Population Characteristics of American Lobster (*Homarus americanus*) Captured in Commercial and Experimental Traps in Minas Passage and Minas Basin, Nova Scotia and Movements after Release Tagged with Streamer and Acoustic Tags

by

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SUMMARY

Potential tidal power development is being explored for Minas Passage, the body of water that connects Minas Basin to the Bay of Fundy. The Minas Passage-Minas Basin region supports an annual fishery for American lobster of ~200*t* worth about $2.86 million a year which may be impacted by future tidal power development. The biology of lobster in this region of Atlantic Canada is poorly known and our study was undertaken to elucidate population and movement characteristics of the local population as a baseline for future reference. The 2017-2018 study is the third in the region over the last ten years and was specifically designed to examine the presence and movement of berried, female lobsters. Overall a total of 9,694 lobsters captured in commercial and experimental lobster traps were examined during 2017 and 2018 for carapace length, sex, reproductive condition and molting phase. Of these 2981 were marked with individual numbered FLOY streamer tags and released for recapture information from commercial fishers and 50 were marked with VEMCO V9-2H acoustic tags attached to their carapace and tracked in Minas Passage and Minas Basin with an array of 56 acoustic receivers. Of the 50 acoustic tagged lobsters released 39 were berried females. Mean carapace length of males during Nov-Dec, 2017 was 101.7 mm; for females, 102.5 mm and during Aug-Oct, 2018 was 121.0 mm for males; for females, 115.7mm. During Nov-Dec, 2017 the male: female ratio of sampled lobsters was 1.0: 1.2 and berried females constituted 33.6% of overall females. During Aug-Oct, 2018 the male: female ratio was 1: 0.6 and 2.0% were egg-bearing. Females released larvae during June and early July, annual molt occurred in late July and egg extrusion commenced in October. Based on experimental lobster trap catches in Minas Passage and Minas Basin, lobsters were spread evenly over the sampled area in August but movement into Minas Passage occurred during autumn and the proportion of berried females in Minas Passage peaked in December at 50.4 %. Movement of lobsters marked with streamer tags in Minas Basin during autumn 2017 was from the Basin to the Passage by winter. A total of 23 (62.1 %) of acoustic tagged lobsters released in the Minas Passage-Basin region were detected after release. Similar to streamer tagged lobsters all moved into or remained in Minas Passage region for the winter. Lobsters marked with streamer tags and acoustic tags in Minas Channel were not detected in Minas Passage. Lobsters marked with streamer tags were observed to migrate throughout the Bay of Fundy and after one year at-large were reported from lobster traps off Advocate and as far away as Grand Manan and SW Nova Scotia. Movement of berried females into Minas Passage in autumn is probably a life history strategy that enhances the development rate of attached eggs in the relatively warmer water in this region during winter compared to the remainder of the Bay of Fundy. We propose the Nova Scotia shore lobster stock unit is independent from the stock along the New Brunswick shore of the Bay of Fundy. If survival of planktonic larvae, juveniles and/or adults is impacted by tidal power development in Minas Passage the productivity of the fishery will decline to the detriment of local fishers.

INTRODUCTION

The fishery for American lobster (*Homarus americanus*) is the largest by value in Atlantic Canada. Landings in 2018 from Lobster Fishing Areas (LFA) 33-35 (Fig. 1; Halifax-Inner Bay of Fundy) were 31,863*t* with a landed value of $502 million (DFO 2018) and represented about 60% of Canadian lobster landings. It is estimated that the annual value of lobsters to the Canadian economy is approximately $3 billion with large exports to the United States, the United Kingdom and China.

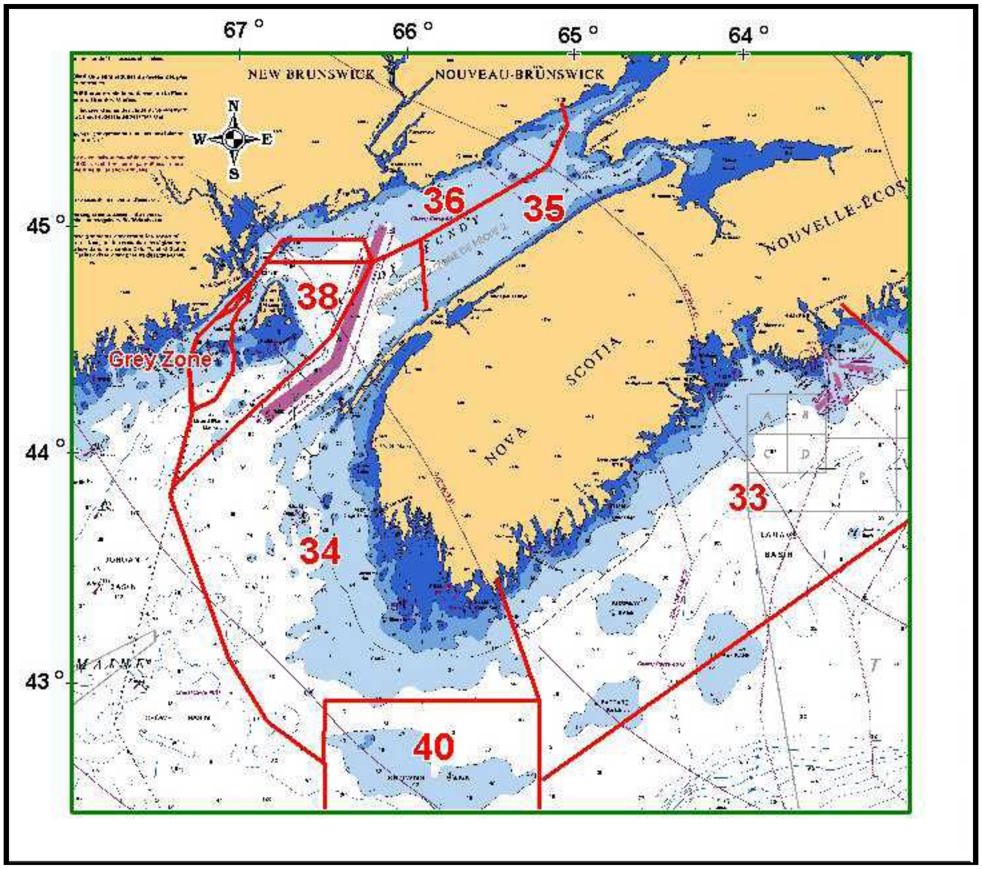

Figure 1. Lobster Fishing Areas in western Nova Scotia and the Bay of Fundy. The Minas Passage-Minas Basin fishery is in LFA 35 (after DFO 2018).

The Minas Passage-Minas Basin lobster fishery has annual landings of approximately 200*t* and during 2018 with a dockside price of $6.50/lb was worth about $2.86 million. A total of 29 fishers, operating out of Parrsboro on the north side of Minas Basin, Delhaven on the south side of the Basin and Halls Harbour in Minas Channel, share the fishery (Morrison 2014).

This well-defined fishery operates in Minas Passage and Minas Basin (Fig. 1; Lobster Fishing Area 35) during spring- summer (May – July 31) and fall (October 15 – December). Although the lobster fishery in this region is actually open during winter, fishing is not possible because of ice movement. Fishing is difficult because the large tides (11-16 m range) and strong currents (3-6 m/s) in this region cause lobster buoys to submerge except around high water and low water slack; a period of about 2-4 hours in each case. Trap hauls usually average only about 100/day/fisher but nevertheless daily yields are high both in the spring-summer and autumn and average about 400-500 kg (Dadswell et al. 2009). In LFA 35 the minimum allowable retention size is 88.5 mm carapace length (CL). Lobsters sampled from fishers traps range from 60 – 200 mm CL and the proportion of shorts (lobster < 88.5 mm CL) to markets is about 1:2. The sex ratio in the catch is approximately 1:1 and there is a high proportion of berried females.

American Lobster Biology

The American lobster is a member of the Arthropod clawed lobster family, Nephropidae. The basic body plan consists of two parts: the cephalothorax which represents the fusion of head and thorax; and the abdomen, often misnamed as the tail (Cobb 1976). Lobster are segmented and have appendages on every segment. Fourteen fused segments comprise the cephalothorax and the last seven segments, the abdomen. The cephalothorax is covered by a heavy, fused shell or carapace, but the abdomen is flexible because each segment has its own shell. It has two, large forward projecting claws which it uses for defense, prey capture and to process its food and habitat (Fig. 2). There are four sets of walking legs in the rear section of the cephalothorax and a large tail fan consisting of flattened appendages called the uropods and the telson. With these appendages lobsters can move rapidly, walking over the bottom or swimming to avoid predators, capture prey or move long distances to remain in preferred temperatures and salinity for growth, reproduction and survival.

The American lobster is distributed from Labrador to North Carolina and is found from the low tide mark out to depths of 400 m (Cobb 1976; Wahle and Steneck 1991). At the northern extent of its range lobster are found inshore at relatively shallow depths (0-100 m) but in the middle and southern portions of its range occur in deeper water and offshore in marine canyons (100-400 m). Lobsters occur on most any substrate from clay to cobble but generally select habitat with rocks where they can hide in crevices or burrow to hide from predators. With their large claws, numerous feet and powerful tails lobster dig away sand and gravel to make tunnels (Cobb 1976). The tunnels are used to hide from predators such as wolf fish, cod, flounder, crabs or other lobsters, for protection when molting and for reproduction.

Lobsters grow by molting their external shell (ecdysis; Cobb 1976). Molting can occur two or three times annually in young, smaller lobsters but for adult lobster takes place once annually usually during the warmest period of the summer (June-August). After molting their shell is soft and the lobster is especially vulnerable to predation. Lobster require 3-4 days to expand the new shell with their body and harden it. Growth of lobsters in the Bay of Fundy is relatively slow compared to growth in other Atlantic coast regions because of the lower annual accumulation of degree days in the cooler Fundy waters. Lobsters in the Bay of Fundy take about 6 years to reach 81 mm CL and another 2-3 years to attain commercial size (88.5 mm CL) and sexual maturity (90-100 mm CL; Campbell 1983).

Figure 2. An American lobster foraging in its natural habitat and clearly illustrating the asymmetrical claws used defense or for capturing and processing its prey. The claw on the right is the larger, heavily toothed crusher claw used to break open thick shelled clams and other heavily armored prey. The claw on the left is the cutter or ripper claw used to tear up the soft portions of prey or capture fast moving prey such as fish.

Lobster reproduction is complex (Cobb 1976). First males build and defend tunnel retreats from other competing males. Then the male produces pheromones which are released into the water to attract females. Reproduction can only take place when the female is in the soft-shell condition immediately after ecdysis. She enters the chosen males' burrow, molts, is mounted by the male and sperm transfer occurs. The female then stores the sperm in seminal vesicles. The male continues to defend the burrow and protects the female until she hardens her shell at which time she departs. About 2-3 mouths later the female makes her own burrow or finds a place to hide and at night turns on her back and releases her eggs which pass through the seminal vesicle, are fertilized, and as they are released through the oviduct the female 'glues' them to the swimmeret appendages on the underside of her abdomen. Individual females release between 5,000-40,000 eggs depending on size (Koopman et al. 2015). The female is now in the 'berried' condition and she carries them on her abdomen for nine to ten months until the larvae are ready to hatch (June-August; Perkins 1971). At this time the female again finds refuge and at night flips her tail to throw the hatching larvae into the water column. About a quarter of her eggs are released each night (Pandian 1970). Individual females reproduce once every other year so the maximum portion of berried females found in a local population seldom exceeds 50% in a given year (Cobb 1976; Campbell 1983).

The larvae are planktonic and swim upward in the water column to the upper 10m of the water column often remaining largely in the upper meter (Scarratt 1973). They pass through four larval stages and remain in the water column for about two months by which time in their fourth stage they finally look like small lobsters. During the fourth stage they commence migrating to the bottom substrate and when they find suitable bottom habitat they settle. Fourth stage larvae most often select cobble bottom (small stones) for settlement and when they have grown enough (two-three more molts) begin making complex burrows in which they hide feeding on the organisms that grow on the burrow walls (Berrill and Stewart 1973; Wahle and Steneck 1991). They move out of their burrows and begin foraging actively on the bottom when they are about 40-50 mm CL. They feed on most any kind of benthic organism including but not restricted to marine worms (Polycheata), isopods and other decapods particularly crabs (Crustacea), bivalve and gastropod mollusks, echinoderms including sea urchins, fish, and plant matter. They are also scavengers and cannibalistic.

American Lobster Movements

During the first years of their life American lobster juveniles remain hidden in or near their shelter to avoid predation (Wahle and Steneck 1991). When mature, lobster migrate to shallow depths in summer and deeper depths in winter and in numerous studies approximately 75% moved <15 km (Campbell 1986; Robichaud and Lawton 1997). Similarly research done in the southern Gulf of St. Lawrence concluded that of 42,445 lobsters that had been tagged and released with 8503 recoveries, most had moved only 2-19 km from their release points (Comeau and Savoie 2002). In the Bay of Fundy, the Gulf of Maine, the offshore regions of the Scotian Shelf and off New England, however, some lobsters undertake long distance migrations of 100 km or more (Campbell 1986; Campbell and Stasko 1986; Robichaud and Lawton 1997). The record distance for travel so far was 798 km by a lobster tagged off Alma in the inner Bay of Fundy and recovered on the southern side of Georges Bank.

In previous studies in Minas Basin lobster movements were found to be predominately over short distances. Dadswell et al. (2009) found that of 447 tag returns from fishers out of 2,633 lobsters tagged in Minas Basin and Minas Passage, only two were recovered elsewhere during the lobster season. Similarly, of 120 lobsters marked with acoustic tags and released in Minas Basin only 40 were detected moving through the receiver arrays in Minas Passage (Morrison et al. 2014). On the other hand, lobsters tagged in Minas Basin and at large for periods up to one year moved up to 100 km into the Bay of Fundy (Dadswell et al. 2009).

The Environment in Minas Basin and Minas Passage

Minas Basin (45º 19’N, 64º 00’W) is a mega-tidal, cul-de sac marine embayment on the eastern side of the inner Bay of Fundy and is semi-enclosed by the Province of Nova Scotia. The triangular basin is 80 km long and 29 km wide at the base and ~2000 km^2 in area. It consists of the central Minas Basin proper, Cobequid Bay the eastern extremity inside Economy Point, and the Southern Bight (Fig. 3). Maximum depth in the Basin is 17 m at low tide. Minas Basin has the largest recorded tides in the world (mean 11 m, maximum 16 m; Garrett 1972) and at low tide about one third of the Basin area (670 km^2) is exposed as tide flat (Bousfield and Liem 1959). The tidal regime is semi-diurnal and an estimated 3 x 10^9 m^3 of water flows in and out of the Basin with each tide (Karsten et al. 2008). Because of the extreme tides the water column is homogeneous for temperature and salinity. Sea surface temperature (SST) ranges from a peak of 16-22 C° in summer (Aug-Sept; Bousfield and Liem 1959) to -1.5– 0.0 C° in winter (Feb; Sanderson and Redden 2015). Winter is characterized by drifting ice pans up to 5 m thick which in some years cover most of the Basin from January to March and severely scour the substrate of the intertidal zone (Desplanque and Mossman 1998).

