consideration. Larval fish (*i.e.*, the ichthyoplankton) may be of particular concern because of their susceptibility to pressure changes and shear forces.

6.5.2 Potential Environmental Interactions

Planktonic forms exhibit limited swimming behaviour, so their ability to evade a TISEC device is almost nil, but most are very small, and these are not likely to be affected by stresses during passage through the device. The exception may be larval stages of fish, many of which have limited swimming capacity but are susceptible to physical stresses such as shear forces or pressure change. The importance of estuarine regions of the Bay as nursery areas results in large numbers of ichthyoplankton in the water column that may be affected by passage through a TISEC device. Larger gelatinous plankton such as jellyfish are likely to be even more susceptible. Non-fish nekton such as euphausiids and squids represent a group of pelagic organisms that might also be more susceptible to both the noise and vibrations associated with excavation and installation, and the stresses of passage through the device during demonstration or commercial phases.

6.5.3 Environmental Planning and Management Considerations

Assessment of the environmental effects of TISEC development in the Bay of Fundy requires a more complete understanding than currently exists of the trophic dynamic pathways that characterize the different parts of the system. The Upper Bay waters act as important nursery grounds for a number of fish species, so that the water column carries fish larvae in abundance. The warm waters and high copepod densities of Minas Basin and Chignecto Bay are important in the life cycle of a number of marine and anadromous fish. The larger planktonic and nektonic invertebrates are more common in the Outer Bay in general, in part because they drift in from spawning grounds elsewhere, although one, the longfin squid (*Loligo pealei*) is a prevalent summer visitor that spawns in Minas Basin. This species is distributed throughout much of the western North Atlantic and is the subject of a fishery from Cape Cod to Cape Hatteras. In the Outer Bay, the shortfin squid, *Illex illecebrosus*, is also common. As with the fish, how these species will respond to and be affected by TISEC development is unknown.

Minas Passage (Nova Scotia)

With one exception, the longfin squid, large planktonic forms or invertebrate nekton are not common in Minas Basin, and thus are not likely to be greatly at risk from TISEC developments. The majority of the plankton is of small size, and is well adapted to high turbidities and high turbulence. However, the longfin squid spawns in the Minas Basin, and may represent a separate stock. Its response to noise is unknown.

Cape Enrage (New Brunswick)

No large invertebrate nekton are known from the Chignecto Bay area, although since jellyfish, ctenophores and squid are largely imported from the Gulf of Maine or Scotian Shelf, it is to be expected that some will be present in Chignecto Bay.

Digby Gut (Nova Scotia)

Large plankton and invertebrate nekton are much more common in the Outer Bay of Fundy in summer months, and are therefore more important factors in the food web of the Annapolis Basin and Digby Gut. Vulnerability to a TISEC installation will depend upon the depth of installation relative to the depth of occurrence of the animals.

Head Harbour Passage (New Brunswick)

The tidal currents and upwelling through Head Harbour Passage lead to high concentrations of nutrients, phytoplankton, and small and large zooplankton, including the trophically important krill, as detailed in Section 5.2.2.1. These organisms form the foundation of a complex and extremely important food web. Construction and operation of a demonstration scale TISEC project should have little direct impact on the pelagic community in terms of suspended sediment, changed current patterns, noise/vibration effects, or trophic effects. However, commercial scale development in the narrow Head Harbour Passage may have the potential to impact pelagic organisms, and hence their predators, there and in adjacent waters.

6.5.4 Data Gaps and Follow-up

The principal concerns regarding invertebrate pelagic organisms are associated with the Outer Bay of Fundy. At present, knowledge of their abundance is derived serendipitously from surveys for ichthyoplankton or larger fish, and may not be obtained at the appropriate depths to assess the impact of TISEC devices. It is therefore necessary to initiate seasonally-based surveys of mid-water species of macroplankton to provide baseline data prior to installation, and a scheme for monitoring effects afterwards. As with the benthic surveys described above, monitoring programmes need to be designed with fixed stations or transects representing both areas expected to be under the influence of the development, and suitable reference areas. Consistency and continuity of sampling is critical, both in time and space, requiring establishment of appropriate protocols, and close supervision of operations. Short-term contracts with different suppliers are generally not suitable for providing the consistency and continuity required; it is therefore desirable that the execution of these monitoring programmes be coordinated by a more permanent agency responsible for the overall research programme for Bay of Fundy marine energy initiatives.

6.6 Marine Mammals

6.6.1 Definition and Rationale for Selection

The marine mammal fauna of the Bay of Fundy is a highly valued component of the ecosystem, especially in the Outer Bay. Included in this group are several species of special concern, including whales (notably the North Atlantic right whale), porpoises, dolphins and seals. TISEC development, at either demonstration or commercial scales, will be expected to have both direct and indirect effects on marine mammals. Tidal lagoon development is likely to take place only in shallower locations in the Upper Bay of Fundy, where marine mammal susceptibility would be focused on porpoises and seals rather than whales.

6.6.2 Potential Environmental Interactions

Potential effects of TISEC projects on marine mammals include the following:

- Deterrent effects of excavation and installation activities associated with noise, vibrations and possibly artificial lighting at night;
- Deterrent effects of operation associated with noise or vibrations, especially those species that use sonar for pursuing prey;
- Disruption of communication between mammals as a result of increased underwater noise;
- Direct collision or contact with TISEC devices;
- Indirect effects through changes in prey distribution and abundance, both of fish that may be deterred from the vicinity of the device and prey that are brought to the surface and concentrated as a result of upwelling.

The susceptibility to these potential effects varies among the mammals that utilize the Bay of Fundy. All may react negatively to the noise of pile-driving or drilling operations; similarly, all mammals use sounds to communicate within their group, many of the whales use low-frequency sounds for long-distance communication, and some species use sonar to track prey. Increasing the noise level in the restricted areas of the passages on a continuing basis could have significant effects either by direct deterrence, by interfering with the animals' ability to navigate or communicate using their own sounds, or to track food. Because of the novelty of TISEC devices, there is little information available to assess these implications; however, research at Danish offshore wind farms has shown that animals using sonar for tracking prey (*i.e.*, porpoises) avoided the wind farms almost entirely during construction, whereas seals do not (Dong Energy *et al*. 2006). However, when the wind farms had been operating for two years, the activity of porpoises in the area returned to pre-construction numbers in one case, whereas in the other case, porpoise activity remained well below baseline. The reasons for this are at present unclear.

There is little evidence that marine mammals come into contact with large stationary objects in the marine environment. Most of their encounters are with fishing gear that may be too small in aspect to be detected underwater (ropes, traps, weirs etc), or with moving objects such as vessels. However, it is not clear whether underwater noise or vibrations from an operating TISEC device will confuse signals and diminish the mammals' capacity to discriminate hard surfaces, which might result in them encountering the device. Although not an exact analogy, it is well known that seals remain in the vicinity of the Annapolis Tidal Generating Station, especially during the shad and gaspereau runs, and on two occasions humpback whales have moved into the Annapolis headpond, probably in pursuit of fish. There are no records that any of these animals have interacted with the turbine itself.

Indirect effects, such as changes in food concentrations as a result of upwelling, are possible implications, especially for those species (*e.g.* minke, finback and right whale) that feed on euphausiids or *Calanus*. Whether this is a significant implication depends upon location of the TISEC development relative to feeding areas, the scale of development, and therefore the extent of changes to mixing zones. Answers to these questions should come from future modeling exercises.

6.6.3 Environmental Planning and Management Considerations

Most marine mammal activity occurs in the Outer Bay of Fundy, and therefore it is there that the primary concerns need to be focused. However, some species range widely through the Bay, and so any site has a potential for interaction with marine mammals. The absence of knowledge about the effects of TISEC devices on behaviour of marine mammals should be a high priority for investigations associated with any demonstration projects. Participation of the whale-watching industry is also essential.

Minas Passage (Nova Scotia)

Minas Basin and Cobequid Bay are regularly visited by harbour seals, harbour porpoise and longfin pilot whales, often in pursuit of migrating shad. Occasionally, grey seals, humpback and minke whales, and white-sided dolphins are also seen within the Minas Basin, which means that they have traversed Minas Passage. Their ability to do so with TISEC devices installed in the Passage cannot be assessed at this time.

Cape Enrage (New Brunswick)

A similar array of mammals and issues identified in Minas Passage applies to the Chignecto Bay sites.

Digby Gut (Nova Scotia)

Except for the largest and rarest of the whales, most of the mammals listed in section 5.2.2.5 (see Table 5.3) are likely present at least occasionally in the Digby Gut area. Many, especially harbour porpoise, harbour and grey seals, move in and out of the Gut regularly in pursuit of fish, and thus pass the potential TISEC site frequently. Their risks will be determined largely by behavioural responses to the device, which remain to be determined.

Head Harbour Passage (New Brunswick)

The Quoddy Region and Head Harbour Passage are rich in marine mammal biodiversity, hosting 19 species. Notable species are the North Atlantic right whale, finback whale, humpback whale, minke whale, harbour porpoise, and harbour seal. Potential impacts from TISEC devices have been detailed above but direct effects cannot be predicted at this time. Anon (2006b) made a preliminary conclusion that risks to marine mammals are expected to be negligible unless noise is determined to be an issue.

6.6.4 Data Gaps and Follow-up

Although it is thought to be unlikely that mammals will remain or venture close to underwater turbines, any risk to marine mammals, however small, must be carefully evaluated. Existing surveys of marine mammal occurrence and movements will need to be enhanced in the vicinity of any proposed TISEC development in order to ensure that the frequency, depth of movement and species distribution are well known prior to deployment. Because of the large areas used by mammals, existing mammal surveys in the Outer Bay should be expanded with a greater attention to the vicinity of high priority energy-generating sites. The formal surveys that currently are conducted, such as those by DFO and the New England Aquarium, should be augmented by recruitment of other marine users in the area, especially whale-watching organizations and local fishers.

The behavioural responses of marine mammals to energy-generating devices are almost entirely unknown, and this is therefore a gap in knowledge that must be filled as part of the assessment of the potential for marine energy development. Tracking of porpoises and seals should be conducted during demonstration and testing of TISEC devices at the Minas Passage facility, but this will provide little information about whales. Experimental studies of the effects on behaviour of marine mammals should be carried out in the Outer Bay, either with any deployment of a TISEC device, or through broadcasting of the noises generated by devices being tested elsewhere.

6.7 Marine Birds

The bird fauna is one of the most important components of the Bay of Fundy, and one that reflects the diversity of habitats and processes that are to be found in the ecosystem. In the Outer Bay, the bird fauna includes a large number of species that travel to the Bay from elsewhere for winter or summer, and others that remain in the area. Many of the smaller marine birds feed in convergence zones on plankton or fish that are brought to the surface by tidally-induced upwelling. Others, like the diving ducks, congregate and feed where access to benthic animals like mussels is available, particularly in the passages. In the Upper Bay, the principal groups are migratory shorebirds that arrive in vast numbers over the late summer to feed on the abundant benthic life of the exposed intertidal zones. It is the richness of the Bay that attracts all of them.

6.7.1 Definition and Rationale for Selection

Although an important part of the ecosystem of the Bay of Fundy, relatively few of the birds will be directly involved with either site preparation or operation of submersed TISEC devices, although noise and vibrations may be important deterrents for those that inhabit the passages favoured for energy conversion. Birds that may be directly impacted by these developments include deep diving species that frequent the Outer Bay of Fundy. Indirect effects, associated with effects on their prey, may be of significance to a wider array of species, including those that depend upon upwelling zones, or on intertidal benthic species that may be affected by development or operation.

6.7.2 Potential Environmental Interactions

Diving birds, such as eiders, frequent the major passages of the islands in the Outer Bay, where they feed on benthic forms such as mussels. Depending upon the depth to which they dive, and the depth of a TISEC development, they may or may not be vulnerable to direct interaction with the device. It is likely, however, that noise or vibrations will be a significant deterrent during the site preparation, and possibly during operation phases. Decrease in turbulence downstream of a TISEC array as a result of energy conversion, might affect the availability of many surface-feeding forms, such as terns, phalaropes, gulls, shearwaters and petrels, to obtain their food. Some of these are already affected by oceanographic changes that appear to have diminished their access to prey (*e.g.* see Minich and Diamond 2005).

Migratory shorebirds, including sandpipers and plovers, that visit the Upper Bay of Fundy in summer on their migration between Arctic breeding grounds and southern wintering grounds, depend upon the abundance of benthic intertidal invertebrates. The distribution and abundance of their prey are a function of sediment properties, which might be changed as a consequence of tidal power development.

6.7.3 Environmental Planning and Management Considerations

Almost no information exists about the effect of TISEC devices on bird life, and this will continue to be the case until practical research is completed with a demonstration scale project. However, experience with Danish wind farms shows clearly that birds respond to arrays of turbines by avoiding them, and although the stimulus inducing them to do so has not been established, it is assumed to be a response to either noise or vibrations. One might therefore suspect that some of these species will be distracted and possibly deterred from areas being used for energy generation, especially those that dive for their food.

Minas Passage (Nova Scotia)

The major concern for the Minas Passage site would be to understand and assess the direct and indirect effects on migratory birds, particularly sandpipers and plovers, that visit to feed on *Corophium, Glycera* and other intertidal invertebrates in the Minas Basin. Few of the principal feeding grounds are found in the immediate vicinity of the Minas Passage, but roosting areas, where the birds rest during high tide, may exist in the region. Roosting birds are very susceptible to disturbance by human activity, and repeated disturbances are thought to represent a significant problem for the birds in that it decreases their ability to put on fat needed for the next phase of their migration. Land-based activities associated with the development of energy conversion devices, and even tourist activities, would be considered a concern if they occur near shorebird roosting sites (Hicklin, pers. comm.).

The more challenging question, relates to the indirect effect on shorebird populations of changes in the patterns of sediment distribution, which will impact their food resources. As indicated below, sediment distributions and properties have exhibited significant changes in recent decades for reasons that are unclear. Decreases in *Corophium* populations have resulted in changes in dispersion and behaviour of the birds, and is thought to be responsible for the more extended period of time being spent by birds in the Minas Basin feeding grounds. Understanding the consequences of decreasing tidal energy in this system through modeling is important to assess the potential implications for shorebirds.

Few diving birds apparently frequent the Minas Passage; although cormorants are common, and a breeding colony exists on Boot Island, it is thought that they mostly forage nearer to shore in shallower waters, and are not likely to interact with any TISEC devices in Minas Passage.

Cape Enrage (New Brunswick)

The issue for birds in Chignecto Bay is exactly comparable to that described for Minas Basin. There are major shorebird feeding grounds at Mary's Point and Dorchester Cape, which are (with the Southern Bight of Minas Basin) part of the Hemispheric Shorebird Reserve system.

Digby Gut (Nova Scotia)

The Outer Bay has a much larger array of marine birds than the Upper bay, including the dabbling and diving ducks, and mergansers. The vulnerability of these at Digby will be similar to that for Head Harbour Passage, as below.

Head Harbour Passage (New Brunswick)

Head Harbor Passage may be critical for feeding, breeding, or as a migratory waypoint for many species of seabirds as detailed elsewhere in this report. Demonstration scale development should have little impact on seabirds. During construction a commercial installation likely will not physically impact individual seabirds as they are mobile and can avoid harm, however excessive vibration may cause avoidance of an area or disruption of feeding or nesting, and moorings, *etc.* may cause entanglement of diving birds (Anon 2006b and references therein). Negative impacts may be especially important to migrating northern phalaropes and Bonaparte's gulls.

Management Opportunities

In addition to the management opportunities described above, numerous natural history or naturalist groups are available in the region that have both local and scientific knowledge and the capacity to expand the scope of monitoring programmes.

6.7.4 Data Gaps and Follow-up

Existing surveys of marine bird occurrence and movements will need to be enhanced in the vicinity of any proposed TISEC development in order to ensure that the frequency and species distribution are well known prior to deployment. As with mammals, it is anticipated that most birds will avoid the vicinity, in which case the primary concern will be the evaluation of the effects of that displacement.

Indirect effects on birds arising as a consequence of changes in the abundance or accessibility of their prey need to be assessed by a combination of research and monitoring. Because of the large areas over which birds may forage, monitoring of their feeding behaviour is a real challenge. Where shorebirds have changed their feeding areas in the Upper Bay of Fundy in the past (assumed to be a response to changes in distribution of principal food species), it has often been some time before their new feeding areas were identified, frequently by local people involved in naturalist pursuits. Local naturalist organizations are an important potential resource for enhancing the monitoring capacity for near-shore bird activity, and should be recruited to that end in the establishment of monitoring programmes. Such groups are not equally available for offshore marine areas where many seabird species forage, but an equivalent exists in the form of whale-watching vessels, fishers and other marine traffic. Consistency and continuity are essential elements, and therefore a continuing, scientifically-based authority should be established to oversee the monitoring and research programme, to provide training of participants and quality-control, storage and analysis of the data.

6.8 Species at Risk

6.8.1 Definition and Rationale for Selection

Those species in the Bay of Fundy that are recognized as at risk inevitably rank as a key environmental issue. The species in this category include five mammals, eight birds and nine fish. They are listed in Section 5.2.5, and several of the mammals and fish discussed in appropriate sections above. Under Canadian law, activities that increase risks to these species require very careful evaluation.

6.8.2 Potential Environmental Interactions

The implications for species at risk mirror those of organisms in their own group, and may be both species- and location-specific.

6.8.3 Environmental Planning and Management Considerations

Effects of TISEC development include direct effects such as mortality from collision with the device, and distraction or deterrence by underwater noise, vibrations and light, and indirect effects resulting from changes to the ecosystem that affect critical habitat, or food and predator relationships. Vulnerability will also be determined by the prevalence of the species in the areas of energy development, or the circumstances of the species when it is in the vicinity of the development. For example, fish on a spawning migration run may be more vulnerable than those on feeding migrations or in residence near a turbine; mammals actively pursuing fish prey may be less sensitive to signals from the turbine than at other times.

Minas Passage (Nova Scotia)

Principal species at risk in the Minas Basin area include the Atlantic salmon and the porbeagle shark, both of which are listed as Endangered by COSEWIC, and the striped bass, which is listed as Threatened. Inner Bay of Fundy salmon populations are now significantly reduced as a result of habitat losses and fishing mortality. Their vulnerability to a TISEC development in Minas Passage arises from the fact that they must negotiate the Passage to move between spawning grounds which remain in the Salmon, Shubenacadie and Gaspereau Rivers, and their feeding grounds in the North Atlantic. Striped bass continue to spawn successfully in the Shubenacadie River, although several other stocks in Minas Basin have declined significantly. There are numerous striped bass in Minas Basin, but not all of these are from local rivers, many having come to the Upper Bay on a feeding migration. Other fish species of concern that may be present occasionally in the Minas Basin include cusk, Atlantic and spotted wolffish, winter skate, and cod.

Finback whales and harbour porpoise, both of which are of Special Concern, also are known to visit Minas Basin. The harbour porpoise (see below) is a regular visitor following schools of fish in summer.

The peregrine falcon, which has become re-established in Minas Basin as a result of an active programme, is considered Threatened by COSEWIC, largely because of its low success elsewhere. This species is not likely to be directly affected by TISEC development, although it may be affected by declines in the abundance of shorebirds, which constitute a principal food source during the summer migration.

Cape Enrage (New Brunswick)

Chignecto Bay has many of the same species as Minas Basin. In addition, there may be some Atlantic wolffish in the outer part of Chignecto Bay, although the majority of the known records within the Bay of Fundy are from the Inner and Outer Bay. This species is not likely to be directly affected by TISEC development in Chignecto Bay, but has the potential to be indirectly be affected by any changes in distribution of scallops.

Digby Gut (Nova Scotia)

Most of the cetaceans and fish listed from the Bay of Fundy occur in the vicinity of Digby Gut. The factors contributing to their vulnerability have been discussed elsewhere in this document.

The Outer Bay of Fundy once had of the highest concentrations of harbour porpoises in the world (Hoyt 1984). Despite its abundance in the Bay, COSEWIC lists the harbour porpoise as a species of Special concern. This is largely due to their susceptibility to by-catch mortality in fishing gear, especially gill nets, and concerns that they are being excluded from a portion of their natural habitat by acoustic devices used in aquaculture operations.

Head Harbour Passage (New Brunswick)

Virtually all the species at risk listed earlier in this report may be present at some time in Head Harbour Passage or its approaches with the exception of shortnose sturgeon. Though any of these species has the potential to suffer negative effects directly or indirectly from a TISEC installation in head Harbour

Passage, the species of most concern are the North Atlantic right whale (Endangered) and the finback whale (Special Concern).

Management Opportunities

In addition to the management opportunities described above, involvement of First Nations, the whale-watching community, fishers and other NGOs would be necessary to achieve more effective understanding of the roles these sites play in the life cycles of species at risk. Recruitment of such participants not only enhances the coverage and diversity of information, but produces two other benefits: enhanced knowledge and involvement of the public in coastal management and environmental issues.

6.8.4 Data Gaps and Follow-up

The major deficit in available information for many of the species at risk is their prevalence in the areas in which TISEC developments might take place, particularly in the Upper Bay. Monitoring of some species is currently under way, especially in the Quoddy region, but these monitoring programmes need to be extended to cover the possible movements of fish and mammals to all areas where development is possible.

As with marine mammals and birds, investigative and monitoring programmes need to be scientifically designed, overseen and coordinated, and continued for a long period. Recruitment of non-government organizations and personnel could enhance the coverage and comprehensive nature of the monitoring programme. A continuing and formally established organization (such as AESN, COOGER or OEER) should be charged with the responsibility for design, training, quality control, and data management and analysis.

6.9 Aquaculture

6.9.1 Definition and Rationale for Selection

The Bay of Fundy is home to a major portion of the aquaculture industry within Atlantic Canada. While not equally applicable to all areas, TISEC sites include regions currently in use, or of potential use, to aquaculture. As such this industry sector represents a major socio-economic force requiring key consideration in terms of potential interaction with ocean energy development.

6.9.2 Potential Environmental Interactions

With the steadily rising demand for seafood and a global shortage of aquaculture sites there will be continued pressure for additional sites (see section 5.2.4) in the Bay of Fundyand therefore potential competition with ocean energy development. The two industries share a need for strongly flowing water, but practical limitations related to swimming capabilities of caged fish and the challenges of maintaining cages in high velocities mean that <u>at present</u> the finfish aquaculture industry tends to operate where current velocities are less than 1 m/sec (Robertson, pers. comm.). Although TISEC devices might be chosen that operate in velocities less than 1.5 m/sec, present options primarily target higher velocity situations. Therefore potential competition between aquaculture sites and ocean energy development sites is not an immediate concern. This may be a future concern if pressure for new aquaculture sites leads to establishment of cages in higher velocities, or if new energy extraction devices enable efficient and cost-effective use of lower velocities.

Potential interactions with existing aquaculture sites could come from site preparation and construction, particularly from sediment re-suspension, noise and vibrational effects. The latter may also be a factor during TISEC operation. In this regard, it is presently unclear what would constitute minimal required separation distances between aquaculture and ocean energy operations but this would likely depend on the particulars of local current and site conditions. A recent buffer zone requirement of one km between locations for ocean energy extraction, set forth by the Government of New Brunswick, (GNB, 2007) has begun to address this issue. However, the minimum distance to aquaculture sites, given as 100 m, may have to be re-examined.

Another area of interaction is infrastructure related, as the development of offshore energy generation sites will require similar shore-based infrastructure that currently supports the fisheries and aquaculture sectors. Presently most wharves are already over subscribed, or in need of upgrading, as they have approached the end of life expectancy. It is expected that new energy-related developments will require upgrading of old or creation of new shore-based facilities, but there remains the possibility that investments in energy may displace traditional fisheries that are economically marginal. In either case, significant improvements and investments are required to meet current and expected industry requirements in wharf utilization.

6.9.3 Environmental Planning and Management Considerations

Minas Passage (Nova Scotia)

There are presently no marine aquaculture sites in the vicinity of this area and environmental conditions are such that sea-based rearing operations are unlikely to be installed in Minas Passage.

Cape Enrage (New Brunswick)

There are presently no finfish aquaculture sites in the vicinity of this area and environmental conditions are such that sea-based operations are unlikely to be installed at Cape Enrage. However, the area has potential for shellfish aquaculture.

Digby Gut (Nova Scotia)

Digby Gut encompasses the transition area between the Bay of Fundy and the Annapolis Basin. A number of marine aquaculture lease sites for salmon, oyster and other species are found within the area. Given the limited space within the area, this site is where aquaculture interactions with ocean energy development are most likely to occur and must be considered very carefully.

Head Harbour Passage (New Brunswick)

Among the four scenarios, this is another where aquaculture-ocean energy interactions described above can potentially occur, as the Passage is within the area of greatest concentration of aquaculture within the Bay of Fundy. Within Head Harbour Passage this includes four lease sites in the very upper reaches and seven leases within the lower section of the Passage, as well as two sites in adjacent Head Harbour (see Fig.5.21). It is important to note that these salmon aquaculture sites are small in size compared to the present industry standard required for economy of scale. Aside from high energy profiles, the proximity of existing submarine power cables crossing near Casco Island and Chocolate Cove are considered advantageous for ocean energy development. Given the distribution of aquaculture sites at the upper and lower reaches of the Passage, the central area of Head Harbour Passage between the two cable crossings would offer the least interaction with current fish rearing facilities.

Management Opportunities

In addition to management opportunities described above, the Fishermen and Scientists Research Organization and the Aquaculture associations would require collaboration to understand the needs, potential conflicts, and mitigation opportunities between these two industries.

6.9.4 Data Gaps and Follow-up.

Uncertainty remains about the necessary setback that would be required between any TISEC device and finfish aquaculture sites. If the device generates low-frequency vibrations that travel further through the water, it will be necessary to assess whether these would cause additional stress to finfish held in sea cages. Research on noise and vibration emissions during site preparation and operation, and the effects that these have on fish is am important research issue. The question is particularly relevant to Head Harbour Passage and Digby Gut, where finfish aquaculture is currently in place.

6.10 Marine Transportation

6.10.1 Issue Definition and Rationale

Marine transportation is a KEI in consideration of potential effects for project related marine traffic and project marine infrastructure as a potential impediment to vessel movements and safety. These issues are regulated under the *Navigable Waters Protection Act* and have effects resulting from the *Ocean's Act* and the *Canada Shipping Act* as they apply to navigation rules and regulations regarding aids to navigation. While commercial shipping is the focus of this section, there is also potential interaction with the following: fishing vessels during normal transit as well as during fishing operations; recreational boating activities; and, navigation channel restrictions due to aquaculture operations and fish farming.

6.10.2 Potential Environmental Interactions

The *NWPA* assessment would include construction and operation phases. An approved site would be required to be marked, as directed by Transport Canada, with appropriate lighted buoys to create effective "no entry" zones, and would require the issuance of Notices to Mariners and Notices to Shipping detailing the areas affected by the construction project. Other conditions may be imposed by the Navigable Waters Protection Program (NWPP) as well. As part of normal vessel requirements, the construction barges and support vessels would be subject to normal Transport Canada Marine Safety Branch regulations and inspections. No construction site would be allowed to completely prevent the conduct of other marine traffic and any restriction would have to be within the accepted limits permitting safe navigation through the area.

Construction and operation phases could also have potential effects on ferry services, the fishing industry, yacht clubs, eco-tourism operators, *etc.*, and further consideration is required.

During the construction phase, there are potentially a number of interactions affecting marine transportation. Construction will require transits of work boats from supply ports to the work site. These voyages will involve the carriage of personnel and small amounts of equipment. Larger pieces of equipment will require the use of self-propelled vessels or towed barges. Towed barges are normally slower than other vessels and involve longer overall lengths which pose additional problems in the area of other shipping activity or in restricted channels. Commercial fishing and aquaculture sites are also to be considered in this phase. Both require normal vessel traffic to reach their sites and aquaculture is also subject to *NWPA* approval which means that existing sites will already have received approval from Transport Canada and the appropriate provincial fishery department to be located in that area. Recreational boating is normally capable of operating in shallow water outside of marked channels and should not be a concern as long as passage is possible.

The general risk of interference with marine transportation, during the operation phase, would be the potential for striking underwater installations at low tides or damaging installed transmission cables.

