Minas Passage Lobster Tracking Study
2011-2013

Final Report
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Prepared for FORCE
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Executive Summary

The development of the Fundy Ocean Research Centre for Energy (FORCE) in-stream tidal turbine test site in Minas Passage, Bay of Fundy has necessitated environmental monitoring of commercially and recreationally valuable species, including the American lobster (*Homarus* americanus) fishery. The upper Bay of Fundy commercial lobster fishery (lobster fishing area 35) is lucrative and supports 75 licensed fishers (Canadian Science Advisory Secretariat, 2013). Adult American lobsters are known to undergo seasonal migration of 10s to 100s of kilometres to avoid cold winter water temperatures (Estrella and Morrissey, 1997, Robichaud and Lawton, 1997); this is of particular importance to ovigerous or berried females (Campbell, 1986, Cowan *et al.* 2007).

Impacts on lobster migration from the testing of tidal energy technology are unknown. Preliminary studies completed in the Minas Passage (Lockhart-Bastian *et al.,* 2009, Collins, 2011) confirmed the presence of lobsters in the area and the FORCE test site. Conventional tagging methods were used with limited success as they provided data only during the fishing season. In order to gain higher temporal resolution and more data on fine-scale movements in and around the FORCE test site, Minas Basin lobsters were tagged with VEMCO tracking technology in both 2011 and 2012.

Prior to lobster tracking, a field test to assess detection range of the technology used was conducted in the Minas Passage using three Vemco VR2w acoustic receivers and six Vemco V13 acoustic transmitters. Transmitters and receivers were mounted in lobster traps and deployed for a three-day period to monitor detection efficiency of bottom moored tags in the Minas Passage. All three receivers logged detections from all transmitters. However, detection of tag transmissions varied throughout the tidal cycle, with the majority of detections occurring at average water column currents speeds of <1.5 m/s. Transmission interference due to ambient environmental noise is considered the cause of reduced detection efficiency at high flow speeds.

In November 2011, 85 adult American lobsters sourced from the commercial catch in Minas Basin were weighed, sexed, measured, and fitted with a Vemco V13 acoustic transmitter and a numbered disc tag to facilitate fisher tag returns. Lobsters were released near their site of capture, several kilometers east of the innermost array of acoustic receivers in Minas Passage. A total of 29 acoustic receiver stations were deployed in three line arrays as "listening gates" spanning the Minas Passage and FORCE test site. Receivers were housed in moored sub buoys that were tethered approximately 3 m above the seafloor.

Between November 2011 and August 2012, 100744 transmissions from 31 (36%) tagged lobsters were detected by receivers in Minas Passage. Most tag detections were logged in the northern region of the Minas Passage, including some within or near the FORCE site. More

female (N=21, including 4 berried) than male (N=10) lobsters were detected. Mean movement rate was estimated at 0.33 ± 0.34 km/day. In some instances, lobsters that moved through the Minas Passage in late fall were detected returning in the spring/early summer. Some lobsters were detected only once or a small number of times while others were within detection range for long periods, logging thousands of detections. Based on tagging studies elsewhere, it is likely that some tags were dislodged from the lobster carapace during the study period. Regardless, the study showed that lobsters use the Minas Passage as a seasonal migration route.

The receiver lines were in place over the winter and spring period of 2012-2013 and thus offered an opportunity to assess lobster movements on a more continuous basis, and to also test the assertions of some lobster fishers that lobsters use the water column and fast flows when traversing through the Minas Passage. In December 2012, 40 adult American lobsters were sourced from the commercial catch in Minas Basin and similarly tagged. Receiver array deployment positions were altered to allow greater coverage of the FORCE test area. From December 2012 until June 2013, 30241 detections from only six (15%) tagged lobsters (2 male, 4 female) were logged on receivers in the Minas Passage. The northern region of the Minas Passage was again the most frequented region by tagged lobsters. Pressure (depth) data indicated movement only at seafloor depths. Mean movement rate (1.21 ± 1.21 km/day) in year 2 was faster than in year 1 of the study. As previously observed, some lobsters remained in range of receivers for longer periods of time than others, possibly due to transmitter dislodgement. The lower number of detected lobsters in year 2 of the study may be due to tagging later in the fall season (early December), at which time many migrating lobsters may have already moved through Minas Passage. A large proportion of Minas Basin tagged lobsters showed no evidence of migration and may suggest that many remain resident and / or do not migrate every year.

It is recommended that future studies address lobster use of the FORCE facility and interactions with tidal turbine infrastructure (cables, moorings) in the FORCE Lease area.

Acknowledgements

This study was supported by funding from FORCE, NSERC (Alexander Graham Bell CGS) and Acadia University. The Ocean Tracking Network is thanked for providing access to tracking technology equipment and field support for the receiver array deployments and recoveries. Richard Karsten and Brian Sanderson provided data on modeled current speeds. Colin Buhariwalla and lobster fishers, Croyden Wood Sr. and the late Croyden Wood Jr and their crews, provided assistance with the tagging of lobsters in Minas Basin. Mark Taylor and crew assisted with receiver deployments and recoveries.

Background

The FORCE tidal energy demonstration area in the Bay of Fundy's Minas Passage is Canada's leading test site for commercial-scale tidal in-stream energy conversion (TISEC) devices. The area poised for testing of TISEC devices is also home to a prosperous commercial lobster fishery. The Bay of Fundy lobster fishery is divided among 4 primary lobster fishing areas (LFA), namely LFA # 34, 35, 36, and 38 (Figure 1). These contribute a significant portion of the overall catch to Canada's highest value fishery. The Minas Passage and inner-Bay of Fundy (iBoF) region are contained within LFA #35. The fishing season within LFA #35 is open from April 1 – July 31 and October 15 – December 31.

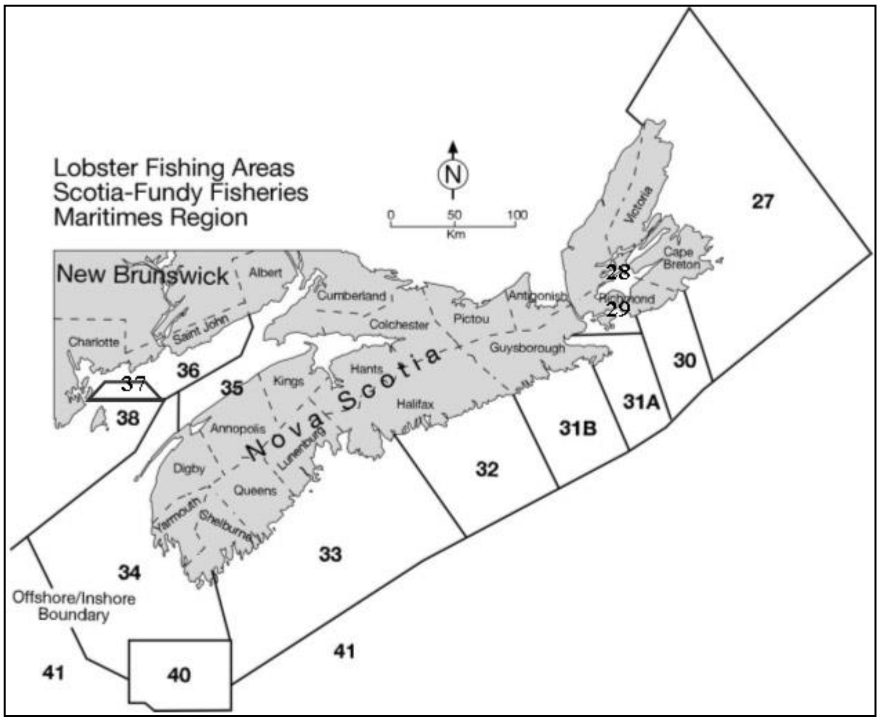

Figure 1. Map of lobster fishing areas (LFAs) in the Scotia and Fundy regions in the Canadian Maritimes (Fisheries and Oceans Canada, 2009).

Local ecological knowledge and anecdotal information from commercial lobster fishers suggests that a regular seasonal lobster migration occurs in the upper Bay of Fundy. Fishing practices (*e.g.* trap placement) in the Minas Basin tend to follow the seaward (west to outer Bay of Fundy) migration of lobsters in the fall-winter season; the reverse migration (into Minas Basin via Minas Passage) and associated fishing practices take place in the spring-summer season. In large part, scientific studies have found similar patterns in nearby areas, as lobsters in the Bay of Fundy and Gulf of Maine have been observed to undertake seasonal migrations on a scale of 10-100's of kilometres, with the most significant migrations being made by lobster of large body size (Campbell 1986; Campbell and Stasko 1986; Robichaud and Lawton 1997). However, little is known of the timing and extent of lobster migration within the upper bay.

Anecdotal information indicates that temperature is likely the dominant migratory queue. Sayings such as “on the first snow, they go” are common in communications with fishers. The Minas Basin is known to experience sub-zero conditions throughout the winter, which would limit growth and development; this is of particular concern to berried lobsters (females with eggs) (Estrella and Morrissey 1997; Cowan *et al*. 2007).

Larger ovigerous lobsters migrate to areas of warmer water temperatures and greater temperature stability, allowing for a higher number of degree days for developing eggs (Cowan *et al*. 2007). The practice of migrating to offshore or warmer waters acts as a buffer against environmental conditions, allowing eggs to fully develop and be extruded the following season.

Past studies of lobster movement within the upper Bay of Fundy have relied upon conventional tagging methods (Lockhart-Bastian *et al*. 2009). These methods (external numbered tags) require tagging of thousands of animals in order to provide sufficient fishery dependent data for interpretation. Studies of this nature also require a significant commitment from fishers to return tags and correctly recorded tag information. Results of a conventional tagging study in 2008 did not reveal any winter out-migration or spring in-migration of Minas Basin tagged lobsters (Lockhard-Bastian *et al.* 2009). The lack of observed migration is potentially an artifact of the study design as lobster migration could have occurred when the LFA 35 fishing season was closed for the winter and early spring (i.e. captures of tagged lobsters by fishers not possible). Interestingly, from that same study, lobsters tagged near Halls Harbour (Minas Channel) were shown to migrate over long distances (up to 100 km) and as far as Digby, NS.

The use of Vemco acoustic tracking technology, already deployed in the Minas Passage for concurrent fish tracking projects (Redden *et al.* 2014), offered an opportunity to examine lobster use of the Minas Passage (and FORCE test area, Figure 2) as a migratory corridor and to collect baseline data for effects monitoring prior to the deployment of TISEC devices.

Electronic tagging of lobsters was conducted over two years: in November 2011 (Phase 1) and December 2012 (Phase II). Phase I included a test of the detection range of Vemco acoustic tags in the Minas Passage.

Study Site Description

The Minas Passage is located in the upper Bay of Fundy and connects the Minas Basin to the Minas Channel. It is approximately 6 km wide, 13 km long, with an average depth of 53 m. The region features semi-diurnal tides and a tidal range in Minas Passage of between 7 m (neap tide) and 13 m (spring tide), with current speeds maxing out at about 6 m/s at the surface and as high as 0.5 m/s just above the seafloor (Oceans Ltd. 2009).

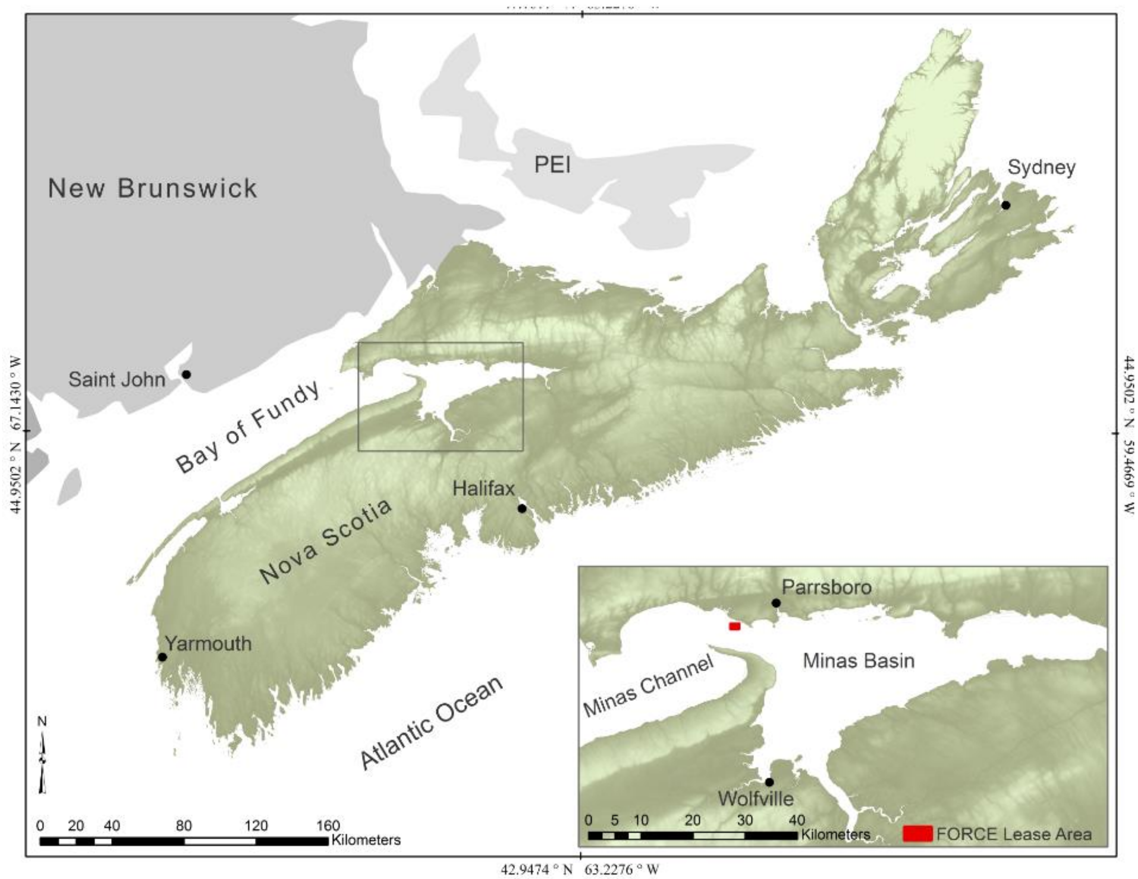

Figure 2. Map of the Canadian Maritimes, inset with map of the southern arm of the upper Bay of Fundy, including the Minas Passage and FORCE test site (shown in red).

