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Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of Cobscook Bay, Maine and adjacent southwestern New Brunswick

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ABSTRACT

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Infectious salmon anemia (ISA) was first detected in salmon farms of southwestern New Brunswick in 1996 and in adjacent Cobscook Bay, Maine in 2001. There was speculation that the virus may have been transmitted through the water between farms in the two jurisdictions. In an effort to help estimate the potential for water exchange of the ISA virus between farms in Cobscook Bay and adjacent areas of southwestern New Brunswick, we used a three-dimensional tidal water circulation and particle transport model. Water exchange scenarios based on the movement of particles during one tidal excursion, as predicted by the model, are compared to those estimated by a simple method assuming a 5-km radius circular zone of water exchange around each farm.

RÉSUMÉ

Chang, B.D., Page, F.H., Losier, R.J., Greenberg, D.A., Chaffey, J.D., and McCurdy, E.P. 2005. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of Cobscook Bay, Maine and adjacent southwestern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2598: iii + 54 p.

L'anémie infectieuse du saumon (AIS) a été décelée pour la première fois dans des fermes de salmoniculture du Sud-Ouest du Nouveau-Brunswick en 1996, et dans celles voisines de la baie Cobscook, au Maine, en 2001. On a émis l'hypothèse voulant que le virus ait été transmis par l'eau entre les fermes de ces deux administrations (pays). Afin d'estimer le potentiel de transport du virus de l'AIS par voie d'eau entre les fermes de la baie Cobscook et les zones adjacentes du Sud-Ouest du Nouveau-Brunswick, nous avons élaboré un modèle tridimensionnel de la circulation des eaux de marée et du transport des particules. Nous avons ensuite comparé les scénarios d'échange d'eau reposant sur le déplacement des particules durant une marée, tels que prédits par le modèle, aux scénarios estimés à l'aide d'une méthode simple, en présumant de l'existence d'une zone d'échange d'eau autour de chaque ferme d'un rayon de 5 km.

INTRODUCTION

BACKGROUND

Cobscook Bay, Maine, USA, and the adjacent area of southwestern New Brunswick (SWNB), Canada, are important areas for the production of farmed salmon. Farms on opposite sides of the international border are as close as 0.6 km apart (Fig. 1). Infectious salmon anemia (ISA) first appeared among salmon farms in SWNB in the summer of 1996 and has been present every year since, resulting in considerable economic loss (McGeachy and Moore 2003). ISA was first documented in Cobscook Bay in early 2001 (Gustafson et al. 2003).

As part of the management strategy for this disease, the salmon farming region of SWNB was partitioned into Bay Management Areas (BMAs) (NBDAFA 2000). The intent of BMAs is to improve cooperation and communication among farm operators, in order to assist in fish health and environmental management. All farms within the same BMA are encouraged to synchronize the placement and harvesting of fish. The boundaries of the BMAs (Fig. 1) were based on fish health, economic and oceanographic considerations (Halse 2002). Initially, oceanographic considerations were a relatively minor factor in defining BMAs, due in part to a lack of oceanographic knowledge. Following the outbreak of ISA in Cobscook Bay, this salmon farming region was partitioned into two management zones, with Zone 1 for even year-class fish and Zone 2 for odd year-class fish (Fig. 1).

Because of the close proximity of farms in the two jurisdictions, there has been speculation that ISA has spread through the water between farms on opposite sides of the border. This project was initiated to examine water circulation and water transport patterns among farms within Cobscook Bay and between farms in Cobscook Bay and those in adjacent areas of SWNB (southern Deer Island and Campobello Island). One objective of this project was to examine the validity of the existing management region boundaries in both jurisdictions, from the oceanographic perspective. We studied this using a three-dimensional tidal circulation and particle transport model. The model results were compared to a simpler approach using a circular zone of influence around each farm. The methodology used in this study has previously been used to examine fish health and oceanography issues at salmon farms in the southern Grand Manan Island area of SWNB (Page and Chang 2002; Page et al. 2004, 2005).

CAUSES OF THE SPREAD OF ISA AMONG SALMON FARMS

Previous studies have suggested that, at the larger scale (in the order of tens of kilometres or more), the spread of ISA is likely related to vectors such as boat traffic and the transport of fish among farms. However, at the smaller tidal excursion scale, physical transport of the ISA virus (from infected fish and discharged fish wastes) in the sea is a possible mechanism for disease spread (Murray et al. 2002). Such passive transport would be in the order of several kilometres or less, limited by the tidal exchange around farms (JGIWG 2000; Murray 2003). The pattern of occurrence of ISA in SWNB (McGeachy and Moore 2003; McClure et al. 2004) suggests that both large-scale vectors (such as movement of boats, fish, personnel, and equipment among farms) and smaller-scale passive transport in seawater among adjacent farms may have occurred.

FISH HEALTH MANAGEMENT ZONES IN OTHER SALMON FARMING AREAS

Hydrographically defined control and surveillance zones or management areas have been implemented in other salmon farming areas as a way to reduce the spread of ISA among salmon farms (Stewart 1998). The Norwegian Animal Health Authority's (2002) "Contingency plan for the control of infectious salmon anaemia in Norway" includes the establishment of Control Zones around ISA-infected farms. The Control Zone is a circular area with a radius of at least one tidal excursion (where known), but not less than 5 km, centred on the infected farm. Conditions applied to all farms within the Control Zone include: increased fish health surveillance; a prohibition of fish movement into or out of the zone; restrictions on the transport of fish through the zone; and a requirement for fallowing and disinfection of all farms prior to restocking. In addition, there is a larger Surveillance Zone which includes all farms whose Control Zones overlap with the Control Zone of the infected farm (a 10- to 20-km radius area around the infected farm).

Similar Control Zones have been used in the Scottish salmon farming industry (JGIWG 2000). A circle with a radius equal to one tidal excursion is drawn around the centre of each farm. In the absence of on-site water current data or computer modelling studies, the tidal excursions were estimated from existing maps of maximum tidal current speeds during spring tides in Scottish coastal waters. When a farm becomes infected, there is a requirement for simultaneous fallowing and increased fish health surveillance at all farms within its Control Zone. A larger Surveillance Zone (or Management Area) consists of all salmon farms having overlapping tidal excursion areas, although in a few cases slight overlaps in tidal excursions are allowed between adjacent zones.

METHODS

The site boundaries for fish farms in SWNB were provided by NBDAFA and the site boundaries for fish farms in the Cobscook Bay area were taken from maps in the Aquaculture Lease Inventory for 2004 (Maine Department of Marine Resources 2004). The farm boundaries were entered into a Geographic Information System (MapInfo Professional® 7.0). The 36 farms in the study area (Fig. 1) were grouped into four regions: Cobscook Bay Management Zone 1, Cobscook Bay Management Zone 2, southern Deer Island (BMA 5 and the southern part of BMA 4) and Campobello Island (BMAs 13, 14 and 15).

Simple estimates of the zone of influence or water exchange around each farm were made by drawing a 5-km radius circle centred on the farm site, then deleting any land areas which fell within this circle, as well as any water areas which were separated from the farm site by land. If it was known that the fish cages were not located at the middle of a site, the circle was centred over the approximate location of the fish cage cluster. These circular areas were drawn using the MapInfo buffer tool, and are henceforth referred to as buffer zones.

More precise estimates of the tidal excursions around farms were made through the use of 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 Cobscook Bay and adjacent SWNB. The model also has the capability of simulating wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing, internal water density and surface winds as current-driving forces, the customized model for this study area has only been run using boundary forcing by the principal diurnal lunar tide, the M_2 tide.

Using the model, pseudo-drogues or numerical particles were released from a starting grid located approximately at the centre of each farm or, where known, at the location of the cage cluster (Fig. 1). For most farms, particles were released simultaneously from 36 points in a 200 × 200 m square grid (40 m between adjacent grid points). In some of the smaller farms, a few of the particle release points were located slightly outside the site boundaries and in two farms (TIFI CC and MF-051), the particle release grids were not square in order to accommodate the irregular shapes of these farm sites. Slightly fewer than 36 particle release points were used at some farms where, because of the proximity to the shore, some of the release points would have been located over land and were therefore eliminated. The particles were released and maintained at 1 m below the sea surface. Each particle was tracked and its position output every 20 min for one tidal cycle (12.42 h). Some particle tracks were shorter than one tidal cycle, because the tracks terminated when they hit the shore. For each farm site, particles were released from every grid point at hourly intervals over a 12-h period (for a total of 432 particle releases from most farms) in order to represent conditions over one entire tidal cycle.

In order to estimate the areal extent of one model-derived tidal excursion area, the marine surface area in the vicinity of each farm was divided into a grid of 100 × 100 m square cells. A farm's tidal excursion area was then estimated as the total of all cells through which passed at least one of the particle tracks from that farm. As a measure of the relative intensity of particle distribution, we calculated the number of particle tracks which passed through each 100 × 100 m cell.

To measure the influence (due to water circulation) each farm had on other farms, we determined which farm sites (receiving farms) were overlapped (at least partially) by each originating farm's water exchange area (as estimated by a 5-km radius buffer zone and by a model-derived tidal excursion area). To measure the influence (due to water circulation) that other farms had on each farm, we determined which water exchange areas (from originating farms) overlapped (at least partially) each receiving farm site. We also determined which farms had overlapping water exchange areas (estimated using 5-km radius buffer zones and model-derived tidal excursion areas).

We compared the interactions among farms using two measures of overlap. The simplest was the presence or absence of overlaps of each water exchange area with farm sites and with water exchange areas. We also used a quantitative measure to estimate the intensity of these overlaps when using the model-derived tidal excursion areas. We counted the number of particle tracks (of the total 432 usually released from most originating farms) which overlapped farm sites and farm tidal excursion areas. For both measures, we compared the similarity among farms by performing cluster analyses with Bray-Curtis similarity coefficients using PRIMER 5 software Clarke and Warwick 1994).

We also used the example of one farm to determine how small changes in farm site location could impact the predicted water exchange areas. Farm MF-411 (just east of Indian Island) was originally proposed to be located slightly further offshore; the centre of the originally proposed site was about 350 m northeast of the centre of its final approved site. We compared the estimated water exchange areas (using 5-km radius buffer zones and model-derived tidal excursion areas) for both sites.

RESULTS

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS USING 5-KM RADIUS CIRCULAR BUFFER ZONES

Figure 2 shows the 5-km radius buffer zones of all farms in the study area. The figure suggests considerable water exchange among farms in the four regions. Figures 3-6 show the buffer zones of all farms in each management region: Cobscook Bay Management Zone 1, Cobscook Bay Management Zone 2, southern Deer Island, and Campobello Island. The areas of the buffer zones of farms in Cobscook Bay ranged from 32.3-55.8 km^2, with a mean of 47.0 km^2 (Table 1). For the adjacent regions of southern Deer Island and Campobello Island, the areas of buffer zones ranged from 33.0-65.7 km^2, with a mean of 45.7 km^2 (Table 1).

The presence or absence of overlaps of buffer zones with farm sites is shown in Table 2. In most instances, where one farm's buffer zone overlapped a second farm's site, the second farm's buffer zone overlapped the first farm's site. This is because all buffer zones were based on 5-km radius circles. There were only 19 instances (4%) out of the total 541 overlaps of buffer zones with farm sites where one farm's buffer zone overlapped a second farm's site, but the second farm's buffer zone did not overlap the first farm's site. These occurred as a result of two aspects of the way that buffer zones were calculated. Firstly, buffer zones were based on 5-km circles drawn around a point located approximately at the center of each farm site; as a result, there were some cases where the center points of two farms were slightly greater than 5 km apart, but part of the site boundaries of one farm (e.g. a larger farm) extended to within 5 km of the second farm, while the site boundaries of the second farm (e.g. a smaller farm) did not extend to within 5 km of the first farm. Secondly, we excluded from the buffer zone any areas which were isolated from the originating site by land; as a result, due to differences in topography around different farms, there were some instances where two farms were within 5 km of each other, but one farm was not within the other farm's buffer zone because it was in an isolated bay that was excluded from that buffer zone.

Each buffer zone overlapped an average of 15.0 farm sites within the study area (including the originating farm site; see Fig. 7, Table 6). The buffer zones of some farms in each region overlapped with farm sites in all four regions. Each buffer zone overlapped an average of 31.0 buffer zones (including the originating farm's buffer zone; see Fig. 8, Tables 3 and 7). The buffer zones of all farms, except that of MF-060 and MF-320 (southern Deer Island) overlapped with buffer zones in all four regions. The buffer zones of farms MF-060 and MF-320 overlapped only with buffer zones of farms in southern Deer Island (BMA 4 south and 5) and Cobscook Bay Zone 2. Note that there were a few overlaps with farm sites (and their buffer zones) not located within the study area (see Fig. 2); these overlaps were not included in our analyses.

The cluster analysis based on the presence or absence of overlaps between buffer zones and farm sites indicated considerable similarity among farms (Fig. 9). No farms were completely separate from all other farms (at 0% similarity). At a similarity level of 7%, there were two clusters: farms MF-060 and MF-320 (southern Deer Island) in one cluster and all other farms in the other.

The cluster analysis based on the presence or absence of overlaps among buffer zones showed much higher similarity (Fig. 10). There were no completely separate clusters at 0-50% similarity.

DESCRIPTIONS OF MODEL-DERIVED TIDAL EXCURSION AREAS

Figure 11 shows the model-derived tidal excursion areas (all hourly releases from each farm combined) of all farms in the study area. The figure suggests considerable water exchange among farms in the four regions, as was the case with buffer zones (Fig. 2). Figures 12-15 show the same information by region: Cobscook Bay Management Zone 1, Cobscook Bay Management Zone 2, southern Deer Island and Campobello Island. Figure 16 shows the tidal excursion areas of each individual farm in Cobscook Bay Management Zone 1, including the relative density of particle tracks present in 100 × 100 m grid cells. Figures 17-19 show the same information for each farm in Cobscook Bay Management Zone 2, southern Deer Island and Campobello Island, respectively.

The model-derived tidal excursion areas were considerably smaller than the 5-km radius buffer zones (Table 1) and were not circular in shape. The tidal excursion areas of Cobscook Bay farms ranged from 5.8-23.5 km^2, with a mean of 14.2 km^2. For farms in the adjacent SWNB region, the tidal excursion areas ranged from 0.4-25.3 km^2, with a mean of 9.9 km^2.

Tidal excursions of farms in Cobscook Bay (Maine) (Fig. 16 and 17)

The model-derived tidal excursion areas of farms CONA BC, IAFI PC, MESI SH and CONA DC, located along the south shore of Moose Island, were three-pronged in shape, extending northwest along the southwestern shore of Moose Island, as well as east toward Campobello Island and then both north and south near the western shore of Campobello Island. The tidal excursion areas of these farms were all quite large, ranging from 20.5-23.5 km^2.

The tidal excursion areas of farms LREN TE and TIFI TW, located near Treats Island, were somewhat similar in shape and size (18.5 and 20.5 km^2, respectively) to those located along the south shore of Moose Island, except they did not approach as close to the shore of Moose Island.

The tidal excursion area of farm SFML LU2, near Lubec, was similar in shape, but much smaller (6.9 km^2), not extending as far, especially in the northerly and northwesterly directions.

The farms located along the northeastern shore of Seward Neck (SFML GN1, SFML GN2, IAFI CL, TIFI CC and CONA CP) had tidal excursion areas extending along the northeastern shore of Seward Neck and also extending west from the northern tip of Seward Neck toward the head of Cobscook Bay. The tidal excursion areas of these farms ranged from 11.4-15.4 km^2. The tidal excursion area of farm SFML RN2, located just south of these farms, showed a similar shape, but did not extend as far west, and was smaller (7.8 km^2). The tidal excursion area of farm CONA SB, located on the northwestern shore of Seward Neck, showed a similar shape and size (14.4 km^2) to those located along the northeastern shore of Seward Neck. The tidal excursion area of farm BPFI BE, located about 1 km north of the northern tip of Seward Neck, showed a similar shape and size (12.2 km^2) to those located along the northeastern shore of Seward Neck, except that it stayed further.

The tidal excursion areas of farms IAFI JK and TIFI JC, located off the northeastern shore of Moose Island, extended south toward farm IAFI HP and north in the middle of the channel between Deer Island and Maine. The sizes of these tidal excursion areas were 5.8-5.9 km^2. The tidal excursion area of farm IAFI HP extended north (as those of farms IAFI JK and TIFI JC), but also extended south and west along the south shore of Moose Island, with a size of 12.2 km^2.

Tidal excursions of farms in southern Deer Island and Campobello Island (New Brunswick) (Fig. 18 and 19)

The tidal excursion area of farm MF-058 (BMA 4), with an area of only 1.4 km^2, extended only south from the release site, just as far as farm MF-057. The tidal excursion area of farm MF-059 (BMA 4), with an area of 6.9 km^2, extended further south, as far as Moose Island, as well as a few kilometers north to near farm MF-060. The tidal excursion area of farm MF-060 (BMA 4) was similar to that of MF-059, but was slightly larger (10.1 km^2), extending further north. The tidal excursion area of farm MF-320 (BMA 4) was small (1.7 km^2), staying close to the northwest shore of Deer Island. The tidal excursion areas of farms MF-060 and MF-320 partially overlapped one farm site located outside of the study area to the north (farm MF-179 in BMA 4); these overlaps are not included in our analyses.

The tidal excursion area of farm MF-049 (BMA 5), located on the western shore of Indian Island, was relatively small (5.0 km^2) and V-shaped, extending north between Indian Island and Deer Island, as well as around the southern tip of Deer Island and north along the western shore of Deer Island. The tidal excursion area of farm MF-050 (BMA 5), located just south of MF-049, covered much the same area as that of MF-049, but also extended into the channel between Indian Island and Campobello Island (but without overlapping farm MF-411) and so was considerably larger (17.5 km^2). The tidal excursion area of farm MF-051 (BMA 5), located along the southeastern shore of Deer Island, opposite Indian Island, showed a similar shape to that of farm MF-050, but was smaller (9.6 km^2). The tidal excursion area of farm MF-411 (BMA 5), located just east of Indian Island, included much the same area as that of MF-050, but also included the eastern shore of Indian Island and so was slightly larger (20.7 km^2). The tidal excursion area of farm MF-057 (BMA 5), located along the southwestern shore of Deer Island,

showed a similar shape to that of MF-411, except that it did not extend into the channel between Indian Island and Deer Island, but did extend into the channel between Moose Island and Seward Neck in Cobscook Bay, and was slightly larger (25.3 km^2).

The tidal excursion areas of farms MF-064 and MF-206 (BMA 13) were both very small (0.4 and 1.4 km^2), mostly confined within narrow channels. The tidal excursion area of farm MF-186 (BMA 13) was large (21.5 km^2), extending both to the north and south, although most of the particle tracks were concentrated near the farm site.

The tidal excursion area of farm MF-052 (BMA 14) was large (24.4 km^2), extending north to near the New Brunswick mainland and south to near Treats Island, Maine. The tidal excursion areas of farms MF-053 and MF-054 (BMA 14) were much smaller (0.9 and 1.9 km^2), confined within BMA 14.

The tidal excursion area of farm MF-055 (BMA 15) was quite large (14.7 km^2) extending mostly northward along the western shore of Campobello Island. The tidal excursion area of farm MF-168 (BMA 15), located just southeast of farm MF-055, was much smaller (2.2 km^2), extending mostly southward toward Lubec. The tidal excursion area of farm MF-056 (BMA 15), located in a small bay just southeast of farm MF-168, was quite large (12.5 km^2), extending northward to overlap the two other farms in BMA 15, as well as westward toward Seward Neck and southward through Lubec Narrows (between Lubec and Campobello Island).

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS USING MODEL-DERIVED TIDAL EXCURSION AREAS

The presence or absence of overlaps of tidal excursion areas with farm sites for the 36 farms in the study area is shown in Table 4. There were 145 overlaps of tidal excursion areas with other farm sites (excluding the 36 overlaps of tidal excursion areas with their originating farm sites), of which there were 79 instances (54%) where one farm's tidal excursion area overlapped a second farm's site, but the second farm's tidal excursion area did not overlap the first farm's site.

Each tidal excursion area overlapped an average of 5.0 farm sites (including the originating farm site; see Fig. 20, Table 8). The tidal excursion areas of farms in Cobscook Bay Zone 1 overlapped farm sites in the same region, as well as some farm sites in Cobscook Bay Zone 2 and Campobello Island. The tidal excursion areas of farms in Cobscook Bay Zone 2 overlapped farm sites in both Cobscook Bay Zones and the tidal excursion area of one farm (CONA DC) overlapped two Campobello Island farm sites. The tidal excursion areas of most farms in southern Deer Island only overlapped southern Deer Island farm sites, but the tidal excursion area of farm MF-60 also overlapped one farm site in Cobscook Bay Zone 2 and the tidal excursion area of farm MF-057 overlapped several farm sites in both Cobscook Bay Zones. The tidal excursion areas of most Campobello Island farms only overlapped Campobello Island farm sites, but the tidal excursion areas of two farms (MF-056 and MF-168) also overlapped some farm sites in Cobscook Bay Zone 1.

Each farm site was overlapped by an average of 5.0 tidal excursion areas (including the receiving farm's tidal excursion area; see Fig. 21, Tables 4 and 8). Farm sites in Cobscook Bay Zone 1

were overlapped by tidal excursion areas of farms in both Cobscook Bay Zones and some were overlapped by tidal excursion areas of southern Deer Island or Campobello Island farms. Farm sites in Cobscook Bay Zone 2 were mostly overlapped by tidal excursion areas of farms within this zone, but four farm sites were also overlapped by tidal excursion areas of farms in Cobscook Bay Zone 1 and two sites were overlapped by tidal excursion areas of southern Deer Island farms. Southern Deer Island farm sites were only overlapped by tidal excursion areas of southern Deer Island farms. Campobello Island farm sites were mostly overlapped by tidal excursion areas of Campobello Island farms, but three farm sites were also overlapped by tidal excursion areas of farms in Cobscook Bay Zone 1 and two of those farm sites were also overlapped by tidal excursion areas of farms in Cobscook Bay Zone 2.