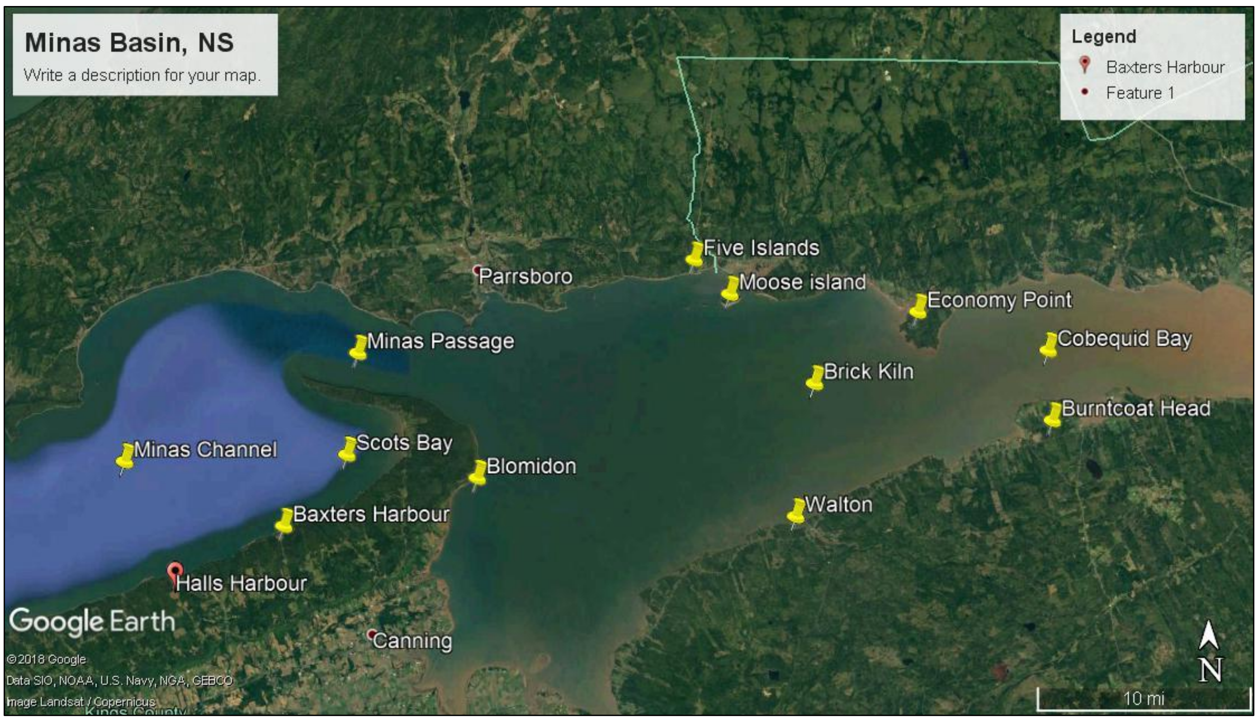

Figure 3. Minas Channel, Minas Passage and Minas Basin at the eastern extent of the inner Bay of Fundy. Locations highlighted with yellow markers are referred to in the text.

Minas Passage is the body of water connecting the inner Bay of Fundy with Minas Basin (Fig. 4). It is 15 km long and ~ 5 km wide with low tide depths of 35–115 m. The Passage is a region of complex and powerful currents caused by the extreme tides and shape of the shoreline. Approximately 14 billion metric tons (*t*) of water flow into and out of the Passage during each phase of the tide cycle, a volume greater than all the rivers on earth (Karsten et al. 2008). Tidal velocities from 3-6 m/s occur in Minas Passage during falling and rising tides and large gyres have been identified around Cape Split and Cape Blomidon (Greenberg 1984). The strong tidal velocities have scoured most of the substrate of Minas Passage to bedrock (AECOM 2009). Minas Passage has SST's of 14-16 C° from June to October (Bousfield and Liem 1959) and because of extensive upwelling the water column is isothermal from bottom to surface (AECOM 2009). The upwelling causes Minas Passage to be warmer in winter than Minas Basin. Winter temperatures range from 6.0 Cº in December to 1.0 Cº in March (Keyser et al. 2016).

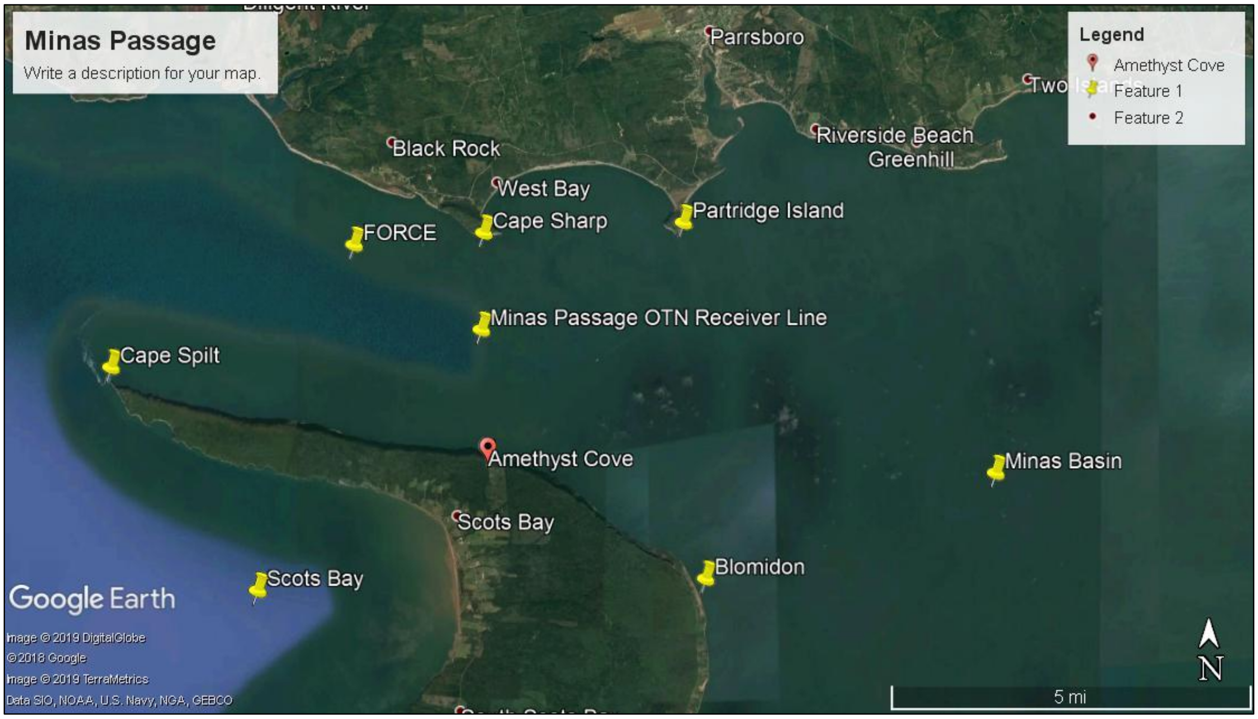

Figure 4. Locations in Minas Passage and Minas Basin referred to in the text.

Development of Tidal Power in Minas Passage.

The exploitation of tidal power for hydroelectricity from Minas Passage has become possible since the development of instream hydro-kinetic devices consisting of a wide range of potential designs (Gill 2005; Karsten et al. 2008). Some designs are axial-flow, hydraulic-lift propeller turbines similar in operation to those found in rivers and estuaries. These turbines have moving blades that can cause mechanical damage to aquatic organisms passing through the turbine draft tube (Dadswell and Rulifson 1994; Hammer et al. 2015). Inside the turbine draft tube there are also changes to the pressure and velocity of the water passing over the turbine blades that can cause mortalities from shear, pressure flux or cavitation (Dadswell and Rulifson 1994; Deng et al. 2005; Buckland et al. 2013; Zangiabadi et al. 2016). In 2018 Cape Sharp Tidal Power Venture installed a 10 blade, 16 m diameter propeller tidal turbine in Minas Passage that was proposed to develop 2 MW of power (Cape Sharp Tidal 2018). Unfortunately the turbine broke down soon after deployment. Other devices in planning stages function like wind turbines or egg beaters (FORCE 2017). Their impact on aquatic organisms has been less studied but may be less than from propeller turbines (Viehman and Zydlewski 2015). Still others produce electricity through the force of the tide on a large, floating kinetic keel (Big Moon Power 2018).

This device appears to have no potential danger to aquatic organisms but will preclude lobster fishers from utilizing the bottom area traversed by the kinetic keel.

The Fundy Ocean Research Center for Energy (FORCE) has developed a reserve for energy and environmental research in Minas Passage were companies can test tidal power hydro-kinetic devices and study their effects on the environment (Fig. 4; FORCE 2017). FORCE has an array of five acoustic receivers on their site. The Ocean Tracking Network (OTN) has an array across Minas Passage between Cape Sharp and the Cape Split headland consisting of 12 receivers.

The development of tidal power in Minas Passage has been an extreme concern to fishers of the region because of the unknown and potentially deleterious effects caused by the devices. Because of this concern for potential effects on the lobster fishery, Big Moon Tidal, lobster fishers, the Marine Institute of Natural and Academic Sciences and Acadia University partnered to study the biology and movements of American lobster in Minas Basin, Minas Passage and Minas Channel to establish a baseline of knowledge. The information gained will be used for comparison to the Minas lobster populations in the future and to determine if any significant effects from tidal power development have occurred.

METHODS

The study involved four stages. First, catches from commercial traps during Nov-Dec, 2017 and study trap sampling during Aug-Oct, 2018 were examined to determine biological characteristics of the lobster population in LFA 35. Second, lobsters supplied by fishers from their traps during Nov-Dec, 2017 were tagged using streamer and acoustic tags and released into Minas Basin, Minas Passage and Minas Channel to examine lobster movements. Third, an acoustic receiver array and experimental lobster traps were deployed in Minas Basin and Minas Passage during Apr-Dec, 2018 to monitor the abundance, reproductive characteristics and movement of the lobster population. Fourth, the movement data collected from lobster sampling, tag returns and acoustic detections from all acoustic receivers in the study area were analyzed. In order to complete our analysis and provide a comprehensive scientific report on the status of American lobster in Minas Passage and Minas Basin we also incorporated data from the 2008 study (Dadswell et al. 2009) for sampling outside the periods covered in the 2017-2018 study and for long-term tag returns.

Lobster Sampling November-December, 2017 and August-October, 2018

Lobster traps were set by fishers and allowed to soak for time periods between 1-3 days. For at-sea sampling personnel went on board the fishing vessels when pre-set lobster traps were hauled. During Nov 1- Dec 22, 2017 sampling was conducted in Minas Channel, Minas Passage and Minas Basin (Fig. 3, 4).

Lobsters were measured for carapace length (CL), examined for sex and whether egg-bearing (berried) and molt stage determined (soft/hard). Lobsters were tagged with streamer tags and released immediately or acoustic tags and released after the Epoxy resin was dry.

A total of 28 experimental lobster traps were deployed in Minas Passage and Minas Basin from Aug 6-Oct 13, 2018 (Fig. 5; Appendix 1). Traps used were the standard, commercial type similar to those used by fishers during the 2017 survey. Traps were set on the north side of Minas Passage (7), south side of Minas Passage (5), north side of Minas Basin (8) and the south side of Minas Basin (8).

Traps were baited and fished every 2-3 days. Captured lobsters were counted, measured for carapace length, examined for sex and whether berried, and assessed for molt stage (soft/hard). Lobsters sampled from fisher lobster traps set in Minas Passage during Jun-Jul, 2008 were treated similarly and results from these data were included with our 2017-2018 data to examine the annual Minas Passage- Basin molting, egg extrusion and larval release cycles.

Lobster catches were analyzed for mean CL of males, female and berried females, sex ratio, proportion of berried females and molt stage. Population characteristics found during 2017 and 2018 were compared using Student's t-test ($p<0.05$; Zar 2010).

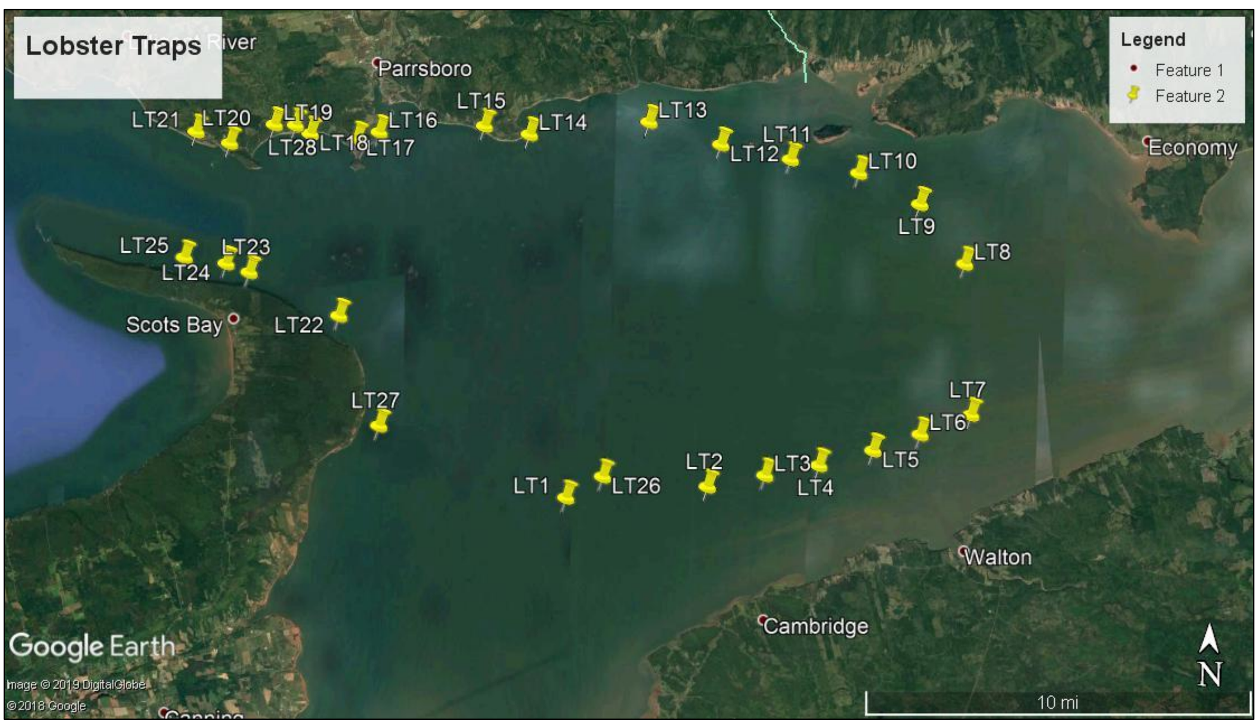

Figure 5. Distribution of experimental lobster traps in Minas Passage and Minas Basin during August 6 – Oct 14, 2018. American lobsters were captured for assessment of abundance, population characteristics, reproductive stage and lobster movement.

Lobster tagging November-December, 2017

Streamer tags used were FLOY yellow, plastic tags with a printed ID number and return address on each tag so that individual lobster could be identified and their return data associated with their ID number (Fig. 6). Printed tags were brightly colored for easy identification when caught by fishermen. Tags were inserted into the flesh on the underside of the abdomen between the second and third segments. Approximately 10 cm of tag was obvious to view on each side of the abdomen. Plastic streamer tags have excellent retention (98%), do not affect the lobster physically, and are usually not lost during molting and other activities (Scarratt 1970; Comeau and Mallet 2003).

Figure 6. A lobster tagged with a yellow FLOY streamer tag through the underside of the abdomen. This lobster was MCG0473. It was a hard-shelled, 70 mm CL male captured off Halls Harbour in Minas Channel on Nov. 3, 2017. To date it has not been recaptured.

Acoustic tags used were VEMCO V9-2H. The tag was attached to the dorsal surface of the lobster carapace with 5-minute epoxy resin adhesive (Fig. 7). First the lobster was placed on a level, damp surface (wet paper towel) to alleviate desiccation. Then the dorsal surface of the carapace was washed with isopropyl (rubbing) alcohol and allowed to dry for five minutes. The epoxy resin was mixed and applied to the carapace surface and the tag pressed into the epoxy. The epoxy was allowed to dry for one-half hour at which time the lobster was released back into the sea. Release sites were fixed for latitude and longitude using a handheld GPS meter (Garmin Etrex HTC; accuracy ± 3 m).

