Impact of finfish farms in eastern Canada (Nova Scotia) on American lobster and rock crab distribution

Running page head: Lobster and crab movements around finfish farms

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ABSTRACT

Keywords: American lobster; Rock crab; Abundance; Acoustic telemetry

1. Introduction

Aquaculture is increasing worldwide and in Canada, particularly regarding finish culture (Fisheries and Oceans Canada 2021, FAO 2022). Finfish farms are known to attract wild animals and interactions between fish farms and wild fishes have been well documented (see Callier *et al.* 2018; Barrett et al. 2019). Many mechanisms have been identified that attract and repel wild fish to and from fish farms: waste feed, farms acting as fish aggregation devices (FADs) or artificial reefs (ARs), biofouling communities on the nets, secondary attraction of predators, benthic changes, and husbandry practices (Callier *et al.* 2018; Barrett et al. 2019). Less is known about how fish farms attract or repel invertebrates, despite the importance of several commercial invertebrate species, including the American lobster (*Homarus americauns*) (Florko *et al*. 2021).

American lobster is the most valuable fishery in eastern Canada (ca. $CAN 2.05 B in 2021; Fisheries and Oceans Canada 2021). There are increasing concerns about the influence of finfish aquaculture sites on lobster distribution patterns and potential changes in food sources that may impact their condition, biology, and catchability (reviewed in Horricks *et al*. 2022). The perception is often that fish farms may negatively impact lobster abundance and condition (Wiber *et al.* 2012; Loucks *et al.* 2014; Grant *et al.* 2016; Loucks *et al.* 2016; Milewski *et al.* 2018). In addition, the rock crab is also fished commercially in eastern Canada, and although the landings of this species are dwarfed by the landed value of lobster, it is of importance in several areas (Fisheries and Oceans Canada 2022). The preferred prey of lobster is rock crab (Gendron *et al*. 2001; Hanson 2009) and unpublished work from southwest New Brunswick suggests that there are clear differences in associations of rock crab and lobster to salmon farm sites making a comparison between the two species of interest.

According to Loucks *et al.* (2014), fish farm activities may impact crustaceans close to salmonid farms by altering their movement and behaviour. Work on lobster movement near mussel farms in Iles-de-la-Madeleine and Prince Edward Island (Lavoie et al. 2022; Lees et al. 2023). In Iles-de-la-Madeleine, lobsters had little affinity to mussel farms, neither setting up territories within farm limits nor remaining in them for extended periods. Work in Prince Edward Island showed that lobsters may use mussel farms for foraging and shelter and that they entered and exited farms frequently, sometimes multiple times a day (Lees et al. 2023). In contrast, rock crabs mostly remained within mussel farm lease boundaries, staying mostly directly below culture structures (Lees *et al*. 2023).

This study evaluated the abundance and movement of decapods in the near vicinity of two salmonid aquaculture leases in Port Mouton and Liverpool Bay, Nova Scotia, Canada, using direct observation of animals and acoustic telemetry. The study was done over a full production cycle in Liverpool Bay, starting with a fallow year (no fish on site) and subsequently evaluating decapod interactions with a farm site at different production stages (fallow, 1-year old fish and 2-year old fish prior to harvesting). Previous work done around the Port Mouton Atlantic salmon/rainbow trout farm suggested it impacts the distribution of market and berried lobster (Loucks *et al*. 2014; Milewski *et al.* 2018), making it of interest in the present study. Results from this study will inform managers on the spatial interactions between two economically important activities in eastern Canada: marine farming of salmonids and lobster/crab fisheries. It is hoped that results from this study will foster the development of a sustainable salmonid aquaculture industry while allowing the continued use of fisheries resources by providing an evidence-based understanding of the links between these two activities.

2. MATERIALS AND METHODS

Study areas

The study was conducted in Port Mouton Bay (43°54'15"N, 64°47'31"N) and in Liverpool Bay (44°01'59"N, 64°39'31"W), Nova Scotia (NS), Canada in 2019, 2020, and 2021 (Figure 1). Port Mouton Bay is partially sheltered with depth varying from 8 to 18 m with the benthic substrate characterized by a mix of sand, gravelly sand, and mud (Piper *et al.* 1986). Liverpool Bay is 4.5 km long, 2.6 km wide, and open to the ocean. Coffin Island protects the northeast entrance to the bay and provides shelter for the current Atlantic salmon pen aquaculture site and proposed sites. Benthic substrate in Liverpool is principally characterised by sand (in the middle of the bay), rock, and gravel (McKee *et al.* 2021). Neither aquaculture site was in use in 2019. Since no further salmonid aquaculture was planned for the Port Mouton site following 2019 (CWM personal communications with the Nova Scotia Department of Fisheries and Aquaculture), the acoustic telemetry study was not continued at this location. As of the writing of this manuscript, there is a proposal to expand finfish aquaculture in Liverpool, NS (Figure 1). During the 2019 field season, the physical structure of the cages (i.e. the floating Polarcirkel fish pens; Klepp stasjon, Norway) were on the Liverpool site (7 × 2 cages, near Coffin Island, NS) and only some buoys and ropes were visible in the north site (at the northwest of the Spectacle Islands) in Port Mouton, alhough no fish were in cages at either site. In 2020, fish were added to the cages in Liverpool and in 2021 the cages contained 2-year-old Atlantic salmon.

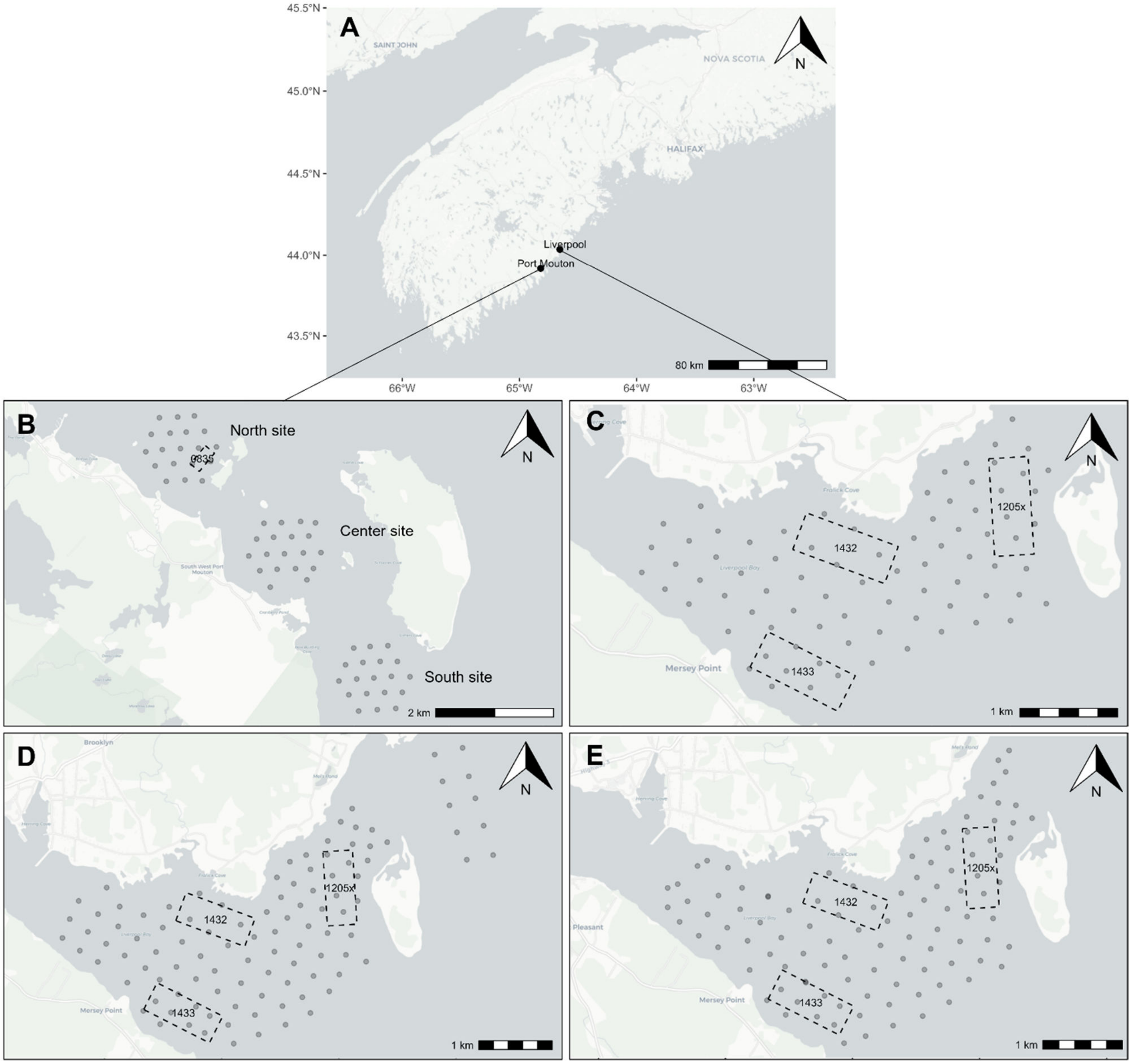

Figure 1. A) Location of the two study sites (black dots) in southern Nova Scotia (Canada). B) Location of the Port Mouton receivers in 2019 where the dashed outline represents the previously farmed site, and in Liverpool in C) 2019, D) 2020, and E) 2021. The grey dots represent the acoustic receivers in the study sites. For C-E, the 1205x polygon represents the finfish lease and the 1432-1433 polygons represent the proposed culture sites (1432 - Fralick Cove and 1433 - Mersey Point).

Observational sampling

In July 2019, a total of 35 transects (50 m long x 2 m wide) were swan by SCUBA divers in five distinct areas (farm site, Fralick Cove, Mersey Point, and two reference sites) in Liverpool Bay. Divers collected all decapods on encounter and brought them to the surface where they were sexed, measured, and counted. In Port-Mouton, SCUBA divers collected decapods on encounter along 50 transects in 5 distinct areas (Proposed farm site, 2 reference sites near the proposed farm, and 2 reference sites to the southeast of these). No transects were done at any location in 2020 due to travel restrictions caused by the COVID-19 pandemic making such voyages impossible. In 2021, 30 transects were sampled in Liverpool Bay (farm site, Fralick Cove, and Mersey Point) with all transects being done in the same way as in 2019.

Acoustic telemetry design and tag deployments

Three receiver models were deployed during the study: VR2W, VR2Tx, and VR2AR (69 kHz, Innovasea). Receivers were deployed in a grid that satisfied the criteria for the VEMCO Positioning System (VPS), fine-scale movement analysis (Orrell & Hussey 2022, Espinoza et al. 2011). At the beginning of the study, a range test was done prior the deployment of the acoustic receiver grid to determine optimal receiver spacing. A synchronisation tag (model V13, 36 mm long and 13 mm diameter, transmission delay between 500-700 s, Innovasea) was deployed 1 m above each VR2W receiver; VR2Tx and VR2AR receivers contain synchronisation tags (transmission delay between 540-660 s, Innovasea) within the units. Two or three reference tags (V9, Innovasea) were used at each site and placed where most receivers could record the signal.

2019

Figure 1 (B and C) shows the design for each location bay with the position of acoustic receivers. A substantial portion of Liverpool Bay was covered with receivers (Figure 1C) and three areas (N = North – where the salmonid farm was, C = Center, and S = South) were studied in Port Mouton (Figure 1B). This was a considerable sampling campaign with a total of 138 receivers deployed (Liverpool = 81 and Port Mouton = 57) in 2019. Receivers were deployed between July 16 and 23 and recovered between November 19 and 22 2019, for a total of 124 days for Liverpool and 121 days for Port Mouton. Each receiver was separated by 250 to 375 m from its neighbour.

A total of 47 rock crabs (34 M and 13 F) and 50 lobsters (29 M and 21 F) were captured and tagged in Liverpool and 51 rock crabs (22 M and 29 F) and 50 lobsters (29 M and 21 F) captured and tagged in Port Mouton (Table 1). All animals were measured (width for crabs and cephalothorax length - CL - for lobsters) before being released at the same place they were caught (farm site, Fralick Cove, and Mersey Point for Liverpool and north, center, and south sites for Port Mouton). Animals were caught using commercial lobster traps or by SCUBA divers on encounter and fitted on a boat with acoustic transmitters (Innovasea V9, 26 mm long and 9 mm diameter, transmission delay between 180-300 s). Transmitters were attached to carapaces cleaned with sandpaper followed by ethanol swabs) using ethyl 2-cyanoacrylate glue (LePage® Ultra Gel Control® Super Glue) and released back into the study arrays. Transmitter attachment required approximately 3 min for each animal, which were then released within about 10 min of being brought to the surface.

2020

A total of 106 receivers was deployed in Liverpool Bay on June 29 to July 13 (Figure 1C) and were recovered November 3 to 4, 2020. Ten of these receivers were installed outside the bay at the northeast and deployed in two lines (Figure 1D). Each receiver was separated by 250 to 375 m from its neighbour. One hundred animals were captured using commercial lobster traps, sexed, measured, and tagged (Table 1): 50 lobsters (30 M and 20 F) and 50 rock crabs (42 M and 8 F).

2021

Following the same methods used in 2019 and 2020, 104 receivers were deployed in Liverpool Bay on July 12 to 15 and recovered on November 9 to 10, 2021 (Figure 1E). A total of 50 lobsters (27 M, 23 F) and 50 crabs (26 M, 24 F) was captured using commercial lobster traps and on encounter by SCUBA divers (Table 1).

Table 1. Number and sex of American lobster (*Homarus americanus*) and rock crab (*Cancer irroratus*) tagged each year and at each site in Nova Scotia, Canada.

			Liverpool			Port Mouton		
Year	Species	Sex	Farm	Fralick Cove	Mersey Point	North	Center	South
2019	Lobster	M	13	5	11	10	7	12
		F	12	0	9	10	8	3
	Rock crab	M	9	0	25	12	2	8
		F	11	0	2	9	13	7
2020	Lobster	M	18	5	7	-	-	-
		F	11	2	7	-	-	-
	Rock crab	M	36	4	2	-	-	-
		F	8	0	0	-	-	-
2021	Lobster	M	10	7	10	-	-	-
		F	10	8	5	-	-	-
	Rock crab	M	8	14	4	-	-	-
		F	12	1	11	-	-	-

Data analysis

Data were analyzed using the open-source statistical software R version 4.3.2 (R Core Team, 2023) and PRIMER-e (v. 7.0.21).

