OERA - Research on Tidal Marine Energy

Acoustic Tracking of Fish Movements in the Minas Passage and FORCE Demonstration Area: Pre-Turbine Baseline Studies (2011-2013)

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Executive Summary

The impact on fish of large tidal in-stream tidal energy converters (TISEC) deployed in very high flow environments (>2 m/s) is unknown. The issue is especially pertinent in areas where migratory fish, including transboundary species of special concern (endangered, threatened or commercial) are present. Direct contact with turbine blades and subsequent injury or mortality, and indirect effects on behaviour and use of natural migratory pathways, continue to be the primary concerns of regulators and many other stakeholders.

To address the potential risk of environmental effects on fish that utilize the FORCE test area as a migratory route and for other movements (e.g. foraging), a multi-year tracking study was conducted to assess the movements of four species of concern - Atlantic sturgeon (regionally threatened), Atlantic salmon (smolts; endangered inner Bay of Fundy population), American eel (silver stage; threatened) and striped bass (endangered Bay of Fundy population). They display broad characteristics of movement and depth preferences, and may provide insight on potential impacts on species with similar natural history characteristics.

The main objectives of the study were to:

1. Determine temporal (seasonal, diel) movements of tagged fishes within the Minas Passage and FORCE test area;
2. Identify broad distribution patterns in the Minas Passage (north to south, east to west);
3. Determine depth preferences and movements in relation to tidal stage (ebb/flood) and current speed;
4. Estimate maximum travel speeds through Minas Passage; and
5. Assess potential risks of fish-turbine interactions at the FORCE site.

VEMCO animal tracking technology was used to detect near year-round animal movements (path, velocity and depth) and behaviour of 386 tagged fish in Minas Passage during 2010-2013. VEMCO VR2w hydro-acoustic receivers provided autonomous, passive, single channel, omnidirectional detection of coded acoustic transmitters which entered the detection radius. Receivers were placed in lines (“listening gates”) at 300-400 m intervals across both the Minas Passage (5 km wide) and the FORCE test site (1 km wide). The arrays were designed to detect the presence of transmitters surgically implanted in fish as they moved within the Minas Passage and during migrations into and out of the Minas Basin. Custom modified A2 Model SUB streamlined instrument floats were fitted with instrumentation (receiver and an acoustic release), and moored 2-3 m above the seafloor for periods up to 1 year.

Fish were implanted with V9, V13 or V16 electronic transmitters, depending on fish size. Most tags included pressure sensors for travel depth determination. Salmon were tagged in the Stewiacke and Gaspereau Rivers; eels were tagged in the Gaspereau River; striped bass were tagged in the Stewiacke River and Minas Basin nearshore areas; and Atlantic sturgeon were tagged from Minas Basin intertidal weirs and an otter trawl fishing vessel.

Results show that the Minas Passage is used for fish migration purposes and other movements by fish tagged in this and other tracking projects. Detection of non-target species included white shark and spiny dogfish.

Atlantic salmon post-smolts traversed the passage in late May to mid-June *en route* to the Bay of Fundy and beyond. Of those smolts detected leaving the river mouths (N=20), nine were detected in Minas Passage as they quickly out-migrated; of these, five were detected by receivers at the FORCE test site.

Tagged American eels (silver stage) were shown to exit the Minas Basin via the Minas Passage during mid-September to mid-November, with movements occurring primarily in the southern half of the passage, over short time periods (1-6 days), and mostly at night during ebb tide. Maximum estimated travel rate was 3 m/s. At the FORCE test area, about 90% of eel detections occurred during ebb flow periods, with movements largely within the top 30 m of the water column.

Atlantic sturgeon sub-adults entered Minas Basin (summer feeding grounds) via Minas Passage in the spring. They made sporadic use of the Minas Passage throughout the summer, prior to exiting to the outer Bay in the fall. Sturgeon detections in the passage were more concentrated in the southern region of the passage. Although sturgeon were detected at all water depths, their movements in and near the FORCE site showed a preference for depths ranging from 15 to 40 m. The highest estimated travel speed (current assisted), between receiver lines, was 3.2 m/s.

Striped bass, especially large bass (>60 cm), spent more time in the Minas Passage and near the FORCE test area than any of the other fish species examined. Residency spanned summer, fall and winter. Of the 165 tagged striped bass, 52 swam through the FORCE tidal turbine test site in the Minas Passage, and many at depths of proposed turbine hub height. Striped bass were detected mostly in the top 40 m of the water column, and were located closer to the surface during the night. Maximum travel rate (tide assisted) across the Minas Passage was 4.0 m/s. Many tagged striped bass moved within Minas Passage throughout the winter months when water temperatures were in the range of 0-3°C. At these temperatures, striped bass are expected to have reduced metabolic rates (i.e. sluggish) and may have limited abilities to detect and avoid turbine infrastructure. This species makes near year-round use of the passage, including the FORCE test site during winter, and may be at considerable risk of interaction with turbines. Modelling of collision probability, based on available tracking data and associated environmental conditions (current speed and water temperature), is currently underway.

Although general trends in the movements of tagged fish were apparent, the tag transmission datasets for Minas Passage represent only a fraction (<40%) of the potential detections of tag transmissions, in large part because of high flow effects (i.e. elevated ambient noise levels) on the detection of complete transmission sequences (8-10 consecutive pings separated by unique spacing intervals). If the receiver does not detect a complete ping sequence, then the transmission is not logged. Detection range (distance) is known to decline as flow speed increases. These effects can result in tagged fish being able to pass through Minas Passage undetected during high flow periods.

The FORCE site represents a relatively small area within the Minas Passage (<20% of the passage width), with a single turbine of about 100 m^2 occupying only 0.02% of the cross sectional area of Minas Passage. It is unknown how well migratory fish can control their movements and avoid structures within the passage when travelling at times of peak current speed. The likelihood of fish-turbine encounters may vary among species and may also increase with increasing numbers of tidal turbines. Risk is largely dependent on fish size, swimming depth, duration of occupancy at the site, sensory abilities, and water temperature (i.e. effects of metabolic rate and alertness). The hypothesis that fish avoid swimming in very fast currents in Minas Passage remains untested due to detection efficiency limitations of acoustic receivers operating in a tidal race.

Recommendations for further work at the FORCE test site include near-field studies using a range of acoustic technologies (e.g. multibeam sonar, acoustic cameras) and applications to examine fish-turbine interactions and fish behaviour (e.g. turbine avoidance) in close proximity to in-stream turbine devices. Species of commercial and conservation importance, and periods of high fish traffic in Minas Passage, should be considered for inclusion in the environmental effects monitoring program.

Acknowledgements

This project was funded by the Offshore Energy Research Association (OERA) of Nova Scotia, the Fundy Ocean Research Centre for Energy (FORCE), an NSERC grant awarded to Michael Stokesbury and Michael Dadswell, Acadia University (Graduate Student Awards), the Canada Research Chairs program, and Fisheries and Oceans Canada. The Acadia Centre for Estuarine Research and Research Operations Manager, Jeremy Broome, coordinated Minas Passage receiver deployments and recoveries and provided equipment maintenance and project management support. Fred Whoriskey and the Ocean Tracking Network at Dalhousie University are thanked for developing and maintaining the OTN-MPS receiver line in Minas Passage, and for providing acoustic releases and technical and field assistance. Some receivers used in this study were provided by Fisheries and Ocean Canada. Murray Scotney and staff at Vemco Ltd and Open Seas Instrumentation Inc are thanked for technical assistance with instrumentation and housings.

We are grateful to several boat captains, including the late Croyden Wood Jr, Mark Taylor, Bob Vaughan, and their crews, for field assistance with instrument deployments and retrievals. Captain Glanville Travis and Charles Travis are thanked for otter trawl captures of Atlantic sturgeon. Weir operators, Tony Lewis and Wayne Linkletter, are thanked for providing access to their fish weirs for tagging of Atlantic sturgeon. Nova Scotia Power Inc staff, specifically Jean-Marc Nicholas, Tim Curry, and Darcy Pettipas, provided equipment, technical support and access to eel sampling sites.

We appreciate the field support provided by many, including members of the Striped Bass Anglers Association of Nova Scotia (SBAANS) and other recreational fishers, OTN technical staff - Duncan Bates, Stéphane Kirchhoff, Ian Beveridge and Susan Dufault, DFO staff – David Hardie, and Acadia University students - Freya Keyser, Colin Buhariwalla, Peter Porskamp, Matthew Baker, Kaycee Morrison, Montana McLean, Sierra Wehrell, William Roberts, Tom Gregoire, Laura Logan-Chesney and Jeff Beardsall. Richard Karsten and Brian Sanderson provided data and figures on tidal height and current speed. Jeremy Broome, Freya Keyser and Montana McLean prepared figures shown in several sections in this report.

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Section 1: Project Introduction

Authors: MJW Stokesbury and AM Redden

1.1 Tidal Power Developments and Potential Impacts on Fish

Worldwide, high flow coastal areas are being examined for the potential to extract tidal energy to reduce dependence on fossil fuels and limit greenhouse gas emissions. Demonstration projects to determine the viability of tidal energy extraction are underway in several countries, including Canada. Several high energy sites in the Bay of Fundy have been identified as locations for potential development. Project viability includes aspects of both potential for, and cost of, energy extraction, and identification of negative environmental impacts, including impacts on resident and migratory fishes.

One of the main anthropogenic pressures that migratory fish face is the blocking of their routes by physical barriers such as dams and tidal barrages. Effects include fish mortality, as documented following turbine operation in an existing dam (causeway) at Annapolis Royal, Nova Scotia (Stokesbury and Dadswell, 1991). Autopsies of dead fish downstream of the turbine at Annapolis Royal indicated a range of causes of death: mechanical strike, pressure change, shearing and cavitation (Dadswell et al., 1986; Stokesbury and Dadswell, 1991). Although a second fish way was subsequently installed in the dam, continued turbine-related fish mortality (including Atlantic sturgeon) and effects on population size structure of at least some species remain concerns.

More recent tidal energy technological developments include stand-alone, seafloor-mounted tidal in-stream energy conversion (TISEC) devices. They do not block off passageways and are currently the preferred alternative to tidal barrages. As a catalyst for TISEC (tidal in-stream energy converter) development in Nova Scotia, a tidal turbine demonstration facility (Fundy Ocean Research Centre for Energy (FORCE) has recently been established in the Minas Passage (Figure 1.1). One of the main objectives of FORCE is to investigate the interactions between the environment and tidal turbine infrastructure. Multiple large scale turbines (capacity of 1 MW or more) are expected to be in operation by 2017. Planned deployment of turbines necessitates the gathering of information about how fish and other commercially valuable or threatened species use Minas Passage. Such data is essential for assessing the potential for direct and indirect interaction with tidal turbines.

To date, there have been no comprehensive field studies to assess the effects on fish behaviour of large TISEC devices deployed in high flow environments (>2 m/s). The issue is especially pertinent in areas where migratory fish, including species of special concern, are present. Direct contact with turbine blades and subsequent injury or mortality is the primary concern of regulators. Indirect effects on behaviour and use of natural migratory pathways is also of concern. In order to address issues of potential risk, baseline information on the temporal and spatial use of the Minas Passage and the FORCE demonstration area, in particular, are required.

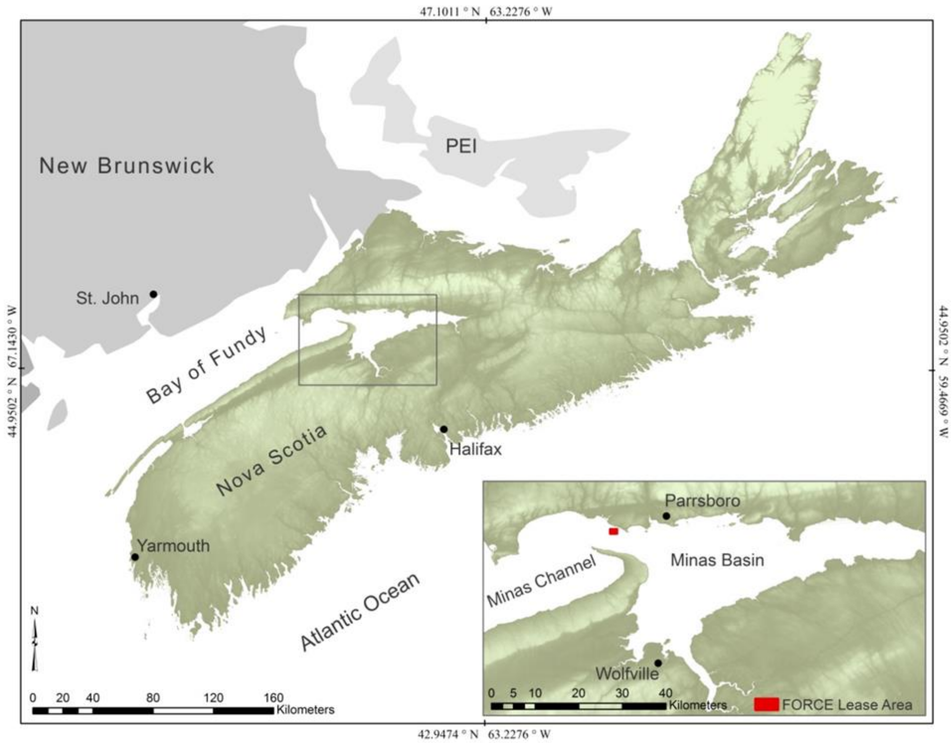

Figure 1.1. *Map of the Maritimes showing the Bay of Fundy and location of the FORCE Crown Lease Area in the Minas Passage, Upper Bay of Fundy, near Parrsboro, Nova Scotia.*

1.2 Bay of Fundy Migratory Fishes

Numerous fish species undertake migrations into the Bay of Fundy on a seasonal basis to feed and/or reproduce (Dadswell et al. 1984; Bradford and Iles 1992; Moore 1998; Rulifson et al. 2008). Commercially fished species include American lobsters (*Homarus americanus*), giant scallops (*Placopecten magellanicus*), spiny dogfish (*Squalus acantius*), Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), American shad (*Alosa sapidissima*), river herring (*Alosa* sp.), winter flounder (*Pseudopleuronectes americanus*), and Atlantic halibut (*Hippoglossus hippoglossus*) (NS Department of Energy 2008).

At-risk species, as designated by the Committee On the Status of Endangered Wildlife In Canada [COSEWIC], also occupy habitat in the Bay of Fundy and include, but are not limited to, the following:

1. Endangered species - inner Bay of Fundy Atlantic salmon (*Salmon salar*), Striped bass (*Morone saxatilis*) and Porbeagle shark (*Lamna nasus*); and
2. Threatened species - Atlantic sturgeon (*Acipenser oxyrinchus*) and American eel (*Anguilla rostrata*).

Populations of these species may be at greater risk following installation and operation of commercial farms of tidal turbines in narrow passages that also serve as migratory routes for fishes. Concerns over widespread impacts of tidal energy turbines, leading to significant declines in fish abundance, have been expressed by Dadswell et al. (1986) and Dadswell and Rulifson (1994).

Any assessment of risk requires seasonal to year-round monitoring of various fish species and how they naturally use waterways where development is planned.

1.3 Approaches to Monitoring Fish Movements

Hydroacoustic technology has been successfully used to track the migratory movements of numerous fish species (e.g. Lacroix and McCurdy, 1996; Cote et al., 2003; Welch et al., 2003; Lacroix et al., 2011), including those in high flow environments (Stokesbury et al., 2012). Telemetry systems involve transmitters (electronic tags) and acoustic receivers deployed in fixed locations. The transmitters produce sequences of high frequency sounds ("pings") at a set ping rate, and these sequences are recorded by the receivers when the transmitter is in close range (up to 700 m but variable depending on flow conditions). Each transmitter's sequence is unique, allowing tagged fish to be individually identified. To examine movement patterns and migration, a "gate" and/or "curtain" set-up is recommended (Heupel et al., 2006). In these formats, receivers are placed in lines across the study site to track fish as they enter and leave the area. In theory, placing receivers close enough to each other so that their detection ranges overlap ensures that all of the tagged fish that enter or leave the study area are detected.

1.4 Prior Fish Tracking Studies in Minas Passage

A pilot fish tracking study conducted in 2010-2011 in Minas Passage (Stokesbury et al. 2012) focused on developing techniques for tracking fish movements in high flow environments and collecting initial baseline data on the summer and fall movements of three species of concern - striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrinchus*) and American eel (*Anguilla rostrata*).

The main recommendations from the initial study were to:

1. extend the baseline study of Atlantic sturgeon, striped bass and American eel to allow examination of variability in movement patterns between years;
2. include tagging of the endangered inner Bay of Fundy Atlantic salmon (smolts); and
3. examine movement patterns (seasonal distribution, depth preferences) in the Minas Passage following the installation of at least one commercial turbine in 2012. This would allow before and after assessment of fish use of the FORCE test area.

1.5 Project Aims

To address the potential for environmental effects on fish that utilize the FORCE test area as a migratory route and for other movements (e.g. foraging) we focused on assessing the movements of four COSEWIC designated species of concern (Table 1.1) that display broad characteristics of movement and depth preferences and which may provide insight on potential impacts on species with similar natural history characteristics.

Table 1.1. *Selected at-risk fish species in the Bay of Fundy region and their status designations as determined by the Committee On the Status of Endangered Wildlife In Canada (COSEWIC).For the most current information, see* http://www.cosewic.gc.ca/eng/sct1/.

Species	Life History	COSEWIC Status
Striped bass (*Morone saxatilis*)	Pelagic	Endangered – Bay of Fundy (BoF) population (as of Nov 2012)
Atlantic salmon (*Salmo salar)*	Pelagic	Endangered – inner BoF population*
American eel (*Anguilla rostrata*)	Demersal	Threatened (as of May 2012)
Atlantic sturgeon (*Acipenser oxyrinchus)*	Demersal	Threatened (as of May 2011)

*Endangered under the Canadian Species at Risk Act (SARA)

At the time of project commencement, it was anticipated that at least one turbine would be installed in 2012, thus providing an opportunity to examine fish movements before and after turbine installation. The initial aims were to:

1) Determine the spatial and temporal patterns in fish movements within the Minas Passage;
2) Based on the movements observed, quantify the potential risk of fish-turbine interaction; and
3) Provide recommendations to developers and regulators on potential mitigation strategies to reduce the risks of negative impacts, if any, of TISEC devices.

As there have been no turbine installations since the project commenced, project aims were modified to focus solely on the collection of data that represent the natural use of the Minas Passage by several fish species of interest. The 2-year project extends the initial pilot project and provides strong baseline information that will inform post-turbine installation impact studies, and future studies on the acoustic detection of fish at FORCE.

The modified aims include:

1) Determination of the temporal (seasonal, diel) movements of tagged fishes within the Minas Passage and FORCE test area;
2) Identification of broad distribution patterns in the Minas Passage (north to south regions, east to west);
3) Determination of movements in relation to tidal stage (ebb/flood) and current speed;
4) Determination of depth preferences, for all species except Atlantic salmon (smolts are too small for pressure tags):

5) Estimation of fish travel speeds through the passage, based on detections of tags on multiple receiver lines; and
6) Identification of potential risk of turbine-fish interactions, based on detections of fish movement in and near the FORCE test site.

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Section 2: Study Site & General Methods

Authors: JE Broome, AM Redden, MJW Stokesbury, D Bates, FM Keyser, R Karsten and B Sanderson

2.1 Site Description

The Minas Passage is located in the Bay of Fundy, Nova Scotia, Canada and connects the Minas Channel to the Minas Basin (Figure 1.1). The 5-6 km wide and 13 km long passage has an average depth of 53 m, reaching about 150 m at its deepest point (Figure 2.1). Mean water depths in and around the FORCE lease area range from approximately 25 to 85 meters (Figure 2.1).

The tide in the Minas Passage is dominated by the M2 tide producing a semi-diurnal tide (high and low tides twice daily), with a period of 12.4 hours. The maximum tidal range in Minas Passage can exceed 13 m and approaches 17 m in areas of Minas Basin (Karsten et al., 2008). The extreme tidal amplitude in the region is caused by resonance; the depth and geometry of the Bay of Fundy/Gulf of Maine are such that the tidal wave takes slightly longer than ¼ period of the M2 tide to transit from the Atlantic Ocean to the tip of Minas Basin (Karsten et al., 2008). During spring tides, current speeds in Minas Passage can exceed 6 m/s at the surface and have been shown to be as high as 3.3 m/s at 3 m above the seafloor (S. Melrose, pers. comm.).

The tides and tidal currents in the upper Bay of Fundy have been simulated using the Finite Volume Coastal Ocean Model (FVCOM) following Karsten et al. (2008) and Karsten et al. (2012). The model only specifies the tides on the open boundary far from the Minas Passage. The tides and currents are allowed to develop in response to the local bathymetry according to basic laws of physics, conservation of mass and momentum. The model has been validated against tide gauge measurements of surface height and ADCP measurements of tidal currents. For validation purposes, simulations were run to coincide with ADCP deployments. A harmonic analysis of the results of these simulations was used to predict the elevation and currents at this study's VEMCO VR2w receiver locations during periods of receiver mooring deployment.

The flood and ebb tides in Minas Passage have very different dynamics. During the flood tide, the flow must pass around Cape Split (Figure 2.2), forcing the flow north so that the flood tide is restricted to the northern 2/3 of the passage (there can actually be a weak return flow along Cape Split). This produces a very strong jet of flow in the northern section of the passage. As shown in Figure 2.2, the FORCE lease area lies on the northern edge of this jet, with strong south-easterly flow through the southern portion of the region that becomes weaker closer to the northern shore of the passage. During the ebb tide, the flow out from the Minas Basin spreads more evenly across the entire passage, resulting in lower flow speeds. Maximum speeds can be 1 to 1.5 m/s lower on ebb than flood at locations in the FORCE area (Figure 2.3).

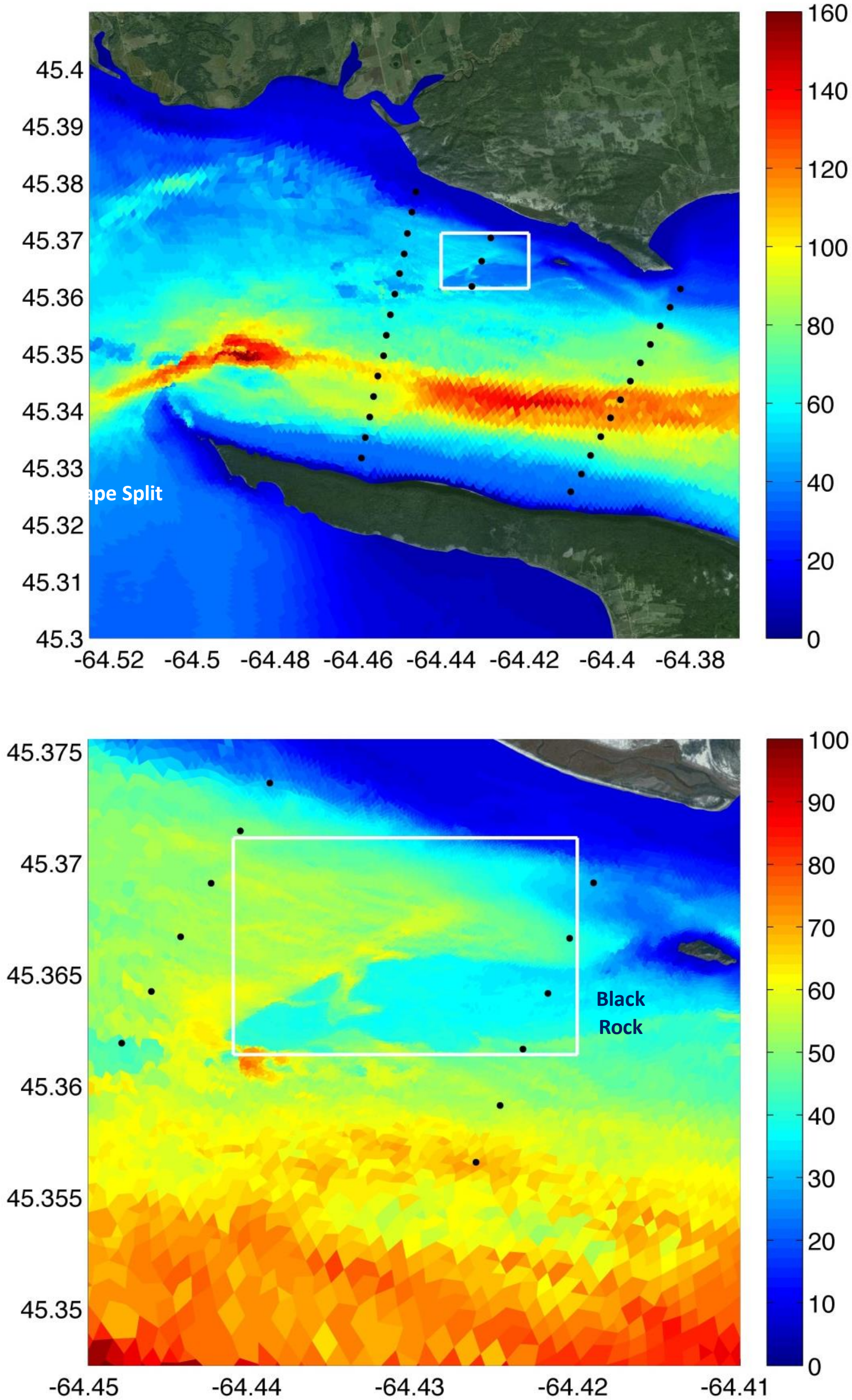

Figure 2.1. *Mean water depths (m) in Minas Passage (top) and within and near the FORCE Crown Lease area (bottom). Locations of moored VEMCO receivers are indicated with the black dots and the white box is the FORCE lease area. Note the locations of Cape Split and Black Rock.*

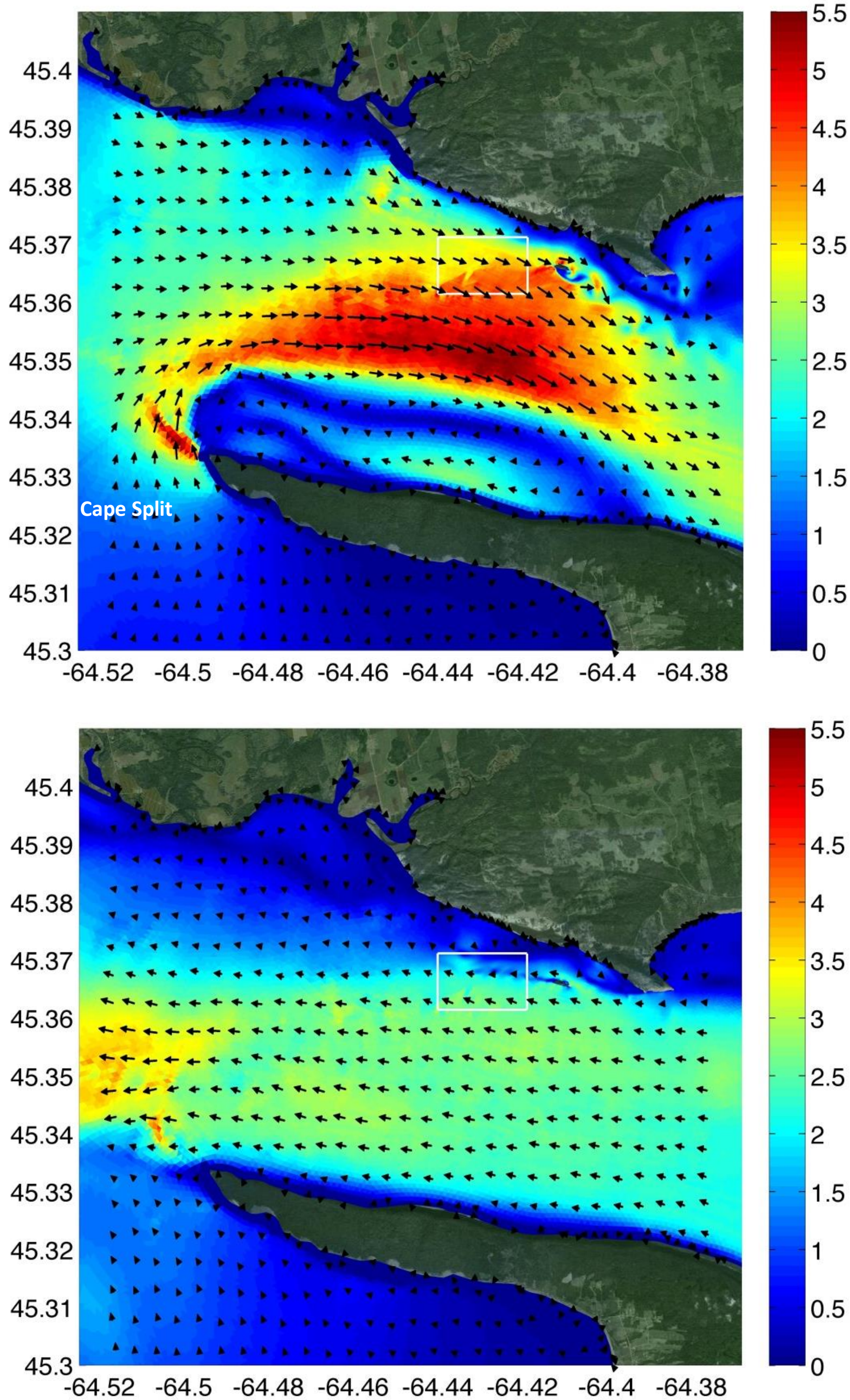

Figure 2.2. *Predicted flow speeds (m/s) and direction in the Minas Passage during a typical flood tide (top) and a typical ebb tide (bottom). The arrows indicate the direction of the flow at the given location. The white box is the FORCE lease area.*

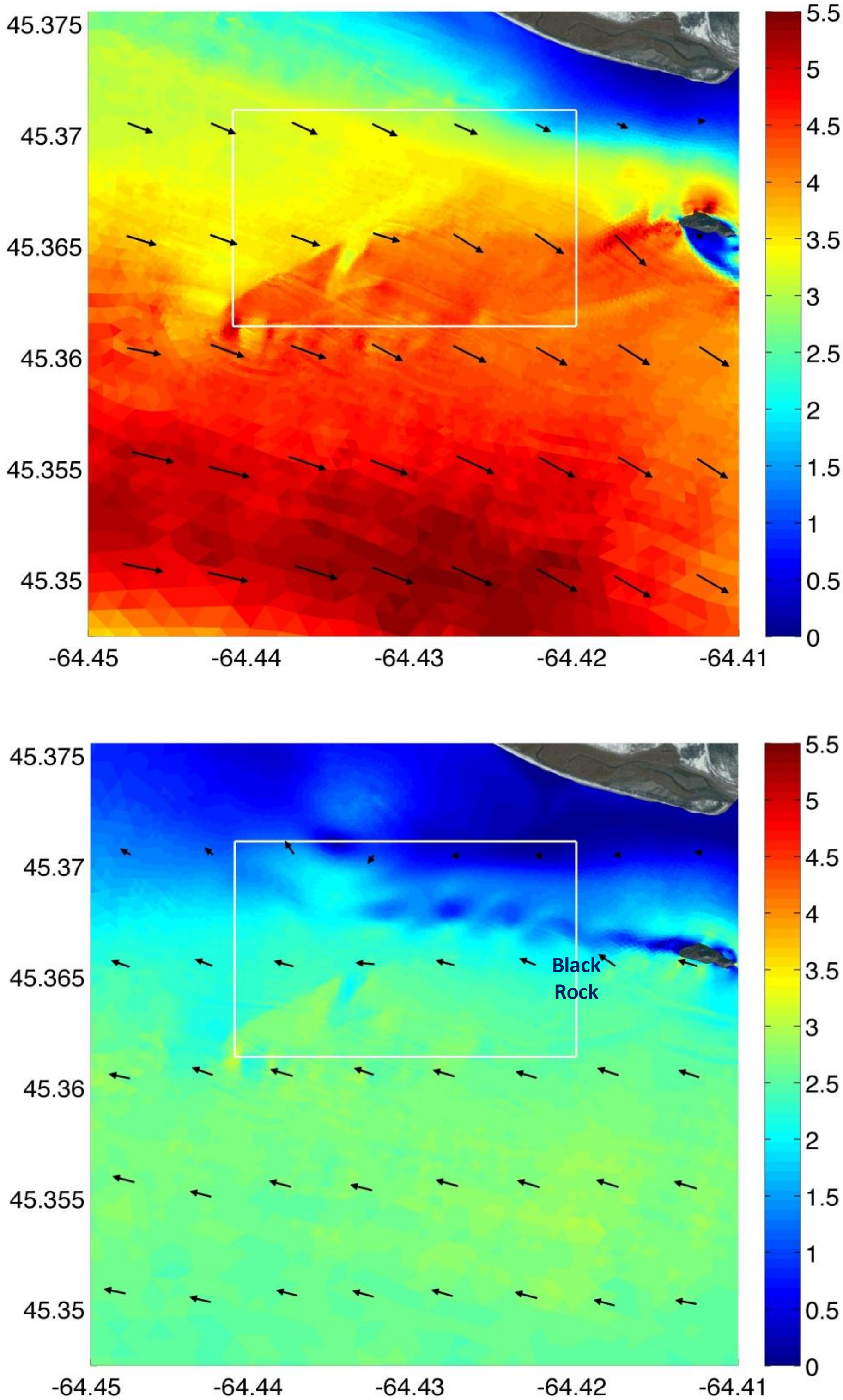

Figure 2.3. *Predicted flow speeds (m/s) and direction in and near the FORCE Crown Lease area during a typical flood tide (top) and a typical ebb tide (bottom). The arrows indicate the direction of the flow at the given location. The white box is the FORCE lease area.*

The local flow regime is also strongly influenced by changes in bathymetry. The shelf that extends from Black Rock through the southern portion of the FORCE test area (Figure 2.4) creates a region of shallow water and results in strong flow as the tide passes over the shelf (Figure 2.3). Downstream of the shelf are regions of weaker flow but higher turbulence. Black Rock and other coastal headlands create an active eddy field throughout the region (the wake of Black Rock is visible in Figure 2.3 - bottom panel). These eddies are especially important during the “slack” periods when they can drive local water speeds above 2 m/s. These eddies also make it difficult to clearly distinguish the change from flood to ebb.

The seafloor of the northern section of the Minas Passage is relatively flat and characterized by erosional trenches and exposed bedrock ridges (Fader, 2009; Figure 2.4). This region exhibits bedrock covered with a layer of surficial sediment, the product of the last glaciation. Adjacent to the small basalt island east of the FORCE site (Black Rock), gravel and sand bedforms dominate. West of Black Rock, and extending into the FORCE lease area, is a large volcanic shelf; surficial sediment consists largely of boulders, cobbles and gravel atop a bedrock base of basalt (Fader, 2009; Shaw et al., 2012). Sediment mobilization of cobbles, gravel and finer sediments is evidenced by low abundance of sessile epibiota on the seafloor at FORCE (Stewart, 2009; Morrison, 2012). During spring tides, current speeds of up to 1.5 m/s have been detected 0.5 m above the seafloor (Oceans Ltd., 2009). Multibeam sonar surveys of the seafloor (2008-2012) indicate significant near-shore slumping of sand and gravel beds, areas of erosion and other shifts in sediment (G. Fader, pers. comm.).

Envirosphere Consultants Ltd. (2009, 2010, 2011) reported on water quality for the Minas Basin and Minas Passage, including water temperature, suspended particulate matter (SPM) concentrations and turbidity. Given near constant strong vertical mixing in Minas Passage, measures of SPM taken at the surface are likely uniform with depth (Envirosphere, 2011). SPM values of about 20 mg/L were observed during the months of February and March, following ice melt, with relatively low SPM (<10 mg/L) and NTU (<2) values during July-September. Net sediment transport tends to be from Minas Passage to the east into Minas Basin (Wu et al., 2011).

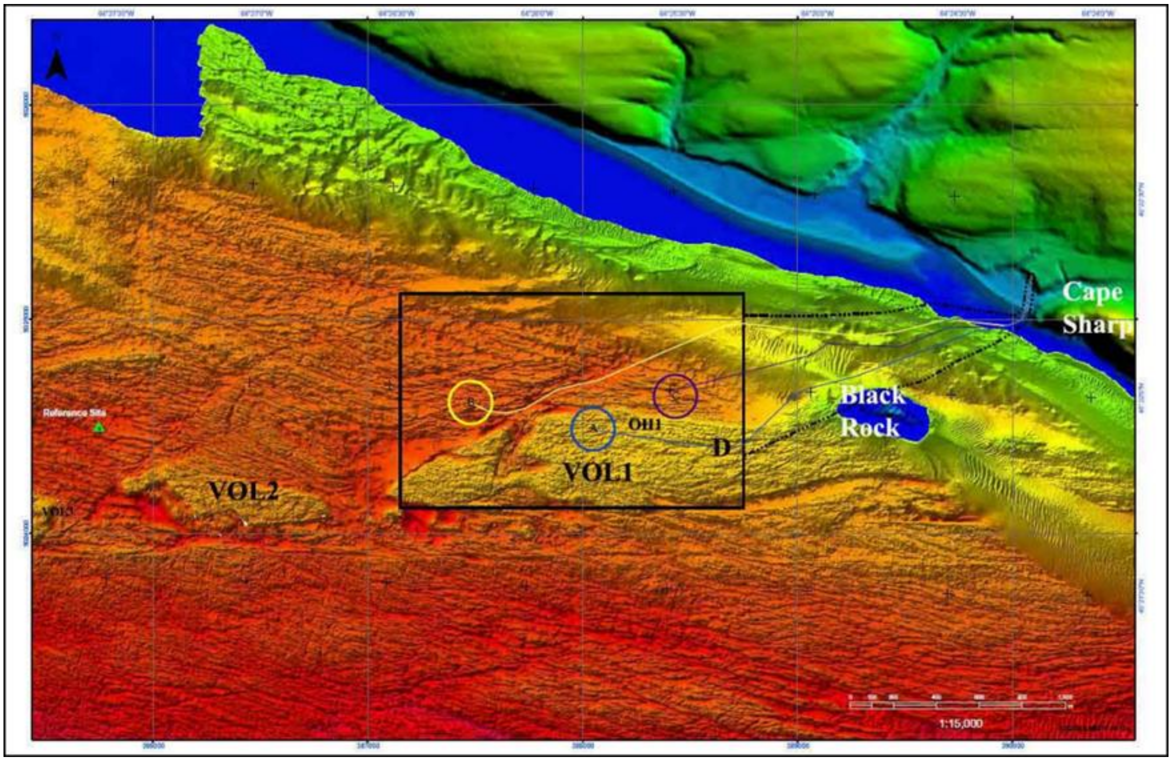

***Figure 2.4**. Multibeam bathymetric map of the FORCE test area and surrounds in Minas Passage, Bay of Fundy, showing volcanic platforms (VOL), gravel waves, troughs, and various bedforms. Black Rock is located east of the FORCE site. Source: GSC (in Fader, 2011).*

2.2 Use of Acoustic Telemetry to Track Fish

The acoustic telemetry system used in this study included receivers and transmitters manufactured by VEMCO, a local company based in Halifax, NS (Figure 2.5, www.vemco.com). VEMCO VR2w hydro-acoustic receivers are passive, single channel, omnidirectional, and function to autonomously detect coded acoustic transmitters which enter the detection radius of the receiver.

Acoustic transmitters (or tags) are attached to fish, most often by surgical implantation, and emit specific ping sequences which are interpreted by acoustic receivers and identify the specific carrier animal, the date and time of detection, and any sensor data (i.e. depth, temperature, acceleration) if tags are programmed to provide this information. The majority of the transmitters used in this study featured internal depth sensors, and this data was passed to the receiver as part of each transmission sequence.

Figure 2.5. *Left: VEMCO VR2w 69kHz acoustic receiver. Right: Size range of VEMCO acoustic transmitter models. Source: www.vemco.com.*

Due to variable body shapes and sizes of the four fish species monitored during this study, multiple transmitter sizes were required. Full descriptions of transmitter specifications for each species are outlined in respective sections of this report.

2.3 Monitoring Sites / Receiver Locations

A summary of the deployment and recovery (or rollover) of receivers during 2011-2013 is shown in Table 2.1. All deployments were completed using a chartered commercial fishing vessel from the port of Parrsboro, NS.

The first set of receiver deployments occurred in April 2011 and consisted of 3 lines of receivers, with spacing of 300-400 m between receivers in each line (Table 2.2 and Figure 2.6). They included:

1. A 14 station Acadia University Line (AUL) spanning Minas Passage from north to south (Figure 2.6) and situated approximately 0.75 km west of the FORCE test site.
2. A 12 station Minas Passage Line (MPS, an Ocean Tracking Network line) arranged North to South and spanning the entire Minas Passage, approximately 2.5 km east of the FORCE test site.
3. A 3 station line array inside the FORCE test site (AUL-T).

Table 2.1. *Summary of at sea receiver deployment and recovery missions in Minas Passage during 2011-2013. Most receivers that were not recovered during 'recovery missions' were later found by fishers or community members when the units became free of their moorings and drifted to shore.*

Year	Date	Objective	Result
2011	Apr 7	Deployment - AUL Line	14 stations deployed
2011	Apr 8	Deployment - MPS Line & FORCE Line	15 stations deployed
2011	Dec 13	Recovery – AUL and MPS Lines	14 of 28 stations recovered
2011	Dec 14	Recovery - AUL and MPS Lines	0 of 14 stations recovered
2012	Jan 16	Recovery - AUL and MPS Lines	0 of 14 stations recovered
2012	Apr 20	Deployment - MPS Line	12 stations deployed
2012	Apr 26	Deployment of AUL Lines	12 stations deployed
2012	Aug 1	Rollover - MPS Line	12 of 12 stations recovered, refurbished, and redeployed
2012	Nov 20	Rollover - AUL Line	10 of 11 stations recovered, refurbished, and 11 units redeployed. First recovery mission conducted in darkness, using vessel overhead lights.
2013	Apr 10	Recovery - MPS Line	9 of 12 stations recovered
2013	Apr 14	Deployment - MPS Line	12 stations deployed
2013	Jun 13	Final Recovery - AUL Lines	10 of 12 stations recovered

***Table 2.2**. Minas Passage acoustic receiver deployment and recovery information from 2011 (Figure 2.6). Receivers were numbered based on their north to south location in the Minas Passage. Receivers were recovered one of three ways: during a recovery mission ("R"), found floating by fishers ("F") or washed-up on shore ("W"). Depth values represent the mean water level in metres at the station position as determined using Richard Karsten's hydrodynamic model.*

Array name	Station name	Latitude	Longitude	Depth (m, MWL)	Deployment (dd/mm/yyyy)	Recovery (dd/mm/yyyy)
AUL-T	AUL-T1	45.37027	-64.42915	36.4	08/04/2011	Not recovered
	AUL-T2	45.36618	-64.43134	52.2	08/04/2011	25/02/2012 (W)
	AUL-T3	45.36176	-64.43372	50.2	08/04/2011	20/03/2012 (W)
AUL	AUL-01	45.37838	-64.44717	12.1	07/04/2011	13/12/2011 (R)
	AUL-02	45.37481	-64.44815	34.0	07/04/2011	27/12/2011 (W)
	AUL-03	45.37108	-64.44924	52.5	07/04/2011	11/12/2011 (F)
	AUL-04	45.36747	-64.44999	50.6	07/04/2011	13/12/2011 (R)
	AUL-05	45.36402	-64.45115	52.5	07/04/2011	17/06/2012 (F)
	AUL-06	45.36040	-64.45226	63.9	07/04/2011	Not recovered
	AUL-07	45.35677	-64.45332	71.2	07/04/2011	11/03/2012 (W)
	AUL-08	45.35320	-64.45431	77.6	07/04/2011	04/05/2012 (W)
	AUL-09	45.34957	-64.45500	104.7	07/04/2011	13/12/2011 (R)
	AUL-10	45.34603	-64.45639	87.8	07/04/2011	02/12/2011 (F)
	AUL-11	45.34241	-64.45738	88.6	07/04/2011	13/12/2011 (R)
	AUL-12	45.33884	-64.45832	47.8	07/04/2011	13/12/2011 (R)
	AUL-13	45.33522	-64.45941	35.1	07/04/2011	19/12/2011 (W)
	AUL-14	45.33161	-64.46032	12.1	07/04/2011	13/12/2011 (R)
MPS	MPS-01	45.36136	-64.38355	29.0	08/04/2011	13/12/2011 (R)
	MPS-02	45.35803	-64.38592	43.7	08/04/2011	27/06/2012 (W)
	MPS-03	45.35479	-64.38830	67.7	08/04/2011	13/12/2011 (R)
	MPS-04	45.35132	-64.39052	77.5	08/04/2011	14/03/2012 (W)
	MPS-05	45.34822	-64.39266	76.7	08/04/2011	13/12/2011 (R)
	MPS-06	45.34505	-64.39537	83.0	08/04/2011	19/12/2011 (W)
	MPS-07	45.34188	-64.39783	123.3	08/04/2011	13/12/2011 (R)
	MPS-08	45.33872	-64.40021	116.9	08/04/2011	14/04/2012 (W)
	MPS-09	45.33537	-64.40264	97.2	08/04/2011	13/12/2011 (R)
	MPS-10	45.33214	-64.40491	67.7	08/04/2011	13/12/2011 (R)
	MPS-11	45.32890	-64.40761	42.8	08/04/2011	13/12/2011 (R)
	MPS-12	45.32570	-64.40989	36.4	08/04/2011	13/12/2011 (R)

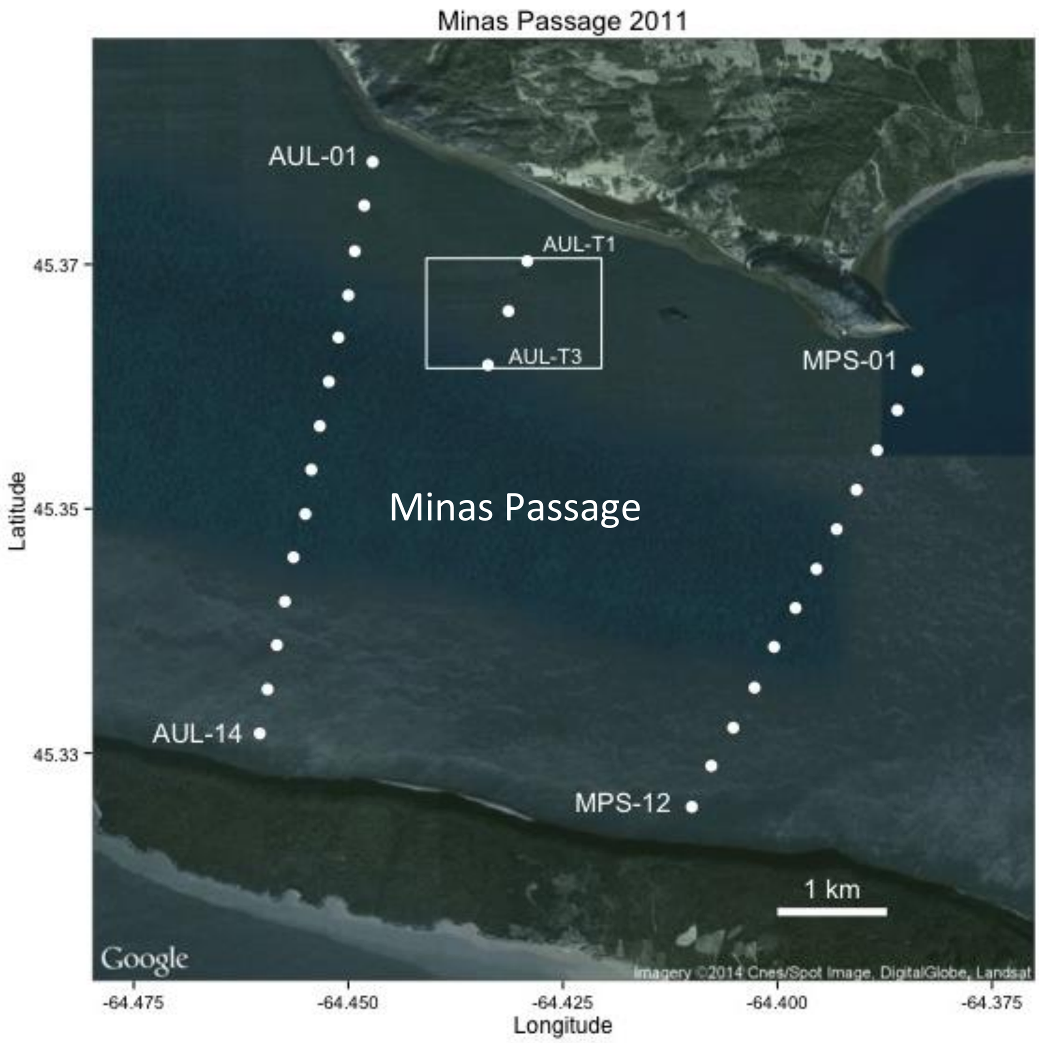

Figure 2.6. *Positions of bottom moored VEMCO VR2w acoustic receiver stations deployed in Minas Passage, NS during 2011. The shaded rectangle indicates the area of the FORCE demonstration site. Dot points indicate the station positions of the Acadia University Line (AUL-01 to AUL-14), the FORCE Line (AUL-T1 to AUL-T3), and the OTN's MPS Line (MPS-01 to MPS-12).*

Deployments in 2012 commenced in April and included the 12 MPS line stations deployed at the same positions as in the previous year. Delayed recovery of equipment from the 2011 season limited the inventory available for redeployment of the AUL line. Given the importance of collecting data in relation to the FORCE site, the 12 available AUL units were positioned in two lines of 6 stations, oriented north to south, and positioned parallel to both the eastern and western boundaries of the FORCE site, with receivers separated by approximately 300m (Table 2.3 and Figure 2.6). Both sets of deployments were conducted using a chartered commercial fishing vessel from the port of Hall's Harbour, NS.