A total of 50 acoustic tags were released during November 1-26, 2017. VEMCO V9-2H tags are 9mm in diameter, 24 mm in length and weigh 2.9 gm in water (VEMCO 2019). At a signal phase of 180 s they have a life span of 324 days. Underwater reception range of acoustic pings was 0-400 m depending on current speeds (Morrison 2014).

Figure 7. An acoustic tag (VEMCO V9-2H) attached to the dorsal portion of a lobster carapace using epoxy adhesive. This is acoustic lobster 986 which was a berried female of 145 mm CL. She was released on the north side of Minas Passage on November 1, 2017 and was detected at the OTN line from November 6-22, 2017 and then at the FORCE site on December 1, 2017. During 2018 she was detected numerous times back at the middle to the northern end of the OTN line before returning to the FORCE site in late July then back to the OTN line in August. During a period of 293 days she moved a minimum distance of 8.8 km.

Deployment of Acoustic Receivers 2017-2018

A total of 11 VEMCO VR2W acoustic receivers were deployed by the Ocean Tracking Network (OTN) at their Minas Passage array from Cape Sharp on the north side of Minas Passage to the Cape Split Headland on the south side of the Passage (Fig. 8). The receivers were deployed and data was available from Nov. 1, 2017-Nov. 20, 2018. Downloads occurred approximately every four months. Receivers were titled MPS001-MPS012. MPS007 was lost after June 2018. Range testing of these receivers indicated that acoustic tag receptions were lost when current speeds exceeded 1.5 m/s or for about 80% of each tidal cycle (Morrison et al. 2014). On the other hand, when current speeds were low (twice every 6 h) receptions were obtained from a distance of 200-400 m. Receiver spacing allowed maximum coverage and optimization of receptions (Clements et al. 2005)

A total of 5 VEMCO VR2W acoustic receivers were deployed by FORCE at their tidal, hydroelectric test site (Fig. 8). The receivers were deployed and data was available from Nov. 30, 2017 to Aug. 23, 2018. Receivers are W1, W2, E1, D1 and S2.

A total of 40 VEMCO VR2W acoustic receivers were deployed on moorings in Minas Passage and Minas Basin during Apr-Dec, 2018 (Fig. 9, Appendix 2). Receiver latitude and longitude at deployment were determined with a handheld Garmin meter. Receivers were deployed on the north side of Minas Passage (M1-M6), north side of Minas Basin (M7-M15), south side of Minas Passage (M34-M40) and in the southern Minas Basin (M16-M33). Receivers were deployed from April 4-Dec. 16, 2018 (Appendix 2). Receivers were visited once a month and downloaded to guard against loss of data.

Analysis of Lobster Movement in Minas Basin, Minas Passage and the Bay of Fundy.

Catch/trap and percent female lobster abundance was determined from trap data collected during Aug 8-Oct 14 and analyzed for seasonal variation. To corroborate trap catch data movement of lobsters marked with streamer tags and acoustic tags were analyzed for direction and distance of movement. Acoustic receptions in Minas Passage and Minas Basin were analyzed with the R-statistics package (R Core Team 2013) for number of detections, acoustic tag identification, duration and time of presence near each receiver. Lobster characteristics and seasonal movement from trap data, acoustic tags and streamer tags were compared for direction and distance moved (Ricker 1975).

Tag returns from commercial fishers and study sampling were mapped using Google Earth and analyzed for lobster characteristics (male/female, berried, molt stage), start and end point of movement, movement direction and distance traveled. Tag returns from the 2008 study (Dadswell et al. 2009) were incorporated with 2017-2018 tag returns to provide further demonstration of long-distance movements in the Bay of Fundy.

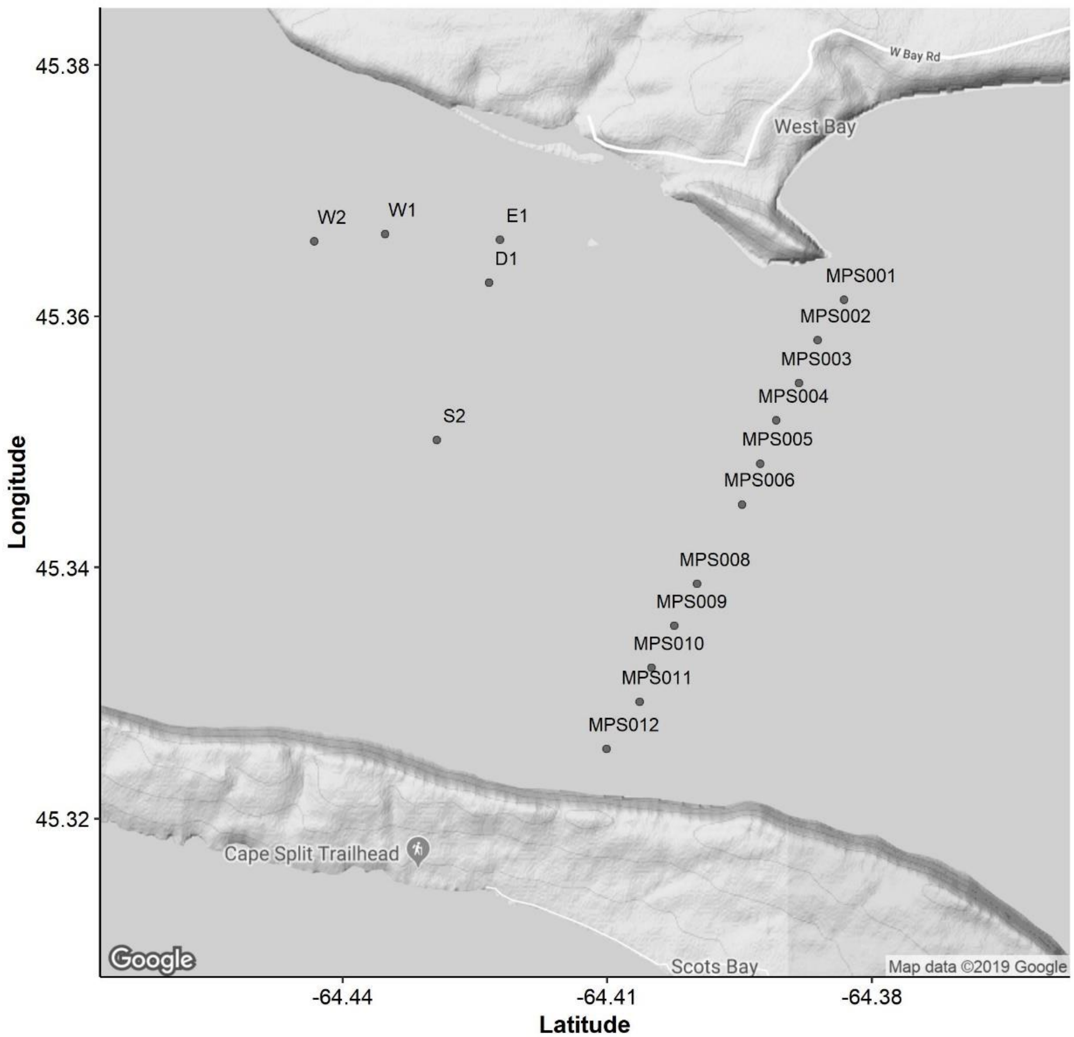

Figure 8. Positions of VEMCO VR2W receivers deployed by the Ocean Tracking Network (MPS001-MPS012) and by FORCE at their tidal power research site (D1-W2) in Minas Passage during 2017 and 2018.

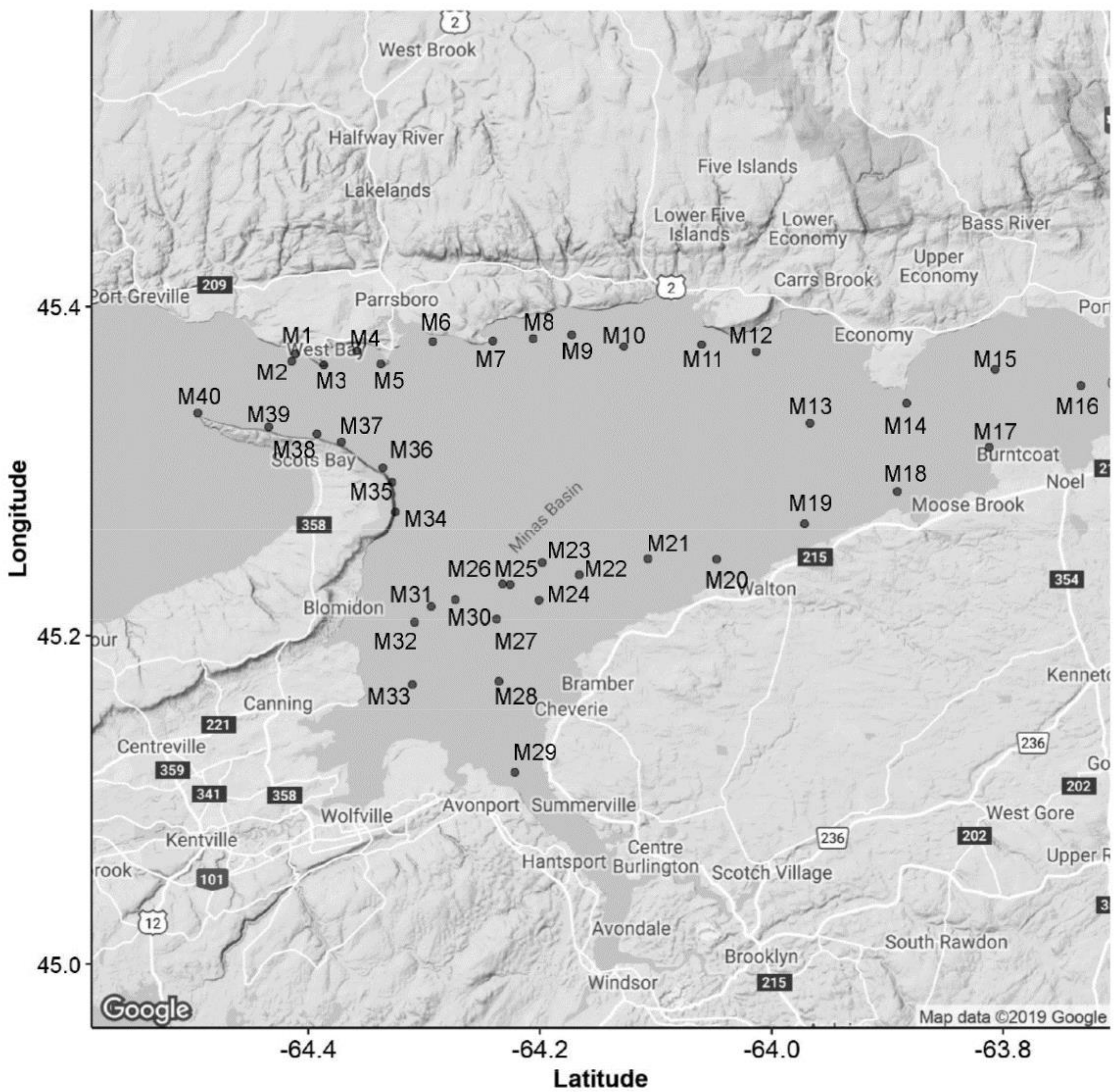

Figure 9. Positions of VEMCO VR2W receivers (M1-M40) in Minas Passage and Minas Basin deployed during Apr-Dec, 2018.

RESULTS

Lobster Population Characteristics

A total of 9,694 lobsters were examined for carapace length, sex, reproductive stage and molt stage, 2413 during Nov. 2-Dec. 22, 2017 and 7281 during Aug. 8-Oct. 14, 2018. Sampled CL of male lobsters in 2017 ranged from 41-165 mm; females, 63-216 mm. Carapace length for males in the 2018 sample ranged from 60-200 mm; females, 67-178 mm. Mean carapace length of males and females were 101.7 ± 8.6 mm and 102.5 ± 9.0 mm in 2017 and 121.0 ± 18.0 mm and 115.7 ± 15.0 mm in the 2018 sample (Fig. 10), respectively. Mean CL of males sampled during Aug-Oct, 2018 was significantly larger than mean CL for males sampled during Nov- Dec, 2017 as were females (t-test, $p < 0.01$). Mean CL of berried females during Nov-Dec, 2017 was 125.1 mm and was significantly greater than the mean CL of non-berried females from the same sample (Fig. 11; t-test, $p<0.01$). There were too few berried females in the Aug-Oct, 2018 sample for comparison to non-berried females from the same sample. The proportion of females in the Nov-Dec, 2017 sample was greater (M: F = 1.0: 1.2) than the proportion of females in the Aug-Oct sample (M: F = 1.0: 0.6).

Among samples taken over two week periods from Jun-Jul, 2008, Aug-Oct, 2018 and Nov-Dec, 2017; berried females represented 35.2% of females in June, declined to 5% of females in July, was <2.0% females during Aug-Sep, then steadily increased to 50.4% of females by December (Table 1). The proportion of soft-shell lobsters in the population also exhibited a seasonal cycle. Soft-shell lobsters were not observed during June, increased to 42.9% during late July then decreased rapidly to 0.1-4.0% during Aug-Dec (Table 1).

Table 1. Total American lobster sampled, females and percent of total, berried females and percent of females and percent softshell in biweekly periods from Minas Passage and Minas Basin during June to December.

Period	Total sampled	Females	% total	Berried	% females	Softshell %
Jun 1-15	532	316	59.4	115	36.3	0.0
Jun 16-30	296	184	62.1	63	34.2	0.0
Jul 16-30	368	144	39.1	8	5.5	42.9
Aug 8-15	1306	578	44.2	1	0.1	0.4
Aug 16-31	2071	911	43.9	5	0.2	0.4
Sep 1-15	1609	592	36.8	7	0.4	0.3
Sep 16-30	1335	376	35.8	17	1.3	2.7
Oct 1-15	1051	344	32.7	24	6.9	3.9
Nov 1-15	994	534	53.7	191	35.7	0.1
Nov 16-30	995	436	43.8	200	45.9	0.1
Dec 1-15	220	141	64.1	54	38.3	0.1
Dec 15-22	772	460	59.5	232	50.4	0.2

