Nova Scotia Tidal Research Summary Report

Researching Tidal Energy – Marine Life: the Nova Scotia Experience

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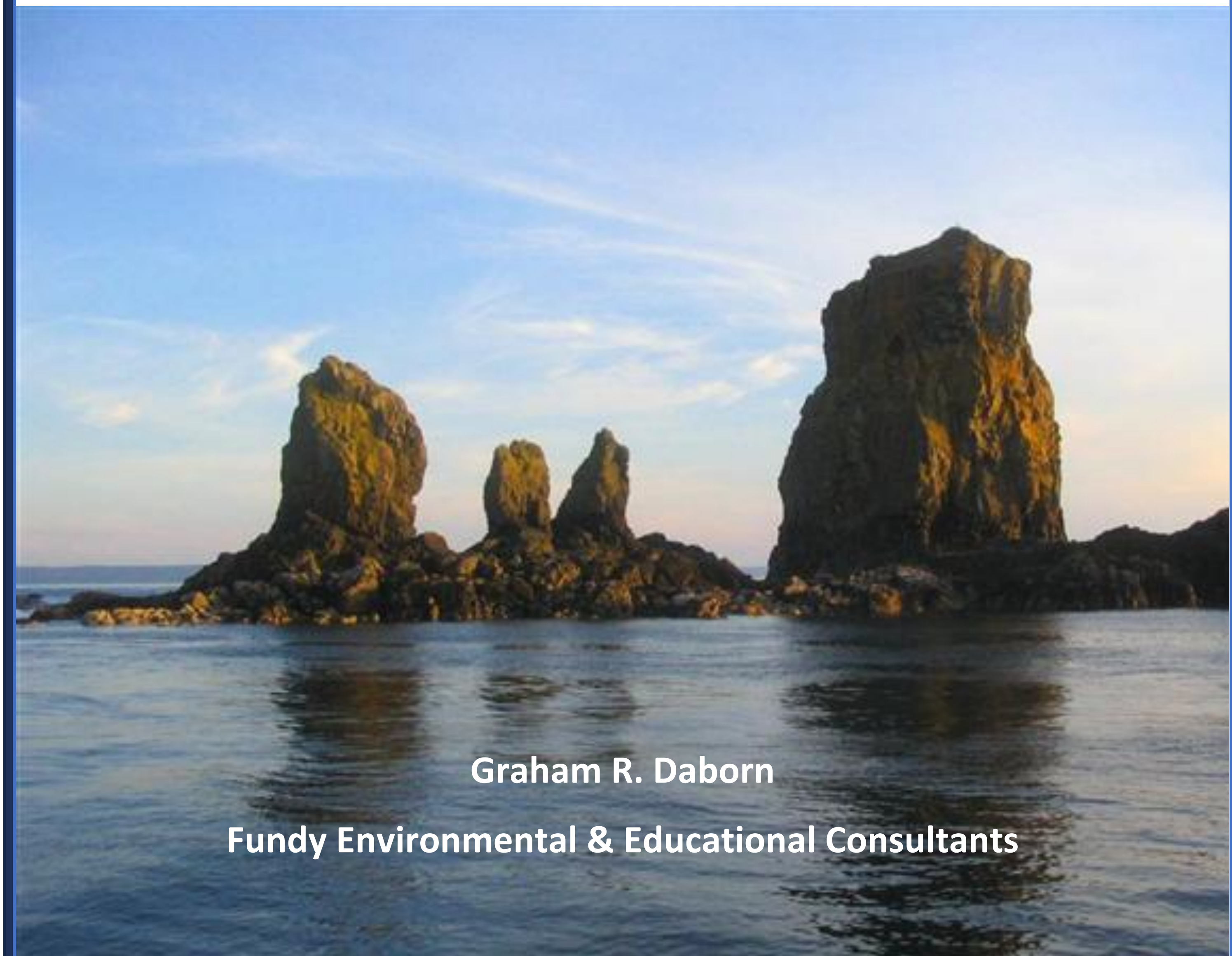

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Researching Tidal Energy — Marine Life: the Nova Scotia Experience.

Executive Summary

During the last decade, Nova Scotia has once again been exploring the potential for electricity generation from the tides of the Province, particularly those of the Bay of Fundy and Cape Breton. Unlike the previous hundred years, the focus has been on new tidal stream technologies that convert energy from tidal flows without the need for barrages or dams. The objectives are: to reduce dependence on fossil fuels and enhance Nova Scotia's energy security for the future; to capitalize on development of new tidal-stream technologies; and to contribute technological and scientific knowledge to the global development of renewable marine energy.

Previous environmental studies, including those at the Annapolis Tidal Generating Station, identified numerous environmental issues of tidal power, many of which are attributed to the dam rather than the turbines. Three Strategic Environmental Assessments (SEAs) have been conducted, two on the Bay of Fundy (2008 and 2014) and one on Cape Breton waters (2012). Each of these examined several options for marine renewable energy, including tides, waves and offshore wind installations, and identified their major environmental and socioeconomic implications. On the basis of the first Bay of Fundy SEA, the province moved to establish the Fundy Ocean Research Centre for Energy (FORCE), and set aside an area in Minas Passage as a test facility for commercial scale tidal stream devices. The FORCE site is now equipped with subsea power and data cables, and will see devices installed for testing at its berths in the next years. Testing of smaller devices is occurring in other locations in the Outer Bay.

The SEAs identified a number of environmental and socio-economic concerns about tidal stream-based electricity generation. Principal concerns have related to:

- the size of the tidal resource;
- the effects of extracting energy from tidal waters on tidal range, current flows, ice, shoreline erosion, turbulence (etc.):
- the direct and indirect effects on fish, birds and marine mammals;
- the direct and indirect effects on bottom-dwelling organisms, marshes and mudflats;
- the direct and indirect effects on fisheries and other resource uses of tidal waters; and
- the opportunities and benefits to the economy and local communities of investments in tidal power.

Numerous research projects have been conducted to address these questions, and, in doing so, considerable technical and scientific innovation and expertise has been developed. A suite of numerical models that describe the energy resource, flows of water, and mixing (etc.) on both large and small scales has been developed, allowing more precise prediction of the effects of extracting energy from the tides. In Minas Passage, Grand Passage, Petit Passage and Digby Gut, the energy of tidal flows would be sufficient to provide more than 2.5 GW of electricity, a

quantity greater than the total installed electricity capacity (~2.3 GW) of the Province, with only a modest effect on the tidal ranges at those sites. Technologies for monitoring the movements of fish and marine mammals have been investigated, particularly in the Minas Passage, and four species of fish and some lobster have been fitted with acoustic tags to investigate their behaviour as they move through the passage where turbines are to be tested. Video and sonar technologies have also been used to examine benthic life in the areas suitable for tidal stream generation, and field investigations have looked at the changes in sediments that might arise from changes to tidal water flows.

As a result of these studies, several concerns have been laid to rest. Ice and electromagnetic forces are considered unlikely to interfere with the turbines or to affect significantly the movements of animals through the passages. Some issues remain to be resolved. Priority issues relate to the behaviour of fish, birds and marine mammals in the vicinity of working turbines, the possible mortality and deterrent effects that an array of turbines might have on the normal migratory behaviour of these animals, and the population level consequences of these. The effects on fisheries for lobster, herring and other finfish and shellfish are being examined, and in some cases this requires selection and further development of suitable monitoring technologies that can withstand the difficult environmental conditions under which tidal energy could be generated.

This assessment of the potential for tidal power generation using modern tidal stream devices is being pursued as a collaborative enterprise involving government agencies, universities and the private sector, with funding primarily from the federal and provincial governments. Costs and risks are high, but the potential benefits are even greater. In addition to the size of the tidal resource, there are immense benefits to accrue from increased knowledge and innovations in technology. An assessment of the value of early involvement in tidal stream development suggests that over the next decades more than $1.7 billion could be added to the provincial GDP, with creation of some 22,000 full time positions and $815 million in labour income.

Throughout the last decade, there has been considerable effort devoted to involving all stakeholders. Public meetings were held in connection with all three SEAs, consultations have been held with Mi'kmaq, fishers and other stakeholders to access local knowledge, and results of directed research made quickly available. In order to provide the public with ready access to information, results of studies have been placed on websites operated by the Offshore Energy Research Association (OERA), Fundy Energy Research Network (FERN) and the Fundy Ocean Research Centre for Energy (FORCE). Handbooks providing information for communities and businesses to participate in tidal energy discussions and guides to engagement of Mi'kmaq and other communities have also been made available. The intent is to ensure that development of tidal-stream energy in Nova Scotia is being pursued with full understanding of the implications among Nova Scotians.

Introduction

Over the last decade, Nova Scotia has once more made significant investments to examine the feasibility of obtaining renewable energy from its tidal waters. The incentives for this investment are:

- to reduce the Province's dependence on fossil fuel, especially coal, for generation of electricity, and achieve the objective of 40% from renewable sources by 2020;
- to enhance Nova Scotia's energy security and stabilize electricity prices;
- the appearance of new technologies for converting tidal energy into electricity; and
- the opportunity to become a significant provider of knowledge and technology to the global marine renewable energy market.

Nova Scotia's assets in this endeavour include the highest tides in the world in the Bay of Fundy, a century of experience in tidal power considerations, and an innovative, knowledge-based community focussed on the marine environment. This review examines what has been achieved since 2007, when Nova Scotia initiated a Strategic Environmental Assessment of tidal energy from the Bay of Fundy, and a test and demonstration facility for commercial-scale tidal stream energy converter devices in Minas Passage.

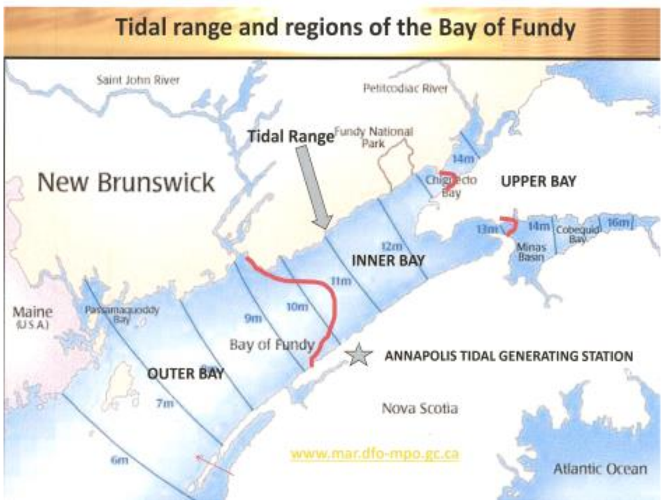
Background

Tidal power is an old technology. Tidal mills (mechanical devices driven by movement of tidal waters) for grinding grain may have been in use for more than two thousand years in Europe and elsewhere, and for at least 400 years in North America. Electricity generation from tidal waters, however, was first seriously considered in the early 20th century for two places: the Bay of Fundy in Canada, and the Severn Estuary in the United Kingdom.

There are two ways in which electricity can be obtained from tidal movements. One is to build an impoundment that becomes filled with water on the rising tide, and, when the sea level has fallen sufficiently on the ebb tide, the retained water is allowed to flow out only through turbines. The turbines can be operated both during the rising tide and the falling tide if there is sufficient difference in water levels inside and outside the impoundment. This is referred to as *tidal range generation.* The alternative, known as *tidal stream generation*, is more analogous to a wind farm: a number of turbines are placed in areas of strong tidal flow and the turbines are driven by the force of the water against the blades. In this case, there is no large dam or impoundment wall.

> ***Tidal range generation***: electricity is generated from the difference in water levels between the outside sea and the water behind a dam or lagoon constructed in tidal waters; it is analogous to a hydroelectric station on a river.
>
> ***Tidal stream generation***: tidal stream turbines are driven by the force of flowing water and do not require storing of the water behind a dam; it is analogous to wind turbine generation.

