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Use of a water circulation model to predict the movements of phytoplankton blooms affecting salmon farms in the Grand Manan Island area, southwestern New Brunswick

by

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ABSTRACT

Chang, B.D., Losier, R.J., Page, F.H., Greenberg, D.A., and Chaffey, J.D. 2007. Use of a water circulation model to predict the movements of phytoplankton blooms affecting salmon farms in the Grand Manan Island area, southwestern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2703: iii + 64 p.

A multi-constituent water circulation model was used to predict the movements of phytoplankton blooms that could affect fish farms in the Grand Manan Island area, Bay of Fundy. Model particles were released from a grid of 659 release points (750 m between adjacent points) around Grand Manan Island. Particles were released from all grid points at 1-h intervals, for a total of 12 releases. Particles were followed for eight tidal cycles (~4 d). We determined which particle tracks intersected each fish farm and the minimum elapsed time between a particle's release and its intersection with a farm. Farms in areas with low velocity currents, such as the Long Island area, were most likely to be affected by blooms originating in the immediate vicinity of the farms. Farms in areas of high-velocity, complex current patterns, such as White Head Island, could be affected by blooms transported from a large area, up to several kilometres away, within 4 d.

RÉSUMÉ

Chang, B.D., Losier, R.J., Page, F.H., Greenberg, D.A., and Chaffey, J.D. 2007. Use of a water circulation model to predict the movements of phytoplankton blooms affecting salmon farms in the Grand Manan Island area, southwestern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2703: iii + 64 p.

Nous avons utilisé un modèle d'étude de la circulation de l'eau aux multiples composantes pour prévoir les mouvements des proliférations de phytoplanctons qui pourraient affecter les établissements de pisciculture autour de l'île Grand Manan, dans la baie de Fundy. Des particules (modèle) ont été rejetées à partir d'une grille de 659 points de rejet (750 mètres entre les points adjacents), autour de l'île Grand Manan. Les particules ont été rejetées de tous les points de grille à une heure d'intervalle, pour un total de 12 rejets. Nous avons suivi le trajet des particules pendant huit cycles tidaux (environ quatre jours). Nous avons déterminé quels trajets de particules croisent chaque pisciculture et nous avons déterminé la durée de temps minimale entre le rejet d'une particule et son contact avec une ferme. Les fermes situées dans des zones à faibles courant, comme dans la région de l'île Long, étaient les plus susceptibles à l'influence des proliférations provenant du voisinage immédiat des piscicultures. Par ailleurs, les piscicultures situées dans des zones au courant rapide et complexe, comme à l'île White Head, risquaient en seulement quatre jours d'être touchées par des proliférations transportées d'une vaste superficie, jusqu'à plusieurs kilomètres de distance.

INTRODUCTION

Phytoplankton blooms can have harmful impacts on finfish aquaculture farms, mainly due to toxic effects, damage to gills or depletion of dissolved oxygen in the water (Buslé 1995; Martin et al. 2001, 2006). Because of the potential economic consequences, fish farmers are interested in getting an early warning of the possibility that phytoplankton blooms could affect their farms, so that they may take management actions that could reduce harmful impacts (Chang et al. 2005a). Therfore, if blooms are reported in the general vicinity of their farm, they are interested in knowing if the bloom is likely to move toward their farm.

One method of predicting the movements of phytoplankton blooms is to use a water circulation model. We have previously used a circulation model to predict the risk of disease transmission via surface waters among salmon farms in southwestern New Brunswick (SWNB) and adjacent Maine (Page et al. 2005; Chang et al. 2005b, 2005c, 2006a, 2006b, 2006c). The tidal excursion area estimates from that project can also be used to predict if a near-surface phytoplankton bloom affecting a particular salmon farm is likely to be transported via water currents to adjacent farms within one tidal excursion (12.42 h). This can be especially useful since workers at salmon farms are usually on site every day, and would likely be the first to observe blooms occurring in the vicinity. Also, some farmers have shown interest in collecting daily water samples and learning how to identify and count phytoplankton in these samples (Chang et al. 2005a).

Phytoplankton blooms of some species, such as *Alexandrium fundyense* (formerly known as *Gonyaulax excavata*) are known to originate offshore (White and Lewis 1982; Martin and White 1988; Martin and Wildish 1994), while blooms of other species, such as *Mesodinium rubrum* appear to originate locally (Martin et al. 2001). Therefore, fish farmers could benefit from knowing the risk that a bloom reported from a variety of sources and locations (i.e. not just from adjacent fish farms) could affect their farm. Reports of bloom occurrences could originate from fishermen, commercial shipping, recreational boat traffic, and scientific monitoring programs. Knowledge of the probable route of offshore phytoplankton blooms that could impact farms could also be used to determine the usefulness and best locations for setting up phytoplankton monitoring stations which could give an early warning of blooms. Farmers would benefit from advance warnings of a few days, so that they could prepare for possible management actions, such as changes to feeding or harvesting schedules.

In this project, we used a tidal circulation model (Greenberg et al. 2005) to estimate water circulation in the vicinity of salmon farms in the Grand Manan Island area in SWNB. This is the same model used in the fish health project mentioned above, except that in the earlier project, we ran the model for just one tidal excursion, using only the M_2 tidal component, while in this project, we ran the model for eight tidal excursions, using multiple tidal components. We used the model to predict the speed and directions of algal blooms which could be transported via surface water currents to each fish farm.

METHODS

Water circulation in the Grand Manan Island area was estimated using a three-dimensional particle tracking model (Greenberg et al. 2005) that was customized to our geographic domain of interest. The geographic domain of the model includes the entire Bay of Fundy and Gulf of Maine. The model estimates the tidal currents by dividing the geographic area into triangles (called finite elements) and by numerically solving the equations of motion at each x,y,z,t grid point within the model domain. When the model is run, a depth profile of the current is calculated at each corner of every triangle every 2.07 s. The circulation model is fully non-linear, has 21 sigma depth levels (reduced in water shallower than 10 m), and has variable horizontal resolution (minimum approximately 50 m). This feature of the finite-element model makes it well suited for covering the wide domain of influence with the required detail in the area of interest needed to resolve local characteristics. The spatial resolution of the model is relatively coarse in the middle of the Gulf of Maine and quite fine in the salmon farming areas of SWNB. The model also simulates wetting and drying of intertidal areas. The model, as used in this study, included boundary forcing by 10 primary tidal components (M_2, S_2, N_2, K_2, K_1, O_1, P_1, L_2, $2N_2$, NU_2). A wind stress was included, based on wind data from NOAA buoy 44027 (Jonesport, Maine; 44°16’12”N, 67°18’36”W) during mid-August (average wind speed 1.866 $m{\cdot}s^{-1}$ from NE).

Using the model, numerical particles were released within an area covering the sea surface from the coast of Grand Manan Island out to the 80 m depth contour line (Fig. 1, 2). The particles were released from a grid of evenly spaced points separated by 750 m in the north-south and east-west directions. Particles were released simultaneously from all 659 grid points at hourly intervals (from hour 0 to hour 11), for a total 12 particles released from each grid point (grand total = 7908 particles released). High tide was near hour 3 and low tide was near hour 9. Particle locations were recorded hourly for 8 tidal cycles (99.4 h or just over 4 d) after each release. The model particles were released and maintained at 1 m below the sea surface.

Using MapInfo Professional® 8.0 software, we determined which particle tracks intersected each salmon farm site in the Grand Manan Island area. Farm site boundaries were provided by the New Brunswick Department of Agriculture and Aquaculture (G. Smith, pers. comm.). We then plotted the release points for each of the particle tracks which intersected each farm site. Because the particles were released from an evenly-spaced grid, the numbers of release points of intersecting particles also provided an indication of the size of the overall area from which the intersecting particles originated (i.e. a larger number indicated a greater area).

We also determined the elapsed time between a particle’s release and its first intersection with a farm site (in some cases a particle’s track intersected the same farm site more than once). This time was estimated as the mid-point (in elapsed time after release) of the first line segment (each segment represented 1 h) of a particle track which intersected a particular farm site. We then determined, of all particles from a particular release point which intersected a particular farm, the shortest elapsed time between release and farm intersection. This would be indicative of the worst case scenario, i.e. the shortest predicted time for a bloom to travel from a particular point to the farm. Because we only recorded the particle locations at hourly intervals, we did not have sufficient data to precisely determine the duration of time that a particle spent within a farm site.

RESULTS

Figures 3a and 3b show example tracks for particles released at hourly intervals from two of the grid points, one from the eastern Grand Manan Island area and one from the southern area. These figures show that, for the particles released from any one point, there can be quite large differences in the particle tracks depending on when (within the tidal cycle) the particles were released. In Fig. 3a, the particle released at hour 5 stopped after 81 h upon hitting land and the particle released at hour 8 stopped after 34 h when it hit an exposed shoal. All other particles were still moving after 8 tidal cycles. In Fig. 3b, all particles were still moving after 8 tidal cycles.

Figure 4a-L shows the particle tracks from all grid points in each hourly release, at intervals of one tidal cycle. Particles showed a general trend of moving offshore over time, although some particles moved inshore and stopped moving upon hitting land or dry intertidal areas. At the end of 8 tidal cycles, 87-89% of particles in each release were still moving. The overall area covered by the particle tracks in all 12 releases showed a general trend of extending away from Grand Manan Island over time, to the north (toward The Wolves and Campobello Island) and to the southeast.

A total of 1376 particles (17% of all particles), released from 180 grid points (27% of all grid points), intersected at least one fish farm within 8 tidal cycles (Fig. 5). Figure 6a-e shows the release points of all particles that intersected each individual salmon farm, as well as the number of particles from each release point that intersected that farm. Figure 7a-e shows, for each individual salmon farm, the minimum elapsed times after release when particles from each release point intersected the farm.

The variation in the numbers of particles intersecting a particular farm among the 12 releases was relatively small for most farms (Table 1). There were quite large variations in the numbers of overlaps with a particular farm among the eight tidal cycles within each hourly release (Tables 2a-L).

The five farms located between the eastern shore of Grand Manan Island and Long Island (MF-213, MF-368, MF-350, MF-002 and MF-349) received particles originating from only two or three grid points located in the immediate vicinity of the farms or just north of them (within 2 km). Only particles originating within a few metres of the farms could reach the farms within one tidal cycle (12.4 h).

Three of the farms located near Ross Island (MF-282, MF-300 and MF-172) received particles originating from 12-26 grid points located mostly to the north of the farms (up to 5-7 km from the farms), but also slightly to the south and east. Particles originating up to 1.5 km from these farm sites could reach these farms within one tidal excursion. Farm MF-298, located about 2 km east of Ross Island, received particles from just six grid points located just north and east of the farm (up to 1.5 km from the farm). Particles originating up to 1.5 km away could reach this farm within one tidal cycle.

The three farms located near White Head Island (MF-316, MF-381 and MF-416) received particles originating from 51-86 grid points (up to 11-12 km from the farms) located to the west (in the Long Pond Bay and Seal Cove areas), north (in the Ross Island area), and offshore to the northeast. Particles originating 2-4 km away could reach these farms within one tidal cycle.

Farm MF-303 (located northeast of Wood Island) received particles originating from 17 grid points located in the vicinity of the farm, in the channel between Wood Island and Grand Manan Island, and south of this channel (up to 9 km from the farm). Only particles originating within 1 km of the farm site could reach this farm within one tidal cycle.

The two farms located just east of Wood Island (MF-403 and MF-408) received particles originating from 43-58 grid points located to the east and south of Wood Island (up to 9 km from the farms). Particles originating 1-2 km away could reach these farms within one tidal cycle. Farm MF-491 (located just south of Wood Island) showed a similar pattern, but received particles from a smaller area (18 grid points, up to 7 km from the farm). Only particles originating less than 1 km away could reach this farm within 1 tidal cycle.

The five farms located in the channel between the western shore of Wood Island and southwestern Grand Manan Island (MF-202, MF-292, MF-003, MF-270 and MF-413) received particles from 7-22 grid points located within this channel and south of it (up to 6-9 km from the farms). Only particles originating within 1 km away could reach these farms within one tidal cycle.

DISCUSSION

Overall, we feel that the model predictions can provide a cost-effective way of estimating the likelihood that a fish farm could be impacted by a phytoplankton bloom. We must, however, always bear in mind that this project's results are derived from a model and that the actual situation may be slightly different, due to inaccuracies in the model, specific conditions such as the wind speed and direction at any given time, and other possible factors.

Our results indicated that the areas from which algal blooms could be transported to fish farms varied considerably among the farming sub-areas within our study area. Maps such as those in Figure 6 can help in estimating the relative risk of an individual farm being affected by algal blooms originating from various locations. If a bloom is observed at a point from where, according to our model results, water will transport the bloom toward a farm most or all of the time (i.e. locations of larger circles in Fig. 6), this suggests a higher risk of the bloom reaching the farm. Where particles from several release points are predicted to intersect a farm, this also suggests a greater likelihood of a bloom affecting a farm, since it indicates that a bloom occurring anywhere over a relatively large area could impact the farm. The actual risk to the farm depends, of course, on whether or not a bloom actually occurs along the predicted water pathways.

The maps in Fig. 6 do not indicate how long it would take a bloom to travel from the point of origin to the farm, and it is possible that the phytoplankton densities could fall to below bloom levels before reaching the farm. Conversely, phytoplankton densities could increase before reaching the farm. Maps such as those in Fig. 7 provide an estimate of the minimum time it would take an algal bloom to reach a farm from any given point. This information, together with knowledge on bloom dynamics (such as estimates of the half-life or doubling time for blooms of a particular algal species) could improve our estimates of the risks of a bloom affecting a farm.

For farms in the Long Island area, the water movement was relatively slow and predominantly from north to south. This means that only blooms originating very close to these farms could be transported to them via water currents within a few days, and since the five farms in the Long Island area are quite close together, a bloom impacting one of these farms could reach the other four farms in a relatively short time. In a previous report (Chang et al. 2006a) we showed, using the same circulation model (but incorporating only the M_2 tidal component), that the water from any one of these five farms could reach one or two of the other farms in the Long Island area within one tidal cycle.

Farms in the Ross Island area could be impacted by blooms originating from slightly larger areas (than was the case for farms in the Long Island area) and blooms could also originate from just south and east of these farms, as well as from the north. Farms in the White Head Island area could be impacted by algal blooms originating from a large area and from various directions, within a relatively short time, due to the stronger, more complex water currents around these farms (see also Page et al. 2005). Farms in the Seal Cove area and northern Long Pond Bay (in the southern Grand Manan Island area) could be impacted by blooms originating from areas similar in size to those affecting Ross Island area farms, while farms in the southern Long Pond Bay area (farms MF-403 and MF-408) were potentially affected by blooms from larger areas.

It has previously been reported that the offshore area to the east of Grand Manan Island is the major source for blooms of *Alexandrium fundyense* impacting inshore areas of SWNB (White and Lewis 1982; Martin and White 1988; Martin and Wildish 1994). Our model results indicated that the nearshore areas of Grand Manan Island which were most likely to be impacted by blooms originating in offshore areas to the east and north would be the White Head Island area, and possibly the Ross Island area, but not the Long Island, Long Pond Bay, or Seal Cove areas. In September 2003, when high levels of *A. fundyense* and some farmed salmon mortalities occurred, high *A. fundyense* levels were observed at most farms in the eastern Grand Manan Island area, including the Long Island, Ross Island, and White Head Island areas, while levels in the Seal Cove and Long Pond Bay areas were much lower (Martin et al. 2006; J.L. Martin, unpublished data). In an earlier study, resting cysts of *A. fundyense* were found in the nearshore areas of Grand Manan Island just north of Long Island, although at lower densities than in offshore areas (White and Lewis 1982). Our circulation model (and field observations) indicates that the Long Island area has low current velocities, with the flow predominantly from north to south. This suggests that the oceanographic conditions in the Long Island area in September 2003 were probably conducive to the development of blooms of *A. fundyense* from resting cysts or cells in the immediate area (rather than blooms being transported from offshore). Water currents could then have transported a bloom in the Long Island area toward the Ross Island area, and from there to the White Head Island area. As mentioned above, the White Head area farms (and possibly the Ross Island area farms) could also have been impacted by blooms originating in offshore areas east of Grand Manan Island.

The time frames used in this study were considered useful for contingency planning at farms. For example, if a bloom was observed at a location from which, according to the model, it would likely be transported to the farm in 4 d, the farm could start preparations for management action (such as changes to smolt transfer, feeding, or harvesting schedules), while at some shorter time interval, management actions would actually be implemented. The results from this study only indicate the likely paths (as predicted by the model) of blooms during the time frame of this study (i.e. up to 4 d). Over longer time periods, the predictions would likely indicate bloom movements over longer distances, possibly impacting more farms, although it would be expected that longer-term predictions would be less accurate.

The predictions derived from this methodology can help in the design of monitoring programs, specifically for determining where monitoring should be conducted if it is to provide an early warning of potential harmful blooms. Factors that should be taken into account when selecting a monitoring site(s) would include: the most likely geographic origins of blooms; the expected time between bloom observation and impacting of farms; and the number of farms that would benefit from monitoring a specific location.

If this approach is deemed useful, then additional work could be done to improve the model and, hence, its usefulness in predicting phytoplankton bloom movements. The multi-constituent model used in this project requires more work to improve its accuracy, as well as more validation against physical and biological field data. The distance between model particle release locations could be decreased to increase model resolution and the release grid could be expanded further offshore. We could also increase the frequency of particle track location recording (the model can track particles at intervals of 2.07 s, but we used hourly records in order to reduce the size of the data files). This would allow us to make more precise estimates of the speed of bloom movements, as well as to predict the length of time a bloom might remain at a farm site. Additional wind data, including variable winds, could be incorporated into the model to provide more accurate predictions for actual wind conditions. Although we chose the Grand Manan Island area as our study area, this methodology could be applied to other salmon farming areas.

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Table 1. Numbers of model particles intersecting each farm site for each release time. Particles were released from all grid points at 12 times, at hourly intervals (hours 0-11). The release time closest to high tide was hour 3 and the release time closest to low tide was hour 9. Each particle was tracked for 8 tidal cycles (99.4 h). Also shown are the total number of particles (all 12 releases combined) intersecting each farm site and the total number of release points of the intersecting particles (all 12 releases combined).

	Hour of release												All releases combined	
Farm	0	1	2	3	4	5	6	7	8	9	10	11	Total no. of intersecting particles	Total no. of release points of intersecting particles
Long Island area														
MF-213	1	2	2	2	2	2	1	2	2	2	2	2	22	2
MF-368	1	1	1	1	1	1	2	2	2	2	2	2	18	2
MF-350	2	2	2	2	2	2	2	2	2	3	2	2	25	3
MF-002	3	3	3	3	3	3	3	3	3	2	3	3	35	3
MF-349	1	1	1	1	1	2	3	3	2	2	3	3	23	3
Ross Island area														
MF-282	6	7	7	8	7	8	8	9	5	7	4	3	79	12
MF-298	3	3	3	3	4	3	3	3	5	4	4	5	43	6
MF-300	8	8	8	10	9	12	8	9	9	9	5	7	102	17
MF-172	11	12	12	13	13	15	13	12	12	13	9	9	144	26
White Head Island area														
MF-316	29	28	30	30	22	30	26	23	30	27	26	24	325	86
MF-381	18	19	17	21	15	16	17	18	20	19	17	14	211	61
MF-416	20	19	22	22	15	21	18	17	17	23	21	17	232	51
Southern Grand Manan Island – east of Wood Island														
MF-303	8	8	8	8	8	8	7	6	9	9	11	8	98	17
MF-403	11	11	11	14	20	16	15	14	15	11	14	12	164	43
MF-408	31	31	30	28	30	26	27	27	28	26	24	20	328	58
MF-491	6	6	6	3	3	5	4	7	4	4	9	4	61	18
Southern Grand Manan Island - west of Wood Island														
MF-202	10	10	10	11	10	12	11	11	8	9	8	8	118	14
MF-292	10	9	9	11	11	11	12	10	9	11	11	13	127	22
MF-003	1	1	1	2	1	1	3	1	2	3	3	1	20	7
MF-270	6	6	6	6	6	7	5	6	6	7	7	8	76	18
MF-413	6	5	5	6	8	7	7	9	6	8	4	8	79	22

Table 2a. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 0. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 0)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	0	1
MF-368	0	0	0	1	1	0	0	0	1
MF-350	0	1	1	0	0	1	0	0	2
MF-002	0	0	1	2	0	0	1	0	3
MF-349	1	1	1	1	0	0	0	0	1
Ross Island area									
MF-282	2	4	4	1	3	3	3	1	6
MF-298	1	2	2	1	0	0	0	0	3
MF-300	1	3	3	3	4	3	2	1	8
MF-172	2	2	3	1	1	2	2	4	11
White Head Island area									
MF-316	3	4	8	5	4	6	2	3	29
MF-381	1	6	4	2	2	3	0	2	18
MF-416	5	5	5	1	2	2	1	0	20
Southern Grand Manan Island – east of Wood Island									
MF-303	1	2	3	4	2	3	0	0	8
MF-403	0	3	4	2	4	3	4	1	11
MF-408	2	6	6	9	8	4	3	3	31
MF-491	1	2	1	1	2	2	0	0	6
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	2	1	3	6	4	4	10
MF-292	1	2	3	4	5	4	4	8	10
MF-003	0	1	1	1	0	0	0	0	1
MF-270	1	2	2	2	2	0	0	0	6
MF-413	2	2	4	0	1	1	0	0	6

Table 2b. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 1. The numbers in the “all” column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 1)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	1	2
MF-368	0	0	0	1	1	0	0	0	1
MF-350	0	1	1	0	0	1	0	0	2
MF-002	0	0	2	2	0	0	1	0	3
MF-349	1	1	1	1	0	0	0	0	1
Ross Island area									
MF-282	2	4	4	1	3	3	3	2	7
MF-298	1	2	3	1	0	0	0	0	3
MF-300	1	4	3	3	4	3	2	1	8
MF-172	2	3	3	1	1	3	3	3	12
White Head Island area									
MF-316	3	4	7	5	4	5	2	3	28
MF-381	1	6	4	2	2	3	2	2	19
MF-416	5	5	5	1	2	2	1	0	19
Southern Grand Manan Island – east of Wood Island									
MF-303	1	2	3	4	2	3	0	0	8
MF-403	1	4	5	3	4	4	4	1	11
MF-408	3	8	8	7	7	3	4	2	31
MF-491	1	2	0	1	2	1	0	0	6
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	2	1	4	6	4	5	10
MF-292	1	2	3	5	5	3	4	8	9
MF-003	0	1	1	1	0	0	0	0	1
MF-270	1	2	2	2	2	0	0	0	6
MF-413	1	3	4	3	1	1	0	0	5

Table 2c. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 2. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 2)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	1	2
MF-368	0	0	0	1	1	0	0	0	1
MF-350	0	1	1	0	0	1	0	0	2
MF-002	0	0	2	2	0	0	1	0	3
MF-349	1	1	1	1	0	0	0	0	1
Ross Island area									
MF-282	3	3	4	2	3	3	3	2	7
MF-298	2	2	3	1	0	0	0	0	3
MF-300	2	4	3	4	5	3	3	1	8
MF-172	2	2	3	1	1	3	4	3	12
White Head Island area									
MF-316	3	5	6	6	5	6	2	4	30
MF-381	1	5	3	2	2	3	0	2	17
MF-416	5	4	6	1	2	3	2	0	22
Southern Grand Manan Island – east of Wood Island									
MF-303	1	2	3	4	2	3	0	0	8
MF-403	1	4	5	3	6	5	5	1	11
MF-408	4	7	8	8	7	4	5	0	30
MF-491	1	2	0	1	2	1	0	0	6
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	2	1	5	6	5	6	10
MF-292	2	2	3	5	5	3	5	8	9
MF-003	0	1	1	1	0	0	0	0	1
MF-270	1	2	2	2	2	0	0	0	6
MF-413	1	3	4	3	1	1	0	0	5

