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Winter presence and temperature-related diel vertical migration of Striped Bass (*Morone saxatilis*) in an extreme high flow passage in the inner Bay of Fundy

1 Freya M. Keyser, Jeremy E. Broome, Rodney G. Bradford, Brian Sanderson and Anna M. Redden
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3 F. M. Keyser, J. E. Broome, B. Sanderson and A. M. Redden. Acadia Centre for Estuarine Research,
4 Acadia University, Wolfville, NS, B4P 2R6, Canada.
5 R. G. Bradford. Fisheries and Oceans Canada, 1 Challenger Drive, Dartmouth, NS, B2Y 4A2, Canada.
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Abstract

During a multi-year fish tracking study, sub-adult and adult life stages of Shubenacadie River Striped Bass (*Morone saxatilis*) were detected throughout winter in the well-mixed, hypertidal waters of the Minas Passage, Bay of Fundy. Thirty-five percent of the Striped Bass tagged with Vemco V16 transmitters were detected by two Minas Passage receiver arrays. Transmissions were received on 82% of winter days (December to April) and by all receivers spanning the width of the passage. Tagged Striped Bass were detected largely within the top 20-40 m during the day. The extent of vertical migration to shallower waters at night showed a strong relationship with water temperature, however, there was no diel vertical movement pattern observed at water temperatures $<1^{\circ}\text{C}$. Our results demonstrate overwintering of a portion of the Shubenacadie River Striped Bass population in high flow inner Bay of Fundy waters, which extends the northern limit of this species' winter marine range. This study is also the first to describe the relationship between daily vertical migration by Striped Bass and low water temperatures. Both findings suggest an elevated potential risk of interaction with an in-stream tidal turbine facility in Minas Passage.

Introduction

Over the last forty years, the number of Bay of Fundy rivers known to serve as spawning areas for Striped Bass, *Morone saxatilis* (Walbaum, 1792), has declined from three to one, with the remaining spawning habitat being the Shubenacadie River (Fig 1) (Bradford et al. 2015). The apparent lack of spawning in both the Saint John River (New Brunswick) and the Annapolis River (Nova Scotia) since the 1970s and 80s lead to the current COSEWIC “endangered” status for the Bay of Fundy designatable unit of Striped Bass (COSEWIC 2012). Regardless, Striped Bass originating from the Shubenacadie River are considered to be abundant, with a prior population estimate for sub-adults and adults in the tens of thousands (Douglas et al. 2003; DFO 2014).

The Shubenacadie River Striped Bass population is one of the most northerly spawning populations of the species and is genetically discrete (Wirgin et al. 1995; Bradford et al. 2015). This population exhibits several attributes that are considered to be characteristic of northerly populations, including use of freshwater environments for overwintering and relatively limited migration ranges when compared to populations that originate further to the south (Rulifson et al. 2008). Adaptations to local environmental conditions include wide thermal and salinity tolerances (Cook et al. 2006; Cook et al. 2010), and eggs of large diameter and low specific gravity (Rulifson and Tull 1999; Bergey et al. 2003). Adult Striped Bass, of US origin, have been observed to tolerate temperatures as low as 0°C (Tagatz 1961; Clark 1968), and sub-adult and adult Striped Bass (40-70 cm fork length) have been found in fresh-brackish waters of the Kouchibouguac and St. Louis rivers, New Brunswick, at temperatures as low as -0.5°C (Bradford et al. 1998).

While it is known that Striped Bass from the Hudson River and Chesapeake Bay stocks in the US overwinter extensively in coastal marine waters (Wingate and Secor 2008; Waldman et al. 2012), the same has not been reported for Canadian populations of Striped Bass. However, marine overwintering of a portion of the Shubenacadie-Stewiacke population has been suggested by Paramore and Rulifson (2001) and Gemperline et al. (2002) based on phenotypic differences among spawning adults, diversity of lipid profiles, and otolith elemental chemistry data that are not consistent with protracted winter residence in freshwater.