For most of the last 100 years, ideas for tidal energy generation involved the first of these approaches: building one or more barrages (i.e. dams) across a tidal estuary or between the islands in a tidal bay. In the Bay of Fundy, this concept has been examined many times since 1912, when an engineer[1] first proposed building dams to enclose Passamaquoddy Bay. Successive proposals in each decade of the century led to extensive examination of both the technical and environmental implications, and culminated in the development of the Annapolis Tidal Generating Station as a demonstration project in 1984: the second grid-connected tidal power plant built anywhere in the world, and the only one in North America. These proposals have led to greatly enhanced understanding of the dynamics of Fundy's tidal waters, its varied habitats[2], life and resources, and the implications of changing those by building barrages or other impoundments.



The present approach in Nova Scotia is based upon the conversion of the kinetic energy of flowing water. Tidal stream (or *hydrokinetic*) turbines are analogous to windmills in that they are driven by the forces of flowing water, rather than the 'head' or pressure of water stored behind a dam. Since the new tidal stream devices do not require construction of barrages, they are somewhat less efficient at converting the energy of tidal flows into electricity, but their environmental implications are substantially different and potentially more acceptable.

At the beginning of 2016, we are on the threshold of the next phase of investigation into tidal power. A major facility for testing commercial scale tidal stream devices has been established, with five berths, four of which are cable-connected, and assignments made for the initial berth holders to deploy their turbines or small arrays. The first deployment is expected by mid-year, and the others in the following 2-5 years. Once these are installed, some of the remaining questions regarding durability, performance, and environmental effects can be addressed.

[1] Wallace Turnbull (1870-1954).

[2] The Bay of Fundy is a very complex system, with substantially different environments near the mouth from those occurring at the head of the Bay. For convenience, we distinguish 3 main regions: the **Outer Bay**, which extends from the Gulf of Maine to the Digby-Saint John line; the **Inner Bay**, from there to Cape Chignecto; and the **Upper Bay**, which includes Minas Basin, Chignecto Bay, Cobequid Bay, Shepody Bay and Cumberland Basin.

Assessing Risk

All energy developments are accompanied by a number of uncertainties: technical, environmental and social. With new developments, existing information and experience are typically inadequate, so that at first it is difficult to assess in detail the risks posed by the development. If it is possible that a development could produce unacceptable consequences, then a sound approach to regulatory approval is to apply the precautionary principle, and to defer approval until such time as knowledge improves sufficiently. Such had been the case with tidal power in Nova Scotia over the last 100 years.

> ***'Adaptive management'*** is a strategy used when there is uncertainty regarding the consequences of a decision or action. Under adaptive management, regulations or other requirements may be relaxed or increased as new information addressing those uncertainties becomes available.

The first Strategic Environmental Assessment (SEA) for the Bay of Fundy in 2008[3] examined several options for marine renewable energy, including offshore wind, waves, and tidal power. The SEA outlined the state of technical development and the potential environmental implications of each option. The report concluded that the generation of electricity using tidal stream devices was technically feasible, and had the advantage — unlike barrage-based approaches of the past — of being implemented in stages. This incremental development feature means that many potential issues, for which the scientific knowledge needed to evaluate risk is currently inadequate, can be addressed over time as experience and further research improve understanding. Tidal stream energy is thus an ideal subject for progress through ***adaptive management***. Following public consultations, the SEA also reported that the Nova Scotia public was cautiously optimistic that the new tidal stream approach in the Bay of Fundy might be beneficial, and have limited and manageable environmental effects. The report encouraged government to develop a clear plan for its assessment.

The 2008 SEA contained 29 recommendations related to: decision-making principles; establishment of a major test facility for commercial-scale tidal stream devices; establishment of regulations and incentives for marine renewable energy development; research to address unanswered questions on environmental and technical issues; and engagement of the First Nations of Nova Scotia, the Mi'kmaq, resource users and the public in decision-making. These have formed the basis for action over the last seven years.[4] One of the recommendations was that, in view of the rapid development in the tidal energy field and the acquisition of knowledge,

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[3] OEER 2008. ***Fundy Tidal Energy Strategic Environmental Assessment***. Final Report. April 2008. 83 pp.; Jacques Whitford 2008. ***Background Report for the Fundy Tidal Energy Strategic Environmental Assessment***. January 2008. 291 pp.

[4] Nova Scotia Department of Energy 2006. ***Fundy Tidal Energy: A Response to the Strategic Environmental Assessment***. 36 pp.

the SEA should be updated five years after it was first conducted. That was duly done[5], the update being delivered in 2014. At the same time, a similar, preliminary SEA[6] examining options for tidal, wave and offshore wind energy was also carried out for the Cape Breton region, another area of potential tidal energy resource in Nova Scotia.

What has been achieved: Marine Science research

The 2008 SEA reviewed the 100 year history of tidal power research in the Bay of Fundy and identified numerous potential environmental issues related to tidal power development. Experience with barrages on the Annapolis, Avon and Petitcodiac estuaries and the Annapolis Tidal Generating Station allows some degree of discrimination between the effects caused by the barrage itself and those specifically associated with tidal energy generation.

In the SEA, environmental effects were clustered into eight Key Environmental Issues:

- Critical physical processes
- Fisheries
- Fish and fish habitat
- Benthic communities
- Pelagic communities
- Marine mammals
- Marine birds
- Species at Risk

Within each Key Environmental Issue were large numbers of specific questions about the potential environmental effects of energy extraction, of the environmental effects of the technologies and the infrastructure deployed, of the effects of the technologies on living organisms, of the effects of research or monitoring, and of the effects of the environment on the technologies themselves. In addition, the 2008 SEA examined potential interactions with other resources in the Bay of Fundy, including: aquaculture, transportation, tourism and recreation, and archaeological and heritage resources.

Because of past experience in the Bay of Fundy, and knowledge gained in international studies of tidal stream technologies, there is a comprehensive understanding of the potential environmental implications of converting tidal energy into electricity. This has been formalised into a 'Pathways of Effects' analysis[7] that summarises the possible interactions between marine

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[5] AECOM 2014. ***Tidal Energy: Strategic Environmental Assessment Update for the Bay of Fundy.*** 213 pp.
[6] AECOM 2012. ***Marine Renewable Energy: Background Report to Support a Strategic Environmental Assessment (SEA) for the Cape Breton Coastal Region, inclusive of the Bras d'Or Lakes.*** 205 pp.; Stantec 2013***. OERA Marine Renewable Energy Strategic Environmental Assessment Cape Breton Coastal Region and Bras d'Or Lakes Phase II -- Community Response Report.*** 85 pp.
[7] Isaacman, L. and G. Daborn. 2011***. Pathways of effects for offshore renewable energy in Canada***. Final Report to Fisheries and Oceans Canada, Ottawa. 71 pp

renewable energy developments (wind, wave and tidal) and the processes, fauna and flora of nearshore marine environments. These environmental issues have been examined many times by different expert groups, and there is confidence that they cover all of the environmental effects to be expected from any tidal power development. However, while the issues are recognised, there remain a number for which the information available is insufficient for an adequate assessment of risk. A scientific workshop[8] to review the state of knowledge relevant to tidal power development, held in Nova Scotia in 2011, identified priority questions that needed to be addressed in the short term[9]. In order to provide as much information exchange and cooperation as possible, an open research network, the Fundy Energy Research Network (FERN), was established in 2009.

For many of the Key Environmental Issues, it was concluded that the environmental conditions at the locations of greatest interest for tidal stream development were still inadequately known. The highly energetic passages at the entrance to Minas Basin, Digby Gut and between the islands along Digby Neck had not recently been surveyed in detail, and information on water depths, current movements, turbulence, and fauna was very limited. Consequently, the first phase of investigation focussed on acquiring precise and up-to-date data on existing conditions. Research projects were funded from a variety of sources: the Offshore Energy Environmental Research Association (OEER)[10], the Fundy Ocean Research Centre for Energy (FORCE), the Atlantic Canada Opportunities Agency (ACOA), Natural Resources Canada, and the Natural Sciences and Engineering Research Council (NSERC). Reports from many of the projects are available on the Offshore Energy Research Association of Nova Scotia (OERA), FORCE or FERN websites[11].

The projects were selected to address the high priority questions related to the Key Environmental Issues.

a) Critical Physical Processes

The dynamic movements of tidal waters affect all of the unique features of the Bay of Fundy, from the erosion of shorelines, to the movements of sediments and ice, and to the great diversity and productivity of animals and plants that live in the Bay or visit it for feeding or spawning. Consequently, it is critical to know how these physical processes would change if part of the energy of the tides is converted to electricity. Understanding the physics is a prerequisite both

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[8] Ryan, C. 2012. ***Tidal energy workshop report.*** Report to OEER and FORCE. 24 pp.

[9] A more recent workshop, held at Nantes in France, reviewed the current state of scientific knowledge about environmental effects, particularly of wave and tidal marine energy developments. The final report is expected during 2016. See: OES IEA 2015. ***Environmental effects of marine renewable energy development: the state of the science***. Annex IV webinar. Available from: www.tethys.pnnl.gov/sites/default/files/AnnexIV-Workshop-Presentation-Final_0.pdf

[10] Now the Offshore Energy Research Association (OERA)

[11] www.oera.ca; www.fundyforce.ca;www.fern.acadiau.ca;

for knowing how much energy may be available, and for assessing the potential effects on the environment.

- Effects on water flows

As tidal water flows into and out of the Bay of Fundy, its motion varies in response to the shape of the channel, its depth, and the nature of the bottom. All areas in the Bay are well mixed from the surface down to the bottom, but where the depth decreases sharply, or the channel becomes narrower, the vertical mixing becomes especially vigorous. In such places there may be extremely dynamic areas of *upwelling*, where the water seems to be boiling, in which deep water and the organisms normally living near the bottom are brought right up to the surface. These are very rich and important feeding areas for many fish, birds and mammals. The extent of this vertical upwelling varies with the force of the tides.

The physical issues that were identified in the 2008 SEA are reflected in the following questions:

- How will the conversion of tidal energy into electricity affect the tidal dynamics (e.g. the heights of tidal waters, the timing of high and low tides, the speed of currents, and the turbulence of the water), both locally and in the Bay generally?
- How much energy can be extracted from the tides at each location?
- How many turbines could be installed without having significant effects on critical physical processes?
- How will the movements and settling of sediments be affected by energy extraction?

Numerical models that describe the flow of water are well established (they are the basis for tide predictions), and have been extensively developed and used for the Bay of Fundy in association with tidal power studies of the last 40 years. However, answers to the above questions required more refined models that enable precise forecasting of water movements at very small scales. In addition, direct and detailed measurements of current flows and turbulence at each site are critical information for numerical models. Such studies have been carried out by several groups since 2008.

Numerical modelling to investigate both the potential energy available in the Minas Passage and the effects of energy extraction on tidal flows in the Minas Basin[12] show that the huge flow of water through the Minas Passage represents about 8 gigawatts (GW) of energy. If 25% of this energy (~2 GW) were to be converted into electricity by an array of turbines (which would require up to 1,000 turbines), the effects on tidal range in the Minas Basin would be a reduction of about 5%. Such a change seems small compared with the natural variation in tidal range

[12] Karsten, R., J. McMillan, M.Lickley and R. Haynes 2008. ***Assessment of tidal current energy in the Minas Passage, Bay of Fundy.*** Journal of Power and Energy 222 (A3): 289-297; Karsten, R., D. Greenberg, M. Tarbotton, J. Culina, A. Swan, M. O'Flaherty-Sproule and A. Corkum 2011. ***Assessment of the potential of tidal power from the Minas Passage and Minas Basin***. Final Report to OEER. 64 pp.; Karsten, R. 2012. ***Tidal energy resource map for Nova Scotia.*** Final Report to OERA. 45 pp.

between spring and neap tides: tides at one location may be 8-9 meters one week, and 12-14 metres the next, depending on the phase of the moon. However, the 5% reduction associated with energy generation would be essentially permanent.

In addition, many other environmental features are affected by the tidal flows in subtle and non-linear ways. For example, the turbulence in the water and the force exerted by it is exponentially related to the rate of flow: doubling the rate of flow increases the force and power by 6 to 8 times. By linking hydrodynamic and sediment models together, researchers[13] have shown that reducing tidal flows by even a small amount would have important effects on mixing processes and on the distribution patterns of sediments in the Minas Basin, both near the turbines and some distance away. In particular, salt marshes and intertidal channels would probably experience changes in sediment supply, mobility and settlement if, for example, a few hundred megawatts of energy was taken out of the system[14]. These changes, however, would be no greater than the natural variation that presently occurs as a result of strong winds or the formation of ice during winter months. Similar, but smaller effects would be expected from tidal energy generation in Digby Gut or the passages between the islands of Digby Neck.

The results show that from Minas Passage alone it would be possible to extract an amount of electricity equivalent to the total electricity use of the Province (~2 GW). The apparent effects on tidal range in Minas Basin would appear relatively modest, but there would be important, more subtle, effects on other important processes, such as the speed of the currents, turbulence, and sediment distribution. All of these physical changes could have important effects on the life and productivity of the Upper Bay of Fundy.

In the Outer Bay, the resource potential and physical characteristics of Petit and Grand Passages and Digby Gut have been extensively examined for the first time[15,16]. Field measurements and refinement of the numerical models has enabled a more precise assessment of the amount of energy potentially obtainable from these sites: allowing for a maximum of 5% reduction in tidal flows as a result of energy extraction, the installed capacity of Grand Passage could be about 5.4 MW, of Petit Passage12 MW, and Digby Gut could have <67 MW. As with the case in Minas Passage, these capacities are much greater than earlier estimates of power potential[17].

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[13] Smith, P. , G. Bugden, Y.Wu, R. Mulligan, and J. Tao. 2012. ***Impacts of tidal energy extraction on sediment dynamics in Minas Basin, Bay of Fundy, NS.*** Final Report to OEER. 27 pp.; Wu, Y., J. Chaffee, D. Greenberg and P. Smith. 2015. ***Environmental effects caused by tidal power extraction in the Upper Bay of Fundy.*** Taylor and Francis On Line.

[14] van Proosdij, D., R. Mulligan, E. Poirier and L. Ashall 2013. ***Implications of tidal energy extraction on sedimentary processes within shallow intertidal areas.*** Final Report to OERA. 87 pp.

[15] Hay, A., R. Karsten, G. Trowse, D. Morin, T. Webster, J. MacMillan, M. O'Flaherty-Sproule, D. Schillinger, R. Cheel, E. Marshall, N. Crowell and K. Collins. 2013. ***Southwest Nova Scotia Resource Assessment.*** Final report to OERA. 5 volumes, 371 pp.;

[16] Each of these sites has been awarded to Fundy Tidal Inc. (FTI) for evaluation as locations for smaller arrays that might enhance electricity supply to more remote coastal communities.

[17] EPRI 2006. ***Nova Scotia In-Stream Energy Conversion (TiSEC) Survey and Characterization of Potential Project Sites.*** Electric Power Research Institute TP-003NS.

- Effects on sediments

Allowing reductions of 5-10% of the tidal flow at each of the potential sites would permit significant amounts of electricity to be obtained, with relatively small effects on the overall dynamics at each site. However, the dynamic flows affect many other important processes. Whether these secondary effects are important depends upon characteristics at each site. In the Outer Bay of Fundy, Minas Passage and in the entrance to Bras d'Or Lakes (Cape Breton), for example, the substrates are primarily hard — either bedrock or coarse sediments such as gravel and boulders. A small reduction in tidal flows is not expected to affect these features in the immediate vicinity of the turbines, but in more distant lower flow areas such as Minas Basin, Annapolis Basin, St. Marys Bay or Bras d'Or Lakes, even small changes in current flows could result in shifts in the patterns of sedimentation that would have secondary effects on the fauna and flora.

- Effects on ice

In the 2008 SEA, ice formation and movements were identified as an important factor in the Upper Bay of Fundy that could have implications for tidal stream installations. The ice tends to form on cold, calm days in winter in Upper Bay waters and on the intertidal zone during low tide. The floating ice sheet in severe winters may become 15 cm thick or more, and extend over several kilometres. This sheet moves in and out with the tide and could present a problem for surface-floating structures. As the tide floods in, the ice sheet is often broken up by the turbulence, and piled into blocks up to several metres thick that become stranded on the intertidal zone. With rising and falling tides, the blocks may acquire a significant sediment load that suggested to some that they could become non-buoyant, and, if entrained in the Minas Passage, carried below the surface where they might interact with submerged or semi-submerged tidal generators. The concerns about ice are as follows:

- What will be the effect on the amount and the nature of ice formed in the winter?
- Does ice that is loaded with sediment represent a threat to tidal turbines or other equipment?

At this stage, there is little reason to suppose that the amount of ice will change as a result of energy developments, but the manner in which it moves around might change. If the height of high water is reduced because of energy extraction, more of the ice might be left stranded at the upper end of the intertidal zone. The second question has been addressed: research[18] has shown

[18] Sanderson, B., A. Redden and J. Broome 2012. ***Sediment-laden ice measurements and observations : implications for potential interactions of ice and large woody debris with tidal turbines in Minas Passage.*** Final

that the probability of large, non-buoyant ice blocks being carried into the Passage is extremely remote. Even if they were, their structural integrity is so low that they would pose no threat to tidal stream devices, although other equipment (e.g. environmental monitoring sensors) might be more vulnerable.

b) Ecological effects

➢ Effects on fisheries

Fisheries resources in the Bay of Fundy are of prime importance. Major fisheries exist throughout the Inner and Outer Bays for finfish, notably herring, mackerel, cod and haddock, and for shellfish, particularly scallops. In the high flow passages that are of interest for tidal energy extraction, the turbulence and strong flows generally restrict fishing in the immediate area to trap-based fisheries for benthic animals such as lobsters. However, these same passages are access routes to spawning or feeding grounds for many fish that are important to commercial and recreational fisheries. The principal question surrounding development of tidal stream energy is:

- Are there any fisheries that could be directly or indirectly affected by tidal stream developments?

In Minas Passage, (also Digby Gut, and Petit and Grand Passage), the principal fishery is for lobster. Although the Minas Passage has a small lobster fishery compared with other regions of the Bay, concerns of local fishers have been the basis of research[19] over the past five years. Trap collections and tagging studies have confirmed fishers' beliefs that lobsters move out through Minas Passage in late fall, and move in again in spring. Some lobsters may remain in the Passage and Minas Basin year round. The risk of direct damage to lobsters by tidal turbines seems to be relatively low, since even bottom-mounted tidal stream devices are supported several metres above the substrate. However, the one study so far conducted in the presence of a turbine[20] indicated some reduction of lobster catchability in the vicinity of the turbine. It is possible that noise or vibrations generated by the turbine act as a deterrent to lobsters, whereas the turbine support infrastructure might be expected to offer some suitable habitat. In addition, the necessary safety zone around the FORCE test site and exclusion zones around tidal

report to OERA. 68 pp.; Trowse, G. 2013. ***On the melt rate of submerged sediment-laden ice.*** M.Sc. thesis, Dalhousie University.

[19] FORCE 2011. ***Fundy Tidal Energy Demonstration Project: Environmental Effects Monitoring Report (September 2009 to January 2011)*** 53 pp.; Morrison, K., J. Broome and A. Redden 2013. ***Minas Passage lobster tracking study.*** ACER Publication No. 119, 38 pp; Dadswell, M., A. Redden, A. Lockhart-Bastien and D. Stanton (2009). ***The Minas Basin lobster stock, its fishery and the movements of tagged lobsters***. Final Report to Minas Basin Pulp and Power. ACER Technical Report 95. 16 pp.

[20] CEF Consultants Ltd. 2011. ***Lobster Catch Monitoring. Summary of Results from Three Surveys with Recommendations for a Revised Survey Design***. Report to FORCE. 44 pp.

turbines will represent some restriction to the lobster industry[21]. It is to be expected that similar considerations will apply to lobster stocks in other locations in the Outer Bay of Fundy or Cape Breton.

Other fisheries (i.e., for fin fish) are pursued in adjacent waters, rather than at the site of tidal turbines. If these passages constitute critical pathways for fish that are harvested elsewhere, there may be direct effects on those fisheries if the turbines cause mortality of fish as they move through. In addition, some effects are likely to be secondary, resulting from changes in physical dynamics and habitat characteristics as described above and below.

In Minas Basin, small local fisheries also exist utilizing intertidal weirs. These weirs trap more than 20 species of fish, including herring, American shad, alewife, blueback herring, Atlantic sturgeon and flounder, that move into the intertidal zone to feed on the rising tide. Scientific monitoring at weirs on the north and south shores of Minas Basin suggest that there are well defined movements of fish around the Minas Basin: fish of a given species are caught earlier in the season on the north shore than on the south. An assessment of the prospects for utilizing weir catch data to monitor changes in Minas Basin fish populations as a result of tidal stream deployments at the FORCE site[22] has so far not been encouraging because of the large annual and seasonal variations in catch composition and size. Nonetheless, weirs in the neighbourhood of a tidal stream installation may still offer a low cost opportunity for monitoring evidence of direct mortality of large fish. Unfortunately, it appears that intertidal weirs are no longer in operation outside of the Minas Basin and Chignecto Bay.

- Effects on fish and fish habitat

The high flows and turbulence in many passages of the Bay of Fundy and Bras d'Or has meant that fisheries based on mobile gear have not developed, although it is apparent that many fish exist or pass through these areas. Because of the absence of pre-existing information on these high-flow passages, OERA and FORCE have supported several important studies on the presence of fish and the conditions of their habitat in the last six years. The central question is:

- Will arrays of tidal stream devices constitute a threat to fish passing through these passages?

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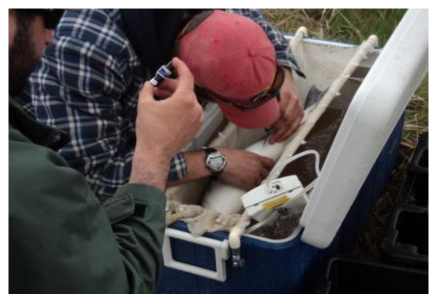
[21] There is a proposal for a safety exclusion zone of 500 m around the whole of the FORCE test site in Minas Passage.

[22] Baker, M. and A. Redden. 2014. ***Investigation of Temporal Patterns in Fish Presence and Abundance at Intertidal Weirs in Minas Basin, Bay of Fundy.*** Weir Study Interim Report to FORCE.50 pp.

This question, however, has several components:

- What proportion of any species utilizes the fraction of the passage that might house turbines?
- Can the fish detect the presence of a turbine when they are heading towards it? If so, how, and how far away?
- If fish are unable to avoid passing through the turbines, what is the probability of harm to the individuals and/or the population?

There have been a few monitoring studies at tidal stream test sites in Europe and the United States using video or acoustic equipment that could image fish in the vicinity of working turbines[23]. There is increasing evidence that fish tend to avoid the vicinity of turbines[24], especially during daytime and when in schools. To date, no study has shown evidence of any fish contacting the device or suffering from its passing through. However, absence of evidence is not the same as absence of risk. Each site has unique characteristics, and different turbines may have different effects. Consequently, each site and deployment needs to be evaluated separately.