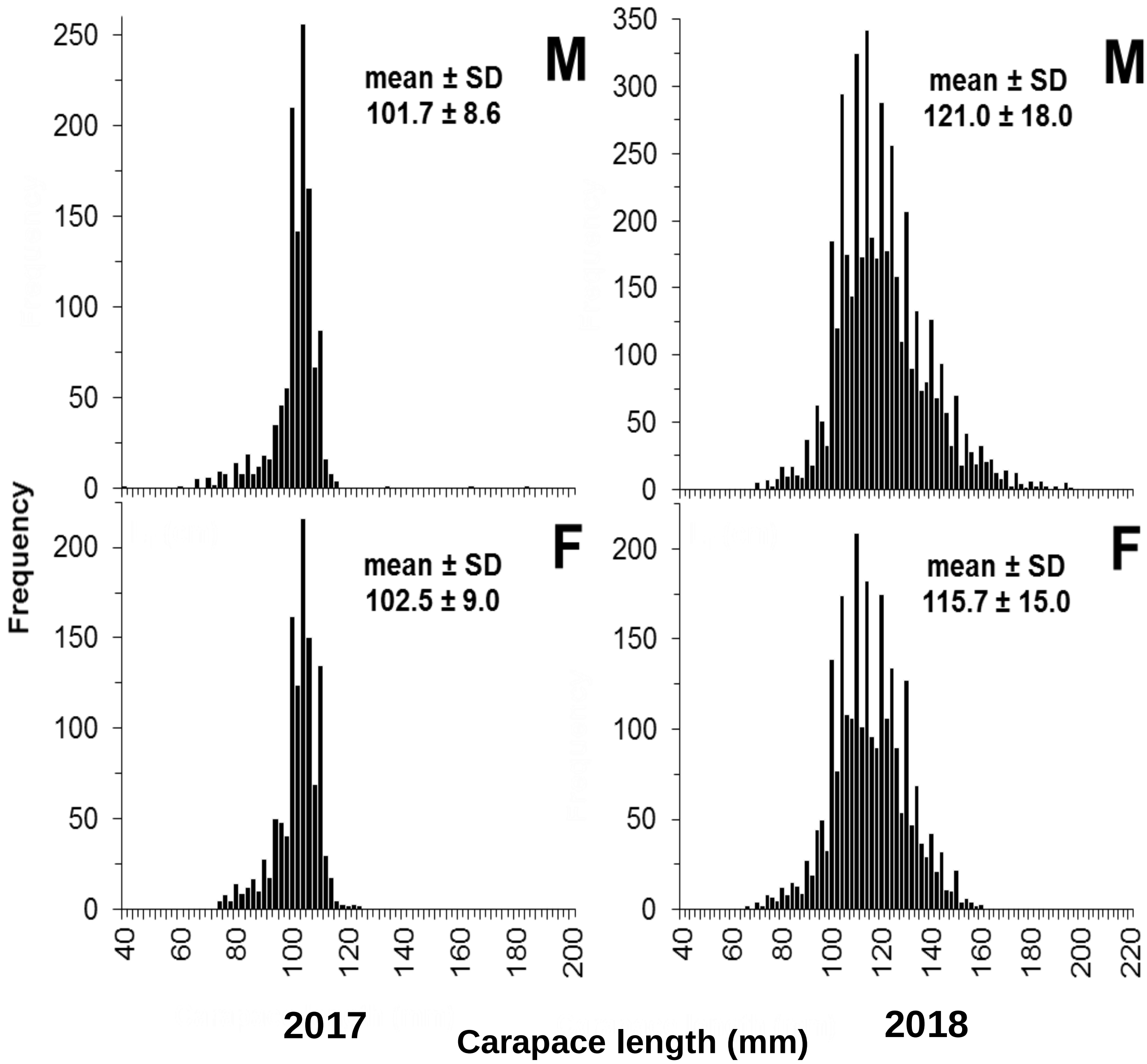

Figure 10. Carapace length (mm) frequency of American lobster tagged in Minas Passage and Minas Basin from Nov-Dec, 2017 and Aug-Oct. 2018. Top (m = males 2017, n = 1,221: 2018, n = 4,708); bottom (F = females 2017, n = 1192; 2018, n = 2,573). Lengths grouped in 2 mm bins.

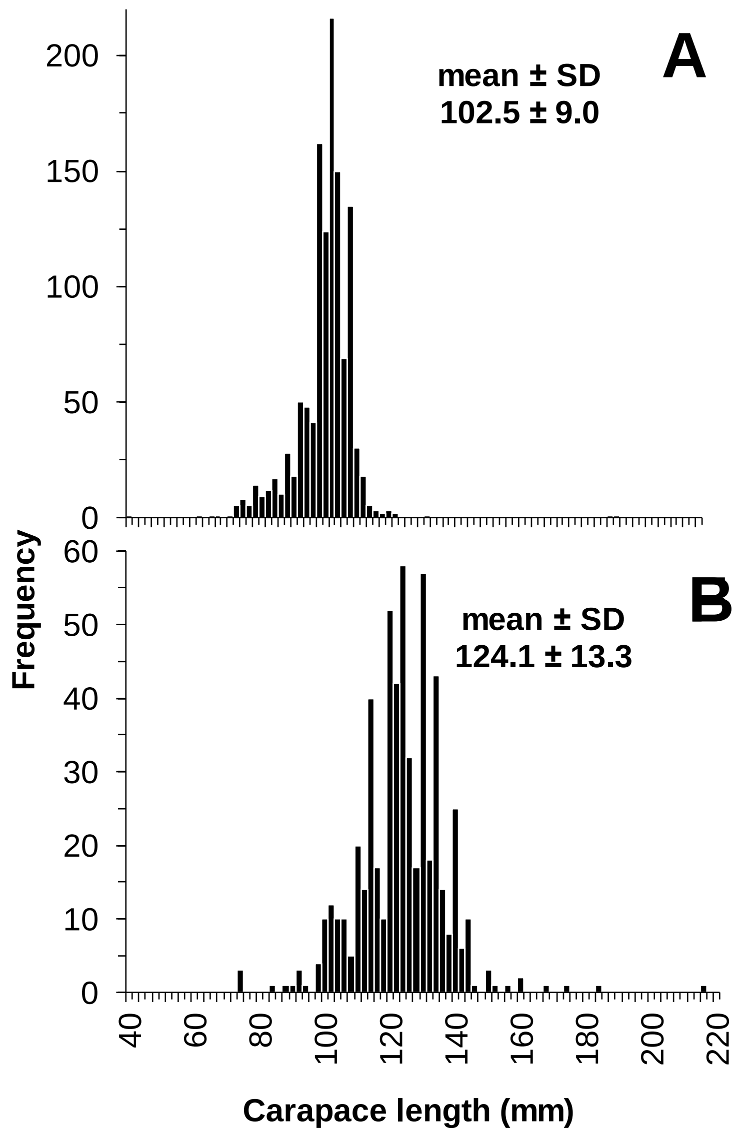

Figure 11. Carapace length (mm) frequency of female non-berried (**A**, n = 1,192) and berried (**B**, n = 557) American lobster tagged in the Minas Passage from November to December 2017. Lengths grouped in 2 mm bins.

Lobster Tagging during Nov-Dec, 2017

A total of 2981 Floy streamer tags were deployed on lobsters ranging from 41-185 CL mm from Nov 1 –Dec 22, 2017 in Minas Channel, Minas Passage and Minas Basin. Streamer tag numbers were from 1-3000. Nineteen tags (0.06%) were either defective or missing. Of streamer tags deployed during 2017, 59 were returned by commercial fishers during 2017, five were returned during 2018 and one was recaptured during study trap survey in 2018.

A total of 50 acoustic tags were deployed in Minas Channel, Minas Passage and Minas Basin during Nov 1-26, 2017 (Table 2). Acoustic tags were deployed on six males (Range 86-105 mm CL), 5 non-berried females (Range 82-107 mm CL) and 39 (78.0%) berried females (Range 98-152 mm CL). Mean CL of berried females tagged was 131.3 mm.

Of the 37 tags deployed in Minas Passage and Basin, a total of 23 (62.2 %) were detected during 2017 or 2018 in Minas Passage. Of the 13 acoustic tags deployed in Minas Channel none were detected by Minas Passage receivers.

Table 2. Acoustic tags applied to American lobster in the inner Bay of Fundy. Sex and condition are: F = female non-berried, FB = Female berried, M = Male. Release sites are HH = off Halls Harbour; BH = off Baxter Harbour, CS = off Cape Split, BR = off Black Rock, MP = Minas Passage, MB = Minas Basin, P = off Parrsboro and B = off Blomidon.

Tag Code	Date Applied	Carapace Length (mm)	Sex	Release Site	Latitude	Longitude
982	Nov 1/17	98	FB	BH	45 14'20"	64 30'25"
983	Nov 1/17	131	FB	BH	45 14"20"	6430'25"
984	Nov 1/17	82	F	MB	45 16'53"	64 12'59"
985	Nov 1/17	105	M	MB	45 16'53"	64 12'59"
986	Nov 1/17	145	FB	P	45 22'10"	64 22'54"
987	Nov 2/17	94	M	P	45 22'10"	64 22'54"
988	Nov 1/17	96	F	P	45 22'10"	64 22'54'
989	Nov 1/17	101	M	P	45 22'10"	64 22'54"
990	Nov 2/17	100	M	MP	45 20'21"	64 19'41"
991	Nov 2/17	98	FB	MB	45 19'55"	64 12'40"
992	Nov 2/17	110	FB	B	45 18'59"	64 21'36"
993	Nov 2/17	86	M	B	45 18 59"	64 21'36"
994	Nov 2/17	102	F	MP	45 19'44"	64 24'38"
995	Nov 2/17	102	M	MP	45 19'44"	64 24'38"
996	Nov 2/17	107	F	MP	45 19'44"	64 24'38"
997	Nov 2/17	119	FB	MB	45 17'37"	64 09'47"
998	Nov 2/17	120	FB	MB	45 17'37"	64 09'47"
999	Nov 2/17	121	F	CS	45 19'18"	64 28'20"
1000	Nov 2/17	116	FB	CS	45 19'18"	64 28'20"
1001	Nov 3/17	130	FB	CS	45 19'18"	64 28'20"
1002	Nov 3/17	112	FB	SB	45 16'08"	64 29'43"

1003	Nov 3/17	122	FB	MP	45 20'58"	64 24'16"
1004	Nov 12/17	135	FB	MP	45 20'58"	64 24'16"
1005	Nov 12/17	136	FB	MB	45 19'59"	64 13'08"
1006	Nov 12/17	124	FB	MB	45 20'59"	64 13'08"
1007	Nov 12/17	141	FB	MB	45 20'59"	64 13'08"
1008	Nov12/17	141	FB	HH	45 13'44"	64 36'47"
1009	Nov 13/17	115	FB	P	45 22'43"	64 16'47"
1010	Nov 13/17	130	FB	MB	45 17'43"	64 10'51"
1011	Nov 13/17	123	FB	P	45 22'04"	64 16'47"
1012	Nov 13/17	122	FB	P	45 22'04"	64 16'47"
1013	Nov 13/17	134	FB	P	45 22'04"	64 16'47"
1014	Nov 18/17	130	FB	P	45 22'23"	64 18'15"
1015	Nov 18/17	136	FB	P	45 22'23"	64 18'15"
1016	Nov 18/17	128	FB	MB	45 18'43"	64 10'33"
1017	Nov 18/17	135	FB	MB	45 18'43"	64 10'33"
1018	Nov 18/17	135	FB	MP	45 20'09"	64 19'27"
1019	Nov 18/17	142	FB	MP	45 22'19"	64 24'47"
1020	Nov 19/17	142	FB	CS	45 19'15"	64 28'24"
1021	Nov 19/17	140	FB	CS	45 19' 15"	64 28'24"
1022	Nov 19/17	152	FB	SB	45 16'45"	64 28'44"
1023	Nov 18/17	141	FB	SB	45 16"45"	64 28'44"
1024	Nov 18/17	140	FB	BH	45 13'41"	64 33'43"
1025	Nov 18/17	136	FB	BH	45 13'41"	64 33'44"
1026	Nov 26/17	100	FB	MB	45 17'40"	64 08'16"
1027	Nov 26/17	100	FB	MB	45 17'40"	64 08'16"
1028	Nov 26/17	135	FB	MB	45 17'40"	64 08'16"
1029	Nov 26/17	140	FB	MP	45 20'43	64 18'44"
1030	Nov 26/17	135	FB	P	45 22'42"	64 16'47"
1031	Nov 27/17	131	FB	P	45 21'57"	64 23'53"

Deployment of Acoustic Receivers, 2017 and 2018.

Total of 522 acoustic pings were recorded from tagged lobsters by receivers in the OTN line during Nov-Dec, 2017 (Fig. 12). These consisted of detections at receivers MPS002, MPS003, MPS009 and MPS011. Seven pings were recorded at the FORCE site receivers E1, W1 and S2 during the same period.

A total of five different acoustic tagged lobsters were detected at the Minas Passage receivers during Nov-Dec, 2017 (Fig. 13). Acoustic tags recorded were 986, 995, 1003, 1013 and 1019. Receptions commenced on November 1 immediately after tagged lobster were released in the vicinity. Lobsters 986, 1003 and 1013 remained near the receivers for extended periods, the others only briefly (Table 3). Receptions at the OTN line consisted of three lobsters (two berried females and one male). Receptions at the FORCE site were from two other berried females.

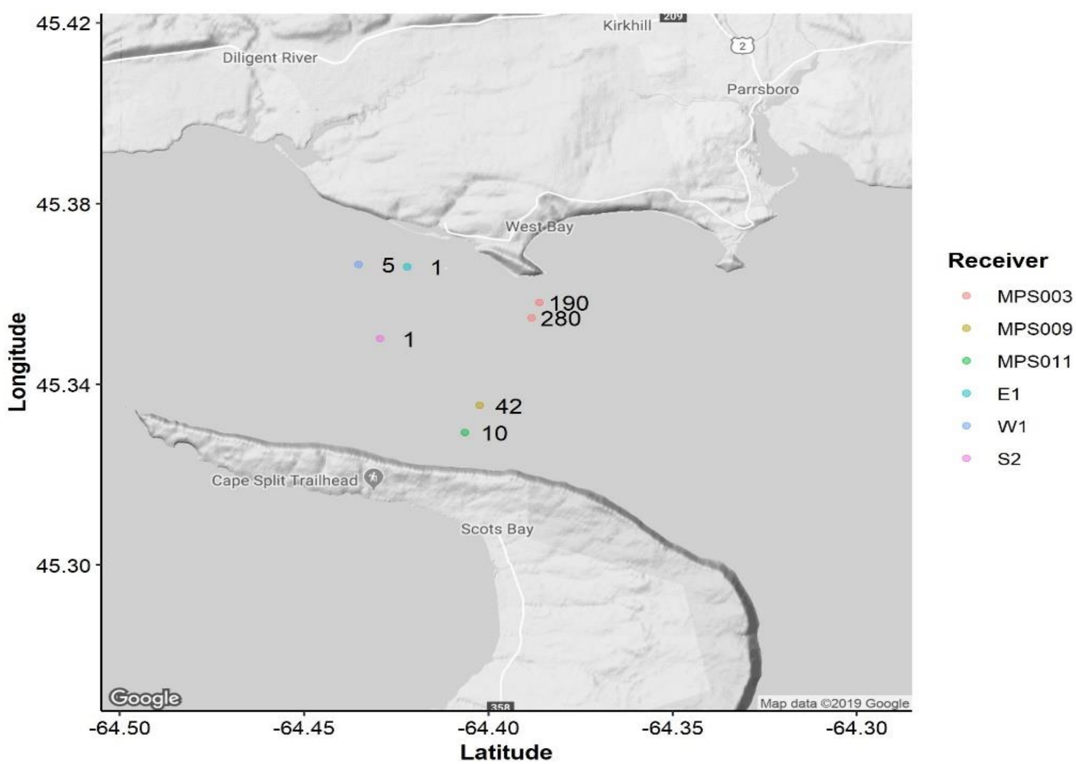

Fig. 12. Total number of receptions of acoustic tagged lobsters at OTN and FORCE sites during 2017.