Each tidal excursion area overlapped an average of 16.8 tidal excursion areas (including each tidal excursion area's overlap with itself; see Fig. 22, Tables 5 and 9). The tidal excursion areas of all farms in Cobscook Bay Zone 1 overlapped the tidal excursion areas of farms in all four regions. The tidal excursion areas of five farms in Cobscook Bay Zone 2 overlapped the tidal excursion areas of farms in all four regions, while one farm (CONA SB) overlapped the tidal excursion areas of farms in all regions except Campobello Island and two farms (IAFI JK and TIFI JC) only overlapped the tidal excursion areas of farms in Cobscook Bay Zone 2 and southern Deer Island. The tidal excursion areas of four southern Deer Island farms overlapped the tidal excursion areas of farms in all four regions, while one farm's (MF-059) tidal excursion area overlapped those in all regions except Campobello Island, two farms' (MF-049 and MF-060) tidal excursion areas overlapped those of farms in Cobscook Bay Zone 2 and southern Deer Island, and two other farms' (MF-058 and MF-320) tidal excursion areas overlapped only those of farms in southern Deer Island. The tidal excursion areas of five farms in Campobello Island overlapped the tidal excursion areas of farms in all four regions, while the tidal excursion area of one farm (MF-054) overlapped those of farms in Cobscook Bay Zone 1 and Campobello Island and the tidal excursion areas of three farms (MF-064, MF-206 and MF-053) overlapped only those of Campobello Island farms.

The cluster analysis based on the presence or absence of overlaps of farm sites by each farm's tidal excursion area indicated considerable similarity among farms (Fig. 23). Only the three farms in BMA 13 could be separated from the other farms at 0% similarity. At a similarity level of 6%, the other 33 farms could be separated into four smaller clusters: one cluster of six farms in BMAs 4 and 5 (MF-049, MF-050, MF-051, MF-411, MF-058 and MF-059); one cluster of four farms in BMAs 14 and 15 (MF-052, MF-053, MF-054, and MF-055); another cluster of three farms in BMAs 4 and 5 (MF-060, MF-320, and MF-057), together with the three northeastern Moose Island farms in Cobscook Zone 2 (IAFI JC, TIFI JC, and IAFI HP); and a large cluster of 17 farms including all other Cobscook Bay farms, together with two farms in BMA 15 (MF-056 and MF-168).

The cluster analysis based on the presence or absence of overlaps of each farm site by farm tidal excursion areas (Fig. 24) was similar to that shown in Fig. 23, but with some small differences in the composition and size of the clusters. The three farms in BMA 13 were separate from all other farms at 0% similarity. At a similarity level of 4%, the remaining 33 farms could be separated into four smaller clusters: one cluster of the five farms in BMA 5 plus two farms in BMA 4 (MF-058 and MF-059); one cluster of the three farms in BMA 14 plus farm MF-055 (BMA 15);

one cluster of two farms in BMA 14 (MF-060 and MF-320) plus the three northeastern Moose Island farms in Cobscook Bay Zone 2 (IAFI JK, TIFI JC, and IAFI HP); and one cluster of the other 17 farms.

The cluster analysis based on the presence or absence of overlaps among tidal excursion areas showed much higher similarity (Fig. 25). There were no completely separate clusters at 0% similarity. At 2 % similarity, two farms in BMA 13 (MF-064 and MF-206) could be separated from the other farms. At 14% similarity level, two farms in BMA 14 (MF-053 and MF-054) could be separated from the other 32 farms.

The cluster analysis based on the intensity of overlap of tidal excursion areas with farm sites (as measured by the number of particle tracks that overlapped each farm site) showed much less similarity among farms (Fig. 26), when compared to the cluster analysis based on the presence or absence of overlaps of farms sites by tidal excursion areas (Fig. 23). At the 0-2% similarity level, the 36 farms could be separated into 10 clusters.

The cluster analysis based on the intensity of overlap among tidal excursion areas (as measured by the number of particle tracks that overlapped each tidal excursion area) was similar to the cluster analysis based on the presence or absence of overlaps among tidal excursion areas, but with lower similarity values (compare Fig. 27 with Fig. 25). At 0% similarity, no clusters could be separated. At 2% similarity, there were two clusters: one cluster of the three farms in BMA 13 and one cluster of all other farms. At 6% similarity, the remaining 33 farms could be separated into two clusters: one cluster of the three farms in BMA 14 and one cluster of the other 30 farms.

ESTIMATION OF POTENTIAL INTERACTIONS AMONG EXISTING MANAGEMENT REGIONS

Interactions between farms in Cobscook Bay Management Zone 1 and Zone 2

Using either 5-km radius buffer zones or model-derived tidal excursion areas to estimate water exchange areas of farms, we predict considerable influence of farms in Cobscook Bay Management Zone 1 on farm sites in Cobscook Bay Management Zone 2 and vice versa (Tables 2 and 4; Fig. 7, 20 and 21). The tidal excursion areas indicate that farms IAFI JK and TIFI JC (northeastern Moose Island in Management Zone 2) are somewhat isolated, as their tidal excursion areas only overlap with each other's farm site and with nearby farm site IAFI HP.

Interactions between southern Deer Island farms and Campobello Island farms

The 5-km radius buffer zones indicate considerable influence of farms in southern Deer Island on farm sites in Campobello Island and vice versa. Only the two northernmost farms in the study area (farms MF-060 and MF-320 in BMA 4) are somewhat isolated, only interacting with farm sites in the same BMA. The tidal excursion areas indicate less connectivity between southern Deer Island and Campobello Island farms: the tidal excursion areas of southern Deer Island farms do not influence Campobello Island farm sites and vice versa, although there are several overlaps of tidal excursion areas of farms in the two regions.

Interactions between farms in Cobscook Bay and adjacent SWNB

The 5-km radius buffer zones indicate considerable influence of northeast Moose Island farms on farm sites in southern Deer Island and vice versa. The tidal excursion areas indicate fewer overlaps: the tidal excursion areas of northeast Moose Island farms do not influence farm sites in southern Deer Island, but the tidal excursion area of farm MF-057 in BMA 5 overlaps several Cobscook Bay farm sites and there is also much overlapping of tidal excursion areas of farms in southern Deer Island with tidal excursion areas of farms in Cobscook Bay.

The 5-km radius buffer zones also indicate considerable influence of farms in Cobscook Bay on farms in Campobello Island and vice versa. The tidal excursion areas indicate somewhat fewer overlaps: the tidal excursion areas of several farms in Cobscook Bay influence farm sites in BMA 15, while the tidal excursion areas of two farms in BMA 15 (MF-056 and MF-168) influence some farm sites in Cobscook Bay Management Zone 1 and there is considerable overlapping of tidal excursion areas of farms in Cobscook Bay and Campobello Island.

ESTIMATION OF THE EFFECTS OF SMALL CHANGES IN FARM LOCATION ON ITS WATER EXCHANGE AREA

The small change in location of farm MF-411 from its originally proposed site to its final approved site (a shift of about 350 m) did not result in much difference in this farm's 5-km buffer zone (Fig. 28 top). The two buffer zones were similar in size (41. 5 km^2 for the proposed site and 41.9 km^2 for the final site) and had identical overlaps with other farm sites and buffer zones. However, there was a significant difference in the model-derived tidal excursion areas of the two sites. The original site's tidal excursion area was slightly larger (21.5 km^2) than of the final site (20.7 km^2) and showed quite a different shape. The original site's tidal excursion area (Fig. 28 bottom) extended into Cobscook Bay, overlapping with three farm sites in Management Zone 1 and one farm site in Management Zone 2, although the density of particle tracks entering Cobscook Bay was low (less than 10 particle tracks per 100 × 100 m cell); the final site's tidal excursion area did not enter Cobscook Bay..

DISCUSSION

The simple approach using 5-km radius buffer zones to estimate water exchange areas suggests considerable water exchange among finfish farms in both Management Zones in Cobscook Bay and adjacent SWNB. The only farms which might be considered separate are farms MF-060 and MF-320 in BMA 4 (southern Deer Island). All other farms would have to be considered to be in one management region.

The model-derived tidal excursion areas are much smaller than the 5-km radius buffer zones and, consequently, suggest much less water exchange among some farms. They still indicate considerable water exchange among farms in the two Management Zones in Cobscook Bay, suggesting that all Cobscook Bay farms should be within the same Management Zone. The only farms in Cobscook Bay that appear to be somewhat isolated are IAFI JK and TIFI JC, off the northeastern coast of Moose Island (in Management Zone 2). However, the tidal excursion area of farm IAFI HP appears to provide a link between those two farms and the other Cobscook Bay

farms, although when the intensity of overlap is considered (as measured by the number of particle tracks which overlap farm sites), the overlap of the tidal excursion area of IAFI HP with the other Cobscook Bay sites appears to be quite small.

The model-derived tidal excursion areas also suggest considerable water connectivity between Cobscook Bay farms and some farms in SWNB, especially those in BMA 5 (southern Deer Island) and BMA 15 (Campobello Island). If the speculation that ISA can be spread through the water is correct, then this indicates the need for collaboration in the fish health management of the salmon farming industries in the two political jurisdictions. When the intensity of overlaps is considered (as measured by the numbers of particle tracks overlapping farm sites), the overlaps between Cobscook Bay sites and BMAs 5 and 15 appear to be relatively small, but may still be potentially important.

Relatively small changes in the location of a farm can result in relatively large changes to the predicted size and shape of the farm's tidal excursion area. This is related to the complex topography of the SWNB area of the Bay of Fundy. Drifter releases and current meter deployments in other locations in SWNB confirm that currents in this area can show large changes within small spatial scales (Page et al. 2004). This highlights the importance of having accurate information on farm site locations and having fine-scale resolution of the bathymetry and hydrography.

It must be noted that the tidal excursions as predicted by the model are determined completely by the M_2 tide. Although the M_2 component is the major component of the tide in this area, other factors such as wind and spring-neap tides do play a role and when these are included in the model, the particle trajectories and exposure maps will be modified to some degree, probably increasing the sizes of the predicted tidal excursion areas.

ACKNOWLEDGEMENTS

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Table 1. Water exchange areas of salmon farms in the Cobscook Bay, southern Deer Island and western Campobello Island areas. Water exchange areas were estimated by two methods: 5-km radius circular buffer zones (excluding land and water areas cut off from the originating farm site by land) and model-derived tidal excursion areas. BMA = Bay Management Area (New Brunswick). The number in brackets following New Brunswick farm names refers to the BMA of the site.

Farm site	5-km radius buffer zone (km^2)	Tidal excursion area (km^2)	Farm site	5-km radius buffer zone (km^2)	Tidal excursion area (km^2)
Cobscook Bay Management Zone 1			**Southern Deer Island BMAs 4-south & 5**		
CONA BC	52.6	20.5	MF-058 (4)	43.0	1.4
CONA CP	47.6	12.2	MF-059 (4)	41.7	6.9
IAFI CL	52.7	15.4	MF-060 (4)	45.8	10.1
IAFI PC	42.4	22.1	MF-320 (4)	46.1	1.7
LREN TE	34.4	18.5	MF-049 (5)	41.9	5.0
MESI SH	55.4	23.5	MF-050 (5)	47.4	17.5
SFML LU2	33.1	6.9	MF-051 (5)	47.6	9.6
SFML RN2	32.3	7.8	MF-057 (5)	47.4	25.3
TIFI CC	52.3	13.1	MF-411 (5)	41.9	20.7
TIFI TW	34.7	20.5	Mean ± SD	44.8 ± 2.7	10.9 ± 8.5
Mean ± SD	43.8 ± 9.4	16.1 ± 6.1			
			Campobello Island BMAs 13, 14 & 15		
Cobscook Bay Management Zone 2			MF-064 (13)	57.9	0.4
BPFI BE	49.4	12.2	MF-186 (13)	65.7	21.5
CONA DC	55.8	20.6	MF-206 (13)	63.2	1.3
CONA SB	49.3	14.4	MF-052 (14)	47.0	24.4
IAFI HP	53.7	12.2	MF-053 (14)	48.5	0.9
IAFI JK	50.3	5.8	MF-054 (14)	33.0	1.9
SFML GN1	48.9	12.0	MF-055 (15)	35.7	14.7
SFML GN2	48.8	11.4	MF-056 (15)	34.5	12.5
TIFI JC	51.7	5.9	MF-168 (15)	34.3	2.2
Mean ± SD	51.0 ± 2.5	11.8 ± 4.7	Mean ± SD	46.6 ± 13.1	8.9 ± 9.6
Cobscook Bay (all)			**Southern Deer I. and Campobello I. (all)**		
Mean ± SD	47.0 ± 8.0	14.2 ± 5.7	Mean ± SD	45.7 ± 9.2	9.9 ± 8.8

Table 2. Overlaps (indicated by shaded squares) of 5-km radius buffer zones with finfish farm sites in Cobscook Bay (Zones 1 and 2) and adjacent areas of SWNB (BMAs 4-south, 5, 13, 14 and 15).

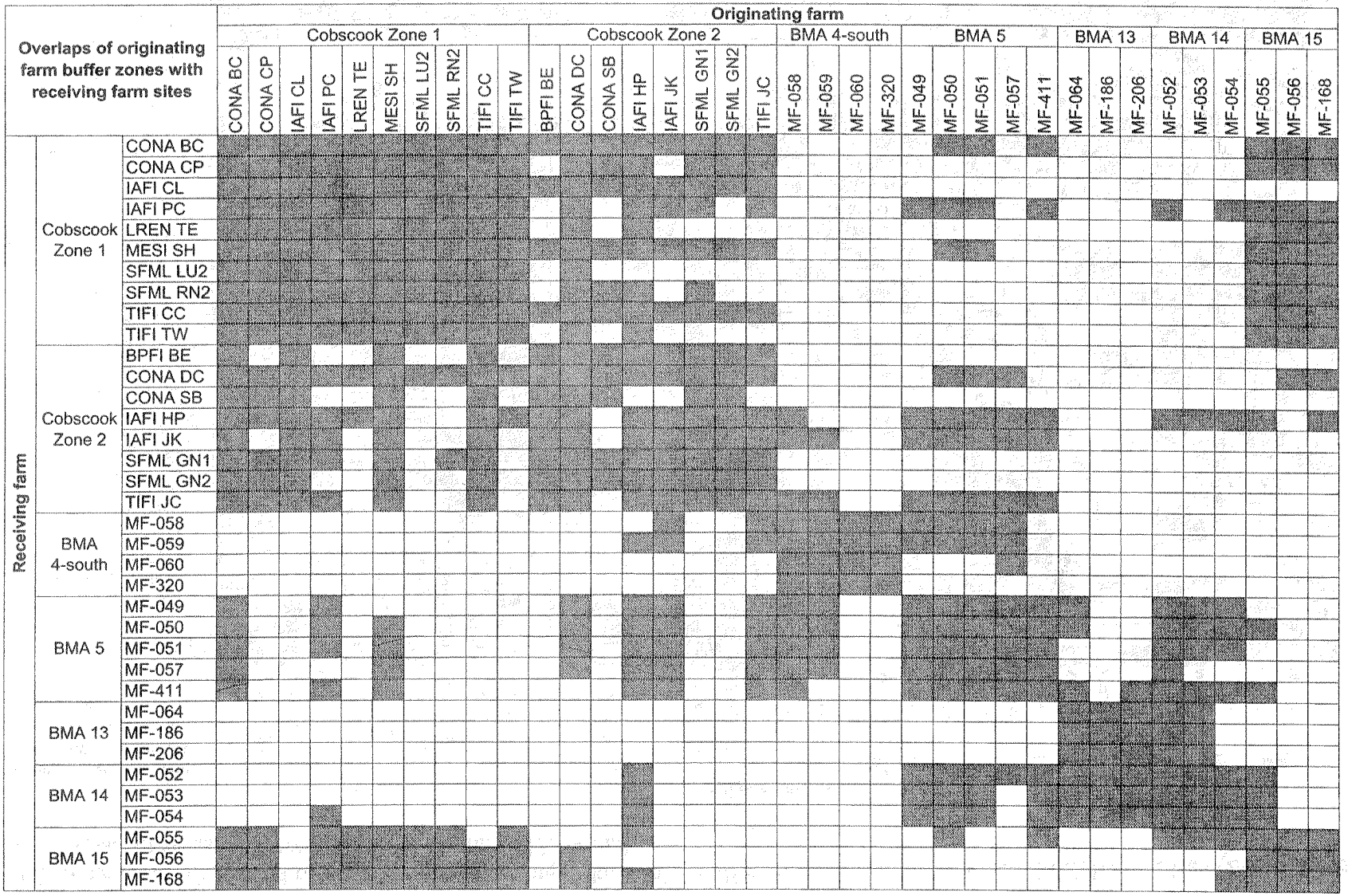


Table 3. Overlaps (indicated by shaded squares) among 5-km radius buffer zones of finfish farm sites in Cobscook Bay (Zones 1 and 2) and adjacent areas of SWNB (BMAs 4-south, 5, 13, 14 and 15).

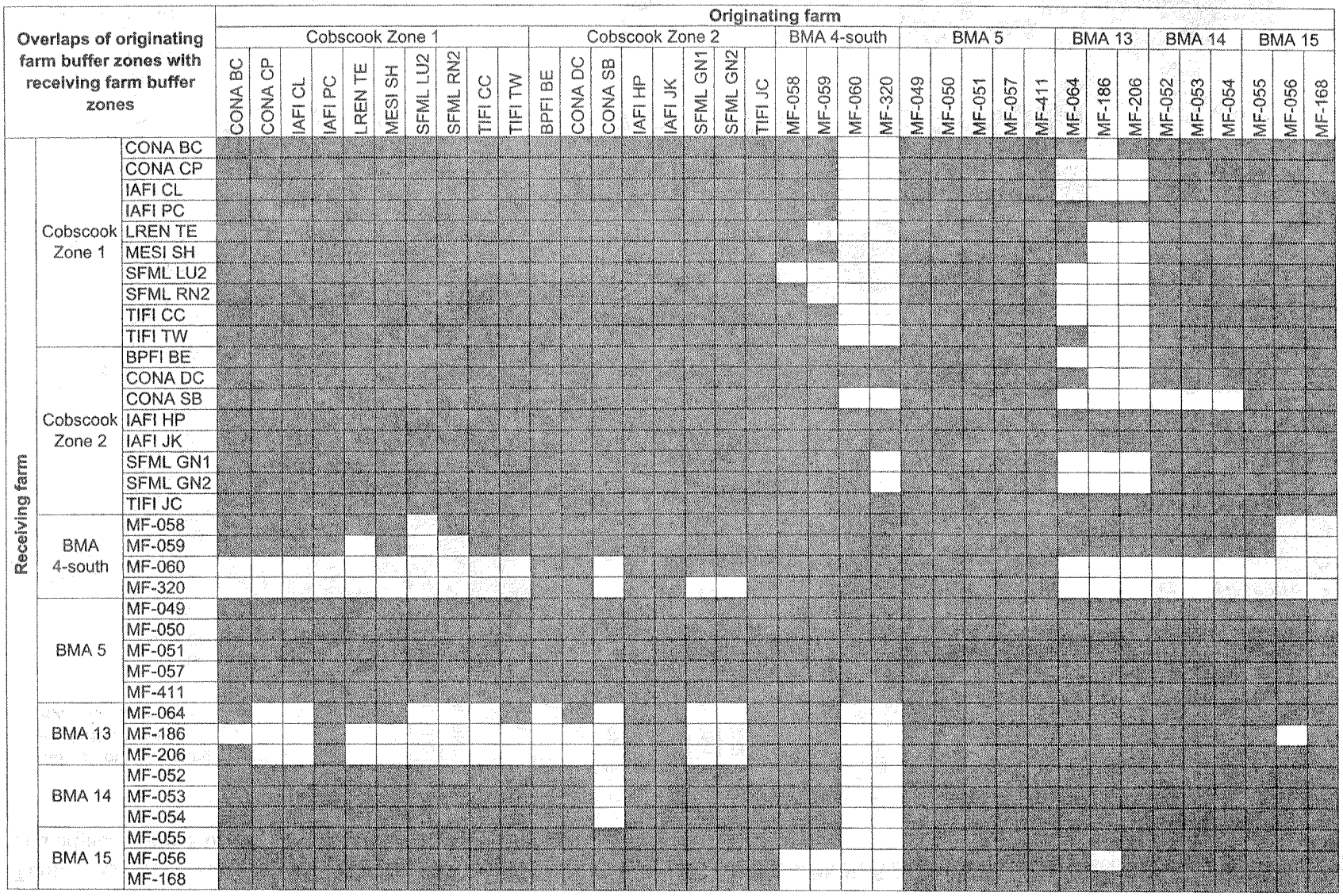


Table 4. Overlaps (indicated by shaded squares) of model-derived tidal excursion areas with finfish farm sites in Cobscook Bay (Zones 1 and 2) and adjacent areas of SWNB (BMAs 4-south, 5, 13, 14 and 15).

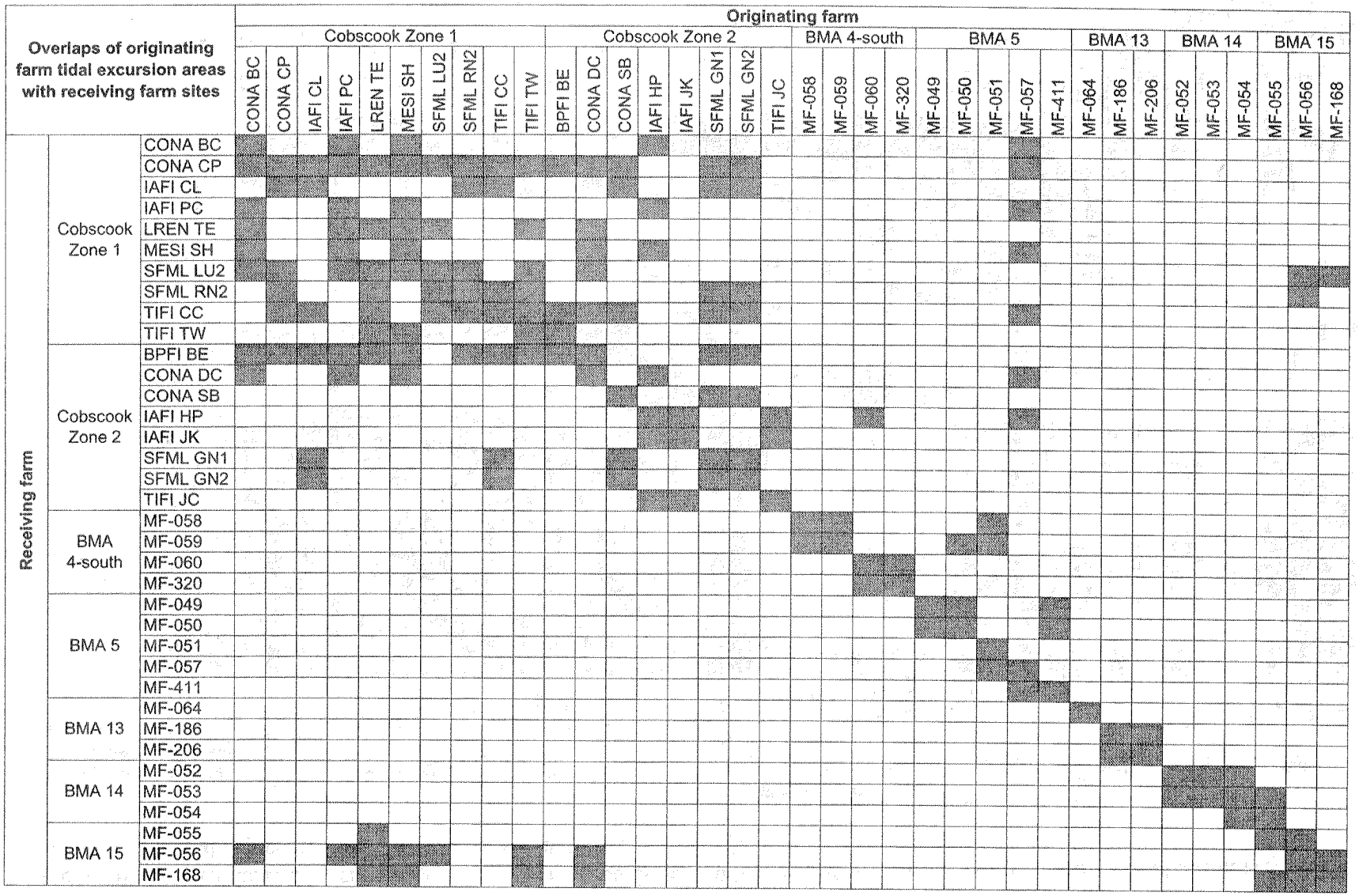


Table 5. Overlaps (indicated by shaded squares) among model-derived tidal excursion areas of finfish farms in Cobscook Bay (Zones 1 and 2) and adjacent areas of (BMAs 4-south, 5, 13, 14 and 15).