Acoustic telemetry data pre-processing

Prior to analysis, data were filtered using a linear regression to remove observations with high positioning error (HPE) (Skerritt *et al.* 2015, Lees *et al.* 2020, Lavoie *et al.* 2022). HPE is a relative measure of error and a calculated position with high HPE provides less precise information on the position of an animal compared to a position with a lower HPE (Lees *et al.* 2023). A regression was done for each site based on the synchronisation tag deployed at each site within each year. HPE filtration was divided for each year of the study in Liverpool Bay. For 2019 in Liverpool Bay, less than 20% of the synchronization tag data were lost by filtering by HPE ≤ 35 (r^2 = 0.99). The animal detections from 2019 were thus filtered with an HPE ≤ 35 and a mean (± SE) position error for individuals of 4.9 ± 0.01 m. For 2020, less than 1% of the synchronization tag data were lost by filtering by HPE ≤ 25 (r^2 = 0.99). Animal detections from 2020 were thus filtered with an HPE ≤ 25 giving a mean position error (± SE) of 12.4 ± 0.02 m. For the last year of the study in Liverpool Bay, less than 5% of the sync tag data were lost by filtering by HPE ≤ 30 (r^2 = 0.88). The 2021 animal detections were thus filtered with an HPE ≤ 30 giving a mean position error (± SE) of 12.09 ± 0.01 m. Synchronization tag data from Port Mouton were filtered by HPE ≤ 30 (r^2 = 0.98) with a loss of less than 5% of the data. The mean position error (± SE) for Port Mouton animal detections with HPE ≤ 30 was 4.07 ± 0.008 m. The first 24 h of all tracking data were excluded at all sites to minimize the impact of tagging on behavior (Lavoie *et al.* 2022).

Only animals with more than 200 detections over the entire deployment at each year were kept for the analyses. A final filtration was used to remove data with individual walking speeds > 10 km d^{-1} as these speeds are abnormal for lobster and rock crabs.

Movement parameters analyses

Animal track analyses were done using the adehabitatLT package (Calenge 2006). When animals leave and then reenter the acoustic telemetry array, some gaps in the data may occur. To avoid such gaps in residence time estimates, distance travelled, and walking speed trajectories were split into separate bursts if the time between detections was >12 h and if the distance was >200 m (Lees *et al.* 2023; Lavoie *et al.* 2022). Residence time and distance travelled correspond to the cumulative time spent and cumulative distance travelled by each animal within the acoustic array, respectively. Walking speed was estimated by dividing the distance interval from each step by the time interval from the same step. Variations in residence time and the distance travelled for Liverpool Bay were examined using 4-way ANOVAs with the fixed factors “Year” (3 levels: 2019, 2020, and 2021), tagging “Site” (3 levels: farm site, Fralick Cove, and Mersey Point), “Species” (2 levels: lobster and crab), and “Sex” (2 levels: M and F). Assumptions of homoscedasticity were evaluated for ANOVA analyses using the Shapiro-Wilk test, as outlined in Quinn & Keough (2002). Data were transformed, where necessary, to satisfy assumptions of ANOVA (square root for the distance travelled). Variation in walking speed for Liverpool Bay was evaluated using PERMANOVA (with 9999 permutations) as data transformations were unable to constrain the data to meet the assumptions of ANOVA (Anderson 2001). The similarity matrix used to this end was constructed based on Euclidean distances. The homogeneity of multivariate dispersion was evaluated using PERMDISP and data transformed (square root). PERMANOVA analyses included the same four factors as the ANOVA analyses.

Variation in movement parameters for Port Mouton individuals were evaluated using 3-way ANOVAs with three fixed factors (“Site,” “Species,” and “Sex”). Assumptions of homoscedasticity were evaluated for each ANOVA analysis using the Shapiro-Wilk test. Data were transformed to satisfy assumptions of ANOVA (square root for the residence time and distance travelled, and log-transformation for walking speed). Differences among treatment means of factors that were deemed significant in the ANOVAs were evaluated using a posteriori Tukey multiple comparison tests.

Home range analyses

The 95% home range for the two species were calculated by kernel density estimations with the “amt” package (Signer et al. 2019) in Liverpool Bay. With the home range results, an overlap with the farm site was measured to determine the utilization percentage for each individual. To compare the home range and the overlap results, PERMANOVA (based on 9999 permutations) analyses were used to identify variation between four fixed factors (“Year,” “Site,” “Species.” and “Sex”). Euclidian distances were used to construct the similarity matrix and data were transformed as necessary (home range: square root; overlap: log+1). Differences among treatments were determined using a posteriori pairwise comparisons, also using PERMANOVA. For Port Mouton, home range data were analyzed with a 3-way ANOVA with three fixed factors (“Site,” “Species,” and “Sex”) and with a fourth root transformation to satisfy assumptions. Differences among treatment means of factors deemed significant in the ANOVA were evaluated using a posteriori Tukey multiple comparison tests.

Animal abundance

Variation in animal abundance observed within transects in Liverpool Bay were examined using PERMANOVA (with 9999 permutations) with the fixed factors “Year” (2 levels: 2019 and

2021), “Site” (3 levels: farm site, Fralick Cove, and Mersey Point), “Species” (3 levels: lobster, rock crab, and Jonah crab), and “Sex” (3 levels: M, F, and juvenile) since data transformation were unable to constrain the data to meet the assumptions of ANOVA (Anderson 2001). The similarity matrix used was constructed based on Euclidean distances. The homogeneity of multivariate dispersion was evaluated using PERMDISP and data transformed (log+1). Differences among treatments were determined using a posteriori pairwise comparisons, also using PERMANOVA.

3. Results

Animal abundance

Three decapod species were observed in the transects at all sites: American lobster, rock crab, and Jonah crab *(Cancer borealis)* (Figure 2). Abundance of Jonah crab was used for abundance analysis, however, no Jonah crab were tagged with acoustic transmitters. Abundance was found significantly different as a function of “Species,” “Sex,” and some factor interactions as “Year × Site × Species” (Table 2). The number of lobsters observed decreased under fish farm from 2019 (fallow year) relative to 2021 (production year II) ($p = 0.0001$) whereas this decline was not observed for rock crabs ($p = 0.4565$) (Figure 2; Table 2).

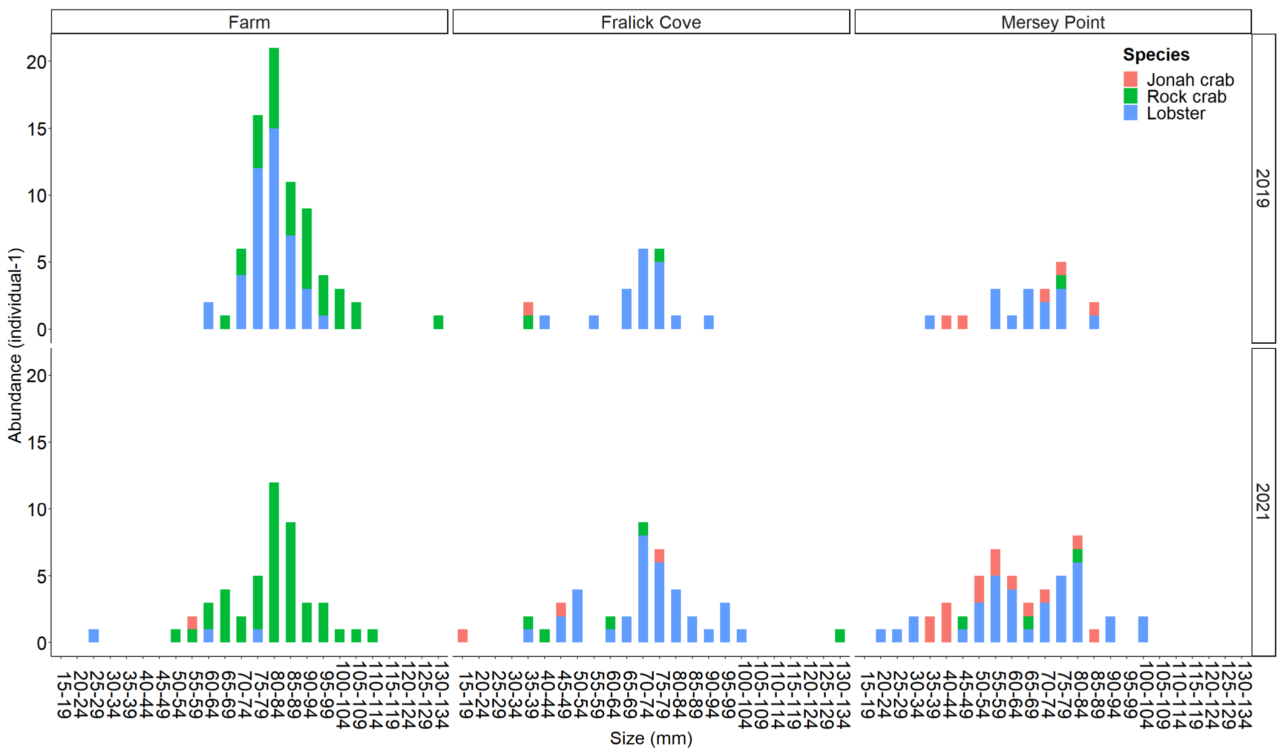

Figure 2. Abundance of American lobster (*Homarus americanus*), rock crab *(Cancer irroratus)*, and Jonah crab *(Cancer borealis)* at each site in Liverpool Bay, Nova Scotia in 2019 and 2021.

Table 2. Results of PERMANOVAs for the animal abundance by year, tagging site, species, and sex. Significant differences at $p < 0.05$ are highlighted in bold.

	Abundance			
Source	***df***	***MS***	***F***	**p**
Year	1	0.0071	0.0394	0.8401
Site	2	0.4920	2.7204	0.0694
Species	2	6.3539	35.135	**0.0001**
Sex	2	1.8742	10.364	**0.0001**
Year×Site	2	1.6892	9.3405	**0.0001**
Year×Species	2	0.4966	2.746	0.0654
Site×Species	4	0.8758	4.8426	**0.0011**
Year×Sex	1	0.0179	0.0988	0.7561
Site×Sex	4	0.5411	2.9922	**0.0203**
Species×Sex	4	0.2777	1.5357	0.1937
Year×Site×Species	4	2.1026	11.626	**0.0001**

Year×Site×Sex	2	0.0785	0.4341	0.6454
Year×Species×Sex	2	0.1651	0.9130	0.4087
Site×Species×Sex	8	0.8626	4.77	0.0001*
Year×Site×Species×Sex	4	0.0595	0.3289	0.8529
Error	351	0.1808		

Animal movement

The number of tagged animals that was detected after filtering and mean animal size for each year are shown in Table 3. In 2020, 21 animals tagged from the previous year were also detected (3 M lobsters; 3 F and 15 M crabs). In 2021, 10 animals tagged in 2020 were detected (1 F and 1 M lobsters; 2 F and 6 M crabs). All animals tagged previously were included in the analyses for a given year.

Table 3. Total detections and mean size of American lobster (*Homarus americanus*) and rock crab (*Cancer irroratus*) at each year and tagging site after filtering.

	Species	Sex	Number of Individuals	Number of Detections	Size (mm) ± SE
Port-Mouton 2019	Lobster	M	19	39 000	86.24 ± 0.001
		F	10	23 682	83.32 ± 0.0004
	Rock crab	M	19	113 720	77.12 ± 0.003
		F	27	212 603	76.97 ± 0.008
Liverpool 2019	Lobster	M	24	99 990	88.03 ± 0.001
		F	19	78 448	88.86 .± 0.003
	Rock crab	M	33	269 358	109.49 ± 0.003
		F	12	118 642	86.99 ± 0.003
Liverpool 2020	Lobster	M	27	92 036	89.13 ± 0.002
		F	18	79 626	87.56 ± 0.008
	Rock crab	M	55	528 323	110.89 ± 0.002
		F	10	111 214	90.43 ± 0.002
Liverpool 2021	Lobster	M	21	80 611	89.60 ± 0.002
		F	21	76 597	86.98 ± 0.001
	Rock crab	M	27	260 245	94.37 ± 0.003
		F	24	184 193	88.10 ± 0.002

Movements of American lobster and rock crabs tagged in Liverpool Bay are highlighted in Figure 3. There is a noted decrease in occupation of the farm site by lobsters over time whereas this effect is not evident for rock crabs.

Residence time only varied as a function of “Species” ($p < 0.0001$; Table 4). Crabs stayed longer in the acoustic array with a mean (± SE) residence time of 57.83 days ± 2.41 compared to 31.80 days ± 1.75 for lobsters (Figure 4) over the three-year study. For all years combined, a single female crab tagged under the farm site in 2019 (100.81 mm CW) stayed the longest time within the array (121.32 days). A male lobster tagged at Mersey Point in 2019 (86.4 mm size) remained the shortest time (1.14 days).

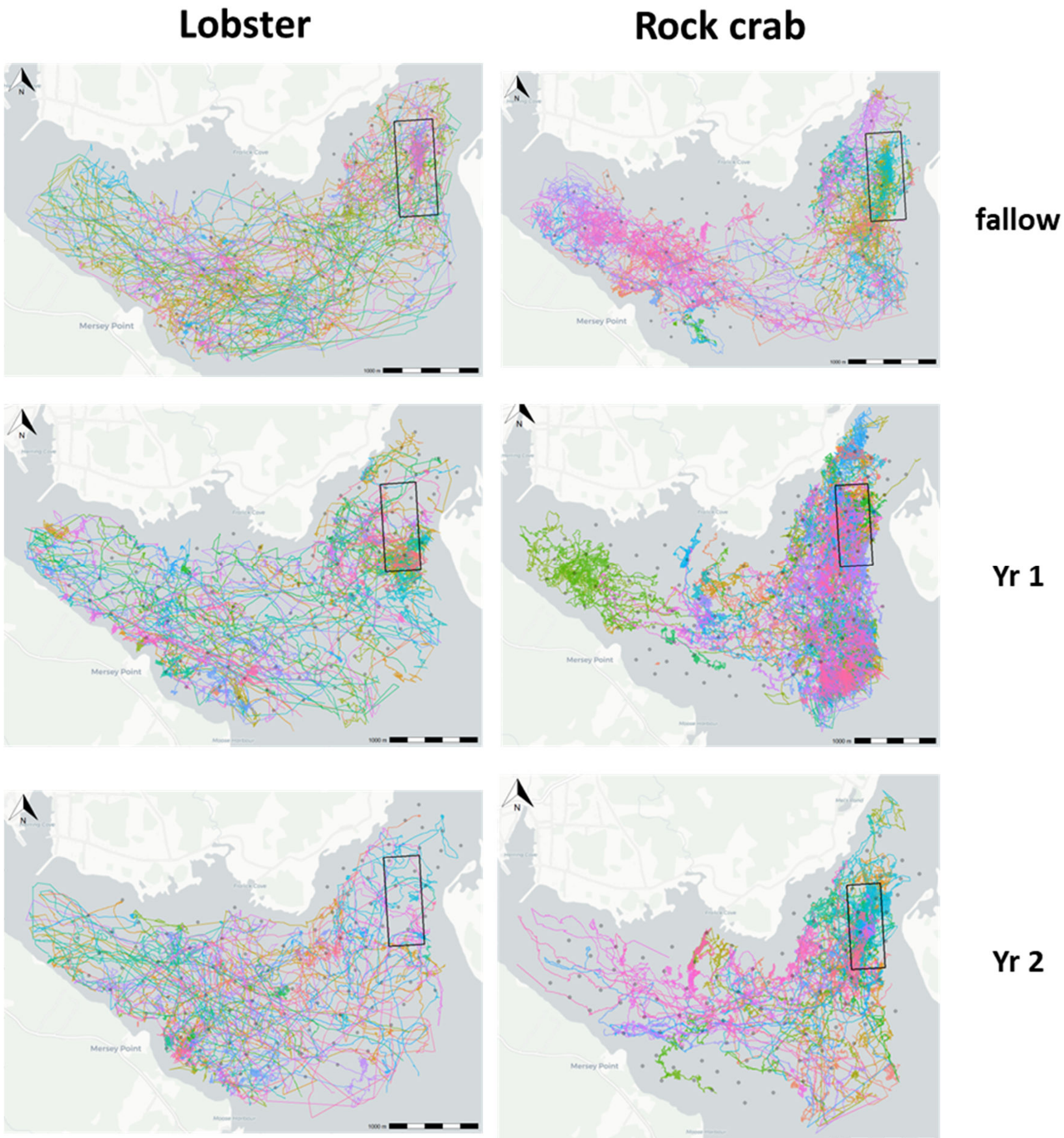

Figure 3. Movement of American lobster (*Homarus americanus*) and rock crab (*Cancer irroratus*) detected within the acoustic array each year in Liverpool Bay, Nova Scotia. Each colour represents an individual animal.