The major challenge has been how to sample these dynamic areas. Drift nets, gill nets and trawls fail to collect fish effectively under high flow conditions, and safety considerations have restricted the scope of trials[25]. Other techniques that have been employed include inserting acoustic tags into selected fish species, and monitoring their movements in Minas Passage by an array of receivers deployed on the bottom[26]. This has been the experience of a collaborative study between scientists from Acadia University and the Ocean Tracking Network based at Dalhousie University. Four species were selected to represent the more than 70 species

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[23] Studies have been carried out in Strangford Lough, Northern Ireland, the European Marine Energy Centre in Scotland, the East River in New York, and in Cobscook Bay, Maine. (cf. Verdant 2010***. Roosevelt Island Tidal Energy Project. FERC No. 12611. Final Kinetic Hydropower License Application***. Vol. 4.;Royal Haskoning 2011. ***SeaGen Environmental Monitoring Programme:*** Final Report. 81 pp.; Viehman, H. 2011. ***Fish in a tidally dynamic region in Maine: hydroacoustic assessments in relation to tidal power development.*** Unpublished M.Sc thesis, Cornell University. 115 pp; ORPC 2013. ***2012 Environmental Monitoring Report.*** 86 pp. and footnote 66 below). The turbines were of different design in each case.

[24] Ocean Energy Systems Annex IV 2015. Environmental effects of marine renewable energy development: the state of the science. Report of Workshop at Nantes (France) 8 September 2015. (Available from: www.tethys.pml.gov/sites/default/files/AnnexIV-Workshop-Presentation-Final_0.pdf)

[25] FORCE 2011. ***Fundy Tidal Energy Demonstration Project: Environmental Effects Monitoring Report (September 2009 to January 2011)***. 53 pp.;CEF 2011. ***Fish surveys in Minas Channel.*** Final report to FORCE. 61 pp.

[26] Redden, A. and M. Stokesbury 2014. ***Acoustic tracking of fish movements in the Minas Passage and FORCE demonstration area: pre-turbine baseline studies***. Final Report to OERA. 161 pp; Broome, J., A. Redden, A. M. Dadswell. K. Vaudry and D. Stewart (2009). ***Population characteristics, movement and angling of the striped bass (Morone saxatilis) summer aggregation in Minas Basin, NS.*** Final Report to Minas Basin Pulp and Power. ACER Technical Report 96. 16 pp.

that are known[27] to pass through the Minas Passage: Atlantic salmon, Atlantic sturgeon, American eel and striped bass. More than 350 fish were fitted with Vemco™ [28] electronic transmitters. These transmitters send out an identification signal that may be picked up when they pass within ~50-100 m of a receiver. Some of the transmitters were provided with pressure sensors that indicate the depth at which the fish is moving.

Important results from this programme have been to show that fish are present in the Passage throughout the year: sturgeon pass through it into Minas Basin in the spring and leave in the fall; Atlantic salmon post-smolts leave in late May; adult American eels migrate out in the fall, mostly at night; but striped bass appear to be present throughout the year. Many other species move in and out on feeding or spawning migrations, including herring, dogfish, shad, flounder and several sharks. The timing of these events, and the activities of other species of fish in the Minas Passage, remain poorly known.

These studies have provided some entirely unexpected information. Although Atlantic sturgeon are generally considered as species that remain near the bottom, in the Minas Passage tagged sturgeon have been shown to move at all depths between the surface and the bottom. Eels, on the other hand, appear to favour the top 30 m of water when they travel on their seaward migration, and move primarily with the ebb tide. Striped bass, recognised as pelagic fish that may be both resident in the Upper Bay of Fundy and migrate there from other river systems (including the USA), have been tracked moving forward and backward through the Passage over successive tides. Most surprisingly, however, tagged striped bass have been recorded throughout the winter months, when water temperatures are 1°C or below[29]. It is currently not known if these animals are extremely cold adapted and therefore active, or whether they are comatose, simply drifting with the tides. If the latter, they may be unable to avoid drifting through an operating turbine during winter months.

Experience with the Annapolis Tidal Generating Station and many hydroelectricity plants around the world has raised concerns about the mortality of fish passing through a tidal range turbine. Mortality rates at Annapolis were found to be higher than originally forecast. This is because the forecasts were based upon the assumption that death would only result from contact with the moving turbine blade. In

[27] Dadswell, M. 2010. ***Occurrence and migration of fishes in Minas Passage and their potential for tidal turbine interaction.*** Appendix F in FORCE 2011.

[28] Vemco is a Nova Scotia company that is a global leader in development of marine acoustic transmitters and receivers.

[29] Redden, AM, MJW Stokesbury, JE Broome, FM Keyser, AJF Gibson, EA Halfyard, MF McLean, R Bradford, MJ Dadswell, B Sanderson and R Karsten. 2015. ***Acoustic tracking of fish movements in the Minas Passage and FORCE Demonstration area: pre-turbine and baseline studies, 2011-2013.*** Summary Report to FORCE. 7 pp.

fact, at Annapolis it was apparent that sudden and large changes in pressure occurred as the fish passed through the turbine, and these pressure changes were sufficient to cause fatal damage to blood vessels. The effects were especially severe on young fish and larvae. The large pressure drop is associated with the difference in water levels in a tidal range situation. Would this apply to tidal stream devices? Recent numerical modelling studies[30] suggest that the pressure drop through a tidal stream device is very much less than in a barrage-based turbine, and well below levels that can be tolerated by fish. Thus, the inability of a fish to avoid passing through a turbine may not be fatal if the animal does not come into contact with the blades.

- Noise and vibrations

A major uncertainty about tidal stream devices is whether their characteristic sounds or vibrations can be detected by fish or other animals against the background noise of the environment, and if so, what the effects would be. The passages of most interest to energy development are naturally extremely noisy places: in addition to human-caused noise (ship noise, drilling, pile-driving, seismic explorations, etc.) high flows cause rocks to move over the bottom, and the turbulence in the water generates extremely high and variable noises as the water flows over solid structures. It has proven technically difficult to measure the natural background noise in these very high flow passages, but recent studies in Minas Passage[31] comparing the effectiveness of mounting hydrophones on the bottom or allowing them to drift with the tide are leading towards a more satisfactory set of technologies for monitoring environmental noise when turbines are installed. Linking the monitoring results with studies of fish behaviour may enable a better understanding of the effects of turbines on fish.

All of this research indicates that the risks to fish are likely to be both species-specific and technology-specific. The behaviour and movements of most of the species that occur in the Minas Passage are presently unknown. Some may favour moving in the deepest parts of the Passage which are unlikely ever to house turbines, and others move closer in shore. Those which favour surface waters for a one-way migration route — such as the American eel — are more likely to be affected by turbines suspended from the surface than those nearer the bottom. Species that undergo movement through the Passage repeatedly and travel at all depths, may be susceptible to tidal stream devices no matter how they are deployed.

Thus, while much has been learned from tagging in the past few years, there remains a great deal of uncertainty about the behaviour, and therefore, vulnerability of fish to tidal energy conversion.

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[30] Zangiabadi, E., I. Masters, A.J. Williams and T.N. Croft. 2014. ***Modelling pressure changes in the vicinity of tidal turbines to assess fish survival rate during turbine passage.*** 3rd Oxford Tidal Energy Workshop, Oxford, UK. Pp. 47-49.

[31] Martin, B, and J. Vallarta 2012. ***Acoustic monitoring in the Bay of Fundy***. Jasco Document No. 00393 Report to FORCE. 31 pp.

Tagging studies give some insight into presence and movements of fish, but cannot, in the absence of other fishery data, be used to estimate abundance or stock size, which are critical elements of risk assessment. In an attempt to resolve this issue, researchers[32] have been investigating the use of active sonar devices to measure fish biomass or abundance, in the hope that such techniques will also enable the study of short-term fish behaviour in the vicinity of operating turbines. Active sonar devices have been widely used in freshwater and other shallow marine habitats, including at tidal stream test sites in Strangford Lough (Northern Ireland) Cobscook Bay (Maine), and in the East River (New York). Tests of several devices in Minas Passage showed increasing fish biomass from April to a peak in June, coincident with movements of herring and other migratory species, followed by declines in later months and then a smaller increase toward November. However, the acoustic devices are less effective in the Minas Passage than in other locations when employed from a surface vessel, primarily because extreme turbulence and air bubbles in the water dissipate the signal in the upper part of the water column, making it difficult to discriminate fish from the background 'noise'. The greater depths and strong currents at the FORCE test site, and the limited battery life of instruments, have so far precluded placement of these expensive devices on the bottom. Many of the moorings used for monitoring devices in the Minas Passage have failed or been damaged because of the powerful water movements, with the result that valuable data — and sometimes valuable instruments — have been lost.

A major asset in this regard has been the development of much more stable and durable platforms that can be safely deployed on and retrieved from the bottom to which different sensors —including acoustic monitoring technologies — can be attached. FORCE has developed a large platform, (called FAST-1[33], for the Fundy Advanced Sensor Technology programme), a self-powered unit which can be deployed near a turbine test site with an array of sensors on board. In its current form, there are sensors for current flow, tide height, salinity, turbidity, and fish detection. In addition, FAST-1 carries VECTRON[34], an array of acoustic Doppler current profiler (ADCP) sensors for detailed measurement of turbulence, which is a critical environmental factor that is poorly characterised. Two other smaller platforms (FAST-2 and -3), are cable-connected and designed to provide real time information on current flows, turbidity, water quality and fish movements, all of which are important to both turbine designers and regulators. These platforms will allow much more extensive monitoring of currents and turbulence, marine life activity, noise levels and seabed stability. It is expected that positioning acoustic monitoring devices on the bottom will enable better monitoring of the movements of

[32] Melvin, G. and N. Cochrane 2014. ***Investigation of the vertical distribution, movements and abundance of fish in the vicinity of proposed tidal power energy conversion devices.*** Final Report to OERA. 375 pp.; Melvin, G. and N. Cochrane 2015. ***Multibeam acoustic detection of fish and water column targets at high flow sites.*** Estuaries and Coasts 38 Supplement: 227-240;FEMTO 2010. ***Acoustic survey analysis.*** Report to FORCE. 7 pp.
[33] See: http://fundyforce.ca/environment/fundy-advanced-sensor-technology-fast
[34] See: http://fundyforce.ca/wp-content/uploads/2013/11/Vectron4.pdf

fish in the vicinity of active turbines in order to answer the vexing question of whether fish that are moving through the Passage are able to detect the presence of a turbine and avoid it.

- Effects on benthic communities

The places of greatest interest for tidal stream deployment have extremely high flows and hard, rocky bottoms. Knowledge of these areas has been limited in the past because of the difficulties of sampling. In recent years, however, use of videocameras and development of multibeam acoustic technologies has enabled a reasonably detailed survey of most of the Bay of Fundy[35], and this has been extended into some of the narrow passages. The detailed imagery provided by multibeam devices, complemented by video surveys[36], led to a test[37] of their use to monitor the seasonal and long term changes in benthic communities that might arise as a result of energy extraction. Although some aspects of the techniques remain to be developed, it seems highly probable that in future repeated multibeam surveys could be used to monitor environmental and even faunal changes in the substrate over very large areas.

Surveys[38] using video and grab samples have shown that in Minas Passage, the bottom-dwelling (i.e. *benthic*) fauna is sparse: dominated by sponges, anemones, barnacles and marine worms. Gravel and small boulder areas harbour very little life because of the extensive movement of the substrate in strong currents; even large boulders that may not themselves move on each tide often carry little living fauna because the rock surface is swept clean by other moving rocks. Mobile organisms include amphipods and lobster that can hide between rocks during flood and ebb. Further away from the highest flow areas, however, the diversity and abundance of organisms both increase as the current speed becomes lower, or as the substrate changes from hard rock to gravel, sand and/or mud. These lower-flow areas have been more extensively studied in the past in relation to earlier tidal power proposals.