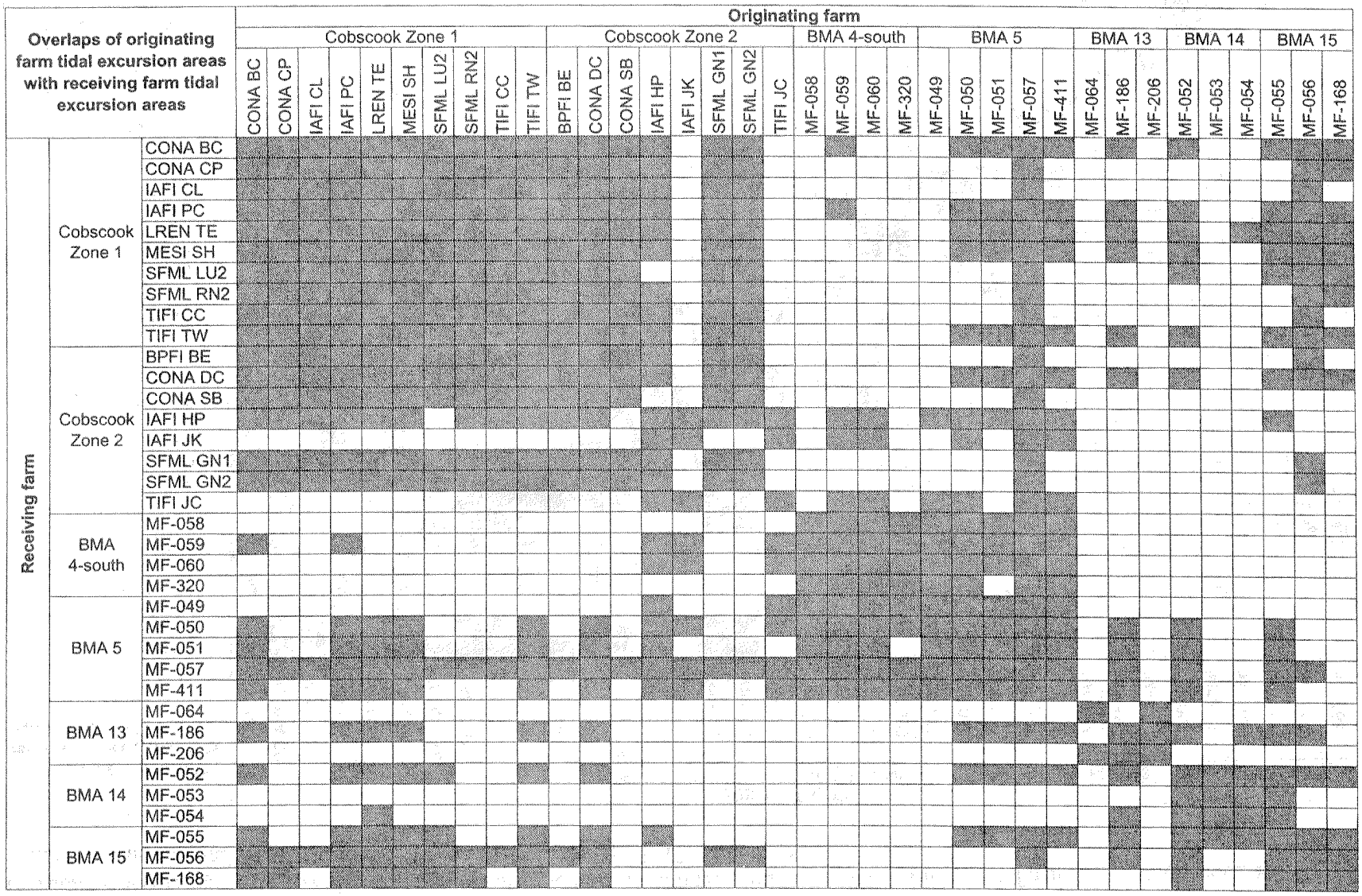


Table 6. Mean numbers of overlaps of 5-km radius buffer zones (from originating farms) with farm sites (receiving farms), by region, for finfish farms in Cobscook Bay (CB), southern Deer Island (SDI) and Campobello Island (CI). The numbers are means (± SD) of all originating farms in each region, including the overlap of each buffer zone with its own farm site.

Originating farm location	Receiving farm location				
	CB Zone 1 (n=10)	CB Zone 2 (n=8)	SDI (n=9)	CI (n=9)	All (n=36)
CB Zone 1	10.0 ± 0.0	5.0 ± 3.0	1.3 ± 2.1	2.7 ± 1.1	19.0 ± 4.4
CB Zone 2	6.5 ± 2.1	7.3 ± 1.0	3.0 ± 3.3	0.9 ± 1.8	17.6 ± 5.9
SDI	1.0 ± 1.3	2.6 ± 1.6	6.6 ± 1.8	1.7 ± 1.8	11.8 ± 5.0
CI	3.2 ± 4.4	0.8 ± 0.7	2.1 ± 2.0	5.4 ± 1.5	11.6 ± 3.8

Table 7. Mean numbers of overlaps among 5-km radius buffer zones, by region, for finfish farms in Cobscook Bay (CB), southern Deer Island (SDI) and Campobello Island (CI). The numbers are means (± SD) of all originating farms in each region, including the overlap of each buffer zone with itself.

Originating farm location	Receiving farm location				
	CB Zone 2 (n=10)	CB Zone 2 (n=8)	SDI (n=9)	CI (n=9)	All (n=36)
CB Zone 1	10.0 ± 0.0	8.0 ± 0.0	6.6 ± 0.7	6.8 ± 1.0	31.4 ± 1.4
CB Zone 2	10.0 ± 0.0	8.0 ± 0.0	8.5 ± 0.8	6.9 ± 2.1	33.4 ± 2.8
SDI	7.3 ± 4.3	7.6 ± 1.0	9.0 ± 0.0	6.6 ± 3.8	30.4 ± 9.0
CI	7.6 ± 3.8	6.1 ± 2.2	6.6 ± 0.9	8.8 ± 0.4	29.0 ± 5.8

Table 8. Mean numbers of overlaps between model-derived tidal excursion areas and finfish farm sites, by region, for farms in Cobscook Bay (CB), southern Deer Island (SDI) and Campobello Island (CI). Top: numbers of farm sites (receiving farms) overlapped by each tidal excursion area (from originating farm). Bottom: numbers of tidal excursion areas (from originating farms) overlapping each farm site (receiving farm). The numbers are means (± SD) of all farms in each region, including the overlap of each tidal excursion area with its own farm site.

	Receiving farm location				
Originating farm location	CB Zone 2 (n=10)	CB Zone 2 (n=8)	SDI (n=9)	CI (n=9)	All (n=36)
CB Zone 1	5.3 ± 1.2	1.6 ± 1.0	0.0 ± 0.0	1.0 ± 1.1	7.9 ± 1.9
CB Zone 2	2.8 ± 1.8	3.0 ± 1.1	0.0 ± 0.0	0.3 ± 0.7	6.0 ± 2.4
SDI	0.6 ± 1.7	0.3 ± 0.7	2.4 ± 0.7	0.0 ± 0.0	3.3 ± 2.2
CI	0.3 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.9	2.7 ± 1.2

	Originating farm location				
Receiving farm location	CB Zone 2 (n=10)	CB Zone 2 (n=8)	SDI (n=9)	CI (n=9)	All (n=36)
CB Zone 1	5.3 ± 2.5	2.2 ± 1.6	0.5 ± 0.5	0.3 ± 0.7	8.3 ± 3.9
CB Zone 2	2.0 ± 3.1	3.0 ± 0.5	0.4 ± 0.7	0.0 ± 0.0	5.4 ± 3.3
SDI	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.9	0.0 ± 0.0	2.4 ± 0.9
CI	1.1 ± 2.1	0.2 ± 0.4	0.0 ± 0.0	2.3 ± 0.9	3.7 ± 2.6

Table 9. Mean numbers of overlaps among model-derived tidal excursion areas, by Bay Management Area (BMA), for finfish farms in Cobscook Bay (CB), southern Deer Island (SDI) and Campobello Island (CI). The numbers are means (± SD) of all originating farms in each region, including the overlap of each tidal excursion area with itself.

Originating farm location	Receiving farm location				
	CB Zone 2 (n=10)	CB Zone 2 (n=8)	SDI (n=9)	CI (n=9)	All (n=36)
CB Zone 1	10.0 ± 0.0	5.9 ± 0.3	3.2 ± 1.3	3.6 ± 1.9	22.2 ± 3.6
CB Zone 2	7.4 ± 4.6	5.3 ± 1.5	3.3 ± 2.5	1.1 ± 1.6	17.0 ± 6.1
SDI	3.0 ± 3.5	2.9 ± 2.4	8.8 ± 0.4	1.4 ± 1.7	16.1 ± 7.4
CI	4.0 ± 3.8	1.0 ± 1.3	1.4 ± 1.9	4.8 ± 1.7	11.2 ± 7.4

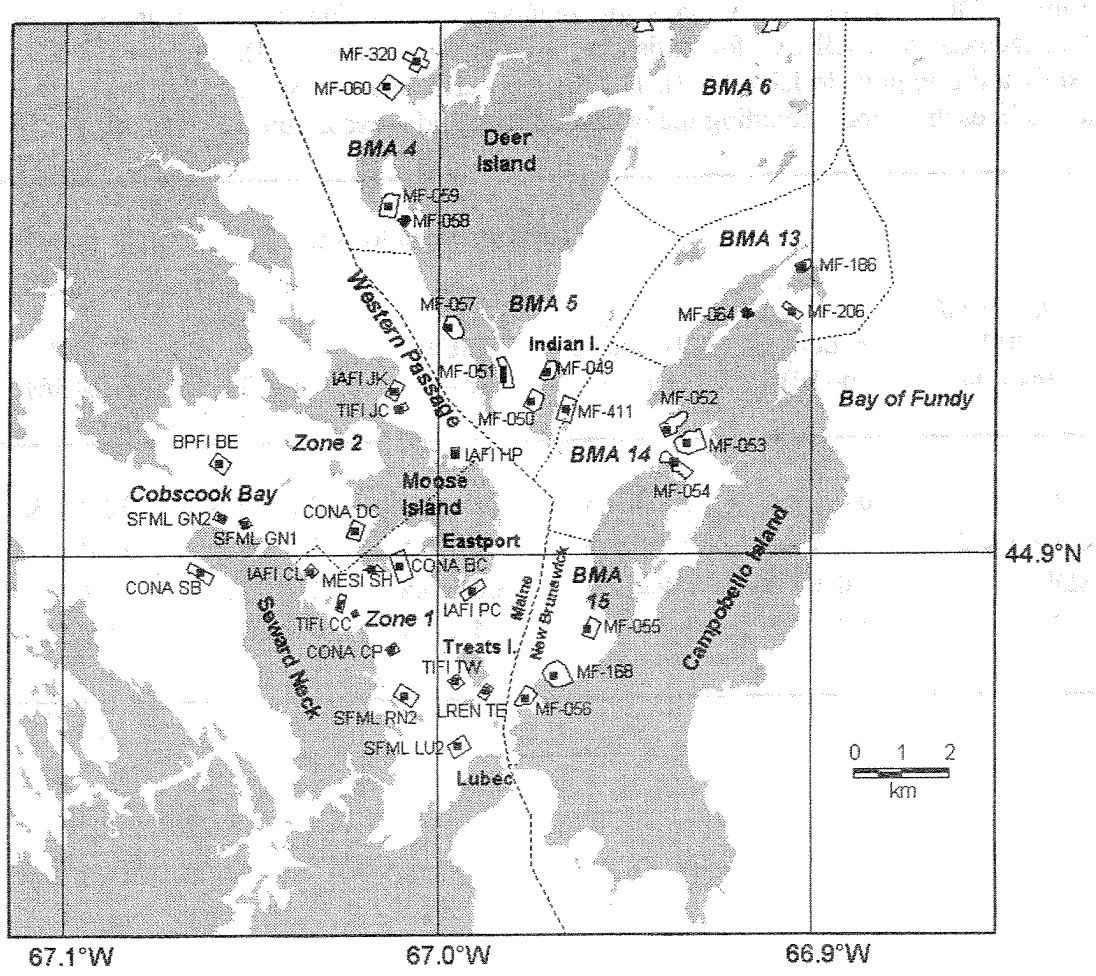


Fig. 1. Map of Cobscook Bay, Maine and the adjacent area of SWNB, showing sites of finfish farms (small white polygons) and starting grids for model particle releases (small black squares within farms) in 2004. Dotted lines are boundaries between management areas: BMAs in New Brunswick and Management Zones in Cobscook Bay.

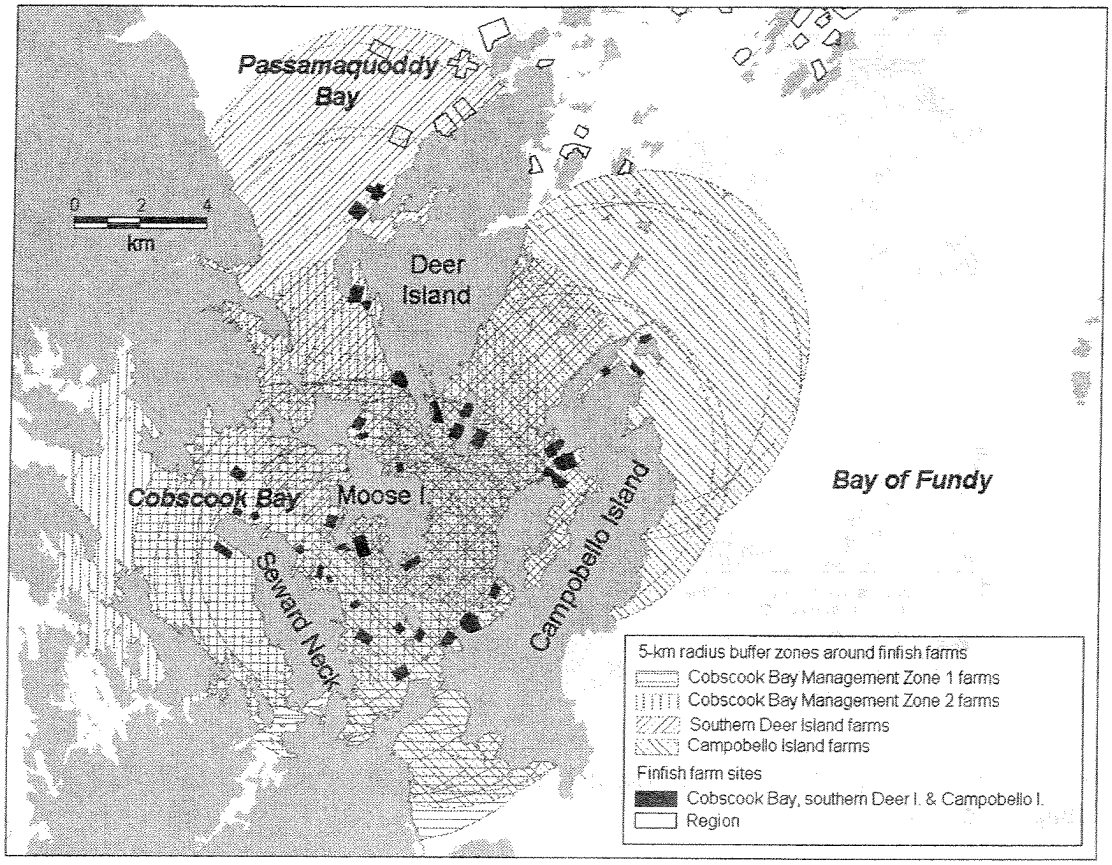


Fig. 2. Map showing 5-km radius buffer zones of all finfish farms in Cobscook Bay and adjacent areas of New Brunswick in 2004.

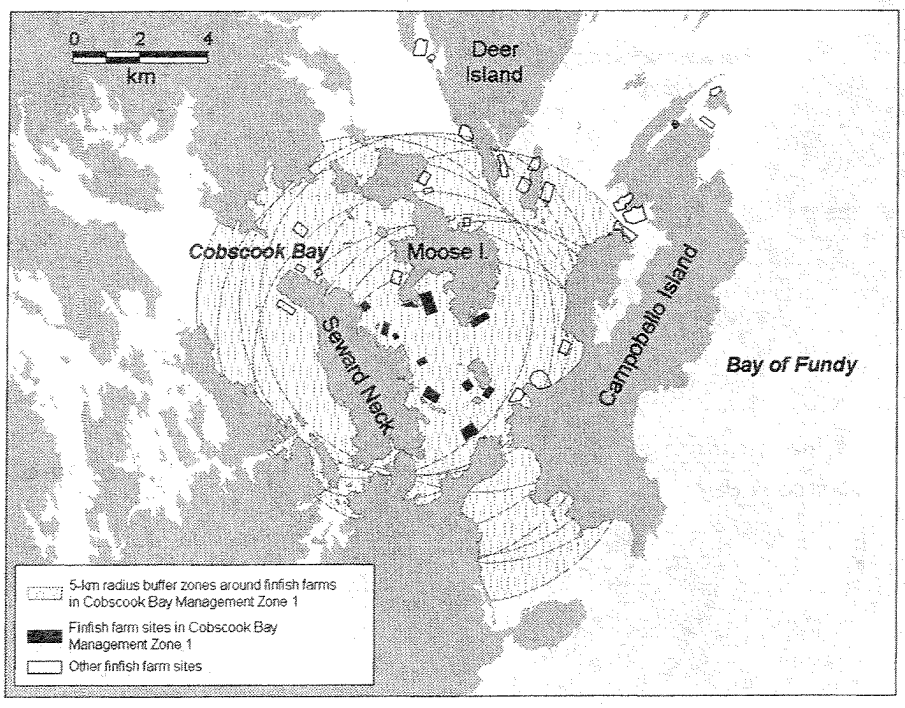


Fig. 3. Map showing 5-km radius buffer zones of all finfish farms in Cobscook Bay Management Zone 1 in 2004.

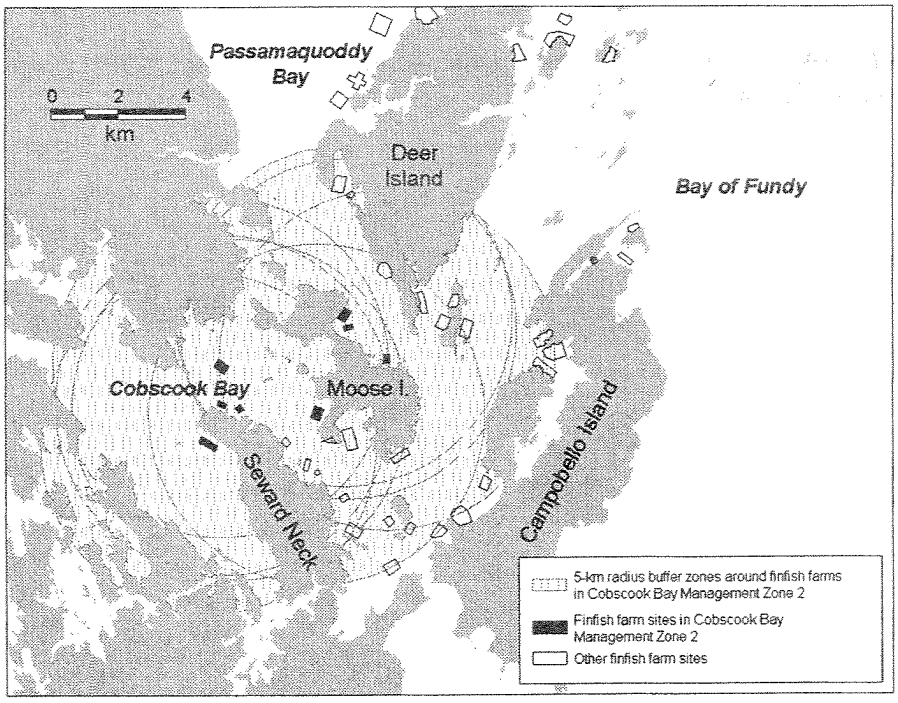


Fig. 4. Map showing 5-km radius buffer zones of all finfish farms in Cobscook Bay Management Zone 2 in 2004.

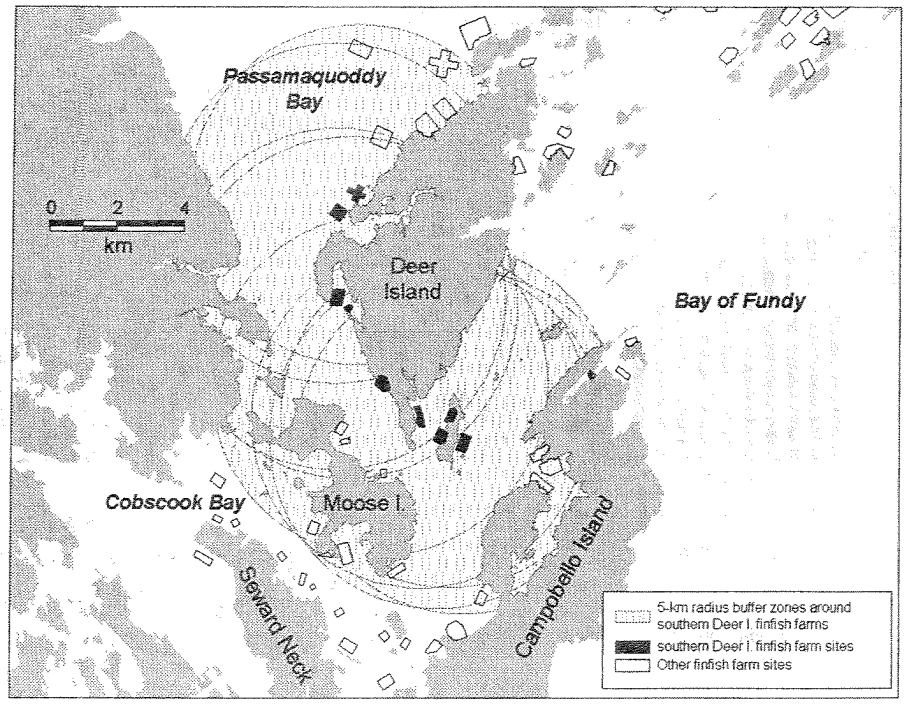


Fig. 5. Map showing 5-km radius buffer zones of all finfish farms in the southern Deer Island area (BMAs 4-south and 5) in 2004.

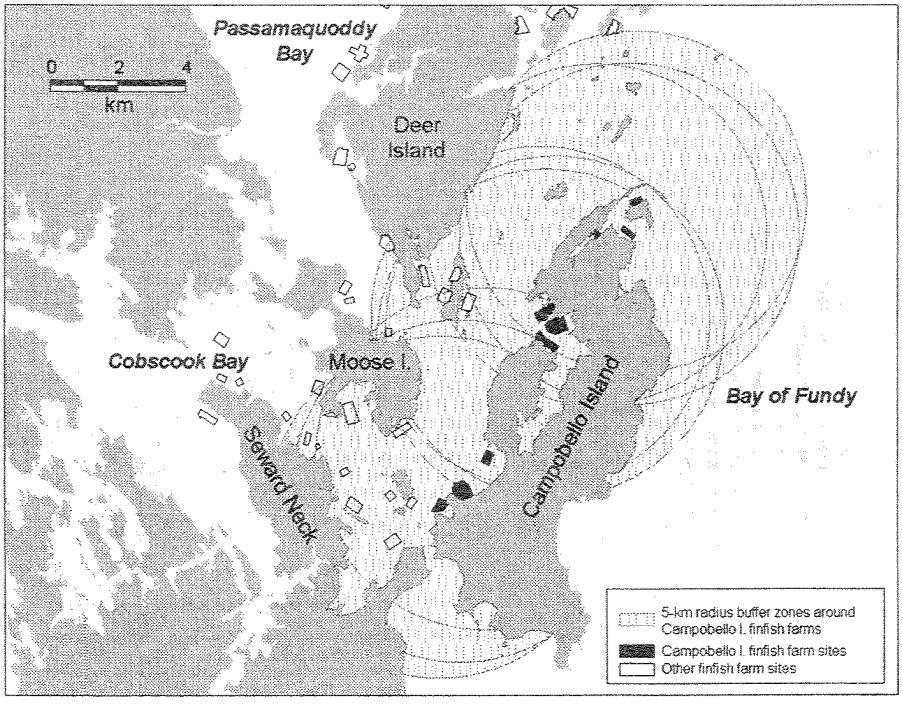


Fig. 6. Map showing 5-km radius buffer zones of all finfish farms in the Campobello Island area (BMAs 13, 14 and 15) in 2004.

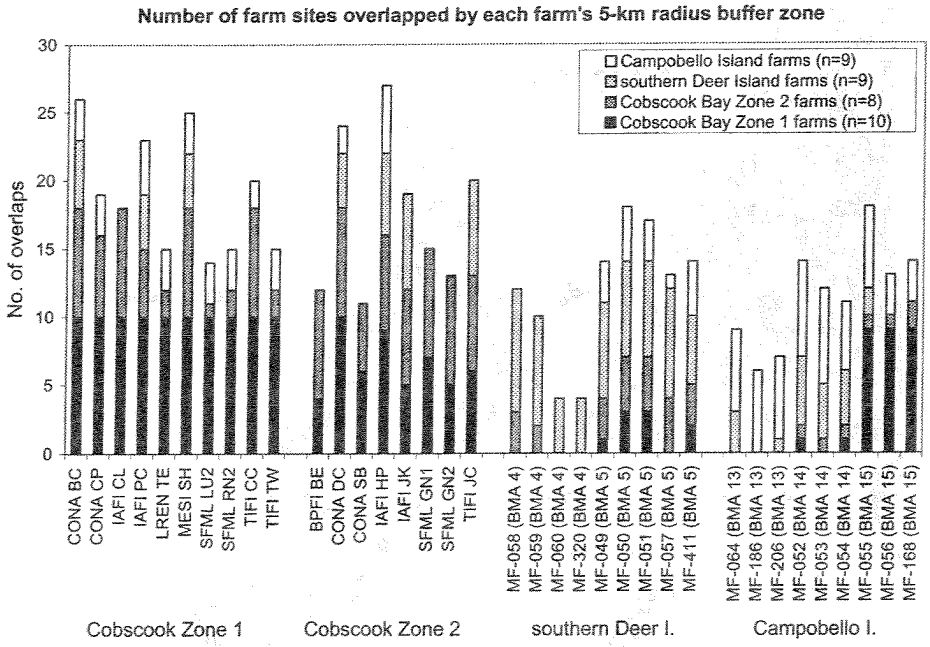


Fig. 7. Number of finfish farm sites overlapped by each farm's 5-km radius buffer zone in the Cobscook Bay, southern Deer Island and Campobello Island areas. The numbers include overlaps with the originating farm. BMA = Bay Management Area (New Brunswick).

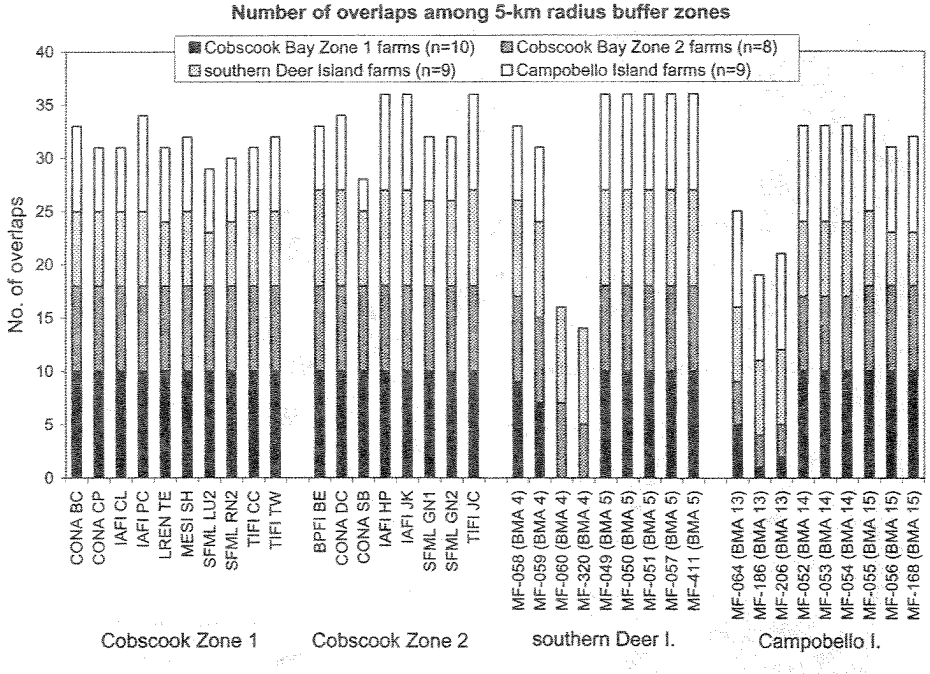
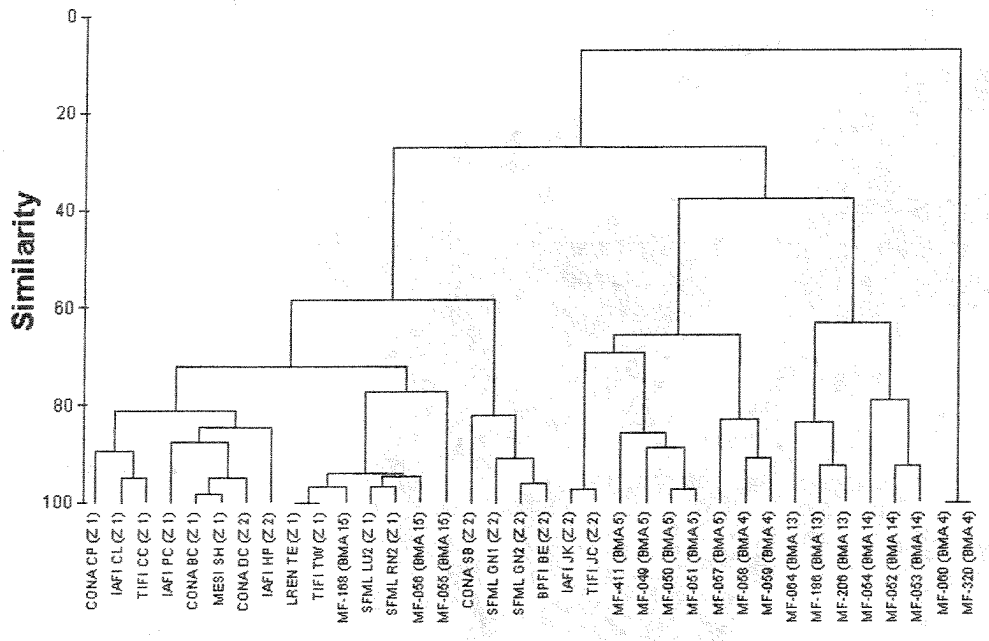
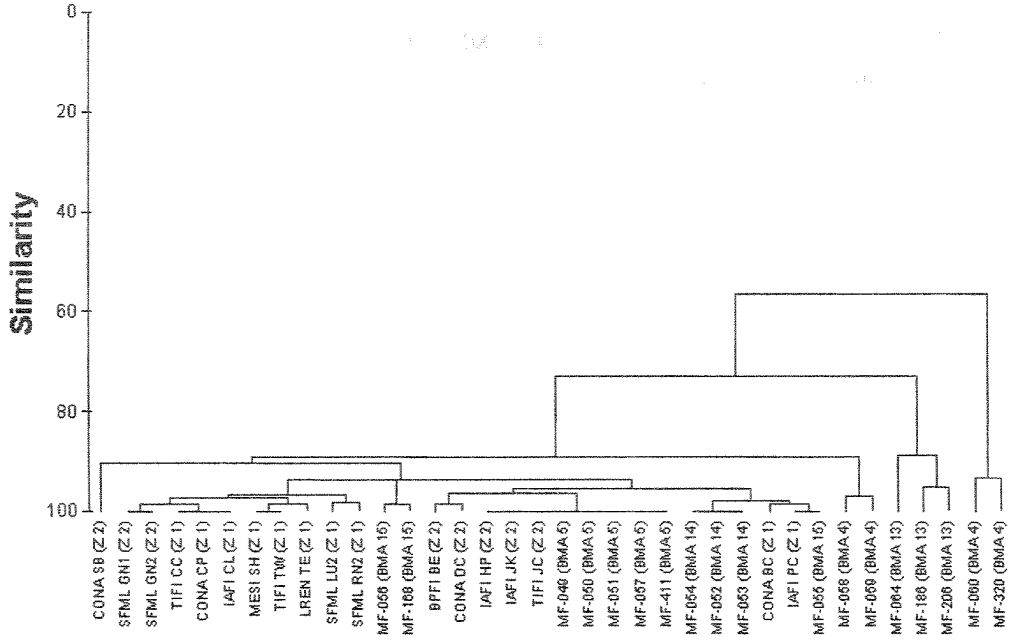


Fig. 8. Number of overlaps among 5-km radius buffer zones of finfish farms in the Cobscook Bay, southern Deer Island and Campobello Island areas. The numbers include overlaps with the originating farm. BMA = Bay Management Area (New Brunswick).



Fig, 9. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps of each finfish farm's 5-km radius buffer zone with farm sites in the Cobscook Bay, southern Deer Island and Campobello Island areas. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.



Fig, 10. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps among 5-km radius buffer zones of finfish farms in the Cobscook Bay, southern Deer Island and Campobello Island areas. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.

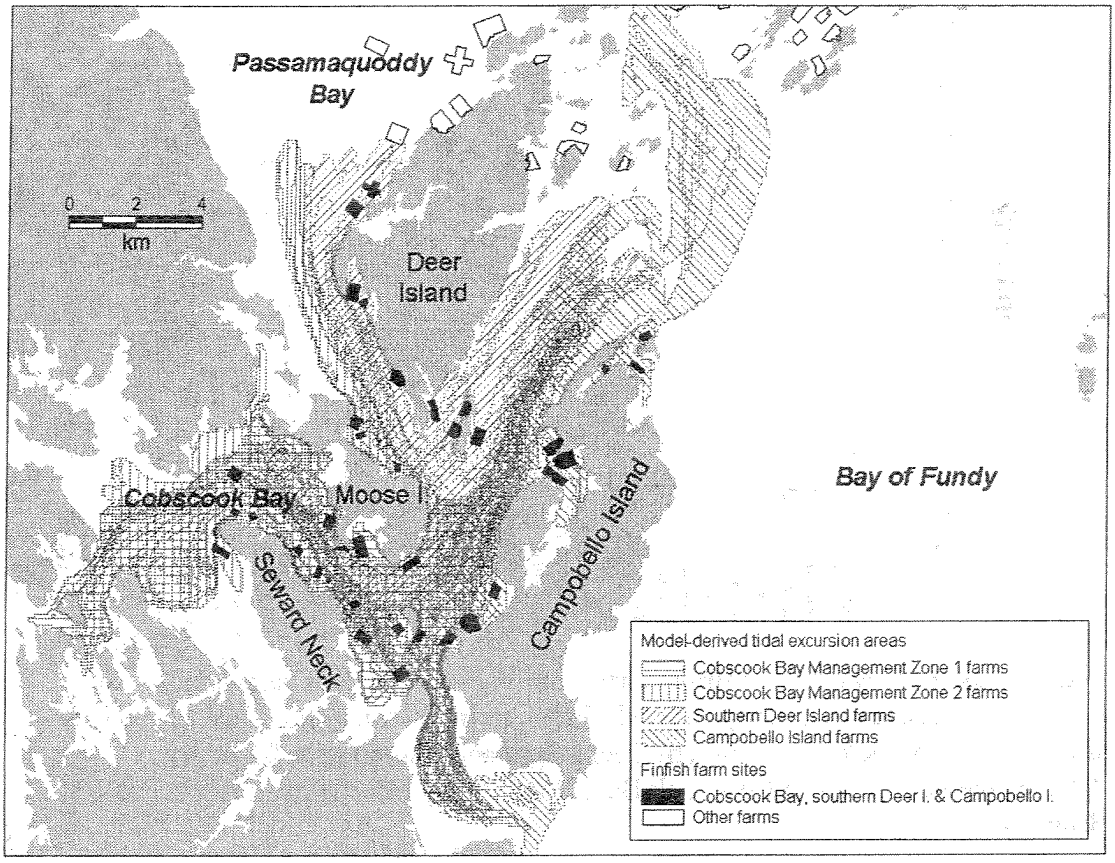


Fig. 11. Map showing model-predicted tidal excursion areas of all finfish farms in Cobscook Bay and adjacent areas of New Brunswick in 2004.

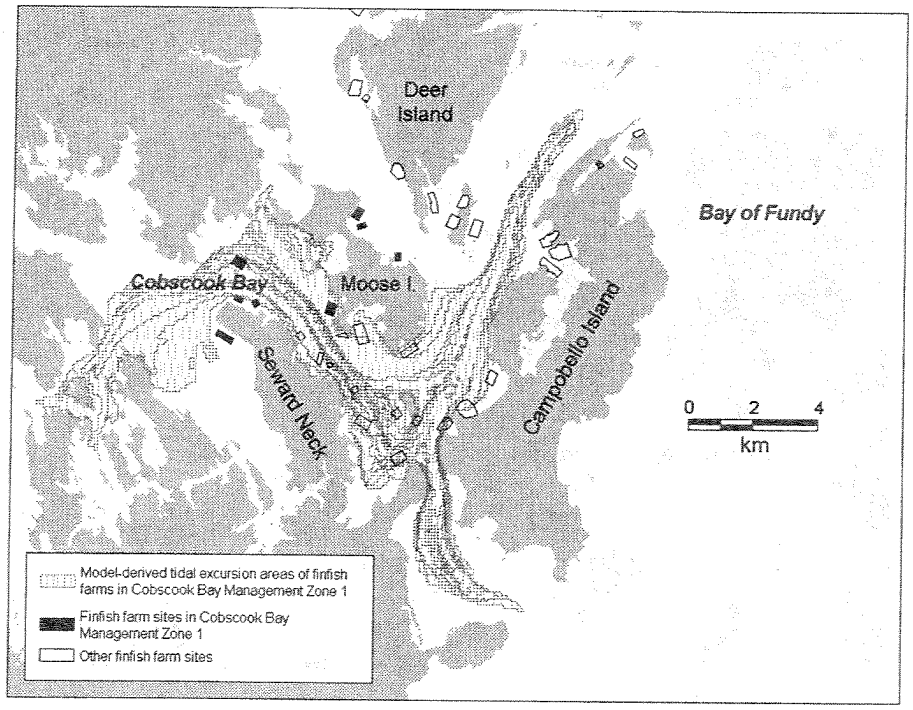


Fig. 12. Map showing model-predicted tidal excursion areas of all finfish farms in Cobscook Bay Management Zone 1 in 2004.

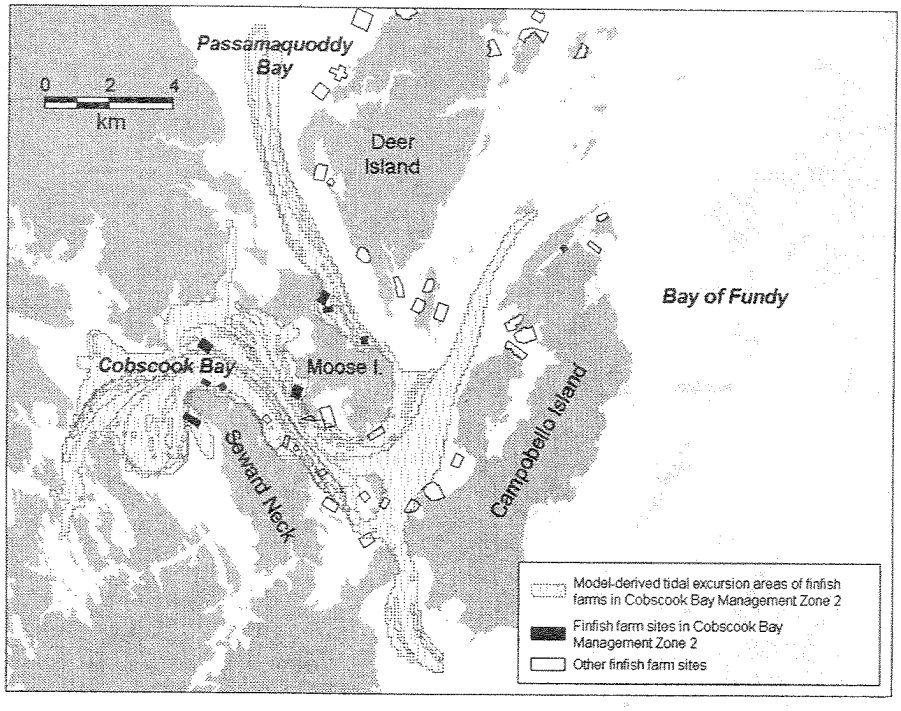


Fig. 13 Map showing model-predicted tidal excursion areas of all finfish farms in Cobscook Bay Management Zone 2 in 2004.

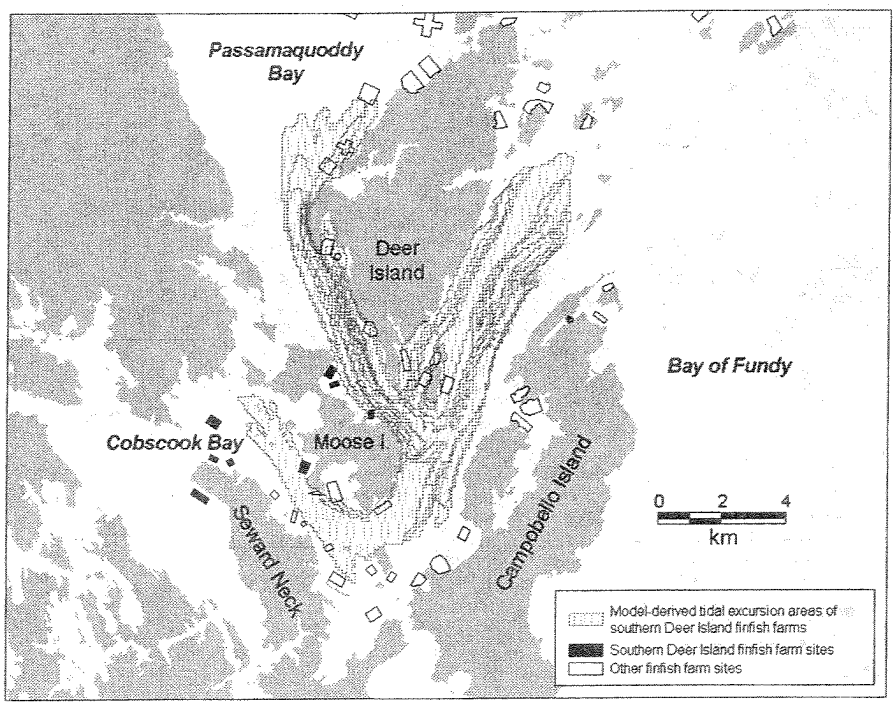


Fig. 14. Map showing model-predicted tidal excursion areas of all finfish farms in southern Deer Island (BMAs 4-south and 5) in 2004.

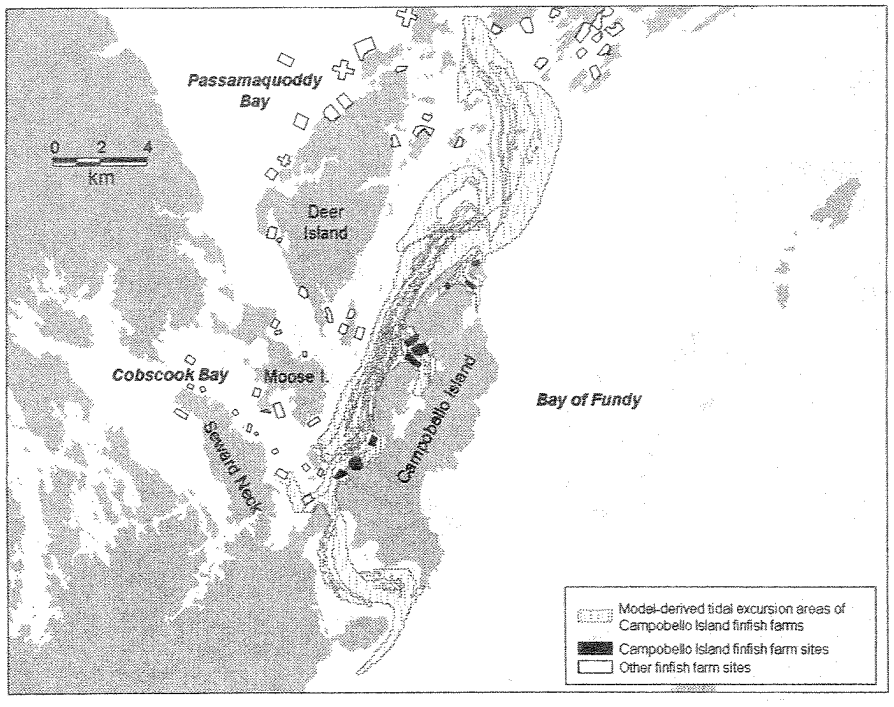


Fig. 15. Map showing model-predicted tidal excursion areas of all finfish farms in the Campobello Island area (BMAs 13, 14 and 15) in 2004.

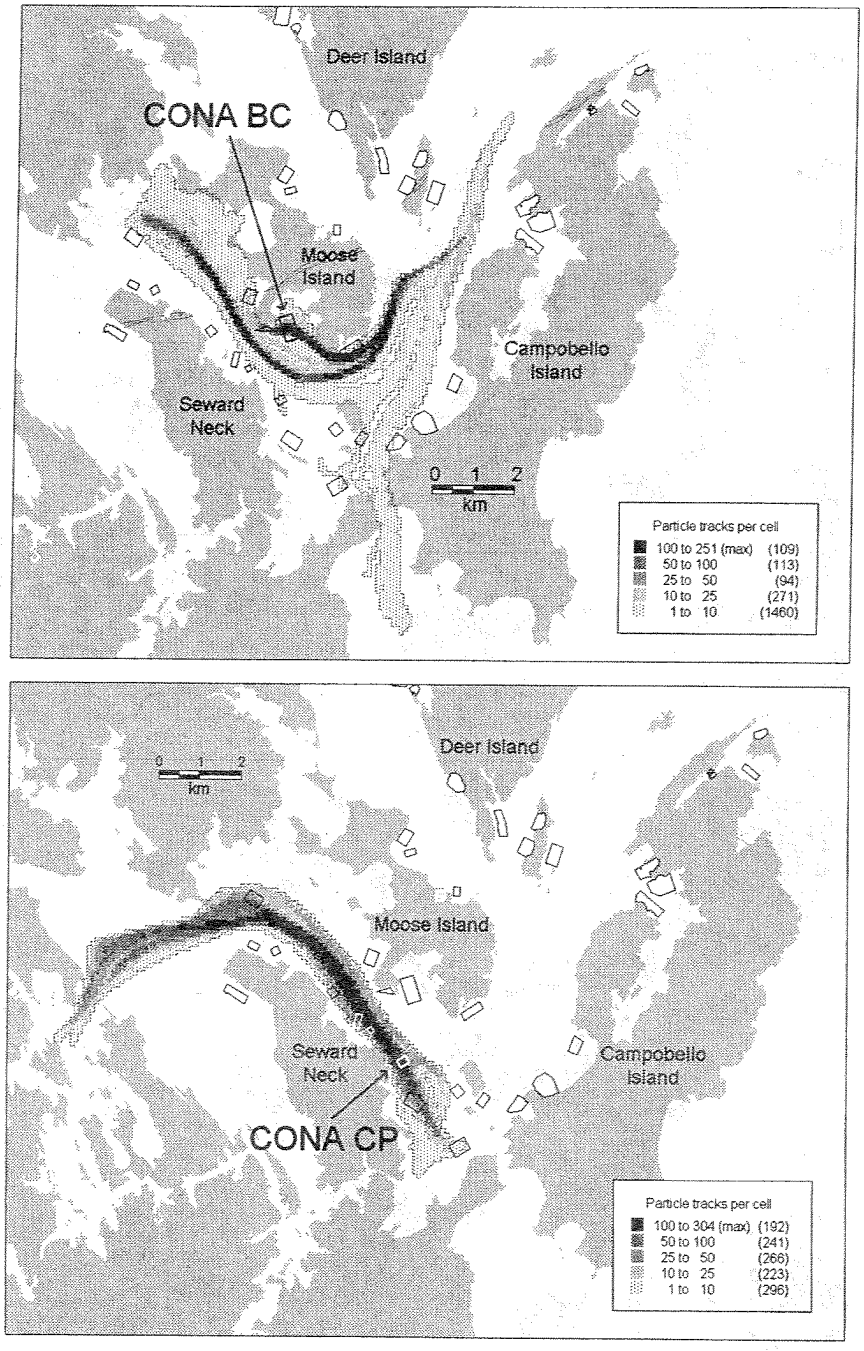


Fig. 16. Model-derived tidal excursion areas of each finfish farm in Cobscook Bay Management Zone 1. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases), at hourly intervals over a 12-h period. Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

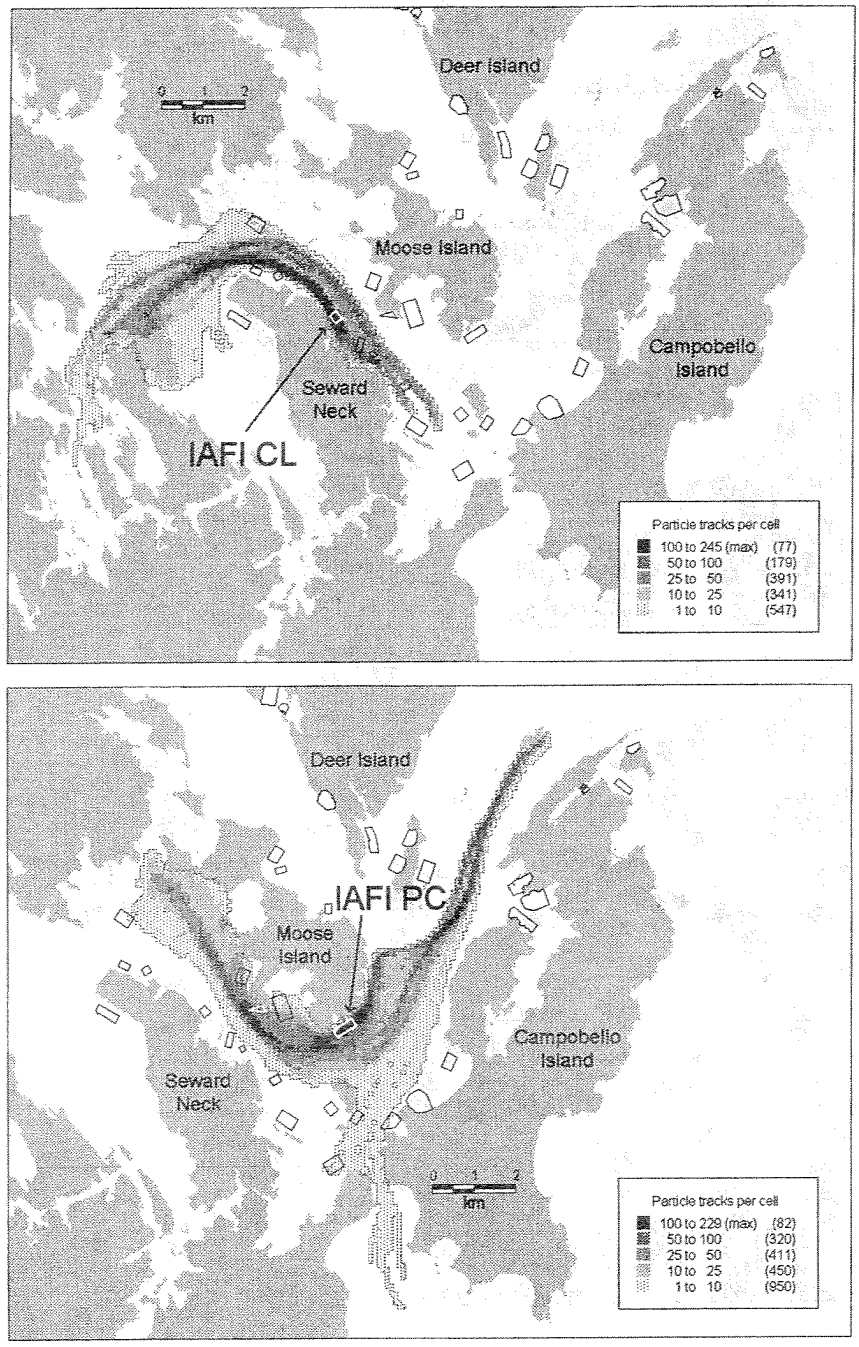
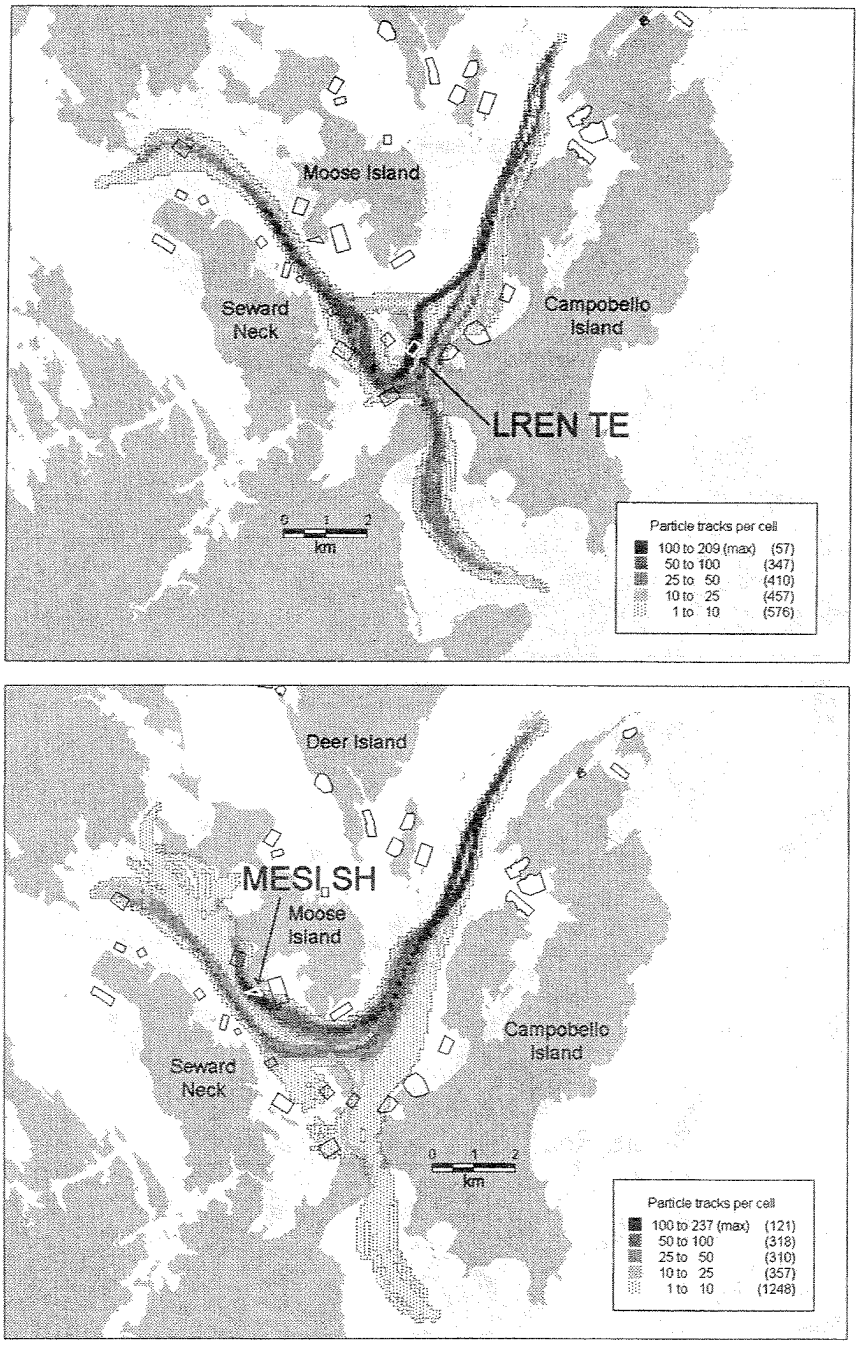


Fig. 16 continued.



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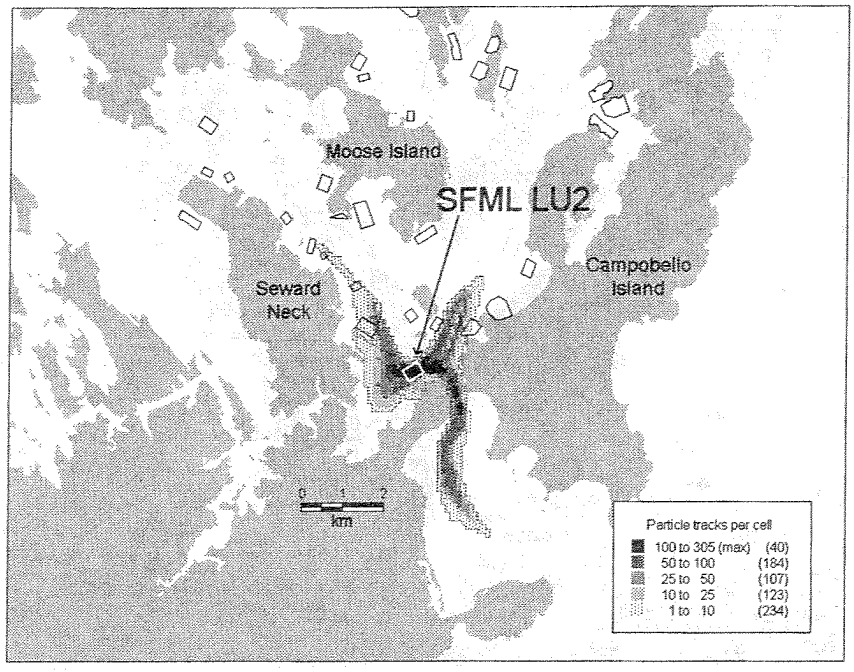


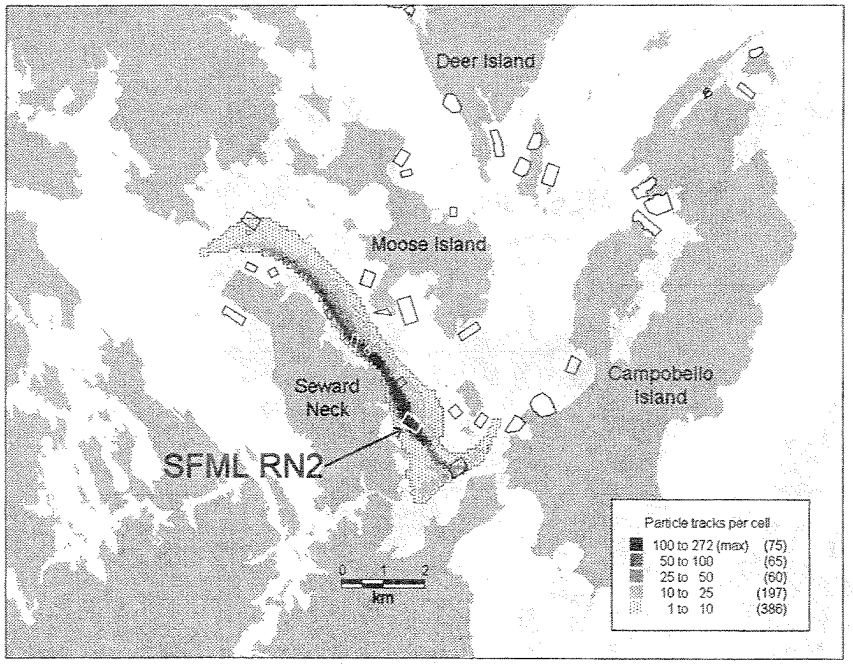
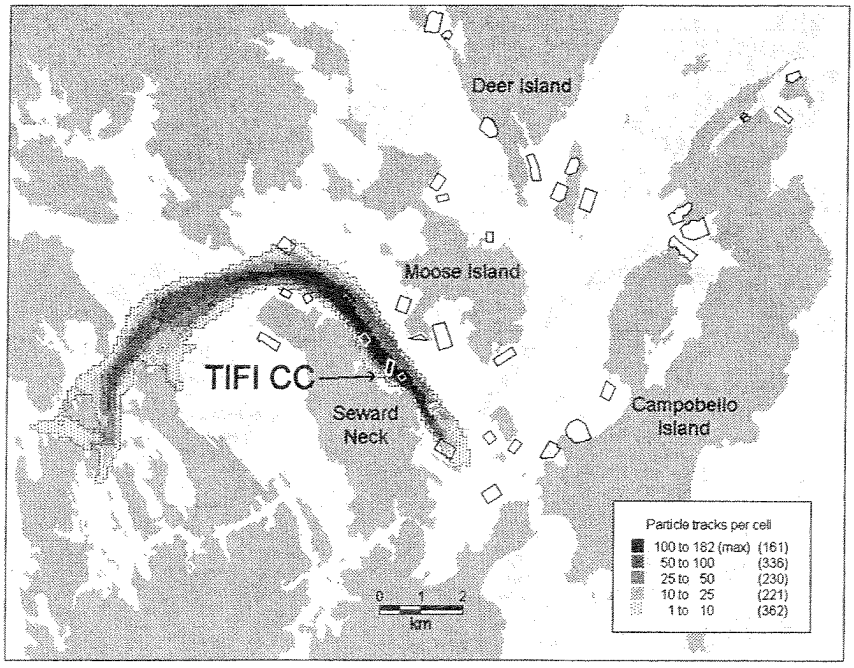


Fig. 16 continued.



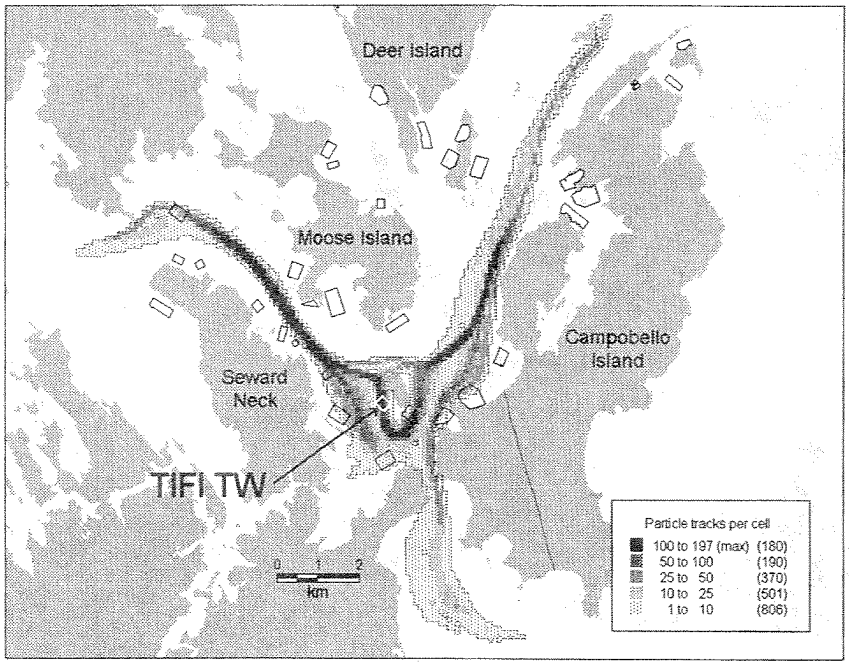


Fig. 16 concluded.

