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by

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EXECUTIVE SUMMARY

This review of the current state of knowledge of fish species presence and use of Minas Passage, Bay of Fundy, was commissioned by the Fundy Ocean Research Centre for Energy (FORCE) to address eight questions raised by Fisheries and Oceans Canada (DFO) about the unknown (but perceived) risk of tidal stream energy development to fish in Minas Passage. To address these questions, this report summarizes the extensive amount of research conducted since the inception of FORCE in 2008 that has improved our understanding of the spatial and temporal distributions of marine and diadromous fishes in Minas Passage, with particular focus on 10 key species of interest. The report also identifies remaining knowledge gaps and suggests future research that could improve our understanding of the real risk to fish from tidal stream energy development at the FORCE tidal demonstration site.

The Bay of Fundy is home to more than 100 fish species, 68 of which are known to navigate through Minas Passage at least once over the course of their life history. Approximately one half of these species are present annually, with the remainder being occasional or irregular visitors. Some of these species are of conservation concern and are afforded legal protection under Canada's *Species at Risk Act* (SARA), while others support valuable commercial or recreational fisheries, or are of cultural significance to local First Nations communities. For many of these species, Minas Passage provides an important seasonal migratory corridor between the Outer Bay of Fundy and Minas Basin and its tributaries. However, Minas Passage has also been identified as a potentially valuable energy source that could be captured using new tidal stream devices. Although research on tidal stream energy devices has been carried out in numerous other high velocity tidal channels around the world, the nature of fish-turbine interactions – including the potential for physical collisions and their population-level consequences – remains inadequately known.

Review of documents related to fish-turbine interactions elsewhere suggests that fish can detect operational devices under varying environmental conditions and can exhibit avoidance and evasive behaviour to prevent collisions. However, the prevailing

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hydrodynamic conditions in Minas Passage, especially the high flow velocity and its associated effects (turbulence, turbidity, prevalence of entrained air in the water column etc.) differ from other sites where fish-turbine interactions have been investigated. Thus, research conducted elsewhere provides only limited insight about whether fish in Minas Passage might also be able to detect and avoid or evade operational tidal stream turbines.

In light of these considerations, DFO provided eight specific questions for FORCE to address in order to improve understanding of the potential for fish-turbine interactions in Minas Passage *a priori*, and to help assess the risk of tidal stream demonstration at FORCE:

1. What is the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices in Minas Passage?
2. How do the different characteristics of tidal energy devices influence the likelihood of harm and/or death of fish and aquatic species at risk?
3. What scale of tidal energy development (project specific and cumulative) can occur in Minas Passage before unacceptable impacts to fish and aquatic species at risk become likely?
4. Are there specific species that are particularly vulnerable to harm and/or death from tidal energy devices in Minas Passage?
5. Are there specific locations within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?
6. Are there specific temporal periods within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?
7. How do environmental factors influence the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices?, and
8. Are there measures that could be implemented to avoid and mitigate harm and/or death to fish and aquatic species at risk from tidal energy devices?

Generally, fish species' presence and abundance in Minas Passage varies seasonally. Migratory species are most abundant during May-June as they move into the Minas Basin and its tributaries for spawning or feeding, and again during September-October as young-of-the-year and feeding adults depart Minas Basin to the Outer Bay of Fundy and regions beyond. However, some species are known to be present in Minas Passage over winter. Generally, the risk of tidal stream energy development to fish at the FORCE tidal demonstration site depends on: i) the temporal distribution of species presence in Minas Passage; ii) the extent to which fish movements through Minas Passage are dictated by tidal advection and their subsequent trajectories; iii) the ability of fish to detect an operational turbine and exhibit avoidance or evasion behaviour to prevent collision (which is influenced by flow speed at time of device detection, fish size and swimming ability); and iv) the size, number of blades and rotational speed of the tidal stream energy device.

During periods of greater tidal flow on both flood and ebb, advection by tidal currents is probably the primary determinant of the horizontal movement of small-bodied fish (e.g., alewife, striped bass, Atlantic salmon) through Minas Passage. Acoustic detections of small-bodied fish using moored and drifter-based receivers show that they can be substantially displaced by tidal currents (i.e. their trajectories approximate those of passively floating drifters) and they can be swept through Minas Passage multiple times during their seasonal migration. However, most of these routes follow a quasi-stable trajectory that passes to the south of the FORCE site and is determined by the dominant tidal current trajectories in Minas Passage. Drifter tracks that do pass through the FORCE site are subsequently dispersed elsewhere and do not pass through the FORCE site for many of the following tidal cycles. This reduces the risk of fish-turbine interaction at the FORCE site for small-bodied fish during periods of elevated flow. Although the movements of large-bodied fish (e.g. white shark) in Minas Passage during periods of elevated flow are not fully understood, they may have greater control over their trajectories by virtue of their body size and swimming abilities.

Relatively large, slowly rotating (e.g. <15 revolutions per minute) tidal turbine designs are expected to present a lower risk of fish mortality in Minas Passage than those that rotate more quickly – regardless of whether they are bottom-mounted, or surface deployed. This is because slowly rotating devices increase the chances of a fish safely passing through the turbine swept area without making physical contact with a turbine blade. The cumulative effects of arrays of tidal energy devices on marine animals are not well understood, as commercial scale tidal arrays in other jurisdictions are currently under development and effects remain to be documented. Thus, it is not yet possible to determine the scale of development that can occur in Minas Passage before 'unacceptable impacts' (as yet undefined, but likely species–specific) to fish and aquatic species at risk may become likely. However, tidal energy development in Minas Passage is presently limited to the FORCE tidal demonstration site (TED: 1.0 x 1.6 km) – a relatively small area located in the northern portion of Minas Passage. Although the FORCE site has five berths available to support tidal technology development, the size of the site places inherent limits on the scale of development that could occur at the site and the subsequent risk to fish. Given the role of tidal advection on the movement of small-bodied fish and their trajectories through Minas Passage, tidal development to the south of the FORCE site – closer to the middle of Minas Passage – could present greater risk of fish-turbine interactions.

Generally, migratory periods (May-June, September-October) represent the time frames of increased risk of fish-turbine interactions in Minas Passage. However, species that may be of greatest risk are those that are present in Minas Passage year round and whose capacity to exhibit avoidance or evasion behaviour may be reduced in winter due to low water temperatures and their effects on fish physiology and swimming capacity. The influence of other environmental factors (e.g. turbulence, entrained air) on the likelihood of fish-turbine interactions, if any, are not well understood. Although acoustic deterrents may be an effective mitigation measure to prevent interactions with tidal devices for some fish (e.g. herrings), this is not something that has been assessed in Minas Passage. Arguably, the most effective mitigation approach will include an enhanced understanding (i.e. improved spatial and temporal resolution) of how fish use Minas Passage.

Knowledge about the spatial and temporal distributions of fish in Minas Passage continues to improve as information gained through the application of various monitoring instruments and methods (e.g. hydroacoustics) is complemented by new, innovative monitoring techniques (i.e. acoustic telemetry) and analytical approaches. Ultimately, however, research about the nature of fish interactions with operational devices in Minas Passage needs to be conducted *in situ* to ensure that tidal stream energy development can proceed without unacceptable impacts for local fish populations. Such information can only be acquired once tidal devices are deployed at the FORCE site and their interactions with fish can be effectively monitored — work that is presently underway.

INTRODUCTION

Understanding the environmental effects of tidal stream energy devices is important for ensuring responsible development of the marine renewable energy sector in Nova Scotia and for yielding regional benefits through active participation in Canada's Blue Economy Strategy. However, the environmental effects of tidal stream energy development in the Bay of Fundy are not completely understood despite more than 20 years of consideration and over a decade of focused research effort. This is partly due to: i) the differing characteristics of marine hydrokinetic energy (MKE) devices currently considered (e.g., bottom-mounted and surface deployed technologies of various designs with differing technical specifications); ii) the varied physical characteristics of installation sites where tidal stream energy development is planned (e.g. Minas Passage, Grand Passage, Petit Passage etc.); iii) incomplete knowledge about the ecological features of these high energy sites; and iv) relatively poor understanding of the responses of marine animals to the presence of operating tidal stream energy turbines under such high flow and turbulent conditions as those experienced in Minas Passage (Figure 1).

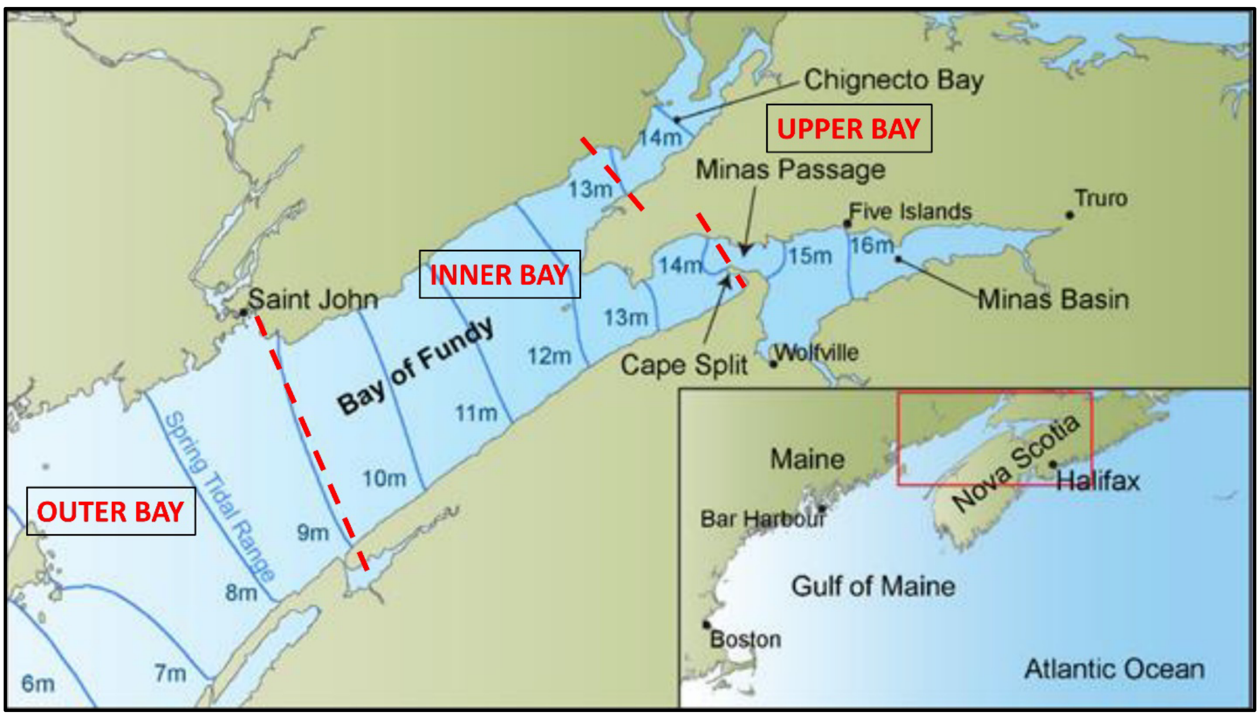

Figure 1: Geographic regions of the Bay of Fundy showing outer, inner and upper sections, including spring tide range isopleths (in metres). (Modified from Cornett et al. 2013).

The Minas Passage has long been recognized as a site with important tidal stream energy development potential. However, after more than a century of marine science investigation into tidal energy in the Bay of Fundy (e.g. Gordon and Dadswell 1984;

Brylinsky *et al.* 1996; Percy *et al.* 1996; Daborn and Redden 2009; Gordon *et al.* 2014), detailed information on the environmental conditions of Minas Passage has historically been incomplete for facilitating commercial scale development of the sector. To a large extent, the absence of information is associated with the inherent difficulties of working in such a hydrodynamically complex environment and the absence of sustained monitoring efforts over extended time frames. This is in spite of the important contributions of Fisheries and Oceans Canada (DFO), the Ocean Tracking Network, numerous university researchers and one commercial fish harvesting organization[3].

Prior to the establishment of the Fundy Ocean Research Center for Energy (FORCE) in 2008, the physical and biological environment of the Minas Passage was relatively poorly understood. Few field studies of Minas Passage and its marine life had been carried out prior to exploration of tidal stream energy, and fish species' presence and occupancy in Minas Passage had to be inferred from studies in the outer Bay of Fundy and in Minas Basin. Consequently, the ability to assess the potential environmental effects of novel marine hydrokinetic energy devices on fish in Minas Passage was inherently difficult. However, since that time, a coordinated research effort has been conducted under the auspices of FORCE that has substantially improved our understanding of the spatiotemporal distributions of fish species in Minas Passage, and of the technologies available to assess the potential risks of tidal stream energy development to fish.

The establishment of FORCE as a tidal energy demonstration (TED) site in Minas Passage for testing MKE devices capable of operating under these challenging hydrodynamic conditions created a need for dedicated resources and effort to quantify the physical environment of the Minas Passage and understand its biological constituents. A substantial amount of new information was consequently gathered from the concerted and coordinated research effort conducted by FORCE and its partners, local university researchers, several tidal stream energy proponents, and various environmental consulting agencies.

The primary environmental concern for tidal stream energy development in other jurisdictions (e.g. Northern Ireland, United Kingdom, United States) is the nature of interactions between rotating turbine blades and marine mammals and (sometimes diving seabirds): specifically, collision risk and its consequences. However, the primary concern in Minas Passage is the nature of interactions with marine and diadromous fishes – several of which are of conservation concern and protected under Canada's *Species at Risk Act* (SARA), of cultural value to First Nations communities, or that support

[3] The only organization other than FORCE and Fisheries and Oceans Canada that has attempted to monitor fish populations over the last two decades in the Minas Passage area has been the Herring Science Council. As with earlier research, time constraints and sampling challenges have limited their presence to occasional visits to the Minas Channel to the west of the FORCE tidal demonstration site, rather than in the Passage itself.

important regional fisheries. Marine animals have developed various sensory systems that allow them to perceive their environments and respond to stimuli using a range of behaviours[4]. For marine mammals, this includes the ability to detect operational turbines and exhibit avoidance or evasion behaviour to prevent being struck by turbine blades (Gillespie *et al.* 2021; Palmer *et al.*, 2021; Hastie *et al.* 2018). Multiple laboratory-based studies provide empirical evidence that supports various fish species' ability also to exhibit avoidance and evasion behaviour of tidal turbines in controlled settings and under flow regimes up to approximately 2.5 m/s (Hammar *et al.* 2013; Yoshida *et al.* 2020, 2021). This is supported by empirical *in situ* evidence for avoidance and evasion at varying distances from an operational device up to 100 m upstream and beyond (Viehman and Zydlewski 2015; Shen *et al.* 2016; Bender *et al.* 2023). Despite these intrinsic abilities, there remains the potential for collision with an operational turbine under the more challenging environmental conditions inherent to Minas Passage (i.e., turbid, noisy, and turbulent fast-flowing currents). As such, greater understanding of collision risk to fish in Minas Passage necessitates *in situ* research with operational turbines.