Preliminary surveys[39] of Grand and Petit Passages show that the substrate is similar: they are generally rocky, but the lower water velocities permit much greater abundance and diversity of animals compared with Minas Passage.

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[35] Shaw, J. and B. Todd 2013. ***Mapping the Bay of Fundy.*** Report for OERA. 35 pp.;Todd, B., J. Shaw, M.Li, V. Kostylev and Y. Wu 2014. ***Distribution of subtidal sedimentary bedforms in a macrotidal setting: the Bay of Fundy, Atlantic Canada.*** Continental Shelf Research 83: 64-85.

[36] FORCE 2011. ***Fundy Tidal Energy Demonstration Project: Environmental Effects Monitoring Report (September 2009 to January 2011)***.

[37] Brown, C. 2014. ***Testing of temporal monitoring techniques for benthic habitat impacts of tidal energy developments.*** Report to OERA. 68 pp.

[38] AECOM 2009. ***Environmental assessment registration document -- Fundy Tidal Energy Demonstration Project, Vol 1. Environmental Assessment.*** Report for FORCE. 247 pp.; Morrison 2014. ***Habitat and seasonal movements of the American lobster, Homarus americanus, in the Minas Basin and Minas Passage of the Upper Bay of Fundy.*** M.Sc. thesis, Acadia University.

[39] Trowse, G. 2011. ***Project description: Outer Bay of Fundy Tidal Energy Project.*** Report to Fundy Tidal Inc. 71 pp.

Studies of these active sites has shown that deployment of turbines would have relatively little direct effect on benthic organisms in the immediate vicinity of the devices. Bottom-mounted structures will obviously cover over some areas, and may cause local scouring of the bottom in the immediate vicinity, but in addition they become part of the substrate themselves, and may even increase habitat diversity to some extent. However, the extraction of energy will change current flows and turbulence (increasing them around the structure, but decreasing them at a distance), and this will have effects on surrounding areas in proportion to the amount of energy extracted.

It is not expected that there will be overall effects on biological productivity of benthic communities. However, changes to the pattern of deposition of sediments is likely to result in changes to foraging of birds and fish. Whether this will have negative, positive or neutral effects on these species remains to be determined.

- Effects on pelagic communities

In addition to the large fish and mammals that occupy the pelagic zone, there are numerous invertebrates and larvae of vertebrates that move with tidal waters and form important parts of the food web. The common presence of seabirds foraging in the upwelling areas in the passages indicates that food is made available there as a result of turbulent waters bringing deeper-lying prey to the surface. Because of the difficulty of sampling, these areas have been poorly studied — many adjacent areas (such as the Minas Basin and the main Bay of Fundy) are much better known. Most of the invertebrate species are small in size, and are thought not to be greatly affected by the strong turbulence of water, nor be susceptible to damage if passing through a large turbine, but larval fish and the larger invertebrates such as jellyfish may be affected by any significant changes in water movements. This is a topic that has received little attention to date, but could be a focus of research when turbines are in place in future.

- Effects on marine mammals

The 2008 SEA identified more than 20 species of marine mammals that have been recorded in the Bay of Fundy. A few are year-round residents, while the majority are seasonal visitors. Most of these species occur mainly in the Outer Bay of Fundy, moving through the passages between islands, but only rarely venturing to the Upper Bay. Because some of the marine mammals are threatened and have high conservation status, as well as being a focus of the tourism and recreation industry, the implications of tidal energy extraction are an important concern. For this reason, OERA and FORCE have supported several research and monitoring activities[40] to understand the extent of mammal use, especially of the Minas Passage area.

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[40] Wood, J., D. Tollit, A. Redden, P. Porskamp, J. Broome, L. Fogarty, C. Booth, and R. Karsten 2013. ***Passive acoustic monitoring of cetacean activity patterns and movements in Minas Passage -- pre-turbine baseline conditions.*** Report to OERA. 71 pp; Redden, A., R. Karsten and J. Wood 2015. ***Assessment of marine mammal presence in and near the FORCE lease area during winter and early spring.*** Final report to OERA; Redden, A., P.

From 2009 to 2015, periodic surveys for marine mammals in the vicinity of the FORCE test site have been made from land and from vessels[41]. The most common mammal in the Upper Bay is the harbour porpoise, representing > 90% of records; a few records of grey seals and harbour seals, and rare observations of white-sided dolphins, minke, long-finned pilot or humpback whales constitute the rest. Observer programmes are notoriously limited in effectiveness because of the cost and the dependence upon daylight and fair weather conditions. Porpoises and dolphins, however, use sounds for tracking their fish prey and for communication: their 'click-trains' can be detected and recorded by passive-acoustic monitoring (PAM) sensors that are deployed in the water, allowing essentially continuous monitoring of the presence of these mammals in an area.

Monitoring using different PAM sensors (C-POD™ and IcListen™ [42]) deployed on the bottom in Minas Passage has now been carried out over all four seasons. No dolphins have been detected during this time, but harbour porpoise sounds have been recorded on most days when sensors were deployed. A few of these animals appear to be present in the vicinity of the FORCE site and in deeper water, although they avoid shallower regions nearer shore. A peak in records indicates more activity — and probably more animals — during May and June when stocks of herring and migratory fish are present in the Passage. A smaller rise in porpoise records occurs in October and November, also coincident with a rise in fish numbers. It is not possible to determine from these records how many mammals are present at any time, in part because the sensors become less effective at picking up their sounds when the current speed rises much above 2 metres/second, which is a good deal of the time during flood and ebb. Monitoring is to be continued in the vicinity of the FORCE site as turbines are deployed for testing over the next few years[43].

Mammal occurrence in the Outer Bay of Fundy is much greater than in Minas Passage. There are numerous species in the vicinity, several of which transit through Grand Passage, although only the smaller species (seals, porpoises) are likely to remain there for prolonged periods of time. Some initial recordings of cetaceans using PAM devices have been carried out, but there is already a wealth of observational data available from local people, fishers and, particularly, the operators of whale-watching businesses. Although limited in many ways, observer programmes have value in that they are less expensive to conduct than vessel-based surveys, and can increase the extent of surveillance. Fundy Tidal Inc. has been experimenting with a phone application[44]

Porskamp and J. Wood 2015. ***Assessing marine mammal presence in and near the FORCE lease area during winter and early spring — addressing baseline data gaps and sensor performance***. Report to OERA and FORCE.;Porskamp, P. 2015. ***Detecting and assessing trends in harbour porpoise (Phocoena phocoena) in and near the FORCE test site.*** M.Sc. thesis, Acadia University.

[41] Envirosphere Consultants 2010. **FORCE Environmental Assessment Addendum Report, Appendix H Marine mammal and sea bird surveys**.

[42] A development of Ocean Sonics Ltd., a Nova Scotia company.

[43] SLR 2015. ***Proposed environmental effects monitoring program 2015-2020.*** Report to FORCE.192 pp.

[44] http://fundytidal.com/news-a-events/98-wheres-the-whale

that could engage many more members of the public in recording mammal and bird sightings. Attempts to utilise observer records, complemented by PAM monitoring for porpoises and dolphins are likely to be a research focus if turbines are deployed in these Outer Bay areas.

- Effects on marine birds

The 2008 and 2014 SEA reports, together with a study to identify potential marine representative areas[45] that could constitute a National Marine Conservation Area[46] in the Bay of Fundy, have shown that more than 130 species of marine birds visit or are resident in the Bay. Most of these are associated with the rich Outer Bay region, where many feed in upwelling areas that include some of the passages between islands. Monitoring has been conducted over the last four years by observers from shore and on vessels in the vicinity of the FORCE test site, and these indicate that marine bird presence in Minas Passage is very limited, although the diversity of birds visiting the site is quite high[41]. As with mammals, observational surveys of birds are limited in effectiveness. It is not anticipated that many species of marine birds are likely to encounter bottom-mounted turbines, but some of the diving ducks (e.g. eiders, loons) and cormorants could well be displaced by surface-based tidal stream devices[47]. For this reason, monitoring of marine birds will need to be continued when and where turbines are installed. An additional reason for such monitoring is that occurrence and increased numbers of marine birds may well prove a useful indicator of other events, such as a fish kill at the site.

- Effects on Species at Risk

A large number of species of mammals, fish and birds have been identified in the two SEAs as species at risk (SAR). Under the Canadian Species at Risk Act (2002), species that have been identified as Endangered or Threatened are to be protected and, where possible, actions taken to reduce their susceptibility to extinction. They therefore have special status compared with other species in environmental assessments. Most of these SAR occur in the Outer Bay, and are more likely to be of concern at tidal sites there. So far, relatively little research has been conducted specifically dealing with SAR in the Outer Bay in the context of tidal energy development, but mammal and bird observational programmes and fish monitoring as described above need to be continued as turbines are deployed. In the Upper Bay, few of the species recorded there are species at risk, the exceptions being the harbour porpoise and several fish that are already the subject of ongoing monitoring.

[45] AECOM 2010. ***A study to identify preliminary marine representative areas, Bay of Fundy Marine Region.*** Final report to Parks Canada. 344 pp

[46] See: http://www.pc.gc.ca/eng/progs/amnc-nmca/pr-sp/index.aspx

[47] cf. Wade 2015. ***Investigating the potential effects of marine renewable energy developments on seabirds.*** Ph.D. thesis, University of Aberdeen. 417 pp.

What has been achieved: Regulations and Policy

The 2008 SEA recommended that the Nova Scotia government establish policy and regulations clearly outlining the conditions under which tidal power development should be allowed, and the decision-making process by which this would be achieved. The approach has been based upon the following guiding principles[48]:

- Protection of the marine ecosystem
- Embracing collaboration and consultation
- Employing an adaptive and staged approach to development
- Ensuring that health and safety are top priorities
- Ensuring environmental protection and conservation of natural resources
- Recognising and respecting other uses and users of the ocean
- Developing the industry in a sustainable manner
- Maintaining and ensuring community sustainability.

The role of science

The challenges presented by new technologies that extract energy from the environment inevitably require that scientific understanding of the environment is adequate to support political decisions and regulatory requirements. Natural oceanographic processes such as water movements, biological interactions and air-sea interactions, for example, are all expressions of the flow of energy in the marine environment. They underlie all human interests in that environment, from fisheries to recreation, transportation, conservation and climate change. Consequently, a sound scientific understanding of those processes is critical for any development that would modify them by changing the amount of energy available.

Tidal forces and the way in which they affect water movements in places such as the Bay of Fundy and the Bras d'Or Lakes are well known, and their general features can be forecast for many years ahead. The biophysical processes that are influenced by tidal movements, however, are much less known, especially in these high flow passages. Any sound and sustainable conversion of energy from such locations necessitates that the risks of development be adequately assessed, and that cannot happen in the absence of sufficient scientific understanding. The advantage of tidal stream technologies, however, is that, unlike the tidal range developments of the past, they can be put in place on a small scale and expanded over time, allowing for an adaptive management approach. It is therefore quite feasible to continue planning for a development while the necessary scientific understanding is achieved.