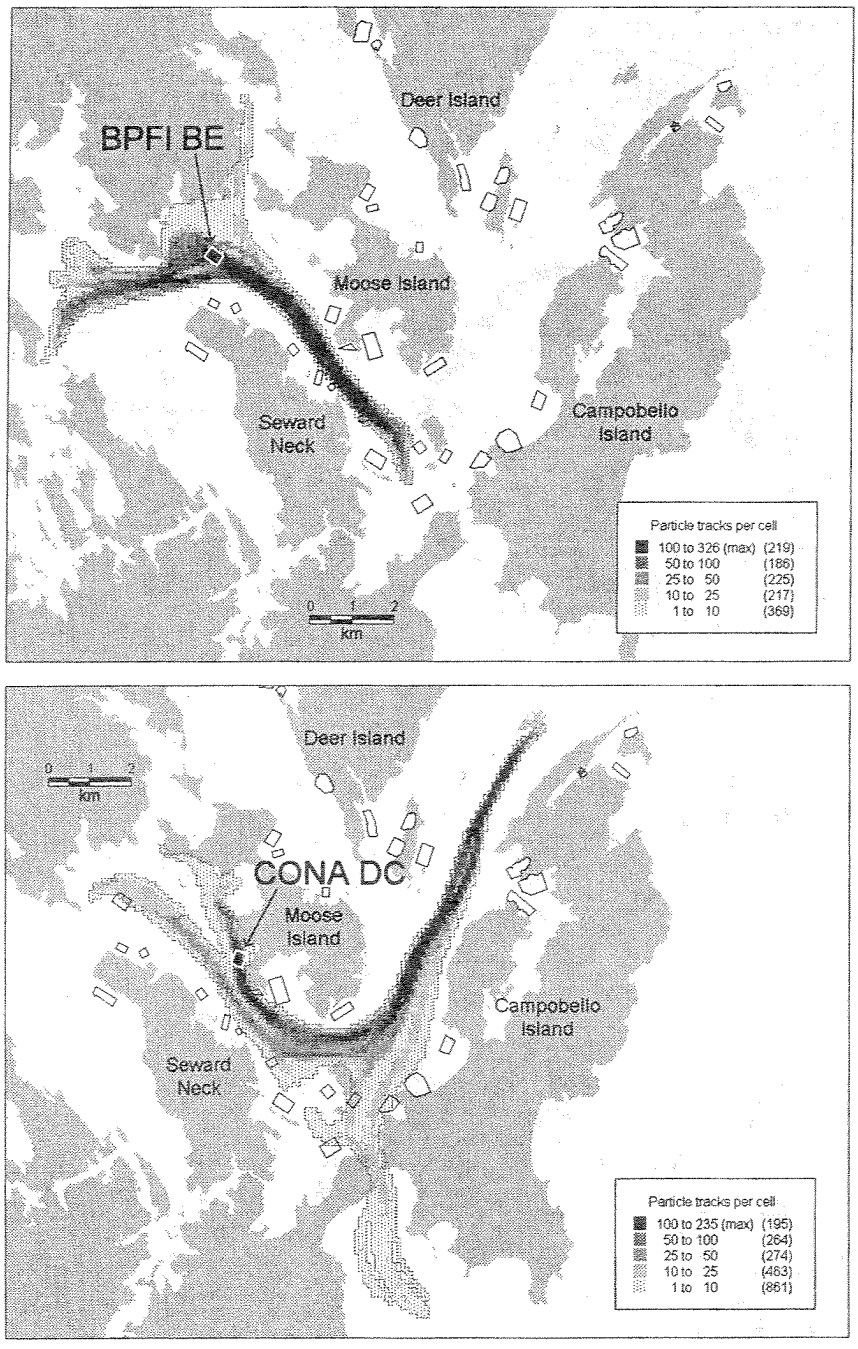


Fig. 17. Model-derived tidal excursion areas of each finfish farm in Cobscook Bay Management Zone 2. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases), at hourly intervals over a 12-h period. Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

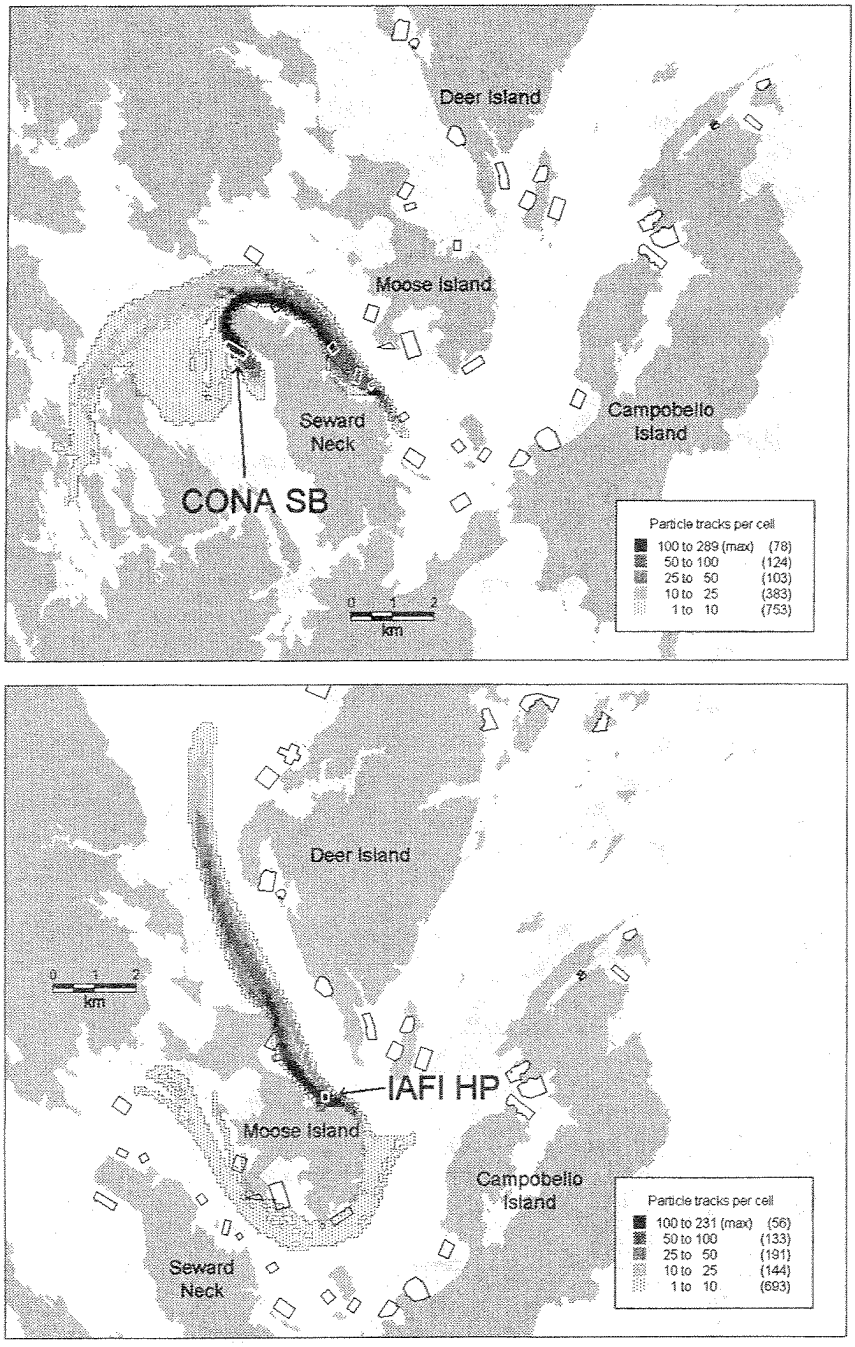


Fig. 17 continued.

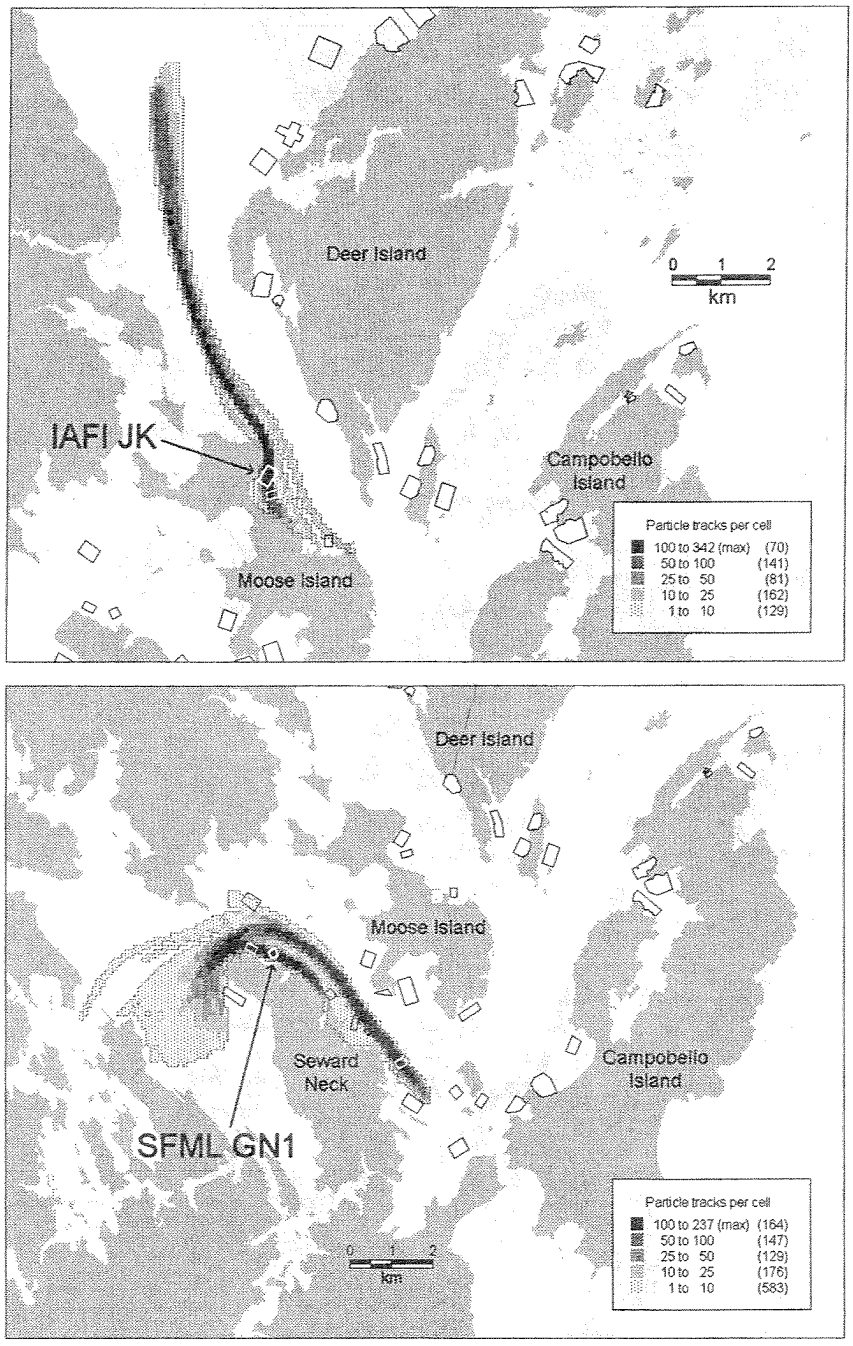


Fig. 17 continued.

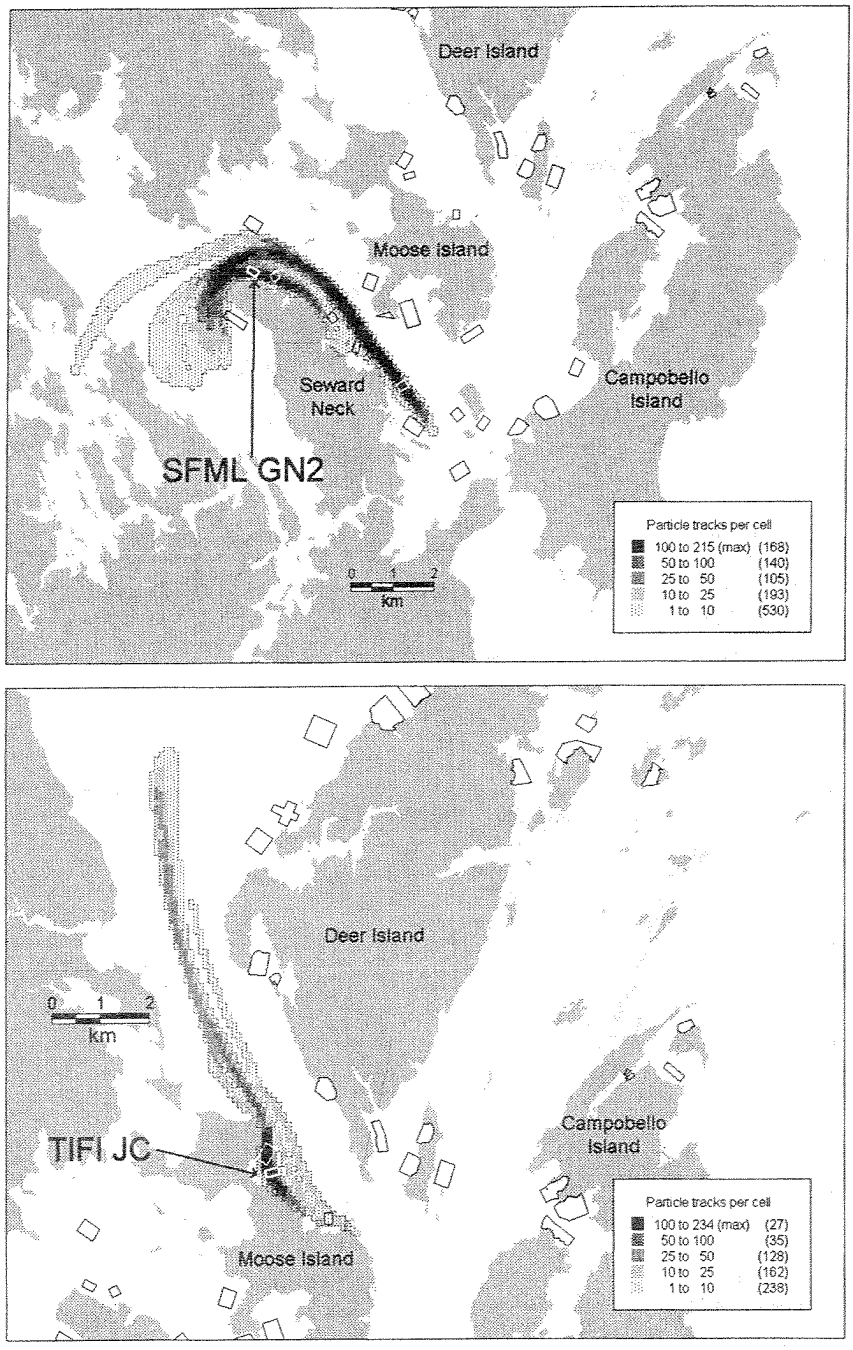


Fig. 17 concluded.

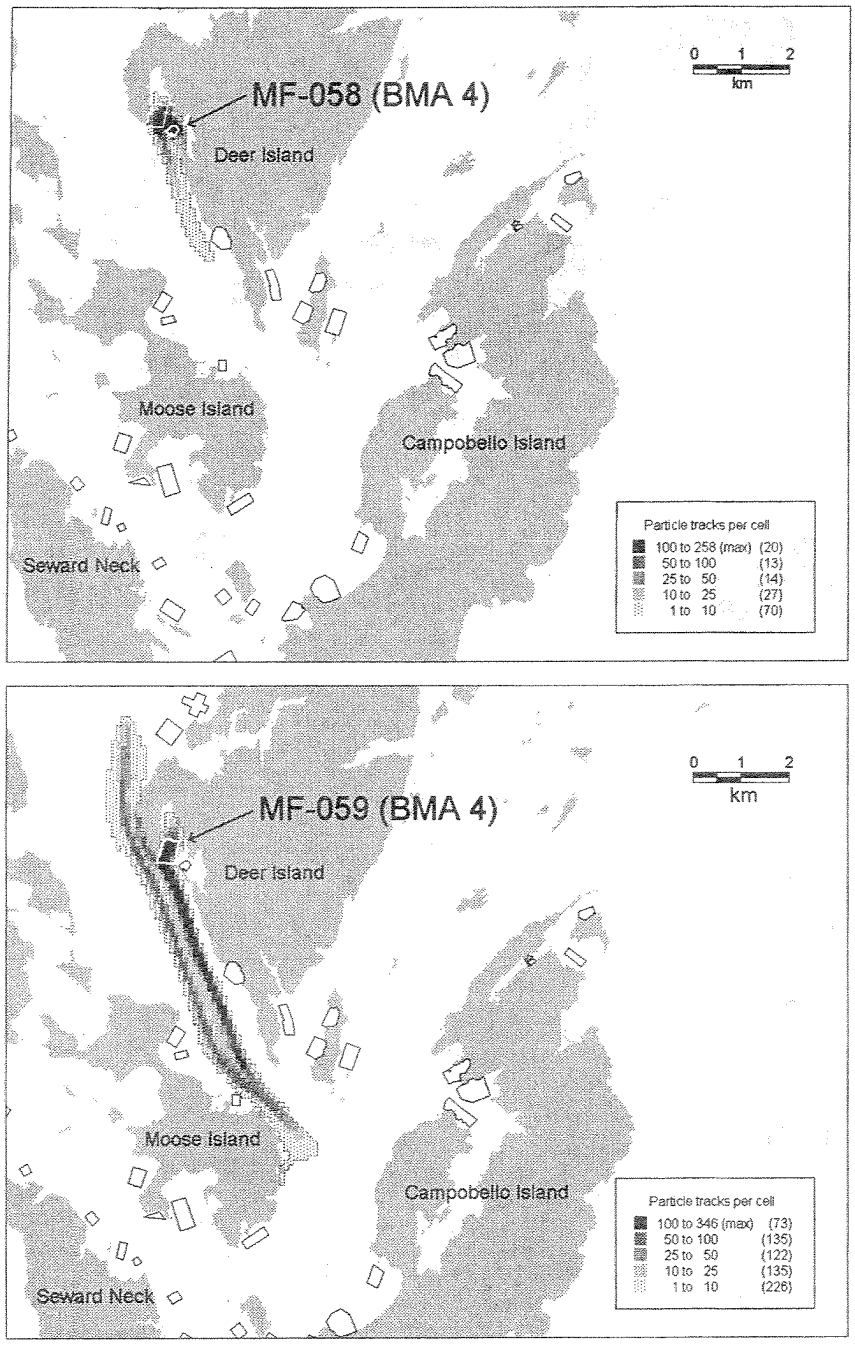


Fig. 18. Model-derived tidal excursion areas of each finfish farm in the southern Deer Island area: BMAs 4-south and 5. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases), at hourly intervals over a 12-h period. Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

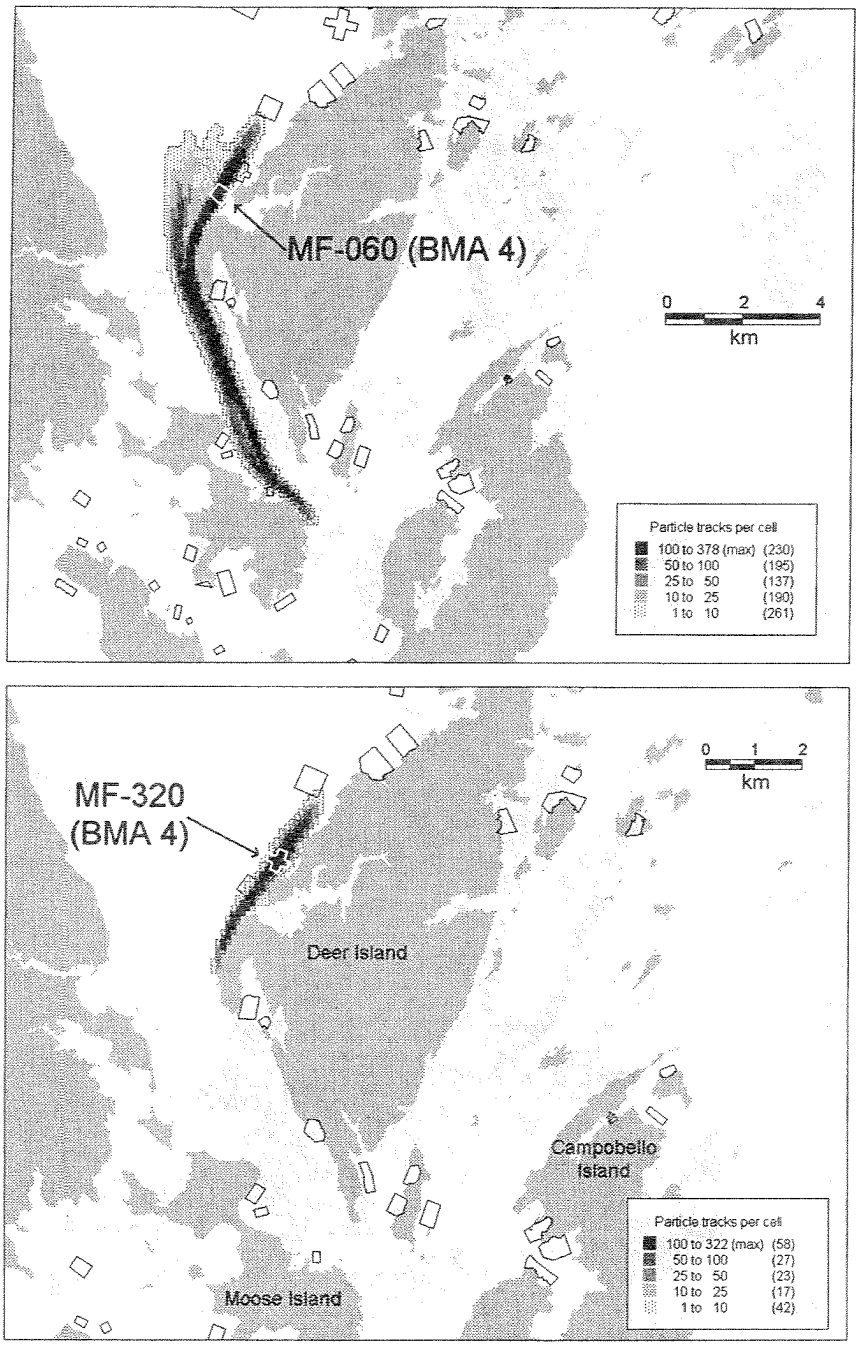


Fig. 18 continued.

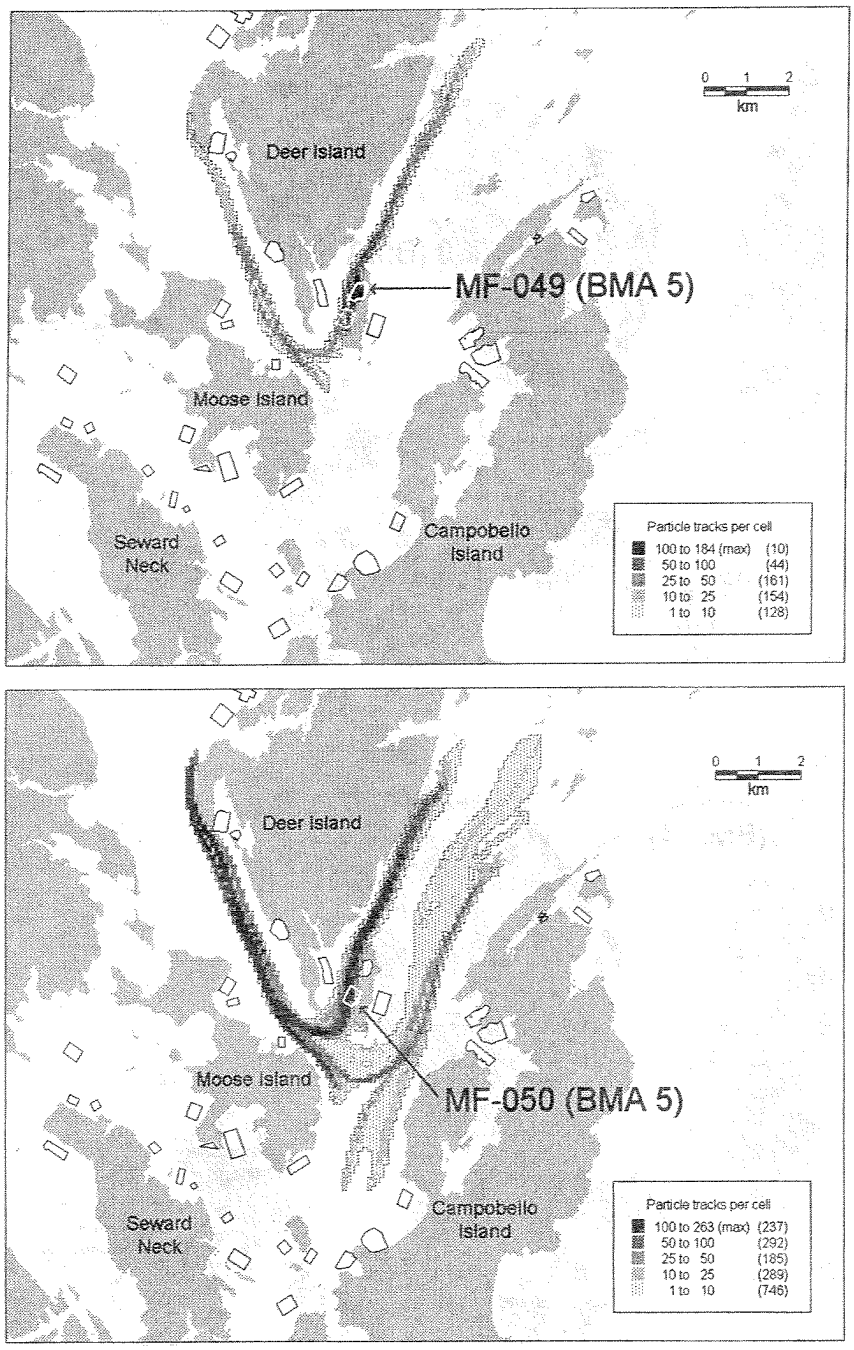
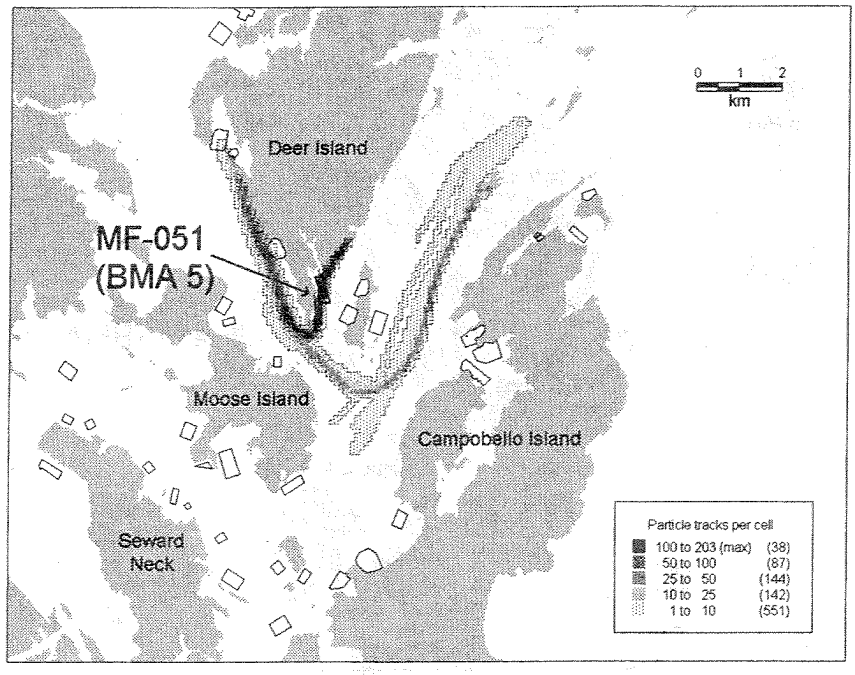


Fig. 18 continued.



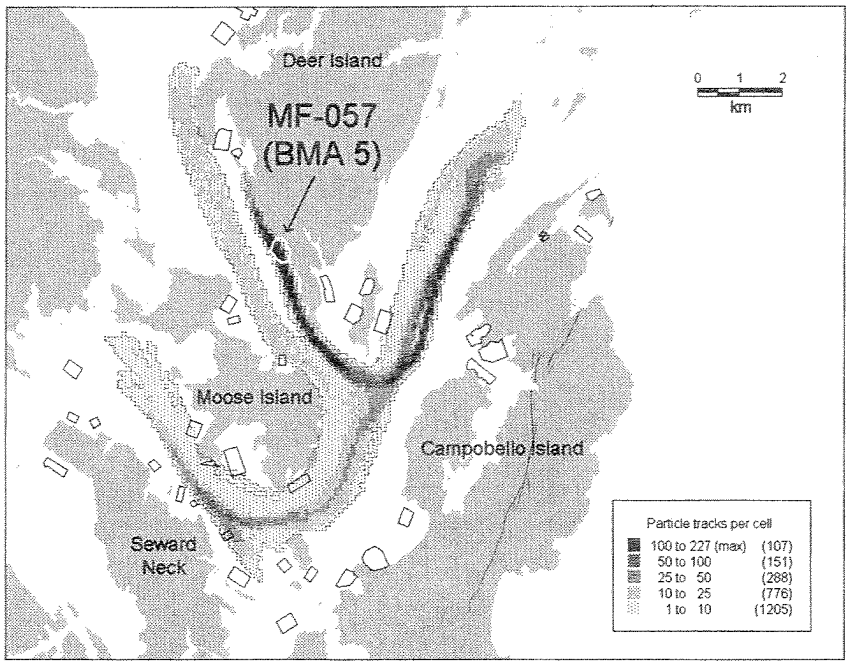


Fig. 18 continued.

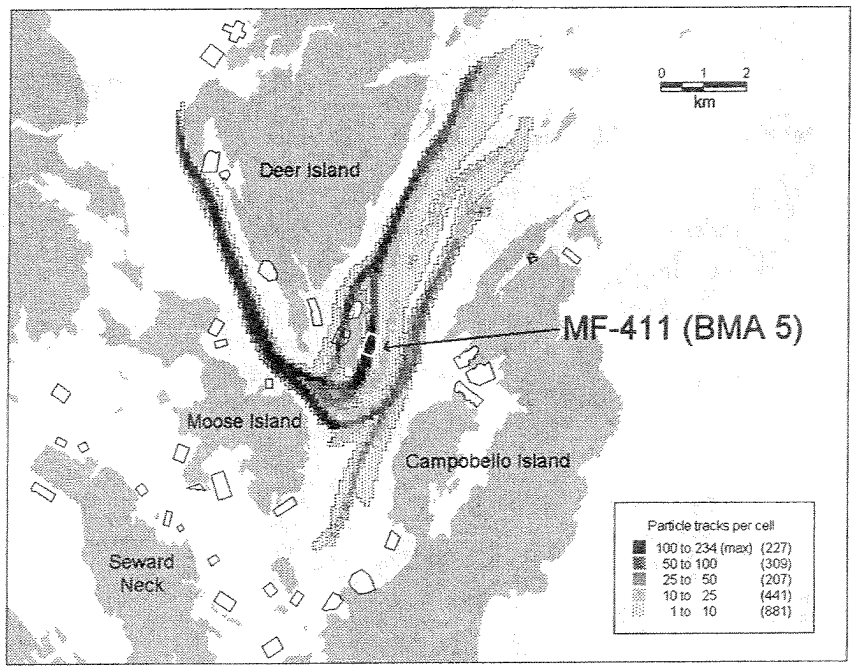


Fig. 18 concluded.

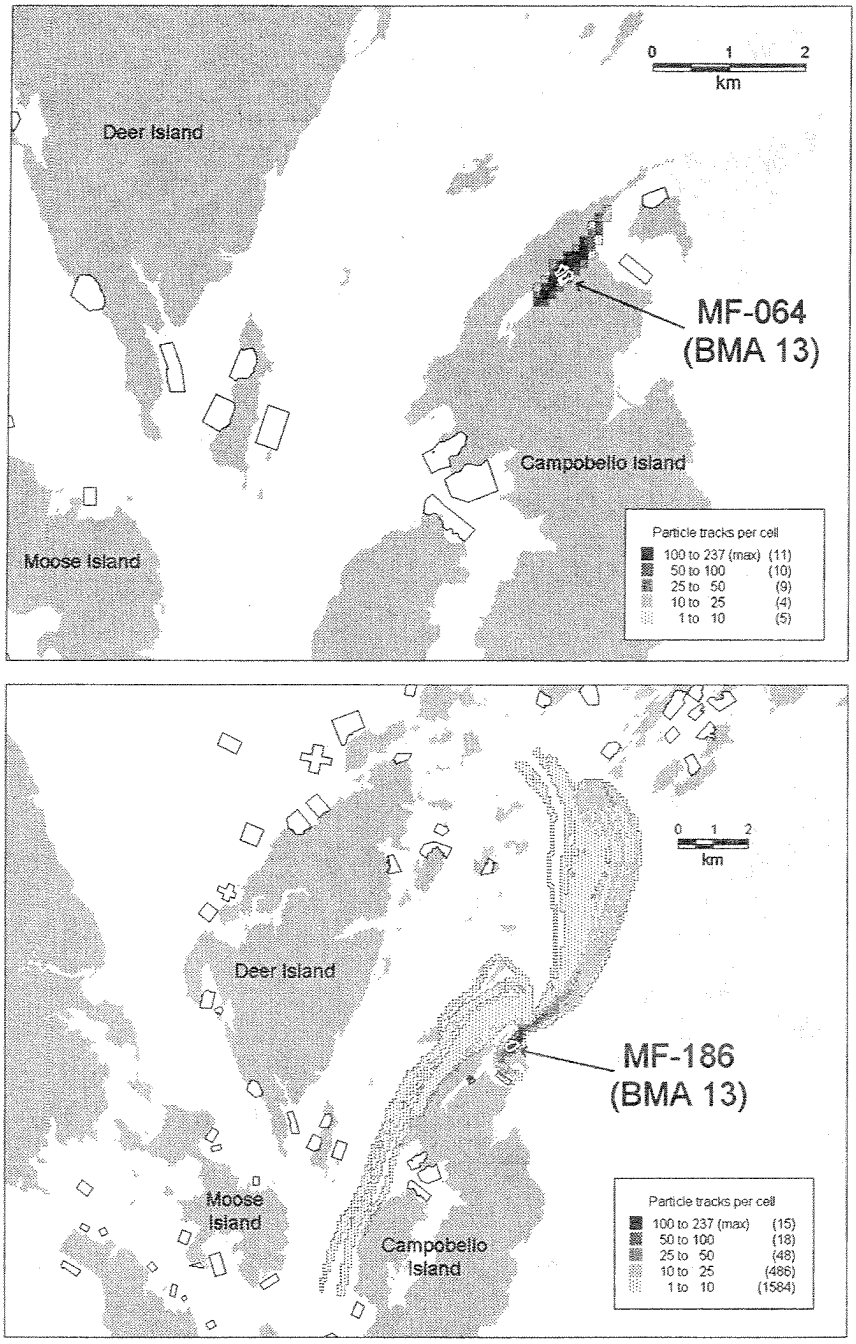
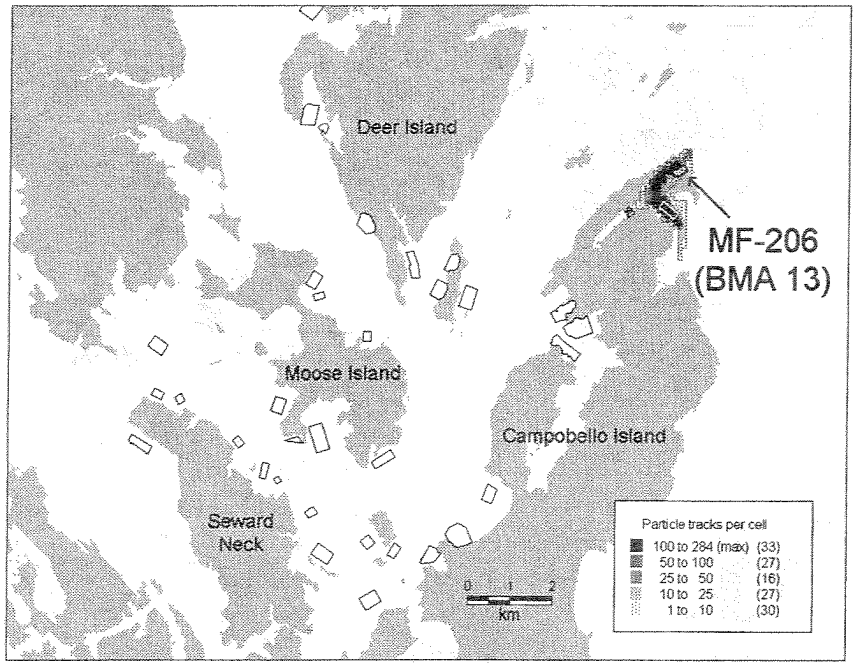


Fig. 19. Model-derived tidal excursion areas of each finfish farm in the Campobello Island area: BMAs 13, 14, and 15. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases), at hourly intervals over a 12-h period. Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.



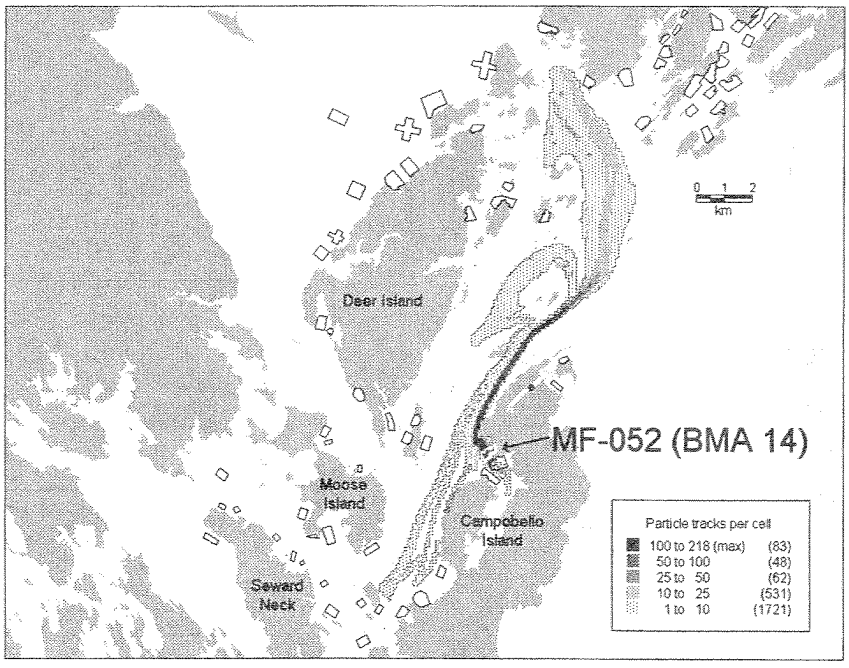
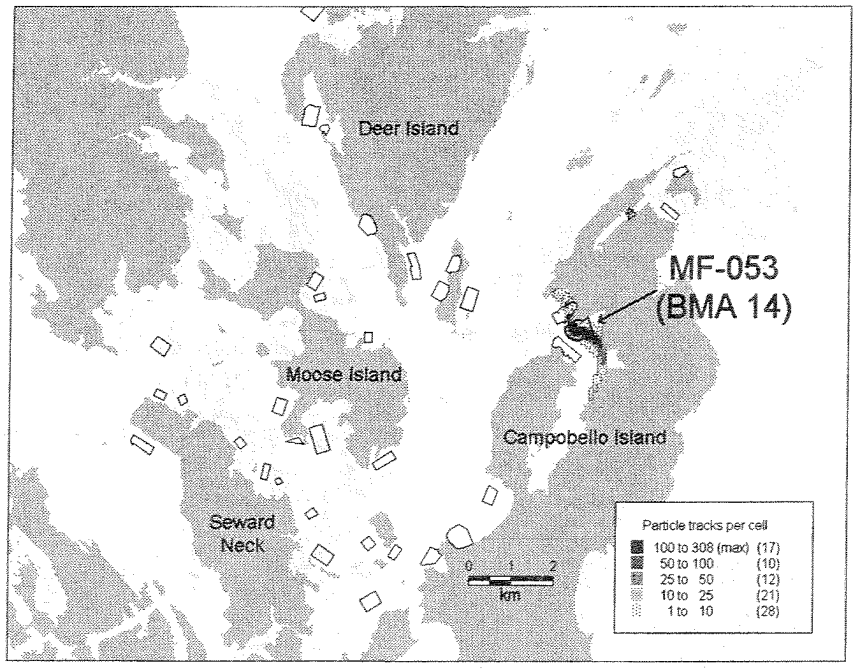


Fig. 19 continued.



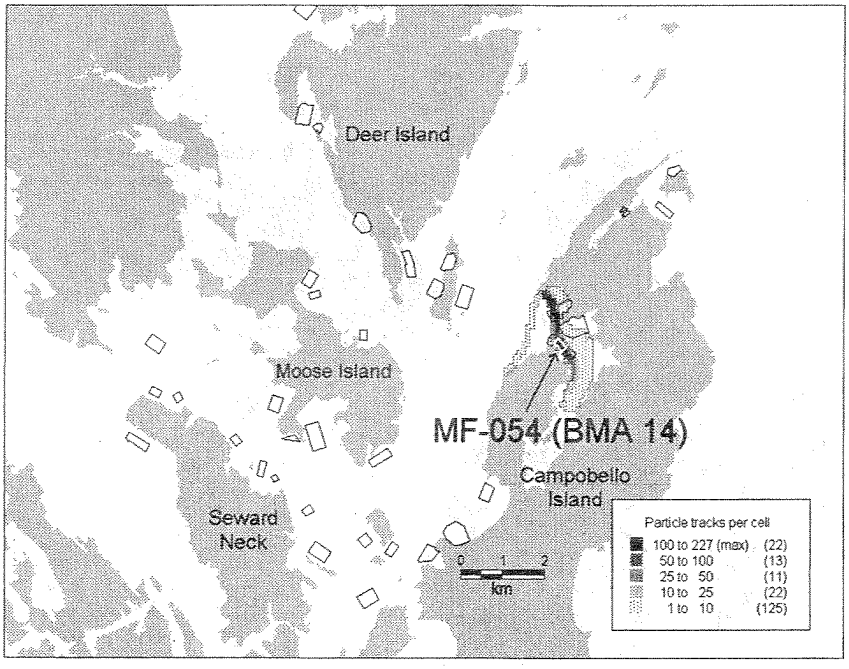


Fig. 19 continued.

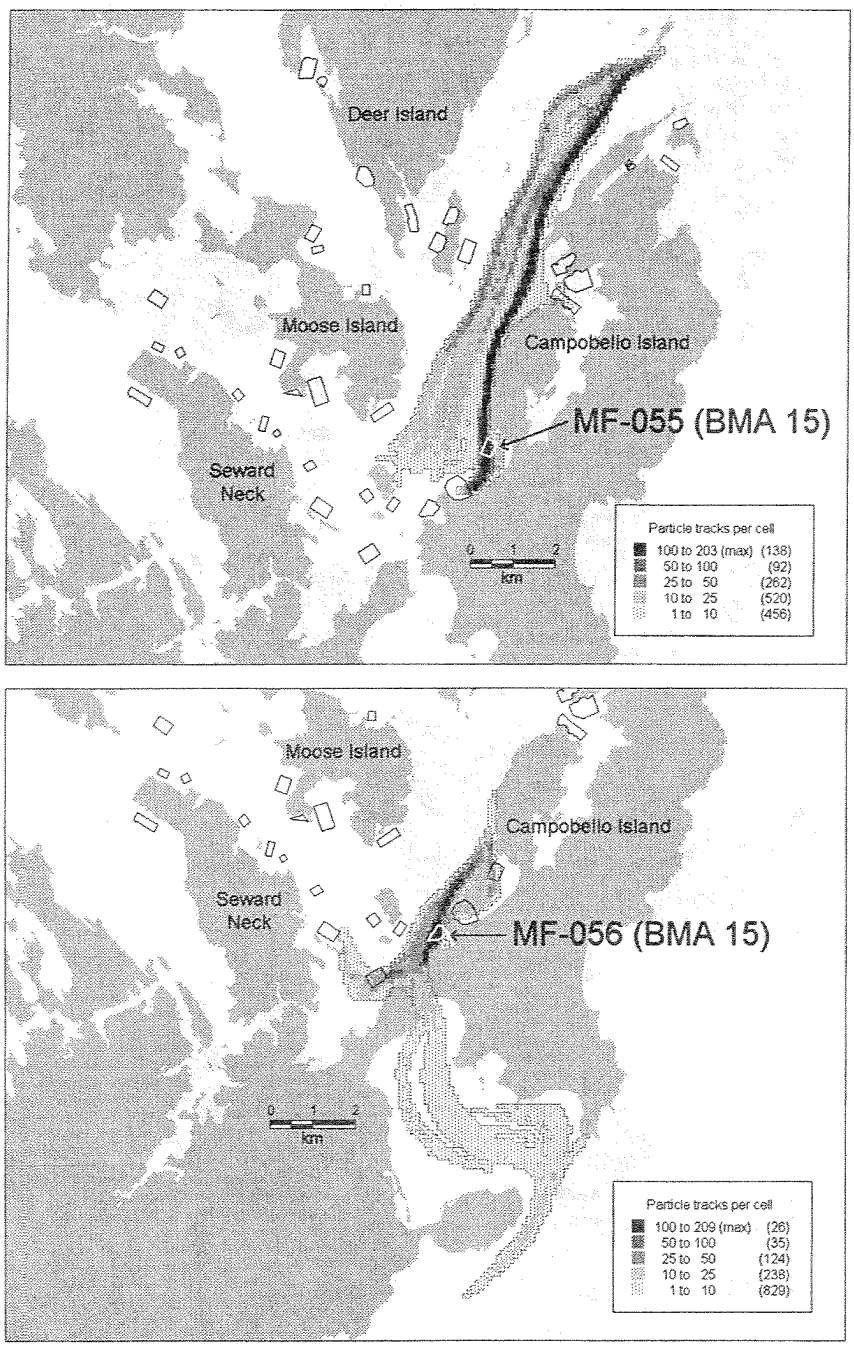


Fig. 19 continued.