Uncertainty about the risk of tidal stream energy development to fish in Minas Passage is related to several factors. First, because of the inherent challenges of conducting field work in Minas Passage, historically there has been relatively limited knowledge about species' spatial and temporal distributions, abundance and demographic structure. Since the inception of FORCE, however, much information has been gained. Second, there is inadequate empirical information about the capacity of different fish species to exhibit avoidance or evasion to operating tidal stream energy devices in high flow (> 3 m/s) environments. Third, there is limited understanding about ecological interactions between fish species in Minas Passage. Finally, the nature of long-term changes in the Bay of Fundy ecosystem associated with post-glacial adjustments, land use changes, long-term hydrodynamic cycles and climate change that may affect the above factors are uncertain.

Considering the above, the need for information about the risk of tidal stream energy development to fish is reinforced by the facts that: i) Minas Passage is an important seasonal migratory corridor for various fish species that use it to access Minas Basin and its tributaries for foraging and/or reproduction; ii) some of these species include migrants from other jurisdictions that represent long distance international connections; and iii)

[4] Commonly scientists distinguish between several responses that enable animals to avoid coming into contact with human structures, including tidal or wind turbines. These behaviours may be classified into 3 phases: *displacement* (i.e. *macro-avoidance*) a reaction at a long distance that enables an animal to move well away from a threatening structure; *evasion*, (i.e. *macro-avoidance)*, whereby an animal may avoid the structure at a moderate distance from it; and *escape* (or *micro-avoidance)* which takes place at the very last moment before contact (e.g. May, R.F. 2015). These different types of response may have several different consequences for the species.

several of these species are of commercial and/or recreational importance, of cultural relevance to First Nations communities, or are protected under the SARA.

Objective

The objective of this study was to synthesize existing information about fish use of Minas Passage contained in peer-reviewed scientific publications, conference proceedings, and 'grey literature' that may or may not have received editorial scrutiny (e.g. consultant and non-governmental reports, undergraduate and graduate student theses, etc.) to establish the current state of knowledge about fish temporal and spatial distribution in Minas Passage. This information is directly relevant for understanding the risk of tidal stream turbines to fish in Minas Passage. Knowledge of fish behaviour around various tidal stream technologies (i.e. bottom-mounted and surface deployed) with differing technical specifications deployed elsewhere are also relevant for understanding risk and is included where appropriate.

In conducting this exercise, this report focused on those fish species that are known to utilize Minas Passage with particular emphasis on those that: i) are of conservation concern and listed on Schedule 1 of the SARA, ii) are of cultural relevance to First Nations communities in the Maritime provinces, and iii) support local commercial and recreational fisheries. This information is then used to help address eight specific questions provided by DFO to improve collective understanding of the potential for fish-turbine interactions in Minas Passage and the risk of tidal stream technology demonstration at the FORCE site. Specifically,

1. What is the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices in Minas Passage?
2. How do the different characteristics of tidal energy devices influence the likelihood of harm and/or death of fish and aquatic species at risk?
3. What scale of tidal energy development (project specific and cumulative) can occur in Minas Passage before unacceptable impacts to fish and aquatic species at risk become likely (i.e., population-level impacts to fish species, death of fish that cannot be adequately counterbalanced through offsetting measures, and impacts that may jeopardize the survival or recovery of SARA-listed aquatic species at risk)?
4. Are there specific species that are particularly vulnerable to harm and/or death from tidal energy devices in Minas Passage?
5. Are there specific locations within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?
6. Are there specific temporal periods within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?

7. How do environmental factors influence the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices?
8. Are there measures that could be implemented to avoid and mitigate harm and/or death to fish and aquatic species at risk from tidal energy devices?

After having addressed these questions, the report identifies remaining knowledge gaps and suggests future research (e.g., monitoring activities and deterrence measures) that could improve our understanding of the real risk to fish from tidal stream energy development in Minas Passage and at the FORCE tidal demonstration site.

Materials and Methods

Relevant peer-reviewed publications and grey literature were identified using key word searches in the following repositories: ISI Web of Science; Google Scholar; Academia; DFO 'Waves'; Tethys knowledge base (www.tethys.pnnl.gov); Acadia University research centre publications and university theses. Key word searches were conducted using the following terms (and combinations thereof): Bay of Fundy; Minas Passage; selected fish species (using both Latin binomial and common names); acoustic technologies; hydroacoustics; tagging studies; stock assessments; monitoring; swimming speed; schooling behaviour; and specific tidal turbine companies with MKE device designs that have been tested in the field (e.g., Atlantis Resources, Open Hydro; ORPC, Verdant Technologies, SeaGen, etc.). Additionally, attempts were made to contact relevant individuals in government agencies, universities and the fishing sector to ensure that the most current information available was identified during the literature search.

RESULTS

This section begins with a general overview of fish species that have been documented to occur in the Minas Passage and the surrounding area, followed by a more detailed discussion of the spatial and temporal distribution for 10 key species of interest in Minas Passage. Current understanding of fish behaviour in the presence of MKE devices is then discussed, followed by responses to the eight questions posed by DFO about the risk of tidal power development to fish in Minas Passage.

Fish species of the Minas Passage and Minas Channel

Although some information about the fish species that utilize Minas Passage and Minas Channel has been accumulating for decades, until recently it had to be inferred from commercial catches, stock assessment surveys and research projects in other areas of the Bay of Fundy that are adjacent to, but do not include, Minas Passage and Minas Channel.

The reason for this exclusion is primarily physical – the extreme hydrodynamic conditions of Minas Passage have largely prevented development of commercial fisheries in the Passage itself (except for lobster and intertidal weir fishing) and has limited those vessels that typically conduct stock assessments and research surveys in the Outer Bay of Fundy from operating in the Minas Passage[5]. For instance, although formal stock assessment surveys for species supporting commercial fisheries have been conducted in the Outer Bay of Fundy since the 1970s, the few attempts to survey Minas Passage were unsuccessful at capturing fish due to time restrictions or other limitations. Surveys of commercial fish stocks in the Outer and Inner Bay of Fundy – where most of the commercial harvesting has historically occurred – have been conducted for more than 40 years (e.g. MacDonald *et al.* 1984; Iles *et al.* 1985; DFO 2021), but rarely included areas close to Minas Channel and Minas Passage. For example, the Herring Science Council has been conducting hydroacoustic surveys of the Atlantic herring spawning stock in Scots Bay since 2001, but the survey stations only occasionally include Minas Channel, and do not extend into Minas Passage (J. Munden, *pers. comm.* 2023).

Interest in the development of tidal power in the Upper and Inner portions of the Bay of Fundy during the 1970s and 1980s ushered in an era of fish-focused research and monitoring programs in Shepody Bay, Chignecto, Cumberland and Minas Basins (Daborn 1977; Gordon and Dadswell 1984) under the auspices of the Fundy Environmental Studies Committee (FESC). Despite this progress, there were virtually no fisheries surveys in Minas Passage prior to the establishment of FORCE in 2008. However, since that time major efforts have been undertaken to investigate the occurrence, movements, seasonality and behaviour of fish transiting through Minas Passage (e.g. Bangley *et al.*. 2022, CEF Consultants 2011; Melvin and Cochran 2012, 2013, 2014, 2015; Redden *et al.* 2014; Sanderson *et al.* 2023c; Stokesbury *et al.* 2012, 2016; Viehman *et al.* 2018). Some of those efforts (e.g. acoustic telemetry research and monitoring) are ongoing and are providing valuable new information about the spatial and temporal distribution and movements of fish in Minas Passage.

Commercial fishing activities in Minas Basin have been conducted for more than a century, primarily using intertidal weirs or small vessels equipped with drift nets or trawls, and it is evident that marine and diadromous fish captured there must have migrated through the Minas Passage at some point in their life cycle. Fisheries using trawls or drift nets are notoriously selective in their catch (species and size), but intertidal weirs capture a wider range of species — albeit only those that advance sufficiently far into the intertidal zone with the rising tide. Despite the long history and reporting of intertidal

[5] It had long been assumed that the turbulence in the Passage was too great for effective use of simple devices such as drift nets, but Brylinsky (2010) showed that such nets can be used, although that study (carried out in mid-July during daylight hours for safety reasons), failed to capture any fish. Similarly, a demonstration survey using a trawl in 2010 indicated that it could work in the Minas Passage, although controlling the depth and location of fishing was difficult (CEF Consultants, 2011).

weir catches, there have been few studies that have comprehensively recorded all species captured. Periodic sampling of Minas Basin intertidal weirs during 1982-1983 recorded 44 species (Dadswell *et al*. 1984a), whereas more recent weekly sampling of two intertidal weirs (Baker 2020; Baker *et al*. 2014) recorded only 26 species. In response to a recommendation from DFO (CSAS 2012), Dadswell *et al*. (2020) conducted a detailed study of catch composition at the Bramber intertidal weir in the southern Minas Basin in which every tide was sampled from 10 April – 22 July, 2017. That study captured 45 species and concluded that intertidal weirs provide a reasonable means for monitoring fish in Minas Basin, but also recognized that relating any changes in catch composition or species demographic structure to tidal turbine operations in Minas Passage would be inherently difficult.

Although 104 fish species have been reported from the Outer Bay of Fundy (Scott, 1983), more recent work has identified 68 marine and diadromous species that are *known* to have navigated Minas Passage due to their recorded presence in Minas Basin (Dadswell and Rulifson 2021) (Table 1). Of the 68 species listed in Table 1, the majority are considered primarily benthic (n=32), followed by primarily pelagic species (n=28), and those that are known to frequently move between these zones (n=8). However, it is important to note that additional fish species may occasionally occur in Minas Basin that have not yet been recorded due to their infrequent presence. In addition to these 68 species, Dadswell and Rulifson (2021) *suspected* that an additional 17 species occur in Minas Basin (Table 2). However, those species have not been recorded from the Minas Passage or Minas Basin, and the bases for their presumed presence in Minas Basin are variable and in some cases seem doubtful. For instance, Dadswell and Rulifson (2021) assumed that Atlantic hagfish (*Myxine glutinosa*) use Minas Passage based on the species' preference for muddy substrate, but the species is commonly associated with deep, cold water habitats (Moyle and Cech 1996) and has not been recorded from bottom trawls, lobster traps or directed surveys in Minas Basin or Minas Passage. Although the species is fairly common in the deeper waters of the Outer Bay of Fundy and Gulf of Maine, its preference for water temperatures < 10 °C, inclination for a sedentary lifestyle, avoidance of strong currents and absence of extensive breeding migrations (Grant 2016; DFO 2018) suggests that it is unlikely to be a common resident of Minas Basin or regularly transit Minas Passage.

Table 1: Marine and diadromous fish species (n=68) known to have navigated Minas Passage due to their recorded presence in Minas Basin (Dadswell and Rulifson 2021).

Common Name	Latin Name
Sea lamprey	*Petromyzon marinus* L. 1758
Sand tiger shark	*Carcharius taurus* Rafinesque 1810
White shark	*Carcharacon carcharias* (L. 1758)
Basking shark	*Cetorhinus maximus* (Gunnerus 1765)

Porbeagle	*Lamna nasus* (Bonneterre 1798)
Spiny dogfish	*Squalus acanthias* L. 1758
Little skate	*Leucoraja erinacea* (Mitchill 1825)
Thorny skate	*Amblyraja radiata (*Donovan 1808)
Winter skate	*Leucoraja ocellata* (Mitchill 1825)
Barndoor skate	*Dipturus laevis (*Mitchill 1818)
Atlantic sturgeon	*Acipenser oxyrinchus* (Mitchill 1814)
Shortnose sturgeon	*Acipenser brevirostris* Lesueur 1818
American eel	*Anguilla rostrata* (Lesueur 1817)
Blueback herring	*Alosa aestivalis* (Mitchill 1814)
Alewife	*Alosa pseudoharengus* (Wilson 1811)
American shad	*Alosa americana* (Wilson 1811)
Atlantic menhaden	*Brevoortia tyrannus* (Latrobe 1802)
Atlantic herring	*Clupea harengus* L. 1759
Atlantic salmon	*Salmo salar* L. 1758
Rainbow smelt	*Osmerus mordax* (Mitchill 1814)
Monkfish	*Lophius americanus* Valenciennes 1837
Fourbeard rockling	*Enchelyopus cimbrius* (L. 1776)
Atlantic cod	*Gadus morhua* L. 1758
Silver hake	*Merluccius bilinearis* (Mitchill 1814)
Red hake	*Urophysis chuss* (Walbaum 1792)
White hake	*Urophysis tenuis* (Mitchill 1814)
Spotted hake	*Urophysis regia* (Walbaum 1792)
Longfin hake	*Urophysis chesteri* (Good and Bean 1878)
Pollock	*Polachius virens* (L. 1758)
Atlantic tomcod	*Microgadus tomcod* (Walbaum 1792)
Atlantic silversides	*Menidia menidia* (L. 1766)
Atlantic saury	*Scomberesox saurus* (Walbaum 1792)
Mummichog	*Fundulus heteroclitus* (L. 1766)
Fourspine stickleback	*Apeltes quadricus*(Mitchill 1815)
Threespine stickleback	*Gasterosteus aculeatus* L. 1758
Blackspotted stickleback	*Gasterosteus wheatlandi* Putnam 1867
Ninespine stickleback	*Pungitius pungitius*(L. 1758)
Northern pipefish	*Syngnathus fuscus* Storer 1839
White perch	*Morone americana* (Gmelin 1789)
Striped bass	*Morone saxatilis* (Walbaum 1792)
Black sea bass	*Centropristis striata*(L. 1758)
Bluefish	*Pomatomus saltatrix* (L. 1766)
Weakfish	*Cynoscion regalis* (Bloch and Schneider 1801)
Scup	*Stenotomus chrysops* (L. 1766)
Black drum	*Pogonias cromis* (L. 1766)

Rock gunnel	*Pholis gunnelus* (L. 1758)
Ocean pout	*Zoarces americanus* (Bloch and Schneider 1801)
Sand lance	*Ammodytes americanus* DeKay 1842
Atlantic mackerel	*Scomber scombrus* L. 1758
Butterfish	*Peprilus triacanthus* (Peck 1804)
Striped sea robin	*Prionotis evolans* (L. 1766)
Sea raven	*Hemitripterus americanus* (Gmelin 1789)
Grubby	*Myoxocephalus aenaeus* (Mitchill 1814)
Longhorn sculpin	*Myoxocephalus decemspinosus* (Mitchill 1814)
Shorthorn sculpin	*Myoxocephalus scorpius* L. 1758)
Tautog	*Tautoga onitis* (L. 1758)
Cunner	*Tautogolabrus dispersus* (Walbaum 1792)
Lumpfish	*Cyclopterus lumpus* L. 1758
Atlantic snailfish	*Liparus atlanticus* (Jordan and Evermann 1898)
Gulf snailfish	*Liparus coheni* Able 1976
Summer flounder	*Paralichthys dentatus (*L. 1766)
American fourspot flounder	*Hippoglossina oblonga*(Mitchill 1815)
Windowpane	*Scophthlmus aequosus* (Mitchill 1815)
Atlantic halibut	*Hippoglossus hippoglossus*(L. 1758)
American smooth flounder	*Pleuronectes putnami* (Gill 1864)
Winter flounder	*Pseudopleuronectes americana* (Walbaum 1792)
Yellowtail flounder	*Limander ferruginea* (Storer 1839)
Ocean sunfish	*Mola mola* (L. 1758)

Table 2: Marine and diadromous fish species (n=17) presumed to inhabit Minas Basin and transit Minas Passage (Dadswell and Rulifson 2021).