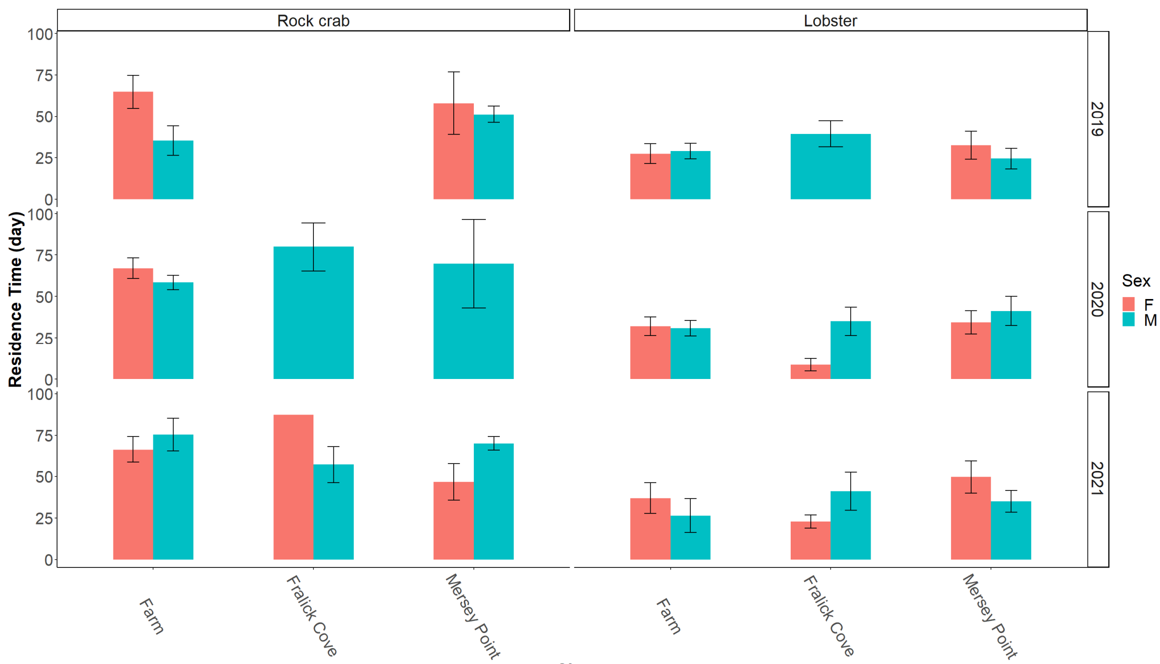

Figure 4. Mean residence time (day ± SE) by species for each tagging site and each year in Liverpool Bay, Nova Scotia. The colors represent the sex of the animals.

Distance travelled varied significantly as a function of "Year," "Species," and the "Site × Species × Sex" interaction (Table 4, Figure 5). In 2020, the mean (± SE) distance travelled by the two species was greater than that for the other years (47.18 ± 3.27 km compared to 35.94 ± 3.13 km for 2019 and 33.69 ± 2.85 km for 2021) (Figure 5). Variation between the species is explained by the greater distance travelled by crabs (48.93 ± 2.77 km) relative to that by lobsters (26.92 ± 1.75) (Figure 5).

Variation in walking speed was only impacted by the factor "Species" (Table 4, Figure 6). Lobsters had a greater walking speed (1.75 ± 0.06 km/day) than crabs (1.22 ± 0.03 km/day).

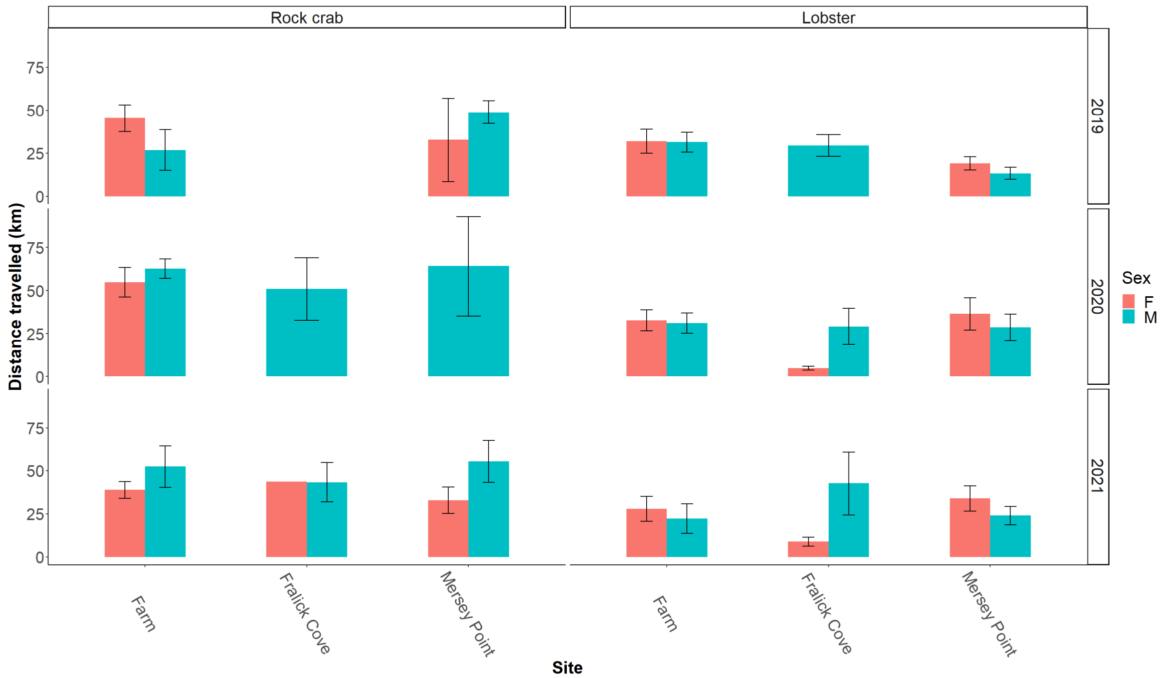

Figure 5. Mean distance travelled (± SE) by species from each tagging site and each year in Liverpool Bay, Nova Scotia. The colors represent the sex of the animals.

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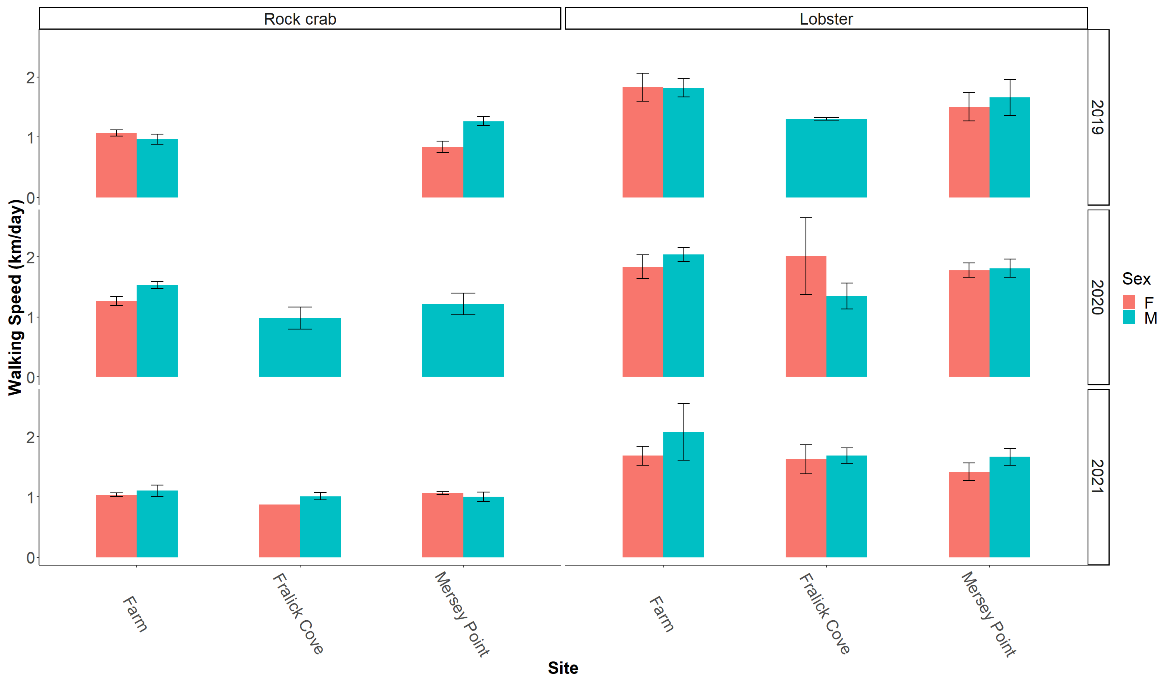

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279 **Figure 6.** Mean walking speed (± SE) by species for each tagging site and each year in Liverpool

280 Bay, Nova Scotia. The colors represent the sex of the animals.

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Table 4. Movement parameter results with the 4-way ANOVAs and PERMANOVA analyses for Liverpool Bay, Nova Scotia. Significant differences at $p < 0.05$ are indicated by bold font.

	ANOVA - Residence Time				*ANOVA - Distance Travelled*				*PERMANOVA - Walking Speed*			
Source	***df***	***MS***	***F***	**p**	***df***	***MS***	***F***	**p**	***df***	***MS***	***F***	**p**
Year	2	1592	2.322	0.1001	2	34.27	5.989	**0.0029**	2	0.0377	0.9863	0.3752
Site	2	62	0.091	0.9131	2	8.00	1.399	0.2487	2	0.0813	2.1272	0.1207
Species	1	49 664	72.430	**1.4^{e-15}**	1	184.60	32.259	**3.6^{e-08}**	1	1.0065	26.322	**0.0001**
Sex	1	312	0.455	0.5006	1	1.71	0.299	0.5847	1	0.0051	0.1342	0.7193
Year×Site	4	564	0.822	0.5119	4	2.59	0.453	0.7700	4	0.0055	0.1428	0.9662
Year×Species	2	470	0.686	0.5045	2	3.70	0.646	0.5250	2	0.0011	0.0298	0.9714
Site×Species	2	907	1.323	0.2682	2	4.22	0.737	0.4796	2	0.0054	0.1408	0.8622
Year×Sex	2	732	1.067	0.3455	2	6.44	1.125	0.3263	2	0.0070	0.1818	0.8302
Site×Sex	2	627	0.915	0.4019	2	9.12	1.593	0.2052	2	0.0130	0.3402	0.7146
Species×Sex	1	179	0.260	0.6103	1	3.24	0.566	0.4526	1	0.0079	0.2069	0.6514
Year×Site×Species	3	1096	1.598	0.1903	3	10.43	1.823	0.1434	3	0.0179	0.4682	0.6998
Year×Site×Sex	3	213	0.311	0.8177	3	1.35	0.237	0.8707	3	0.0320	0.8374	0.4837
Year×Species×Sex	2	1256	1.831	0.1623	2	4.51	0.787	0.4561	2	0.0264	0.6913	0.5015
Site×Species×Sex	2	2025	2.953	0.0539	2	17.43	3.045	**0.0493**	2	0.0123	0.3223	0.7208
Year×Site×Species×Sex	1	78	0.114	0.7362	1	2.42	0.423	0.5159	1	0.0292	0.7623	0.3834
Error	260	686			260	5.72			260	0.0382		

All movement parameters for the animals tagged in Port Mouton Bay varied as a function of tagging "Site" and "Species" (Table 5). Residence time for all the animals tagged in the north site differed significantly from that in the center and south and the time passed in the study area differed between lobsters and crabs with respectively 15.19 ± 2.86 days and 39.04 ± 4.30 days (Figure 7). The same pattern was observed for the distance travelled by animals tagged in the north site differing from that of animals tagged in the two other sites ($p = 0.0004$ for the center site and $p < 0.0001$ for the south site). The mean (± SE) distance travelled by the lobster differed from that for crabs (Figure 8). Walking speed differed between south and center sites ($p = 0.003$), and south and north sites (p < 0.0001). Mean walking speed for lobsters was significantly different (Table 4, Figure 8).

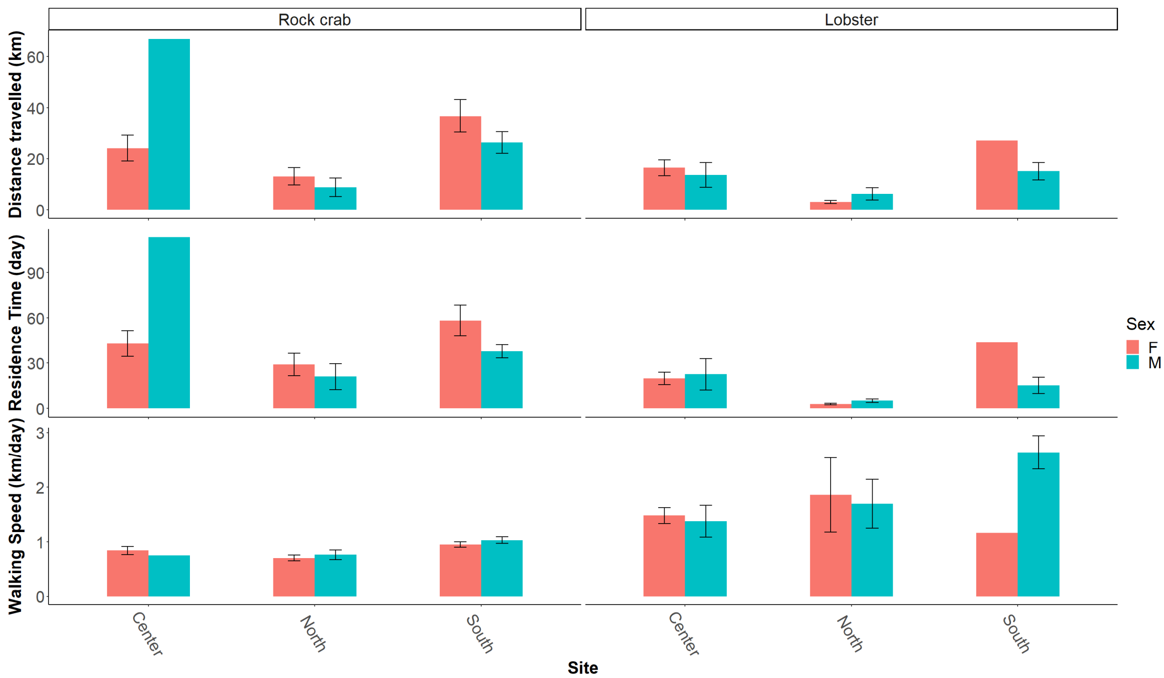

Figure 7. Mean movement parameters (± SE) by species for each tagging site in Port Mouton, Nova Scotia. The colors represent the sex of the animals.