Table 2.3. *Minas Passage acoustic receiver deployment and recovery information from 2012-2013 (see Figure 2.7). Receivers were numbered based on their north to south location in the Minas Passage. Receiver recovery included: planned recovery mission ("R"), found floating by fishers ("F") or washed-up on shore ("W"). Depth values represent the mean water level in metres at the station position as determined using Richard Karsten's hydrodynamic model.*

Array name	Station name	Deploy No.	Latitude	Longitude	Depth (m, MWL)	Deployment (dd/mm/yyyy)	Recovery (dd/mm/yyyy)
AUL	AUL-01	1	45.37106	-64.41826	11.2	26/04/2012	20/11/2012 (R)
	AUL-02	1	45.36848	-64.41994	30.4	26/04/2012	20/11/2012 (R)
	AUL-03	1	45.36585	-64.42167	44.3	26/04/2012	20/11/2012 (R)
	AUL-04	1	45.36339	-64.42319	36.5	26/04/2012	20/11/2012 (R)
	AUL-05	1	45.36058	-64.42492	51.5	26/04/2012	24/11/2012 (W)
	AUL-06	1	45.35792	-64.42659	61.2	26/04/2012	14/09/2012 (W)
	AUL-07	1	45.37580	-64.43500	14.1	26/04/2012	20/11/2012 (R)
	AUL-08	1	45.37331	-64.43667	27.2	26/04/2012	20/11/2012 (R)
	AUL-09	1	45.37091	-64.43862	47.8	26/04/2012	20/11/2012 (R)
	AUL-10	1	45.36853	-64.44067	52.1	26/04/2012	20/11/2012 (R)
	AUL-11	1	45.36601	-64.44269	54.7	26/04/2012	20/11/2012 (R)
	AUL-12	1	45.3636	-64.44469	56.0	26/04/2012	20/11/2012 (R)
	AUL-01	2	45.36910	-64.41900	11.2	20/11/2012	13/06/2013 (R)
	AUL-02	2	45.36661	-64.42046	30.4	20/11/2012	14/06/2013 (F)
	AUL-03	2	45.36414	-64.42180	44.3	20/11/2012	30/04/2013 (F)
	AUL-04	2	45.36164	-64.42333	36.5	20/11/2012	13/06/2013 (R)
	AUL-05	2	45.35911	-64.42473	51.5	20/11/2012	13/06/2013 (R)
	AUL-06	2	45.35656	-64.42622	61.2	20/11/2012	13/06/2013 (R)
	AUL-07	2	45.37357	-64.43887	14.1	14/04/2013	13/06/2013 (R)
	AUL-08	2	45.37143	-64.44068	27.2	04/12/2012	13/06/2013 (R)
	AUL-09	2	45.36908	-64.44247	47.8	20/11/2012	13/06/2013 (R)
	AUL-10	2	45.36668	-64.44434	52.1	20/11/2012	13/06/2013 (R)
	AUL-11	2	45.36423	-64.44613	54.7	20/11/2012	13/06/2013 (R)
	AUL-12	2	45.36191	-64.44796	56.0	20/11/2012	Not Recovered
MPS	MPS-01	1	45.36126	-64.38355	29.0	20/04/2012	01/08/2012
	MPS-02	1	45.35808	-64.38615	44.8	20/04/2012	01/08/2012
	MPS-03	1	45.35470	-64.38853	68.9	20/04/2012	01/08/2012
	MPS-04	1	45.35171	-64.39046	77.3	20/04/2012	01/08/2012
	MPS-05	1	45.34815	-64.39310	80.6	20/04/2012	01/08/2012
	MPS-06	1	45.34491	-64.39548	84.9	20/04/2012	01/08/2012
	MPS-07	1	45.34188	-64.39792	123.3	20/04/2012	01/08/2012
	MPS-08	1	45.33878	-64.40033	118.6	20/04/2012	01/08/2012
	MPS-09	1	45.33544	-64.40265	97.2	20/04/2012	01/08/2012
	MPS-10	1	45.33207	-64.40510	67.8	20/04/2012	01/08/2012
	MPS-11	1	45.32887	-64.40774	42.2	20/04/2012	01/08/2012
	MPS-12	1	45.32552	-64.41000	35.8	20/04/2012	01/08/2012
	MPS-01	2	45.36130	-64.38349	29.0	01/08/2012	14/04/2013
	MPS-02	2	45.35808	-64.38595	44.8	01/08/2012	14/04/2013

MPS-03	2	45.35482	-64.38837	68.9	01/08/2012	14/04/2013
MPS-04	2	45.35158	-64.39069	77.3	01/08/2012	06/07/2013 (W)
MPS-05	2	45.34835	-64.39312	80.6	01/08/2012	14/04/2013
MPS-06	2	45.34512	-64.39553	84.9	01/08/2012	14/04/2013
MPS-07	2	45.34187	-64.39786	123.3	01/08/2012	14/04/2013
MPS-08	2	45.33865	-64.40029	118.6	01/08/2012	14/04/2013
MPS-09	2	45.33536	-64.40266	97.2	01/08/2012	14/04/2013
MPS-10	2	45.33206	-64.40509	67.8	01/08/2012	14/04/2013
MPS-11	2	45.32883	-64.407326	42.2	01/08/2012	14/04/2013
MPS-12	2	45.32569	-64.40988	35.8	01/08/2012	14/04/2013

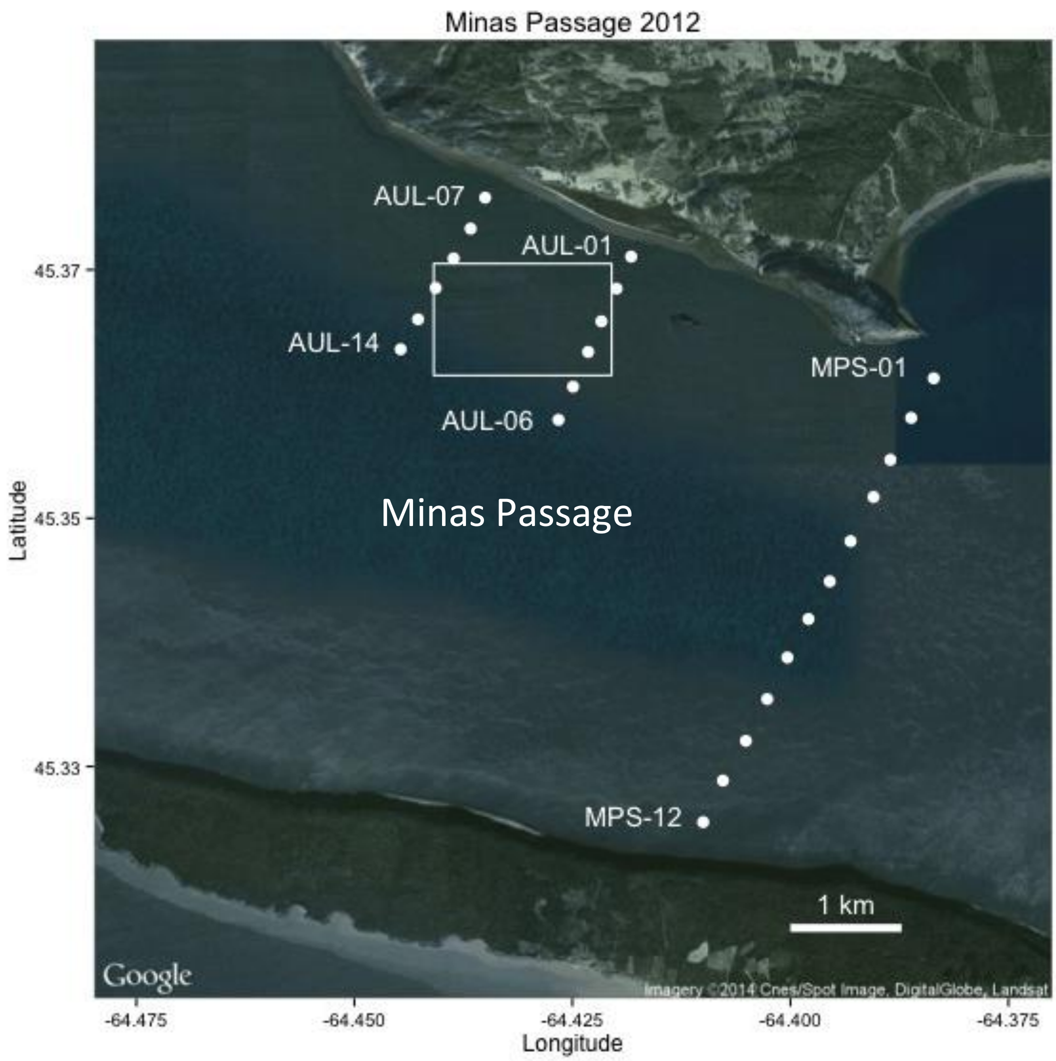

Figure 2.7. *Positions of bottom moored VEMCO VR2w acoustic receiver stations deployed in Minas Passage, NS during 2012-2013. The shaded rectangle indicates the area of the FORCE demonstration site. Points AUL-01 to AUL-12 are station positions of the two Acadia University receiver lines, and MPS-01 to MPS-12 are station positions of the OTN-MPS line.*

2.4 Receiver Moorings

The extreme tidal conditions within Minas Passage present significant challenges to deployment and subsequent recovery of long-life, bottom-moored instrumentation. This project incorporated recommendations on mooring design from the pilot study (Stokesbury et al. 2012).

Custom modified A2 Model SUB streamlined instrument floats (Open Seas Instrumentation, Musquodoboit Harbour, NS) were used to house VR2w acoustic receivers which were connected by two delrin clamps to the fiberglass strongback of a Teledyne Benthos 875-TD acoustic release mechanism (Teledyne-Benthos, North Falmouth, Mass., USA) (Figure 2.8). Instrument packages were bolted to steel brackets within the SUB floats. Floatation was provided by two 33cm diameter VINY Ball trawl floats which contributed 35kg of positive buoyancy.

Mooring weight consisted of steel anchor chain links totaling approximately 200-225kg, generally prepared in 4 sections of 4-5 links each (Figure 2.9). Anchor links were connected using ½" diameter galvanized steel chain passed through individual weight sections. The chain was secured using a bolted ½" galvanized steel safety shackle and pinned with a 316 stainless steel cotter pin. A 2m riser of ½" galvanized chain was connected at its terminus to a ½" galvanized steel swivel using a ½" galvanized safety shackle. The swivel was then connected to a 3/8" 316 stainless steel D shackle, which was isolated from the swivel using a PVC bushing to prevent contact of dissimilar metals, and then secured using 316 stainless steel lock wire. Prior to deployment the D shackle was fit over the 875-TD acoustic release arm and the release mechanism closed to complete assembly.

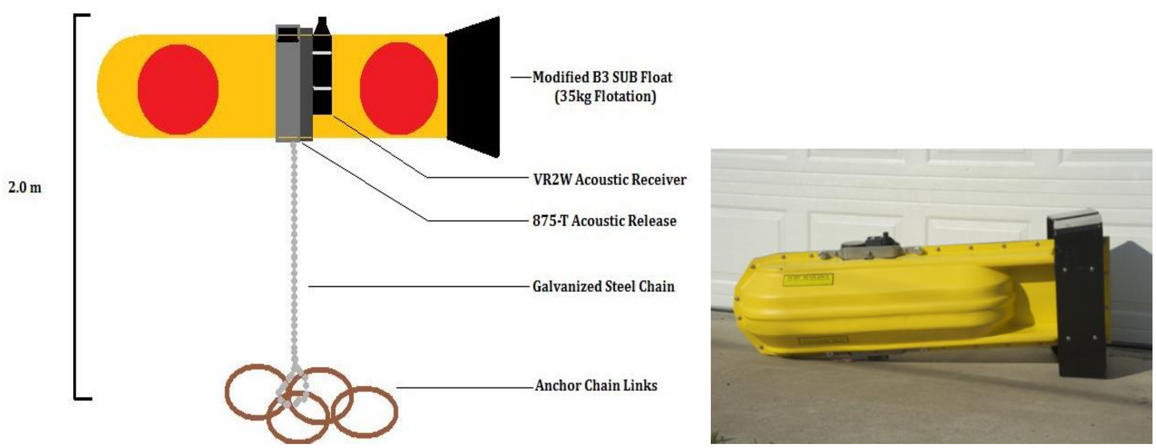

Figure 2.8. *Left: Diagram indicating internal orientation of the VR2w Receiver and Benthos Teledyne acoustic release (not to scale, from Stokesbury et al., 2012). Right: photo of SUB flotation package with instrument package installed.*

Figure 2.9. *Mooring weights are prepared on the wharf at Hall's Harbour, NS prior to deployment on April 20, 2012. Pictured L-R: J. Broome (Acadia), I. Beveridge (OTN), and G. Redden (Crew – F/V Greyhound). Photo Credit: J. Beardsall. The components and cost of a single receiver station are itemized in Table 2.4.*

Prior to the 2012 deployment season, several small modifications were made to further enhance the operational lifespan of acoustic receiver moorings. Modifications included: an upgraded delrin clamping mechanism attaching the VEMCO VR2w receivers to acoustic release strongback, installation of long life (up to 5yr) lithium cell acoustic release batteries, more robust (from 5/16" to 3/8") stainless drop shackles at the acoustic release attachment point, addition of a second swivel at the anchor base, and extra safety shackles at the anchor connection point. These modifications were enacted after observations of failure points from equipment recovered in 2011.

Following August and November 2012 equipment rollovers it was clear that these relatively inexpensive modifications made significant improvements to the operation and survivability of the moorings. Inspection of recovered equipment indicated minimal damage to buoy housings and tail fins. Acoustic release arms were found to have considerably less wear, and communications with all acoustic releases were consistent and strong.

Table 2.4. *Approximate cost of instrument mooring components required to assemble a single receiver ("listening") station in Minas Passage. Total cost per moored unit was about $10,000.*

Equipment	Supplier, Location	Value (excluding taxes)
SUBS A2 Streamlined Instrument Buoy – VR2 Modification	Open Seas Instrumentation, Musquodoboit Harbour, NS	$3250.00
VEMCO VR2w Acoustic Receiver	VEMCO, Halifax, NS	$1410.00
Teledyne Benthos 875-TD Acoustic Release	Teledyne Benthos, North Falmouth, Mass., USA	$3875.00
200-250kg Scrap Steel Anchor Material	Various	~$400.00
Hardware (clamps, chain, shackles, swivels, etc.)	Various	~$250.00

2.5 Mooring Deployment and Retrieval Methods

2.5.1 Deployment

All station positions were pre-programmed using Fugawi Marine Navigation software (Version 4.0, Northport Systems Inc., Toronto, ONT), which was also used for precise vessel navigation to each station location. Prior to approaching each station, mooring components were arranged at the stern of the vessel. The anchor and instrument floatation package was connected via an acoustic release. Fully assembled moorings were approximately 2m in height. On the final approach toward the station position the flotation package was placed into the water over the stern. The anchor weight was released when directly over station.

All receiver moorings were deployed within Minas Passage prior to release of tagged fish. Deployments generally occurred near high water slack (at the end of flooding tide, through the beginning of ebbing tide) when tidal current velocities were <1 m/s. Despite attempts to operate during periods of low current velocity, maintaining position was often difficult. In order to accurately deploy the station the vessel had to approach the site from an upstream position relative to tidal current direction and allow the vessel to drift toward the station while making slight adjustments to the heading.

Despite very good deployment accuracy, based on surface coordinates, the instrument units would have experienced some drift (estimated to be up to 50 m) during descent. Deployment coordinates (Tables 2.3 and 2.4) are referenced to surface position of the vessel and not the exact final bottom position of the receiver.

2.5.2 Recovery

Instrument recovery required the use of a Teledyne Benthos UDB-9000 universal deck communication unit (Teledyne Benthos, North Falmouth, MA USA) and corresponding low frequency (LF) transducer. On arrival at the station for unit retrieval the transducer of a UDB-9000-LF deck unit was lowered over the side of the vessel and a series of acoustic communications were transmitted. The deck unit was programmed with unique parameters of the 875-TD acoustic release for a given station. If the series of wakeup and release commands were detected and successfully decoded by the acoustic release the unit would initiate the release process. The 875-TD unit releases by rotating a shaft, which in turn opens an arm that holds a stainless steel drop shackle. When released, the drop shackle separates the instrument / floatation unit from the anchor weight and riser chain, which are sacrificed. The flotation of the SUB buoy brings the instrument package to the surface for collection and data offload.

2.6 Summary of Fish Tagging

A total of 266 fish, representing four species, were captured during 2011-2012 and surgically implanted with acoustic tags. Tagging took place at several locations in the Minas Basin, or in rivers draining into the Minas Basin (Table 2.5 and Figure 2.10). Specific tagging methodology relative to each of the target species is described in Sections 3-6.

***Table 2.5**. Summary of fish tagging activities during 2010-2012. Includes 30 sturgeon tagged in 2010. Locations of tagging/release sites are shown in Figure 2.10.*

Species	Year	Tagging Location	Number of fish tagged
Atlantic sturgeon (N=114)	2010*	Minas Basin (trawl)	29
		Five Islands (weir)	1
	2011	Minas Basin (trawl)	41
		Five Islands (weir)	12
	2012	Minas Basin (trawl)	26
		Five Islands (weir)	5
Striped bass (N=85)	2011	Stewiacke River	20
		Grand Pre	20
	2012	Stewiacke River	7
		Grand Pre	31
		Kingsport	7
American eel (N=45)	2011	Gaspereau River	15
	2012	Gaspereau River	30
Atlantic salmon (N=52)	2011	Gaspereau River	35
		Stewiacke River	27

* sturgeon tagged in 2010 had long life tags (several years) that were detected in subsequent years.

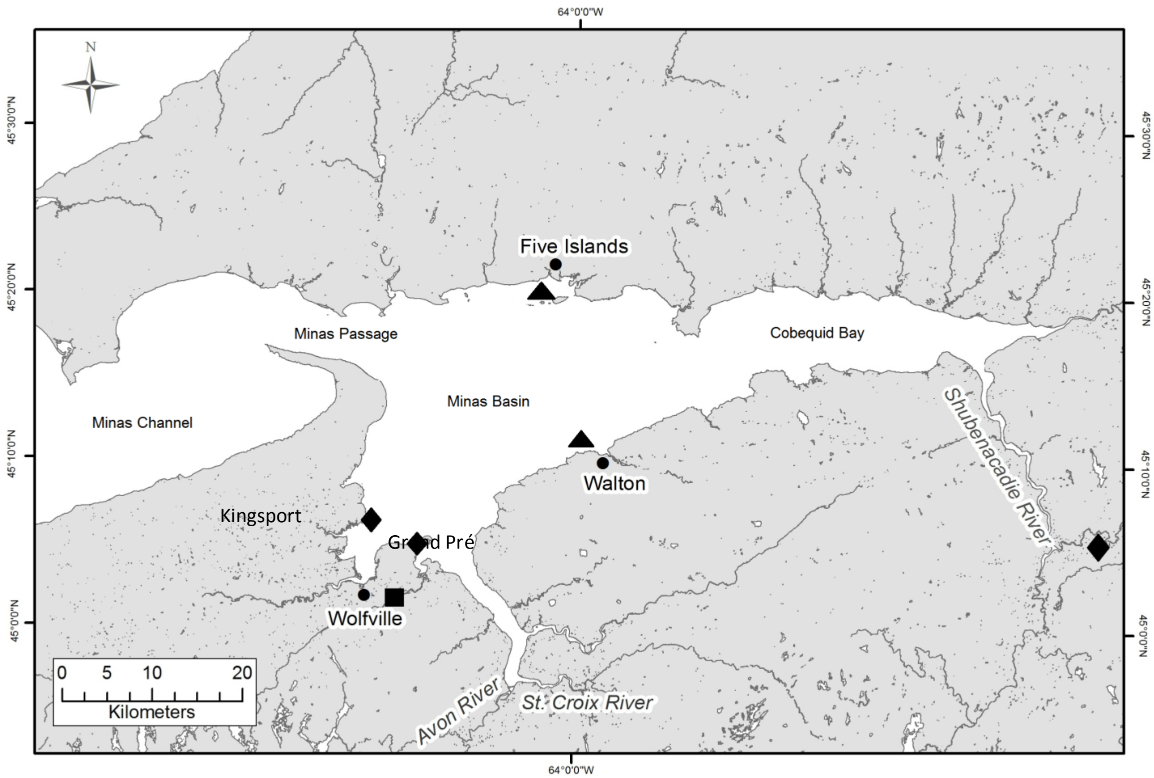

***Figure 2.10**. Overview of fish tag release sites in Minas Basin and tributaries. Atlantic sturgeon tag release sites are indicated by two black triangles near Five Islands and Walton. A single black rectangle near Wolfville indicates the Gaspereau River tag release site for American eels and Atlantic salmon. The black diamond icon at the far eastern edge of the map indicates the approximate location of striped bass and Atlantic salmon tagging in the Stewiacke River. Two additional black diamonds located in the southern portion of Minas Basin indicate striped bass tagging sites near Kingsport and Grand Pré (Guzzle).*

2.7 Receiver Data Download and Processing

VEMCO VUE software was used to download receiver log files (VRLs) from recovered receivers. Receiver clock drift is a known issue that can occur in all study environments, but can be exaggerated by extended deployment periods (D. Webber – VEMCO, pers. comm.). Using VUE, a linear correction factor was applied to individual receiver VRL files to adjust for time drift over the deployment period. Drift corrected VRL files were then compiled into a VEMCO Database (VDB) containing the detection histories of all receivers deployed during the study season. The VDB was then filtered to separate detections by species. Complete detection histories for each species were then exported from the VUE program into .csv spreadsheet format for further analysis.

Most transmitters used in this study included pressure (i.e. depth) sensors. Pressure values were converted to depth from surface (m) using transmitter specific slope and intercept values provided by VEMCO.

Spreadsheet programs were then used to separate detection histories of individual tagged fish to examine patterns at the level of a single fish, as recommended by Rogers and White (2007). Detections for each fish were then ordered by date and time of detection and examined for false detections or duplicates. Detections of the same transmission at multiple receivers, where the time between detections was less than the minimum transmission delay, were considered duplicate detections of a single transmission, and were highlighted for removal in selected analyses.

2.8 Receiver Performance under High Flow Conditions

2.8.1 Receiver Detection of Transmissions

Acoustic telemetry has proven to be a valuable tool in the study of mobile aquatic organisms, but like any other technology, has certain limitations (Clements et al., 2005; Heupel et al., 2006; Simpfendorfer et al., 2008; Titzler et al., 2010). Several factors known to influence detection performance are present within Minas Passage and include: environmental noise induced by current speed, turbulent flow conditions, high sediment loads, and entrained air bubbles. These factors induce limitations on both the overall range of transmitted signals and the effective reception of those signals by the receiver.

In a prior detection range study in Minas Passage (Broome and Redden, 2012), transmission detection efficiency of VEMCO receivers was found to decrease as a function of both distance and current velocity, for each of four transmitter output power levels examined. As expected, higher power transmitter models (V16 and V13) achieved better overall detection range and a higher detection frequency than lower power transmitter models (V9 and V7).

Because the detection radius of a receiver is influenced by current speed, the range is largest during slack water periods and at a minimum during mid-tide stages when flow speeds are high. Because the tag detection radius at mean water column current velocities of >2m/s is significantly reduced, any detections are probably associated with tagged animals travelling in very close proximity to the receiver. Flow-enhanced travel speeds may result in some fish moving between adjacent receiver stations (300-400m apart) without being detected.

The frequency distribution of current speed varies among receiver stations (see Figure 2.11 and Appendices A2.1-A2.3), which also differ in water depth and distance from shore. Current speeds >1.5 m/s and >2.0 m/s occur about 50% and 30% of the time, respectively (Figure 2.11).

Patterns of detection, in relation to current speed, are similar among all four species tagged in this study (Figure 2.12). Tag detections were uncommon at speeds >2 m/s. It is unknown whether fish avoid Minas Passage during periods of high current velocity, or if they are present and simply cannot be detected due to flow effects on detection efficiency.

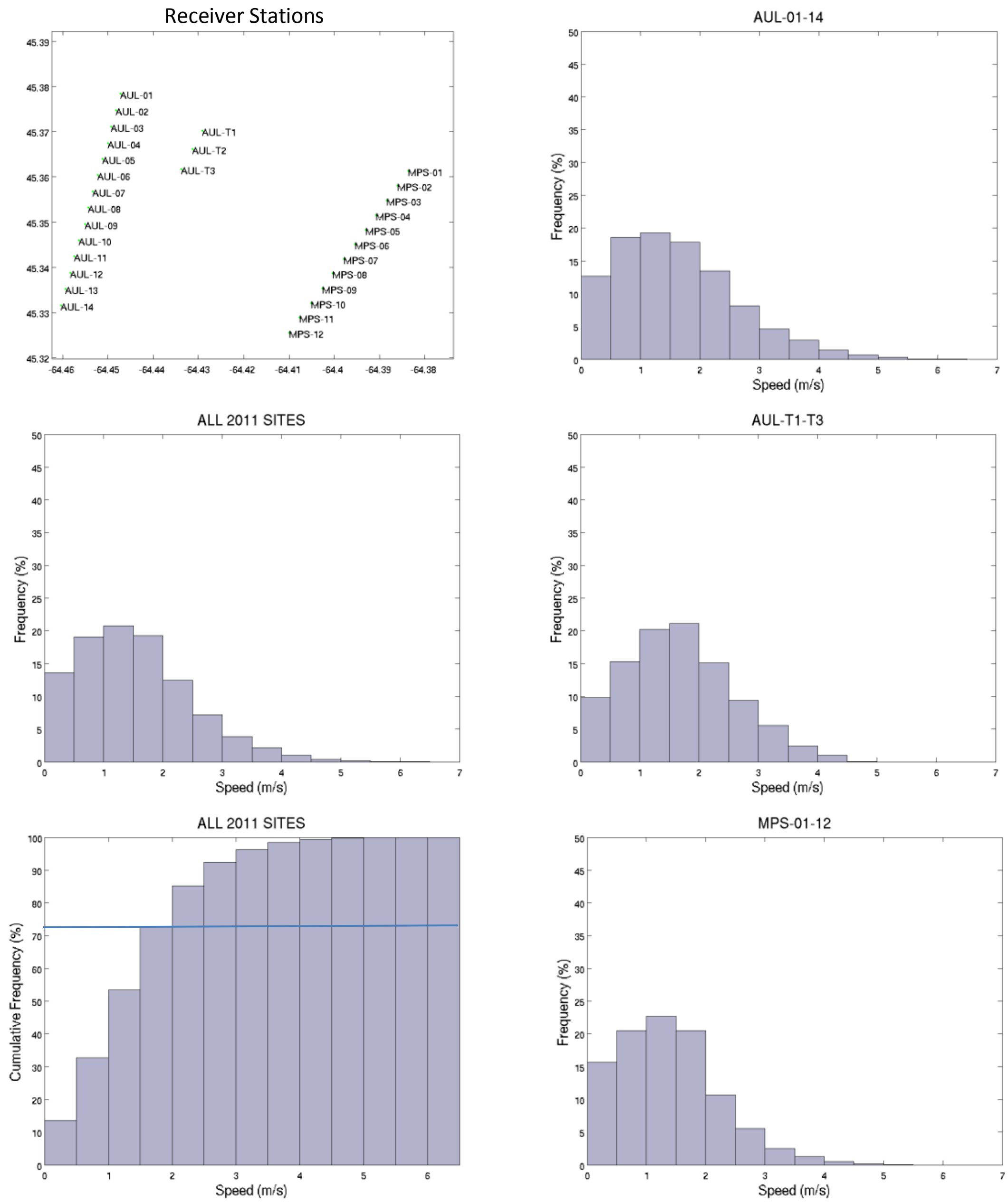

Figure 2.11. *Top left: receiver stations. Frequency distributions of average water column current speed (m/s) over a 2 month period, for all sites combined (left, middle) and for each of the three receiver lines (AUL, AUL-T and MPS) (right side, top to bottom). The bottom left panel features cumulative frequency for average current speed and shows that during about 30% of the time, average water column current speeds are greater than 2 m/s.*

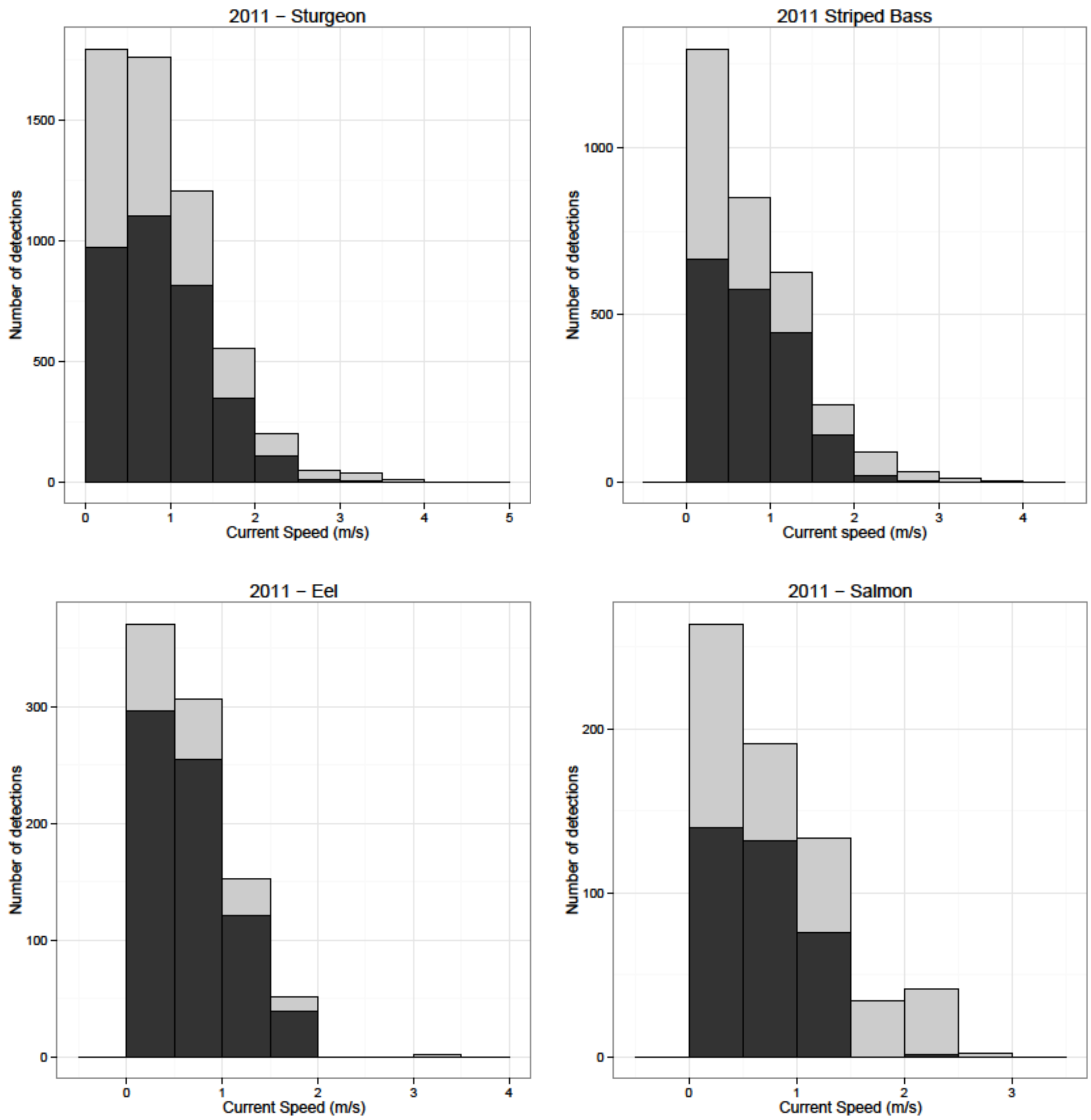

Figure 2.12. *Numbers of detections of tagged fish in 2011, in relation to average water column current speed (m/s) at the time of detection, for each of four species - Atlantic sturgeon, striped bass, American eel and Atlantic salmon. Dark and light bars represent detections during ebb tide and flood tide, respectively. There were relatively few tag detections when average water column current speed exceeded 2m/s. See Figure 2.11 for current speed frequencies.*

2.8.2 Limitations

The tag transmission datasets for Minas Passage represent less than 40% of the actual transmissions that occurred within 200 m of the receivers, in large part because of these factors:

1. High flow regime. An increase in current speed increases ambient noise levels that reduce detection range. This can result in a lack of detection of tagged fish passing through Minas Passage receiver lines, especially when current speeds exceed 1.5 m/s. In addition, some sites are naturally noisier than others (Tollit et al., 2011; Wood et al., 2013). The Minas Passage tag detection dataset is thus an under-representation of the presence of tagged fish in the passage.

2. Incomplete transmissions, especially during high flows. Full transmission sequences generally consist of 8-10 consecutive pings separated by unique spacing intervals. If the receiver does not detect a complete ping sequence, then the transmission is not logged.

3. Loss of a few receivers (<5%) containing tag detections (i.e. units not yet recovered).

Furthermore, receiver clock drift can lead to unreliable detection times. Given the speed of sound in water we would expect that any simultaneous detections of the same transmission by multiple receivers would occur at the same time for very closely located receiver units, and perhaps a second apart for receivers able to log the detection at greater distances. However, due to receiver clock drift the time at which receivers log a simultaneous transmission is offset, with the degree of offset being variable between receiver units and the amount of offset proportional to the study duration. Drift correction applied within the VEMCO VUE program assumes a constant drift of the internal clock from the point of receiver initialization. Care needs to be taken in utilizing drift corrected data to determine the location of first detection, directionality, and travel rates (between receiver stations).

2.8.3 Assumptions

Moored receivers were assumed to remain in the same place over the course of the detection period and within 50 m of the surface coordinates at the time of deployment.

Acoustic transmitters of similar model were assumed to behave similarly and with equal probability of detection. It was also assumed that all transmitters were active from the time of implantation up to the battery life expiration date.

It was assumed that all of the acoustic receivers behaved similarly with regards to detection efficiency, despite differences in receiver location conditions (depth and current regime).

Lastly, we assumed that our detections of tagged fish represent actively moving live fish and not the movements of predators that may have ingested a tagged individual.

2.9 References

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Section 3: Atlantic Sturgeon Movements

Authors: MJW Stokesbury, MF McLean, AM Redden, JE Broome, D Bates and MJ Dadswell

3.1 Background on Atlantic Sturgeon

Atlantic sturgeon (*Acipenser oxyrhynchus*) is an anadromous species that matures in seawater and spawns in freshwater (Scott and Scott, 1988). This species is known to range from as far north as Ungava Bay, Newfoundland and Labrador (Scott and Scott, 1988) to as far south as northern South America (Vladykov and Greeley, 1963). Atlantic sturgeon spawn in rivers above the head of tide and juveniles utilize estuarine habitat for early growth. Juveniles migrate from natal estuaries in the northern portion of their range at approximately 10 years of age. They are excellent osmoregulators and may move back and forth between salt and fresh water when necessary or desired (Krayushkina, 1998). In the Canadian portion of their range Atlantic sturgeon males mature at ~20 y and females at ~25 y (Dadswell, 2006). Growth in Atlantic sturgeon is sexually dimorphic. Females generally grow to a total length (TL) of 1.8-3.0 m and males to a TL of 1.4 – 2.1 m (Dadswell, 2006). The largest female recorded was captured in 1924 at Maugerville, New Brunswick and was 4.59 m long and weighed 364.9 kg (Vladykov and Greeley, 1963). Large females are very fecund. For example a ripe female captured in the St. Lawrence River weighing 158 kg contained a calculated 3,755,745 eggs (Vladykov and Greeley, 1963).

Atlantic sturgeon are a demersal feeding species and are thought to associate with the bottom in shelf areas, however, many characteristics of their marine phase, including depth distribution have not been well studied (Stein et al., 2004). The entire marine phase of Atlantic sturgeon has been designated as a knowledge gap (NOAA sturgeon workshop, Arlington VA, USA February 2011). Atlantic sturgeon are usually considered a near shore, estuarine dependent species but they have been recorded as far offshore as Sable Island in Canada (Scott and Scott 1988) and the edge of the continental shelf in the north eastern USA (Stein et al., 2004).

In many areas of the USA Atlantic sturgeon populations are severely reduced. In 1979, Atlantic sturgeon received an Appendix II listing by the Convention for the International Trade of Endangered Species (CITES). This listing limits the trade of Atlantic sturgeon between participating countries. By 1998 all USA fisheries were closed (ASMFC, 1998). In 2012, the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service listed four of the five Distinct Population Segments (DPSs) in the USA as endangered. The DPSs listed as endangered were the New York Bight, Chesapeake Bay, Carolina, and South Atlantic (NOAA, 2012). The Gulf of Maine DPS was listed as “threatened” (NOAA, 2012).

In Canada, the Saint John River, New Brunswick and the St. Lawrence River, Quebec, have Atlantic sturgeon populations that support small directed fisheries (Dadswell, 2006; DFO, 2009). Recently the Maritime Provinces population was designated as threatened under the COSEWIC, based on the assumption that the entire population is solely sustained by the spawning stock located within the Saint John River (COSEWIC, 2011).

3.1.1 Genetic Makeup of Atlantic Sturgeon in Minas Basin

Atlantic sturgeon that move through Minas Passage to exploit feeding habitat in Minas Basin are from both Canadian and USA stocks (Wirgin et al., 2012). Atlantic sturgeon captured in Minas Basin and tagged with conventional spaghetti tags (sub-adults and adults) have been re-captured in coastal regions of the USA and as far north as the Gaspe Peninsula (Dadswell, unpublished data). There have been 11 recaptures in Minas Basin of sturgeon tagged in the USA from as far south as the Hudson River, NY and 10 recaptures from the Saint John River, NB (Dadswell, unpublished data).

Genetic analysis indicates that ~60% of the sturgeons sampled in Minas Basin were from the Saint John River stock, 32-34% from the Kennebec River stock, and 1-2% from the Hudson River stock (Wirgin et al., 2012). As a result, Atlantic sturgeon from listed, endangered DPS's in the USA, and the threatened DPS in the northern USA and the COSEWIC designated threatened population in Canada, may be vulnerable to negative impacts of in-stream tidal energy conversion devices at times when Atlantic sturgeon are travelling through Minas Passage.

3.1.2 Migration Paths

Atlantic sturgeon are commonly captured in Minas Basin as bycatch in weirs along the coast of Five Islands in early May (Wehrell et al., 2008, Beardsall et al., 2013). Electronically tagged sturgeon have also been recorded in early May in the Southern Bight of the Basin (McLean et al., in press). The main body of Atlantic sturgeon move into the Minas Basin along the northern shore past Five Islands and Economy, Nova Scotia during May-June, then move into areas of the Southern Bight off Walton, the mouth of the Avon River and Kingsport in June-September to feed on soft bodied invertebrates (McLean et al., 2013). Sturgeon leave Minas Basin during early autumn as water temperatures fall. Little is known about how Atlantic sturgeon use Minas Passage, except that they must traverse the passage when entering and exiting the Minas Basin since they do not remain in the Basin during winter.

3.1.3 Depth Distribution

Pop-up satellite tagging, using pressure sensitive tags, has demonstrated that Atlantic sturgeon occupy mostly shallow depths from 6 to 50 m (Erickson et al., 2011). McLean et al. (2013) found that they feed in the intertidal regions of Minas Basin at high tide. We hypothesized that they remain in near shore areas when moving through the Minas Passage in order to avoid high tidal velocities (Karsten et al., 2008) in the mid-passage region, which has a maximum depth in excess of 120 m (Figure 2.1).

3.1.4 Speed of Movement

Current speeds have been shown to have an effect on green sturgeon migration speed off the west coast of North America (Lindley et al. 2008). It has not been demonstrated, however, that sturgeon use selective tidal stream transport. Selective tidal stream transport has been demonstrated in many diverse migratory species of fish including sockeye salmon (Levy and Cadenhead, 1995), American eels (McCleave and Kleckner, 1982; McCleave and Wippelhauser, 1987), plaice (Weihs, 1978, Metcalfe et al., 1990), American shad (Dadswell et al., 1987), sole, cod and dogfish and has been shown to have widespread significances for fish migration in areas such as the European continental shelf (Arnold and Cook, 1984). It has also been suggested that this may be a type of transport that provides directional movement for fish not capable of accurate navigation (Metcalfe et al., 1990). Many sturgeon species undergo long distance migrations (Lindley et al., 2008; Erickson et al., 2011) and have been shown to have migration speeds up to 58 km/d (Lindley et al., 2008); sturgeon of approximately 2 m length commonly migrate at speeds of about 40 km/d (slightly less than 0.5 body lengths per second; Lindley et al., 2008).

3.1.5 Study Objectives

Since Atlantic sturgeon is considered to be demersal, this tracking study offers the additional opportunity to test the hypothesis that Atlantic sturgeon associate with the bottom when they are present in Minas Passage. To characterize the usage of the Passage by Atlantic sturgeon we attempted to address: 1) seasonality, when are Atlantic sturgeon present in Minas Passage?; 2) spatial distribution, what portion of Minas Passage is most heavily used by Atlantic sturgeon?; 3) depth distribution, what are the depth preferences of sturgeon when they are present in Minas Passage?; and 4) speed, at what speed do sturgeon move through Minas Passage?. To address these questions we used uniquely coded acoustic transmitter tags (Voegli et al., 1998) which measured pressure (depth) and were deployed on sturgeon while they were aggregated in the Minas Basin. Arrays of acoustic receivers (VR2w, Vemco ltd.) were installed close to the substrate spanning the Minas Passage and in close proximity to the proposed site for operation of in-stream tidal power turbines (Fig 3.2). These receivers provided archived tag transmissions that included time stamped measurements of depth as the sturgeon moved through the passage toward the outer Bay of Fundy. Information on sturgeon seasonality, spatial distribution, depth preferences and speed was collected and analyzed. This information is central to developing predictions of impacts on Atlantic sturgeon of in-stream tidal power developments in Minas Passage.

3.2 Methods

3.2.1 Minas Basin Features

Minas Basin is a shallow estuarine water body connected to the Bay of Fundy by Minas Passage through which 14 billion tonnes of water transit the system during each phase of the semi-diurnal tides (Figure 3.1). Average tidal amplitude in Minas Basin is 11.5 m with some surpassing 16 m on spring tides (Bousfield and Leim, 1959). Much of Minas Basin has a depth less than 25 m at low tide, compared to the Minas Passage which reaches depths up to 115 m (Bousfield and Leim 1959; Percy 2001). Minas Basin and Minas Passage experience vertical mixing by the tides causing uniform temperatures and salinities (Bousfield and Leim, 1959). These physical characteristics and extreme tides along with shallow bathymetric gradients create a 1-2 km wide intertidal zone that attracts a summer feeding aggregation of Atlantic sturgeon (i.e., May-October; Yeo and Risk, 1981; McLean et al., 2013).

3.2.2 Tagging and Tracking

Atlantic sturgeons were captured by intertidal weir and otter trawl during the summer months (May to August) of 2010, 2011, and 2012. Transmitters (V16, 16 mm x 65 mm, Vemco/Amirix Inc., Nova Scotia; Table 3.1) were surgically implanted into the abdominal cavity of Atlantic sturgeon. Tagging was performed under the Department of Fisheries and Oceans Scientific Licence to Fish # 322595 and Acadia Animal Care Committee protocol # 07-11. To facilitate transmitter insertion a large PVC cradle capped on one end was tipped at a 45 angle to allow water to pool. A stock solution of 10 mg/L of MS222 was mixed with 20 L of fresh seawater (anesthetic solution of MS222 = 0.5 mg/L) and poured into the PVC cradle. Atlantic sturgeon were placed dorsal side up with their head and gills fully submerged in the anaesthesia bath until opercular beats were slowed and they were unresponsive to gentle stimulus such as a tail grab. Anaesthetised sturgeon were removed from the bath and placed ventral side up on a moistened tarpaulin. A 3-4 cm incision was made on the ventral surface on either side of the *linea alba,* generally posterior to the pelvic girdle. A transmitter was inserted and pushed approximately 4 cm anteriorly using the tip of a blunt probe.

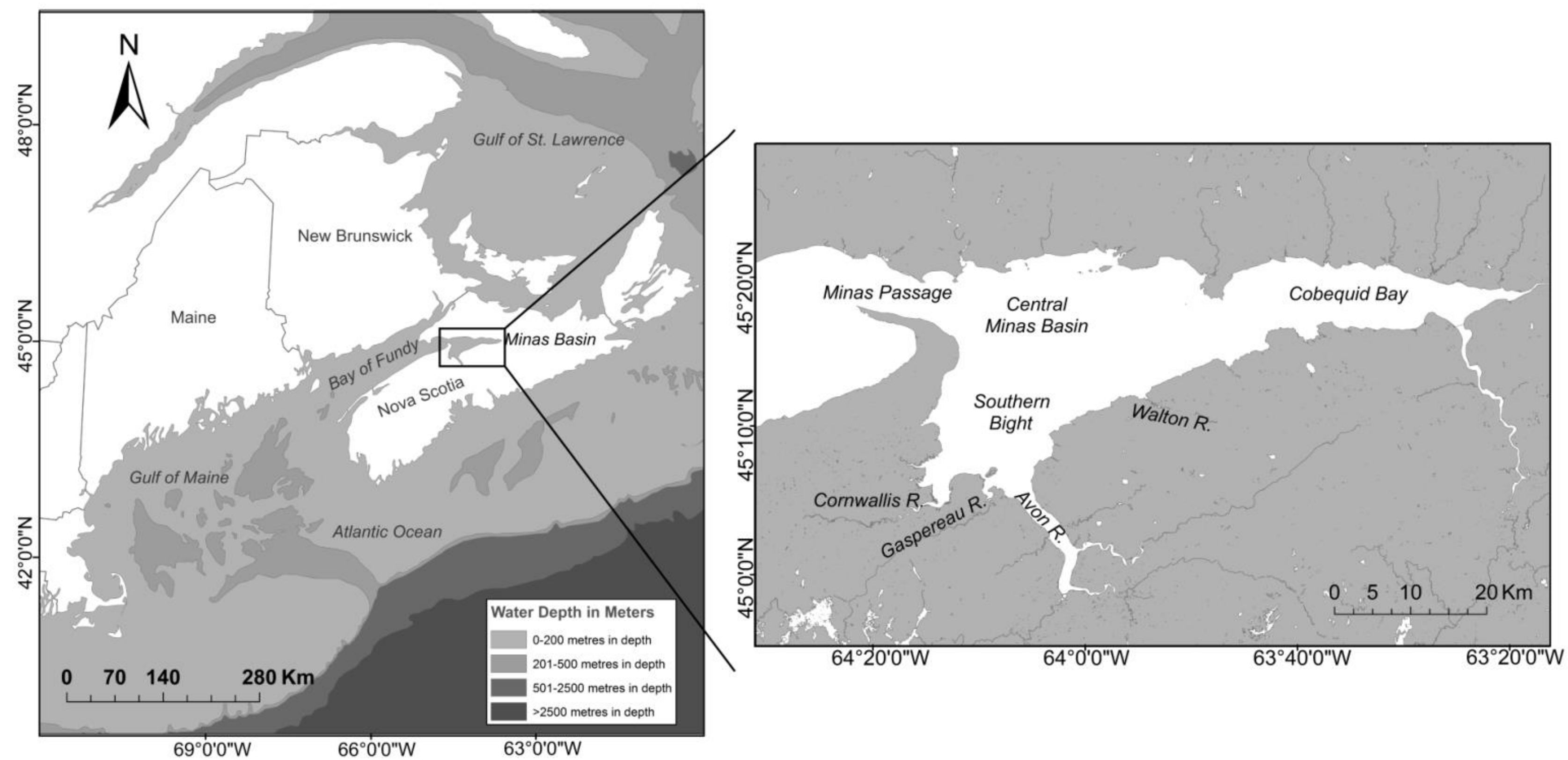

Figure 3.1. *Location of the Minas Basin, in the north-eastern portion of the Bay of Fundy, east of Minas Passage. The Minas Basin is designated by three distinct regions: Central Minas Basin, Cobequid Bay, and Southern Bight.*

Table 3.1. *Summary of coded acoustic tag models used during Atlantic sturgeon tagging project in Minas Basin during summers of 2010, 2011, and 2012 (n = 115). All models supplied by Vemco/Amirix, Inc., Halifax, NS, Canada. Tags from the earlier 2010 pilot study are included in this study as they were set to transmit for multiple years.*

Tag model	Year	Number used during study	Dimensions (mm)	Weight in air (g)	Battery life (days)	Power output (dB)
V16-6x	2010	17	16 x 95	34	1633	160
	2012	13				
V16P-6x*	2010	8	16 x 98	36	1287	160
	2011	53				
	2012	19				
V16TP-6x*	2010	5	16 x 98	36	1609	160

Note *tag includes environmental sensor (i.e., pressure and/or temperature)

Two horizontal mattress sutures, using sterile absorbable 1/0 Ethilon monofilament nylon sutures with a reverse cutting edge (Johnson & Johnson, Ontario), were used to close the incision site. All equipment, including transmitters, was disinfected prior to surgery using a 10% Betadine solution, followed by a saline rinse. Surgeries lasted 2-4 minutes excluding anaesthesia and recovery time. Post-surgery, sturgeon were held in a recovery tank and allowed sufficient time for the anaesthesia to wear off and for their condition to be monitored before being released in near the capture site. All sturgeon were also marked with an external dart tag (FLOY) and internal Passive Integrated Transponder tags (PIT) for identification purposes, measured to the nearest fork length in cm, weighed to the nearest Kg, and sampled for DNA prior to release.

Methods associated with receiver detections of tagged Atlantic sturgeon are described in Section 2 of this report.

3.2.3 Data Analysis

As a tagged sturgeon passes through an acoustic array, a signal is sent and recorded, often by more than one receiver. An acoustic signal will reach the nearest receiver first, then at the speed of sound traveling in water it will reach other receivers further away from the tagged animal. To remove this bias from the data set, each detection from an individual tag that was recorded by a second or consecutive receiver after up to 20 seconds from the first recording was deleted from the data set. This time period is within the blanking period of the tags. From this we know that successive detections were repeat detections of a single transmission. Double reception also biases the data toward the nearest receiver which is useful. The actual position, distance of the fish from the receiver, is unknown but must be within the receiver's detection range. Detection range varies with several factors (see Section 2 and www.Vemco.com), the greatest of which, in Minas Passage, is current speed. Range tests indicated that maximum range at slack water is approximately 500 m, and that the range at high flows is reduced to possibly 10s of metres (Broome and Redden, 2012). This creates a serious bias as transmissions at low flow are well represented in the data set and those at high flow, underrepresented. There is currently no accurate way to correct for this bias.

3.3 Results

In total, 114 Atlantic sturgeon were captured, tagged and released in Minas Basin during 2010, 2011 and 2012. In 2010, 30 Atlantic sturgeon were captured and tagged. Twenty-nine of these were captured by otter trawl off Cheverie, and one sturgeon was captured by a weir at Five Islands. In 2011, 53 Atlantic sturgeon were tagged, 41 were captured by trawl and 12 were captured by weir. In 2012, 31 Atlantic sturgeon were tagged, 26 captured by otter trawl and five captured by weir.

The fork lengths of the Atlantic sturgeon captured, measured and tagged in Minas Basin (N = 110, Mean = 132.5 cm FL, SD = 18.0) indicated that most sturgeon were likely sub-adults. The sturgeon could not be sexed so it is not known what proportion of the fish were males and what proportion were females, or if there were differences in fork length between sexes. Mean fork length varied between years (Figure 3.2), as follows:

- 2010 (N = 30, Mean = 135.8 cm FL, SD = 16.9);
- 2011 (N = 53, Mean = 125.6 cm FL, SD = 15.6);
- 2012 (N = 27, Mean = 142.3 cm FL, SD = 18.5).

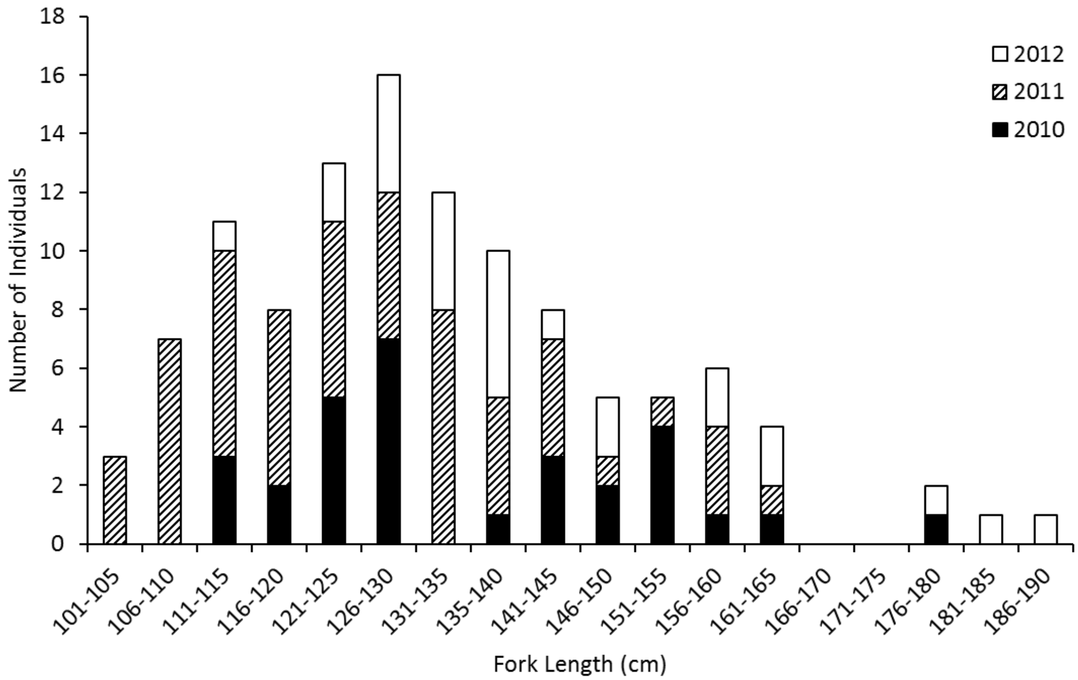

***Figure 3.2**. Cumulative fork length (cm) frequencies for captured and acoustically tagged Atlantic sturgeon during the 2010, 2011 and 2012 field seasons in Minas Basin, Bay of Fundy, Nova Scotia, Canada.*

3.3.1 Acoustic Detections Biased by Flow

As noted previously, the detection range of acoustic receivers is severely reduced at high flow. The Bay of Fundy is a complex system where strong currents (Smith et al. 1984) interact with shoals to produce upwelling and eddies (Trites and Garrett, 1983) so bodies of water move at different speeds. When the Minas Passage detections from acoustically tagged Atlantic sturgeon and other fishes were examined we found that the data set contained detections that are biased toward times of slow current speed (Figure 2.12).

3.3.2 Seasonality and Annual Return

Fish tagged in Minas Basin in summer 2010 migrated out through the Minas Passage into the outer Bay of Fundy in September and October (Figure 3.3). OTN hydrophone infrastructure was removed from Minas Passage for the winter in late November 2010 and then redeployed in spring 2011. Soon after the line was redeployed sturgeon began logging on to the receivers as they entered Minas Passage (May 2011). The majority of tagged fish moved through the Passage into Minas Basin by mid-late June. Sturgeon were periodically present in the Passage throughout the summer months and a more temporally dispersed out migration was observed in 2011 (September - October, Fig 3.3 and 3.4). Sturgeon arrived in the Passage in May 2012; only a few fish logged on to Minas Passage receivers during summer. The 2012 departure from the Basin was later, occurring mostly during late October and early November (Fig 3.5). Many sturgeon tagged in 2010 - 2012 returned to the Passage during 2013. This data set is not complete as the receivers were downloaded before the in-migration was complete.

The majority of Atlantic sturgeon tagged in 2010 (N = 30) returned and were detected by receivers in 2011 (87%) and in 2012 (70%). The majority of tagged 2011 tagged Atlantic sturgeon returned to the Passage and were detected in 2012 (66%; Table 3.2).