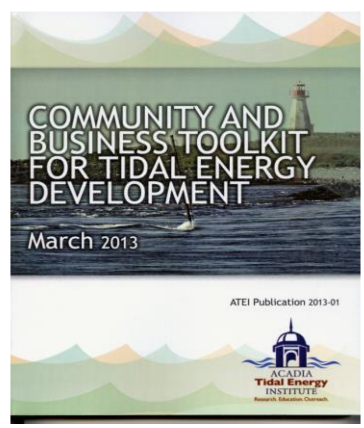
Recognising that Nova Scotia's tidal waters are still inadequately known in spite of a century of research, and that the new technologies offer somewhat different challenges from the old tidal

[48] Nova Scotia ***Marine Renewable Energy Strategy*** May 2012.

range-based ones, there have been major initiatives to ensure that relevant information is gathered from any source to complement the direct research initiatives described above. In 2011, Canada and the United Kingdom signed a Cooperation Agreement[49] that included collaboration on the development of technologies for commercial-scale electricity generation from marine renewable energy. This initiative has been accompanied by extensive consultation between the Nova Scotia Department of Energy officials and government and business interests in the UK. Following a memorandum of understanding (MoU) between the Nova Scotia Department of Energy, the OERA and the UK's Technology Strategy Board (TSB, now InnovateUK) signed in 2014, a programme to support partnerships between Canadian and UK researchers and business interests[50] has been developed, based upon a joint investment of $1.4M CAD. Other MoUs have been signed between Dalhousie University and the University of Strathclyde (Scotland), Acadia University and Saint Andrews University (Scotland) and Acadia and the University of Maine (USA) to encourage collaborative research on tidal energy.

The role of engagement and consultation

Consultation and cooperation within Nova Scotia are considered essential bases for progress in tidal energy development. There is explicit recognition of the need to consult with Mi'kmaq and engage local communities in the collection of information and advice, and to ensure that developers and other vested interests engage these stakeholders effectively at all stages of development. In 2007, the Association of Mi'kmaq Chiefs and the Governments of Canada and Nova Scotia signed an agreement laying out the requirements and protocol for consultation with Mi'kmaq over a wide variety of issues, including governance, wildlife and wildlife management, fisheries, forestry, land management and energy. Subsequently, a guidance document for such consultation has been prepared[51].



Under this agreement, two Mi'kmaq Ecological Knowledge Studies[52] have been conducted in relation to the tidal power issue, covering the FORCE site and the Outer Bay of Fundy sites. These studies recognize that Mi'kmaq have had a long history of use of resources from all the areas now considered for tidal energy generation. Many of these activities, including fishing for lobsters, mackerel, flounder, haddock, herring and clams, continue to the present day. In the Outer Bay, especially,

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[49] ***Canada-United Kingdom Joint Declaration***, 22 September 2011.

[50] ***Joint Canada-UK Competition for Collaborative R&D Funding to Develop Enhanced Sensing Technologies for Tidal Energy Applications***. September 2014***.***

[51] ***Mi'kmaq-Nova Scotia-Canada Framework*** Agreement 2007. 15pp.; ***Terms of Reference for a Mi'kmaq-Nova Scotia-Canada Consultation*** Process 2010. 5 pp.;Nova Scotia Office of Aboriginal Affairs 2012. ***Proponents' guide: The role of proponents in Crown consultation with the Mi'kmaq of Nova Scotia.*** 20 pp.

[52] Membertou Geomatics Consultants 2009 and 2012. ***Mi'kmaq Ecological Knowledge Study.*** Phase I: Fundy Tidal Energy Demonstration Site 83 pp.; Phase II: Outer Bay of Fundy sites. 107 pp.

Mi'kmaq utilised a wide array of marine resources, including scallops, crabs, urchins, numerous fish species and— at least historically—seals, porpoises and walrus.

In a similar vein, guidance documents[53] have been prepared, funded by OERA and ACOA, for enabling more effective public communication on the tidal power issue. The *Community and Business Toolkit for Tidal Energy Development* provides an extensive summary of the nature of tidal power, the technological advancements under way, and the economic and environmental issues that need to be addressed. This document, and its companion[54], the *Tidal Energy Community Engagement Handbook* outline the need and the means for enhancing community knowledge and engagement.

The regulatory context

In developing the regulatory context for tidal energy development, the Province of Nova Scotia has initiated a number of actions:

- A Joint Federal—Provincial assessment process was established between the Canadian Environmental Assessment Agency (CEAA) and the Nova Scotia Department of Environment (NSE) in 2009 for the FORCE site in the Minas Passage. Subsequent changes to the Canadian Environmental Assessment Act in 2014 have determined that in-stream tidal energy projects of less than 50 MW size will not require a federal review, and will thus be managed under Nova Scotia's Environmental Assessment Regulations. Any tidal stream development larger than 50 MW will require a review under the Canadian Environmental Assessment Act[55]. Tidal range projects, such as a lagoon or a barrage of more than 5 MW in size, however, would trigger a federal environmental assessment.
- The Nova Scotia Renewable Electricity Plan[56] in 2010 laid out a path for the Province to move away from dependence upon fossil fuels. The plan required that, commencing 2015 until 2020, at least 25% of the electricity supplied to customers by any load-serving entity must be derived from renewable resources; from 2020 onward, this fraction must equal or exceed 40%. In early 2016, Nova Scotia Power announced that it had surpassed the 2015 goal—producing 26.6% of the province's electricity from renewable energy sources.[57] The plan also outlined a Developmental Feed-in Tariff (FIT) for commercial scale tidal energy

[53] ATEI 2013. ***Community and business toolkit for tidal energy development.*** 304 pp.
[54] ATEI 2013 ***Tidal energy community engagement handbook***. ATEI report to OERA. 46 pp
[55] ***Canadian Environmental Assessment Act*** 2012.
[56] Nova Scotia Department of Energy 2010. ***Renewable Electricity Plan .*** 28 pp. ***Renewable Electricity Regulations*** N.S. Reg.14/2014. As amended by Order in Council 2014-06
[57] http://www.nspower.ca/en/home/newsroom/news-releases/nova-scotia-power-sets-renewable-energy-record.aspx

developments and a Community-based Feed-in Tariff (COMFIT) to support community-owned renewable energy projects such as wind and tidal power. The Developmental FIT applies to projects with devices greater than 500kW in size. The FIT and COMFIT[58] rates, which provide payment to the developers for electricity produced by tidal power, were established by the Utility and Review Board in 2013 and 2011 respectively.

- Conducted a public consultation process to ascertain opinion on the elements to be included in the Province's approach to development. The Fournier Report (2011)[59] emphasised the critical need for transparency and public involvement in planning, the fundamental importance of a foundation on good science, the need for a business plan, and for continuing a funded research programme to address remaining uncertainties. It also made specific recommendations for marine renewable energy legislation.
- A Marine Renewable Energy Strategy[45], released in May 2012, affirmed the aim of establishing Nova Scotia as a 'global leader' in the development of technologies and systems for environmentally sustainable marine energy. A goal of 300 MW from tidal energy was established. As recommended in the Fournier Report, the elements of the strategy are to: build and maintain public trust through science, accountability and transparency; develop sustainable technologies; and build a marine renewable energy industry in Nova Scotia.
- An economic assessment[60] (2015) has been prepared outlining the potential and opportunities of tidal energy development in the context of global developments. There is a substantial potential for renewable marine energy around the world, and, in addition to the opportunities for tidal power locally, Nova Scotia could contribute knowledge and expertise to other countries if it becomes an 'early adopter' in tidal energy development. Areas of particular promise include: resource modelling and site characterization; design and manufacture of purpose-built marine vessels, moorings, etc.; environmental sensors and instrumentation; data management; and marine cable installation and interconnection. The value of tidal stream development to the Nova Scotia GDP has been estimated at as much as $1.7 billion over the next 25 years. It could create as many as 22,000 jobs with $815 million in labour income, and avoid GHG emissions representing up to $1 billion in costs. In-stream tidal power, however, is still a nascent technology world-wide, and therefore there is considerable risk that it might fail to become

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[58] Feed-in tariffs for Developmental Projects (>500 kW) were set at $0.53/kWh for the first 16,640 kWh, and $0.42/kWh for electricity in excess of 16,640 kWh for a period of 15 years; Community Feed-in tariff is $0.652/kWh for 20 years.

[59] Fournier, R. 2011. ***Marine renewable energy legislation: a consultative process.*** Report to the NS Government. 79 pp.

[60] Gardner Pinfold and ATEI 2015. ***Value proposition for tidal energy development in Nova Scotia, Atlantic Canada and Canada.*** Report to OERA and ACOA. 102 pp.

sufficiently competitive with other energy sources. The Report is nonetheless optimistic, and highlights the need for public (i.e. government) support both in the near term and beyond (e.g. to 2040).

- A Marine Renewable-energy Act (Bill 110, passed December 2015)[61] that formalises the objectives, principles and responsibilities for achieving renewable energy from the marine environment. This bill defines: the areas of Nova Scotia's coastal waters (Bay of Fundy and the Bras d'Or Lakes) where marine renewable energy development may be a priority; procedures for acquiring licenses or permits; the framework of royalties, rents and fees; the requirement to consult widely, especially with Mi'kmaq, users and communities; and the rules for collection, use and disclosure of information. Proclamation of the Act is expected in late 2016.
- Preparation of a ***Statement of Best Practices for In-stream tidal energy development and operation*** in collaboration with Marine Renewables Canada. This document[62] outlines standards and practices for risk assessment, site assessment, environmental assessment and monitoring, deployment and operation, and engagement of stakeholders including Mi'kmaq and the community.

Underlying all of these initiatives is recognition of the critical importance of scientific knowledge, stakeholder engagement and adaptive management in decision-making. There remain many uncertainties about the effectiveness of various technologies, and about their environmental effects, and the absence of answers leaves the whole enterprise vulnerable to criticism from groups and individuals who, for various reasons, are antagonistic toward pursuit of marine renewable energy. The technical and scientific uncertainties need to be addressed by a focussed research program that is thorough and uses the best available technologies, the results of which are conveyed rapidly to the public. Only by such a transparent process can the social license for MRE development be assured[63].

These diverse initiatives have enabled Nova Scotia to become recognised as a potentially significant player in tidal energy globally. They have encouraged large international developers of tidal energy technology to consider the province as a place for testing technologies, in line with the concept that meeting the 'Fundy standard' could become an important criterion for success elsewhere. If the remaining uncertainties regarding technologies and their environmental implications can be resolved, the framework is in place that should enable Nova Scotia to

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[61]Government of Nova Scotia 2015. ***Bill 110 Marine Renewable-energy Act.*** Available from: http://nslegislature.ca/legc/bills/62nd_2nd/3rd_read/b110.htm

[62] Nova Scotia Department of Energy and Marine Renewables Canada 2014. ***Statement of best practices for in-stream tidal energy development and operation.*** Available from: http://energy.novascotia.ca/sites/default/files/Statement%20of%20Best%20Practices%20Booklet.pdf

[63] Dempsey, S. 2014. ***Developing, securing and maintaining social license for tidal energy development: a Nova Scotia case study.*** Presentation to 5th International Ocean Energy Conference, Halifax, NS. June 2014.

capitalize on its extraordinary tidal resource and the skills in marine science available in the province.

What remains to be achieved: A Strategic Research Plan

The distinction between ***research*** and ***monitoring*** is not always very clear. In general, ***research*** applies to investigation of facts that are currently unknown; ***monitoring***, on the other hand, examines how things change through time as a result of either natural causes or human actions. For example, determining the identity and abundance of fish using a passage, and their spatial use of that passage in relation to probable tidal stream deployment sites, constitutes basic research; assessing whether that species' composition, abundance or behaviour changes as a result of tidal energy conversion, is the purpose of monitoring. The techniques used may be the same in each case.

A strategic research plan needs to focus on long term goals, and identify research themes, especially those needed if tidal energy conversion expands in the future. Its purpose should be to assess the risks and benefits of large scale energy conversion, not just the effects of one or a few turbines that are currently being tested. Since almost all environmental interactions are non-linear, the environmental effects of 100 turbines will not be merely 100 times those of a single turbine. Consequently, the research plan must aim to forecast the ***cumulative*** effects: the manner in which effects change in magnitude as the number of turbines or the amount of energy being converted to electricity is to change over time.