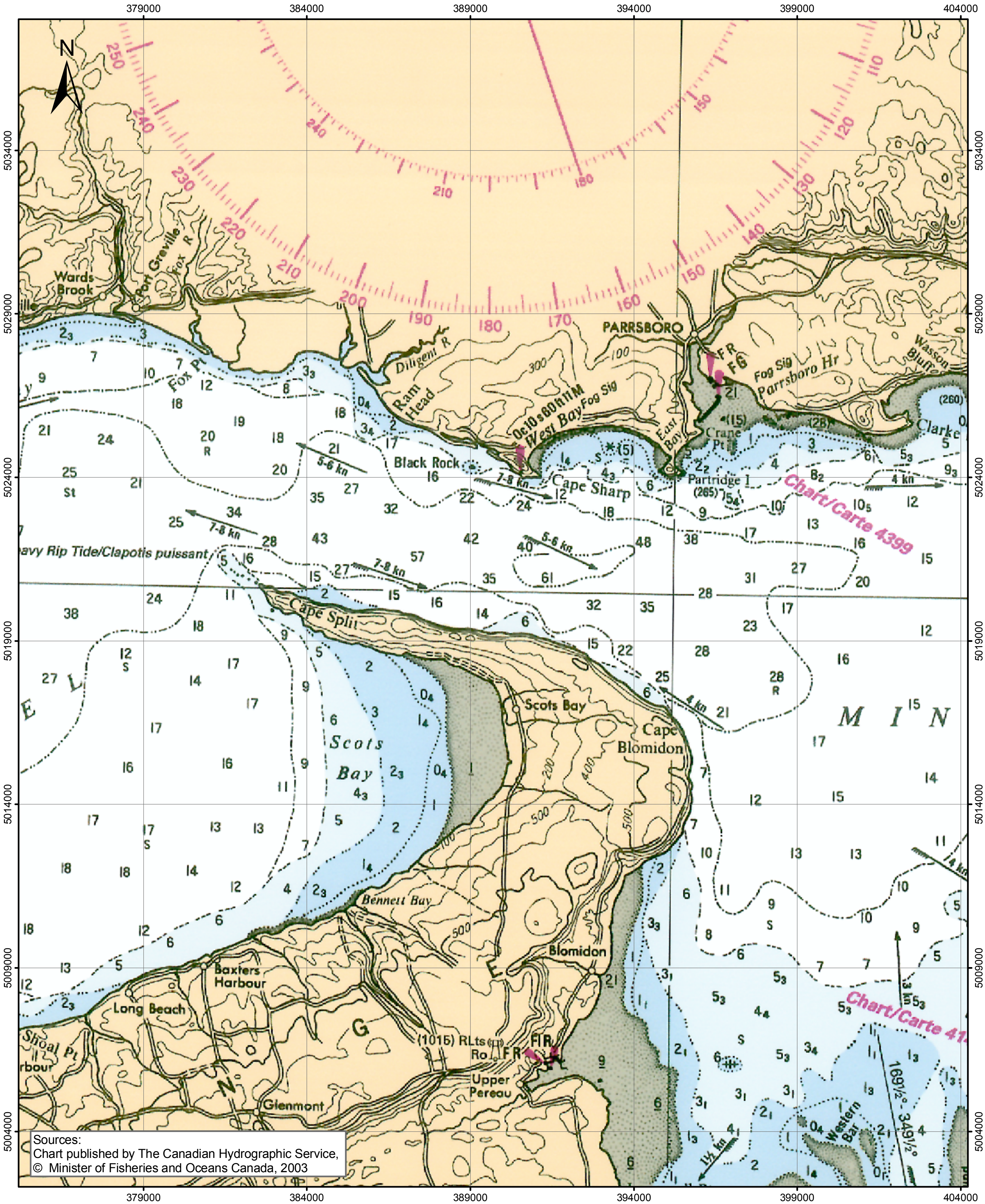
6.10.3 Environmental Planning and Management Considerations

Zones would be required to ensure that no anchoring, or other actions which might result in damage to submerged equipment and cables would occur. This must be done in conjunction with Transport Canada, and the marine transportation users. All of the above is accomplished through negotiation with Transport Canada and would require Notices to Mariners being posted which would result in permanent markings being established on the appropriate marine navigation charts.

Minas Passage, NS

An excerpt from the Canadian Hydrographic Services (CHS) chart for the Minas Passage area is included as Figure 6.1.

In 2006, there were 251 movements of bulk carriers and 156 movements of tugs assisting them at Hantsport in the Minas Basin. There are an average of 30 bulk carrier movements per month from November to April and 20 movements per month during the remainder of the year (MCTS 2007). These movements are carried out with local-knowledge pilots aboard to assist the vessel's Master. Entry to Hantsport, by the gypsum carriers, can only be undertaken on the rising tide and departure must occur just after the high tide period. This leaves only a very short period between arrival and departure in order to ensure that grounding does not occur. Any reduction of water depth may result in a decrease of cargo carrying capacity and thus in revenue generation. Consultations with the gypsum company and the Atlantic Pilotage Authority should include discussions of the water depth and channel requirements of existing as well as replacement vessels which may be larger with deeper draft.



Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: Nov. 27, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-023

Figure 6.1
Representative Project Location
Minas Passage, N.S.

0 1,200 2,400 4,800 7,200 9,600 12,000
Meters

ACADIA CENTRE FOR ESTUARINE RESEARCH
New Nouveau Brunswick
Jacques Whitford
OEER FUNDY TIDAL ENERGY

Drift ice has occasionally been a problem and would require vessel support in keeping the ice away from working barges and other surface activities. In-year information can be obtained from the Canadian Coast Guard Ice Centre in Dartmouth, NS.

Digby Gut, NS

An excerpt from the CHS chart for the Digby Gut area is included as Figure 6.2.

The depth of water in Digby Gut is approximately 30 metres at lowest low water. In 2006, Digby Harbour averaged 60 to 100 vessel movements per month from October to April and 105 to 216 movements per month from May to September. The higher summer average was due to increased ferry traffic and research vessel movements. (MCTS 2007)

The Digby/Saint John ferry provides twice daily service during the summer months and once daily during the remainder of the year. This vessel is the largest ferry in the Bay of Fundy services at 146.3 metres in length with a beam of 20.5 metres and draws 4.6 metres of water. (Bay Ferries 2007) The narrowest width of the main channel, with a minimum water depth of 7 metres, is approximately 0.5 km, thus restricting vessel manoeuvrability. Any further restriction to this channel may adversely affect the safety of navigation. Consultation with Bay Ferries will determine actual requirements to ensure navigation safety.

In addition to the ferry service, there is a large fishing fleet that uses the main channel as well as aquaculture sites alongside the channel. Local environmental groups are active in this area and should be included in any consultation activities. (EPRI-NS 2006)

Any restrictions to this channel during installation of tidal power equipment may also affect fishing vessels and recreational boaters using the Digby Gut and consultation meetings should be considered with these groups.

Cape Enrage, NB

An excerpt from the CHS chart for the Cape Enrage area is included as Figure 6.3.

Cape Enrage is the name given to the southern tip of Barn Marsh Island, an island located in Albert County, New Brunswick, roughly half way between Riverside-Albert and Fundy National Park on Rte. 915. The island itself is surrounded by jagged sea cliffs that are often more than 50 metres high, and is separated from the mainland by a narrow tidal creek. Cape Enrage derives its name from the large reef that extends south into Chignecto Bay, which causes the water off the point to become extremely violent, particularly at half tide when the reef is partially exposed and the water is moving quickly. (Wikipedia 2007) There is a large scallop and lobster fishery near the Cape Enrage area.

Vessel traffic in this area is limited to commercial fishing and recreational boating. There would be a requirement for ensuring that barges and gear were adequately secured to prevent them from breaking away during the violent wave motion experienced at various times in that area. Worker safety would also be a major concern while working on barges that are subject to the wave and tidal actions.

It is unlikely that anything more than the general requirements mentioned at the start of this section would be required however, the Alma Fishermen's Association as well as the New Brunswick Fisheries Department and the Nature Trust of New Brunswick should be consulted.

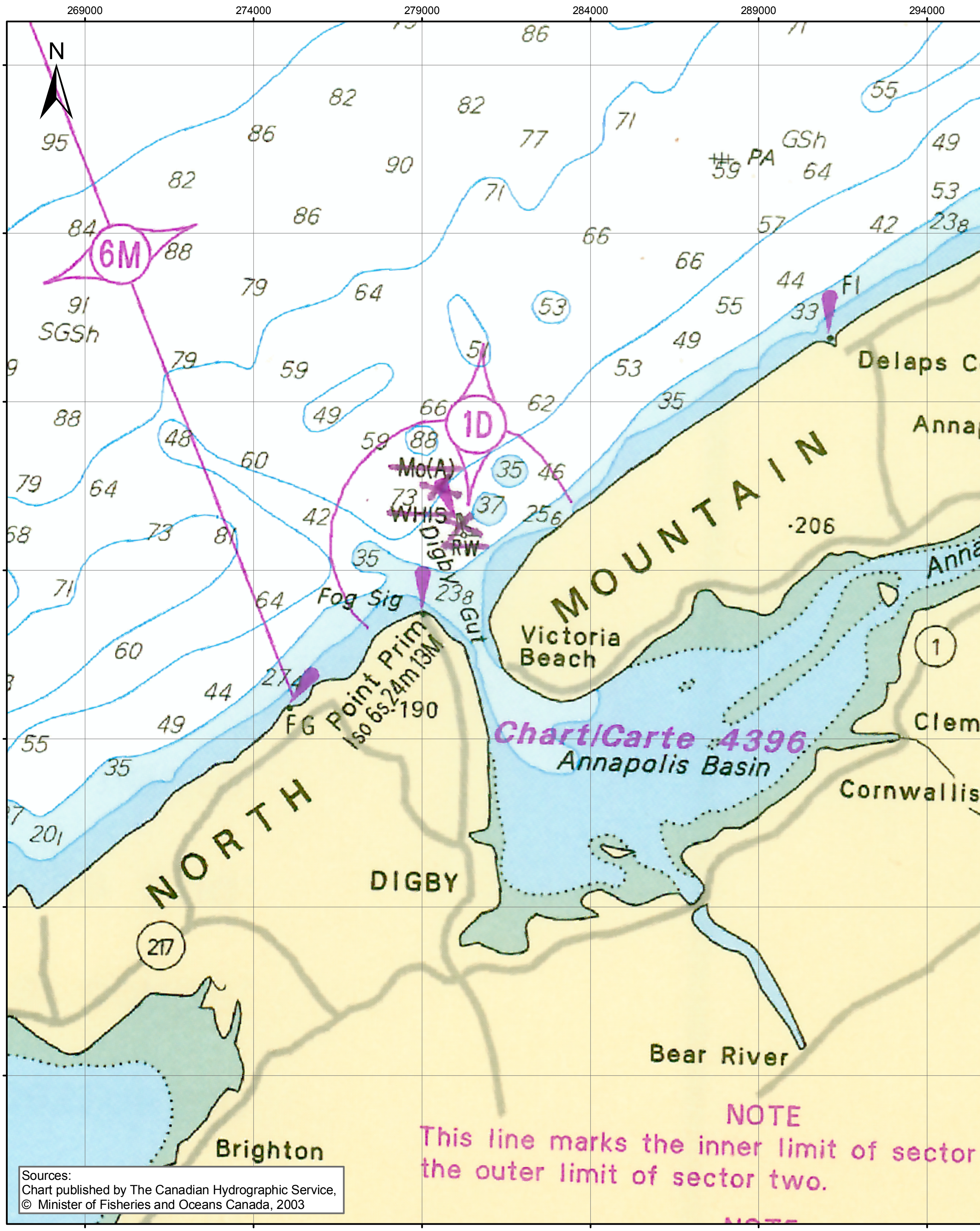


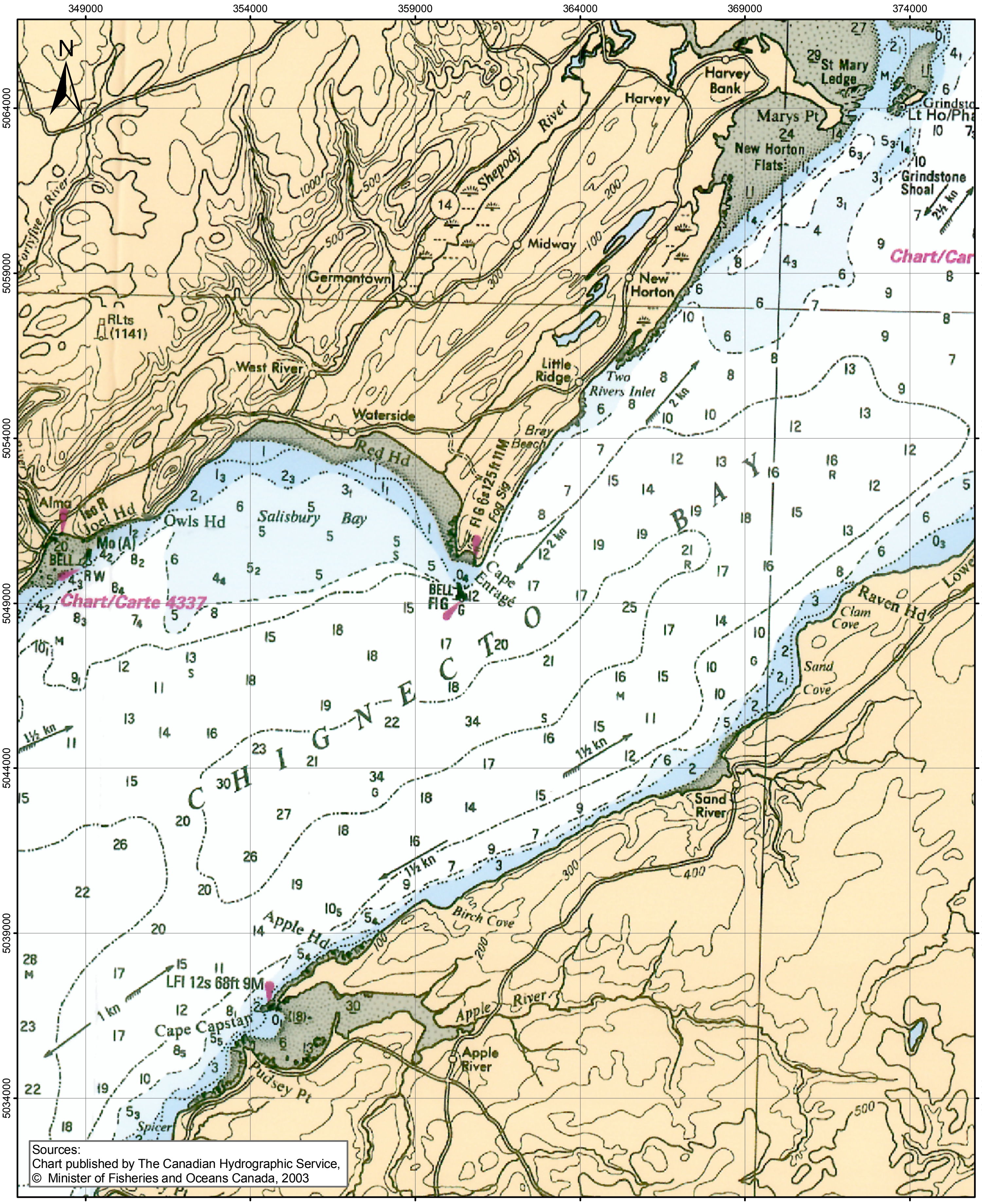
Figure 6.2

Representative Project Location Digby Gut, N.S.

Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: Nov. 27, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-024

0 1,200 2,400 4,800 7,200 9,600 12,000
Meters

ACADIA ESTUARINE CENTRE FOR RESEARCH · New Nouveau Brunswick · Jacques Whitford · OEER FUNDY TIDAL ENERGY



Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: Nov. 27, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-022

Figure 6.3

Representative Project Location Cape Enrage, N.B.

0 1,200 2,400 4,800 7,200 9,600 12,000
Meters

Acadia Centre for Estuarine Research
New Brunswick / Nouveau Brunswick
Jacques Whitford
OEER Fundy Tidal Energy

Head Harbour, NB

An excerpt from the CHS chart for the Head Harbour area is included as Figure 6.4.

The Deer Island/Campobello ferry provides hourly service from 6 AM to 11 PM. The Deer Island/Eastport/Campobello service is a half-hourly service provided during the summertime only. The Letete/Deer Island ferry provides half-hourly service during the main part of the day and hourly service in the early morning and late evenings (NB Government 2007). These latter are all shallow draft vessels (less than 2 metres). Residents of this area are dependent upon ferry service and interference must be avoided, or mitigated to an extent that is acceptable. Consultation with the New Brunswick Transportation Department ferry service branch would be required to identify any potential areas of conflict.

Another of concern is the ship traffic proceeding through the Passage to United States waters and the port of Eastport Maine. A controversial issue exists surrounding the American desire to consider the construction of a Liquefied Natural Gas (LNG) facility in that area. There is considerable opposition from Canada because of the risk involved in the carriage of this type of cargo and the particularly narrow and turbulent area which must be transited. The vessels must pass through Canadian waters to reach the U.S. port and it is not clear if this would be permitted under the right of innocent passage or if it is, in fact, Canadian internal waters. The difference between the two conditions will determine how much authority Canada has in determining if such transits are permissible.

Consultation meetings would also be required with the commercial fishing and aquaculture industries.

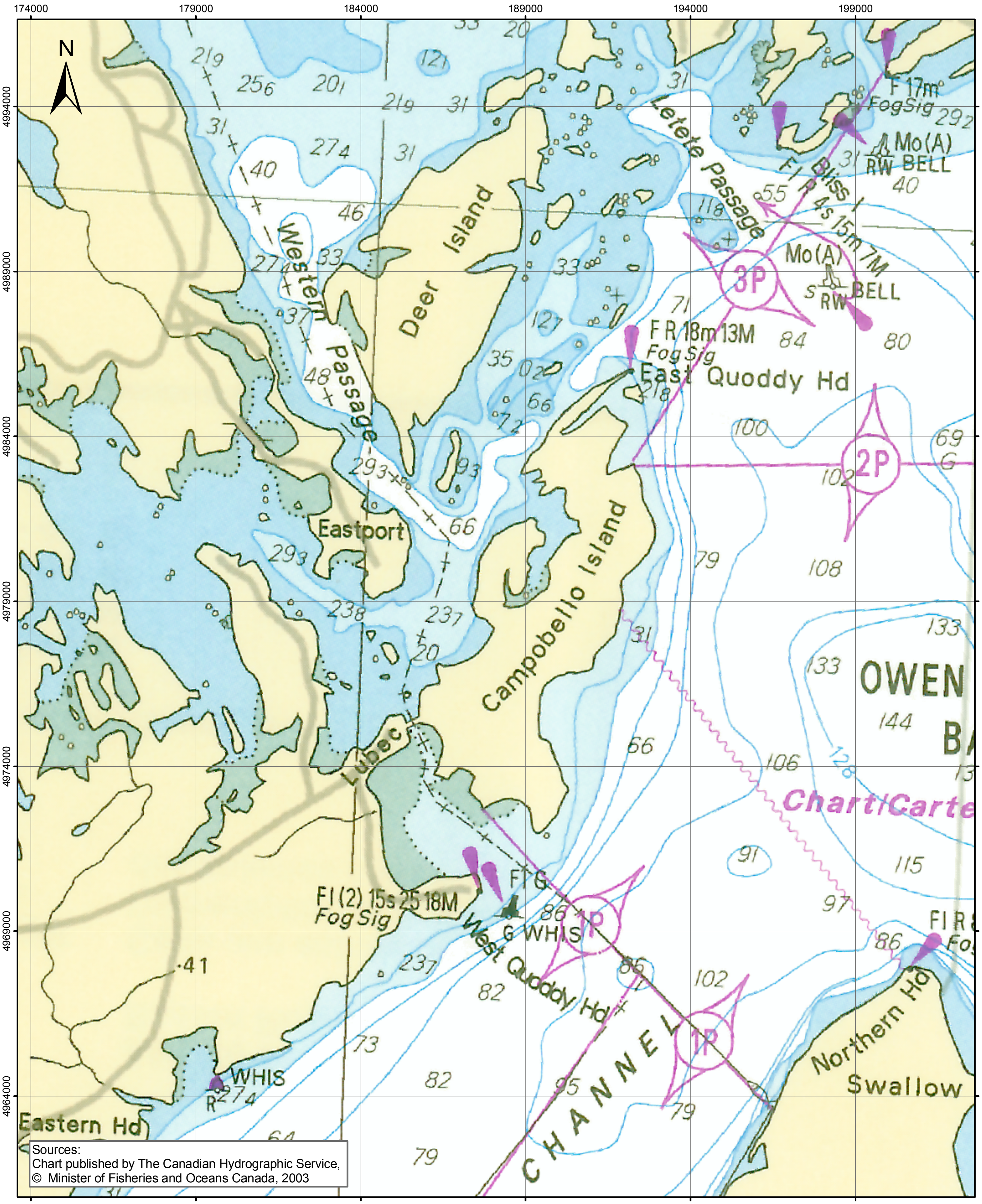
Management Opportunities

In order to reduce potential conflicts, it is important that all persons, groups, or companies that may have an interest in the proposed sites have an opportunity to voice concerns or to obtain further information. By ensuring convenient passage in the area of construction, recreational boaters would have little interaction with Project activities *NWPA* requirements would protect the right, and safety, of other marine users of the waters under consideration.

The major area of difficulties may be those affecting cargo shipments from Hantsport, ferry traffic in the Digby Gut and Head Harbour areas since all of those activities have high financial implications and will require early consultation to determine if problems actually exist and, if they do, what acceptable alternatives can be considered. Early involvement of federal government representatives should be considered to facilitate discussions with U.S. interests if the Head Harbour site appears to pose any potential restriction to vessel traffic movements into Maine ports.

6.10.4 Data Gaps and Follow-up

There are a number of issues with potential to affect the safety of navigation which must be further investigated. Any of the potential sites would be subject to the requirement for an *NWPA* application which would trigger a site specific environmental assessment under *CEAA*.



Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: Nov. 27, 2007
Project No.: 1028476
Figure Tracking: 1028476-JW-025

Figure 6.4

Representative Project Location Head Harbour Passage, N.B.

0 1,200 2,400 4,800 7,200 9,600 12,000
Meters

Acadia Centre for Estuarine Research
New Brunswick Nouveau
Jacques Whitford
OEER Fundy Tidal Energy

During the conduct of the site specific environmental assessment all potential effects on navigation safety and associated mitigative measures would be identified. Consultation during, or prior to, this process should take place including but not necessarily limited to the following stakeholders:

- Hantsport gypsum facility - current issues affecting vessel operations and the future capacity to provide raw product;
- The Atlantic Pilotage Authority - vessel channel requirements;
- The Nova Scotia Provincial Parks - potential interference;
- Bay Ferries - navigation safety issues in Digby Gut;
- The New Brunswick Transportation Department ferry services branch -ferry operations;
- The NS and NB fishery departments - fishery and aquaculture activities in site area;
- Canadian Hydrographic Services - channel information and the potential to modify transit areas if required;
- The Canadian Coast Guard
  - Marine Traffic and Communication Services - current shipping information
  - Icebreaking branch - potential for the interference
  - Aids to Navigation Program - the requirements for marker buoys and lights; and
- Transport Canada, Marine Safety Branch to determine project vessel regulations and the status of Head Harbour Passage in relation to U.S. interests in the creation of a liquefied natural gas terminal which would require transits, by U.S. vessels, through those Canadian waters.

6.11 Tourism and Recreation

6.11.1 Definition and Rationale for Selection

The following section provides an overview of key tourism and recreational activities within the Bay of Fundy and identifies the potential interactions that may result from the deployment of tidal devices. For instance, construction activities such as pile driving, and installing structures and cables may potentially disrupt marine users through exclusion zones. Similarly, the presence of turbines and routine maintenance activities may cause temporary or permanent inconveniences for maritime users. Primary attention will be paid to activities that occur directly in the marine environment, including recreational boating and vessel traffic. A more detailed discussion of marine vessel traffic is found in found in Section 6.10 while a Section 6.2. (fisheries) addresses the interaction of the Project with Fisheries and Aquaculture.

In addition, land-based tourism and recreation activities may rely indirectly on the Bay of Fundy as tourism draws. For instance, coastal hiking trails promoting scenic vistas of the Bay of Fundy may also interact with Project-related activities and are also considered in this study.

6.11.2 Potential Environmental Interactions

With respect to the key phases involved in a Project, potential interactions will occur during Construction, Operation, and Maintenance activities. The nature of these phases and their potential interactions with tourism and recreational activities are discussed below. Construction and Maintenance activities will have similar interactions with both direct and indirect marine users and as such will be addressed together.

Construction activities include the installation of structures, pile driving, and cable installation. Maintenance activities involve any preventative care and/or repairs that may become necessary to tidal power infrastructure. These activities can interact with both direct and indirect marine users. For example, marine uses of the area, including marine mammal watching, sea kayaking, and recreational boating, may be restricted during Construction and Maintenance activities. Land use may similarly be restricted during the operation of shore-based components of a Project, including the substation. In such instances, shoreline access may be restricted for safety purposes.

Construction and Maintenance activities may also interact with indirect marine uses. The Bay of Fundy boasts an extensive coastal trails system that markets itself on vistas of stunning scenery. Indirect marine users' quality of experience may be decreased by the visual presence of required Construction equipment in the marine environment. Similarly, on-shore construction zones for land-based components of a Project may diminish the quality of experience for many users.

Operation of the Project may disrupt direct marine users. For example, the presence of a turbine and associated infrastructure may necessitate boating exclusion zones. This would preclude recreational sea kayaking and boating, and commercial marine mammal tours from operating in these areas. Such route alterations may dramatically affect users quality of experience and may also have economic implications for tourism operators along the Bay of Fundy.

In addition, visual impact could be a concern, dependent on turbine design; particularly for indirect users who participate in the numerous land-based coastal activities that incorporate sight-seeing of the marine environment. These include hiking trails, coastal drives, and scenic locations.

6.11.3 Environmental Planning and Management Considerations

The following section provides a more focused discussion of Project related activities and their interactions with tourism and recreational activities for the four scenarios identified for the purpose of this study.

Minas Passage (Nova Scotia)

Minas Passage connects Minas Channel to Minas Basin and Cobequid Bay. It is a rectangular body of water that trends north-west to south-east, with its outer corner points being Ram Head and Cape Split and its inner corner points being Cape Blomidon and Parrsboro Harbour (EPRI 2006a).

With respect to tourism, the industry is growing in the region, particularly, the eco-tourism industry. For instance, sea kayaking is increasingly popular at Cape Split and Cape Blomidon. Several tour providers operate out of communities along the Minas Passage, and offer sea kayaking tours at numerous locations along Minas Passage, where scenic views of Nova Scotia's unique geology and cliffs are possible.

The whale watching industry in this area is small-scale. No commercial operators were registered with the Nova Scotia tourism association. Recreational boating in this area is also likely minimal.

Land based activities that utilize the Minas Passage indirectly are prevalent in the area. For example, Blomidon Provincial Park is located in Cape Blomidon, on the north-eastern inner corner of Minas Passage. Open from mid-May to early September, the park offers a 70-site campground with woodland and open-sites, two picnic areas, an unsupervised beach, and various hiking trails. Scenic views of the Minas Passage are available along these trails.

In addition, Cape Split is located on the south-east outer corner of the Minas Passage. Once privately owned, the property was recently sold to the Government of Nova Scotia and is being transformed into a provincial park. An extremely popular 7.5 km dirt hiking trail has existed for decades on Cape Split, taking approximately 2.5 hours each way to the tip of the headland. The point of Cape Split is meadowed, allowing scenic vistas of the entrance to Minas Passage.

Visual impact could be a concern, dependent on the turbine design; specifically for indirect users who utilize the trail systems to explore the scenic views.

During Construction and Maintenance, marine uses of the area may be restricted to avoid collisions, this representing a temporary disruption to existing marine users at this site. Land uses may likewise be restricted and disrupted temporarily during Construction of the shore-based components of a Project. For example, shoreline access in the vicinity of a Project may be restricted for safety purposes.

Similarly, Operation of the Project may disrupt direct marine users. For instance, exclusion zones may need to be established, dependent on the turbine design, which would potentially disrupt sea kayaking operators in the area.

Digby Gut (Nova Scotia)

Digby Gut is the name for the passage that joins the Bay of Fundy to Annapolis Basin. Digby Gut is approximately 4 km long and 0.75 km wide at its narrowest point (EPRI 2006a).

The Digby area markets itself as "the scallop capital of the world," and uses this as a tourism draw. There is considerably less direct tourism and recreation use on the waters of the Digby Gut than in other areas. However, the waterway is extremely busy. It is home to the large fishing fleet that regularly uses this passage to access the Bay of Fundy. In addition, the terminal for the ferry between Digby and Saint John, New Brunswick, is located just inside the guy on its western shore. More details on these marine uses are located in Section 6.10.

The town of Digby is located at the head of Digby Neck, and serves as the entry point to Nova Scotia's most prominent whale watching location: Brier Island, which sits at the most southern tip of Digby Neck. There are numerous whale watching opportunities along Digby Neck; however, the majority operate out of Brier Island which is approximately 70 kms from Digby Gut.

The ferry running from Digby to Saint John, New Brunswick travels the Digby Gut frequently. During peak season (June to October), there are 4-6 daily trips. This is in addition to the frequent use of Digby Gut by the local fishing fleet.