Acoustic tracking studies of sub-adult and adult Striped Bass tagged in the Minas Basin and the Stewiacke River, a tributary of the Shubenacadie River, have demonstrated extensive use of the Minas Basin and Minas Passage during the spring, summer, and autumn months (Broome 2014; Keyser 2015). The Minas Passage (Fig 1) connects the Minas Basin to the Bay of Fundy and serves as a migratory corridor for numerous mobile aquatic species, including Striped Bass (Dadswell et al. 1986; DFO 2012; DFO 2013; DFO 2014). The Minas Passage is also the location of a recently completed tidal energy demonstration facility (Fundy Ocean Research Center for Energy) where large, commercial-scale, in-stream turbine technologies will be tested in 2016 and beyond. The risk of Striped Bass interaction with operational in-stream tidal turbines that will be installed at FORCE is unknown, but may be enhanced when flow conditions exceed critical swimming speed and/or during periods of cold temperature (i.e. winter) when metabolic activity level is likely to be reduced (Keyser 2015). Encounter probability and collision risk will also depend on whether the areas and water column depths used by Striped Bass are occupied by installed tidal turbines.

During a large, multi-year acoustic telemetry project (2011-2013), conducted to describe the Minas Passage movements of Striped Bass (Redden et al. 2014), we identified a previously unknown marine overwintering area. This paper focuses on the winter detections of sub-adult and adult Striped Bass. Our study objectives were to determine the wintertime temporal and spatial (including depth) distribution of Striped Bass in the Minas Passage, in relation to the location of the FORCE turbine test site and water temperatures during the December to April period.

Materials and Methods

Site description

The Bay of Fundy is a highly dynamic hyper-tidal system, with a 12.4 h tidal periodicity and the highest known tides in the world (>16m in the Minas Basin). Current speed in the Minas Passage, a high flow, 5 – 6 km wide constriction between Minas Basin and Minas Channel (Fig 1), can approach 6 m/s (Karsten et al. 2008). Tidal range in Minas Passage varies from 6.5 m (neap tide) to 13 m (spring tide), with estimates of tidal excursion (for a uniform cross-section) ranging from 25-50 km over the neap-spring tidal

cycle (Brian Sanderson, unpublished data). Bathymetry is variable in the passage and maximum depth is 170 m (Garrett 1972).

The water column in the Minas Passage is well-mixed with regard to suspended sediment, temperature, and salinity, which is typically 30 ppt, but slightly higher and more stable during the winter due to reduced freshwater runoff (Greenberg 1984). During late winter, mobile surface ice is commonly observed moving through the passage on the outgoing and incoming tides (Parker et al. 2007). This ice is largely generated in the creeks and on the shores of the Minas Basin where it becomes sediment-laden yet remains buoyant (Sanderson and Redden 2015).

Sea surface temperatures (SST) are generally below 6°C from mid-December to mid-May, and can drop to as low as -1.5°C during February and March (NOAA/OAR/ESRL PSD High Resolution SST data website, <http://www.esrl.noaa.gov/psd/>). Temperature sensors deployed on the seafloor of the FORCE test site in Minas Passage during the winter of 2014-2015 recorded a similar temperature range: 6.5°C in December to -1.5°C in March (Ocean Networks Canada Data Archive 2015, www.oceannetworks.ca).

Field and Laboratory Methods

Vemco acoustic telemetry was used to track the movements of sub-adult and adult Striped Bass in the Minas Passage from June 2012 to April 2013. As this study focuses on Striped Bass behaviour in the newly identified overwintering area, the tracking dataset includes only the period between December 1, 2012 and March 31, 2013 (hereinafter “winter”). For tagging and tracking purposes, Striped Bass were caught by angling at one of three sampling locations: the tidal reach of the Stewiacke River (45.160770, -63.330940), and along the shores of Grand Pré (45.13710, -64.28640) and Kingsport (45.166450, -64.346480) (Table 1; Fig 1). VEMCO V16P-4H transmitters (randomized signal delay between 45 and 95 seconds, estimated battery life of 774 days, 71 mm long, power output of 158 dB re 1 µPa at 1 m, and weight of 26 g in air) were surgically implanted in 17 Striped Bass, ranging in size from 0.52 – 0.87 m (fork length) and 1.69 – 2.52 kg. Transmitter weight (in air) was 1 - 2% of the body weight of tagged Striped Bass, which lies within an acceptable range (Adams et al. 1998; Douglas et al. 2009; Cooke et al. 2011; Smircich and Kelly 2014). Striped Bass were tagged in accordance with DFO Scientific License #322857 and Acadia University Animal Care Protocol 06-12.

Striped Bass ages and weights were calculated using known relationships with fork length, as described by Broome (2014). Genomic DNA, isolated from fin clip samples collected at the time of tagging, were stored and later analyzed at the Marine Gene Probe Laboratory at Dalhousie University. Based on genetic data of Striped Bass reference collections, all tagged Striped Bass in this study were confirmed to be of Shubenacadie River origin.

A total of 23 VEMCO VR2W acoustic receivers (receiver frequency of 69 kHz, 308 mm long, 73 mm diameter, weight of 50 g in water, and estimated battery life of 15 months) were deployed in the Minas Passage in late 2012 (Fig 1). Receivers were moored in three lines (linear gates), one spanning the eastern side of the passage (“MPS” line), and two short lines that bordered the FORCE test area (east and west sides, “AUL-E” and “AUL-W” lines, respectively) (Fig 1). Receivers were moored 300-400 m apart, based on a Minas Passage detection range study which showed that detection efficiency decreased as flow speed and distance between receivers increased (Broome et al. 2015). In that study, less than 40% of V16 transmissions were detected by receivers at distances greater than 500m, and fewer than 5% of transmissions were detected beyond 800m (Broome 2014).

Each of the 23 deployed receivers was attached to a Teledyne Benthos 875-TD acoustic release and mounted within a SUB streamlined instrument float (Open Seas Instrumentation). Each SUB unit was connected to a 2 m steel chain riser coupled to a mooring anchor weighing 200 - 225 kg. The flotation units were acoustically released and retrieved in Spring 2013. The risers and mooring weights were sacrificed. One of the 23 units (MPS-03) was never recovered (Fig 1).

Additional receivers were deployed in the low intertidal zone of the Minas Basin, the Gaspereau River, and the Stewiacke River during the spring, summer and fall months of 2012. Detection data from these locations were useful in assessing post-surgery survival of transmitter-tagged Striped Bass.

Data analysis

Detection data for individual Striped Bass were analyzed using VEMCO’s VUE software, and the R statistical environment (R Core Team, 2013), using the packages *reshape2* (Wickham 2007), *plyr* (Wickham 2011), *dplyr* (Wickham and Francois 2015), *lubridate* (Grolemund and Wickham 2011) and *ggplot2* (Wickham 2009). The R package *sp* (Pebesma and Bivand 2005) and ArcGIS 10.2 for Desktop

were used to produce maps. Sunrise and sunset times from the package *maptools* (Bivand and Lewin-Koh 2014) were used to classify detections as occurring during the night or day.

A total of 7925 Striped Bass tag transmissions were detected during the four-month (December to April) study. Throughout analysis, care was taken to avoid the over representation of transmissions due to duplicated detections (when a single transmission was detected by multiple receivers). Because complexities related to both clock drift and detection probability (Smith 2013; Broome 2014; Meckley et al. 2014; Vemco 2014) remained following drift correction attempts, the number of detection days (and not the number of detections) was used to characterise the horizontal distribution patterns of detected Striped Bass in Minas Passage. A detection day is defined as a single day (UTM) during which at least one transmitter detection was recorded. For depth distribution analyses, precise locations and exact times of detection were not required. Duplicate detections were thus removed. Filtering was conducted in R to identify pairs or groups of detections of the same fish by multiple receivers within 40 seconds of each other at the same detection depth. The 40-second interval was selected based on the ping rates (45-95 seconds) of the transmitters. This method ensured that each transmission detected was represented in the dataset by a single depth.

A temperature sensor was attached to one of the SUB units but was never recovered. As a proxy, sea surface temperature (SST) data for Lobster Fishing Area 35 (which contains the Minas Passage) were obtained from Fisheries and Oceans Canada (DFO) for the years 2007 – 2010, as provided by the National Oceanic and Atmospheric Administration (NOAA) through their Pathfinder V5 project. SST for 2011 and 2012 were retrieved directly from NOAA's data repository. Sea surface temperature data for the 2012-2013 winter period were not available.

In the Minas Passage, water is swept over large horizontal distances during the tidal period. In order to estimate how the presence of Striped Bass is related to water level, we show a histogram that compares two distributions: the distribution of water levels at times of detection ("detection events"), and the distribution of water levels at 30-minute intervals spanning the four months over which detections were measured ("detection period"). Both of the frequency distributions used the same 1 m water level bins (Fig 4, upper panel) and were compared using a chi-square independence test ($\alpha=0.05$). The ratios of the two

sets of frequencies are shown in Fig 4 (lower panel). Water level was obtained from a hydrodynamic model simulation of Minas Passage (Karsten et al. 2008).

Results

All 17 Striped Bass surgically implanted with acoustic transmitters were detected post-surgery by at least one receiver moored in Minas Basin. Six of these tagged individuals (35%) were detected in the Minas Passage on more than one day during the winter period (Table 1). They spanned in size from 0.52 - 0.73 m fork length (ages estimated at 6-10 years), and collectively, were detected on 99 of the 121 days of the study period. One additional tagged individual was only detected once. Given the potential for this one tag transmission to be a false detection, it was not considered in any analyses (Binder et al. 2016).

Five of the six Striped Bass were detected by both receiver arrays in the Minas Passage (Fig 1) and during multiple winter months (Fig 2). Daily presence was lowest during a four-week period spanning early February to early March (coldest period, SST $<1^{\circ}\text{C}$). Temporal patterns in Striped Bass detection at the FORCE test site (AUL lines) were similar to those for the Minas Passage (MPS) line. All but one of the detected bass were detected by multiple receivers moored at the FORCE test site (Table 2). Striped Bass were detected by the MPS line (11 receivers spanning the passage) on 93 days and at the FORCE site on 73 days (11 receivers in the two AUL lines). Numerous short duration, between-array movements, including within the FORCE test site, were also detected (Fig 2).

Five tagged Striped Bass were detected by most (at least 18) or all (22) receivers recovered from the Minas Passage, with detections most frequent in the middle of the passage (Fig 3). Each of these five bass were detected on 34 to 46 winter days, with detections spanning 2-4 months; the other Striped Bass was detected on seven days during a two week period in February (Table 2). Over the study period, there was no evidence that photoperiod was a determining factor in Striped Bass presence or detection frequency.

Striped Bass were more commonly detected at times when the water level was 3-4 m below mean water level (Fig. 4, detection events). These levels were compared to water level frequencies at 30-minute intervals throughout the entire 4 month detection period. A chi-square test showed no significant difference between the two sets of frequencies ($p\text{-value} = 0.93$, degrees of freedom = 13) and thus indicates that the likelihood of Striped Bass detection is independent of water level. The ratio of the frequencies of water

levels during detection events to those during the entire detection period (Fig 4 lower panel) is close to 1 for all water level bins, except for very high (>6 m) and very low (beyond -6 m) water levels, both of which occurred rarely (<0.5% of the time).

Striped Bass typically occupied the top 40 m of the water column, regardless of variable bathymetry (max = 170 m) across the Minas Passage (Fig 5). FORCE and MPS arrays showed similar Striped Bass depth distribution patterns during the day (90% of depths between 20 and 37 m) and during the night (90% of depths between 6 and 28 m). At both arrays, there were approximately twice as many detections recorded during the night than during the day. Striped Bass were detected largely at 20-40m depth during the day from December to March (Fig 5). A linear regression analysis showed a statistically significant relationship between SST and Striped Bass detection depth in the Minas Passage during the night ($\text{depth} = 26.868 - 3.703 \cdot \text{SST}$, $p\text{-value} < 0.0001$), but not during the day (Fig 6). At SST below 1°C (February and March), diel vertical migration was not observed.

Discussion

Our study has identified the Minas Passage as a marine overwintering habitat for at least part of the population of Shubenacadie River Striped Bass and extends the understanding of the northern extreme of this species' winter marine range. It is also the first study to note a relationship between extent of vertical migration of Striped Bass and water temperature during the winter months. Both findings raise new questions regarding Striped Bass wintertime use of the Bay of Fundy region and potentially other coastal waters in Atlantic Canada.

Winter presence and distribution

In this study, a surprising proportion (35%) of tagged Bay of Fundy Striped Bass were detected in the Minas Passage during early December 2012 to late March 2013. They included individuals tagged at all three tagging locations (one from Stewiacke, one from Grand Pré, and four from Kingsport), with estimated ages ranging from 6-10 years. Their presence over long time periods (up to 4 months) was unexpected given the cold water temperatures and well-mixed conditions in the Minas Passage, and known use of bottom waters in Grand Lake, Nova Scotia, as overwintering habitat. In 2002, Douglas et al. (2003)

estimated that tens of thousands of subadult and adult Striped Bass overwintered in ice-covered Grand Lake.

Interestingly, four of the six detected bass were temporarily absent during a four-week period in February-March, when sea surface temperatures were seasonally at their lowest ($<1^{\circ}\text{C}$) and mobile surface ice in the Minas Passage was observed. The two Striped Bass detected during the coldest period were not detected beyond early March. Why some Striped Bass occupy the Minas Passage during the winter months remains unknown, and is somewhat concerning given the likely (albeit unquantified) effects of low temperature on adult Striped Bass metabolic activity and survival. Shubenacadie-origin Striped Bass held in captivity in freshwater are lethargic and feed minimally at temperatures below 10°C (J. Duston, Dalhousie University, Truro, Nova Scotia, personal communication, 2015). While a reduction in activity minimizes energetic stress caused by low temperatures (Hurst and Conover 2001), extreme low temperatures (approximately 0°C) can be lethal for juvenile (about 25 cm) Striped Bass (Kelly and Kohler 1999). The observed frequency of Striped Bass detections in the Minas Passage during the winter months, and the fact that detections mostly occurred in the faster flow mid-region of the Minas Passage (based on MPS array detections), suggests that they may be moving somewhat passively back and forth within the passage as the tide ebbs and floods.

This study showed detections of tagged Striped Bass in the Minas Passage at all water level heights within the 13 m tidal range (Fig 4). Although no receivers were deployed outside the Minas Passage to track movements into and out of the passage, frequency patterns in water levels at the times of tag detection suggest that Striped Bass were also present in the waterbodies adjacent to the Minas Passage – Minas Basin and Minas Channel. Given that tidal currents of up to 6 m/s are characteristic of the Minas Passage (Karsten et al., 2008), it is highly likely that Striped Bass movements were largely current-assisted, with movements into the Minas Basin on the flood tide and into the Minas Channel on the ebb tide. We can therefore expect that the marine distribution of Bay of Fundy Striped Bass during winter extends well beyond the Minas Passage. Based on tidal excursion estimates for the Minas Passage (Brian Sanderson, unpublished data), Striped Bass could be tidally transported up to 20 km from the FORCE turbine test site by both ebb tides (into the Minas Channel) and flood tides (into the Minas Basin).

Diel vertical migration

Striped Bass were generally detected in the upper 40m of the water column in the Minas Passage, which includes most of the water column at the FORCE turbine test site. Diel vertical migrations of various fish species have been associated with movements of prey that avoid predation during daytime by swimming deeper, and moving closer to the surface to feed at night (Neves 1981; Fortier and Leggett 1983; Sainmont et al. 2013). The tendency for Striped Bass to remain in the upper 40 m of the water column is consistent with the depth distribution of prey fish (e.g. Atlantic Herring) in the Minas Passage, as detected via multibeam sonar on January 10, 2009 (Melvin and Cochrane 2015). However, Striped Bass in captivity generally do not feed below 10°C (J. Duston, Dalhousie University, Truro, Nova Scotia, personal communication, 2015). If Striped Bass are not feeding in the Minas Passage during winter, what is driving the observed wintertime diel vertical migration pattern? It may be an endogenous temperature-related rhythm, possibly coupled with one or more other environmental variables (e.g. light levels, surface ice). Our study shows no evidence of diel vertical migration below 1°C SST (February and March, Fig 6), suggesting that, at very low water temperatures, Striped Bass are in a lethargic or torpid state and not responsive to environmental or other cues that might otherwise stimulate diel vertical migration behaviour.

Implications and Recommendations

This study demonstrates significant winter presence of sub-adult and adult Bay of Fundy Striped Bass in the Minas Passage. Given the effects of current speed on tag transmission detection efficiencies (Broome et al. 2015), our findings likely underestimate the ecological importance of the Minas Passage and adjacent waters as critical overwintering habitat. High flow environments like the Minas Passage create current-induced noise that results in high variability in the detection range of acoustic telemetry tags during the tidal cycle, including little to no detection when depth-averaged current speed exceeds 2 m/s (Broome 2014). Even if the detected proportion (35%) of tagged Striped Bass is representative of the local population, then thousands of Striped Bass may be residing in the Minas Passage during winter, and potentially at risk of encountering in-stream tidal turbines while in a cold temperature-induced lethargic state.

To better address aspects of risk, we recommend winter collection of Striped Bass from the Minas Passage and/or adjacent marine areas to: 1) acquire body-size, sex, and age frequency profiles of the

wintering population, 2) support genetic assessments of population(s) of origin, 3) enable verification of the absence of glycoproteins that protect tissues against freezing, and 4) confirm lack of winter feeding via gut tract and liver analyses. Muscle tissue samples from winter collected fish could also be analyzed for fatty acid composition as there are indications that under culture conditions fatty acids can directly affect cold tolerance in Striped Bass (Londrville and Sidell 1996; Kelly and Kohler 1999). We also recommend assessments of the lower incipient lethal temperature for cold-adapted juvenile, sub-adult, and adult Striped Bass.

This study raises concerns that low winter temperatures may reduce or inhibit response and avoidance behaviours of Striped Bass, which could increase the risk of fish-turbine interactions for overwintering individuals. While this study does not directly address the risk of fish-turbine collision for Striped Bass overwintering in the Minas Passage, the presence of Striped Bass throughout the water column at the FORCE turbine test site means that they could be at risk of encountering turbines moored at any depth. To further support our findings of overwintering Striped Bass in the Minas Passage and surrounds, additional acoustic tagging that covers a broad size (age) range of Striped Bass, and year-round tracking of tagged fish by receivers positioned inside and outside of the passage, is recommended. To determine if Striped Bass (and other fishes) detect and avoid in-stream turbines, near-field studies that use coupled acoustic and imaging technologies, mounted on or in close proximity to installed turbine infrastructure, will be required.

Our detection of overwintering sub-adult and adult Striped Bass in the Minas Passage, and tidal excursion estimates, suggests that Shubenacadie River (and possibly US origin) Striped Bass may be using a much larger area of the Bay of Fundy as overwintering marine habitat. A greater focus on determining the extent of marine winter habitat and patterns in winter residency for northern populations would help address a major knowledge gap for the species (Waldman et al. 2012; Bradford et al. 2015) and would assist the management of Striped Bass populations.

This study demonstrates significant Striped Bass presence in the Minas Passage and the FORCE test site during the winter months. Sub-adult and adult Striped Bass occupied the top 40m of the water column but were rarely detected above 15 m depth from early January to late March (SST <4°C). Little to no diel vertical migration was observed when SST was <1°C. The extent of vertical migration to surface

waters at night was strongly related to water temperature, and suggests cold-temperature effects on metabolic activity levels. While the ability of Striped Bass to detect and avoid tidal energy infrastructure in a high-flow environment remains unknown, these findings suggest that risk of Striped Bass-turbine interaction may be enhanced during winter.

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469

Figure Captions

Fig 1. Top: Map of the Nova Scotia portion of the inner Bay of Fundy. The Minas Passage connects the Minas Channel to the Minas Basin, and is 5-6 km wide. The FORCE tidal turbine test site (rectangle, 1 km x 1.6 km) is located in the northern part of the Minas Passage. Striped Bass tagging locations are indicated by solid black circles. Bottom: Map of receiver locations in the Minas Passage during winter 2012-2013. Filled circles show locations of recovered receivers, while the X indicates a receiver that was deployed but lost. Land is shaded grey. The rectangle denotes the location of the FORCE tidal turbine test area. Map data were adapted from numerous CanVec files provided by Natural Resources Canada at www.geogratis.ca.

Fig 2. Average winter sea surface temperature (SST) during 2007-2012 (top), and daily presence of tagged individuals at each receiver array (middle = FORCE array, bottom = MPS line) during the winter period (December 1, 2012 – March 31, 2013). SST were smoothed using locally weighted scatterplot smoothing (black line), and 95% confidence intervals are shown by grey shading. The horizontal dashed line in the top panel indicates 6°C, and the dashed rectangle encloses the coldest period of winter when only two Striped Bass were detected.

Fig 3. Spatial distribution during winter for individual Striped Bass detected on multiple days in 2012-2013. Open circles represent receiver locations, and the sizes of filled circles represent the number of detection days at a receiver. The single location where a receiver was deployed but lost is marked with an X. Plots are sorted by fork length from shortest (0.52 m, top left) to longest (0.73 m, bottom right). Receivers were deployed from November 2012 – April 2013.

Fig 4. The upper panel shows the frequency of occurrence of water levels at the times when tags were detected (“detection events”, grey columns) and the frequency of water levels at 30 minute intervals spanning the detection period (black columns). Detection events were irregularly distributed within the December 1, 2012 – March 31, 2013 detection period. Water level was obtained from a hydrodynamic model for Minas Passage (Karsten et al. 2008). The lower panel shows the ratios of the two sets of water level frequencies. The dashed horizontal line shows a 1:1 ratio.

Fig 5. Kernel density plots for Striped Bass detection depths at the FORCE array (top, max depth = 50m) and at the MPS line (bottom, max depth = 130m), for both day (left) and night (right), during the winter in the Minas Passage. Dashed line indicates approximate bottom depth at the FORCE test site.

Fig 6. Striped Bass detection depths (m) versus sea surface temperatures (°C, estimated using locally weighted scatterplot smoothing) for all daytime (left) and nighttime (right) detections in the Minas Passage. Line represents linear model of relationship. Grey shading represents 95% confidence interval. Eight daytime detections at >50m depth, by a single fish on a single day in late January, are not shown but are included in the model.

Tables and Figures

Table 1. Summary of Striped Bass V16 tag transmission detections in the Minas Passage during December 1, 2012 – March 31, 2013 (121 days). The percentage detected is relative to the number of Striped Bass tagged in that location, while the percentage of detection days is relative to the number of days that receivers were deployed.

Tagging location	Number tagged	Number detected (%)	Detection days (%)
Grand Pré	3	1 (33)	35 (28.9)
Stewiacke	7	1 (14)	35 (28.9)
Kingsport	7	4 (57)	76 (62.8)
All	17	6 (35)	99 (81.8)

Table 2. Detection summary for each Striped Bass detected in the Minas Passage during winter 2012-2013. A detection day is a day on which a detection is recorded. Ages were estimated using an age-length relationship for Bay of Fundy Striped Bass (Broome 2014).

Tagging location	Fish code	Fork length (m)	Age (yr)	Detection days at FORCE	Detection days at MPS Line	Detection days in Passage
Grand Pré	G28	0.52	6	18	33	34
Stewiacke	S03	0.63	8	25	25	35
Kingsport	K45	0.61	8	0	7	7
Kingsport	K41	0.66	9	20	30	35
Kingsport	K43	0.68	9	29	33	46
Kingsport	K44	0.73	10	24	32	37
All	NA	NA	NA	73	93	99

5 individuals
404 detections

5 individuals
939 detections

FORCE

6 individuals
1315 detections

6 individuals
2720 detections

MPS