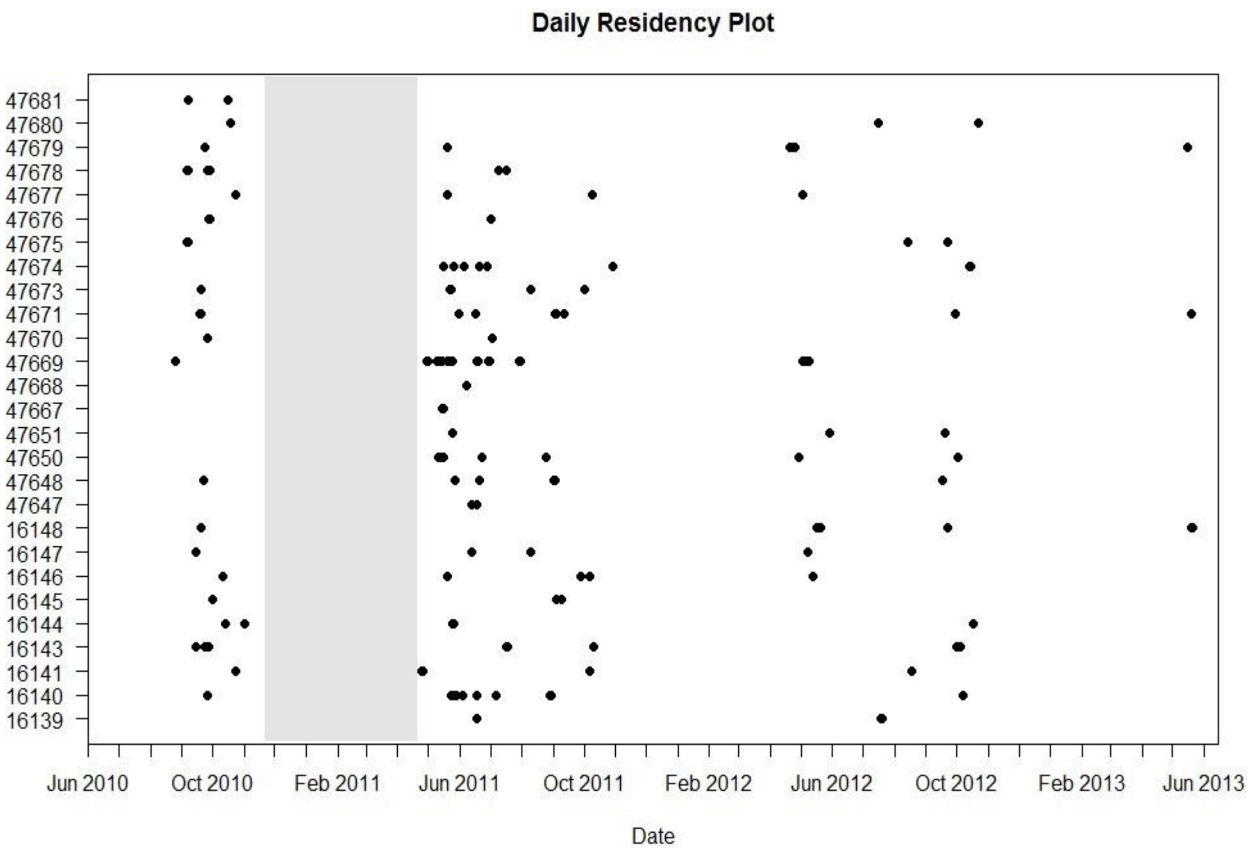

Figure 3.3. *Daily residency plot for Atlantic sturgeon tagged with internal acoustic transmitters in Minas Basin, Nova Scotia in 2010, and detected in Minas Passage, Nova Scotia in 2010-2013. Each dot indicates a day when a tagged sturgeon was detected by a hydroacoustic receiver in Minas Passage. Shaded area indicates time period when acoustic receivers were not present in the Minas Passage. During winter 2011 – 2012 the OTN Minas Passage line (MPS) was removed, but partial coverage was still provided by the Acadia line (AUL).*

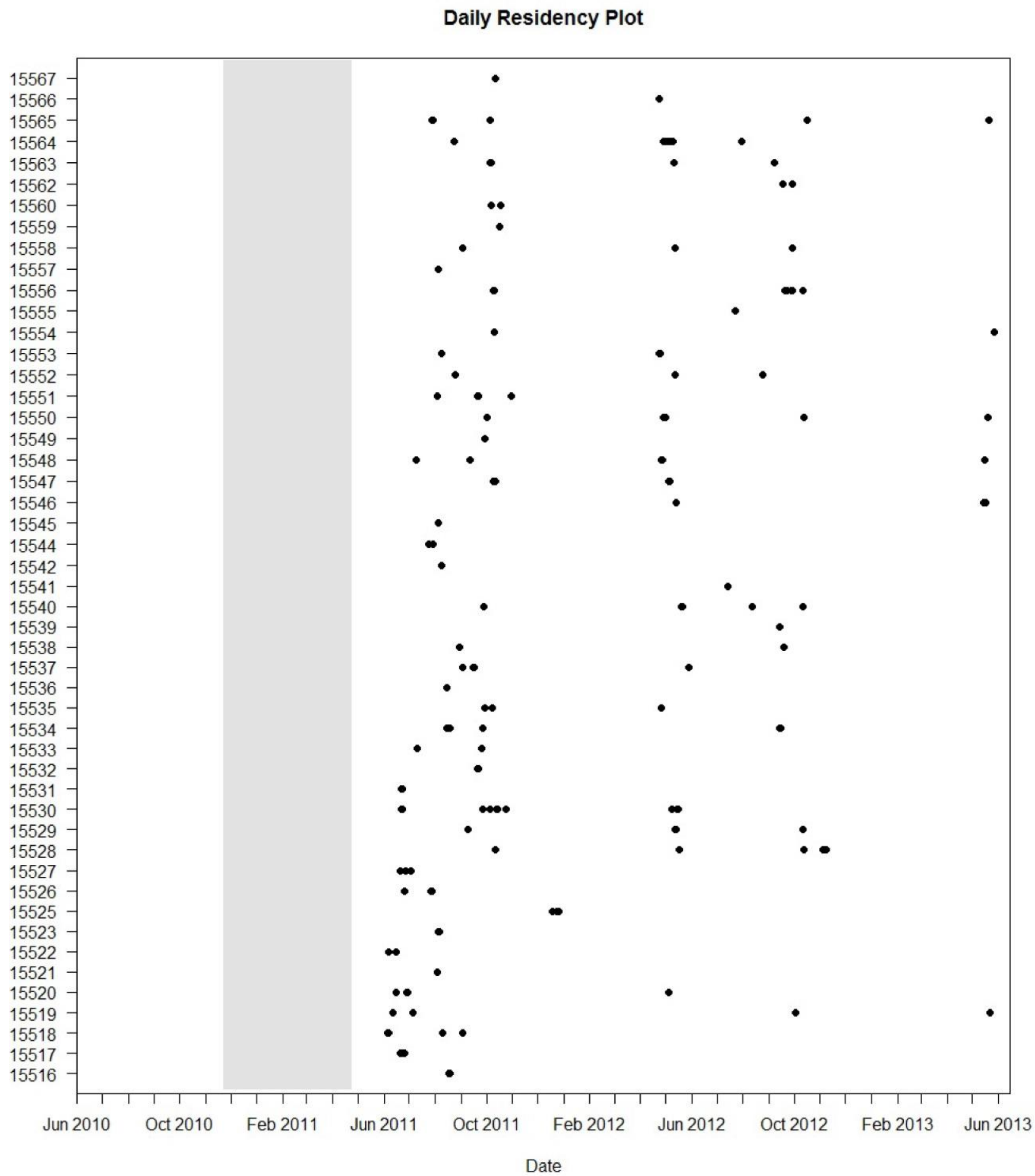

Figure 3.4. *Daily residency plot for Atlantic sturgeon tagged with internal acoustic transmitters in Minas Basin, Nova Scotia in 2011, and detected in Minas Passage, Nova Scotia in 2011-2013. Each dot indicates a day when a tagged sturgeon was detected by a hydroacoustic receiver. During winter 2011 – 2012 the OTN Minas Passage line (MPS) was removed, but partial coverage was still provided by the Acadia line (AUL).*

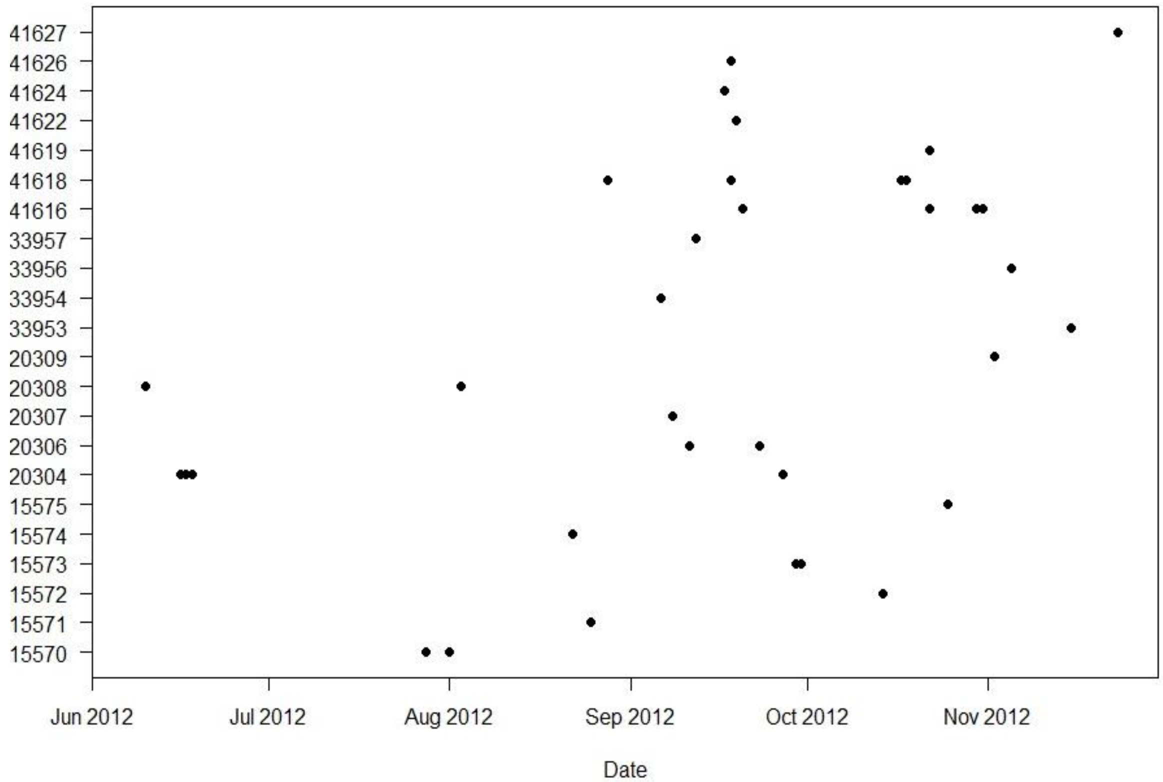

Figure 3.5*. Daily residency plot for Atlantic sturgeon tagged with internal acoustic transmitters in Minas Basin, Nova Scotia in 2012, and detected in Minas Passage, Nova Scotia in 2012. Each dot indicates a day when a tagged sturgeon was detected by a hydroacoustic receiver.*

Table 3.2. *Summary of yearly return of acoustically tagged Atlantic sturgeon to Minas Passage during 2010 - 2012 (n = 114).*

Year Tagged	Total Tagged	Number Detected in 2010	Number Detected in 2011	Number Detected in 2012
2010	30	22	26	21
2011	53	----	48	35
2012	31	----	----	31

3.3.3 Spatial Distribution

During the autumn migration in 2010, most sturgeon detected by the MPS line array were in the south part of the Passage (Figure 3.6). One receiver, MPS-04, was not retrieved. Several sturgeon were detected by the FORCE receiver array, a line about 1 km long in the northern section of the Minas Passage. As this line was not extended across the entire passage it is not clear how detections in the FORCE area relate to those that may have been detected in the central and southern parts of that section of the Minas Passage.

The movement pattern present in 2011 indicated use of the passage during the summer feeding period. Again, the southern portion of the MPS line recorded the majority of tagged individuals; fewer sturgeon were detected in the deeper central region and along the north side of the passage.

In 2011, the AUL array was deployed as a line array across the Passage and tagged Atlantic sturgeon were recorded in large numbers both in the north and the south, with slightly fewer animals detected in the centre of the passage (Figure 3.7). By this time 83 marked sturgeon had been released in the Minas Basin. It appears that directed migration may be more common along shore, although sturgeon did occupy habitat for significant amounts of time in all areas.

A Kernel density plot of 2012 detections (Figure 3.8) shows the majority of detections were clustered in the southern area of the passage. As with 2010 and 2011, fewer individuals logged on in the centre and the north. Two shorter lines of acoustic receivers were deployed to the east and west of the FORCE test site in 2012 and sturgeon logged on to these lines throughout the season. Sturgeons were not commonly detected in Minas Passage during the summer period of 2012.

An overall frequency distribution of detections across the MPS line indicates that the southern portion of the Passage is used the most at almost a 2:1 ratio (Figure 3.9). There are some gaps in the dataset; a few receivers were not recovered in 2010 and 2013 (e.g. MPS-04), which may have resulted in some bias toward portions of the passage that had complete receiver coverage. Regardless, sturgeon preference for the southern region of the Passage is apparent.

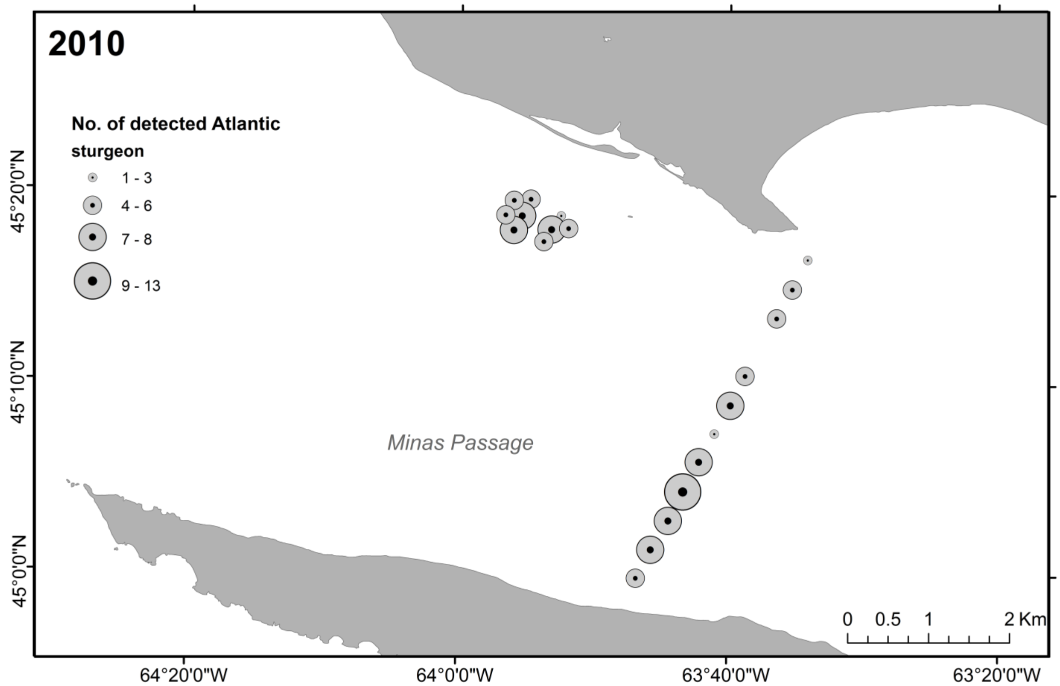

Figure 3.6. *Distribution of the number of tagged Atlantic sturgeon individuals that were recorded by hydroacoustic receivers in Minas Passage, Bay of Fundy, Nova Scotia is 2010.*

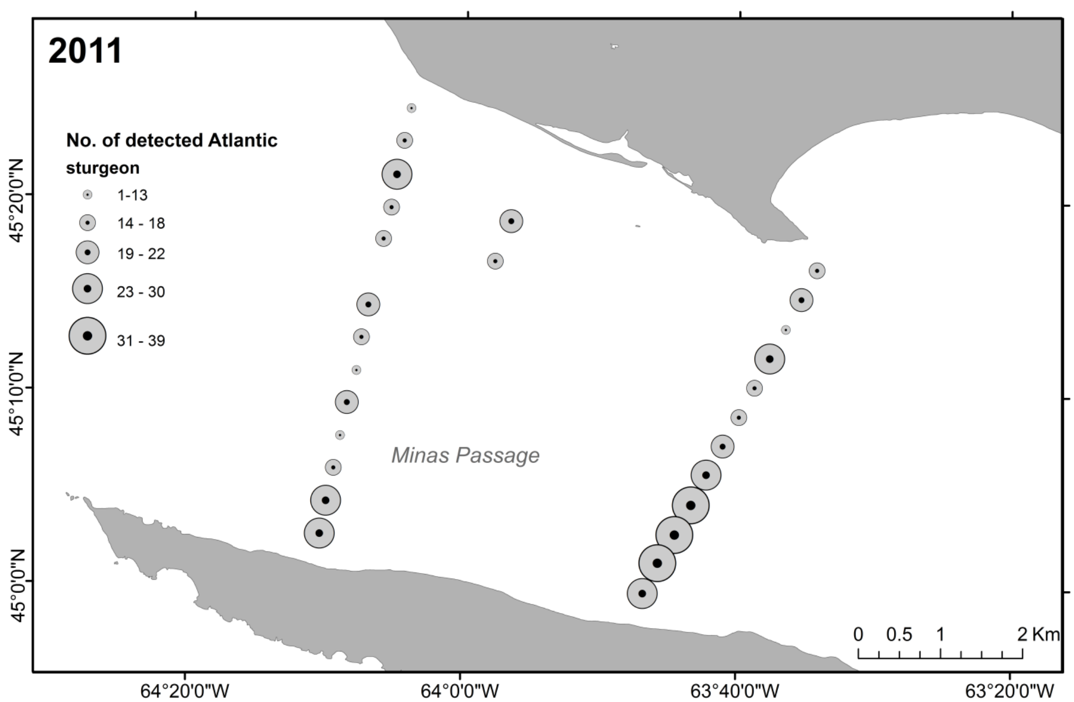

Figure 3.7. *Distribution of the number of tagged Atlantic sturgeon individuals that were recorded in 2011 by hydroacoustic receivers in Minas Passage, Bay of Fundy, Nova Scotia.*

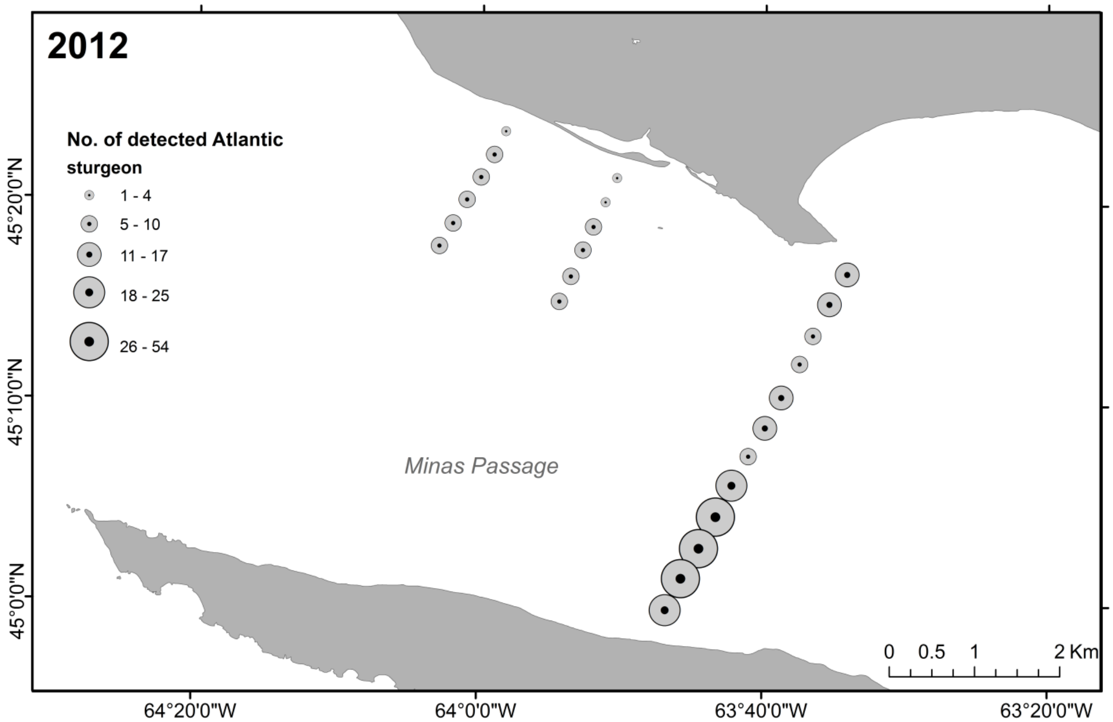

Figure 3.8. *Distribution of the number of tagged Atlantic sturgeon individuals that were recorded in 2012 by hydroacoustic receivers in Minas Passage, Bay of Fundy, Nova Scotia.*

3.3.4 Depth Distribution

Distribution of detections of acoustically tagged sturgeon carrying pressure sensors was examined for summer/fall 2010, spring/summer 2011, summer/fall 2011, spring /summer 2012, summer/fall/ 2012 and spring 2013. There were different patterns of detections during these periods however no seasonal or inter-annual patterns were evident (see Section 3.6). To provide a more complete picture of what depth Atlantic sturgeon occupied when they were present in the passage, regardless of season or year, we compiled the data from 2010-2013 (Figure 3.9). As receivers in the MPS line were placed in the same position each year (with little error) this allows a more complete examination of the depth distribution over time. Also, as it spans 3 years any inter-annual variability is represented in the data set.

Depths across the MPS line during this three year period indicate that sturgeon consistently frequented depths between 10 and 50m (Figure 3.9), with the majority of detections in the 20 to 40m depth range. To examine the influence of bottom depth on depth of swimming we ran a regression. The results of the regression indicate that bottom depth does not have a significant influence on swimming depth (P = 0.12; df = 11) in Minas Passage.

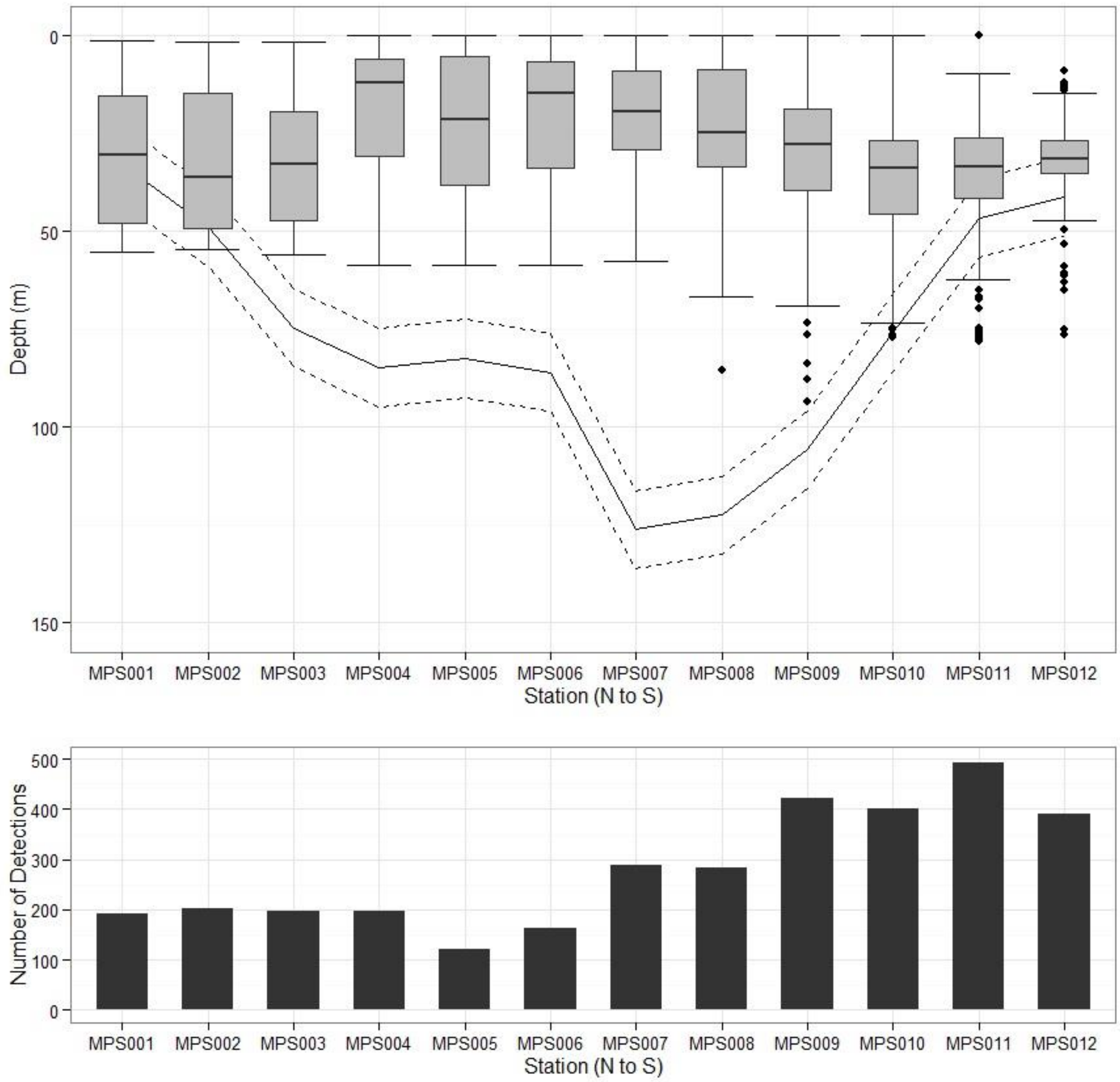

Figure 3.9. *Acoustic detections of tagged Atlantic sturgeon recorded in Minas Passage by the MPS line of receivers from October 2010 to May 2013. Note: Due to loss of receivers certain areas had periods when coverage was not available during months when sturgeon were present, including summer/autumn 2010 (MP004 and MP007 were not recovered) and spring/summer 2013 (MP003, MP004 and MP007 were not recovered). Top panel: Swimming depths of acoustically tagged Atlantic sturgeon. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical variation in depths due to high and low tides. Bottom panel: number of detections recorded by each receiver.*

Acoustic receivers deployed at the FORCE test site in different array geometries each year from 2010 to 2012 demonstrated that sturgeon did frequent this area (1054 tag detections in 3 years). Sturgeon at the FORCE site were most commonly distributed from 15 to 35 m in depth (Figure 3.10), with sturgeon higher in the water column during the night than during the day (Figure 3.11).

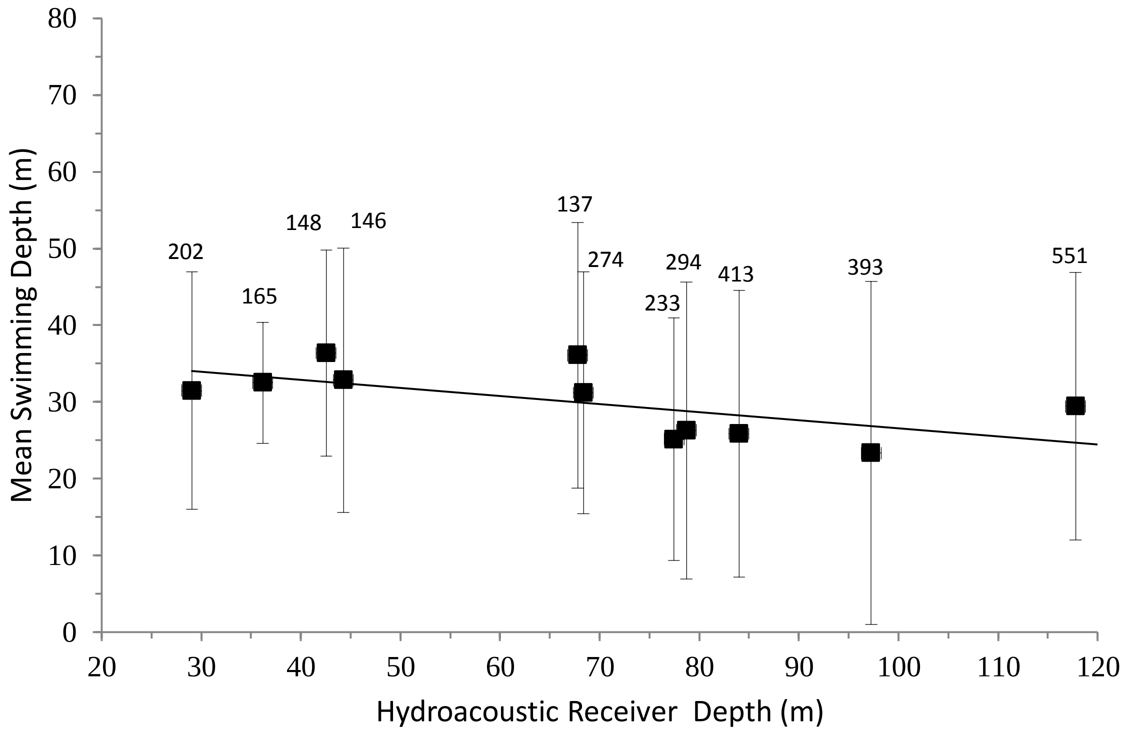

Figure 3.10. *Relationship between Atlantic sturgeon swim depth reported by pressure sensitive acoustic tags, and bottom depth of hydroacoustic receivers deployed in the Minas Passage Line Array (MPS) by the Ocean Tracking Network (squares = mean; whiskers = SD; data labels = N of detections). The relationship between swimming depth and bottom depth is not significant (P = 0.12; df = 11;* R^2 *= 0.482; y = -0.1049x + 37.059).*

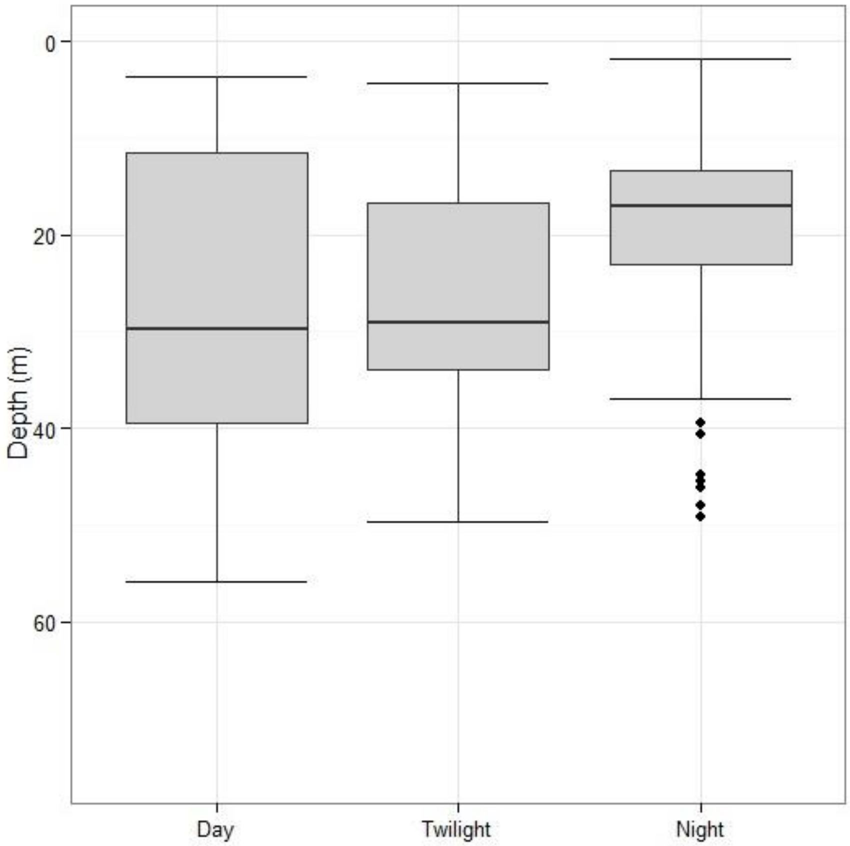

Figure 3.11. *Atlantic sturgeon swim depth measured at the FORCE test site 2010 to 2013. Categories are day, twilight (the period one hour before to one hour after dawn and dusk) and night. Depths were measured by pressure sensitive acoustic tags, Number measurements were Day = 497, Twilight = 192, Night = 365).*

3.3.5 Travel Rates

When evaluating speed of movement in acoustic tagging studies the fastest speeds between two points are the most meaningful. As the location and therefore path of the fish is not known for periods between detections at the acoustic receivers the fastest speeds usually represent the straightest line followed between two points. In this case the fastest speeds likely correspond also to the velocity of the water moving in the same direction as the sturgeon. The fastest speed that was recorded for an Atlantic sturgeon moving to the west through the passage was exhibited by a fish that logged on to receiver MPS 9 at 23:43 on 21 September 2011, and then logged on to receiver AUL 10 at 00.05 on 22 September 2011. This fish was 125 cm (FL) when tagged on 8 July 2011. The calculated speed of movement for this fish was 3.19 m/s, the equivalent of 2.6 body lengths per second. The fastest speed that was recorded for an Atlantic sturgeon moving to the east through the passage was by a fish that logged on to receiver AUL 6 at 04:09 on 21 May 2012, and then logged on to receiver MPS 6 at 4:23 on the same day. This fish was 113 cm (FL) when tagged on 8 July 2011. The calculated speed of movement for this fish was 3.23 m/s (2.9 body lengths per second).

3.4 Discussion

Measured fork lengths indicate that ~60% of Atlantic sturgeon captured in the Minas Basin are sub-adults (Wehrell et al. 2008). Maturity for Atlantic sturgeon may occur at different ages, and fork lengths for different populations. The more southern populations tend to mature at a younger age, while the more northern populations tend to mature at an older age. Northern male Atlantic sturgeons mature at approximately 140 - 150 cm (Dadswell, 2006). The component of mature adults found in Minas Basin during summer are from the Saint John River, rivers in the USA or possibly from some local rivers where spawning has not been reported in the scientific literature (i.e., the Kennetcook, St. Croix or the Stewiacke; Wirgin et al., 2012). Since the majority of Atlantic sturgeon tagged were sub-adults or males there was a high return rate for sturgeon to the Minas Basin over the three years of the study. It is possible that fish that did not return were virgin female adults who left the summer aggregation to spawn the following year in natal rivers. In the context of turbine deployment and operation, and interactions with turbines, we may make some predictions. It has been demonstrated that in a direct interaction with a turbine, smaller (shorter) fish have less chance of being struck by a blade during passage (Dadswell and Rulifson, 1994). Sub-adult sturgeon, however, are large and generally over 1 m long. As size increases, the probability that fish would encounter and interact with one or more blades also increases.

3.4.1 Seasonality

During winter, sea water temperatures in Minas Basin are low (often below 0°C). In this study, we expected sturgeon to move into Minas Basin in the spring, as temperatures climb, and to leave during the autumn as temperatures fall. Given the risk of sensor equipment loss over winter, due to potential submerged sediment-laden ice and debris in Minas Passage, receiver infrastructure was removed in late fall and re-deployed in spring 2010 and 2011. During 2010 and 2011, as expected, the tagged sturgeon moved into Minas Passage in spring. Atlantic sturgeon were present sporadically in Minas Passage throughout the summer, and then exited Minas Basin through Minas Passage in the fall. In 2012, the third year of this study, acoustic hydrophone infrastructure was present over winter in Minas Passage as researchers at ACER were examining the movement of American lobsters in Minas Passage and much of this movement was predicted to occur during the winter months. The presence of the hydrophone infrastructure in Minas Passage during winter provided corroborating evidence that Atlantic sturgeon are not present in Minas Passage during the winter months. There were no detections from tagged sturgeon present in Minas Passage from late November to May. Therefore, for approximately 6 months of the year (late November to late April), turbine infrastructure could operate in Minas Passage with no negative impact to Atlantic sturgeon populations.

3.4.2 Spatial Distribution

During the three year period covered by this study spatial information on how Atlantic sturgeon use Minas Passage indicate that they use the southern portion of the passage the most. We must keep in mind that the information available from the middle of the Passage over the greatest depth contains a bias, as the hydroacoustic receivers were mounted close to the bottom. Fish high up in the water column over the centre of the passage were, therefore, further from their bottom mounted receivers than fish were in shallower depths along the north and south shore. So detections in the middle of the Passage are likely under-represented in the data set due to limited detection range, particularly at high flow. In relation to planning for deployment of turbine infrastructure, our data indicate that the southern portion of the Passage is the most important area for sturgeon movement. However, detection data at receivers deployed in the FORCE test site indicate that sturgeon do frequent that area as well. As the arrays at the FORCE test site did not span the Minas Passage we cannot predict what proportion of the detections were in this area, only that there were a substantial number of detections at FORCE over the three years of the study. In summary, it appears that the southern portion of Minas Passage is the most important corridor for migrating Atlantic sturgeon, however, they do frequent all areas of the Passage.

3.4.3 Depth Distribution

The hypothesis that sturgeon are associated with the bottom while moving through Minas Passage was rejected as there was not a significant relationship between bottom depth and swimming depth. However, we must keep in mind that our data is biased toward slow current speeds. Atlantic sturgeon are generally considered a demersal fish, but their depth distribution over a known bottom depth in the marine environment has not previously been examined. In this study Atlantic sturgeon demonstrated preferences for depths between 20 and 40 m in both shallow areas and deep portions of the Passage (> 100 m). Atlantic sturgeon have been reported to prefer near-shore shallow depths in the marine environment (Erickson et al. 2011) however few observations have been made from deeper offshore areas. It is not known if the Minas Passage depth distributions are representative of depth patterns in other areas, especially those with lower flow rates.

The detection and swimming depth data in this study is biased toward times of reduced flow. It is apparent that sturgeon display pelagic movement though the Passage during low flow periods. Other possible behaviours, such as tidal stream transport (Levy and Cadenhead, 1995), where fish move close to the bottom, seeking slower current speeds, during periods of fast flow in a direction not desired by the fish, would not be apparent in our dataset. Therefore it must be kept in mind that the depth distribution of sturgeon at high flows (above approximately 1.3 m/s) is not known.

Atlantic sturgeon depth distribution at the FORCE test site indicate that sturgeon occupy depths between 15 and 35 m and are slightly higher in the water column at night than during twilight or during the day (Figure 3.11). Since sturgeon in Minas Passage are not associated with the bottom and they are known to be bottom feeders of soft bodied invertebrates generally inhabiting sand and mud in the intertidal zone (McLean et al., 2013), we assume that they are not demonstrating feeding behaviour that would be effected by the diel cycle. Atlantic sturgeon may be demonstrating a preference for low light levels and therefore may be moving to deeper depths during the day.

In the context of interactions with tidal power generation, it is important that we define the depth distribution of animals in areas targeted for installation and operation of in-stream tidal turbine devices. As Atlantic sturgeon show a preference for certain depths (20 to 40 m) over the entire eastern end of the passage and 15 to 35 m at the FORCE test site, turbine developers need to take this into account when attempting to mitigate possible impacts. As no operational turbines were present in Minas Passage during the three years of this study it was not possible to determine if Atlantic sturgeon were capable of detecting and avoiding turbine infrastructure. We have, however, determined the natural depth distribution for sturgeon in this area.

Methods to overcome technological limitations, including use of coupled acoustic and archival tags, can be used on large fish to fill in some information gaps. One of the Atlantic sturgeon tagged in our study was double tagged with acoustic and archival technology (Figure 3.12). In this figure we see that the acoustic tag is detected by receivers in Minas Passage, therefore placing the fish in the area of interest. The archival tag attached to the fish continues to sample depth (and temperature and light level) every minute. The result is a complete depth track of a fish passing through Minas Passage that is not biased by loss of information as current speed increases. Coupling these two technologies provides more data on depth preferences of fish passing through the Minas Passage.

3.4.4 Travel Rate

The fastest speed of movement calculated from data provided by tagged Atlantic sturgeon in Minas Passage was approximately 2.8 body lengths per second, over a distance of approximately five km. There are energetic costs to swimming fast, particularly for sturgeon as they create substantial drag in the water at high speed (Webb, 1986). Some fish may have very fast burst swimming speed that may be used as an escape response or to attack prey (maintained for > 20 s; Beamish 1978), prolonged fast swimming speeds, particularly in a fish that has a slow metabolism such as a sturgeon (Singer et al., 1990), produces exhaustion in a short time period (Peake et al. 1997). Green sturgeon were shown to commonly migrate at a speed of 0.25 body lengths per second (BL/s; Lindley et al. 2008). Swim speed and time to exhaustion have been investigated for lake sturgeon (*Acipenser fulvescens*; Peake et al., 1997). It was found that large lake sturgeon (106 cm – 132 cm), swimming in a flume at a swimming speed of approximately 120 cm/s, were exhausted in 5 – 13 minutes. Therefore, it is most probable that Atlantic sturgeon are moving with the tides and are moving at a faster speed than they would be accustomed to without tidal currents. Again, as stated above our acoustic data is severely biased toward times of reduced flow, therefore, tagged sturgeon likely move faster through Minas Passage than has been recorded in this study. In the context of turbine operation, developers should keep in mind that fish speeds while traversing the Minas Passage are very fast and may influence the animal's ability to detect and avoid turbine infrastructure.

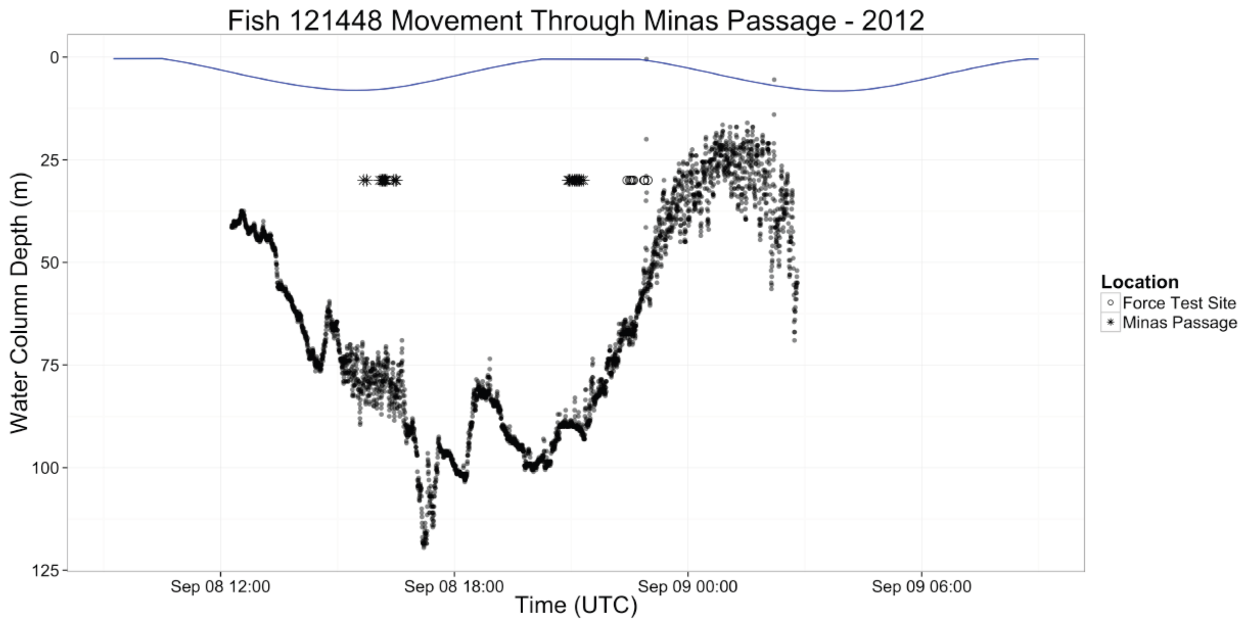

***Figure 3.12**. Depth profile for an Atlantic sturgeon tagged with a pop-up satellite archival tag, and an acoustic tag (depths not shown) moving through Minas Passage in September 2012. Acoustic tag detections place the sturgeon near receiver stations at the FORCE test site and elsewhere in the Minas Passage, at times of low to moderate flows. The archival tag measures pressure (depth) at 1 minute intervals but the location of the archival tag within Minas Passage is unknown. Tidal height is represented by the blue line at the top of the figure.*

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3.6 Appendix

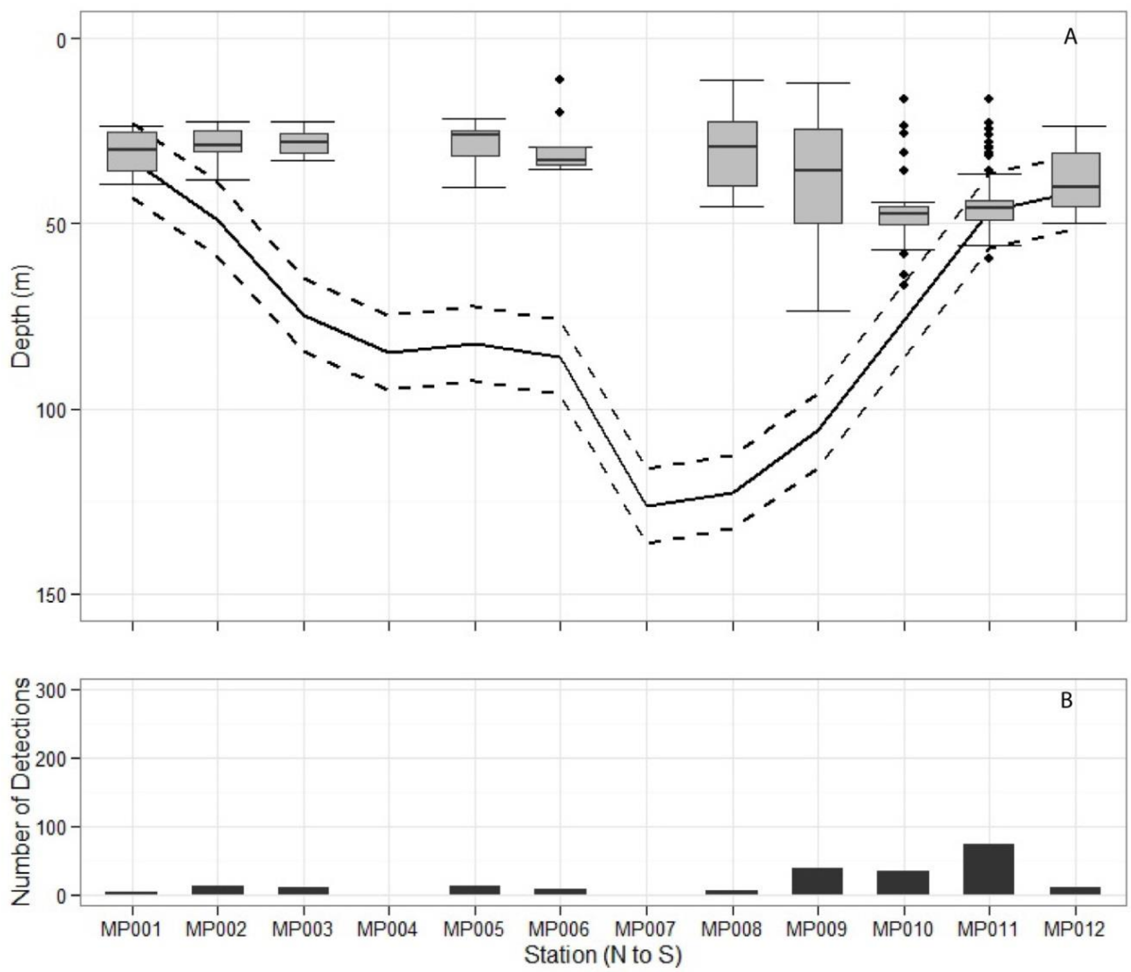

Figure A3.1. *During August, September and October of 2010, 10 Atlantic sturgeon fitted with pressure sensing acoustic tags were detected on an OTN-MPS line of VR2W receivers across Minas Passage, which connects Minas Basin to the rest of the Bay of Fundy. Note: Two receivers, MP004 and MP007, were not recovered.* ***A.*** *Swim depths of acoustically tagged Atlantic sturgeon were assessed every 15 seconds. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical depths of the bottom during high and low tides.* ***B.*** *The number of detections made by each receiver varied with slightly more detections being made by south shore receivers (i.e., MP009 to MP012).*

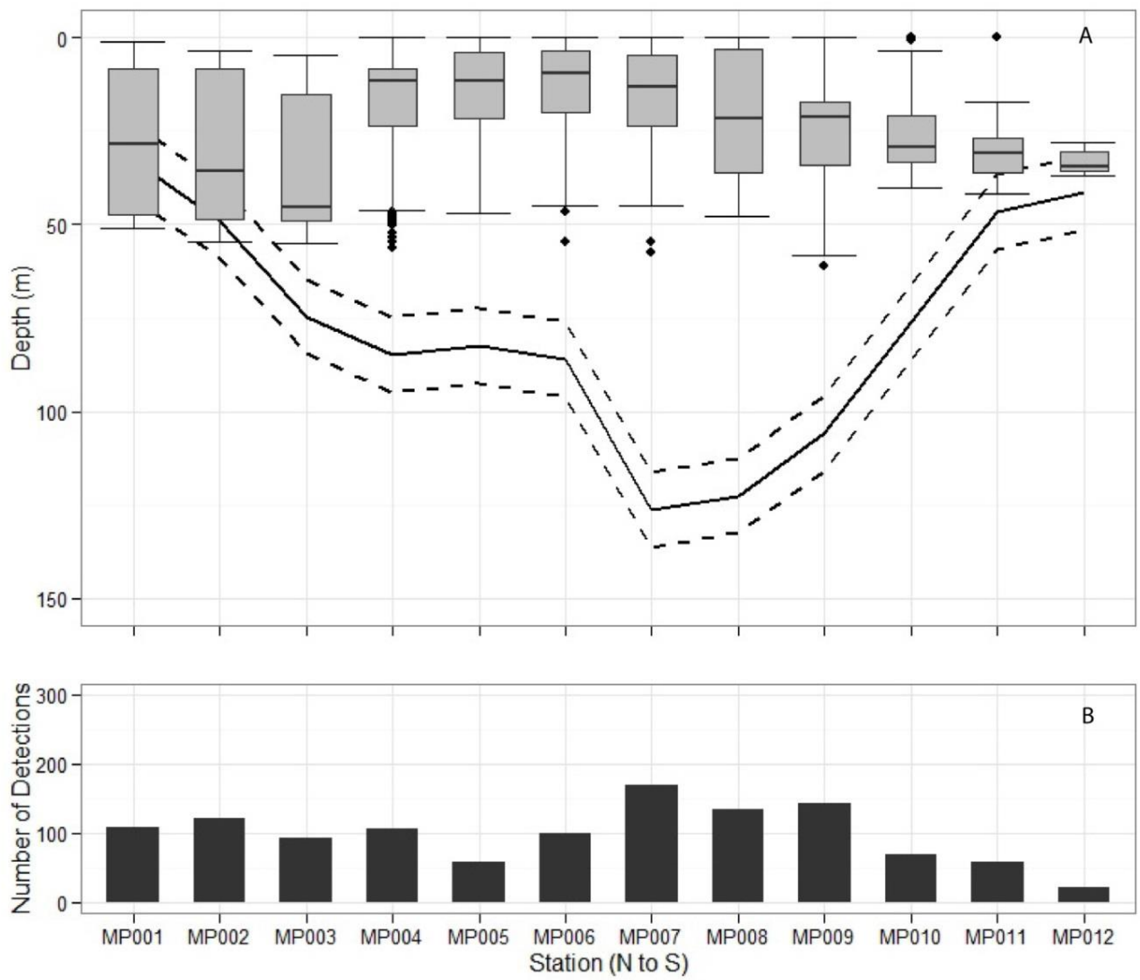

Figure A3.2. *During spring/summer of 2011, 22 Atlantic sturgeon fitted with pressure sensing acoustic tags were detected on the MPS line of VR2W receivers across Minas Passage, which connects Minas Basin to the rest of the Bay of Fundy.* ***A.*** *Swim depths of acoustically tagged Atlantic sturgeon were assessed every 15 seconds. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical depths of the bottom during high and low tides.* ***B.*** *The number of detections made by each receiver was variable but slightly more detections were made on the north shore and mid-passage receivers.*

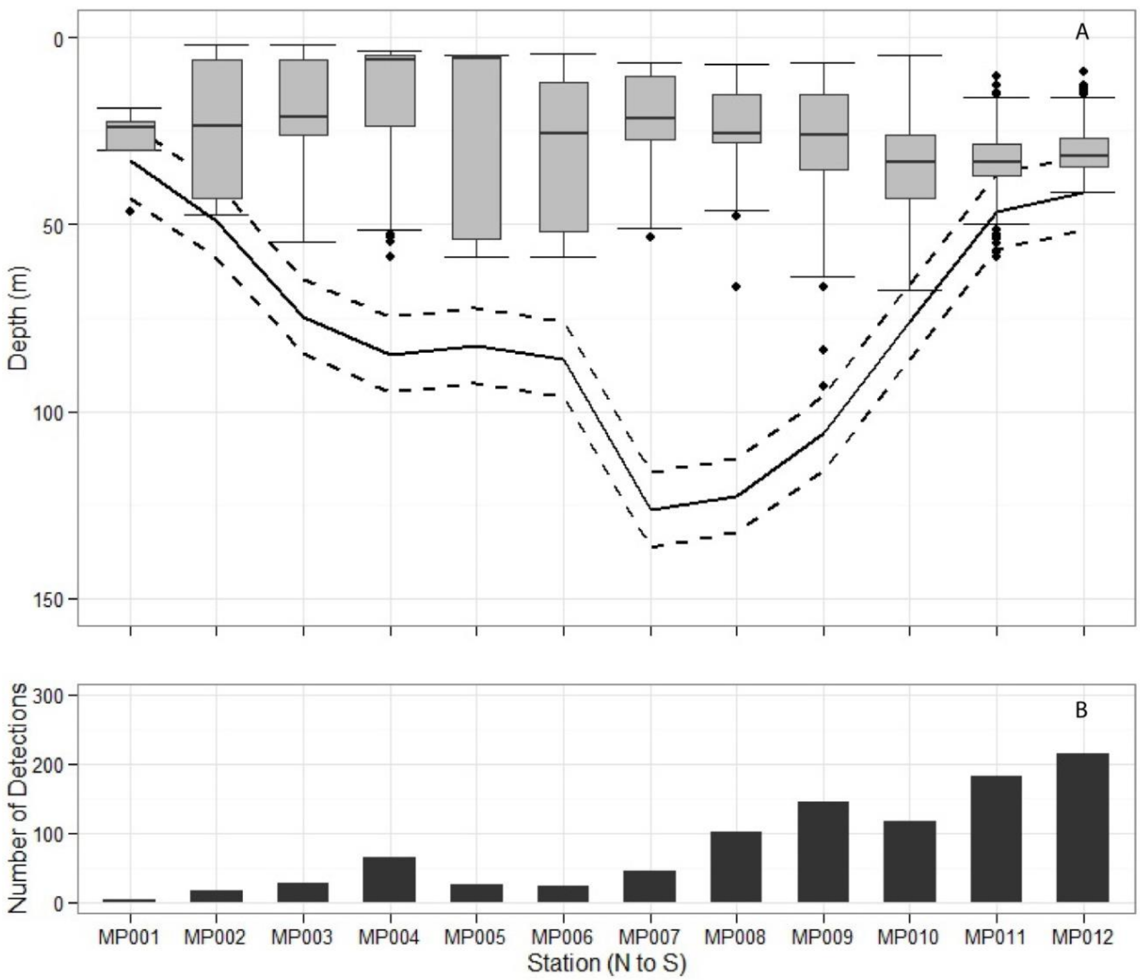

Figure A3.3. *During summer/fall of 2011, 43 Atlantic sturgeon fitted with pressure sensing acoustic tags were detected on the MPS line of VR2W receivers across Minas Passage, which connects Minas Basin to the rest of the Bay of Fundy.* ***A.*** *Swim depths of acoustically tagged Atlantic sturgeon were assessed every 15 seconds. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical depths of the bottom during high and low tides.* ***B.*** *The number of detections made by each receiver varied with more detections being made by south shore receivers.*