The seafloor in the Minas Passage is primarily cobble and gravel in the southern portion, with boulders and a scoured volcanic platform (Figure 3) nearer to the northern shore, including the FORCE test site (Fader 2009). The Minas Channel and Minas Basin differ from the Minas Passage in that they are less scoured by tidal currents and have finer grained particles, sometimes including large mobile bedforms (Swift and Borns Jr. 1967; Fader 2009).

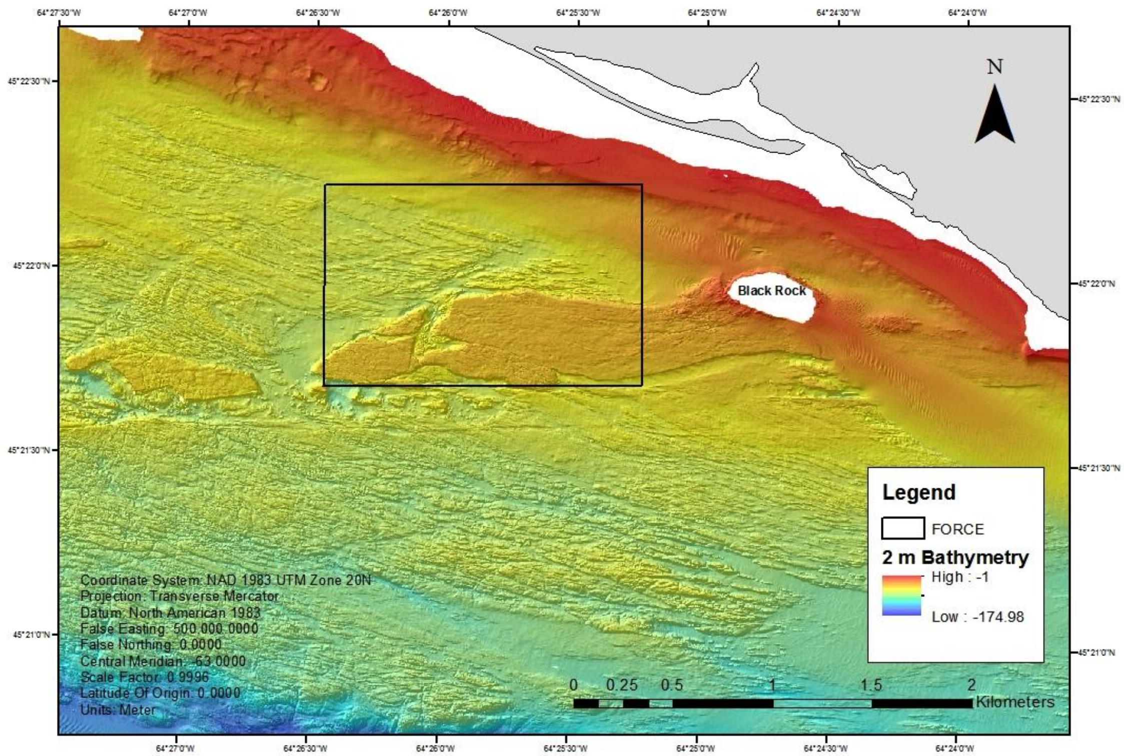

Figure 3. FORCE Crown Lease Area (Minas Passage, Bay of Fundy) with underlying bathymetry (sourced from Seaforth Geosurveys Inc.).

The FORCE test site (1 km x 1.6 km) is located approximately 9 km west of the Town of Parrsboro. It features fast current speeds (up to 6 m/s), short slack water periods (20 minutes or less), and a scoured seafloor of primarily sedimentary rock and volcanic basalt platforms (FORCE 2011).

Prior surveys of the seafloor macrobiota within the FORCE site indicate both low abundance and low biodiversity of largely sessile invertebrates, dominated by encrusting yellow breadcrumb sponge (Stewart 2009; Morrison 2012). In contrast to the Minas Passage, the epibenthic biota in the Minas Basin is more diverse due to less extreme flow conditions and finer surficial seafloor substrate (Brylinsky 2008; Stewart and Levy 2010).

Vemco Technology Range Test

Objective

The purpose of the range test was to determine the detection range (distance) of the transmissions of seafloor-located Vemco tags during high-flow conditions in the Minas Passage.

Range Test Methodology

A Fisheries and Oceans Canada scientific permit (ID# 333819) to conduct pre-season range testing and tagging of lobster during the fall commercial season was obtained in both 2011 and 2012.

The field range test took place over three full days, from October 8-10, 2011, with receivers and tags deployed on October 7. A series of six Vemco V13 acoustic transmitters were attached to the inside of lobster traps and deployed in the Minas Passage east of Black Rock (Figure 3), in an east-west oriented line, spaced approximately 100 m apart. Three acoustic receivers (Vemco VR2w) were strapped within lobster traps and deployed in a north-south oriented line, spaced about 100 m apart, intersecting the line of acoustic transmitters).

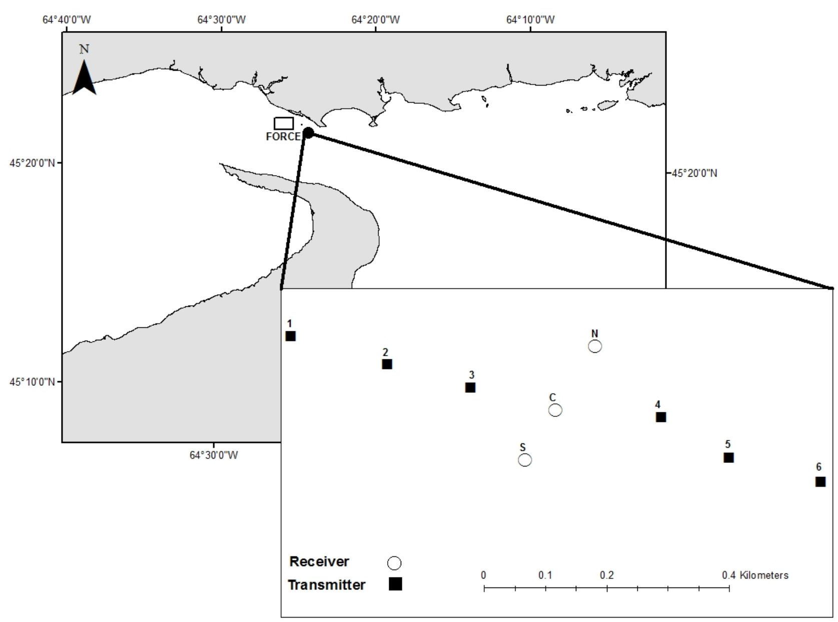

Figure 4. Arrangement of Vemco tags and receivers for the 2011 range test. Three lobster traps fitted with VR2w acoustic receivers (open circles) were spaced 100 m apart in a north to south orientation (north, central, south receiver). Six traps fitted with a V13 transmitter (solid black squares) were deployed 100-150 m apart in an east to west orientation.

Range Test Results

After 3 days of deployment, a recovery mission successfully retrieved all but one trap (containing transmitter 1). Deployment and recovery positions of lobster traps varied for some traps, likely due to tidal current-induced trap movements. Regardless, the array provided information on the acoustic detection of tag transmissions in relation to tidal conditions.

A total of 8473 transmissions were detected from Oct 8-10, 2011, with most detections received at the central receiver (RC) and from transmitter 2 (Table 1). Transmitters 1 and 6, those farthest away from the centrally located line of receivers, recorded the fewest transmissions (Table 1).

Table 1. Number of transmissions logged by acoustic transmitters (T1:T6) at acoustic receiver stations (RN, RC, RS) from October 8-10, 2011 during a field range test in Minas Passage, Bay of Fundy. Distances between transmitters and receivers are shown in Figure 4.

	Oct 8			Oct 9			Oct 10			Total
	RN	RC	RS	RN	RC	RS	RN	RC	RS	
T1	12	15	80	121	28	147	100	49	99	651
T2	149	224	233	241	293	260	198	258	151	2007
T3	3	242	273	10	181	270	105	189	119	1392
T4	241	302	271	231	148	170	246	24	134	1767
T5	206	64	216	285	143	266	229	73	203	1685
T6	141	1	139	219	2	162	162	0	145	971
Total	2812			3177			2484			8473

All three range test receivers detected all six transmitters but the number (and proportion) of detections recorded by each receiver varied over the 72-hour test period. With the exception of transmitter 3, there were fewer tag detections with increasing distance from the receiver (Figure 5).

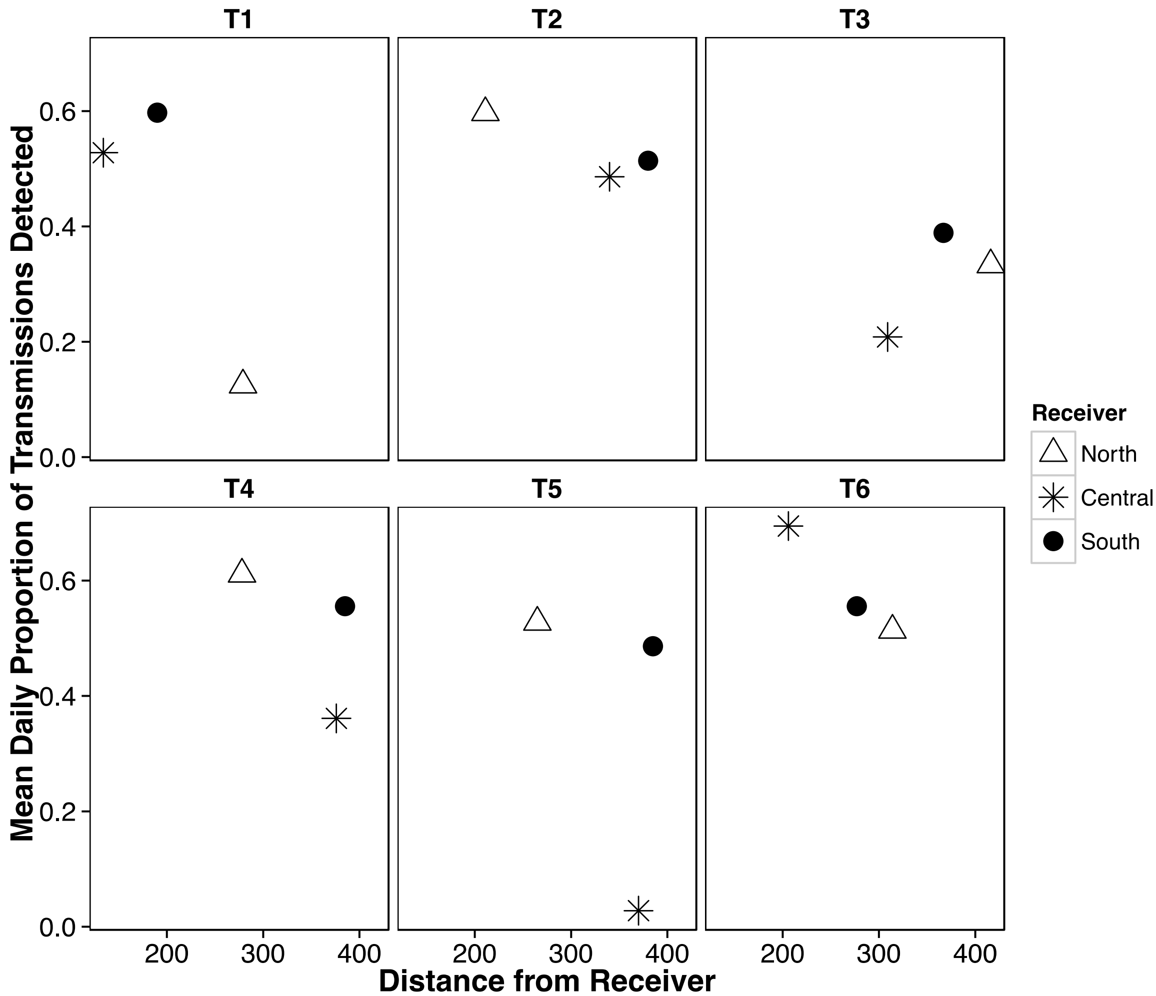

Figure 5. A comparison by transmitter of number of transmissions detected at the north, central, or south receiver station based on ditance between transmitter and receiver.