Table 5. Movement parameter results for the 3-way ANOVAs for Port Mouton, Nova Scotia. Significant differences at $p < 0.05$ are indicated by bold font.

	Residence Time				***Distance Travelled***				***Walking Speed***			
Source	***df***	***MS***	***F***	**p**	***df***	***MS***	***F***	**p**	***df***	***MS***	***F***	**p**
Site	2	29.81	7.245	**0.0015**	2	31.443	14.138	**8.47**$^{e-06}$	2	1.386	11.008	**7.94**$^{e-05}$
Species	1	111.51	27.102	**2.25**$^{e-06}$	1	24.389	10.966	**0.0015**	1	9.162	72.750	**4.25**$^{e-12}$
Sex	1	5.37	1.305	0.25754	1	2.685	1.207	0.27602	1	0.035	0.281	0.598
Site×Species	2	1.23	0.299	0.74291	2	1.018	0.458	0.63469	2	0.143	1.136	0.328
Site×Sex	2	8.86	2.154	0.12444	2	2.899	1.303	0.27882	2	0.104	0.823	0.444
Species×Sex	1	1.73	0.420	0.51926	1	0.587	0.264	0.60914	1	0.049	0.387	0.536
Site×Species×Sex	2	9.46	2.299	0.10869	2	7.105	3.194	**0.0477**	2	0.148	1.174	0.316
Error	63	4.11			63	2.224			63	0.126		

Farm attraction

Variation between individual home ranges was significantly different as function of the Site × Species interaction such that the overlap with the farm area increases for rock crab over time whereas as that for lobster shows the opposite pattern (Table 6). The total home range for the three years for the lobsters tagged under the farm site differs from the crab home ranges (Figure 8). Overlap of crab and lobster distributions with the farm area are highlighted in Figure 9.

Home range for Port Mouton individuals varied as a function of "Site" and "Species" (Table 7) such that there was a higher home range for lobster than rock crabs (Figure 10). For tagging sites, north and the south sites differed (p = 0038).

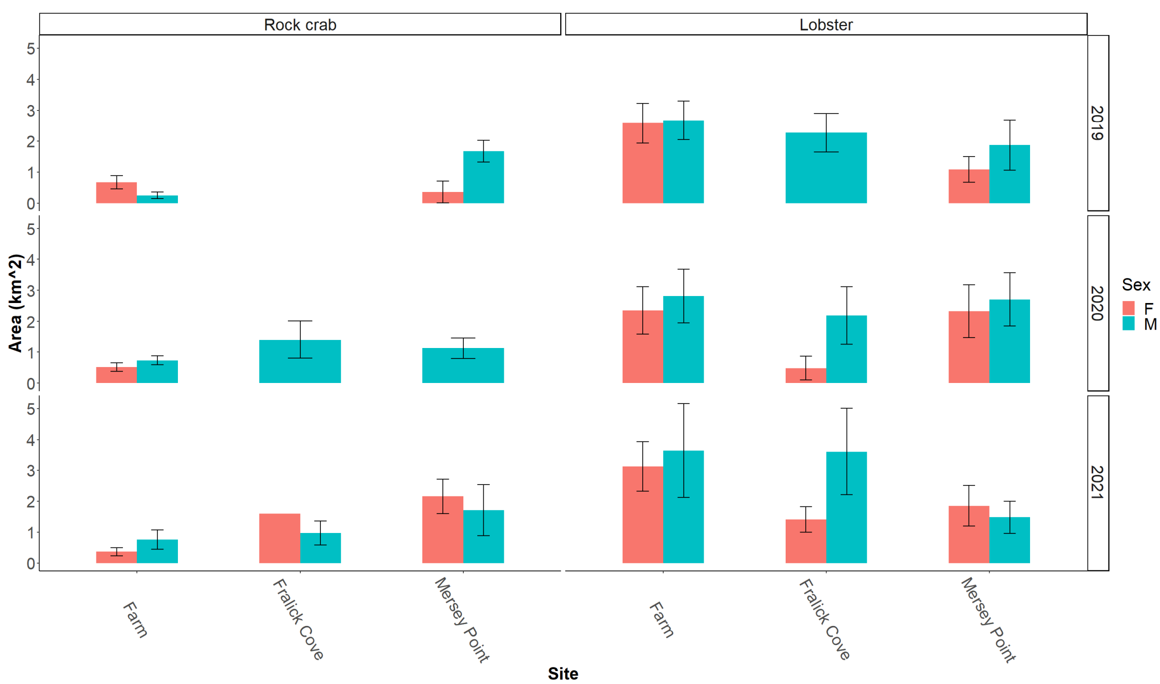

Figure 8. Mean (± SE) home range by species for each tagging site and year in Liverpool Bay. The colors represent the sex of the animals.

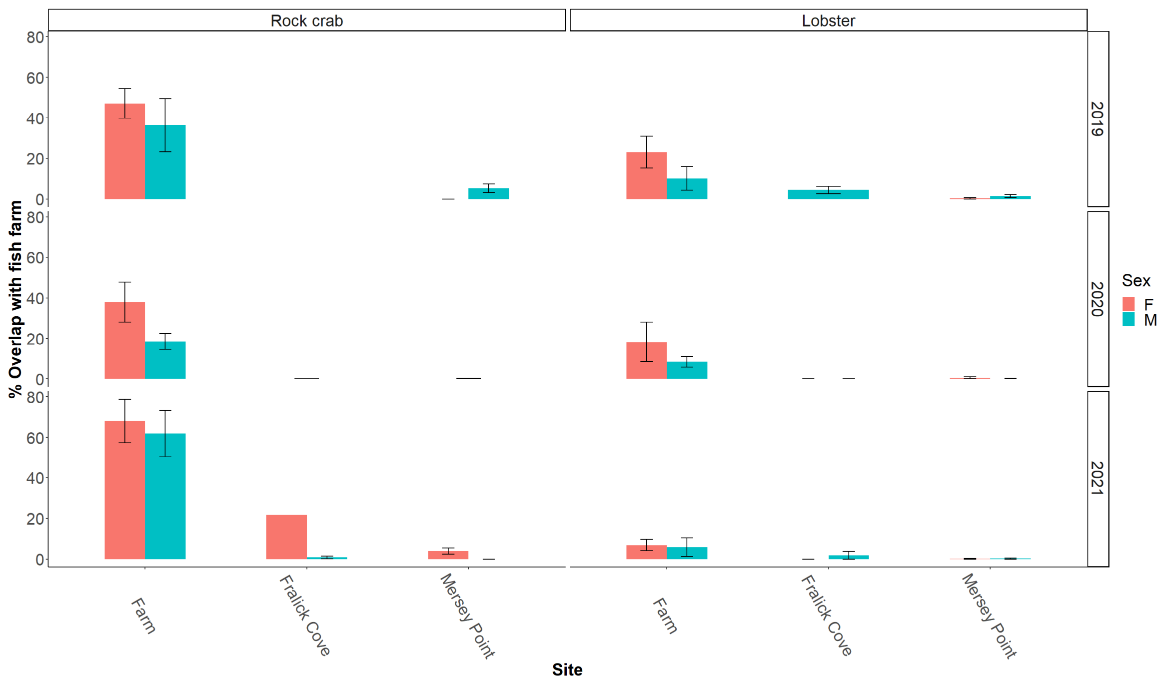

Figure 9. Mean (± SE) area overlap with fish farm by species for each tagging site and year in Liverpool Bay. The colors represent the sex of the animals.

Table 6. Results of PERMANOVAs for home range and the area that overlaps with the fish farm. Significant differences at $p < 0.05$ are indicated by bold font.

	Home range				*Overlap with fish farm*			
Source	***df***	***MS***	***F***	**p**	***df***	***MS***	***F***	**p**
Year	2	0.2037	0.4311	0.6508	2	0.6904	0.4966	0.6139
Site	2	0.0464	0.0981	0.9096	2	54.491	39.191	**0.0001**
Species	1	1.8079	3.826	0.0532	1	18.231	13.112	**0.0003**
Sex	1	0.0701	0.1484	0.6929	1	9.7329	7.0002	**0.0097**
Year×Site	4	0.1381	0.2922	0.8791	4	0.8343	0.6001	0.6639
Year×Species	2	0.0607	0.1284	0.8801	2	2.3159	1.6656	0.1919
Site×Species	2	1.8829	3.9848	**0.0213**	2	4.8358	3.478	**0.0344**
Year×Sex	2	0.0494	0.1044	0.9059	2	0.6401	0.4604	0.6393
Site×Sex	2	0.0690	0.1461	0.866	2	1.5641	1.125	0.3225
Species×Sex	1	0.5502	1.1644	0.2795	1	8.0102	5.7612	**0.0189**
Year×Site×Species	3	0.7779	1.6462	0.1848	3	3.1079	2.2353	0.0837
Year×Site×Sex	3	0.3236	0.6848	0.5642	3	3.4636	2.4911	0.063
Year×Species×Sex	2	0.0199	0.0422	0.9588	2	1.4864	1.0691	0.3469
Site×Species×Sex	2	0.6468	1.3688	0.2562	2	2.6662	1.9176	0.145

Year×Site×Species×Sex	1	0.4836	1.0233	0.3055	1	1.2318	0.8860	0.3417
Error	260	0.4725			260	1.3904		

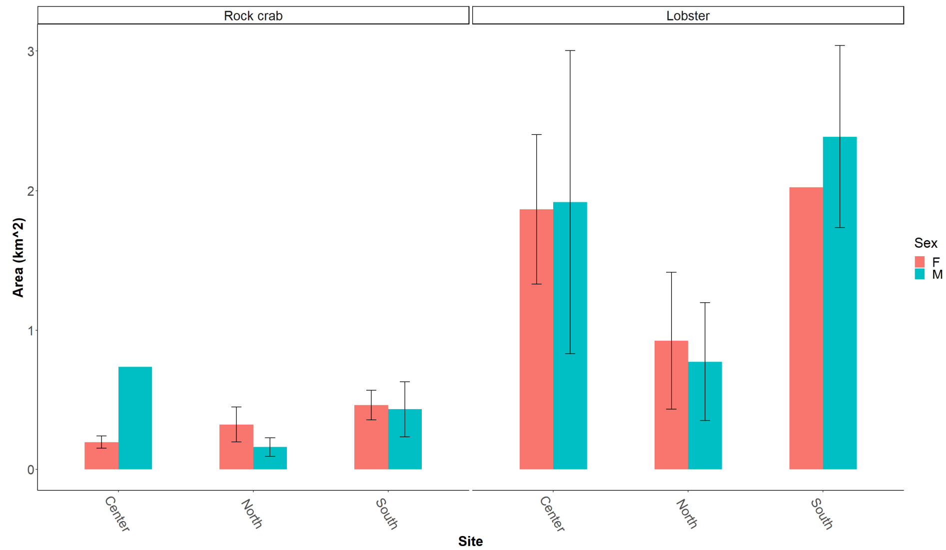

Figure 10. Mean (± SE) home range by species for each tagging site in Port Mouton.

Table 7. Home range results for the 3-way ANOVAs for Port Mouton, Nova Scotia. Significant differences at $p < 0.05$ are indicated by bold font.

	Home range			
Source	***df***	***MS***	***F***	**p**
Site	2	388.7	5.658	**0.0055**
Species	1	2319.4	33.762	**2.22^{e-07}**
Sex	1	48.5	0.706	0.4041
Site×Species	2	70.2	1.022	0.3658
Site×Sex	2	8.7	0.126	0.8817
Species×Sex	1	9.3	0.135	0.7146
Site×Species×Sex	2	70.1	1.020	0.3664
Error	63	68.7		

DISCUSSION

This study evaluated the distribution (abundance and movement) of two decapods (American lobster and rock crab) of commercial and ecological importance over a full production cycle in Liverpool Bay and a few years post-salmonid production at a decommissioned finfish aquaculture site in Port Mouton, Nova Scotia. In general terms, Atlantic salmon aquaculture in Liverpool Bay was observed to affect the abundance and movement of both American lobster and rock crabs.

Many organisms may be associated with finfish farms because of the physical structure they provide and the trophic subsidy they offer in terms of lost feed and faeces (Callier et al. 2018). While the bulk of this work has focused on fish, birds, and marine mammals (Barrett et al. 2019), other taxonomic groups have also been the focus of studies, including benthic invertebrates (Callier et al. 2018). Indeed, several studies have shown that decapods use and assimilate waste from marine finfish farms. For example, northern shrimp (*Pandalus borealis*) fatty acid signatures were altered close to farms relative to those caught distant from farms (Olsen et al. 2012). Likewise, caramote prawn (*Melicertus kerathurus*) show isotopic evidence that animals close to the farm had been feeding on farm waste (Izquierdo-Gomez et al. 2015). Woodcock et al. (2018) showed that brown crab (*Cancer pagurus*) showed fatty acid and stable isotope evidence of being affected by the farm at distances up to 1 km from the farm. A study on American lobster and rock crabs found that both species had fatty acid profiles indicating that they had been feeding on feed waste or faeces by comparing the results from animals in similar locations without fish farms (Sardenne et al. 2020). Likewise, Baltadakis et al. (2020) showed that juvenile European lobster (*Homarus gammarus*) at a control site differed those deployed adjacent to an Atlantic salmon farm in terms of fatty acid signatures due to organic loading from the farm.

Several studies have evaluated the abundance of decapods around fish farms in eastern Canada with a focus on lobster. For example, Lawton (2002) observed that lobster in the area of a Grand Manan, New Brunswick, Canada, salmon farm were less abundant during a period when farms were operational, particularly for egg-bearing (berried) lobster, than in periods when salmon were not in fish cages and that historical patterns of site occupation returned when the farm was removed. Milewski et al. (2018) suggested that lobster catches of both commercial and berried females decreased during farming operations at a Port Mouton, Nova Scotia, Canada salmonid farm. Likewise, Wiber et al. (2012) suggest that fishers in the Bay of Fundy, New Brunswick, believe that berried female lobster avoid areas where salmon aquaculture has established. However, Grant et al. (2016) suggested that this is not the case and that longer-term studies suggest that salmon farms have no obvious impact on lobster abundance. For example, Grant et al. (2019) sampled lobster under a Grand Manan salmon farm over 8 years and at appropriate reference areas and did not observe variation in lobster abundances between the two habitat types (farm and reference) for either market size or berried females. The present study noted a marked decrease in the abundance of lobster from the fallow year relative to the year when the farm contained two-year-old fish, although this trend was not observed in reference areas (Fralick Cove and Mersey Point). In contrast, this effect was not observed for rock crabs. Milewski et al. (2018) suggested that the salmonid farm in Port Mouton created benthic conditions due to excess feed that were unfavorable to lobsters. However, Milewski et al. (2018) invoke mechanisms occurring at a larger spatial scale (e.g. hypoxia and sulphide levels, as outlined in Hargrave et al. 1997, for example) than patterns observed in the present study and the data to support predicted effects in Milewski et al. (2018) show the opposite pattern than would be predicted (i.e. there were fewer berried lobster in the region surrounding the farm in fallow years than in years when fish were in cages).