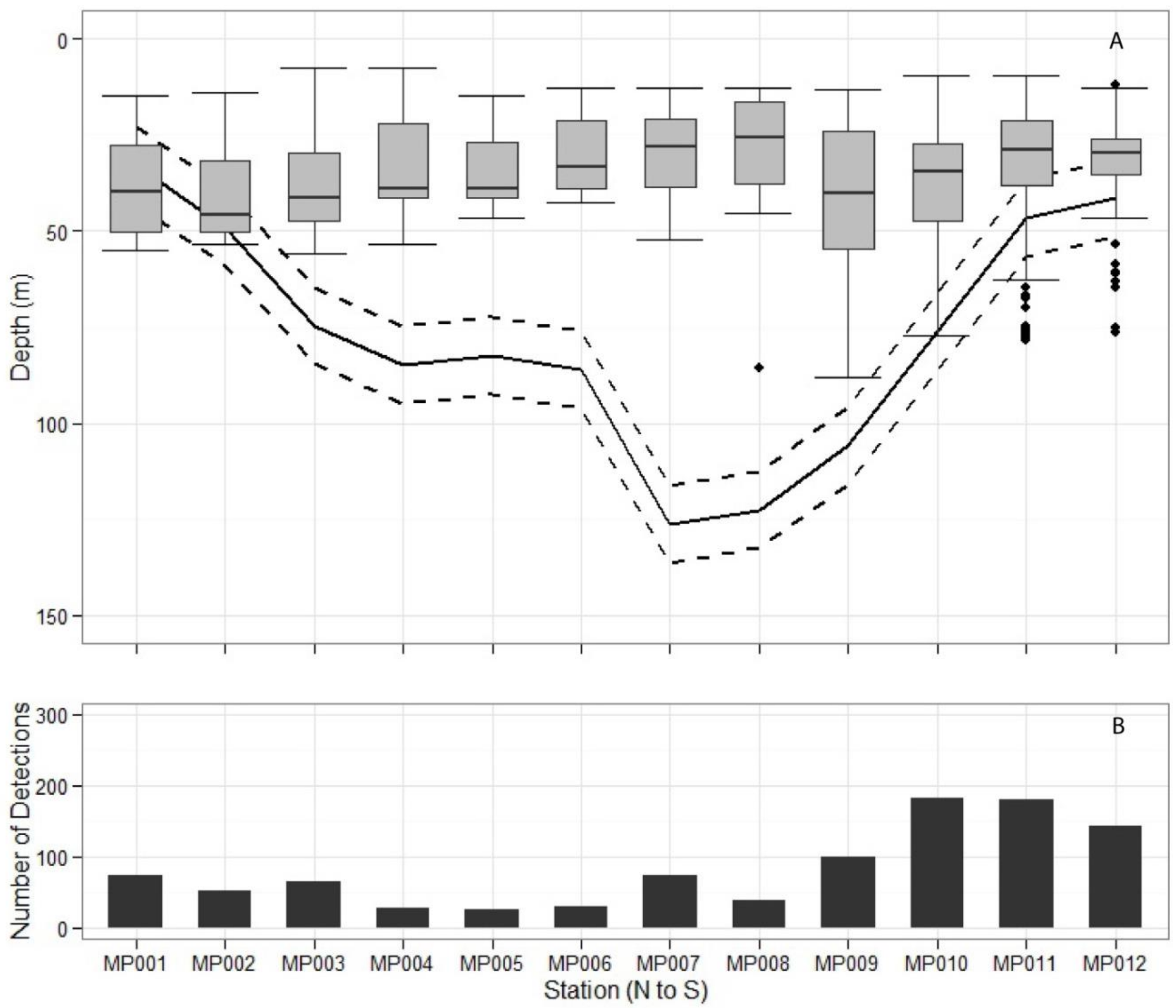

Figure A3.4. *During spring/summer of 2012, 30 Atlantic sturgeon fitted with pressure sensing acoustic tags were detected on an OTN-MPS line of VR2W receivers across Minas Passage, which connects Minas Basin to the rest of the Bay of Fundy.* ***A.*** *Swim depths of acoustically tagged Atlantic sturgeon were assessed every 15 seconds. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical depths of the bottom during high and low tides.* ***B.*** *The number of detections made by each receiver was variable but more detections were made on the south shore receivers.*

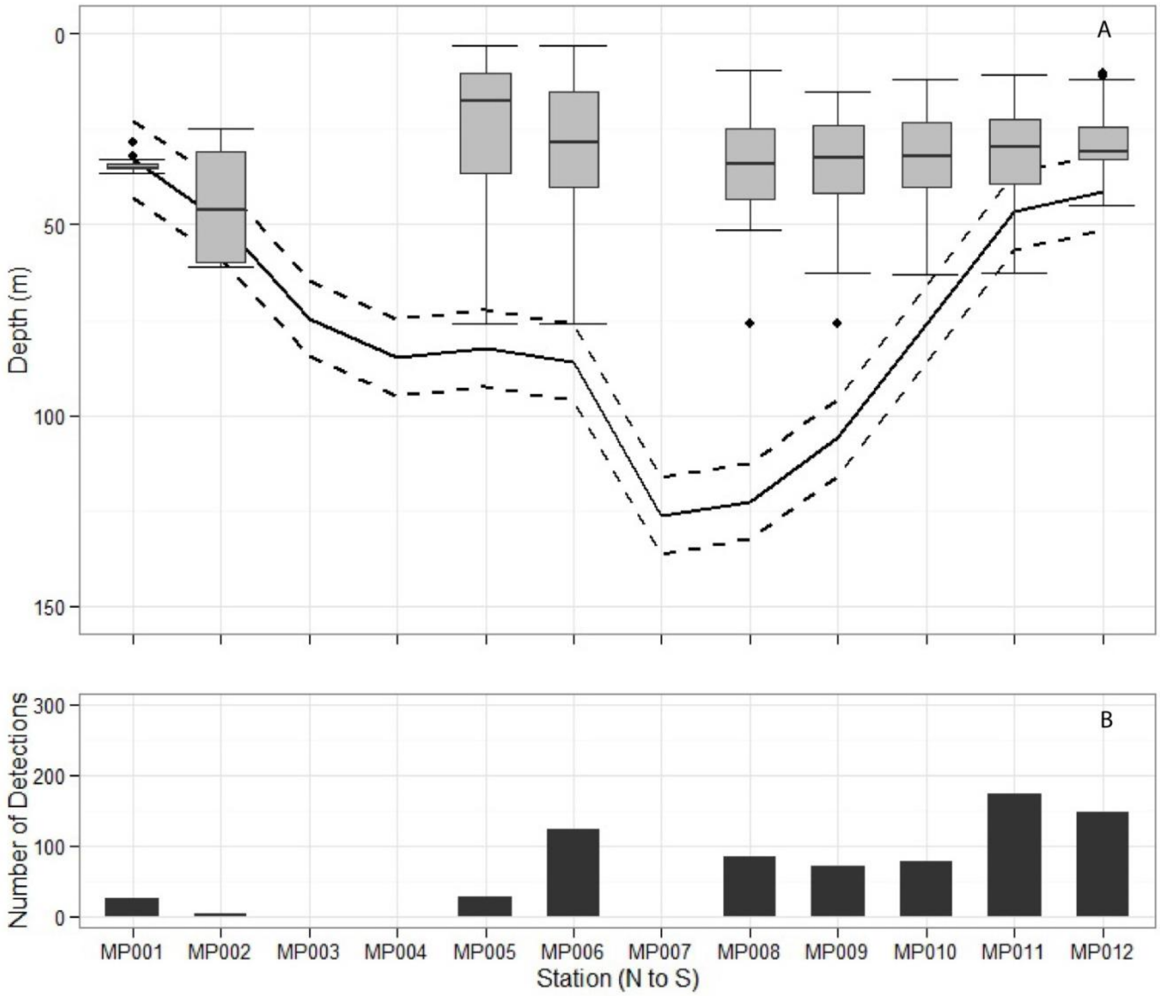

Figure A3.5. *During summer/fall of 2012, 40 Atlantic sturgeon fitted with pressure sensing acoustic tags were detected on an OTN-MPS line of VR2W receivers across Minas Passage, which connects Minas Basin to the rest of the Bay of Fundy. Note: Three receivers, MP003, MP004 and MP007, were not recovered.* ***A.*** *Swim depths of acoustically tagged Atlantic sturgeon were assessed every 15 seconds. Solid line represents the bottom depth of Minas Passage at slack water. Dotted lines represent the hypothetical depths of the bottom during high and low tides.* ***B.*** *The number of detections made by each receiver was variable but more detections were made on the south shore receivers.*

Section 4: Striped Bass Movements

Authors: FM Keyser, JE Broome, AM Redden, MJW Stokesbury and R Bradford

4.1 Background on Striped Bass

4.1.1 Life History

The Atlantic striped bass (*Morone saxatilis*) is an anadromous fish species distributed along the Atlantic coast from the St. Lawrence Estuary to northern Florida (Rulifson et al., 2008). The Bay of Fundy population is one of three remaining Canadian striped bass populations identified by COSEWIC, and has been recently elevated from Threatened status to Endangered status (COSEWIC, 2012a), in large part due to a decline in spawning locations.

Historically, the Bay of Fundy striped bass population consisted of three (3) unique stocks. Historically, spawning occurred in the Shubenacadie-Stewiacke, Saint John and Annapolis Rivers. Currently there is evidence of successful spawning in only one river, the Shubenacadie-Stewiacke River (COSEWIC, 2004; COSEWIC, 2012). Anthropogenic changes to habitat have been identified as major factors affecting spawning in the Saint John and Annapolis Rivers (COSEWIC, 2012).

Spawning in the Shubenacadie-Stewiacke River occurs in the spring and usually begins on a neap tide once the water temperature reaches 18°C (Rulifson and Tull, 1999). In the summer, post-spawning, adult and young-of-the-year striped bass move to the Minas Basin (Rulifson et al., 2008). Juveniles (up to 3 years for males, and 4 – 6 years for females) tend to remain year-round in brackish waters of the Minas Basin, while adults adopt one of two post-spawning migration patterns (Bradford et al., 2012). Some adults migrate seaward to the outer Bay of Fundy and beyond, while others return to overwinter in the Shubenacadie watershed, specifically in Grand Lake (Rulifson et al., 2008). The Bay of Fundy striped bass aggregation includes individuals from American stocks that have adapted divergent migration behaviours (Secor, 1991). Both native Bay of Fundy striped bass and American striped bass have been found overwintering in Grand Lake (Rulifson et al., 2008).

Striped bass take advantage of feeding opportunities whenever and wherever possible (Bradford et al., 2012). Their diets differ depending on life stage; larvae feed mainly on zooplankton, and juveniles on small crustaceans, annelid worms, and insects; adult striped bass have been known to feed on alewives, herring, smelt, eels, flounders, mummichogs, rock gunnels, sand lance, silver hake, silversides, shad and some invertebrates (Scott and Scott, 1988; COSEWIC, 2012). Adult striped bass have few predators, but juveniles may be eaten by Atlantic tomcod, Atlantic cod, silver hake, or even adult striped bass (Scott and Scott, 1988).

4.1.2 Migration

Throughout their range, striped bass exhibit a variety of migratory strategies (Secor, 1999). Early conventional tagging studies used mark-recapture methods to identify four general overriding patterns: 1) stocks located at both the southern and northern extents of the range undergo limited scale migrations; 2) the largest scale Atlantic coastal migrations are undertaken by stocks originating in the central portion of the range, namely those from Chesapeake Bay, Delaware, and Hudson Rivers; 3) the Atlantic coastal migratory population consists of large adult bass of which many are females; 4) following spawning, the Atlantic coastal migratory population moves north in summer, then moves south in fall toward overwintering areas in the southern portion of the range (Merriman, 1941; Chapotan and Sykes, 1961; Nichols and Miller, 1967; Clarke, 1968; Kohlenstein, 1981; Boreman and Lewis, 1987; Waldman et al., 1990).

Conventional tagging studies within the Bay of Fundy indicate that the summer resident striped bass population is composed of a mixed stock aggregation (Rulifson and Dadswell, 1995; Rulifson et al., 2008). Atlantic coastal migrants enter the Bay of Fundy to feed and overlap in habitat range with native bass. The makeup of this aggregation is likely highly variable both seasonally and annually (Rulifson and Dadswell, 1995; Rulifson, et al., 2008; Bradford et al., 2012). It is possible that migrant bass may share overwintering sites with native bass in some years (Rulifson et al., 2008), however, there is no evidence that these individuals attempt to breed with striped bass from Canadian populations (Jessop, et al., 2003). While striped bass tagged in the Bay of Fundy have been recaptured in the Hudson River and in Chesapeake Bay (Wirgin et al., 1995), these fish have not been identified as originating from the Bay of Fundy population.

Conventional tagging studies are useful but limited in that they are fishery dependent and require the return of tags. As such, conventional tagging is not applicable for areas with low fishery effort (commercial or recreational) and is not a practical solution for precise determination of migratory pathways or swimming depth selection.

In recent decades, the development of advanced techniques has greatly increased the knowledge base relative to the diversity of striped bass migratory patterns. Methodologies include: otolith analysis (Secor et al., 2001; Gemperline et al., 2002; Morris et al., 2003; Zlokovitz et al., 2003), genetic investigation (Wirgin et al., 1993; Wirgin et al., 1995; Robinson and Courtenay, 1999; Gautier et al., 2013), and acoustic tracking (Able and Grothes, 2007; Ng et al., 2007; Wingate and Secor, 2007; Douglas, 2009; Mather et al., 2009; 2010; Pautzke et al., 2010; Wingate et al., 2011; Able et al., 2012). These techniques have permitted tremendous advancements in resolution of the large scale migratory patterns previously described as well as many newly discovered smaller scale movement patterns.

The adult marine phase of the striped bass life cycle is not well known for populations in the northern region of the species range. These stocks of striped bass, including Canadian stocks, are generally thought to exhibit a reduced migratory range (Setzler et al., 1980). It has been suggested that the Shubenacadie-Stewiacke stock may be contained entirely within Minas Basin (Douglas et al., 2003). Prior acoustic tracking studies have confirmed that striped bass originating from the Shubenacadie-Stewiacke stock have a migratory extent which ranges minimally to Minas Passage, including the FORCE test site (Stokesbury et al., 2012). The extent of the seaward migration of striped bass leaving the Bay of Fundy is currently unknown. Information related to depth selection of striped bass in the marine environment is also currently lacking from available literature.

Disruption to migration (seaward or to overwintering sites including Grand Lake) can be detrimental to striped bass**.** Barriers such as hydroelectric dams and tidal generating stations are known to impact the demographics of striped bass populations (Stokesbury and Dadswell, 1991; COSEWIC, 2012). At present it is unknown whether or not TISEC devices installed and operating in the Minas Passage at FORCE will affect the movements of striped bass. The varied seasonal presence of US origin striped bass within the upper Bay of Fundy (Wirgin et al. 1995; Rulifson et al. 2008) may also expose trans-boundary migrant striped bass to unknown levels of risk.

4.1.3 Study Objectives

To investigate potential risk of turbine-striped bass interactions, we examined the temporal and spatial movements of electronically tagged striped bass in the Minas Passage from 2011 to 2013. Movement patterns with respect to location with the Minas Passage, seasonal and diel cycles, travel speed, and swimming depth were investigated using VEMCO animal tracking technology.

4.2 Methods

4.2.1 Tagging

VEMCO acoustic transmitters were surgically implanted in a total of 85 striped bass in 2011 (n=40) and 2012 (n=45), all of which were caught by rod and reel angling in the Shubenacadie-Stewiacke River or near shore areas of the Southern Bight of the Minas Basin (Figure 3.1).

Section 2.2 of this report provides details on the acoustic receivers used to detect tagged fish throughout this study. In 2011, 40 striped bass were tagged using V13P-1H pressure-sensitive transmitters (36 x 13 mm, 6 g, 69 kHz, 156 dB) that signalled once every 45-95 seconds over a 170 day period (Table 4.1; Appendix 4 – Table 1). Twenty striped bass were caught in the Stewiacke River (45.16077, -63.33094), approximately 6.5 km upstream from the confluence with the Shubenacadie River, and twenty were caught in the Minas Basin at a site locally known as “The Guzzle” (45.1371, -64.2864), located near Grand Pré (Figure 2.10). Tagging in Stewiacke took place on May 24 and 25, 2011, while tagging near Grand Pré occurred on June 25 and 26, 2011.

In 2012, 45 striped bass were tagged (Table 4.1). Angling occurred along the Stewiacke River (45.14379, -63.35016, May 21-22, 2011), and near Grand Pré (June 11-19, 2011), as well as off of Kingsport (45.16645, -64.34648, July 20-27, 2011). V13P-1H pressure-sensitive transmitters were surgically implanted in 28 striped bass caught near Grand Pré; 8 of these transmitters were programmed to last 81 days with signalling delays of 15-45 seconds, and 20 were programmed for 170 days with delays of 45-95 seconds. V16P-4H pressure-sensitive transmitters (71 x 16mm, 26g, 69 kHz, 158 dB) were surgically implanted in 3 striped bass near Grand Pré, as well as all individuals tagged in Stewiacke and off Kingsport (Table 4.1; Appendix 4 – Table 1). These transmitters were programmed to signal for 774 days with delays of 45-95 seconds.

Striped bass were tagged in accordance with DFO Scientific License #322857 and Acadia University Animal Care Protocols 06-11 and 06-12.

***Table 4.1**. Summary of tagging activities in 2011 and 2012. Transmitter identification numbers, fork lengths of tagged striped bass and other tagging information can be found in Appendix 4, Tables 1 and 2.*

Year	Tagging location	Tagging dates	Striped bass tagged	Transmitter model	Tag life (days)	Signal time delay (s)
2011	Stewiacke	May 24-25	20	V13P-1H	170	45-95
	Grand Pré	June 25-26	20	V13P-1H	170	45-95
2012	Stewiacke	May 21-22	7	V16P-4H	774	45-95
	Grand Pré	June 11-19	8	V13P-1H	81	15-45
		June 11-19	20	V13P-1H	170	45-95
		June 11-19	3	V16P-4H	774	45-95
	Kingsport	July 20-27	7	V16P-4H	774	45-95

Methods for surgical implantation of transmitters in striped bass were consistent with Stokesbury et al. (2012), and followed those described in Douglas et al. (2009). All striped bass were anesthetized using 10% by volume Eugenol (clove oil; Hilltech, Vanleek Hill, ONT) in ethanol (95% EtOH) solution. The Eugenol/Ethanol mixture was added to a 40 L container with water from the tagging site to produce a 40mg/L anesthesia bath. Striped bass deemed suitable for surgery were placed immediately into the anesthesia solution and were monitored for induction of Stage 4 anesthesia (loss of equilibrium, no reaction to external stimuli, and regular but decreased opercular rate). Anesthetized striped bass were then positioned in a wet surfaced surgical trough. The surgical area was disinfected using a minimal amount of Aqueous 2% Stanhexidine, 4% Ethanol topical disinfectant solution (Omega Laboratories). A sample of scales (10mm x 30mm) was removed from around the incision site for later age determination. A 20-25mm incision was then made using a 10-gauge sterilized scalpel approximately 15mm offset of, but parallel to, the ventral midline. A sterilized Vemco transmitter was then inserted and positioned forward into the body cavity anterior to the incision site. The incision was closed with 2 interrupted horizontal mattress sutures using 4-0, non-absorbable, nylon monofilament suture material, and a 19mm semi-circular needle. Upon closing, the incision area was thoroughly irrigated with an Aqueous 2% Stanhexidine, 4% Ethanol topical disinfectant solution (Omega Laboratories). Striped bass were then held in a flow through holding tank until proper equilibrium was regained, at which point they were released back to the water at the capture site.

Receivers were deployed in the Minas Passage in spring of 2011 (Figure 2.6) and 2012 (Figure 2.7) and recovered following 6-12 months of deployment as shown in Tables 2.2 and 2.3. This study also includes striped bass tag detections from Minas Passage during an overwinter deployment (Dec 2012 to June 2013). A description of the Minas Passage, the flow regime, and receiver mooring locations and deployment periods can be found in Section 2 of this report.

4.2.2 Data Analysis

Following receiver recovery, data was downloaded to a computer using VEMCO's VUE software. The downloaded data was then exported to Microsoft Excel for viewing of raw detection data. Data were then imported to the R statistical package for detailed data analysis. Ages of tagged striped bass were calculated using fork lengths (in cm) and an age-length relationship derived by Jeremy Broome (Acadia University, unpublished data). Site depth, tide state (ebb/flood) and current speed data are shown in Figures 2.1-2.3.

Data on both number of tagged fish detected and number of transmissions recorded by receivers were analysed, keeping in mind the numerous variables and assumptions involved in using acoustic telemetry. Receiver data was corrected for clock drift. At times of low flow (<1 m/s), one tag transmission was often detected by multiple receivers. This effect was less common at higher flows because detection range decreases dramatically as current speed increases (Broome and Redden, 2012).

4.3 Results

4.3.1 Detection Summary

Acoustically tagged striped bass were detected in the Minas Passage from June – November 2011, and from June 2012 – April 2013 (Table 4.2). Approximately 30% of striped bass tagged each year were detected by receivers placed in and around the FORCE test site (Table 4.2).

Table 4.2. *Detection results for striped bass tagged in 2011 and 2012. The number of individual striped bass and the percentage of tagged individual striped bass (in parentheses) detected by each array are shown. Locations of receivers and lines are shown in Figures 2.6 & 2.7.*

Tagging year	Number of striped bass tagged	Receiver line	Number of individuals detected (% of all fish tagged)
2011	40	AUL	22 (55%)
		FORCE	13 (32.5%)
		MPS	22 (55%)
		All	25 (62.5%)
2012	45	AUL (E & W)	14 (31.1%)
		MPS	19 (42.2%)
		All	20 (44.4%)

4.3.2 Detection Summary for 2011

In 2011, 75% of the striped bass tagged in the Stewiacke River, and 50% of those tagged on the shores of Grand Pré were detected in the Minas Passage (Table 4.3). The total number of detections logged in 2011 was 3137, and the majority of detections were of Stewiacke-tagged bass. Striped bass tagged in Grand Pré were generally smaller and younger than those tagged in Stewiacke. It is unknown whether the individuals tagged in Grand Pré were of spawning age, so they have been classified as summer migrants, while those tagged in Stewiacke were assumed to be spawners. Larger bass (fork lengths greater than or equal to 60 cm) were detected more often in the Minas Passage than smaller bass (Table 4.4). Both the numbers of transmissions detected and numbers of fish present were highest in July, August and October (Table 4.5).

Table 4.3. *Size and age related detections of spawning (Stewiacke) and summer migrant (Grand Pré) striped bass detected in the Minas Passage between June and December of 2011.*

Tagging location	Grand Pré	Stewiacke	Total
Number of individuals tagged	20	20	40
Fork length range (cm)	38.2 – 60.7	63.3 – 81.0	38.2 – 81.0
Age range (year)	4 - 8	9 - 12	4 - 12
Number of individuals detected	10	15	25
Total number of detections	210	2927	3137

Table 4.4. *Number of receiver detections and number of individuals detected (shown in parentheses) per month (J, J, A, S, O, N = June, July, August, September, October, and November, respectively) for different size ranges (fork lengths, in cm) in 2011, for all receivers recovered from the Minas Passage.*

Fork length range (cm)	**Number tagged**	**Number detected**	**Number of transmissions detected per month (individual fish detected)**					
			J	**J**	**A**	**S**	**O**	**N**
38 – 50	13	5	0	0	13 (2)	27 (2)	16 (4)	0
50 – 60	6	4	0	0	21 (1)	43 (1)	4 (2)	2 (1)
60 – 70	13	10	632 (5)	1116 (9)	164 (6)	0	100 (4)	0
70 – 80	7	5	222 (1)	224 (3)	305 (4)	27 (3)	2 (1)	163 (2)
80 - 90	1	1	24 (1)	4 (1)	0	0	28 (1)	0

***Table 4.5**. Number of striped bass detected in 2011, number of detections (in parentheses), and percentage of total detections (in italics) per month ("J, J, A, S, O, N' = June, July, August, September, October, and November, respectively) for spawner (Stewiacke) and summer migrant (Grand Pré) striped bass at each array ("AUL" = Acadia University Line, "F" = FORCE line, "MPS" = Minas Passage Line) in 2011.*

Tagging site	Array	# of recovered receivers	Number of individuals detected per month (total number of detections) *percentage of total detections*						
			J	J	A	S	O	N	Total
Stewiacke	AUL	13	6 (322) *36.7*	10 (540) *40.2*	7 (207) *41.2*	3 (17) *17.5*	4 (21) *14.0*	2 (20) *12.1*	14 (1127) *35.9*
	F	2	3 (30) *3.4*	9 (79) *5.9*	3 (29) *5.8*	1 (1) *1.0*	1 (11) *7.3*	2 (2) *1.2*	12 (152) *4.8*
	MPS	12	6 (526) *59.9*	11 (648) *48.2*	8 (226) *44.7*	2 (9) *9.3*	6 (98) *65.3*	1 (141) *12.1*	15 (1648) *52.5*
Grand Pré	AUL	13	NA	1 (37) *2.8*	3 (22) *4.4*	3 (70) *72.2*	3 (5) *3.3*	0	8 (134) *4.3*
	F	2	NA	0	1 (2) *0.4*	0	0	0	1 (2) 0.1
	MPS	12	NA	1 (40) *3.0*	3 (17) *3.4*	0	4 (15) *10.0*	1 (2) *1.2*	7 (74) *2.4*
ALL	--	27	7 (878)	13 (1344)	13 (503)	6 (97)	12 (150)	3 (165)	25 (3137)

4.3.3 Detection Summary for 2012-2013

In 2012-2013, 86% of the striped bass tagged in the Stewiacke were detected in the Minas Passage. While 71% of those tagged near the shores of Kingsport were detected, only 29% of Grand Pré tagged fish were detected (Table 4.6). Striped bass tagged in Grand Pré were generally smaller and younger than those tagged in Stewiacke and Kingsport. The Grand Pré and Kingsport striped bass were summer migrants, while the Stewiacke bass were known spawners. The total number of detections logged in 2012-2013 was 8134, and the majority of detections were of Kingsport-tagged striped bass (Table 4.6).

As in 2011, larger bass (fork lengths ≥60 cm) were detected more often in the Minas Passage than smaller bass (Table 4.7). Detection numbers were highest in the winter months (Table 4.8). The number of striped bass present peaked in October, but was generally consistent throughout the study period (Table 4.8).

Table 4.6*. Number, size range, and age of striped bass detected in Minas Passage during June 2012 to April 2013.*

Tagging location	Grand Pré	Stewiacke	Kingsport	Total
Number of individuals tagged	31	7	7	45
Size range (cm)	39.8 – 65.6	62.6 – 87.4	61.0 – 73.0	40 - 87
Age range (years)	4 - 9	8 - 13	8 - 10	4 - 13
Number of individuals detected	9	6	5	20
Total number of detections	1852	2673	3609	8134

Table 4.7*. Number of tag transmissions and individuals detected (shown in parentheses) per month (J, J, A, S, O, N, D, J, F, M, A = June, July, August, September, October, November, December, January, February, March and April, respectively) for different size ranges of striped bass (fork lengths, in cm) in 2012 and 2013, for all receivers recovered from the Minas Passage.*

Fork length range (cm)	Number of fish tagged	Number of fish detected	Number of detections per month (individuals detected)										
			2012							2013			
			J	J	A	S	O	N	D	J	F	M	A
39 – 50	28	6	55 (1)	0	17 (1)	10 (2)	62 (4)	43 (1)	1 (1)	0	0	0	0
50 – 60	2	2	0	0	0	16 (1)	1 (1)	0	0	522 (1)	435 (1)	446 (1)	0
60 – 70	11	9	4 (1)	467 (4)	71 (3)	34 (2)	219 (3)	744 (1)	1605 (3)	722 (3)	317 (2)	873 (3)	50 (1)
70 – 80	3	2	0	110 (1)	0	59 (1)	0	0	302 (1)	640 (1)	3 (1)	294 (1)	0
80 - 90	1	1	12 (1)	0	0	0	0	0	0	0	0	0	0

Table 4.8. *Number of individuals detected in 2012-2013, number of detections (in parentheses) and percentage of total detections (in italics) per month ("J, J, A, S, O, N, D, J, F, M, A" = June, July, August, September, October, November, December, January, February, March and April, respectively) for spawner (Stewiacke and Kingsport) and summer migrant (Grand Pré) bass at each array ("A-E" = Eastern Acadia University Line, "A-W" = Western Acadia University Line, "MPS" = Minas Passage Line) in 2012 and 2013. Refer to Figure 4 for identification of individual striped bass. Tagging site codes: SR =Stewiacke River, GP =Grand Pre, KP = Kingsport.*

Site	**Array**	**Number of individuals detected (number of detections) and *percentage of total monthly detections***											
		2012							**2013**				
		J	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**ALL**
SR	A-W	1 (7) *9.9*	2 (94) *16.3*	1 (5) *5.7*	0	1 (72) *25.5*	1 (143) *18.2*	1 (105) *5.5*	1 (29) *1.5*	0	1 (81) *5.0*	1 (14) *28.0*	5 (550) *6.8*
	A-E	1 (4) *5.6*	2 (51) *8.8*	2 (3) *3.4*	0	1 (87) *30.9*	1 (37) *4.7*	1 (49) *2.6*	1 (79) *4.2*	0	1 (49) *3.0*	1 (18) *36.0*	5 (377) *4.6*
	MPS	1 (1) *1.4*	4 (199) *34.5*	2 (59) *67.0*	1 (25) *21.0*	2 (57) *20.2*	1 (564) *71.7*	1 (392) *20.5*	1 (277) *14.7*	0	1 (154) *9.5*	1 (18) *36.0*	6 (1746) *21.5*
GP	A-W	0	1 (124) *21.5*	2 (11) *12.5*	0	2 (7) *2.5*	1 (6) *0.8*	0	1 (33) *1.8*	1 (55) *7.3*	0	0	5 (236) *2.9*
	A-E	0	1 (80) *13.9*	1 (2) *2.3*	0	2 (5) *1.8*	0	0	1 (58) *3.1*	1 (118) *15.6*	1 (1) *0.1*	0	5 (264) *3.2*
	MPS	2 (59) *83.1*	1 (29) *5.0*	2 (8) *9.1*	3 (26) *21.8*	5 (54) *19.1*	1 (37) *4.7*	1 (1) *0.1*	1 (431) *22.9*	1 (262) *34.7*	1 (445) *27.9*	0	8 (1352) *16.6*
KP	A-W	NA	0	0	1 (1) *0.8*	0	0	3 (54) *2.8*	3 (116) *6.2*	1 (19) *2.5*	3 (88) *5.5*	0	3 (278) *3.4*
	A-E	NA	0	0	1 (3) *2.5*	0	0	3 (93) *4.9*	3 (216) *11.5*	2 (88) *11.7*	3 (138) *8.6*	0	3 (538) 6.6
	MPS	NA	0	0	2 (64) *53.8*	0	0	3 (1214) *63.6*	3 (645) *34.2*	1 (213) *28.2*	3 (657) *40.7*	0	5 (2793) *34.3*
ALL	--	3 (71)	5 (577)	4 (88)	6 (119)	8 (282)	2 (787)	5 (1908)	5 (1884)	4 (755)	5 (1613)	1 (50)	20 (8134)

4.3.4 Seasonal Movements

During the 2011 receiver deployment period, striped bass were first detected in the Minas Passage on June 15. Some individuals were present continuously throughout the study period (June to November 2011), while others were present sporadically. There was no clear seasonal pattern among summer migrants (striped bass tagged at the Guzzle in Grand Pré), but spawners (tagged in Stewiacke River) were present more often in the summer months. Furthermore, spawners were detected on more days than summer migrants, and spawners were often detected by multiple arrays on a single day. Striped bass were detected at the FORCE test site on 16 different days, mostly during the summer months (Figure 4.1, Table A4.3). The last detection of striped bass in the Minas Passage in 2011 occurred on November 13, the same day that the majority of receivers were retrieved during a recovery mission. Some receivers were retrieved earlier or later after being found by fishers or washed up on shore (details in Section 2).

In 2012, striped bass were first detected in the Minas Passage on June 28. Grand Pré summer migrant bass were detected rarely and sporadically during June 2012 to April 2013, while spawners and Kingsport summer migrants were detected much more frequently (Figure 4.2). Striped bass were present year-round in the Minas Passage, though individual presence varied throughout the year. Some individuals were present mostly in winter, while others were present mainly in the summer or fall.

This study reports the <u>first records of winter detections of striped bass in the Minas Passage</u> (Figure 4.2), a result we were not expecting. Six individual striped bass (one tagged at Grand Pré, one in Stewiacke, and four off Kingsport) were detected on numerous days from November 2012 to April 2013. Striped bass were detected near the FORCE test site on 112 different days during the full receiver deployment period (Figure 4.2, Table A4.4). During the 2012-2013 study, striped bass were last detected in the Minas Passage on April 6, 2013.

4.3.5 Spatial Distribution

In 2011, tagged striped bass were detected at all 27 of the recovered receiver stations. The highest numbers of detections occurred at the OTN-MPS line, on the eastern side of the Minas Passage, and in the mid to southern region of the passage (Figure 4.3). Post-spawners were detected by a greater number of receivers and over a broader area than summer migrants.

In 2012-2013, tagged striped bass were detected on receivers throughout the Minas Passage. As in 2011, detection numbers were greatest in the south eastern region of the Minas Passage (Figure 4.4; Figure 4.5). There were higher detections of spawners and Kingsport-tagged migrants than Grand Pré-tagged migrant striped bass. Sixteen individuals (36% of all tagged bass) were detected during the summer/fall receiver deployment in 2012 (June to November), with 10 of these individuals detected by AUL receivers located on either side of the FORCE test site (22% of all tagged bass). During the winter deployment (December 2012 to May 2013), 8 individuals were detected (18% of all tagged bass), and 5 of these individuals (or 11%) were detected by either AUL East or AUL West receivers. Throughout the entire receiver deployment period, a total of 20 striped bass were detected. Fourteen individuals (31%) were detected in or near the FORCE test site; 9 were summer migrants (6 from Grand Pré and 3 from Kingsport), and 5 were Stewiacke spawners (Table 4.2).

Furthermore, it was found that many of the large striped bass (>60 cm TL) moved back and forth through the Minas Passage numerous times (Figure 4.6). These movements spanned the entire passage (north to south).

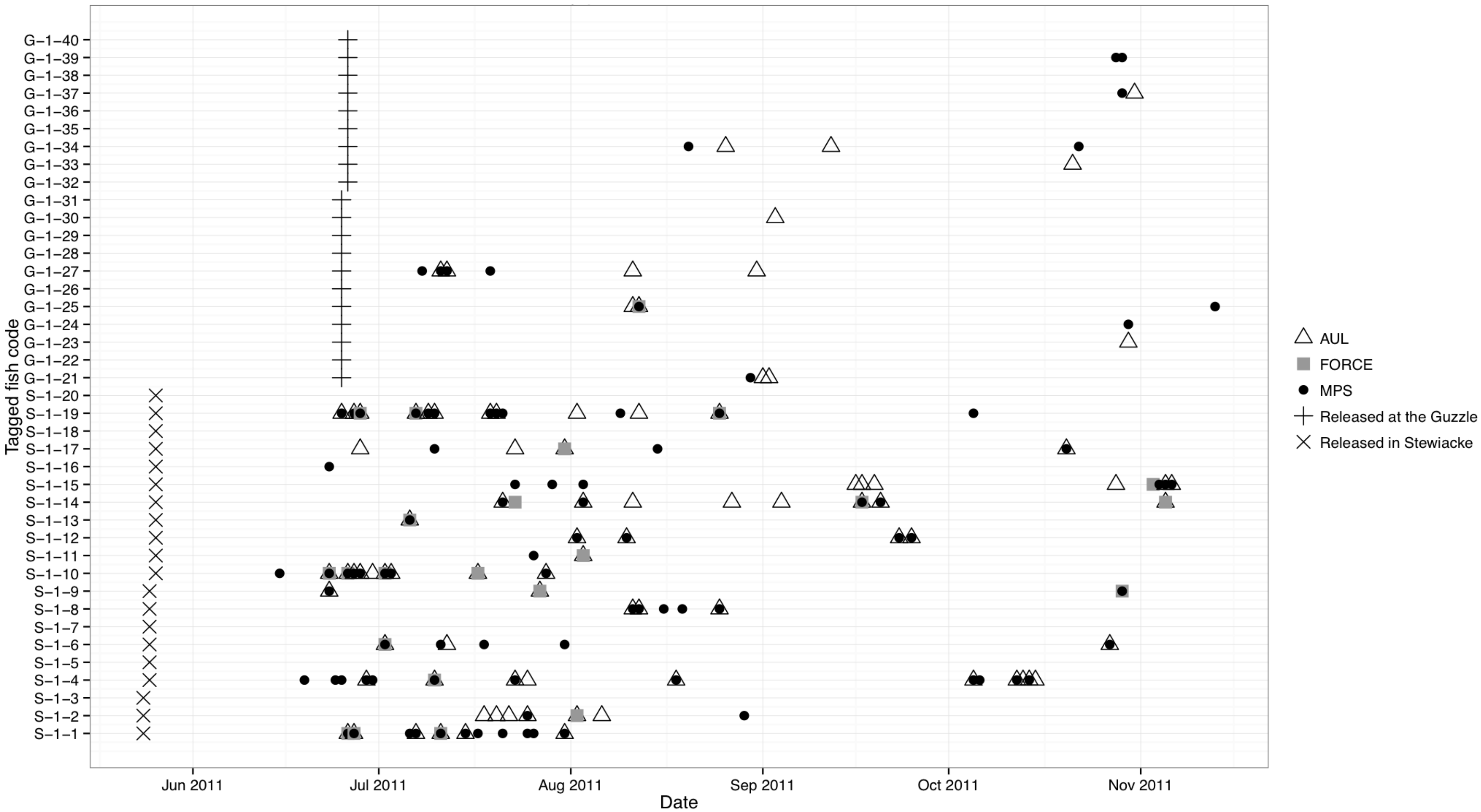

Figure 4.1. *Daily detections of tagged striped bass during 2011. Symbols indicate release dates and array(s) where individuals were detected.*

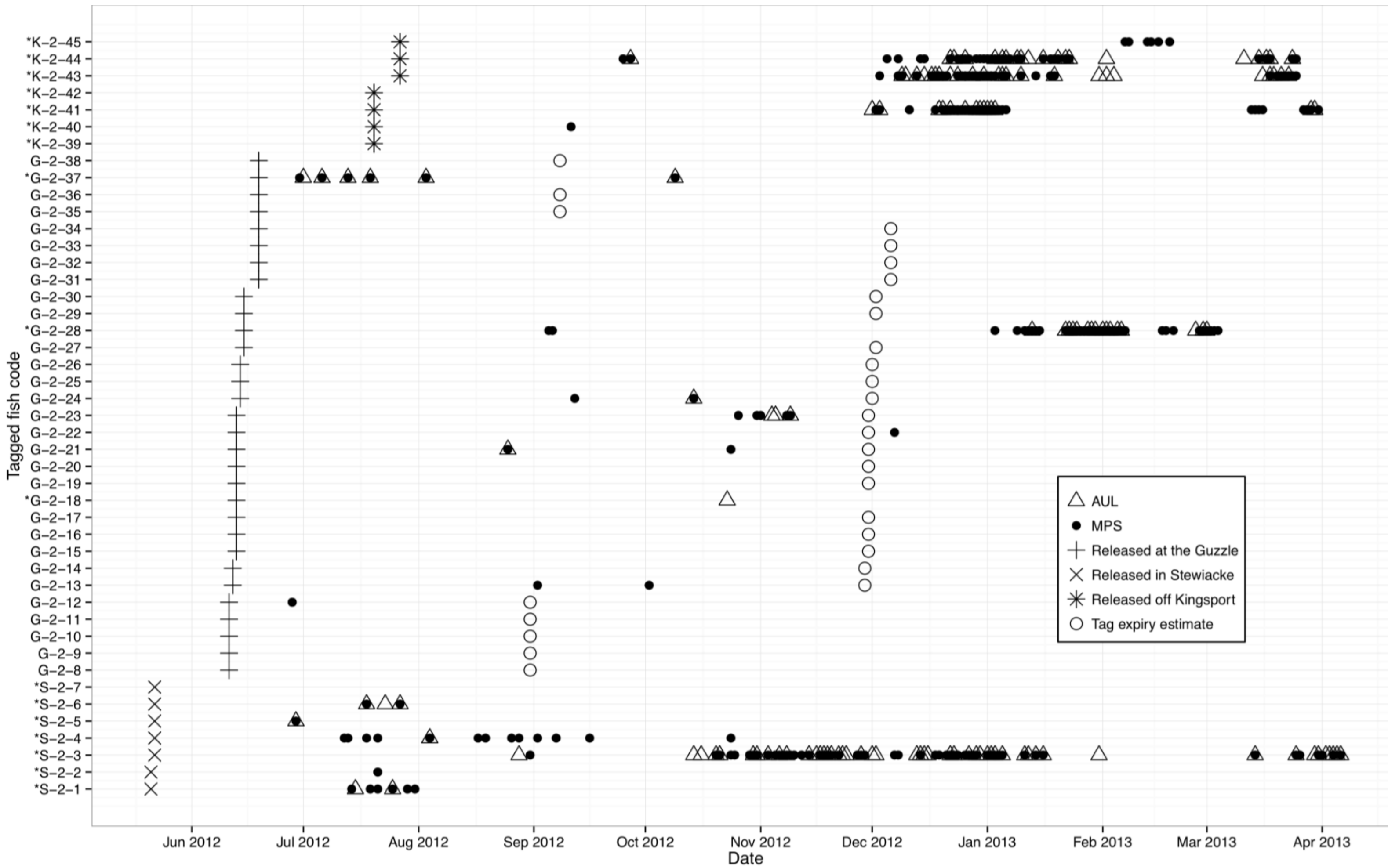

Figure 4.2. *Daily detections of tagged striped bass during 2012 and 2013. Symbols indicate release dates, tag expiry dates, and array(s) where individuals were detected. Individuals whose codes contain an asterisk were tagged with 774 day V16 transmitters.*

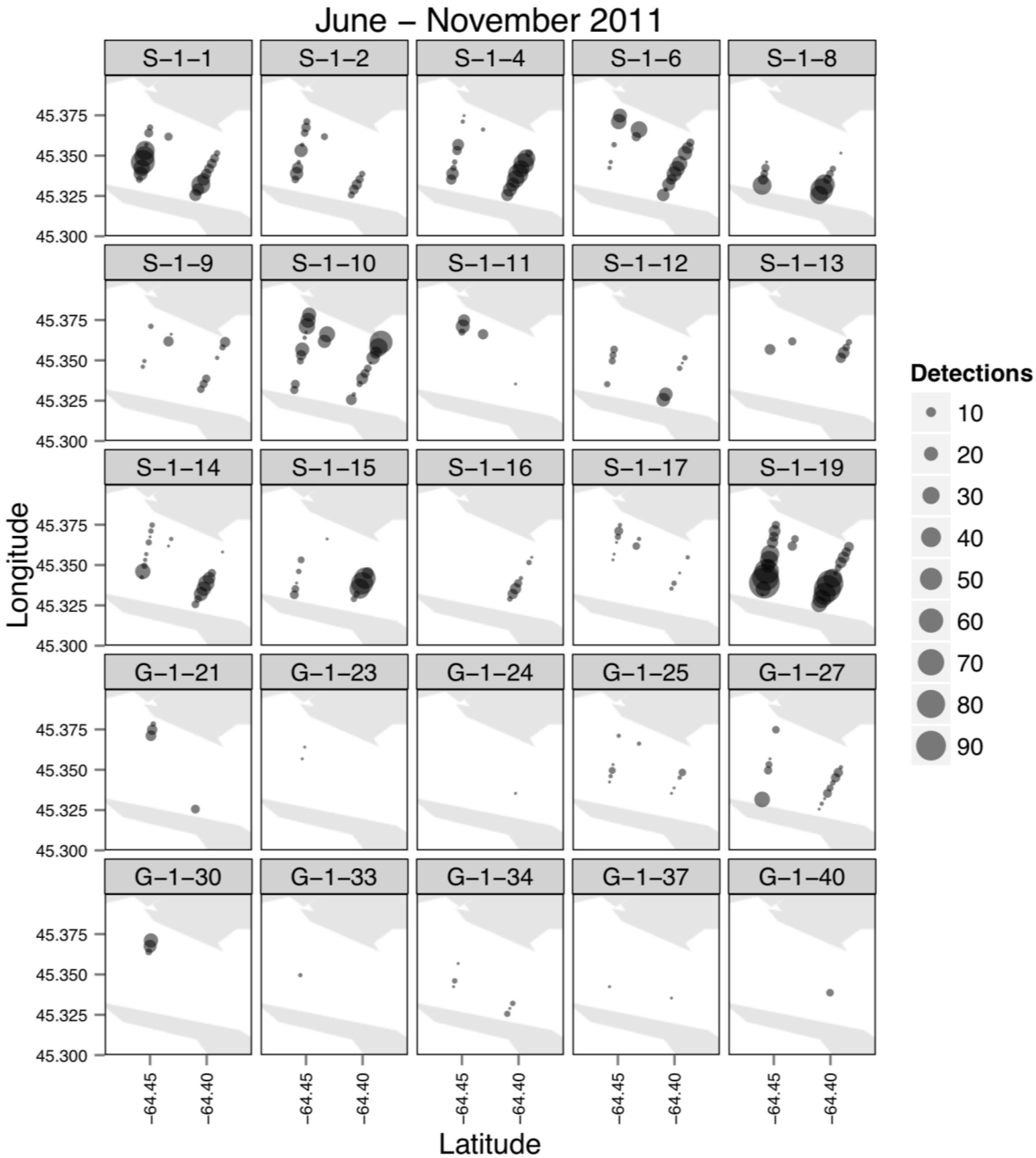

***Figure 4.3**. Spatial distribution of detections of bass tagged in 2011. The size of each circle is proportional to the number of detections at each location. Identification codes are given above each plot; codes beginning with "S", and "G" correspond to individuals tagged in Stewiacke, and Grand Pré, respectively.*

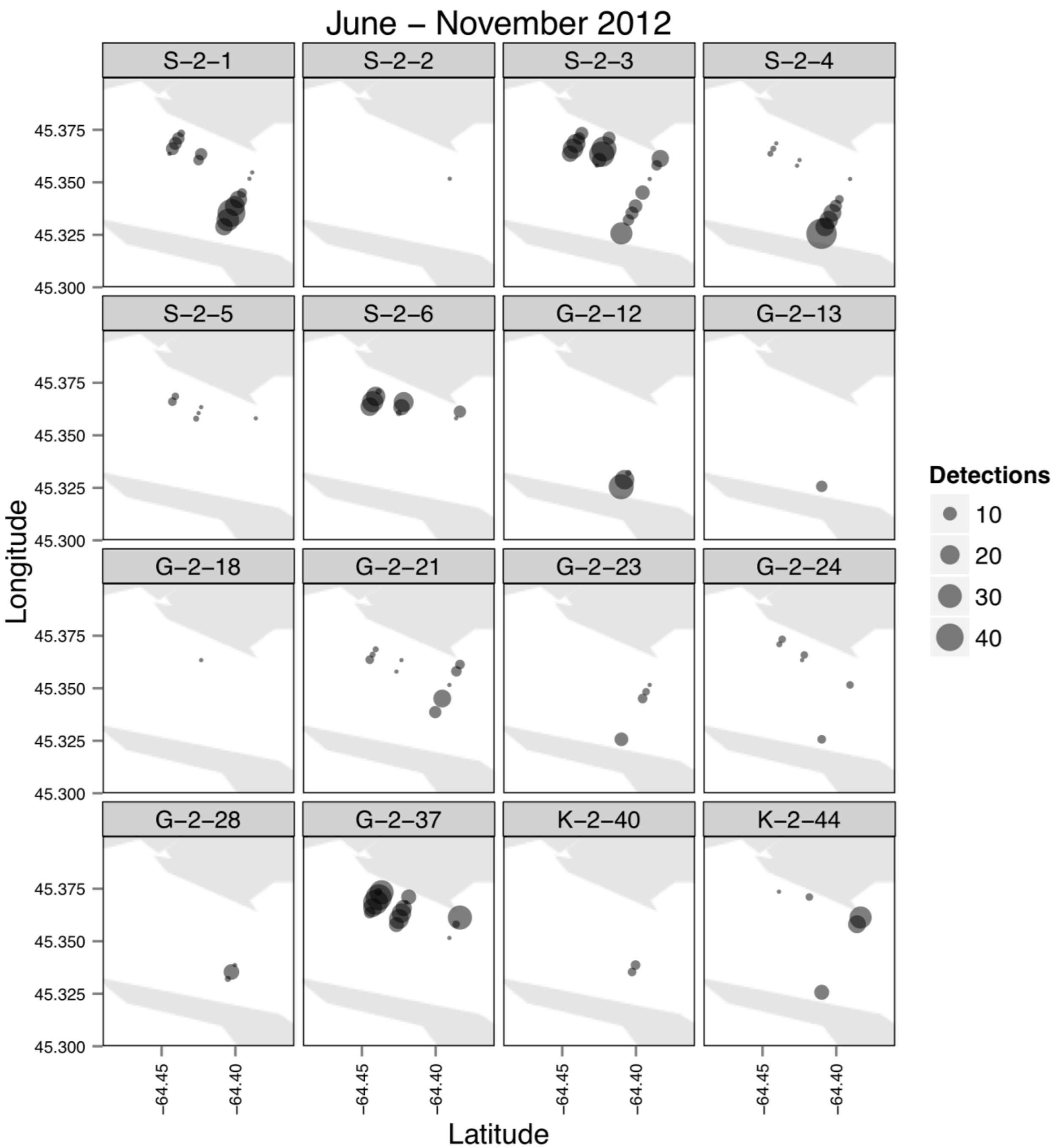

Figure 4.4. *Spatial distribution of detections from June to November 2012 of bass tagged in 2012. The size of each circle is proportional to the number of detections at each location. Identification codes are given above each plot; codes beginning with "S", "G", and "K" correspond to individuals tagged in Stewiacke, Grand Pré, and Kingsport, respectively.*

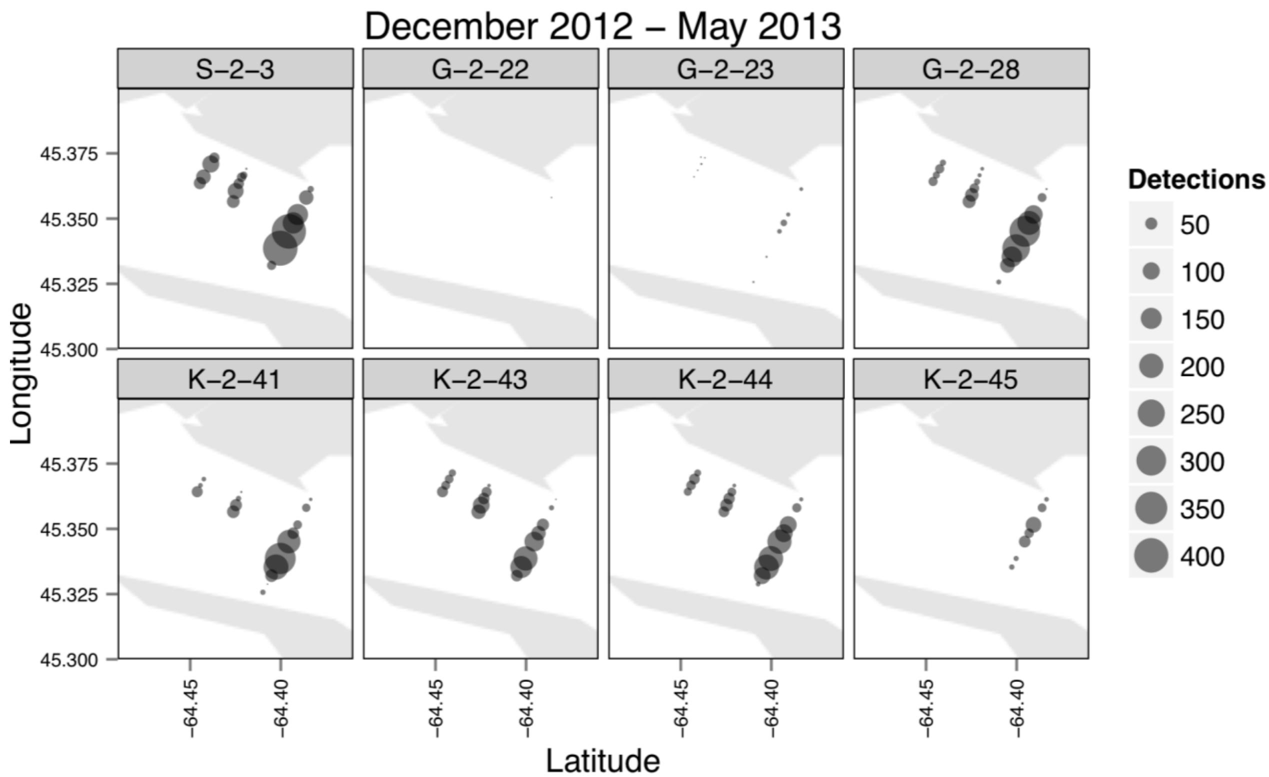

Figure 4.5. *Spatial distribution of detections from December 2012 to May 2013 of bass tagged in 2012. The size of each circle is proportional to the number of detections at each location. Identification codes are given above each plot; codes beginning with "S", "G", and "K" correspond to individuals tagged in Stewiacke, Grand Pré, and Kingsport, respectively.*

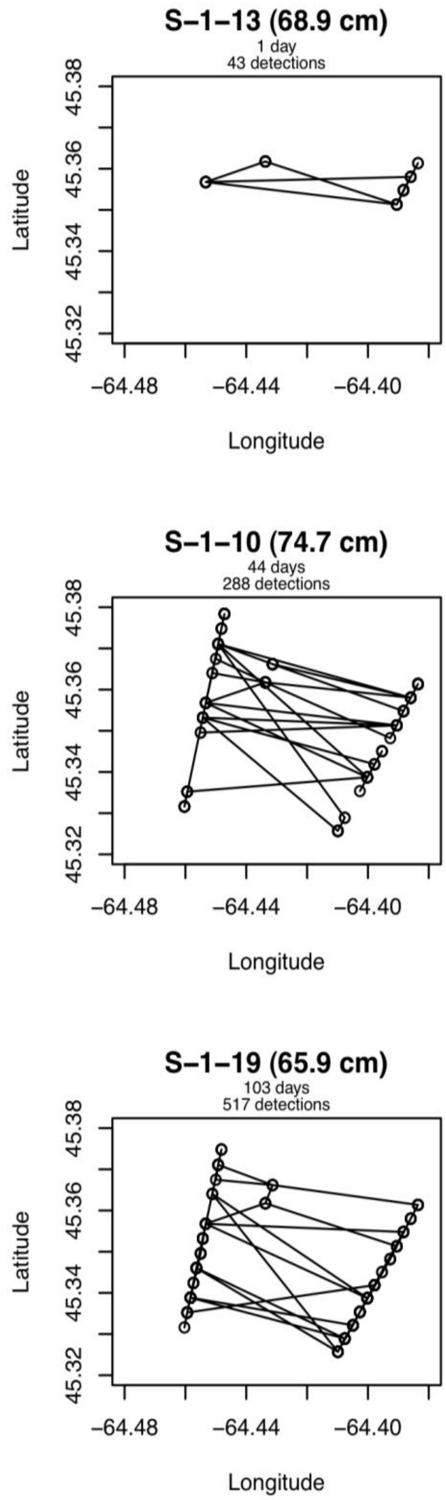

Figure 4.6. *Movement between receivers (based on order of detections) for three individual striped bass tagged in Stewiacke in 2011. Time periods of detection in the plots above span from 1 day to 103 days. Note that data was filtered to address detections of a single transmission by multiple receivers.*

4.3.6 Depth Distribution

Based on transmitter pressure sensor data, striped bass were detected at depths throughout the water column in all areas of the Minas Passage, though the majority of detections occurred within the top 40 metres of the water column (Figure 4.7; Figures A4.1-A4.6). Small striped bass (<60 cm) were often detected within a narrower range of depths than larger bass, and were generally detected higher in the water column. Furthermore, it was observed that striped bass were usually lower in the water column during the daytime, and closer to the surface at night (Figure 4.8 and Figure 4.9, Figures A4.1-A4.6). This trend held true over both receiver deployment periods at both the MPS (eastern Minas Passage) and FORCE site receivers (Figure 4.10; Figure 4.11). Striped bass showed no difference in depth distribution during ebbing or flooding tides (Figure 4.12 and Figure 4.13).