Cumulative effects refers to the combined effects of past, present and future changes to an environment. These changes may be the consequence of several different human activities or developments, increases in scale of development, together with natural changes that result from long term and large scale processes. These may all combine to produce complex, non-linear effects that far exceed each individual change.

Environmental concerns.

The 2008 SEA[3] and 2011 workshop[9] identified numerous questions that needed to be addressed regarding the scientific and socio-economic implications of tidal stream development in the Bay of Fundy. During the last seven years, a great deal of research has been undertaken to address the highest priority questions — the ones that might constitute 'show-stoppers', capable of impeding or preventing tidal power development. As a result, there is increasing confidence in the ability to assess the level of risk associated with each issue. Some of the issues have been 'retired' in the sense that either they are no longer considered of high risk, or they lack critical information, or because our ability to measure or monitor them is so inadequate that further effort is unjustified at this time[64]. Examples include: the need for more refined numerical models for assessment of

[64] The following refers only to issues associated with tidal stream developments. Some of these retired topics would remain as issues if *tidal range* approaches (e.g. lagoons) were to be considered in future.

the size of the tidal resource and predicting the environmental consequences of energy extraction; the threat to bottom-mounted turbines from non-buoyant ice; the barrier effects of electromagnetic fields associated with power cables; and the subtle effects on 'far-field' sites.

In spite of the extensive research of the past seven years, there remain a few significant questions that must be addressed by continuing research. Environmental effects can be both site-specific and technology-specific. As a result, not all similar research carried out in other tidal environments or with different technologies can be transferred to the Nova Scotia case without confirming its applicability. In addition, some issues are also still unresolved elsewhere, so that research in Nova Scotia can be truly of global significance. A strategic research plan needs to answer a number questions, all of which have been recognised for a long time.

Responsibility for providing answers to the remaining questions is divided between several groups: the proponent(s) (including berth holders at the FORCE test site and license holders at the Digby Neck and Bras d'Or sites); FORCE for the test area in Minas Passage; federal and provincial regulatory and research agencies; First Nations; stakeholder groups such as fishers and tourism operators; and academia. Proponents are interested in the performance of their devices, the factors that affect that performance, and any environmental effects that could influence regulatory approval. They will, accordingly, be monitoring conditions in the vicinity of their installations. In addition, it is unwise for any activity to be conducted near tidal stream devices or arrays without the full cognisance and cooperation of the developer. For this reason, responsibility for monitoring and environmental effects assessment in the 'near-field' needs to be taken by the device owner. For the FORCE site, the proposed new Environmental Effects Monitoring Programme[65] assigns responsibility to each berth holder for research and monitoring within 100 m of a device. In Minas Passage, FORCE has responsibility to provide baseline data and ongoing monitoring of conditions for its pre-approved test centre, and for adjacent areas outside of the test area (i.e. the 'mid-field'). At larger scales, responsibility for research (as opposed to effects monitoring) remains with public agencies and universities.

- **Fish**

Fish, both commercial and non-commercial species, remain one of the highest priority ecosystem components because most tidal stream-suitable locations are used by numerous species. Assessing the risk to these species requires: a) knowledge of their seasonal and long term abundance, distribution and movements in the area in relation to the location of tidal stream devices; and b) their capacity for avoiding interaction with the devices. Considerable research has been carried out on the mortality of fish passing through turbines in hydroelectricity plants over the last half century, and models of the possible encounter rate of a fish and a turbine structure are well established. Recently, these models have been modified to incorporate concerns over pressure changes, cavitation and shear stresses, and applied to tidal range

[65] SLR 2015. ***Proposed Environmental Effects Monitoring Programs 2015-2020 Fundy Ocean Research Centre for Energy.*** Report to FORCE. 192 pp.

installations[66]. Estimates of mortality range from less than 1% to more than 50%, depending upon the species and size of the fish, the size of the turbine, and the difference in water levels on either side of the dam. In these tidal range situations, however, the fish may have no alternative to travelling through the turbine, and therefore such results have little direct application to the situation with tidal stream devices.

Research is still needed to address the following questions:

1. Where, and when, do different species of fish utilize the tidal stream-suitable sites? What fraction of the population is involved?

Attempts to provide this information in the absence of local fisheries-based data have been partially successful in the Minas Channel and Passage using surveys with downward-looking acoustic technologies. Refinement of those techniques to improve target recognition (i.e. to be able to count, identify and assess the size of fish against a 'noisy' background) is a research requirement, as is more complete seasonal coverage. Tagging studies based on a few representative species provide more detailed information on individual presence, persistence and depth of movement (etc.), and valuable information regarding risk to high priority species, but cannot provide information about population level effects, nor of the effects on the many other species using the habitat.

2. Can fish detect the presence of tidal stream devices as they approach them? If so, how and at what distance? What is their potential for avoiding the devices?

The most challenging aspect in assessing risk to fish is understanding their behavioural responses in the presence of working tidal stream devices. Use of encounter probability models, which estimate the likelihood of a fish to be moving in the same water mass that will pass through the turbine, can provide an upper limit to the level of risk; but without knowledge of their reactive behaviour as they approach the turbine, it is not possible to estimate the real risk and consequence of interaction. All fish are sensitive to noise in their environment, and all turbines emit characteristic sounds: until we know whether those sounds can be detected against the extremely noisy background of these passages, and whether fish are able to take evasive action, we cannot estimate true risk. Daytime video observations from a small number of deployments[67] have shown that fish may collect around a turbine when it is not moving, and then disperse when

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[66] Turnpenny, A.W.H., S. Clough, K.P. Hanson, R. Ramsey and D. McEwan. 2000. ***Risk assessment for fish passage through small, low-head turbines.*** Technical report for Energy Technology Support Unit: Harwell, UK,20. ETSU Report No. H/06/00054/REP.

[67] Broadhurst, M., S. Barr and C.Orme. 2015. ***In-situ ecological interactions with a deployed tidal energy device: an observational pilot study.*** Ocean and Coastal Management. http//dx.doi.org/10.1016/j.occoaman.2014.06.008.

generation begins. One experimental study with a simulation of a turbine[68] suggests that fish will attempt to avoid a turbine when it is operating.

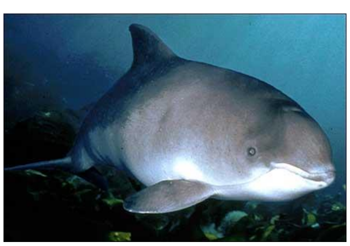
This remains a major research challenge. Evasive responses of fish to turbines are almost certainly species-, device- and location-specific. The solution is deployment of acoustic devices in the vicinity of working turbines that can monitor precisely the movements of fish as they approach the device, both night and day. Appropriate technologies are available, although much refinement of signal processing is still required to provide better understanding of behavioural responses. The development of the FAST sensor platforms[33,34], combined with turbine-mounted devices, provides a mechanism for deploying an array of acoustic sensors that can track fish and mammals in the vicinity of operating turbines and obtain detailed observations about their behavioural responses. Such research and monitoring needs to be carried out with all new deployments, and be extended in time to cover seasonal variation in fish and mammal presence. It clearly requires a well-organised, collaborative research programme involving the technology providers, FORCE (for the Minas Basin site), university researchers, and government agencies.

3. If fish are able to avoid working turbines, what number of turbines will effectively prevent use of the passage as a migratory route or feeding site?

Even if fish are able to avoid individual turbines and move past a generating site through the adjacent water, there will nonetheless be a limit to the number of turbines employed because the available space through which the fish could move will diminish as the number of turbines increases. A very large array could, therefore, constitute a barrier to forward movement of fish through the passage. The answer to this question requires a much better understanding of the behavioural response of fish to a turbine than is presently available. It is also likely that behaviour of schooling fish will be different from solitary species. Tagging studies cannot resolve that uncertainty.

- **Marine mammals**

The second major category of research need relates to marine mammals. As with fish, mammals are highly sensitive to sounds in the marine environment, using them for communication and tracking prey. The behaviour of some species can be monitored using passive acoustic



monitoring (PAM) sensors, which detect the sounds made by animals such as dolphins and porpoises themselves. However, experience has shown that these devices become less effective the faster the water flows, because the 'signal to noise' ratio becomes very small. There is a clear need for further research to improve the effectiveness of PAM sensors. Other marine mammals such as seals

[68] Amaral, S., M. Bevelhimer, G. Cada, D. Giza, P. Jacobson, B. McMahon, and B. Pracheil. 2015. ***Evaluation of behavior and survival of fish exposed to an axial-flow hydrokinetic turbine***. North American Journal of Fisheries Management 35: 97-113;

and larger whales are readily imaged on echosounding equipment, but the relatively short range, narrow beam, and interference from backscatter generated by tidal turbulence present a challenge because evasive behaviour of mammals might occur at some distance from a turbine.

Because the diversity of mammals using different parts of the Bay of Fundy varies considerably, there are significant site-related factors. Numerical models that calculate encounter rates provide only limited information about the risk to mammals[69]. In Minas Passage, the principal species of concern is the harbour porpoise, which can be tracked by PAM devices, but in the outer Bay of Fundy numerous other species are involved. Unlike most fish species, loss of a single mammal through interaction with a tidal stream device will constitute a problem for energy development.

The questions remaining are similar to those for fish:

1. Can mammals detect the presence of tidal stream devices as they approach them? If so, how and at what distance? What is their potential for avoiding the devices?

Evidence from studies in Northern Ireland, Scotland and the USA[67,70] suggests strongly that mammals avoid coming close to working turbines, although they may quickly move in again when the device shuts down. Limited research indicates that turbine-generated sounds may be distinguished up to several hundred metres from a device[71]. If this is the case, avoidance may occur at a considerable distance from a turbine, requiring monitoring of behaviour at distances greater than the 'near-field'. At present, the importance of Fundy or Bras d'Or passages to mammals as feeding areas or transit routes is inadequately known. Are these critical habitat or simply one of a number of options? This needs to be determined in advance if we are to know whether displacement from these locations will be detrimental to any marine mammal. More research is clearly needed to quantify that.

- **Marine birds**

A number of marine bird species utilise the tidal waters of the Bay of Fundy. Some of these are found feeding in many of the high flow passages, either on small marine life brought to the surface by turbulence (e.g. phalaropes, some ducks, gulls, petrels etc.) or on shallow water benthic species which they can reach by diving (e.g. eider, scoter etc.). Another group is comprised of shorebirds (sandpipers, plovers, etc.) that frequent intertidal areas. A large proportion of each group consists of migratory species for whom these tidal waters are an

[69] e.g. Wilson, B., S. Benjamins, J. Gordon, J. Macaulay, S. Calderan and N. van Geel. 2014. ***Estimates of collision risk of harbour porpoise and marine renewable energy devices at sites of high tidal- stream energy.*** Report prepared for the Scottish Government. 78 pp.
[70] Royal Haskoning 2011. ***SeaGen Environmental Monitoring Programme: Final Report.*** 81 pp; ORPC Maine LLC. 2014. ***Cobscook Bay Tidal Energy Project: 2013 Environmental Monitoring Report***. 502 pp.
[71] Collar, C., J. Spahr, B. Collar, J. Thomson, C. Bassett, J. Graber, R. Cavagnaro, J. Talbert, A. deKlerk, A. Reay-Ellers, D. Tollit, J. Wood, A. Copping, T. Carlson, and M. Halvorsen. 2012. ***Study of the acoustic effects of hydrokinetic tidal turbines in Admiralty Inlet, Puget Sound.*** Final report to the US Department of Energy under DOE Award DE-EE0002654.

important resource for a significant part of their life cycle. The Canadian Wildlife Service conducts annual surveys of seabird and shorebird concentrations in several areas of the Bay of Fundy[72]. These show that the Outer Bay provides extremely important habitat for a wide variety of marine diving and surface-feeding birds throughout the year, whereas the Upper Bay has relatively small numbers of these groups. The Upper Bay, however, is critical habitat for migratory shorebirds, for whom the intertidal mudflats are internationally significant habitat.

Much work has been done in the past on shorebird use of intertidal areas, especially in the Upper Bay of Fundy. In spite of this, it is unclear how important these habitats truly are, partly because the abundance of intertidal prey has been varying significantly, and also because there have been global changes in shorebird abundance in recent decades. Given the difficulty of predicting and measuring the effects of changes to sediment regimes in 'mid-field' or 'far-field' locations as a result of tidal energy extraction, it seems unlikely that additional research on sediment behaviour itself will produce definitive answers about the effects of energy extraction on shorebirds, but continued monitoring of shorebird populations is crucial.

The issue of other marine birds that use the passages, however, is different.

1. What is the probability that diving species will encounter a working turbine? Will marine birds that dive for their food avoid the vicinity of a working turbine? If so, what is the effect on the use of the habitat by the population?

Answers to these questions might be obtained from shore- or boat-based observations, although these are limited by light and weather conditions. An alternative possibility that is being tested by FORCE is the use of shore-based radar, which is presently being assessed for study of water flow, wave heights and turbulence[73]. If it proves suitable, radar could substantially improve our ability to monitor bird activity. In the meantime, continued surveys by land- or sea-based observers will be an important monitoring activity. Such investigations could also be useful in giving notice of other events: a fish kill, for example, might be signalled by unusual gathering and foraging activity of surface-feeding marine birds.

- **Noise in the environment**

Learning more about the background acoustic environment is also a priority research activity for any site in which tidal stream devices may be deployed. Locally produced hydrophones are available, and current research is under way to develop more effective shrouding that can minimise extraneous noise generated around the hydrophone by water movements. Increased knowledge of background noise, the additional sound signatures of each turbine, and the distance

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[72] cf. Allard, K., A. Hanson and m. Mahoney. 2014. Summary: Important marine habitat areas for migratory birds in Eastern Canada. Can. Wildl. Serv. Tech. Report No. 530. 26 pp.

[73] No report appears to be available yet.

upstream of the devices that such sounds can be distinguished will contribute significantly to the ability to assess risk to fish and mammals. One study[71] has indicated that sounds generated by a tidal stream device in a high flow environment can penetrate more than 100 metres upstream of the turbine, and possibly as far as 1.5 km. It is critical to know if these can be distinguished by animals from the extreme levels of background noise in order to assess the true risk to marine organisms.

1. How far does turbine-generated sound penetrate upstream and downstream of a device? What factors influence that transmission?

Developing an acoustic numerical model that would predict the effects of current velocity and turbulence on the transmission of sounds in tidal stream-suitable waters would be an asset. Sound transmission in water is a complex function involving temperature, turbulence, and ambient noise levels, the latter two of which are extremely variable in time and space. Direct measurements of sound transmissibility in turbulent waters are difficult and time-consuming, but experiments using both static and drifting hydrophones will provide necessary information about the penetration of turbine sounds as well as the presence and activity of some marine mammals. These data are essential for development of a predictive model that would enable forecasting of turbine sound levels at varying distances, and allow estimate of the potential 'sound barrier' effect as larger numbers of turbines are deployed.

- **Deterrence**

In the event that fish and/or mammals are unable to avoid tidal stream turbines deployed in the Bay of Fundy, one potential mitigation approach could be to use a deterrent device, such as is used in many aquaculture operations to drive away mammals and birds from aquaculture cages. The question becomes:

1. If mammals and/or fish are unable to avoid passing through a turbine, are there remedial solutions that would deter their approach?

Two different technologies have been developed to use underwater noise to drive animals away from aquaculture sites[74]: low-powered acoustic deterrent devices (ADDs) and high-powered acoustic harassment devices (AHDs). The former have been used to displace marine animals from the areas of devices that could potentially harm them, and the latter to prevent animals preying on caged salmon (etc.) by causing acoustic pain to the predator. These deterrent technologies obviously raise their own environmental concerns: seals become habituated to ADDs, rendering them less effective, whereas AHDs could cause unacceptable effects by damaging hearing of fish, birds and mammals. Research is needed to find an effective, but non-destructive deterrent to discourage fish and mammals from approaching operating turbines. If

[74] Milewski, I. 2000. Impacts of salmon aquaculture on the coastal environment: a review. Discussion document for Marine Aquaculture and the Environment. Available at: www.iatp.org/files/Impacts_of_Salmon_Aquaculture_on_the Coastal_E.pdf

such deterrents are used, creating a negative sound stimulus in the vicinity of turbines, will this increase the barrier effect of a turbine array? This would be a very important research initiative to minimise the environmental effects of marine energy conversion.

- **Accelerated corrosion**

Moorings, cables and other metal materials deployed in high flow coastal environments have proven to be much less durable than expected from experience in more benign conditions, resulting in the loss of environmental monitoring equipment, and raising concerns about the longevity of submarine data and electrical cables. Called "flow-accelerated corrosion", it occurs when the protective oxide layer on metal surfaces (e.g. iron or copper) is dissolved away by rapid flow of water, especially if at high temperature and under pressure, or if the water is too acid or too alkaline. This has been a significant issue for the nuclear power industry. The cause appears to be electrochemical[75]. While stainless steel is not susceptible to this kind of corrosion, it is expensive, and tends not to be used for that reason. Research is needed to identify both the local causes and potential solutions that would enable equipment and cables to be deployed in these high flow environments for longer periods of time.

- **Data management**

During the next five years, each of the groups involved in tidal energy research and monitoring (berth- and site license-holders, FORCE, universities, government agencies, Mi'kmaq and other resource users) will be generating large quantities of data about the environment of Nova Scotia's tidal waters. Managing those data, and combining them into an accessible, comprehensive data base that all stakeholders can both contribute to and benefit from, is a critical need as tidal energy development moves forward. An interactive mapping tool[76] has been developed as a platform for integration and exchange of environmental information relevant to tidal energy generation in the Bay of Fundy. The separate responsibilities of stakeholders will not achieve the necessary foundation for wise, sustainable exploitation of tidal energy resources unless they are well coordinated. Designing and populating a data management system is a crucial element toward that end.

Summary

The last decade has seen considerable investment of money and time in Nova Scotia to investigate the potential of new technologies to enable the vast energy of tidal waters to be used for electricity generation. The motivations for this are: to reduce dependence on fossil fuels and enhance Nova Scotia's energy security for the future; to capitalize on development of new tidal-stream technologies; and to contribute technological and scientific knowledge to the global development of renewable marine energy. Much has been learned about the new tidal stream

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[75] The lowest corrosion occurs at pH values between 8 and 9.5.
[76] cf. https://sites.google.com/site/nstidalenergywebmap/

technologies, about our tidal environments, and about the potential benefits to accrue in terms of knowledge- and innovation-based employment. While there still remains doubt about the full costs of electricity generation in very high flow environments, the knowledge and technologies required for assessment of risks are increasing rapidly. If tidal stream devices can withstand the challenges (i.e. meet the 'Fundy standard'), it should soon be possible to determine the extent to which the extraordinary power of the tides can be safely and cost-effectively converted into electricity.

Based upon the cumulative knowledge held by First Nations communities and resource users (especially fishers), and the experience of many decades of research into Bay of Fundy tidal power, the environmental implications of using the new technologies have been identified, and several of these are now well enough known that their level of risk can be forecast with considerable confidence. These include the effects on tidal movements, both close to a generation site and further away, the effects on surrounding shorelines, marshes and intertidal zones, and the effects of ice and of electromagnetic forces associated with submarine cables. There remain, however, a number of environmental and socioeconomic implications that cannot be addressed adequately until more experience is gained with tidal stream turbines in the water.

Chief among the environmental concerns are the direct and indirect effects of tidal stream arrays on fish and marine mammals. Research of the past few years has confirmed that a number of fish and mammal species are present in the passages suitable for tidal energy generation, and therefore there is potential for interaction with tidal stream turbines. Numerous fish species pass through Minas Passage at various times during the year, and at least one species (the striped bass) is now known to be present all year—even in winter when low water temperatures raise doubts about whether the animals are active or comatose. The principal mammal of concern in the Upper Bay is the harbour porpoise, which makes regular forays in pursuit of fish, but in the passages of the Outer Bay many more species of fish and mammals are present, and their responses will need to be known in order to assess risk.

For both fish and mammals, the behavioural responses of free-moving animals to underwater turbines are inadequately known. This is partly because there has been limited experience with long-term deployment of tidal stream devices anywhere in the world, but more particularly because established monitoring technologies appear to be less effective in these very turbulent, high flow locations. In addition, much has had to be learned about design of reliable moorings and protecting delicate sensing instruments needed to investigate animal behaviour and environmental conditions in sufficient detail.

At the sites most suitable for tidal stream energy fisheries are generally limited to fixed gear techniques, particularly for lobster. However, these passages are used by many other species that are harvested in other locations. Consequently, understanding whether the fish can detect operating turbines before they encounter them, and whether they have the ability then to avoid interaction, remains to be determined. Although the passages are naturally very noisy places, a limited amount of research suggests that noise generated by a turbine might be detectable some distance away, allowing for the possibility that schools of fish may be able to take evasive action. If that proves not to be the case, and the risk to any fishery is considered significant, it may be possible to mitigate the effect by using acoustic deterrents.

If continued research indicates that fish, birds and/or mammals are unable to avoid interaction with tidal stream turbines, it will be essential to know whether acoustic deterrents such as those used in fish farming operations are an option for mitigation of effects. Experience has shown that acoustic deterrents may either lose their effectiveness over time, or cause direct harm to some species. Habituation of mammals to acoustic deterrent devices near a turbine may be less apparent than at a fish cage, since there is a continuing attraction (i.e. the fish) at the latter. The planned deployment of turbines with effective sonar detection devices is an obvious opportunity for assessing this potential approach to mitigation.

Although marine birds are less likely to be directly at risk from working turbines than are fish and mammals, they are nonetheless important components of the ecosystem, and many are of international significance. It is essential to understand the direct and indirect effects of energy extraction from the tides on seabirds and shorebirds, because, in addition to their intrinsic value, they may offer a means of detecting more subtle environmental changes. Refinement of new monitoring technologies, such as shore-based radar, would provide a valuable tool for use in this and other environmental monitoring activities.

The strategic research plan needs also to address the ongoing challenge of understanding the role of natural and anthropogenic noise in the environment and its effects on organisms. Technologies are becoming available, some of which are being developed by local companies, and these have the potential to provide not only essential information for prediction of effects on animals in Nova Scotia, but also an exportable product to the global community.

A robust, collaborative, and thorough strategic research plan thus needs to be put in place that will focus on the following issues:

- The direct and indirect effects on fish, birds and mammals that utilise areas suitable for tidal energy generation;
- Understanding the behaviour of fish, birds and mammals in the presence of working tidal stream devices;
- Developing effective encounter and risk prediction models for fish, birds and mammals;
- Understanding and modelling the effects of turbine-generated noise and its implications for fish, birds and mammals;
- Assessing the effects on fisheries, especially for lobster and schooling migratory species;
- Assessing the potential for acoustic deterrents;
- Developing an effective data management system that brings together all the varied data being collected by different stakeholders in an accessible, shareable form; and

- Determining how to increase the durability of energy extraction and monitoring devices in these high flow habitats.

At the beginning of 2016, we are on the threshold of the next phase of investigation into tidal power. A major facility (FORCE) for testing commercial scale tidal stream devices has been established, with five berths, and plans made by the berth holders to deploy their turbines or small arrays. The first deployment is expected by mid-year, and the others in the following 2-5 years. As these are installed, the remaining questions regarding durability, performance, and environmental and socioeconomic implications can be addressed.