In the Digby Gut area, there are few land based activities that utilize the area indirectly. As noted, the area is at the entrance to Digby Neck, and along this narrow band of land is a scenic driving trail offering panoramic views of the areas unique land forms and geology. It is however unlikely that there will be interactions between land based indirect users and Project-related activities, therefore, visual impact is likely to be minimal. The most scenic views are located further down Digby Neck. However, the location of this site would be a highly visible symbol to local residents of the region's commitment to clean, green technology.

During Construction and Maintenance, marine users of the area may be restricted to avoid collisions, there representing a temporary disruption to existing marine users at this site, particularly the ferry and fishing fleets. Nearby land uses may likewise be restricted and disrupted temporarily during Construction of the shore-based components of a Project. For example, shoreline access in the vicinity of a Project may be restricted for safety purposes.

Similarly, Operation of the Project may disrupt direct marine users. For instance, exclusion zones may need to be established, dependent on the turbine design, which would potentially disrupt sea kayaking operators in the area.

Head Harbour (New Brunswick)

Head Harbour Passage trends southwest to northeast from Friar Roads, and is the main shipping entrance channel to Passamaquoddy Bay from the adjacent Bay of Fundy. Its south-eastern shore is Campobello Island and its north-western side is formed by a series of islands, including Deer Island, and rocks and shallow shoals (EPRI 2006a).

Campobello Island is situated in close proximity to the Northern Right-whale conservation area at the mouth of the Bay of Fundy, and as a result, the whale watching industry is extensive. There are eight whale watching operators registered with Bay of Fundy Tourism (Bay of Fundy Tourism Partnership 2007); and these operators, located on the northwest shore of Campobello Island, as well as those on Indian Island, utilize Head Harbour Passage to access the Bay of Fundy. There is a commercial kayaking operator on the south-eastern shore of Deer Island that offers trips that would likely travel along Head Harbour Passage. In addition, the ferry that runs between Campobello Island and Deer Island travels just outs Head Harbour Passage. However, additional tourism and recreational activities that directly occur in Head Harbour Passage are minimal.

Land based activities that utilize Head Harbour Passage are also minimal. Provincial road 774 transects that island and is linked to Maine via the FDR Memorial Bridge, which is located at the south-western most tip of the island. Herring Cove Provincial Park is located on the eastern side of the island, as is the Roosevelt-Campobello International Park. East Quoddy Head Lighthouse, located at the north-eastern tip of the island, overlooks Head Harbour Passage, and Project related activities may be visible to visitors to this area.

Visual impact is likely to be intermediate. As noted, East Quoddy Head Lighthouse has a scenic view of Head Harbour Passage, and the community of Wilson's Beach is located on the shores of Head Harbour Passage. However, the location of this site is somewhat unfrequented and to those who do visit the area, a Project would be a highly visible symbol to local residents of the region's commitment to clean, green technology.

During Construction and Maintenance, marine users of the area may be restricted to avoid collisions, thus representing a temporary disruption to existing marine users at this site, particularly, the whale watching operators who travel this body of water to access the Bay of Fundy. Land uses may likewise be restricted and disrupted temporarily during Construction of the shore-based components of a Project. For example, shoreline access in the vicinity of a Project may be restricted for safety purposes.

Similarly, Operation of the Project may disrupt direct marine users. For instance, exclusion zones may need to be established, dependent on the turbine design, which would require permanent route alteration for marine users.

Cape Enrage (New Brunswick)

The upper Bay of Fundy splits into two large bodies of water on either side of Cape Chignecto, Nova Scotia. To the north is Chignecto Bay and to the south is the Minas Channel. Cape Enrage is a prominent coastal bedrock projection into Chignecto Bay (EPRI 2006b).

Cape Enrage is located along a major New Brunswick tourist route, nestled between Hopewell Cape, home of the Hopewell Rocks attraction, and Fundy National Park. As a result, tourism and recreation is a major industry in the area. The most prominent activity that occurs in the marine environment is sea kayaking adventures. Visitors can explore the coast, the unique cliff formations, and caves that are navigable at low tide. Fossil hunting occurs on part of the beach at low tide.

Cape Enrage was named the "Best View in Canada", and as a result, indirect users of the waterbody vis-à-vis scenic views are plentiful. Available activities include rock climbing, beach combing, hiking, exploring one of the oldest lighthouses in the province, participating in training workshops, and camping. A full service on-site restaurant is available, and a small gift shop allows visitors the opportunity to purchase souvenirs of their trip. All of these activities market themselves around the beautiful views of the Bay of Fundy.

In addition, in the valley between the two ridges of Cape Enrage, 65 acres of the salt marsh is owned by the Nature Trust of New Brunswick, and protected as the Cape Enrage Nature Preserve (EPRI 2006b).

Visual impact could be a major concern, dependent on turbine design and placement. The area is famous for its panoramic and pristine views of the Bay of Fundy and Construction and Operation and Maintenance activities may temporarily or permanently reduce the quality of experience for visitors to the area.

During Construction and Maintenance, marine uses of the area may be restricted to avoid collisions, this representing a temporary disruption to existing marine users at this site, particularly, the sea kayakers who travel this area to explore the coastline. Land uses may likewise be restricted and disrupted temporarily during Construction of the shore-based components of a Project. For example, shoreline access in the vicinity of a Project may be restricted for safety purposes.

Management Opportunities

While each potential site is located at a unique location, each would experience similar interactions with Project-related activities. For instance, Construction and Maintenance activities, including pile driving, installation of structures, and cable installation, would potentially cause temporary inconveniences to direct marine users. Land users may also be temporarily disrupted during Construction of land based components of a Project.

In addition, Operation activities, such as the presence of turbines, may cause permanent inconveniences to marine users, including temporary or permanent marine vehicle route alteration, prohibitions on activities in specific locations, and reduced access to tourism and recreational areas.

Such interactions can be mitigated through exact turbine siting, turbine design, and conducting Project-related activities in off-peak seasons. At all potential sites, consultation with nearby tourism and recreational operators would be an important step to ensuring interactions would be as minimal as possible.

Visual impact is a potential concern at all locations to varying degrees. The Nova Scotia and New Brunswick tourism and recreation industry is heavily dependent on the Bay of Fundy and the unique attractions along its coast. Visual disturbances during all phases of a Project can reduce the quality of experience of visitors. This said, a previous study reported that that individuals would be no more objectionable to the visual presence of a turbine than to an offshore lighthouse (EPRI 2006a). That same study also determined that when viewed from cliff heights, the surface expression of tidal power devices would appear almost insignificant against the immense scale of the Bay of Fundy and its bordering coastlines (EPRI, 2006a). Moreover, the visual presence of turbines can be seen as testaments to the regions dedication toward finding alternative, renewable, and clean energy sources.

6.11.4 Data Gaps and Follow Up

Given the scale of the study area and the strategic nature of this report, it was not practical to collect all information and tourism and recreational activities in these areas. The goal of this report was to highlight key activities that are likely to occur in potential TISEC sites, and to identify potential constraints and management strategies. For the purposes of this report, the information collected is considered to be sufficient to allow only broad, high-level consideration of the likely interactions between potential Projects and tourism and recreation.

Generally, information on fixed, formal recreational activities is available. However, information on formal and unregulated activities (*e.g.* informal water sports activities) is more difficult to ascertain. The same can be said for tourism operators and activities. Information on the number of operators in these areas was ascertained through each province’s tourism operator’s registry; it is possible that unregistered operators conduct business in these areas as well. Ultimately, it will be necessary for those promoting individual Projects to undertake a more thorough data collection to establish the effects of their Project on tourism and recreation. This would include consultation with the Canadian

Coast Guard and other relevant tourism / recreational groups to obtain a more thorough understand of tourism and recreational activities that may occur in the marine environment of a given Project.

6.12 Archaeological and Heritage Resources

6.12.1 Definition and Rationale for Selection

Archaeological and Heritage Resources is a KEI in recognition of stakeholder interest in ensuring the effective management of these resources. Archaeological and heritage resources are defined as any physical remnants found on top of and/or below the surface of the ground that inform us of past human use of and interaction with the physical environment. For the purposes of this study, this includes all such marine historic resources found below the surface of the Bay of Fundy, including but not restricted to shipwrecks. These resources may date from the earliest time of human occupation in the study area up to the relatively recent past and include both built and depositional resources.

6.12.2 Potential Environmental Interactions

The installation and maintenance of structures on land and the driving of piles and installation of cables underwater could potentially disturb or destroy unknown terrestrial and/or marine archaeological and heritage resources. This includes those sites considered by affected First Nations and Aboriginal people, communities, or provincial heritage regulators to be of major importance due to factors such as rarity, condition, spiritual importance, or research importance.

The operation phase may result in the alteration of water flow rate, which could affect the rate of erosion of the shoreline and/or sedimentation under the water. The erosion of the shoreline could disturb or destroy previously unknown terrestrial archaeological resources. Changes in the sedimentation patterns under water could expose previously buried marine archaeological resources and subject them to disturbance or destruction through erosion and other natural forces, as well as potentially destructive human forces such as draggers and divers.

6.12.3 Environmental Planning and Management Considerations

Minas Passage, Nova Scotia

Minas Passage is the narrow channel between Cape Split and Parrsboro that separates the Bay of Fundy from Minas Basin and Cobequid Bay. The narrowness of the passage creates turbulent seas that are hazardous to navigation and this is evidenced by the number of shipwrecks in the area. There are 16 recorded shipwrecks within Minas Channel (Figure 5.22), all dating from the nineteenth century, most of which are in the Parrsboro area, on the north shore of the channel.

There are five recorded archaeological sites within Minas passage that date to the Martime Woodland period (2500 to 500 years ago), mainly on the south side of Cape Split. There are also seven recorded historic archaeological sites in the area, six on the south side of Cape Split and a single one on the north shore. It should be noted, however, that this apparent concentration of archaeological sites is the result of an intensive, muliti-year archaeological survey by Michael Deal of Memorial University in

Newfoundland and may not necessarily reflect higher archaeological potential when compared to the other study areas.

Digby Gut, Nova Scotia

Digby Gut is the narrow entrance to the Annapolis Basin, with steep-sided shore on both sides. While it is a wide passage, it was obviously hazardous at times because there are at least seven wrecks recorded there and a significant eighteenth century vessel that may or may not have wrecked there (Figure 5.22). The Northern Shipwrecks Database has no eighteenth century vessels listed as wrecked in Digby Gut, but the Maritime Museum of the Atlantic records the Caesar, which went down in 1710 on the way to besiege Port Royal in the Annapolis Basin, with the cost of 26 lives. It seems that this is an erroneous record as other sources list the vessel as going down on the west side of Goat Island, which is opposite Port Royal. The remainder of the wrecks are from the nineteenth century: Matilda, 1829; Matilda, 1841; Linnet, 1856; Pilot, 1856; Morden, 1860; an unknown wreck from 1869; and, Annie May, 1894.

There is only record of a single, nineteenth century archaeological site in Digby Gut at Victoria Beach. However, as mentioned above, the number of archaeological sites recorded in an area may be more a reflection of the level of effort than archaeological potential. There has never been an intensive archaeological survey conducted in the Digby Gut area so its archaeological potential cannot be determined by simply looking at the number of recorded archaeological sites.

There may be some potential for the presence of submerged Archaic (5000 to 2500 years ago) archaeological sites to exist off the shores of Digby Gut. Fader's work off Digby Neck has shown submerged landforms that would have been above sea level during the Palaleo Indian and Archaic periods and which could have been used by the people hunting there at the time (Fader 2005). That would explain the recovery of Archaic artifacts from trawlers in the Bay of Fundy, particularly off Digby Neck.

Cape Enrage, New Brunswick

As the name implies, this is an area known for turbulent seas but both shipwreck databases list only a single vessel as having wrecked there in the nineteenth century: the Nancy in 1829. This is problematic given the hazardous location of the in the Bay of Fundy and the fact that the situation was dangerous enough to shipping that locals petitioned for a light station on the cape, which was eventually built in 1840. It would seem that more in-depth research would reveal many more wrecks than are recorded in the two sources used for this report.

Head Harbour Passage, New Brunswick

Head Harbour Passage is located at the head of Passamaquoddy Bay, on the north side of Campobello Island. This area has an early history of European exploration and there was a short-lived attempt by the French at establishing a settlement on St. Croix Island in 1604 (the survivors moved to found Port Royal in 1605). Unfortunately, the wreck records do not reflect this early history nor do they seem to reflect the amount of shipping traffic that would have passed through the area. There are only two recorded shipwrecks, both from the second half of the nineteenth century: Day Spring, 1867; and, W.E.

Duryea, 1878. As with Cape Enrage, it does not seem that the shipwreck data available necessarily reflect the reality of the number of ships that went down in and around Head Harbour Passage.

Management Opportunities

A desktop study is by nature limited in its scope and it cannot provide concrete data relating to the physical presence of marine archaeological resources within the study areas. In general, a detailed bathymetric survey, most likely using side-scan sonar, would be conducted in each of the areas to determine the presence of marine historic resources. Any potential resources would then be examined using video cameras mounted on Remotely Operated Vehicles (ROV's). If a historic resource is confirmed, a shipwreck, for example, a mitigation plan would be developed and submitted to the relevant regulatory authorities. This would include a detailed archival research program to determine the age and cultural origin of the resource. While complete avoidance of the resource is the most desirable mitigation strategy, if that is not feasible, there may be a requirement to completely excavate the resource, which would involve a major conservation component, or to conduct a salvage excavation and recording scheme where the elements in need of conservation would be reburied to preserve them.

6.12.4 Data Gaps and Follow-up

One of the most significant data gaps for Nova Scotia has to do with the nature of recorded archaeological sites. The Archaeological Sites Database held by the Nova Scotia Museum consists of a collection of Maritime Archaeological Resource Inventory (MARI) forms, many of which are over 100 years old and are based on unsubstantiated isolated finds. As a result, much of this database is unreliable and does not necessarily represent the archaeological record of a specific area. The province of Nova Scotia has also not been the subject of a comprehensive archaeological survey that would have given a complete historical overview of Aboriginal and historic archaeological sites. In general, the number of recorded sites in a certain area, Cape Blomidon for example, most likely reflects the duration and intensity of a specific archaeological survey program rather than the true nature of the archaeological record in the province. Understudied areas will show few, if any sites, and many of the existing records may be old and unreliable.

There is a data gap with the archaeological records of New Brunswick as the Archaeological Services Unit declined to release any site data until the geographic parameters for the New Brunswick study areas were better defined. ASU also had concerns about who would have access to the site data.

The data gaps for shipwrecks are very similar to those of terrestrial sites in that the records are old, scattered, and unreliable. While a vessel may be reported as sinking after hitting a rock at a specific location, the records cannot speak of what happened to it afterwards or its present condition. The language of many of the records is also ambiguous and it is possible that some vessels recorded as 'sunk' may have been refloated at some time.

It is assumed that follow-up will include a detailed archival background component for each study area, which would include meeting with local historical societies and the sport diving community. This would be followed by a comprehensive archaeological survey, which would include a detailed bathymetric survey of the seabed to determine the presence of marine heritage resources. Once the locations of the land-based facilities and the transmission corridors are determined a detailed terrestrial archaeological survey will also be conducted.

6.13 Economic Development

6.13.1 Definition and Rationale for Selection

This section identifies potential interactions pertaining to economic development which may occur through the deployment of tidal in-stream energy conversion (TISEC) devices or the potential development of current generation tidal lagoon facilities within the Bay of Fundy. The potential economic impact of these activities presents both direct and tertiary benefits for local communities and regional businesses. Opportunities may exist to maximize these economic benefits, including government participation in providing access for local businesses regarding tender opportunities, the assessment of potential benefit agreements in future commercial developments, and development of skilled labour for local communities.

Subsequent infrastructure may be required as a result of tidal energy development in the Bay of Fundy, which could be utilized by the public, local businesses, and leveraged to assist other local industry. These, and other potential economic opportunities, are considered herein.

6.13.2 Potential Environmental Interactions

The potential development of tidal energy in the Bay of Fundy, in particular, deployment and operation of TISEC technologies, will require various support services. Initial work would be necessary prior to the deployment of each technology. Additional services will be required during the deployment of each TISEC device, and throughout the entire operation of the tidal demonstration facility.

Pre-Deployment Considerations

The scope of this initial work may include, but is not limited to:

- technology design and innovation;
- materials research and testing including antifouling materials and coatings;
- vessel deployment logistics;
- device manufacturing and fabrication;
- device transportation and assembly;
- services related to baseline data collection and analysis;
- environmental assessments; and
- project planning and permitting.

Trained personnel will be required to operate specialized equipment, oversee facilities management, provide various pre-deployment services, operation and maintenance of the TISEC devices, and other support services.

Potential support services may include, but are not limited to:

- provision of diving equipment and services;
- land and marine-based geotechnical surveys and mapping;
- environmental assessments;
- bathymetric surveys and mapping;
- resource mapping and modeling;
- project management, planning, and permitting;
- sub-sea and land-based cable laying;
- substation construction, operation, and management;
- utility upgrades and integration with existing infrastructure;
- transportation upgrades to existing roads including planning and construction;
- planning and construction for upgrades to existing docking facilities; and
- supply, operation, and maintenance of heavy-lift, survey, and maintenance vessels.

Deployment and Maintenance Considerations

The deployment of TISEC technologies will require the use of some local infrastructure, equipment, and personnel.

Potential equipment may include, but is not limited to:

- deployment and survey vessels;
- diving equipment;
- technical instrumentation;
- conveyors;
- cranes; and
- other loading equipment.

Additional operational services may require environmental and marine life monitoring, as well as TISEC device operation, monitoring, and maintenance.

Required infrastructure may include, but is not limited to:

- new and existing roads;
- commercial and industrial space;
- land-based maintenance facilities;
- accommodations;
- use of wharfs; and
- docking facilities.

6.13.3 Environmental Planning and Management Considerations

This section identifies potential economic opportunities for local communities and regional businesses as a result of potential tidal energy development within the Bay of Fundy.

The Minas Passage, located north of the Town of Parrsboro, was identified by EPRI as having some of the greatest tidal currents in the world. As such, the Minas Passage would provide greater tidal resources, thereby reducing the cost of power produced in comparison to locations with lesser tidal resources. This large resource makes the Minas Passage a desirable location for potential tidal energy development. With established docks and loading infrastructure, the Town of Parrsboro could facilitate support services for each of the identified potential project sites within the Bay of Fundy, particularly those within the Minas Passage.

According to Statistics Canada, 2006 data reported Nova Scotia's population to be 913,462, an increase of 0.6% over 2001. For the same 2006 period, the Town of Parrsboro, N.S. was reported to have a population of 1,401, a decrease of 8.4% from 2001 data.

In comparison, the Province of New Brunswick had a reported population of 729,997 in 2006, a 0.1% increase over 2001. According to 2006 data, the City of Saint John, N.B., was reported to have a population of 68,043, a 2.3% decrease from 2001.

In both cases, these communities have experienced a drop in population, while both provinces observed negligible increases in the total population in comparison to the reported 2006 National average, which observed a 5.4% increase over 2001 data. There is, however, an opportunity for these local communities to develop additional skilled labour, create jobs, and supply potential tidal energy developments.

Supporting services that may be required could be sourced through a combination of local and provincial suppliers. Currently, both New Brunswick and Nova Scotia have a strong capacity in manufacturing, engineering, construction, and other related support services which could supply tidal energy project development in the Bay of Fundy.

Maximizing local benefits could occur through a number of avenues. Coordinated tender postings and community tender information meetings could assist local business to understand potential opportunities. Various project tenders could be packaged into smaller contracts as to allow local SMEs to bid on projects that they otherwise may not have the capacity to complete the work. As such, there may be value in packaging tenders to scale to assist smaller communities in identifying local workforce and service providers, creating a potential for developers to reduce costs where applicable.

Larger service providers could provide training to the local workforce to assist with various aspects of tidal energy projects. Additional training could be provided through local and regional academic institutions. Local job fairs could facilitate project work and identify skilled labour for service providers.

Potential local and regional benefits could exist with respect to primary manufacturing and metal fabricators including potential production of:

- turbine rotors;
- blades;

- generators;
- turbine Ducts;
- gravity-based and fixed mounting structures; and
- other proprietary TISEC components.

Miscellaneous procurement could include items such as restraint, power, and control cables.

Both the Province of New Brunswick, and the Province of Nova Scotia, could benefit from the development of tidal energy within the Bay of Fundy. Benefits for the Provinces could result in real economic growth including the potential to develop benefit agreements for project developers in prospective commercial tidal energy developments. These benefit agreements could require royalties directly related to government funding issued, or could be based on utilization of the respective Province's resources.

Current activities in the Ocean and Marine Energy Sector exist within Canada, creating opportunities for collaborative research. Natural Resources Canada has established a Technical Advisory Committee for Ocean Energy which will facilitate technology development, innovation, research, and service capabilities within Canada. Additional opportunities exist to build collaborative research networks, and centres of excellence. Networks of Centres of Excellence (NCE) could be engaged from academia to develop and fund an Academic-led Ocean & Marine Network of Centres of Excellence. The NCE brings together industry leaders, experts, and academic researchers to conduct collaborative research in priority sectors. Similarly, the Business-led Networks of Centres of Excellence (B-NCE) could be engaged by industry to lead an Ocean & Marine Energy Business-led Network of Centres of Excellence. Full details on these programs can be found on the Network of Centres of Excellence website (www.nce.gc.ca).

The importance of potential tidal energy developments to the Provinces of New Brunswick and Nova Scotia is significant. Potential benefit agreements could enhance the delivery and retention of economic benefits, both for local communities, and the Provinces. While tidal energy developers will need to identify project-specific service and supply needs to adequately determine local supply opportunities, prospective tidal energy development would enhance sector activity, create jobs, increase Provincial revenues, develop capacity, and position the region's business communities for growth in export markets as a world leader in tidal energy development.

6.13.4 Data Gaps and Follow-up

While there is potential to develop benefit agreements in prospective commercial tidal energy developments, it may be necessary to study previous benefit agreements as developed for the petroleum industry. The Nova Scotia Department of Energy and the New Brunswick Department of Energy were consulted within the scope of this report. It was acknowledged that there is a need to further explore scenarios to identify potential benefit agreements that may provide economic benefits or spin-offs for local businesses within the service and supply chains associated with the development of tidal energy. Due to the magnitude differential between projects in the offshore, and potential tidal energy developments, it would be important to note the economic factors and potential benefits that may occur as a result of developing benefit agreements for tidal energy projects. A study on potential benefit agreements should identify the potential financial implications for project developers and note any effects on project feasibility.

Recognizing the importance of assessing the supply chain opportunities for local businesses, the Nova Scotia Department of Energy has issued an RFP for a "consultant to assess current and proposed renewable energy projects in Nova Scotia with a focus on wind power and in-stream tidal, and to identify opportunities in the service & supply chains of these projects". Work conducted under this RFP will address some of the gaps related to tidal energy project-specific supply requirements which can then be identified as service and supply chain opportunities for local businesses.

Readily available, detailed information on economic statistics, local businesses, and existing capacity is limited (within the general scope of this evaluation) for coastal communities such as Parrsboro. Statistics Canada had limited information on smaller coastal communities, in comparison to large urban municipalities. To assist local coastal communities where potential tidal development may occur, such as the Town of Parrsboro, It would be beneficial for local businesses and tidal energy developers to be able to reference an Atlantic Canada service and supply capability report and directory which details the capabilities of the entire energy sector, including renewable energy, with a focus on local supply capabilities. Currently, there is not a directory that encompasses the energy sector in Atlantic Canada to this extent. It is recommended that an Energy Sector Capability Study be commissioned for Atlantic Canada to address the supply-chain deficiencies within Atlantic Canada's Energy Sector, particularly within Nova Scotia and New Brunswick.

In discussions with representatives of the Town of Parrsboro, it was acknowledged that limited information was available pertaining to potential service and supply chain opportunities associated with tidal energy development. While this document does contain a discussion on the types of services and supplies which may be required as a result of tidal energy development projects, further information should be made available from tidal energy developers as to inform local businesses of prospective service and supply opportunities.

Should potential tidal energy projects proceed in the Bay of Fundy, technology specific information may be required from the project developers as to assist with local tendering for services required. This will assist with identifying tender opportunities for local businesses, as well as help identify where services for tender packages may be scaled to allow greater potential participation from local businesses.

While tendering opportunities may assist local businesses, the local labour force could benefit from prospective job opportunities. Government and potential tidal energy project developers should consider undertaking project specific training and job fairs in communities within close proximity to potential tidal energy developments to enable increased local participation and decrease potential project costs.

7.0 CUMULATIVE INTERACTIONS

Identifying and addressing cumulative effects is an important prerequisite to development. Environmental interactions of individual projects and activities can overlap spatially and temporally to create cumulative environmental or socioeconomic interactions. This is a particular concern for major developments whereby residual effects (*i.e*., after mitigation is applied) including indirect effects, may be amplified as a function of the scale of the development. Cumulative effects are especially evident in the aquatic environment, where developments may have off-site implications that are propagated over considerable distances. In some cases, these cumulative effects can interact additively or synergistically to create effects greater than those of individual projects and have important regional consequences. While the focus for cumulative effects assessment is often within the context of large project development, smaller, incremental changes (*e.g.,* cumulative loss of coastal wetlands) also requires attention.

Cumulative effects assessment is now a required component of many regulatory environmental assessment regimes such as the *Canadian Environmental Assessment Act* (*CEAA*). It is the intent of cumulative effects assessment to ensure that proposed projects and activities (*e.g*., tidal power developments) consider the effects of other past, present and likely future regional projects and activities in combination with environmental consequences of project-specific assessment to attempt to better understand and manage the regional consequences of proposals during the planning stage. In general, cumulative interactions with past, present and ongoing projects and activities are addressed as part of the review of baseline or existing environmental conditions. As such cumulative effects of other past and present projects and activities are included in the discussion of existing conditions for the Bay of Fundy (Section 4), albeit at a very high, regional level.

Regulatory guidance for cumulative effects assessment has been provided (*e.g*., under *CEAA*) to bound or limit the consideration of potential future projects and activities to those where meaningful, measurable interactions can occur. In general, consideration of potential future projects and activities to be considered for cumulative effects assessment should have a reasonable likelihood of occurring and not be simply hypothetical. Typically, other projects and activities to be considered will have at least submitted regulatory applications for approval or some other advanced planning process. Full identification of other likely future projects and activities that could occur anywhere in the Bay of Fundy was not considered within the scope of this study.

This section outlines some of the cumulative effects expected to arise from development of tidal energy conversion in the Bay of Fundy including effects associated with the cumulative removal of tidal energy. This discussion is, by necessity, highly qualitative; substantive cumulative effects assessment requires the investigation of overlapping spatial and temporal effects which can occur most meaningfully with the context of project-specific assessment or a much more in-depth regional assessment.

7.1 Effects of Energy Extraction

Conversion of tidal stream energy into electricity will result in a net reduction in the amount of kinetic energy that remains in the system on each tide. Because many of the biophysical characteristics of the Bay of Fundy ecosystem—from the fate of sediments to the movements of migratory fish and the feeding potential of marine birds and baleen whales—depend upon the consequences of high tidal flows, any reduction in such flows needs to be carefully evaluated.

It is expected that the effects will be magnified in proportion to the scale of the TISEC development, both in terms of the amount of energy extraction at a site, as well as the repetition of sites around the Bay of Fundy. A single demonstration project at one site will likely have negligible effects on the biophysics of that part of the ecosystem, but a number of such sites may begin to exert identifiable effects. Cumulative effects on several biophysical features of the Bay would be expected if successful demonstration of the efficacy of TISEC devices were to lead to replication of energy extraction sites at different locations around the Bay. If, for example, fish are unable to detect and avoid TISEC devices, and in their migration encounter them several times, the cumulative effect could be reductions in the populations of fish, or their success in completing migrations, *etc*. Similarly, the cumulative effect of several separate reductions in tidal energy could include significant changes in sediment deposition and distribution, or in tidal upwelling areas, that have secondary effects on important biota.

Single commercial scale projects, consisting of large numbers of TISEC turbines arrayed in close proximity (*e.g.* where inter-unit distance and relative orientation are selected to maximize the efficiency of energy conversion, but minimize the 'footprint' of the development), or large tidal lagoons, may well exert cumulative effects on the biophysics that are measurable and less acceptable.

Our ability to forecast the full ecosystem effects of larger scale or number of commercial TISEC developments is at present very limited. Although existing hydrodynamic models could be used both to assess the potential extractable energy and to examine the effects of reduction in energy, they have not been effectively applied to this time to predict the capacity for tidal projects in the Bay of Fundy. Present estimates of energy potential are crude, and variable (see Section 4.3 and 4.4). The lack of site-specific hydrodynamic modeling for the purpose of understanding the acceptable arrangement and extent of commercial scale tidal development in the Bay of Fundy is a critical data gap. To facilitate such modeling, long term records of current velocity at varying depths throughout the water column, and at different locations in each potential site, are required. Such modeling has become standard for wind energy developments; a major collaborative effort is required to develop similar predictive modeling for proposed tidal power developments.