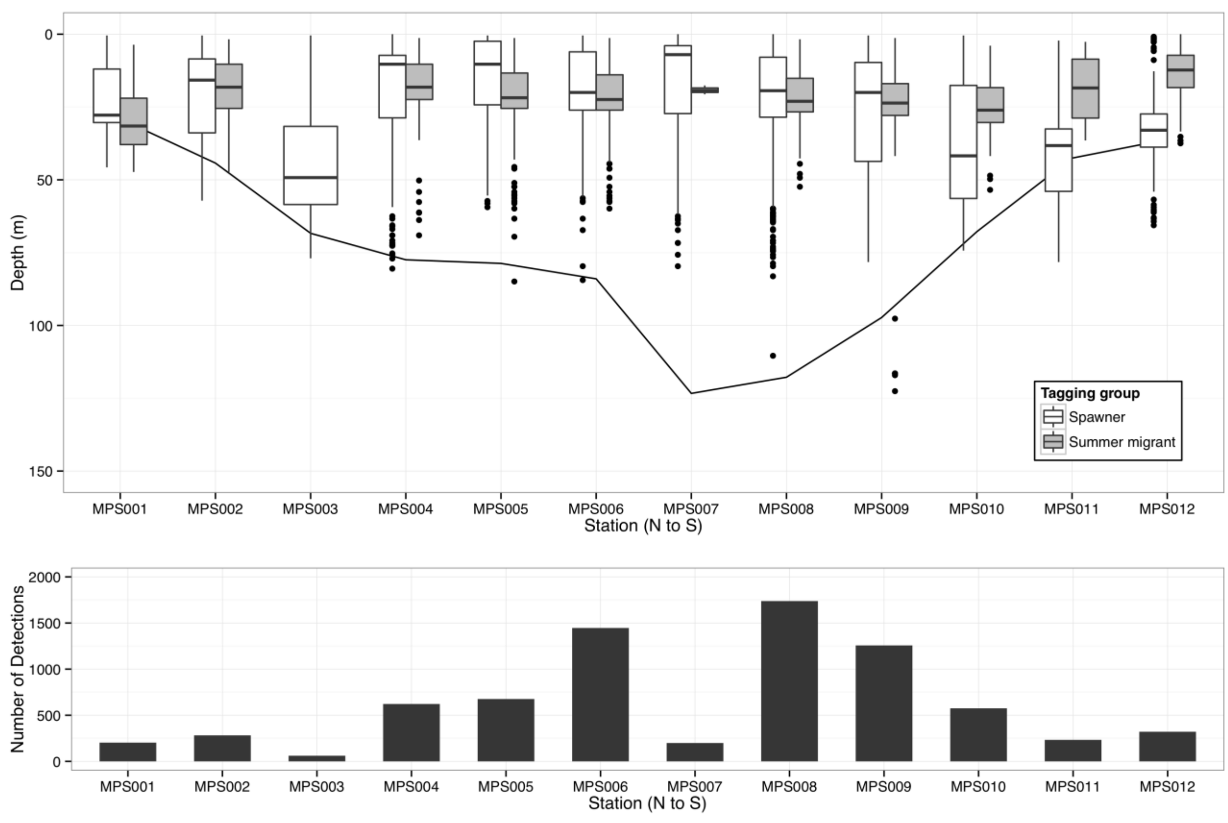

Figure 4.7*. Top: Detection depths at the MPS array (eastern Minas Passage) for all striped bass detected during 2011 and 2012-2013 receiver deployments. Bottom: Frequency of detections by each MPS receiver during 2011 and 2012-2013 receiver deployments.*

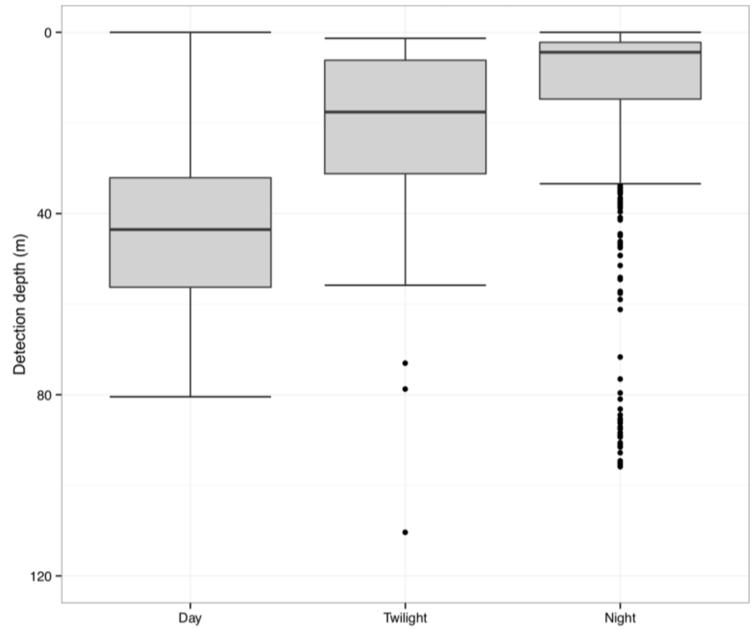

Figure 4.8. *Boxplots of striped bass detection depths in 2011, during day, twilight (1 hour before and after dusk and dawn), and night. The numbers of detections within each diel category are: Day – 1011; Twilight – 263; Night - 691. Duplicate detections of the same transmission by multiple receivers have been filtered out.*

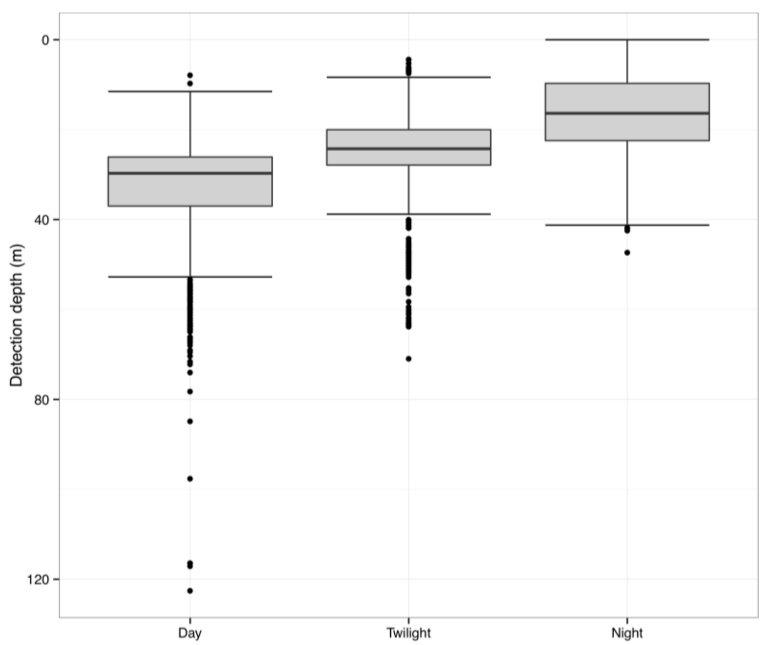

Figure 4.9. *Boxplots of detection depths of striped bass tagged in 2012, at all receivers, during day, twilight (1 hour before and after dusk and dawn), and night. The numbers of detections within each diel category are: Day – 1549; Twilight – 849; Night - 2880. Duplicate detections of the same transmission by multiple receivers have been filtered out.*

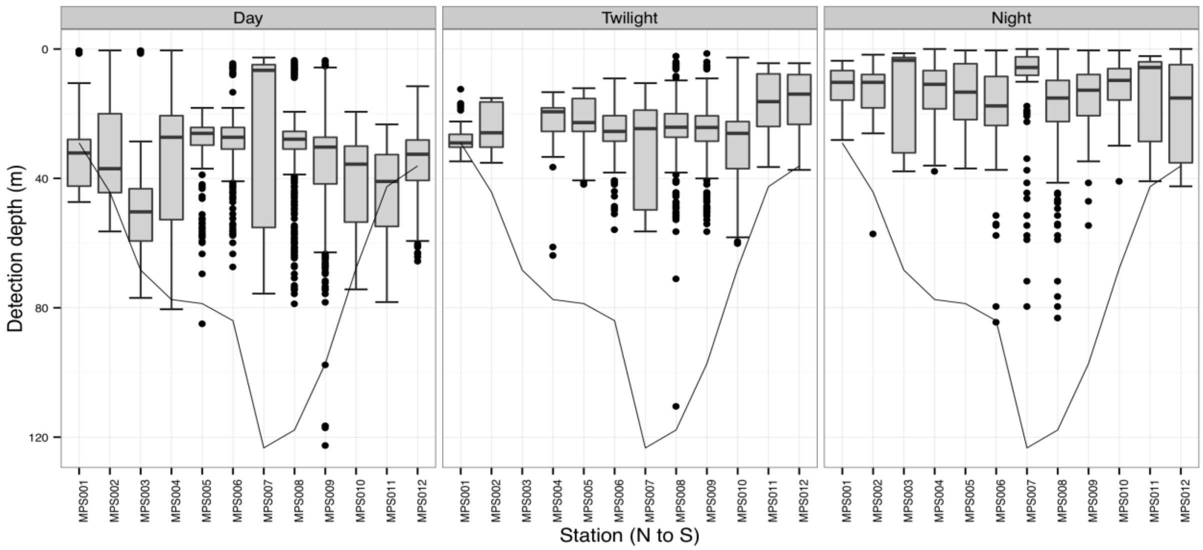

Figure 4.10. *Boxplots of detection depths at the MPS array of striped bass tagged in 2011 and 2012, during day, twilight (1 hour before and after dusk and dawn), and night. The numbers of detections within each diel category are: Day – 2567; Twilight – 1215; Night – 3831.*

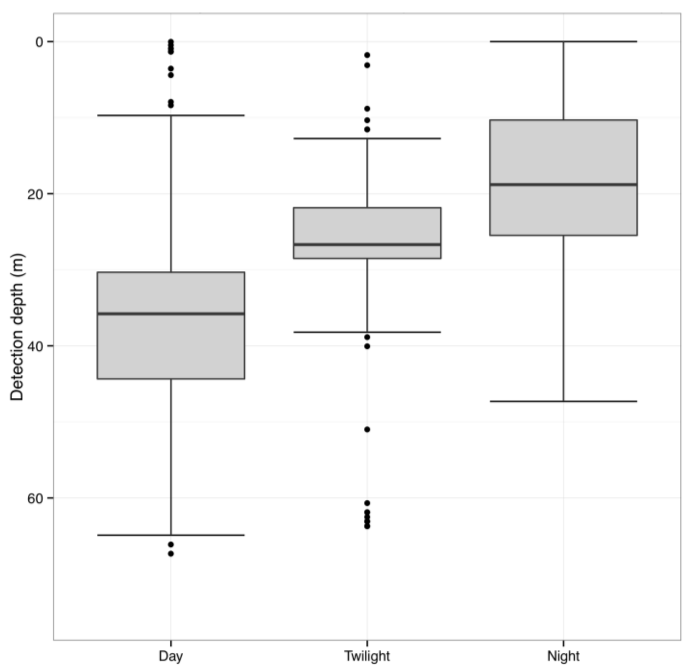

Figure 4.11*. Boxplots of detection depths at the FORCE site of striped bass tagged in 2011 and 2012, at all receivers, during day, twilight (1 hour before and after dusk and dawn), and night. The numbers of detections within each diel category are: Day – 527; Twilight – 208; Night - 847. Detections of the same transmission by multiple receivers have been filtered out.*

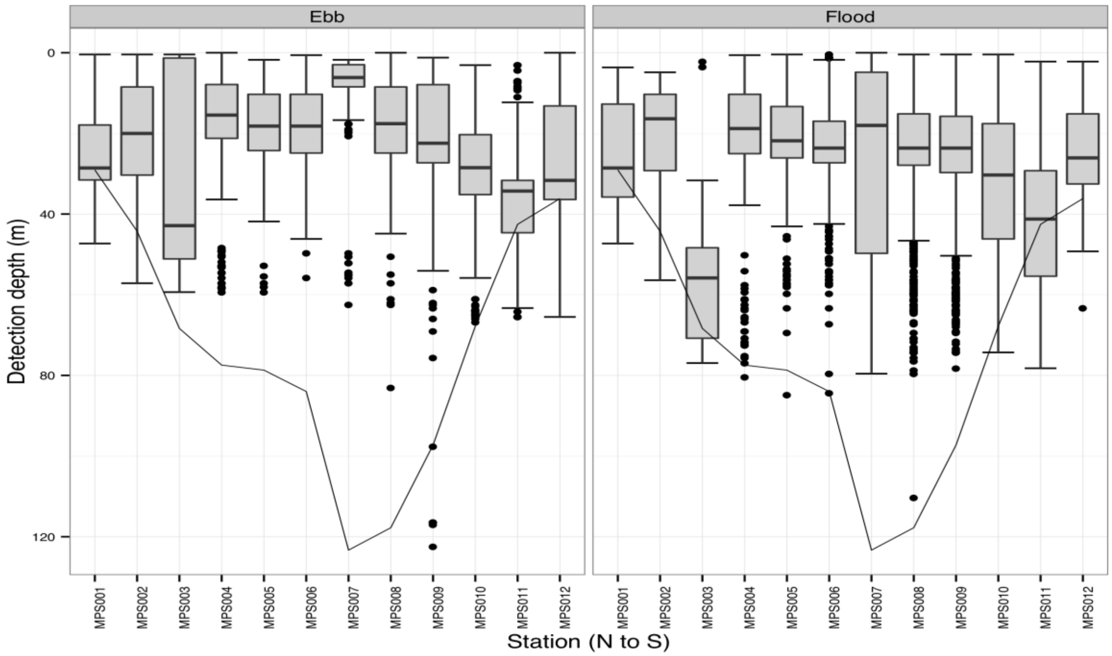

***Figure 4.12**. Boxplots of detection depths at the MPS array of striped bass tagged in 2011 and 2012, during ebb and flood tides. The numbers of detections within each tidal category are: Ebb – 3289; Flood - 4324.*

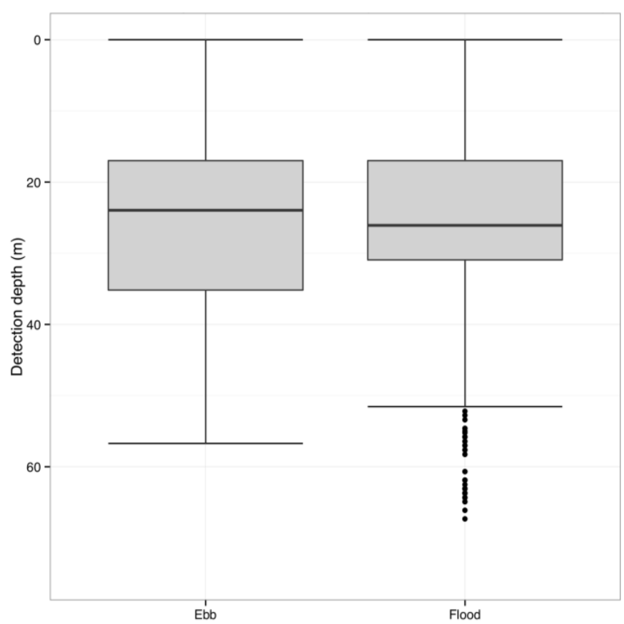

***Figure 4.13**. Boxplots of detection depths at the FORCE site of striped bass tagged in 2011 and 2012, at all receivers, during ebb and flood tides. The numbers of detections within each tidal category are: Ebb – 556; Flood – 1026. Duplicate detections of the same transmission by multiple receivers have been filtered out.*

4.3.7 Travel Velocity

In 2011, the receiver arrays detected 39 striped bass crossings between the MPS and AUL lines (about 5 km) that occurred within 60 minutes or less. These crossings were deemed “direct” crossings because it was assumed that fish would have had to swim directly through the passage in order to cross within one hour. Average water column current speeds when direct crossings occurred ranged from 0.3 m/s to 2.0 m/s. Travel velocities of directly crossing fish ranged from 1.0 m/s to 3.4 m/s. Of the 39 crossings identified, the average travel duration, between east and west receiver lines, was 36 minutes.

During the 2012-2013 study, the fastest travel velocity determined was 4.0 m/s (6.2 body lengths/s) for a striped bass moving from the MPS array to the eastern AUL array (approximately 2.8 km). Average water column current velocity at the time of this crossing was 2 m/s.

4.4 Discussion

4.4.1 Size-Related Activity of Striped Bass

In this study, larger striped bass from Stewiacke and Kingsport (61.0 - 87.4 cm) were detected in the Minas Passage far more often than smaller bass (Grand Pré-tagged; 38.2 - 65.6 cm). Prior studies have noted that striped bass mature at 3-5 years of age (fork lengths of 35 – 55 cm), and that they remain in brackish water until maturation (Bradford et al., 2012). It is likely that the younger, smaller striped bass moved mostly within the Minas Basin, while the larger, older individuals ventured into the faster flows of Minas Passage and possibly further towards the Bay of Fundy and beyond (Bradford et al., 2012).

4.4.2 Seasonality in Movements

The results of this study showed that at least some striped bass use the Minas Passage during the cold winter months. This finding differs from previous studies that suggest two contingents (or migratory groups) within the population – one contingent that migrates seaward post-spawning, and a second contingent that returns from the Bay of Fundy to overwinter in Grand Lake (Rulifson et al., 2008; COSEWIC, 2012a). If the Bay of Fundy striped bass population consisted of only those contingents, the data would show more distinct concentrations of detections in the passage during discrete periods of time. Instead, seasonal (including winter) activity in the Minas Passage was identified but appears variable. Many individuals were detected numerous times by different arrays over the course of hours, days, weeks and months, demonstrating that at least some move back and forth through the passage multiple times.

Unexpectedly, some tagged striped bass were detected within the Minas Passage during the winter months in 2012-2013. Individuals detected during the winter spanned 41 - 73 cm in length, and included bass tagged in Stewiacke, Kingsport and Grand Pre. Why some individuals remained in and near the passage throughout the winter remains unknown. Other individuals detected in the summer months appear to have migrated from the study area to the Bay of Fundy since they were not detected again though it is also possible that their return to the Minas Basin was undetected. It is likely that individuals detected in the passage in both the summer and fall, but not during winter, returned to Grand Lake to overwinter.

Due to the variable presence of individuals over time (especially during the winter), it seems likely that there are more than two contingents of striped bass with divergent migration behaviours within the Bay of Fundy. This phenomenon has been found in other populations of striped bass, including the Hudson River population (Secor, 1999).

4.4.3 Spatial Distribution

While tagged striped bass were detected throughout the Minas Passage, they tended to spend more time on the eastern side of the Minas Passage (MPS array), especially in the mid to southern region. Individuals tagged in Stewiacke and Kingsport were generally larger than the Grand Pré summer migrants, and likely to be stronger swimmers, capable of spending more time within the passage, possibly chasing prey. Furthermore, there did not appear to be a single migratory route through the Minas Passage; striped bass were detected throughout the Passage, with no preference for any particular pathway. So, while striped bass have been found to swim in and near the FORCE site, they are not obliged to take this path.

4.4.4 Depth Distribution

This study found that large striped bass (>60 cm) tend to swim over a wider range of water column depths in the Minas Passage than smaller individuals (<60 cm), which is consistent with detections of striped bass tagged in 2010 (Stokesbury et al., 2012). It is likely that swimming depth is related to body size since larger fish are stronger swimmers, and therefore more likely to pursue prey to any depth. Furthermore, adult striped bass are known to be more piscivorous than juveniles (COSEWIC, 2012), which supports the suggestion that large fish may have been moving in Minas Passage for the purposes of foraging.

The majority of detections occurred in the top 40 m of the water column, but detections occurred as deep as 123 m. At the FORCE site, striped bass were detected at all depths in the water column.

Another interesting finding was the diel pattern in swimming depth; striped bass swim deeper during the day and shallower at night. This could be due to temperature and/or light preferences of striped bass and/or their prey. Many prey species vertically migrate over the course of a day. They avoid predation during daytime by swimming deeper (where there is less light), and move closer to the surface to feed at night (Sainmont et al., 2013).

4.4.5 Travel Velocities

Travel speeds of striped bass through the Minas Passage were calculated using the times and distances swum by directly crossing fish (in 2011, <60 minutes from MPS line to AUL line). At first glance, travel speeds up to 4 m/s (6.2 body lengths per second, or BL/s) seemed extreme, as some were higher than the critical swimming speed of striped bass - 4.9 BL/s (Hurst and Conover, 2001). However, the currents accounted for much of the swimming speed observed. Crossing fish usually swam with the tide, which helps conserve much of their energy. It is unknown how well striped bass can control their movements within the passage if they are travelling at maximum current speeds (>5 m/s) or if they avoid these extreme conditions. Due to the detection limitations of acoustic receivers operating under very high flow conditions, our study was unable to detect any transmissions during peak flow periods.

4.5 Conclusions

Analysis of location and depth data showed that 27 of 85 tagged striped bass moved through the FORCE tidal turbine test site in the Minas Passage, and many at depths that would include turbine hub height. Five of these 27 fish were detected at FORCE during the cold winter months (Sea Surface Temperatures <3°C) and during this period may have been relatively docile. The Bay of Fundy striped bass population may be at risk of direct and indirect fish-turbine interactions if they are unable to sense and avoid turbines. To date, no studies have been performed on the ability of striped bass to avoid TISEC devices. One would assume, however, that any avoidance ability that striped bass have would be reduced at very high current speeds and possibly also at low temperatures.

The probability of a striped bass-turbine encounter would be dependent, at least in part, on the frequency of travel at turbine hub height in the FORCE test area. Other contributing factors are likely to be fish size and physiological condition. Because the size of a single 1MW turbine (about 100 m^2), relative to the cross-sectional area of Minas Passage, is small (about 0.02%), it is likely that a single turbine would have minimal impact on the Bay of Fundy population of striped bass. The installation of turbine arrays, however, increases the level of potential risk.

This study was unable to examine the movements of striped bass at very high current speeds due to current velocity effects on ambient noise and tag transmission detection performance of VEMCO acoustic receivers. Other technologies will be required to examine the behaviour of striped bass (and other fishes) in close proximity to in-stream tidal turbines.

4.6 References

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4.7 Appendix

Table A4.1. *Transmitter information for striped bass tagged in 2011. S-Stewiacke; G-Guzzle.*

Tagged fish code 2011	Trans-mitter type	Trans-mitter ID	Est. tag life (days)	Fork length (m)	Tagging location	Release date and time
S-1-1	V13P-1H	4987	170	0.680	Stewiacke	2011-05-24 23:56:14
S-1-2	V13P-1H	4988	170	0.686	Stewiacke	2011-05-24 24:29:39
S-1-3	V13P-1H	4989	170	0.726	Stewiacke	2011-05-24 24:40:30
S-1-4	V13P-1H	4990	170	0.664	Stewiacke	2011-05-25 12:06:09
S-1-5	V13P-1H	4991	170	0.641	Stewiacke	2011-05-25 12:13:30
S-1-6	V13P-1H	4992	170	0.633	Stewiacke	2011-05-25 12:36:00
S-1-7	V13P-1H	4993	170	0.639	Stewiacke	2011-05-25 12:43:00
S-1-8	V13P-1H	4994	170	0.745	Stewiacke	2011-05-25 23:43:15
S-1-9	V13P-1H	4995	170	0.810	Stewiacke	2011-05-25 23:58:43
S-1-10	V13P-1H	4996	170	0.747	Stewiacke	2011-05-26 00:08:00
S-1-11	V13P-1H	4997	170	0.699	Stewiacke	2011-05-26 00:19:44
S-1-12	V13P-1H	4998	170	0.760	Stewiacke	2011-05-26 00:28:00
S-1-13	V13P-1H	4999	170	0.689	Stewiacke	2011-05-26 00:39:43
S-1-14	V13P-1H	5000	170	0.783	Stewiacke	2011-05-26 00:47:30
S-1-15	V13P-1H	5001	170	0.728	Stewiacke	2011-05-26 01:02:45
S-1-16	V13P-1H	5002	170	0.679	Stewiacke	2011-05-26 01:15:00
S-1-17	V13P-1H	5003	170	0.684	Stewiacke	2011-05-26 01:23:43
S-1-18	V13P-1H	5004	170	0.644	Stewiacke	2011-05-26 01:49:14
S-1-19	V13P-1H	5005	170	0.659	Stewiacke	2011-05-26 02:12:00
S-1-20	V13P-1H	5006	170	0.703	Stewiacke	2011-05-26 02:27:00
G-1-21	V13P-1H	5007	170	0.427	Grand Pre	2011-06-25 11:10:00
G-1-22	V13P-1H	5008	170	0.486	Grand Pre	2011-06-25 11:17:00
G-1-23	V13P-1H	5009	170	0.538	Grand Pre	2011-06-25 11:54:00
G-1-24	V13P-1H	5010	170	0.430	Grand Pre	2011-06-25 12:06:00
G-1-25	V13P-1H	5011	170	0.526	Grand Pre	2011-06-25 12:14:00
G-1-26	V13P-1H	5012	170	0.403	Grand Pre	2011-06-25 12:50:00
G-1-27	V13P-1H	5013	170	0.607	Grand Pre	2011-06-25 12:59:00
G-1-28	V13P-1H	5014	170	0.496	Grand Pre	2011-06-25 13:16:00
G-1-29	V13P-1H	5015	170	0.524	Grand Pre	2011-06-25 13:30:00
G-1-30	V13P-1H	5016	170	0.550	Grand Pre	2011-06-25 13:53:00
G-1-31	V13P-1H	5017	170	0.392	Grand Pre	2011-06-25 14:00:00
G-1-32	V13P-1H	5018	170	0.388	Grand Pre	2011-06-26 11:14:00
G-1-33	V13P-1H	5019	170	0.544	Grand Pre	2011-06-26 12:07:00
G-1-34	V13P-1H	5020	170	0.494	Grand Pre	2011-06-26 12:22:00
G-1-35	V13P-1H	5021	170	0.421	Grand Pre	2011-06-26 12:27:00
G-1-36	V13P-1H	5022	170	0.420	Grand Pre	2011-06-26 13:18:00
G-1-37	V13P-1H	5023	170	0.382	Grand Pre	2011-06-26 13:29:00
G-1-38	V13P-1H	5024	170	0.460	Grand Pre	2011-06-26 13:40:00
G-1-39	V13P-1H	5025	170	0.470	Grand Pre	2011-06-26 13:56:00
G-1-40	V13P-1H	5026	170	0.530	Grand Pre	2011-06-26 14:09:00

Table A4.2*. Transmitter information for striped bass tagged in 2012. S-Stewiacke; G-Guzzle, K-Kingsport.*

Tagged fish code 2012	Trans-mitter type	Trans-mitter ID	Est. tag life (days)	Fork length (m)	Tagging location	Release date and time
S-2-1	V16P-4H	14377	774	0.654	Stewiacke	2012-05-21 23:52:00
S-2-2	V16P-4H	14378	774	0.671	Stewiacke	2012-05-21 23:56:00
S-2-3	V16P-4H	14379	774	0.626	Stewiacke	2012-05-22 00:09:00
S-2-4	V16P-4H	14380	774	0.690	Stewiacke	2012-05-22 00:33:00
S-2-5	V16P-4H	14381	774	0.874	Stewiacke	2012-05-22 00:52:00
S-2-6	V16P-4H	14382	774	0.790	Stewiacke	2012-05-22 01:10:00
S-2-7	V16P-4H	14383	774	0.660	Stewiacke	2012-05-22 01:23:00
G-2-8	V13P-1H	3429	81	0.486	Grand Pre	2012-06-11 20:22:00
G-2-9	V13P-1H	3436	81	0.480	Grand Pre	2012-06-11 20:25:00
G-2-10	V13P-1H	3435	81	0.430	Grand Pre	2012-06-11 22:29:00
G-2-11	V13P-1H	3433	81	0.457	Grand Pre	2012-06-11 22:45:00
G-2-12	V13P-1H	3434	81	0.453	Grand Pre	2012-06-11 23:29:00
G-2-13	V13P-1H	7402	170	0.415	Grand Pre	2012-06-12 10:11:00
G-2-14	V13P-1H	7403	170	0.458	Grand Pre	2012-06-12 10:24:00
G-2-15	V13P-1H	7404	170	0.434	Grand Pre	2012-06-13 10:36:00
G-2-16	V13P-1H	7405	170	0.424	Grand Pre	2012-06-13 11:23:00
G-2-17	V13P-1H	7406	170	0.420	Grand Pre	2012-06-13 11:42:00
G-2-18	V16P-4H	14384	774	0.528	Grand Pre	2012-06-13 12:13:00
G-2-19	V13P-1H	7398	170	0.456	Grand Pre	2012-06-13 12:25:00
G-2-20	V13P-1H	7397	170	0.431	Grand Pre	2012-06-13 12:31:00
G-2-21	V13P-1H	7399	170	0.420	Grand Pre	2012-06-13 12:40:00
G-2-22	V13P-1H	7400	170	0.410	Grand Pre	2012-06-13 12:50:00
G-2-23	V13P-1H	7401	170	0.435	Grand Pre	2012-06-13 13:53:00
G-2-24	V13P-1H	7392	170	0.414	Grand Pre	2012-06-14 12:20:00
G-2-25	V13P-1H	7393	170	0.470	Grand Pre	2012-06-14 12:27:00
G-2-26	V13P-1H	7394	170	0.410	Grand Pre	2012-06-14 13:32:00
G-2-27	V13P-1H	7395	170	0.430	Grand Pre	2012-06-15 12:13:01
G-2-28	V16P-4H	14385	774	0.515	Grand Pre	2012-06-15 12:40:00
G-2-29	V13P-1H	7396	170	0.404	Grand Pre	2012-06-15 13:30:00
G-2-30	V13P-1H	7387	170	0.403	Grand Pre	2012-06-15 14:24:00
G-2-31	V13P-1H	7388	170	0.426	Grand Pre	2012-06-19 16:33:00
G-2-32	V13P-1H	7389	170	0.398	Grand Pre	2012-06-19 16:45:00
G-2-33	V13P-1H	7390	170	0.398	Grand Pre	2012-06-19 16:55:00
G-2-34	V13P-1H	7391	170	0.403	Grand Pre	2012-06-19 17:16:00
G-2-35	V13P-1H	3430	81	0.422	Grand Pre	2012-06-19 17:26:00
G-2-36	V13P-1H	3432	81	0.414	Grand Pre	2012-06-19 17:49:00
G-2-37	V16P-4H	14388	774	0.656	Grand Pre	2012-06-19 18:27:00
G-2-38	V13P-1H	3431	81	0.454	Grand Pre	2012-06-19 19:09:00
K-2-39	V16P-4H	14387	774	0.653	Kingsport	2012-07-20 03:24:00
K-2-40	V16P-4H	14390	774	0.680	Kingsport	2012-07-20 05:22:00
K-2-41	V16P-4H	14389	774	0.657	Kingsport	2012-07-20 06:13:00
K-2-42	V16P-4H	14386	774	0.704	Kingsport	2012-07-20 07:03:00
K-2-43	V16P-4H	14391	774	0.680	Kingsport	2012-07-27 09:05:00
K-2-44	V16P-4H	14394	774	0.73	Kingsport	2012-07-27 09:41:00
K-2-45	V16P-4H	14393	774	0.61	Kingsport	2012-07-27 09:58:00

Table A4.3. *Striped bass detections and days detected at FORCE in 2011. S-Stewiacke; G-Guzzle.*

Fish tag Code 2011	Date of first detection	Array of first detection	Date of last detection	Array of last detection	Days at liberty	Days detected at FORCE	% of days detected at FORCE
S-1-1	06/26/2011	MPS	07/31/2011	AUL	36	3	8.33
S-1-2	07/18/2011	AUL	08/29/2011	MPS	43	1	2.33
S-1-3	NA	NA	NA	NA	NA	NA	NA
S-1-4	06/19/2011	MPS	10/15/2011	AUL	119	1	0.84
S-1-5	NA	NA	NA	NA	NA	NA	NA
S-1-6	07/02/2011	MPS	10/27/2011	MPS	118	1	0.85
S-1-7	NA	NA	NA	NA	NA	NA	NA
S-1-8	08/11/2011	MPS	08/25/2011	MPS	15	0	0.00
S-1-9	06/23/2011	AUL	10/29/2011	MPS	129	2	1.55
S-1-10	06/15/2011	MPS	07/28/2011	AUL	44	4	9.09
S-1-11	07/26/2011	MPS	08/03/2011	AUL	9	1	11.11
S-1-12	08/02/2011	AUL	09/25/2011	AUL	55	0	0.00
S-1-13	07/06/2011	MPS	07/06/2011	AUL	1	1	100.00
S-1-14	07/21/2011	MPS	11/05/2011	FORCE	108	3	2.78
S-1-15	07/23/2011	MPS	11/06/2011	MPS	107	1	0.93
S-1-16	06/23/2011	MPS	06/23/2011	MPS	1	0	0.00
S-1-17	06/28/2011	AUL	10/20/2011	AUL	115	1	0.87
S-1-18	NA	NA	NA	NA	NA	NA	NA
S-1-19	06/25/2011	AUL	10/05/2011	MPS	103	3	2.91
S-1-20	NA	NA	NA	NA	NA	NA	NA
G-1-21	08/30/2011	MPS	09/02/2011	AUL	4	0	0.00
G-1-22	NA	NA	NA	NA	NA	NA	NA
G-1-23	10/30/2011	AUL	10/30/2011	AUL	1	0	0.00
G-1-24	10/30/2011	MPS	10/30/2011	MPS	1	0	0.00
G-1-25	08/11/2011	AUL	11/13/2011	MPS	95	1	1.05
G-1-26	NA	NA	NA	NA	NA	NA	NA
G-1-27	07/08/2011	MPS	08/31/2011	AUL	55	0	0.00
G-1-28	NA	NA	NA	NA	NA	NA	NA
G-1-29	NA	NA	NA	NA	NA	NA	NA
G-1-30	09/03/2011	AUL	09/03/2011	AUL	1	0	0.00
G-1-31	NA	NA	NA	NA	NA	NA	NA
G-1-32	NA	NA	NA	NA	NA	NA	NA
G-1-33	10/21/2011	AUL	10/21/2011	AUL	1	0	0.00
G-1-34	08/20/2011	MPS	10/22/2011	MPS	64	0	0.00
G-1-35	NA	NA	NA	NA	NA	NA	NA
G-1-36	NA	NA	NA	NA	NA	NA	NA
G-1-37	10/29/2011	MPS	10/31/2011	AUL	3	0	0.00
G-1-38	NA	NA	NA	NA	NA	NA	NA
G-1-39	10/28/2011	MPS	10/29/2011	MPS	2	0	0.00
G-1-40	NA	NA	NA	NA	NA	NA	NA
ALL	6/15/2011	MPS	11/13/2011	MPS	152	16	10.53

Table A4.4. *Striped bass detections and days detected at FORCE in 2012-2013. S-Stewiacke; G-Guzzle, K-Kingsport.*

Fish code 2012	Date of first detection	Array of first detection	Date of last detection	Array of last detection	Days at liberty	Days detected at FORCE	% of days detected at FORCE
S-2-1	07/14/2012	MPS	07/31/2012	MPS	18	2	11.11
S-2-2	07/21/2012	MPS	07/21/2012	MPS	1	0	0.00
S-2-3	08/28/2012	AUL	04/06/2013	AUL	222	27	12.16
S-2-4	07/12/2012	MPS	10/24/2012	MPS	105	1	0.95
S-2-5	06/29/2012	MPS	06/29/2012	AUL	1	1	100.00
S-2-6	07/18/2012	MPS	07/27/2012	AUL	10	3	30.00
S-2-7	NA	NA	NA	NA	NA	NA	NA
G-2-8	NA	NA	NA	NA	NA	NA	NA
G-2-9	NA	NA	NA	NA	NA	NA	NA
G-2-10	NA	NA	NA	NA	NA	NA	NA
G-2-11	NA	NA	NA	NA	NA	NA	NA
G-2-12	06/28/2012	MPS	06/28/2012	MPS	1	0	0.00
G-2-13	09/02/2012	MPS	10/02/2012	MPS	31	0	0.00
G-2-14	NA	NA	NA	NA	NA	NA	NA
G-2-15	NA	NA	NA	NA	NA	NA	NA
G-2-16	NA	NA	NA	NA	NA	NA	NA
G-2-17	NA	NA	NA	NA	NA	NA	NA
G-2-18	10/23/2012	AUL	10/23/2012	AUL	1	1	100.00
G-2-19	NA	NA	NA	NA	NA	NA	NA
G-2-20	NA	NA	NA	NA	NA	NA	NA
G-2-21	08/25/2012	MPS	10/24/2012	MPS	61	1	1.64
G-2-22	12/07/2012	MPS	12/07/2012	MPS	1	0	0.00
G-2-23	10/26/2012	MPS	11/09/2012	MPS	15	4	26.67
G-2-24	09/12/2012	MPS	10/14/2012	MPS	33	1	3.03
G-2-25	NA	NA	NA	NA	NA	NA	NA
G-2-26	NA	NA	NA	NA	NA	NA	NA
G-2-27	NA	NA	NA	NA	NA	NA	NA
G-2-28	09/05/2012	MPS	03/04/2013	MPS	181	16	8.84
G-2-29	NA	NA	NA	NA	NA	NA	NA
G-2-30	NA	NA	NA	NA	NA	NA	NA
G-2-31	NA	NA	NA	NA	NA	NA	NA
G-2-32	NA	NA	NA	NA	NA	NA	NA
G-2-33	NA	NA	NA	NA	NA	NA	NA
G-2-34	NA	NA	NA	NA	NA	NA	NA
G-2-35	NA	NA	NA	NA	NA	NA	NA
G-2-36	NA	NA	NA	NA	NA	NA	NA
G-2-37	06/30/2012	MPS	10/09/2012	MPS	102	6	5.88
G-2-38	NA	NA	NA	NA	NA	NA	NA
K-2-39	NA	NA	NA	NA	NA	NA	NA
K-2-40	09/11/2012	MPS	09/11/2012	MPS	1	0	0.00
K-2-41	12/01/2012	AUL	03/31/2013	MPS	121	10	8.26
K-2-42	NA	NA	NA	NA	NA	NA	NA
K-2-43	12/03/2012	MPS	03/25/2013	MPS	113	18	15.93
K-2-44	09/25/2012	MPS	03/25/2013	MPS	182	18	9.89
K-2-45	02/07/2013	MPS	02/19/2013	MPS	13	0	0.00
ALL	06/28/2012	MPS	04/06/2013	AUL	283	112	39.58

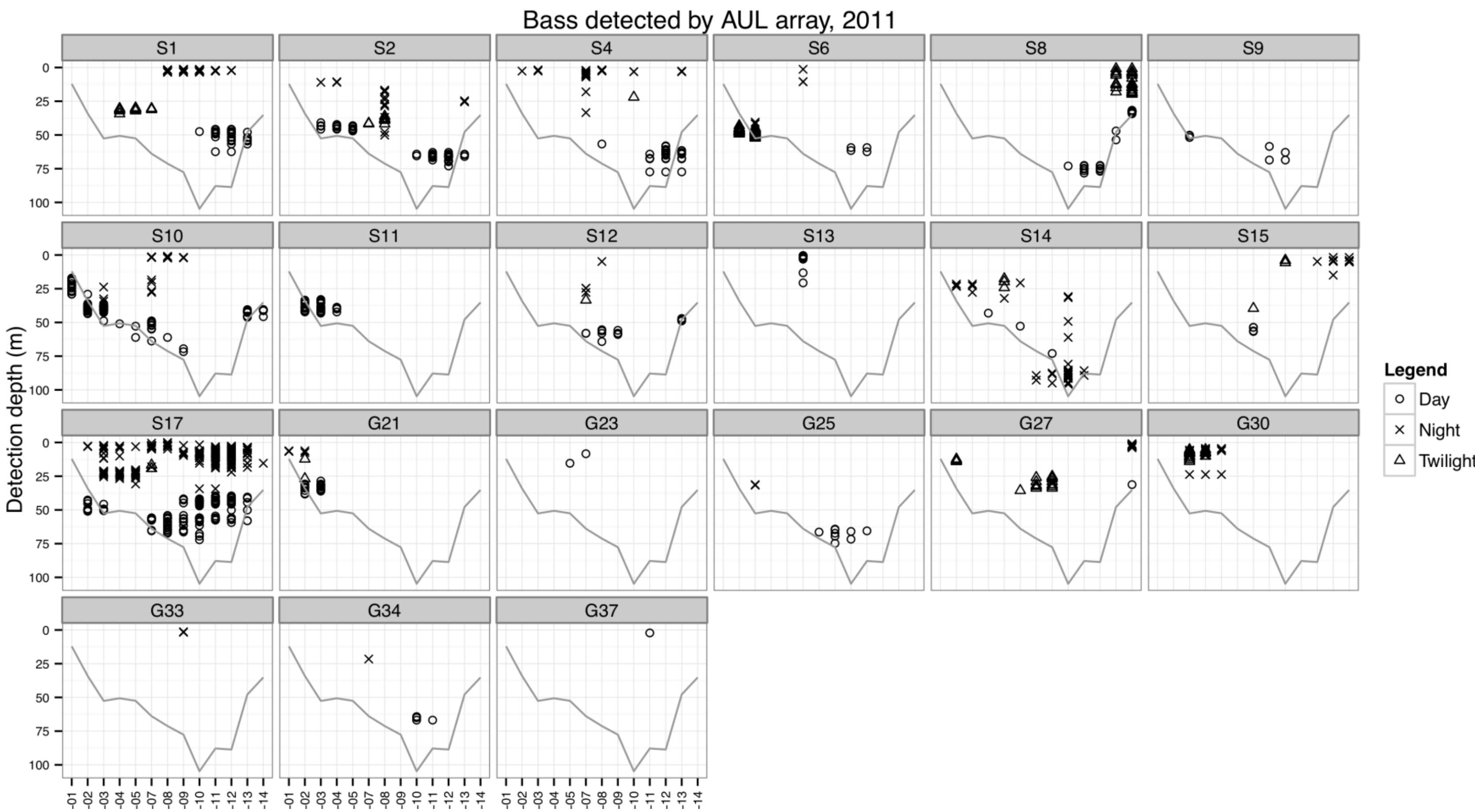

Figure A4.1. *Depth distribution of bass tagged in 2011 and detected by the AUL array. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle.*

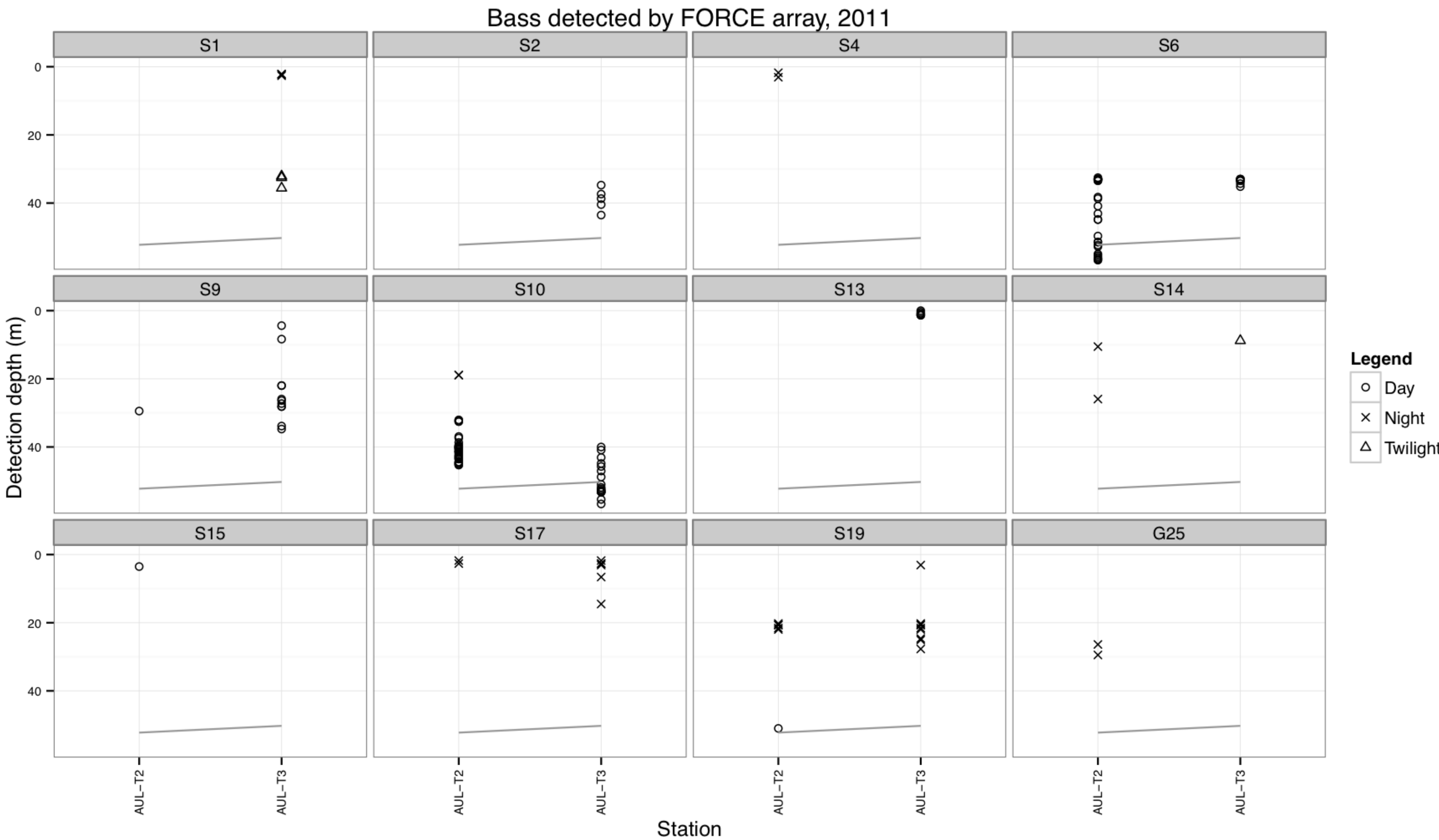

Figure A4.2. *Depth distribution of bass tagged in 2011 and detected by the FORCE array. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle.*

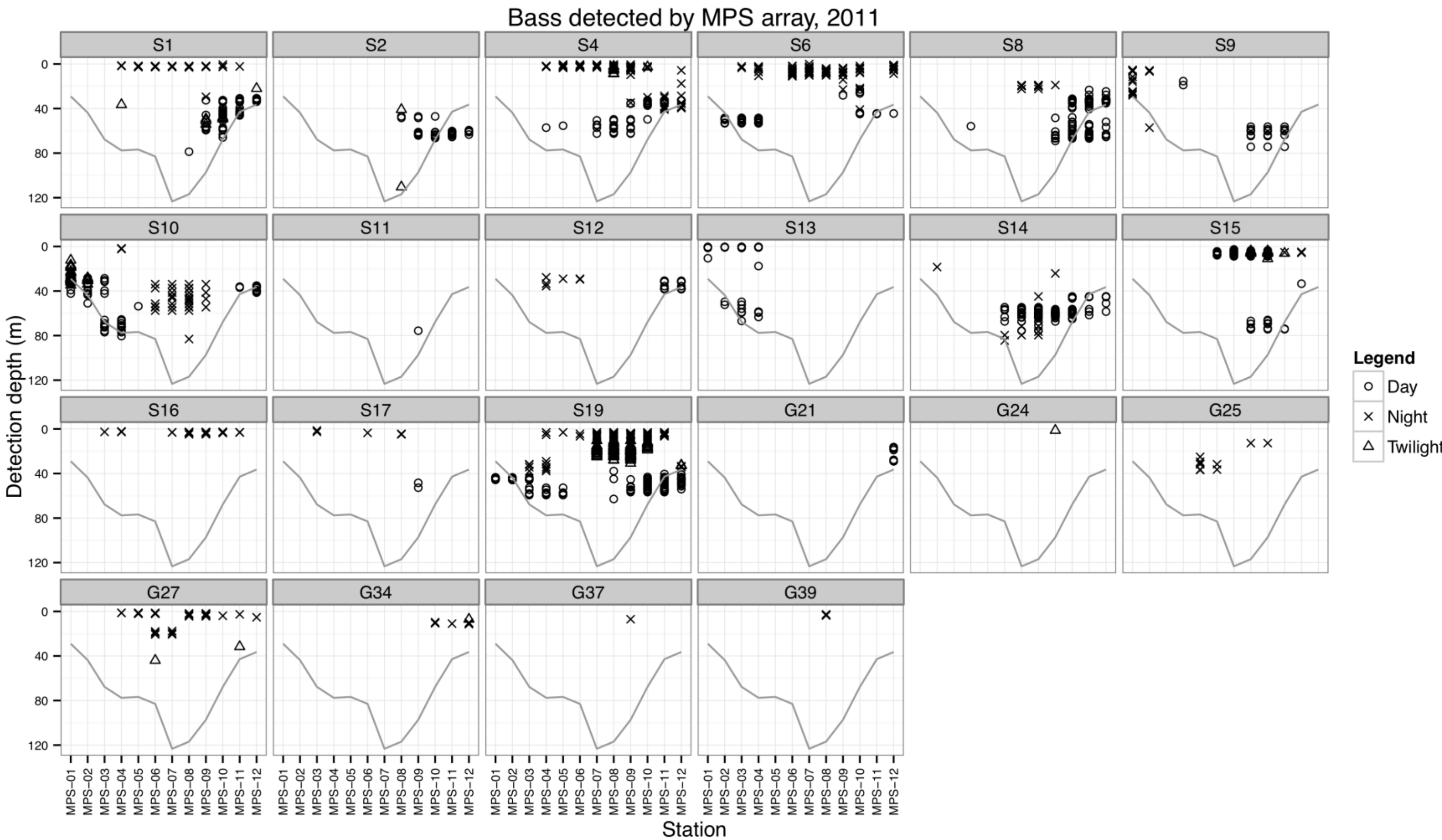

Figure A4.3. *Depth distribution of bass tagged in 2011 and detected by the MPS array. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle.*