Examination of data in relation to current speed shows transmissions were logged during 40-60% of each study day, with few or no transmissions logged when current speeds on the ebb and flood tides were greater than 1.5 m/s (Figure 6). This pattern was generally consistent for transmitters located within 200 m of receivers.

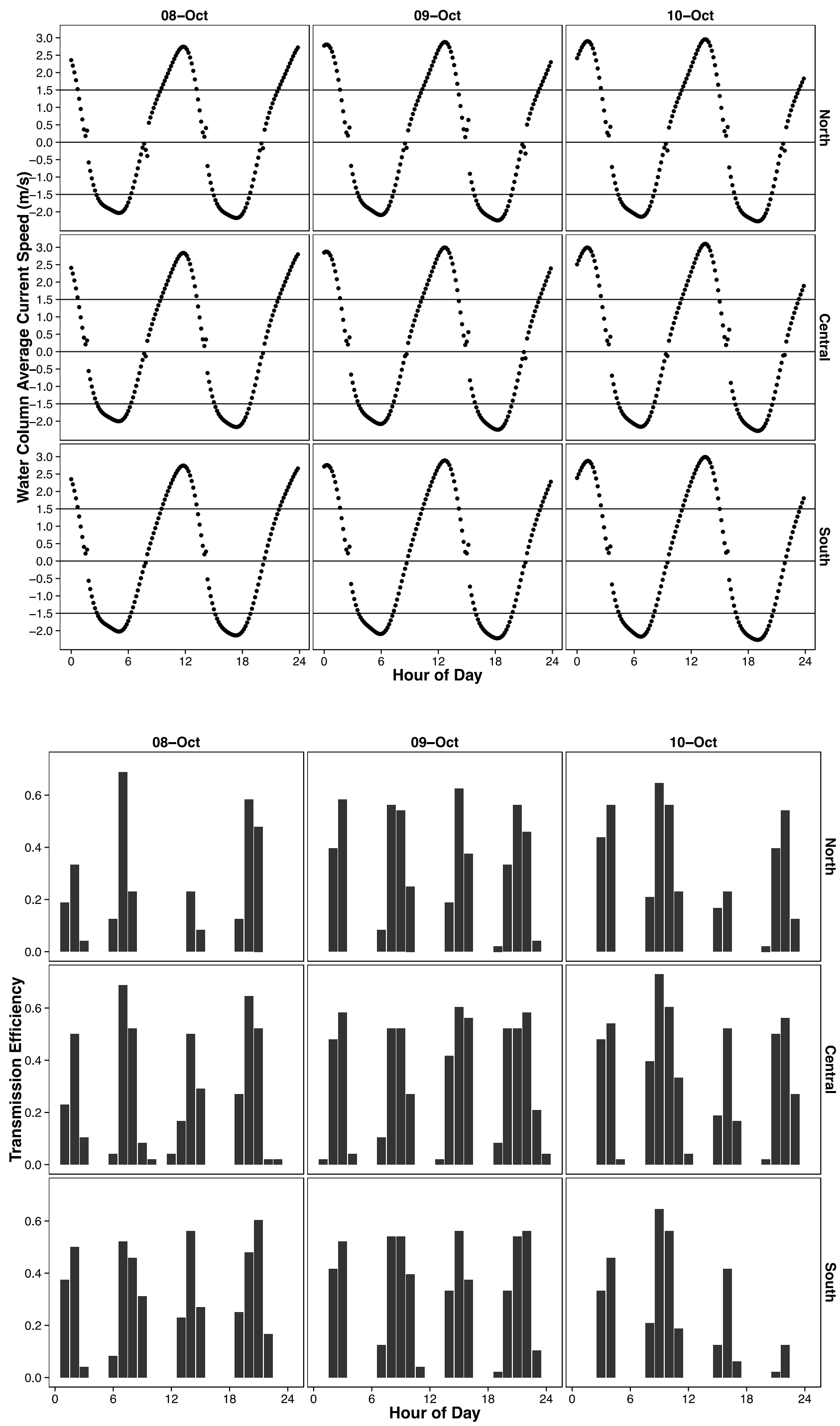

Figure 6. Top panel: depth-averaged current speed (m/s), by time of day, at all three receiver stations, during 8-10 October, 2011. Positive current speed values indicate a flooding tide and negative values indicate an ebbing tide. Bottom panel: proportion of transmissions logged per hour for transmitter 2 (ID number 3448). Current speed data provided by Brian Sanderson, and generated using the hydrodynamic model of Richard Karsten (Acadia University).

From the range test detection statistics, three performance metrics were calculated to assess receiver performance: code detection efficiency (CDE), rejection coefficient (RC), and noise quotient (NQ) (Simpendorfer *et al*. 2008). The first metric, code detection efficiency, reports the proportion of detections recorded relative to sync intervals logged. Sync intervals indicate the start of each transmission sequence, and as such this value is used as a proxy for the number of transmissions. CDE is calculated by dividing the number of valid detections by the number of sync signals (Simpendorfer *et al*. 2008). The overall mean code detection efficiency was found to be 0.377 and indicates that 37.7% of expected (or maximum number of) transmissions were successfully logged (Table 2).

The second metric, rejection coefficient (RC), is a proportion relating the number of rejected signals to the number of sync intervals logged; signals would be rejected if checksums (small, arbitrary segment of data) were invalid. The mean rejection coefficient was found to be 0.043, meaning that 4.3% of all transmissions were rejected due to invalid ping sequences (Table 2).

The final metric, noise quotient (NQ), relates the number of detected pings to the number of expected pings during all transmissions; this metric is calculated by subtracting the number of syncs multiplied by the number of pulses comprising a valid code/sequence from the total number of pulses detected (Simpendorfer *et al*. 2008). The mean noise quotient in this study was found to be -4275, with variable levels between receivers and within a given receiver through the study period (Table 2). All values were strongly negative, indicating that environmental noise was interfering with transmission detection, and were especially high on the 9^{th} and 10^{th} of October 2011.

Table 2. Summary of detection performance data and calculated metrics (code detection efficiency (CDE), rejection coefficient (RC) and noise quotient (NQ)) for all transmitters during 3 full days of range testing in the Minas Passage: October 8-10, 2011.

Receiver	Date	Detections	Pings	Syncs	Rejects	CDE	RC	NQ
North	08/10	543	8116	1302	35	0.417	0.027	-2300
	09/10	752	14439	2443	113	0.308	0.046	-5105
	10/10	1040	15713	2579	97	0.403	0.038	-4919
Central	08/10	346	5093	954	42	0.362	0.044	-2539
	09/10	849	13744	2279	107	0.372	0.046	-4488
	10/10	795	13721	2287	137	0.347	0.059	-4575
South	08/10	491	7444	1170	44	0.419	0.037	-1916
	09/10	1212	19553	3248	148	0.373	0.045	-6431
	10/10	1277	19581	3223	148	0.396	0.046	-6203

Range Test Conclusions

Results from the range test indicate that environmental background noise is a primary factor in determining success of using Vemco acoustic tracking technology in the Minas Passage. However, calculated performance metrics indicate that this equipment falls within the acceptable range of use for this study.

Significant day-to-day variability was observed in numbers of detections recorded. However, patterns of detection were largely consistent across all three receivers. It is likely that the immediate physical orientation of the trap on bottom (upright or overturned), the seafloor structure, and the extent of tidally-induced movement impacted the detection results. Other factors influencing the detection efficiency of moored receivers include hydrodynamic and other noise, *eg.* bedload transport, flow patterns around bottom features, and strumming/rattling of lobster traps. Harsh physical conditions, *i.e.* turbulent water and high flow-induced ambient noise, have been shown to impact acoustic telemetry systems (Clements *et* al. 2005; Berge *et al.* 2012; Welsh *et* al. 2012; Redden *et al*. 2014).

Throughout the range test, there were few tag transmissions at high depth-averaged current speeds (>1.5 m/s). Multi-path effects or transmission collisions (Smith *et al.* 1998) are potential sources of error but were not a significant issue in this test. The three metrics calculated for the range test inform us that the majority of transmissions lost or interrupted are a result of the Minas Passage environment.

Year 1 Acoustic Tracking of Lobsters

Objectives

The main objectives of the acoustic tracking study in year 1 were to:

1) acoustically track and describe adult lobster movements from Minas Basin to the Minas Passage and FORCE test area; and
2) examine travel rates of migrating adult male and female lobsters.

Acoustic Tracking Methodology

Lobsters used in this study were collected from the Minas Basin commercial catch of Croyden Wood Jr. on November 1, 2011.

Following a two-day soak, traps were retrieved as part of the normal fishing routine in the northern and central regions of the Minas Basin. Only adult lobsters (market size), including egg-bearing or berried females were banded and held onboard. Eighty-five of the largest lobsters (41 male, 44 female) were set aside for tagging using both a Vemco acoustic tag and a Floy disc tag.

Study lobsters were sexed, measured (carapace length, Table 3), weighed using an Ohaus digital scale, and fitted with a 0.5 inch Floy disc tag (Figure 7). Each disc tag was attached at the base of one of the claws using a zip-tie and had a unique four-digit identifier code.

Table 3. Number and size (carapace length, range and mean) of male, female, and berried female lobsters tagged in 2011.

2011 Lobsters	Number Tagged	Size Range (mm)	Mean (mm) ± SD
Male	41	90-144	105 ± 12.6
Female	33	90-123	104 ± 8.27
Berried Female	11	82-97	95.5 ± 9.44

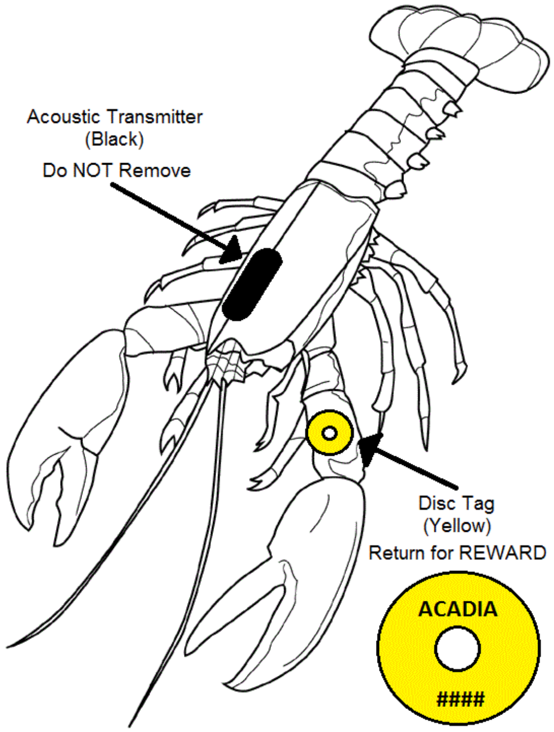

Figure 7. Attachment positions of the VEMCO V13/V13P acoustic transmitter and Floy disc tag. This diagram was provided to local fishers in an information package.

The carapace of each lobster was dried using paper towel, roughed using 80-grit sandpaper, and cleaned using an iso-alcohol wipe to increase the ability of the epoxy to adhere the acoustic transmitter to the carapace, as described by Bowlby *et al*. (2007). Lepage Speed Set epoxy (pre-mixed) was applied to the dry, sanded, cleaned area on the lobster carapace, slightly offset from the dorsal midline. A VEMCO V13 or V13P (pressure sensor, accurate within five metres) acoustic transmitter, roughed with 80-grit sandpaper, was then placed in the epoxy. V13 and V13P are 69 kHz, 45 mm long coded transmitters that emit an identifiable ping at pre-determined rates; ping rates were set to 60-120 seconds. Unique ping sequences allow transmitters to be detected by acoustic receivers, providing timed-stamped location data for specific transmitters and the animals to which they are attached.

Lobsters were then placed in individual plastic tubs, allowing the epoxy to cure, typically 10-20 minutes. Once the epoxy had hardened, lobsters were moved to a large holding crate until they were released. Just prior to lobster release, the bands were removed from the claws of tagged lobsters. In tagging year one, five lobsters were released directly on the MPS detection line (MPS 03) as a test of detection efficiency. The remaining 2011-tagged lobsters were released in groups of four from the stern of the vessel in 300 m intervals along a 3 km line running east to west, approximately 3 km east and 6 km south of Parrsboro Harbour (Figure 8).

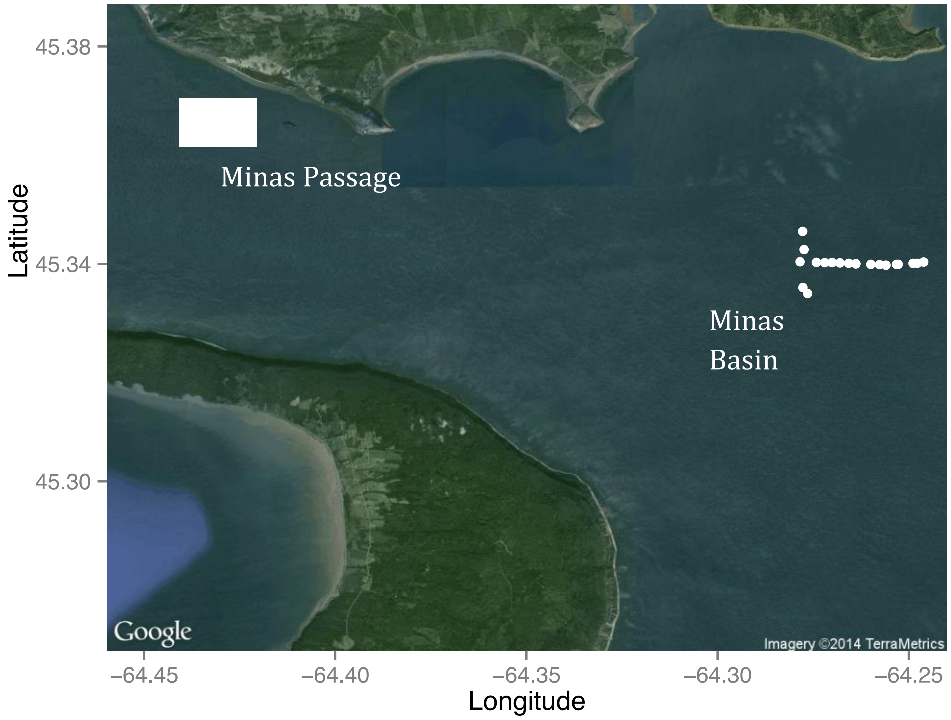

Figure 8. Year 1 tagged lobster release points (circles) in Minas Basin, November 1, 2011. White rectangle represents FORCE test area.

Three lines of moored VEMCO VR2w 69 kHz acoustic receivers were used to detect movement of tagged lobsters. Receiver arrays were strategically deployed as “listening gates” to detect lobster movement through the Minas Passage and FORCE test site (Figure 9). Receivers were housed in sub-buoys, tethered 2-3 m above the seafloor (Figure 10).

In the 2011 receiver arrangement, two receiver lines spanned either end of the Minas Passage (MPS line at eastern end of passage, AUL line at western end of passage) and a short receiver line was positioned down the middle of the FORCE site (AULT line); receivers were spaced 400 m apart, with 29 receiver units in total (Figure 9).

On April 20 and 26, 2012, the MPS line (12 units, 400 m apart) and two 6-station receiver lines at either end of the FORCE site (AULW and AULE, units 300 m apart) were deployed (Figure 9).

A scheduled recovery mission of receiver stations was conducted during December 13-14th, 2011; 14 stations were successfully recovered and another 14 were retrieved sporadically throughout the following year as mooring hardware deteriorated. Only one unit was not recovered. For further details of the multi-year receiver deployments, see Redden *et al.* (2014).

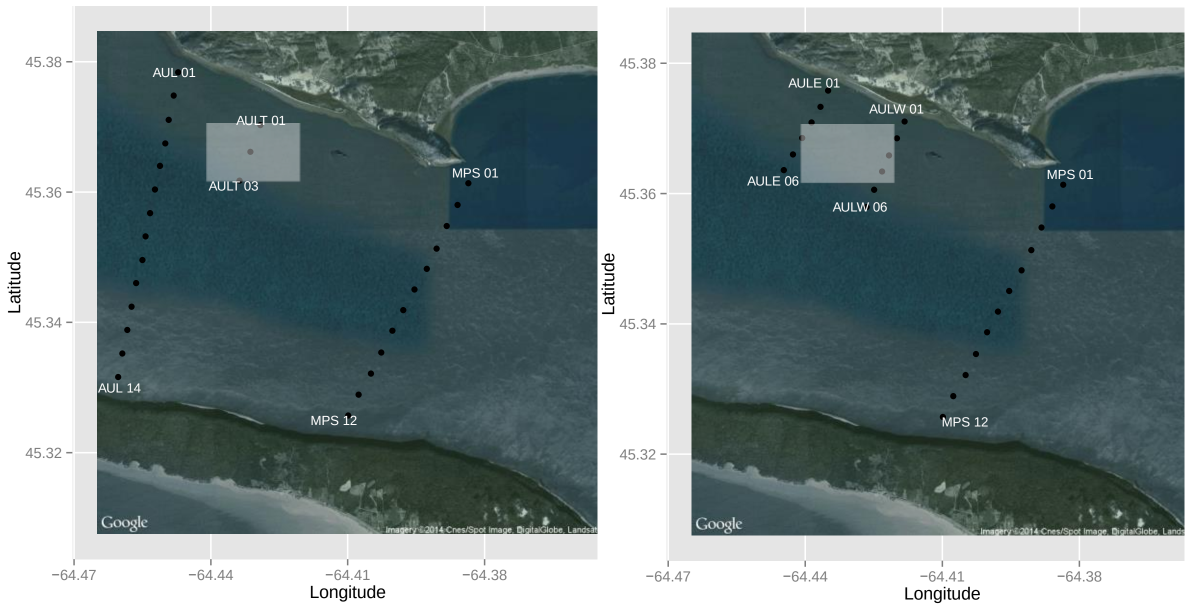

Figure 9. Vemco VR2w acoustic receiver stations and arrays (MPS, AULT, AUL, AULE, AULW) in Minas Passage during 2011 (left) and 2012 (right).

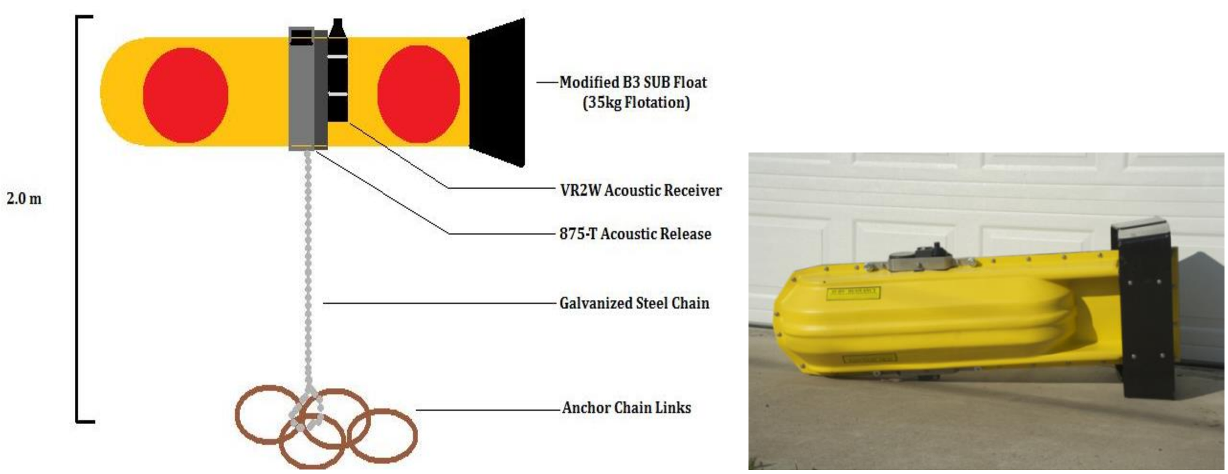

Figure 10. Left: Diagram indicating internal orientation of the VR2w Receiver and Benthos Teledyne acoustic release (not to scale, from Redden *et al*. 2014). Right: photo of SUB flotation package with instrument package installed.

Fisher Communications

Local fishers were informed of this study prior to the tagging of lobsters. Wharf visits were carried out on October 11, 2011 (Parrsboro, Advocate) and October 24, 2011 (Harbourville, Halls Harbour, Scots Bay, Delhaven) to facilitate face-to-face communication with fishers and to put up posters in high traffic areas. Information packages containing a letter, project summary poster, and tag return sheet were mailed out to notify LFA #35 fishers of the project. A study notification was also posted in the spring of 2012 edition of the Fisherman and Scientists Research Society Newsletter – "Hook, Line, and Thinker" (http://www.fsrs.ns.ca/newsletter/HLT2012-1.pdf, pg. 53).

Data Analyses

VEMCO User Environment (VUE) software was used to transform the acoustic transmissions stored as a VRL file into workable datasets. VEMCO VR2w receivers have the ability to detect transmissions from other VEMCO transmitters within range of the receiver station. Filters were applied to select only those transmitters associated with this study.

Clock drift over the duration of the deployments (up to 1 year) was assessed for each receiver. Clock drift is the gain or loss of time on a receiver's internal clock, caused by slight variations in the crystal oscillator, the time keeping mechanism within each receiver, or due to changes in temperature (Webber 2009). The amount of clock drift per receiver was determined by comparing the upload time on the PC (with VUE installed) with the upload time on the receiver in question. Clock drift is assumed to be linear. VEMCO provides an autocorrect clock drift function that can be applied to the VRL file in VUE.

After the drift correction algorithm was applied, data were examined for duplicate transmission detections. When acoustic receivers are deployed in arrays, there is a chance that two different receivers may detect the same transmission if the transmitter is within range of both units. Duplicate transmissions were verified by comparing the transmitter identification number, depth at point of detection (if the transmitter had a pressure sensor) and by comparing whether transmissions received at the same receiver stations occurred within the minimum ping rate set for the transmitter. However, because receiver internal clocks drift at different rates, determination of the first of multiple detections, received within short intervals, could not be made with certainty. Consequently, duplicate detections were not removed from the dataset.

Range test data was assessed using three metrics: code detection efficiency (CDE), noise quotient (NQ) and rejection coefficient (RC) (Simpendorfer et al. 2008) followed by determination of detection efficiency. For the purposes of this study, detection efficiency refers to the probability of detecting a transmission from a tag (based on proportion of successful transmissions logged compared with the expected number of transmissions emitted).

A detection efficiency of 50% is assumed to be the minimum working rate and this is known to decrease with distance from receiver (Kessel, 2014).

The tracking datasets were examined for movement patterns of individual lobsters with regard to detection location, residency time, time of year, sex, berried state of females, movement rate, and movement direction. It was expected that adult females would exhibit greater movement rates and travel farther than male lobsters. The Kruskal-Wallis test ($\alpha = 0.05$) was used to test for differences in movement rates between the sexes (male, female, berried female).

Results: Year I Lobster Tracking

All five of the tagged lobsters released near the MPS03 receiver station were detected by that receiver, providing evidence of effective detection of tagged lobsters. Out of the 85 lobsters tagged, 31 were detected in the Minas Passage at 29 different receiver stations and all line arrays (Figure 9). A total of 100,744 transmissions, from 31 detected lobster tags, were logged from November 1, 2011 through August 23, 2012 (Figure 11).

Most of the fall transmissions were received along the easternmost MPS line, with detections at all 12 stations spanning the passage; however, most lobsters were detected in the northern half of Minas Passage (Figures 12 and 13). Some lobsters were detected at many stations within the MPS array, indicating north-south movements. In the spring to summer 2012 period, tagged lobsters were spread throughout the line with many detected within the central region of the passage (Figure 12). Only five tagged lobsters were detected at multiple receiver line arrays.

Two of the 6 transmitters equipped with pressure sensors (3427, 8642), for determining depth of lobster, were detected in the Minas Passage. Based on pressure sensor data and known water depths at each station, there was no evidence of passive tidal movement of lobsters within the water column.

Overall, female lobsters were detected more often than males (Table 4). At the MPS and AULT receiver arrays, more females were detected than males. At the AULE and AUL arrays, equal numbers of each sex were detected.

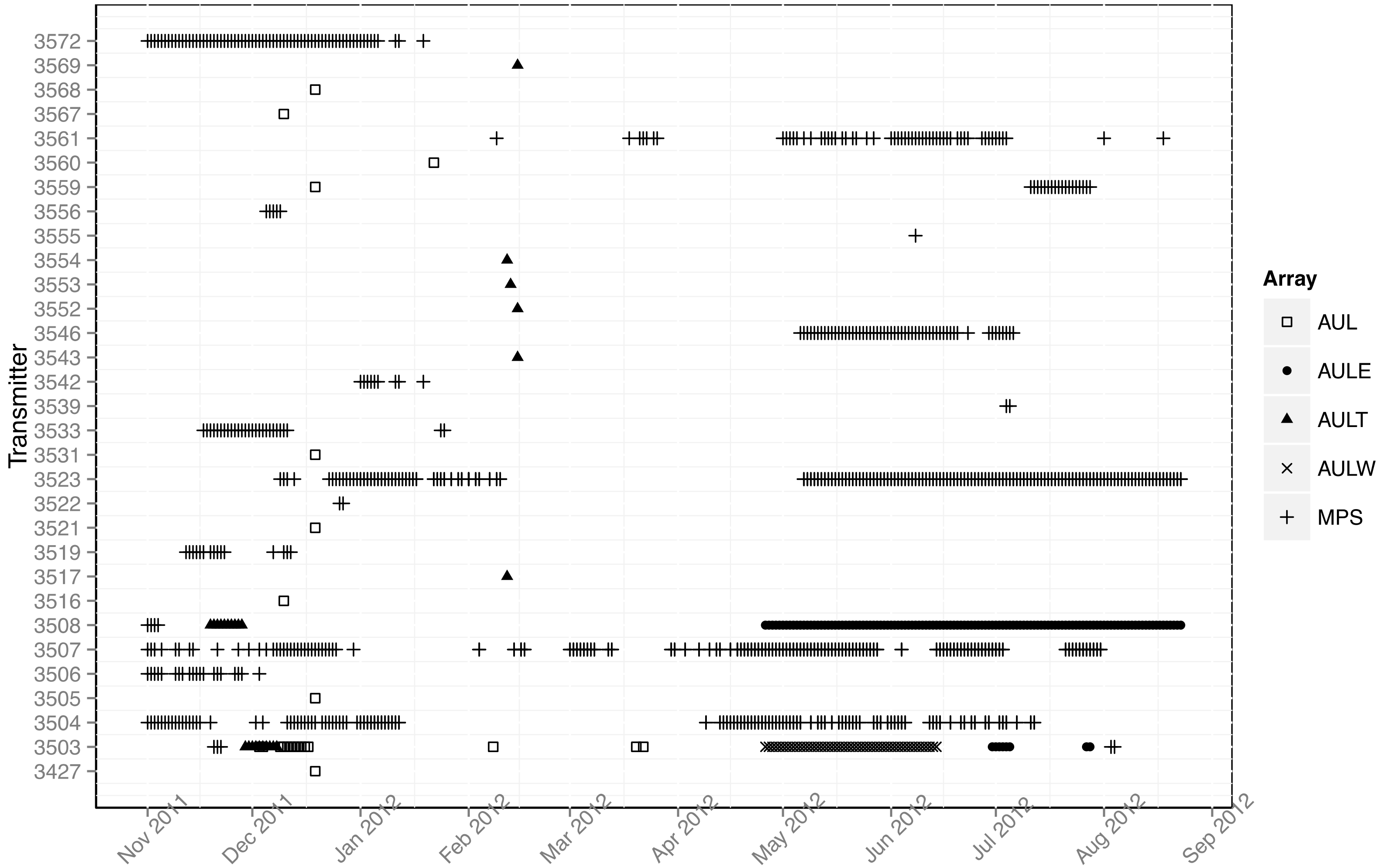

Figure 11. Daily presence of 2011-tagged lobsters at moored receiver arrays in the Minas Passage. Lobsters were tagged and released on November 1, 2011 and detections were logged until late August, 2012.

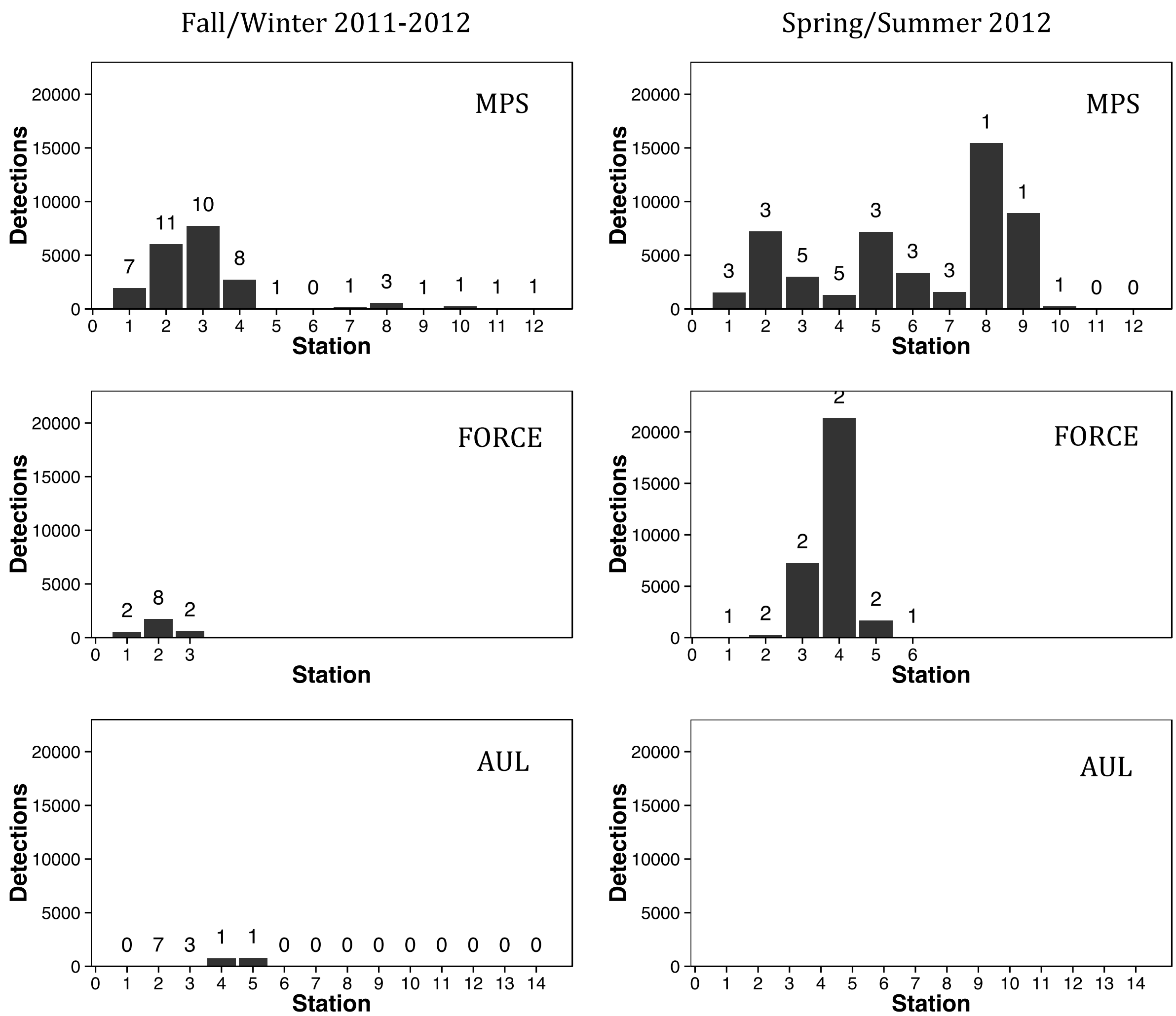

Figure 12. Tag detections (2011-2012) by array and station. Left panel: late fall/overwinter period (Nov 2011 – March 2012) detections of 2011-tagged lobsters at MPS (top), FORCE (AULT) site (middle), and AUL (bottom) receiver arrays in Minas Passage. Right panel: spring/summer 2012 (April – August 2012) detections of 2011-tagged lobsters at MPS (top) and FORCE (AULW and AULE) (middle) receiver arrays in Minas Passage. Numbers atop bars indicate the number of lobsters detected at that station. Note: AUL array not deployed during spring-summer 2012 period.

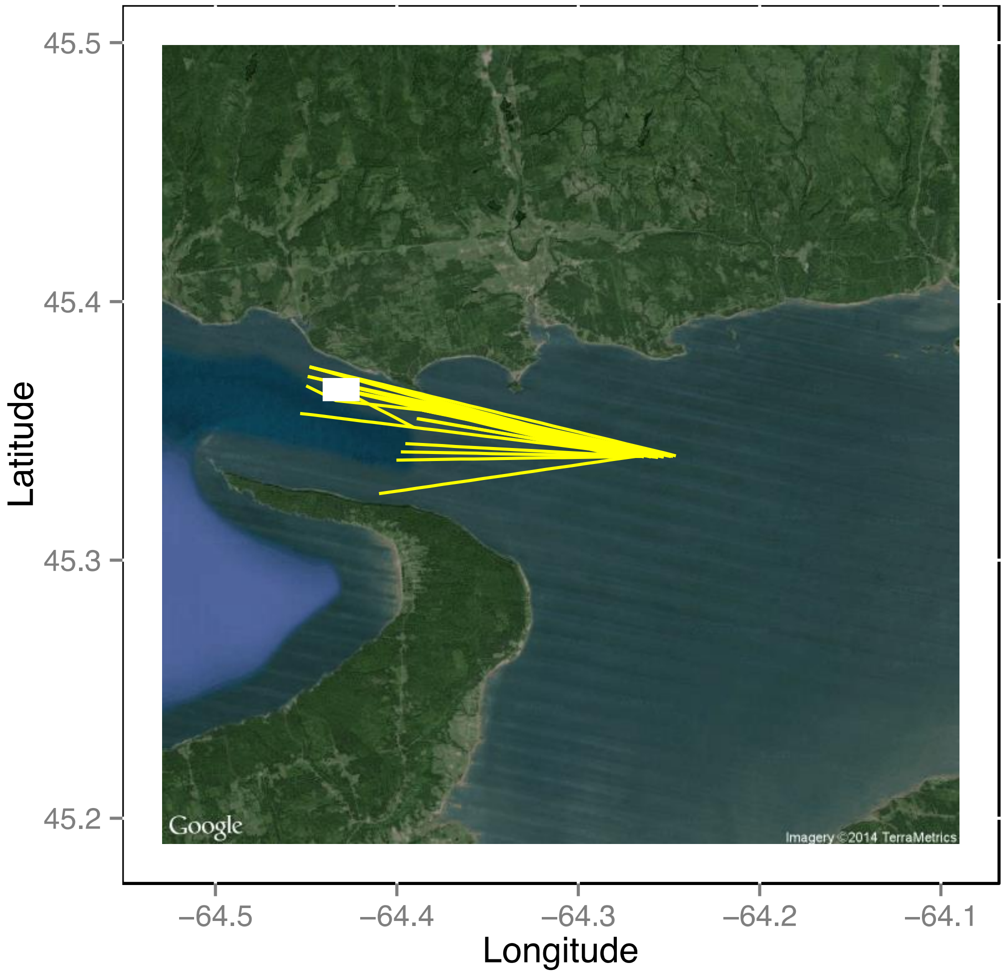

Figure 13. Trajectories of 2011-tagged lobsters from point of release to detection in the Minas Passage. FORCE test site shown in white.

Table 4. Number of 2011-tagged males (M), females (F), and berried female (F_B) lobsters detected by receiver array in the Minas Passage. Asterisk indicates FORCE test site.

	# M	# F	# F_B	Total
MPS	4	13	0	17 (20.0%)
AULT*	2	4	2	8 (9.41%)
AUL	5	3	2	10 (11.8%)
AULE*	1	1	0	2 (2.35%)
AULW*	0	1	0	1 (1.18%)
All receivers	10	17	4	31 (36.5%)

Two of the 2011-tagged lobsters (3508 and 3523) were detected for 9-10 months, until battery exhaustion, indicating that they were relatively stationary or that the tags had been dislodged from the carapace. A similar case was observed in 2012 with transmitter 7668.

Detection patterns with respect to tidal cycle were plotted for June 1, 2012 using data collected from transmitter 3523 (Figure 14). The time at which most transmissions were logged was when the average water column current speed was less than 1.5 m/s. This lobster was first detected in late November 2011 at MPS stations 10 and 11, and was present within detection range of MPS 09 to MPS 12 until 31 December 2011. Lobster transmitter 3523 was again detected at the MPS line (stations 09 and 10) during May through August 2012.

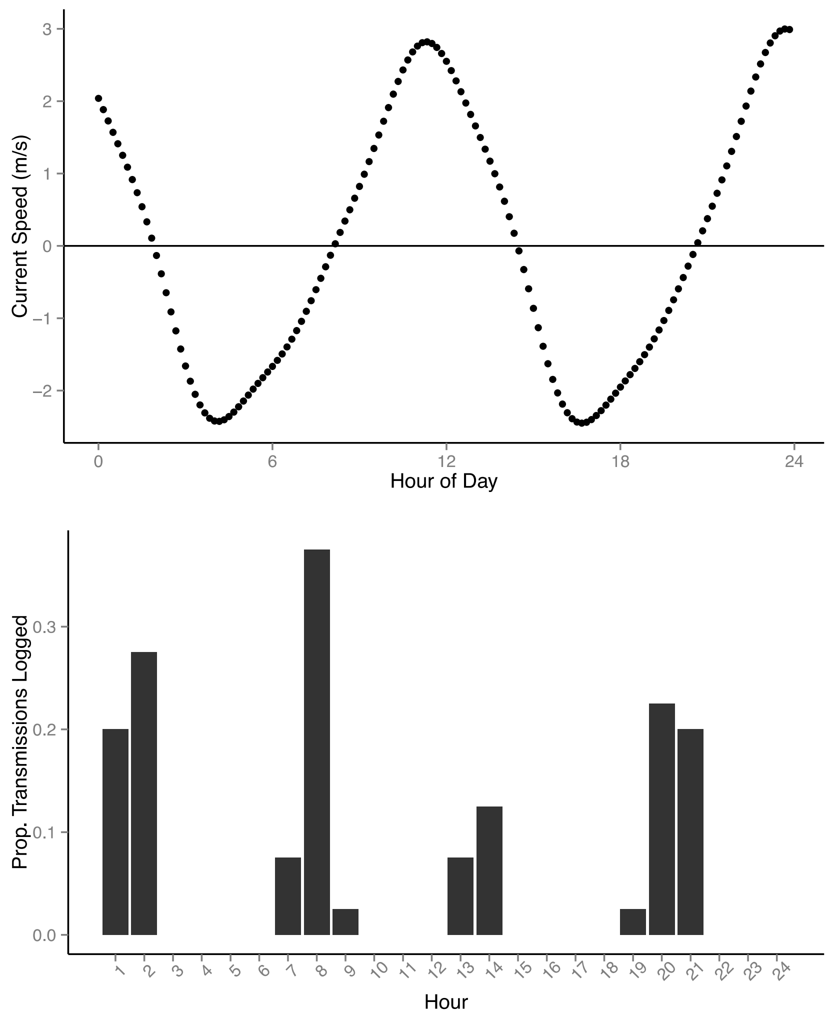

Figure 14. Top: modeled depth-averaged current speed (m/s) on June 1st, 2012 at station MPS 08. Horizontal line indicates slack water. Bottom: the proportion of the tag 3523 transmissions emitted per hour (based on one transmission per 90 sec) that were detected at MPS 08 on 1 June 2012. Modeled current data provided by Richard Karsten and Brian Sanderson.

Some tagged lobsters were in receiver range for short periods of time (days) while others were detected continuously for several months. In some instances, the latter case can be indicative of a dislodged transmitter. Detection distribution plots for tagged lobsters are shown in Figures 15-16. Overall, there were few detections in and near the FORCE test site. Most tag detections were logged on receivers of the MPS line.

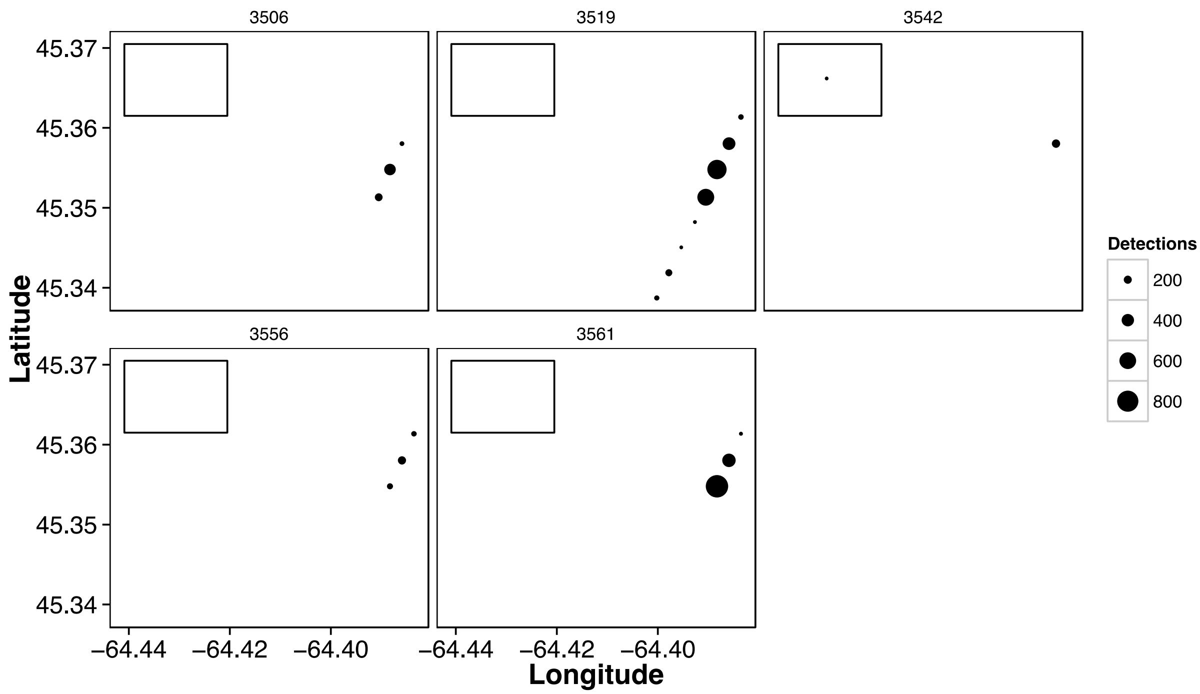

Figure 15. Plots of tag detections (2011-tagged lobsters) logged by Minas Passage receivers during 2011-2012. Dot sizes (10-800 detections per tag) indicate number of transmissions received. FORCE site shown as black rectangle.

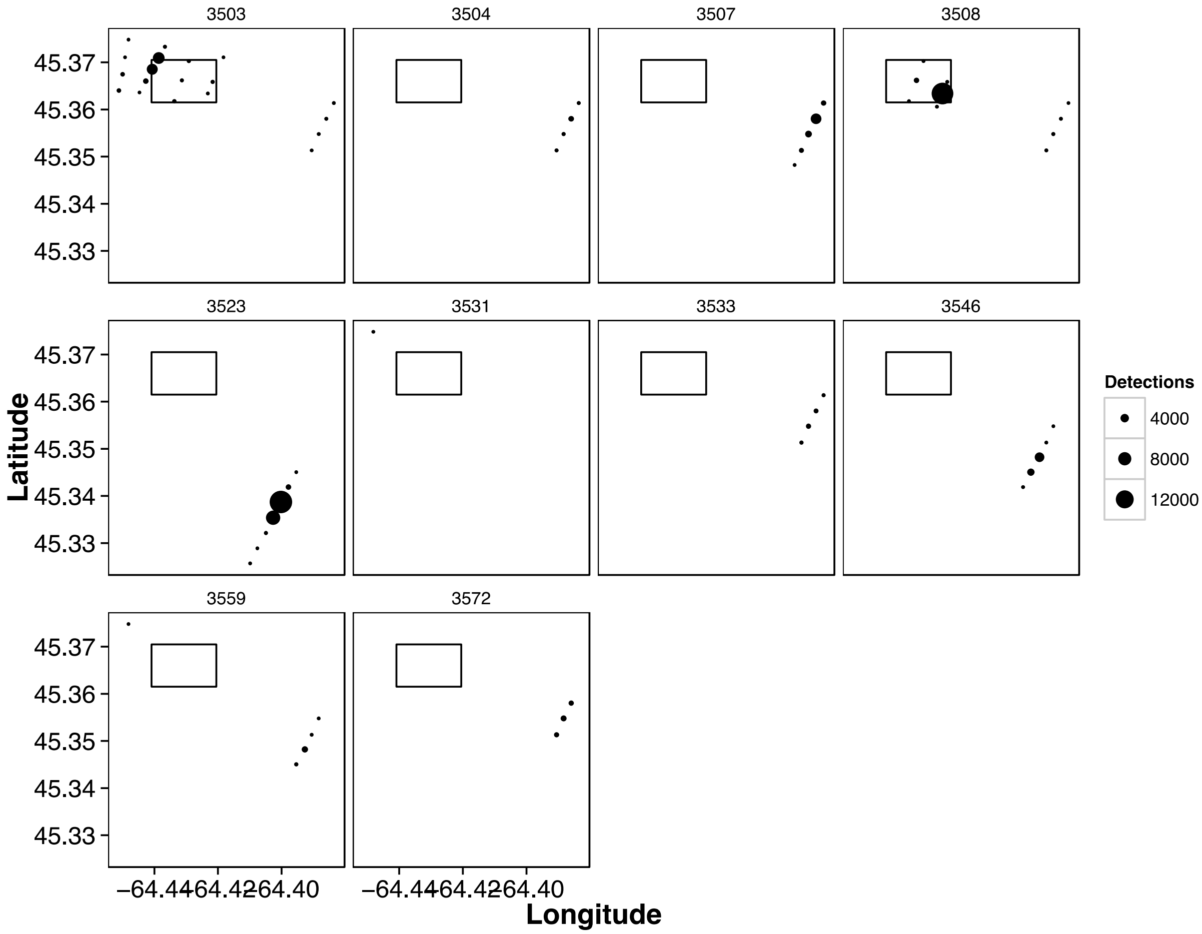

Figure 16. Plots of transmission detections (2011 tagged lobsters) logged by Minas Passage receivers from 2011-2012. Dot sizes (>1000 per tag) indicate number of transmissions received. FORCE site shown as black rectangle.

Speed of lobster movement between receivers (assuming a straight path) was calculated for males and females (with and without eggs), by dividing the distance traveled by the time since release. Mean travel rates (Table 5) were not significantly different (H=0.2206, df=2, p=0.8956). Although female lobsters exhibited a greater range of travel rates (exceeding 1.5 km/day) than male lobsters, the movements of lobsters of both sexes rarely exceeded 500 m/d; most of the estimated travel rates were <250 m/d (Figure 17). It should be noted that these movement rate calculations are minimum estimates (overall displacement through time) and it is possible that lobsters moved more quickly or slowly between points of detection; it is unlikely that movement occurred in straight lines. Angle of movement of tagged lobsters during the fall 2011 outward migration showed, as expected, that the majority of lobsters moved in a north-westerly direction through the Minas Passage (Table 5).

Table 5. Estimated movement rates (kilometres per day) and angles (degrees from north) for 2011-tagged lobsters. Speeds were calculated for distances between the release position and a detection point or between two detection points. F=female, M=male, F_B= berried female.

Sex	**N**	**Mean Rate of Movement (km/day)** ± SD	**Mean Direction of Movement (angle from north, degrees)** ± SD
All	31	0.33 ± 0.34	283 ± 63.7
M	8	0.27 ± 0.12	284 ± 15.4
F	23	0.35 ± 0.39	282 ± 64.8
F_B	5	0.24 ± 0.17	283 ± 13.5

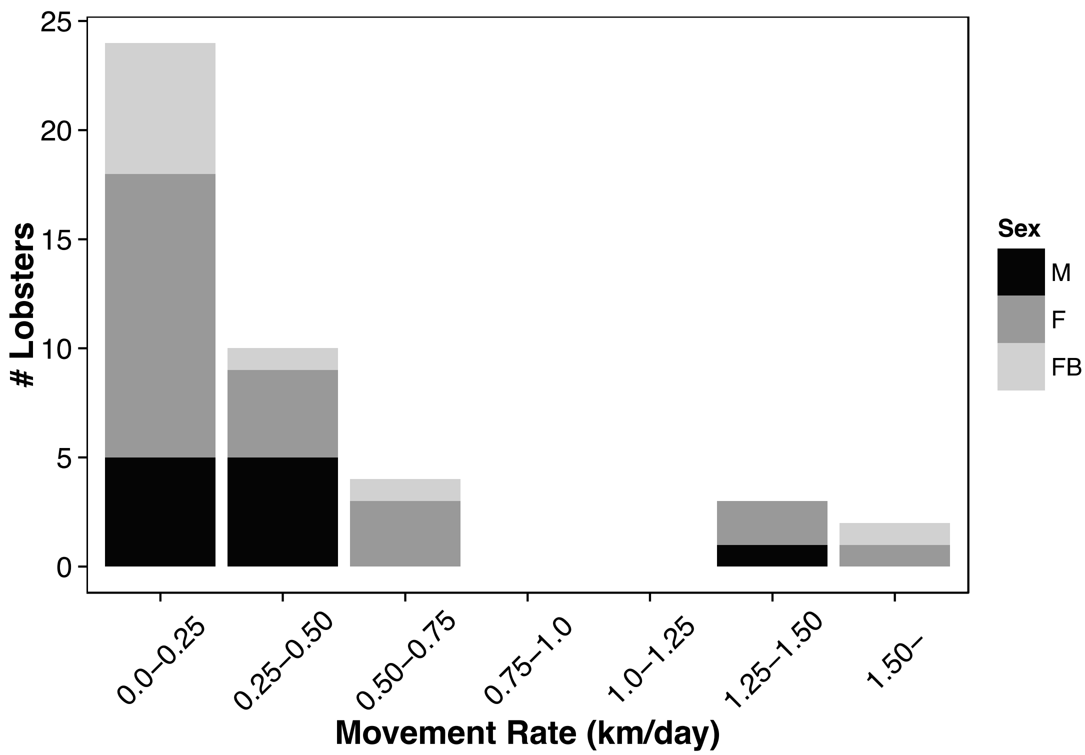

Figure 17. Movement rates of female (F), berried female (F_B), and male (M) lobsters tagged in 2011 and detected in the Minas Passage (n=31 lobsters).

Fisher Tag Returns

Fishery-dependent data were obtained from disc-tag returns from LFA 35 lobster fishers. A reward of $25 per recapture report was provided to fishers; despite this incentive, it is known that several tags are still outstanding from fishers for the 2011-2012 fishing season. In total, 18 tags were returned (17 from 2011 tags, 1 from 2012 tags) by five fishers (Table 6). Eight recaptured lobsters were female, including one berried, and 10 were male.

Four 2011- tagged lobsters, two male and two female, were recaptured within the central and eastern Minas Basin within 16 days of their release. Four more 2011-tagged lobsters, two male and two female, were recaptured in the central and western Minas Basin within 2 months of their release (1 November). The remaining nine 2011-tagged lobsters were recaptured the following spring (N=8, four male, three female, one berried female), and one male was recaptured in November 2012. The single recaptured 2012-tagged lobster was a male retrieved in the western Minas Basin in spring 2013, approximately five months after its release.

Because tag return data are only possible when the lobster fishing season is open, it provided no further insights into overwintering tendencies of lobsters in the Minas Passage and Basin. Tag return data were also unable to increase knowledge of the migratory extent of tagged lobsters.

Fishers were asked to report the presence/absence of the acoustic transmitter; 14 of 18 tag return reports included this information. Return data indicated that the acoustic tags remained attached in 11 of 14 lobsters recaptured, a 78.5% retention rate. Tag losses were only reported for recaptured lobsters that were at large for longer than 150 days.

Six of the recaptured lobsters were detected by an acoustic receiver in the Minas Basin (Five Islands) or Minas Passage. One 2011-tagged female lobster (3519) was detected acoustically by 7 receivers on the MPS (north to south) receiver array in November and December 2011; it was recaptured by a fisher in Minas Basin the following spring.

Table 6. Fisher tag return data for 2011 and 2012-tagged lobsters, indicating transmitter number, sex (M=male, F=female, F_B=berried female), if transmitter was attached upon recapture (Y=yes, N=no, ND=no data), recapture location (MB=Minas Basin, w=west, c=central, e=east), distance from release (km), date recaptured, and if the lobster was also detected at a receiver station (Y/N).

Tagging Year	Trans. #	Sex	Trans. attached (Y/N)	Recap. Location	Dist. from Release (km)	Recap. Date (yy-mm-dd)	Days at Large	Tag Detection (Y/N)
2011	3424	M	Y	MB (w)	2.67	2011-12-05	34	N
	3426	M	Y	ND	ND	2012-05-19	200	N
	3509	M	Y	MB (e)	28.8	2012-06-19	231	N
	3519	F	N	ND	ND	2012-05-21	202	Y
	3522	F	N	MB (c)	13.2	2012-06-01	157	Y
	3524	F	Y	MB (w)	2.73	2011-12-06	35	N
	3526	F_B	Y	MB (c)	3.47	2012-05-19	200	Y
	3530	M	Y	MB (c)	1.77	2011-12-05	34	N
	3544	M	ND	MB (c)	2.45	2012-11-15	380	N
	3555	M	Y	MB (c)	0.88	2011-11-09	8	Y
	3557	F	Y	MB (w)	4.91	2011-11-16	15	N
	3561	F	Y	MB (c)	1.02	2011-11-09	8	Y
	3563	M	N	MB (c)	3.37	2012-06-20	232	N
	3566	F	Y	ND	ND	2011-12-16	45	N
	3569	M	Y	ND	ND	2011-11-14	13	Y
	3570	F	ND	ND	ND	2012-06-18	230	N
	3571	M	ND	ND	ND	2012-05-25	206	N
2012	8630	M	ND	MB (w)	2.1	2013-05-16	163	N

Year 1 Main Conclusions

Recovery rate of receivers was very high (96%) but data gaps remain. Receiver units not recovered may hold data on lobsters that passed through the MPS line undetected. In a few cases, lobsters were detected by the AUL (FORCE) lines but not the MPS receiver line array which is closer to the Minas Basin.

Lobsters were detected moving through the Minas Passage, preferentially using the northern half of the passage. Female lobsters tended to move further and many moved faster than males. Of the 31 lobsters detected, 22 were detected at the MPS line, 10 at the FORCE site (AULT, AULE and AULW), and 10 at the AUL line. None of the berried females tagged in 2011 were detected at the MPS line but four were detected for brief periods of time at the AULT or AUL line. The detection of lobsters carrying eggs in the western region of Minas Passage in mid/late December supports the hypothesis that berried females exit to the outer Bay of Fundy.

Tagged lobsters showed a preference for the northern half of the Minas Passage, with more than two thirds of transmissions logged in this area. This could be an artifact of where the lobsters were sourced and released; lobsters used in this study were obtained from LFA 35 fishers working from Parrsboro, located on the northern shore of the Minas Basin. Lobsters collected from the northern region of Minas Basin would be expected to travel along the northern shore of the Minas Passage. Exceptions included one 2011-tagged lobster (female) first detected in late fall 2011 at the southern end of the MPS array and a few others detected in the deeper central region of Minas Passage.

Prolonged localized presence of a transmitter may indicate a dislodged transmitter or a lobster remaining resident within range of a receiver station. It appears that some lobsters only travel as far west as the MPS line or remain within the Minas Basin year-round. Fisher tag returns assisted in providing data within the Minas Basin, but only when the fishing season was open.

The data gap resulting from a lack of winter detection data, due to recovery of receivers for maintenance purposes, is addressed in the 2^{nd} year of study. Tag return data submitted by LFA 35 fishers supplemented the acoustic dataset but provided time and location data only for tagged lobsters recaptured within the Minas Basin.

Year 2 Acoustic Tracking of Lobsters

Objectives

The 2012-2013 study is an extension of the 2011 lobster tracking project, and aims to address questions left unanswered with the previous study. Objectives were to:

1) utilize acoustic receivers moored throughout the winter months to monitor lobster use of Minas Passage during winter, spring and summer;

2) gauge the level of seasonal exchange of lobster between the Minas Basin and outer Bay of Fundy and assess the likelihood of overwintering in the Minas Basin; and

3) examine detection and movement patterns based on sex.

Acoustic Tracking Methodology

A scientific permit to tag adult lobsters with acoustic transmitters was issued by DFO on November 20th, 2012. Information packets were mailed to all licensed lobster fishers within LFA #35 in advance of conducting tagging operations. Mail outs included a letter describing the project, an informational poster with images depicting the position of tags on the lobster, and a tag return sheet with contact information.

Forty lobsters (20 male, 20 female) were sourced from Croyden Wood Sr.'s commercial fishing operation in the Minas Basin, NS on December 4, 2012. Tagging in 2012 was conducted 1 month later than in 2011 to reduce the likelihood of lobster recaptures and subsequent relocation by fishers. Lobsters greater than 90 mm carapace length (Table 7) were selected and processed using the same methodology as during 2011, but with additional application of epoxy over the top of the transmitter (Figure 18).

Table 7. Number and size (range, mean) of lobsters (male, female, berried female) tagged in December 2012. Half of the lobsters in each group were fitted with V13 tags containing a pressure (depth) sensor (V13P).

2012	Number Tagged (Pressure tags)	Size Range (mm)	Mean CL ±SD
Male	20 (10)	96 – 142	112 ± 14.7
Non-berried Female	10 (5)	96 – 122	106 ± 8.14
Berried Female	10 (5)	91 – 119	101 ± 10.2

Figure 18. American lobster fitted with a VEMCO V13 acoustic tracking transmitter, and conventional numbered disc tag attached by cable tie above the knuckle.

The tag ping rate was modified to 45-90 seconds to allow detection of flow-assisted lobster movements, if any. The expected battery life of transmitters with and without a pressure sensor was 148 and 196 days, respectively.

After tagging and drying of the epoxy, lobsters were released from the starboard side of the vessel at a pre-selected location east of the inner most array of acoustic receivers. The targeted release point, 45.35675, -64.33468, was located off of Partridge Island, approximately four kilometres from the MPS line array of receivers.

Acoustic receiver station positions for 2012 are shown in Figure 9. Further methodology and data analysis are described in the Year 1 lobster tracking section.

Results: Year 2 Lobster Tracking

Only six (15%) of the 40 lobsters tagged in 2012 were detected at the receiver arrays in the Minas Passage: four females (two berried) and two males. The majority of detections were logged at the MPS array (Table 8, Figures 19-21) with all other detections logged at the FORCE (AULE and AULW) lines. All detections were logged by stations located within the northern half of the Minas Passage. The maximum number of lobsters detected at a single receiver station was four (Figure 20).

Table 8. Summary of tag transmissions logged, by receiver array and sex of lobster.

Tag #	Sex	Pressure Sensor (Y/N)	Battery Life End Date	Number of Detections		
				MPS	AULE	AULW
7668	F	N	2013-06-18	28938	0	0
7672	M	N	2013-06-18	267	0	0
7675	(F_B)	N	2013-06-18	171	207	0
7678	(F_B)	N	2013-06-18	521	0	0
8642	F	Y	2012-05-01	136	0	0
7667	M	N	2013-06-18	0	0	1
				30033	**207**	**1**

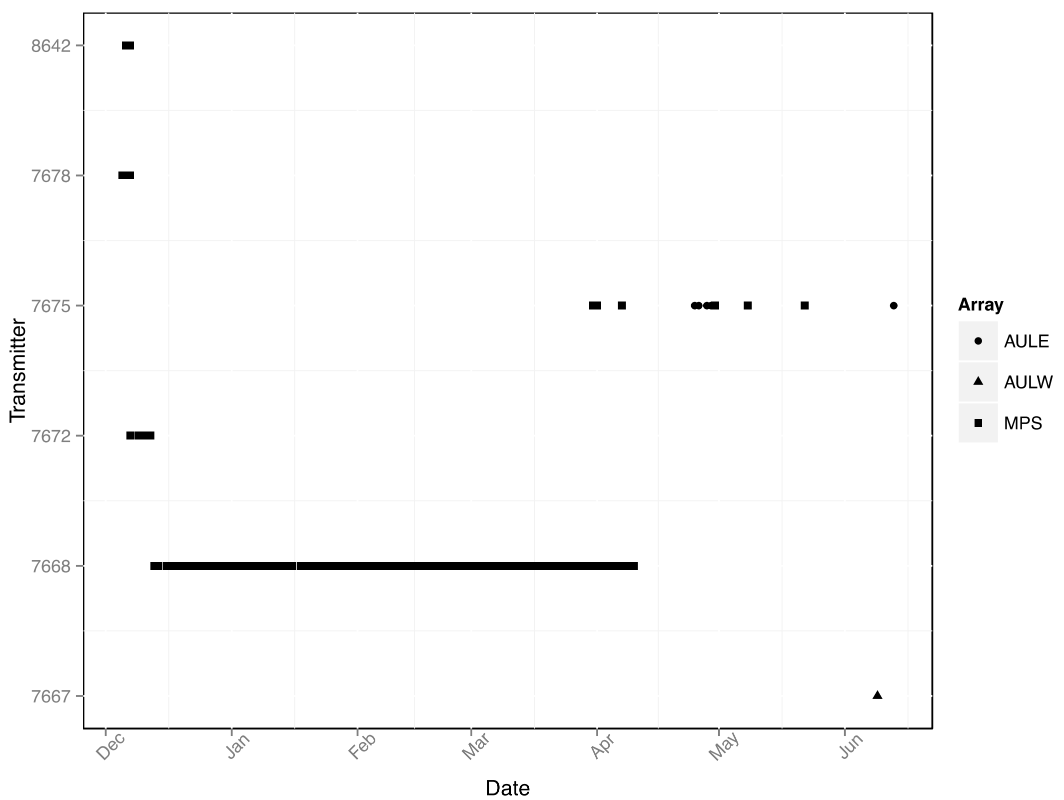

Figure 19. Detection of 2012-tagged lobsters, by receiver array, over the study period. Lobsters were tagged and released in Minas Basin on December 4, 2012.

One tagged female lobster was detected for a period of five months at the MPS line, logging the most transmissions of any 2012-tagged lobster (Table 8, Figure 19). Other detected lobsters were within detection range of receivers for shorter periods of time (1-12 days). Four lobsters were detected within a week of their release at the MPS line, with the remaining two detected in spring/summer 2013. The first transmission logged was on December 5, 2012 at the MPS line and the last on June 13, 2013, within three days of expected battery life expiration.

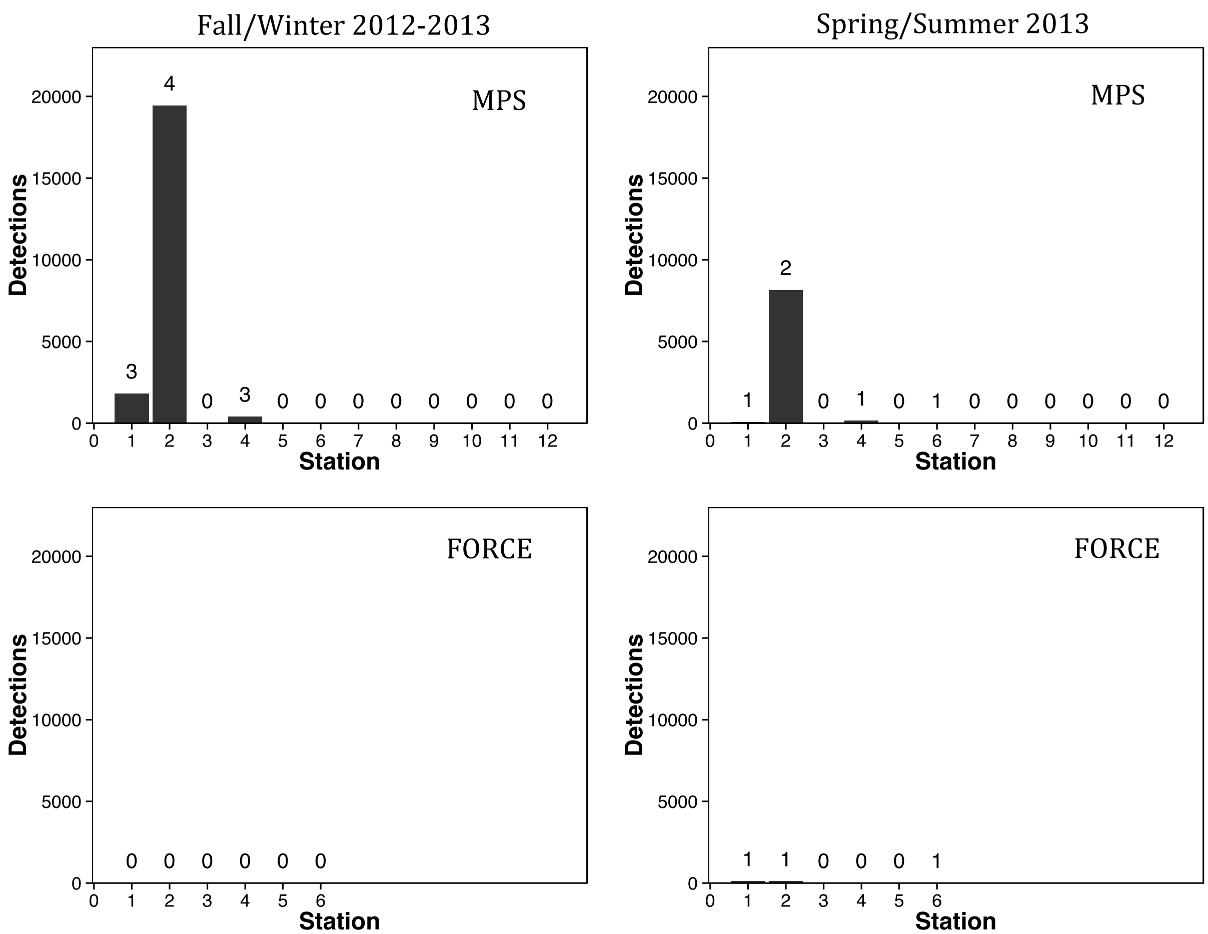

Figure 20. Tag detections (2012-2013) by array and station. Left panel: late fall/overwinter period (Dec 2012– Feb 2013) detections of 2012-tagged lobsters at MPS (top) and FORCE (AULW and AULE) (bottom) receiver arrays in Minas Passage. Right panel: spring/summer 2013 (March – June 2013) detections at MPS (top) and FORCE site (bottom) receiver array. Numbers atop bars indicate number of lobsters detected at that station.

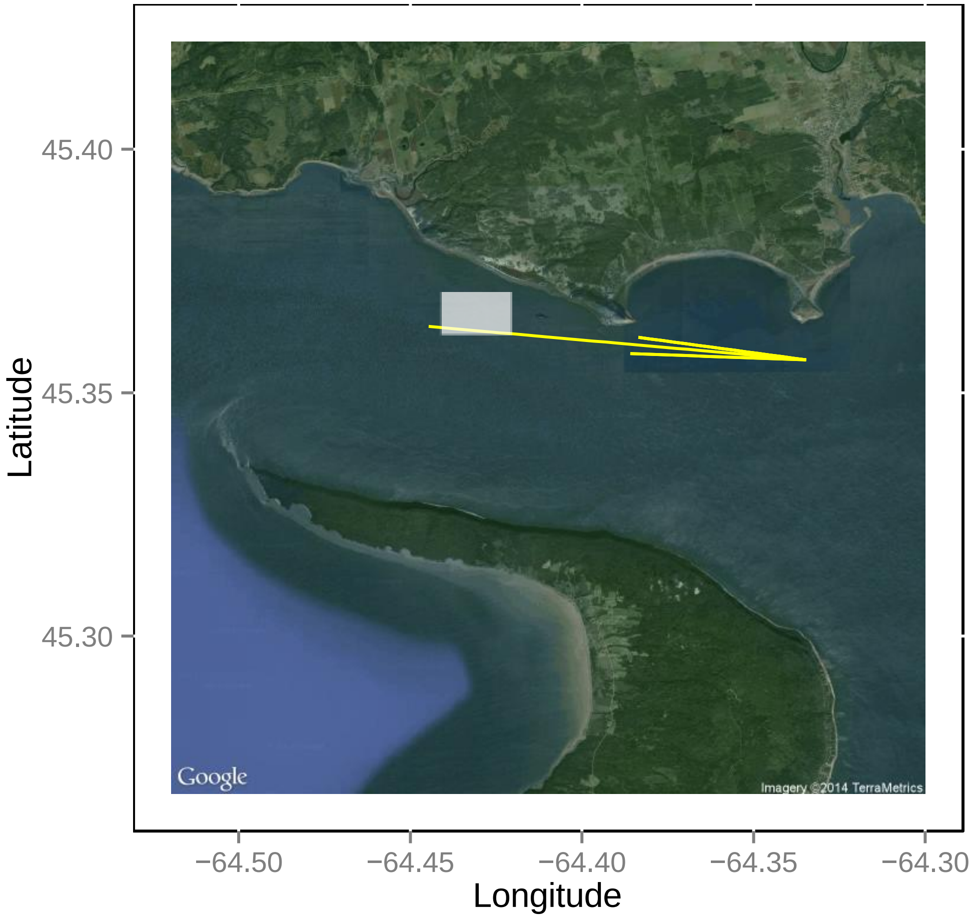

Figure 21. Trajectories of tagged lobsters from point of release to moored acoustic receiver arrays in the Minas Passage, 2012.

Detected transmitter 8642 was equipped with a pressure sensor that indicated movement between depths of 26 and 80 m. These values coincide with the depths of two receivers (MPS 01, MPS 02) that detected the lobster. Again, there was no evidence of lobsters moving within the water column (tide-assisted).

Movement rates were calculated for those tagged lobsters detected at one of the moored receiver arrays soon after tagging. The overall mean movement rate was 1.21 km/day ± 1.47 km/day (Table 9, Figure 22). Females moved more quickly than males. All detected lobsters were located in the northern portion of the Minas Passage, traveling with trajectories greater than 263 degrees from north (Table 9).

Table 9. Distance travelled, time between release and first detection, movement rate (km/day, assuming straight line movement path), and angle of travel (degrees from north) for tagged lobsters detected in Minas Passage.

Sex	N	Distance (km)	Time until 1st Detection (days)	Mean Movement (km/day ± SD)	Mean Angle of Movement (± SD)
All	7	4.6 ± 1.83	48.5 ± 73.6	1.21 ± 1.21	282 ± 21.0
M	2	6.3 ± 3.36	94.7 ± 130	0.69 ± 0.91	277 ± 2.12
F	5	3.9 ± 0.42	30.0 ± 49.3	1.42 ± 1.68	284 ± 25.4
F_B	3	3.9 ± 0.59	46.7 ± 61.6	1.27 ± 2.04	288 ± 35.2

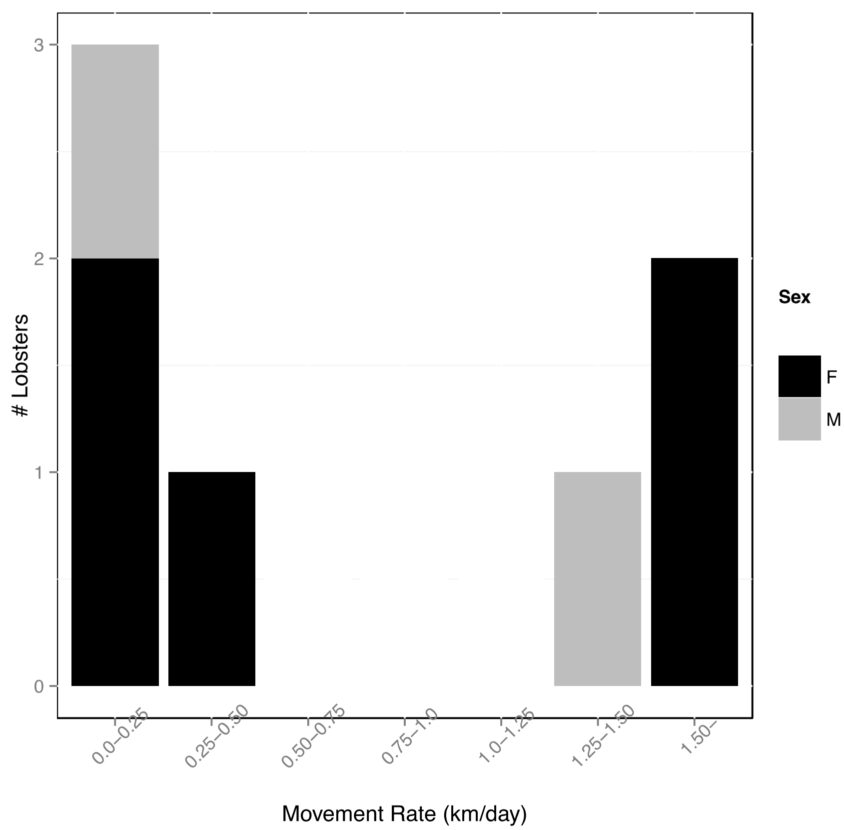

Figure 22. Movement rates (km/day) of tagged lobsters between the point of release and a receiver line or between multiple receiver lines. F=female, M=male.

Year 2 Main Conclusions

Compared with the 2011-tagged lobster detection data, the number of 2012-tagged lobsters detected was much lower (39% and 13%, respectively). This may be attributed to tagging animals later in the season (December vs. November), especially if lobster migration (for those that do migrate) commences prior to early December. Those lobsters that were detected in 2012-13 were, for the most part, detected at the innermost receiver array soon after they were released. None of these lobsters were detected on the receiver lines in western Minas Passage. And no lobsters showed evidence of current-assisted movement within the water column.

Late fall migratory movements across the northern side of the Minas Passage were observed in both years of study. However, it appears that a large proportion of the upper Bay of Fundy lobsters remain within Minas Basin (and possibly Minas Passage) throughout the winter months. This suggestion was supported by several lobster fishers during post study interviews. It is possible that migration occurs every second year in association with adult lobster molt cycles.

Final Comments

Compared to marine mammals, fishes, and diving seabirds, juvenile and adult American lobsters are at low risk of direct interaction with turbine blades at the FORCE test site. The effects of bottom-mounted infrastructure (electrical cables, moorings) on lobster are unknown; however, any increase in habitat heterogeneity due to installation of TISEC devices is likely to attract lobsters to turbine berth areas.

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