Lobster and crab movements differed and varied spatially across years in Liverpool Bay and spatially in Port Mouton. As for lobster within mussel leases (Lavoie et al. 2022, Lees et al. 2023), lobster in Liverpool Bay showed little affinity to the salmon farm there as the lobster caught and released adjacent to or below the farm did not stay in the area in the fallow year and this effect only increased in subsequent production years. This is reflected by the spatial overlap of lobster distribution with the salmon farm, which declined over time. In contrast, rock crabs seem to be associated with farms, even in the fallow year. This is likely due to fall-off of fouling organisms (mussels *Mytilus edulis*) in the fallow year (McKindsey, personal observations) and consuming salmon feed during production years (Sardenne et al. 2020). The effect of mussel fall-off on rock crab distributions was previously noted in Prince Edward Island by Lees et al. (2023) and rock crabs are known to consume salmon feed from laboratory studies (Drolet et al. 2022). Thus, as opposed to lobster, the spatial overlap of crab distributions increased over time.

Other movement metrics also varied by species. Both walking speed and home range in Liverpool Bay were greater for lobster than for rock crab, as was also observed for these species in the areas surrounding mussel culture sites in Prince Edward Island (Lees et al. 2023). The same effect was also observed in Port Mouton. Other movement metrics (distance travelled and residence time) were both lower for lobster than for rock crab as these are reflected by the quicker movement of lobsters leaving the acoustic arrays established in both study sites more rapidly than rock crabs.

Given the results from this study, it is unclear what effects salmonid aquaculture may have on decapods in the surrounding area. While both American lobster and rock crab uptake nutrients from aquaculture activities (Sardenne et al. 2020), it is also known that a diet of only salmon feed may have negative impacts on rock crab condition (Drolet et al. 2022). However, this clearly does not occur under field conditions as crabs were clearly attracted to fallen mussels in the farm area in the fallow year. Similar work on lobster is underway (Drolet, personal communications). Variation in the overlap of lobster distributions with the farm area over time indicates that lobsters are les abundant in the farm area as aquaculture production increases. However, there was no indication that movement of lobsters in areas adjacent to the farm diminished. Likewise, the spatial overlap of rock crabs with the farm increased over time, although the movement of animals adjacent to the farm remained similar over the three years of the study. As for Bay of Fundy aquaculture sites (Walters 2007), salmonid aquaculture will continue to interact with decapods throughout eastern Canada. It is hoped that the results presented here will inform the discussion on the importance of such interactions.

ACKNOWLEDGEMENTS

We are grateful to Émilie Simard, Frédéric Hartog, Jean-Daniel Tourangeau-Larivière, Simon Jacques, and Delphine Cottier from Fisheries and Oceans Canada, and Todd Mosher, David Cook, and Jennifer Feehan from the Nova Scotia Department of Fisheries and Aquaculture for their help in project planning and field assistance. This study was supported by Fisheries and Oceans Canada and the Nova Scotia Department of Fisheries and Aquaculture. We also thank the fish farmer collaborator, Cooke Aquaculture, for allowing access to their site.

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Supplementary Material

3.1.1 2019 – Liverpool and Port-Mouton

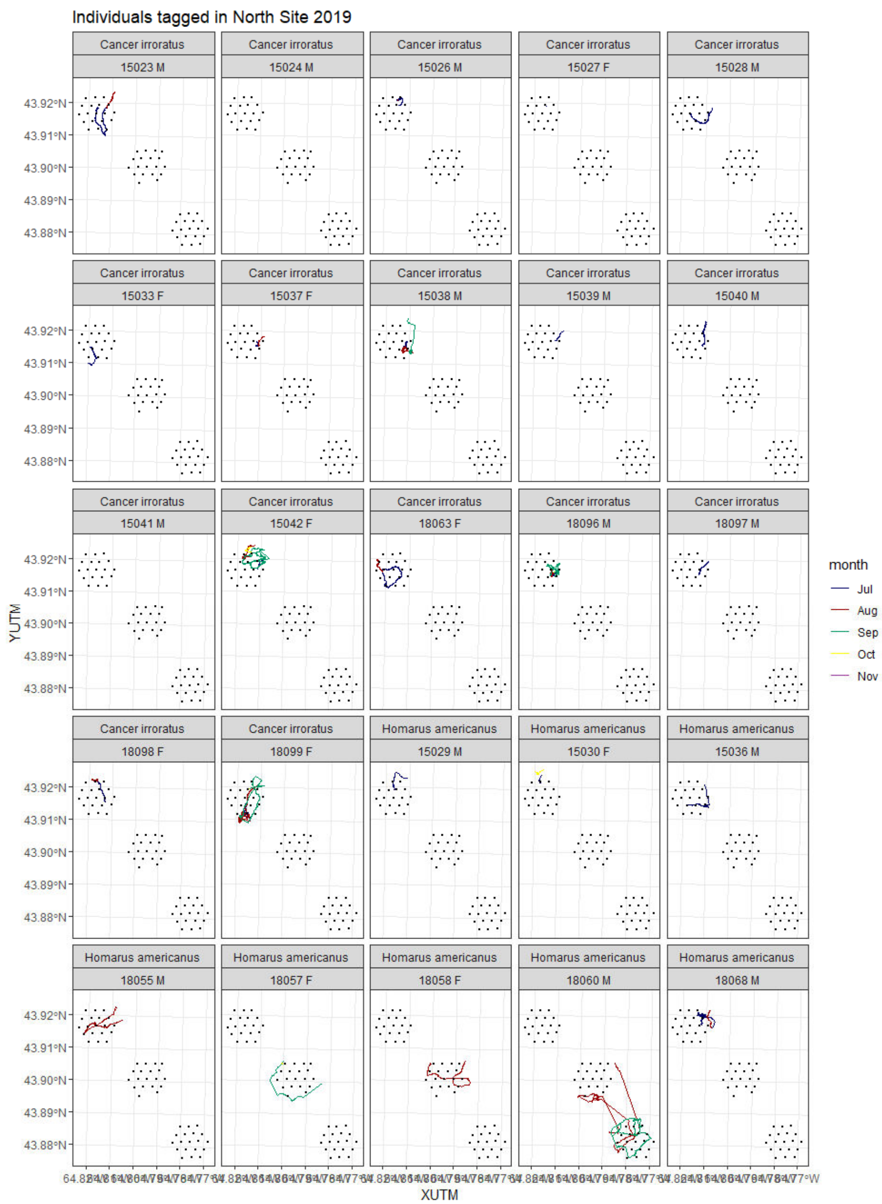


Figure X. Tracks for animals tagged in the North site, Port-Mouton 2019. The black dots indicate receiver locations.

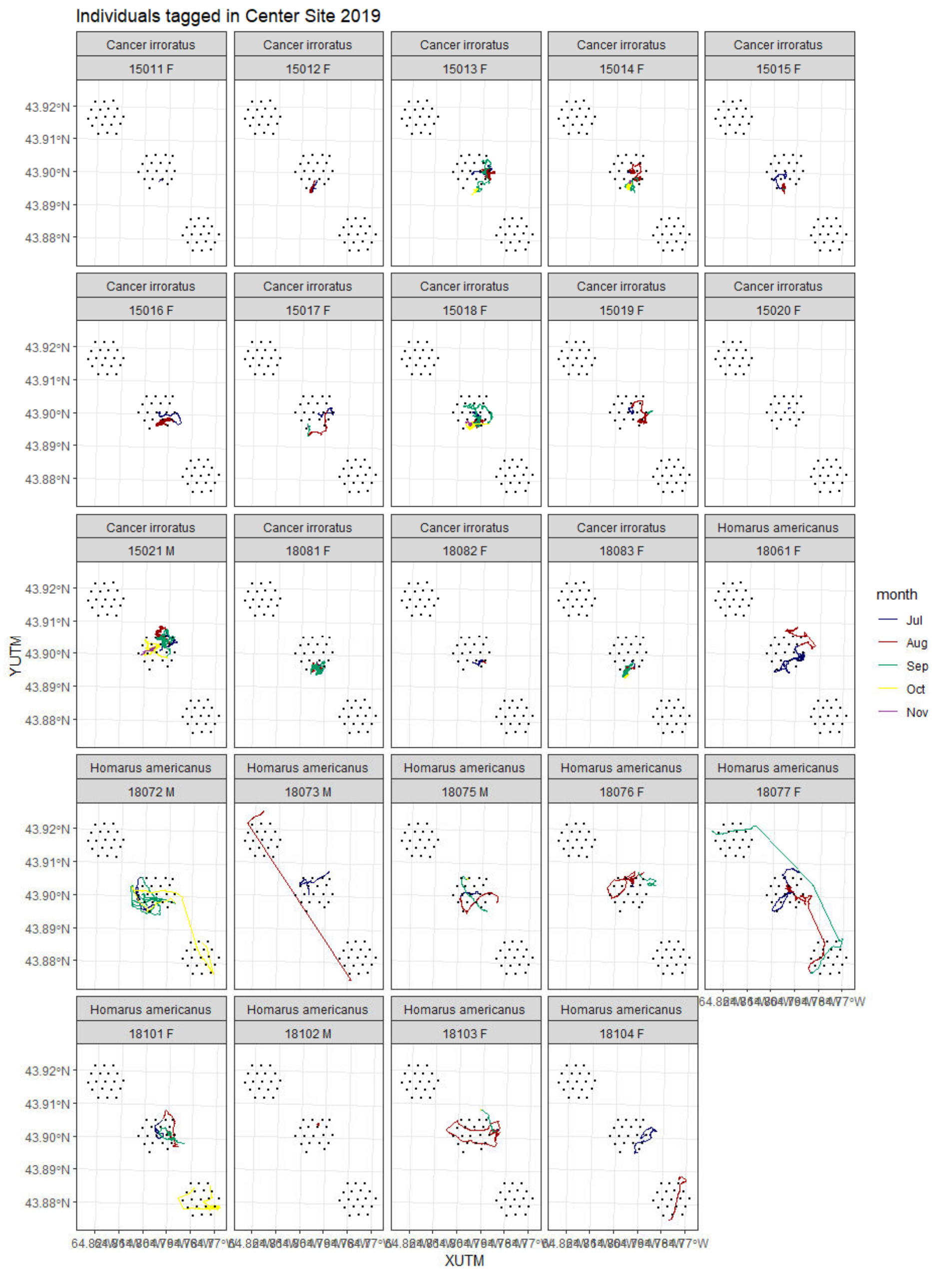


Figure X. Tracks for animals tagged in the Center site, Port-Mouton 2019. The black dots indicate receiver locations.

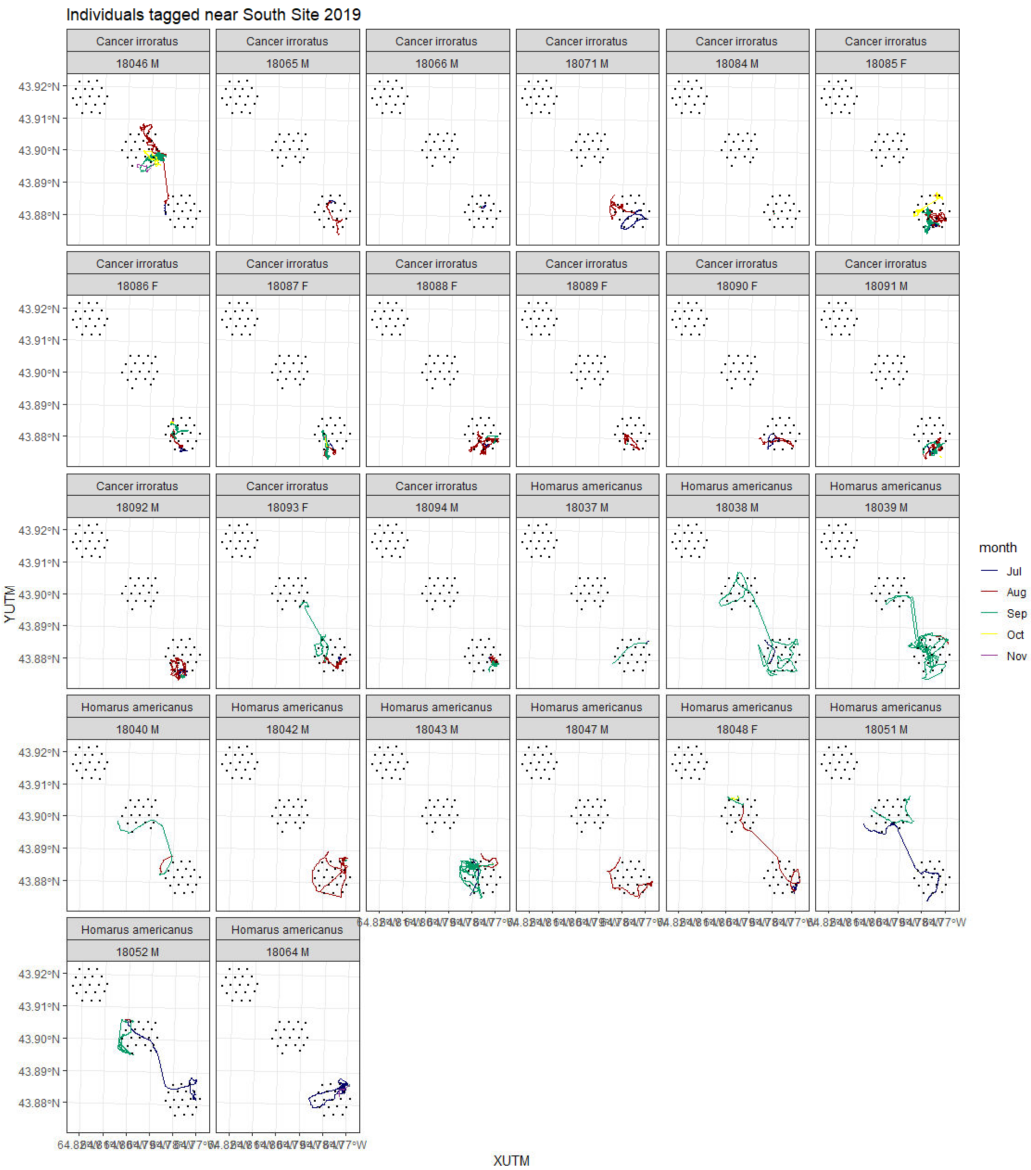


Figure X. Tracks for animals tagged in the South site, Port-Mouton 2019. The black dots indicate receiver locations.

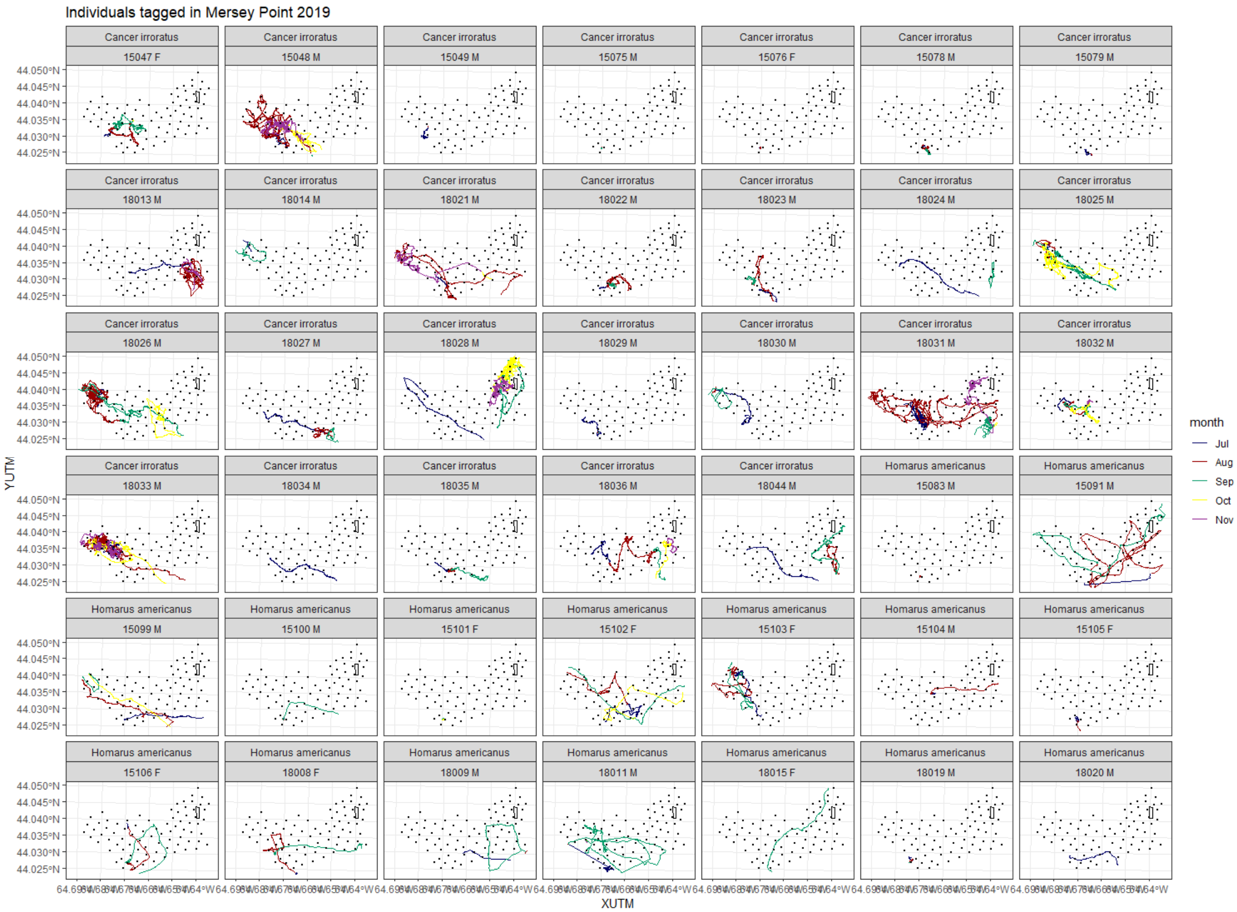


Figure X. Tracks for animals tagged at Mersey Point, Liverpool 2019. The black dots indicate receivers and the farm is represented by the black polygon.

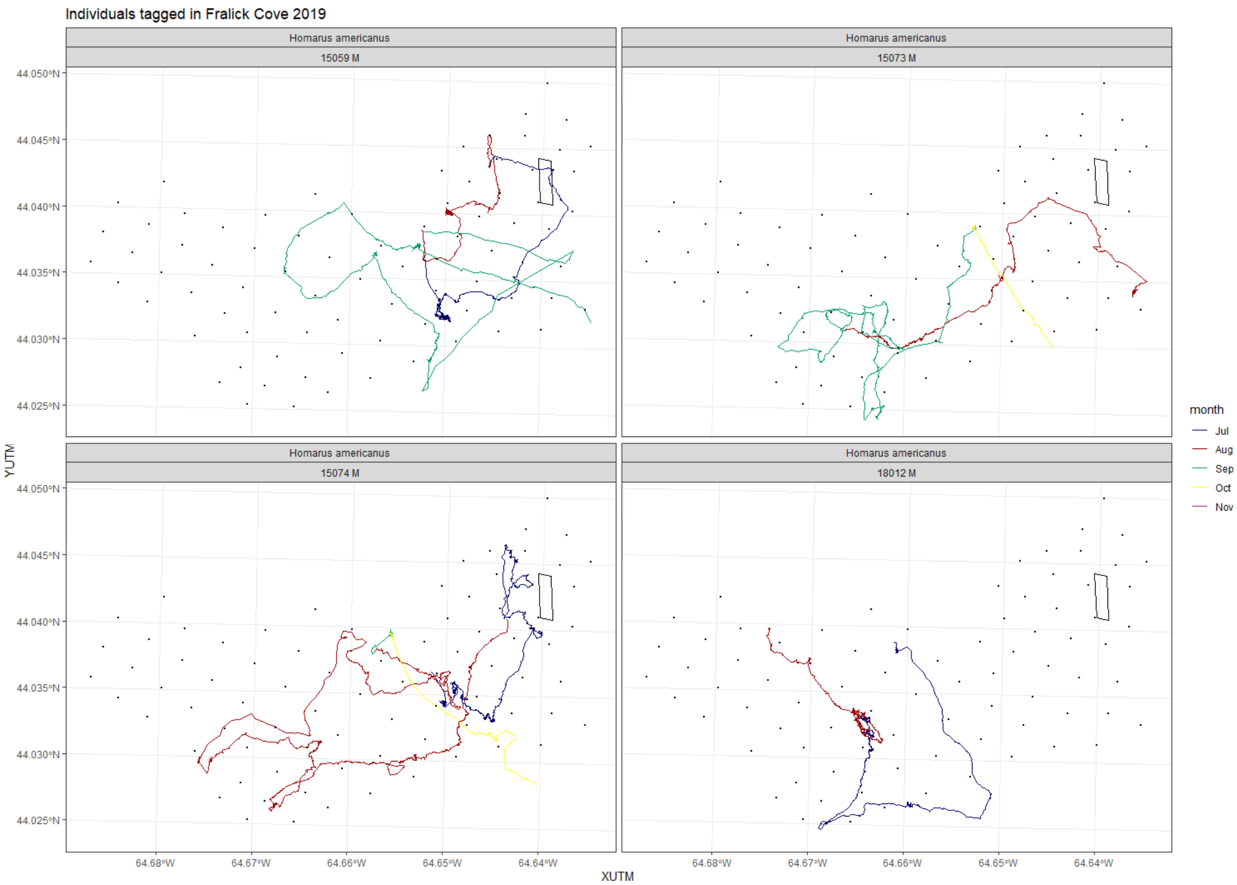


Figure X. Tracks for animals tagged at Fralick Cove, Liverpool 2019. The black dots indicate receivers and the farm is represented by the black polygon.

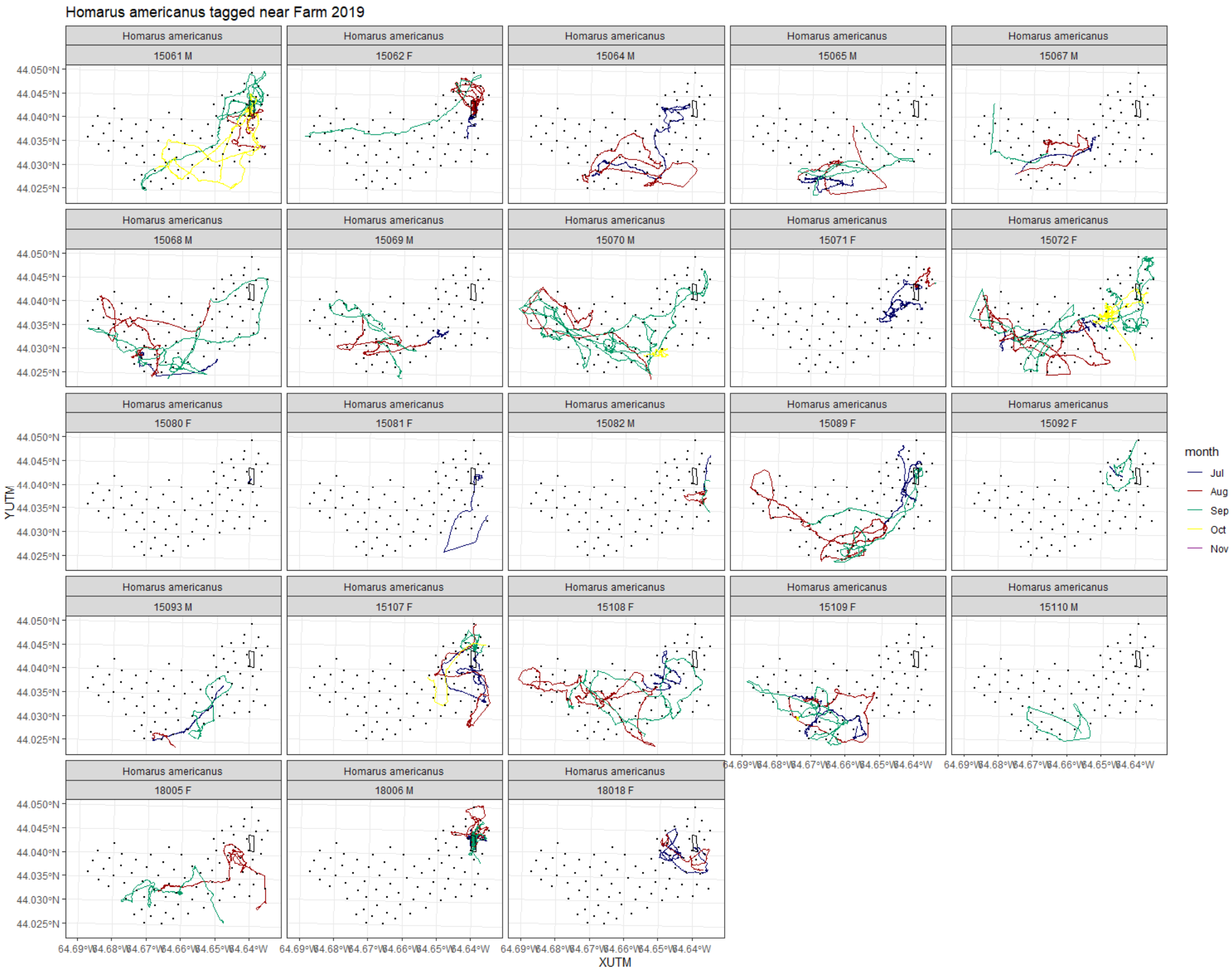


Figure X. Tracks for lobsters tagged near the fish farm area, Liverpool 2019. The black dots indicate receivers and the farm is represented by the black polygon.

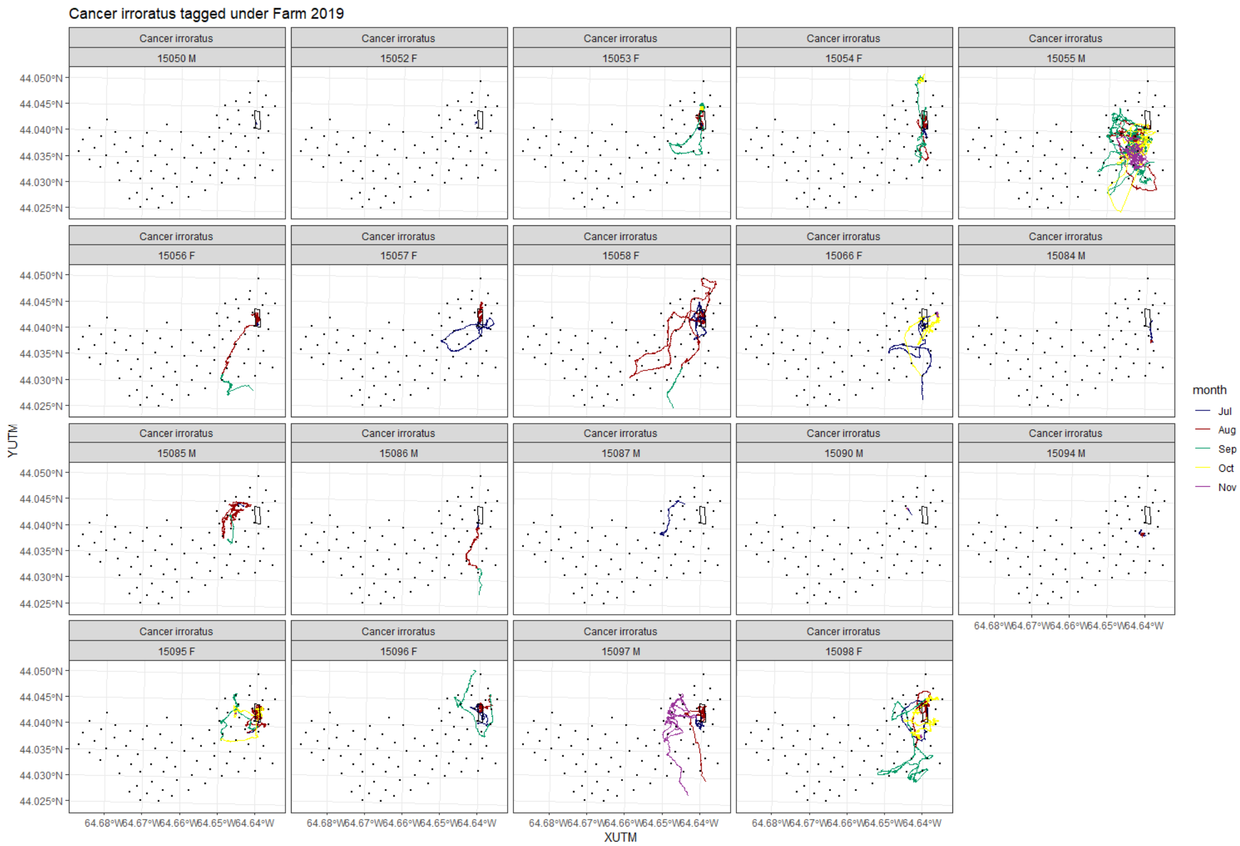


Figure X. Tracks for crabs tagged near the fish farm area, Liverpool 2019. The black dots indicate receivers and the farm is represented by the black polygon.

3.1.2 2020 – Liverpool

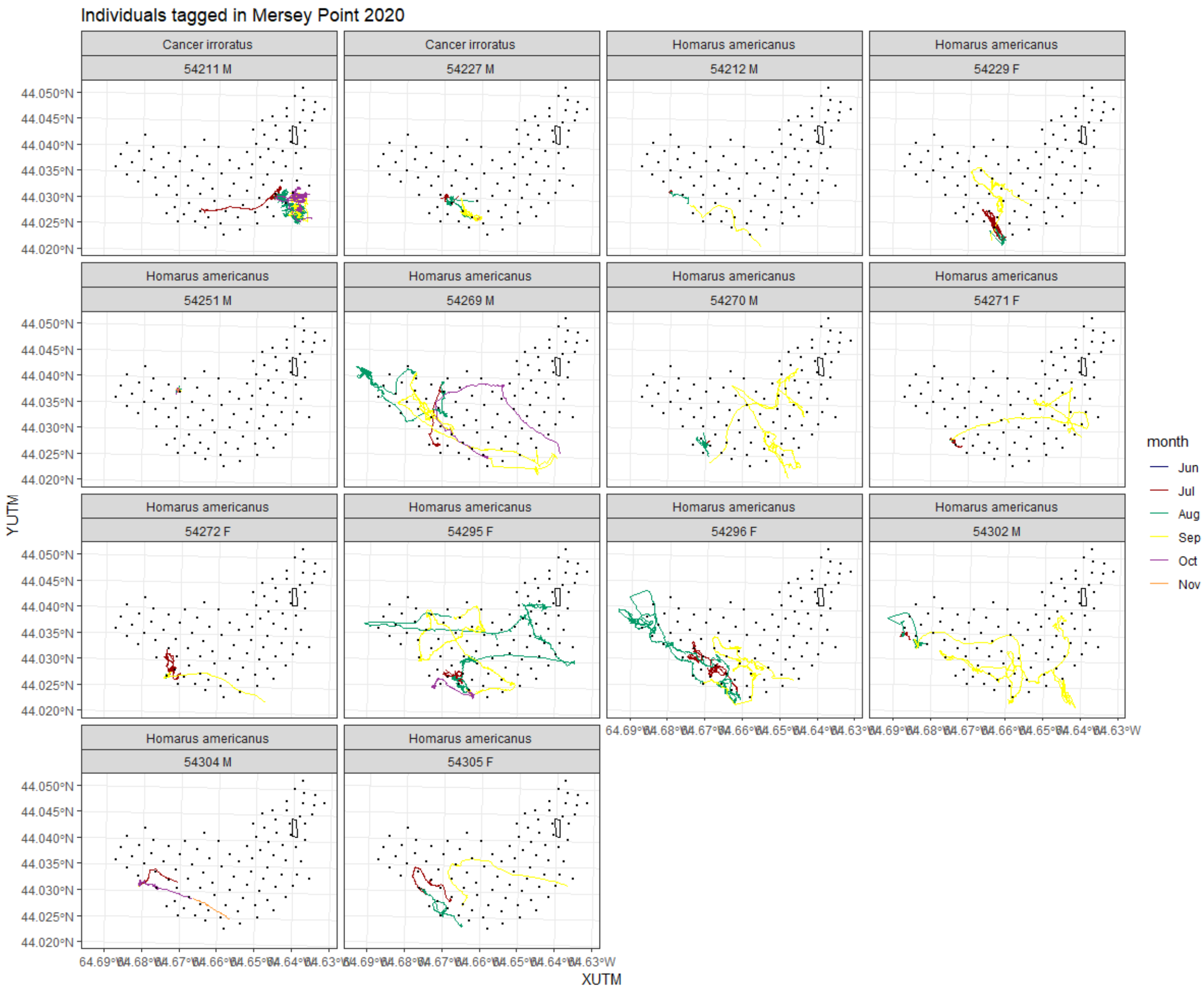
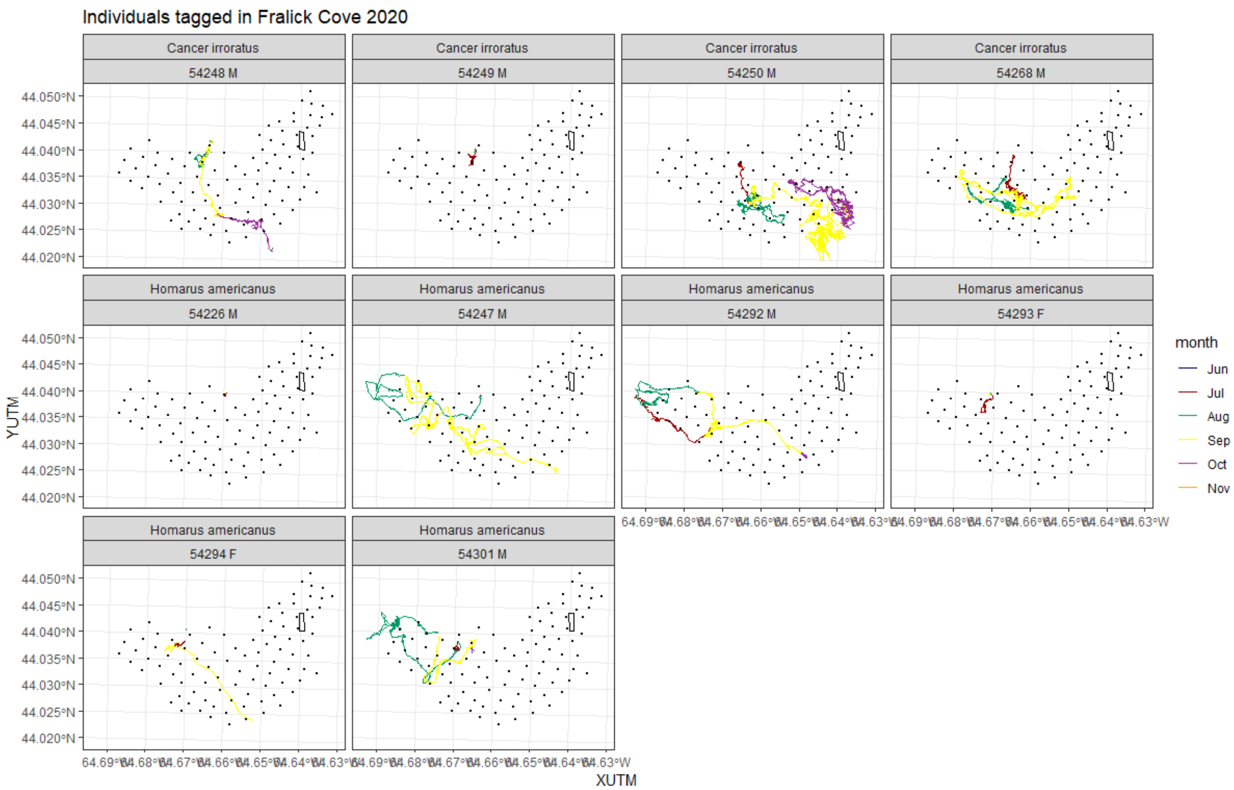


Figure X. Tracks for animals tagged at Mersey Point, Liverpool 2020. The black dots indicate receivers and the farm is represented by the black polygon.



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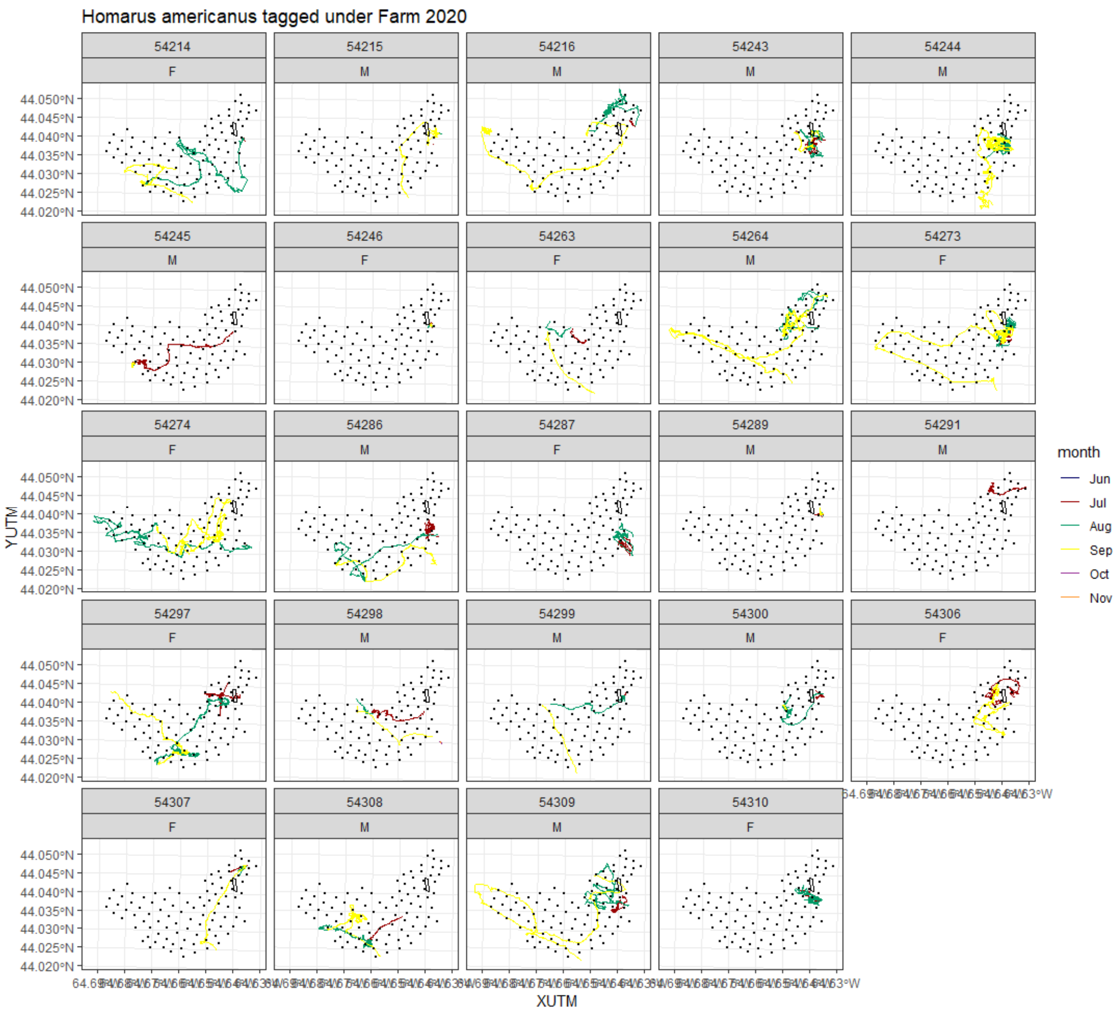

Figure X. Tracks for lobsters tagged near the fish farm area, Liverpool 2020. The black dots indicate receivers and the farm is represented by the black polygon.

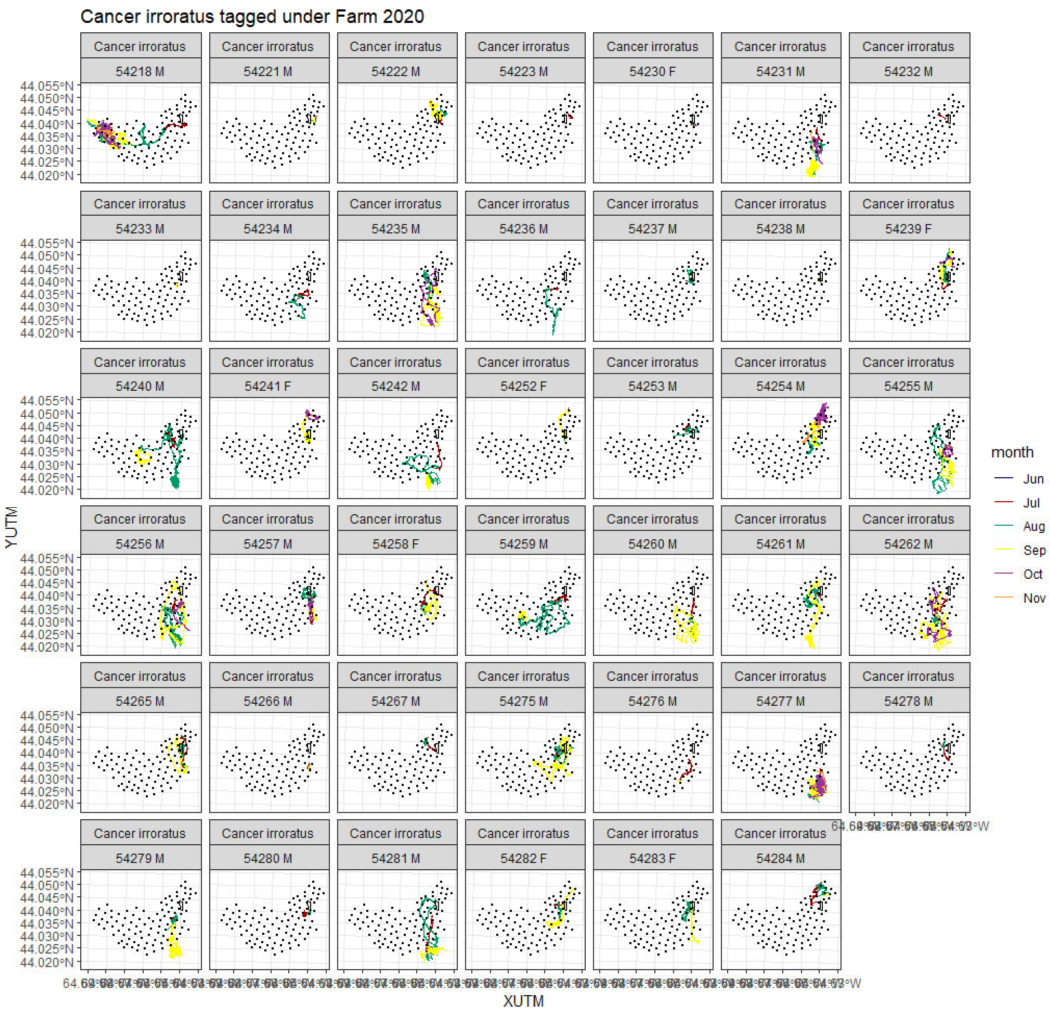

Figure X. Tracks for crabs tagged near the fish farm area, Liverpool 2020. The black dots indicate receivers and the farm is represented by the black polygon.