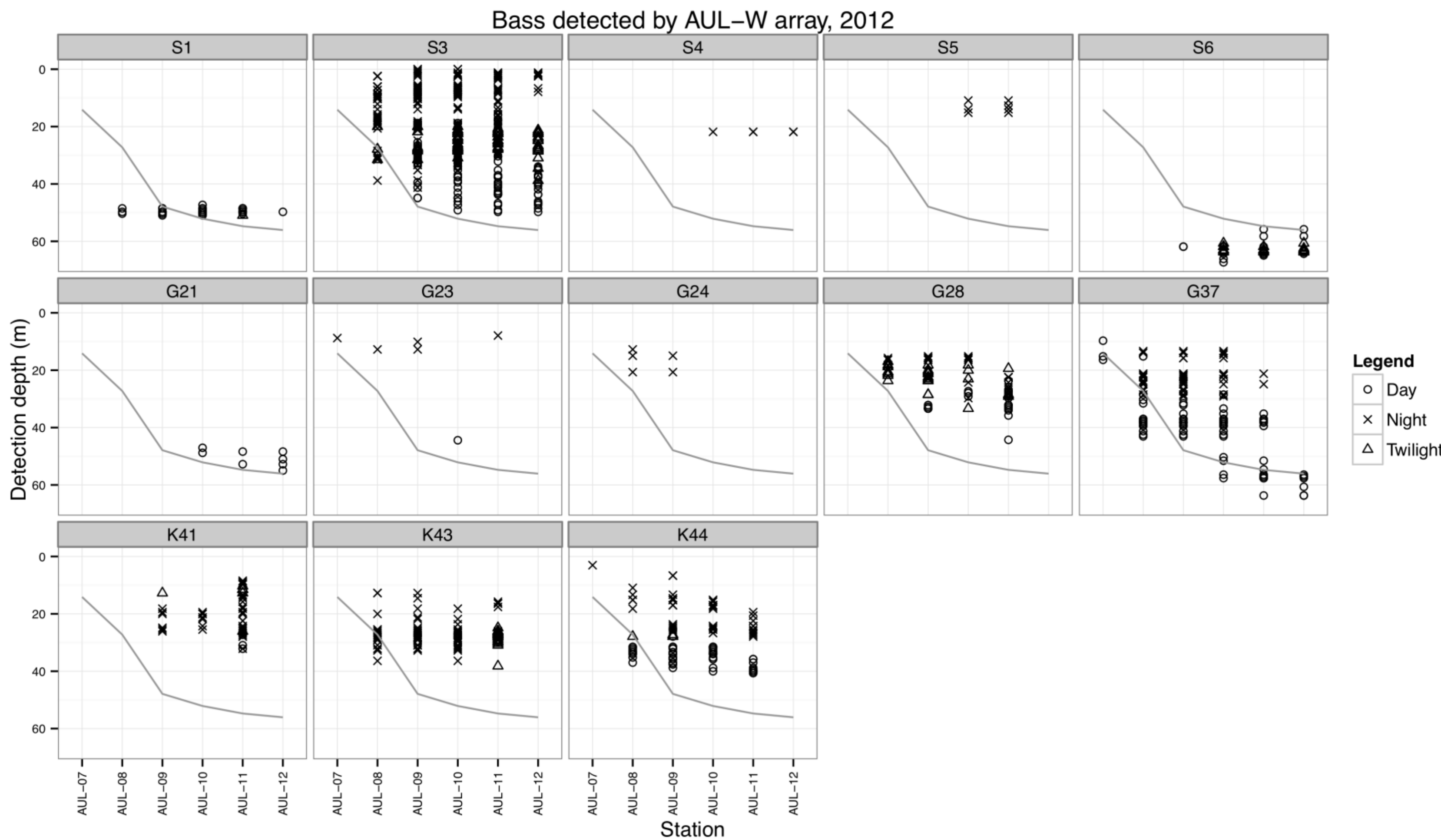

Figure A4.4. *Depth distribution of bass tagged in 2012 and detected by the AUL-W array in 2012 and 2013. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle; K-Kingsport.*

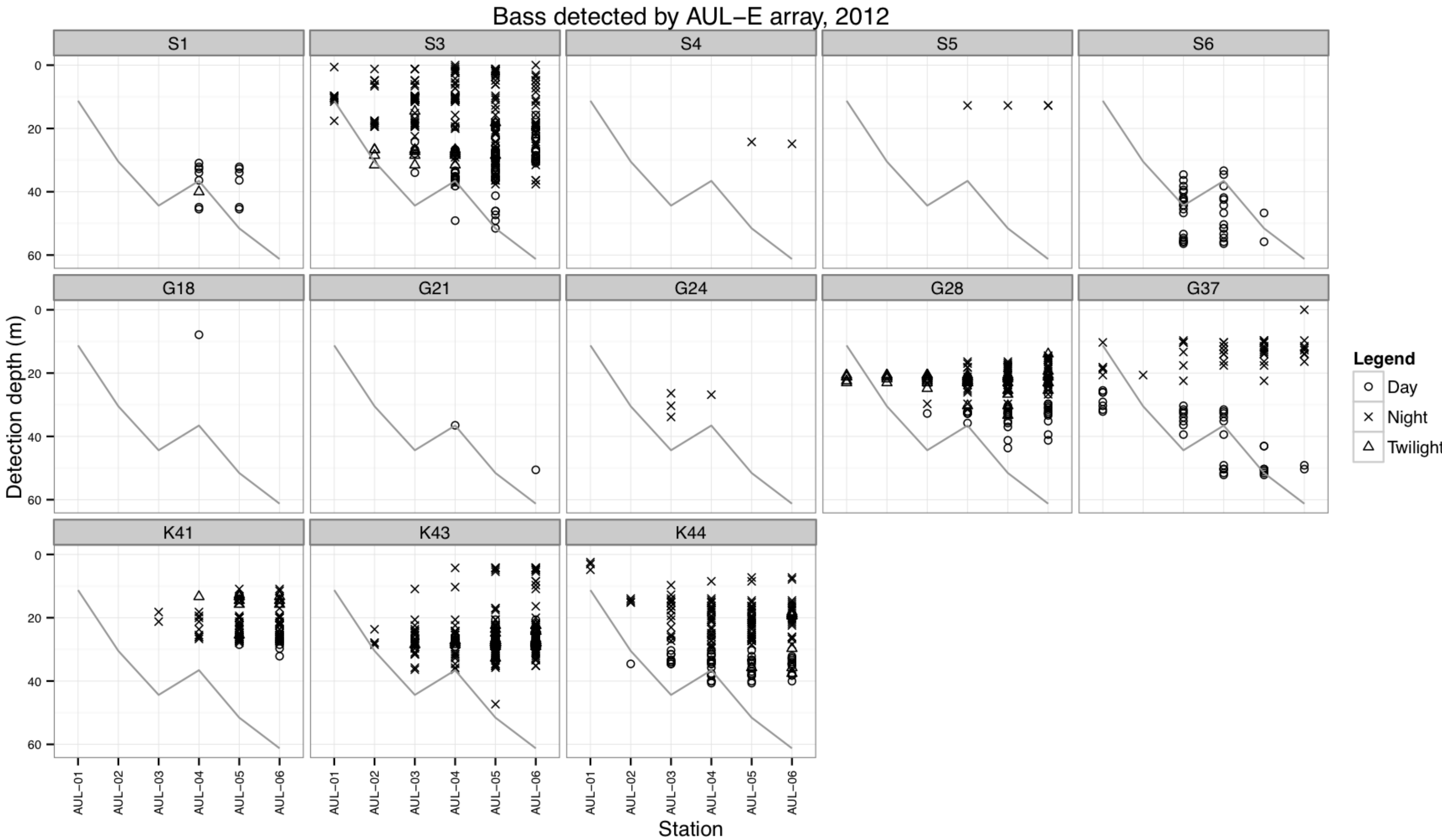

Figure A4.5. *Depth distribution of bass tagged in 2012 and detected by the AUL-E array in 2012 and 2013. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle; K-Kingsport.*

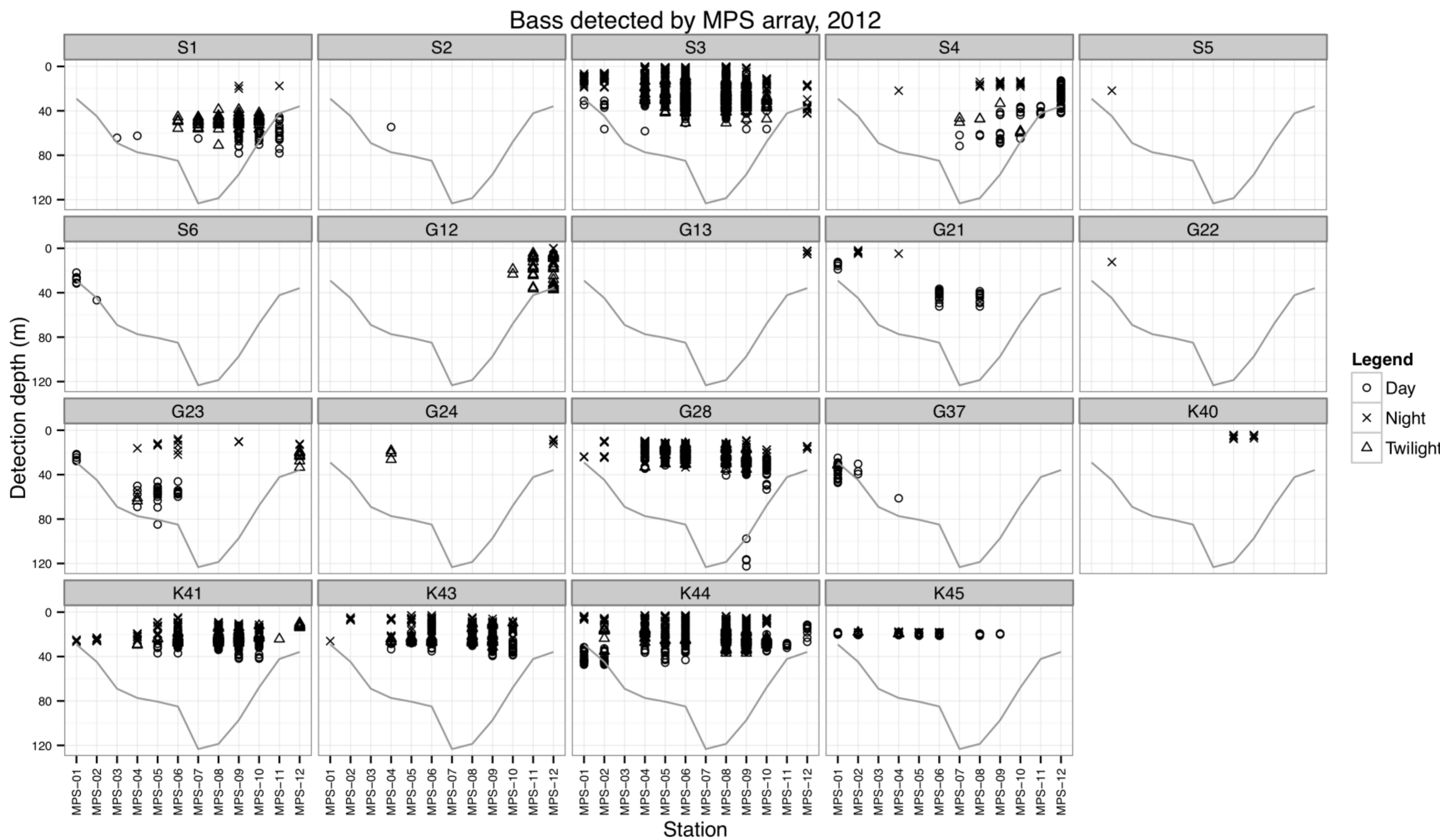

Figure A4.6. *Depth distribution of bass tagged in 2012 that were detected by the MPS array in 2012 and 2013. Symbols indicate whether the detection occurred during the night (after 19:59:59 and before 8:00:00 AST) or day (after 7:59:59 and before 20:00:00 AST). Receiver depth at each station is indicated by the grey line. S-Stewiacke; G-Guzzle; K-Kingsport.*

Section 5: American Eel Movements

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5.1 Background on American Eel

The American eel *(Anguilla rostrata*) is the only catadromous species in North America, and is widely dispersed across freshwater and estuarine habitats of Eastern Canada and the United States (Scott and Scott, 1988). The broad habitat distribution of the American eel makes them an important component of aquatic ecosystem biodiversity in Canada (COSEWIC, 2006; COSEWIC, 2012). American eels function as a high level predator, as a prey species for other higher order predators, including humans, and have supported significant commercial, recreational, and Aboriginal fisheries in Canada (COSEWIC, 2006, COSEWIC, 2012). The American eel exhibits a cryptic behavior and complex life history, creating difficulty and uncertainty for management and protection of the species (Jessop, 1987; Oliviera et al., 1999; Haro et al., 2000).

American eels are panmictic, meaning that animals from the entire range constitute one population with a common spawning site, the Sargasso Sea (Tesch, 1977; McCleave, 1987). Mating occurs randomly and thus maximizes genetic diversity (Tesch, 1977; Oliviera, 1999). Transparent and leaf-shaped American eel larvae (known as leptocephali) are carried by oceanic currents from the Sargasso Sea, along the coast of North America for up to one year before transitioning into glass eels and making their way toward estuaries and freshwater systems. At this stage, glass eels begin to take on pigmentation and are referred to as elvers. Elvers grow and develop to the yellow eel stage (sexually immature adult). Growth parameters and age of maturation are highly sexually dependent, where female eels are generally larger and older at maturation than males (Oliviera, 1999). Interestingly, females are also found in higher proportion at more northern latitudes, and occupy habitat further inland than males (Kreuger and Oliviera, 1999; Jessop et al., 2002; Jessop, 2008). Those that stay resident in the lower portions of rivers or coastal areas are generally males of smaller body size (Kreuger and Oliviera, 1999; Jessop et al., 2002; Jessop, 2008).

American eels may develop for ≥20 years in freshwater or estuarine systems before beginning the process of sexual maturation (Scott and Scott, 1988; COSEWIC, 2012). The life cycle of the American eel culminates with a metamorphosis from yellow stage to silver stage. This transition involves a suite of both physical and physiological adaptations that prepare the silver eel for spawning as well as the significant associated migratory journey to the Sargasso Sea. Changes include a darkening of the skin to a dark black sheen on the dorsal side and the characteristic silver on the ventral side, an increase in body weight and length, thickening of the skin, an increase in eye diameter and a degeneration of the digestive tract (Jessop, 1987; Oliviera, 1999; COSEWIC, 2012). American eels are semelparous, and will make only one migratory journey to the Sargasso Sea to spawn, after which they die (Tesch, 1977; McCleave, 1987; Oliviera et al., 1999).

Recent decades have seen dramatic declines in abundance of American eels over a significant portion of the species range (Castonguay et al., 1994; Haro et al., 2000; COSEWIC, 2006; COSEWIC, 2012). Declines observed in populations of Lake Ontario and the upper St. Lawrence River are most notable and well documented (Castonguay et al., 1994; Haro et al., 2000). Losses from inland waterways in the northern portion of the species range are particularly troubling because, in general, larger and more fecund female eels are found in higher proportion in these locations (COSEWIC, 2012). While losses from any portion of a population can be significant, the selective loss of females from northern areas can greatly reduce overall reproductive capacity of the population. Although trends in abundance in other areas are highly variable, strong declines are apparent in several indices, and similar large scale declines have also been observed in the closely related European eel (Haro et al., 2000; COSEWIC, 2006; Cairns et al., 2008). Due to the apparent downward trend in Canadian populations, American eels were listed in 2006 as a species of special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC, 2006), and in 2012 the status was upgraded to Threatened level (COSEWIC, 2012).

Population declines have been associated with several primary threats, including: habitat alteration, dams/turbines, fishery harvest (both adult and juvenile life stages), alterations in ocean conditions related to climate change, contaminants, and parasites (Haro et al., 2000; COSEWIC, 2006; Bradford et al., 2009; COSEWIC, 2012). Downstream survival of American eel passing by anthropogenic structures, most notably hydroelectric turbines and dams, has been a major focus of research, management, and population restoration activities (Haro et al., 2000; Carr and Whoriskey, 2008; COSEWIC, 2012). Recent interest in the development of tidal in-stream energy conversion (TISEC) devices introduces a new potential threat to migratory life stages of the American eel (Dadswell et al., 1986; Bradford et al., 2009).

The Minas Passage is a critical pathway through which all eels departing the Minas Basin must pass to access the open Atlantic Ocean en route to the Sargasso Sea. This study investigates the spatial (location, depth) and temporal (diel, seasonal) use of the passage by American eels and the potential for arrays of turbines to interact with out-migrating silver stage American eels departing from the Gaspereau River. Movements in relation to current speed and tidal state are also examined.

5.2 Methodology

5.2.1 Eel Collection

During fall 2011 and 2012, downstream migrating silver stage American eels were collected from bypass facilities of a hydroelectric dam in the Gaspereau River system (Figure 2.10) at White Rock (45.0623, -64.3808). The collection chamber was set nightly near dusk by inserting steel grates to block downstream passage of fish which are concentrated in a flow through chamber. The collection chamber (Figure 5.1) was checked promptly each morning for American eels captured during the overnight period.

In 2011, bypass collection traps were operated from September 24-30 and from October 19-21 resulting in capture of 109 American eels, 15 of which were deemed suitable in size for acoustic tagging. During 2012, trapping activities occurred from September 10-14, 2012 and resulted in capture of 40 American eels, 30 of which were tagged.

***Figure 5.1**. Bypass collection structure used during 2011 and 2012 to capture downstream migrating silver stage American eel from the Gaspereau River system at White Rock. The steel grate, located in the foreground, was installed nightly to collect eels within the lower concrete holding area. A green flow through circular tank, located in the background, was used to hold eels for approximately 24hrs post-surgery until release.*

5.2.2 Tagging Procedure

Silver stage American eels were selected by careful examination of external characteristics including: coloration, ocular diameter, skin thickness, and overall body size (Jessop, 1987; Cottrill, 2002; Durif et al., 2009). American eels deemed to be silver stage, free of any external damage, and of sufficient size to undergo the surgical procedure (2011: >0.65m TL; 2012: >0.5m TL) were selected. Given the size selection parameters, all eels tagged in this study were likely females. Although external characteristics were used as a primary method to distinguish silver stage American eels, this method is not definitive (Cottrill et al., 2002). Therefore downstream movement from fully fresh to brackish waters was used post-hoc to further confirm selection of silver stage individuals for surgical implantation.

Each eel selected for tagging was surgically implanted with a coded depth-recording acoustic transmitter. Transmitter specifications varied with year as shown in Table 5.1. Surgical procedures followed were consistent between tagging seasons, and similar to those described by Carr and Whoriskey (2008) and Bradford et al. (2009). Handling of American eels was performed while wearing surgical gloves to limit damage and mucous loss, and all surgical tools were soaked for ~24 hours in a medical disinfectant solution of 2% activated Gluderaldehyde (BM 28+; Groupe B.M. Inc., Montreal, PQ). During surgery, tools were cold disinfected between usages, and transmitters were soaked in ethanol (95% EtOH), then rinsed thoroughly with distilled water prior to insertion.

Table 5.1. *Summary of VEMCO 69kHz acoustic transmitter surgically implanted in silver stage American eels during 2011 and 2012.*

Tagging Year	Number Implanted	Transmitter Model	Output Power (dB @ 69kHz)	Delay (sec)	Weight in Water (g)	Est. Battery Life (days)
2011	15	V13P-1H	158	15-45	6.0	81
2012	22	V9P-2L	147	15-45	3.5	105
2012	8	V9P-6L	147	20-60	2.2	62

American eels were anesthetized individually using a 10% by volume Eugenol (clove oil; Hilltech, Vanleek Hill, ONT) in ethanol (95% EtOH) solution. The Eugenol/Ethanol mixture was added to the water available at the tagging site to produce a 100mg/L anesthesia bath. Individual eels deemed suitable for surgery were placed into the anesthesia solution and were monitored for induction of Stage 4 anesthesia (loss of equilibrium, no reaction to external stimuli, and regular but decreased opercular rate). Average anesthesia induction times were 5:19 min (SD= ±0:38, n=15), and 5:14 min (SD= ±1:02, n=30) in 2011 and 2012, respectively. Anesthetized eels were placed on a standard wet surface measuring board and total length measured to the nearest millimeter (mm), then transferred to a plastic weigh boat and weighed to the nearest gram (g) using a Ohaus digital scale. Finally, each anesthetized American eel was positioned in a wet foam surfaced surgical trough, ventral side facing upward. The surgical area was disinfected using a minimal amount of Betadine 10% povidone–iodine topical disinfectant solution (Purdue Pharma, Pickering, ONT). A 20-25mm incision was then made using a sterile 10-gauge scalpel along the ventral midline. A transmitter was then inserted and positioned forward into the body cavity anterior of the incision site. The incision was closed with 2 simple interrupted sutures using 4-0, non-absorbable, nylon monofilament suture material and a 19mm semi-circular needle (Ethicon, Markham, ONT). Upon closing, the incision area was thoroughly irrigated with additional Betadine 10% povidone–iodine topical disinfectant solution. Average surgical procedure completion times, including length and weight measurements, were 3:43 min (SD= ±1:10, n=15) and 4:44 min (SD= ±2:25, n=30), in 2011 and 2012 respectively. Implanted eels were then promptly returned to a freshwater flow through recovery tank and held for ~24hrs to regain proper equilibrium and to ensure that no immediate post-surgical mortality occurred. All implanted eels were successfully released the morning following the surgical procedure. Transmitter to eel weight ratio did not exceed 1.5% in any implanted individual. Collection methods for American eels and all surgical procedures were reviewed and conducted under DFO Scientific License #322857, and Acadia University Animal Care Protocol #06-11 and #06-12.

5.2.3 Data Treatment and Analysis

A description of the study site and receiver locations and deployments is provided in Section 2 of this report. Receiver log files (VRL's) were downloaded from recovered VEMCO VR2w receiver units, and imported into the VUE (VEMCO User Environment) software program to create a single database for each deployment season. Receiver clock drift is a known issue that can occur in all study environments, but can be exaggerated by extended deployment periods (D. Webber – VEMCO, pers. comm.). The VUE program was used to apply a linear drift correction factor, to compensate for internal clock drift between times of receiver initialization and download.

American eels in the Minas Passage may move in either direction (i.e. seaward or landward), may be detected on one, two or all three arrays of receivers (i.e. the OTN-MPS line, the Acadia University line or the FORCE array, see Section 2 for differences between 2011 and 2012 deployment arrangements) and may be detected on several distinct occasions separated by extended periods of time (i.e. days). Thus, in an effort to provide a meaningful description of American eel movement patterns in tag detections, the data are described in two general manners; 1) by examining all raw detections, or 2) detection events, where each migration event consists of a sequence of detections within the Minas Passage (any combination of receivers), where any two consecutive detections are separated by no more than 30 minutes. A single detection event may span several receivers.

5.3 Results

5.3.1 Detection Summary

In total, 45 silver stage American eels were tagged with acoustic transmitters (15 in 2011 and 30 in 2012). During the 2011 season all 15 American eels tagged were detected successfully by receivers within the Gaspereau River system, and all were detected on the receiver located at the river mouth, approximately 14 km from the release site. The river exit duration (days post-release) averaged 14 days (SD = ±7.8, n=15) (Table 5.2). American eels detected by the river mouth receiver were assumed to have exited the river and out-migrating toward Minas Passage. Of the 15 American eels detected leaving the river, 11 were subsequently detected by acoustic receiver stations within Minas Passage, and 2 of these were detected by two receivers located within the FORCE test site (Table 5.4).

During 2012, a larger sample size of American eels was permitted through the use of smaller V9P transmitters. In total, 30 American eels were surgically implanted with acoustic transmitters during 2012 (Table 5.3). Of the 30 eels tagged, 28 were detected by the last downstream receiver at the mouth of the Gaspereau River; the number of days post release averaged 27 days (SD = ±6.9, n=28) (Table 5.1). All eels detected by the river mouth receiver were assumed to have exited the river and were out-migrating toward Minas Passage. Of the 28 eels that departed the Gaspereau River, 10 were detected by receiver stations within Minas Passage, and 6 of these 10 eels were detected by receivers positioned within the FORCE test site (Table 5.4).

Table 5.2. *Summary of 2011 tag release metadata and time at liberty indices for individual silver stage American eels. Days Post Release (dpr) indicates the number of days following release from the Gaspereau River. NA (not applicable as not detected).*

Eel Code	TL (m)	Wt (kg)	Release Date	River Exit (dpr)	First Detect in Minas Passage (dpr)	Days at Large (dpr)	Days Detected in Minas Passage	Receiver Stations Logging Detections	Total Detects in Minas Passage	Max Depth (m)
1	0.82	0.92	2011-09-24	8	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
2	0.65	0.59	2011-09-24	12	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
3	0.65	0.50	2011-09-24	17	27	27	1	3	11	77.3
4	0.68	0.63	2011-09-24	11	23	23	1	4	101	101.3
5	0.77	0.81	2011-09-24	12	27	27	1	8	54	54.5
6	0.70	0.62	2011-09-24	5	29	29	1	1	2	22.4
7	0.66	0.56	2011-09-25	25	26	26	1	2	42	45.7
8	0.67	0.59	2011-09-25	13	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
9	0.69	0.83	2011-09-25	10	27	31	5	3	222	13.6
10	0.80	0.96	2011-09-25	17	30	30	1	4	99	50.1
11	0.68	0.70	2011-09-26	9	23	23	1	6	146	105.9
12	0.68	0.53	2011-09-26	24	25	26	2	6	126	104.2
13	0.74	0.68	2011-09-26	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
14	0.75	0.73	2011-09-29	20	22	22	1	6	80	69.9
15	0.82	1.20	2011-10-21	0	3	3	1	1	1	90.5

Table 5.3. *Summary of 2012 tag release metadata and time at liberty indices for individual silver stage American eels. Days Post Release (dpr) indicates the number of days an event occurred following release from the Gaspereau River. NA (not applicable as not detected).*

Eel Code	TL (m)	Wt (kg)	Release Date	River Exit (dpr)	First Detect in Minas Passage (dpr)	Days at Large (dpr)	Days Detected in Minas Passage	Number of Stations Logging Detections	Total Detects in Minas Passage	Max Depth (m)
1	0.68	0.57	2012-09-11	28	35	35	1	1	1	38.6
2	0.77	0.77	2012-09-12	30	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
3	0.59	0.41	2012-09-12	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
4	0.67	0.57	2012-09-12	29	43	49	4	3	29	110.3
5	0.58	0.36	2012-09-12	29	33	33	1	1	3	0.4
6	0.52	0.28	2012-09-12	31	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
7	0.61	0.40	2012-09-12	30	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
8	0.74	0.81	2012-09-12	30	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
9	0.54	0.28	2012-09-12	31	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
10	0.62	0.49	2012-09-12	17	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
11	0.60	0.53	2012-09-12	32	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
12	0.62	0.40	2012-09-12	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
13	0.65	0.41	2012-09-12	33	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
14	0.54	0.28	2012-09-12	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
15	0.84	1.05	2012-09-13	32	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
16	0.62	0.45	2012-09-13	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
17	0.64	0.59	2012-09-13	5	31	32	2	5	16	36.4
18	0.64	0.49	2012-09-13	26	28	28	1	4	43	24.6
19	0.61	0.39	2012-09-13	29	34	34	1	2	5	28.5
20	0.61	0.42	2012-09-13	28	31	31	1	7	44	49.2
21	0.61	0.43	2012-09-13	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
22	0.78	0.87	2012-09-13	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
23	0.59	0.36	2012-09-13	29	30	30	1	1	2	74.3
24	0.77	0.76	2012-09-13	29	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
25	0.66	0.55	2012-09-14	30	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
26	0.71	0.61	2012-09-14	5	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
27	0.85	1.21	2012-09-14	30	55	57	3	5	38	39.5
28	0.75	0.84	2012-09-14	33	37	37	1	1	6	1.5
29	0.78	0.98	2012-09-14	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
30	0.68	0.62	2012-09-14	28	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

Table 5.4. *Summary of eel detection records at primary receiver location areas in this study. Note that positions of acoustic receiver arrays in and near FORCE varied between years (see Chapter 2 for receiver station details).*

Season	# Eels Tagged	Eels Detected within River	Eels Detected at River Mouth	Eels Detected in Minas Passage	Eels Detected at FORCE
2011	15	15/15	15/15	11/15	2/11
2012	30	28/30	28/28	10/28	6/10

5.3.2 Temporal Distribution

During 2011, acoustically tagged American eels were released September 24 – October 21 (Figure 5.2). The first American eel detection within Minas Passage occurred on October 17, with the last detection occurring on October 26. In 2012, eels were released over a more condensed period from September 11-14. Despite this, eels were detected over a longer time frame with the first detection in Minas Passage occurring October 11 and the final detection recorded on November 10 (Figure 5.3). American eels were detected in proximity of the FORCE test site on 2 unique days during 2011, and on 6 unique days during 2012. During 2012, receiver infrastructure remained in place throughout the winter period. No detections of tagged American eels were recorded during winter of 2012-2013.

Average number of days at large, from time of release to last recorded detection, was 24 days (SD= ±7.6, n=15) in 2011 (Table 5.2) and 36 days (SD = ±7.9, n=10) in 2012 (Table 5.3). Of detected eels, average number of days detected in Minas Passage was 1.4 days (SD = ±1.2, Max = 5) in 2011 and 1.6 days (SD = ±1.0, Max = 4) in 2012. The most rapid transit time observed in this study was completed by the largest tagged eel (82 cm, Eel 15) (Table 5.2). It was released and departed Gaspereau River within a single day on October 21, 2011, and was last detected within Minas Passage just 3 days later on October 24, 2011.

Individual eels had as many as 11 unique detection events during 2011 and as many as 4 unique detection events in 2012. Mean duration of each event during 2011 was 18 minutes (SD= ± 21 minutes, n=32, Range = 1 - 82 minutes) and during 2012 was 8 minutes (SD= ± 11, n=20, Range = 1 – 48 minutes) (Figure 5.4).

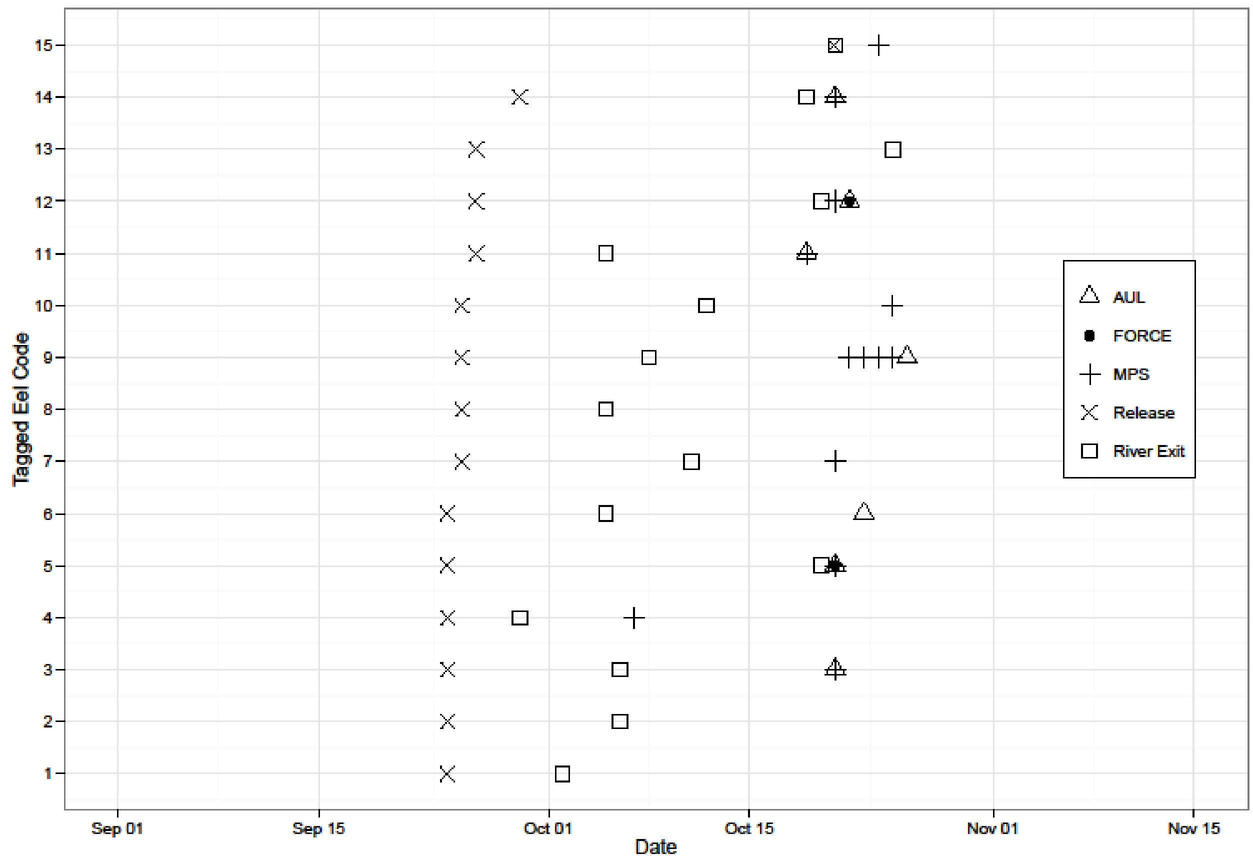

Figure 5.2. *Gaspereau River release dates and presence-absence daily detection history of 15 tagged silver stage American eels as detected at the river mouth and within Minas Passage during fall 2011*

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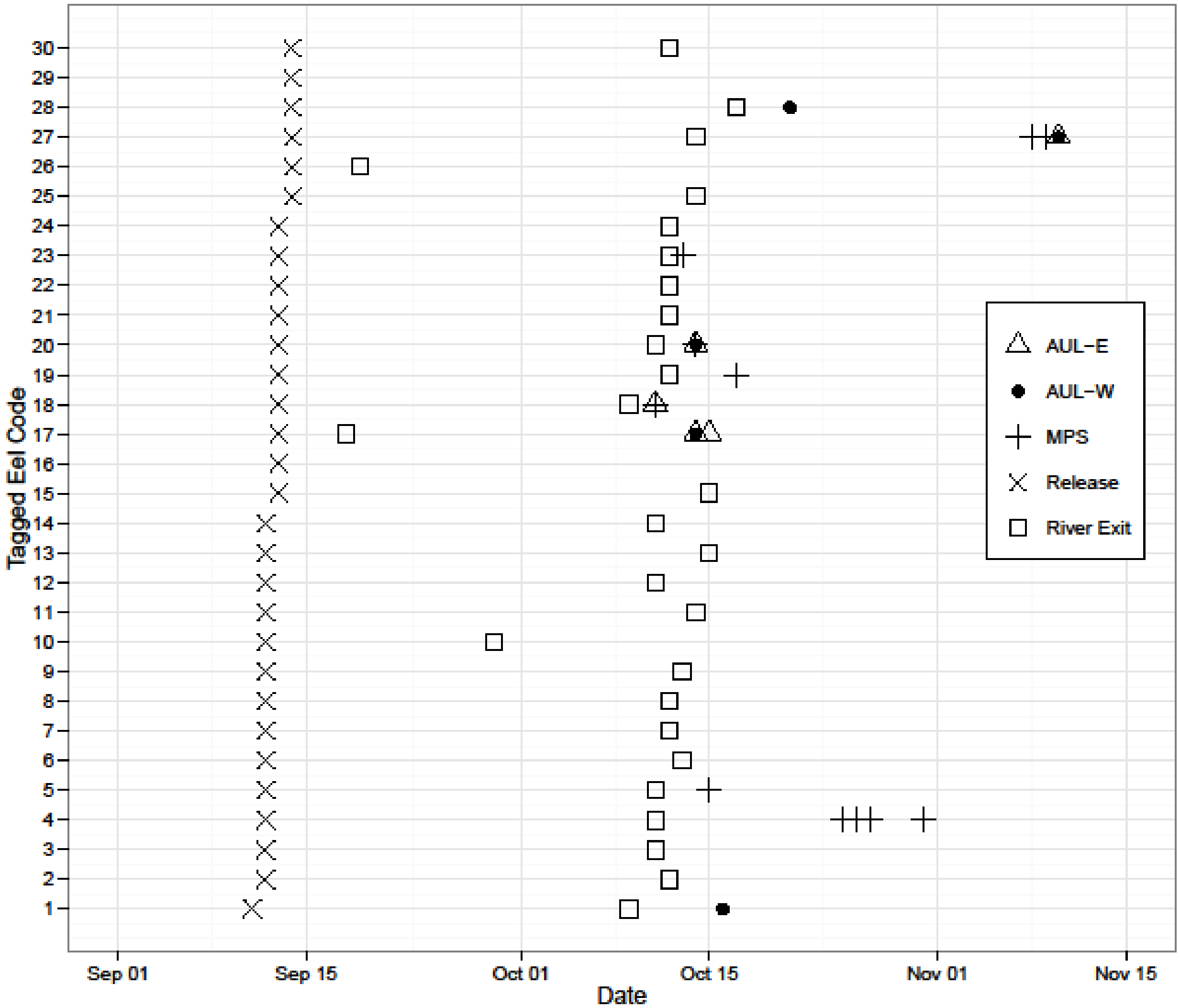

Figure 5.3. *Gaspereau River release dates and presence-absence daily detection history of 30 tagged silver stage American eels as detected at the river mouth and within Minas Passage during fall 2012.*

Figure 5.4. *Barplot of the frequency of detection event periods, in minutes. A detection event is defined by a period of detections with no time gap >30min between successive detections. Black and grey bars indicate detections occurring during 2011 (n=32, 11 eels) and 2012 (n=20, 10 eels), respectively. Detection events frequently spanned multiple receivers and/or more than one receiver array.*

5.3.3 Spatial Distribution

In 2011, American eel transmissions were logged by 20 of 27 recovered receivers. Transmissions from individual American eels were often detected simultaneously by multiple receivers during certain periods of the tide when transmissions were capable of being detected by as many as four (4) receiver stations. During 2012, American eel transmissions were logged by 15 of 24 recovered receiver stations. Transmissions from individual American eels were detected simultaneously across multiple receivers during certain periods of the tide when transmissions were capable of being detected by as many as two (2) receiver stations.

No obvious spatial distribution pattern was observed in Minas Passage to indicate a preferred migratory pathway within Minas Passage. American eels were distributed broadly across receiver lines in both 2011 (Figure 5.5) and 2012 (Figure 5.6).

Long range detections were reported for a single American eel, 2012 - Code #14. Eel #14 was detected on November 4, 2012 in a single detection event lasting 13 minutes (21 detections logged) by a receiver deployed in Northeast Channel, South of Browns Bank (42.3313, -65.9062). The receiver was deployed as part of the NERACOOS monitoring system and reported by researchers from NOAA in Maine, USA.

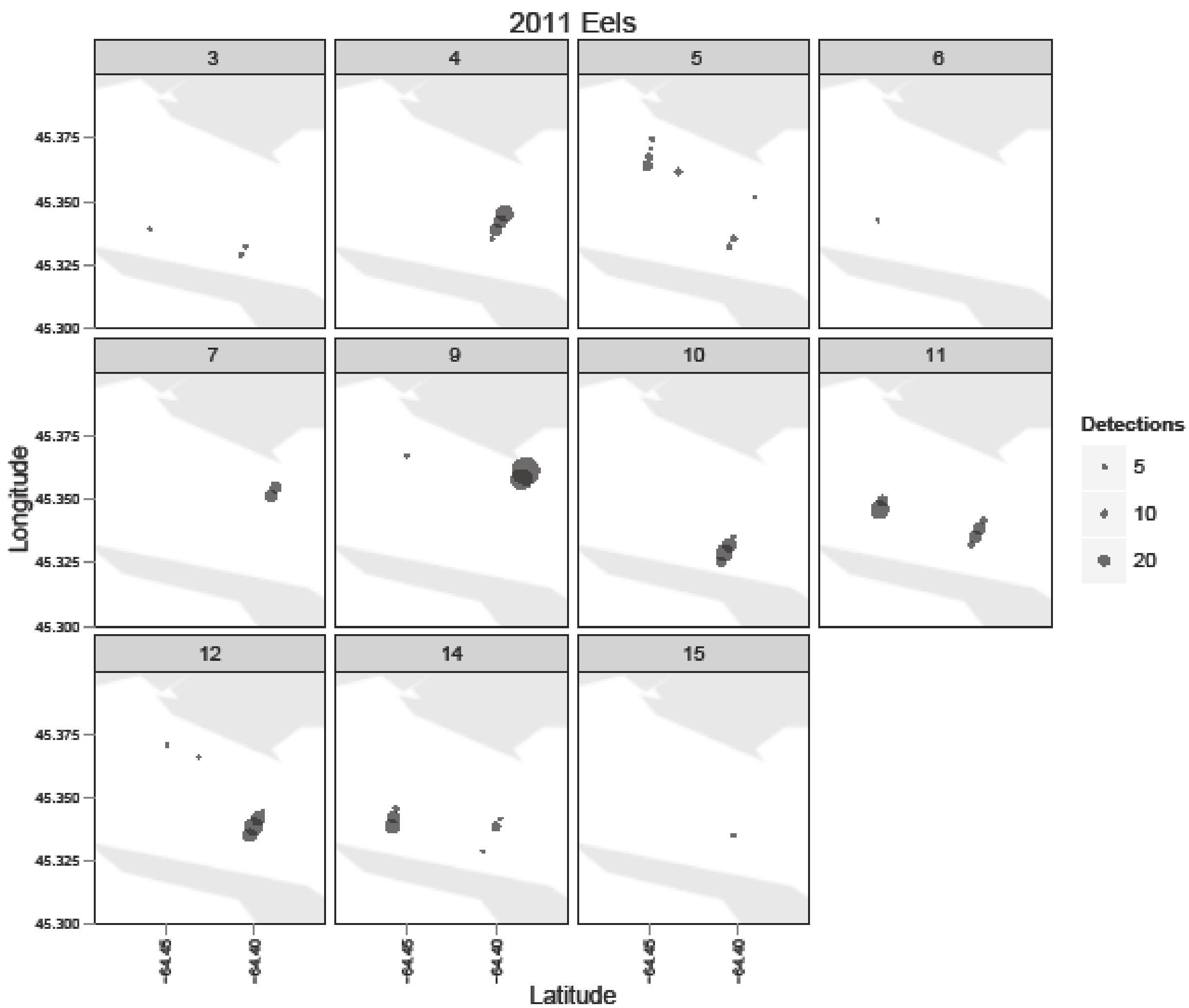

Figure 5.5. *Raw detection density histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings within Minas Passage during fall 2011. The diameter of the dark grey circles is proportional to the number of detections recorded at that receiver station. Individual panels denote individual American eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.2. See Section 2 – Figure 2.6 for receiver station positions.*

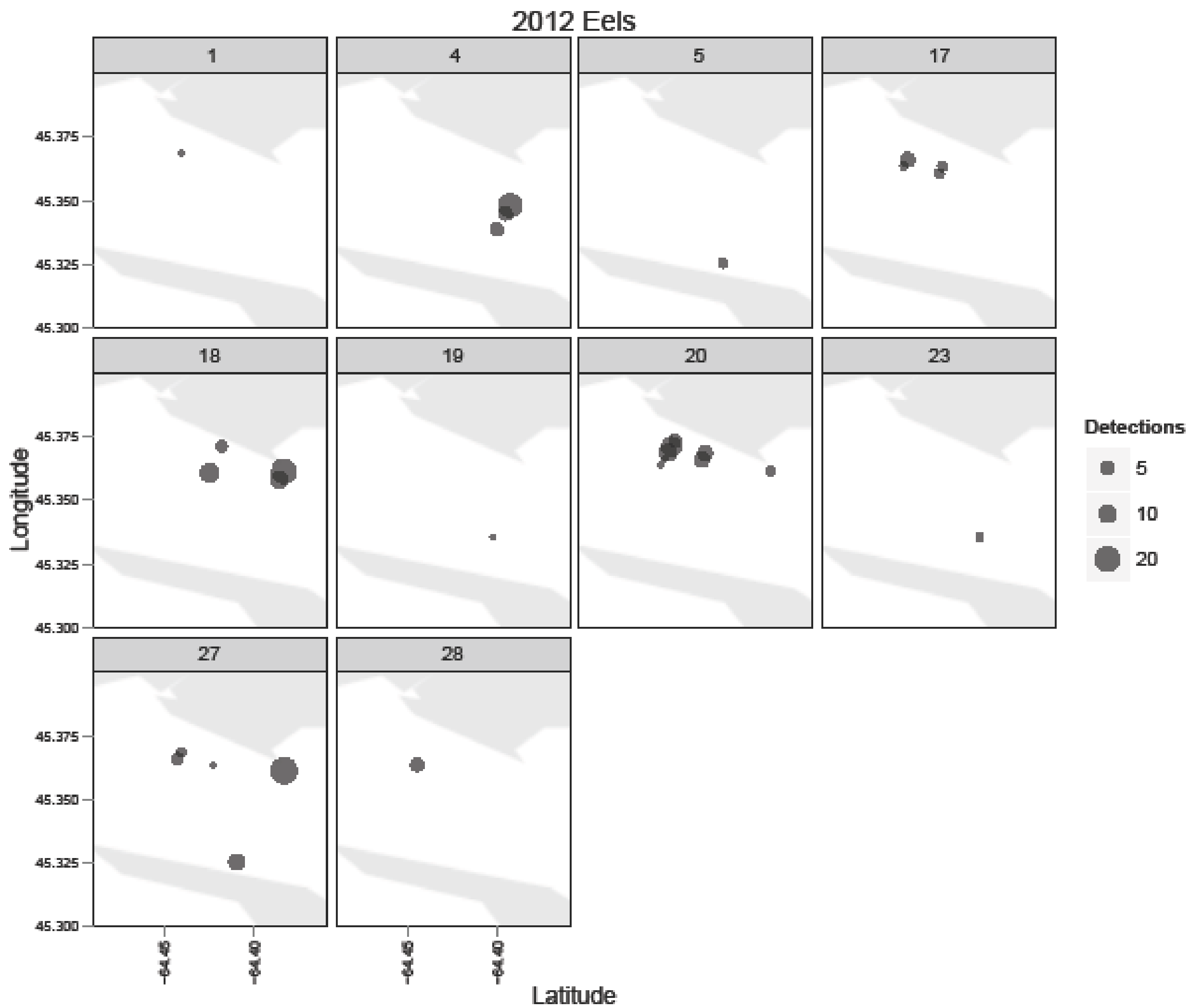

Figure 5.6. *Raw detection density histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings within Minas Passage during fall 2012. The diameter of the dark grey circles is proportional to the number of eel detections recorded at that receiver station. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.3. See Section 2 – Figure 2.7 for station positions.*

5.3.4 Depth Distribution

Out-migrating silver stage American eels were detected at various depths within Minas Passage ranging from surface waters to over 110m depth, indicating no selection for specific depths while exiting Minas Passage (see 5.8 Appendix, Figures A5.1 - A5.10). Individual eels were detected over a wide range of depths during short periods of detection (minutes). This observation suggests diving behaviour.

Diel Trends

Detection data pooled across all receiver lines and years of study (Figure 5.7) show that eels occupied a wider range of depths during the night and moved nearer to the surface during the day (Figure 5.7). This trend, which is the opposite trend of that observed for Atlantic sturgeon and striped bass, was observed for the inner MPS line (figure 5.8) but not for the FORCE line receivers (Figure 5.9), most likely due to the limited number of daytime detections (N=21) in this region of the passage.