7.2 Effects on Common Infrastructure

TISEC developments, at both the demonstration and pilot scale, require some of the same facilities as other industries such as aquaculture and fisheries. These include wharf and site facilities. As the scale of TISEC development expands, the pressure on existing land-based facilities such as wharves, access points and service facilities (*e.g.*, engineering, fuel supplies, repair shops, *etc.*) will become greater. At present, in most areas considered suitable for TISEC development at the commercial scale, the existing infrastructure is either fully occupied or in need of significant upgrading (see Section 3). A strategy for dealing with congestion or competition for support services is necessary.

7.3 Effects of Exclusion Zones

To minimize interference between activities, marine industries require partial or complete control over portions of the marine environment within which they operate. Therefore, addition of a new use such as a TISEC array or a tidal lagoon, creates the need for clear policy and fair allocation to prevent or reduce marine use conflicts. Some activities can coincide; for example, if all TISEC devices are completely submerged, with adequate clearance, then various shipping activities can continue with the exception of periods of site preparation, deployment or recovery of the turbines. Other activities are clearly incompatible in close proximity to TISEC; these include most fishing techniques, aquaculture cages, recreational diving, *etc*. As the size and/or number of tidal energy developments increases in the Bay of Fundy, especially in areas currently used for aquaculture or active commercial fisheries, the conflicts are expected to grow.

In order to facilitate TISEC development, a comprehensive policy of allocation of coastal resources is needed. The Strategic Environmental Assessment, of which this background document is a part, is an important step toward identifying potential resource and use conflicts, and facilitating consultation with other resource users potentially affected by tidal power development in the Bay of Fundy. Ongoing communication and consultation, together with site specific environmental impact assessments for proposed tidal power developments in the Bay of Fundy, will be essential components in identifying conflicts among users and identification of specific mitigative measures. Regulatory authorities, such as Transport Canada and Fisheries and Oceans Canada, will have specific responsibilities for ensuring the reasonable allocation of marine uses and addressing potential conflicts, particularly with respect to any new exclusion zones.

7.4 Effects of Other Developments

For four centuries, the Bay of Fundy has been changed as a result of human activities, many of which have had important effects upon its natural features. Examples include: the conversion of saltmarshes to agricultural (and now residential) land; creation and expansion of harbours and the development of shipbuilding; damming of rivers and estuaries; and overharvesting of resources. The near future seems to promise much of the same: proposals are in hand for LNG terminals in New Brunswick and Maine; TISEC development; attempts to conserve natural habitats and species through the creation of protected areas in the Bay of Fundy; initiatives to expand tourism and recreation activities, *etc*. The capacity of the ecosystem and the communities surrounding the Bay to sustain all of these activities is nonetheless finite.

Issues to be considered for potential cumulative effects assessment would be those that are currently pressuring systems in the Bay of Fundy or have a reasonable likelihood of occurring in the future; these include: shoreline infill; aquaculture; commercial fishery; shipping; industrial marine terminals; creation of marine reserves or other restricted areas; and other energy projects. It is impossible to undertake a cumulative effects assessment at a strategic level without more specific information regarding potential future likely developments that could overlap spatially or temporally with tidal projects. It is assumed that all proposed tidal energy projects in the Bay of Fundy will be assessed under *CEAA* and require a cumulative effects assessment for that process. That process will include the scoping of specific past, present and likely future projects and activities with potentially overlapping, measurable environmental and socioeconomic effects. Where required, this process will also identify specific means to mitigate and monitor cumulative effects. It is understood that some mitigative and monitoring measures will require collaborative efforts and participation in regional planning from a number of proponents and resource users and governments.

It is relevant in this context to indicate that there is a spectrum of options for tidal power development in the Bay of Fundy. At one scale, there is the potential for a large commercial array of devices, or a tidal lagoon, to yield a significant amount of electricity that would be fed into the grid to defray dependence upon some fossil fuels, or defer the need for constructing new thermal generating plants to meet rising demands in the near future. At the other extreme, is the potential for small scale, localized TISEC installations that are intended to meet a more local need (*e.g.*, a processing plant or other local industry), and might therefore involve one or a few turbines only. Clearly, a tidal lagoon or a large scale TISEC array has cumulative effects that would affect the immediate portion of the ecosystem in proportion to the number and size of turbines. It is equally important, however to recognize the potential cumulative effects of a number of small TISEC developments distributed around the Bay. While they may be too small to exert measurable effects on ecosystem processes, they have potential to exert a cumulative effect if they were to interfere successively with migrating species at different parts of their route, or collectively to modify the exchange of water between the main Bay and one of its subsidiary basins. A Bay-wide planning concept is needed to avoid what has been called the "tyranny of small, independent decisions".

7.5 Effects of Other Ecosystem Changes

Among the major contributors to changes the Bay of Fundy ecosystem has been the construction of dams and causeways during the last century. The tidal dams at Moncton (NB), Annapolis Royal (NS) and Windsor (NS) have been blamed for locally significant effects on fish stocks, mixing processes, and sediments. Recently, following extensive study of the options for the Petitcodiac Causeway, a decision was made to remove a large part of the dam, enabling the tide to return towards its historic reach in the river, with the desired recovery of some migratory fish stocks and the reappearance of the tidal bore. Opening up the dam will have some significant effects on the ecosystem of Shepody Bay, Cumberland Basin and Chignecto Bay, because it will remobilize a vast amount of sediment that has accumulated in the estuary over the last half century, reduce the frictional losses of energy over that portion of the estuary, and presumably increase the current velocities in large parts of the system. The examination of the options for dam removal was not conducted to include the effects on possible TISEC development in the region, but it is clearly a necessary consideration in assessing the potential long term future of TISEC development in that system. The same would apply if a similar decision was to be made for the Windsor Causeway on the Avon Estuary.

7.6 Effects of Site Preparation

One of the remaining uncertainties regarding the potential effects of site clearance and preparation in potential TISEC deployments sites, especially in the Upper Bay, relates to the sensitivity of the substrate. Present evidence indicates that while some areas of the Minas Passage and Chignecto Bay have exposed bedrock, others may consist of a coarse overlying lag of cobble and boulder-sized sediments that protects an underlying deposit of marine clays and glacial sediments (see Section 5.1.1 above). In the absence of the protective lag, these finer sediments will be remobilized and dispersed by tidal currents. Disturbance of this protective layer during site preparation could induce progressive changes in water depth, and mass movement of sediments away from the site, to be deposited elsewhere. As with many changes to fundamental properties in the Bay of Fundy, disturbance does not have to be immediately evident to produce a significant effect; even subtle changes to the integrity of this layer may yield, over subsequent years, progressive changes to the hydrodynamics of the channel, with consequent effects on sediments and biota. Because of this risk, preliminary studies of the substrate and underlying geology must be thorough and precise.

8.0 SUMMARY AND CONCLUSIONS

This report represents a summary of background information on ocean renewable energy which is intended to facilitate an ongoing Strategic Environmental Assessment (SEA) of potential tidal power development projects in the Bay of Fundy.

Based on an issues scoping exercise a list of key environmental issues (KEIs) was prepared to focus this background information. The report suggested several representative tidal development scenarios, potential environmental and socioeconomic issues, and a number of planning considerations to reduce or avoid potential adverse interactions. One of the key components of this study is the identification of data gaps that make it difficult to predict accurately environmental consequences of potential interactions with project activities. Table 8.1 provides a summary of the data gaps and associated recommendations by KEI. A discussion of key study findings follows the table.

TABLE 8.1 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
Critical Physical Processes	▪ Lack of detailed, site specific information on vertical and horizontal current structure and substrates for validation of models. ▪ Inadequate fine-scale hydrodynamic and sediment models relevant to selected sites of tidal energy development. ▪ Limited knowledge of the overall distribution and dynamics of sediments in the Bay of Fundy. ▪ Inadequate application of hydrodynamic models to assess the impacts of TISEC developments.	▪ Gather site specific information about substrates and sediment movement and currents for proposed development locations using in situ monitoring with ADCP and sediment sensors. ▪ Complete the high density multibeam bathymetric studies of the Bay, and complete the analysis of existing data. ▪ Adapt or refine hydrodynamic models to provide adequate small-scale analyses of the potential and effects of energy extraction developments. ▪ Hydrodynamic modeling should be used to assist with the selection of sites for TISEC developments in order to optimize the extractable tidal energy potential and minimize cumulative effects on physical or biological processes.
Fisheries	▪ Absence of information on fish behaviour with respect to TISEC technologies. ▪ Inadequate knowledge on the effects of remobilized sediments on commercially important species of fish and shellfish. ▪ Questions about EMF from sub-sea cables and the effects on demersal fish and shellfish. ▪ More specific information is required regarding the number of fishing operations, vessels and products, and locations of fixed gear fisheries. Present data gathered for fisheries management purposes is insufficient for assessment of tidal power implications.	▪ Conduct experimental and field-based monitoring studies of fish behavior and mortaility, in the vicinity of tidal power devices. ▪ Conduct experimental studies of fish responses to vibrations or noise generated by TISEC devices. ▪ Conduct experimental studies of effects of high suspended sediments on migratory and commercial fish species. ▪ Work with fishing groups to obtain better fisheries data particularly with respect to activities near proposed development sites. ▪ Determine specific infrastructure requirements (e.g., wharves, supply bases) and necessary upgrades for each proposed project.

TABLE 8.1 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
	▪ Assumed existing infrastructure such as wharves would be used to support TISEC development projects—infrastructure status and availability or requirements for tidal power development is not well known. ▪ Lack of clarity on set-back requirements for marine energy developments.	▪ Gather detailed information on potential adverse effects on local fisheries, and necessary mitigative measures (including project site selection). ▪ Establish consultative group including fishers and developers to create effective set-back guidelines.
Fish and Fish Habitat	▪ Data on distribution, seasonality and trophic relations of many non-commercial species of fish are not available. ▪ Absence of information on fish behaviour and/or mortality with respect to TISEC technologies, particularly with respect to noise and vibration. ▪ Questions about EMF from sub-sea cables and the effects on demersal fish.	▪ Conduct experimental and field-based monitoring studies of fish behavior and mortality, in the vicinity of tidal power devices ▪ Conduct experimental studies of fish responses to vibrations or noise generated by TISEC devices ▪ Establish an ongoing and updatable database of knowledge about local and migratory fish stocks. ▪ Identify potential mitigative measures for effects on fish populations
Marine Habitat and Benthic Communities	▪ Available data on existing benthic communities are limited in the Outer Bay. ▪ Available data on existing benthic communities of the Upper Bay are limited, especially in view of some significant changes that have happened in the Bay since the data were obtained. ▪ Little existing data for many areas in the Bay.	▪ Replication of broad benthic surveys that were conducted in the 1970's. ▪ Establishment of long-term survey transects of benthic habitats and communities in priority areas for energy developments, including reference (i.e. non-impacted) sites. ▪ Creation of a coordinating agency to ensure consistency and quality of monitoring activities.
Pelagic Communities	▪ Similar to Fisheries and Fish and Fish Habitat issues noted above with respect to pelagic species.	▪ Similar to Fisheries and Fish and Fish Habitat issues noted above with respect to pelagic species.
Marine Mammals	▪ Lack of data on marine mammal behavioural responses to TISEC devices. ▪ Limited data available on the occurrence of marine mammals in the Upper Bay of Fundy.	▪ Study long term effects of health and behavior (e.g., mortality, migration, avoidance, attraction) of tidal power development on marine mammals including monitoring of results from pilot and demonstration projects in the Bay of Fundy and elsewhere. ▪ Establish long term monitoring programmes for marine mammals in the Upper Bay of Fundy, incorporating NGO resources. ▪ Identify and assess possible mitigative measures for effects of TISEC development on mammals.
Marine Birds	▪ Lack of data on marine seabird and shorebird activity in the area of priority sites. ▪ Lack of information on the trophic relationships of many marine birds,	▪ Establish long term monitoring programmes for marine birds in the Upper Bay of Fundy, incorporating NGO resources. ▪ Surveys to support project-specific

TABLE 8.1 Summary of Data Gaps and Recommendations

Key Environmental Issue	Data Gap	Recommendation
	and their ability to adjust feeding preferences.	environmental assessment prior to deployment. ▪ Identify and assess possible mitigative measures for effects of TISEC development on birds, including the secondary effects associated with changes in prey availability.
Species At Risk	▪ Requirement for better site -specific information on species presence (depending on species and location).	▪ Establish an ongoing and updatable database of knowledge about local and migratory species at risk in the Bay of Fundy. ▪ Identify and assess potential mitigative measures for different species at risk. ▪ Work with Species Recovery Teams to develop comprehensive strategies for species at risk that use areas of high priority for energy extraction. ▪ Where necessary, conduct species-specific surveys in high priority areas.
Aquaculture	▪ Similar to Fisheries above (including lack of knowledge concerning appropriate setback distance from TISEC devices).	▪ Similar to Fisheries above.
Marine Transportation	▪ Uncertainty regarding level of interaction with other marine transportation users in the study area.	▪ Stakeholder consultation (other marine users). ▪ Regulatory consultation (e.g., NWPA process). ▪ Detailed navigation safety assessments and underkeel clearance surveys in the context of site specific project EA and project site selection.
Tourism and Recreation	▪ Lack of information on informal and unregulated recreational activities.	▪ Project-specific data gathering as part of site specific EA process (including shore based facilities) .
Marine and Coastal Archaeological and Heritage Resources	▪ Uncertainty regarding the location and condition of many potential archeological and heritage resources (marine and shore-based) in the study area.	▪ Detailed site specific bathymetric survey using side-scan sonar as part of project specific EA process. Follow up with ROV survey if sonar shows potential resources. ▪ Detailed archeological survey may be necessary as part of shore-based facility site selection and EA process.
Economic Development	▪ Uncertainty in identification of specific business opportunities for local business. ▪ Local capacity not clear.	▪ Local economic benefits study in context of project specific EA process. ▪ It is recommended that an Energy Sector Capability Study be commissioned for Atlantic Canada to address the barrier to supply-chain deficiencies within Atlantic Canada's Energy Sector, particularly within Nova Scotia and New Brunswick. ▪ Study potential benefit agreements. ▪ Project-specific job fairs.

As has been known for at least 100 years, a major energy resource is present and available in the Bay of Fundy. The development of new TISEC technologies should enable some of that energy to be extracted with far fewer environmental consequences than most of the earlier proposals for tidal power development in the Bay. Compared to dam-based or lagoon-style proposals, the new stand alone devices make an incremental development process possible. This would enable an iterative assessment of the environmental consequences of development, and therefore a ready option to cease further development whenever it is determined that the environmental or socioeconomic implications of further expansion are unacceptable. The incremental approach also requires relatively less initial capital investment since each device begins to yield a benefit following deployment; for dam-based and lagoon designs, a substantial infrastructure must be in place before revenue can be generated.

TISEC technology is in a very early stage of development. Many potentially applicable devices are barely beyond the prototype stage, and few have been tested for prolonged periods in the marine environment. While the technology is developing rapidly in the case of the few that have been field tested, they all lack adequate examination for their potential environmental effects. Even where field testing has included some degree of environmental effects monitoring, it is not possible to transfer the limited information so far available on the environmental effects from those test sites to the Bay of Fundy context. It is therefore necessary to establish facilities at one or more sites in the Bay of Fundy at which such technologies can be tested and thoroughly monitored. TISEC devices currently in development are highly varied in design and include many operating features. In addition, at this stage of the design evolution, it is unclear that any single design will become a standard for application in all tidal current situations. It is therefore probable that new TISEC variants will arise, and there could be a continuing need to maintain the testing readiness for future evaluations, as is being done at EMEC. The recent decision to create a test facility in Minas Passage, which will become a centre of excellence in relation to the applications and implications of marine energy technologies, is an important initiative.

The exact tidal energy available at any given site in the Bay of Fundy has not yet been adequately assessed. Present estimates are weak: two approaches have produced widely different results, and the numbers obtained are based on inadequate data and some crude approximations. The inability to assess the scale of the resource renders conclusions about the potential scale of development unreliable at present. Thorough application of existing hydrodynamic models is required, supported, where necessary, by field validation.

The environmental implications of TISEC development are uncertain in several respects. It is often assumed in reports that important fauna will avoid the turbines, but the responses to these technologies have rarely been tested. It is probable that responses to TISEC devices are both technology— and species— specific. A principal function of the proposed test facility should be the rigorous examination of the behavioural responses of important species to the TISEC installation. Some research, such as the examination of the responses of fish and mobile invertebrates to electromagnetic fields of buried cables could be carried out experimentally, and/or in relation to existing submarine cables. Other research questions relate to the effects of noise during construction and of vibrations during operation of the device. A comprehensive research program should be initiated in the very near future to ensure that such questions do not impede development and application of acceptable technologies.

In spite of more than a century of research in the Bay of Fundy, the present status of many phenomena and parameters of importance to TISEC development remains uncertain. This is attributable to three things:

- Absence of sufficient monitoring programs in the Bay. Programs do exist to monitor the movements of marine mammals, some fish and some birds, and contaminant levels in mussels and mammals, but the monitoring of water levels has decreased in recent decades, and, given the nature of both local and global changes, this is a significant impediment. There are no continuing monitoring programmes for benthic or pelagic organisms, or for non-fishery species of fish.
- The continuing changes taking place in the Bay of Fundy. Some of these are natural (*e.g.,* sea level rise, tidal evolution, sea floor erosion, *etc.*), whereas others are clearly anthropogenic (*e.g.,* the long term ecosystem effects of dams on tributaries, and the food web effects of overharvesting resources).
- Lack of site-specific information. Due to the diversity of conditions and habitats in the Bay, each site that may be used for energy extraction is to some extent unique. While research institutions have been attempting to deal with the lack of information (*e.g.,* the multibeam bathymetry work conducted by the Bedford Institute of Oceanography and the University of New Brunswick, and the sediment dynamics work coordinated by the Acadia Centre for Estuarine Research), resources have been limited and important gaps remain.

In addition, there is considerable uncertainty with respect to potential resource conflicts associated with setbacks or exclusion zones from TISEC devices and effects on fisheries, aquaculture and navigation/shipping.

The future of TISEC developments may be modified by a variety of future changes in the Bay of Fundy ecosystem. These include: the possible development of other energy installations requiring larger vessels that will move through passages where TISEC might be installed; the system-scale changes that could arise from removal of some established tidal dams; or the creation of a large tidal lagoon.

There is a clear need for a coordinated research and monitoring program to address the existing lack of data with respect to dynamic processes, nature of the bottom topography, prevalence of species of interest in areas of potential TISEC deployment, and responses of fauna to the technology and site modifications. This information will be required to provide an adequate foundation for the preparation of site-specific environmental assessments.

A coordinated research and monitoring program should take a holistic, multidisciplinary approach that utilizes the resources of the scientific community at universities and research agencies, and combines it with the resources of other stakeholders. The scientific community in the region is well experienced in such integrated research. During the tidal power investigations of the 1970s and 1980s, the Fundy Environmental Studies Committee (FESC) oversaw the collaborative research efforts of more than 50 scientists in government agencies and regional universities to build a better understanding of the Bay of Fundy ecosystem, particularly in relation to the implications of tidal power development. Re-creation of an equivalent, independent (of both government and private sectors) body to oversee the research and monitoring needed should be a high priority. It is also necessary to incorporate the advice and assistance of First Nations, non-government organizations, as well as industry representatives.

Development of the TISEC opportunities in the Bay of Fundy requires effective collaboration between the two provinces. Even where specific sites are located entirely within the boundaries of one province, it is essential that a unified approach is taken toward development for several reasons:

- Sites separated geographically in the Bay of Fundy system are nonetheless linked by the migrations and other movements of fish, birds, mammals and some crustaceans; they are shared resources that bind the regions of the Bay together.
- The cumulative effects of large commercial arrays or of numerous individual developments are likely to have effects beyond their immediate locality.
- Existing and necessary infrastructure is not necessarily available in both provinces (e.g., most technical support capacity within the Bay is found in Saint John).
- Limited financial resources in the Atlantic region may require interprovincial and/or federal cooperation where it is reasonable to share efforts.

Any energy extraction development in the Bay of Fundy needs to be in conformity with an established and comprehensive coastal zone management policy in each province. (In this connection, the contemporary view is that the coastal zone extends landward beyond the high water mark to include estuaries and the rivers that empty directly into the marine environment. This view underlies both Canada's *Oceans Act* and the former Coastal 2000 policy in Nova Scotia). Where such a policy is lacking or incomplete, completion and implementation should be a high priority in order that a policy vacuum does not impede progress. The same is true for policy development and financial support for renewable energy development which must keep pace with the commitments to reduce greenhouse gases and air pollutants.

In summary, it is recommended that a cautionary, staged approach be taken with respect to development of TISEC technology projects in the Bay of Fundy. Many unknowns exist and it is the recommendation of this study team that a small number of pilot scale projects proceed with significant monitoring and adaptive management plans. This would allow for future expansion into demonstration and commercial scale developments, provided environmental and socioeconomic components in the Bay of Fundy are not compromised, to the satisfaction of government and local stakeholders. This would be accomplished by gathering data to address the data gaps and allow for design considerations and development of appropriate mitigation measures. The end result would be confident predictions of potential environmental effects through project-specific environmental impact assessment.

9.0 LITERATURE CITED AND OTHER SOURCES

Abend, A.G. and T.D. Smith. 1999. Review of distribution of the long-finned pilot whale (*Globicephaala melas*) in the North Atlantic and Mediterranean. NOAA Technical Memorandum NMFS-117.

Ahrens, M.A. 1990. Atlantic herring. DFO Underwater world Fact Sheet. Communications Directorate, Ottawa.

Alain, B. 2005. Taking stock: A profile of Canada's aquaculture industry. In: VISTA on the Agri-Food Industry and the Farm Community, Statistics Canada, 21-004-XIE. http://www.statcan.ca/bsolc/english/bsolc?catno=21-004-X20050058671

AMEC. 2005. Environmental impact assessment report for modifications to the Petitcodiac River causeway. Document TE23520.4 submitted to New Brunswick Department of Supply and Services by AMEC Earth and Environmental Services, Fredericton, N.B.

Amiro, P. 2003. Population studies of Inner Bay of Fundy Atlantic salmon (*Salmo salar)* to 1999. Report 2488, Bedford Institute of Oceanography, Dartmouth, NS.

Amos, C.L. 1984a. An overview of sedimentological research in the Bay of Fundy. Pp. 31-43 *In* Gordon, D.C. Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256.

Amos, C.L. 1987. Fine-grained sediment transport in Chignecto Bay, Bay of Fundy, Canada. Contin. Shelf Res. 7: 1295-1300.

Amos, C.L. 1995. Siliclastic tidal flats. Pp. 273-306 *In* G.M.E. Perillo (Ed). Geomorphology and Sedimentology of Estuaries. Developments in Sedimentology No. 53. Elsevier, Amsterdam.

Amos, C.L. and B.A. Zaitlin. 1985. The effect of changes on tidal range on a sublittoral macrotidal sequence, Bay of Fundy, Canada. Geo-Marine Letters 4: 161-169.

Amos, C.L. and D. Mosher. 1985. Erosion and deposition of fine-grained sediments from the Bay of Fundy. Sedimentology 32: 815-832.

Amos, C.L. and G.H.E. Joice.1977. The sediment budget of the Minas Basin, Bay of Fundy, N.S. Data Series/BI-D-77-3/June 1977. Bedford Institute of Oceanography, Dartmouth NS. 411 pp.

Amos, C.L. and K. T. Tee. 1989. Suspended sediment transport processes in Cumberland Basin. J. Geophys. Res. 94: 14407-14417.

Amos, C.L. and T.T. Alfoldi. 1979. The determination of suspended sediment concentration in a macrotidal system using LANDSAT data. J. Sediment. Petrol. 49: 0159-0174.

Amos, C.L., M. Brylinsky, H.A. Christian and G.R. Daborn. 1994. Biophysical controls on stability of fine sediments – steps toward a comprehensive model. P. 2106 *In* P.G. Wells, and P.J. Ricketts. (Eds.) 1994. Coastal Zone Canada '94, 'Coopewration in the Coastal Zone': Conference Proceedings, Vol. 5. Coastal Zone Canada Association, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

Amos, C.L., N.A. Van Wagoner and G.R. Daborn. 1988. The influence of subaerial exposure on the bulk properties of fine-grained intertidal sediment from Minas Basin, Bay of Fundy. Est. Coastal Shelf Sci. 27 : 1-13.

Anderson, J.M. 2007. The salmon connection: the development of Atlantic salmon aquaculture in Canada. Glen Margaret Publ., Tantallon, N.SAmos, C.L. 1978. The postglacial evolution of the Minas Basin, N.S.: a sedimentological interpretation. J. Sed. Petrol. 48: 965-982.

Anonymous 2000b. Southwestern New Brunswick (LFA 36-38) green sea urchins. DFO Science. Stock Status Report. C3-49.

Anonymous 2000c. Nova Scotia sea urchins. DFO Science Stock Status Report C3-48.

Anonymous 2007. Whites Point Quarry and Marine Terminal Environmental Impact Statement. Volume III.

Anonymous. 1997. Southwest Nova winter flounder, American plaice and yellowtail flounder. DFO Science Stock Status Report A3-21.

Anonymous. 1998. Periwinkle (*Littorina littorea*). DFO Science, Stock Status Report C3-46.

Anonymous. 2002a. Wolffish on the Scotian Shelf, Georges Bank and in the Bay of Fundy (4VWX and 5YZc). CSAS Stock Status Report 2002/A3-31.

Anonymous. 2002b. Monkfish on the Scotian Shelf and northeast Georges Bank (4VWX and 5Zc). CSAS Stock Status Report 2002/A3-30.

Anonymous. 2002c. Scallop production areas (SPA's) in the Bay of Fundy. DFO Maritimes Region. Stock Status Report C3-56.

Anonymous. 2005. Stock assessment report on scallops (*Placopecten magellanicus*) in scallop production areas 1 to 6 in the Bay of Fundy. CSAS Science Advisory Report 2005/072.

Anonymous. 2006a. Atlantic halibut on the Scotian Shelf and Southern Grand Banks (Div 3NOPs4VWX). CSAS Science Advisory Report 2006/038.

Anonymous. 2006b. Instream tidal power in North America – environmental and permitting issues. Devine Tarbell & Associates, Inc. report EPRI-TP-007-NA to the Electric Power Research Institute, Inc., Palo Alto, CA.

Appy, T.D., L.E. Linkletter and M.J. Dadswell. 1980. A guide to the marine flora and fauna of the Bay of Fundy: Annelida: Polycheata. Fish. Mar. Serv. Fish. Envir. Canada Tech. Rep. 920.

Archipelago Marine Research Ltd., December 2006. *Tidal Turbine Project – Race Rocks Ecological Reserve Environmental Monitoring. Final Report.*

Armitage, I.A. and M.K. Gingras. 2003. Sedimentologic and environmental implications of Atlantic sturgeon (Acipenser oxyrhynchus) feeding traces, Bay of Fundy, New Brunswick, Canada. Annu. Mtg. Geol. Soc. Amer. Pap. 234-12.

Atlantic Geoscience Society 2001. *The Last Billion Years: a Geological History of the Maritime Provinces of Canada.* Halifax: Atlantic Geoscience Society, Nimbus Publishing. 212 pp.

Atlantic Tidal Power Programming Board. 1969. Report on the Feasibility of Tidal Power Development in the Bay of Fundy. Appendix 3. Ice and Sediments.

Baird & Associates, 2007a. *Potential impacts to physical processes caused by the development of alternative energy on the US OCS.* Report submitted to Research Planning Inc., March 2007.

Baird & Associates, 2007b. *Examination of the Physical and Biological Implications of Using Buried Channel Deposits and Other Non-Topographic Features as Beach Nourishment Material*. U.S. Department of the Interior, Minerals Management Service, Herndon, VA, MMS OCS Report MMS 2007-048. 231 pp. + appendices

Baird & Associates, 2007c. *Scour Assessment, Design and Monitoring*. In proceedings of the Confederation Bridge Engineering Summit. Charlottetown, PEI. 19-22 August 2007.

Baumgartner, M.F and B.R. Mate. 2005. Summer and fall habitat of North Atlantic right whales (*Eubalaena glacialis*) inferred from satellite telemetry. Can. J. Fish. Aquat. Sci. 62:527-543.

Baumgartner, M.F., T.V.N. Cole, P.J. Clapham and B.R. Mate. 2003. North Atlantic right whale habitat in the lower Bay of Fundy and on the SW Scotian shelf during 1999-2001. Mar. Ecol. Prog. Ser. 264:137-154.

Bay Ferries 2007. Bay Ferries sailing schedule. www.nfl-bay.com/

Bay of Fundy Ecosystem Partnership. 2005. Fundy's Minas Basin. URL: http//www.bofep.org/. (Accessed December 9, 2005).

Bay of Fundy Tourism Partnership. 2007. Web page. Accessed 17 October 2007 from <http://www.bayoffundytourism.com>.

BEAK Consultants Ltd. 1991. Technical review of fish passage studies at Annapolis Tidal Generating Station. Final Report, BEAK No. 9228.1

Beanlands, D.R., R. Branton, and R. Mohn. 2000. Status of monkfish in 4VWX5Zc DFO. Canadian Stock Assess. Sec. Res Doc. 2000/143.

Begg, G.A. 1998. A review of stock identification of haddock, *Melanogrammus aeglefinus*, in the Northwest Atlantic Ocean. Marine Fisheries Review Fall, 1998:1-18.

Benedet L., Stive, M., Hartog, W., Walstra, D. and Van Koningsveld, M., 2006. *Effects of wave diffraction and initial bathymetric conditions on beach fill volume change predictions*. In Proceedings of the International Conference on Coastal Engineering 2006, San Francisco CA, 2-8 September 2006.

Black and Veatch, July 2005. *Tidal Stream Energy Resource and Technology Summary Report – Rev. 3* Issue 4.

Bleakney, J. S. and D. E. McAllister. 1973. Fishes stranded during extreme low tides in Minas Basin, Nova Scotia. Can. Field-Naturalist 87:371-376

Bleakney, J.S. 1982. A sea-level scenario for Minas Basin. Pp. 123-125 *In:* Daborn, G.R. 1982 (Ed.). Effects of Changes in Sea-Level and Tidal Range on the Gulf of Maine—Bay of Fundy system. Acadia Centre for Estuarine Research, Acadia University, Wolfville. Publication No. 1. 133 pp.

Botsford, L.W., A. Campbell and R. Miller. 2004. Biological reference points in the management of North American sea urchin fisheries. Can. J. Fish. Aquat. Sci. 61:1325-1337.

Boulva, J. and I.A. McLaren. 1979. Biology of the harbor seal, *Phoca vitulina*, in Eastern Canada. Bull. Fish. Res. Bd. Can. No. 200. 24p.

Bourque, D., G. Morin and T. Landry. 2001. Predation on soft-shell clams (Mya arenaria) by the nemertean Cerebratulus lacteus in Atlantic Canada: implications for control measures. Hydrobiologica 456:33-44.

Bousfield, E.L. and A.H. Leim. 1958. The fauna of Minas Basin and Minas Channel. Bull. Nat. Mus. Can. 166: 1-30.

Bradford, R.D. and T.D. Iles. 1993. Retention of herring *Clupea harengus* larvae inside Minas Basin, inner Bay of Fundy. Can. J. Zool. 71:56-63.

Bredin, K.A., S.H. Gerriets and L. Van Guelpen. 2004. Distribution of rare, endangered and keystone marine vertebrate species in Bay of Fundy seascapes. Pp. 83-98 *In* Wells, P.G., G.R. Daborn, J.A. Percy, J. Harvey and S.J. Rolston. (Eds). 2004. Health of the Bay of Fundy: Assessing key issues. Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum, "Taking the Pulse of the Bay", Wolfville, Nova Scotia, May 13-16, 2002. Environment Canada – Atlantic Region, Occasional Report No. 21, Environment Canada, Dartmouth, Nova Scotia and Sackville, New Brunswick, 416 pp.

Brown, M. 2005. Struggling in an urban ocean:the plight of the North Atlantic Right Whale. Pp. 33-41 *In* J.A. Percy, A. J. Evans, P.G. Wells and S. J. Rolston. (Eds). 2005. The Changing Bay of Fundy: Beyond 400 Years. Proceedings of the 6th Bay of Fundy Workshop held September 29th to October 2nd 2004, Cornwallis, NS. Environment Canada – Atlantic Region Occasional Report no. 23, Environment Canada, Sackville, NB. 524 pp.

Brown, R.G.B. and D.E. Gaskin. 1989. Summer zooplankton distributions at the surface of the outer Bay of Fundy, eastern Canada. Can. J. Zoo. 67:2725-2730.

Brugère, C. and N. Ridler. 2004. Global aquaculture outlook in the next decades: an analysis of national aquaculture production forecasts to 2030. FAO Fisheries Circular No. 1001: 47 pp.

Brylinsky, M. and G.R. Daborn. 1987. Community structure and productivity of the Cornwallis Estuary. Cont. Shelf Res. 7: 1417-1420

Brylinsky, M., G.R. Daborn, D.J. Wildish, M.J, Dadswell, P.W. Hicklin, C.D. Duncan, W.T. Stobo, M.D. Brown and S.D. Kraus. 1997. The biological environment of the Bay of Fundy. Pp. 63-101 *In* Percy, J.A., P.G. Wells and A. J. Evans (Eds). 1997. Bay of Fundy Issues: a scientific overview.

Proceedings of a Workshop, Wolfville, NS, January 29 to February 1, 1996. Environment Canada – Atlantic Region Occasional Report no. 8, Environment Canada, Sackville, NB. 191 pp.

Buerkle, V. 1990. Results of the 1990 winter acoustic surveys of NAFO Division 4WX herring stocks. CAFSAC Res. Doc. 90/67.

Bundy, A. and L.P. Fanning. 2005. Can Atlantic cod (*Gadus morhua*) recover? Exploring trophic explanations for the non-recovery of the cod stock on the eastern Scotian Shelf, Canada. Can. J. Fish. Aquat. Sci. 62:1474-1489.

Buzeta, M-I., R. Singh, and S. Young-Lai. 2003. Identification of significant marine and coastal areas in the Bay of Fundy. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2635: xii + 177pp + figs.

Cabilio, P., D. L. DeWolfe and G.R. Daborn. 1987. Fish catches and long-term tidal cycles in Northwest Atlantic fisheries: a nonlinear regression approach. Can. J. Fish. Aquat. Sci. 44:1890-1897.

Caddy, J.F. 1979. Long-term trends and evidence for production cycles in the Bay of Fundy scallop fishery. Rapp. P. v. Reun. Cons. Int. Explor. Mer 175:97-108.

Caddy. J.F. and R.A. Chandler. 1976. Historical statistics of landings of inshore species in the Maritime provinces 1847-1973. Environment Canada. Fish. Mar. Serv. Tech Rep. 639

Campana, S.E., W. Joyce, L. Marks, L. Natanson, N.E. Kohler, C.F. Jensen, J.L. Mello, H.L. Pratt Jr., and S. Myklevoll. 2002. Population dynamics of the Porbeagle in the Northwest Atlantic Ocean. N.A. J. Fish. Manag. 22: 106-121.

Campbell, A. 1992. Characteristics of the American lobster fishery of Grand Manan, New Brunswick., Canada. N. Amer. J. Fish. Mgt. 12: 139-150.

Campbell, A. and D.G. Robinson. 1983. Reproductive potential of three American lobster (*Homarus americanus*) stocks in the Canadian Maritimes. Can. J. Fish Aquat. Sci. 40: 1958-1967.

Campbell, A. and A.B. Stasko. 1986. Movements of lobsters *Homarus americanus* tagged in the Bay of Fundy, Canada. Mar. Biol. 92: 393-404.

Carruthers, E.H., J.D. Neilson and P.Perley. 2005. Long-term changes in the feeding of *Pollachius virens* on the Scotian Shelf: responses to a dynamic ecosystem. J. Fish Biol. 66: 327-347.

Casavant, A. 2006. Instream tidal power plant feasibility study – general environmental and federal permitting issues. Devine Tarbell & Associates, Inc. http://oceanenergy.epri.com/attachments/streamenergy/briefings/05-9-10-06_Final_East_Coast_Briefing_Env_and_Reg_Issues.pdf

CEFAS, 2006. *Scroby Sands Offshore Wind Farm Coastal Processes Monitoring. Final Report*. Report prepared for The Department of Trade and Industry, UK. Contract Ref. No. AE0262.

Chardine, J.W. 2005. A possible reason for the disappearance of phalaropes from around Deer and Campobello Islands: availability of their favourite prey. Pp. 105-106 *In* J.A. Percy, A. J. Evans, P.G. Wells and S. J. Rolston. (Eds). 2005. The Changing Bay of Fundy: Beyond 400 Years.

Proceedings of the 6th Bay of Fundy Workshop held September 29th to October 2nd 2004, Cornwallis, NS. Environment Canada – Atlantic Region Occasional Report no. 23, Environment Canada, Sackville, NB. 524 pp.

Chou, C.L., L.A. Paon, J.D. Moffatt and B. M. Zwicker. 2001. High copper contamination in lobster from the inner Bay of Fundy and Saint John Harbour. P. 137 *In* Chopin, T. and P.G. Wells. (Eds). 2001. Opportunities and challenges for protecting, restoring and enhancing coastal habitats in the Bay of Fundy. Proceedings of the 4th Bay of Fundy Science Workshop, Saint John, New Brunswick, September 19-21, 2000. Environment Canada, Atlantic Region Occasional Report No. 17, Environment Canada, Dartmouth, Nova Scotia, 237 pp.

Chou, C.L., L.A. Paon, J.D. Moffatt and B. M. Zwicker. 2004. Heavy metals in rock crab (*Cancer irroratus*), lobster (*Homarus americanus*) and sediments from the Inner Bay of Fundy, Atlantic Canada. Pp.153-159 *In* Wells, P.G., G.R. Daborn, J.A. Percy, J. Harvey and S.J. Rolston. (Eds). 2004. Health of the Bay of Fundy: Assessing key issues. Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum, “Taking the Pulse of the Bay”, Wolfville, Nova Scotia, May 13-16, 2002. Environment Canada – Atlantic Region, Occasional Report No. 21, Environment Canada, Dartmouth, Nova Scotia and Sackville, New Brunswick, 416 pp.

Chou, C.L., L.A. Paon, J.D. Moffatt and T. King. 2003. Selection of bioindicators for monitoring marine environmental quality in the Bay of Fundy, Atlantic Canada. Mar. Poll. Bull. 46:756-762.

Christie, D.S. 1983. Birds. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Cobb, J.S. 1976. The American lobster: the biology of *Homarus americanus*. Zoology/NOAA Sea Grant. URI Mar. Tech. Rep. 49.

Conner, R.F., G.L. Chmura and C. B. Beecher. 2001. Carbon accumulation in Bay of Fundy salt marshes: implications for restoration of reclaimed marshes. Global Biogeochemical Cycles. 15(4):943-954.

Coon, D. 1999. An ecological sketch of some Fundy fisheries. Conservation Council of New Brunswick, Fredericton, NB. 32 pp.

Corey, S. 1983. Larger zooplankton of the Quoddy Region. *In* Thomas, M.L.H. (Ed). 1983. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 193-200.

Corey, S. and W.R. Milne. 1987. Recurrent groups of zooplankton in the Bay of Fundy and southwest Nova Scotia regions Can. J. Zoo. 65:2400-2405.

COSEWIC 2003.

Crecco, V.A. and T. Savoy. 1987. Review of the recruitment mechanisms of the American shad: the critical period and match-mismatch hypotheses reexamined. Amer. Fish soc. Sym. 1: 455-468.

Crewe, B., G. Brewster, H. Kolstee and R. Gordon. 2005. Sediment movement in the Salmon River estuary, Truro, Nova Scotia. Pp. 123-125 *In* J.A. Percy, A. J. Evans, P.G. Wells and S. J. Rolston.

(Eds). 2005. The Changing Bay of Fundy: Beyond 400 Years. Proceedings of the 6th Bay of Fundy Workshop held September 29th to October 2nd 2004, Cornwallis, NS. Environment Canada – Atlantic Region Occasional Report no. 23, Environment Canada, Sackville, NB. 524 pp.

CSAS 2007a. Framework and assessment indicators for lobster (*Homarus americanus*) in the Bay of Fundy, lobster fishing areas (LFA's) 35,36 and 38. CSAS Science Advisory Report 2007/037.

CSAS. 2005a. Recovery assessment report on NAFO Subareas 3-6. Porbeagle Shark. CSAS. Science Advisory Report 2005/043.

CSAS. 2004a. Allowable harm assessment for inner Bay of Fundy salmon. CSAS Stock Status Report 2004/030

CSAS. 2004b. 4VWX herring. CSAS Stock Status Report 2004/034.

CSAS. 2007b. Recovery assessment potential for Right whale (Western North Atlantic Population). CSAS Science Advisory Report 2007/027.

Daborn, G.R. 1977. (Ed). *Fundy Tidal Power and the Environment*. Acadia University Institute Publication No. 28. 304 pp.

Daborn, G.R. 1984. Zooplankton studies in the Upper Bay of Fundy since 1976. Pp. 135-162 *In* Gordon, D.C. Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256. 686 p.

Daborn, G.R. 1986. Effects of tidal mixing on the plankton and benthos of estuarine regions of the Bay of Fundy. *In* Bowman, M.J., C.M. Yentsch and W.T. Peterson (Eds). *Tidal Mixing and Plankton Dynamics*. Lecture Notes in Coastal and Estuarine Studies Vol. 17 : 390-413. Springer-Verlag. N.Y.

Daborn, G.R. 1997. Fundy Marine Ecosystem Science Project: Science overview. Ch. 1 *In* Percy, J.A., P.G. Wells and A. J. Evans (Eds). 1997. Bay of Fundy Issues: a scientific overview. Proceedings of a Workshop, Wolfville, NS, January 29 to February 1, 1996. Environment Canada – Atlantic Region Occasional Report no. 8, Environment Canada, Sackville, NB. 191 pp.

Daborn, G.R. 2007. Homage to Penelope: Unravelling the ecology of the Bay of Fundy System. Pp. 12-23 *In* Pohle, G.E., P.G. Wells and S.J. Rolston. (Eds). 2007. Challenges in environmental management in the Bay of Fundy—Gulf of Maine. Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, NN, 24-27 October 2006. Bay of Fundy Ecosystem Partnership Technical Report No. 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS. 309 pp.

Daborn, G.R. and M. J Dadswell. 1988. Natural and anthropogenic changes in the Bay of Fundy—Gulf of Maine—Georges Bank system. Pp. 529-542 *In* M.I. El-Sabh and T.S. Murty (Eds.). Natural and Man-made Hazards. Reidel Publishing,

Daborn, G.R., C.L. Amos, B. Brylinsky, H. Christian, G. Drapeau, R.W. Faas, J. Grant, B. Long, D.M. Paterson, G.M.E. Perillo, and M.C. Piccolo. 1993. An ecological cascade effect: migratory shorebirds affect stability of intertidal sediments. Limnology and Oceanography. 38: 225-231.

Daborn, G.R., C.L. Amos, B. Brylinsky, H.A. Christian, G. Drapeau, G. Perillo, M.C. Piccolo, and G. Yeo. 1991. Littoral Investigation of Sediment Properties. Final Report. Acadia Centre for Estuarine Research, Acadia University, Wolfville, N.S. Report No. 17. 239 pp.

Daborn, G.R., C.L.Amos, H.A. Christian and M. Brylinsky. 1995. Stability of the shoreline at Fort Anne National Historic Site. ACER Report No. 37. 183 p.

Daborn, G.R**.,** M. Brylinsky and D. Van Proosdij. 2003. Ecological studies of the Windsor Causeway and Pesaquid Lake. Acadia Centre for Estuarine Research, Report No. 69. 111 pp.

Dadswell, M. J. 2006. A review of the status of Atlantic sturgeon in Canada, with comparisons to populations in the United States and Europe. Fisheries 31: 218-229

Dadswell, M.J. 1979. Biology and population characteristics of the shortnose sturgeon, *Acipenser brevirostrum* LeSueur, 1818 (Ostreichthyes:Acipenseridae), in the Saint John River estuary, New Brunswick, Canada. Can. J. Fish. Aquat. Sci. 57: 218-2210.

Dadswell, M.J. 1984. The status of shortnose sturgeon, *Acipenser brevirostrum*, in Canada. Can. Field-Naturalist. 98: 75-79.

Dadswell, M.J. 1985. Status of blueback herring, Alsoa aestivalis, in Canada. Can. Field-Naturalist. 99: 409-412.

Dadswell, M.J. 1986. Stock structure of American shad, *Alosa sapidissima*, in the Gulf of Maine and Bay of Fundy. CAFSAC Res. Doc. 86/97.

Dadswell, M.J., G.D. Melvin and P.J. Williams. 1983. Effect of turbidity on the temporal and spatial utilization of the Inner Bay of Fundy by American shad (*Alosa sapidissima*) (Pisces:Clupeidae) and its relationship to local fisheries. Can. J. Fish. Aquat. Sci. 40 (Supplement 1): 322-330.

Dadswell, M.J., G.D. Melvin, P.J. Williams and D.E. Themelis. 1987. Influence of origin, life history and chance on the Atlantic coast migration of American shad. Amer. Fish. Soc. Sym. 1: 313-330.

Dadswell, M.J., G.D. Melvin, P.J. Williams and G.S. Brown. 1984b. Possible impact of large-scale tidal developments in the upper Bay of Fundy on certain migratory fish stocks of the Northwest Atlantic. Pp. 577-599. In. Gordon, D.C. Jr., and M.J. Dadswell (Eds.) Update on marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1256.

Dadswell, M.J., R. Bradford, A.H. Leim, G.D. Melvin, R.G. Appy and D.J. Scarratt. 1984a. A review of fish and fisheries research in the Bay of Fundy between 1976 and 1983. Pp 163-294 *In* Gordon, D.C. Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256.

Dadswell. M.J. and R.A. Rulifson.1994. Macrotidal estuaries: a region of collision between migratory marine animals and tidal power development. Biol. J. Linnean Soc. 51:93-113.

Dalrymple, R.W, and R.N. Rhodes. 1995. Estuarine dunes and bars Pp. 359-422 *In* G.M.E. Perillo (Ed). *Geomorphology and Sedimentology of Estuaries*. Developments in Sedimentology No. 53. Elsevier, Amsterdam.

Dawe, *E.G.* and E.B. Colbourne. 1997. Trends in the abundance of short-fin squid (*Illex illecebrosus*) and environmental conditions in the Northwest Atlantic. CSAS Research Doc. 1997/060.

Day, J.C. and J. C. Roff. 2000. Planning for Representative Marine Protected Areas: A Framework for Canada's Oceans. Report for the World Wildlife Fund, Toronto, Canada.

Department of Fisheries and Oceans 2001a. Gaspereau Maritime Provinces overview. DFO Science Stock Status Report D3-17.

Department of Fisheries and Oceans 2005. Commercial species of the Scotia Fundy Region. Backgrounder B-MAR-05- 03E.

Department of Fisheries and Oceans Canada. 2006. Maritimes Species at Risk Website. URL: http://www.mar.dfo-mpo.gc.ca/masaro/english/main_page.html/. (Accessed January 2006).

Department of Fisheries and Oceans, Reports and Publications. 2005. Aquaculture in Eastern Canada - A Growing Opportunity. http://www.dfo-mpo.gc.ca/aquaculture/multimedia/ppt_200511_e.htm

Department of Fisheries and Oceans. 1996. Bay of Fundy soft-shell clams. DFO Atlantic Fisheries. Stock Status Report 96/127.

Department of Fisheries and Oceans. 1998. Rockweed in the Maritimes. DFO Science Stock Status Report. C3-57.

Department of Fisheries and Oceans. 2005. Stock assessment of northwest Atlantic Harp seals. Canadian Science Advisory Secretariat Science Advisory Report 2005/037. 12p.

Desplanque, C. and D.J. Mossman. 1998. A review of ice and tide observations in the Bay of Fundy. Atlantic Geology 34: 195-209.

Desplanque, C. and D.J. Mossman. 2004. Tides and their seminal impact on the geology, geography, history and socio-economics of the Bay of Fundy, Eastern Canada. Atlantic Geology 40: 1-130.

Devine Tarbell & Associates (DTA). 2006. Instream Tidal Power in North America Environmental and Permitting Issues. EPRI-TP-007-NA. June 2006.

Dickie, L.M. 1955. Fluctuations in the abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Bay of Fundy. J. Fish. Res. Board Can. 12:797-857.

Dong Energy, Vattenfall, Danish Energy Authority and Danish Forest and Nature Agency. 2006. Danish Offshore Wind: Key Environmental Issues. Copenhagen, Denmark 142 pp.

Douglas, S.G., R.G. Bradford, and G. Chaput. 2003. Assessment of striped bass (*Morone saxatilis*) in the Maritime Provinces in the context of species at risk. CSAS Res. Doc. 2003/08.

DTI, 2007. *Tidal Current Energy: Device Performance Protocol*. Preliminary report prepared for The Department of Trade and Industry, UK. Version 1.3 Report prepared by The University of Edinburgh. MRF/02/0000 00006/00/00 URN 07/ 838.

Durbin, E. 1996. Zooplankton dynamics of the Gulf of Maine and Georges bank region, p.53-67. In, G.T. Wallace and E.F. Braasch [eds.], Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop. St. Andrews, N.B. Rargom Report 97-1.

Dyer, C., S. Wehrell and G.R. Daborn. 2005. Fisheries management issues in the Upper Bay of Fundy. Acadia Centre for Estuarine Research, Acadia University, Publication No. 80. 126 pp.

Elner, R. W. 1981. Diet of green crab *Carcinus maenus* (L.) from Port Hebert, southwestern Nova Scotia. J. Shellfish Res. 1: 89-94.

Emerson, C.W. and D.J. Wildish. 1986. Pelagic – benthic coupling at the mouth of the Bay of Fundy. Ophelia 26: 165-180.

EPRI, 2005. *Survey and Characterization – Tidal In Stream Energy Conversion Devices*. Electric Power Research Institute Inc. report TP-004-NA prepared by Electric Power Research Institute, EPRI solutions, Virginia Polytechnic Institute and State University, Mirko Previsic Consulting, National Renewable Energy Laboratory. 131 pp

EPRI, 2006. Instream Tidal Power in North America Environmental and Permitting

EPRI, 2006a. *System Level Design, Performance, Cost and Economic Assessment – New Brunswick Head Harbour Passage Tidal In-Stream Power Plant*. Electric Power Research Institute Inc. report TP-006-NB prepared by Global Energy Partners LLC, Virginia Polytechnic Institute and State University, Mirko Previsic Consulting, and Brian Polagye Consulting. 84 pp.

EPRI, 2006b. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices." *EPRI – TP – 001 NA Rev 3*. http://archive.epri.com/oceanenergy/streamenergy.html#reports.

EPRI, 2006c. *System Level Design, Performance, Cost and Economic Assessment – Minas Passage Nova Scotia Tidal In-Stream Power Plant*. Electric Power Research Institute Inc. report TP-006-NS prepared by Global Energy Partners LLC, Virginia Polytechnic Institute and State University, Mirko Previsic Consulting, and Brian Polagye Consulting. 90pp.

EPRI, 2006d. "New Brunswick Tidal In-Stream Energy Conversion (TISEC) Survey and Characterization of Potential Project Sites". *EPRI – TP – 003 NB Rev 1*. http://archive.epri.com/oceanenergy/streamenergy.html#reports.

EPRI, 2006e. "Nova Scotia Tidal In-Stream Energy Conversion (TISEC): Survey and Characterization of Potential Project Sites". *EPRI - TP- 003 NS Rev 2*. http://archive.epri.com/oceanenergy/streamenergy.html#reports.

EPRI-NS 2006. Electric Power Research Institute. *System Level Design, Performance, Cost and Economic Assessment-Minas Passage Nova Scotia Tidal Power In-stream Power Plant.* EPRI-

TP-006-NS.
http://archive.epri.com/oceanenergy/attachments/streamenergy/reports/006_NS_RB_06-10-06.pdf

Faas, R.W., H.A. Christian, G.R. Daborn and M. Brylinsky. 1992. Biological control of mass properties of surficial sediments : an example from Starrs Point mudflat, Minas Basin, Bay of Fundy. Proceedings of the Nearshore and Estuarine Cohesive Sediment Transport Workshop, St. Petersburg, Fla. 42: 360-377.

Faber Maunsell and Metoc PLC, March 2007. *Scottish Marine Renewables Strategic Envionmental Assessment (SEA) Environmental Report*. Scottish Executive.

Fader, G.B.J. and R.O. Miller. 1994. A preliminary assessment of the aggregate potential of the Scotian Shelf and adjacent areas. Pp 230-262 *In* P.G. Wells and P.J. Ricketts (Eds.) Coastal Zone Canada '94, 'Cooperation in the Coastal Zone': Conference Proceedings Vol 1.. Coastal Zone Canada Association, Bedford Institute of Oceanography, Dartmouth, NS.

Fader, G.B.J., L.H. King and B. MacLean. 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy. Can. Hydrogr. Serv. Mar. Sci. Paper 19: 23 pp.

Fader, Gordon (2005) Marine Archaeology Offshore Digby Neck, Bay of Fundy. Unpublished report.

Falconer, C.R., I.M. Davies and G. Topping. 1983. Trace metals in the common porpoise *Phocoena phocoena*. Mar. Environ. Res. 8:119.

FAO Fisheries Department. 2006. State of world aquaculture. FAO Fisheries Technical Paper, 500: 134pp.

FERC Order AD07-14-000: July 19, 2007

Field, J.D. 1997. Atlantic striped bass management: where did we go right. Fisheries 22: 6-8.

Fish, C.J. and M.W. Johnson. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. J. Biol. Board Can. 3:189-322.

Floyd, T. and J. Williams. 2004. Impact of green crab (*Carcinus maenus* L.) on a population of soft-shell clams (*Mya arenaria* L.) in the southern Gulf of St. Lawrence. J. Shellfish Res. 23:457-462.

Frank, K.T. 1992. Demographic consequences of age-specific dispersal in marine fish populations. Can. J. Fish. Aquat. Sci. 49:2222-2231.

Fried, S. 1999. Gulfwatch. Fundy Issues No. 12, Bay of Fundy Ecosytem Partnership. 8 pp.

Gardner, J.P. and M.L.H. Thomas. 1987. Growth and production of a *Littorina littorea* (L.) population in the Bay of Fundy. Ophelia 27:181-195.

Garrett, C.J.R. 1972. Tidal resonance in the Bay of Fundy and Gulf of Maine. Nature 238: 441-443.

Garrett, C.J. R. 1977. Tidal influences on the physical oceanography of the Bay of Fundy and Gulf of Maine. Pp. 101-115 *In* Daborn, G.R. (Ed.) 1977. Fundy Tidal Power and the Environment. Acadia University Institute Publication No. 28.

Gaskin, D.E and G.J.D. Smith. 1979. Observations on marine mammals, birds and environmental conditions in the Head Harbour region of the ay of Fundy, p. 69-86, In, D.J. Scarratt [ed.], Evaluation of recent data relative to potential oil spills in the Passamaquoddy area. Fish. Mar. Serv. Tech. Rep. 901...

Gaskin, D.E. 1983. The marine mammal community. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Gaskin, D.E. 1985. *The Ecology of Whales and Dolphins*. Heinemann, London and Exeter, New Hampshire.

Gaskin, D.E. 1992. The status of the harbour porpoise. Can Field Nat. 106:36-54.

Gaskin, D.E., A.J. Read, P.F. Watts and G.J. D. Smith. 1985. Population dispersal, size and interactions of Harbour porpoises in the Bay of Fundy and Gulf of Maine. Can. Tech. Rep. Fish. Aquat. Sci. No. 1291. 28p.

Gaskin, D.E., R. Frank and M. Holdrinet. 1983. Polychlorinated biphenyls in harbour porpoises *Phocoena phocoena* (L.) from the Bay of Fundy, Canada, and adjacent waters, with some information on chlordane and hexachlorobenzene levels. Arch. Environ. Contam. Toxicol. 12 (2):211-219.

Gates, A.D. and A.D.J. O'Neill. 1977. The climate of the Bay of Fundy. Pp. 116-124 *In* Daborn, G.R. 1977. (Ed). *Fundy Tidal Power and the Environment*. Acadia University Institute Publication No. 28. 304 pp.

Gibson, A.J.F. and R. Meyers. 2003. Biological reference points for anadromous alewife (*Alosa pseudoharengus*) fisheries in the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci. 2468.

Gill, A.B., Gloyne-Phillips, I., Neal, K.J. and Kimber, J.A., 2005. *The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms – A Review*. COWRIE-EM Field 2-06-2004.

Ginn, M.G. and D. J. Hamilton. 2007. Use of alternate foraging strategies and food resources by semipalmated sandpipers (*Calidris pusilla*) on mudfalts in the Upper Bay of Fundy. Pp. 181-182 *In* Pohle, G.E., P.G. Wells and S.J. Rolston. (Eds). 2007. Challenges in environmental management in the Bay of Fundy—Gulf of Maine. Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, NN, 24-27 October 2006. Bay of Fundy Ecosystem Partnership Technical Report No. 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS. 309 pp.

Godin, G. 1972. The analysis of tides. University of Toronto Press, Toronto. 264 pp.

Godin, G. 1992. Possibility of rapid changes in the tide of the Bay of Fundy, based on a scrutiny of the records from Saint John, NB. Cont. Shelf Res. 12:327-338.

Gordon, D.C and P.J. Cranford. 1994. Export of organic matter from a macrotidal salt marsh in the Upper Bay of Fundy, Canada, Pp. 257-264, In W.J. Mitsch [ed.], Global Wetlands. Elsevier.

Gordon, D.C. Jr. and C. Desplanque. 1983. Dynamics and environmental effects of ice in the Cumberland Basin of the Bay of Fundy. Can. J. Fish. Aquat. Sci. 40: 1331-1342.

Gordon, D.C. Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256. 686 p.

Gordon, D.C. Jr., P. J. Cranford and C. Desplanque. 1985. Observations on the ecological importance of salt marshes in the Cumberland Basin, a macrotidal estuary in the Bay of Fundy. Estuarine, Coastal and Shelf Science. 20:205-227.

Government NB. 2007. Interim Policy on Allocation of Crown Lands for Research in Support of In-Stream Tidal Power Generation. Government of New Brunswick. (http://www.gnb.ca/0078/Policies/CLM0192007E.pdf).

Greenberg, D.A. 1977. Effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. Pp.200-232 *In* Daborn, G.R. 1977. (Ed). *Fundy Tidal Power and the Environment.* Acadia University Institute Publication No. 28. 304 pp.

Greenberg, D.A. 1984. A review of the physical oceanography of the Bay of Fundy. Pp. 9-30 *In* D.C. Gordon, Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256. 686 p.

Greenberg, D.A., and C.L. Amos. 1983. Suspended sediment transport and depositional modeling of the Bay of Fundy, Nova Scotia – a region of potential tidal power development. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 20-34.

Greenberg, D.A., B.D. Petri, G.R. Daborn and G.B. Fader. 1997. The physical environment of the Bay of Fundy. Ch. 2 *In* Percy, J.A., P.G. Wells and A. J. Evans (Eds). 1997. Bay of Fundy Issues: a scientific overview. Proceedings of a Workshop, Wolfville, NS, January 29 to February 1, 1996. Environment Canada – Atlantic Region Occasional Report no. 8, Environment Canada, Sackville, NB. 191 pp.

Gregory, R.S. and G.R. Daborn. 1982. Notes on adult lumpfish, *Cyclopterus lumpus* L., from the Bay of Fundy. Proc. N.S. Inst. Sci. 32 : 321-326.

Griffin, R.B. 1999. Sperm whale distributions and community ecology associated with a warm-core ring off Georges bank. Mar. Mammal Sci. 15(1):33-51.

Hagerman, G., G. Fader, and R. Bedard. 2006. New Brunswick tidal in-stream energy conversion (TISEC): survey and characterization of potential project sites. Report EPRI-TP-003 NB Rev 1 to the New Brunswick Department of Energy and New Brunswick Power, 100 pp. http://archive.epri.com/oceanenergy/streamenergy.html#reports

Hagerman, G.; Fader, G.; Carlin, G.; Bedard, R. 2006a. Nova Scotia Tidal In-Stream Energy Conversion (TISEC): Survey and Characterization of Potential Project Sites. http://archive.epri.com/oceanenergy/streamenergy.html#reports

Hamilton, D.J. and A.W. Diamond. 2000. Shorebirds, snails and *Corophium*: complex interactions on an intertidal mudflat. Pp. 107-8 *In* Chopin, T. and P.G. Wells (Eds.). Opportunities and Challenges for Protecting, Restoring and Enhancing Coastal Habitats in the Bay of Fundy. Proceedings of the 4th Bay of Fundy Science Workshop, Saint John, NB, September 19-21. Environment Canada – Atlantic Region Occasional Report no. 17, Environment Canada, Dartmouth, NS,.

Hare, G.M. 1977. Atlas of the major Atlantic coast fish and invertebrate resources adjacent to the Canada – United States boundary area. Fish. Mar. Serv. Tech. Rep. 681.

Hargrave, B.T., D.E. Duplisea, E. Pfeiffer and D.J. Wildish. 1993. Seasonal changes in benthic fluxes of dissolved oxygen and ammonium associated with marine cultured Atlantic salmon. Mar. Ecol. Progr. Ser. 96: 249-257.

Hargrave, B.T., N.J. Prouse, G.A. Phillips and P.A. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper Bay of Fundy. Can. J. Fish. Aquat. Sci. 40(suppl. 1):229-243.

Haskoning UK Ltd, June 2005, Seagen Monitoring Programme, Strangford Narrows, Marine Current Turbines, Ltd, Draft Report.

Hicklin, P.W. 1987. The migration of shorebirds in the Bay of Fundy. Wilson Bulletin 99: 540-570.

Hicklin, P.W. 2005. Returning visitors: semipalmated sandpipers in Shepody Bay. Pp. 114-118 *In* Percy, J.A., A. J. Evans, P.G. Wells and S. J. Rolston. (Eds). 2005. The Changing Bay of Fundy: Beyond 400 Years. Proceedings of the 6th Bay of Fundy Workshop held September 29th to October 2nd 2004, Cornwallis, NS. Environment Canada – Atlantic Region Occasional Report no. 23, Environment Canada, Sackville, NB. 524 pp.

Hicklin, P.W. and P. C. Smith. 1979. The diets of five species of migrant shorebirds in the Bay of Fundy. Proc. N.S. Inst. Sci. 29: 2201-2210.

Hooker, S.K. R.W. Baird and M.A. Showell.1997. Cetacean strandings and bycatches in Nova Scotia, Eastern Canada, 1991-1996. IWC Document SC/49/05 (1997). 11p.

Horsley & Witten, Inc. 1998. Impacts of contaminants on the resources of the Gulf of Maine. Report prepared for the Commission for Environmental Cooperation, Montreal, Canada. 93p.

Hoyt, E. 1984. The whales of Canada. Camden House Publishing, Ontario.128 pp.

Hughson, W.B. 1977. Fundy avifauna: an overview. Pp. 180-186 *In* Daborn, G.R. 1977. (Ed). *Fundy Tidal Power and the Environment.* Acadia University Institute Publication No. 28. 304 pp.

Hunt. J. J. and J. D. Neilson. 1993. Is there a separate stock of Atlantic cod on the western side of the Bay of Fundy? N.A. J. Fish. Manag. 13: 421-436.

Huntsman, A.G. 1918. The effect of the tide on the distribution of the fishes of the Canadian Atlantic coast. Trans. Roy. Soc. Canada 12 (Ser. III): 61-67.

Huntsman, A.G. 1922. The fishes of the Bay of Fundy. Contributions to Canadian Biology 1921(3): 49-72.

Huntsman, A.G. 1931. The maritime salmon of Canada. Biol. Board Can. XXI.

Huntsman, A.G. 1938. International Passamaqoddy fishery investigations. J. Cons. Inter. Explor. Mer. 13:1-357.

Huntsman, A.G. 1952. The production of life in the Bay of Fundy. Trans. Roy. Soc. Canada 46 (Ser. III): 15-38.

Iles, T.D. 1979. The ecology of the herring fisheries of the Bay of Fundy. Can. Fish. Mar. Serv. Tech. Rep. 901: 27-52.

IMO, 2005. *International Convention on The Control of Harmful Anti-Fouling Systems on Ships*. IA680E. International Maritime Organization. ISBN 9789280141955

Isaacman, L.A. 2005. Historic examination of the changes in diadromous fish populations and potential anthropogenic stressors in the Avon River watershed, Nova Scotia. Unpublished M.E.S. thesis, Dalhousie University. 114 pp.

Jermolajev, *E.G.* 1958. Zooplankton of the inner Bay of Fundy. J.Fish. Res. Board Can. 15:1219-1228.

Jessop, B. 1996. Eel fisheries in the Maritimes (Anguilla rostrata). DFO Atlantic Fisheries Stock Status Report 96/14E

Johnson, J. 2007. Ocean energy in Canada. Presentation to ALL-Energy Conference, Scotland, May 23, 2007. [source: http://www.oreg.ca/oreg_presentations.html]

Johnston, D.W. 1995. Spatial and temporal differences in heavy metal concentrations in the tissues of harbour porpoises (*Phocoena phocoena* L.) from the Western North Atlantic. M.Sc. Thesis. University of Gulf, Guelph, Ontario, Canada. 152p.

Johnston, D.W., L.H. Thorne and A.J. Read. 2005. Fin whales *Balaenoptera physalus* and minke whales *Balaenoptera acutorostrata* exploit a tidally driven island wake ecosystem in the Bay of Fundy. Mar. Ecol. Prog. Ser. 305:287-295.

Joyce, W., S.E. Campana, L.J. Natanson, N.E. Kohler, H.L. Pratt and J.F. Jensen. 2002. Analysis of stomach contents of the Porbeagle shark (*Lamna nasus*) in the Northwest Atlantic. ICES j. Mar. Sci. 59:1263-1269.

Kaczmarska, I. and M. Trites. 2004. Mudflat diatoms in the Bay of Fundy: What is known about them? Pp. 195-199 *In* Wells, P.G., G.R. Daborn, J.A. Percy, J. Harvey and S.J. Rolston. (Eds). 2004. Health of the Bay of Fundy: Assessing key issues. Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum, “Taking the Pulse of the Bay”, Wolfville, Nova Scotia, May 13-16, 2002. Environment Canada – Atlantic Region, Occasional Report No. 21, Environment Canada, Dartmouth, Nova Scotia and Sackville, New Brunswick, 416 pp.

Keizer, P.D. and D. C. Gordon Jr. 1985. Nutrient dynamics in Cumberland Basin, Chignecto Bay – a turbid macrotidal estuary in the Bay of Fundy. Neth. J. Sea Res. 19: 193-205.

Kelley, J.T., A.R. Kelley and S.Apollonio. 1995. Landforms of the Gulf of Maine. Pp. 19-36 *In* Conklin, P.W. (Ed.). 1995. *From Cape Cod to the Bay of Fundy: An Environmental Atlas of the Gulf of Maine.* MIT Press, Cambridge, Massachusetts. 258 pp.

Klawe, W.L. and L.M. Dickie. 1957. Biology of the bloodworm *Glycera dibranchiata* Ehlers, and its relation to the bloodworm fishery of the Maritime Provinces. Bull. Fish. Res. Board Can. 115.

Knight, J., Jacques Whitford, discussion related to distribution capabilities, E-mail September 20, 2007.

Knight, R.J. and R.W. Dalrymple. 1976. Winter conditions in a macrotidal environment, Cobequid Bay, Nova Scotia. Rev. Geogr. Montreal, 30: 68-85.

Kovacs, K.M., K.M. Jones and S.E. Welke. 1990. Sex and age segregation by *Phoca vitulina concolor* at haul-out sites during the breeding season in the Passamaquoddy Bay region, New Brunswick. Mar. Mammal. Sci. 6:204-214.

Lakshminarayana, J.S.S. 1983. Phytoplankton of the Quoddy Region. *In* Thomas, M.L.H. (Ed). 1983. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 176-192.

Laney, R.L., J.E. Hightower, B.R. Versak, M.F. Mangold, W.W. Cole Jr. and S. E. Winslow. 2007. Distribution, habitat use, and size of Atlantic sturgeon captured during cooperative winter tagging cruises, 1988-2006. Amer. Fish. Soc. Sym. 56:167-182.

Lawton, P., D.A. Robichaud, D.S. Pezzack, M.B. Strong and D.R. Duggan. 1998. The Atlantic lobster, *Homarus americanus*, fishery in the Bay of Fundy (LFA 35, 36, and 38). DFO CSAS Research Document 98/73.

Legaré, J.E.H. and D.C. MacLellan. 1960. A qualitative and quantitative study of the plankton of the Quoddy Region inj 1957 and 1958 with special reference to the food of the herring. J. Fish. Res. Board Can. 17: 409-448.

Leim, A. H. 1924. The life history of the shad (*Alosa sapidissima* (Wilson)) with special reference to the factors limiting its abundance. Contr. Canadian Biology (New Series) 2: 163-284.

Leim, A.H. and W.B. Scott. 1966. Fishes of the Atlantic coast of Canada. Fish. Res. Board Can. Bull. 155.

Link, J.S.; Brodziak, J.K.T., editors, and Brodziak, J.K.T.; Dow, D.D.; Edwards, S.F.; Fabrizio, M.C.; Fogarty, M.J.; Hart, D.; Jossi, J.W.; Kane, J.; Lang, K.L.; Legault, C.M.; Link, J.S.; MacLean, S.A.; Mountain, D.G.; Olson, J.; Overholtz, W.J.; Palka, D.L.; Smith, T.D. 2002. Status of the Northeast U.S. Continental Shelf Ecosystem: a report of the Northeast Fisheries Science Center's Ecosystem Status Working Group. Northeast Fish. Sci. Cent. Ref. Doc. 02-11; 245 p.

Loder, J.W. and C.J. R. Garrett. 1978. The 18.6 –year cycle of sea surface temperature in shallow seas due to variations in tidal mixing. J. Geophys. Res. 83: 1967-1970.

Logan, A., A.A. MacKay, and J.P.A. Noble. 1983. Sublittoral hard substrates. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Loring, D.H. 1979. Baseline levels of transition and heavy metals in the bottomn sediments of the Bay of Fundy, Nova Scotia, Canada. Proc. N.S. Inst. Sci. 29: 335-346.

Loring, D.H. 1982. Geochemical factors controlling the accumulation and dispersal of heavy metals in the Bay of Fundy sediments. *Can. J. Earth Sci.* 19: 930-944.

Lundy, M. 1996. Scotian Shelf sea cucumber. DFO Atlantic Fisheries Stock Status Report 96/125E.

MacDonald, J.S., M.J. Dadswell, R.G. Appy, G.D. Melvin, and D.A. Methven. 1984. Fishes, fish assemblages, and their seasonal movements in the lower Bay of Fundy and Passamaquoddy Bay, Canada. Fishery Bulletin 82(1): 121-139.

MacKay, A. 2005. Online slide show. In: BayofFundy.ca – The Bay of Fundy Connection. http://www.bayoffundy.ca/LNG/.

MacKay, A.A. and R.K. Bosein. 1979. Bay of Fundy Resource Inventory Vol 5. The Wolves Islands. Final Report to the New Brunswick Departnemt of Fisheries, Reference NB78-1B, 97 pp.

MacKay, K.T. 1967. An ecological study of mackerel, *Scomber scombrus*, in the coastal waters of Canada. Fish. Res. Board Can. Tech. Rep. 31.

Mahone, R., R.W. Smith, B.B. Bernstein and J.S. Scott 1984. Spatial and temporal patterns of groundfish distribution on the Scotian Shelf and in the Bay of Fundy, Canada 1970-1981. Can. Tech. Rept. Fish. Aquat. Sci. 1300.

Martin, J.F., K. Haya, L.E. Burridge and D.J. Wildish. 1990. *Nitzschia pseudodelictissima* a source of domoic acid in the Bay of Fundy, eastern Canada. Mar. Eco. Prog. Ser. 67:177-182

Martin, J.L., M.M. LeGresley and P.M. Strain. 2001. Phytoplankton monitoring in the Western Isles Region of the Bay of Fundy during 1977-98. Can. Tech. Report. Fish. Aquat. Sci. no. 2349.

McAlpine, D.F. and R.J. Walker. 1999. Additional extralimital records of the harp seal, *Phoca groenlandica*, from the Bay of Fundy, New Brunswick. Can. Field. Nat. 113: 290-292.

McCleave, J.D., R.C. Kleckner and M. Castonguay. 1987. Reproductive sympatry of American and European eels and implications for migration and taxonomy. Amer. Fish. Soc. Sym. 1: 286-297.

McCracken, F.D. 1960. Studies of haddock in the Passamaquoddy Bay region. J. Fish. Res. Board Can. 17: 175-182.

MCTS 2007. Canadian Coast Guard, Marine Traffic and Communications Services. Data obtained from INNAV reports for 2006.

Melvin, G.D., M.J. Dadswell and J.D. Martin. 1986. Fidelity of American shad, *Alosa sapidissima* (Osteichthyes:Clupeidae) to its river of previous spawning. Can. J. Fish. Aquat Sci. 43: 640-646.

Mercier, F.M. and D.E. Gaskin. 1985. Feeding ecology of migrating Red-necked phalaropes (*Phalaropus lobatus*) in the Quoddy Region, New Brunswick, Canada. Can. J. Zool. 63: 1062-1067.

McKinley, R.S. and H. Kowalyk. 1989. Effectiveness of fish protection scheme in repelling or diverting fish in the intake-forbay of the Annapolis Tidal Power Station. Ontario Hydro Report No. 89-110-P

Michel, J., Dunagan, H., Boring, C., Healy, E., Evans, W., Dean, J.M., McGillis, A. and Hain, J., 2007. *Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf*. U.S. Department of the Interior, Minerals Management Service, Herndon, VA, MMS OCS Report 2007-038. 254 pp.

Middleton, G.V. 1977. The sediment regime of the Bay of Fundy. Pp. 125-130 *In* Daborn, G.R. 1977. (Ed). *Fundy Tidal Power and the Environment*. Acadia University Institute Publication No. 28.

Miller, R. J. and S.C. Nolan 2000. Management of Nova Scotia sea urchin fishery: a nearly successful habitat based management regime. CSAS Research Document 2000/19.

Milne, W.R. and S. Corey. 1986. Distributional patterns of the ctenophores *Pleurobrachia pileus* and *Beroe cucumis* in the Bay of Fundy region, Canada. Can. J. Zool. 64:2639-2644.

Minas Basin Pulp & Power Joins With ATEC to Develop Fundy Tidal Power, Press Release, Halifax, Nova Scotia June 4, 2007.

Mitchell, E. and V.M. Kozicki. 1975. Autumn stranding of a northern bottlenose whale (*Hyperoodon ampullatus*) in the Bay of Fundy, Nova Scotia. J. Fish. Res. Board Can. 32:1019-1040.

Moore, T.M. 1998. Population characteristics of the spiny dogfish, Squalus acanthias Linnaeus 1758, from geographically distinct locations in Atlantic Canada during the summer and fall of 1996. Unpublished B.Sc. (Hons) Thesis, Acadia University, Wolfville, NS.

Morrison, R.I.G., C. Downe and B. Collins. 1994. Population trends of shorebirds on fall migration in Eastern Canada, 1974-1991. Wilson Bulletin 106: 431-447.

National Oceanic and Atmospheric Administration 2007. Marine mammal stick assessment: Killer whale (*Orcinus orca*) western North Atlantic Stock. NOAA Technical Memorandum NMFS-NE-169.

National Oceanic and Atmospheric Administration 2007. Marine mammal stock assessment: Fin whale (*Balaenoptera physalus*) western North Atlantic stock. NOAA Technical Memorandum NMFS-NE-169.

National Oceanic and Atmospheric Administration. 2007. Marine mammal stock assessment: Minke whale (*Balaenoptera acutorostrata*) Canadian east coast stock. NOAA Technical Memorandum NMFS-NE-169.

Nelson, R.W.P., K. Ellis and J.N. Smith. 1985. Environmental monitoring report for the Point Lepreau, N.B. nuclear generating station – 1983. Can Tech. Rept. Hydrogr. Ocean Sci. No. 59. vi + 146 p.

New Brunswick Department of Agriculture and Aquaculture. 2007. Aquaculture 2005. http://www.gnb.ca/0168/30/ReviewAquaculture2005.pdf.

New Brunswick Government. Department of Tourism and Parks. 2003. CIMA 2003: Consumer Interests, Motivators, and Attitudes. Accessed 20 September 2007 from <http://www.gnb.ca/0397/documents/ CIMA-e.pdf>.

New Brunswick Government. Department of Tourism and Parks. 2006. 2005-2006 Annual Report. Accessed 19 September 2007 from <http://gov.nb.ca/0397/documents/annual_report 2005 -06.pdf>.

Noer, H., Christensen, T., Clausager, I., and Petersen, I., 2000. *Effects on birds of an offshore wind park at Horns Rev: Environmental impact assessment*. NERI report prepared for Elsamprojekt A/S.

Nova Scotia Government. Department of Tourism, Culture, and Heritage. 2005. Tourism Activity by Region: 2004. Accessed 19 September 2007 from <http://www.gov.ns.ca/dtc/pubs/insights/AbsPage.aspx?ID=1299&siteid=1&lang=1>.

Nova Scotia Museum 1996. The Natural History of Nova Scotia. Halifax: Nova Scotia Museum, Nimbus Publishing. 2 Vols. 822 pp.

Parker, M., M. Westhead and A. Service. 2007. Ecosystem overview report for the Minas Basin, Nova Scotia. Oceans and Habitat Report 2007-5, Oceans and Habitat Branch, Fisheries and Oceans Canada.179 pp.

Parsons, G.J. 1986. Floating algal rafts and their associated fauna in Passamaquoddy Bay, New Brunswick. Unpublished M.Sc. Thesis. Acadia University, Wolfville, N.S.

Partridge, V.A. 2000. Aspects of the winter ecology and spring recolonization of the Windsor Mudflat. Unpublished MSc thesis, Department of Biology, Acadia University, Wolfville, NS.

Pelletier, B.R. and R.M. McMullen. 1972. Sedimentary patterns in the Bay of Fundy and Minas Basin. Pp. 153-187 *In* T.J. Gray and O.K. Gashus (Eds.). *Tidal Power*. Plenum Press, NY.

Percy, J.A. 1997. Marine Resources of the Bay of Fundy. Pp 103-137. Percy, J.A., P.G. Wells and A.J. Evans. Bay of Fundy Issues: a Scientific Overview. Environment Canada – Atlantic Region. Occasional Report 8.

Percy, J.A. and J. Harvey (Eds.). 2000. Tidal barriers in the Inner Bay of Fundy: Ecosystem impacts and restoration opportunities. Conservation Council of New Brunswick publication. 133 pp.

Percy, J.A., P.G. Wells and A. J. Evans (Eds). 1997. Bay of Fundy Issues: a scientific overview. Proceedings of a Workshop, Wolfville, NS, January 29 to February 1, 1996. Environment Canada – Atlantic Region Occasional Report no. 8, Environment Canada, Sackville, NB. 191 pp.

Perez, J.A.A. and R.K. O'Dor. 2000. Critical transitions in the early life history of short- finned squid, *Illex illecebrosus* as reconstructed from gladius growth. J. Mar. Biol. Assoc. UK 80:509-514.

Perley, M.H. 1852. Report on the Sea and River fishes of New Brunswick. Queen's Printer, Fredericton, N.B.

Prouse, N.J., D.C. Gordon Jr., B.T. Hargrave, C.J. Bird, J. Machlachlan, J.S.S. Lakshminarayana, J. Sita Devi and M.L.H. Thomas. 1984. Primary production: organic matter supply to ecosystems in the Bay of Fundy. Pp. 65-95 *In* Gordon, D.C. Jr. and M. J. Dadswell (Eds.). 1984. Update on the marine environmental consequences of tidal power development in the upper reaches of the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. 1256.

Rangley, R.W. 1994. The effects of seaweed harvesting on fish: a critique. Environmental Biology of Fishes. 39:319-323.

Rangeley, R.W. and D.L. Kramer. 1995. Tidal effects on habitat selection and aggregation by juvenile pollack (*Pollachius virens*) in the rocky intertidal zone. Mar. Ecol. Progr. Ser. 126: 19-29.

Ray, S. and V. Jerome. 1987. Copper, zinc, cadmium and lead in scallops (*Placopecten magellanicus*) from the Maritimes. Can. Tech. Rep. Fish. Aquat. Sci. 1519: iii + 29p.

Read, A.J. and A.A. Hohn. 1995. Life in the fast lane: The life history of Harbour porpoises from the Gulf of Maine. Mar. Mam... Sci. 11(4): 423-440.

Redden, A.M. and G.R. Daborn. 1991. Viability of subitaneous copepod eggs following fish predation on egg-carrying calanoids. Marine Ecology - Progress Series, 77 : 307-310.

Reid, P.R. 1982. Aspects of the winter ecology and behaviour of bald eagles (*Haliaectus leucocephalus alaseanus* Townsend) on the Shubenacadie River, Nova scotia. M.Sc. Thesis, Acadia University, Wolfville, NS

Robichaud, D.A. and C. Frail. 2006. Development of the Jonah crab, *Cancer borealis*, and rock crab, *Cancer irroratus*, fisheries in the Bay of Fundy (LFA's 35-38) and off southwest Nova Scotia (LFA 34): exploratory to commercial status (1995-2004). Can. Manu. Rep. Fish. Aquat. Sci. 2775.

Robichaud, D.A. and P. Lawton. 1996. Inshore Gulf of Maine Jonah crab. DFO Atlantic Fisheries Stock Status Report 96/111E.

Robinson, S.M.C. 1993. The soft-shell clam fishery in the Canadian Maritimes: an industry in change. J. Shellfish Res. 12: 145.

Robinson, S.M.C. 1994. The green sea urchin, *Strongylocentrus droebachiensis*, fishery – the Bay of Fundy. Can. MS Rep. Fish. Aquat. Sci. 2247: 90-94.

Robinson, S.M.C. 1995. Clam enhancement trials in the Bay of Fundy.

Robinson, S.M.C., S. Bernier and A. McIntyre. 2001. The impact of scallop drags on sea urchin populations and benthos in the Bay of Fundy , Canada. Hydrobiologia 465:103- 114

Rodgers, H.M. 1936. The estuary of the Saint John River. Its physiography, ecology, and fisheries. Masters of Arts Thesis. University of Toronto. Toronto, Ontario.

Rodhouse, R., *E.G.* Dawe and R.K. O'Dor. 1998. Squid recruitment dynamics. FAO Rome, Fish. Tech. Pap. 376.

Roff, J.W. 1983. Microzooplankton of the Quoddy Region. 1983. 64: 201-214 *In* Thomas, M.L.H. (Ed). 1983. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci..

Roland, A.E. 1982. Geological Background and Physiography of Nova Scotia. Halifax, Nova Scotia Institute of Science. 311 pp.

Rubenstein, B. 1994. An apparent shift in distribution of ice seals, *Phoca groenlandica*, *Cystophora cristata*, and *Phoca hispida*, toward the east coast of the United States. M.A. Thesis, Boston University, Boston, MA.45p

Rulifson, R.A. 1994. Status of anadromous *Alosa* along the east coast of North America. Amer. Fish. Soc. Anadromous Alosa Symposium 1994: 134-158.

Rulifson, R. A., S. A. McKenna and M.J. Dadswell. Intertidal habitat use, population characteristics, movement and exploitation of striped bass in the inner Bay of Fundy, Canada. Trans. Amer. Fish. Soc. (in press).

Rulifson, R.A. and M.J. Dadswell 1995. Population characteristics of striped bass in Atlantic Canada. Trans. Amer. Fish. Soc. 124: 477-507.

Rulifson, R.A. and K.A. Tull. 1998. Striped bass spawning in a tidal bore river: the Shubenacadie estuary, Atlantic Canada. Trans. Amer. Fish. Soc. 128:613-624.

Sanders, R. and E. Baddour. 2006. Documenting ice in the Bay of Fundy, Canada. Report No. CR-2006-01. National Research Council of Canada. 60 pp.

Sanders, R. Ph.D and Baddour, E. Ph.D, June 2007, Proceedings of OMAE 2007 International Conference on Offshore Mechanics and Arctic Engineering, Tidal Power and Ocean Ice in the Bay of Fundy, Canada, 1968-2007.

Saunders, R.L. 1981. Atlantic salmon (*Salmo salar*) stocks and management implications in the Canadian Atlantic provinces and New England, USA. Can. J. Fish. Aquat. Sci. 38: 1612-1625.

Schell, T.M. and G.R. Daborn. 1994. Biophysical interactions in the 'microbore' during flooding of estuarine tidal flats. Pp. 1902-1915 *In* P.G. Wells, and P.J. Ricketts. (Eds.) 1994. Coastal Zone Canada '94, 'Coopewration in the Coastal Zone': Conference Proceedings, Vol. 5. Coastal Zone Canada Association, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

Scott, D.B. and D.A. Greenberg 1983. Relative sea-level rise and tidal development in the Fundy tidal system. Can. J. Earth Sci. 20: 1554-1564.

Scott, W.B. 1983. Fishes. *In* Thomas, M.L.H. (Ed). 1983. Marine and coastal systems of the Quoddy Region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 156-175.

Scott, W.B. and M.G. Scott. 1988. Atlantic fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219.

Selzer, L.A. and P.M. Payne. 1988. The distribution of white-sided (*Lagenorhynchus acutus*) and common dolphins (*Delphinus delphis*) vs. environmental features of the continental shelf of the northeastern United States. Mar. Mammal Sci. 4(2):141-153.

Sharp, G. 1981. An assessment of *Ascophyllum nodosum* harvesting methods – southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1012.

Sharp, G. and R. Semple. 1997. Rockweed. DFO, CSAS Res. Doc. 97/31.

Shepherd, P.C.F. and J.S. Boates. 1999. Effects of a commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy Hemispheric Shorebird Reserve. Conservation Biology 13:347-356.

Shepherd, P.C.F. and J.S. Boates. 1999. Effects of baitworm harvesting on the amphipod *Corophium volutator* and on the semipalmated sandpiper *Calidris pusilla*. Conservation Biology 13: 347-356.

Shepherd, P.C.F., V.A. Partridge and P.C. Hicklin. 1995. Changes in sediment types and invertebrate fauna in the intertidal mudflats of the Bay of Fundy between 1977 and 1994. Tech. Rept. Ser. 237 Can. Wildl. Serv., Environ. Conserv. Branch, Environment Canada.

Simon, J.E. and P.A. Comeau. 1994. Summer distribution and abundance trends of species caught on the Scotian Shelf from 1970-92, by the research vessel groundfish survey. Can. Tech. Rep. Fish. Aquat. Sci. 1953.

Sinclair, M. and M.J. Tremblay. 1984. Timing of spawning of herring (*Clupea harengus harengus*) populations and the match-mismatch theory. Can. J. Fish. Aquat. Sci. 41:1055-1065.

Singh, R., B.A. MavDonald, M.L.H. Thomas and P. Lawton. 1999. Patterns of seasonal and tidal feeding activity in the dendrochirote sea cucumber *Cucumaria fondrosa* (Echinodermata: Holothuroidea) in the Bay of Fundy, Canada. Mar. Eco. Prog. Ser. 187:133-145.

Smith, S. J., M.J. Lundy, D. Roddick and S. Rowe. 2005. Scallop production areas in the Bay of Fundy: stock status report for 2005 and forecast for 2006. DFO. CSAS. Research Document 2005/079.

Solomon, D.J. 1988. Fish passage through tidal energy barrages. Contractor's Report No. ETSU TID 4056. Energy Technology Support Unit, UK Department of Energy. 76 pp.

Southwest New Brunswick Marine Resources Planning (SNBMRP). 2006. Public survey final report. Corporate Research Associates Inc., www.cra.ca.

Spares, A.D., J.M. Reader, M.J. Stocksbury, T. McDermott, L. Zikovsky, T.S. Avery and M.J. Dadswell. 2007. Inferring marine distribution of Canadian and Irish Atlantic salmon (*Salmo salar* L.) in the North atlantic from tissue concentrations of bioaccumulated Cesium 137. ICES J. Mar. Sci. 64:374-404.

Spear, B.J. 2007. U.S. Management of Atlantic sturgeon. Amer. Fish. Soc. Sym. 56: 339- 346.

Sprague, A.J., A. W. Diamond and D.J. Hamilton. 2005. Factors affecting movement of semipalmated sandpipers (*Calidris pusilla*) migrating through the Upper Bay of Fundy. Pp. 110-113 *In* Percy, J.A., A. J. Evans, P.G. Wells and S. J. Rolston. (Eds). 2005. The Changing Bay of Fundy: Beyond 400 Years. Proceedings of the 6th Bay of Fundy Workshop held September 29th to October 2nd 2004, Cornwallis, NS. Environment Canada – Atlantic Region Occasional Report no. 23, Environment Canada, Sackville, NB. 524 pp.

Statistics Canada (2005). Aquaculture Statistics 2004. 23-222-XIE, 44pp. http://www.statcan.ca/english/freepub/23-222-XIE/2004000/bfront1.htm

Statistics Canada, 2007. (http://www.statcan.ca)

Steele. 1983. In: Thomas M.L.H. (Ed.). 1983. Marine and Scott, W.B. 1983. Fishes. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Stein, A.B., K.D. Freidland, and M. Sutherland. 2004. Atlantic sturgeon marine distribution and habitat use along the northeastern coast of the United States. Trans. Amer. Fish. Soc. 133: 527-537.

Steneck, R.S. 1997. Fisheries-induced biological changes to the structure and function of the Gulf of Maine ecosystem. Pp 151-165. Proceedings of the Gulf of Maine Ecosystem Dynamics: A Scientific Symposium and Workshop.

Steneck, R.S. and C.J. Wilson 2001. Large-scale and long-term, spatial and temporal patterns in demography and landings of the American lobster, *Homarus americanus*, in Maine. Mar. Freshwater Res. 52: 1303-1319.

Stephenson, R.L. 1993. Herring Larvae and hydrology: studies and observations from the Bay of Fundy and the Gulf of Maine. Cons. Inter. Explor. Mer C.M. 1993/H.

Stephenson, T.A. and A. Stephenson. 1972. *Life Between Tidemarks on Rocky Shores*. W.H. Freeman, San Francisco. 425 pp.

Stevens, G.R. 1977. Geology and tectonic framework of the Bay of Fundy—Gulf of Maine region. Pp. 82-100 *In* Daborn, G.R. (Ed.) 1977. *Fundy Tidal Power and the Environment*. Acadia University Institute Publication No. 28.

Stobo, W.T. and G.M. Fowler. 1994. Aerial surveys of seals in the Bay of Fundy and off southwest Nova Scotia. Can. Tech. Rep. Fish Aquat. Sci. 1943. 57p.

Stobo, W.T., B. Beck and J.K. Horne. 1990. Seasonal movements of grey seal (*Halichoerus grypus*) in the northeast Atlantic,, p.199-213, In W.D. Bowen [ed.] Population biology of sealworm (*Pseudoterranova decipiens*) in relation to its intermediate and seal hosts. Can. Bull. Fish. Aquat. Sci. 222.

Stokesbury, K.D.E. and M.J. Dadswell. 1989. Seaward migration of juvenile alosids from an estuary in Atlantic Canada. Can. Field-Naturalist. 103: 338-393.

Stokesbury, M.J., G. Lacroix, M.J. Dadswell, E.L. Prince, and D. Knox. 2001. Identification by scale analysis of farmed Atlantic salmon juveniles in S.W. New Brunswick rivers. Trans. Amer. Fish. Soc. 130: 815-822.

Stone, H.H. and G.R. Daborn. 1987. Diet of alewives, *Alosa pseudoharengus*, and blue-back herring (*A. aestivalis*) (Pisces:Clupeidae) in Minas Basin, Nova Scotia, a turbid, macrotidal estuary. Env. Biol. Fish 19:55-67.

Strong, K.W. and G.R. Daborn. 1979. Patterns of growth and energy utilization of an intertidal isopod. J. exp. Mar. Biol. Ecol. 41 : 101-123.

Strong, K.W. and G.R. Daborn. 1980. The influence of temperature on energy budget variables, body size and seasonal occurrence of the isopod *Idotea baltica* (Pallas). Can. J. Zool. 58 : 1992-1996.

Sumer, B.M. and Fredsøe, J., 2002. *The Mechanics of Scour in the Marine Environment*. World Scientific Publishing Co. Pte. Ltd., Singapore. ISBN 981-02-4930-6.

Summers, W.C. 1971. Age and growth of *Loligo pealei*,, a population study of the common Atlantic coast squid. Biol. Bull. 141:189-201.

The Engineering Business Ltd. 2005. Stingray Tidal Stream Energy Device – Phase 3. DTI Technology Programme URN 05/864. 130 pp.

Thomas, M.L.H. (Ed). 1983. *Marine and coastal systems of the Quoddy Region, New Brunswick*. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Thomas, M.L.H. 1983a. Tidal pool systems. In: Thomas M.L.H. (Ed.). 1983. Marine and Scott, W.B. 1983. Fishes. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Thomas, M.L.H. 1994. Littoral communities and zonation on rocky shores in the Bay of Fundy, Canada: an area of high tidal range. Biol. J. Linn. Soc. 51:149-168.

Thomas, M.L.H., D.C. Arnold, and A.R.A. Taylor. 1983. Rocky intertidal communities. In: Thomas M.L.H. (Ed.). 1983. Marine and coastal systems of the Quoddy region, New Brunswick. Can. Spec. Publ. Fish. Aquat. Sci. 64: 306 pp.

Thurston 1994. *H. Thurston and P. Larsen 1994.* State of the environment: Gulf of Maine fact sheet. (as quoted in The History of Geological Development by George Ferguson http://www.bayoffundy.com/geologicalformation.aspx)

Thurston 1998. *Thurston, H. and Horner, S. 1998*. Tidal Life. Nimbus. Toronto. (as quoted in The Atlantic Marine Trades Association website http://www.boatinginatlanticcanada.com/geographics/newbrunswick.htm)

Titan Environmental Surveys, Ltd, April 2004, Strangford Lough Site Surveys Final Report (CS0101/R1/V1).

Trippel, E.A. and L.L. Brown. 1993. Assessment of pollack (*Pollachius virens*) in Divisions 4VWX and subdivision 5Zc for 1992. DFO Atlantic Fisheries research Document 93/60.

Trites, M., P. Hicklin, J. Ollerhead and I. Kaczmerska. 2004. Benthic diatoms from two intertidal mudflats in the Upper Bay of Fundy. Pp. 200-207 *In* Wells, P.G., G.R. Daborn, J.A. Percy, J. Harvey and S.J. Rolston. (Eds). 2004. Health of the Bay of Fundy: Assessing key issues. Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum, “Taking the Pulse of the Bay”, Wolfville, Nova Scotia, May 13-16, 2002. Environment Canada – Atlantic Region, Occasional Report No. 21, Environment Canada, Dartmouth, Nova Scotia and Sackville, New Brunswick, 416 pp.

Trites, R.W. and C.J. Garrett. 1983. Physical oceanography of the Quoddy Region. Pp. 9-34 *In* Thomas, M.L.H. (Ed). 1983. *Marine and coastal systems of the Quoddy Region, New Brunswick*. Can. Spec. Publ. Fish. Aquat. Sci. 64.

Triton Consultants, Ltd, 2006. *Canada Ocean Energy Atlas (Phase 1) Potential Tidal Current Energy Resources Analysis Background*.

Ugarte, R.A. 2007. Review of the management of rockweed (*Ascophyllum nodosum*) harvesting in New Brunswick after a decade of its initiation. Pp. 108-116 *In* Pohle, G.E., P.G. Wells and S.J. Rolston. (Eds). 2007. Challenges in environmental management in the Bay of Fundy—Gulf of Maine. Proceedings of the 7th Bay of Fundy Science Workshop, St. Andrews, NN, 24-27 October 2006. Bay of Fundy Ecosystem Partnership Technical Report No. 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS. 310 pp.

Ugarte, R.A. and G. Sharp. 2001. A new approach to seaweed management in eastern Canada: the case of *Ascophyllum nodosum*. Cah. Biol. Mar. 42:63-70.

Ugarte, R.A., G. Sharp and B. Moore. 2006. Changes in the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. Plant morphology and biomass produced by cutter rack harvests in southern New Brunswick, Canada. J. Appl. Phy. 18:351-359.

Uthe, J.F. and C.L. Chou. 1987. Cadmium in sea scallop (*Placopecten magellanicus*) tissues from clean and contaminated areas. Can. J. Fish. Aquat. Sci. 44:91-98.

Verdant Power, December 2006, Roosevelt Island Tidal Energy Project, Study Plans.

Wahle, R. 2007. New England lobster settlement index update 2006 - testing new tools. Hook, Line and Thinker 2007-2, 7-9.

Wallace, J. 1993. Environmental considerations. In: Heen, K., Monahan, R.L., and F. Utter. Salmon aquaculture. Halsted Press, Toronto.

Wang, J.Y. D.E. Gaskin and B.N. White 1996. Mitochondrial DNA analysis of the Harbour porpoise, *Phocoena phocoena*, sub-populations in North American waters. Can. J. Fish. Aquat. Sci. 53:1632-1645.

Watson, E.E. 1936. Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy. J. Biol. Bd. Canada 2: 141-208.

Watts, P. and D.E. Gaskin. 1985. Habitat index analysis of the harbour porpoise, *Phocoena phocoena*, in the southern coastal Bay of Fundy, Canada. J. Mamm. 66:733-744.

Wehrell, S. 2005. A survey of the ground fish caught by the summer trawl fishery in Minas Basin and Scots Bay. Honours Thesis, Department of Biology, Acadia University, Wolfville, Canada.

Wells, P.G. 1999. Environmental impacts of barriers on rivers entering the Bay of Fundy: Report of an ad hoc Environment Canada Working Group. Technical Report Series No, 334, Canadian Wildlife Series. 45 pp.

Wells, P.G., P.D. Keizer, J.L. Martin, P.A. Yeats, K.M Ellis and D.W. Johnston. 1996. The chemical environment of the Bay of Fundy, p. 37-61. *In* J.A. Percy, P.G. Wells and A.J. Evans [eds.], Bay of Fundy Issues: a scientific overview. Environment Canada - Atlantic Region. Occasional Report No.8.

Westgate, A.J. and K.A. Tolley. 1999. Geographical differences in organochlorine contaminants in harbour porpoises (*Phocoena phocoena*) from the Western North Atlantic. Mar. Ecol. Prog. Ser. 177:255-268.

Whoriskey, F.G., P. Brooking, G. Doucette, S. Tinker, and J.W. Carr. 2006. Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA. ICES Journal of Marine Science, 63: 1218-1223.

Wikipedia 2007. *Wikipedia, The Online Dictionary.* http://en.wikipedia.org/wiki/Cape_Enrage

Wildish, D. A. *et al.* (+ 22 co-authors). 1998. Population analyses of horse mussels of the inner Bay of Fundy based on estimated age, valve allometry and biomass. Can. Tech. Rep. Fish. Aquat. Sci. 2257:43pp.

Wildish, D.J. and G.B.J. Fader. 1998. Pelagic-benthic coupling in the Bay of Fundy. Hydrobiologia 375/376: 369-380.

Wildish, D.A. and D. Kristmanson. 1997. *Benthic Suspension Feeders and Flow*. Cambridge University Press, Cambridge, U.K. 407 pp.

Wildish, D.A., H.M. Akagi and G.B.J. Fader. 1999. Horse mussel reef project in the Inner Bay of Fundy. Pp. 21-22 *In* J. Ollerhead, P.W. Hicklin, P.G. Wells and K. Ramsey (Eds.) Understanding Change in the Bay of Fundy Ecoystem. Proceedings of the 3rd Bay of Fundy Science Workshop, Mount Alison University, Sackville, N.B. Environment Canada, Atlantic Region Occasional Report No. 12, Environment Canada, Sackville, N.B. 143 pp.

Wildish, D.J. and D.D. Kristmanson. 1979. Tidal energy and sublittoral macrobenthic animals in estuaries. J. Fish. Res. Board Can. 36: 1197-1206.

Wildish, D.J. and D.L. Peer. 1983. Tidal current speed and production of benthic macrofauna in the lower Bay of Fundy. Can. J. Fish. Aquat. Sci. 40 (Suppl. 1): 309-321.

Wildish, D.J. and G. Pohle. 2005. Benthic macrofaunal changes in the Letang Inlet: a quarter century view of an industrialized area. *In* B.T. Hargrave (Ed.) Environmental Effects of Finfish Aquaculture. The Handbook of Environmental Chemistry, Vol. 5. Water Pollution. Springer-Verlag, Berlin.

Wildish, D.J., H.M. Akagi, D.L. McKeown and G. W. Pohle. 2007. Ecology of passive pockmarks in Passamaquoddy Bay. P. 33 *In* Pohle, G.E., P.G. Wells and S.J. Rolston. (Eds). 2007. Challenges in environmental management in the Bay of Fundy—Gulf of Maine. Proceedings of the 7th Bay of

Fundy Science Workshop, St. Andrews, NN, 24-27 October 2006. Bay of Fundy Ecosystem Partnership Technical Report No. 3, Bay of Fundy Ecosystem Partnership, Wolfville, NS. 310 pp.

Wildsmith, B. 1981. Annapolis valley tidal project. Atl. Salmon J. Oct. 1981: 28-29.

Williams, R.R.G. and G.R. Daborn. 1984. Spawning of the American shad, *Alosa sapidissima*, in the Annapolis River, 1976. Proc. N.S. Inst. Sci. 34 : 15-23.

Williams, R.RG., G.R. Daborn and B.M. Jessop. 1984. Spawning of striped bass, *Morone saxatilis*, in the Annapolis River 1976. Proc. N.S> Inst. Sci. 34: 15-23.

Williamson, A. 1992. Historical lobster landings for Atlantic Canada 1892-1989. Can. MS Rep. Fish Aquat. Sci. 2164.

Wilson, W.H. 1991. The importance of epibenthic predation and ice disturbance in a Bay of Fundy mudflat. Ophelia Suppl. 5: 507-514.

Wirgin, I., B. Jessop, S. Courtenay, M. Pedersen, S. Maceda and J.R. Waldman. 1995. Mixed-stock analysis of striped bass in two rivers of the Bay of Fundy as revealed by mitochondrial DNA. Can. J. Fish. Aquat. Sci. 52:961-90.

Woodley T.H. and D.E. Gaskin. 1996. Environmental characteristics of North Atlantic right and fin whale habitat in the lower bay of Fundy, Canada. Can. J. Zool. 74:75-84.

Zaitlin, B.A. 1987. Sedimentology of the Cobequid Bay—Salmon River estuary, Bay of Fundy, Canada. Unpublished Ph.D. thesis, Queen's University, Kingston, Ontario. 391 pp.

P:\envsci\102xxxx\1028476 SEA Bay of Fundy\ESIA Input\final report\master sections\Newest Masters\FINALREPORT-Diane.doc

APPENDIX A

DTI Device Rating Criteria

dti

PRELIMINARY TIDAL CURRENT ENERGY DEVICE PERFORMANCE PROTOCOL

CONTRACT NUMBER:
MRF/02/00006/00/00

URN NUMBER: 07/838

The DTI drives our ambition of ‘prosperity for all’ by working to create the best environment for business success in the UK. We help people and companies become more productive by promoting enterprise, innovation and creativity.

We champion UK business at home and abroad. We invest heavily in world-class science and technology. We protect the rights of working people and consumers. And we stand up for fair and open markets in the UK, Europe and the world.

PRELIMINARY
TIDAL CURRENT ENERGY: DEVICE PERFORMANCE PROTOCOL

Version 1.3 - February 2007

Commissioned by
The Department of Trade and Industry

MRF/02/00006/00/00
URN 07/838

Prepared by
The University of Edinburgh

First published 2007

The Department of Trade and Industry (DTI) commissioned this protocol in April 2006. A draft submission for consultation was released in July 2006 and discussed at a workshop held on the 19th July. This preliminary stage of the document was released in August 2006. This updated version of the preliminary document is in response to comments received from the client, submitted in February 2007. All versions of the protocol have been prepared by Dr. Scott J. Couch and Henry Jeffrey of The University of Edinburgh.

Disclaimer

Acknowledgements

The authors acknowledge consultation with the following individuals and organisations:

Individuals	Organisation
Carolyn Heeps	Crown Estate
David Philips	Crown Estate
Gary Shanahan	Department of Trade and Industry
Dave Cousins	European Marine Energy Centre
Neil Kermode	European Marine Energy Centre
Jenny Norris	European Marine Energy Centre
George Smith	Heriot Watt University
Hamish Ellon	Hydro Contracting
Kelso Riddell	iXSurvey
Peter Wilks	iXSurvey
John Griffiths	JWG Consulting
Simon Meade	Lunar Energy
Jeremy Thake	Marine Current Turbines
David Ainsworth	Marine Current Turbines
Emma Robertson	Open Hydro
Tony Sanders	RS Aqua
Ewen Morrison	Scott Wilson Consultancy
Neil Hepburn	Scottish & Southern Energy
Donald Preston	Scottish & Southern Energy
Ralph Manchester	SMD Hydrovision
Fred Gardner	Teamwork Technology
Alan Owen	The Robert Gordon University
George Gibberd	Tidal Generation
John Armstrong	Tidal Stream
Ian Bryden	University of Edinburgh
Jamie Taylor	University of Edinburgh
Robin Wallace	University of Edinburgh
William Batten	University of Southampton
Andy Grant	University of Strathclyde
Norman Perner	Voith-Siemens Hydro

Contents

Definitions

The following definitions describe terminology as it is used within this document.

"Acceptance Date"	The date on which the Grant offer acceptances duly signed by the Scheme participant are returned to the Secretary of State, accompanied if a condition of grant offer by evidence that all necessary private sector finance for the Project has been secured and is unconditional.
"Acoustic Doppler (AD) device"	An instrument which generates a 3-dimensional current profile by analyzing the Doppler-shift of fixed-frequency acoustic echoes. The instrument measures the Doppler-shifted, fixed-frequency echoes backscattered from scatterers (plankton and sediment) in the water and converts the echoes to north/south, east/west, and vertical velocity components. Velocity profiles are determined by range gating echoes so that velocities are determined at pre-set intervals along the acoustic path (called bins).
"Bathymetry"	The underwater equivalent of topography. Bathymetry describes the spatial variations of water depth measured from the sea surface to the sea-bed.
"Centroid"	the point that may be considered as the centre of a one- or two-dimensional figure, the sum of the displacements of all points in the figure from such a point being zero.
"Chart datum"	The height of water at the lowest astronomical tide (LAT).
"Commissioning date"	The date on which the Scheme participant has declared the Eligible Facility to be commissioned, being (i) No earlier than the date on which the first kWh of Metered Energy has been delivered to the Distributor. (ii) No later than 2 years after the Acceptance Date.
"COP standard"	Code of practice for the metering of energy transfers for settlement purposes. The appropriate COP standard to apply is determined by the rated capacity of the facility.
"Device performance envelope"	Device performance is not characterised by a single value or criterion, a power curve, annual energy production and continuous record of the operational status of each device is utilised. Together, these performance criteria describe the 'device performance envelope'.

"Distributor" The UK Public Electrical Supplier or the UK Transmission Line Operator that operates the electrical network into which electrical energy generated by the Facility is distributed.

"Eligible Facility" The part of the Facility that is eligible for Capital Grant and Revenue Support from the Scheme.

"Ensemble average" Terminology used by AD device manufacturers to describe the processed output produced by an AD device. The ensemble average encompasses various internal processing typically including time averaging over a series of measurement samples (pings) and manipulation of the output from the various beams of the device to produce a co-located 'geographical' output.

"Facility" The generating station, comprising of multiple generator units and any associated infrastructure, which is capable of the metered export of electrical energy.

"IHO Order 1" States the Standards recommended for the scale of surveys and the density of soundings; accuracy of horizontal position; accuracy of depth and other various measurements. Issued by the International Hydrographic Organisation.

"Metered Energy" Electrical energy generated by the Eligible Facility and delivered to the Distributor net of any electrical energy imported into the Eligible Facility.

"Metering System" An electrical metering system compatible with the requirement specified in clause 5.

"MRDF" Marine Renewable Deployment Fund.

"Performance surface" The area of resource that the operational part of the device impinges upon. In the case of a ducted, shrouded, vaned or similar device operation, the performance surface is defined as the cross-sectional area of the inlet. In the case of a horizontal axis turbine, the performance surface is defined as the cross-sectional area swept by the turbine blades. In the case of a vertical axis turbine, the performance surface is defined as the vertical cross-sectional area swept by the turbine blades (i.e. the swept area perpendicular to the horizontal flow).

"Power curve" The Power curve is a graphical representation depicting the performance of a converter device at a measured current velocity (metres per second) relative to the power produced (kilowatts)).

"Principal current direction" The u- and v- velocity components of a tidal current record make up a bivariate data set. The principal angle for a bivariate data set can be calculated as described by Presendorfer (1988). This principal angle defines the principal current direction. Mathematically, the principal covariance of basis vectors parallel and perpendicular to the principal current direction is 0.

"Project" The work, costs, funding, payments, timeline and deliverables for the construction and operation of the Eligible Facility that is supported by the DTI under the Scheme.

"Project monitoring officer" The individual who is monitoring the Project on behalf of the Secretary of State. The Project monitoring officer acts as the arbiter in determining a course of action that meets the 'fit-for-purpose' remit of the protocol to ensure that the solution neither advantages nor disadvantages the individual Scheme participant affected under circumstances when deviation from the protocol procedures is unavoidable.

"Scheme" The Wave and Tidal Stream Energy Demonstration Scheme.

"TEC" Tidal Energy Converter. A device used to convert energy from tidal currents to electrical power.

"Test-site" Location of the TEC array.

"Test-site envelope" An area the extent of the proposed array footprint plus a minimum extent of 1km up and downstream and 100 metres either side, perpendicular to the flow direction.

"WGS 84" World Geodetic System 1984. The datum used for GPS positioning and adopted by the protocol as the universal positioning specification.

Symbols & Units

"m" metres.
"m/s" metres per second
"V" velocity magnitude
"ρ" density (kg/m^3).
"A" Area (of the performance surface).
"U" In the case of a fixed (e.g. non-yawing) TEC device, the velocity component perpendicular to the device performance surface. In the case of a TEC device capable of orientating to present the performance surface into the principal current direction, the velocity vector magnitude.
"$U_{perf(i)}$" the averaged representative current velocity in bin i (m/s).

"$P_{(i)}$"	the averaged measured power output in bin *i* (Watts).
"$U_{perf(i,j)}$"	the representative current velocity of data set *j* in bin *i*.
"$P_{(i,j)}$"	the measured power output of data set *j* in bin *i*.
"$N_{(i)}$"	the number of 10 minute data sets in bin *i*.

Background

The DTI's Wave and Tidal Stream Energy Demonstration Scheme, part of the Marine Renewable Deployment Fund (MRDF) supports the development of full-scale, grid-connected, multi-device wave and tidal-current energy demonstration facilities. An important objective of the Scheme is the production of transparent, unambiguous, consistent and meaningful assessments of the performance of tidal devices and arrays of tidal devices. This will enable the performance of devices to be effectively validated and, consequently, enable government, industry and the finance/investment community to form soundly based judgements of the commercial prospects of the technologies being demonstrated. To ensure that the performance of different devices is assessed on a consistent basis, there is a need for an explicit written protocol, which will form part of the contract between MRDF Scheme Participants and the Secretary of State. The protocol sets out in detail how performance assessment should be conducted.

This document proposes a preliminary Protocol for the performance testing of tidal current energy devices/arrays. Feedback on the initial draft Protocol document has been compiled, and where deemed appropriate, incorporated into the finalised preliminary protocol. This exercise is detailed in the accompanying "Response to feedback" document. It is acknowledged at this stage that knowledge gaps exist which impact on the proposed Protocol. These knowledge gaps have been identified in the accompanying documentation. Research to address the key knowledge gaps will inform the content of the final Protocol document adopted by the DTI for the MRDF Scheme.

1 Scope

1.1 Overview

There are currently no recognised or common procedures for assessing and comparing the performance of full scale tidal energy converter (TEC) devices at sea. The need for a clearly defined performance testing protocol is however obvious as proposed device technologies reach the stage of full-scale, grid-connected operation. It is acknowledged that significant 'grey' areas of fundamental understanding restrict the present development of a hard and fast procedure for performance testing at the level of a British or International Standard as exists for more mature technologies.

1.2 Objectives

The purpose of this document is to outline a preliminary protocol that is fit-for-purpose within the limitations of current understanding, and therefore ready for immediate application within the confines of the MRDF Scheme. Fit-for-purpose in this context is defined as obtaining an effective balance between quality and quantity of data collection, processing and delivery and operational achievability without being overly burdensome on the Scheme participants. The protocol must meet the needs of the TEC developer community while providing reliable data to inform the relevant governmental, planning and financial stakeholders. The overall objective of the protocol is therefore to provide a robust and auditable procedure for determining the performance characteristics of an individual TEC or array of similar TEC devices.

This protocol specifies two separate procedures. Both procedures specify a field based measurement program, data analysis methodology and standardised reporting format, which are as follows:

- The first procedure specifies a methodology for characterising the resource available at the intended location of the test site.
- The second procedure specifies a methodology for characterising the device performance envelope. Device performance is characterised using a measured power curve, measured annual energy production and a continuous record of operational status.

These points outline the major requirements of the MRDF Scheme protocol. Individual developers may wish to conduct more rigorous monitoring and analysis of the resource and device performance than that specified in this protocol. This falls outside the scope of the MRDF Scheme protocol and is therefore at the individual developer's discretion.

2 Normative References

IEC 61400-12-1 Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines

IEC 60044-1: 1996, Instrument transformers – Part 1:
Current transformers.

IEC 60186:1987, Voltage transformers (amended 1988 and 1995).

IHO S44: 1998, IHO Standards for Hydrographic Surveys, 4th edition.

3 Procedure to characterise the local resource

3.1 Rationale

TEC device power production is fundamentally limited by the magnitude of the resource available for harvesting. Site selection is therefore a key design consideration. Matching of an efficient device with an appropriate resource will optimise device performance. It is therefore necessary to adequately characterise the local resource to enable long-term performance assessment, and predictions of energy production prior to deployment.

The tidal current resource at a particular location can be reliably predicted based upon harmonic analysis of the in-situ current measured across a defined period. A 30-day continuous record prior to device deployment is acceptable for meeting the requirements of the MRDF Scheme, as this enables accurate distinction between 23 of the major tidal constituents using harmonic analysis. These tidal constituents will then be used to predict the tidal current and the associated kinetic energy across the lifetime of the intended device deployment for that particular site.

3.2 Data Collection

Site and resource data are to be obtained prior to any site development taking place. If the data specified in clause 3.2.1 or 3.2.2 already exist, are accessible, and meet or exceed the standard specified in the protocol, submission of these data supersedes the requirement for further data collection to characterise the local resource at the discretion of the project monitoring officer.

3.2.1 Test site

The test-site envelope shall be surveyed in accordance with the minimum requirements of IHO “Order 1” standard as prescribed by the 4th edition of the IHO Standards for Hydrographic Surveys (1998). The purpose of the IHO standard relates to navigation, a similar level of accuracy and resolution is suitable for adoption within the protocol. The requirements of sections 4.1 and 4.3 of the IHO standard are not deemed necessary and hence not required in order to comply with this protocol.

3.2.2 Resource measurement - pre deployment

The current resource at the test-site should be measured using an Acoustic Doppler (AD) device suitable for measuring the variation of the horizontal current velocity profile vertically through the water column. The AD device should have a minimum of three acoustic beams. The AD device should also have a pressure sensor capable of recording the variation in depth due to the tidal cycle. The manufacturer guaranteed error associated with the selected AD device must be less than ± 2.0% of the measured current velocity. The AD device must have a velocity range of at least ± 5 m/s and resolution better than ± 0.01 m/s. The AD device shall be bottom mounted within the test-site envelope, orientated to capture a vertical snapshot, and located at the centroid of the intended array, or nearest position which meets the following requirement. The difference in depth between the AD and nearest intended TEC deployment position must be established from the pre-installation site survey data to be less than ± 15% of the depth to chart datum. The AD device should obtain discrete samples at a minimum resolution of 20 seconds between samples. The AD device recording period should be set as a minimum resolution of 10-minute time-stamped ensemble average data (i.e. 10 minute ensemble average or less). If the recording period is shorter than 10 minutes, the period should be a suitable multiple of 10 minutes. The AD record should be binned at a minimum resolution of 2 metres. The minimum required measurement period is 30 days. A contiguous record should be obtained across the measurement period. Any deviation from this methodology must be agreed in writing with the project monitoring officer prior to the inception of data collection.

3.2.3 Time-keeping

Time shall be universally set throughout all record keeping to Greenwich Mean Time (GMT).

3.2.4 Data analysis

For the purposes of characterising the local resource, the record spanning the measurement period at the centroid of the performance surface should be extracted (e.g. at the depth of the rotor axis in the case of a horizontal-axis turbine). The record should be suitably manipulated to provide a 10-minute resolution data set. The data should be analysed to determine the principal current direction. The data set should then be processed along the principal current direction using a recognised, referenced method of harmonic analysis capable of determining a minimum resolution of 20 tidal constituents, including the 10 most significant constituents as defined in standard order (see table 1).

Common name	Speed (degrees/hour)	Rank in standard order
M2	28.9841042	1
S2	30.0000000	2
N2	28.4397295	3
K1	15.0410686	4
M4	57.9682084	5
O1	13.9430356	6
M6	86.9523127	7
MK3	44.0251729	8
S4	60.0000000	9
MN4	57.4238337	10

Table 1: Tidal constituents in standard order

The determined constituents are then to be used as the bases for a tidal prediction spanning the lifetime of the intended deployment within the MDRF Scheme remit at a minimum resolution of 30 minutes. The data should be processed using a recognised, referenced method of tidal prediction capable of incorporating all the tidal constituents derived from the preceding harmonic analysis. The tidal prediction data should then be used to determine the variation of the kinetic energy flux over the performance surface of the participants' intended TEC device throughout the predicted time period using equation (1).

$$P_{KE} = \frac{1}{2}\rho A U^3 \qquad [1]$$

The analysis in section 3.2.4 should be conducted by a competent individual with suitable experience in performing tidal prediction and harmonic analysis.

3.2.5 Reporting

At the conclusion of the measurement and analysis process (which must be completed prior to inception of device installation), the following outputs should be reported to the project monitoring office acting on behalf of the DTI:

- Site survey report detailing the output from clause 3.2.1, and the intended position of each intended TEC device (in latitude and longitude coordinates (WGS 84) specifying degrees as a decimal number to five decimal places after the point).
- Specification of the AD device deployed and the user defined settings employed.
- A spreadsheet detailing the measurement record from the AD device output throughout the period used to derive the tidal constituents (current velocity components in units of mm/s), including the signal-to-noise ratio and standard deviation where this data is available. The output from the pressure sensor will also be reported at the same recording interval.
- The principal current direction of the AD data measurement record derived from the 30-day measurement period in degrees to one decimal place after the point. The principal current direction can also be defined as the major

principal axis, with the minor principal axis lying at right angles to the major principal axis.

- The amplitude (to 4 decimal places after the point) and phase (degrees to 4 decimal places after the point) of each tidal constituent determined in clause 3.2.4.
- The annual summed value of the kinetic energy flux (kWh per year) available across the performance surface of the participant's intended TEC device (assuming orientated perpendicular to the principal current direction in the case of a fixed (e.g. non-yawing device)) using a prediction of the resource variability based upon the harmonic analysis of the site. Predictions for each year of the project lifetime within the MRDF scheme should be returned.

4 Procedure to characterise the TEC device performance envelope

4.1 Rationale

The performance envelope of an individual TEC device will be characterised using a power curve produced using measured in-situ data, analysis of the operational status of each device, and annual energy produced by the eligible facility (described in sections 4 and 5 respectively). The power curve relates the variation of electrical power produced by a particular TEC device to the variation in the magnitude of the incident resource (characterised as the current velocity). **The Scheme participants are responsible for *providing the data* necessary for the production of a power curve.** The DTI or its designated representative will independently utilise this data to produce a power curve representative of that participant's device performance. The intended procedure for production of the power curve is detailed in section 4.4 for reference purposes. The data provided by each Scheme participant to the DTI for power curve production is generated by collecting simultaneous measurements of current velocity and power output of an individual device for a 15-day period during device operation. This ensures that a fully representative range of tidal current velocities and associated power outputs will be captured. The data required to produce a power curve as detailed in section 4.3 must be submitted within 18 months of the commissioning date of the eligible facility. It is the prerogative of each individual Scheme participant to repeat the data collection procedure to inform the production of an updated power curve as and when appropriate after the initial submission, to be submitted as being representative of an improved version of the technology deployed. The most recently derived power curve is deemed to be representative of the current state-of-the-art performance of the developers TEC device technology, and will be incorporated in the annual review released by the DTI.

4.2 Data collection

The data collection procedure in clause 4.2.1 must be conducted simultaneously with the data collection procedure in clause 4.2.2. The data collection fulfilling clauses 4.2.1 and 4.2.2 must relate to the same individual TEC device within the array. The data collection covers a 15-day continuous measurement period. Time shall be universally set throughout all data collection to Greenwich Mean Time

(GMT). Time synchronisation between the incident resource and delivered power measurement record bins is required.

4.2.1 Incident resource measurement

Incident resource measurement should be conducted using an Acoustic Doppler (AD) device suitable for measuring the current profile variation vertically through the water column. The AD device should have a minimum of three acoustic beams. The AD device should also have a pressure sensor capable of recording the variation in depth due to the tidal cycle. The manufacturer guaranteed error associated with the selected AD device must be less than ± 2.0% of the measured current velocity. The AD device must have a minimum velocity range of at least ± 5 m/s and resolution better than ± 0.01 m/s. The AD device should obtain discrete samples at a minimum resolution of 20 seconds between samples. The AD device recording period should be set as a minimum resolution of 10-minute time-stamped ensemble average data (i.e. 10 minute ensemble average or less). If the recording period is shorter than 10 minutes, the averaging period should be a suitable multiple of 10 minutes. The AD record should be binned at a minimum resolution of 2 metres. The required measurement period is 15 days. A contiguous record should be obtained throughout the measurement period.

The project developer has two options for AD device placement as follows:

1. One AD device should be deployed at the TEC to be monitored. The AD device should be deployed perpendicular to the TEC along the minor principal axis of the tidal resource (as reported in clause 3.2.5). The AD device should be bottom mounted, positioned no more than 60 metres away from the centre-line of the TEC device and orientated to capture a vertical snapshot. The difference in depth between the TEC and AD device positions must be established from the pre-installation site survey data to be less than ± 15% of the depth to chart datum.
2. Two AD devices should be deployed at the TEC to be monitored. The AD devices should be deployed immediately up- and down-stream of the TEC along the major principal axis of the tidal resource (as reported in clause 3.2.5). The AD devices should be positioned no less than 3 performance surface widths (e.g. 3 diameters in the case of a horizontal axis turbine) from the TEC device, and no more than 120 metres from the TEC device. Both devices should be bottom mounted and orientated to capture a vertical snapshot. The difference in depth between the TEC and AD device positions must be established from the pre-installation site survey to be less than ± 15% of the depth to chart datum.

Any deviation from this methodology must be agreed in writing with the project monitoring officer prior to the inception of data collection

4.2.2 Power production measurement

A similar approach is adopted as prescribed by the IEC 61400-12-1 International standard for wind turbine performance assessment.

The net electric power of the TEC device selected for monitoring shall be measured using a power measurement device (e.g. power transducer) and be based on measurements of current and voltage on each phase.

The class of the current transformers shall meet the requirements of IEC 60044-1 and the class of the voltage transformers, if used, shall meet the requirements of IEC 60186. They shall be of a minimum accuracy class of 0,5.

The accuracy of the power measurement device, if it is a power transducer, shall meet the requirements of IEC 60688 with a minimum accuracy class of 0,5. If the power measurement device is not a power transducer then the accuracy should be equivalent to class 0,5 power transducers. The operating range of the power measurement device shall be set to measure all positive and negative instantaneous power peaks generated by the TEC device. The power transducer shall be calibrated to traceable standards. The power measurement device shall be mounted between the TEC device and the electrical connection to ensure that only the net active electric power (i.e. reduced by self-consumption) is measured. If a separate cable is used for importing of electricity, this also needs to be separately monitored to the same standards. It shall be stated whether the measurement devices are located on the TEC device side or the network side of the transformer.

The voltage and current shall be reported as an ensemble average recorded over the same averaging period as adopted for reporting resource characteristics in section 4.2.1. It will be the responsibility of the TEC operator to supply this power production data in a time stamped format over a 15-day period corresponding with the 15-day incident resource measurement to enable direct comparison and performance assessment. To facilitate the auditing of this power production the TEC operator shall also provide copies of the accredited meter operator, contiguous 30-minute sampled data record over the same 15-day period. In the situation where multiple eligible facilities utilise a common grid connection point, metering meeting the relevant COP standard must be installed at a point before the facilities output combines in order to produce the same standard of data specific to each eligible facility.

4.3 Reporting

Upon completion of the data collection procedure outlined, the following outputs should be reported to the project monitoring officer acting on behalf of the DTI:

- Specification of the AD device deployed and the user defined settings employed.
- A spreadsheet detailing
  - o the 15-day recorded measurement record obtained from the AD device output throughout the period necessary to produce a

representative power curve (current velocity components in units of mm/s), including the signal-to-noise ratio and standard deviation if this data is available. The output from the pressure sensor should also be reported at the same recording interval.
  - the recorded measurement record of net electrical power produced by the monitored turbine spanning the required 15-day measurement period.
- A copy of the 30-minute record of power production from the facility produced by the accredited meter operator coincident with the 15-day measurement period. In the situation where multiple eligible facilities utilise a common grid connection point, metering meeting the relevant COP standard must be installed at a point before the facilities output combines in order to produce the same standard of data specific to each eligible facility.

4.4 Production of the power curve

This section details the approach intended to be adopted by the DTI for analysing the data collected by the Scheme participants in order to produce a power curve representative of the measured TEC device performance. Production of this power curve is not the Scheme participants responsibility. The power curve is produced by plotting the incident current resource record (x-axis) against the power production record (y-axis). A similar methodology to that used by the wind industry (IEC Standard 61400-12-1) is adopted. The spatial dislocation between the AD and TEC devices is deemed insignificant when considering a record averaged over any more than a few seconds, and therefore no correction is required.

4.4.1 Data analysis

The incident current resource record obtained by the AD device(s) provides a time-averaged representation of the horizontal velocity variation with depth. The record should be suitably manipulated to provide a 10-minute resolution data set. For the purposes of producing a power curve, the average current across the performance surface has to be derived. Each vertical data bin is considered to be representative of the resource in that vertical layer across the whole performance surface width. The vertical variation of the current record in each measurement record then has to be integrated across the performance surface area to produce a representative averaged velocity acting across the performance surface for plotting on the power curve. In the case of a fixed TEC device, only the component of velocity perpendicular to the performance surface should be considered. For a TEC device capable of orientating the performance surface into the principal current direction, the recorded velocity vector magnitude irrespective of direction is to be analysed. Equation (2) should be used for integrating the velocity record across the performance surface

$$U_{perf} = \left(\frac{1}{A} \int_A U^3 dA \right)^{1/3} \qquad (2)$$

Where A is the performance surface

4.4.2 Determination of the measured power curve

The measured power curve is determined by applying the method of bins to the data set using 0.05 m/s bins (e.g. 0.00 – 0.05, 0.05 – 0.10, etc.), and by calculation of the mean values of current resource acting across the performance surface and device power output for each current resource bin according to the equations:

$$U_{perf(i)} = \frac{1}{N_{(i)}} \sum_{j=1}^{N_i} U_{perf(i,j)} \quad (3)$$

$$P_{(i)} = \frac{1}{N_{(i)}} \sum_{j=1}^{N_{(i)}} P_{(i,j)} \quad (4)$$

4.4.3 Presentation of the measured power curve

When publishing data relating to the measured power curve, the DTI will present the data both in tabular and graphical form. For each current velocity bin the table shall list:

- Velocity bin;
- Averaged current velocity (U_{perf});
- Averaged power output ($P_{(i)}$) ;
- Number of data sets in the bin ($N_{(i)}$);

The graphic representation of the power curve will show the averaged power output as a function of the averaged current velocity.

5 Procedure for reporting TEC operational status and annual energy production

5.1 Rationale

In order fully assess TEC device operation, performance data relating to net annual electrical power production and operational status are required. The following section outlines the procedure for recording and reporting of this information. The data requested is to be submitted annually to the project monitoring office acting on behalf of the DTI.

5.2 Measuring operational status

The operational status of the TEC shall be monitored by the devices own controller in order to provide sufficient auditable status signals to meet the reporting requirements of clause 5.3.

5.3 Reporting

In order to assess the annual performance of each individual TEC device in the eligible facility, Scheme participants shall provide the following data on an annual basis measured from the commissioning date:

- Copies of the statements received from the accredited meter operator detailing the overall power produced by the eligible facility throughout the preceding 12-month period. In the situation where multiple eligible facilities utilise a common grid connection point, metering meeting the relevant COP standard must be installed at a point before the facilities output combines in order to produce the same standard of data specific to each eligible facility.
- An auditable report constructed from the output of each individual TEC device's control system spanning the preceding 12-month period which indicates:
    - Number of hours each device was available for production.
    - Number of hours each device was unavailable for production because of a device fault
    - Number of hours each device was unavailable for production due to planned maintenance as outlined in the MRDF Scheme grant application.
    - Number of hours each device was unavailable due to external factors mandated by an independent third-party (e.g. grid faults). This will only be deemed acceptable when accompanied by appropriate supporting documentation supplied by the relevant third-party detailing the external factors involved and the length of time that these conditions impacted on the Eligible Facility. Unsubstantiated claims of device unavailability due to external factors will be re-allocated as unavailability due to a device fault.

Bibliography

Barltrop, N., Grant, A., Varyani, K.S. & Pham, X.P., 2005: Wave-Current Interaction in Marine Current Turbines. *6th European Wave and Tidal Energy Conference*, University of Strahclyde, Glasgow.

Bedard, R., Previsic, M., Siddiqui, O., Hagerman, G. & Robinson, M., 2005: EPRI Survey and Characterisation - Tidal In Stream Energy Conversion Devices, 128 pp.

Carbon Trust, 2006: Future marine energy. Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy, CTC 601.

Couch, S. J., 2001: Numerical Modelling of Tidal Flows around Headlands and Islands, Department of Civil Engineering, University of Strathclyde, PhD. thesis, 345 pp.

DTI, 2005: Marine Renewables: Wave and Tidal-stream Energy Demonstration Scheme, 18 pp.

——, 2005: Marine Renewables: Response to comments received on proposals for the £50M 'Marine Renewables Deployment Fund', 15 pp.

——, 2005: Planning and Consents for Marine Renewables: Guidance on Consenting Arrangements in England and Wales for a Pre-Commercial Demonstration Phase for Wave and Tidal-Stream Energy Devices (Marine Renewables), 12 pp.

——, 2006: DTI Wave and Tidal-stream Energy Demonstration Scheme Application Form for Competition 1 Only, 12 pp.

——, 2006: DTI Wave and Tidal-stream Energy Demonstration Scheme Guidance Notes for Applicants. Competition 1 Only.

——, 2006: Wave and Tidal-stream Energy Demonstration Scheme: Grant Template Letter, 38 pp.

EMEC, 2006: Performance Assessment For Wave Energy Conversion Systems in the Open Sea Test Facilities, 21 pp.

Elexon Ltd., 2005: Balancing and Settlement Code Procedure: Metering Protocol Approval and Compliance Testing (Version 6.0)BSCP601, 24 pp.

——, 2005: Code of Practice three: Code of Practise for the metering of circuits with a rated capacity not exceeding 10MVA for settlement purposes (Issue 5)Issue 5, 40 pp.

——, 2005: Code of Practise Five: Code of Practise for the metering of energy transfers with a maximum demand of up to (and including) 1MW for settlement purposes, 39 pp.

Forum for Renewable Energy Development in Scotland, 2004: Harnessing Scotland's marine energy potential - Marine Energy Group (MEG) report 2004, #0-7559-4266-3.

Future Energy Solutions, 2002: Opportunities for marine energy in Scotland: A report for the Scottish Executive, 63 pp.

Hagerman, G., Bedard, R., Polagye, B., Robinson, M. & Previsic, M., 2005: EPRI Guideline for Preliminary Estimation of Power Production by Tidal in Stream (Current) Energy Conversion Devices, 38 pp.

Hagerman, G., Polagye, B., Bedard, R. & Previsic, M., 2006: Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices, 57 pp.

International Electrotechnical Commission, 2005: Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines, IEC 61400-12-1, 90 pp.

Knauss, J. A., 1978: *Introduction to physical oceanography*. 1st ed. Prentice-Hall, Inc., 338 pp.

Network of European Measuring Institutes (measnet), 2000: Power Performance Measurement Procedure Version 3, 7 pp.

Pond, S. P., G.L., 1978: *Introductory dynamic oceanography*. 1st ed. Pergamon Press Ltd., 241 pp.

RESOLVE, Inc., Washington D.C., 2005: Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. *Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop*, Washington D.C., 111.

Riso National Laboratory, 2001: European Wind Turbine Testing Procedure Developments. Task 1: Measurement Method to Verify Wind Turbine Performance Characteristics, Riso-R-1209(EN), 120 pp.

——, 2002: Wind Turbine Power Performance Verification in Complex Terrain and Wind Farms, Riso-R-1330(EN), 56 pp.

Teledyne R.D. Instruments, cited 2006: http://adcp.com

Thake, J., 2005: Development, Installation and Testing of a Large-Scale Tidal Current Turbine, 74 pp.

The Engineering Business Ltd., 2003: Stingray Tidal Stream Energy Device - Phase 2.0

The Open University, 1999: *Waves, Tides and Shallow-Water Processes*. 2nd ed. Butterworth-Heinemann, 227 pp.

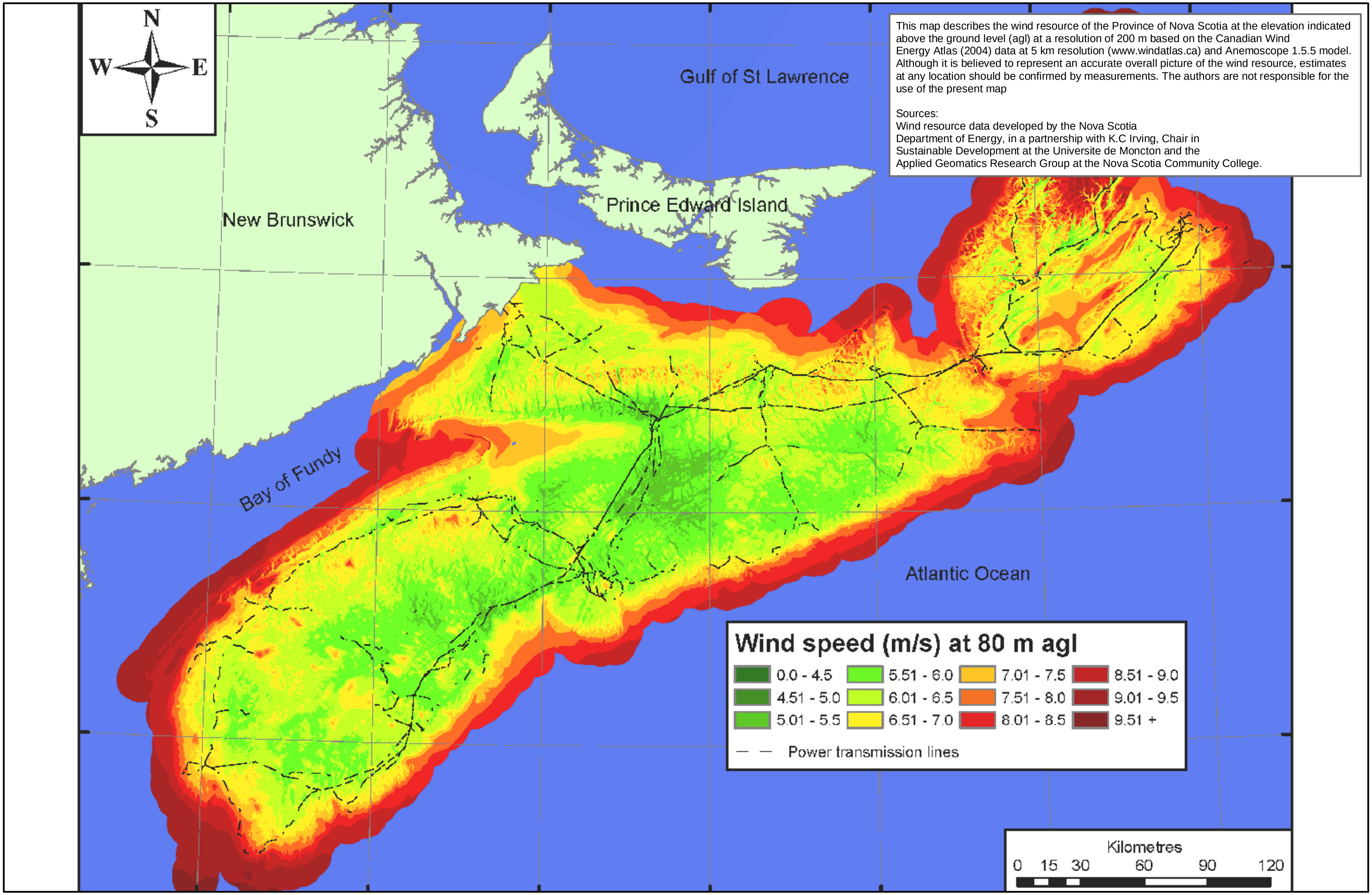
The Robert Gordon University University, 2002: Factors Influencing the Performance of Horizontal Axis Tidal Current Turbines (Internal Report).

United States Department of Commerce, 2000: Tide and Current Glossary, 29 pp.

Zersas, C., 1999: Tidal Current Analysis Procedures and Associated Computer Programs, NOAA Technical Memorandum NOS CO-OPS 0021, 103 pp.

APPENDIX B

Nova Scotia and New Brunswick Wind Resource Maps



Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: January 11, 2008
Project No.: 1028476
Figure Tracking: 1028476-JW-031

Figure B1

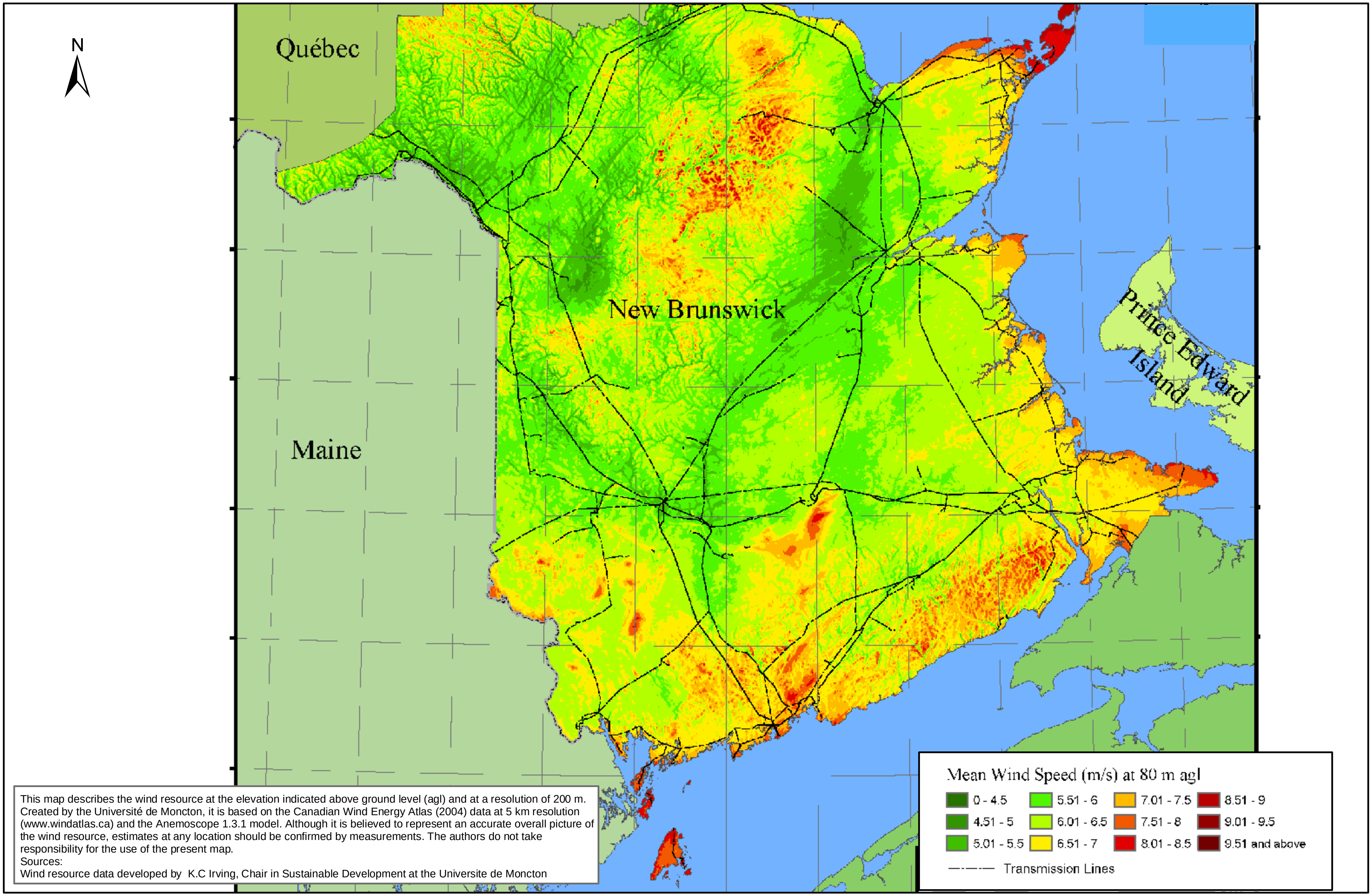
Wind Resource Map, Nova Scotia
(Up to 10 km Offshore)

ACADIA ESTUARINE CENTRE FOR RESEARCH

New Brunswick Nouveau Brunswick

Jacques Whitford

OEER FUNDY TIDAL ENERGY



Map Parameters
Projection: UTM-Nad83-Z20
Scale 1:150,000
Date: January 11, 2008
Project No.: 1028476
Figure Tracking: 1028476-JW-032

Figure B2

Wind Resource Map, New Brunswick

Acadia Estuarine Centre for Research

New Nouveau Brunswick

Jacques Whitford

OEER Fundy Tidal Energy