Common Name	**Latin Name**
Atlantic hagfish	*Myxine glutinosa* L. 1758
Thresher shark	*Alopias vulpinus* (Bonneterre 1798)
Shortfin mako shark	*Isurus oxyrinchus* Raffinesque 1810
Smooth dogfish	*Mustelus canis* (Mitchill 1815)
Greenland shark	*Somniosus microcephalus* (Bloch and Schneider 1801)
Atlantic torpedo	*Tetronarce nobiliana* (Bonaparte 1835)
Smooth skate	*Malcoraja senta* (Garman 1885)
Brook trout	*Salvelinus fontinalis* (Mitchill 1814)
Brown trout	*Salmo trutta* L. 1758
Coho salmon	*Oncorhynchus kisutch* (Walbaum 1792)
Rainbow trout	*Oncorhynchus mykiss* (Walbaum 1792)
Capelin	*Mallotus villosus* (Müller 1776)

Haddock	*Melanogrammus aeglefinus* (L. 1758)
Radiated shanny	*Ulvaria subbificata (*Storer 1839)
Atlantic wolffish	*Anarhichas lupus* L. 1758
Inquiline snailfish	*Liparus inquinilus* Able 1973
Witch flounder	*Glyptocephalus cynoglossus* (L. 1758)

The development of more systematic fish surveys and monitoring activities in Minas Passage since the inception of FORCE, including the establishment of an acoustic receiver array by the Ocean Tracking Network in 2010, has improved our understanding of the seasonal changes in fish presence in Minas Passage. Much of this information relates to the spring, summer and fall seasons, and is derived from studies of migratory species that visit the Upper Bay of Fundy for reproduction and/or feeding. For instance, American shad (*Alosa sapidissima*) returning to the Upper Bay of Fundy are comprised of two groups: i) fish returning during late April to spawn in natal rivers, and ii) fish originating from rivers across their native range (from Florida north) on a feeding migration that are present during June to late August; both groups leave the Upper Bay of Fundy by the end of September (Dadswell *et al*. 1984a). This model of seasonal occurrence in the Upper Bay of Fundy has been assumed for several other diadromous species, including alewife (*A. pseudoharengus*), blueback herring (*A. aestivalis*), Atlantic sturgeon (*Acipenser oxyrhinchus*), and striped bass (*Morone saxatilis*) (e.g. Wehrell 2005, 2014; Rulifson *et al*. 2008; McLean *et al*. 2014). Further, the movement of large numbers of migratory fish to the Upper Bay of Fundy during spring is probably accompanied by shark species that have not been regularly reported from this area.

The seasonal occurrence for 35 marine and/or diadromous fish that are known to transit Minas Passage (Dadswell 2010; Dadswell and Rulifson 2021) is provided in Table 3 and indicates that migratory species are generally present in the Upper Bay of Fundy from April through October and may navigate Minas Passage during this period. However, recent acoustic telemetry work conducted by Stokesbury *et al*. (2012) and Redden *et al*. (2014) included a variety of diadromous species and detected striped bass in Minas Passage[6] over winter when water temperatures were as low as -1.5 °C (Keyser *et al*. 2016).

In addition to seasonal variation in species occurrence and abundance, there are longer term fluctuations in fish stocks associated with varying exploitation rates of fisheries in different jurisdictions, variations in year class strength, and cyclical changes in ecosystem productivity that have been identified in the Bay of Fundy that may elicit species-specific effects. For instance, the 18-year Nodal Cycle of the tides has been shown to affect the abundance of commercial fish stocks in the Bay-of Fundy – Gulf of Maine – Georges Bank (FMG) system (e.g. Campbell and Wroblewski 1986; Cabilio *et al*. 1987). Although the

[6] See also: Taylor, *et al* 2016; Viehman *et al* 2018.

relative variation in tidal range over the Nodal Cycle is small, the variable vertical mixing caused by tidal movements causes significant changes in the productivity of the Outer Bay of Fundy, and are detectable in long term catch records throughout the FMG system despite changes in fishing techniques and fishing effort over more than 150 years (Cabilio *et al.* 1987). As the tidal range in the Bay of Fundy continues to increase (Greenberg *et al.* 2012) and is amplified by the accelerating rate of sea level rise, fluctuations in the abundance and diversity of species occurring in Minas Passage are inevitable.

Table 3: Seasonal presence for 35 marine and diadromous species known to transit Minas Passage (source: Dadswell 2010).

Species	**Life stage**[7]	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Sea lamprey	Adult				■	■	■						
	Immature				▒	▒	▒						
White shark	Adult								■				
Basking shark	Adult							■	■	■	■		
Porbeagle	Adult							■	■	■			
Spiny dogfish	Adult				■	■	■	■	■				
	Immature								▒	▒	▒		
Little skate	Adult						■	■	■	■			
Thorny skate	Adult						■	■	■	■			
Winter skate	Adult	■	■	■	■	■	■	■	■	■	■	■	■
Barndoor skate	Adult	■	■	■	■	■	■	■	■	■	■	■	■
Atlantic sturgeon	Adult				■	■	■	■	■				
	Immature								▒	▒	▒		
American eel	Adult								■	■	■		
	Immature				▒	▒							
Blueback herring	Adult			■	■	■	■	■	■	■	■		
	Immature								▒	▒	▒		
Alewife	Adult			■	■	■	■	■	■	■	■		
	Immature								▒	▒	▒		
American shad	Adult				■	■	■	■	■	■	■		
	Immature								▒	▒	▒		
Atlantic menhaden	Adult					■	■						
	Immature									▒	▒		
Atlantic herring	Adult			■	■	■	■	■	■	■			
	Immature	▒	▒	▒									▒
IBoF Atlantic salmon	Adult							■	■	■	■		
	Kelt											■	■

[7] 'Adult' refers to the reproductive life stage (i.e., capable of spawning), whereas 'Immature' refers to early life history stages (e.g., larvae, juveniles, etc.) that are not yet capable of reproduction.

	Post-smolt												
Rainbow smelt	Adult												
Monkfish	Adult												
Fourbeard rockling	Adult												
Atlantic cod	Adult												
Silver hake	Adult												
Red hake	Adult												
	Immature												
White hake	Adult												
Pollock	Adult												
Atlantic tomcod	Adult												
	Immature												
Striped bass	Adult												
	Immature												
Atlantic mackerel	Adult												
Butterfish	Adult												
Lumpfish	Adult												
Atlantic halibut	Adult												
Winter flounder	Adult												
	Immature												
Threespine stickleback	Adult												
Blackspotted stickleback	Adult												

Key species of interest

Of the species listed in Table 1, three are found in Minas Passage that are also listed on Schedule 1 of the *Species at Risk Act* and are protected by the *Fisheries Act*[8]. This includes Atlantic salmon (Inner Bay of Fundy population) and white shark that are both listed as 'Endangered', and shortnose sturgeon which is a species of 'Special concern'. However, the distribution of shortnose sturgeon in Canadian waters is limited to the Saint John River, New Brunswick, where it typically remains in its natal river or estuary (DFO 2016) and is only occasionally recorded in Minas Basin (Dadswell *et al.* 2013). Although the Atlantic wolfish is also listed as a species of 'Special concern', it is unlikely to be found in Minas Passage (Table 2).

[8] https://www.canada.ca/en/environment-climate-change/services/species-risk-act-accord-funding/listing-process/aquatic-species-protected-fisheries-act.html

In addition to species of conservation concern, there are several species of historic or contemporary commercial importance (e.g., Atlantic herring, American shad, alewife, spiny dogfish), ecological significance (e.g., Atlantic tomcod; DFO 2012) and cultural relevance to regional Mi'kmaq communities (e.g., American eel, Atlantic sturgeon, striped bass; S. Denny, *pers. comm.* 2023) that are of concern with respect to the potential effects of tidal stream energy development in Minas Passage. Indeed, one of the most important species to Mi'kmaq communities around Minas Basin is the American eel that, in addition to providing as much as 90% of food in some seasons and localities, was also important for eel skin, which was used to make ropes or bind wounds, and oil that was effective against mosquitoes (Engler-Palma *et al.* 2013; Denny *et al.* 2012).

Because of their conservation status, economic value, and cultural relevance to First Nations, the following 10 species have been the subject of various research efforts in the Upper Bay of Fundy and are of key interest for understanding how fish use Minas Passage:

1. Inner Bay of Fundy Atlantic salmon (*Salmo salar*)
2. Atlantic sturgeon (*Acipenser oxyrhinchus*)
3. Atlantic tomcod (*Microgadus tomcod)*
4. American eel (*Anguilla rostrata*)
5. American shad (*Alosa sapidissima*)
6. Alewife (*Alosa pseudoharengus)*
7. Spiny dogfish (*Squalus acanthias*)
8. White shark (*Carcharodon carcharias*)
9. Striped bass (*Morone saxatilis*)
10. Atlantic herring (*Clupea harengus*)

This section summarizes the current state of knowledge about the spatial and temporal use of Minas Passage for these species.

Atlantic salmon (Inner Bay of Fundy population-IBoF)

Inner Bay of Fundy Atlantic salmon (IBoF salmon) populations possess distinct genetic traits and exhibit unique life history characteristics relative to the remainder of the species' range (Amiro 2003; Amiro *et al.* 2003, DFO 2010). Consequently, IBoF salmon have been identified as a designatable unit (DU: they are discrete and represent an evolutionarily significant unit for the species — COSEWIC 2006). Consequently they are listed as *Endangered* under Schedule I of the *Species at Risk Act* (DFO 2003; DFO 2021b).

Genetic research reveals that IBoF salmon can be partitioned into the 'Chignecto Bay subunit' (rivers 26-50 in Figure 2) and the 'Minas Basin subunit' (rivers 1-25 in Figure 2) (Verspoor et al. 2002). Measurements to date (Lacroix 2013) indicate that adults belonging to the Chignecto Bay subunit do not enter Minas Passage and have little if any potential for overlap with the FORCE site. However, IBoF salmon post-smolts and kelts[9] from the Minas Basin subunit that depart their natal river in spring do transit Minas Passage, and may therefore pass through the FORCE site (Sanderson *et al*. 2023b; Sanderson *et al. in prep.*[10]). Minas Basin becomes severely cooled during winter (Sanderson and Redden 2015), and Lacroix (2008) found that kelts from the Minas Basin subunit that began their seaward migration in autumn passed quickly through Minas Passage, whereas those that began out-migration in spring made more extensive use of Minas Basin, so that tidal excursion makes them more likely to pass through the FORCE site (Sanderson *et al*. 2021).

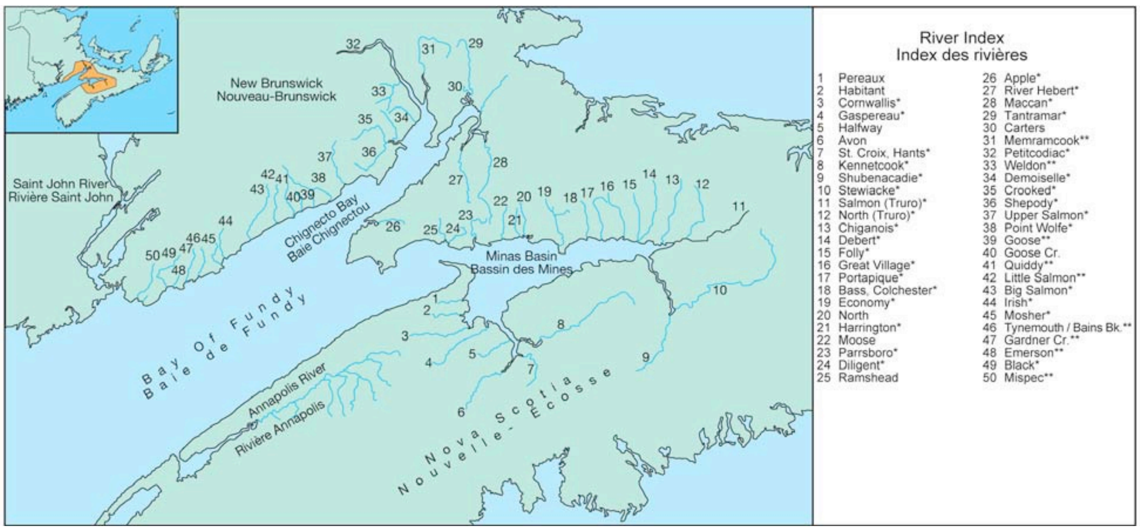

Figure 2: The location of the iBoF Atlantic salmon DU and the approximate location of 50 rivers within the region occupied by the DU. Not all rivers and tributaries within the DU are shown.

Recreational catch data and historical electrofishing suggests that 32 rivers (* in Fig.2) supported self-sustaining Atlantic salmon populations. Another 10 rivers and streams (**) are reported to have produced salmon. The remaining rivers were sampled in 2000, 2002 and/or 2003 (source: DFO 2008).

Mature IBoF salmon return to the Minas Basin between May and October, occupy natal rivers during autumn for spawning (October-November), and typically return to sea by December (Amiro *et al*. 2003; COSEWIC 2006; DFO 2013a). This suggests that most kelts from the Minas Basin subunit have relatively little potential for overlap with the FORCE site during the fall spawning period. After 2-4 years in freshwater, juveniles (parr) smoltify and migrate to the ocean as post-smolts in spring (May-June) where they grow to adulthood and typically return to spawn in their natal river after one year at sea (1SW;

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[9] A kelt is a salmon that has spawned the previous autumn and over-wintered in the river or estuary (DFO 2018b).

[10] Sanderson et al. *in prep.* Measuring tidal advection and migration of Atlantic salmon kelts to calculate the number of encounters with turbines at a tidal energy demonstration site.

‘grilse’), or as repeat spawners (Amiro *et al.* 2003; COSEWIC 2006). Historically, most IBoF salmon first spawned as grilse and subsequently spawned multiple times in consecutive years (Ducharme 1969; Ritter 1989). While Outer Bay of Fundy salmon populations undergo extensive marine migrations to the north Atlantic Ocean, IBoF salmon marine migration appears restricted to the Outer Bay of Fundy, northern Gulf of Maine and possibly to the Scotian Shelf (COSEWIC 2006; DFO 2010; Lacroix 2013). However, the Gaspereau River population is an exception – although it is genetically similar to other Minas Basin subunit populations, it displays marine migratory patterns and life history traits similar to Outer Bay of Fundy and Atlantic coast salmon populations (Amiro and Jefferson 1996; DFO 2001).

As shown for Atlantic salmon elsewhere (Lacroix 2008; Renkawitz *et al.* 2012; Godfrey *et al.* 2015; Macaulay *et al.* 2020), IBoF salmon post-smolts (Sanderson *et al.* 2023c; Solda 2024) and kelts (Sanderson *et al. in prep.*) occupy the upper portions of the water column in Minas Passage: 36% of post-smolts are found within the upper 8m of the water column in Minas Passage (B. Sanderson, *pers. comm.* 2024). As such, post-smolts and kelts from the Minas Basin subunit may encounter tidal turbines deployed near the surface at the FORCE site from the beginning of the spring migration (May) through to the fall migration (December). Tidal devices whose swept areas are deeper in the water column have much less overlap with IBoF salmon, and present a reduced risk of collision.