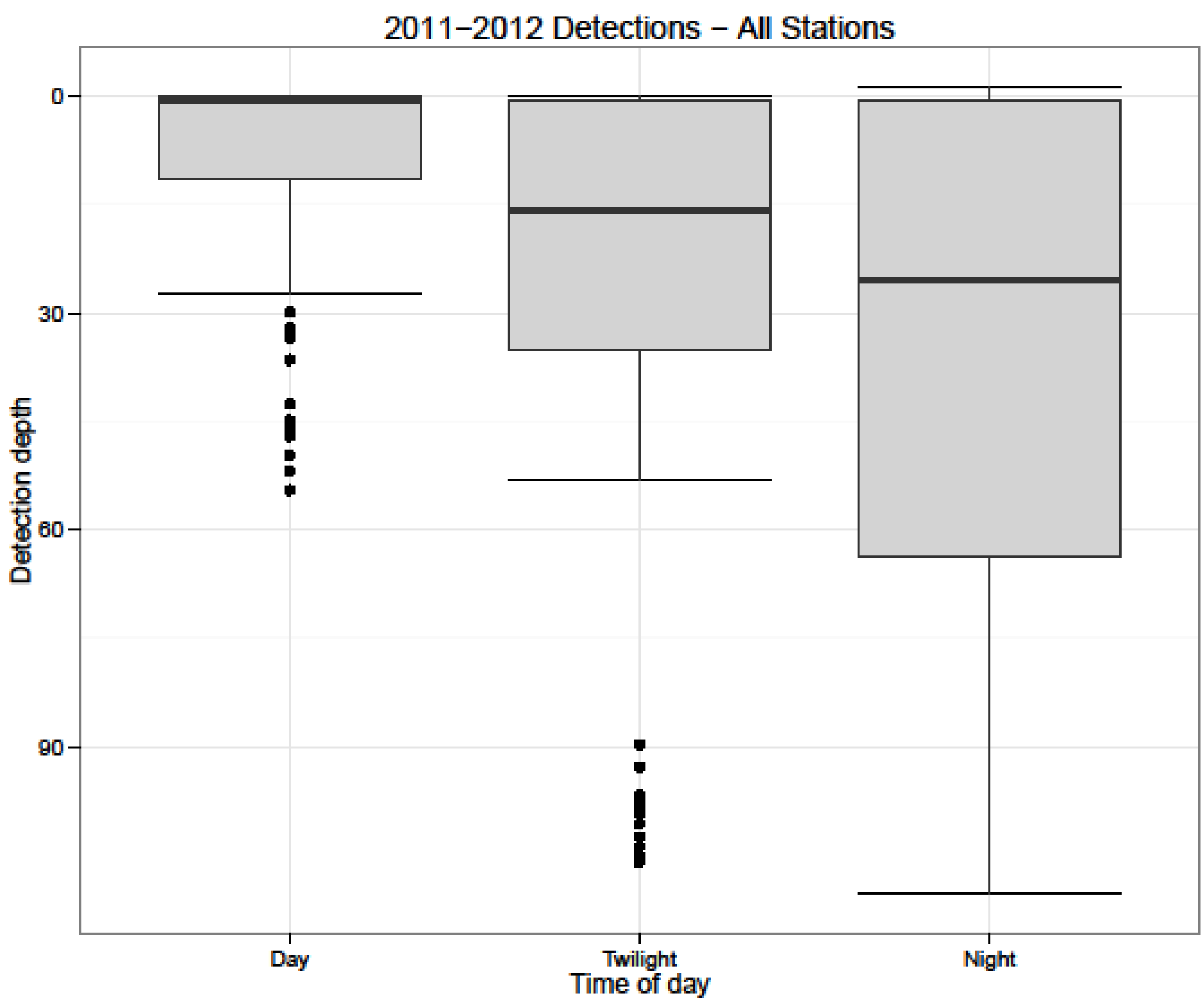

Figure 5.7. *Boxplots of all raw American eel detection depths recorded by receiver stations deployed within Minas Passage during 2011-2012. Detections are separated by diel period: day (n= 205 detections), twilight (1 hour before and after dusk and dawn, n= 155 detections), and night (n= 711 detections).*

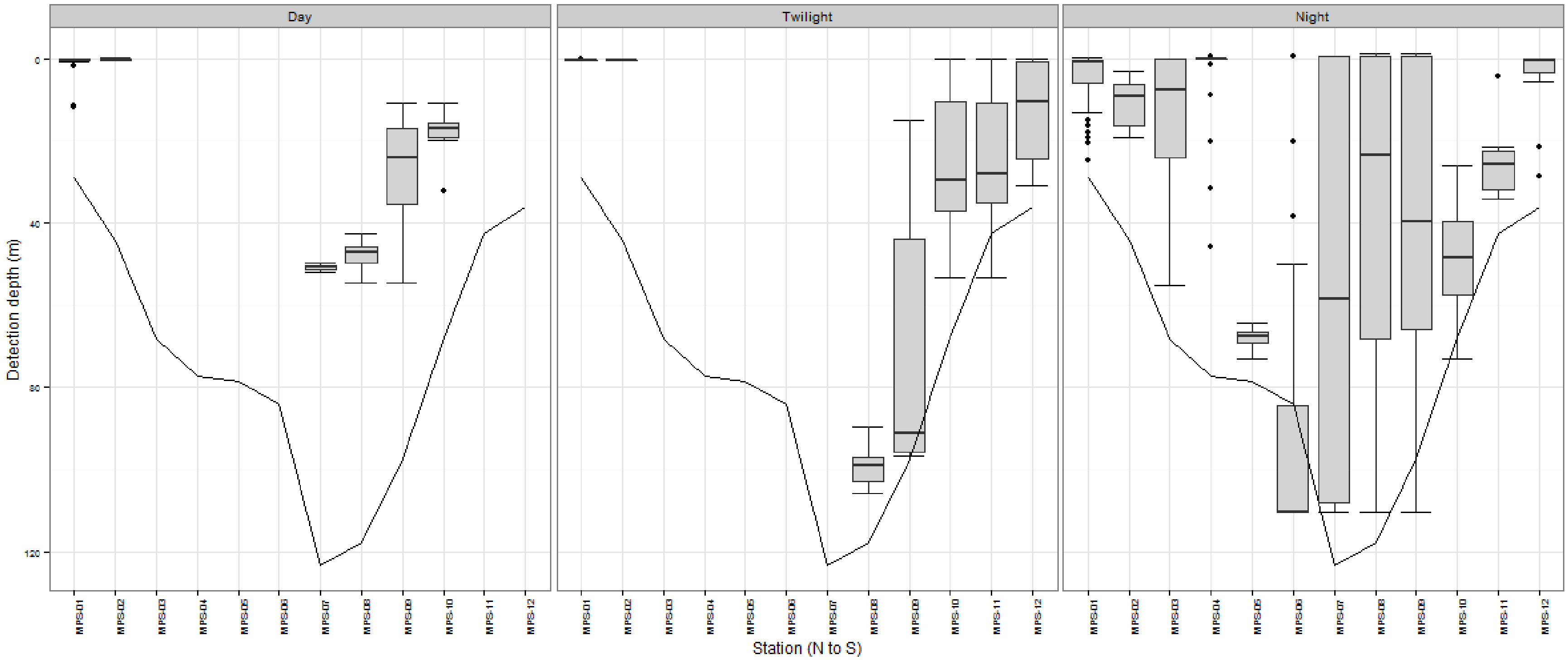

Figure 5.8*. Detection depth data during the day, twilight and night periods for MPS array receivers and both years (2001 and 2012). Day (n= 182 detections), twilight (1 hour before and after dusk and dawn, n= 155 detections), and night (n= 457 detections). Station positions are oriented in a North to South layout, and the solid black line indicates the approximate bottom contour provided by the average of depths for each station over both deployment seasons.*

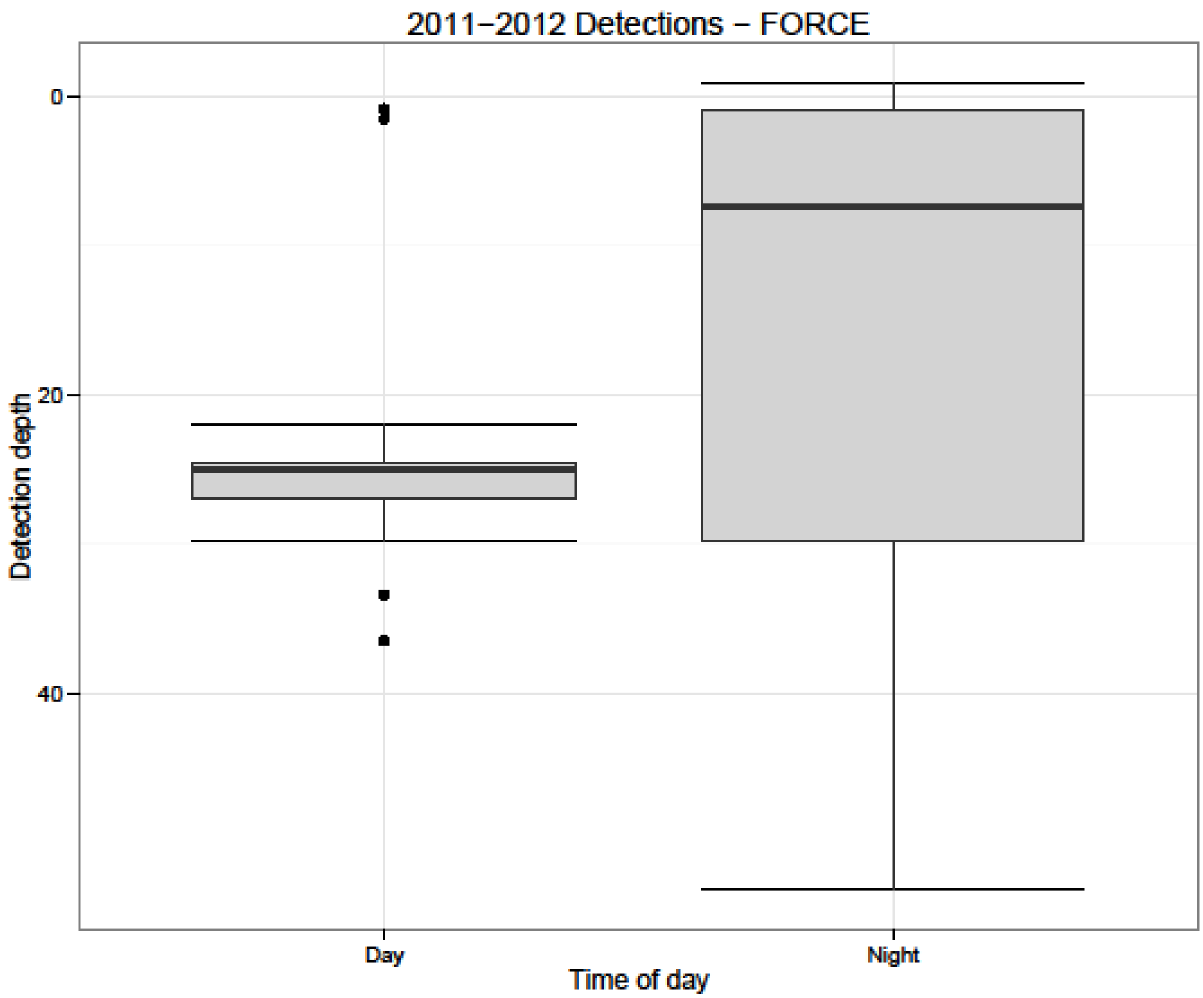

Figure 5.9. *Boxplots of American eel detection depths recorded from a combined 14 acoustic receiver stations deployed during 2011-2012 in the FORCE test site. Detections are separated by diel period: day (n= 21 detections), twilight (1 hour before and after dusk and dawn, n= 0 detections), and night (n= 78 detections).*

Ebb vs Flood

For all Minas Passage receivers, greater than four times as many American eel detections were logged during ebb tides (direction of outward migration) than during flood tides. In addition, eels were detected over a narrower range of depths and closer to the surface (i.e. faster flow) as the tide receded (Figure 5.10). Most of the flood tide detections were by receivers located in the southern half of the Minas Passage (Figure 5.11). At the FORCE test area, there were 9x more eel tag detections during ebb than flood, and eel movements detected were largely in the top 20 m (Figure 5.12).

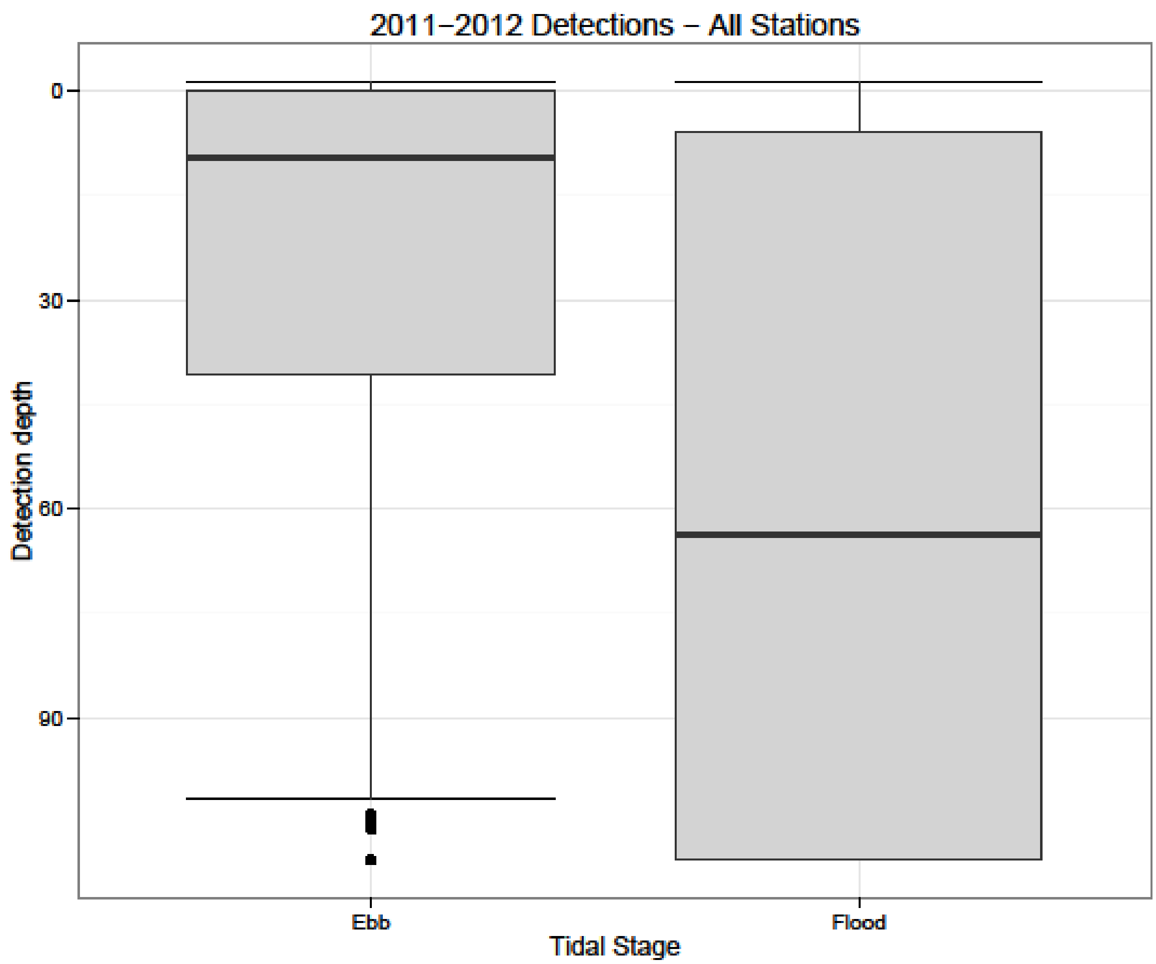

***Figure 5.10**. Boxplots of all raw American eel detection depths recorded by receiver stations deployed within Minas Passage during 2011-2012. Detections are separated by tidal stage: ebb (n= 873 detections), and flood (n= 198 detections).*

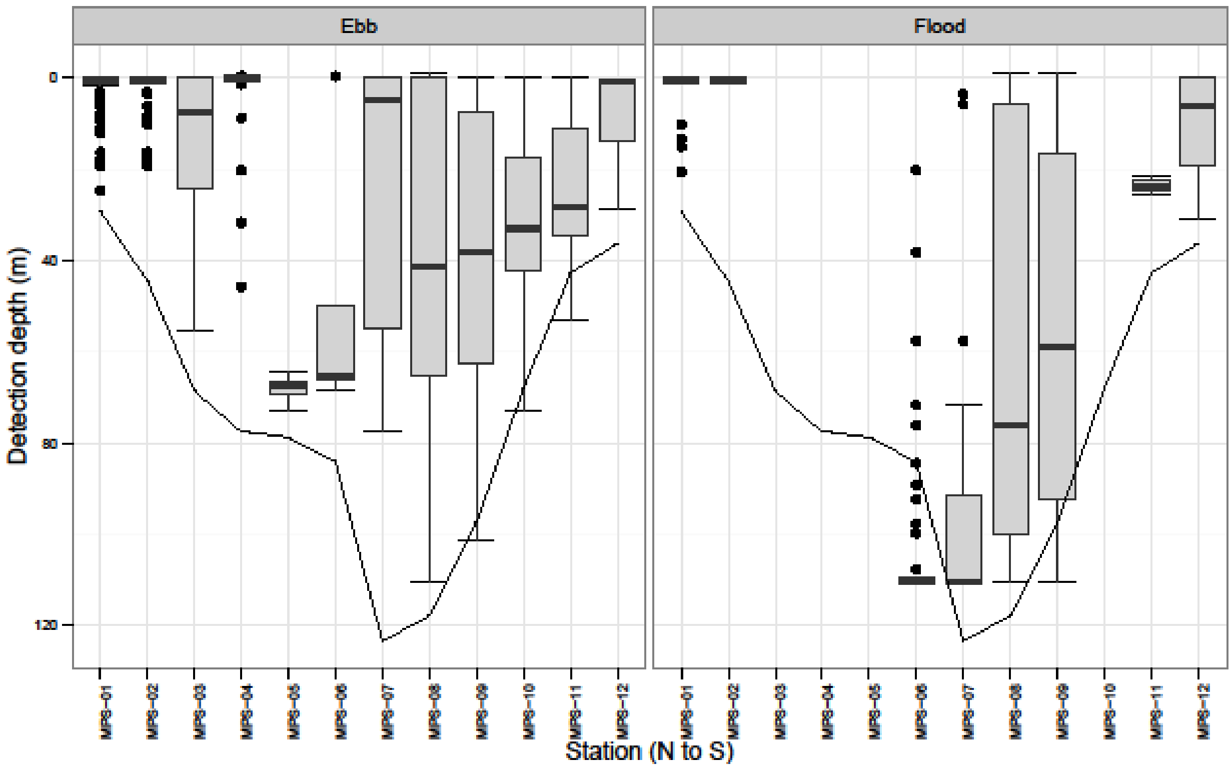

Figure 5.11. *Combined boxplots of all 2011 and 2012 detection depth data from the MPS array. Boxplots indicate the detections recorded during each tidal stage: ebb (n= 625 detections), and flood (n= 169 detections). Station positions are oriented in a North to South layout, and the solid black line indicates the approximate bathymetric contour, taken as the average deployment depth, at mean water level (MWL) for each station over both deployment seasons.*

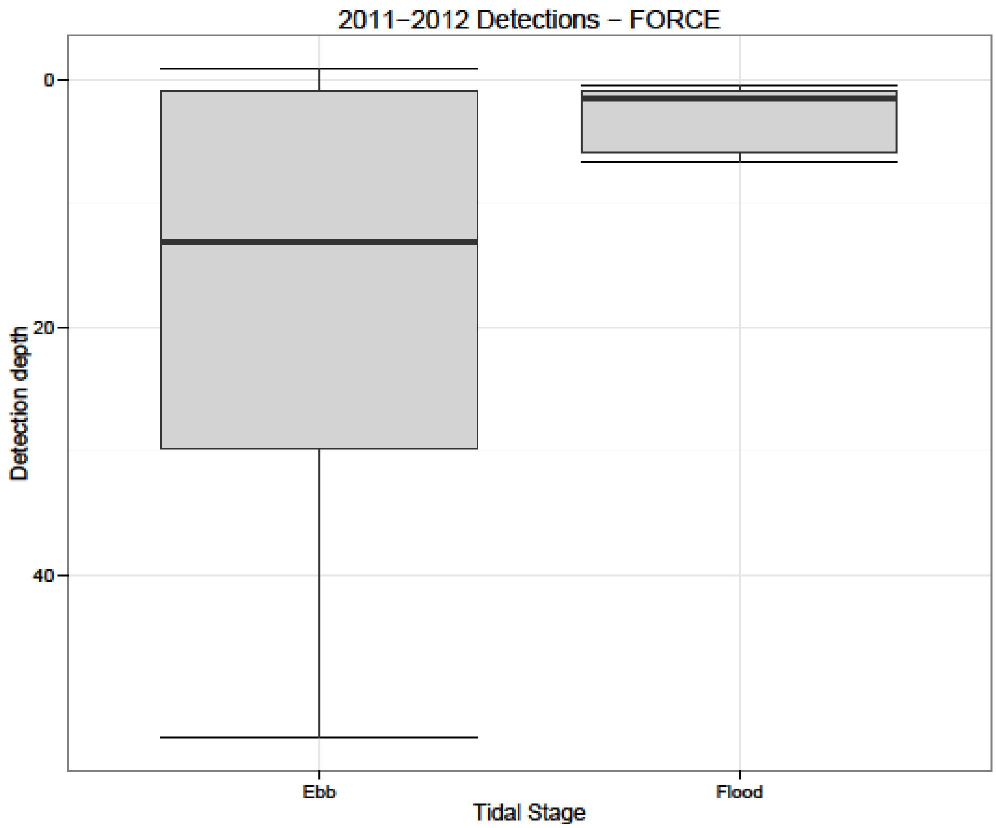

Figure 5.12. *Boxplots of American eel detection depths recorded from a combined 14 acoustic receiver stations deployed during 2011-2012 in the FORCE test site. Detections are separated by tidal stage: ebb (n= 89 detections), and flood (n= 10 detections).*

5.3.5 Travel Velocity

Consecutive detections by multiple receiver lines were used to calculate eel travel velocities. Eight of nine directed movements were recorded during ebb tide. Consecutive detections between lines that occurred less than 3hrs apart and covered a distance greater than 3km were used in calculations of velocity. The average travel velocity was 1.66 m/s (±0.75, n=9). The fastest travel velocity (3.0 m/s, 3.8 BL/s) was for an American eel (77 cm TL) detected in 2011 on both stations MPS-04 and AUL-T3 during an outward migration movement on an ebbing tide at night. Average water column velocity at the time of detection was 1.8m/s.

Detection of a single tagged eel off Southwest Nova Scotia in late 2012, 24 days after existing the Gaspereau River (450 km travel distance), permitted the examination of a long distance travel rate for eel #2012-14. It was not detected departing the Minas Passage en route to the Gulf of Maine. The travel rate averaged over 24 days was 0.21m/s or 0.38 BL/s.

5.4 Discussion

5.4.1 Tagging

During both study years, the majority of surgically implanted eels were observed to exhibit a post-surgical hesitation period prior to making directed downstream movements, a pattern similar to reports from other studies of tagged silver stage eels (Carr and Whoriskey, 2008; Bradford et al, 2009). Post-surgical hesitation was observed in the eels that were captured and released in September 2011. A single eel captured during October 2011, #2011-15, the largest tagged eel during both study years, showed the most rapid exit, possibly due to greater advancement in the silvering process and readiness to migrate more quickly. This result is consistent with other studies of larger and more mature eels later in the fall collection season (Jessop, 1987; Carr and Whoriskey, 2008). As it was not expected that silver stage American eels would be impeded by, or require an acclimation period to, salt water (Bradford et al., 2009), the delayed exit from the river is attributed to post-surgical hesitation and pre-migration development needs.

Lack of detection of all tagged eels within Minas Passage raises concerns about potential sources of tag loss and missed detections. For those eels detected leaving the Gaspereau River, but not subsequently detected within Minas Passage, it is possible that they may have: 1) been predated, 2) experienced delayed post-surgical mortality or tag shedding, or 3) were able to evade detection while passing quickly through Minas Passage on an ebb tide.

Recent studies have highlighted losses of tagged American eels due to predation by Porbeagle sharks in the Gulf of St. Lawrence (Beguer-Pon et al., 2012). Many potential predators of American eels are seasonally present in Minas Passage, including dogfish and other sharks, large striped bass, and bluefish.

Internal surgical implantation of transmitters is considered to be the most effective attachment technique for long term migration studies (Cotrill et al., 2004), and downstream detection of 15 of 15 eels in 2011, and 28 of 30 eels in 2012, indicated that post-surgical survival was high. Therefore delayed mortality was not deemed a significant factor impacting this study. The long range detection of eel #2012-14 indicates that at least one animal was able to retain its transmitter and evade predators while passing through the Minas Passage and beyond, to be subsequently detected at another receiver station in the Gulf of Maine.

5.4.2 Temporal Distribution

Silver stage American eels departed the Gaspereau River toward Minas Basin in the months of September and October in both study years. Detection data indicates that American eels are present within Minas Passage for a short time period; however the time of tagging/release ultimately influences when detections occur in Minas Passage. It is likely that the timeframe outlined, mid-September through early-November, would predict the majority of the migration timing of eels originating from systems draining into the Minas Basin. However, it is important to note that silver stage American eels may migrate through Minas Passage over a longer period than this study indicates. The timeframe over which American eels initiate and complete migration from an area varies seasonally based on environmental factors, with migration movements of individual eels spanning from late August – December (Jessop, 1987; COSEWIC, 2006; COSEWIC, 2012).

Overall detection counts for American eels within Minas Passage were low and the timeframe over which detection events occurred was generally short, indicating rapid transit through Minas Passage. This was expected due to the single passage nature of American eel out-migration. In general, detections were most prevalent during ebb tides, and during night-time periods which were consistent with results reported by Stasko and Rommel (1974) and Tesch (1978).

Although most eels detected appeared to be making a single outward migration, a few eels were detected in the Minas Passage multiple times during a tidal cycle (refer to Figure 5.4). There were no detections of eels past the first week in November in both years.

5.4.3 Spatial Distribution

There was no indication, in either 2011 or 2012, that American eels migrating through Minas Passage follow a specific route. Greater eel detection in and near the FORCE site in 2012 (60% of tagged eels detected) was a function of receiver location and density; receiver stations in the AUL line arrays were concentrated in the northern region of the passage during 2012.

It should also be noted that in 2012, we used a smaller transmitter model (V9P) to permit tagging of smaller sized eels which allowed a larger sample size to be tagged. Use of tags with lower overall output power, however, reduces the distance over which a transmission can be projected and ultimately reduces the number of receivers simultaneous logging a single transmission.

5.4.4 Depth Distribution

American eels migrating through Minas Passage showed depth preferences based on time of day, with eels found in the top 40 m during the day time and throughout the water column (to 100 m) during the night. On rare occasions, eels were detected in the FORCE test site during flood tides; at these times, eels were travelling in surface waters (top 5 m). About 90% of the detections at FORCE were during ebb flow periods and these were concentrated in the top 30 m of the water column. Eels were detected at much greater depths in the southern half of the passage, with most detections occurring during the night.

Selective tidal transport would allow eels to sustain directed migratory movement or to hold position during peak tidal exchange (Parker and McCleave, 1997; Bradford et al., 2009). Prior eel studies suggest that eels use vertical dive behavior during high flows to access lesser boundary layer currents found at deeper depths. If eels are present in the passage as the tide turns, the most energy efficient strategy would be to move within greater depths during periods of flood tide (Figures 5.11), and utilize shallower (and faster) depths during out-migration on the next ebb tide (Stasko and Rommel, 1974).

Bradford et al. (2009) reported that acoustically tagged American eels swam both with and against tidal currents with no observed preference for depth while exiting the tidally dominated Passamaquoddy Bay, NB. That area exhibits less extreme tidal current velocities than Minas Passage, and is likely to be less challenging for out-migrating eels.

5.4.5 Travel Velocity

The fastest travel rate determined for tagged American eels was 3.0m/s (3.8 BL/s) during an ebbing current velocity of 1.8m/s, indicating tide assisted movement on the ebbing tide. This travel rate is significantly faster (5x) than eel travel rates reported by Bradford et al. (2009) for Passamaquoddy Bay, a less energetic macro-tidal estuary.

5.5 Conclusions

Twenty-one of the 45 acoustically tagged eels (47%) were detected within Minas Passage, and of those, 8 were detected within the FORCE test site. While silver stage American eels were detected in the Minas Passage from mid-September to mid-November, individual eels use the passage for only short periods (1-6 days) as they out-migrate to the Bay of Fundy and beyond.

American eels utilize all regions of the Minas Passage with no specific out-migration pathway. Depths of transit through Minas Passage were highly variable among and within individuals, and ranged from the surface to 110m. Most movements occurred in October on night-time ebb tides and are the periods of highest risk for eel-turbine interactions.

Currently there is no evidence that American eels are capable of detecting and actively avoiding interaction with TISEC infrastructure. No studies have been performed to test the ability of American eel to avoid TISEC devices. The literature related to hydroelectric turbine passage of eels is extensive but not directly comparable. Other monitoring technologies will be required to fill the two remaining knowledge gaps we see as critical: 1) determination of whether or not American eels and other fish are present in Minas Passage during the periods of highest current velocity, and 2) examination of behavior and avoidance of fish in close proximity of TISEC devices. An additional concern, but outside the scope of this report, is the potential risk to in-migrating glass eels (juvenile stage).

5.6 References

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5.7 Appendix

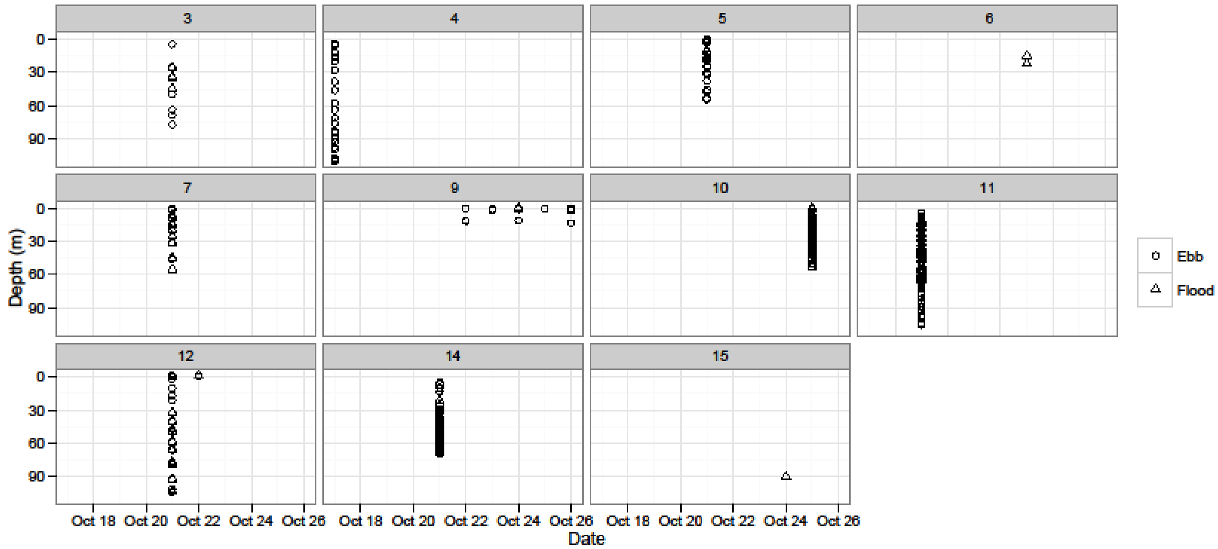

Figure A5.1. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected within Minas Passage as during fall 2011. Legend symbols indicate the tidal detection period when the detection occurred. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.2.*

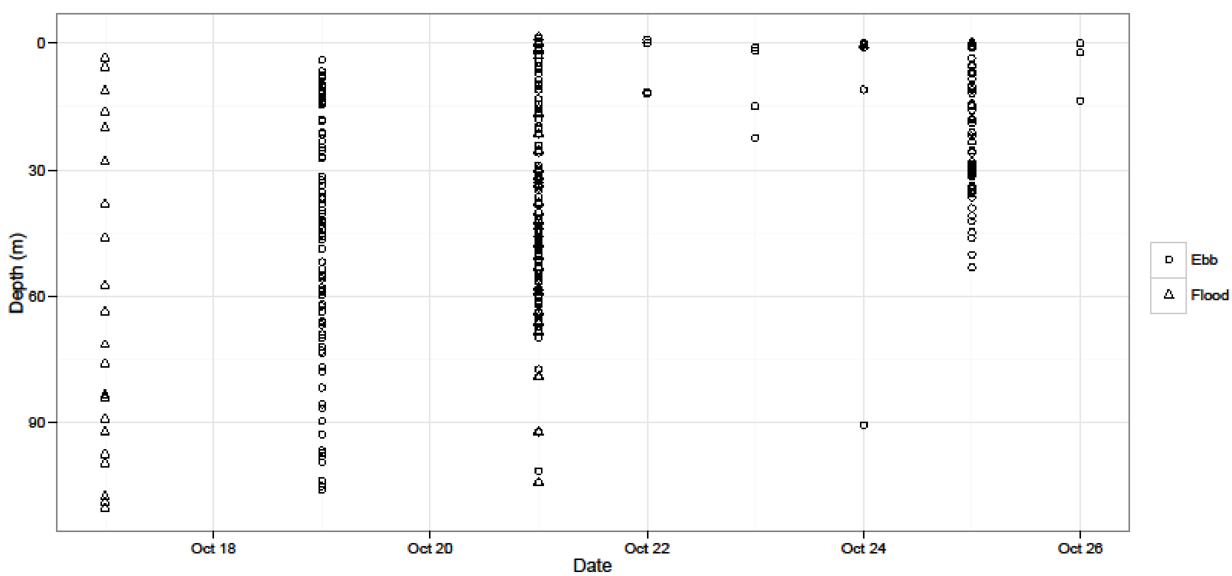

Figure A5.2. *Composite depth plots of swimming depth (m) of all silver American eels (n=10) as detected by receiver stations within Minas Passage during 2011. Detections occurring during Ebb tide periods are indicated by open circles, while detection occurring during Flood tide periods are indicated by open triangle symbols.*

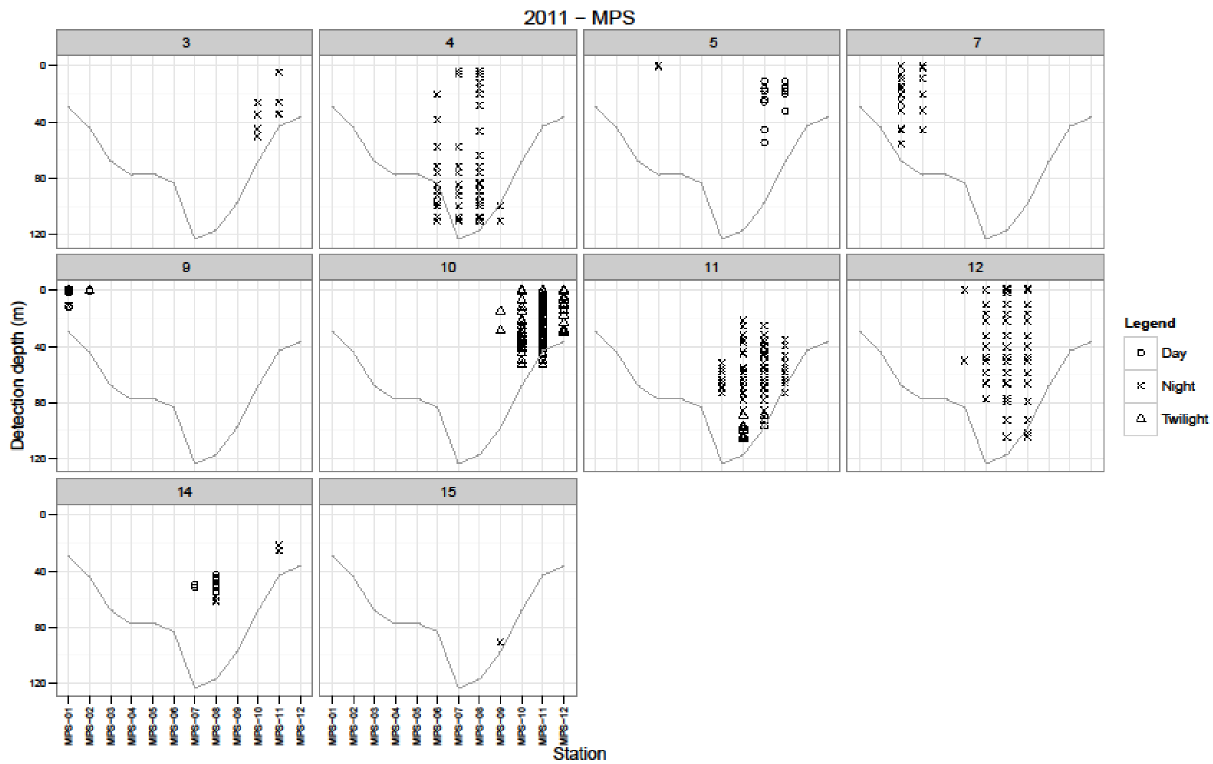

***Figure A5.3**. Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the MPS array within Minas Passage during fall 2011. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.2.*

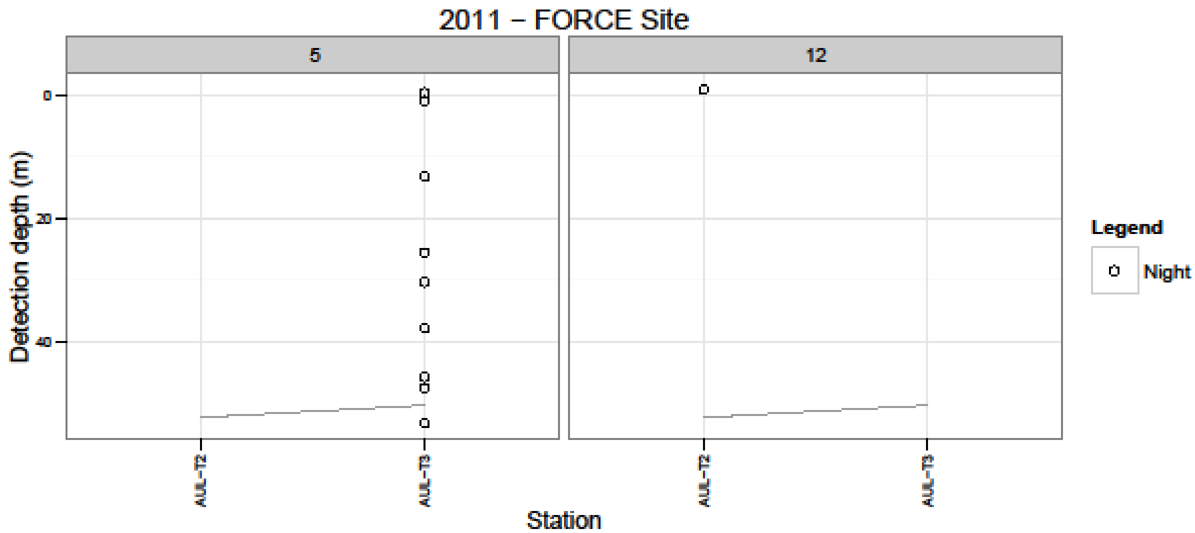

Figure A5.4. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the FORCE array within Minas Passage as during fall 2011. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.2.*

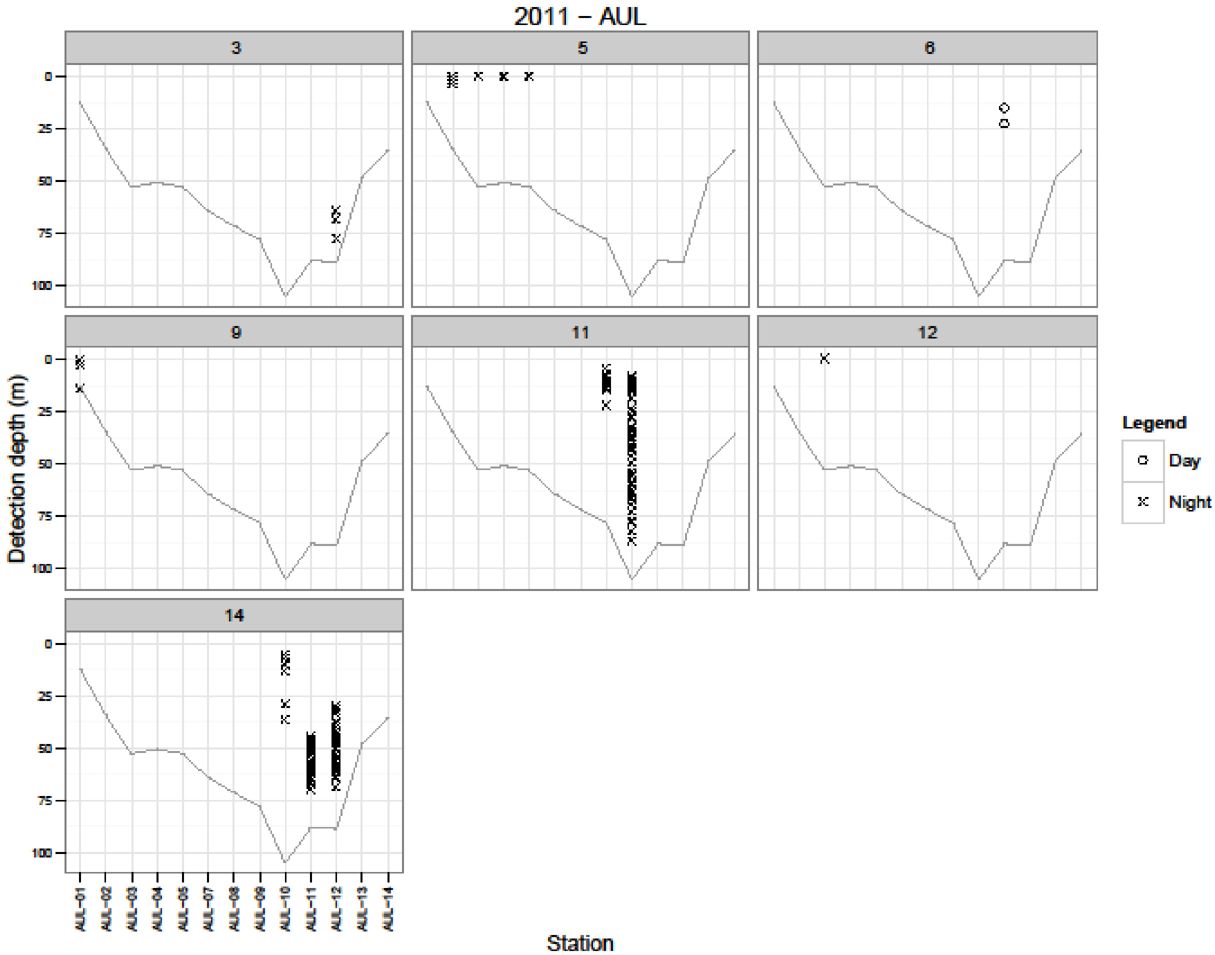

Figure A5.5. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the AUL array within Minas Passage as during fall 2011. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.2.*

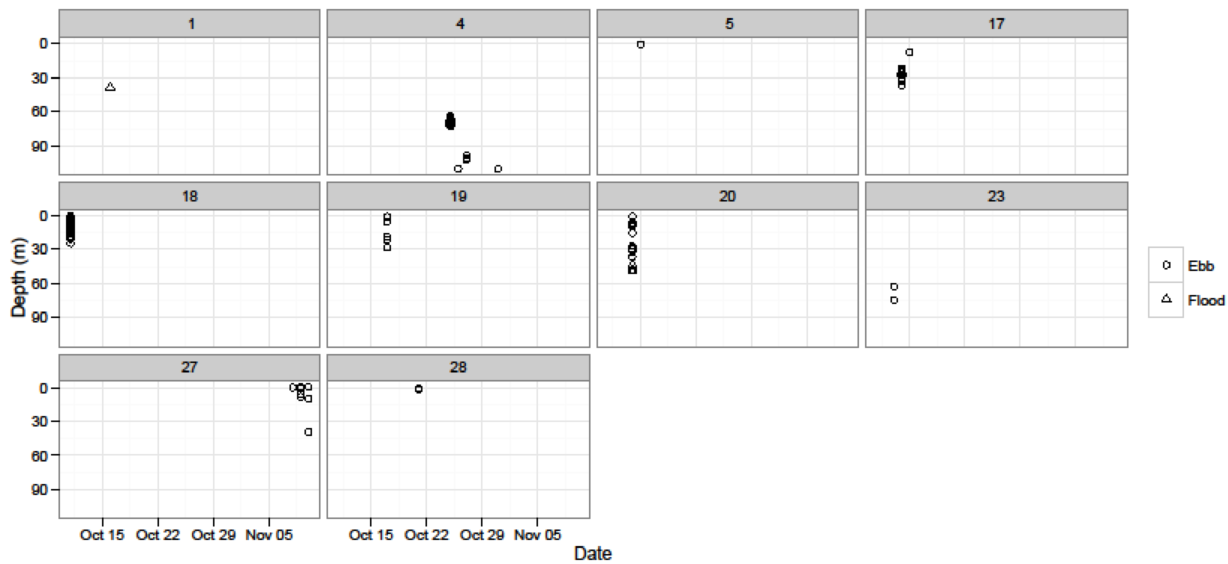

Figure A5.6. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the AUL array within Minas Passage as during fall 2012. Legend symbols indicate the tidal period when the detection occurred. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.3.*

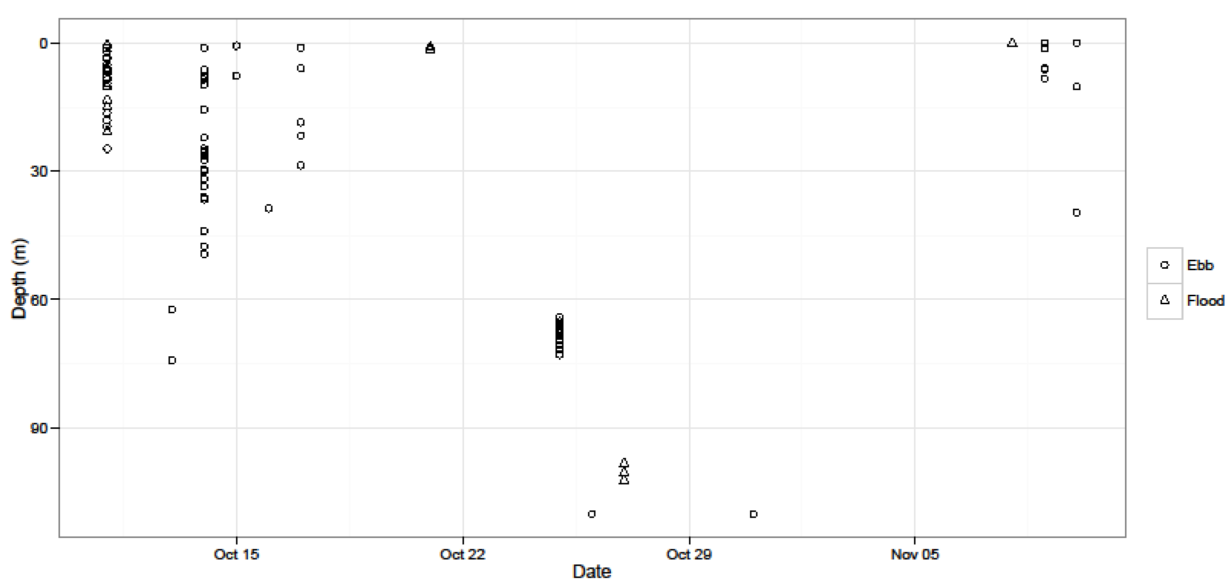

Figure A5.7. *Composite depth plots of swimming depth (m, from surface) of all silver American eels (n=10) as detected by receiver stations within Minas Passage during 2012. Detections occurring during ebb tide periods are indicated by open circles, while detections occurring during flood tide periods are indicated by open triangle symbols.*

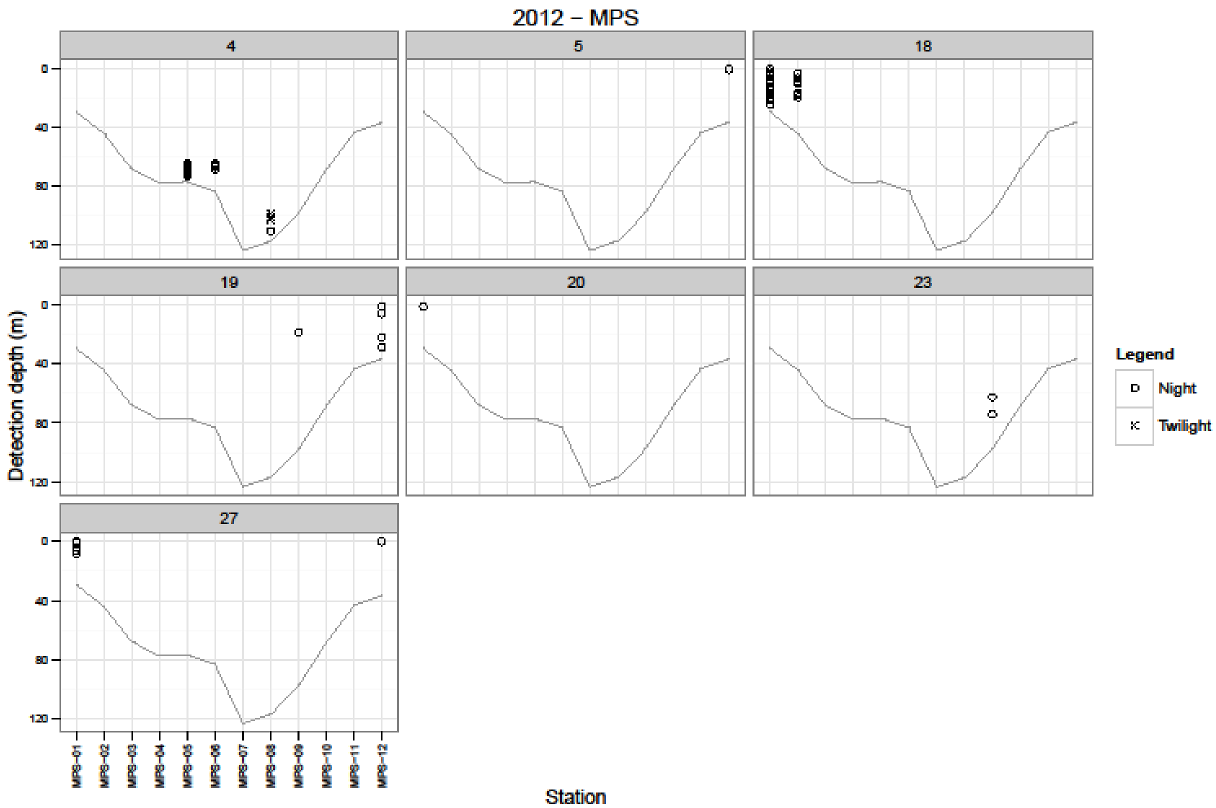

Figure A5.8. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the MPS array within Minas Passage as during fall 2012. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.3*

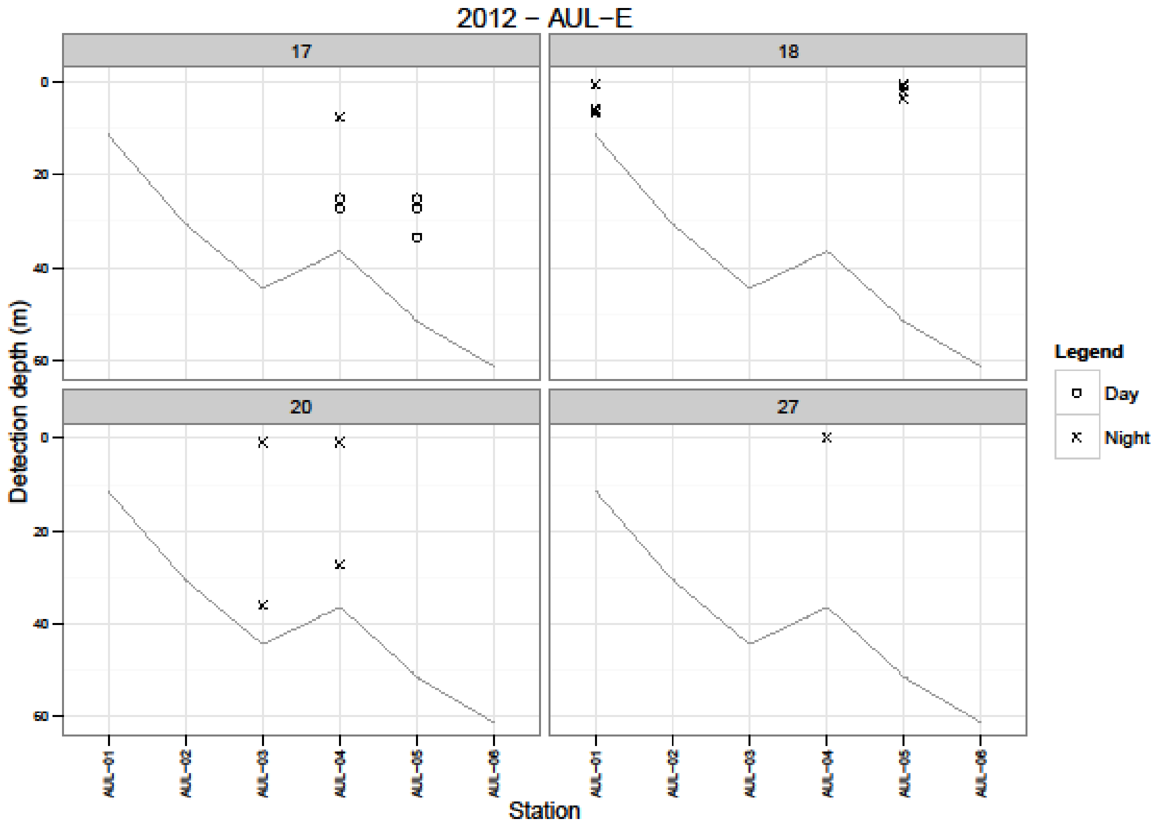

***Figure A5.9**. Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the AUL-E array within Minas Passage as during fall 2012. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.3.*

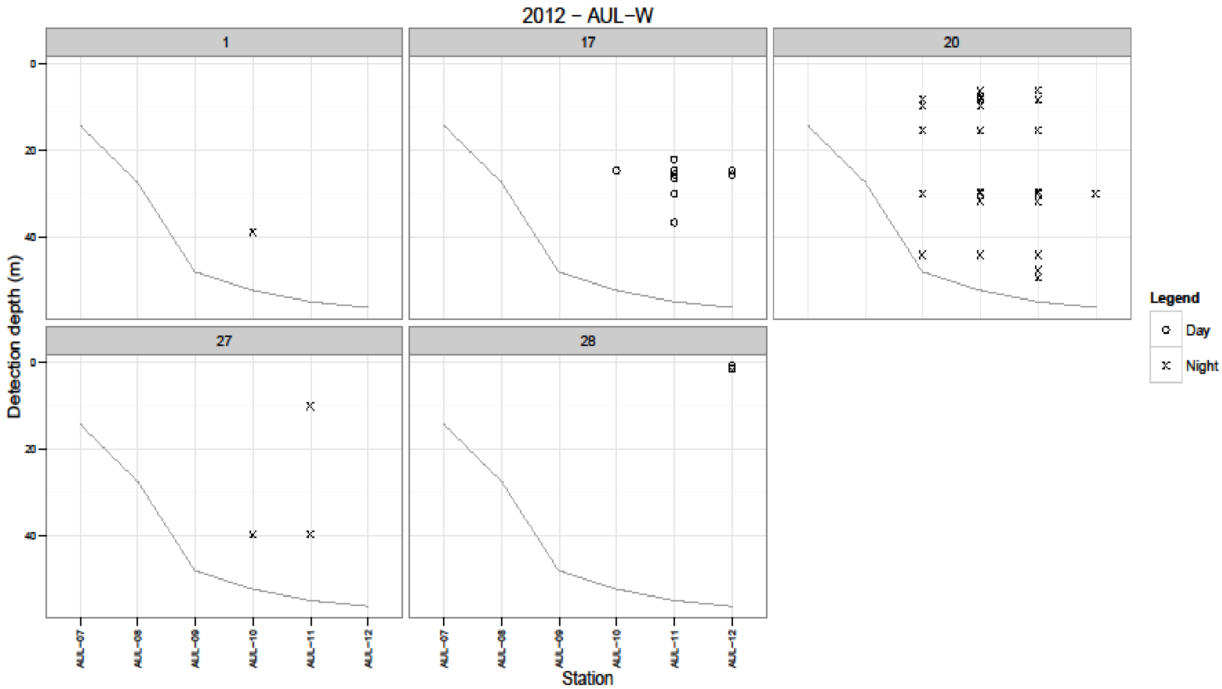

Figure A5.10. *Depth of detection (m, from surface) histories for transmitter implanted silver stage American eel as detected by acoustic receiver moorings comprising the AUL-W array within Minas Passage as during fall 2012. Legend symbols indicate the diel detection period when the detection occurred. Sunrise and sunset times were obtained from NOAA, twilight periods encompass ±1hr around the predicted sunrise and sunset time. The continuous black line indicates the approximate cross passage bathymetry between station positions. Individual panels denote individual eels, where the number at the top of the panel corresponds to the specific eel as outlined in Table 5.3.*

Section 6: Atlantic Salmon Movements

Authors: AJF Gibson, EA Halfyard, AM Redden, MJW Stokesbury and JE Broome

6.1 Background

Atlantic salmon, *Salmo salar*, is an anadromous species of fish whose North American range extended from the Hudson River in New York State to the outer Ungava Bay in Québec (COSEWIC 2010). Within Canada, there are 728 rivers in which Atlantic salmon are or were present within the last half century (DFO and MNRF 2008). Populations in these rivers are thought to be relatively discrete because of the high fidelity or homing behaviour to natal rivers exhibited by the species. In a recent review of the conservation status of Atlantic salmon, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identified 16 groups of salmon populations, known as designatable units (DU's), each of which is considered distinct from the other groups (COSEWIC 2010). Three of these DU's have populations occupying rivers that flow into the Bay of Fundy: the inner Bay of Fundy (iBoF) DU, the outer Bay of Fundy DU, and the Southern Upland (SU) DU (Figure 6.1). These three DU's were assessed as "Endangered" by COSEWIC in November 2010. Inner Bay of Fundy Atlantic Salmon is listed as "Endangered" under Schedule 1 of Canada's Species at Risk Act (SARA). Listing decisions for the other two DU's have not been made at the time of the writing of this report.

This section includes information about the presence of Atlantic salmon from these three DU's in the Minas Passage as well as the results of an acoustic tracking study designed to monitor the movement of post-smolts through the passage.

6.1.1 Life Cycle (adapted from Gibson and Bowlby 2013)

Atlantic salmon are anadromous fish, meaning that while they are obligated to reproduce in fresh water, most spend part of their lives in the ocean to feed and grow. They are iteroparous, meaning that they can spawn several times before they die. After spawning for the first time, some individuals may spawn again in consecutive years, while others may spawn in alternate years and others may switch between alternate and consecutive repeat spawning. For populations around the Bay of Fundy, spawning typically occurs in November. After spawning, adults (known as "kelts") may return to the sea or may remain in fresh water until the following spring.

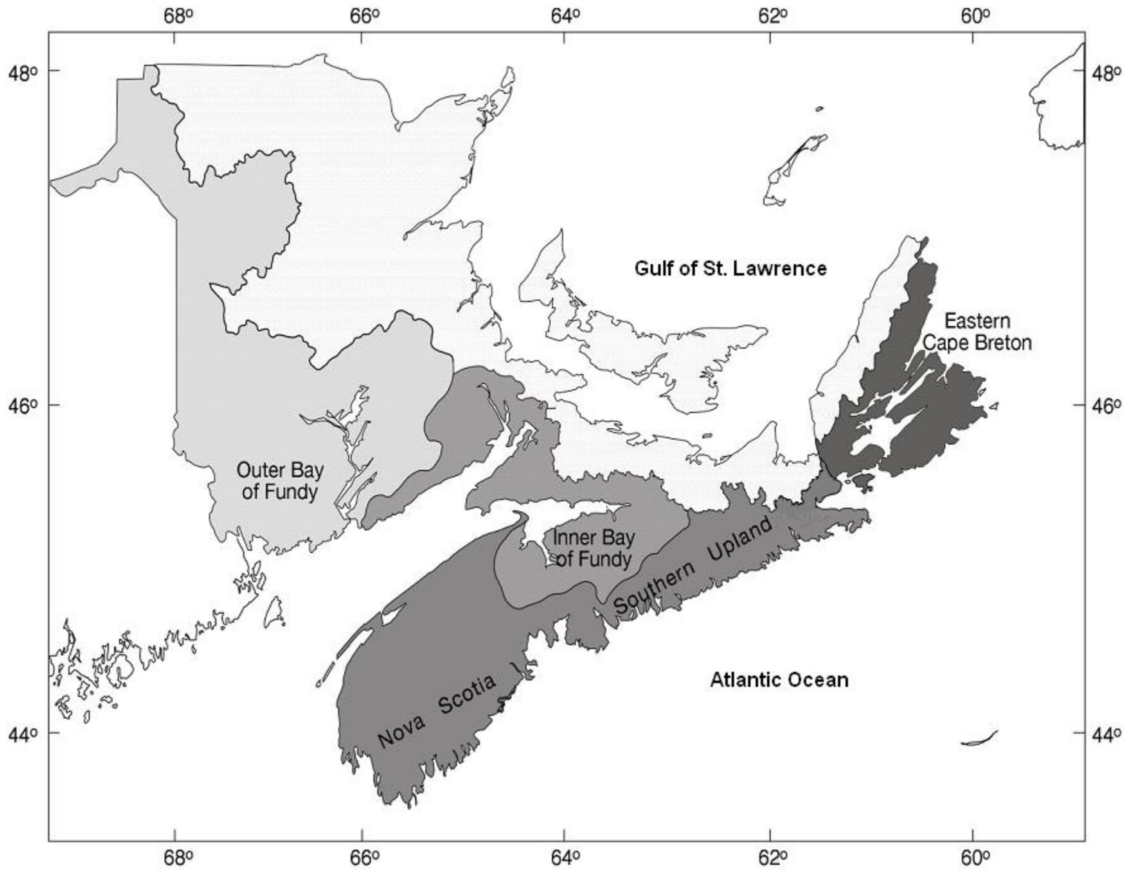

***Figure 6.1**. Map showing the areas in fresh water where Atlantic salmon of the inner Bay of Fundy, outer Bay of Fundy and Southern Upland designatable units are found (from Bowlby et al. 2013).*

Eggs are deposited in nests excavated in the gravel substrate in fresh water. Hatching begins in April and the yolk-sac larvae (known as "alevins") remain in the gravel until May or June. After emergence from the gravel, the young (now called "fry") begin feeding. As they grow, their behaviour changes and they tend to be found in different places in the river. By autumn, they are referred to as "parr". Parr in Bay of Fundy rivers typically remain in fresh water for 2 to 4 years, most leave the rivers at age-2 or age-3. Prior to leaving the river, parr undergo physical changes that allow them to survive in the ocean. These juvenile salmon are now referred to as "smolt" and will migrate to the sea during late April, May and early June. Timing of the smolt run varies somewhat among populations and with environmental conditions. Once salmon reach the marine environment, these immature salmon are referred to as "post-smolts". Within Bay of Fundy populations, salmon mature after either one or two winters at sea (called "one sea-winter salmon" or 1SW, "two sea-winter salmon" or 2SW, respectively), although historically a small proportion also matured after three winters at sea (called "three sea-winter salmon" or 3SW). The proportion of salmon maturing after a given number of winters at sea is highly variable among populations. For example, most iBoF populations have a high proportion of 1SW salmon, whereas outer Bay of Fundy populations have a higher portion of 2SW salmon. Adult run timing is variable. In some populations, the majority of salmon return to the rivers during late spring or early summer whereas, in others the majority may return during the fall.

6.1.2 Utilization of the Minas Passage by Life Stage

There are three stages at which salmon utilize the Minas Passage throughout their lives: as post-smolts, as adults returning to rivers to spawn, and as kelts. In a recent review of important marine habitat for iBoF salmon, DFO (2013 – their Appendix 1) summarized the use of the Minas Basin and Chignecto Bay by post-smolts as a migration route to the Outer Bay of Fundy (May-June) and as a feeding area (June to September); by maturing adults as a migration route to fresh water (May to October); and by kelts as a migration route to the Bay of Fundy for re-conditioning and feeding (winter/spring).

6.1.3 Utilization of the Minas Passage by each Designatable Unit

There are no published studies that directly summarize the utilization of the Minas Passage by either the oBoF or SU Atlantic salmon. Salmon from populations in the Minas Basin must pass through the Minas Passage to reach feeding and rearing areas in the Bay of Fundy and beyond, whereas salmon from populations in Chignecto Bay, the outer Bay of Fundy, and the Southern Upland may or may not move through the Minas Passage while foraging at sea.

The most extensive data set for evaluating use of the Minas Passage comes from historical tagging programs, in which an individual salmon was given a tag (Carlin or Floy tags were typically used) and was subsequently recaptured either by commercial or recreational fishers, or at salmon counting facilities. Tagging programs were carried out in the majority of rivers in the Maritimes throughout the mid-1960s and 1970s, and in a few rivers until 1998 (Ritter 1989). In general, tagging was done on hatchery-produced smolts before they were released in rivers.

When interpreting tagging data, it is important to remember that the number of tag recoveries depends on the distribution of fishing effort (i.e. where and when people are trying to capture fish), the number of tags applied to fish in each population as well as the distribution of fish (i.e. where the fish are at a given time). Because these factors varied from region to region and year to year, the tag returns cannot directly be interpreted as the proportion of each population found in an area, but they do provide a guide to relative importance of a region such as the Minas Basin to salmon from each DU.

Overall, the vast majority of tag returns in the Maritimes Region were from salmon released into the Southern Upland and outer Bay of Fundy regions (Table 6.1). Comparatively few returns were from salmon released into rivers flowing into the Minas Basin or into Chignecto Bay, in part due to the lower number of tagged fish released into those rivers. Of the 5,178 tag returns from salmon released into Southern Upland rivers, only one was from the Minas Basin, suggesting few salmon from this DU utilize the Minas Basin. Similarly, only three of the 11,575 tag returns from salmon released in the outer Bay of Fundy rivers were from the Minas Basin, leading to the conclusion that utilization of the Minas Basin by oBoF salmon is also uncommon. In contrast, about 1% of tag returns from salmon from Chignecto Bay (including Big Salmon River) were from the Minas Basin, suggestive of a higher rate of use of the area by these stocks. Of the tags that were returned from the Minas Basin, 87% were from fish that were tagged in Minas Basin Rivers; 9% of these tags were from salmon released in rivers flowing into Chignecto Bay.

Table 6.1. *Summary of the historical Carlin and Floy tagging data for Atlantic salmon from populations in the three designatable units in the Maritimes Region. The number recaptured is the total number of fish recaptured that were tagged in each region. (i.e. the sum of those inside and outside of the Minas Basin). The percentages are not indicative of the percentages of the designatable unit passing through the Minas Passage because fishing effort varied from region to region.*

Designatable Unit	Region	Number Recaptured	Number recaptured in the Minas Basin	Percent of all captures from each region that are from Minas Basin	Percent of Minas Basin recaptures from each Region
Southern Upland		5158[a]	1[b]	<1%	1%
inner Bay of Fundy	Minas Basin	172[b]	80[b]	46%	87%
inner Bay of Fundy	Chignecto Bay	710[b]	8[b]	1%	9%
outer Bay of Fundy		11,575[c]	3[b]	<1%	3%

[a]Bowlby et al. (2013); [b]DFO unpublished data; [c]ICES (2008)

6.1.4 Status of Inner Bay of Fundy Atlantic Salmon

Wild iBoF salmon have declined to critically low levels and are currently at risk of extinction (DFO 2008). Abundance of adult Atlantic salmon in iBoF rivers has been estimated to be about 40,000 adults earlier in the 20th century; abundance was reduced to as few as 250 adults by 1999, with no evidence that abundance has increased significantly since that time. Population modelling under current conditions indicate a very high probability that, without human intervention, iBoF salmon will be extinct within 10 years (DFO 2008). To date, the primary activity that has been used to prevent the extinction of iBoF salmon has been Live Gene Banking (LGB), a form of captive breeding and rearing designed to minimize the loss of the genetic diversity and support the recovery of salmon populations into iBoF rivers once conditions are suitable for their survival. Salmon populations are extirpated from most, if not all, rivers without some form of captive rearing in place.

6.1.5 Migration of iBoF Atlantic Salmon Post-Smolts in the Minas Passage

A directed study to document the movement and migration of iBoF post-smolts in the Minas Passage was undertaken during the spring of 2011 using acoustic telemetry. Acoustic tags were implanted in Atlantic salmon smolts from the Gaspereau and Stewiacke rivers and these fish were released into their river of origin above the head of tide. Their migration through the Minas Passage was monitored using the acoustic receivers deployed in the passage (see Section 2).

6.2 Methods

6.2.1 Capture and Tagging

The movements and migration of Atlantic salmon smolts was monitored in the Stewiacke River and the Gaspereau River using acoustic telemetry. In the Gaspereau River, smolts were captured in the White Rock bypass facility (a bypass at a hydroelectric installation) while smolts on the Stewiacke River were captured by angling with a single, barbless hook. These smolts were wild-acclimated fish, originally released as hatchery-origin parr or fry 1-3 years prior. Smolts were anaesthetized in 80-100ppm of tricane methane sulphonate (MS222, Syndell Laboratories, Vancouver, BC, Canada), buffered with calcium carbonate to maintain ambient pH. The time to reach stage 4 anaesthesia was dependant on water temperature but was generally 180s-240s. Smolts were then placed ventral-side up in a v-shaped surgery tray where a soft rubber tube, outfitted with a variable flow valve, delivered a maintenance dose (30 ppm) of anaesthetic in well-aerated water. Individually-coded acoustic tags (v9-6L, 3.6g in air, 9mm by 24mm, Amirix/Vemco, Halifax, N.S., Can.) were implanted intraperitoneally in smolts via single incision (approx. 13 to 15 mm in length) located on the linea alba, immediately anterior to the pelvic girdle. Incisions were closed with 3 simple interrupted sutures using 4/0 nylon monofilament sutures and a 2=1=2 knot design (following Tera and Aberg 1976). Prior to surgery, all tools were soaked for 24 hours in a medical disinfectant solution with 2% Gluderaldehyde (BM 28+, Groupe B.M. Inc., Montreal, PQ, Can.) and during surgery, 3 complete sets of tools were rotated with cold disinfection between usages. Prior to release, post-surgery smolts were allowed a brief period (approx. 1 hour) to recover from the effect of anesthesia. A total of 62 smolts, ranging from 138 to 210mm fork length (FL), were tagged between mid-May and early June (Table 6.2). The ratio of transmitter weight (2.9g in air) to smolt weight in air averaged 6.8% (sd=3.0%, max. 14.4%).

Table 6.2. *Summary of acoustic telemetry tag information and in-river receiver deployments.*

River	Year	Release	Release Date	Number Released	Tag Model	Mean FL ± sd (mm)	Receivers Deployed
Gaspereau	2011	1	11-May	15	V9P-6L	189 ± 10	7
Gaspereau	2011	2	17-May	20	V9-6L	193 ± 8	7
Stewiacke	2011	1	25-May	12	V9-6L	147 ± 6	8
Stewiacke	2011	2	27-May	15	V9-6L	150 ± 8	8

6.2.2 Telemetry

Acoustic receivers (Vemco VR2 and VR2W) were moored at various locations in the river and estuarine portions of each river (Figure 6.2), in addition to the Minas Passage (see Section 2, Figures 2.6 and 2.7). River and estuary receivers were bottom-moored and fastened to a riser rope ~2m above an anchor and ~1m below a trawl float. Anchors were outfitted with a weighted drag line to aid in recovery. The detection efficiency of these receivers were unknown, however receivers were deployed with the intention that they provided acoustic ‘gates’, past which tagged fish were unlikely to migrate without being detected.

6.2.3 Analysis

Atlantic salmon in the Minas Passage may move in either direction (i.e. seaward or landward), may be detected on one, two or all three arrays of receivers (i.e. the OTN-MPS line, the Acadia University line or the FORCE array) and may be detected on several distinct occasions separated by extended periods of time (i.e. days). Thus, in an effort to provide a meaningful description of salmon movement and patterns in tag detections, the data are described in two general manners; 1) all raw detections, or 2) summary ‘migration events’, where each migration event consists of a sequence of detections within the Minas Passage (any combination of receivers), where any two consecutive detections are separated by no more than 30 minutes. For example, a tag may be detected 30 times over 45 minutes (average of one per 1.5 minutes) and then not detected again until 3 hours later, when five more detections occurred across eight minutes. Thus, there would be two migration events for this salmon, one spanning 45 minutes and a second spanning eight minutes. A single migration event may span several receivers.

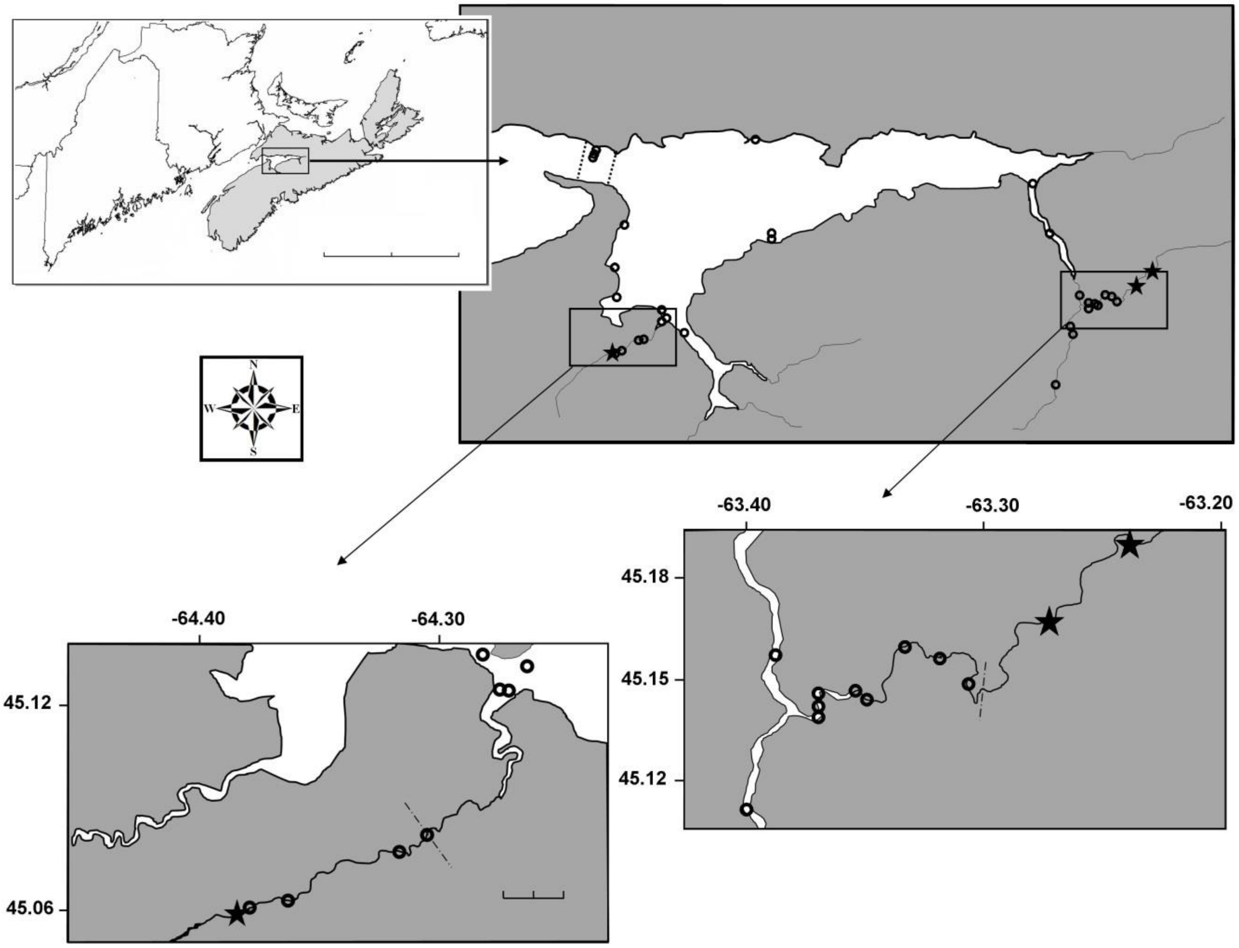

Figure 6.2*. Map of the inner Bay of Fundy, the Stewiacke River estuary and the Gaspereau River estuary in Nova Scotia, Canada. Open circles represent the approximate location of acoustic receivers, and stars represent the approximate location of release sites. The dashed lines in the Minas Passage indicate the approximate position of Minas Passage receiver arrays.*

To examine diel detection patterns, Rayleigh's uniformity test (Moore et al. 1998) implemented in the 'CircStats' package for R, which assesses the significance of a mean resulting vector ($\bar{r}$) was used. To examine the influence of tidal stage and current velocity on patterns of salmon detections, tide and current data were used, as described in Section 2.

6.3 Results

In total, 62 Atlantic salmon smolts were released into the Stewiacke and Gaspereau Rivers in May of 2011. Releases occurred on two dates in each river (Table 6.2); releases were later in the Stewiacke River because smolts in this river migrate later in the spring than those in the Gaspereau River. V9P-6L tags, which include a pressure sensor, were used during the first release in the Gaspereau River, but these tags were large enough that, based on visual observation, swimming performance of the smolts was impaired. The smaller V9-6L tags, which do not have a pressure sensor, were used in subsequent tag deployments.

Only 20 (33%) tagged smolt were available for assessment of migration corridors near the Minas Passage as tag loss (i.e. predation, natural mortality or tag failure) was high in the rivers and estuaries, and only these 20 salmon (12 from the Gaspereau and 8 from the Stewiacke) were detected exiting their natal river and entering the Minas Basin (Table 6.3). Once in the Minas Basin, 45% of the post-smolts (n = 9) were subsequently detected on at least one receiver in the Minas Passage. None of the smolts from the first release in the Gaspereau River were detected in the Minas Passage, possibly due to the effects of the larger tag on swimming performance and subsequent survival.

Atlantic salmon post-smolts were detected in the Minas Passage between May 23rd and June 12th 2011 (mean ± s.d. = May 28th ± 6.1 days, Figure. 6.3). Considering individual release times, salmon were first detected in the Minas Passage on average 8.2 day post-release (2.2 days, range = 5.7 to 11.7 days). Because salmon required some time to navigate the river and estuary, detection in the Minas Passage occurred on average 5.0 days after exiting their respective estuaries (range = 1.6 to 7.2 days). Salmon were detected on some other receivers deployed along the shore of the Minas Basin and, consequently, it is not anticipated that post-smolts travel in a straight line from their estuaries to the Minas Passage. Therefore, it is not useful to calculate straight-line distance travelled or average velocity estimates.

Table 6.3. *Summary of 2011 tag detections for each of the two study rivers. The mouths of river was defined as Maitland (Stewiacke) and Boot Island (Gaspereau). MPS= Minas Passage Line (Ocean Tracking Network); AUL = Acadia University Line; FORCE = Fundy Ocean Research Centre for Energy.*

River	Year	Release	Number Released	Proportion Detected at Mouth of River	Number Detected in Minas Passage (MPS)	Number Detected in Minas Passage (AUL)	Number Detected in Minas Passage (FORCE)	Total Unique Salmon Detected in Minas Passage
Gaspereau	2011	1	15	3 / 15	0	0	0	0
Gaspereau	2011	2	20	9 / 20	5	7	4	7
Stewiacke	2011	1	12	2 / 12	1	1	1	1
Stewiacke	2011	2	15	6 / 15	1	1	0	1

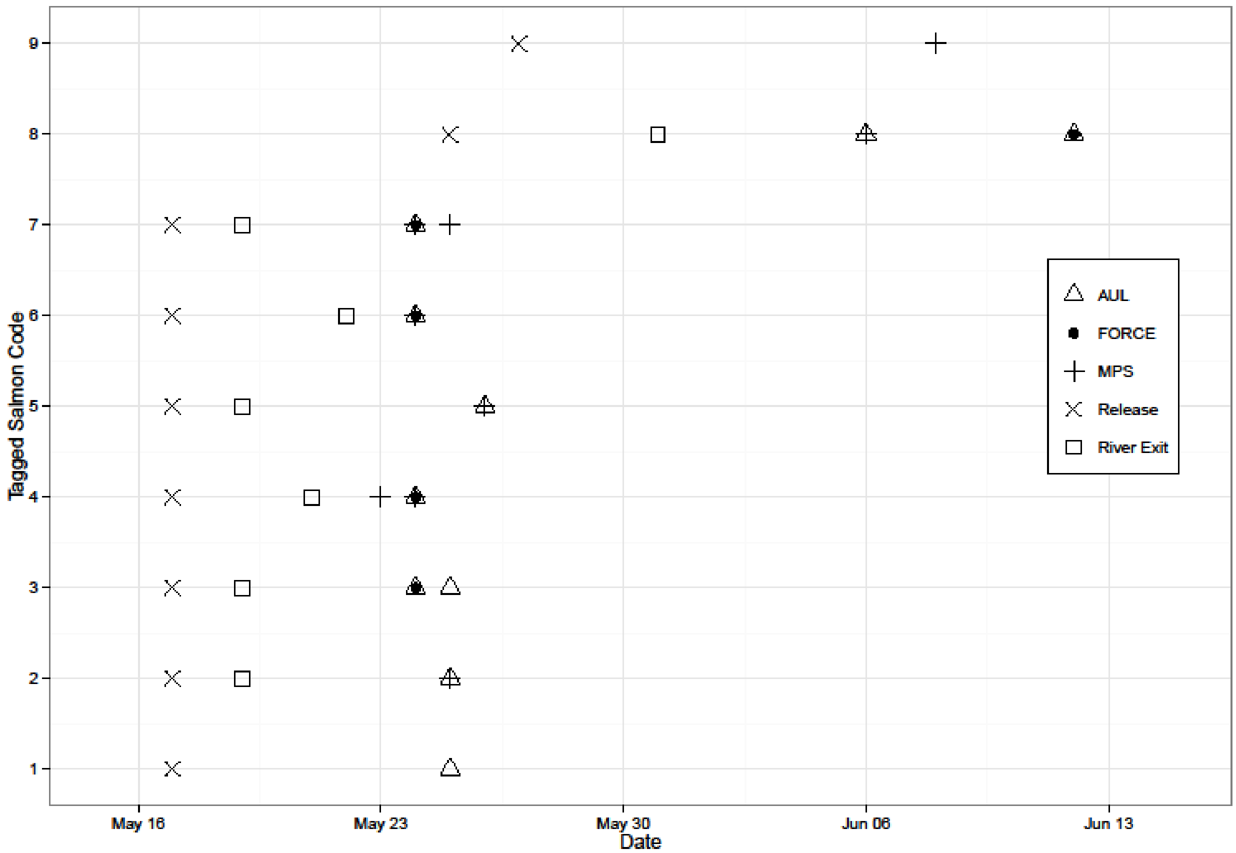

Figure 6.3. *Detections of individual salmon smolts/ post-smolts, at each migration milestone (i.e. release or river exit) or receiver array, within the Minas Passage. Note that salmon 5, 7 & 8 showed evidence of both seaward and landward movement through the Minas Passage. Salmon generally traversed the Minas Passage rapidly and all migrations were in the direction of the current. Salmon travelled at an average ground speed of 2.01 m/s (sd= 1.06 m/s, n=15). Relative to current velocity, salmon travelled an average of 1.05 m/s faster than ambient velocity (sd= 0.80 m/s). Not all salmon movement was unidirectional, and 3 of 9 salmon were detected migrating in both the seaward and landward direction (Figure 6.3). Salmon post-smolts were detected throughout the diel cycle (Figure 6.4), however there was some evidence that detections were more frequent between sunset and sunrise (mean cluster timing, Rayleigh's Test,* $\bar{r}$ *=0.34, p=0.02).*

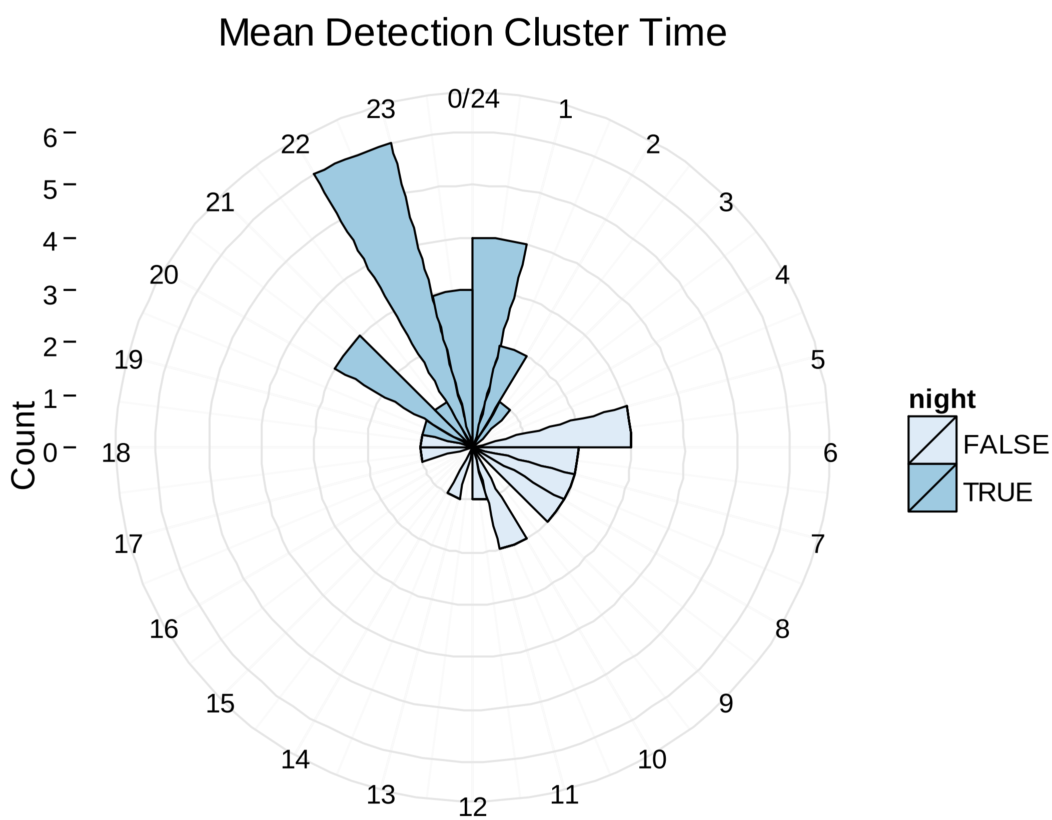

***Figure 6.4**. Circular plot of Atlantic salmon post-smolt detection times across all Minas Passage receivers. The circular histogram represents the hourly frequency of the average time per cluster of detections (all consecutive detections with < 30mins separation between any two detections), per individual. Detections occurring between sunset and sunrise (i.e. night) are shown in dark grey, daytime detections shown in light grey.*

The mean duration of detections for each migration event (Figure 6.5) was 9.0 minutes (sd= 13.0 minutes, n=36, max = 50.1 minutes). Results were similar at the FORCE site where salmon migration events spanned an average of 7.51 minutes (sd= 9.07 minutes, n=6) and consisted of between 1 and 34 detections while within range of FORCE receivers.

There was no obvious pattern to the spatial distribution of tag detections in the Minas Passage as salmon were largely spread across both the Ocean Tracking Network Minas Passage Line (MPS) and Acadia University Line (AUL) of receivers (Figure 6.6). Of the nine salmon detected traversing the receiver arrays, seven did so in a unidirectional (seaward) direction, however two salmon were detected also moving in a landward direction.

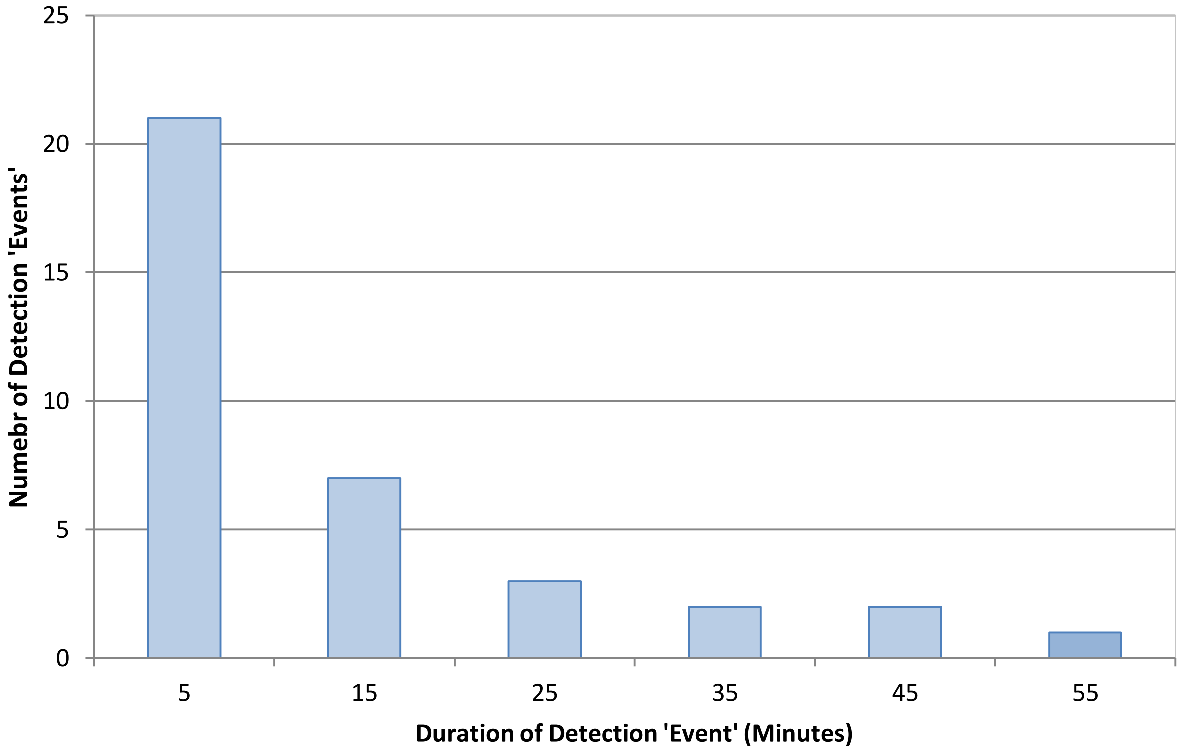

Figure 6.5. *Histogram of the duration of consecutive detections (detection clusters or events). For example, there were 22 detection events that lasted between 0 and 10 minutes. Detection events frequently spanned multiple receivers or more than one receiver array.*

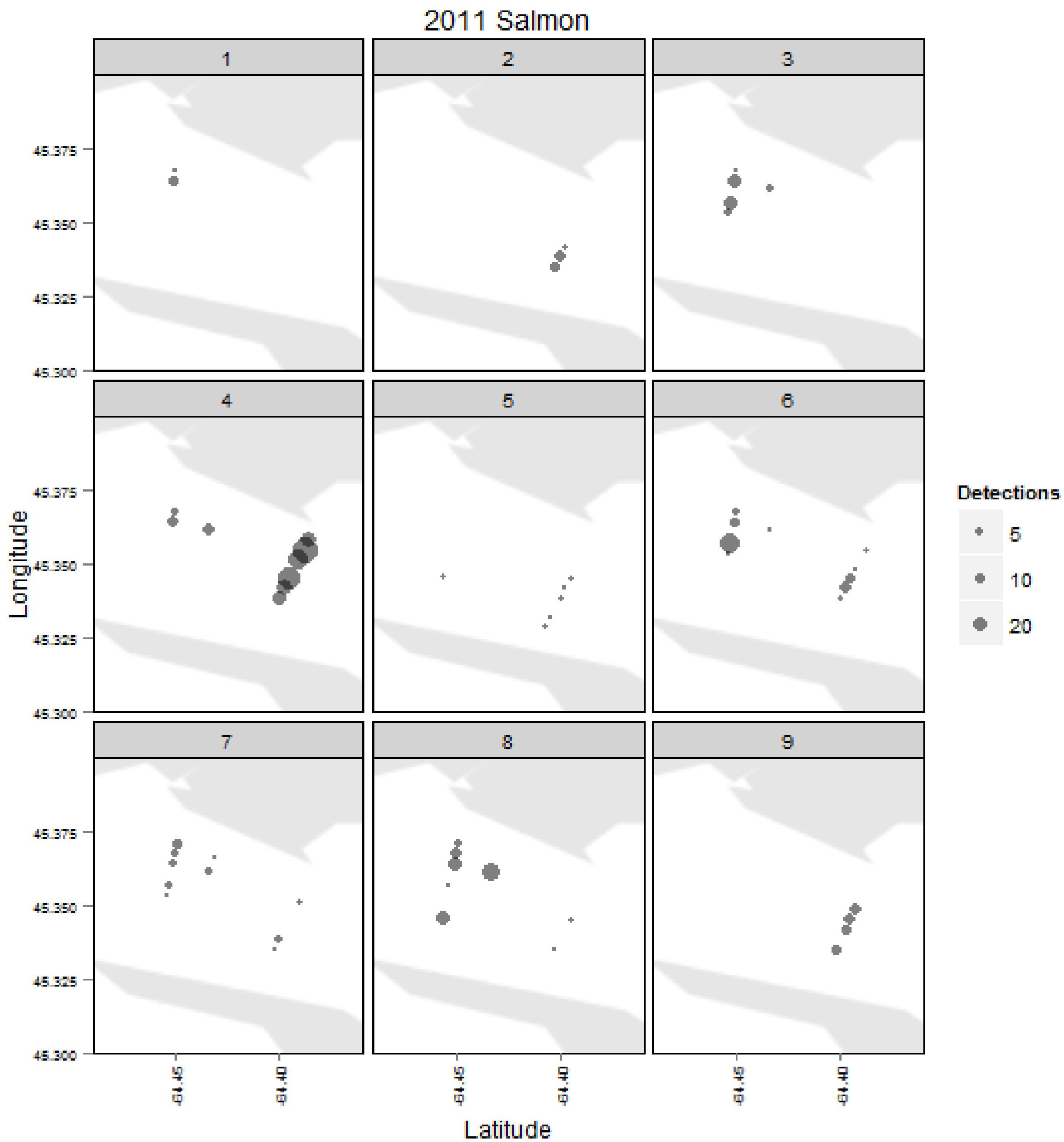

Figure 6.6*. Density plot of raw detections (i.e. all detections) on the three arrays of receivers in the Minas Passage. Each panel represents an individual salmon smolt.*

6.4 Discussion

This study provides evidence of the approximate timing and spatial extent of Atlantic salmon migration within the Minas Passage. However, given the low number of salmon detected in this area (n=9), caution should be exercised when interpreting the temporal or spatial distribution of salmon. The approximately three week window when detections occurred may approximate the timing of most salmon post-smolt migration through this area and are consistent with the timing reported in DFO (2013). It is possible that some salmon remained alive within the Minas Basin and did not emigrate from the Minas Basin, however this life history strategy has not been documented. Additionally, the Minas Passage receivers and an additional 9 others remained deployed in the Minas Basin throughout the summer and fall of 2011. None of these receivers provided additional detections after early June, suggesting that few smolts were present in the Minas Basin.

Salmon appear to migrate through the passage during the low-velocity periods associated with slack tide. However, it is important to consider the effect of acoustic gear performance as detection efficiency is expected to be low during the noisy environment of high water velocities (e.g. Simpfendorfer et al. 2008, Melnychuk and Christensen 2009). Sentinel range testing at the OTN-array (MPS) within the Minas Passage suggests that daily detection efficiency is generally low (<40%), although this encompasses relatively high efficiency during slack tide periods and relatively low efficiency during high velocity ebb or flood tide periods (E.A. Halfyard, unpublished data). For these reasons, migration during high-velocity time periods cannot be discounted.

A consideration for risk assessment of the proposed tidal energy installation is the duration of occupancy of the area; specifically the number of times individual salmon migrate through the area and the rate at which migration occurs. The results of this study provided evidence of bi-directional migration indicative that at least some salmon may traverse the passage several times rather than use the area as a simple thoroughfare; and that some post-smolts may reside within the detection range of the acoustic receivers for extended periods of time.

An average migration rate of 1.05 m/s (relative to ambient current velocity) while moving through the Minas Passage was estimated during this study. This far exceeds the results of other studies (e.g. Hedger et al. 2008, Davidsen et al. 2009, Halfyard et al. 2012). A potential explanation may be that this behaviour represents a period of high energy-output swimming as salmon attempt to traverse this dynamic environment as rapidly as possible. Alternatively, the ambient current velocities used in the analyses, which are averaged across depths, may not accurately reflect the velocities at the actual depths that the salmon are swimming.

This study does not provide information regarding depth selection by salmon smolts in the Minas Passage. Atlantic salmon post-smolts are thought to occupy the near-surface waters, and both telemetry studies (LaBar et al. 1978, Moore et al., 1998, Davidsen et al. 2008) and fishing gear (Dutil and Coutu 1988, Holm et al. 2000, Holst et al. 2000; Holm et al. 2003,) suggest that salmon generally occupy the upper 5m of the water column. In the Bay of Fundy (Lacroix and Knox 2005) and nearby Gulf of Maine (Sheehan et al. 2011), Atlantic salmon post-smolts have been captured in surface trawl surveys. However, there is also evidence that salmon post-smolts dive to greater depths, with some preference for slightly deeper water during the day (LaBar et al. 1978, Reddin et al., 2006, Davidsen et al. 2008). The swimming depth of salmon in a high velocity, highly turbulent environment is unknown.

Poor detection efficiency during periods of high current velocity may account for the lack of detections at velocities greater than approx. 2.5 m/s. Accordingly, salmon may use the Minas Passage during mid-tidal stage when current velocity is high, but are not detected. Likewise, if current velocity though the Minas Passage is dynamic, the spatial distribution of salmon detections may reflect detection efficiency in addition to salmon distribution.

The issue of tag expulsion (loss of tags through failed closure of sutures, *via* trans-coelom migration or *via* trans-intestinal migration) was not considered a significant issue in this study because the duration of tracking was generally less than the reported onset of significant tag expulsion (Chisholm & Hubert, 1985; Welch *et al.,* 2007; Chittenden *et al.,* 2009; Brown *et al.,* 2010). As such, the results presented here should be considered reliable estimates of tag availability, with mortality estimated confounded only by the issue of detection efficiency and predation-related losses (i.e. tagged smolt inside a predator's gastrointestinal tract).

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Section 7: Conclusions & Recommendations

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7.1 General Comments

This multi-species fish tracking project represents the first large scale, near year-round, acoustic tracking study of electronically tagged fish moving between receiver arrays ("listening gates") within a high flow tidal race. It extends the 2010-2011 pilot tracking study of Atlantic sturgeon, striped bass and American eel (Stokesbury et al, 2012), and collectively provides multi-year baseline information on fish movements of key species in Minas Passage. The study also includes results of the movements of inner Bay of Fundy Atlantic salmon (smolts), a population listed as endangered under the Species at Risk Act (SARA).

Other novel aspects of the study include further advancements in instrument mooring design (using SUBS streamlined instrument buoys) to increase mooring longevity and stability on the seafloor. During this project, equipment and materials were tested and designs improved, resulting in a very durable, high flow mooring system that is now in use for global OTN deployments in other high flow areas (e.g. the Strait of Gibraltar, Spain and Morocco; the Bass Straits, Australia). Overall instrument recovery in Minas Passage has been very high (97%) relative to other studies that have deployed moored acoustic instruments (passive and active) in and near the FORCE test site.

At the time of project commencement, it was anticipated that at least one turbine would be installed at FORCE in 2012, thus providing an opportunity to examine fish movements before and after tidal turbine deployments. Due to delays in turbine installations, the project aims were modified to focus solely on the natural use of the Minas Passage by those fish species tagged. Our tracking dataset extends from 2010 to 2013 and provides strong baseline information that will help define future environmental studies (monitoring and research), including passive and active acoustic detection of fish at and near FORCE. The data presented here will also be useful in post-turbine installation impact assessments.

Tracking methodologies employed in this study and results for all four species examined are described in detail in prior sections of this report. In this section, we highlight some the main findings for each of the fish species tagged and tracked, identify limitations and knowledge gaps, discuss potential risks of fish interactions with turbines at FORCE, and provide recommendations to FORCE, including suggestions for future monitoring and research.

7.2 Fish Use of Minas Passage

7.2.1 Atlantic sturgeon

Atlantic sturgeon sub-adults (N=114, 100-190 cm) were captured and tagged in Minas Basin and detected in Minas Passage (including FORCE) sporadically throughout the summer prior to their fall migration to the outer Bay of Fundy. There were no sturgeon detections in the passage during late November to May (i.e. present for 6 months of the year). In late spring, Atlantic sturgeon returned, traversing Minas Passage *en route* to Minas Basin, an important summer feeding area. Tagged sturgeon were detected on all receivers in the passage but were more frequently detected in the southern half of Minas Passage.

Due to their bottom feeding nature, it was expected that Atlantic sturgeon would be associated with the benthos while moving through Minas Passage. Interestingly, there was no significant relationship shown between bottom depth and swimming depth. Sturgeon displayed pelagic movement in the deeper areas of the passage and showed a preference for depths of 20 to 40 m over the entire eastern side of Minas Passage. At the FORCE site, sturgeon travel depths of 15 to 40 m were detected, with sturgeon located higher in the water column at night (15 to 25 m) than during the day. As the available detection dataset is biased toward detections during slow to moderate current speeds, travel depths during very high current speeds are unknown.

The fastest tide-assisted travel rate calculated from consecutive detections of tagged Atlantic sturgeon in Minas Passage, over a distance between receiver lines of approximately five km, was 2.9 body lengths per second (about 3.2 m/s). It is probable that Atlantic sturgeon move regularly with the tides and travel at faster speeds in Minas Passage than they would be accustomed to in the absence of strong tidal currents.

7.2.2 Striped bass

Striped bass spawn in the Stewiacke River and are commonly fished (recreationally) in the Shubenacadie/Stewiacke system in spring and Minas Basin during summer. Striped bass from American stocks also utilize the Minas Basin for summer feeding. Movements of tagged striped bass in the Minas Passage and FORCE test site were detected near year-round, including winter, but with much variation in movement among individuals. Striped bass tagged in May (Stewiacke River) and during the summer months (Southern Bight of the Minas Basin) appeared in the passage from June onwards. Of the 165 tagged striped bass, 52 were detected travelling through the FORCE tidal turbine test site. Large striped bass (>60 cm) were generally more active in the Minas Passage, and were detected in and near the FORCE test site more often than smaller striped bass. Bi-directional movements of individual striped bass within Minas Passage were detected over both short (within 1 day) and long (several months) periods of time.

Most tag detections of striped bass indicate their presence in the top 40 m of the water column, with movements closer to the surface during the night (i.e. diel migration). The maximum estimated travel rate (tide assisted) across the Minas Passage (between receiver lines) was 3.9 m/s. Unexpectedly, many tagged striped bass (about 35% of winter active tags) moved within Minas Passage during the winter months when the sea surface water temperatures are 0-3°C. At these temperatures, striped bass are expected to be sluggish (i.e. reduced metabolic rate) and thus may have limited abilities to sense and avoid turbine infrastructure, especially during high flow periods. Modelling of the probability of collision, based on environmental conditions (e.g. flow speed, water temperature) and available detection datasets, will be an important next step in predicting striped bass risk of interaction with turbines at FORCE.

7.2.3 American eel (silver stage)

During mid-September to mid-November, 21 of the 45 tagged silver stage eels (47%) were detected within Minas Passage. Of these, 8 were detected within the FORCE test site but only for short periods (1-6 days) as they out-migrated to the Bay of Fundy and beyond. Maximum estimated travel speed, between receiver lines, was 3 m/s.

American eels utilized all areas of the Minas Passage, and while there was no specific out-migration route, they were detected more often in the middle to southern part of the passage. Depths of transit through Minas Passage ranged from the surface to 110 m and were highly variable among and within individuals. Most movements occurred in October on night-time ebb tides. At FORCE, about 90% of silver stage eel detections occurred during ebb flow periods, with movements largely in the top 30 m of the water column. It is unknown if eels can detect and avoid large in-stream tidal turbines. An additional concern, but outside the scope of this project, is the potential risk to in-migrating glass eels (early juvenile stage).

7.2.4 Atlantic salmon (smolts)

Of the 62 tagged Atlantic salmon smolts released into the Stewiacke and Gaspereau Rivers in May of 2011, 20 were detected at the river mouths; of these, nine (45%) were detected on at least one receiver in the Minas Passage, on average 5 days after exiting the river. Five smolts were detected by receivers at the FORCE site, where migration detection events were on average 7.5 minutes long.

While most smolts appeared to move in a uni-directional path through Minas Passage, two showed bi-directional movements, indicative that at least some salmon traverse the passage several times prior to exiting to the outer Bay. No specific migratory path through Minas Passage was evident as smolts were detected at most receiver stations. Smolts travelled an average of 1 m/s faster than depth-averaged current speed and were more frequently detected in the Minas Passage at night. Given the low number of salmon smolts detected in the Minas Passage, temporal and spatial distribution patterns should be interpreted with circumspection.

Travel depths of salmon smolts in Minas Passage (and other high flow environments) are unknown but other telemetry studies and fish catch data suggest that salmon smolts generally occupy the upper 5 m of the water column (see Section 6.5 for references).

7.3 Limitations and Identified Knowledge Gaps

As flow speed increases, the efficiency of the Vemco VR2W-69 kHz receiver in detecting Vemco acoustic tag transmissions decreases. Our dataset includes low numbers of tag detections at times when depth-averaged current speed exceeds 1.5 m/s (about 50% of the time in Minas Passage). At times of higher current speed, tagged fish may be in close proximity to receivers but tag transmissions not logged. This can result in tagged fish passing undetected through Minas Passage. Why does this happen? The ambient noise associated with high flows and moving bedload (largely gravel and cobble) interferes with the detection of complete tag transmissions (8-10 consecutive pings separated by unique spacing intervals). If the receiver does not detect a complete ping sequence, then the transmission is not recorded. Because receiver detection efficiency is reduced during high flow periods, the dataset on movements and travel depths of fish includes only low to moderate flow speeds. Whether or not fish avoid extreme flows and travel deeper in the water column when current speed is high remains unknown.

The animal tracking technology used in this study is useful for examining temporal and spatial patterns in the movement of tagged fish but cannot be used to address behaviour (e.g. avoidance) of fish in close proximity to marine structures like turbines. That would require the use of near-field sensors such as multibeam sonars and acoustic cameras, which may also have detection limitations during peak flows.

Laboratory/flume tank tests have been used elsewhere to examine behavioral responses of fish to small turbines at flows of up to 1.5 m/s but we do not consider the results of these tests to be comparable to the field conditions in Minas Passage where maximum surface water current speed is known to be 6 m/s (see section 2).

Over the course of our project, fish tagged in other studies were detected by receivers in Minas Passage. These species include striped bass, Atlantic salmon, Atlantic sturgeon, white shark and spiny dogfish. Of particular interest are white sharks. The white shark is a listed endangered species under the Species at Risk Act (SARA). In a tagging program initiated off the coast of Massachusetts (USA), 28 white sharks were tagged with electronic tags (as of Sept 2013). Of these 28 fish, 3 (11%) passed through the Minas Passage, including the FORCE site. As with all other species, tagged fish represent only a small portion of the animals in a population. Given that >10% of the tagged endangered white sharks moved through Minas Passage, it is highly likely that large numbers of non-tagged white sharks also use this area.

Our dataset includes four fish species of concern. There are many other species which are common in the region but for which movement data is lacking. These include species of commercial value, such as Atlantic herring, schooling fish that are present in large numbers, and captured in intertidal herring weirs in both the Minas Passage and Minas Basin (Figure 7.1). Other clupeids found in high abundance and potentially at risk are American shad, alewife and blueback herring. Duration of occupancy in Minas Passage is unknown for these migratory species.

Figure 7.1*. Atlantic herring catch in an intertidal weir in Bramber, Minas Basin. Source: Darren Porter.*

7.4 Risk of Fish-Turbine Interactions

Factors contributing to risk of fish interaction with a tidal turbine at high flow speeds include: duration and timing of occupancy at turbine development sites, fish size, swimming depth (and diel trends), physiological status, and ability to detect and avoid infrastructure under a range of flow and temperature conditions. Swimming depths of all four species overlap with the expected range of tidal turbine hub heights at FORCE. Of the four species examined, two (American eel and Atlantic salmon) showed relatively low likelihood of collision with turbines at FORCE based on very short residency times of salmon smolts and silver stage eels in Minas Passage, which serves broadly as an out-migration corridor. Atlantic sturgeon are present in the Minas Basin for half the year and move throughout the Minas Passage, but mostly in the middle to southern end. Adult striped bass appear frequently in Minas Passage (numerous multi-directional movements) during most of the year, with a marked presence in winter, making this species perhaps the most vulnerable of the four species examined. Further analysis of the data will include the creation of a probability model of the collision risk for striped bass (and possibly other species).

Although risk of fish-turbine interaction is low with single devices, it is expected to increase as the number of turbines in a tidal race increases. To date, there have been very few in-stream turbines installed across the globe and no evidence of fish collisions. In contrast to some tidal development sites, Minas Passage is a very large tidal race (5 km wide). One commercial size turbine (1 MW, 100m^2) is estimated to occupy only about 0.02% of the cross-sectional area of the passage. Detection of collision events with a small number of turbines, if they happen, is likely to be difficult, given the effects of high flows on the performance of hydroacoustic sensors normally used to observe fish behaviour around marine structures. Further work on developing sensors to detect fish in high flow environments, especially in close proximity to turbines (within meters) is needed to assess environmental impacts on fish populations of commercial and conservation concern.

7.5 Recommendations

Based on the results of this project and learnings from sensor technology applications at FORCE and other tidal energy sites, we recommend the following considerations and activities:

1. Couple various monitoring approaches, including the FORCE FAST platform, sensors in autonomous landers and SUBS buoys, and possibly fish weir surveys, to monitor the movements of commercial species (schooling herring and other susceptible species) and species of "conservation concern", as designated by COSEWIC and/or listed under SARA.
2. Use multiple sensor technologies to examine fish behaviour (e.g. avoidance) within close proximity of installed turbines (e.g. via multibeam sonar and/or acoustic cameras) at FORCE. Real-time observations from cabled sensors are preferred.
3. Use available fish detection datasets and associated environmental data (e.g. current speed and water temperature) to model collision probabilities for fish species of interest.
4. Include periods of high fish traffic through Minas Passage when designing an environmental effects monitoring program (EEMP).
5. Following turbine installations at FORCE, monitor coastlines and fish weirs for evidence of fish-turbine interactions; provide a call-in number to report fish kills or evidence of blade strikes.
6. Engage regulators and tidal energy device and project developers in discussions on fish monitoring for detection of fish-turbine interactions and potential mitigation options if collisions are detected.