3.1.3 2021 – Liverpool

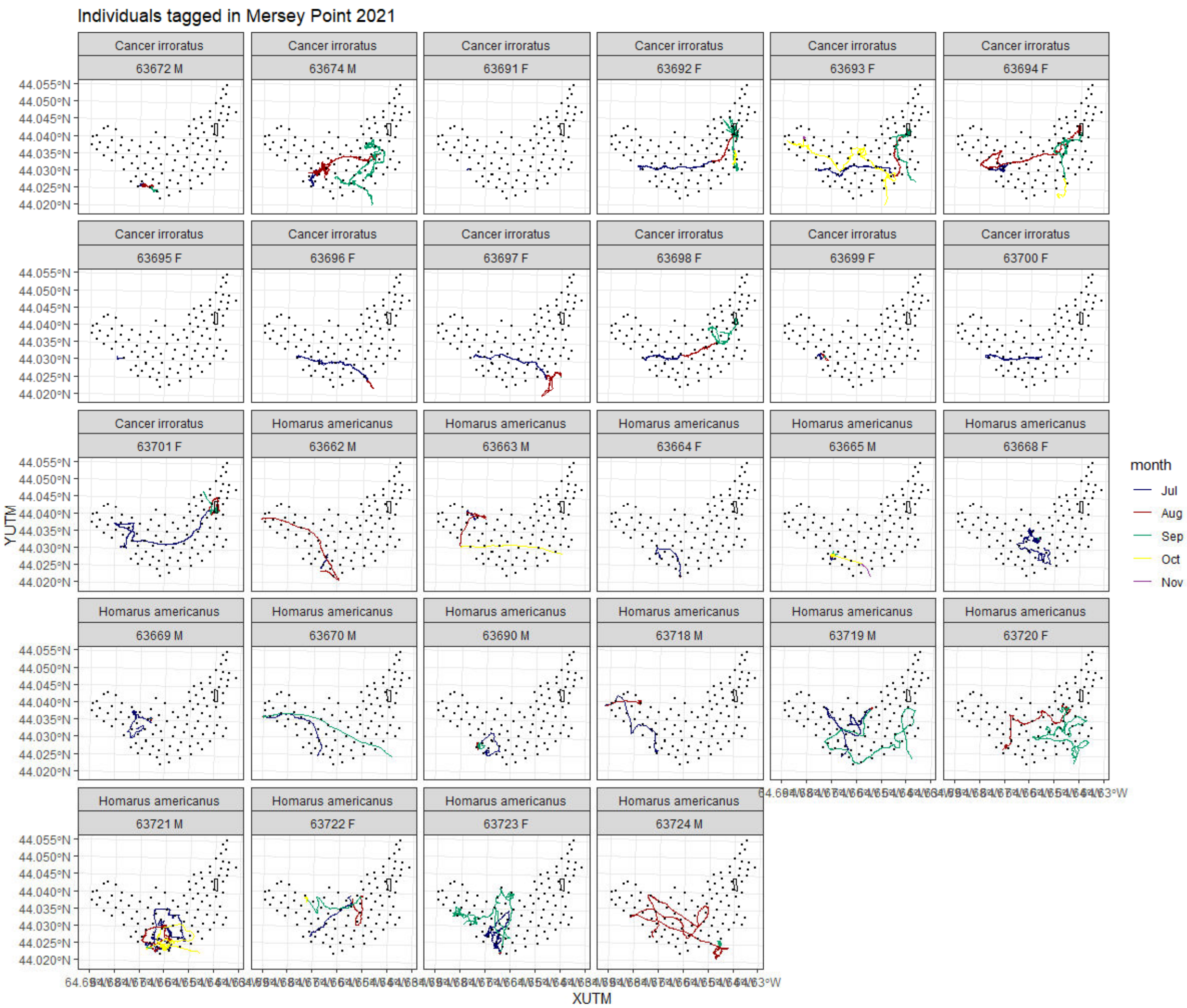

Figure X. Tracks for animals tagged at Mersey Point, Liverpool 2021. The black dots indicate receivers and the farm is represented by the black polygon.

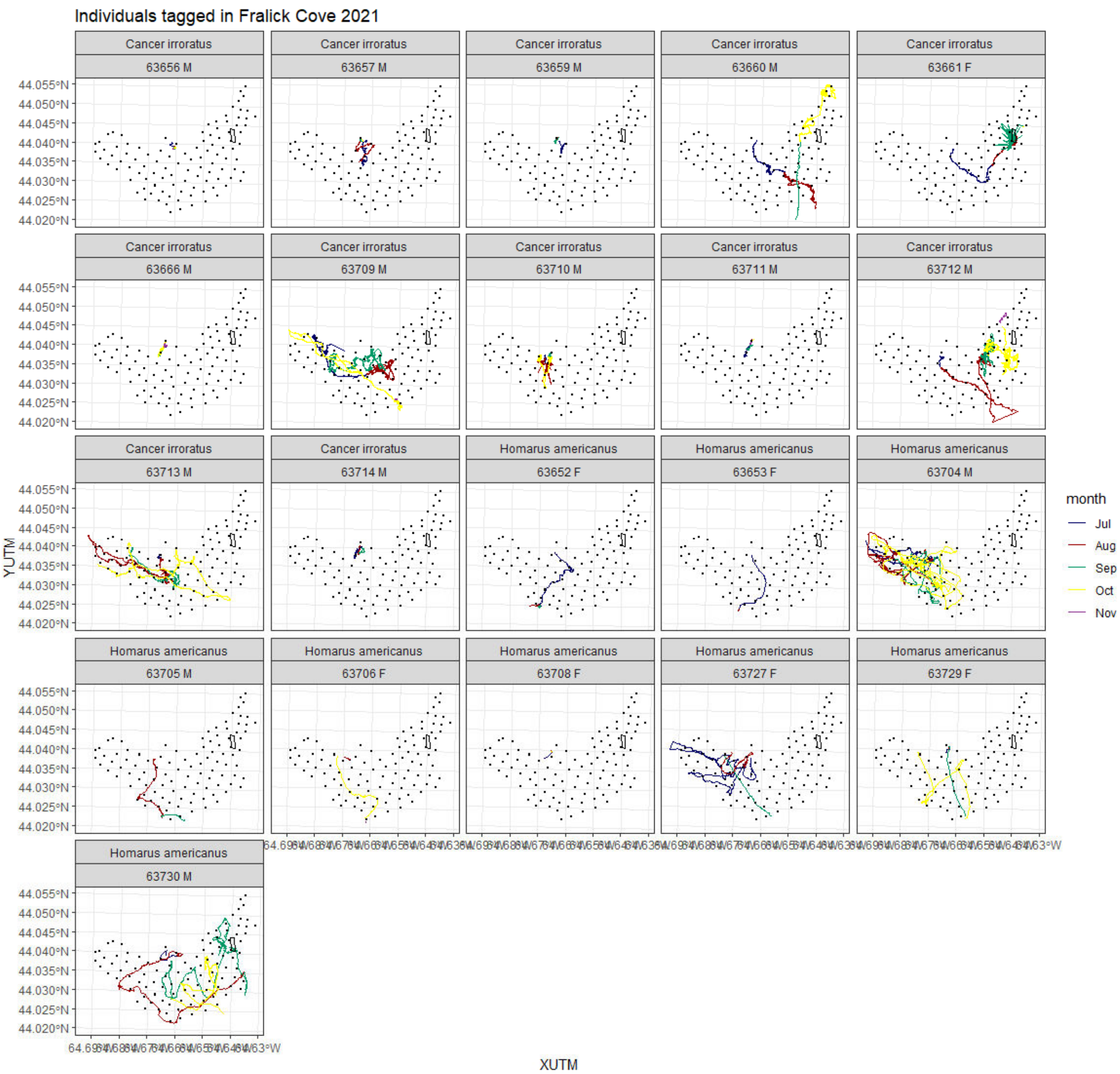

Figure X. Tracks for animals tagged at Fralick Cove, Liverpool 2021. The black dots indicate receivers and the farm is represented by the black polygon.

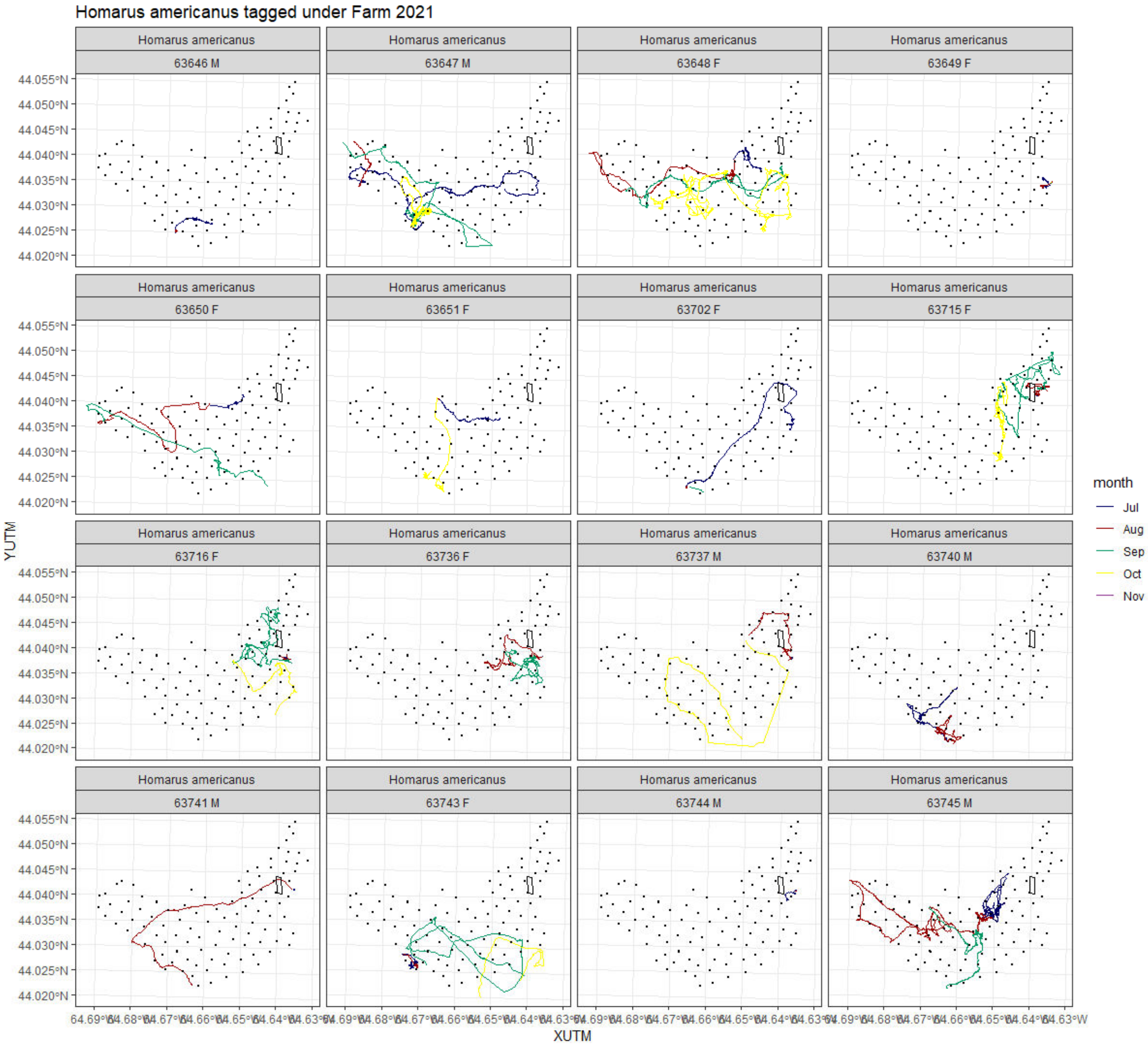

Figure X. Tracks for lobsters tagged near the fish farm area, Liverpool 2021. The black dots indicate receivers and the farm is represented by the black polygon.

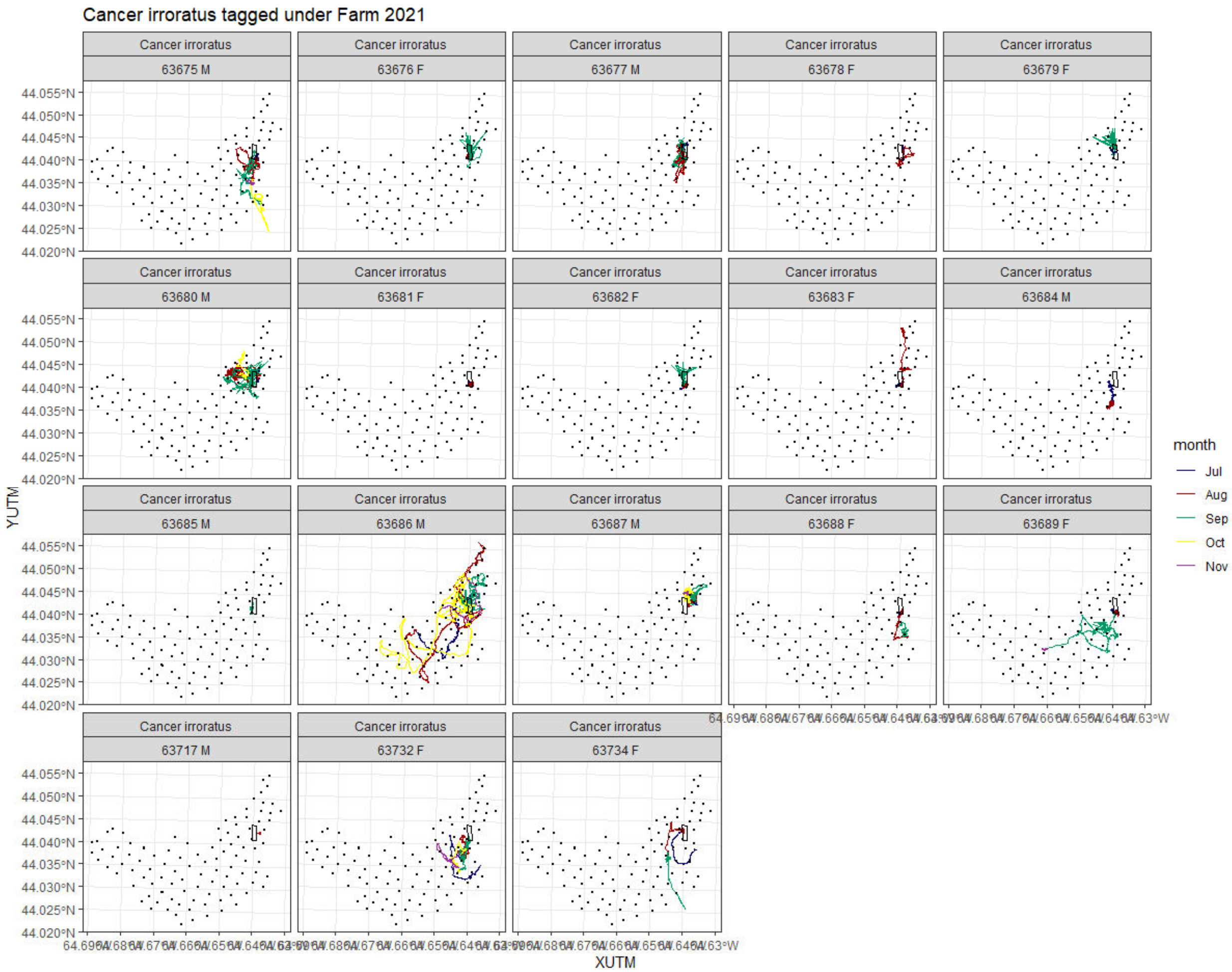

Figure X. Tracks for crabs tagged near the fish farm area, Liverpool 2021. The black dots indicate receivers and the farm is represented by the black polygon.