Advection by tidal currents is an important determinant of the horizontal movement of IBoF post-smolts and kelts through Minas Passage during periods of elevated tidal flow. Detections of acoustically tagged post-smolts from the Gaspereau River and Stewiacke River by moored and drifter-based receivers show that post-smolts are substantially displaced by tidal currents and can be swept through Minas Passage multiple times during their seaward migration (Sanderson *et al.* 2023c); similar results have recently been observed for Gaspereau River kelts during their spring out-migration (Sanderson *et al. in prep.*[10]). However, the majority of these routes follow a quasi-stable trajectory that passes to the south of the FORCE tidal demonstration site near the middle of Minas Passage (Sanderson *et al.* 2021) (Figure 3). Additionally, drifter tracks that do pass through the FORCE tidal demonstration site have been observed to subsequently disperse elsewhere (Sanderson *et al.* 2021, 2023b), and do not pass through the FORCE site for many of the following tidal cycles. If, as seems probable, the path of these juvenile stages is determined by the current, the risk of collisions for IBoF salmon post-smolts and kelts during periods of elevated tidal flow should be decreased.

Acoustic tag detection data have been used to develop an analytical approach for determining the risk of fish-turbine interactions at the FORCE site, and applied to IBoF salmon post-smolts (Sanderson *et al.* 2023c) and kelts (Sanderson *et al. in prep.*). During periods of elevated flow, an acoustic receiver suspended below a drifter can detect an acoustically tagged fish over extended periods of time, whereas a moored receiver can detect a tagged fish only briefly before it passes out of the receiver detection range. Detections of tagged fish during these brief periods are called 'passing events', and the potential for harmful fish-turbine interaction might be expected to scale with the number of passing events through the FORCE site.

The detection efficiency of a moored receiver to detect a transmitted acoustic signal has been empirically quantified as a function of range and current speed at the FORCE site (Sanderson *et al.* 2023a); the applicability of such detection efficiency has been demonstrated using acoustic tags suspended beneath drifters (Sanderson *et al.* 2023b). Using this information, it is possible to convert a passing event into a probability that a tagged fish passes within some distance of a moored receiver. Imagining that a moored receiver represents a turbine, this amounts to the probability of fish position relative to the device. In this way, a passing event can be converted into encounter probability – defined here as the probability that the passing event occurred within the swept area of a tidal turbine. Summing encounter probabilities for each tagged fish and averaging by the number of tagged fish then provides an estimate for the expected number of encounters (i.e. the expected number of times that an individual would pass through the turbine swept area) (Sanderson *et al.* 2023a, 2023b, 2023c; Sanderson *et al. in prep*). In principle, the expected number of encounters might be fewer, because fish may detect an operational device and exhibit avoidance or evasion behaviours to prevent being struck.

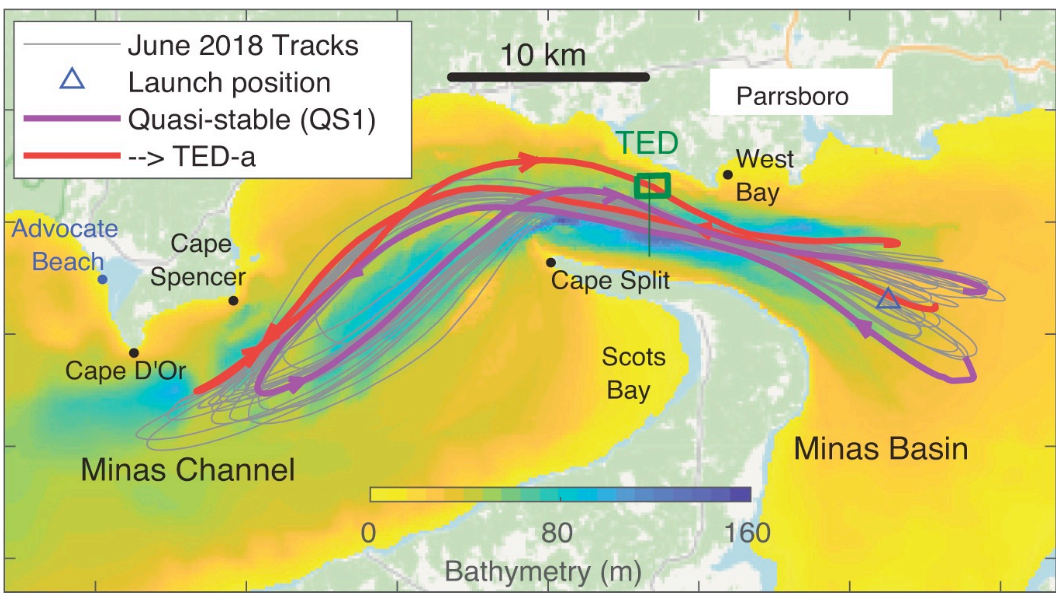

Figure 3: Drifter track plotted from June 11-23, 2018 (grey) generally follows a quasi-stable trajectory (magenta). The drifter passed through the FORCE tidal demonstration site (TED) on two flood tides (red), but was swept to the south by the other 21 flood and 23 ebb tides (source: Sanderson et al. 2021)

For a hypothetical tidal turbine with a cross-stream width of 38 m deployed near the sea surface at the FORCE site, the expected number of encounters with IBoF salmon post-smolts during their seaward migration from Gaspereau River (GR) and Stewiacke River

(SR) in spring 2019 was 0.003 and 0.01, respectively (after accounting for new data on post-smolt swimming depth in Minas Passage) (Sanderson *et al*. 2023c). Kelt swimming depths in Minas Passage are slightly deeper than post-smolts, and 70% were within the depth range of the hypothetical device. The expected number of encounters for spring out-migrating IBoF salmon kelt from the Gaspereau River with this device during May-December – when kelts are most likely to be in Minas Passage – was 0.028 (Sanderson et al. *in prep*.). Kelts that undergo seaward migration in the fall are known to quickly pass beyond Minas Passage (Lacroix 2008) and are anticipated to have even fewer expected encounters (B. Sanderson, *pers. comm*. 2024). Consequently, ***estimates of encounter probability calculated using this approach represent an upper limit on mortality***, ***if one assumes that all encounters are fatal***, and does not consider avoidance or evasion behaviour, or that fish can pass through the swept area of a device unharmed.

Atlantic sturgeon

There has been a great deal of research on Atlantic sturgeon in the Upper Bay of Fundy during the last few years. The Atlantic sturgeon is a large, long-lived anadromous fish that spawns in numerous rivers along the North American coast from Florida to Labrador (Taylor *et al*. 2016). Because the species comprises a mixed-stock assemblage when at sea, it is jointly managed by Canada and the United States; however, knowledge of the movements of sturgeon while at sea is limited (Whipplehauser *et al*. 2016; Stokesbury *et al*. 2012). Although the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed Atlantic sturgeon as 'Threatened' in 2011 (DFO 2013b), it has not been listed under Schedule I of the *Species at Risk Act*.

In the Bay of Fundy, the Atlantic sturgeon was previously believed to spawn in several major rivers (i.e., Saint John River, Shubenacadie River, Avon River and Annapolis River) (Isaacman, 2005; Dadswell and Rulifson 2021). However, in recent decades, there are no confirmed reports of Atlantic sturgeon spawning activity from the Avon River or Annapolis Rivers. Although Atlantic sturgeon are still found in the Annapolis Basin and lower Annapolis River, there is no evidence that these are of Annapolis River origin and are assumed to be foraging animals from the Saint John River, Shubenacadie River, or rivers in the United States (Dadswell *et al*. 2016).

Atlantic sturgeon are abundant in Minas Basin, and an estimated 6,000-14,000 juveniles, sub-adults and adult fish are believed to forage in Minas Basin during the year (Wehrell 2014; DFO 2013b).

Atlantic sturgeon enter Minas Basin during May and June to feed primarily on intertidal polychaetes (McLean *et al*. 2013; Logan-Chesney 2016) and leave again during September and October (Dadswell *et al.* 2016; Stokesbury *et al.* 2016). Although this is consistent with increased detections of acoustically tagged Atlantic sturgeon in Minas Passage during May and October, detections in Minas Passage have occurred from April through December (C. Bangley, *pers. comm.* 2024). Acoustic detections have not been recorded in Minas Passage over winter. Most of these foraging individuals (~62%) seem to originate from the Saint John River, which may be close to its historic maximum population size (Dadswell *et al.* 2013) and providing an important source of migrants, with the remainder originating from rivers in the United States (Wirgin *et al.* 2012; Logan-Chesney 2016). Social Network Analysis of the co-occurrence of tagged Atlantic sturgeon from the Saint John River and the Kennebec River, Maine, suggests that while they are in Minas Basin, the same individuals tend to remain as a group within the same feeding area for much of their foraging time. However, these groups may be a mixture of fish from different origins (Lilly 2020; Lilly *et al.* 2020).

Recent tagging studies in the Minas Basin have revealed previously unknown patterns of behaviour in Atlantic sturgeon. Between 2010 and 2014, 132 individuals were electronically tagged in Minas Basin and their movements recorded by sensors in the Southern Bight and in Minas Passage (Beardsall *et al.* 2016; Stokesbury *et al.* 2016). Atlantic sturgeon preferentially utilized the southern portion of Minas Passage most of the time, but some were detected at acoustic receiver stations in the northern portion of the Passage where the FORCE site is located (Stokesbury *et al.* 216). Given the general assumption that sturgeon are a demersal species, Logan-Chesney (2016) reported that sturgeon in the Minas Basin exhibited a greater frequency of surfacing or 'porpoising' behaviour in shallow waters than expected. 'Porpoising' is assumed to be associated with the need to refill the swim bladder with air to assist with buoyancy control. This pelagic behaviour continued during migration through Minas Passage. Atlantic sturgeon in Minas Passage travelled at depths of 15 to 45 m (mean 31.5 m) and this corresponds to the depth at which bottom-mounted turbines might be deployed at the FORCE site (Stokesbury *et al.* 2016). However, most of those detections were from acoustic receivers deployed in the deeper, southern portion of Minas Passage, and not the northern portion of Minas Passage where the FORCE site is located.

Atlantic tomcod

Atlantic tomcod are small (maximum length ~24 cm), abundant pelagic fish found near shore and in shallow waters throughout the Bay of Fundy, and down the Atlantic coast of North America. They are anadromous and spawn in freshwater just above the head of tide during December and January (Dadswell and Rulifson 2021). Atlantic tomcod are present throughout Minas Basin, even in the most turbid regions, throughout the year. Historically, they were an extremely important food fish for First Nations communities, because of their abundance and availability (Cox 1921; Donovan 2022). Atlantic tomcod play an important ecological role in Minas Basin; they provide a food source for many of the larger piscivorous fish and birds that feed in the Upper Bay of Fundy, and compete with many other fish and birds as they forage on benthic invertebrates, especially the mud shrimp (*Corophium volutator*).

Atlantic tomcod occur in Minas Passage and Minas Channel in shallow waters near shore but have not been the focus of much research there. They may be present across Minas Passage but have not been noted in previous trawl sampling. Dadswell and Rulifson (2021) suggest that they may be abundant in Minas Passage during winter, but since their preference is for shallower waters, it is unlikely that they would be present in great numbers at the FORCE site where turbines would be deployed.

American eel

The American eel is a widespread catadromous species (i.e., it matures in freshwater but spawns in marine waters) that historically occurred in all North American freshwaters, estuarine and coastal marine waters connected with the Atlantic Ocean as far north as the mid-Labrador coast (Casselman 2003; Macgregor *et al.* 2008). Although dramatic declines in freshwater abundance in the St. Lawrence River drainage prompted COSEWIC to assess the American eel as a 'Species of Concern' in 2006 (COSEWIC 2006b) and 'Threatened' in 2012 (COSEWIC 2012), it has not been listed under Schedule I of the *Species at Risk Act*;[11]

Historically, the American eel has been fished as long as people have lived around the Bay of Fundy (Dyer *et al.* 2005; Deveau 2022); both adults (silver eels) and juveniles (elvers, glass eels, and yellow eels) were important food sources for Mi'kmaq communities (Denny *et al.* 2012; Poirier 2013; Stevens 2015) and are considered to be spiritual beings (Prosper 2001). Elvers and glass eels have also been heavily commercially fished in recent decades, primarily to meet the demand of Asian food markets (Jessop 2021)[12].

American eels maturing in all drainages leading to the Atlantic Ocean and Gulf of Mexico spawn in the Sargasso Sea. Adults die after spawning and the eggs hatch into leptocephalus larvae that drift in surface waters (e.g., the Gulf Stream) that transport them closer to shore, at which time they transition into the elver stage as they move inshore and into estuaries. When in tidal waters, eels adopt a *selective tidal stream transport* (STST) strategy, whereby they rise towards the surface on the flood tide to

[11] https://www.canada.ca/en/environment-climate-change/services/species-risk-act-accord-funding/listing-process/aquatic-species-protected-fisheries-act.html

[12] In 2023 DFO prohibited fishing for elvers throughout the Atlantic provinces because of increased unlicensed harvesting and the status of the American eel stocks (DFO 2023).

promote landward advection by tidal currents, but descend to deeper water on the ebb tide to maintain location (Deveau 2022).

The species is present in most rivers that are tributary to the Bay of Fundy, although a number of dams limit access to upstream portions of several watersheds. Elvers migrate through Minas Passage in surface waters near the shoreline during April and May; however, these seaward movements appear to be occurring earlier in the year, possibly in response to climate change (Jessop 2021; Seidov *et al.* 2019). Although the seaward migration of silver eels is believed to occur from August through October (Dadswell and Rulifson, 2021), monitoring of acoustically tagged eels in Minas Passage during 2011-2013 indicated that they migrate through the passage from mid-September to mid-November (Redden *et al.* 2014a). This migration primarily took place during the ebb tide phase over a period of 1-6 days, with individuals swimming in the upper 30 m of the water column (Redden *et al.* 2014a). It is important to acknowledge that the timing of migratory movements for silver eels may be impeded by dams that can delay outmigration to marine habitats: at least until increased water levels overtop dams and facilitate seaward movement (Acou *et al.* 2008).

The abundance of silver eels moving though Minas Passage during any given year is unknown, largely because there are no population estimates for the species in most of the rivers that are tributary to Minas Basin. While the species is apparently abundant in Minas Basin and its tributaries, they are rarely captured in intertidal weirs – presumably because they are adept at finding openings in the weir structure (Dadswell *et al.* 2020) – and are able to avoid most sampling technologies (except purposely-designed baited eel pots and eel traps).

Recent tagging studies (Béguer-Pon *et al.* 2015) have indicated that the seaward migration of adult eels involves an eastward migration across the Scotian Shelf rather than a southerly movement along the coast of North America.

American shad

The American shad is a pelagic anadromous fish that spawns in many of the rivers tributary to the Bay of Fundy, including those in Minas Basin. The conservation status of the species has not been assessed by COSEWIC, and American shad are not listed under Schedule I of the *Species at Risk Act*. Shad have supported important commercial fisheries in rivers and coastal areas in the Upper Bay of Fundy for more than 250 years (Dadswell *et al.* 1984); particularly since the 1840s when drift netting began in the region (Dyer *et al.* 2005). However, overfishing and the construction of dams that blocked access to historical spawning grounds across the species' native species range led to dramatic declines in abundance during the late 1800s.

American shad migrating to the Upper Bay of Fundy are comprised of fish returning to their natal rivers to spawn, and fish from across the remainder of their native range (from Labrador south to Florida) that are on an annual feeding migration (Dadswell *et al.* 1984; 2016)[13]. The species' migratory movements in the Bay of Fundy are believed to follow the residual current patterns (i.e., those entering the Bay of Fundy follow along the Nova Scotia shore, pass through Minas Passage, and after spawning or feeding, leave Minas Basin and follow along the New Brunswick shore as they depart the Bay of Fundy (Dadswell *et al.* 1983; 1984; 2021).

Mature adults returning to spawn in their natal rivers in Minas Basin migrate through Minas Passage during spring and early summer – typically April through June. Spawning adults move upriver to freshwater habitat just above the head of tide, spawn and then return to estuarine and marine waters to feed and continue their annual migration (Dadswell 1983). The seaward movement of post-spawners begins in June; acoustically tagged adult American shad from the Kennetcook River, NS, were primarily detected passing through Minas Passage in June and July (C. Bangley, *pers. comm.* 2024). Because Minas Passage is not a particularly productive feeding area for a filter-feeding species like American shad, their movement through Minas Passage is suspected to occur relatively quickly. Indeed, recent analysis of acoustic tag detection data from Minas Passage suggests that seaward-moving post-spawn American shad may leave Minas Passage entirely on a single ebb tide (B. Sanderson, *pers. comm. 2024*). Although shad tend to remain at depth during the day and rise higher in the water column when in clear coastal waters, the species is typically found closer to the surface in the turbid waters of the Upper Bay of Fundy throughout the day (Dadswell *et al.* 1983).

After spawning, American shad larvae hatch and grow in the lower portions of rivers for 3-4 months before outmigration to estuarine and marine habitats. The seaward migration of young-of-the-year (YOY) takes place during August through October and occurs at an average rate of 3-4 km/day (Melvin *et al.* 1985). The temporal and spatial distribution of YOY American shad in Minas Passage has not been investigated.

Although intertidal weir studies in Minas Basin indicate that American shad are still fairly common, they are less abundant than in the past. Dadswell *et al.* (2020) conducted a detailed study of catch composition at the Bramber intertidal weir in the southern Minas Basin in which every tide was sampled from 10 April – 22 July, 2017 (i.e., 144 tides) and recorded only 7,176 American shad; representing ~1% of the total catch. This is considerably fewer than the 500 - 1,000 American shad caught per tide as reported by

[13] It should be noted that drift and weir net fishers were long aware that there were detectable differences in appearance of shad caught in Fundy waters at different times in the summer, suggesting origin in different stocks.

Dadswell *et al.* (1983), and far fewer than the >100,000 American shad caught on single tides in Minas Basin during the 19th century (Prince 1912).

Alewife and *Blueback herring*

The alewife (*Alosa pseudoharengus*) is one of two small-bodied anadromous[14] river herring species — the other being blueback herring (*A. aestivalis*) — found in Nova Scotia rivers and coastal waters, including Minas Basin. These sister species are morphologically similar and distinguishing between them in the field is difficult; they are often jointly referred to as 'gaspereau'. COSEWIC has not assessed the conservation status of either species, and neither is listed under Schedule I of the *Species at Risk Act*. Like American shad, gaspereau have long been an important food fish, but in recent decades stocks have experienced substantial declines. This has been attributed to a variety of factors including bycatch in commercial fisheries (Bethoney *et al.* 2014), overharvesting of spawning migrants in rivers, or a combination of natural and/or anthropogenic changes to breeding habitats (Gibson *et al.* 2017; Rulifson and Dadswell 2020).

Alewife spawn in rivers from northeastern Newfoundland to North Carolina, whereas blueback herring spawn in rivers from Nova Scotia to Florida (Dadswell *et al.* 1983; Dadswell *et al.* 2020; Rulifson and Dadswell 2020). Little is known about their at-sea migration and feeding habits but, like American shad, gaspereau that migrate to the Upper Bay of Fundy represent breeding populations across much of their native ranges (Rulifson and Dadswell 2020). Minas Basin appears to be a significant feeding location for both species, and at times of migration into Minas Basin, there may be large, dense schools of gaspereau that migrate with the flood tide through Minas Passage (D. Porter, *pers. comm.* 2023). Alewives migrate through Minas Passage and enter Minas Basin in May to spawn in local rivers, ponds or other stretches of slow-moving streams over several weeks (Gibson *et al.* 2017). Blueback herring tend to migrate and spawn 2-4 weeks later in faster-moving water.

Post-spawn adults may remain in freshwater or move to the estuary for the remainder of the summer. The timing of out migration from Minas Basin and back through Minas Passage appears to be related to the availability of sufficient fat reserves and can occur in July for some post-spawn adults (Rulifson and Dadswell 2020). Acoustically tagged adult alewife from the Avon River, NS, were primarily detected migrating through Minas Passage in June and July (C. Bangley, *pers. comm.* 2024). Additional acoustic tagging studies have revealed that alewife may forage over large parts of the Minas Basin before

[14] Some alewife stocks introduced to lakes in Canada and the USA have adapted to an entirely freshwater life cycle.

ultimately departing, and may repeatedly transit through Minas Passage before finally exiting to the Inner Bay of Fundy (Tsitrin *et al*. 2020; 2022).

Young-of-the-year gaspereau typically remain in freshwater until late August or September before moving seaward (Gibson *et al*. 2017). However, the temporal and spatial distributions of YOY alewife and blueback herring in Minas Passage have not been investigated

During the 1980s, exploitation rates on gaspereau in Bay of Fundy rivers often exceeded 80% on each spawning run. However, this was restricted by quota to c. 55% during the early 2000s, and resulted in a modest recovery (Gibson *et al* 2017). McIntyre (*et al*. 2007) reported that total run size for gaspereau in the Gaspereau River, NS, in recent years was c. 800,000 fish, but escapement was still below the 400,000 fish target each year. Local fishery catches were traditionally exported to the Caribbean and central America for food or used as bait in lobster traps in the Atlantic region.

Spiny dogfish

The spiny dogfish is a small-bodied, slow growing and long-lived shark species (~35-40 years) that occurs widely in the waters of the Northwest Atlantic Ocean. The centre of their marine distribution appears to be the Gulf of Maine and Bay of Fundy region, with stocks moving south in winter and as far north as southern Newfoundland in summer (DFO 2014). COSEWIC has not assessed the conservation status of the species, and it is not listed under Schedule I of the *Species at Risk Act*. Spiny dogfish appear to favour water temperatures between 6-11 ^{o}C (Jensen 1965; Moore 1998) and are ovoviviparous (i.e., eggs hatch inside the female and gestation occurs over several months before birth). The location of both breeding and pupping grounds of Canadian stocks is unknown, but is assumed to be in the deeper waters off the Atlantic Coast of Canada (DFO 2007)..

Historically, spiny dogfish were of minor commercial importance: the first directed fishery occurred in the United States during World War II, but an expanded fishery prosecuted primarily by foreign fleets occurred during the 1960s-1970s in the Cape Cod/Gulf of Maine region until establishment of the exclusive economic zone (i.e. 200 mile limit) in 1977. Afterwards, the commercial harvest was dominated by fishers from the United States and Canada and controlled by quota. Spiny dogfish stocks in US waters were declared overfished in 1998 (particularly with respect to larger females), and in many areas the species could only be taken as bycatch (Dyer *et al*. 2005). In Canada, the quota has been set at 2500 mt since 2004 (DFO 2014).

Moore (1998) reported on an extensive study of spiny dogfish captured by long line, trawling and intertidal weirs in the Minas Basin in 1996. Total catch by all methods was

1,789 fish; the majority of which were caught by trawling in deeper water. The vast majority (99%) of spiny dogfish caught in Minas Basin were females, 56% of which were mature adults; whereas, the majority (98%) of female dogfish captured in the Outer Bay of Fundy were immature.

Studies of spiny dogfish captured by intertidal weirs in Minas Basin over the last decade have failed to show large numbers of fish. For example, Baker *et al.* (2014) captured few spiny dogfish (< 10 animals per tide) at either of the two intertidal weirs monitored during their study, and only on two sample dates each. Similarly, a detailed study of catch composition at the Bramber intertidal weir in the southern Minas Basin in which every tide was sampled from 10 April – 22 July, 2017 (i.e., 144 tides) recorded only 10 spiny dogfish among an estimated 670,000 fish; indicating that this species does not commonly advance onto the intertidal zone in Minas Basin (Dadswell *et al.* 2020).

Although Dadswell and Rulifson (2021) suggest that 1-2 million dogfish are to be found in Minas Basin during summer months, and will be negotiating Minas Passage in April/May and again in September/October, it is difficult to reconcile that claim with existing contemporary data. Recent analyses of acoustically tagged spiny dogfish revealed detections in Minas Passage during every month except March, but in greater abundance during June through December (C. Bangley, *pers. comm.* 2024). Although spiny dogfish were not detected over winter (January-March), this was probably due to an absence of acoustic receivers deployed in Minas Passage during that period.

White shark

The white shark is a highly mobile marine fish that is broadly distributed throughout the world's pelagic and coastal waters in subtropical and temperate seas (DFO 2024). Those found in Atlantic Canadian waters belong to the Northwest Atlantic population that is listed as *Endangered* under Schedule I of the *Species at Risk Ac*— a conservation status that is largely a consequence of incidental catch in commercial fisheries that has led to a >70% decline in population abundance since the 1960s (COSEWIC 2021). However, recent work suggests that population abundance may be increasing as a result of conservation efforts and management actions undertaken during the 1990s (Curtis *et al.* 2014).

White shark have been confirmed from waters throughout Atlantic Canada where they are most frequently observed during June to September (DFO 2024) and predominately in waters 12-19 °C (Bowlby et al. 2022). Increased acoustic tracking efforts suggest that juveniles and sub-adults may use coastal Atlantic Canadian waters more often than previously thought (Skomal *et al.* 2017; Bastien *et al.* 2020; Bowlby *et al.* 2022), and exhibit predictable seasonal migratory patterns and a coarse level of regional fidelity over successive years (Bastien *et al*. 2020; Franks *et al*. 2021; Bowlby *et al*. 2022). While they may make extensive vertical movements in the water, white sharks in Atlantic Canadian waters are primarily surface-oriented; spending 95% of their time in the upper 50 m of the water column, and more than half their time in the top 20 m (Skomal *et al*. 2017; Bowlby *et al*. 2022).

Until recently, records of white shark were rare from the Bay of Fundy: according to DFO there were only 34 records since 1874 in the whole of eastern Canada (DFO 2006c). However, acoustic receiver deployments in Minas Passage detected 37 acoustically tagged (69 kHz; Pulse Position Modulation (PPM) tags) white sharks during 2011-2023, with detections occurring from June through October (C. Bangley, *pers. comm*. 2024). These 37 individuals comprised both sexes, were 2.4 – 4.6 m in length at time of tagging, and likely represent older sub-adults approaching sexual maturity. Approximately 1/3 of these individuals were detected in multiple years (providing support for regional fidelity to the Minas Basin), and were observed to make multiple transits through Minas Passage over the course of a season (C. Bangley, *pers. comm*. 2024). While white shark were detected at all receiver stations in Minas Passage, more individuals were detected at receivers deployed near Cape Sharp and along the southern portion of Minas Passage near the Blomidon peninsula than in the middle of Minas Passage or at the FORCE tidal demonstration site (C. Bangley, *pers. comm*. 2024). Indeed, the average number of acoustic detections suggests increased prevalence of white shark along the Blomidon peninsula shoreline, and in proximity to Black Rock, Cape Sharp and Partridge Island, than in the center of Minas Passage or at the FORCE tidal demonstration site (C. Bangley, *pers. comm*. 2024). Residence times suggest that white shark quickly transit through Minas Passage and spend most of their time in the Southern Bight (around 'the Guzzle') and near Five Islands where they likely forage (C. Bangley, *pers. comm*. 2024). However, challenges with the detection of PPM acoustic signals during periods of high tidal flow in Minas Passage (Sanderson *et al*. 2017; Sanderson *et al*. 2023a) suggest that our understanding of how white shark utilize Minas Passage is incomplete, and that estimates of passing events and their trajectories through Minas Passage may be conservative.

Striped bass

Striped bass are small-bodied anadromous fish native to Atlantic Coastal rivers in Canada and the United States (Hill *et al*. 1989) and support important recreational fisheries in both countries. Although the St. Lawrence River population is listed as *Endangered* under Schedule I of the *Species at Risk Act*, the Bay of Fundy population has not been officially listed; however, it is currently under consideration for addition. Striped bass from the Bay of Fundy are considered a DU by COSEWIC (COSEWIC 2012) and have been identified by that organization as 'Endangered' (COSEWIC 2021).

Striped bass used to spawn in several rivers tributary to the Bay of Fundy, including the Petitcodiac River, Annapolis River and Avon River, but now appear to be restricted to the Shubenacadie River drainage and possibly the Saint John River[15]. In summer, adults and juveniles may forage in the Minas Basin, where they are commonly captured by recreational fishers. In winter, many YOY and adult striped bass remain in, or return to, the rivers and lakes of the Shubenacadie River drainage as water temperatures in Minas Basin and Minas Passage decline to < 1 ^{o}C (Zions *et al.* 2017). However, Dadswell and Rulifson (2021) report that striped bass are abundant near shore in Minas Passage and are present all year. Although some striped bass from the United States portion of the species' range enter Minas Basin during a seasonal feeding migration (Rulifson *et al.* 2008; Keyser 2015), most Canadian origin striped bass are believed to remain in Canadian waters throughout their life (DFO 2003a).

Initially, acoustic tagging of Shubenacadie River origin striped bass suggested that few individuals ventured further seaward than Minas Basin (Rulifson *et al.* 2008; Keizer 2015; Andrews *et al.* 2017). However, an extensive striped bass acoustic tagging program conducted during 2011-2013 revealed acoustic detections in Minas Passage throughout the year and revealed that Minas Passage may serve as an important overwintering site (Redden *et al.* 2014; Sanderson and Redden 2016). Relatively few fish are detected over winter and spring (December - May) compared to summer and fall (July-November) (C. Bangley, *pers. comm.* 2024) and presumably reflect a seasonal difference in occupancy of Minas Passage. During the day, most (~90%) acoustic detections indicated that fish were swimming at depths between 20-37 m (regardless of the water depth at various locations in Minas Passage), but at night swimming depth decreased to 6-28 m (Keizer *et al.* 2016); indicating some level of diel migration. Some tagged fish that were not recorded in Minas Passage over winter may have moved to the Outer Bay of Fundy where warmer waters (6-10 ^{o}C) may have been available. Importantly, some fish were still present in Minas Passage when water temperatures were <1 ^{o}C, when striped bass are assumed to be lethargic and probably not feeding[16]. It cannot, however, be assumed that striped bass at such low temperatures are insensitive to their surroundings.

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[15] The population in the Saint John River was classified as Endangered by COSEWIC in 2004 (COSEWIC 2004), a decision attributed in part to the construction of the Mactaquac Dam in 1968, but largely reflective of a lack of information and scientific surveying (Andrews *et al.* 2017). There appears to be a land-locked stock in freshwater above the Mactaquac Dam that may not migrate out of the river at all (Andrews *et al* 2019). It remains unclear how many of the striped bass present in the lower Saint John River are derived from local recruitment rather than from migratory movements of other river stocks, possibly those from the Shubenacadie River drainage in Nova Scotia (Rulifson *et al.* 2008; Keizer 2015; Andrews *et al.* 2017).

[16] Striped bass are thought to cease feeding at temperatures below 10 C (pers. com. from Dr. J. Dustin, Dalhousie University, to Keyser *et al.* 2016).

Atlantic herring

Atlantic herring is one of the most abundant fish species in the Inner and Upper Bay of Fundy and has comprised one of the most valuable commercial fisheries in the region for more than a century (Koeller 1979). The area supports two important Atlantic herring spawning grounds: i) Minas Basin (i.e., north shore of Minas Basin around Five Islands), and ii) Scots Bay (Tobin-van den Heuvel *et al.* 2022). Dadswell and Rulifson (2021) estimate that the combined biomass of the Atlantic herring stocks from the Bay of Fundy (i.e, Scots Bay) and Southwest Nova Scotia at about 500,000 t[17]; the Minas Basin portion represents a small fraction of this biomass. The Scots Bay spawning population reproduces in late summer (July - October), whereas the Minas Basin spawning population appears to be the sole remaining spring (May - June) spawning stock in the Bay of Fundy-Gulf of Maine area (Koeller 1979; Bradford and Iles 1991)[18]. As a result of their earlier spawning, Minas Basin Atlantic herring grow rapidly in the highly productive waters of Minas Basin and undergo metamorphosis before the end of the summer, whereas those from Scots Bay may not metamorphose until the following spring.

Due to the absence of directed Atlantic herring surveys in Minas Passage itself, use of the area has been largely inferred based on survey results and knowledge from adjacent regions. Attempts to assess Atlantic herring stocks in the Bay of Fundy have been conducted since 1969 using larval herring surveys at two stations near Minas Passage: i) Scots Bay, and ii) north shore in the vicinity of Minas Channel (Iles *et al.* 1985). Surveys of adult Atlantic herring in the Scots Bay area have been part of the Integrated Fisheries Management Plan for Atlantic Herring in the Maritimes Region since 1999 (Singh *et al.* 2016). Over that period, the timing of the first annual surveys has steadily advanced by approximately 8 weeks (i.e., from the end of July to the end of May; Debertin 2021), potentially reflecting effects associated with climate change. Although in theory these surveys extend into the Minas Channel, it is relatively uncommon for any stations to be located further east of a line from Cape D'Or to Halls Harbour, and almost never within Minas Passage or Minas Basin (Debertin, 2021).

Local fishers report the presence of large, dense schools of Atlantic herring at times in both the Scots Bay - Minas Channel area and in Minas Basin (D. Porter, *pers. comm.*

[17] It is not clear how this estimate was derived. According to the latest herring assessment, the Southwest Nova/Bay of Fundy biomass was ~323,000 t in total, below the 1999-2020 average biomass of 348,000 t. Of the total the Scots Bay component alone was ~186,000 t in 2020 - a major increase from the ~133,000 t in 2019 (DFO 2021c). Because the German Bank/ Trinity Ledge component has decreased markedly there has been a significant reduction in SWN/BoF TAC for 2022 (Johnson 2022).

[18] Previously, it was thought that several spring spawning stocks were present in the Bay of Fundy (e.g. Messieh 1970), but except for the Minas Basin stock it appears these had vanished by the end of that decade (Koeller 1979).

2023)[19]. Recent surveys indicate that, while the biomass of the Scots Bay component has fluctuated over the last two decades, the stock appears to be near its highest level at 186,000 t (DFO 2021c). Tagging studies have indicated that herring spawned in the Scots Bay region have been recaptured in the Outer Bay of Fundy and Gulf of Maine (Clark 2006; Stephenson *et al.* 2009), supporting the contention that there is considerable mixing of different stocks during the non-breeding season. It is also probable that some of the Atlantic herring caught in Minas Basin fisheries are from Scots Bay, and that some of the Minas Basin stock exits through Minas Passage and Minas Channel.

Summary of fish presence in Minas Passage

Although it is clear that there is potential for a large number of species to be present at various times in Minas Passage, the majority of these occur relatively rarely, or in small abundance. The ten species considered above include those that are the most numerous of the small-, medium-, and large-bodied fishes in Minas Passage, a few of which are present as adults, YOY, or both over extended periods (e.g., Atlantic herring, spiny dogfish, striped bass, American shad, alewife and Atlantic sturgeon). A few additional species not considered in detail above (e.g. migratory stocks of rainbow smelt, pollock, and mackerel) may be abundant for relatively short periods of time but may also be largely absent outside of these migration periods. A good deal of effort has been directed over the last few years to investigate i) how many of a given species are present in Minas Passage and for how long, and ii) where and at what depths they migrate through Minas Passage. This information is important for helping to contextualize the potential risk from the development of tidal energy in Minas Passage.

Assessing the biomass of both pelagic and groundfish species in coastal waters using hydroacoustics (i.e. scientific echosounders) has a long history (e.g. Didrikas and Hansson 2004; Bonanno, *et al.* 2005; Overholtz *et al.* 2006; Debertin 2020; Viehman *et al.* 2022). Since the establishment of the FORCE site, there has been a major effort to evaluate fish presence in Minas Passage using this approach (e.g. Melvin and Cochrane 2012, 2013, 2014, 2015; Daroux and Zydlewski 2017). Techniques used at the FORCE site included vessel-based surveys along predetermined transects, and stationary bottom-mounted, upward-looking surveys from subsea platforms (Viehman *et al.* 2022). Unfortunately, the approach has limited application in Minas Passage because of the complex hydrodynamics that can entrain air in the water column and obscure acoustic signal reflections from fish — especially in the upper portions of the water column (Viehman *et al.* 2022).

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[19] Dadswell and Rulifson (2021) refer to huge 'bait balls' of herring that would be at great risk from any turbine located in Minas Passage. The statement obviously assumes that under such conditions the fish would be unable to detect its presence and avoid it. Experimental testing could resolve that uncertainty.

Although hydroacoustic surveys are useful in many marine environments, they require precise physical sampling of species presence, size and depth distribution for comparison with acoustic target records (Viehman *et al.* 2017; Viehman *et al.* 2022; Whitton *et al.* 2022) — a non-trivial challenge to acquire in the turbulent waters of Minas Passage. Indeed, the inherent difficulties of identifying acoustic targets to species in Minas Passage are well described (e.g. Melvin and Cochrane 2014; Viehman and Redden 2018; Viehman *et al.* 2022). Although Melvin and Cochran (2017) compared four hydroacoustic technologies and found they all provided useful information about the presence, and occasionally abundance of fish, none were sufficient to provide a comprehensive assessment either because of technology limitations, or because of the effects of turbulence or turbidity. However, some of the tested technologies did identify seasonal changes in fish abundance in Minas Passage that correlated with the spring migration of several species, followed by a substantial decline in abundance during August, and a modest increase in abundance during November that correlated with the seasonal exodus of anadromous and foraging migrant species from Minas Basin. However, linking acoustic targets to untagged species remains an elusive proposition for hydroacoustic surveys in Minas Passage, and alternative approaches (e.g. acoustic telemetry) could provide species-specific information that is of potentially greater value for understanding the potential risk of tidal stream energy development.

Indeed, expansion of acoustic tagging efforts and the establishment of acoustic receiver arrays in Minas Passage has greatly improved the ability to detect species, describe species' temporal and spatial use (including depth distribution) of Minas Passage during seasonal migration, and advance analytical approaches for understanding the likelihood of fish-turbine encounters (e.g. Redden *et al.* 2014; Keyser *et al.* 2016; Stokesbury *et al.* 2016; Sanderson *et al.* 2017, 2021, 2023a, b, c; Tobin van den Heuvel *et al.* 2022; Tsitrin *et al.* 2020, 2022). Monitoring of acoustically tagged fish in the presence of operational tidal turbines in Minas Passage provides an opportunity to conduct localization experiments (Smith 2013) to examine the capacity of different species to exhibit behavioural responses (i.e., avoidance, evasion) under varying tidal flow conditions, which are directly relevant for quantifying the potential risk of fish-turbine interactions.

Current state of knowledge: fish behaviour in the presence of MKE devices

Marine animals possess a suite of sensory systems that permit them to accurately perceive their aquatic environments and respond appropriately to stimuli by exhibiting a range of behaviours (Copping *et al.* 2023). Although vision can play an important role in the detection of a MKE device by fish (Hammar *et al.* 2013), most fish species derive more information about their environment from sound cues (e.g. via particle motion, vibrations etc.) than from vision, olfaction or electroreception (Nedelec *et al.* 2016; Popper and

Hawkins 2018; Risch *et al.* 2024). However, the extent to which complex hydrodynamics and their associated effects (turbulence, turbidity, entrained air), such as those experienced during periods of elevated flow in Minas Passage, might obscure cues from an operational MKE device, or the ability of fish to detect cues under these conditions, remains unknown.

Mounting empirical evidence collected across a range of environmental conditions suggests that when marine animals can detect an operational MKE device, they exhibit avoidance or evasion behaviours (Wilson *et al.* 2006; ABPMER. 2010) to prevent being struck by rotating turbine blades (Viehman and Zydlewski 2015; Fraser 2018; Joy *et al.* 2018; Williamson *et al.* 2019; Gillespie *et al.* 2021; Onoufriou *et al.* 2021; Palmer *et al.* 2021; Smith 2021; Bender *et al.* 2023). Laboratory-based studies (e.g. flume tests) support field observations that fish can exhibit avoidance and evasion behaviours under controlled conditions with relatively low flow (i.e., < 2.5 m/sec) (Castro-Santos and Haro 2013; Amaral *et al.* 2015; Yoshida *et al.* 2020, 2021; Müller *et al.* 2023). Information about the extent to which free-swimming fish can detect an operational device and exhibit avoidance and/or evasion in environments dominated by greater flow rates is improving (Shen *et al.* 2016; Grippo *et al.* 2020), and will be influenced by various factors including flow speed at the time the device is detected, fish size and swimming ability (Zhang *et al.* 2017), and the size and rotational speed of the device. Monitoring of fish movements in the vicinity of MKE devices in East River, New York (Bevelhimer *et al.* 2015; 2017), Cobscook Bay, Maine (Shen *et al.* 2016; Grippo *et al.* 2020), and the Fall of Warness, Scotland (Broadhurst *et al.* 2014; Fraser *et al.* 2018) have failed to provide evidence of collision between fish and the rotating blades of a MKE device[20]. Empirical evidence of avoidance and evasion behavior in the presence of operational MKE devices is steadily increasing (e.g. Bender *et al.* 2023), and in some instances demonstrates avoidance behaviour at distances > 100 m upstream from the turbine swept area (Viehman and Zydlewski, 2015; Shen *et al.* 2016). Information about the ability of fish in Minas Passage to detect and exhibit avoidance or evasion behaviour across a range of tidal flow conditions can only be acquired once an operational MKE device is deployed at the FORCE site.

Although MRE infrastructure deployed in the water column and at the sea surface can act as a fish aggregating device (FAD) (Wilhelmsson *et al.* 2006) – via the thigmotactic response (Brickhill *et al.* 2005) – it is unlikely that most fish species in Minas Passage could maintain their position in the water column during elevated tidal flow speeds. As sustained tidal flow velocity exceeds some fish swimming speeds, fish are either advected with the flow or seek protection in areas with reduced flow velocity (e.g. in the wake of

[20] Some recent evidence, however, suggests that fish passing through the swept area of ***river turbines*** may become disoriented, leading to other aspects of vulnerability (Courtney *et al.* 2022).

the MKE device Fraser *et al.* 2017; Williamson *et al.* 2019). Indeed, saithe fish (*Pollachius virens)* have been observed congregating around bottom-mounted tidal stream devices during periods of higher flow in the Shetland Islands, and as current speeds increase, they descend in the water column to around the base of the device, taking shelter in the lee of the substructure and in the boundary layer near the substrate (Sparling *et al.* 2020; Smith 2021). However, bottom-mounted devices are considerably closer to the substrate, and it seems unlikely that fish congregating around a surface-deployed device at the FORCE site (i.e., > 30 m from the sea floor) would exhibit similar behaviour (Copping *et al.* 2021).

Dadswell and Rulifson (2021) make multiple statements about the vulnerability of fish to tidal energy development in Minas Passage based on their experience with the barrage-based Annapolis Tidal Generating Station located in the Annapolis River (see also Dadswell and Rulifson 1994; Dadswell *et al.* 2018). However, these statements are not relevant to MKE devices because they do not reflect the essential differences in the operating characteristics of tidal range vs. MKE turbines, or the potential behavioural responses of fish to these fundamentally different technologies. Indeed, Brown *et al.* (2023) recently conducted a major review of the characteristics of MKE devices and concluded that they present minimal risk to fish, particularly in comparison to turbines commonly used in hydroelectric facilities and tidal barrages. Although results are not yet conclusive, the information collected so far from multiple behavioural studies indicates that many fish can detect and exhibit behavioural responses (i.e., avoidance, evasion) to prevent contact with an operational MKE device (Copping *et al.* 2021).

RESPONSES TO DFO QUESTIONS

This section addresses eight questions provided by DFO to improve understanding of the potential for fish-turbine interactions in Minas Passage and the risk of MKE demonstration at the FORCE site.

1. What is the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices in Minas Passage?

Collision risk describes the likelihood that animals might be harmed by coming into contact with the moving parts of a MKE device (Wilson *et al.* 2006). Collisions between animals and MKE devices are thought to be the greatest risk of tidal device operations, but are expected to occur infrequently (Copping and Hemery 2020). The environmental effects of pressure changes, cavitation and shear forces from modern MKE devices are also considered unlikely to cause substantial harm to fish (Polagye *et al.* 2014; Hammar *et al.* 2013; Amaral *et al.* 2015; Bevelhimer *et al.* 2015; 2017; Grippo *et al.* 2017; Sparling *et al.* 2020; Copping *et al.* 2021).

Collision risk for fish from MKE devices in Minas Passage depends on a variety of interdependent factors (Copping et al. 2023). These include the temporal distribution of species presence in Minas Passage, the extent to which their movements through Minas Passage are dictated by tidal advection, and whether those trajectories will intersect with a MKE device. If so, the risk is further determined by the capacity of the fish to detect the MKE device and to subsequently exhibit behavioural responses (avoidance or evasion) to prevent being struck by a rotating turbine blade (which itself is influenced by flow speed at time of device detection), fish size and swimming ability, as well as the size and rotational speed of the MKE device.