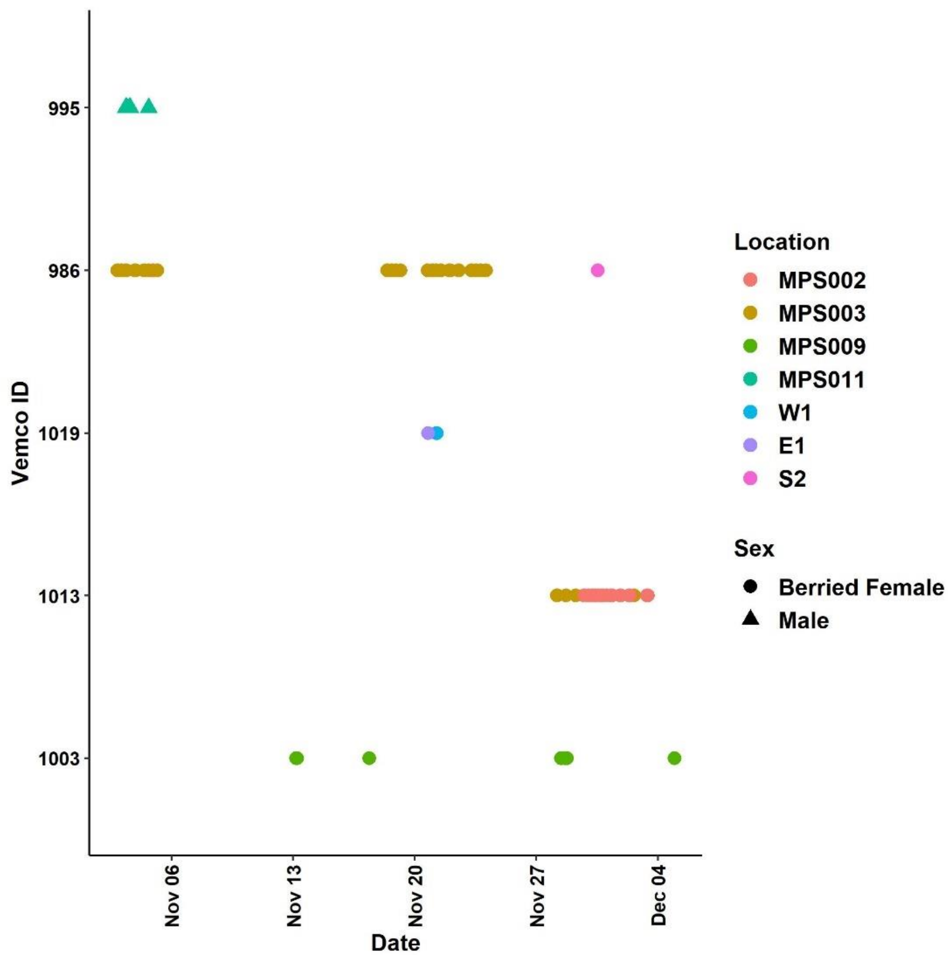

Figure 13. Receptions of individual acoustic tagged, sexed lobsters at OTN and FORCE receivers in Minas Passage during Nov-Dec, 2017.

A total of 6387 pings from acoustic tagged lobsters were recorded at OTN receivers during Jan-Nov, 2018 (Fig. 14). These consisted of receptions at receivers MPS1-MPS11. A total of only four pings were detected at the FORCE site at receiver D1.

A total of 17 individual tagged lobsters were recorded at the OTN and FORCE receiver sites during Jan-Nov, 2018. Acoustic tags recorded were 986, 989, 991, 992, 1003, 1004, 1009, 1011, 1012, 1014, 1015, 1018, 1027, 1028 and 1030 (Fig. 15). Most lobsters passed a receiver during a short period (Table 3). Five lobsters remained near a receiver for extended periods. Receptions at the OTN line consisted of 15 female lobsters that had been berried when tagged and one male. Receptions at the FORCE site were of two females that had been berried when tagged.

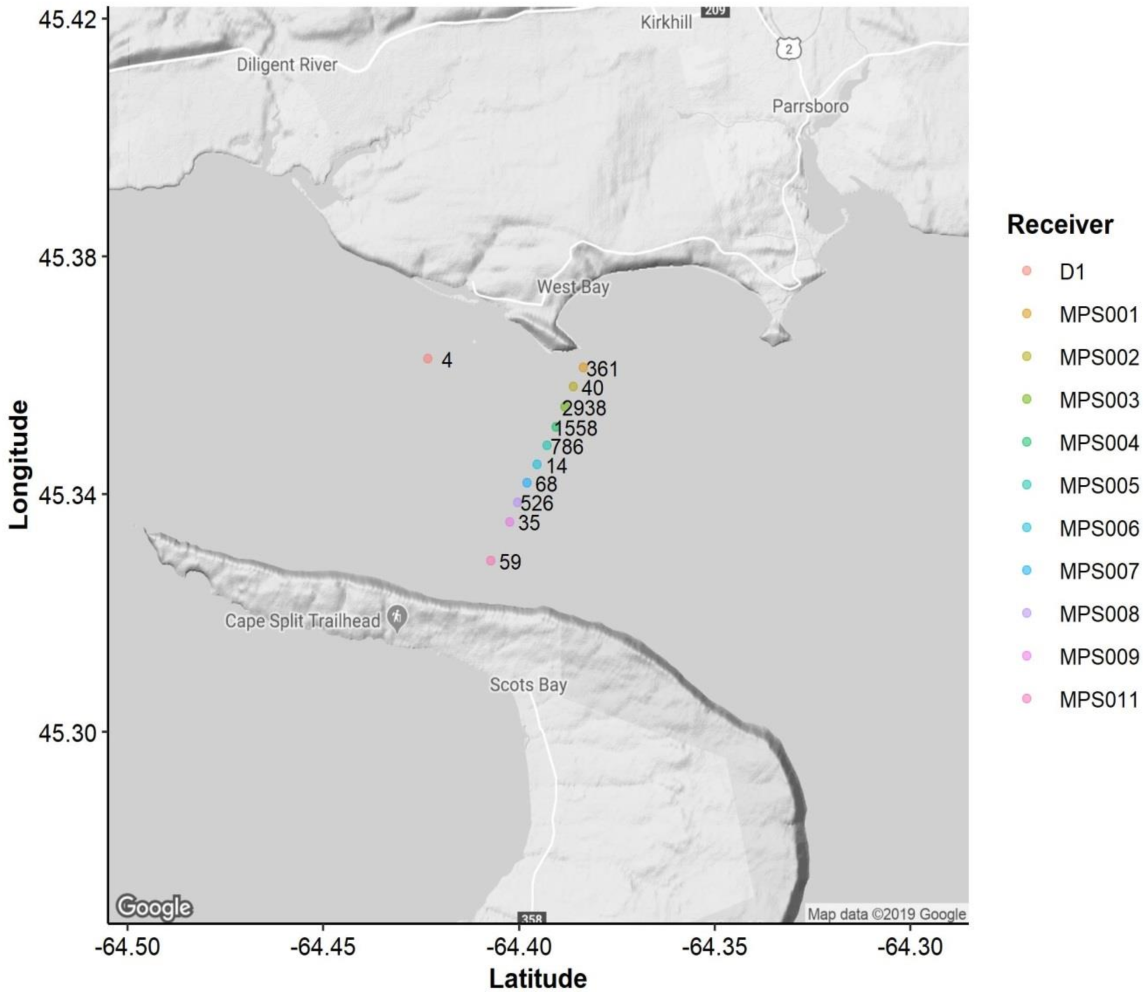

Figure 14. Total number of detections of acoustic tagged lobsters at OTN and FORCE receivers in Minas Passage during Jan-Nov, 2018.

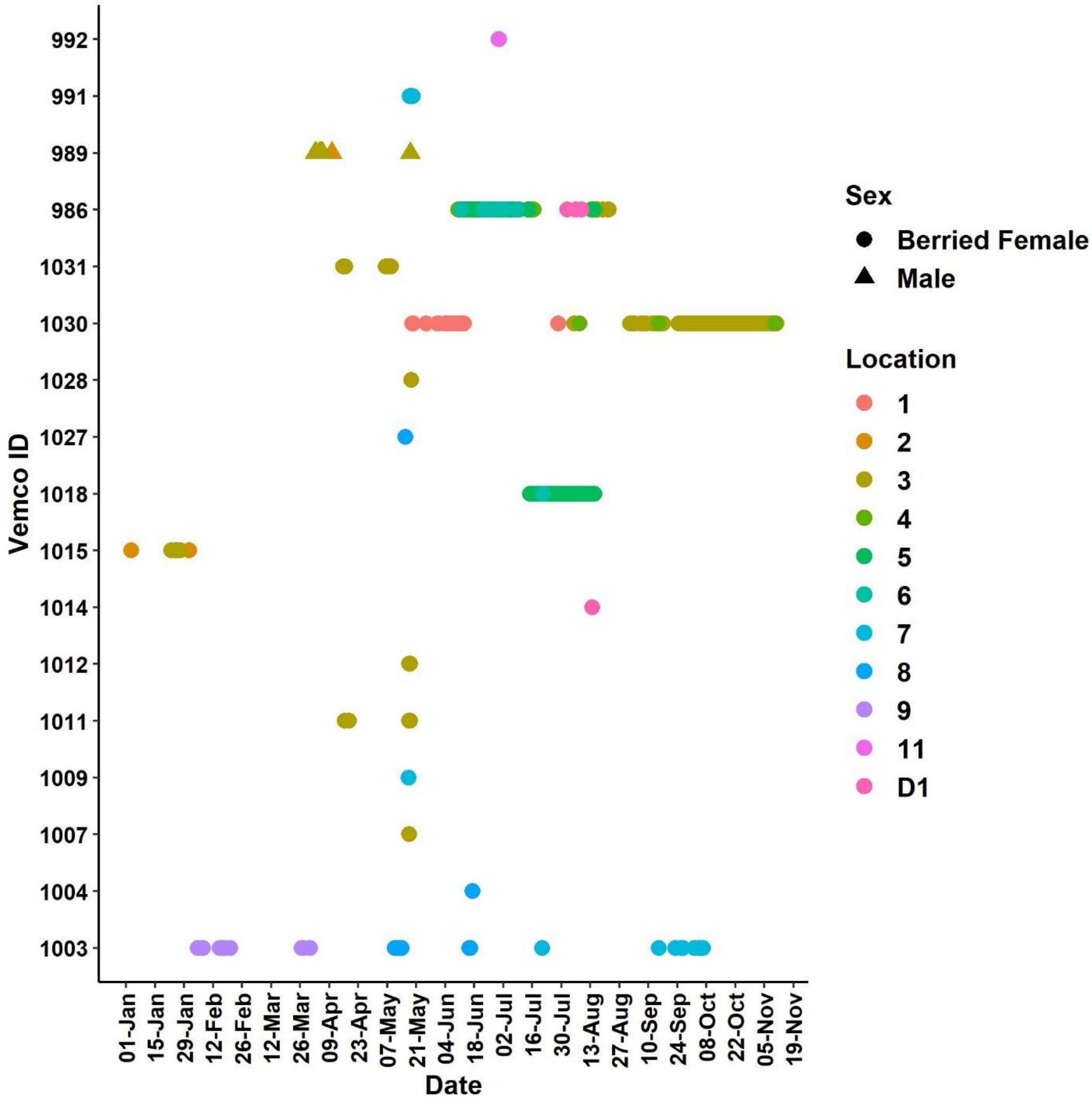

Figure 15. Receptions of individual acoustic tagged, sexed lobsters at OTN and FORCE receivers in Minas Passage during Jan-Nov, 2018.

A total of 2241 acoustic pings from tagged lobsters were received at study receivers deployed from May-Dec, 2018 on the north side of Minas Passage and a total of 1507 were detected at receivers deployed on the south side of Minas Passage during the same period (Fig. 16). These included receptions at receivers M3, M5 and M6 on the north side and M34, M37, M38, M39 and M40 on the south side.

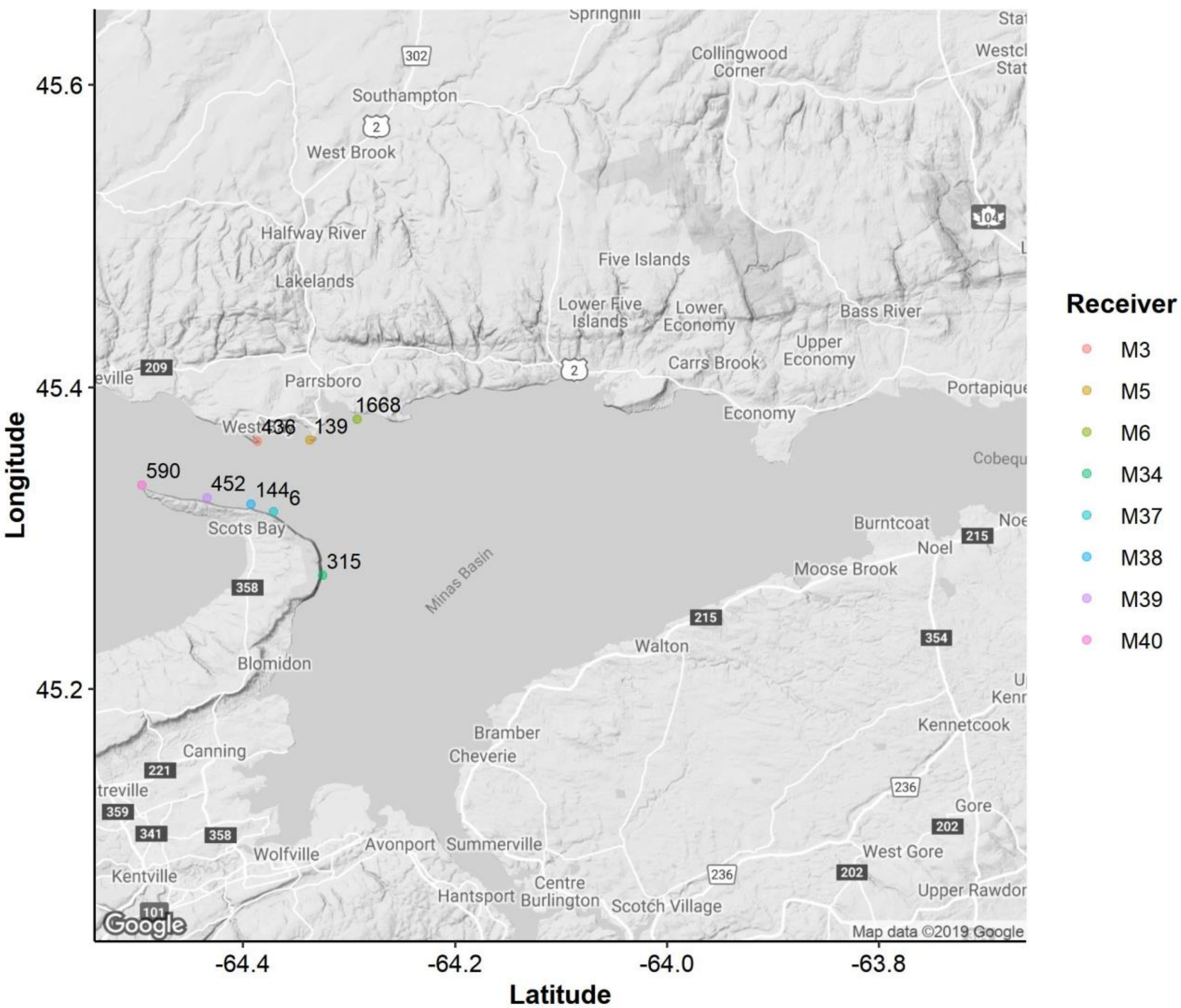

Figure 16. Total number of receptions of acoustic tagged lobsters at study receivers in Minas Passage and Minas Basin during Apr-Dec, 2018.

A total of six individual acoustic tagged lobsters were detected at study receivers on the north and south sides of Minas Passage during May-Aug, 2018 (Fig. 17). Lobsters detected were 984, 992, 996, 997, 1030 and 1031 (Table 3). These detections included four female lobsters that were berried when tagged and two females were non-berried when tagged. One lobster remained for an extended period near a receiver, the remainder for periods of a month or less.