Table 2d. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 3. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 3)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	1	2
MF-368	0	0	0	1	1	0	0	0	1
MF-350	0	1	1	0	0	1	0	0	2
MF-002	0	1	2	2	0	0	1	0	3
MF-349	1	1	1	1	0	0	0	0	1
Ross Island area									
MF-282	3	4	4	3	4	4	4	2	8
MF-298	2	2	3	1	0	0	0	0	3
MF-300	2	4	3	3	6	5	5	2	10
MF-172	2	2	3	1	1	3	4	4	13
White Head Island area									
MF-316	2	5	6	3	3	4	3	6	30
MF-381	1	3	4	2	1	5	1	5	21
MF-416	6	5	5	1	1	3	2	0	22
Southern Grand Manan Island – east of Wood Island									
MF-303	0	2	3	2	1	3	1	1	8
MF-403	2	3	4	3	4	4	4	3	14
MF-408	4	6	8	10	6	3	1	1	28
MF-491	1	2	0	0	1	0	0	0	3
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	2	2	5	6	5	6	11
MF-292	2	3	3	5	5	6	6	7	11
MF-003	0	2	1	0	0	0	0	0	2
MF-270	1	2	3	2	2	0	0	0	6
MF-413	2	3	4	3	1	1	1	1	6

Table 2e. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 4. The numbers in the “all” column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 4)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	1	2
MF-368	0	0	0	1	1	0	0	0	1
MF-350	1	1	1	0	0	1	0	0	2
MF-002	0	1	2	2	1	0	1	0	3
MF-349	1	1	1	1	0	0	0	0	1
Ross Island area									
MF-282	3	4	4	2	3	3	4	3	7
MF-298	1	2	2	1	1	0	0	0	4
MF-300	3	4	3	3	5	4	3	2	9
MF-172	3	3	3	3	2	3	3	2	13
White Head Island area									
MF-316	3	5	7	3	2	1	1	3	22
MF-381	1	3	4	1	4	1	0	2	15
MF-416	4	6	2	2	0	2	0	1	15
Southern Grand Manan Island – east of Wood Island									
MF-303	0	2	3	3	3	2	1	1	8
MF-403	3	5	8	9	12	6	5	2	20
MF-408	5	4	11	12	11	5	1	2	30
MF-491	1	2	0	1	0	0	0	0	3
Southern Grand Manan Island – west of Wood Island									
MF-202	1	2	2	2	5	4	4	8	10
MF-292	2	2	5	8	4	5	5	7	11
MF-003	0	1	1	1	0	0	0	0	1
MF-270	1	2	2	1	0	1	1	0	6
MF-413	2	1	4	4	3	0	0	0	8

Table 2f. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 5. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 5)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	1	0	0	0	1	2
MF-368	0	0	1	1	1	0	0	0	1
MF-350	1	1	1	1	0	1	0	0	2
MF-002	0	1	2	2	0	1	1	0	3
MF-349	1	1	1	1	1	0	0	0	2
Ross Island area									
MF-282	3	4	4	3	3	4	5	3	8
MF-298	2	1	2	1	0	0	0	0	3
MF-300	3	4	4	3	6	4	5	2	12
MF-172	3	3	3	3	2	4	2	4	15
White Head Island area									
MF-316	3	5	3	5	5	4	2	5	30
MF-381	1	5	3	2	2	3	0	2	16
MF-416	5	6	2	2	3	3	1	1	21
Southern Grand Manan Island – east of Wood Island									
MF-303	0	2	3	3	2	1	1	2	8
MF-403	2	6	7	6	9	5	2	1	16
MF-408	5	4	9	8	6	7	1	1	26
MF-491	1	2	0	2	2	0	0	0	5
Southern Grand Manan Island – west of Wood Island									
MF-202	1	2	2	4	4	4	6	5	12
MF-292	2	2	5	6	4	5	6	6	11
MF-003	0	1	1	0	0	0	0	0	1
MF-270	1	1	2	2	0	1	1	1	7
MF-413	1	3	4	3	2	0	0	0	7

Table 2g. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 6. The numbers in the “all” column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 6)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	0	0	1
MF-368	0	0	1	1	1	0	0	1	2
MF-350	1	1	1	0	0	1	0	0	2
MF-002	0	1	2	2	0	1	1	0	3
MF-349	1	1	1	1	1	0	0	1	3
Ross Island area									
MF-282	3	3	4	1	2	3	4	3	8
MF-298	2	2	3	1	0	0	0	0	3
MF-300	2	3	3	4	6	4	3	1	8
MF-172	3	2	3	1	2	2	5	4	13
White Head Island area									
MF-316	2	6	6	1	4	4	4	1	26
MF-381	2	6	2	1	1	3	2	0	17
MF-416	5	7	4	1	2	1	0	0	18
Southern Grand Manan Island – east of Wood Island									
MF-303	0	2	2	2	2	1	0	1	7
MF-403	1	5	8	8	7	4	4	2	15
MF-408	5	5	11	11	2	1	2	1	27
MF-491	1	2	0	2	0	0	0	0	4
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	1	2	4	2	4	8	11
MF-292	2	2	3	5	6	5	5	6	12
MF-003	0	1	1	1	0	1	0	0	3
MF-270	1	2	1	2	1	1	0	0	5
MF-413	1	5	4	3	2	2	1	1	7

Table 2h. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 7. The numbers in the “all” column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 7)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	1	0	2
MF-368	0	0	1	1	1	0	0	1	2
MF-350	1	1	0	0	1	1	0	0	2
MF-002	0	1	1	1	0	1	0	0	3
MF-349	1	1	1	0	1	0	2	0	3
Ross Island area									
MF-282	3	3	4	3	4	2	3	3	9
MF-298	2	2	2	1	0	0	0	0	3
MF-300	2	3	5	5	6	3	4	3	9
MF-172	3	4	4	2	4	3	3	0	12
White Head Island area									
MF-316	4	9	2	0	5	4	1	1	23
MF-381	3	7	1	1	1	2	3	2	18
MF-416	7	6	0	1	2	2	0	0	17
Southern Grand Manan Island – east of Wood Island									
MF-303	1	2	3	2	2	0	0	0	6
MF-403	1	4	5	3	5	10	7	1	14
MF-408	6	7	10	9	5	5	3	1	27
MF-491	1	2	1	3	3	0	0	0	7
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	1	2	4	4	5	5	11
MF-292	2	2	3	4	5	4	5	6	10
MF-003	0	1	1	0	0	0	0	0	1
MF-270	1	3	2	2	0	0	1	1	6
MF-413	2	3	5	4	3	2	0	0	9

Table 2i. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 8. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 8)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	1	0	2
MF-368	0	0	1	1	1	0	0	1	2
MF-350	1	1	0	1	1	1	0	0	2
MF-002	0	1	1	1	1	1	0	0	3
MF-349	1	1	1	0	1	0	0	0	2
Ross Island area									
MF-282	3	3	2	3	2	2	2	2	5
MF-298	2	2	3	0	0	0	0	0	5
MF-300	3	4	3	4	5	2	3	2	9
MF-172	2	3	1	4	5	3	1	2	12
White Head Island area									
MF-316	4	9	3	4	5	3	4	4	30
MF-381	3	5	3	3	4	2	1	2	20
MF-416	6	6	4	1	0	1	0	0	17
Southern Grand Manan Island – east of Wood Island									
MF-303	3	2	1	3	3	0	1	2	9
MF-403	1	3	5	4	6	7	5	4	15
MF-408	6	8	7	8	9	5	2	2	28
MF-491	2	1	0	1	2	0	0	0	4
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	2	2	3	4	2	4	8
MF-292	2	3	3	4	5	6	4	5	9
MF-003	0	1	1	0	1	0	0	0	2
MF-270	1	3	1	2	3	1	0	0	6
MF-413	2	3	3	1	1	1	1	0	6

Table 2j. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 9. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 9)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	1	0	0	0	1	0	2
MF-368	0	0	1	1	0	0	0	1	2
MF-350	1	0	0	1	1	0	0	1	3
MF-002	0	0	1	1	0	1	0	0	2
MF-349	1	1	0	0	1	0	0	0	2
Ross Island area									
MF-282	2	2	2	3	5	4	3	3	7
MF-298	2	2	3	1	1	0	0	0	4
MF-300	3	4	3	3	4	4	4	1	9
MF-172	2	3	3	4	4	3	1	2	13
White Head Island area									
MF-316	4	5	3	6	5	5	4	3	27
MF-381	6	4	1	3	3	2	2	3	19
MF-416	6	5	2	4	2	3	2	1	23
Southern Grand Manan Island – east of Wood Island									
MF-303	4	3	3	2	3	1	1	1	9
MF-403	1	4	7	5	4	2	1	1	11
MF-408	4	4	12	9	6	4	1	1	26
MF-491	3	1	1	0	0	0	0	0	4
Southern Grand Manan Island – west of Wood Island									
MF-202	0	0	3	2	2	5	2	6	9
MF-292	2	3	4	5	8	6	4	7	11
MF-003	1	1	1	0	1	0	0	0	3
MF-270	1	4	4	2	2	0	0	0	7
MF-413	2	2	3	4	1	1	0	0	8

Table 2k. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 10. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 10)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	0	0	0	0	1	0	2
MF-368	0	0	1	1	0	0	0	1	2
MF-350	1	1	0	1	1	0	0	0	2
MF-002	0	1	1	1	0	1	0	0	3
MF-349	1	1	0	0	2	1	0	0	3
Ross Island area									
MF-282	2	2	2	1	2	2	2	2	4
MF-298	3	3	1	1	0	0	0	0	4
MF-300	3	4	3	3	2	1	1	0	5
MF-172	2	2	2	4	3	2	1	2	9
White Head Island area									
MF-316	4	8	0	6	6	2	3	2	26
MF-381	5	3	1	1	3	2	3	3	17
MF-416	9	3	2	1	2	1	0	3	21
Southern Grand Manan Island – east of Wood Island									
MF-303	5	3	3	2	3	1	2	2	11
MF-403	1	4	3	6	5	6	3	2	14
MF-408	4	4	8	10	4	4	4	1	24
MF-491	3	3	0	3	2	0	1	1	9
Southern Grand Manan Island – west of Wood Island									
MF-202	0	1	2	2	2	4	3	2	8
MF-292	2	3	4	6	7	5	4	5	11
MF-003	1	1	1	0	0	1	0	0	3
MF-270	1	2	1	2	4	2	0	0	7
MF-413	3	1	1	1	0	0	0	0	4

Table 2L. Numbers of model particles which intersected each farm site in each tidal cycle (1-8) in hourly release 11. The numbers in the "all" column do not represent the sums of the individual tidal cycle values, because in some instances the same particle intersected the same farm site in more than one tidal cycle.

	Tidal cycle (hourly release 11)								
Farm	1	2	3	4	5	6	7	8	All
Long Island area									
MF-213	1	1	0	0	0	0	1	0	2
MF-368	0	0	1	1	0	0	0	1	2
MF-350	1	1	0	1	1	0	0	0	2
MF-002	0	2	1	1	0	1	0	0	3
MF-349	1	1	0	1	2	0	0	0	3
Ross Island area									
MF-282	2	2	2	1	1	1	0	1	3
MF-298	4	2	1	1	0	0	0	0	5
MF-300	3	4	4	4	3	1	1	0	7
MF-172	2	3	1	4	3	3	0	0	9
White Head Island area									
MF-316	2	7	2	7	4	3	1	2	24
MF-381	2	2	1	2	3	2	1	2	14
MF-416	9	1	2	2	1	0	0	2	17
Southern Grand Manan Island – east of Wood Island									
MF-303	4	3	2	2	2	1	0	1	8
MF-403	1	3	3	5	7	3	2	1	12
MF-408	5	4	5	6	6	2	1	2	20
MF-491	3	1	0	0	0	0	0	0	4
Southern Grand Manan Island – west of Wood Island									
MF-202	0	2	1	4	5	4	3	2	8
MF-292	2	3	4	5	7	5	8	5	13
MF-003	0	1	1	0	0	0	0	0	1
MF-270	1	2	1	1	4	2	2	1	8
MF-413	2	1	1	5	4	3	0	0	8

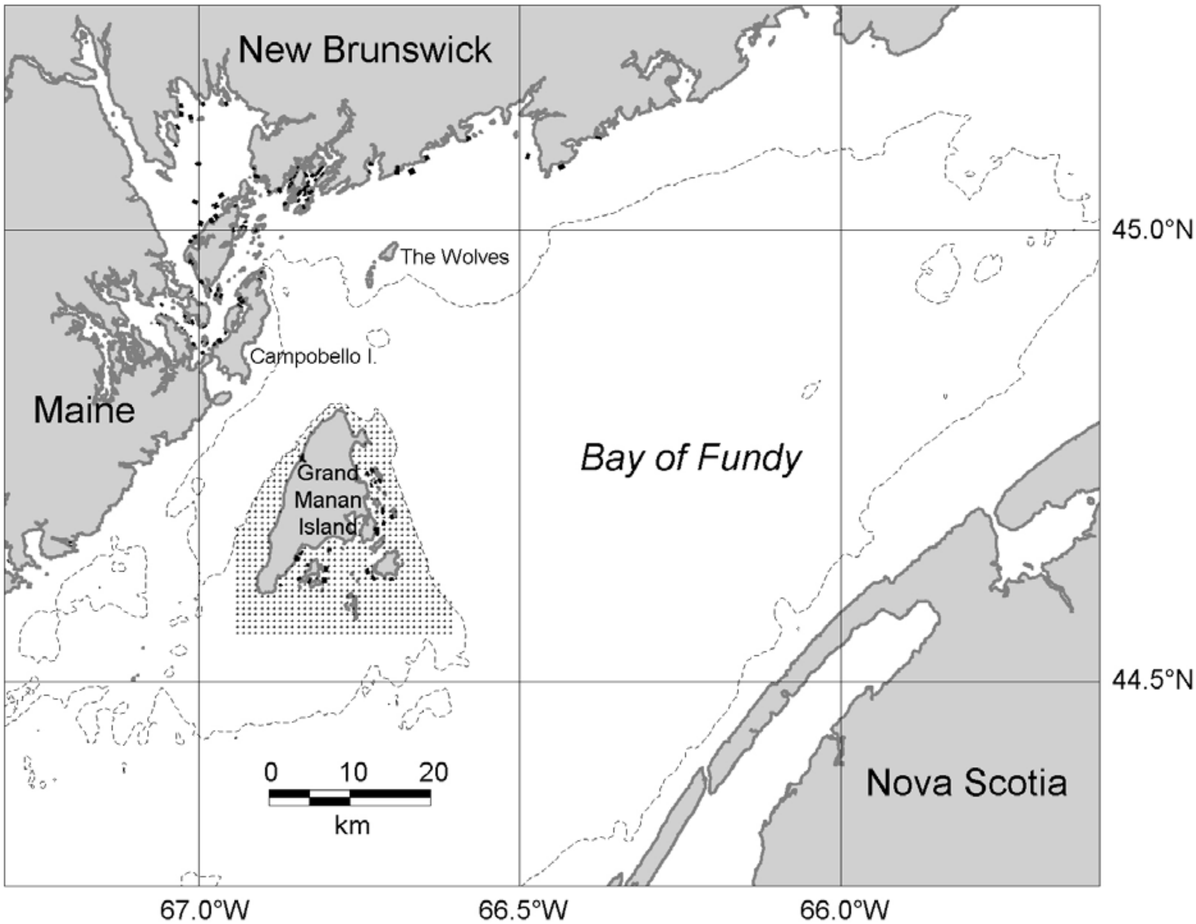


Fig. 1. Map of the lower Bay of Fundy area, showing the model particle release grid around Grand Manan Island. The dashed line is the 80 m depth contour. Finfish aquaculture farm sites are shown as small black polygons.

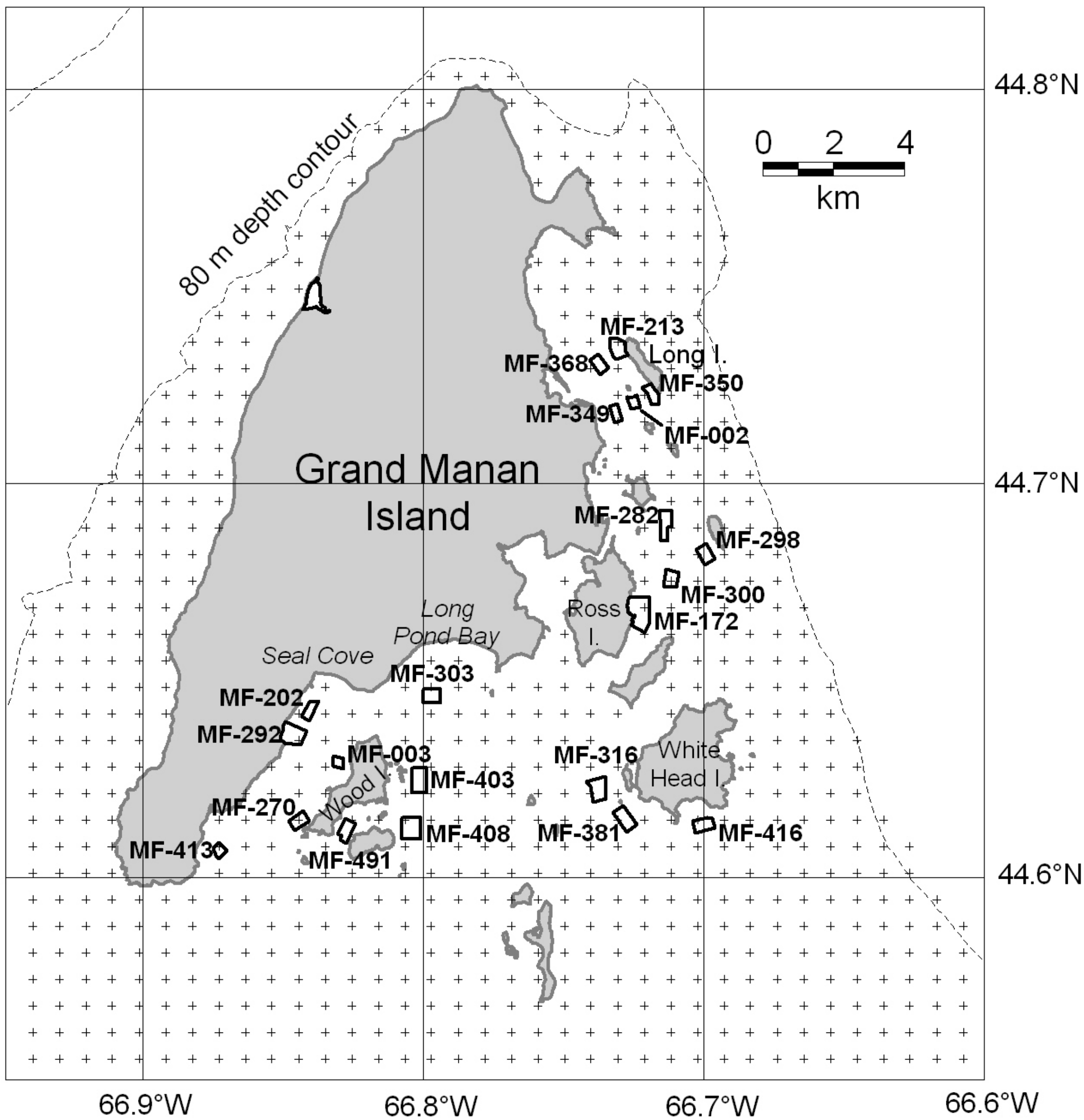


Fig. 2. Detail map of the model particle release grid around Grand Manan Island, Bay of Fundy. Locations of model particle releases are shown as small crosses; release points are separated by 750 m in the north-south and east-west directions. Finfish aquaculture farm sites are shown as small polygons (outlined in black).

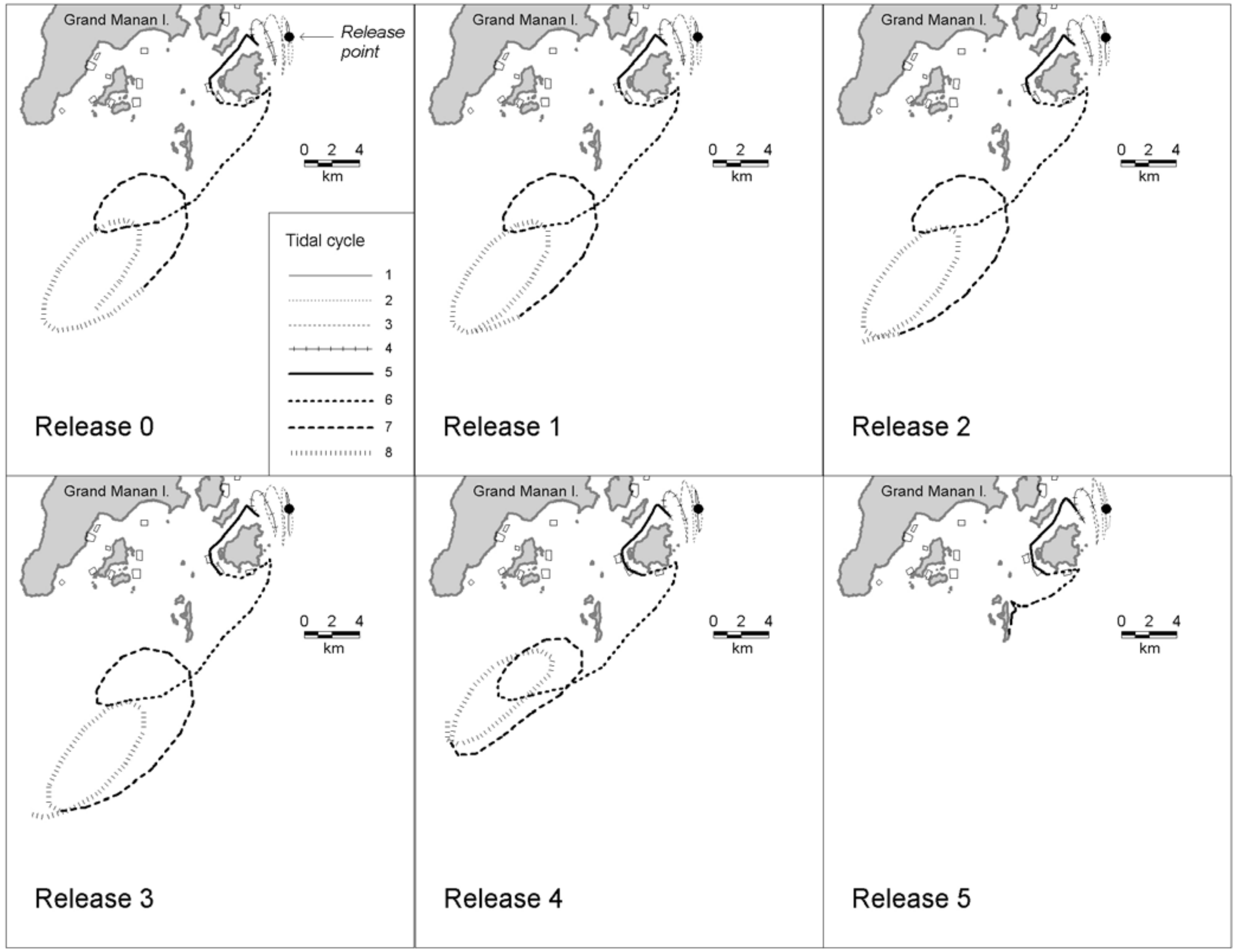


Fig. 3a. Example model particle tracks from a release point in the eastern Grand Manan Island area. Each panel shows the track for one of 12 particles released at hourly intervals (hours 0-11) from the same starting point (indicated by a black dot). Each panel shows the trajectory over 8 tidal cycles (see legend in first panel). The release time closest to high tide was hour 3 and the release time closest to low tide was hour 9. The particle from release 5 stopped upon hitting land 81 h after release and the particle from release 8 stopped upon hitting a shoal 34 h after release.