Of the 68 fish species that are known to migrate through Minas Passage (Table 1), at least one half are present on an annual basis, with the remainder being occasional or irregular visitors. Of the regular users of Minas Passage, the majority appear to use Minas Passage as a migratory corridor and comprise either diadromous species moving between spawning grounds and foraging/growth areas (e.g., American eel, American shad), or marine species accessing foraging or pupping grounds in Minas Basin (e.g. white shark and spiny dogfish respectively). Most of the regular users migrate through Minas Passage during spring and again during fall (e.g. alewife; Gibson *et al.* 2017), but some appear to be present throughout much of the year (e.g. striped bass - Sanderson and Redden 2016). While some species appear to transit Minas Passage rather quickly (e.g. American shad - B. Sanderson, *pers. comm. 2024*), others may move through Minas Passage repeatedly on successive tides before being swept into or out of Minas Basin or the Inner Bay of Fundy (e.g. IBoF salmon post-smolts - Sanderson *et al.* 2023c). Although many of the spawning migrants (e.g. American shad, alewife, Atlantic herring, striped bass) are pelagic in habit and are potentially moving through Minas Passage at depths where they could encounter both bottom-mounted and surface-deployed MKE devices, species that are typically considered demersal in habit may also be found near the surface (e.g., Atlantic sturgeon- Logan-Chesney 2016; Lilly 2020; Stokesbury *et al.* 2012, 2016). Consequently, there is much nuance in species-specific use patterns of Minas Passage by many fishes that complicates determination of the likelihood of harm from MKE devices. For each species under consideration we require detailed information about its spatial and temporal distribution in Minas Passage that is presently often incomplete.

During periods of elevated flow in Minas Passage, advection by tidal currents are the primary determinants of the horizontal movement of small-bodied fish like alewife (Tsitrin *et al.* 2022, striped bass (Keyser *et al.* 2016), IBoF salmon post-smolts (Sanderson *et al.* 2023c) and kelts (Sanderson *et al.* 2021; Sanderson *et al. in prep.*). Indeed, acoustic detections of some small-bodied fishes using moored and drifter-based receivers show that they can be substantially displaced by tidal currents, and their trajectories approximate the tracks of passive drifters. However, the majority of these routes follow a quasi-stable trajectory that passes to the south of the FORCE site near the middle of Minas Passage (Figure 3; Sanderson *et al*. 2021) and that adheres to the dominant tidal current trajectories (Figure 4).

Modeling of tidal flows through Minas Passage reveals that during the flood tide, surface currents are deflected to the north by Cape Split, resulting in the formation of a strong gyre in the southern portion of Minas Passage (Figure 4 top and middle panels — R. Karsten, *pers. comm*. 2023; Sanderson and Redden 2016; Sanderson *et al*. 2021). This gyre is expected to restrict the inward movement of fish along the southern side of Minas Passage, resulting in their movement primarily through the middle of Minas Passage during flood tide. While the entire width of Minas Passage may be used during outmigration on the ebb tide, higher current velocities are found along the deeper, southern portion of Minas Passage (Figure 4 bottom panel) that coincides with the movement of a substantial fraction of fish species in Minas Passage (e.g., Bangley *et al*. 2022; Beardsall *et al*. 2016; Daroux and Zydlewski 2017a, b; Keyser 2015; Keyser *et al* 2016; Melvin and Cochrane 2013; Redden *et al*. 2014a,b; Sanderson 2016; Sanderson and Redden 2016; Sanderson *et al*. 2017,2021; Stokesbury *et al*. 2012, 2016; Viehman and Zydlewski 2017; Viehman and Redden 2018; Viehman *et al*. 2017, 2018, 2022).

While the majority of drifter tracks pass to the south of the FORCE site along quasi-stable trajectories near the middle of Minas Passage, those that do pass through the FORCE site have been observed to subsequently disperse elsewhere as described above (Sanderson *et al*. 2021, 2023b), and do not pass through the FORCE site for many of the following tidal cycles. This reduces the risk of fish-turbine interaction at the FORCE site for small-bodied fish during periods of elevated flow.

Indeed, Sanderson *et al*. (2023c) describe an analytical approach based on acoustic tag detections of IBoF salmon post-smolts in Minas Passage to estimate the expected number of encounters (i.e. expected number of times an individual would pass through the turbine swept area) with a hypothetical surface-deployed MKE device at the FORCE site. The expected number of encounters with IBoF salmon post-smolts from the Gaspereau River and Stewiacke River was 0.003 and 0.001, respectively (after accounting for new data on post-smolt swimming depth in Minas Passage). However, the expected number of encounters may well be fewer, because fish may detect the MKE device and exhibit avoidance or evasion behaviours to prevent being struck. Therefore, estimates of encounter probability calculated using the approach of Sanderson *et al*. (2023c) represent upper limits on mortality, because this assumes that all encounters are fatal, and does not consider avoidance or evasion behaviour, or that fish can pass through the swept area of a MKE device unharmed.

Other small-bodied fish whose movements through Minas Passage are also determined by tidal advection and current trajectories (e.g., alewife, striped bass, IBoF salmon kelt) may have a similarly low expected number of encounters with a surface-deployed MKE device at the FORCE site. The extent to which the movements of large-bodied fishes (e.g., white shark) in Minas Passage are influenced by tidal advection is not fully understood, but they may have greater control over their trajectories during periods of elevated flow by virtue of their body size and control over their trajectories during periods of elevated flow (C. Bangley, *pers. comm.* 2024).

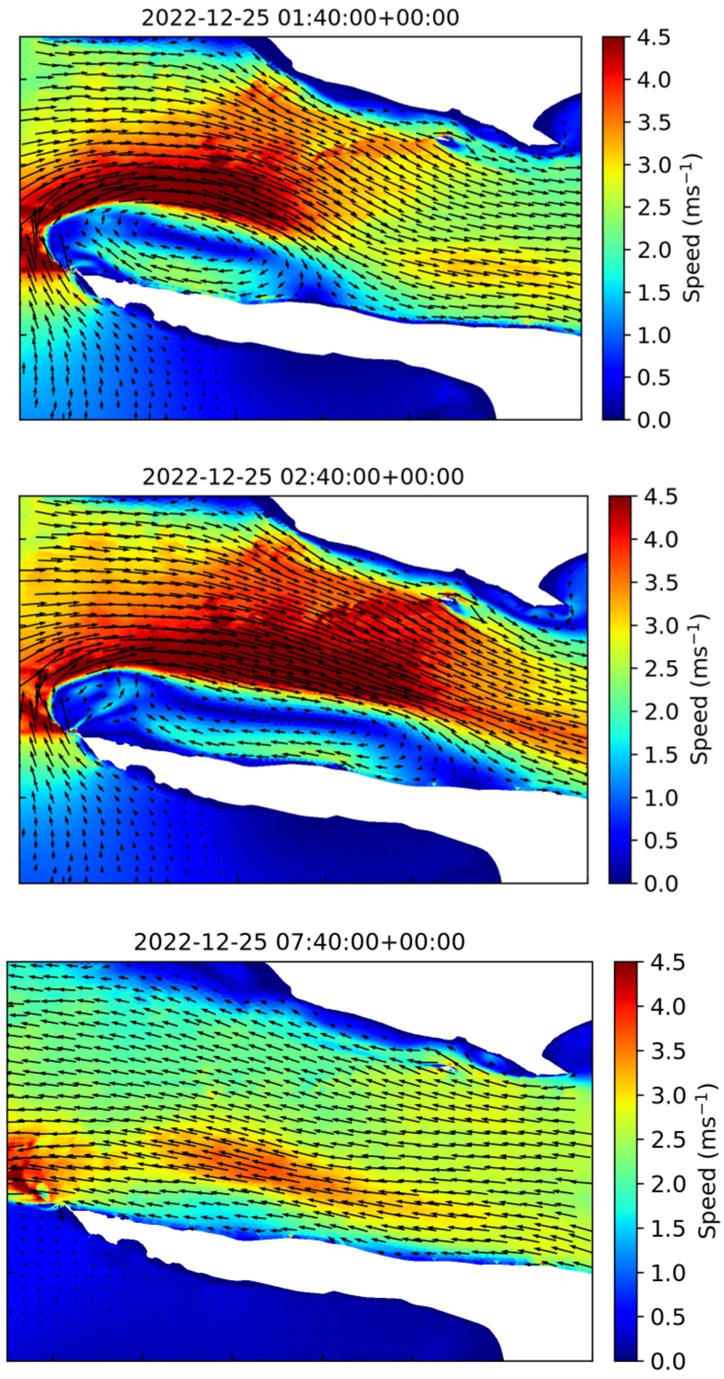

Figure 4: Modeled current speed through Minas Passage during early flood (top panel), late flood (middle panel) and ebb (bottom panel) tide phases. The arrows indicate velocity vectors, and the background is coloured by tidal current speed (m/sec). (Source: Sanderson et al. 2023).

Fish behaviour in Minas Passage and their ability to detect a MKE device at the FORCE site and exhibit avoidance and evasion behaviour to prevent collision is presently unknown., Empirical evidence of avoidance and evasion behavior in the presence of operational MKE devices is increasing (e.g., Bender *et al.* 2023), and in some instances demonstrates avoidance behaviour at distances > 100 m upstream from the turbine swept area (e.g. Viehman and Zydlewski, 2015; Shen *et al.* 2016). However, some species that are present in Minas Passage during winter (e.g., striped bass; Sanderson and Redden 2016) may become inactive or 'dormant' (Tagatz 1961; Kelly and Kohler 1999) when water temperatures decrease to -1.5C, are likely drifting passively with the dominant tidal current (Keyser *et al.* 2016), and may have reduced capacity to detect a device and exhibit avoidance or evasion behaviour. Furthermore, the extent to which the complex hydrodynamics of Minas Passage and their associated effects (turbulence, turbidity and entrained air) might obscure cues from an operational MKE device, or the ability of fish to detect and respond to those cues is unknown and can only be acquired once an operational MKE device is deployed at the FORCE site.

2. How do the different characteristics of tidal energy devices influence the likelihood of harm and/or death of fish and aquatic species at risk?

Understanding the potential risk of MKE devices to fish and aquatic species at risk requires knowledge of the various technologies used to extract kinetic energy from tidal currents. Although more than 40 tidal stream technologies were developed to the prototype stage between 2006-2013, a convergence towards horizontal-axis turbines has recently been observed (IRENA 2020; Kempener and Neuman 2014). Some well-developed and deployed horizontal-axis turbines (e.g. Atlantis AR1500 – Risch *et al.* 2024) use blades that are radially attached to a horizontal shaft, and either the hub or blades typically turn 180 degrees to accommodate reversing flow direction on flood and ebb tides (IRENA 2020; Kempener and Neuman 2014) (Figure 5a). However, for some surface-deployed designs, the entire device may rotate 180 degrees on a turret system as the tide switches between flood to ebb phases (e.g., PLAT-I).

Vertical-axis turbines are less common and use blades that are positioned parallel to a rotating shaft, allowing the device to extract energy irrespective of the tidal flow direction (IRENA 2020) (Figure 5b). The blades of both horizontal- or vertical-axis turbines can also be enclosed in a duct (funnel or shroud) that concentrates and streamlines the flow to increase power generation (e.g., Open Hydro) (IRENA 2020; Kempener and Neuman 2014) (Figure 5c). Horizontal- and vertical-axis turbines (open or ducted) can be deployed near the surface on floating tidal energy platforms, or bottom-mounted on the seafloor using a gravity-based mooring. Additional tidal stream technologies like reciprocating devices that use oscillating hydrofoils attached to an arm (Figure 5d), Archimedes screws that use a helical-shaped impeller (Figure 5e), kinetic paddle wheels with accelerator plates that concentrate tidal flows, and tidal kites that move in a figure-eight trajectory through the tidal stream to generate power (Figure 5f), are largely in the prototype demonstration phase. Although some of these technologies may ultimately be considered for demonstration at the FORCE tidal demonstration site, the sector is converging towards horizontal-axis turbines, and these are likely to form the basis of commercial scale tidal stream energy development in the foreseeable future.

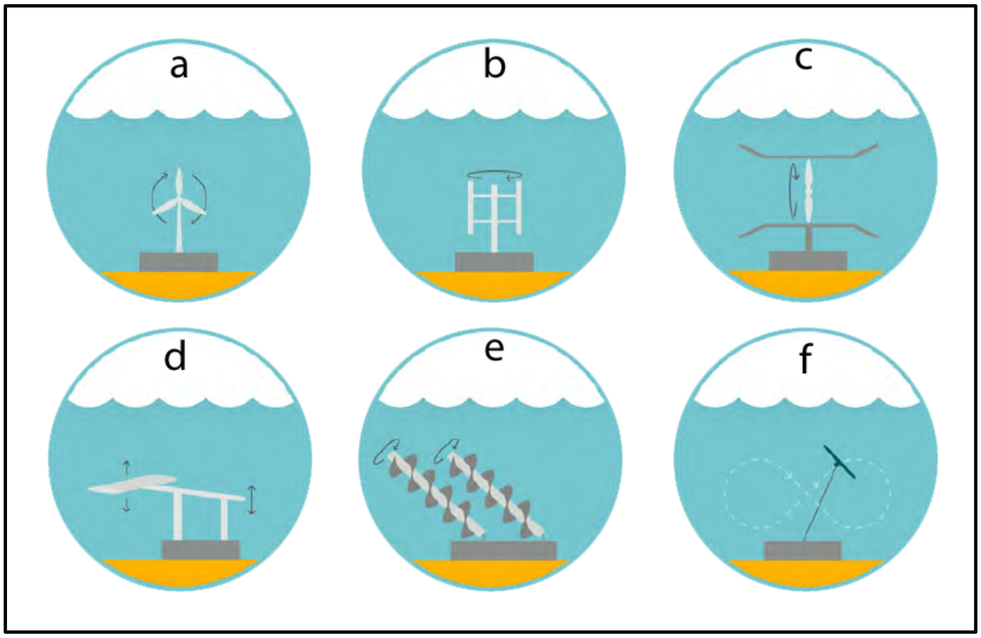

Figure 5: Different tidal energy technologies (reproduced from (IRENA, 2020))

As indicated above, the effects of pressure changes, cavitation and shear forces from modern MKE devices are unlikely to cause substantial harm to fish (Polagye *et al.* 2014; Hammar *et al.* 2013; Amaral *et al.* 2015; Bevelhimer *et al.* 2015; 2017; Grippo *et al.* 2017; Sparling *et al.* 2020; Copping *et al.* 2021). Although Brown *et al.* (2023) conducted an extensive review of tidal stream technologies and concluded that MKE devices can be designed that represent a low risk to fish, collision risk with horizontal-axis turbines remains a primary concern in Minas Passage.

MKE devices are designed to begin rotating when the flow rate reaches a speed at which power generation becomes viable; often referred to as the 'cut in' speed of the device (Copping *et al.* 2023). The cut in speed varies among MKE device designs but is typically about 1.0-1.5 m/sec (Lewis *et al.* 2021; Ouro *et al.* 2023). Once a MKE device begins to rotate, the rotational speed (rpm) will be proportional to the speed of the tidal flow; increasing the tip speed of the blade with increasing flow rates. If a fish were to enter the rotor swept area of a horizontal-axis turbine, the probability of collision with a turbine blade will depend on several factors, including: i) the rotational speed of the device; ii) the particular part of the turbine blade closest to the fish (as the tip of the blade moves much faster through the water than positions along the blade that are closer to the rotor); iii) the rotor diameter; and iv) the size, length, and swimming speed of the fish (Copping *et al.* 2018). Although tip speed is an important parameter for determining the likelihood of harm or death to fish, the rotational speed of the turbine is not expected to be a determining factor as larger turbines rotate at a speeds proportionally slower than smaller turbines, while tip speed remains the same at a specific tidal flow speed (Manwell *et al.* 2009). Thus, relatively large, slowly rotating (< 15 revolutions per minute) horizontal-axis turbines are expected to present a lower risk of collision with fish in Minas Passage than those that rotate more quickly – regardless of whether they are bottom-mounted, or surface-deployed.