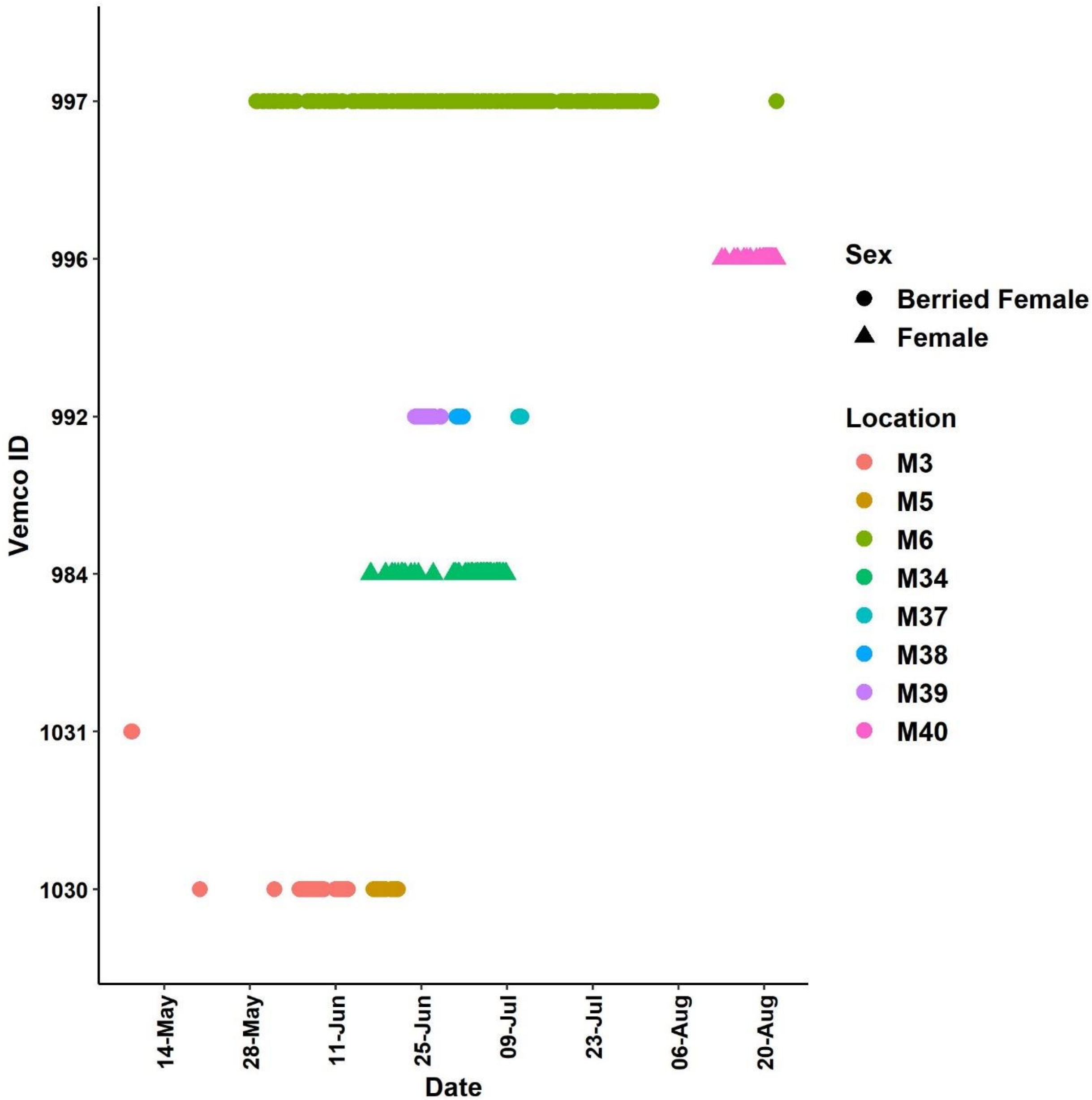

Figure 17. Receptions of individual acoustic tagged, sexed lobsters at study receivers in Minas Passage and Minas Basin during May-Aug. 2018.

Table 3. Detection of acoustic tags at receivers in Minas Passage during 2017 and 2018 and movement of tagged lobsters. Tagging and reception sites are MB= Minas Basin, B= off Blomidon, P= off Parrsboro, MP=Minas Passage. Receivers were **FORCE** - E1, W1, D1, S2; **OTN** - 1-11; **Study** - M1-M6, M39-M34.

Tag #	Tagging Site	Reception Receiver and Month		
		MP 2017	MP 2018	Study MP 2018
984	MB	-	-	M34, Jun-Jul
986	P	3- S2, Nov-Dec	5-6-5-D1-4-3, Jul-Aug	-
989	P	-	3-2-3, May	-
991	MB	-	8, May	-
992	B	-	11, Jul	M39-M38-M37, Jun
995	MP	9, Nov	-	-
996	MP	-	-	M40, Aug
997	MB	-	-	M6, May-Aug
1003	MP	9, Nov	9-8-7, Jun-Oct	-
1004	MP	-	7, Jun	-
1007	MB	-	3, May	-
1009	P	-	7, May	-
1011	P	-	3, Apr-May	-
1012	P	-	3, May	-
1013	P	3-2-3-2, Nov-Dec	-	-
1014	P	-	11, Aug	-
1015	P	-	3-2-3, Jan-Feb	-
1018	MP	-	5-6-5, Jul-Aug	-
1019	MP	E1-W1, Nov	-	-
1027	MB	-	8, May	-
1028	MB	-	3, May	-
1030	P	-	1-3, May - 4-3-4, Aug-Nov	M3-M5, May-Jun
1031	P	-	3-3, Apr-May	M3, May

Acoustic tags # 982, 983, 999, 1000, 1001, 1002, 1008, 1020, 1021, 1022, 1023, 1024, 1025 were released in Minas Channel in Scots Bay, off Cape Split and off Halls Harbour and were not detected at the Minas Passage receivers during the study.

Movement of American lobster in Minas Basin, Minas Passage and the Bay of Fundy.

Experimental trap deployments during Aug-Oct, 2018 indicated there was a fluctuation in the abundance and sex ratio of adult lobsters in Minas Basin during Aug - Oct, 2018 (Table 4). Lobster catch/trap was similar or only slightly less in Minas Basin traps than in Minas Passage during August (mean 12.4 vs 16.0). During September into October catch/trap in Minas Basin declined to a mean of 7.7 lobsters while the catch/trap in Minas Passage increased to a mean of 20.1 in early September and remained high into late September (18.6) and early October (14.7). At the same time the proportion of females in the Minas Basin trap catches declined from a high of 37.0% in early August to 15.5% by mid- October. Since the lobster fishery was closed during this period and would not affect catch/trap the data suggests there was a movement of predominately female lobsters out of Minas Basin and into Minas Passage during this period.

Table 4. Catch/trap and % females for American lobster catches in experimental traps set in Minas Basin and Minas Passage during August 8-October 14.

	S Minas Basin		N Minas Basin		S Minas Passage		N Minas Passage	
Set Period	Catch /Trap	% female	Catch /Trap	% Female	Catch /Trap	% Female	Catch /Trap	% Female
Aug 8 - Aug 14	12.6	34.5	12.3	38.7	19.6	49.6	12.5	41.8
Aug 27-Sept 4	11.2	30.2	11.1	24.2	25.1	42.6	15.1	37.6
Sep 15-Sep 24	6.7	22.4	8.2	23.5	20.8	40.9	16.4	42.2
Oct 6- Oct 14	6.6	13.7	9.3	17.4	16.3	40.9	13.1	52.2

Movement of streamer tagged lobsters in Minas Basin and Minas Passage recaptured by lobster fishers during the period Nov 1 - Dec 22, 2017 indicated that the majority of short-term movement (mean distance 8.4 km) was from Minas Basin towards Minas Passage (Fig. 18). At the same time lobsters tagged in Minas Passage remained in the Passage. Lobsters tagged with streamers in Minas Channel (Scots Bay) during the same period also demonstrated short distance movement but from shallow to greater depths. Unfortunately tag returns from Minas Basin and Minas Passage ceased after fishers lifted their traps in late December, 2017.

One streamer tagged lobster was captured during 2018 in study traps (Lobster 1440). Lobster 1440 was tagged on the north side of Minas Passage on Nov 18, 2017, recaptured by a fisher 3 km away on Nov 27, 2017 and then captured in a study trap another 6 km away in West Bay (Fig. 4) on Sep 8, 2018. She was berried when tagged but had released her larvae when recaptured in September, 2018.

Lobsters marked with acoustic tags in Minas Basin during November moved from their tagging location into Minas Passage (mean distance 18.2 km; Fig. 19) or were detected in the Passage during the following months (Fig. 15). Those tagged in Minas Passage largely remained in the Passage (Figs. 7, 15) or moved through the Passage later from unknown locations. Based on the high occurrence of receptions from deep-water locations in the Passage this habitat appeared to be preferred by lobster (Fig. 14). In addition, the large majority of receptions was at the northern end of the OTN line (receivers 3, 4; Table 3).

Ten (58.8%) of the acoustic marked lobsters that were detected in the Passage were there for only a short period during May-June (Fig. 15; Table 3). Their short period of detection and the fact all were berried females, suggests there may have been a return migration from the Bay of Fundy into Minas Basin during spring.

Six lobster tagged on the north side of Minas Passage (Parrsboro) were only detected at the north side of the OTN line (Table 3) and two lobsters tagged on the south side of the Passage were only detected at the OTN line there (992, 996; Fig. 19). Two acoustic tagged lobsters (1030, 1031) crossed from the north side of Minas Passage to the south side (Table 3). One streamer tagged lobster also moved from the north side to the south side of the Passage (Fig. 18).

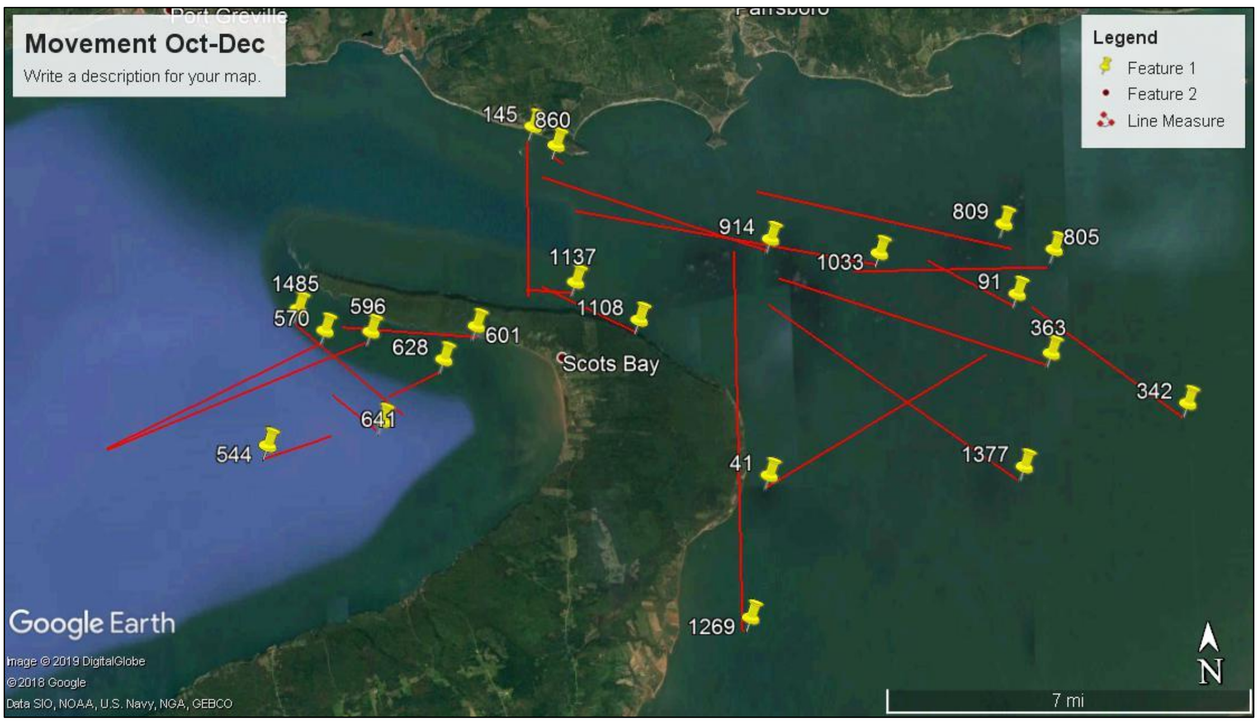

Figure 18. Movement of selected American Lobster tagged with FLOY streamer tags during Nov-Dec, 2017. Yellow symbols mark location of tagging in early November. Tag returns ceased after fishers lifted their traps in late December.

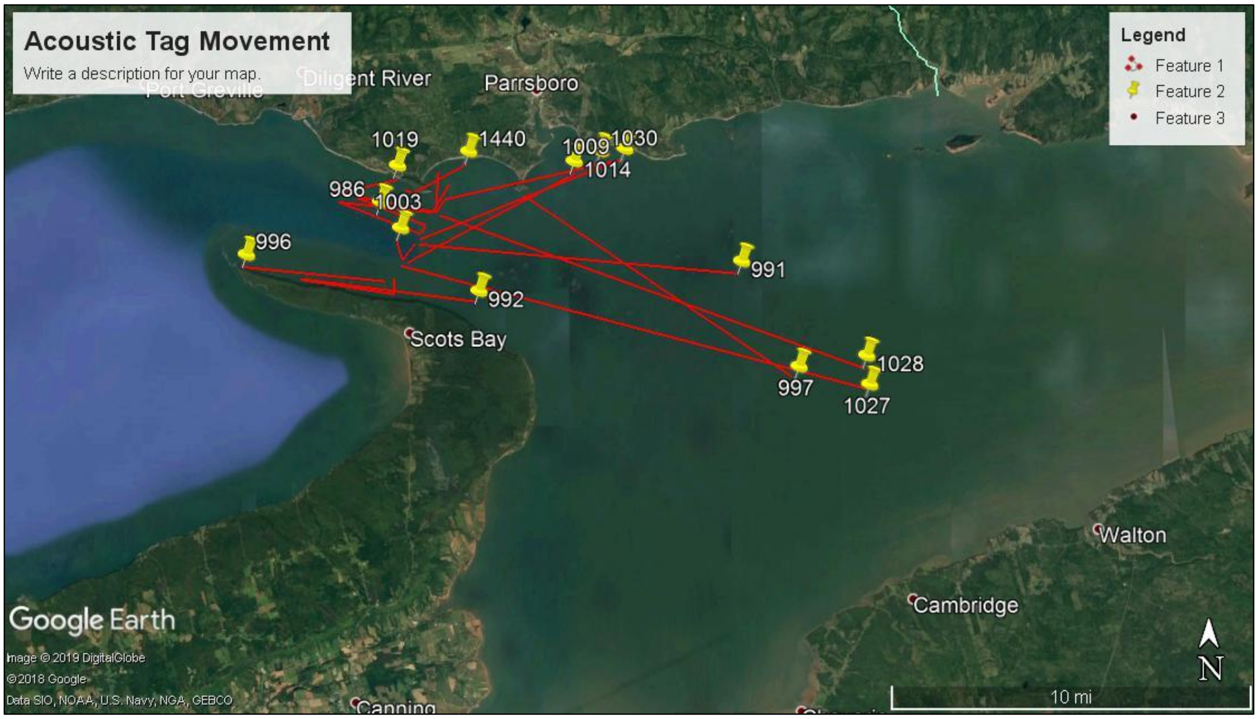

Figure 19. Movement of selected acoustic marked lobsters in Minas Basin and Minas Passage. Yellow symbols mark the location of lobster tagging.

Streamer tags returned from commercial fishers after tagging during 2008 and 2017 demonstrated there was a proportion of the lobsters tagged in Minas Passage that carried out long distance movements (>30 km) into the Bay of Fundy (Figs. 20, 21). Most long-distance returns came after one year at large but a few lobsters moved long distances during short periods (Table 5). Lobsters L1043 and L1140 moved distances of 129 km and 106 km during June to November at estimated rates of 1.23 km/d and 1.0 km/d, respectively. Lobster 1194 moved 202 km to the lower Bay of Fundy off Brier Island and lobsters MCG1424 and MCG1770 moved 195 km and 203 km, respectively, into the southwestern Bay of Fundy over a period of one year (Table 5; Fig. 21).