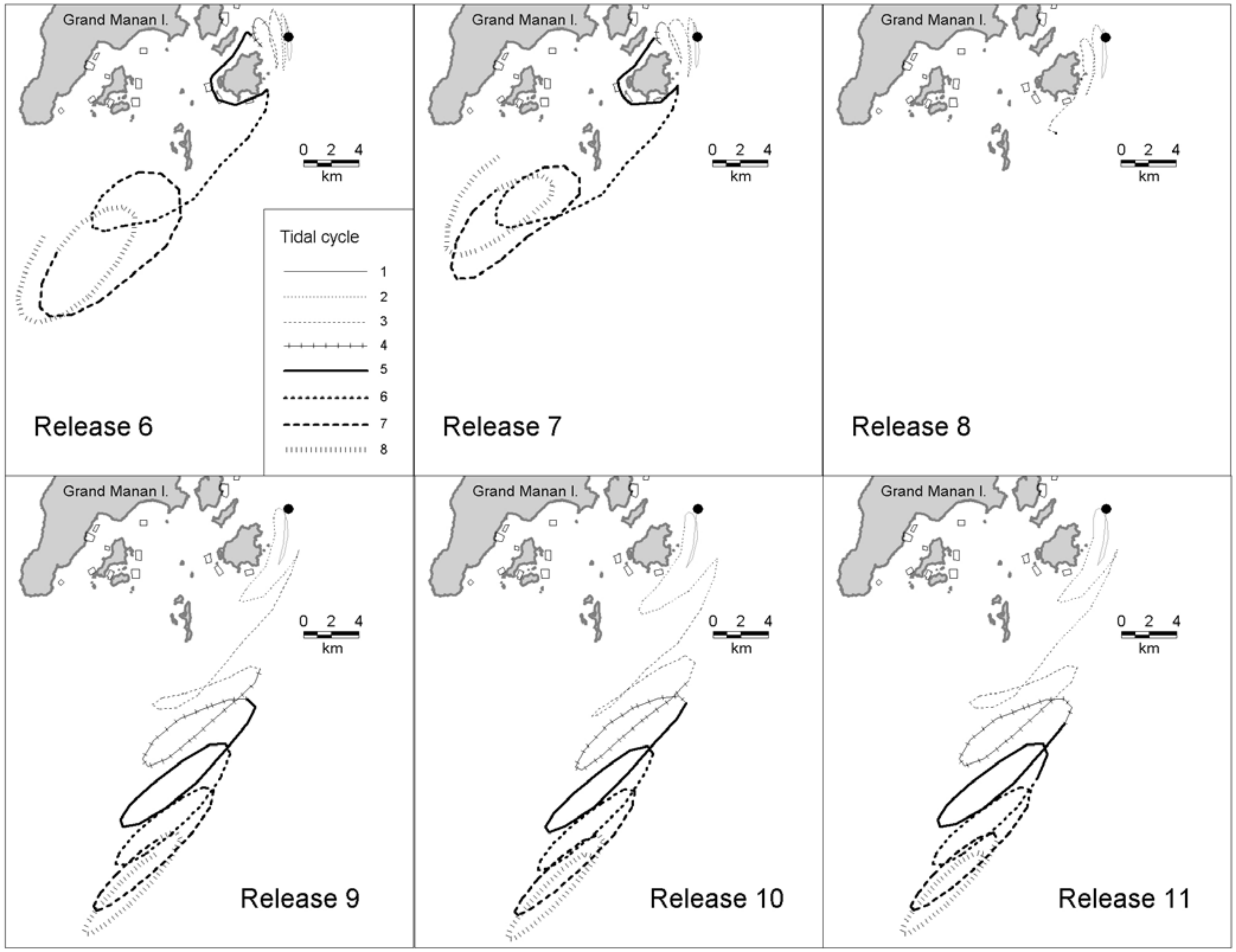


Fig. 3a continued.

Fig. 3b. Example model particle tracks from a release point in the southern Grand Manan Island area. Each panel shows the track for one of 12 particles released at hourly intervals (hours 0-11) from the same starting point (indicated by a black dot). Each panel shows the trajectory over 8 tidal cycles (see legend in first panel). The release time closest to high tide was hour 3 and the release time closest to low tide was hour 9.

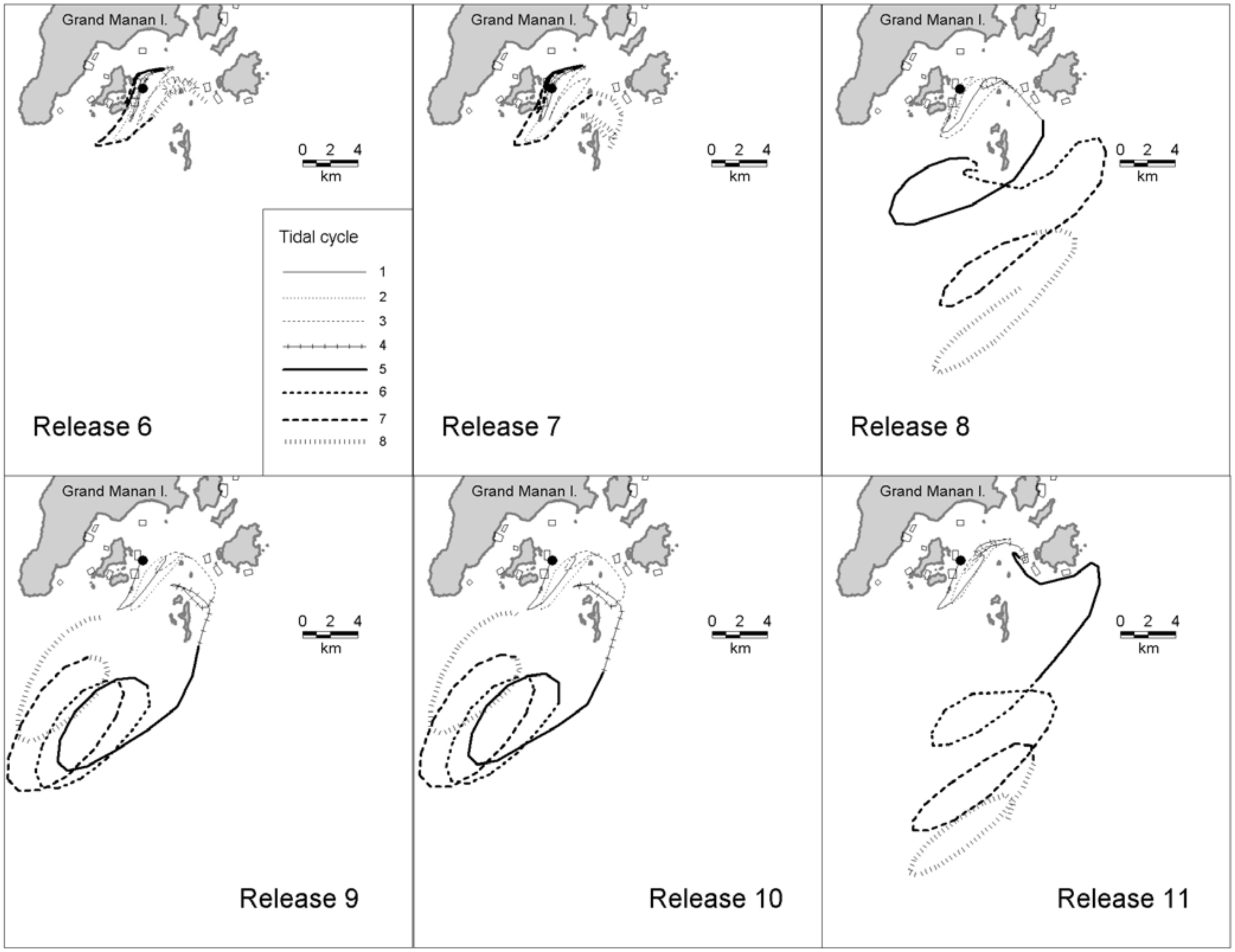


Fig. 3b continued.

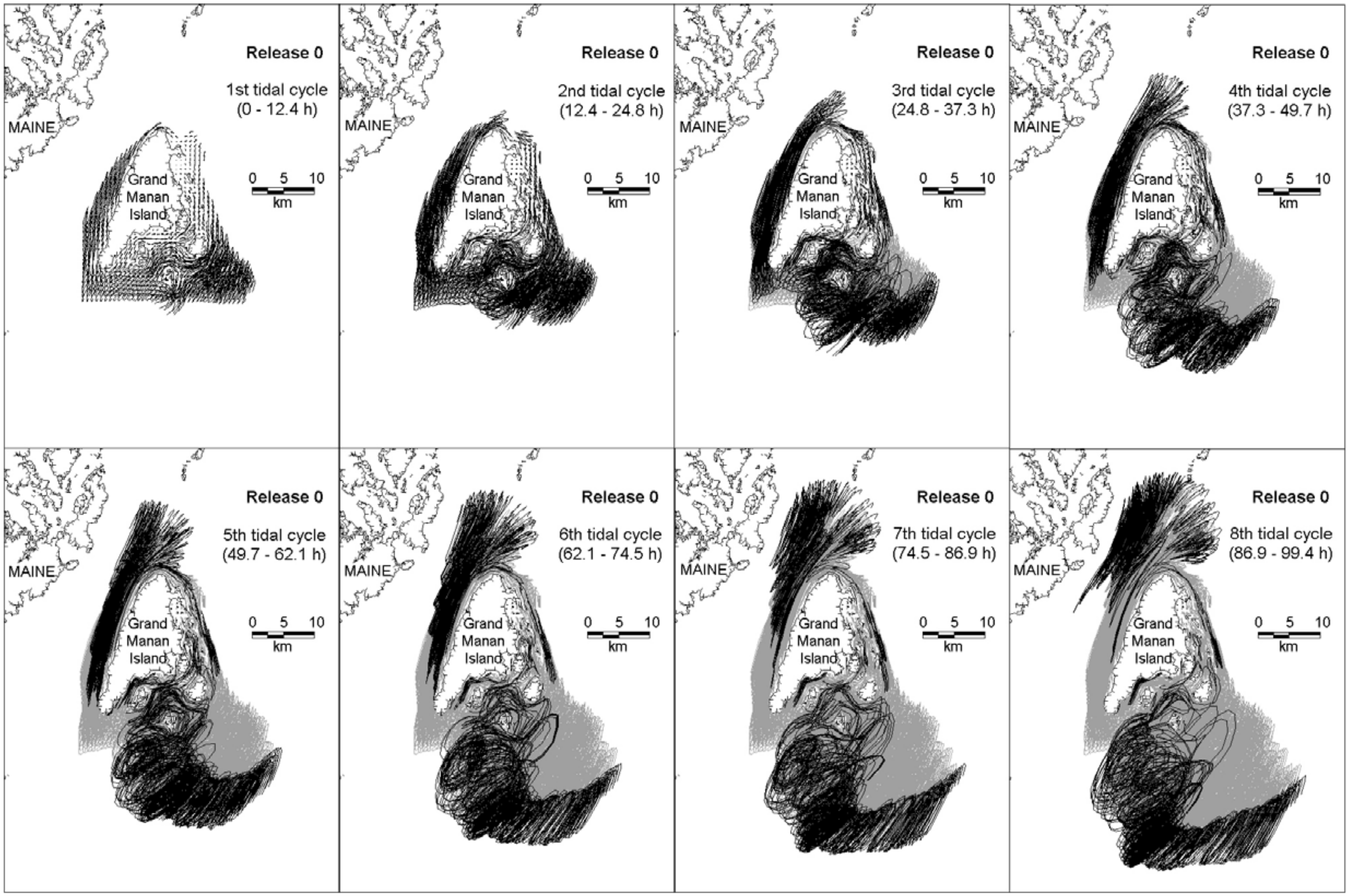


Fig. 4a. Tracks for all particles in release 0. The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

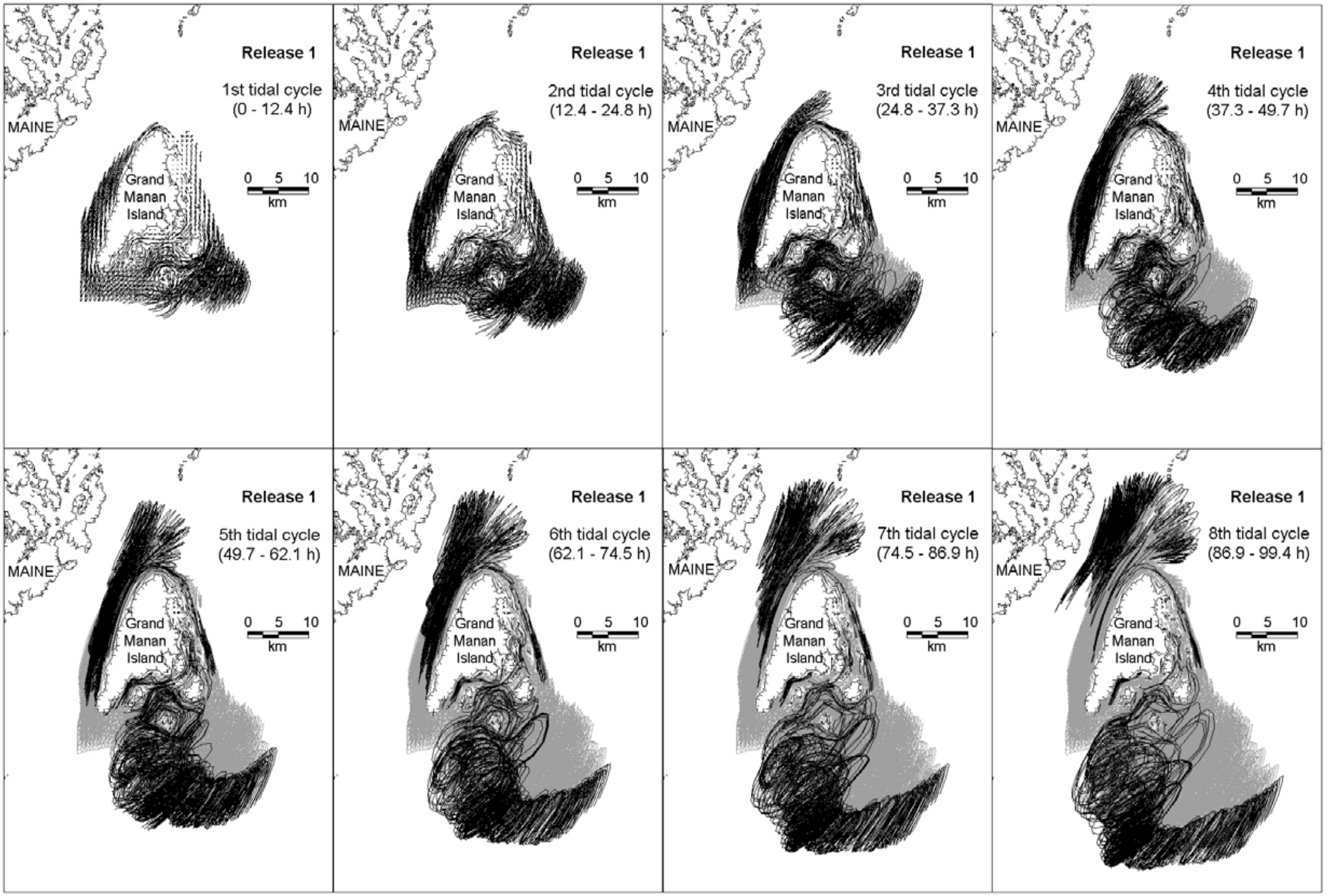


Fig. 4b. Tracks for all particles in release 1 (1 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

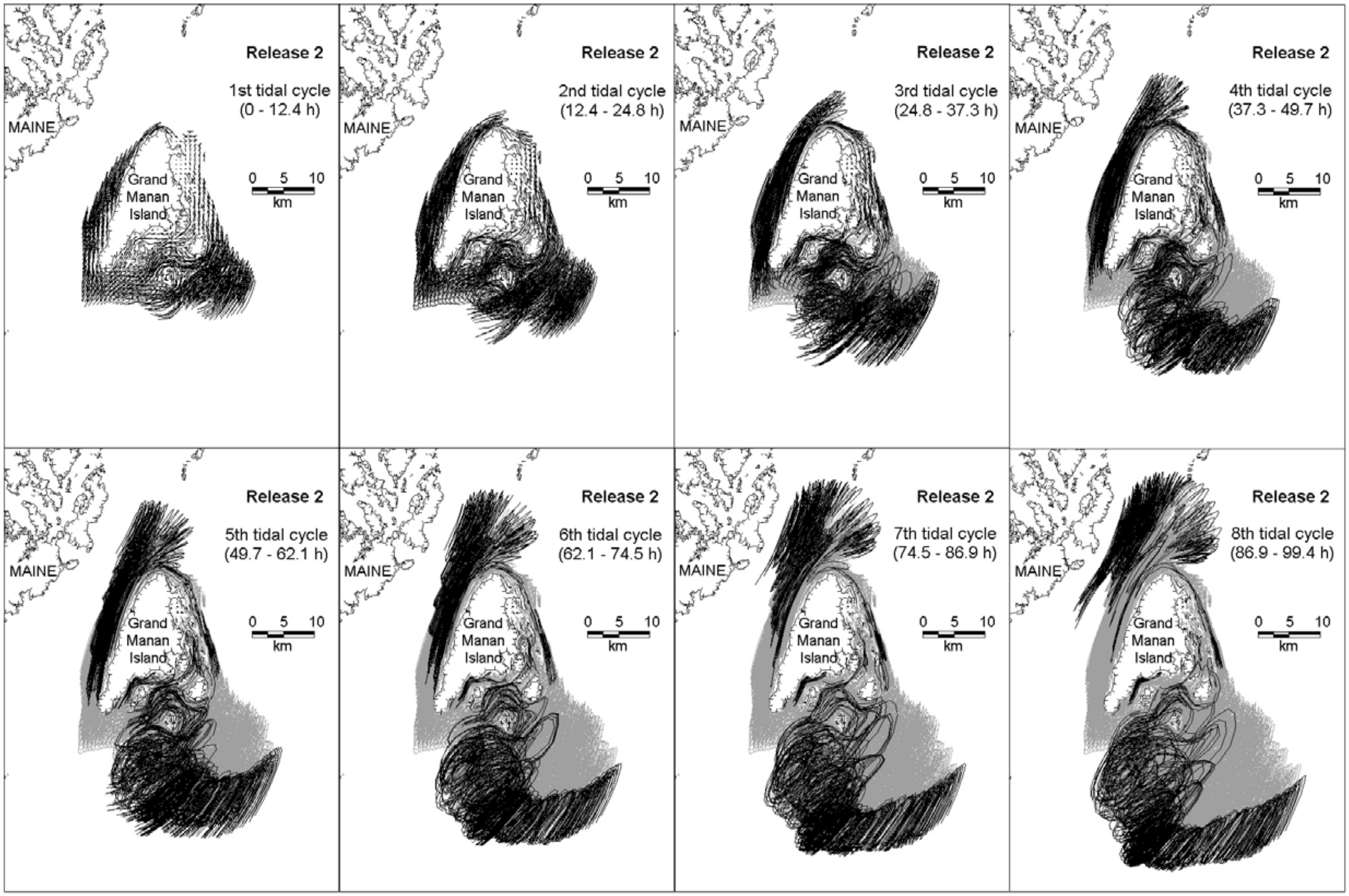


Fig. 4c. Tracks for all particles in release 2 (2 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

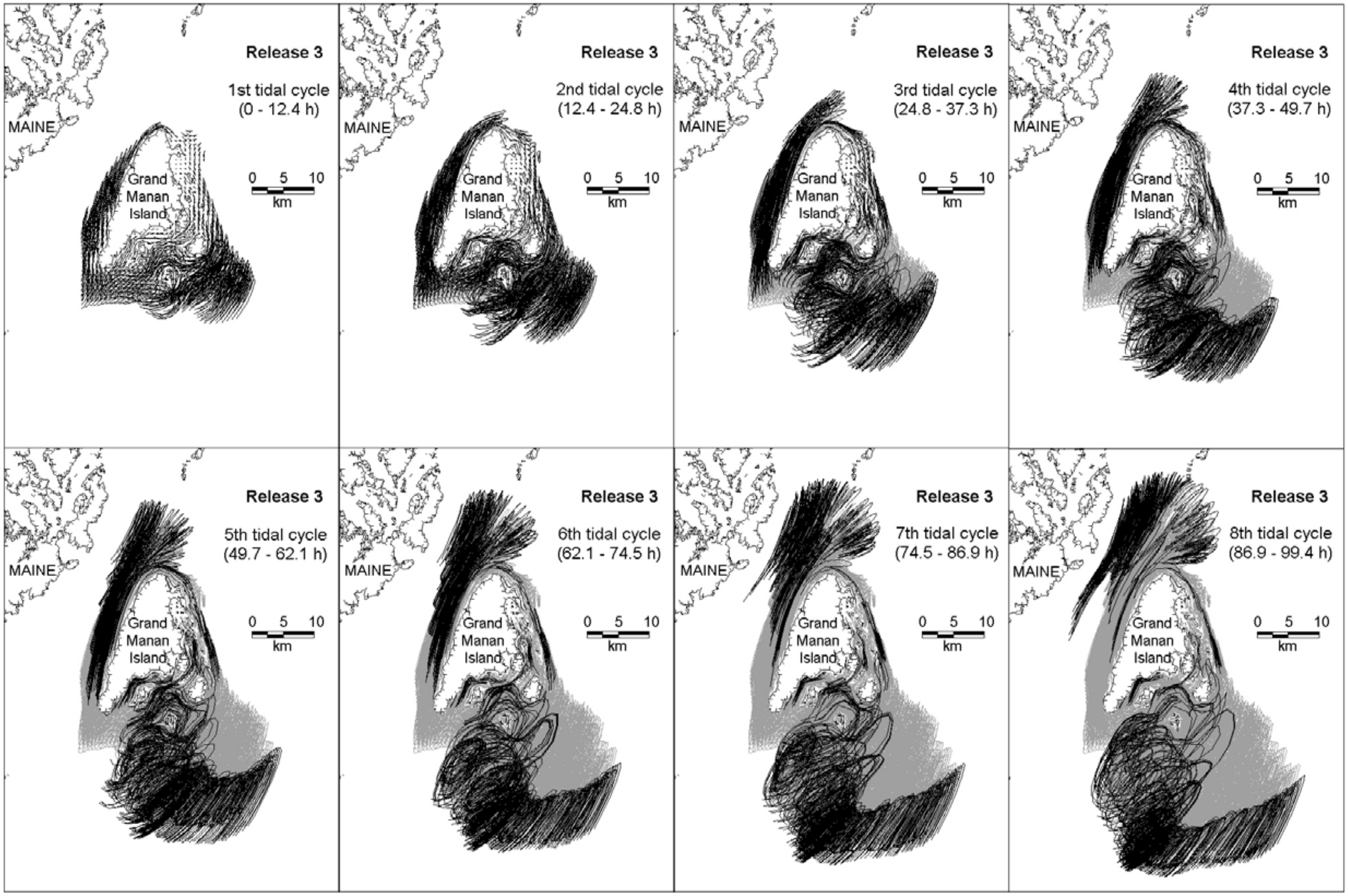


Fig. 4d. Tracks for all particles in release 3 (3 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