3. What scale of tidal energy development (project specific and cumulative) can occur in Minas Passage before unacceptable impacts to fish and aquatic species at risk become likely?

How the magnitude of environmental effects scale with an increasing number of MKE devices remains uncertain. The cumulative effects of arrays of tidal energy devices on fish are not well understood as commercial scale arrays are currently under development in various jurisdictions and their environmental effects are yet to be documented. However, Hasselman *et al.* (2023) developed generalized concepts for how environmental effects might scale for seven stressor-receptor interactions (including collision risk) using terminology adapted from the cumulative environmental effects literature that are applicable to tidal energy development in Minas Passage.

Collisions may manifest as additive, antagonistic or synergistic effects (see Table 2 in Hasselman *et al.* 2023) depending on the configuration and location of an array. If an array is configured to optimize energy extraction and is installed across an important migratory corridor (i.e., 'in parallel'; Wilson *et al.* 2006) with no alternative routes for fish to access important resources (e.g., foraging grounds, spawning habitat, etc.), then effects may be additive or perhaps synergistic. Under this scenario, migratory fishes would need to navigate through the array and may have an elevated risk of collision as they attempt to access resources. Additive effects could also arise under this scenario if fish exhibit avoidance or evasion behaviours to prevent collisions. Ultimately, how effects of collisions manifest for arrays may be site specific and technology specific (e.g., surface-deployed vs. bottom-mounted devices; linear or staggered positioning, etc.) and dependent on a variety of additional factors, including the physical habitat characteristics of the environment, the species under consideration, and their capacity to exhibit avoidance and evasion behaviour (Hasselman *et al.* 2023).

It is not yet possible to determine the scale of tidal energy development that could occur in Minas Passage before 'unacceptable impacts' (i.e., species-specific population level consequences) to fish and aquatic species at risk may become likely. However, tidal energy development in Minas Passage is presently limited to the FORCE tidal demonstration site (1.0 x 1.6 km) – a relatively small area located in the northern portion of Minas Passage. Given the role of tidal advection, the trajectories of small-bodied fish through the middle of Minas Passage, and the expected number of encounters between fish and MKE devices at the FORCE, the risk of collision seems inherently small. Although the FORCE site has five berths available to support tidal technology development, the size of the site and its location in Minas Passage places inherent limits on the scale of development that can occur at the site and the subsequent risk to fish.

4. Are there specific species that are particularly vulnerable to harm and/or death from tidal energy devices in Minas Passage?

Fish species that occur in Minas Passage for the greatest amount of time and that incur multiple transits through the area during their migration into and out of Minas Basin, particularly during winter when water temperatures may reduce swimming activity (Tagatz 1961; Kelly and Kohler 1999), may be particularly vulnerable to collision risk. This could include striped bass that may be drifting passively with the dominant tidal currents during winter (Keyser *et al.* 2016; Sanderson and Redden 2016) and may have reduced capacity to exhibit avoidance or evasion behaviour. However, small-bodied fish like striped bass may be deflected around the turbine swept area by the pressure field generated by a turbine operating at the Betz limit that diverts approximately one-third of the upstream flow (Betz, 1966) (e.g. ABPMR 2010; Grippo and Hlohowskyj 2012). This blocking effect provides a purely physics-based discounting factor on collision risk (Garrett and Cummins 2007) and is an important factor to include when considering the potential for harm from an operational MKE device.

Large-bodied fish such as white shark may have reduced likelihood of safely passing through the turbine swept area without being struck by a turbine blade. However, preliminary results from acoustic tagging data suggest that white shark can maintain control over their movements in Minas Passage across a broad range of tidal flow conditions (C. Bangley, *pers. comm.* 2024).

5. Are there specific locations within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?

Water during tidal flow is concentrated in the southern two-thirds of the Minas Passage throughout the tidal cycle (Figure 4). During periods of elevated flow in Minas Passage, advection by tidal currents dominates the movements of small-bodied fish like alewife (Tsitrin *et al.* 2022), striped bass (Keyser *et al.* 2016), IBoF salmon post-smolts

(Sanderson *et al.* 2023c) and kelts (Sanderson *et al.* 2021; Sanderson *et al. in prep.*). Their movements approximate those of passive drifters that follow a quasi-stable trajectory that passes to the south of the FORCE site near the middle of Minas Passage (Figure 3; Sanderson *et al.* 2021) and that adheres to the dominant tidal current trajectories (Figure 4). As such, MKE deployment to the south of the FORCE site – closer to the middle of Minas Passage – could present greater risk of fish-turbine interactions than the present location of where tidal energy demonstration is planned. If the FORCE site was to be extended southwards of its present location, the potential for fish-turbine interactions would doubtless increase, but given existing uncertainties about fish behaviour in the presence of operational MKE devices in Minas Passage, this does not necessarily imply that the risk of collision would also increase.

6. Are there specific temporal periods within Minas Passage where tidal energy devices present a greater risk to fish and aquatic species at risk?

Fish presence and abundance in Minas Passage varies seasonally. Although some resident species are present in Minas Passage year-round (e.g., striped bass), the greatest abundance and diversity of migratory species (alewife, American shad, herring, dogfish, white shark etc.) occurs during May-June as they move into Minas Basin and its tributaries for spawning or feeding, and again during September-October as young-of-the-year and feeding adults depart Minas Basin to the outer Bay of Fundy and regions beyond. During July and August, the biomass of fish is somewhat lower in Minas Passage (Melvin and Cochrane 2010; 2017; Redden *et al.* 2014a; Keyser *et al.* 2016*; S*tokesbury *et al.* 2017; Viehman *et al.* 2018; 2021); thereby reducing potential for fish-turbine interactions. Moreover, as indicated above, for the majority of these species, their movements are expected to follow quasi-stable trajectories (Figure 3; Sanderson *et al.* 2021) that mostly pass to the south of the FORCE site and closer to the middle of Minas Passage, adhering to the dominant tidal current trajectories in Minas Passage (Figure 4).

Winter (January-March), when water temperatures in Minas Passage may be reduced to between -1.5 to 0 ^{o}C (Redden *et al.* 2014a; Sanderson and Redden 2016) may present a period of increased risk of collision for some resident species. For instance, striped bass may become inactive or 'dormant' under these conditions, are likely drifting passively with the dominant tidal current (Keyser *et al.* 2016) and may have reduced capacity to exhibit avoidance or evasion behaviour.

7. How do environmental factors influence the likelihood of harm and/or death to fish and aquatic species at risk from tidal energy devices?

Some environmental factors could influence the outcome of fish-turbine interactions and the likelihood of collision. For instance, if a fish was on a trajectory that would result in it passing through the swept area of a turbine, water flow velocity could reduce the amount of time the fish has between initially detecting the device and successfully exhibiting avoidance or evasion behaviour. Although reaction time to device detection might remain the same, elevated current speeds would reduce the amount of time available to successfully exhibit those behaviours, potentially leading to the fish passing through the swept area and increasing the likelihood of collision.

Reduced water temperatures during winter may reduce the capacity of some species to exhibit avoidance or evasion behaviour. Some species (e.g. striped bass) may become inactive or 'dormant' in Minas Passage during winter (Sanderson and Redden 2016), may exhibit reduced swimming activity (Tagatz 1961; Kelly and Kohler 1999) and may be drifting passively with dominant tidal current (Keyser *et al*. 2016).

The extent to which complex hydrodynamics and their associated effects (e.g., turbulence, turbidity, extent of entrained air), such as those experienced during periods of elevated flow in Minas Passage, might influence the likelihood of collisions, if any, are not well understood. Of these, entrained air might obscure cues/signals generated from a surface-deployed tidal turbine that may be used to detect the device and instigate avoidance or evasion behaviour, or entrained air may affect the ability of fish to detect those cues/signals during periods of high flow.

8. Are there measures that could be implemented to avoid and mitigate harm and/or death to fish and aquatic species at risk from tidal energy devices?

Although acoustic deterrent devices may be an effective mitigation measure to prevent interactions with tidal turbines for some fish species (e.g., Gibson and Myers 2002; Popper *et al*. 2004), this is not something that has been assessed in Minas Passage. Given the seasonal presence of many migratory species in Minas Passage and their most likely trajectory through the middle and southern portions of Minas Passage as they migrate into and out of Minas Basin, the apparent low risk of collision for fish at the FORCE site does not justify a great deal of effort to test various acoustic deterrent devices. However, some preliminary testing using ultrasonic deterrents during periods when large schools of fish (alewife, American shad, Atlantic herring) are anticipated to be present in Minas Passage may provide valuable information about their effectiveness if required at some later time. Arguably, the most effective mitigation approach will include enhanced understanding of how fish use Minas Passage and their responses to the presence of an operational MKE device deployed at the FORCE site.

KNOWLEDGE GAPS AND FUTURE RESEARCH

Minas Passage is an inherently challenging place to conduct fish research and much remains to be understood about the spatial and temporal distribution of various fish species and their response(s) to the presence of MKE devices at the FORCE site. Considering the inherent limitations of some monitoring technologies (e.g., hydroacoustics) associated with the complex hydrodynamics of Minas Passage and its effects (turbulence, turbidity, entrained air), acoustic telemetry may provide the most effective way to improve our collective understanding of species-specific use patterns of Minas Passage, and species-level responses to tidal turbines at the FORCE site.

Recent advances in the application of acoustic telemetry and development of analytical approaches are providing new insight about the likelihood of fish-turbine encounters at the FORCE site (Sanderson *et al*. 2023 a,b,c) that could be expanded to other species to help understand the risk of tidal energy demonstration in Minas Passage. This could include commercially valuable species that have not previously been the subject of acoustic tagging efforts (e.g. Atlantic herring) and those that are of cultural relevance that require additional tagging effort (e.g. American eel, Atlantic tomcod). With deployment of a MKE device at FORCE, dense arrays of acoustic receivers could be deployed to conduct localization experiments (Smith 2013) to examine the capacity of different species to exhibit avoidance and evasion behaviors under varying tidal flow conditions. This information would be directly relevant for quantifying the potential risk of fish-turbine interactions and improving our understanding of the realized risk to fish from tidal stream energy development in Minas Passage and at the FORCE tidal demonstration site.

SUMMARY AND CONCLUSIONS

Understanding the environmental effects of MKE devices on fish in Minas Passage is important for ensuring the responsible development of the marine renewable sector in Nova Scotia. Despite more than a century of contemplation and over a decade of focused research since the inception of FORCE, the effects of tidal stream devices on fish in Minas Passage remains largely unknown, partly because of the absence of deployed MKE devices. Nonetheless, in anticipation of sector development, much research has been conducted for a variety of fish species that are of conservation concern, of cultural relevance to First Nations communities, or support important regional fisheries. However, this information exists as a series of peer-reviewed publications, conference proceedings, and reports in the grey literature whose information has not been collated. The objective of this work was to synthesize this information to establish the current state of knowledge about fish temporal and spatial distribution in Minas Passage to help inform the risk of tidal stream energy demonstration at the FORCE site[21].

Of the 68 species of marine and diadromous fishes that are known to navigate Minas Passage at least once over the course of their life history, approximately one half are present annually, with the remainder being occasional or irregular visitors. The majority of the regular users of Minas Passage appear to use it as a migratory corridor and comprise either diadromous species moving between spawning grounds and foraging/growth areas (e.g., American eel, American shad) or marine species accessing foraging grounds in Minas Basin (e.g., white shark). Most of the regular users migrate through Minas Passage in spring (May-June) and again in fall (September-November), but some are present year round (e.g., striped bass). Summer is a time of relatively low fish abundance in Minas Passage. While some species appear to transit Minas Passage rather quickly (e.g. on a single ebb or flood tide – American shad), others may move through Minas Passage repeatedly on successive tides before being swept into or out of Minas Basin (e.g. IBoF salmon post-smolts). Although many of the spawning migrants (such as American shad, Atlantic herring) are pelagic in habit and may be moving through Minas Passage at depths where they could encounter both surface-deployed and bottom-mounted MKE devices, species that are normally considered demersal in habitat (e.g., Atlantic sturgeon) may be found near the surface. As such, there is much nuance in species-specific use patterns of Minas Passage by many fishes that complicates the determination of the likelihood of harm from MKE devices.

During periods of elevated tidal flow in Minas Passage, advection by tidal currents plays an overarching role in the spatial distribution of small-bodied fish like alewife, striped bass, IBoF salmon post-smolts and kelts. Indeed, the routes of fish moving through Minas Passage appear to follow a quasi-stable trajectory that passes to the south of the FORCE site near the middle of Minas Passage (Figure 3) and adheres to the dominant tidal current trajectory (Figure 4). Trajectories that do pass through the FORCE site have been observed to subsequently disperse elsewhere, and do not pass through the FORCE site for many of the following tidal cycles. This reduces the risk of fish-turbine interaction at the FORCE site for small-bodied fish during periods of elevated flow. Indeed, an analytical approach based on acoustic tag detections of IBoF salmon post-smolts indicated the expected number of encounters with a MKE device at the FORCE site was ≤ 0.003 (Sanderson *et al.* 2023c). The extent to which the movement of large-bodied fishes such as white shark are dictated by tidal advection is not fully understood, but they may have greater control over their movements by virtue of their size and swimming ability. It is

[21] Given the widespread activity *vis à vis* tidal waters and tidal power generation from hydrokinetic devices, it is possible that some examples have been missed.

also very likely that their acute sensitivity to electromagnetic and hydrodynamic forces would keep them at some distance from any operating turbine.

Fish have been shown to exhibit avoidance and evasion behaviour in the presence of operational MKE devices elsewhere. However, it is not known whether the complex hydrodynamics of Minas Passage and their associated effects (e.g., turbulence, turbidity, entrained air) might obscure cues from an operational device, or affect the ability of a fish to detect and respond to those cues. Due to cold water temperatures, resident species that are present in Minas Passage during winter such as striped bass may be relatively inactive (dormant) and have reduced capacity to exhibit avoidance or evasion behaviour at this time of year.

With respect to MKE technologies, relatively large, slowly rotating (< 15 revolutions per minute) horizontal-axis turbines are expected to present reduced risk of collision to fish in Minas Passage compared with those that rotate more quickly – regardless of whether they are bottom-mounted, or surface-deployed. Slowly rotating MKE devices increase the chances of a fish safely passing through the turbine swept area without making contact with a turbine blade. Tidal device deployment in Minas Passage is presently limited to the FORCE test site – a relatively small area in the northern portion of Minas Passage that places inherent limits on the scale of development and risk to fish.

Acoustic telemetry is providing valuable information about the spatial and temporal distribution of various fish species in Minas Passage and new insights into the likelihood of fish-turbine encounters and could be expanded to include commercially important species and those that have not so far been the focus of much tagging effort. Acoustic telemetry also provides an opportunity to conduct localization experiments around deployed MKE devices and to examine the potential for various species to exhibit avoidance and evasion behaviour under varying conditions in Minas Passage. This information is directly relevant for quantifying the risk of fish-turbine interactions at the FORCE tidal demonstration site. Without the deployment and monitoring of an operational device, however, many of the questions about the potential risk to fish from turbines in Minas Passage will remain unanswered.

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