Lobsters that were tagged in Minas Passage during 2008 and were recovered in the Bay of Fundy were all smaller, immature individuals of 74-91 mm CL (Table 5). Four of the five lobsters tagged in Minas Passage during Nov-Dec, 2017 and recovered in the Bay of Fundy were mature females (118-140 CL mm) that had been berried when tagged. The fifth individual tagged in 2017 was again an immature female (85 CL mm).

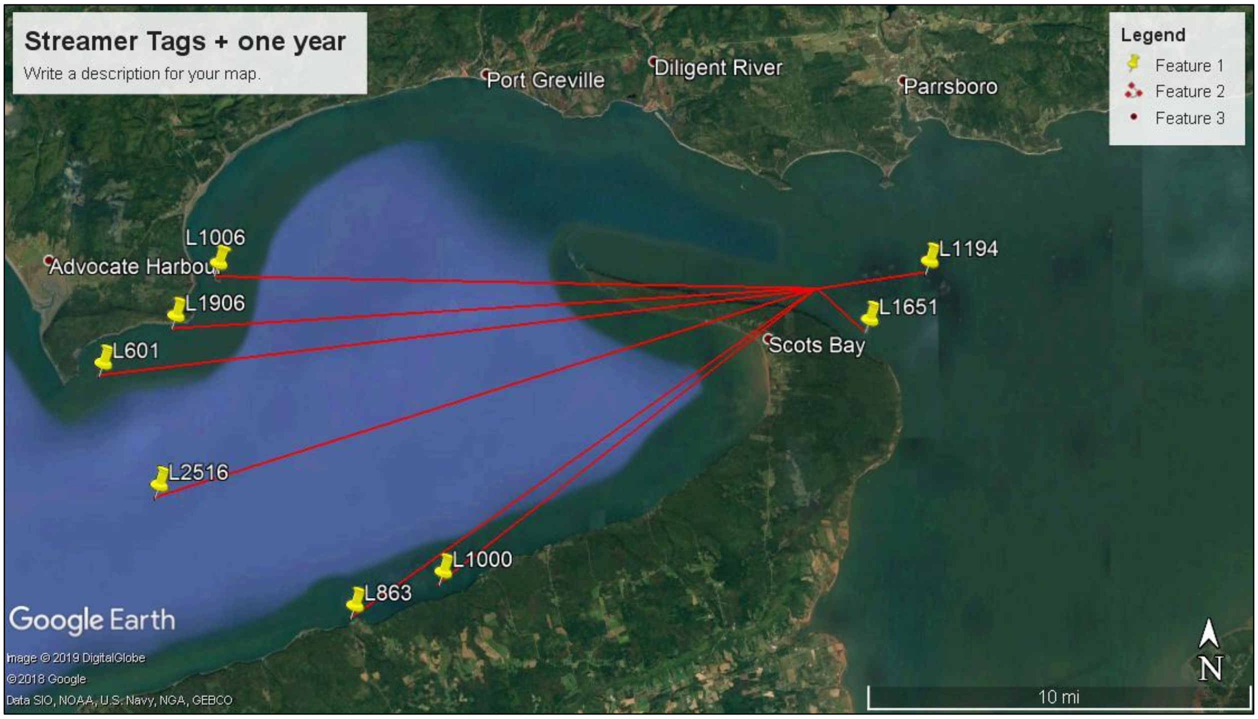

Figure 20. Movement after one year of American lobster tagged with FLOY streamer tags in Minas Passage during 2008. Yellow symbols mark the recapture point of each lobster.

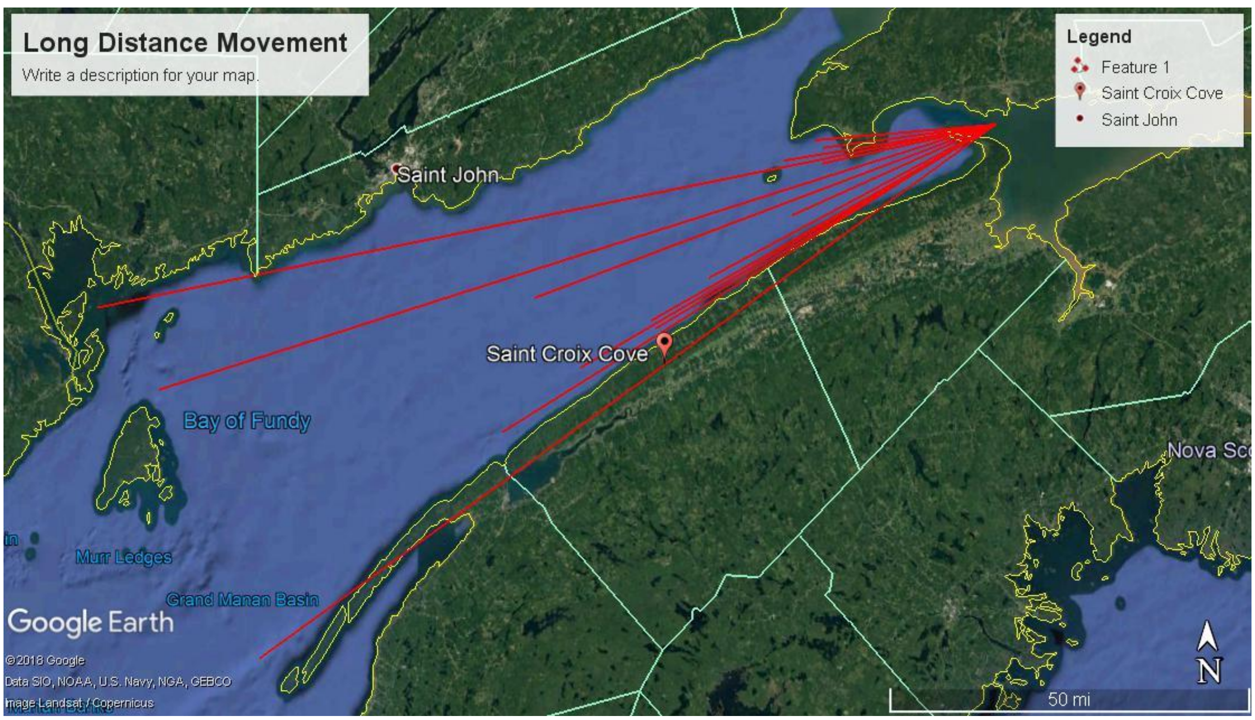

Figure 21. Long-distance movement of selected American lobster tagged with FLOY streamer tags during 2008 and 2017. All lobsters were tagged in Minas Passage (~45º 20’30”, 64 23’ 20”) during the summer and fall commercial fishing seasons. Distances are straight line representations and do not represent the actual movement of individual lobsters.

Table 5. Long distance, recapture locations of American lobsters in the Bay of Fundy marked with streamer tags in Minas Passage during 2008 and 2017. Distance is measured as a straight line (SLD) and probably does not represent the actual distance traveled during the days at large.

Tag Number	Date Tagged	Date Recaptured	Recapture Location	Lat	Long	SLD (km)	At large (d)
L0599	25/06/2008	11/10/2009	Isle Haute	45 16'49"	64 58'14"	47	471
L1043	08/07/2008	21/10/2008	off Digby Gut	44 45'09"	65 46'32"	129	105
L1119	12/07/2008	26/11/2009	off St. Croix Cove	44 57'04"	65 20'17"	88	347
L0890	23/07/2008	10/11/2008	off St. Croix Cove	44 58'06"	65 19'54"	86	107
L1052	28/07/2008	05/11/2008	off Port George	45 03'00"	65 11'12"	72	98
L1194	30/07/2008	15/11/2009	Lower Bay of Fundy	44 17'59"	66 27'32"	202	470
L1140	30/07/2008	15/11/2008	off Annapolis Royal	44 52'30"	65 33'02"	106	106
L2501	06/10/2008	21/07/2009	off Advocate	45 18'15"	64 51'35"	39	390
L2714	06/10/2008	28/10/2009	off Advocate	45 16'23"	64 52'50"	40	386
MCG0152	02/11/2017	25/11/2018	off Harbourville	45 10'17"	64 56'59"	49	387
MCG1119	18/11/2017	15/11/2018	mid Bay of Fundy	45 00'51"	65 40'64"	109	361
MCG1424	18/11/2017	24/11/2018	Owen Basin, NB	44 50'03"	66 44'09"	195	371
MCG1770	26/11/2017	20/11/2018	Deer Island, NB	44 59'50"	66 54'40"	203	358
MCG2690	22/12/2017	16/11/2018	off Advocate	45 19'12"	64 52'43"	40	391

DISCUSSION

The lobster fishery in the Minas region is a well defined stock that is fished mainly in Minas Passage by a limited number of fishers. Except for short-term studies in the Minas region during 2008 and 2011-12, previous studies on population characteristics and movements in the Bay of Fundy sampled and marked lobster only along the New Brunswick shore. All of the New Brunswick studies had similar results indicating that the Bay of Fundy NB stock compared to other stocks in the Canadian Maritimes consisted of a high proportion of large lobsters, high levels of berried females (Campbell 1983; Robichaud and Lawton 1997) and some members of the population moved long distances (Campbell 1986; Campbell and Stasko 1986; Robichaud and Lawton 1997). We found similar biological characteristics and movements for the Minas or Bay of Fundy NS stock.

Population Characteristics

Minas Passage- Basin lobsters were characterized by a high proportion of large, adult lobsters. Mean size of lobster among samples were 101.7 and 121.0 mm CL for males and 102.5 and 115.7 mm CL for females. Maximum size attained in males was 200 mm CL and in females, 216 mm CL. Mean CL of berried females (124.1 mm) was significantly larger than the non-berried, female population (102.5 mm). Mean and maximum CL of Minas lobsters were similar to lobsters sampled along the NB Fundy shore where mean CL was greater than 100 mm and maximum CL exceeded 180 mm (Robichaud and Lawton 1997); but greater than mean and maximum CL among lobster stocks sampled along the Atlantic shore of Nova Scotia (Dadswell 1979; Miller et al. 1987) or in the Gulf of St. Lawrence (Wilder 1963; Comeau and Savoie 2002), where mean and maximum lengths seldom exceed 100 and 150 mm CL.

Sex ratio of lobsters in the Minas region was approximately equal numbers of males and females, similar to the proportional representation found in most other sampled populations (Cobb 1976). Male:female ratios found in samples were 1:1.2 during Nov-Dec and 1:0.6 during Aug-Oct. The seasonal variation observed was probably caused by female movement to preferred overwintering locations (Campbell and Pezzack 1986).

The proportion of berried females in the Minas Passage and Basin samples during late autumn (30-50%) was similar to lobster from the NB Fundy stock sampled around Alma in Chignecto Bay during the same period, a region in the Bay of Fundy with similar oceanographic characteristics as the Minas region (Campbell and Stasko 1986). In most other regions of the Canadian Maritimes concentrations of lobster with a high proportion of berried females are rare and the observed proportion of berried females in samples is low (< 10%; Campbell and Robinson 1983; Campbell and Pezzack 1986).

Female lobsters in the Minas region began to extrude eggs during late September and early October. The proportion of berried females accounted for more than 30% in Oct-Nov and extrustion was complete by December when the berried female proportion of the population reached 50.4 %. A proportion of 50% berried females in a sample is the highest possible situation since female lobsters only produce eggs every second year (Cobb 1976; Campbell 1983). Berried females were most abundant in Minas Passage during autumn and winter and this location is obviously extremely important to the life cycle of lobsters in the Fundy NS stock. Choice of overwintering in this location is probably due to warmer temperatures in the Passage compared to Minas Basin. The threshold temperature of 3.4 C^{o} for eggs to develop (Perkins 1972; Campbell and Stasko 1986) occurs there during most of the winter (Keyser et al. 2016).

The molt cycle of lobsters in the Minas region is opposite to the egg extrusion cycle (Cobb 1976). Hard-shelled lobsters accounted for 95-100% of lobster sampled from August to June. The Minas population molted during late-July when soft-shelled animals represented up to 42.9% in samples. By mid-August molting was complete.

Movement of Lobsters

Movement of lobsters in the Minas region of the Bay of Fundy demonstrated by seasonal sampling and marking with streamer and acoustic tags occurred over both short and long distances depending on season and the time period at large. Lobsters exhibited both short-distance movement in reponse to seasonal change (summer-winter) and long-distance movement perhaps caused by life history requirements.

Based on the catch/trap and female proportion in catches, trap sampling on a two-week cycle in Minas Passage-Basin during Aug - Oct demonstrated a 10-30 km movement of predominately female lobsters from Minas Basin into Minas Passage. This seasonal movement between Minas

Basin and Minas Passage was corraborated by both streamer and acoustic tagging of lobsters. Lobsters marked by streamer tags in Minas Basin moved up to 5-10 km towards Minas Passage during a six week period in Nov-Dec. Lobsters marked with acoustic tags demonstrated similar movement, traversing a distance of 5-20 km from Minas Basin into Minas Passage during Nov-Dec.

The results of our acoustic tagging were similar to previous findings. Morrison et al. (2014) found that of 120 acoustic tagged lobsters released in Minas Basin 3-11 km from Minas Passage, 37 (30.8%) were detected in the Passage at either one of the two OTN lines that were deployed during 2011-2012 or at the FORCE site. Both studies also found that tagged lobster were most commonly detected at the northern end of the OTN line and that they exhibited over-winter and long-term residence in the deepwater of Minas Passage. Time spent with lobster fishers demonstrated they knew this distribution of the lobsters well and concentrated their fishing effort in the northern, deeper area of the Passage (Dadswell, pers. obs.).

Another similarity between this study and Morrison et al. (2014) was that acoustic tagged lobsters often moved past acoustic receiver arrays without being detected. During the acoustic study in 2011-2012, there were two receiver lines across Minas Passage east and west of the FORCE site. Numerous tagged lobsters that were released in Minas Basin were first logged at the FORCE site or the western most OTN array proving they moved past the eastern OTN array without detection. During our study lobsters tagged in Novenber were often undetected in Minas Passage until May-June, but because of all the evidence for movement of lobsters into Minas Passage during late autumn we suggest that many passed the OTN line during Nov-Dec, 2017 without being detected. Since the period of low current speed when acoustic tags would have been detected by the receivers occurs during an extremely narrow window in the Passage (Karsten 2008) this possibility seems relatively plausible.

Trap sampling and tagging evidence leads us to propose that there may be an annual movement (migration) of lobster into and out of Minas Basin. The fact that a large proportion of the acoustically tagged lobsters observed moving through Minas Passage in May-Jun were berried females (76.5 %), and since the ratio of females to males in the Basin must have increased during this period to be highest during August suggests this migration exists. Whether the seasonal movement is related to egg release by females in the warmer water of Minas Basin or to obtain better foraging opportunities is yet to be proven.

Summer-winter movements of lobsters in the Canadian Maritimes have been well established in numerous studies. Campbell (1986) found that lobsters in the lower Bay of Fundy moved onshore to warmer water in summer and offshore to where warmer water occurred in winter and proposed that the movements were related to egg development. Similar seasonal movements have been described for tagged lobsters in the Gulf of St. Lawrence. Den Heyer and co-workers (2009) found that the distance of summer-winter lobster movement varied from 2.3-19.4 km depending on where the lobsters were tagged and the steepness of the bottom slope. Comeau and Savoie (2002) demonstrated a mean summer-winter movement distance of 12.3 km from shallow to deep water and back.

Long distance movement of lobsters from Minas Passage into the Bay of Fundy was exhibited by lobsters marked with streamer tags both in 2008-2009 and 2017-2018. Movements of >30 km were demonstrated for both male and female immature lobster 70-90 mm CL and for large (110-140 mm CL) females that were berried when tagged. Some of the immature lobsters moved distances up to 100+ km during a period of four months (Minas Passage to Digby). The large females moved distances up to 200 km over a period of approximately one year (Minas Passage to NB and southern NS).