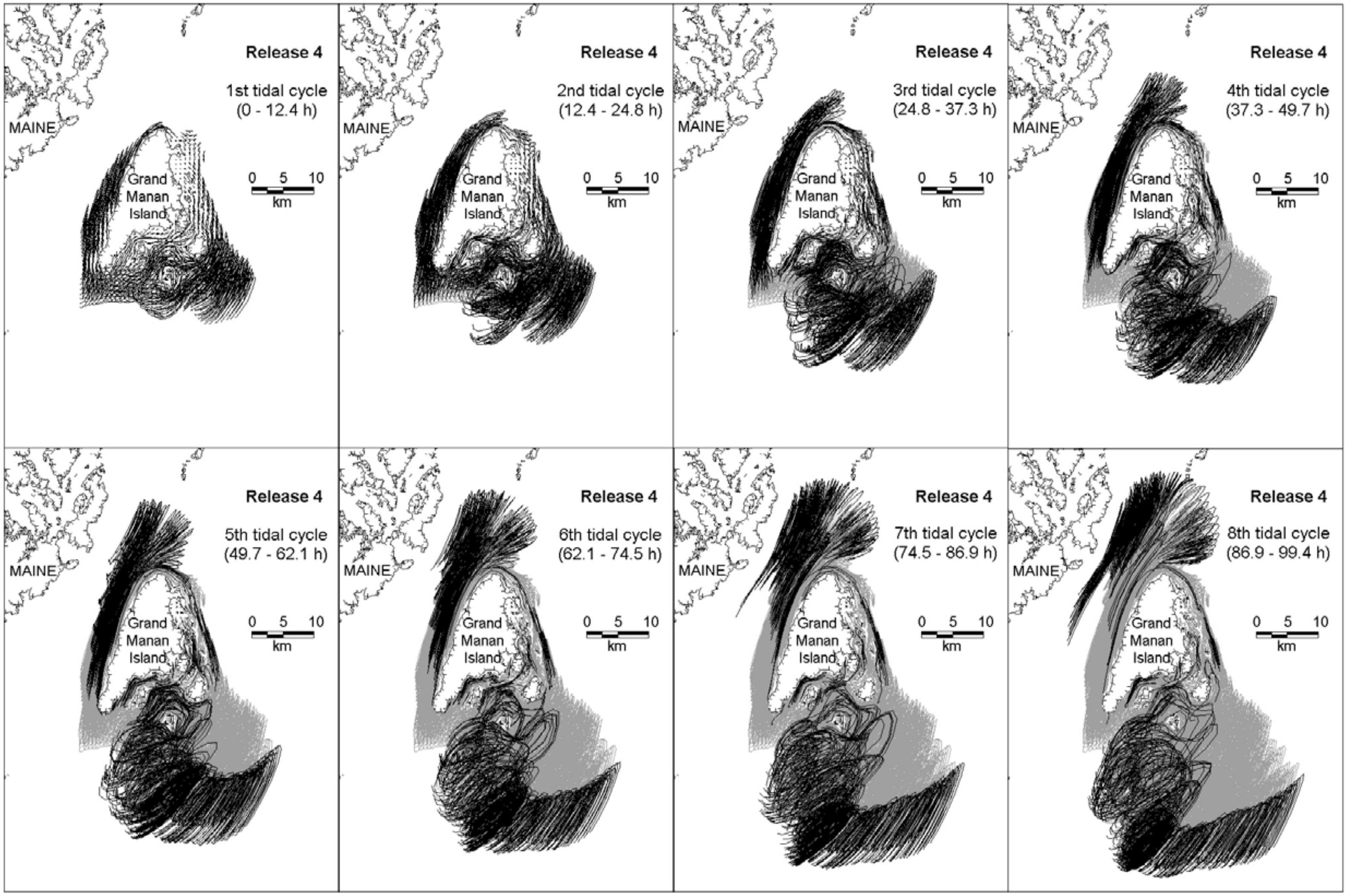


Fig. 4e. Tracks for all particles in release 4 (4 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

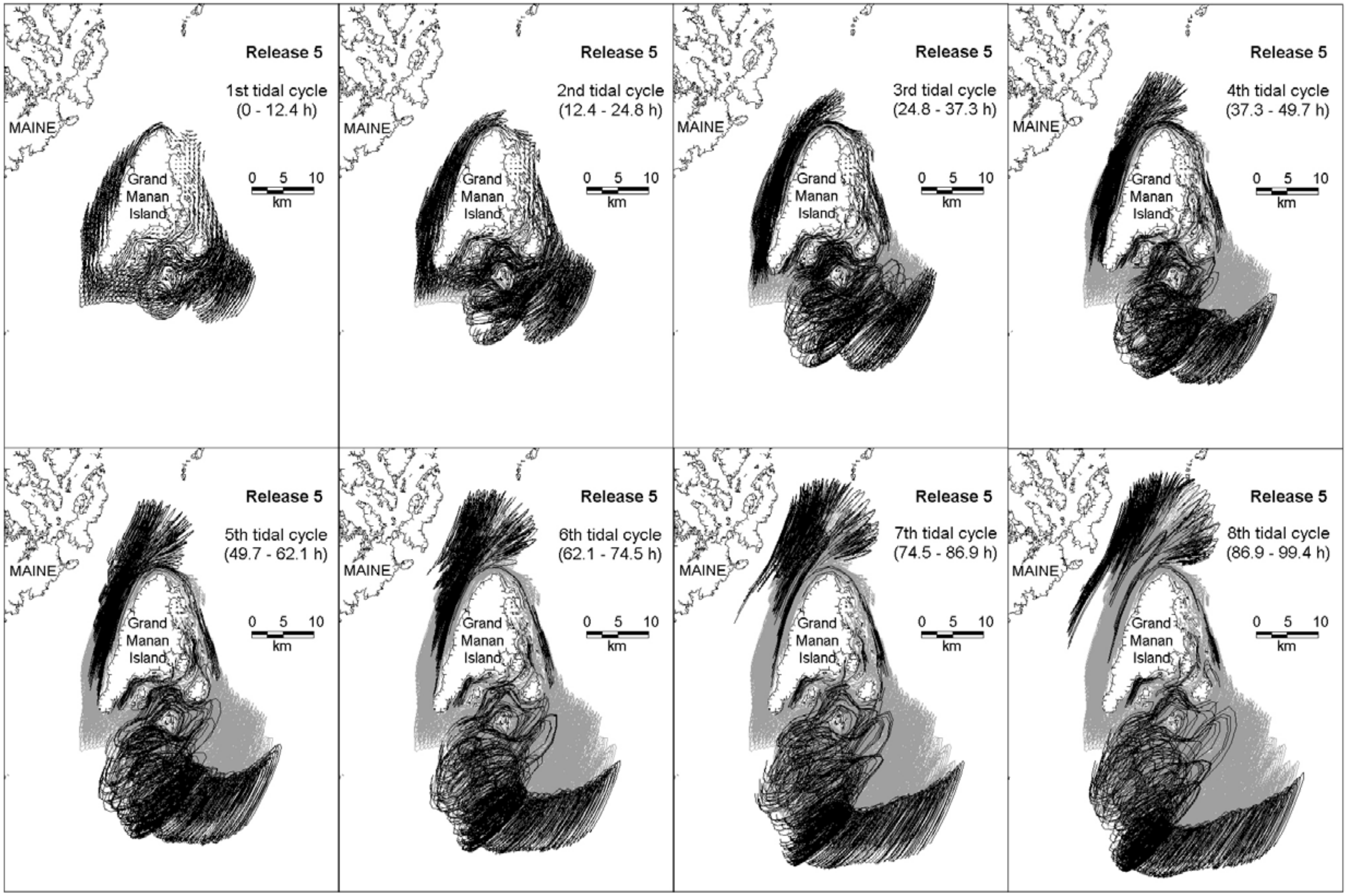


Fig. 4f. Tracks for all particles in release 5 (5 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

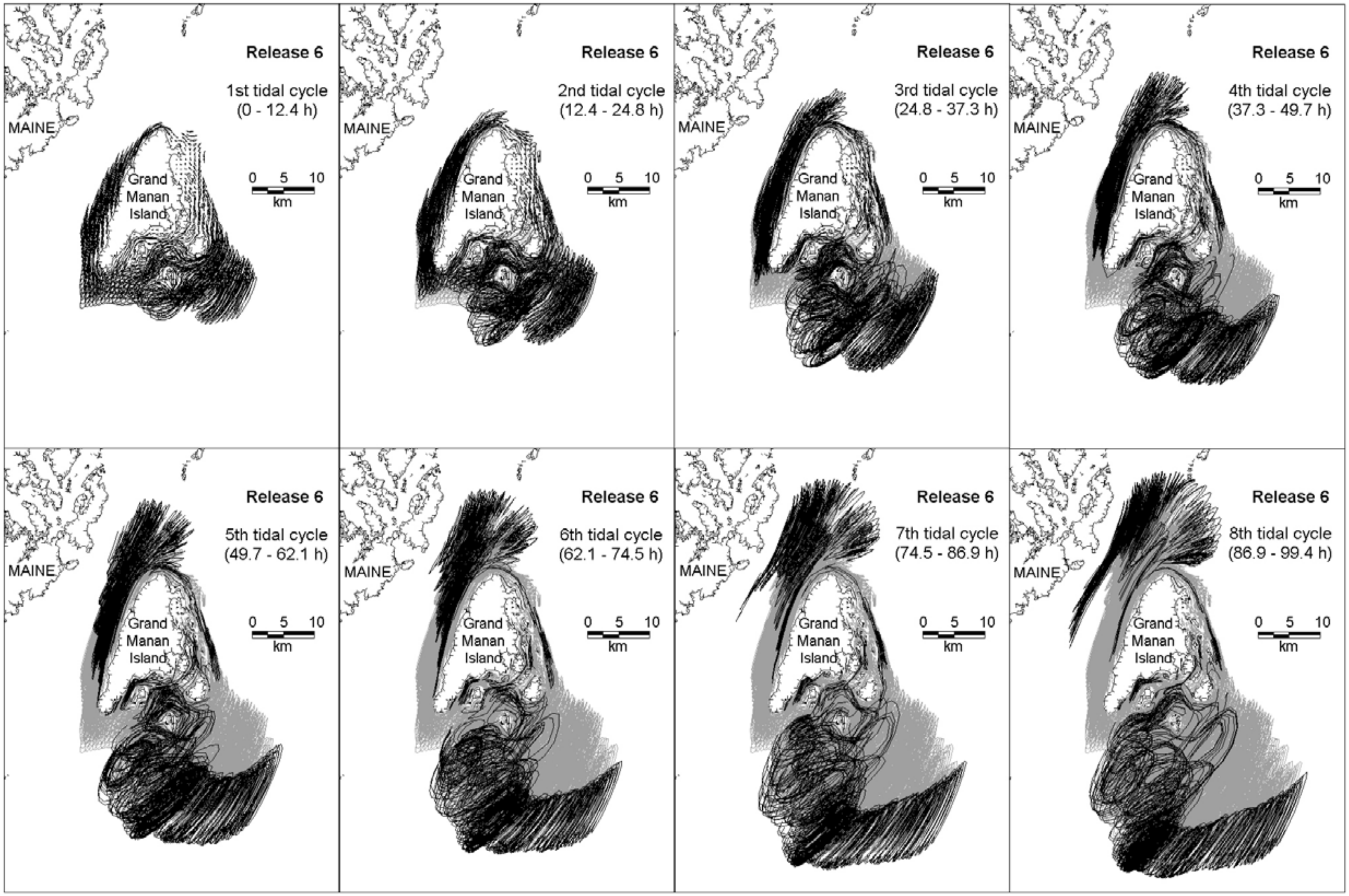


Fig. 4g. Tracks for all particles in release 6 (6 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

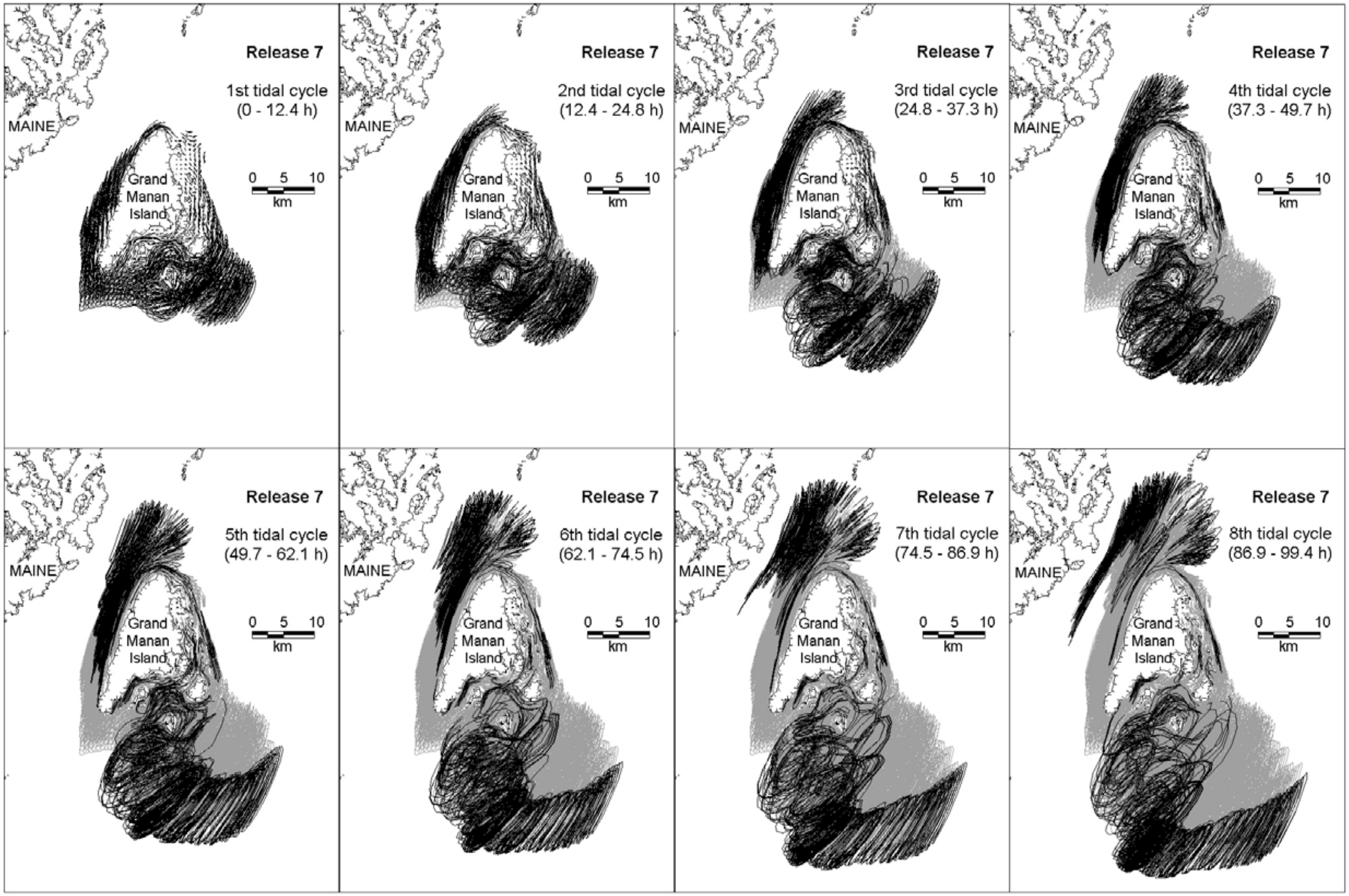


Fig. 4h. Tracks for all particles in release 7 (7 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

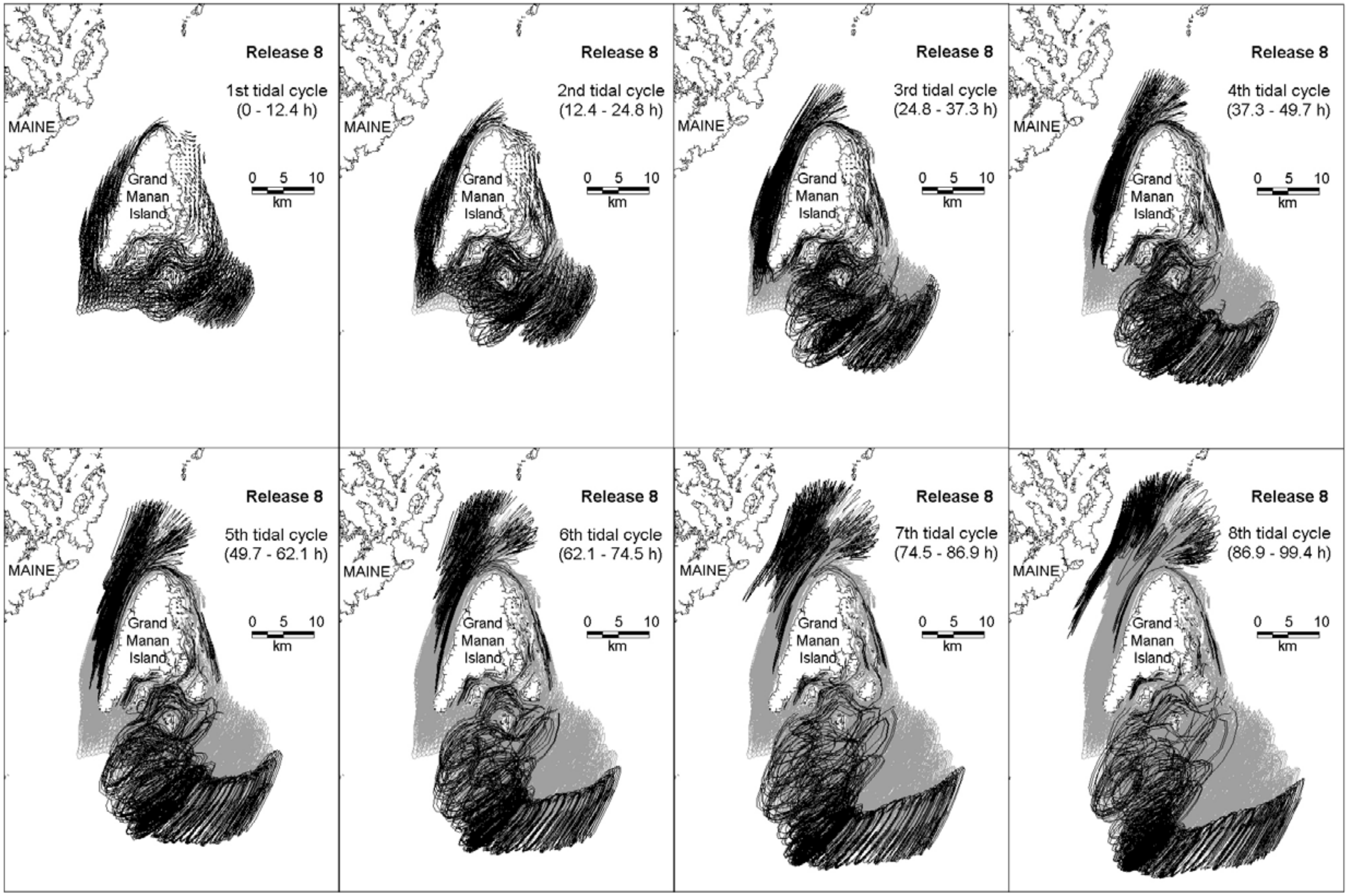


Fig. 4i. Tracks for all particles in release 8 (8 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

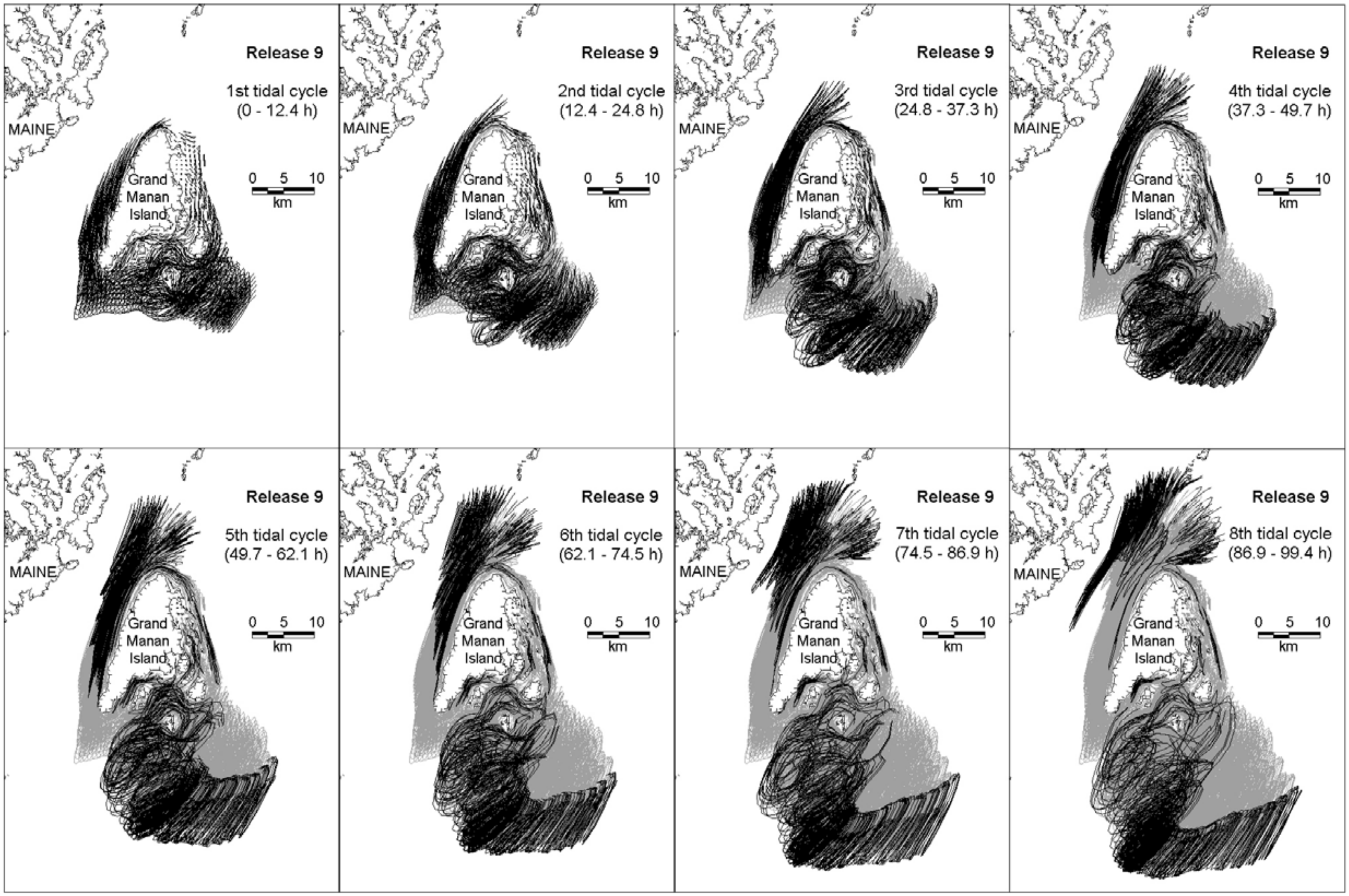


Fig. 4j. Tracks for all particles in release 9 (9 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

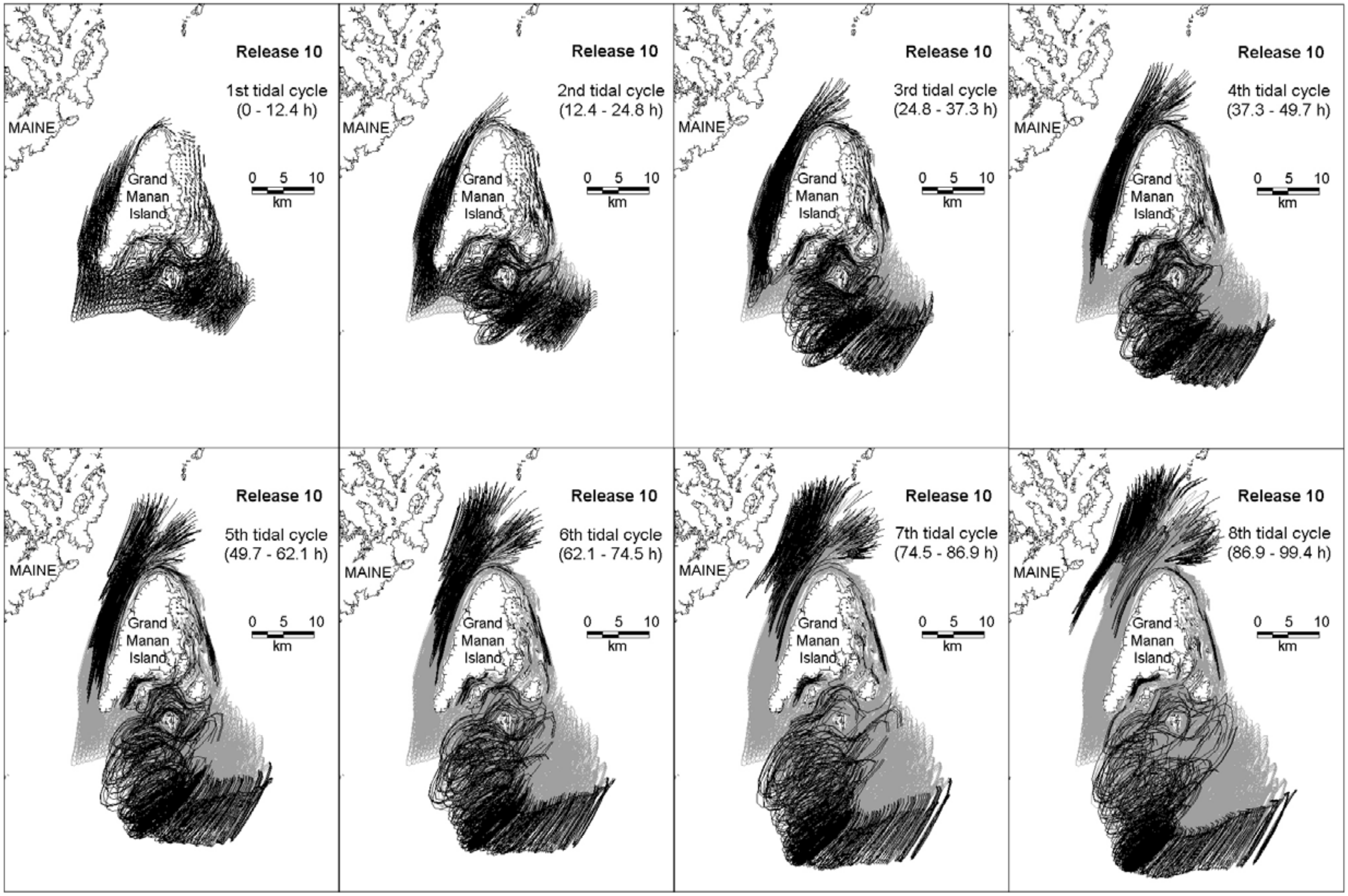


Fig. 4k. Tracks for all particles in release 10 (10 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

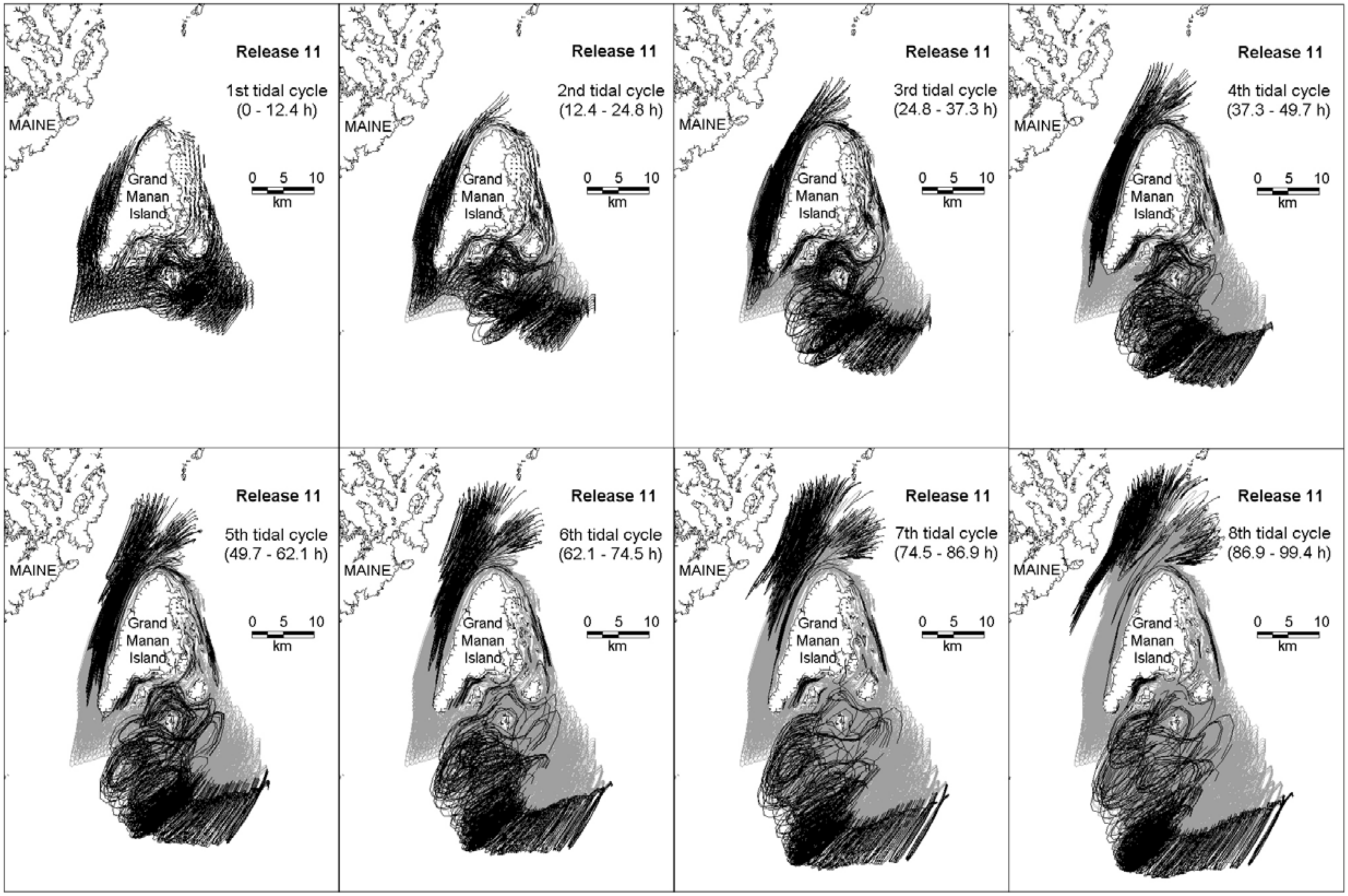


Fig. 4L. Tracks for all particles in release 11 (11 h after release 0). The panels show the tracks over 8 consecutive tidal cycles, with the particle tracks during the indicated tidal cycle in black, and the particle tracks during previous tidal cycles in grey. Particle release points are shown in Fig. 1 and 2.

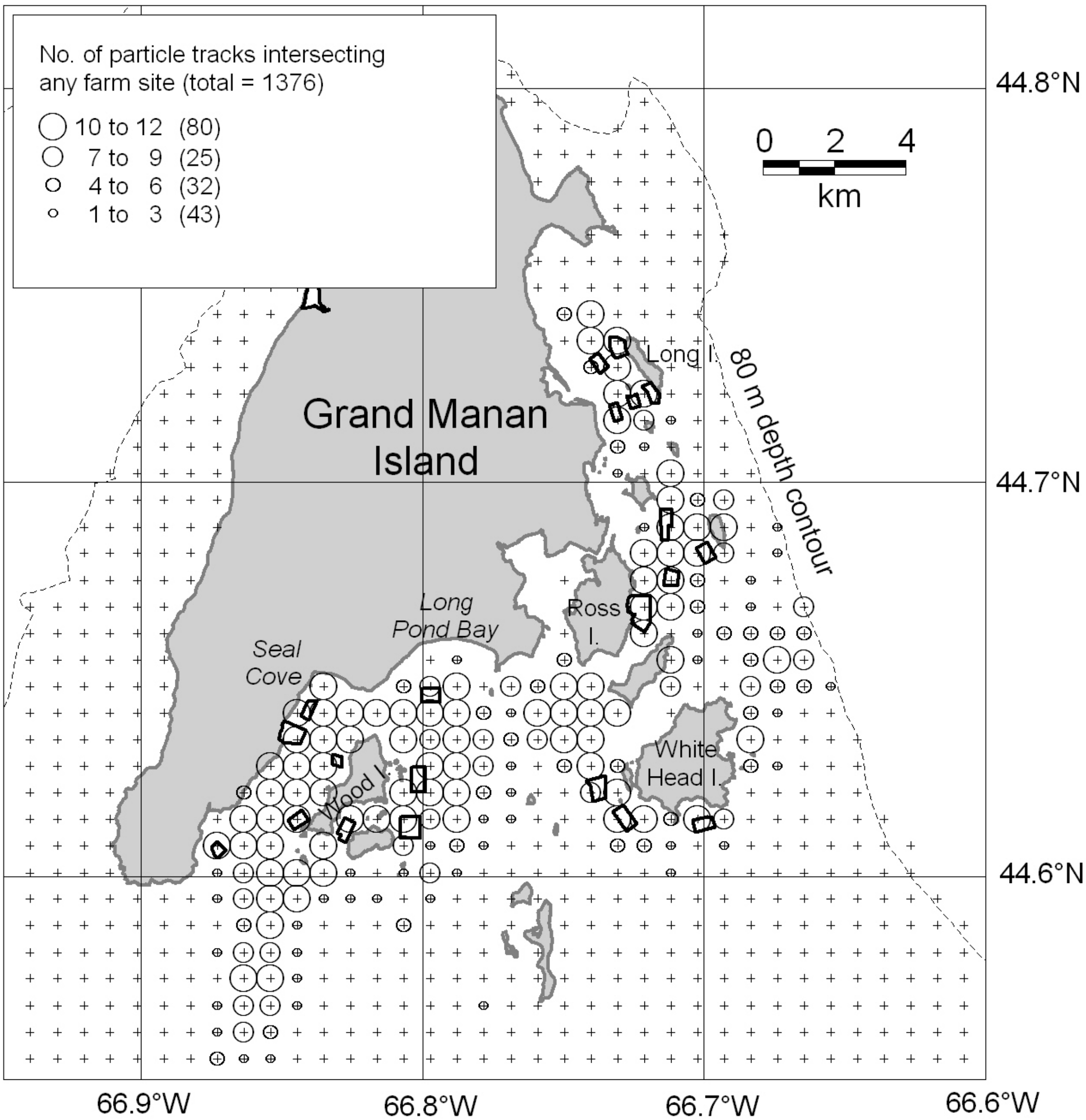


Fig. 5. Map of the model particle release grid around Grand Manan Island, Bay of Fundy, showing the release locations of all model particles, indicating which locations released particles which intersected at least one finfish aquaculture farm site within 100 h after release (8 tidal cycles). Small crosses indicate all model particle release locations (12 particles were released from each point, at hourly intervals); circles of varying sizes indicate the release locations of particles which intersected at least one farm site (see map legend; the numbers in parentheses in the legend represent the number of release points within each category); small polygons (thick, black outlines) indicate finfish farm sites.

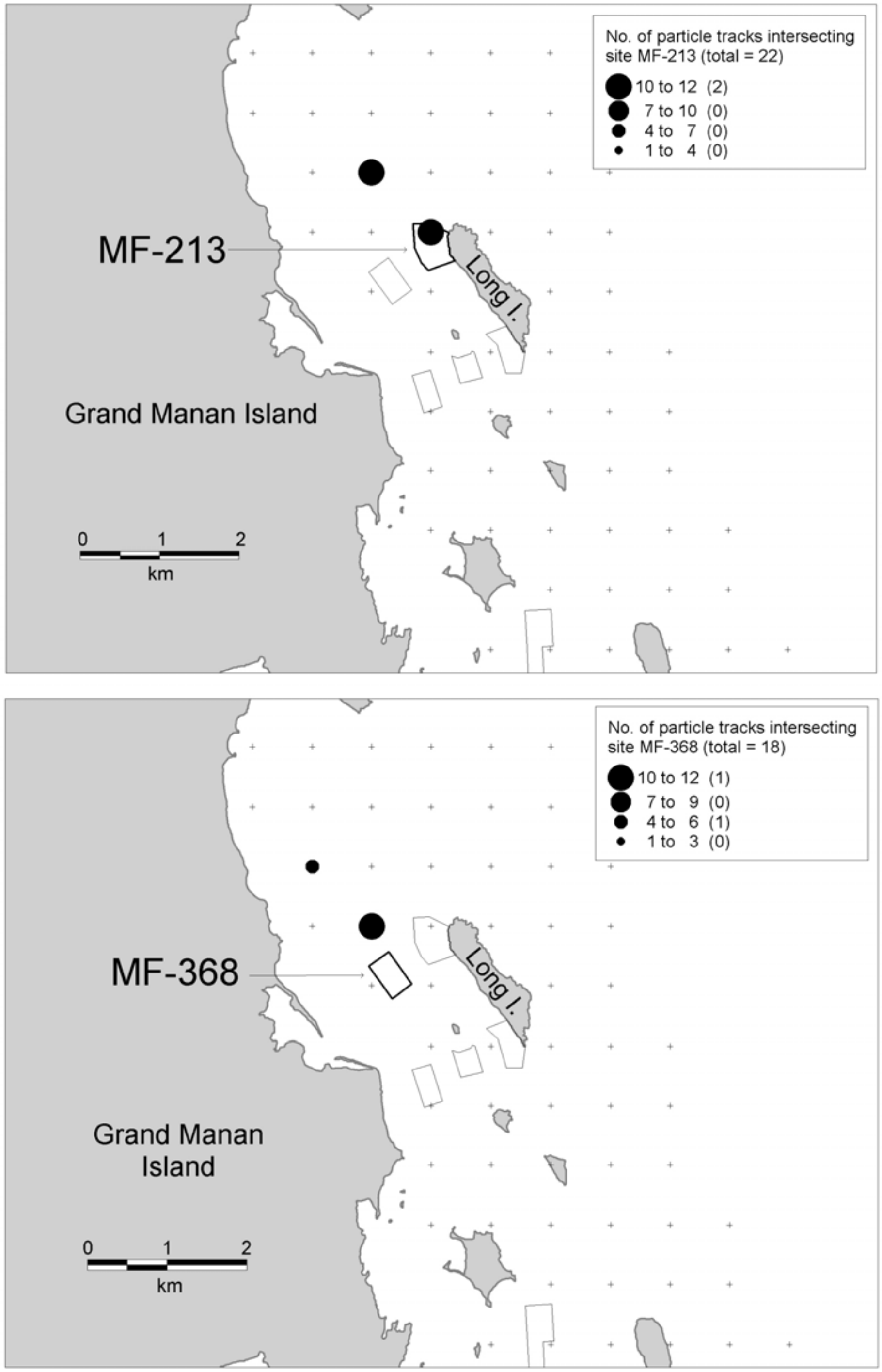
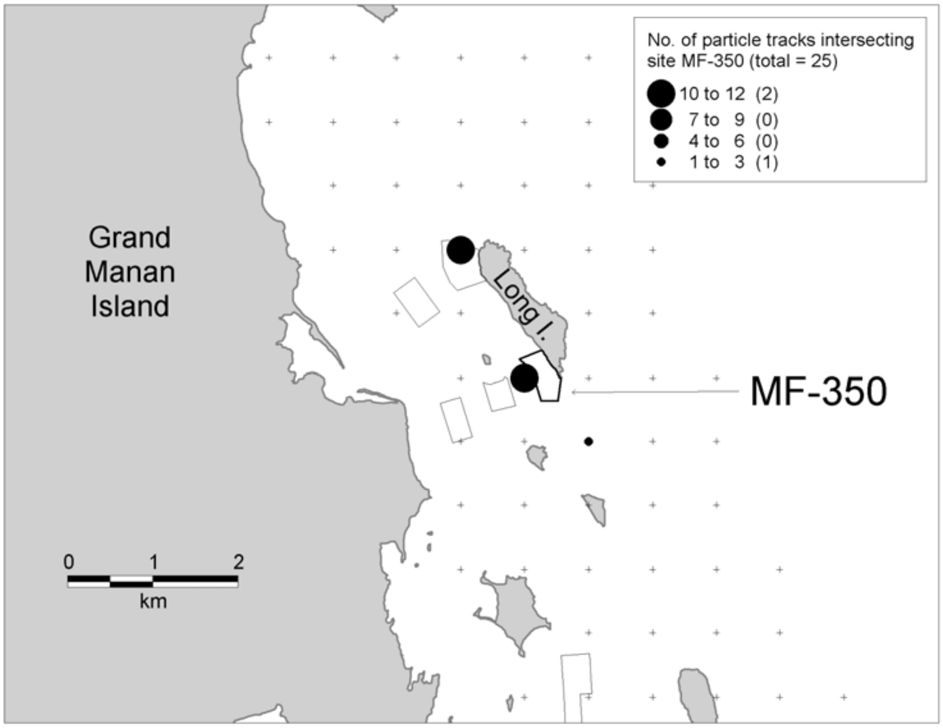


Fig. 6a. Maps showing release points of model particles whose tracks intersected each farm site in the Long Island area within 100 h after release (8 tidal cycles). Farms are shown as small polygons; small crosses represent all particle release points; black circles indicate release points of particles whose tracks intersected the farm site indicated with a thick outline; the size of the circles represents the number of particles originating from this point, which intersected the farm site (see map legend); the numbers in parentheses in the legend represent the number of release points in each category.



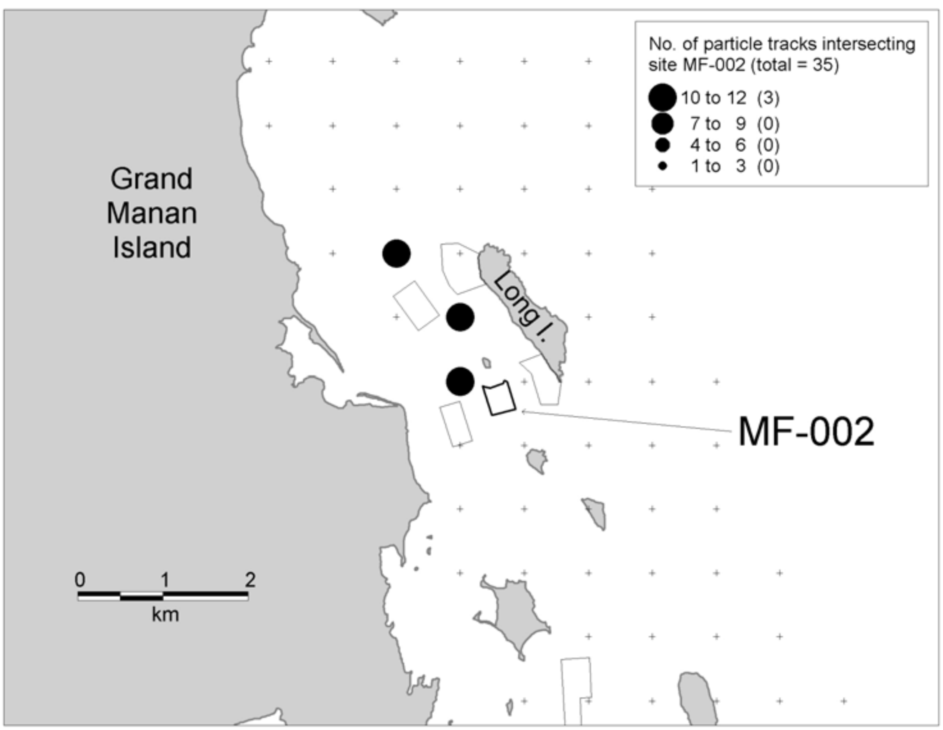


Fig. 6a continued.

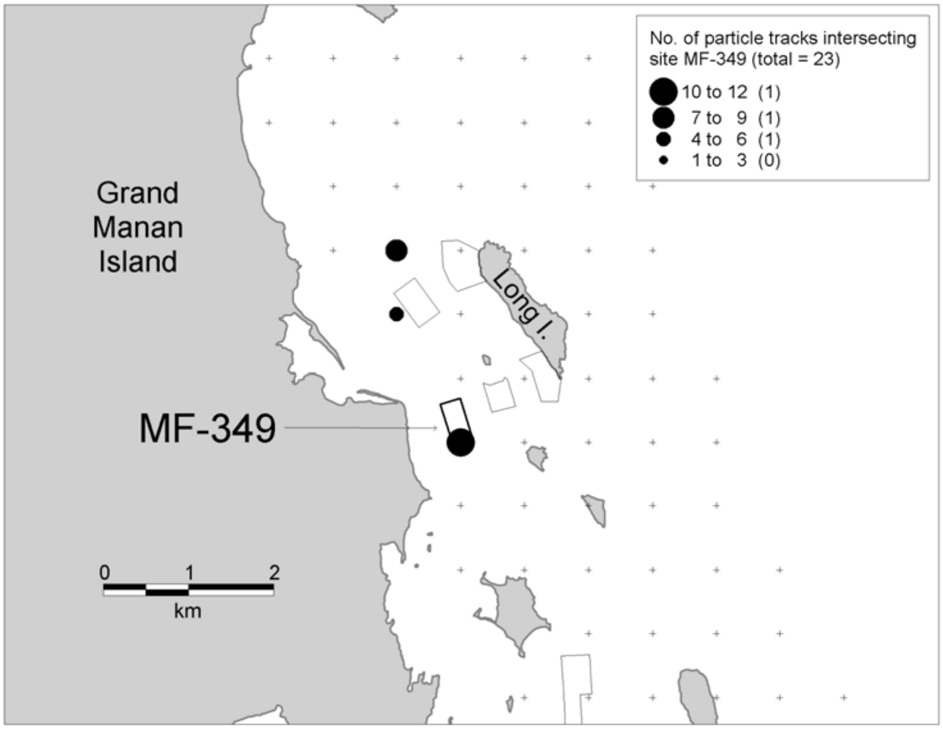


Fig. 6a concluded.

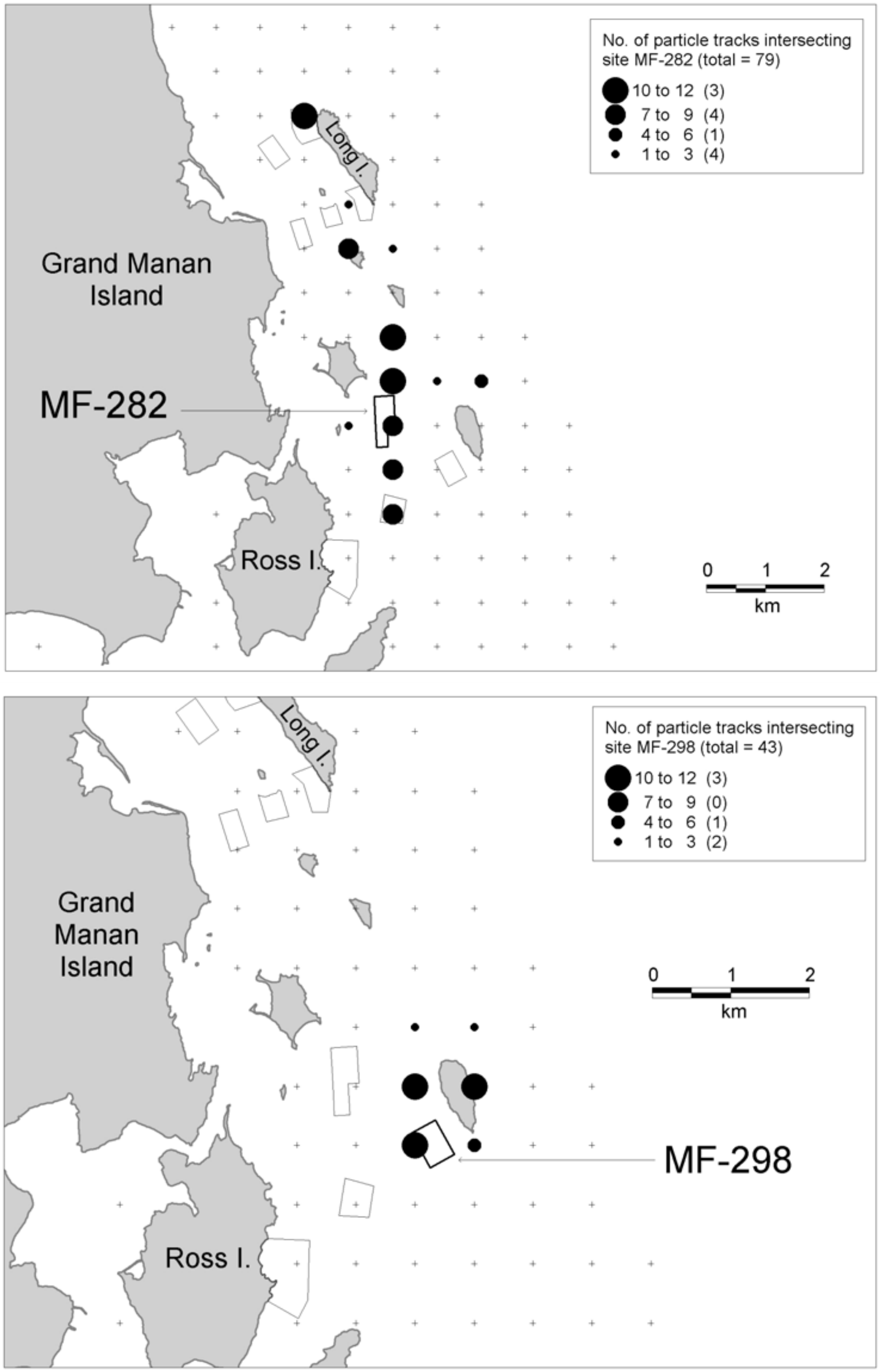


Fig. 6b. Maps showing release points of model particles whose tracks intersected each farm site in the Ross Island area within 100 h after release (8 tidal cycles). Refer to caption for Fig. 6a.

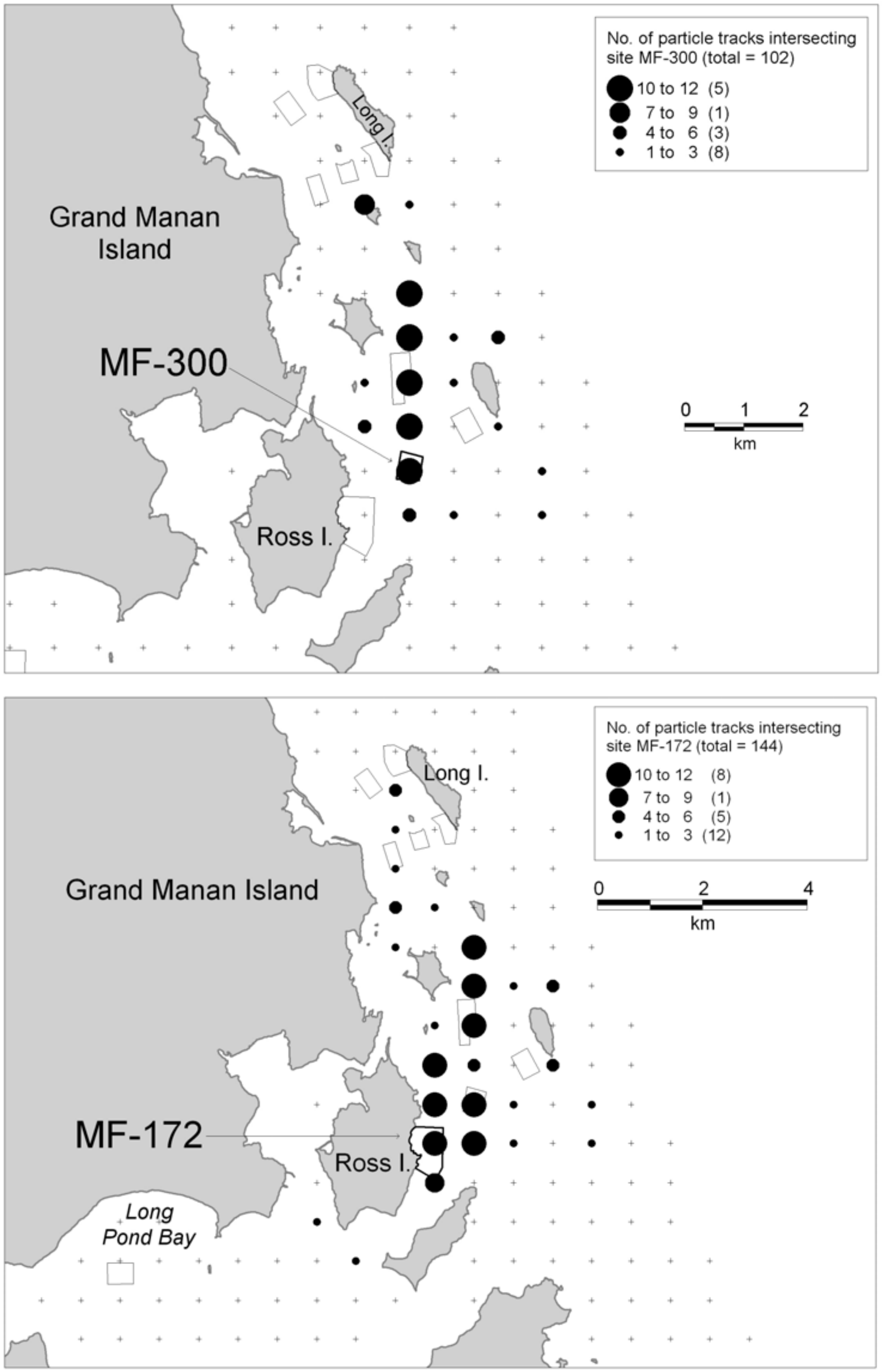
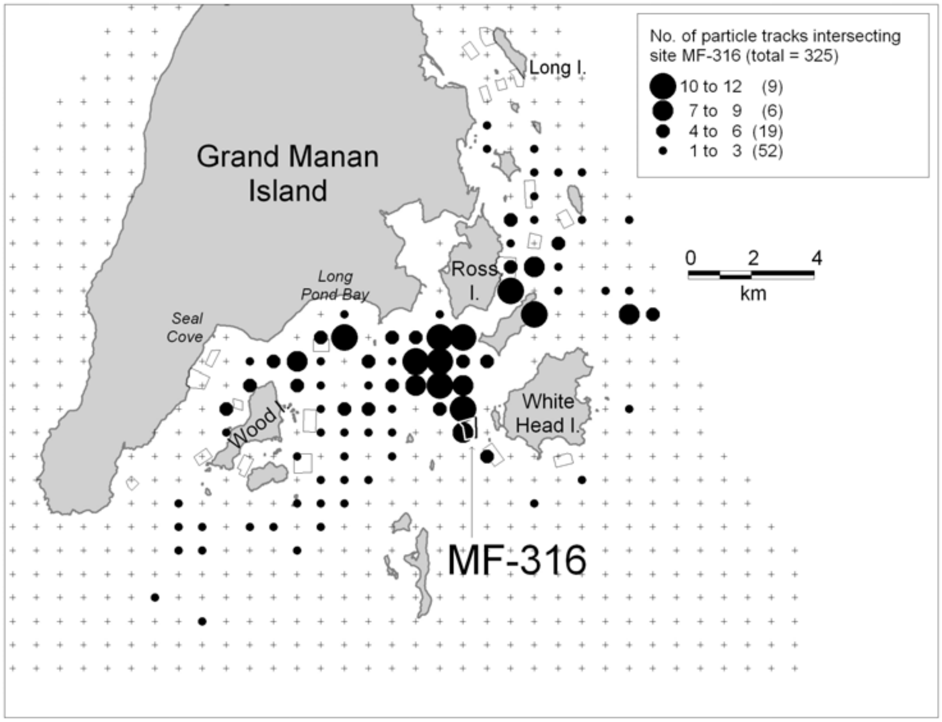


Fig. 6b concluded.



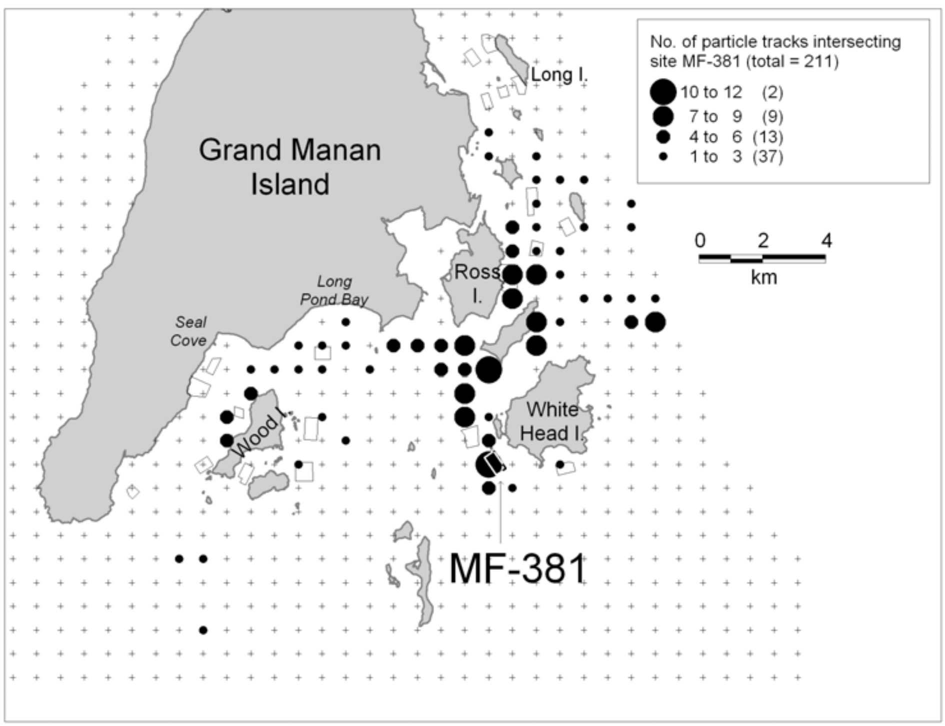


Fig. 6c. Maps showing release points of model particles whose tracks intersected each farm site in the White Head Island area within 100 h after release (8 tidal cycles). Refer to caption for Fig. 6a.

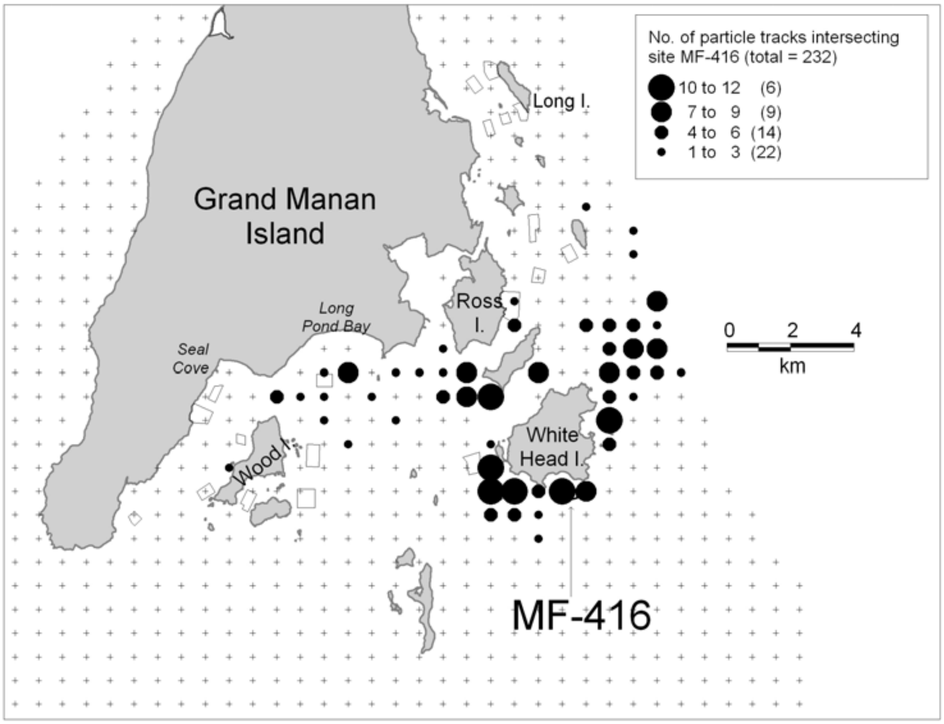


Fig. 6c concluded.

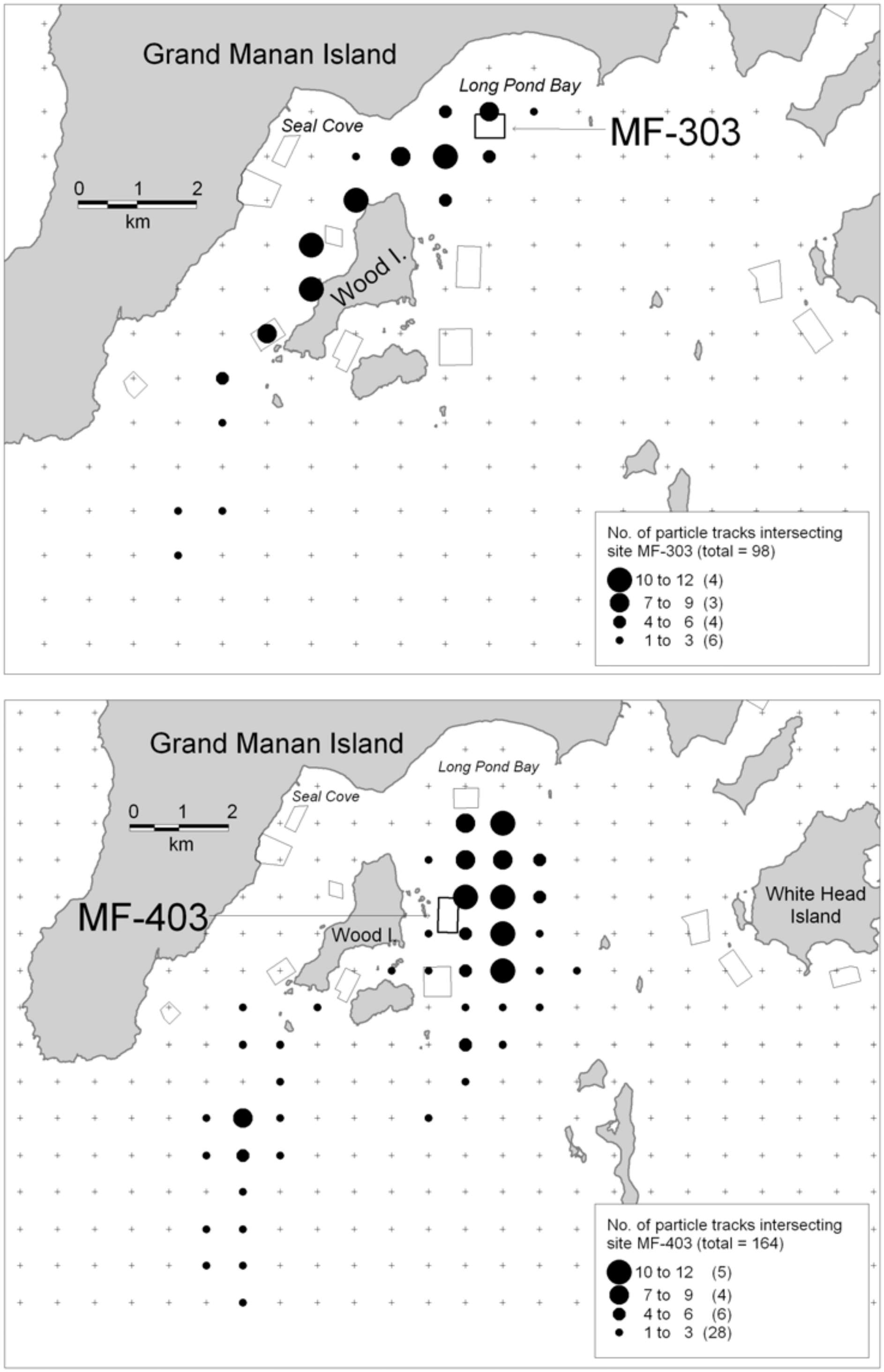
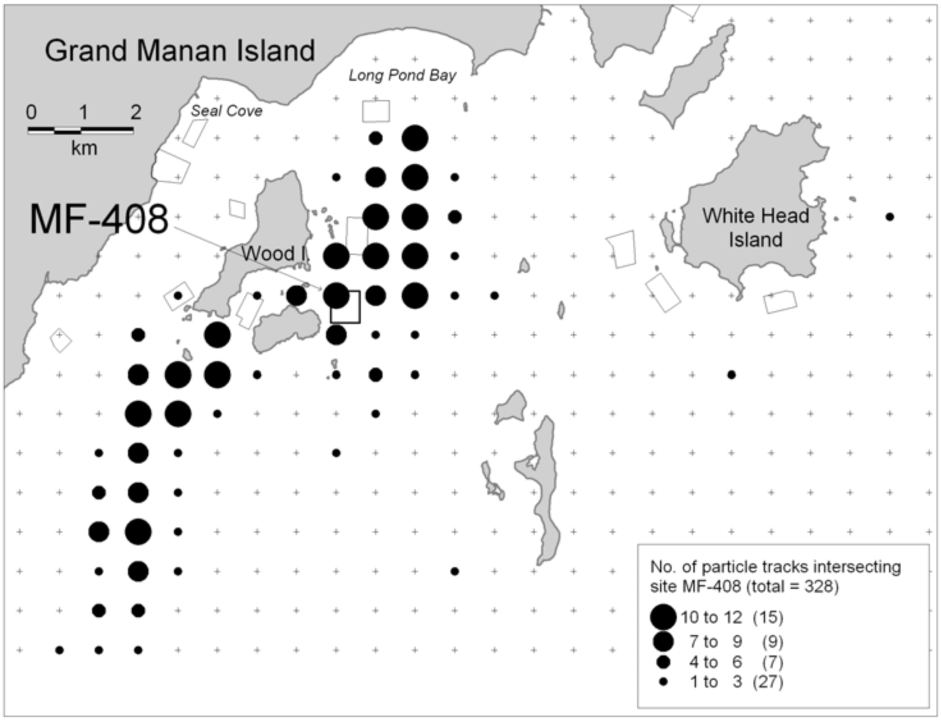


Fig. 6d. Maps showing release points of model particles whose tracks intersected each farm site in the Long Pond Bay area within 100 h after release (8 tidal cycles). Refer to caption for Fig. 6a.



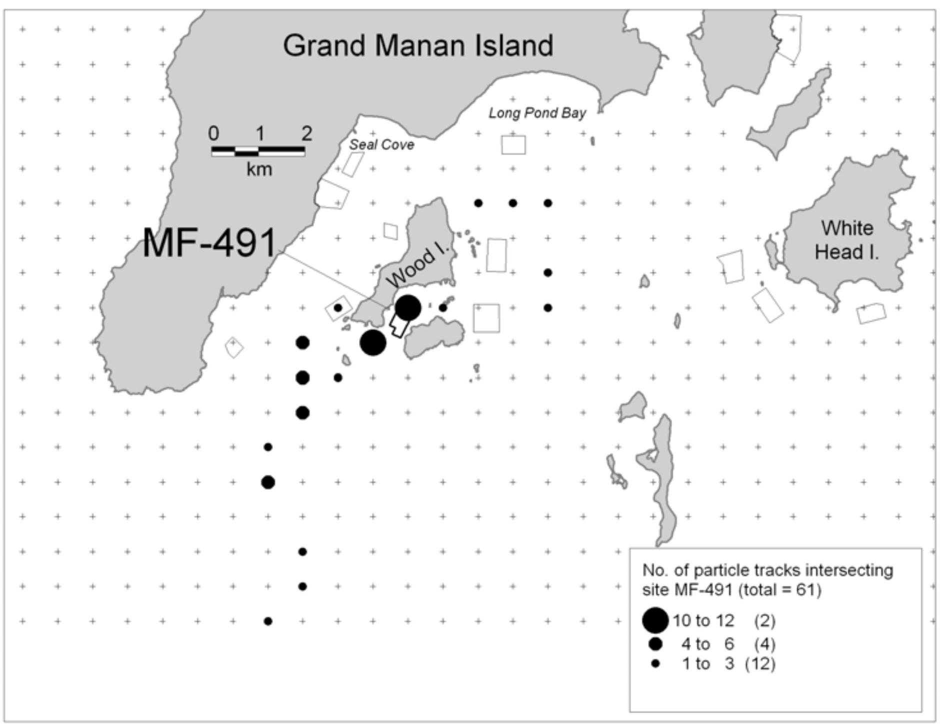
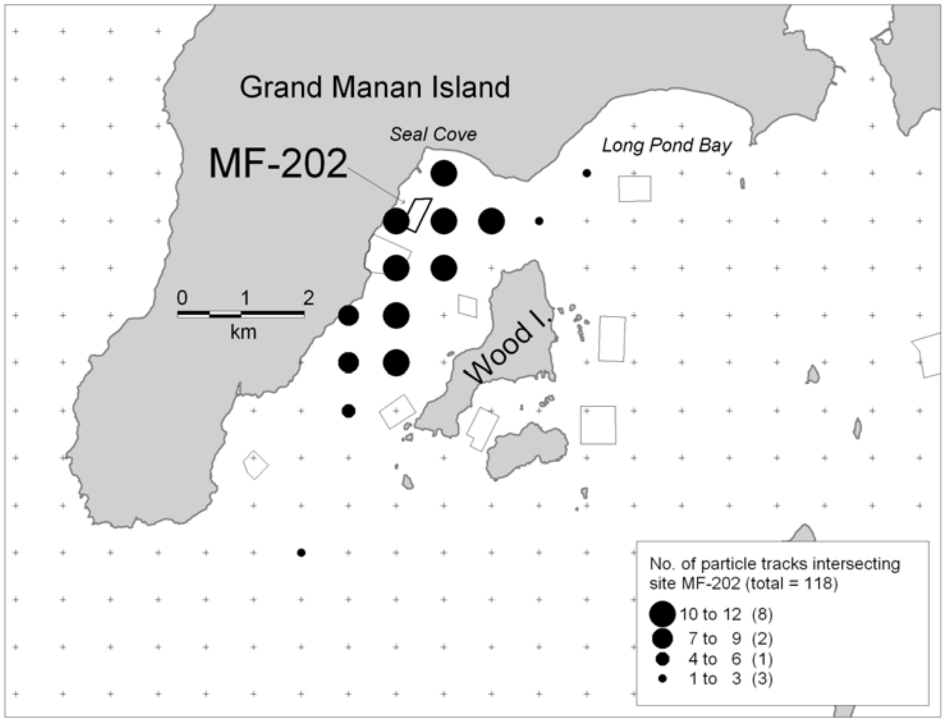


Fig. 6d concluded.



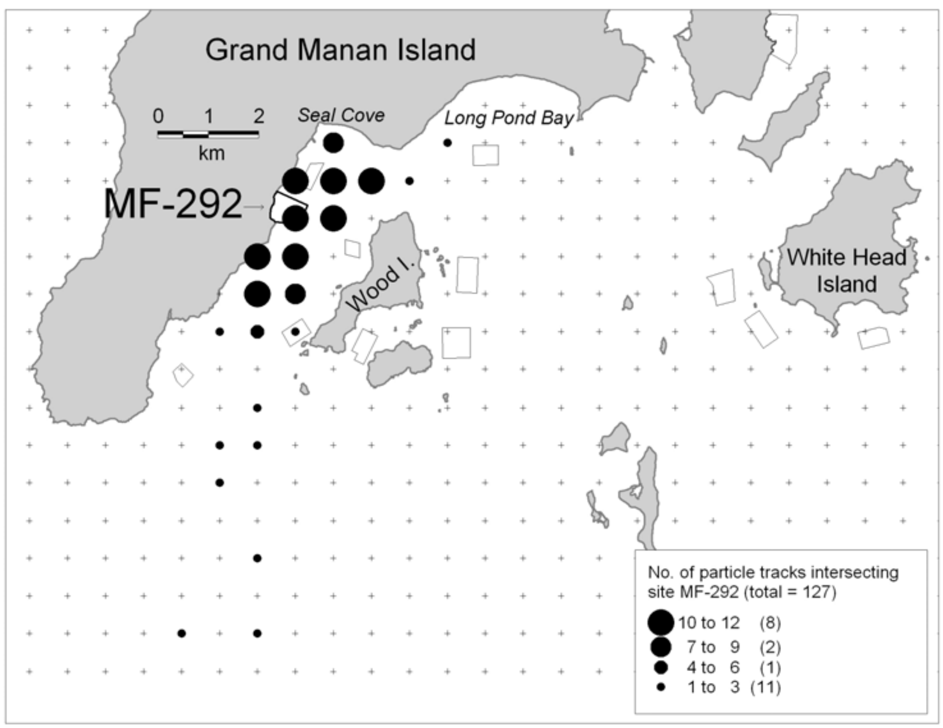
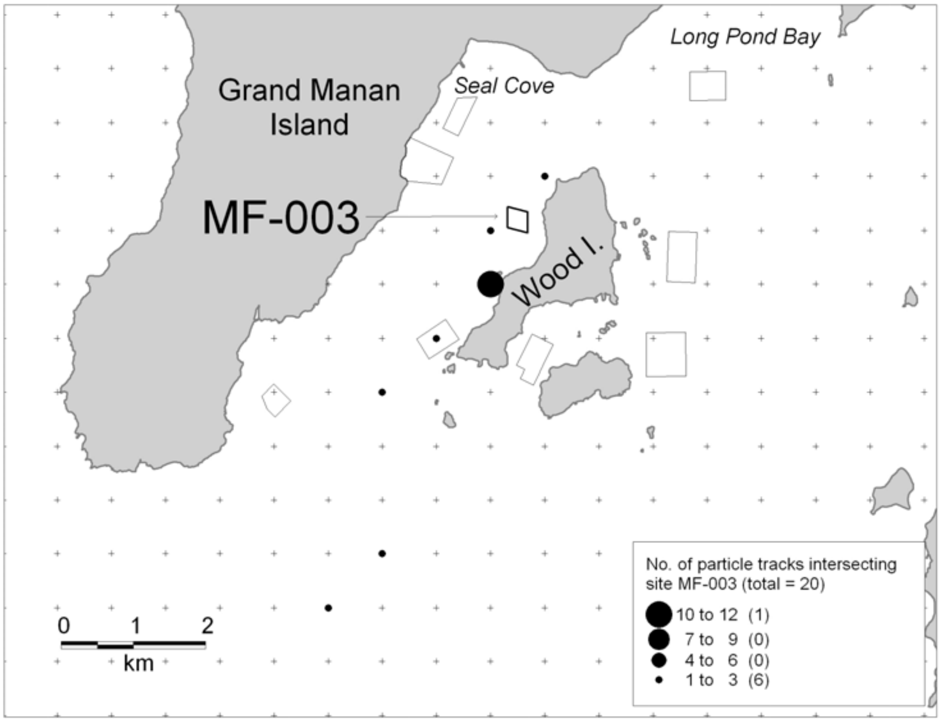


Fig. 6e. Maps showing release points of model particles whose tracks intersected each farm site in the Seal Cove area within 100 h after release (8 tidal cycles). Refer to caption for Fig. 6a.



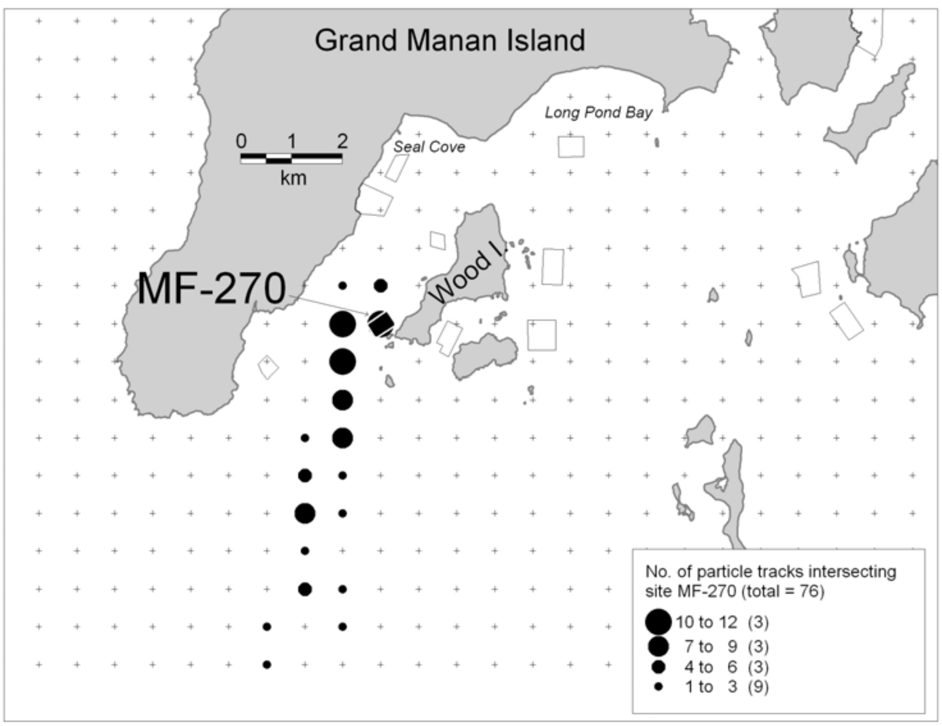


Fig. 6e continued.

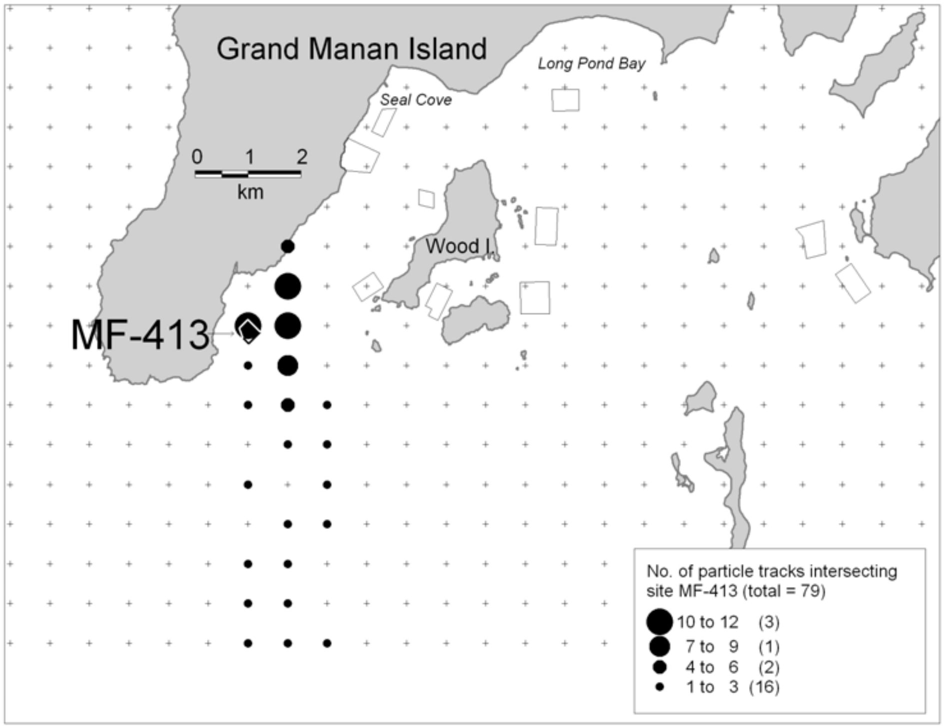
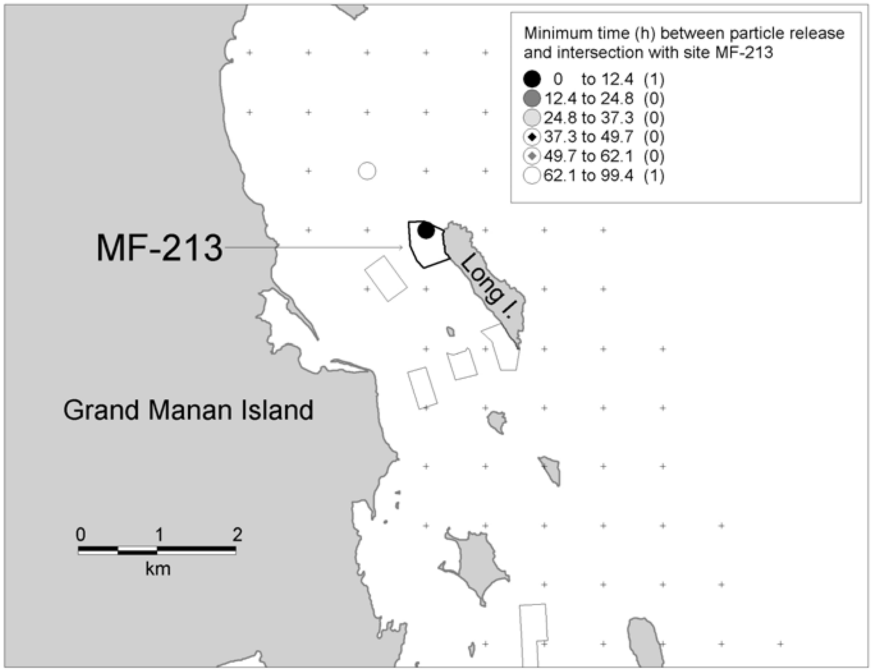


Fig. 6e concluded.



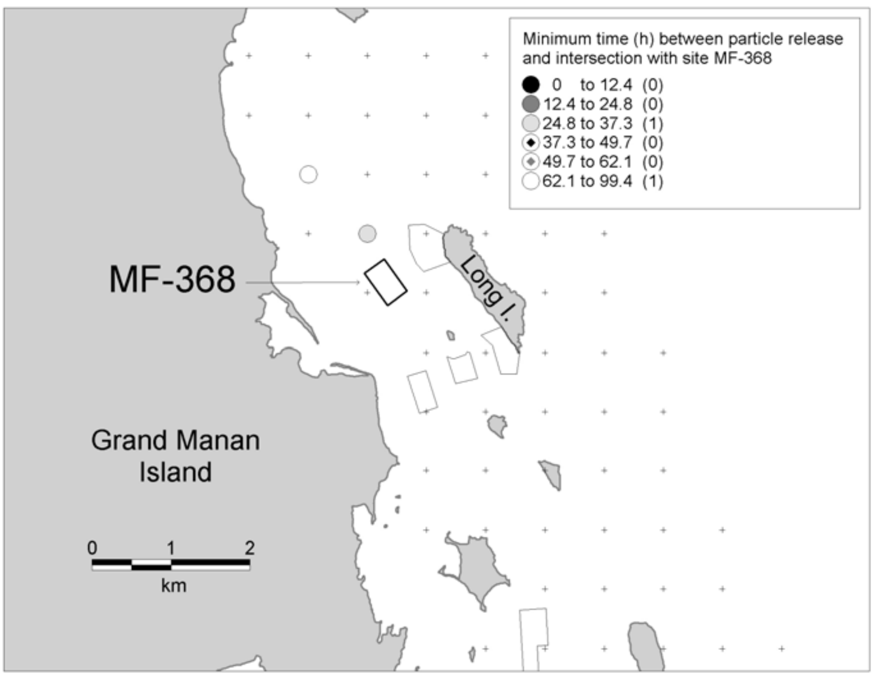


Fig. 7a. Maps showing the time elapsed between particle release from each release point and the intersection of particles with each farm in the Long Island area. Farm sites are shown as small polygons; small crosses represent all particle release points; circles indicate release points of particles whose tracks intersected the farm site indicated with a thick outline; the shading of the circle indicates the time elapsed between a particle's release and its intersection with the farm site (see map legend); where there was more than one intersecting particle from the same release point, the particle with the shortest time between release and farm site intersection was used; the numbers in parentheses in the legend represent the number of release points in each category.

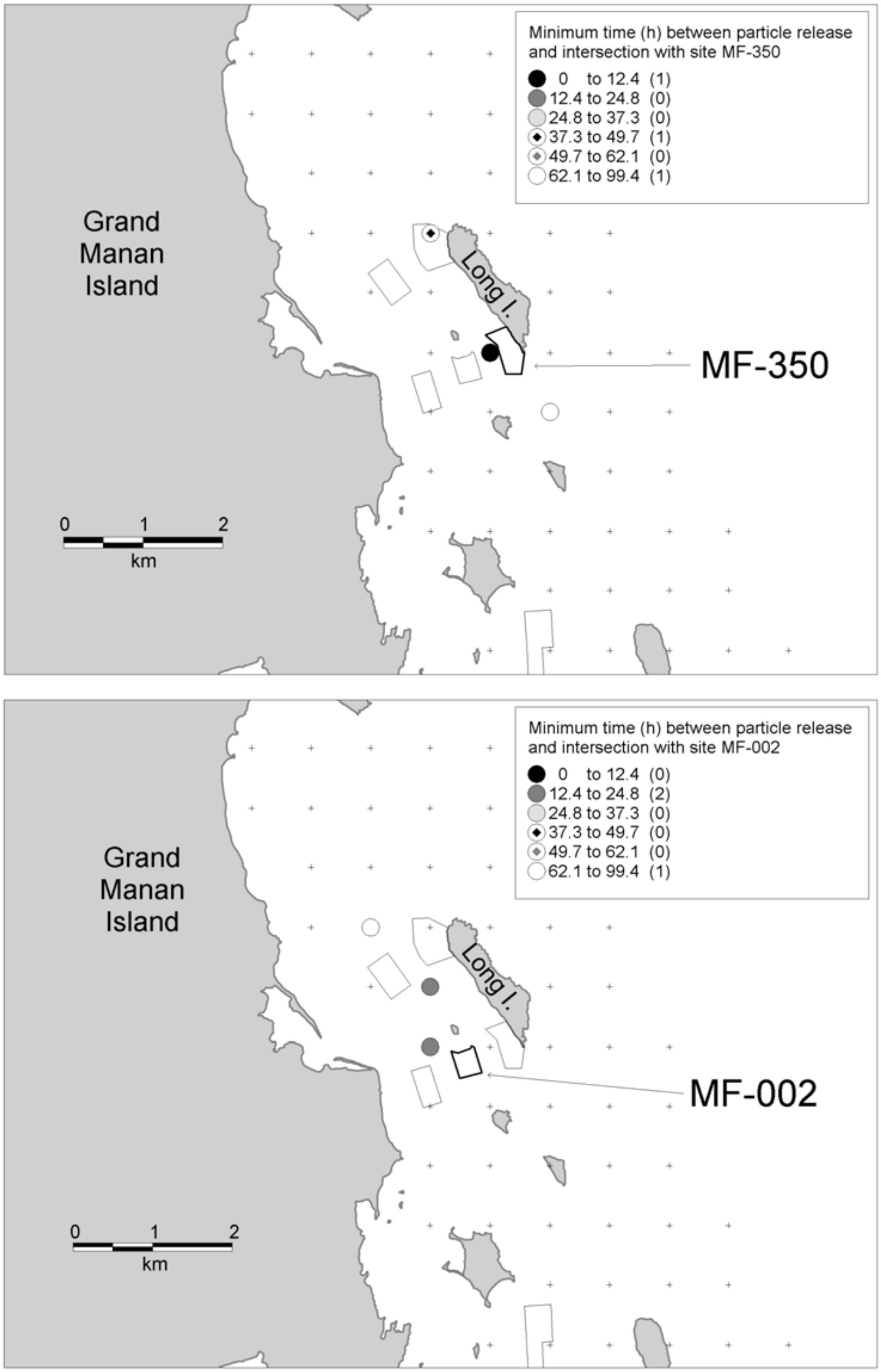


Fig. 7a continued.

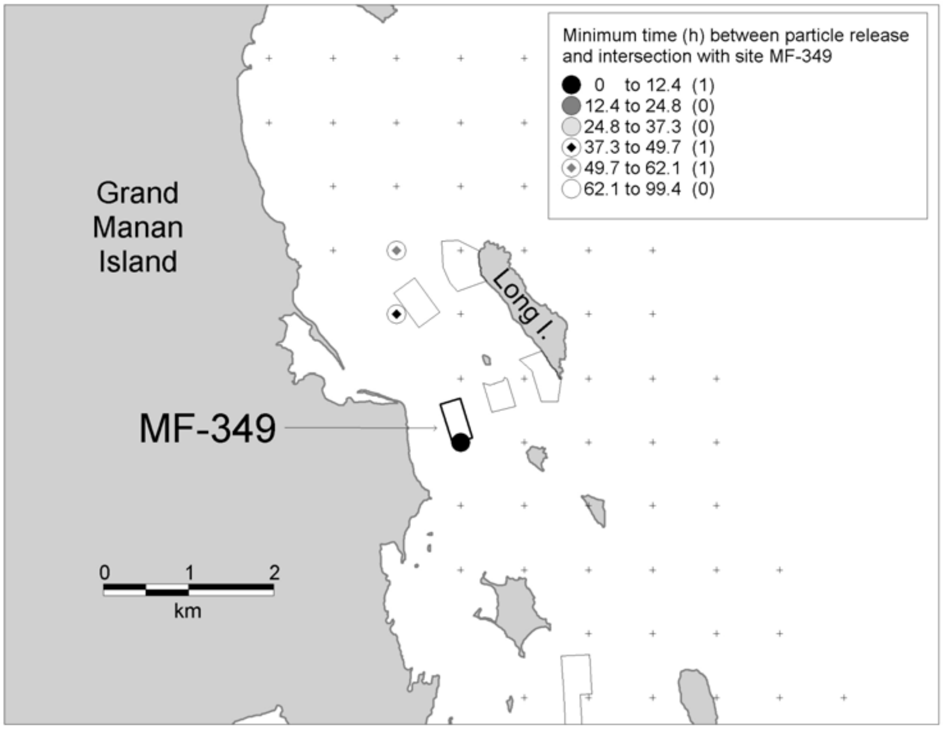


Fig. 7a concluded.

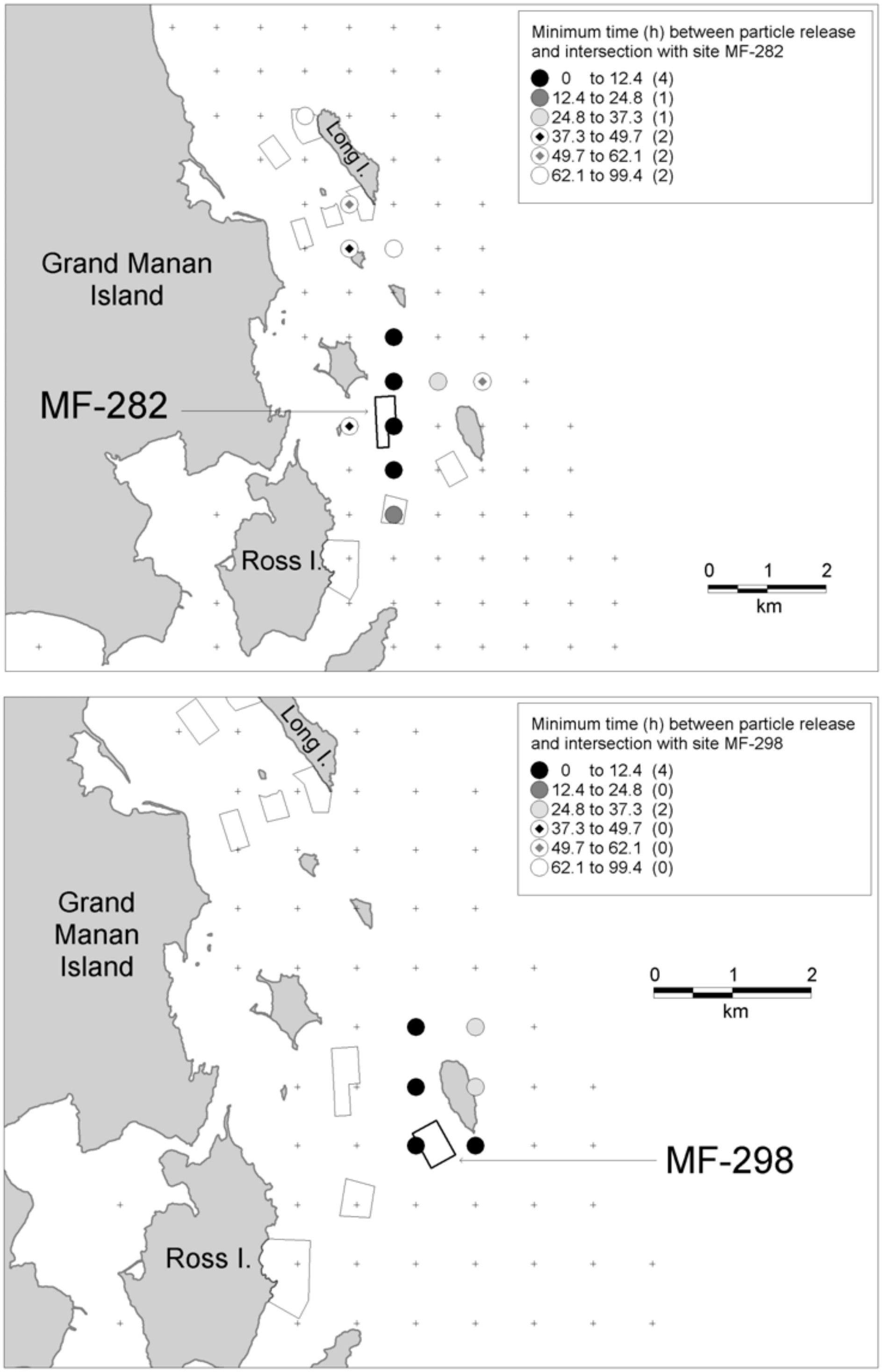
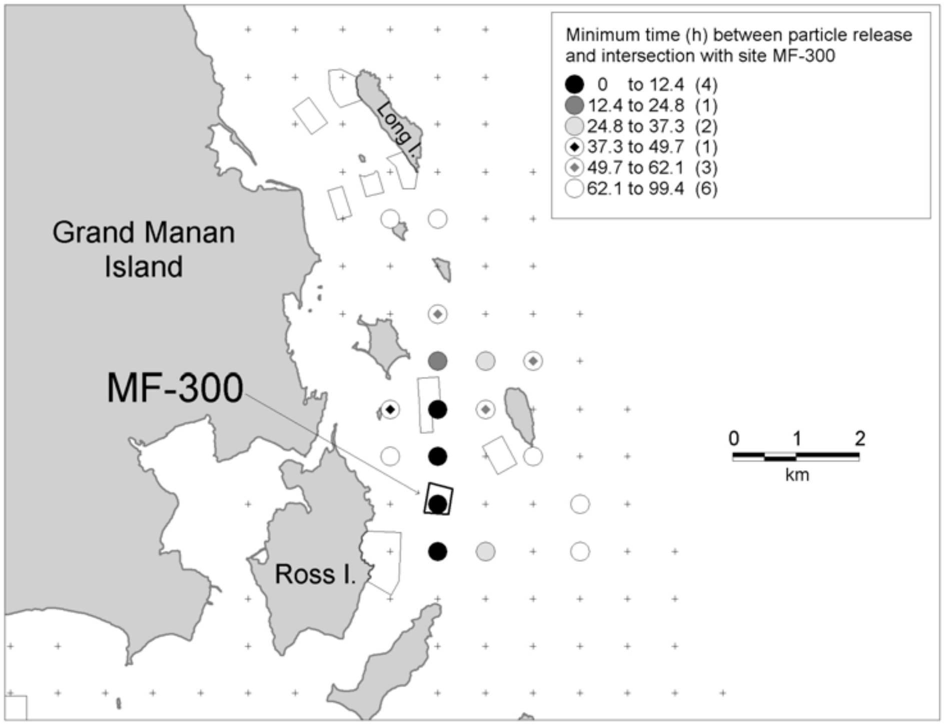


Fig. 7b. Maps showing the time elapsed between particle release from each release point and the intersection of particles with each farm in the Ross Island area. Refer to caption for Fig. 7a.



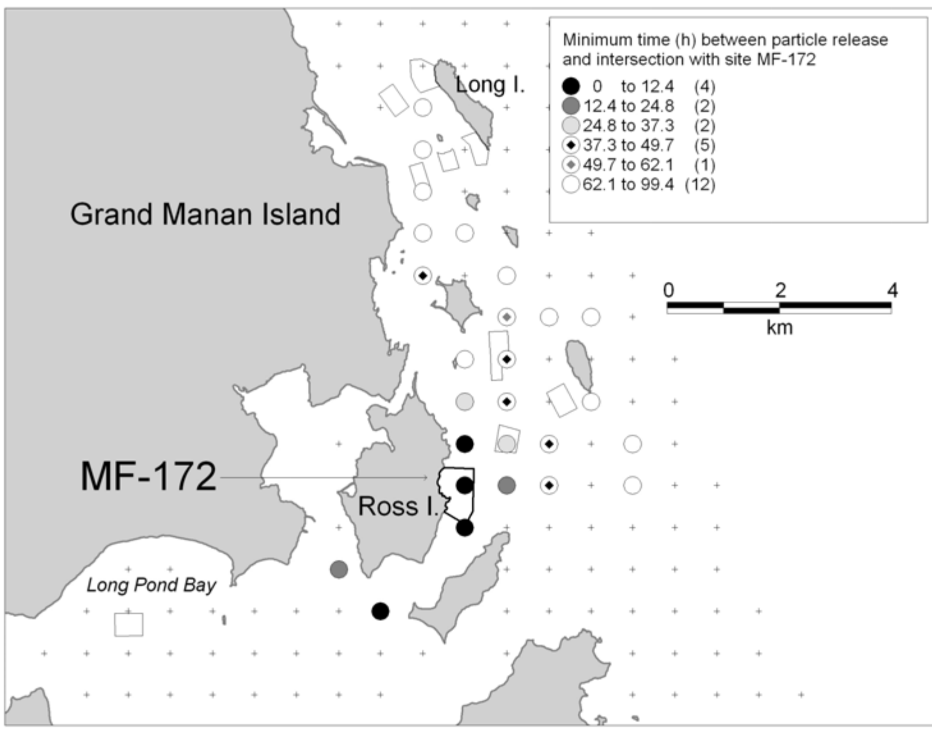
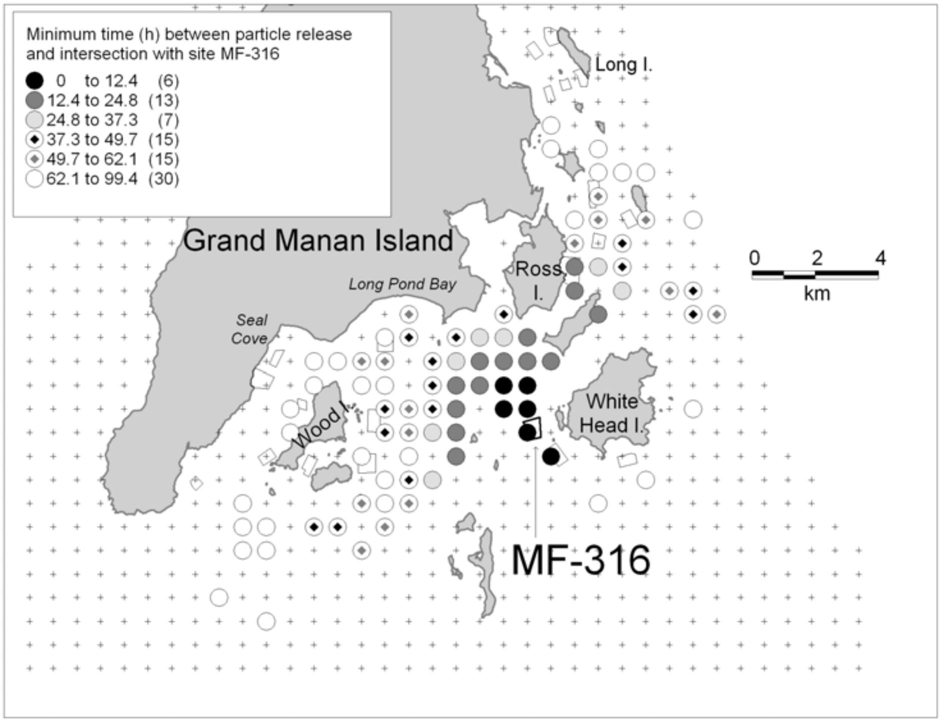


Fig. 7b concluded.



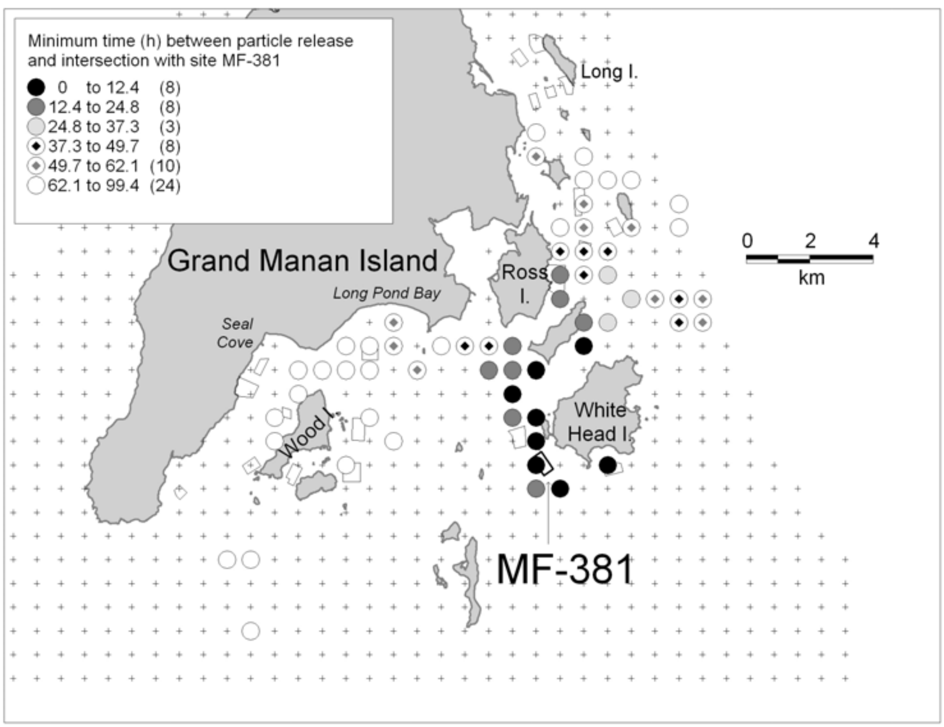


Fig. 7c. Maps showing the time elapsed between particle release from each release point and the intersection of particles with each farm in the White Head Island area. Refer to caption for Fig. 7a.

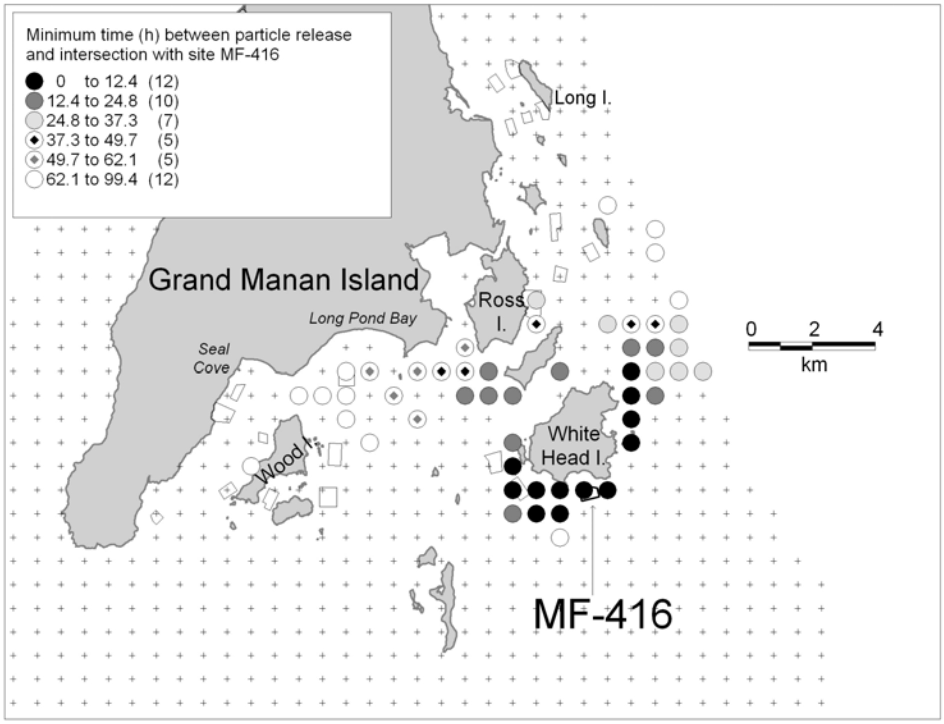


Fig. 7c concluded.

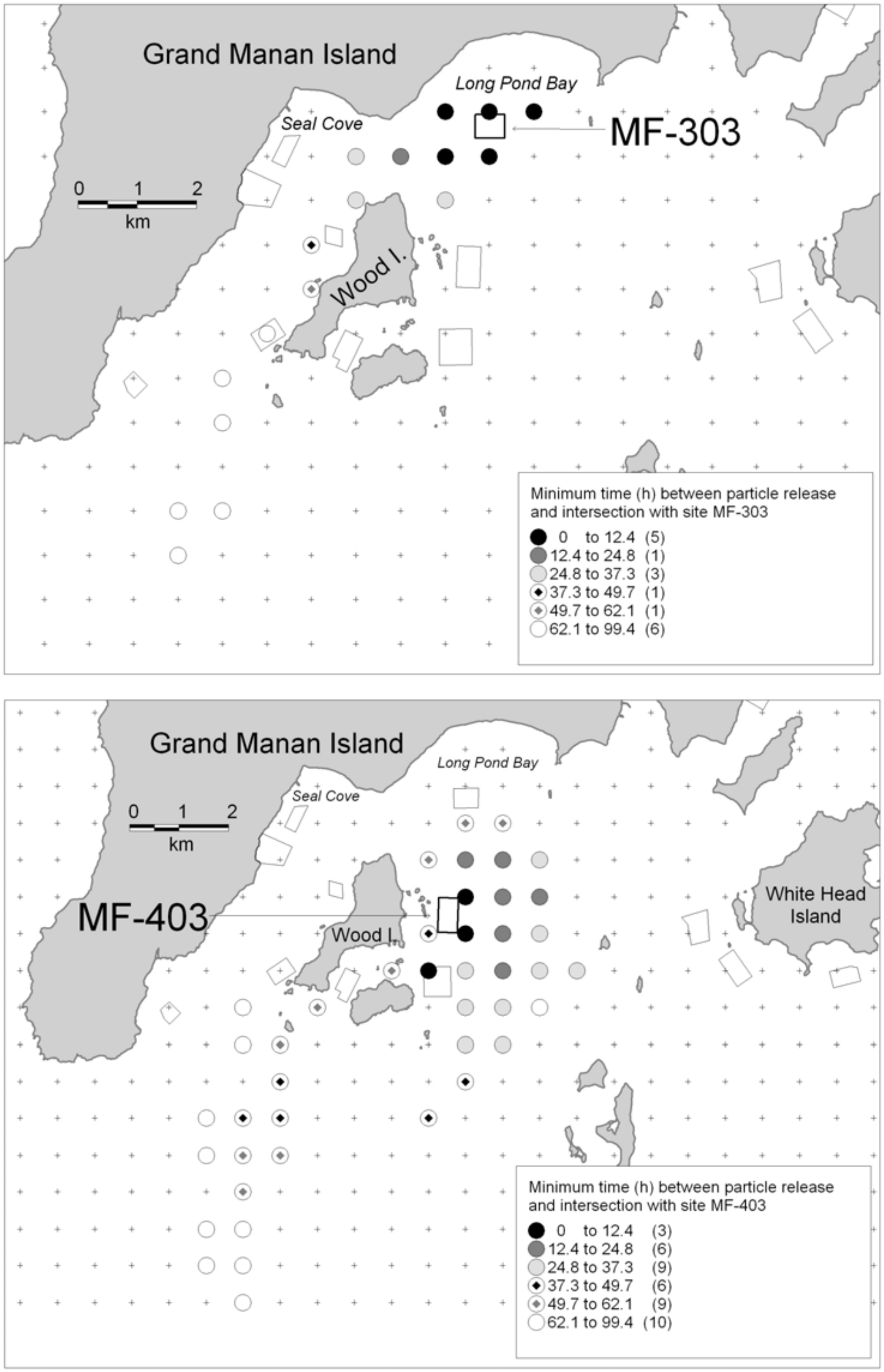


Fig. 7d. Maps showing the time elapsed between particle release from each release point and the intersection of particles with each farm in the Long Pond Bay area. Refer to caption for Fig. 7a.

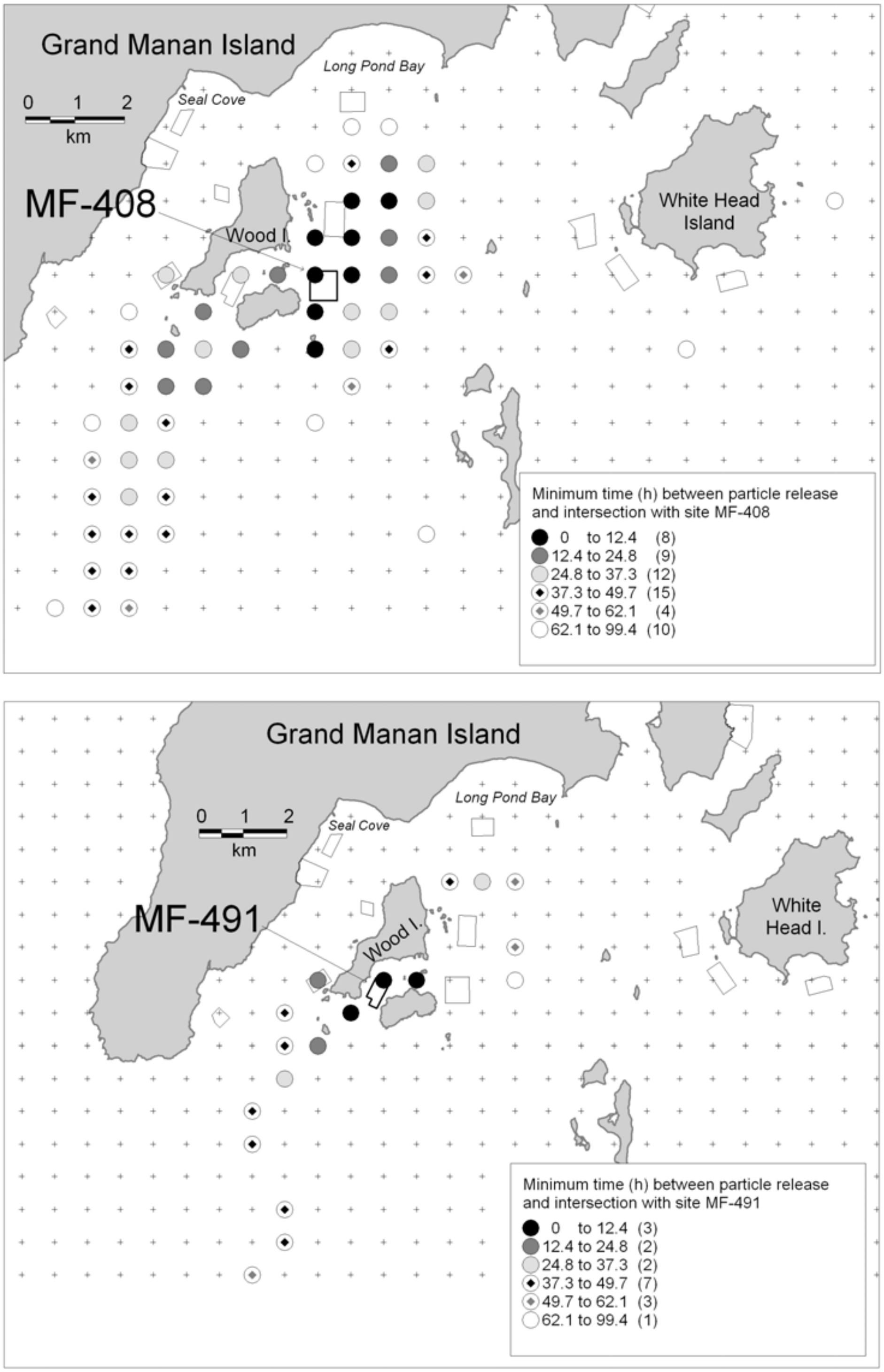


Fig. 7d concluded.

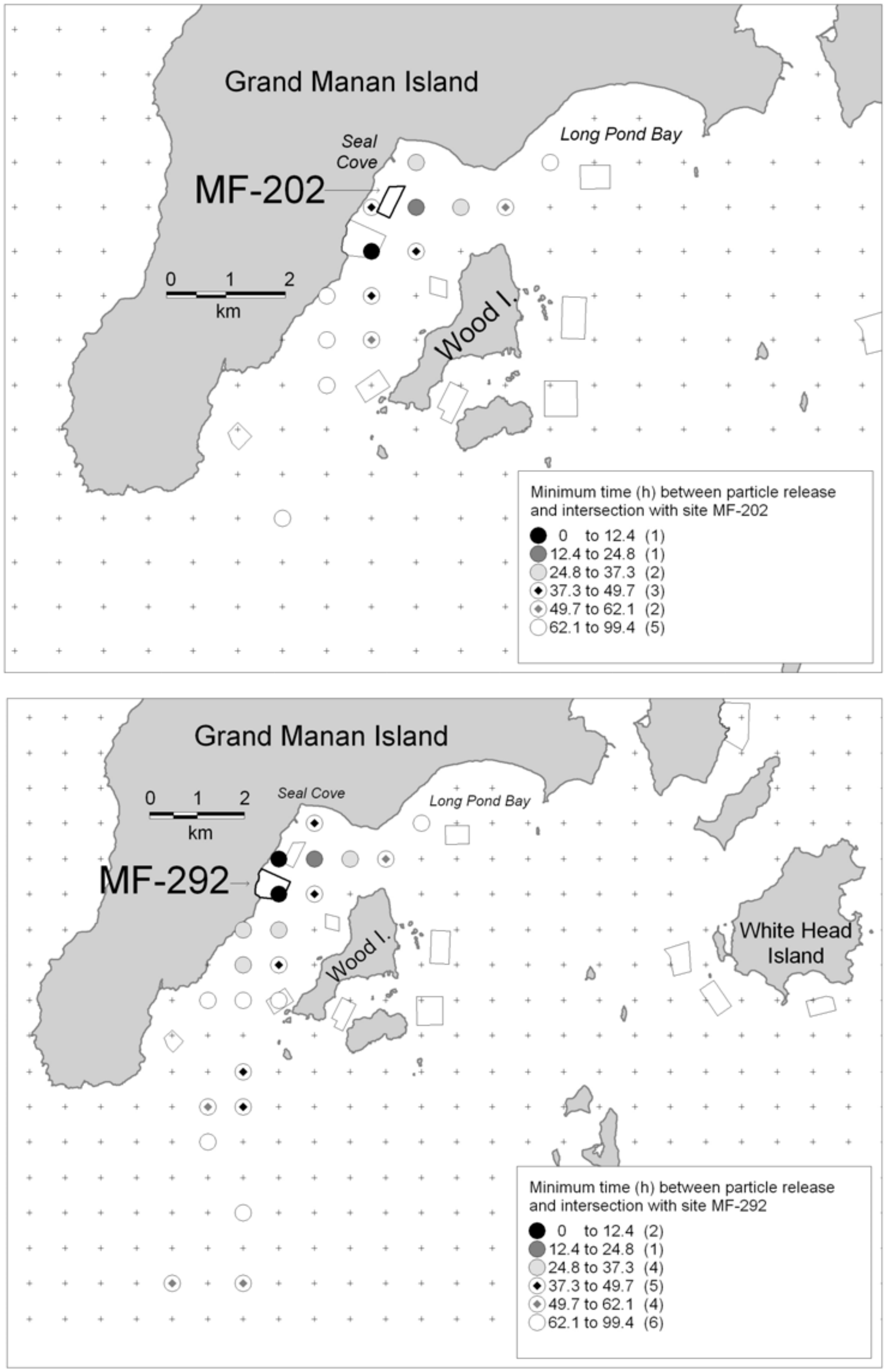


Fig. 7e. Maps showing the time elapsed between particle release from each release point and the intersection of particles with each farm in the Seal Cove area. Refer to caption for Fig. 7a.

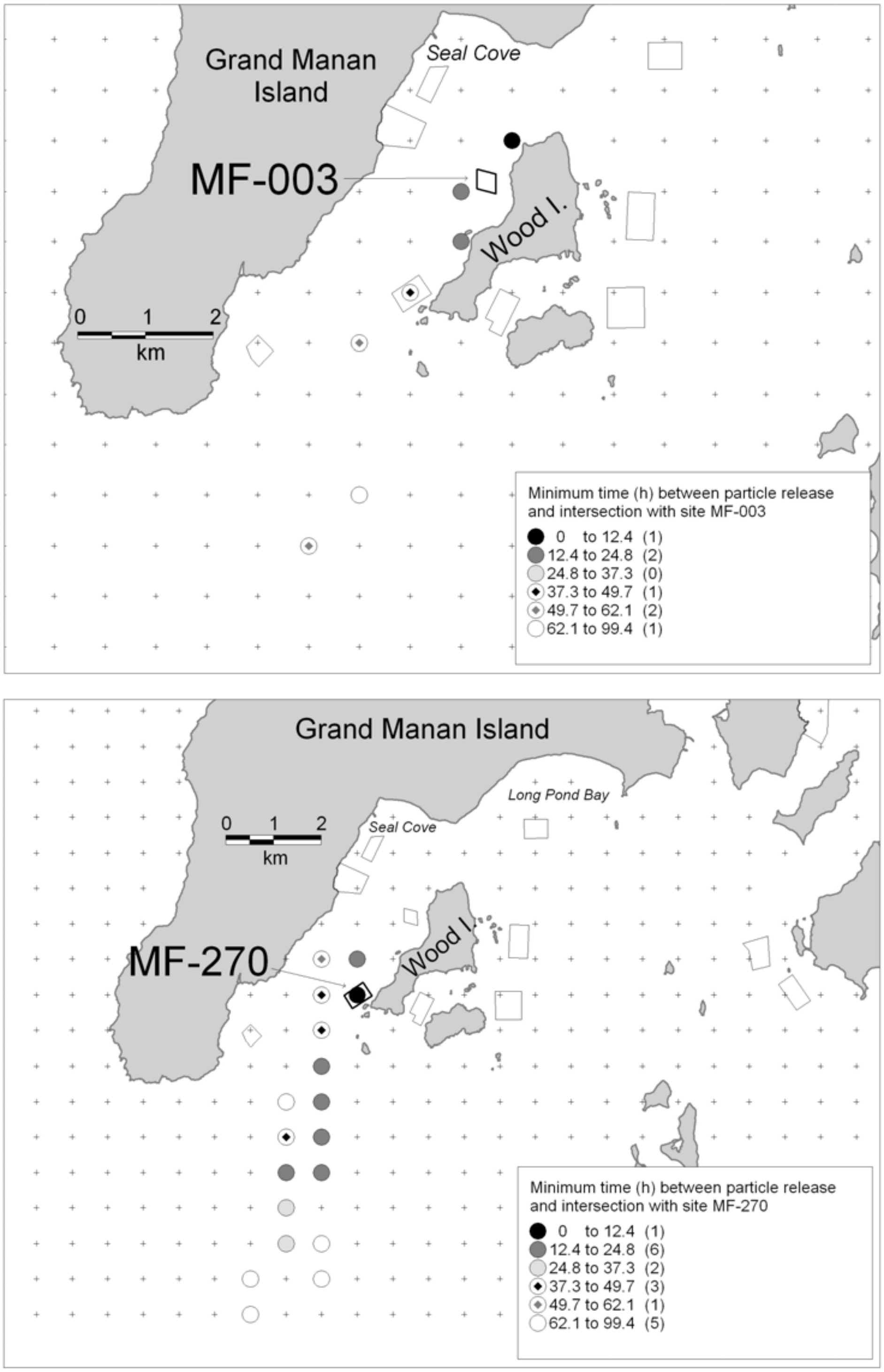


Fig. 7e continued.

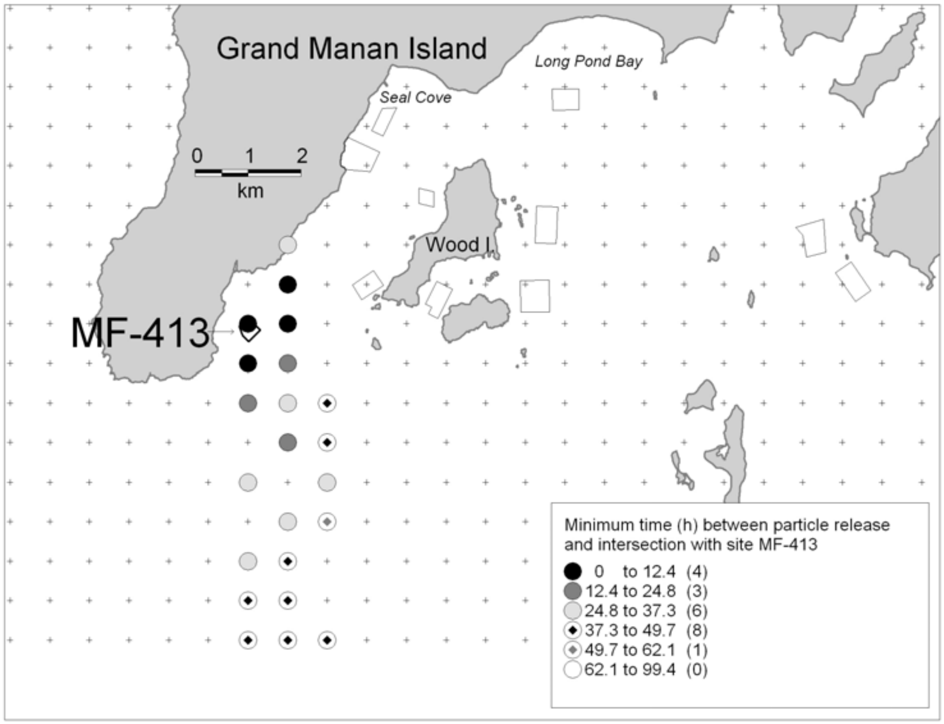


Fig. 7e concluded.