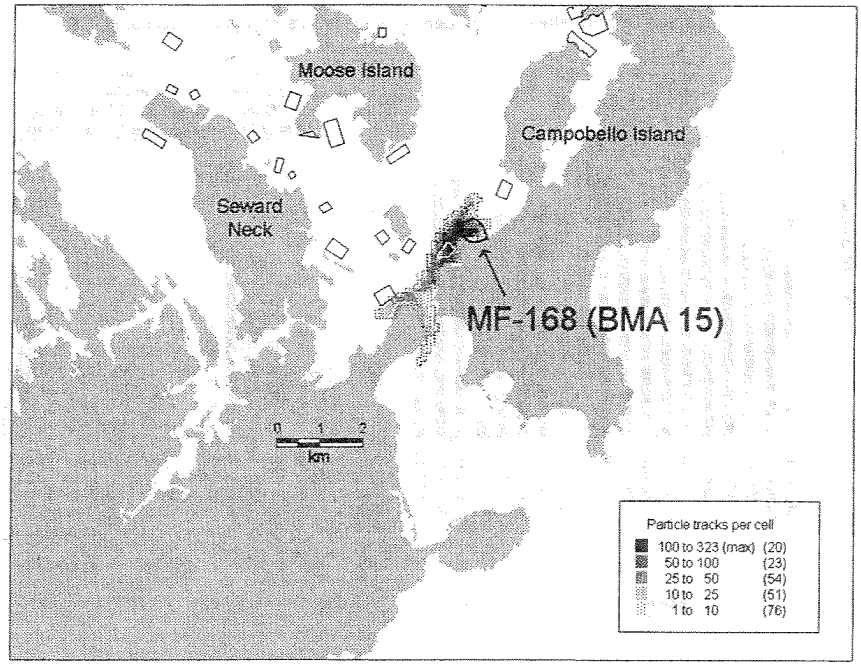


Fig. 19 concluded.

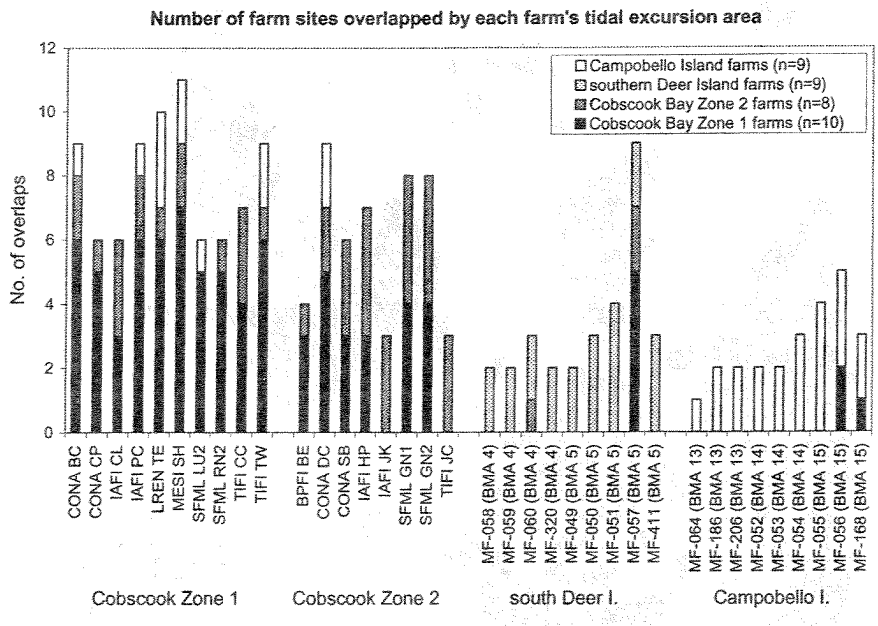


Fig. 20. Number of finfish farm sites overlapped by each farm's tidal excursion area (model-derived) in the Cobscook Bay, southern Deer Island and Campobello Island areas. The x-axis lists the farms from which the tidal excursion areas originated. The numbers include overlaps with the originating farm. BMA = Bay Management Area (New Brunswick).

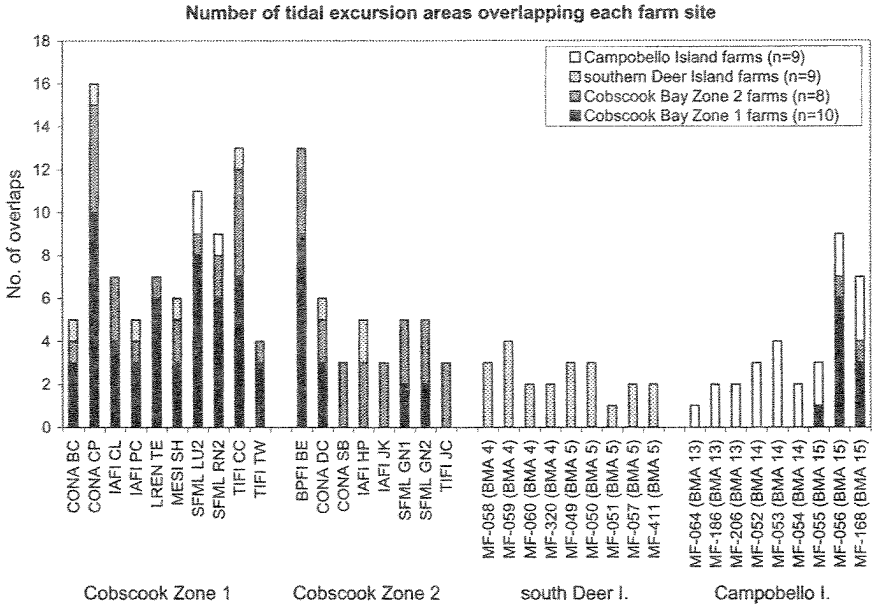


Fig. 21. Number of model-derived tidal excursion areas overlapping each farm site in the Cobscook Bay, southern Deer Island and Campobello Island areas. The x-axis lists the receiving farms. The numbers include overlaps with the originating farm. BMA = Bay Management Area (New Brunswick).

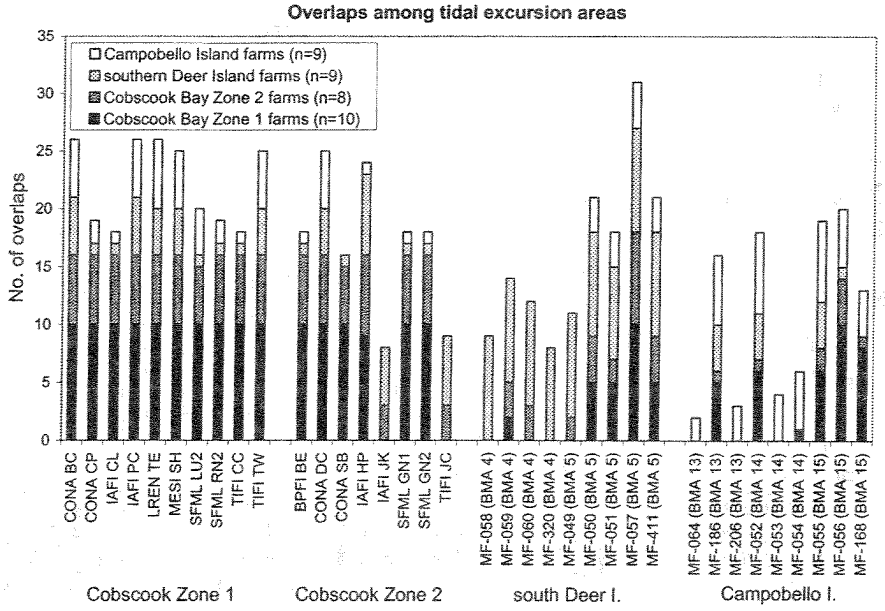
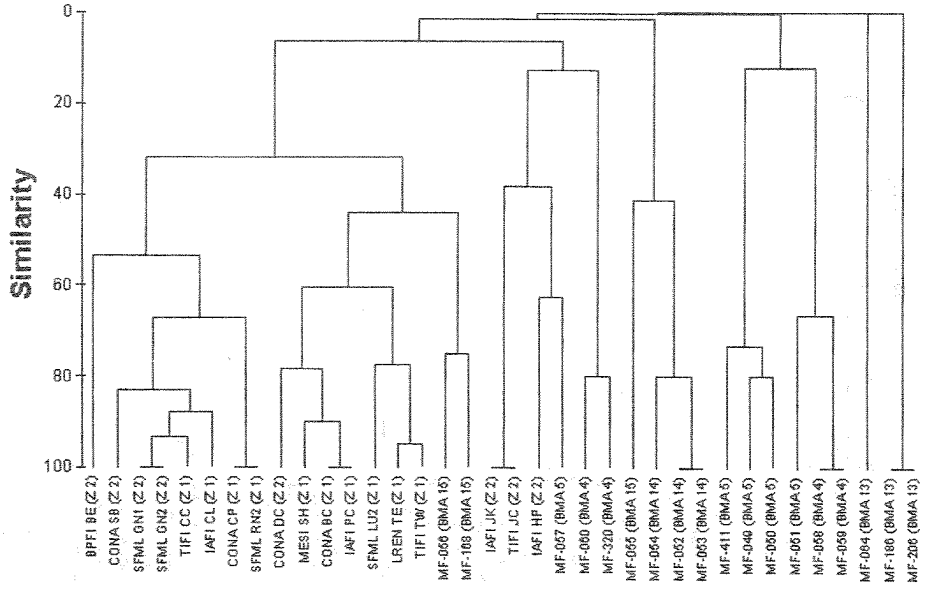
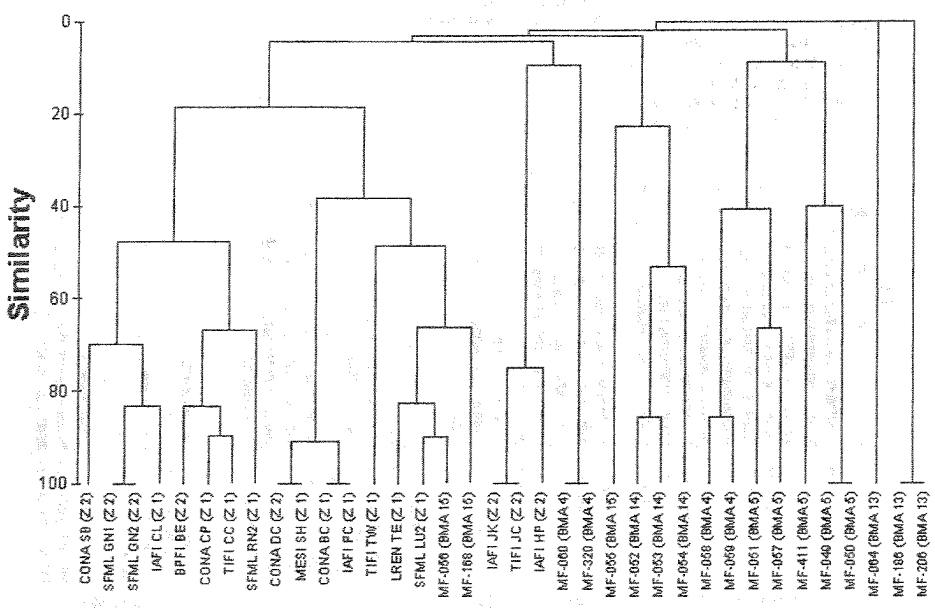


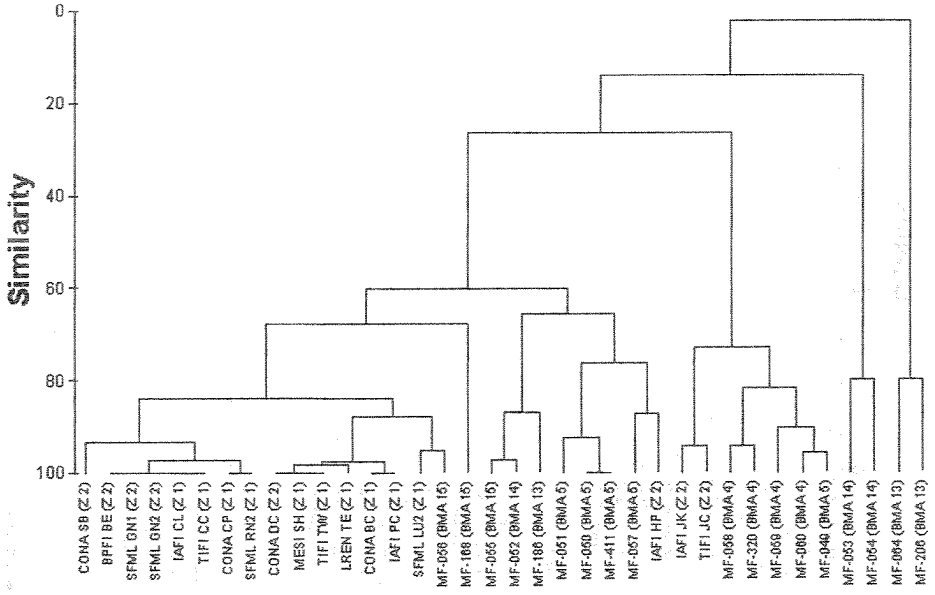
Fig. 22. Number of overlaps among model-derived tidal excursion areas of finfish farms in the Cobscook Bay, southern Deer Island and Campobello Island areas. The numbers include overlaps with the originating farm. BMA = Bay Management Area (New Brunswick).



Fig, 23. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps of finfish farm sites by each farm's model-derived tidal excursion area, for finfish farm sites in Cobscook Bay, southern Deer Island and Campobello Island. The x-axis lists the farms from which the tidal excursion areas originated. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.



Fig, 24. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps by model-derived tidal excursion areas with each finfish farm site in the Cobscook Bay, southern Deer Island and Campobello Island areas. The x-axis lists the receiving farms. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.



Fig, 25. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps among model-derived tidal excursion areas of finfish farms in Cobscook Bay, southern Deer Island and Campobello Island. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.

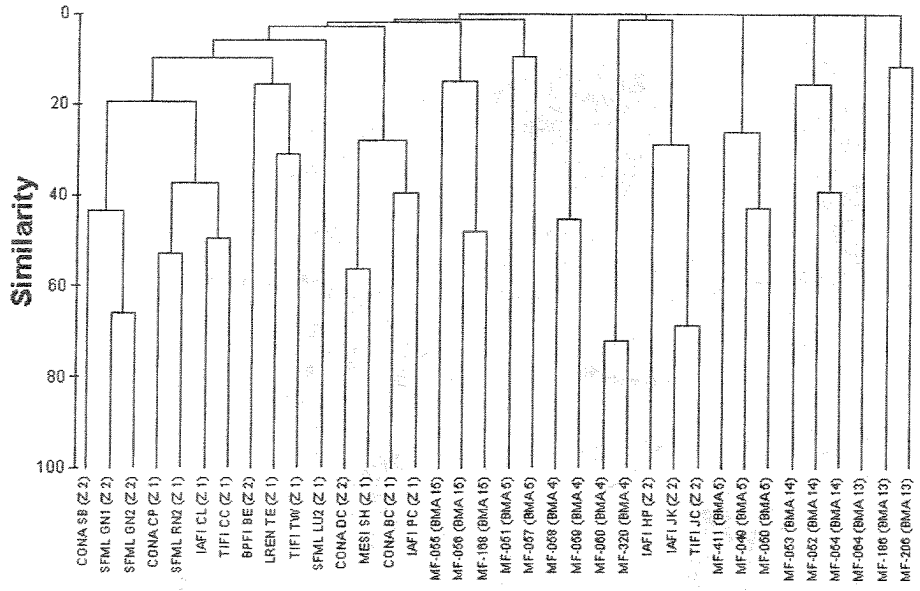


Fig. 26. Cluster analysis using Bray-Curtis similarity coefficients calculated on the number of model-derived particles from each finfish farm which overlap farm sites in the Cobscook Bay, southern Deer Island and Campobello Island areas. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.

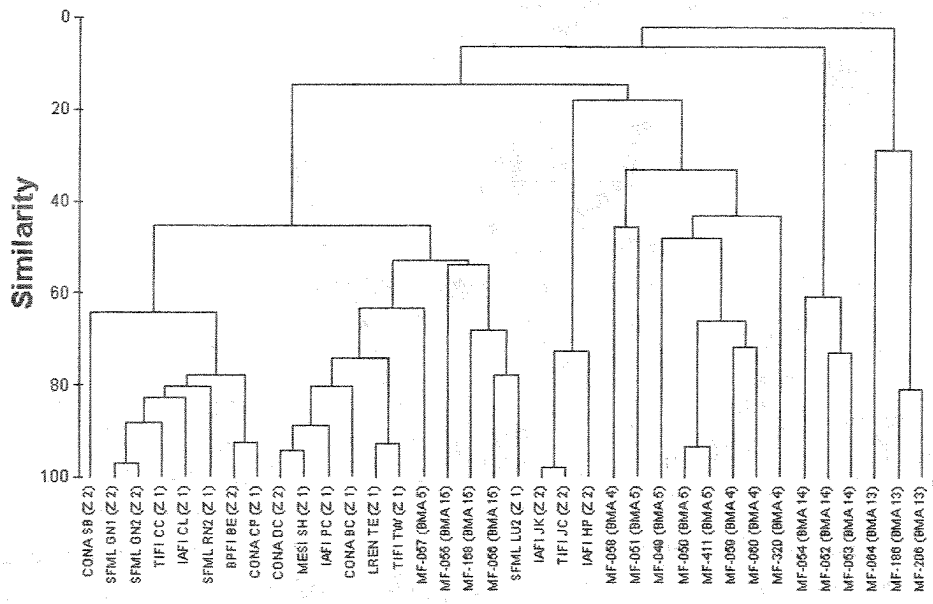


Fig. 27. Cluster analysis using Bray-Curtis similarity coefficients calculated on the number of model-derived particles from each finfish farm which overlap tidal excursion areas of farms in the Cobscook Bay, southern Deer Island and Campobello Island areas. Z = management zones in Cobscook Bay; BMA = Bay Management Areas in New Brunswick.

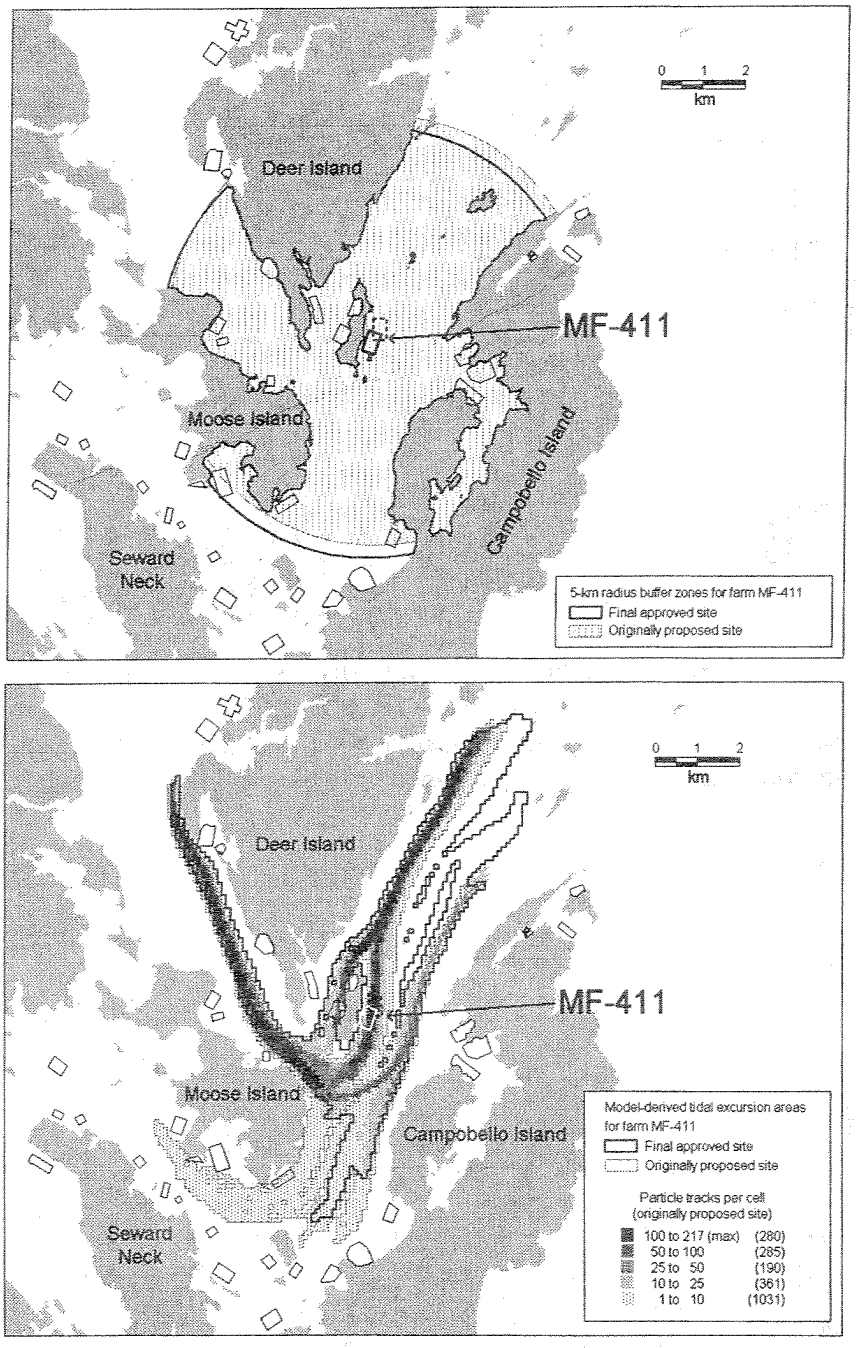


Fig. 28. Comparison of water exchange areas as estimated by 5-km radius buffer zones (top) and model-derived tidal excursion areas (bottom) for the original site proposed for farm MF-411 and the final approved site for this farm. The boundaries of the final approved site are shown as a thick solid line and the boundaries of the originally proposed site are shown as a thick dotted line in the top figure. See Fig. 18 for the particle track density map for the final approved site MF-411.