Long distance movement and migration, expecially by large females, has been well documented for Bay of Fundy lobsters. Campbell (1986) and Campbell and Stasko (1986) demonstrated that female lobsters tagged off Grand Manan and off Alma in the inner Bay of Fundy moved distances of 200-800 km into the Gulf of Maine. In contrast lobsters tagged on the outer coast of Nova Scotia and the in the Gulf of St. Lawrence have never been found to move distances greater than 60 km (Miller et al. 1987, Comeau and Savoie 2002). It has been suggested that the Fundy long-distance movement is a result of the large tides and extensive drift of lobster larvae in the region (Quinn et al. 2017).

On the other hand, even with all the long distance movement demonstrated in the Bay of Fundy, few tagged lobsters have been found to cross the Bay of Fundy from the New Brunswick shore to the Nova Scotia shore, a distance in most cases of only 40-70 km. Out of 647 tagged lobsters that had moved more than 100 km, Campbell and Stasko (1986) found that only 13 (2%) crossed the Bay from tagging sites at Grand Manan, Chance Harbour and Alma in New Brunswick. Likewise, Robichaud and Lawton (1997) found that out of 100 tagged lobsters recovered, only 11 had crossed the Bay from New Brunswick to Nova Scotia. In both studies lobsters predominately moved down the New Brunswick shore to the Gulf of Maine.

Long-distance tag returns from this study demonstrated similar regional movement. Lobsters tagged in Minas Passage largely moved down the Nova Scotia shore. Out of 26 tags recovered that had moved distances >30 km only two crossed the Bay of Fundy to New Brunswick. We suggest that the lobster stocks on the two sides of the Bay of Fundy are largely independent due to egg release locations. Berried females from Fundy NB stock concentrate between Grand Manan and Alma, the Fundy NS stock, in Minas Passage and Minas Basin.

This situation has probably evolved over time because of the tidal, residual currents in the Bay of Fundy (Fig. 22, Bumpus and Lauzier 1965, Dadswell 1979). The current flows into the Bay of Fundy on the Nova Scotia shore and into Minas Basin before crossing the Bay to flow out on the New Brunswick side. Females and their larvae released in the Minas Passage appear to be independent from females and their larvae released in Chignecto Bay creating two stocks the Fundy NS stock and the Fundy NB stock .

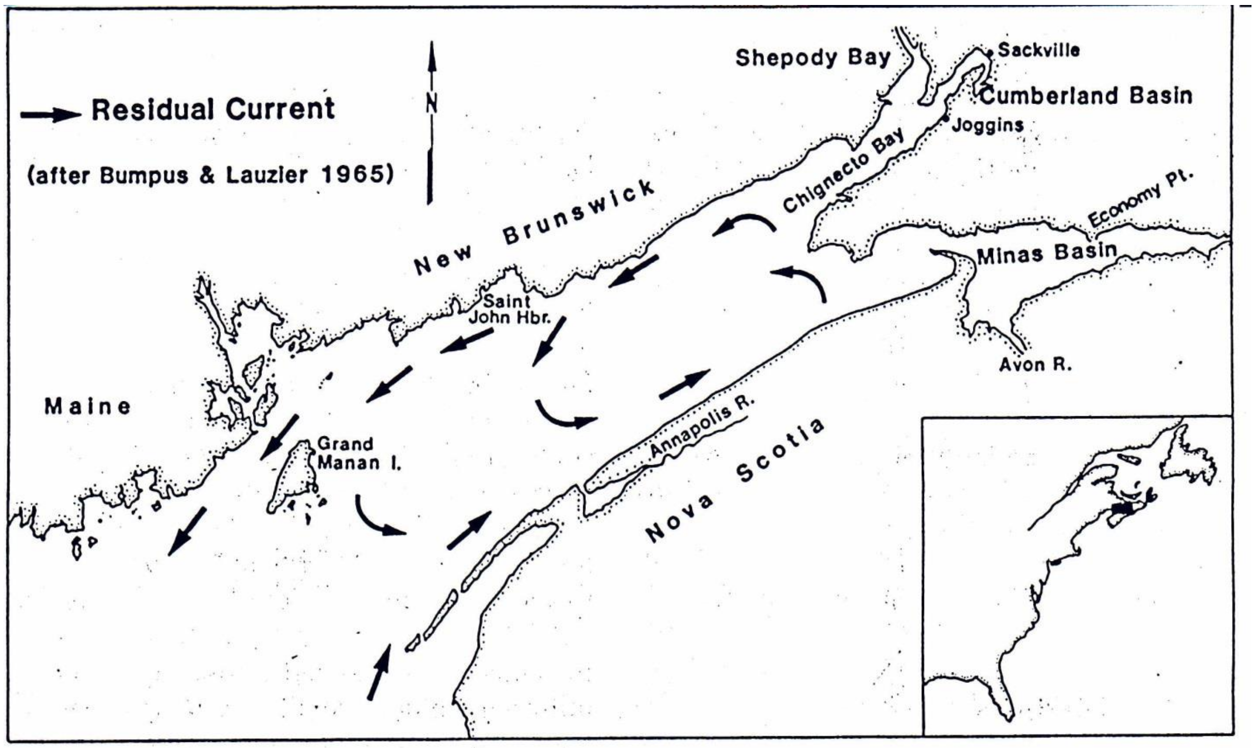

Figure 22. Tidal residual current in the Bay of Fundy (after Bumpus and Lauzier 1965).

Tidal Power Development and Lobsters

Tidal power development in Minas Passage has progressed slowly. An instream, propellor tidal turbine was deployed in the Passage during 2009 (AECOM 2009) and another design of the same turbine type in 2017 and 2018 (Cape Sharp Tidal 2018). Both turbines broke down after deployment periods of only a few weeks. At present there are no tidal turbines deployed at the FORCE site.

Propellor turbines are known to cause mortality to organisms because of mechanical strike, pressure flux, shear and cavitation in the turbine draft tube (Dadswell and Rulifson 1994). Since the instream propellor turbine designs are raised above the substrate (FORCE 2017) it is unlikely there will be much interaction between these turbines and benthic organisms such as lobsters. Lobster larvae, however, are pelagic and can remain in the pelagic zone for periods up to two months (Scarratt 1973; Cobb 1976). Since larvae have a discrete size (~1-20 mm) there is a potential level of interaction between the spinning blades of a propellor turbine and larvae. Although the calculated level of interaction is low (< 1%) there will be some degree of mortality because instream turbines operate during all periods of tidal flow and an immense volume of water containing larvae will pass through the turbine (FORCE 2017). It is also known that lobster larvae are very sensitive to pressure change (Ennis 1975). Whether or not pressure flux in the propellor turbine draft tube will have deliterious effects on lobster larvae is unknown.

It is uncertain what future plans there are for tidal hydro-kinetic deployment in Minas Passage and/or what sort of devices will be deployed. Since the Fundy NS lobster stock utilizes Minas Passage extensively, it would be unwise to deploy types of instream tidal turbines in this region that may impact the lobster population. All future studies on deployment of various types of tidal turbines in Minas Passage should include studies of their potential impact on American lobster. The Big Moon Kinetic Keel is on the surface and should be relatively benign towards lobsters except for its exclusion of lobster fishers from its aquatic footprint.

Conclusions

The lobster population in the Minas region is characterized by adults of large size with a high proportion of berried females. There is a large-scale movement of berried female lobsters into Minas Passage from Minas Basin during autumn. Females apparently concentrate in Minas Passage because of favorable temperature there during winter for development of larvae. The deeper region of Minas Passage appears to be preferred habitat for lobster. Tidal power devices deployed in this region should be avoided if they are demonstrated to be detrimental to adult lobster or drifting larvae.

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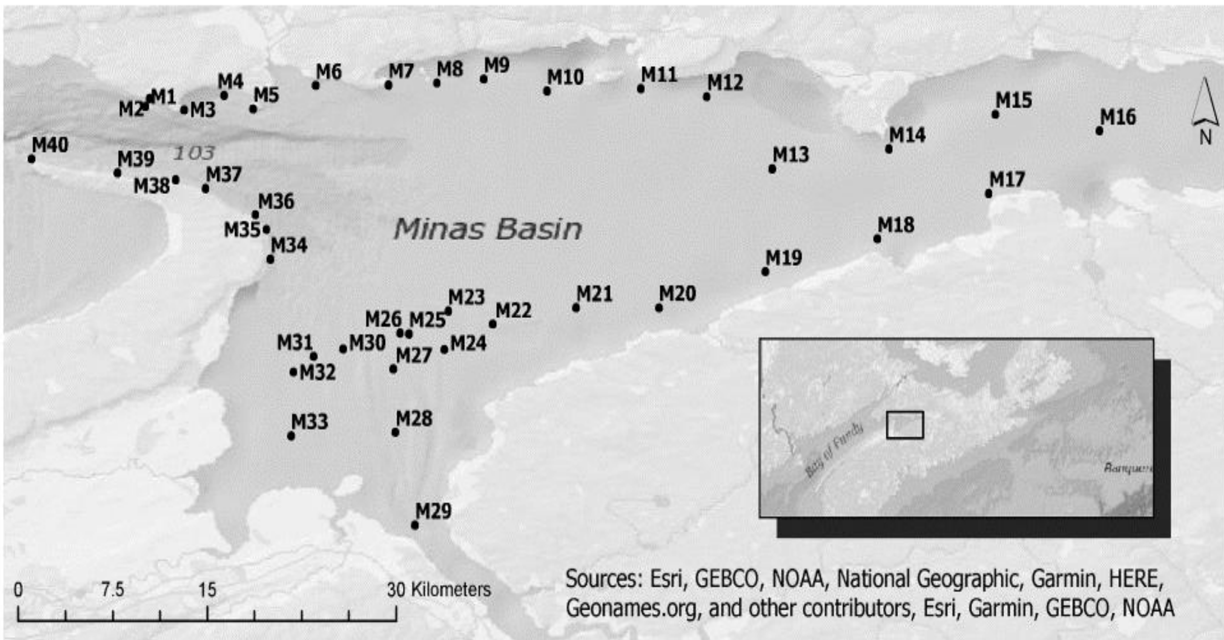
Appendix 1. Lobster trap deployment locations in Minas Basin and Minas Passage during 2018.

Lobster Trap	**Location**	**Latitude**	**Longitude**
LT1	Walton 1	45 14'25"	64 13'15"
LT2	Walton 2	45 14'43"	64 08'42"
LT3	Walton 3	45 15'01"	64 06'56"
LT4	Walton 4	45 15'17"	64 05'15"
LT5	Walton 5	45 15'38"	64 03'34"
LT6	Walton 6	45 16'03"	64 02'02"
LT7	Walton 7	45 16'32"	64 00'25"
LT8	Brick Kiln	45 19'53"	64 00'41"
LT9	White Rock	45 21'13"	64 02'14"
LT10	Moose Island	45 21'50"	64 04'14"
LT11	Long Island	45 22'06"	64 06'24"
LT12	Pinnacle Rock	45 22'24"	64 08'38"
LT13	Moose River	45 12'32"	64 10'55"
LT14	Clarke HD	45 22'48"	64 14' 14"
LT15	Green Hill	45 22'50"	64 16'11"
LT16	Ottawa House	45 22'26"	64 19'31"
LT17	Gerry’s Weir	45 22'17"	64 20'17"
LT18	Dickson Bar	45 22'20"	64 21'58"
LT19	West Bay 1	45 22'32"	64 22'33"
LT20	FORCE	45 22'04"	64 24'17"
LT21	Black Rock	45 22'26"	64 25'26"
LT22	Big Eddy Cove	45 18'20"	64 20'41"
LT23	False Harbor	45 19'16"	64 23'33"
LT24	Amethyst Cove	45 19'25"	64 24'21"
LT25	McCully Point	45 19'32"	64 25'39"
LT26	Walton 8	45 14'51"	64 12'16"
LT27	Blomidon	45 15'51"	64 19'16"
LT28	West Bay 2	45 22'28"	64 24"40"

Appendix 2. Receiver deployment locations in Minas Passage and Minas Basin during the 2017-2019 lobster study.

Receiver	Location	Latitude	Longitude	Deployment Date	Retrieval Date
M1	Black Rock	45 22'26"	64 24'04"	04/04/2018	N/A
M2	Spruce Island	45 22'20"	64 24'03"	29/04/2018	N/A
M3	Cape Sharp	45 21'52"	64 23'19"	29/04/2018	28/11/2018
M4	Dickson Bar	45 22'20"	64 21'58"	14/07/2018	28/11/2018
M5	Partridge Island	45 21'54"	64 20'23"	29/04/2018	16/12/2018
M6	Parrsboro	45 22'44"	64 17'55"	18/05/2018	N/A
M7	Green Hill Point	45 22'44"	64 14'44"	18/05/2018	N/A
M8	Two Brothers	45 22'49"	64 12'37"	18/05/2018	16/12/2018
M9	Moose River	45 22'58"	64 10'36"	18/05/2018	N/A
M10	Little Five Islands	45 22'53"	64 07'09"	18/05/2018	16/12/2018
M11	Moose Island	45 22'37"	64 03'08"	18/05/2018	16/12/2018
M12	White Rock	45 22'32"	64 00'48"	18/05/2018	16/12/2018
M13	Brick Kiln	45 19'45"	63 58'00"	18/05/2018	N/A
M14	Economy Point	45 20'46"	63 53'00"	18/05/2018	N/A
M15	Little Bass River	45 21'42"	63 48'44"	19/05/2018	N/A
M16	Cobequid Bay	45 21'11"	63 43'59"	19/05/2018	N/A
M17	Burntcoat Head	45 18'52"	63 48'43"	19/05/2018	N/A
M18	Tenecape	45 17'25"	63 53'49"	19/05/2018	N/A
M19	East Walton	45 16'08"	63 58'24"	19/05/2018	16/12/2018
M20	Walton	45 14'46"	64 02'29"	19/05/2018	N/A
M21	Pembroke	45 14'19"	64 06'40"	18/05/2018	N/A
M22	Hogs Back	45 14'12"	64 09'58"	18/05/2018	N/A
M23	Cambridge Flats	45 14'39"	64 11'53"	14/06/2018	N/A
M24	Mutton Cove	45 13'29"	64 12' 04"	19/05/2018	28/11/2018
M25	Middle Ground	45 13'51"	64 13'57"	14/06/2018	28/11/2018
M26	TEMPERATURE	45 13'53"	64 13'56"	02/09/2018	28/11/2018
M27	Southern Cross Bar	45 12'35"	64 14'24"	24/05/2018	10/12/2018
M28	Western Bar	45 10'32"	64 14'15"	14/06/2018	10/12/2018
M29	Avonport	45 07'02"	64 13'18"	14/06/2018	10/12/2018
M30	Boot Island	45 13'18"	64 16'22"	14/06/2018	N/A
M31	Deepwater	45 13'04"	64 17'38"	14/06/2018	28/11/2018
M32	The Wreck	45 12'09"	64 18'31"	14/06/2018	28/11/2018
M33	Cornwallis River	45 10'12"	64 18'36"	14/06/2018	28/11/2018
M34	Blomidon #1	45 16'52"	64 19'30"	04/04/2018	25/11/2018
M35	Blomidon #2	45 17'35"	64 19'41"	17/05/2018	25/11/2018
M36	Blomidon #3	45 18'11"	64 20'14"	17/05/2018	16/12/2018
M37	Blomidon #4	45 19'04"	64 22'27"	17/05/2018	16/12/2018
M38	Blomidon #5	45 19'22"	64 23'55"	17/05/2018	25/11/2018
M39	Blomidon #6	45 19'37"	64 26'04"	17/05/2018	25/11/2018
M40	Cape Split	45 20'11"	64 29'44"	17/05/2018	25/11/2018



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Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA