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Evaluation of Bay Management Area Scenarios for the Southwestern New Brunswick Salmon Aquaculture Industry:

Aquaculture Collaborative Research and Development Program Final Project Report

by

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ABSTRACT

Chang, B.D., Page, F.H., Losier, R.J., Lawton, P., Singh, R., and Greenberg, D.A.. 2007. Evaluation of bay management area scenarios for the southwestern New Brunswick salmon aquaculture industry: Aquaculture Collaborative Research and Development Program final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2722: v + 69 p.

As result of the continued presence of infectious salmon anemia (ISA) at salmon farms in southwestern New Brunswick (SWNB), the provincial government and the aquaculture industry proposed a new Bay Management Area (BMA) framework for this salmon farming region. This new framework included a reduced number of larger BMAs, stocking of farms in each BMA every 3 yr, and mandatory, synchronized fallowing of farms within BMAs before restocking. We examined the potential risks of water-borne disease spread between BMAs, comparing the old and new BMA frameworks. We estimated the zones of influence around farms using simple 2-km and 5-km radius circular zones and more precise estimates of tidal excursion areas, derived from a circulation model. We then examined the overlaps between the estimated zones of influence and fish farms and the overlaps among zones of influence, as predictors of the risks of water-borne disease transmission among the farms. We also used the tidal excursion areas to examine the potential for interactions between finfish farms and commercial fisheries. The model-derived tidal excursion areas of most farms in SWNB, except the eastern mainland area, have been previously reported. A report on the tidal excursion areas of farms in the eastern mainland area is included as an appendix.

RÉSUMÉ

Chang, B.D., Page, F.H., Losier, R.J., Lawton, P., Singh, R., and Greenberg, D.A.. 2007. Evaluation of bay management area scenarios for the southwestern New Brunswick salmon aquaculture industry: Aquaculture Collaborative Research and Development Program final project report. Can. Tech. Rep. Fish. Aquat. Sci. 2722: v + 69 p.

Vu la présence constante de l’anémie infectieuse du saumon (AIS) dans les salmonicultures du Sud-Ouest du Nouveau-Brunswick, le gouvernement provincial et l’industrie de l’aquaculture ont proposé un nouveau système de zones de gestion des baies (ZGB) pour cette région salmonicole. Dans le cadre de ce nouveau système, les ZGB sont plus larges et moins nombreuses, l’ensemencement des fermes salmonicoles de chaque ZGB se fait aux trois ans, et la mise en jachère des fermes situées à l’intérieur des ZGB est obligatoire et se fait de façon synchronisée avant le repeuplement. Nous avons examiné les risques de propagation de maladies d’origine hydrique entre les ZGB, en comparant l’ancien système de ZGB au nouveau système. Nous avons évalué les zones d’influence autour des salmonicultures; pour ce faire, nous avons simplement tracé des zones circulaires de deux à cinq kilomètres de rayon, puis nous avons évalué plus précisément les zones de mouvement des marées déterminées à partir d’un modèle de circulation. Ensuite, nous avons examiné les chevauchements entre les zones d’influence estimatives et les exploitations piscicoles ainsi que les chevauchements entre les diverses zones d’influence et nous les avons utilisés comme agents de prévision des risques de transmission de maladies d’origine hybride parmi les exploitations de salmoniculture. Nous avons également

utilisé les zones de mouvement des marées pour examiner la possibilité d’interactions entre les sites de pisciculture et les lieux de pêche commerciale. Nous avons déjà fait état des zones de mouvement des marées obtenues par modèle de la plupart des exploitations salmonicoles du SONB, sauf en ce qui concerne la partie continentale de l’Est. Un rapport sur les zones de mouvement des marées des fermes de la partie continentale de l’Est est inclus en annexe.

INTRODUCTION

The salmon aquaculture industry of southwestern New Brunswick (SWNB) began in the late 1970s and has grown to become a major economic force in this region. In 2000, the Province of New Brunswick implemented the *Bay of Fundy Marine Aquaculture Site Allocation Policy* (NBDAFA 2000) in order to address the challenges the industry was facing at the time: the need to improve production efficiencies; the need to standardize fish health management practices; and the need to ensure environmental sustainability. At the time, the industry was suffering severe economic losses resulting from an outbreak of infectious salmon anemia (ISA) which started in 1996 (McGeachy and Moore 2003). The policy identified two priority management tools that needed to be implemented: single year-class farming (only one generation of fish on a site at any time), and organization of fish farms within a bay management area (BMA) framework.

Twenty-one BMAs were designated to cover all SWNB finfish farms licensed in 2000; a minor revision in 2002 resulted in 22 BMAs (Fig. 1). Within this BMA framework, salmon farms were required to operate as single year-class operations. Farms operated on a 2-yr rotation system, with smolt entries in either odd or even years. All farms in the same BMA (with a few exceptions) had fish of the same year-class. This BMA framework did not include farms which were approved between 2001 and 2006 along the eastern mainland coast of SWNB (the Maces Bay area and eastward).

The 2000 policy noted that the BMA boundaries were to be based on a combination of oceanographic, fish health and business considerations. Oceanographic considerations were included because studies in Norway in the 1990s indicated that ISA could be spread passively in seawater between farms (Vågsholm et al. 1994; Jarp and Karlsen 1997). Studies in Scotland and the SWNB/Maine area have also indicated that passive transport of ISA in seawater has occurred at the local scale (JGIWG 2000; Murray 2003; McClure et al. 2005; Gustafson et al. 2007). The policy stated that the oceanographic considerations were to be based on existing information; however, in 2000, the oceanographic information available for SWNB was very limited. We subsequently conducted a project in which we used a water circulation model to predict the potential for water-borne spread of ISA among farms in SWNB (Page and Chang 2002; Page et al. 2004; Chang et al. 2005a). The results of that project showed that there was considerable water exchange (within one tidal cycle) among adjacent BMAs.

Despite the implementation of the 2000 policy and BMA framework, ISA continued to cause significant economic impacts in SWNB (M. Beattie, New Brunswick Department of Agriculture and Aquaculture [NBDAA], St. George, NB, pers. comm.). Analysis of ISA prevalence data suggests that, in addition to the shortcomings of the BMA framework from the oceanographic point of view, there are other factors contributing to the persistence of ISA. For example, the 2000 policy allows for holdovers of fish on sites (i.e. up to 20% of market fish can remain on a site when the new year-class smolts are introduced), and these holdovers appear to be a major factor in the continuing prevalence of ISA in SWNB (M. Beattie, pers. comm.).

A government-industry task force was set up in 2004 with a mandate to review the challenges then facing the salmon farming industry of Atlantic Canada, and to make recommendations to foster a sustainable industry. The report of the task force (Anon. 2005) and the subsequent sustainability plan developed by the SWNB industry (NBSGA 2005) recommended the creation of a new system of effective BMAs, based on biophysical environment, risk management (fish health, environment), and infrastructure needs. In order to accomplish this, sites would have to change from a 2-yr rotation system to a 3-yr system, with a mandatory fallowing period (synchronized among all farms in the same BMA) between consecutive year-classes. Such a system would eliminate holdovers, while giving farmers the flexibility to harvest fish on a market schedule, rather than a production cycle. The reports also noted the need for aquaculture to be integrated with other coastal resource users.

In response to those reports, an industry-government steering committee was set up to oversee the development of a new BMA framework for the SWNB fish farming industry. This project was initiated in 2005 to assist in the development of the new BMA framework. The project was a collaboration between researchers in the Fisheries and Oceans Canada (DFO) Maritimes Region and the New Brunswick Salmon Growers' Association (NBSGA), with funding from the DFO Aquaculture Collaborative Research and Development Program (ACRDP).

The objectives of this project were to produce a series of maps describing the spatial distribution of aquaculture sites, estimates of the zones of potential near-surface influence around farms, and the distribution of major fishery resources in the coastal zone of SWNB. Zones of influence around farms were estimated using a simple method, drawing circular areas around farms, and a more complex method, using a circulation model to estimate the tidal excursion areas for each farm. The model-derived tidal excursion areas of farms in SWNB, with the exception of the eastern mainland area, have been previously reported (Page et al. 2005; Chang et al. 2005b, c, 2006a, b). The tidal excursion areas of farms in the eastern mainland area of SWNB were estimated as part of this project, and are reported in Appendix 1.

The maps were then used to determine the overlaps of the estimated zones of influence with other farms and with the major fisheries resources. Overlap analyses were produced for each of several BMA framework scenarios that were suggested. The results were communicated to industry and regulators at various meetings. This report includes only the analyses for the old BMA framework that was in place from 2002-2005 and the new BMA framework which was implemented starting in 2006 (Fig. 2).

The new BMA framework includes three large BMAs: BMA 1 (Passamaquoddy Bay, Deer Island, and most of Campobello Island), with smolt entries in 2006, 2009, and 2012; BMA 2, comprised of sub-areas 2a (Back Bay, Bliss Harbour, and Lime Kiln Bay) and 2b (eastern Grand Manan Island, including White Head Island), with smolt entries in 2007, 2010, and 2013; and BMA 3, comprised of subareas 3a (the eastern mainland coast of SWNB, from Beaver Harbour to Haleys Cove) and 3b (southern Grand Manan Island, excluding White Head Island), with smolt entries in 2008, 2011, and 2014. There are also three much smaller BMAs: BMA 4 (Harbour de Loutre, Campobello Island); BMA 5 (Dark Harbour, Grand Manan Island); and BMA 6 (Letete Passage). Smolt entry times are not specified for BMAs 4 and 5, while BMA 6 is designated as an alternate species zone (non-salmonids). Beaver Harbour (within BMA 3a) has been designated as a potential wharf area for the aquaculture industry.

METHODS

Maps were created using MapInfo Professional® version 8.0 software. The coordinates for farm and BMA boundaries and the Allowable Production Levels (APLs) of farms in October 2005 were provided by NBDAA (G. Smith, St. George, NB); the inclusion of APLs (the maximum number of fish allowed on a farm) in site licenses was discontinued after 2005. We included 94 finfish farm sites in our analyses. Excluded were two farms which have been inactive for several years (MF-333 in Letete Passage and MF-361 in the Magaguadavic River estuary) and three recently deleted sites (MF-064 in Head Harbour, Campobello Island; MF-255 at Macs Island; and MF-362 at Tinkers Island). Included was a recently approved, but not yet active, site at Haleys Cove (MF-494), east of Maces Bay.

Simple estimates of the zone of influence around each farm were made by drawing 2-km and 5-km radius circular areas centred on each farm site, using the MapInfo buffer tool. Areas of land within the circular areas were excluded, as were areas of water that were cut off from the farm site by land. More precise estimates of the tidal excursion areas around farms in SWNB were made using a three-dimensional particle tracking model (Greenberg et al. 2005) that was customized to our geographic domain of interest. The model has the capability of including boundary forcing using multiple tidal constituents, internal water density, and surface winds as current driving forces; however, the customized model for the SWNB area was run using only boundary forcing by the principal lunar semi-diurnal tidal constituent (M_2). The model-derived tidal excursion areas for most finfish farms in SWNB (with the exception of the eastern mainland area) have been previously published in a series of technical reports (Page et al. 2005; Chang et al. 2005b, c, 2006a, b). The tidal excursion area for farm MF-256 in this report is slightly different than that previously reported (Chang et al. 2005c, 2006b) due to a recent adjustment in the location of this farm. The model-derived tidal excursion areas of farms in the eastern mainland area of SWNB were estimated as part of this project, and are reported in Appendix 1. The combined zone of influence of all farms in a BMA was determined by merging the individual zones of influence of all farms in the BMA.

We determined the overlaps of each farm's zone of influence with other farm sites using the three estimates of zones of influence (2-km and 5-km radius circular areas, and model-derived tidal excursion areas). We compared the numbers of overlaps using the old and new BMA frameworks. We also examined the overlaps among farms' zones of influence.

To estimate the potential for interactions between finfish farming and commercial fisheries in SWNB, we used geo-referenced fisheries landings data, reported to the nearest minute (latitude and longitude), from the DFO commercial fisheries landings database. We selected the most economically important fisheries in SWNB for which geo-referenced data were available: herring (*Clupea harengus harengus*), sea scallop (*Placopecten magellanicus*), sea urchin (*Strongylocentrotus droebachiensis*), and groundfish (all species combined). Maps were created showing the total reported catches for 2000-2003 within 1 × 1 minute grid squares. Data on herring weir locations and catches for 2000-2003 were provided by M. Power (DFO, St. Andrews Biological Station). We determined the volume of landings of these species taken within the new BMAs and within farm tidal excursion areas. We also expressed these volumes in terms of percentages of the total landings for these species in SWNB. For the latter, we defined the SWNB region as the portion of the Northwest Atlantic Fisheries Organization (NAFO) fishing area 4Xs west of 66°14’15” West longitude, plus the portion of NAFO area 5Yb immediately west of NAFO area 4Xs to the Canada-USA border (including most of the disputed “grey” zone) and north of 45°16’00” North latitude (marine surface area of 5 129 km^2).

Geo-referenced landings data were not available for lobster (*Homarus americanus*), which is currently the most economically important fisheries species in SWNB. As an estimate of geo-referenced lobster habitat, the seafloor less than 60 m deep was classified into three habitat types: soft bottom, cobble/gravel, and rock. Harding (1992) reported that juvenile and adult lobsters prefer rock or cobble substrates over soft (sand or mud) substrate. Juvenile lobster density data collected in SWNB by Lawton (1993) indicated that rock and cobble/gravel substrates in shallow waters were the best lobster nursery habitats.

RESULTS

GENERAL INFORMATION ON THE OLD AND NEW BMA FRAMEWORKS

Information on the BMA sizes, numbers of farms, lease areas of farms, and total allowable production levels for the old and new BMA frameworks is given in Table 1. The old BMA framework had 22 BMAs, plus some farms outside of the BMA structure (Fig. 1). The new BMA framework has five large BMAs, plus three small ones, encompassing all licensed fish farms in SWNB (Fig. 2). The three large BMAs in the new framework (BMAs 1, 2 [2a+2b], and 3 [3a+3b]) include 93% of the 94 licensed fish farms and 95% of the estimated production capacity (based on APLs in 2005). The total area of the new BMAs (637.9 km^2) is larger than the total area of the old BMAs (431.5 km^2), mainly because new BMA 3a includes farms in the Maces Bay area and eastward which were not included in the old BMA framework. Among the three large BMAs in the new framework, the number of farms and the total APL in new BMA 3 are both considerably smaller than those in new BMAs 1 and 2 (Table 1).

SIZES OF ZONES OF INFLUENCE AROUND FARMS

Data on the mean sizes of the zones of influence of all farms in each old BMA, as estimated by 2-km and 5-km radius circular zones and model-derived tidal excursion areas, are given in Table 2a. Analogous data for the new BMAs are given in Table 2b (see also Fig. 3, 4, and 5). In most BMAs there were some overlaps among the zones of influence of adjacent farms, so the areas of the combined zones of influence were usually less than the sums of the areas of the individual zones of influence.

The circular zones of influence predicted similarly sized zones for all farms, with differences among farms due only to the amount of land within the circular areas. The 2-km radius circular zones of influence were mostly confined within their new BMAs; consequently, the combined 2-km radius zones of influence were mostly smaller than the corresponding new BMAs, except in the cases of the smallest of the new BMAs (4, 5, and 6). Comparing the three large BMAs, the largest combined 2-km radius zone of influence was for BMA 1 (158.4 km^2), followed by BMA 3 (113.3 km^2) and BMA 2 (95.6 km^2). The 5-km radius circular zones of influence often extended beyond the new BMA boundaries; consequently, the areas of the combined 5-km radius zones of influence were larger than the corresponding new BMAs. Comparing the three large BMAs, the largest combined 5-km radius zone of influence was for BMA 3 (384.8 km^2), followed by BMA 1 (367.2 km^2) and BMA 2 (292.9 km^2).

The model-derived tidal excursion areas were not circular in shape and showed much larger differences in marine surface areas among farms, due to differences in the water circulation in different locations. The tidal excursion areas were small and confined within their new BMAs where water velocity magnitudes were low, such as in Passamaquoddy Bay (old BMA 1a) and Beaver Harbour (old BMA 11). Tidal excursion areas were largest, extending beyond the new BMA boundaries, where water velocities were high, such as in southern Deer Island (old BMA 5), southern Grand Manan Island (old BMA 21), and especially White Head Island (old BMA 19). The average sizes of the model-derived tidal excursion areas were generally similar to those of the 2-km circular zones, and much smaller than those of the 5-km circular zones. The main exception was for farms in the White Head Island area (old BMA 19), where the model-derived tidal excursion areas were similar in size to the 5-km circular zones. The circular zones of influence, by definition, predicted maximum displacements of 2 and 5 km. The maximum particle displacements in the model-derived tidal excursions averaged 4.1 km (Table 3), with a range among individual farms of 0.3-15.0 km. Comparing the three large BMAs, the largest combined tidal excursion area was for BMA 2 (163.7 km^2), followed by BMA 1 (113.9 km^2) and BMA 3 (102.2 km^2).

OVERLAPS OF ZONES OF INFLUENCE WITH FISH FARMS AS AN INDICATOR OF THE RISK OF DISEASE SPREAD

The average number of farms within each old BMA, whose zones of influence (as estimated by 2-km and 5-km radius circular areas and model-derived tidal excursion areas) overlapped other farm sites is given in Tables 4a-c; the equivalent values for the new BMAs are given in Tables 5a-c. There were no differences between the old and new BMA frameworks in the total numbers of farms whose zones of influence (using any of the three estimation methods) overlapped any other farm sites. This was because both old and new BMA frameworks were based on the same farm locations. The total number of farms whose zones of influence overlapped any other farm sites was highest with the 5-km radius circular zones of influence and lowest with the model-derived tidal excursion areas (in both old and new BMA frameworks).

Except where there were only one or two farms in a BMA, there were more overlaps of zones of influence with farm sites in the same BMA than with farm sites in other BMAs. With the new BMA framework, there were small increases in the numbers of farms whose zones of influence overlapped other farm sites in the same BMA, while there were large decreases in the numbers of farms whose zones of influence overlapped farm sites in other BMAs (Table 6). For the 2-km circular zones of influence and the model-derived tidal excursion areas, the total number of farms whose zones of influence overlapped farm sites in other BMAs in the new BMA framework decreased to three and four, respectively, while for the 5-km circular zones of influence, there were 35, which was less than half the number under the old BMA framework. For the overlaps of model-derived tidal excursion areas with farm sites in other BMAs, three of these involved farms in new BMA 6 which has been designated for alternate species only; the tidal excursion areas of two farms in BMA 6 overlapped with a farm site in BMA 2a, while the tidal excursion area of the westernmost farm in BMA 2a overlapped the easternmost farm site in BMA 6. The only other overlap of a tidal excursion area with a farm in another of the new BMAs involved the tidal excursion area of a farm in southern Campobello Island with a farm site in BMA 4 (Harbour de Loutre, Campobello Island).

Similar data for the overlaps among zones of influence are given in Tables 7-9. As would be expected, the numbers of overlaps among zones of influence were higher than the numbers of overlaps of zones of influence with farm sites. The total numbers of overlaps among zones of influence (using any of the three estimation methods) did not change between the old and new BMA frameworks. The total number of overlaps among zones of influence was highest using the 5-km radius circular estimates and lowest with the model-derived tidal excursion areas (in both old and new BMA frameworks). The numbers of overlaps with zones of influence of farms in the same BMA increased slightly under the new BMA framework, while the numbers of overlaps with zones of influence of farms in other BMAs and Cobscook Bay decreased, especially using the 2-km radius circular zones of influence and the model-derived tidal excursion areas (Table 9). The overlaps of model-derived tidal excursion areas of farms in new BMA 1 with those of farms in other BMAs involved farms in new BMA 4 (Harbour de Loutre, Campobello Island), except for one farm (near the northern tip of Campobello Island) whose tidal excursion area also overlapped with those of farms in new BMAs 2a and 6. For farms in new BMA 2a, the overlaps of tidal excursion areas with those of farms in other BMAs involved farms in new BMA 6, except for the westernmost farm in new BMA 2a, whose tidal excursion area also overlapped with those of farms in new BMAs 1, 4, and 6. There were overlaps of the tidal excursion areas of five farms in new BMA 2b (eastern Grand Manan Island) with those of two farms in new BMA 3b (southern Grand Manan Island).

OVERLAPS OF NEW BMAs AND ZONES OF INFLUENCE WITH FISHERIES RESOURCES

Herring weirs are located nearshore (Fig. 6), with more than half of the SWNB catch during 2000-2003 occurring within the new BMAs (Table 10a). Many herring weirs are located in areas not utilized for fish farming, such as the Wolves Islands, the eastern shore of Campobello Island, and northern Grand Manan Island. Herring purse-seining occurred mostly further offshore, with less than 10% of the 2000-2003 SWNB catch occurring within the new BMAs (Fig. 6, Table 10a). About half of the SWNB scallop catch in 2000-2003 occurred within the new BMAs, mostly in the Maces Bay area (new BMA 3a) and Grand Manan Island (new BMAs 2b and 3b) (Fig. 7, Table 10a). The sea urchin fishery is mostly inshore, with 85% of the SWNB catch occurring within the new BMAs (Fig. 8, Table 10a). The SWNB groundfish fishery is mostly offshore, with less than 3% occurring within the new BMAs (Fig. 9, Table 10a).

The overlaps of farms’ zones of influence (as estimated by the model-derived tidal excursion areas) with the herring weir, scallop and sea urchin fisheries were smaller than the overlaps of these fisheries with the new BMAs (Fig. 10-13; Table 10b). The largest overlap was with the sea urchin fishery (64% of the SWNB catch), followed by the scallop (26%) and herring weir (17%) fisheries. For the herring purse-seine fishery, the overlap of the fishery with tidal excursion areas (10% of the fishery) was slightly larger than the overlap of the fishery with BMAs (7% of the fishery), while for the groundfish fishery, the overlap of the fishery with tidal excursion areas was similar in magnitude to the overlap of the fishery with BMAs (3% of the fishery) (Table 10b).

For the lobster fishery, geo-referenced catch data were not available. The potential for impacts of finfish farming on preferred lobster habitat was estimated by examining the overlaps of BMAs, farm lease areas, and model-derived tidal excursion areas of farms with rock, cobble/gravel, and soft sediment seafloor habitats at depths less than 60 m (Fig. 14). More than 75% of the cobble/gravel, about 25% of the rocky seafloor, and 37% of the soft sediment seafloor less than 60 m depth in SWNB occurred within the new BMAs (Table 11a). Only 3% of the cobble/gravel and less than 1% of the rocky and soft sediment seafloor overlapped with farm lease areas (Table 11b), while 56% of the cobble/gravel, 28% of the rocky seafloor, and 21% of the soft sediment seafloor overlapped with the farm tidal excursion areas (Fig. 15, Table 11c).

DISCUSSION

The total area of farm leases and their zones of influence did not change between the old and new BMA frameworks, since there were no changes in the numbers of farms, their sizes, or their locations, just changes in the BMA structure. The three large BMAs in the new framework include approximately 95% of the production capacity (based on APLs in 2005). Because the new BMA framework is meant to allow a 3-yr rotation cycle, these three BMAs should have approximately equal fish holding capacities. However, BMA 3 has significantly lower capacity than BMAs 1 or 2 (based on APLs). This means that there is the need to either increase capacity in BMA 3 or decrease capacity in BMAs 1 and 2 in order attain balanced production among the three year-classes.

ESTIMATES OF ZONES OF INFLUENCE AROUND FISH FARMS

The model-derived tidal excursion areas were derived from a circulation model that uses the principal semi-diurnal lunar tidal component (M_2), together with precise data on the coastline and bathymetry for this area. They should, therefore, produce more precise estimates of the zones of influence around fish farms, compared to simple circular zones. One clear difference is that the model-derived zones of influence were generally not circular in outline. The 2-km radius circular zones were, on average, similar in area to the model estimates, but underestimated the maximum displacement of particles during one tidal cycle. The 5-km radius circular zones, on the other hand, predicted a maximum particle displacement that was similar to the model predictions, but predicted a zone of influence much larger in area than the model predictions. Overall, the 5-km circular zones predicted the highest numbers of overlaps between zones of influence and farm sites, and among zones of influence, while the model-derived tidal excursion areas predicted the fewest numbers of overlaps.

For most of SWNB, the M_2 tidal component is by far the most important influence on water circulation, so the tidal excursion areas estimated from model runs using this tidal constituent alone should be good predictions of the overall tidal excursion areas. However, in some areas, such as northern Passamaquoddy Bay, where currents are relatively low, the M_2 tidal component is relatively less important and other forces, such as wind, are relatively more important. Therefore, in such areas, the tidal excursion areas based on model runs using the M_2 tide alone are probably underestimates, and accordingly, the intensity of overlaps of estimated tidal excursion areas from farms in northern Passamaquoddy Bay with other farms or fisheries resources would be underestimates.

FISH HEALTH ISSUES

In Norway and Scotland, hydrographically-based management zones have been used to help control the spread of water-borne diseases, such as ISA, among fish farms. In Norway, control zones were established around ISA-infected farms (Norwegian Animal Health Authority 2002). These are circular zones with a radius of at least one tidal excursion, but not less than 5 km. Within the control zones, there are requirements for fallowing and disinfection of farms, restrictions on fish transfers, and increased fish health surveillance. In addition, larger surveillance zones are established, consisting of all farms whose tidal excursions overlap with the infected farm's control zone. In Scotland, control zones are circular areas with a radius of one tidal excursion (based on maps of tidal current speeds) around ISA-infected farms, while larger management areas (or surveillance zones) consist of all farms with overlapping control zones (JGIWG 2000).

When a system of management zones was implemented in SWNB in response to the outbreak of ISA, there was little available oceanographic information and the resulting framework of 22 BMAs did not adequately serve to control the spread of this disease. As a result, a project was undertaken to better understand the water circulation patterns around fish farms in SWNB. The results of that study (Page et al. 2005; Chang et al. 2005a, b, c, 2006a, b) confirmed that the old BMA framework did not provide an adequate degree of water separation between most of the 22 BMAs, and would clearly not meet the criteria used for the definition of surveillance zones or management areas in Norway and Scotland. The new BMA framework implemented in 2006 greatly improves the amount of water separation between BMAs. There are only four farms whose model-derived tidal excursion areas overlap farm sites in other BMAs in the new framework. Three of these involve farms in new BMA 6, which has been designated for non-salmonid species only, while the other one involves small BMA 4 (Harbour de Loutre, Campobello Island). There is a total of 32 farms whose model-derived tidal excursion areas overlap those of farms in other BMAs in the new framework. Most of these overlaps also involve farms in new BMAs 4 and 6. If new BMA 4 is integrated into new BMA 1 and if new BMA 6 is only used for non-salmonids, then from the salmon health point of view, there would only remain a small risk of water-borne disease spread between new BMAs 1 and 2a, due to a few overlaps among tidal excursion areas involving four farms (one from BMA 1, one from BMA 4, and two from BMA 2a), while there would be no overlaps of tidal excursion areas with farm sites between farms in new BMAs 1 and 2a. The risk of water-borne disease spread among the new BMAs would be higher in the event of a disease that could spread between non-salmonids and salmon.

In the Grand Manan Island area, under the new BMA framework, there are no overlaps of the tidal excursion areas of farms in any one BMA with farm sites in another BMA. There are however, some overlaps of the tidal excursion areas of farms in one BMA with the tidal excursion areas of farms in another BMA, involving five farms in new BMA 2b and two farms in new BMA 3b. This suggests that, ideally, these two BMAs should be combined.

It is also understood that there is considerable water connectivity between farms in new BMA 1 and farms in Cobscook Bay, Maine. Therefore, these two areas must be managed on the same year-class and fallowing rotation. This results in one very large BMA, so that if one farm in this BMA is infected, the management implications may affect a very large number of farms. Because of the close proximity of farms in this area, there does not appear to be any easy way to divide the area into smaller BMAs. One possibility might be to separate out the few farms in northern Passamaquoddy Bay. These farms do appear to be tidally isolated from the rest of new BMA 1, although wind-driven circulation may reduce this isolation. The risk of disease spread to or from these farms could be reduced further if the farm at Tongue Shoal (just east of St. Andrews) was eliminated.

INTERACTIONS WITH FISHERIES RESOURCES

Since the new BMA framework does not change the numbers or locations of fish farms in SWNB, there should be no significant changes to the potential impacts of aquaculture on fisheries resources or activities as a result of the change to the new BMA framework. Since most finfish aquaculture in SWNB currently occurs close to shore, the fishing activities most affected would be those for species which are fished mainly nearshore. These would include the herring weir and sea urchin fisheries, and inshore components of the lobster and scallop fisheries. Fishing activities which occur mostly away from shore, such as herring purse seining, the groundfish fishery, and offshore scallop and lobster fishing, would be less impacted. There is, however, some interest in offshore aquaculture, which could lead to potential impacts on fisheries occurring further from shore (Chang 2003; Chang et al. 2005d).

Our fisheries interactions analyses only looked at the overlaps between finfish aquaculture and fishing activities (except for lobster, where geo-referenced data was not available). Critical habitats (e.g. spawning grounds, nursery habitats, migration routes) of commercially-fished species may exist where fishing is not occurring (especially for species with pelagic or migratory life stages), and there is the potential for interactions between these critical habitats and aquaculture. Reports on the locations of spawning areas for herring and groundfish (cod, haddock, pollock) in SWNB suggest that there would be few overlaps with fish farms or their zones of influence, since the active spawning areas of these species are mostly offshore or in nearshore areas where there is no fish farming (Coon 1999; Graham et al. 2002). However, these reports noted that, historically, these species also spawned in some nearshore areas which are currently used for fish farming or could be influenced by fish farms. They also noted that nearshore areas in SWNB are important nursery areas for herring and groundfish.

Our lobster fishery interaction analyses examined the overlaps between aquaculture and preferred juvenile lobster habitat, as represented by shallow cobble/gravel or rocky seafloor types. The analysis indicated the potential for considerable overlap between the preferred juvenile lobster habitats and fish farm zones of influence. Note that the overlap figures are probably overestimates, because we used the near-surface tidal excursion areas to estimate the zones of influence. If particle sinking was included in the model runs, the estimated zones of influence on the seafloor would be smaller than the near-surface tidal excursion areas, because the particles would stop moving once they hit the seafloor. Harding (1992) reported that adult lobsters also prefer rocky or cobble substrates over mud or sand substrates; however, Lawton (1992) noted that there is substantial fishing for adult lobsters over soft bottom (mud). Also, shallow, soft sediment, nearshore areas around Grand Manan Island are important for berried females (Campbell 1990; Coon 1999; D. Robichaud, DFO, Biological Station, St. Andrews, NB, pers. comm.), and some of these areas overlap with fish farms or their zones of influence.

CONCLUSIONS

The new BMA framework should benefit fish health management of the salmon aquaculture industry in SWNB, since it will greatly reduce the numbers of overlaps of farms' zones of influence with farm sites in other BMAs. However, there is still some potential for water-borne transmission of diseases between BMAs, which could be further reduced through the removal of some farms and/or combining some BMAs. The new BMA framework should not increase potential fisheries interactions, compared to the old framework. The potential interactions will be with fisheries which are largely conducted in nearshore areas, such as the herring weir and sea urchin fisheries, as well as inshore components of the lobster and scallop fisheries. Expansion of finfish farming into inshore areas not currently utilized, or into offshore areas, will increase the potential for interactions with fisheries activities and resources.

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Table. 1. Bay Management Area (BMA) sizes, numbers of farms, lease areas, and allowable production levels (APLs, in October 2005) in the old (2002-2005) and corresponding new (starting 2006) BMA frameworks. X = confidential data (APLs for BMAs with three or fewer farms). Data source: New Brunswick Department of Agriculture and Aquaculture (St. George office).

Old BMA framework					New BMA framework				
BMA	BMA area (km^2)	No. of farms	Lease area (km^2)	APL (No. of fish)	BMA	BMA area (km^2)	No. of farms	Lease area (km^2)	APL (No. of fish)
1a	100.5	7	1.36	1 200 000					
1b	28.1	2	0.48	X					
2	17.9	1	0.27	X					
3	10.0	4	0.96	1 130 000					
4	18.5	5	0.77	1 416 000	1	236.0	33	5.63	7 778 000
5	12.6	5	0.62	1 158 000					
6	24.2	4	0.55	892 500					
13	12.3	2	0.13	X					
15	5.1	3	0.50	X					
Subtotals	**229.2**	**33**	**5.63**	**7 778 000**					
8	8.4	8	0.86	1 490 000					
9	8.4	7	1.18	1 375 000	2a	40.5	23	3.16	3 940 000
10	18.3	8	1.12	1 075 000					
Subtotals	**35.1**	**23**	**3.16**	**3 940 000**					
17	25.0	5	0.73	1 060 000					
18	26.4	4	1.05	1 300 000	2b	80.4	12	2.47	3 730 000
19	29.2	3	0.69	1 370 000					
Subtotals	**80.6**	**12**	**2.47**	**3 730 000**	*2a+2b*	*120.9*	*35*	*6.63*	*7 670 000*
11	12.7	2	0.28	X					
12	6.0	1	0.42	X	3a	204.0	10	2.88	3 745 000
No BMA	-	7	2.18	2 885 000					
Subtotals	**18.7**	**10**	**2.88**	**3 745 000**					
20	13.9	5	0.80	1 304 000	3b	59.9	9	1.80	2 694 000
21	31.2	4	1.00	1 390 000					
Subtotals	**45.1**	**9**	**1.80**	**2 694 000**	*3a+3b*	*263.9*	*19*	*4.68*	*6 439 000*
14	8.2	3	0.52	X	4	2.6	3	0.52	X
16	4.9	1	0.08	X	5	4.2	1	0.08	X
7	10.0	3	0.40	X	6	10.3	3	0.40	X
Totals	**431.5**	**94**	**16.93**	**23 122 000**	**Totals**	**637.9**	**94**	**16.93**	**23 122 000**

Table 2a. Marine surface areas of zones of influence of farms in each old BMA used from 2002-2005. Three estimates of the zones of influence were used: 2-km radius circular zones, 5-km radius circular zones, and model-derived tidal excursion areas. The combined areas were estimated by merging the individual zones of influence of all farms in each BMA (because of overlaps between individual zones of influence, the combined figure was usually less than the sums of the individual zones of farms in a BMA).

		Marine surface areas of zones of influence of farms (km^2)					
		2-km radius circular zones		5-km radius circular zones		Model-derived tidal excursion areas	
Old BMA	No. of farms in BMA	Mean ±SD	Combined	Mean ±SD	Combined	Mean ±SD	Combined
1a	7	10.2 ± 1.0	42.2	49.6 ± 6.4	102.8	0.8 ± 0.2	5.3
1b	2	12.4 ± 0.0	24.9	70.9 ± 3.3	109.0	3.4 ± 2.7	6.8
2	1	11.1 ± 0.0	11.1	64.9 ± 0.0	64.9	2.9 ± 0.0	2.9
3	4	8.0 ± 1.6	18.8	57.1 ± 3.2	91.1	1.1 ± 0.7	4.1
4	5	7.9 ± 1.4	22.5	46.2 ± 4.8	83.4	4.7 ± 3.8	15.5
5	5	9.5 ± 1.5	19.2	45.3 ± 3.4	63.5	15.6 ± 8.2	40.6
6	4	8.7 ± 2.3	17.0	57.2 ± 4.9	81.6	3.5 ± 3.3	10.8
7	3	7.8 ± 1.3	16.3	48.9 ± 2.2	74.3	10.3 ± 3.0	20.6
8	8	5.7 ± 2.6	18.5	41.1 ± 10.7	74.5	3.6 ± 6.1	23.1
9	7	9.2 ± 0.7	18.5	56.0 ± 5.0	75.2	1.9 ± 1.0	6.9
10	8	6.7 ± 0.6	14.5	38.1 ± 5.4	52.4	2.9 ± 2.4	12.6
11	2	5.3 ± 1.0	6.5	30.8 ± 5.2	34.7	0.2 ± 0.0	0.4
12	1	6.4 ± 0.0	6.4	45.8 ± 0.0	45.8	1.5 ± 0.0	1.5
13	2	9.5 ± 1.4	12.4	64.5 ± 1.8	72.2	11.4 ± 14.3	22.3
14	3	6.1 ± 1.0	7.9	42.8 ± 8.6	53.7	9.1 ± 13.3	25.7
15	3	6.9 ± 1.0	10.5	34.8 ± 0.8	43.7	9.8 ± 6.7	25.6
16	1	5.7 ± 0.0	5.7	37.3 ± 0.0	37.3	*	*
17	5	10.7 ± 1.0	19.5	53.5 ± 5.3	68.7	1.9 ± 0.5	6.3
18	4	10.6 ± 1.7	20.9	61.5 ± 4.0	85.1	9.8 ± 5.7	32.0
19	3	10.5 ± 0.8	21.3	70.0 ± 1.7	100.5	75.6 ± 24.2	114.7
20	5	8.9 ± 1.8	22.3	45.7 ± 11.6	87.7	4.3 ± 2.9	18.6
21	4	9.9 ± 0.4	28.4	61.3 ± 10.4	91.4	16.7 ± 11.9	40.1
no BMA	7	9.1 ± 1.2	61.9	50.9 ± 6.3	241.3	8.0 ± 8.1	47.2

* the tidal excursion area for the one farm in old BMA 16 was not determined, but it would be mostly confined within the small (0.3 km^2), isolated, semi-enclosed bay where the farm is located.

Table 2b. Marine surface areas of zones of influence of farms in each new BMA implemented starting in 2006. Three estimates of the zones of influence were used: 2-km radius circular zones, 5-km radius circular zones, and model-derived tidal excursion areas. The combined areas were estimated by merging the individual zones of influence of all farms in each BMA (because of overlaps between individual zones of influence, the combined figure was usually less than the sums of the individual zones of farms in a BMA).

Old BMA	No. of farms in BMA	Marine surface areas of zones of influence of farms (km^2)					
		2-km radius circular zones		5-km radius circular zones		Model-derived tidal excursion areas	
		Mean ±SD	Combined	Mean ±SD	Combined	Mean ±SD	Combined
1	33	9.1 ± 1.9	157.1	51.6 ± 10.0	360.0	5.7 ± 7.0	113.9
2a	23	7.1 ± 2.1	34.6	44.6 ± 10.7	97.7	2.8 ± 3.8	23.3
2b	12	10.6 ± 1.1	61.0	60.3 ± 7.9	195.5	23.0 ± 33.7	140.4
2a+2b	*35*	*8.3 ± 2.5*	*95.6*	*50.0 ± 12.3*	*293.2*	*9.7 ± 21.7*	*163.7*
3a	10	8.1 ± 2.0	70.7	46.4 ± 10.0	259.8	5.8 ± 7.5	49.0
3b	9	9.4 ± 1.7	42.6	52.6 ± 13.2	119.3	9.8 ± 10.0	53.2
3a+3b	*19*	*8.7 ± 1.9*	*113.3*	*49.3 ± 11.7*	*379.1*	*7.7 ± 8.8*	*102.2*
4	3	6.1 ± 1.0	7.9	42.8 ± 8.6	52.2	9.1 ± 13.3	25.7
5	1	5.7 ± 0.0	5.7	37.3 ± 0.0	37.3	*	*
6	3	7.8 ± 1.3	16.3	48.9 ± 2.2	73.9	10.3 ± 3.0	20.6
All farms	94	8.6 ± 2.2	386.9	50.0 ± 11.1	997.9	7.9 ± 14.6	389.0

* the tidal excursion area for the one farm in new BMA 5 was not determined, but it would be mostly confined within the small (0.3 km^2), isolated, semi-enclosed bay where the farm is located.

Table 3. Maximum displacement of model particles during one tidal cycle. Using a tidal circulation model, the displacement was measured as the straight-line distance from a particle's starting point to its position at any given time. For each farm, the particle which had the maximum displacement during one tidal cycle (12.4 h) was determined. The values shown are the means of the maximum particle displacements of all farms in each BMA.

Old BMA	Number of farms in BMA	Maximum displacement of model particles (km) (mean ± SD)	New BMA	Number of farms in BMA	Maximum displacement of model particles (km) (mean ± SD)
1a	7	1.1 ± 0.4	1	33	3.8 ± 3.0
1b	2	2.2 ± 0.6			
2	1	2.7 ± 0.0	2a	23	2.8 ± 2.1
3	4	1.3 ± 0.6	2b	12	6.2 ± 5.3
4	5	4.8 ± 3.0	*2a+2b*	*35*	*4.0 ± 3.9*
5	5	7.2 ± 0.7			
6	4	3.2 ± 2.2	3a	10	3.6 ± 2.7
7	3	8.0 ± 0.0	3b	9	4.0 ± 1.2
8	8	3.1 ± 3.0	*3a+3b*	*19*	*3.8 ± 2.0*
9	7	2.4 ± 1.4			
10	8	2.8 ± 1.9	4	3	5.7 ± 2.3
11	2	0.4 ± 0.1			
12	1	2.6 ± 0.0	5	1	*
13	2	5.2 ± 5.2			
14	3	5.7 ± 7.3	6	3	8.0 ± 0.0
15	3	7.3 ± 3.6			
16	1	*	All farms	94	4.1 ± 3.4
17	5	1.8 ± 0.3			
18	4	6.0 ± 3.4			
19	3	14.0 ± 0.9			
20	5	3.4 ± 0.5			
21	4	4.8 ± 1.4			
no BMA	7	4.6 ± 2.4			
All farms	94	4.1 ± 3.4			

* the tidal excursion area for the one farm in old BMA 16 (= new BMA 5) was not determined, but it would be mostly confined within the small (0.3 km^2), isolated, semi-enclosed bay where the farm is located.

Table 4a. Numbers of finfish farms whose 2-km radius circular zones of influence overlap farm sites in southwestern New Brunswick (SWNB), excluding the overlap of a zone of influence with its own farm site. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

Old BMA	No. of farms in BMA	No. of farms whose 2-km circular zones of influence overlap:			
		Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	6	0	6	0
1b	2	0	0	0	0
2	1	0	1	1	0
3	4	3	4	4	0
4	5	5	1	5	0
5	5	5	1	5	3
6	4	4	0	4	0
7	3	2	1	3	0
8	8	8	8	8	0
9	7	7	6	7	0
10	8	8	5	8	0
11	2	2	0	2	0
12	1	0	1	1	0
13	2	2	0	2	0
14	3	3	0	3	0
15	3	3	0	3	2
16	1	0	0	0	0
17	5	5	0	5	0
18	4	4	0	4	0
19	3	3	0	3	0
20	5	4	2	4	0
21	4	3	1	3	0
no BMA	7	0	1	1	0
Totals	94	77	32	82	5

Table 4b. Numbers of finfish farms whose 5-km radius circular zones of influence overlap farm sites in SWNB, excluding the overlap of a zone of influence with its own farm site. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

Old BMA	No. of farms in BMA	No. of farms whose 5-km circular zones of influence overlap:			
		Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	7	2	7	0
1b	2	2	2	2	0
2	1	0	1	1	0
3	4	4	4	4	0
4	5	5	5	5	2
5	5	5	5	5	5
6	4	4	4	4	0
7	3	3	3	3	0
8	8	8	8	8	0
9	7	7	7	7	0
10	8	8	8	8	0
11	2	2	2	2	0
12	1	0	1	1	0
13	2	2	2	2	0
14	3	3	3	3	3
15	3	3	1	3	3
16	1	0	0	0	0
17	5	5	5	5	0
18	4	4	4	4	0
19	3	3	1	3	0
20	5	5	5	5	0
21	4	4	4	4	0
no BMA	7	6	2	6	0
Totals	94	90	79	92	13

Table 4c. Numbers of finfish farms whose model-derived tidal excursion areas overlap farm sites in SWNB, excluding the overlap of a tidal excursion area with its own farm site. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

Old BMA	No. of farms in BMA	No. of farms whose model-derived tidal excursion areas overlap:			
		Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	2	0	2	0
1b	2	0	0	0	0
2	1	0	0	0	0
3	4	3	1	3	0
4	5	5	0	5	1
5	5	5	2	5	1
6	4	2	2	2	0
7	3	3	2	3	0
8	8	7	2	8	0
9	7	7	5	7	0
10	8	8	2	8	0
11	2	0	0	0	0
12	1	0	0	0	0
13	2	2	0	2	0
14	3	3	0	3	0
15	3	3	1	3	2
16*	1	0	0	0	0
17	5	5	0	5	0
18	4	3	2	4	0
19	3	2	0	2	0
20	5	4	1	4	0
21	4	3	0	3	0
no BMA	7	1	0	1	0
Totals	94	68	20	70	4

* the tidal excursion area for the one farm in old BMA 16 was not determined, but it would be mostly confined within the small, isolated, semi-enclosed bay where the farm is located, and would not overlap any other farms.

Table 5a. Numbers of finfish farms whose 2-km radius circular zones of influence overlap farm sites in SWNB, excluding the overlap of a zone of influence with its own farm site. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

New BMA	No. of farms in BMA	No. of farms whose 2-km circular zones of influence overlap: Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	30	1	30	5
2a	23	23	1	23	0
2b	12	12	0	12	0
2a+2b	*35*	*35*	*1*	*35*	*0*
3a	10	4	0	4	0
3b	9	7	0	7	0
3a+3b	*19*	*11*	*0*	*11*	*0*
4	3	3	0	3	0
5	1	0	0	0	0
6	3	2	1	3	0
Totals	94	81	3	82	5

Table 5b. Numbers of finfish farms whose 5-km radius circular zones of influence overlap farm sites in SWNB, excluding the overlap of a zone of influence with its own farm site. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

New BMA	No. of farms in BMA	No. of farms whose 5-km circular zones of influence overlap: Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	33	13	33	10
2a	23	23	15	23	0
2b	12	12	1	12	0
2a+2b	*35*	*35*	*16*	*35*	*0*
3a	10	9	0	9	0
3b	9	9	0	9	0
3a+3b	*19*	*18*	*0*	*18*	*0*
4	3	3	3	3	3
5	1	0	0	0	0
6	3	3	3	3	0
Totals	94	92	35	92	13

Table 5c. Numbers of finfish farms whose model-derived tidal excursion areas overlap farm sites in SWNB, excluding the overlap of a zone of influence with its own farm site. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

New BMA	No. of farms in BMA	No. of farms whose model-derived tidal excursion areas overlap: Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	22	1	22	4
2a	23	22	1	23	0
2b	12	11	0	11	0
2a+2b	*35*	*33*	*1*	*34*	*0*
3a	10	1	0	1	0
3b	9	7	0	7	0
3a+3b	*19*	*8*	*0*	*8*	*0*
4	3	3	0	3	0
5*	1	0	0	0	0
6	3	3	2	3	0
Totals	94	69	4	70	4

* the tidal excursion area for the one farm in new BMA 5 was not determined, but it would be mostly confined within the small, isolated, semi-enclosed bay where the farm is located, and would not overlap any other farms.

Table 6. Summary table of numbers of finfish farms whose zones of influence overlap farm sites in SWNB (excluding the overlap of each zone of influence with its own farm site). Three estimates of the farm zones of influence were used: 2-km radius circular zones, 5-km radius circular zones, and model-derived tidal excursion areas.

	Total number of farms whose zones of influence overlap:			
BMA framework	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
2-km radius circular zones of influence				
Old	77	32	82	5
New	81	3	82	5
5-km radius circular zones of influence				
Old	90	79	92	13
New	92	35	92	13
Model-derived tidal excursion areas				
Old	68	20	70	4
New	69	4	70	4

Table 7a. Numbers of finfish farms whose 2-km radius circular zones of influence overlap the 2-km radius circular zones of influence of other farms in SWNB. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

		No. of farms whose 2-km circular zones of influence overlap the 2-km circular zones of influence of:			
Old BMA	No. of farms in BMA	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	7	0	7	0
1b	2	0	2	2	0
2	1	0	1	1	0
3	4	4	4	4	0
4	5	5	5	5	2
5	5	5	5	5	5
6	4	4	3	4	0
7	3	3	2	3	0
8	8	8	8	8	0
9	7	7	7	7	0
10	8	8	8	8	0
11	2	2	1	2	0
12	1	0	1	1	0
13	2	2	0	2	0
14	3	3	3	3	0
15	3	3	0	3	3
16	1	0	0	0	0
17	5	5	3	5	0
18	4	4	1	4	0
19	3	3	0	3	0
20	5	5	4	5	0
21	4	4	4	4	0
no BMA	7	2	0	2	0
Totals	94	84	62	88	10

Table 7b. Numbers of finfish farms whose 5-km radius circular zones of influence overlap the 5-km radius circular zones of influence of other farms in SWNB. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

		No. of farms whose 5-km circular zones of influence overlap the 5-km circular zones of influence of:			
Old BMA	No. of farms in BMA	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	7	3	7	0
1b	2	2	2	2	0
2	1	0	1	1	0
3	4	4	4	4	0
4	5	5	5	5	5
5	5	5	5	5	5
6	4	4	4	4	0
7	3	3	3	3	0
8	8	8	8	8	0
9	7	7	7	7	0
10	8	8	8	8	0
11	2	2	2	2	0
12	1	0	1	1	0
13	2	2	2	2	2
14	3	3	3	3	3
15	3	3	3	3	3
16	1	0	0	0	0
17	5	5	5	5	0
18	4	4	4	4	0
19	3	3	3	3	0
20	5	5	5	5	0
21	4	4	4	4	0
no BMA	7	7	3	7	0
Totals	94	91	85	93	18

Table 7c. Numbers of finfish farms whose model-derived tidal excursion areas overlap the tidal excursion areas of other farms in SWNB. Farms are grouped into BMAs according to the old bay management framework used from 2002-2005.

		No. of farms whose model-derived tidal excursion areas overlap the tidal excursion areas of:			
Old BMA	No. of farms in BMA	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1a	7	2	0	2	0
1b	2	0	0	0	0
2	1	0	1	1	0
3	4	3	2	4	0
4	5	5	5	5	2
5	5	5	5	5	5
6	4	3	3	3	0
7	3	3	3	3	0
8	8	8	4	8	0
9	7	7	7	7	0
10	8	8	8	8	0
11	2	0	0	0	0
12	1	0	0	0	0
13	2	2	1	2	0
14	3	3	3	3	2
15	3	3	3	3	3
16*	1	0	0	0	0
17	5	5	2	5	0
18	4	4	3	4	0
19	3	3	3	3	0
20	5	5	2	5	0
21	4	4	3	4	0
no BMA	7	6	0	6	0
Totals	94	79	58	81	12

* the tidal excursion area for the one farm in old BMA 16 was not determined, but it would be mostly confined within the small, isolated, semi-enclosed bay where the farm is located, and would not overlap the tidal excursion areas of any other farms.

Table 8a. Numbers of finfish farms whose 2-km radius circular zones of influence overlap the 2-km radius circular zones of influence of other farms in SWNB. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

New BMA	No. of farms in BMA	No. of farms whose 2-km circular zones of influence overlap: Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	33	4	33	10
2a	23	23	8	23	0
2b	12	12	0	12	0
2a+2b	*35*	*35*	*8*	*35*	*0*
3a	10	5	0	5	0
3b	9	9	0	9	0
3a+3b	*19*	*14*	*0*	*14*	*0*
4	3	3	3	3	0
5	1	0	0	0	0
6	3	3	2	3	0
Totals	94	88	17	88	10

Table 8b. Numbers of finfish farms whose 5-km radius circular zones of influence overlap the 5-km radius circular zones of influence of other farms in SWNB. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

		No. of farms whose 5-km circular zones of influence overlap:			
New BMA	No. of farms in BMA	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	33	27	33	15
2a	23	23	23	23	0
2b	12	12	8	12	0
2a+2b	*35*	*35*	*31*	*35*	*0*
3a	10	10	3	10	0
3b	9	9	8	9	0
3a+3b	*19*	*19*	*11*	*19*	*0*
4	3	3	3	3	3
5	1	0	0	0	0
6	3	3	3	3	3
Totals	94	93	75	93	18

Table 8c. Numbers of finfish farms whose model-derived tidal excursion areas overlap tidal excursion areas of other farms in SWNB. Farms are grouped into BMAs according to the new bay management framework implemented starting in 2006.

		No. of farms whose model-derived tidal excursion areas overlap:			
New BMA	No. of farms in BMA	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
1	33	25	10	25	10
2a	23	23	9	23	0
2b	12	12	5	12	0
2a+2b	*35*	*35*	*14*	*35*	*0*
3a	10	6	0	6	0
3b	9	9	2	9	0
3a+3b	*19*	*15*	*2*	*15*	*0*
4	3	3	3	3	2
5*	1	0	0	0	0
6	3	3	3	3	0
Totals	94	81	32	81	12

* the tidal excursion area for the one farm in new BMA 5 was not determined, but it would be mostly confined within the small, isolated, semi-enclosed bay where the farm is located, and would not overlap the tidal excursion areas of any other farms;

Table 9. Summary table of numbers of finfish farms whose zones of influence overlap zones of influence of other farms in SWNB. Three estimates of the farm zones of influence were used: 2-km radius circular zones, 5-km radius circular zones, and model-derived tidal excursion areas.

	Total number of farms whose zones of influence overlap the zones of influence of:			
BMA framework	Farms in the same BMA	Farms in other BMAs	Any farms in SWNB	Farms in Cobscook Bay
2-km radius circular zones of influence				
Old	84	62	88	10
New	88	17	88	10
5-km radius circular zones of influence				
Old	91	85	93	18
New	93	75	93	18
Model-derived tidal excursion areas				
Old	79	58	81	12
New	81	32	81	12

Table 10a. Commercial fisheries catches within the new BMAs. Data shown are for the most important fisheries in SWNB for which geo-referenced catch data is available. Top table: catches (t) within each new BMA. Bottom table: same data expressed as percentages of the SWNB totals. Data sources: Fisheries and Oceans Canada, commercial fisheries database (mobile gear catch data); M. Power, Fisheries and Oceans Canada, St. Andrews Biological Station (herring weir catch data).

		Total catches 2000-2003 (t)				
New BMA	No. of farms in BMA	Herring weir	Herring purse seine	Sea scallop	Sea urchin	Ground-fish
1	33	8 444.7	0.0	299.0	377.5	37.6
2a	23	6 545.6	0.0	3.8	79.9	0.0
2b	12	13 722.4	2 501.9	463.2	1 871.9	9.3
3a	10	540.5	155.0	938.6	605.4	24.3
3b	9	174.0	199.0	211.4	320.6	15.0
4	3	0.0	0.0	10.3	49.9	0.6
5	1	0.0	0.0	0.0	0.0	0.3
6	3	19.0	0.0	8.7	15.8	0.0
All BMAs	94	29 446.2	2 855.9	1 935.0	3 321.0	87.1
SWNB	94	56 717.4	39 913.6	3 971.1	3 881.9	3 071.2

		Total catches 2000-2003 as % of total SWNB catch				
New BMA	No. of farms in BMA (% of total)	Herring weir	Herring purse seine	Sea scallop	Sea urchin	Ground-fish
1	35.1	14.9	0.0	7.5	9.7	1.2
2a	24.5	11.5	0.0	0.1	2.1	0.0
2b	12.8	24.2	6.3	11.7	48.2	0.3
3a	10.6	1.0	0.4	23.6	15.6	0.8
3b	9.6	0.3	0.5	5.3	8.3	0.5
4	3.2	0.0	0.0	0.3	1.3	0.0
5	1.1	0.0	0.0	0.0	0.0	0.0
6	3.2	0.0	0.0	0.2	0.4	0.0
All BMAs	100.0	51.9	7.2	48.7	85.6	2.8

Table 10b. Overlaps of commercial fisheries catches with the model-derived tidal excursion areas of farms in each new BMA. Data shown are for the most important fisheries in SWNB for which geo-referenced catch data is available. Top table: catches (t) within the combined tidal excursion areas of farms in each BMA. Bottom table: same data expressed as percentages of the SWNB totals.

New BMA	Combined tidal excursion area of farms in BMA (km^2)	Total catches within tidal excursion areas of farms in each BMA 2000-2003 (t)				
		Herring weir	Herring purse seine	Sea scallop	Sea urchin	Ground-fish
1	113.9	4 393.0	0.0	208.5	323.7	42.3
2a	23.3	1 931.7	54.0	1.9	82.4	0.0
2b	140.4	746.0	3 933.2	658.9	1 805.0	19.0
3a	49.0	0.0	0.0	39.4	83.1	12.4
3b	53.2	32.0	198.0	237.3	263.6	13.4
4	25.7	337.9	0.0	135.4	193.4	1.5
5	*	0.0	0.0	0.0	0.0	0.0
6	20.6	3 469.9	54.0	21.6	97.7	0.0
All BMAs†	389.0	9 437.3	4 079.2	1 049.0	2 495.2	87.1
SWNB	389.0	56 717.4	39 913.6	3 971.1	3 881.9	3 071.2

New BMA	Combined tidal excursion area of farms in BMA (% of total)	Total catches within tidal excursion areas of farms in each BMA 2000-2003, as % of total SWNB catch				
		Herring weir	Herring purse seine	Sea scallop	Sea urchin	Ground-fish
1	29.3	7.7	0.0	5.3	8.3	1.4
2a	6.0	3.4	0.1	0.0	2.1	0.0
2b	36.1	1.3	9.9	16.6	46.5	0.6
3a	12.6	0.0	0.0	1.0	2.1	0.4
3b	13.7	0.1	0.5	6.0	6.8	0.4
4	6.6	0.6	0.0	3.4	5.0	0.0
5	*	0.0	0.0	0.0	0.0	0.0
6	5.3	6.1	0.1	0.5	2.5	0.0
All BMAs†	100.0	16.6	10.2	26.4	64.3	2.8

* the tidal excursion area for the one farm in new BMA 5 was not determined, but it would be mostly confined within the small (0.3 km^2), isolated, semi-enclosed bay where the farm is located; no fishing data was available for this bay.

† the values for “All BMAs” are slightly smaller than the sums of the values for individual BMAs, because there are some overlaps between tidal excursion areas of farms in different BMAs.

Table 11a. Areas of seafloor habitat types (for depths <60 m) within the new BMAs. Top table: areas (km^2) within each BMA. Bottom table: same data expressed as percentages of the SWNB totals.

New BMA	No. of farms in BMA	Marine area of BMA (km^2)	Seafloor type <60 m depth within each BMA (km^2)		
			Soft	Cobble/gravel	Rock
1	33	236.0	170.2	34.8	6.7
2a	23	40.5	15.2	3.0	1.8
2b	12	80.4	31.9	20.6	8.0
3a	10	204.0	169.7	7.9	7.3
3b	9	59.9	38.2	9.2	4.7
4	3	2.6	1.6	0.2	0.1
5	1	4.2	1.6	0.4	0.0
6	3	10.3	3.5	1.6	3.6
All BMAs	94	637.9	431.8	77.7	32.0
All SWNB	94	637.9	1 165.0	100.0	130.7

New BMA	No. of farms in BMA (% of total)	Marine area of BMA (% of all BMAs)	Seafloor type <60 m depth within each BMA (% of SWNB totals)		
			Soft	Cobble/gravel	Rock
1	35.1	37.0	14.6	34.8	5.1
2a	24.5	6.3	1.3	3.0	1.4
2b	12.8	12.6	2.7	20.6	6.1
3a	10.6	32.0	14.6	7.9	5.6
3b	9.6	9.4	3.3	9.2	3.6
4	3.2	0.4	0.1	0.2	0.1
5	1.1	0.7	0.1	0.4	0.0
6	3.2	1.6	0.3	1.6	2.7
All BMAs	100.0	100.0	37.1	77.7	24.5

Table 11b. Areas of seafloor habitat types (for depths <60 m) overlapped by finfish aquaculture farms (lease areas) within the new BMAs. Top table: areas (km^2) within each BMA. Bottom table: same data expressed as percentages of the SWNB totals.

New BMA	No. of farms in BMA	Marine area of farm leases in BMA (km^2)	Total farm area within each seafloor type <60 m depth (km^2)		
			Soft	Cobble/gravel	Rock
1	33	5.63	4.15	0.79	0.15
2a	23	3.16	1.84	0.44	0.20
2b	12	2.47	1.12	0.95	0.23
3a	10	2.88	2.27	0.26	0.13
3b	9	1.80	1.34	0.32	0.09
4	3	0.52	0.36	0.00	0.01
5	1	0.08	*	*	*
6	3	0.40	0.08	0.14	0.05
All BMAs	94	16.94	11.16	2.90	0.85
All SWNB	94	16.94	1 165.00	100.00	130.70

New BMA	No. of farms in BMA (% of total)	Marine area of farm leases in BMA (% of total)	Total farm area within each seafloor type <60 m depth (% of SWNB totals)		
			Soft	Cobble/gravel	Rock
1	35.1	33.2	0.36	0.79	0.11
2a	24.5	18.7	0.16	0.44	0.15
2b	12.8	14.6	0.10	0.95	0.18
3a	10.6	17.0	0.19	0.26	0.10
3b	9.6	10.6	0.12	0.32	0.07
4	3.2	3.1	0.03	0.00	0.00
5	1.1	0.5	*	*	*
6	3.2	2.3	0.01	0.14	0.04
All BMAs	100.0	100.0	0.96	2.90	0.65

* the one farm in new BMA 5 is located within a small (0.3 km^2), isolated, semi-enclosed bay; data on the bottom type within this bay was not available.

Table 11c. Areas of seafloor habitat types (for depths <60 m) overlapped by model-derived tidal excursion areas in new BMAs. Top table: areas (km^2) within each BMA. Bottom table: same data expressed as percentages of the SWNB totals.

New BMA	No. of farms in BMA	Combined tidal excursion area of all farms in BMA (km^2)	Total area of tidal excursion areas within each seafloor type <60 m depth (km^2)		
			Soft	Cobble/gravel	Rock
1	33	113.9	51.72	25.95	4.29
2a	23	23.3	13.97	2.71	1.69
2b	12	140.4	98.80	16.30	21.16
3a	10	49.0	39.14	1.59	1.89
3b	9	53.2	37.84	7.43	5.72
4	3	25.7	12.73	7.38	2.71
5	1	*	*	*	*
6	3	20.6	15.38	1.94	1.76
All BMAs†	94	389.0	243.81	56.41	36.49
All SWNB	94	389.0	1 165.00	100.00	130.70

New BMA	No. of farms in BMA (% of total)	Combined tidal excursion area of all farms in BMA (% of total)	Total area of tidal excursion areas within each seafloor type <60 m depth (% of SWNB totals)		
			Soft	Cobble/gravel	Rock
1	35.1	29.3	4.44	25.95	3.28
2a	24.5	6.0	1.20	2.71	1.29
2b	12.8	36.1	8.48	16.30	16.19
3a	10.6	12.6	3.36	1.59	1.45
3b	9.6	13.7	3.25	7.43	4.38
4	3.2	6.6	1.09	7.38	2.07
5	1.1	*	*	*	*
6	3.2	5.3	1.32	1.94	1.35
All BMAs†	100.0	100.0	20.93	56.41	27.92

* the tidal excursion area for the one farm in new BMA 5 was not determined, but it would be mostly confined within the small (0.3 km^2), isolated, semi-enclosed bay where the farm is located; data on the bottom type within this bay was not available.

† the values for "All BMAs" are slightly smaller than the sums of the values for individual BMAs, because there were some overlaps between tidal excursion areas of farms in different BMAs.

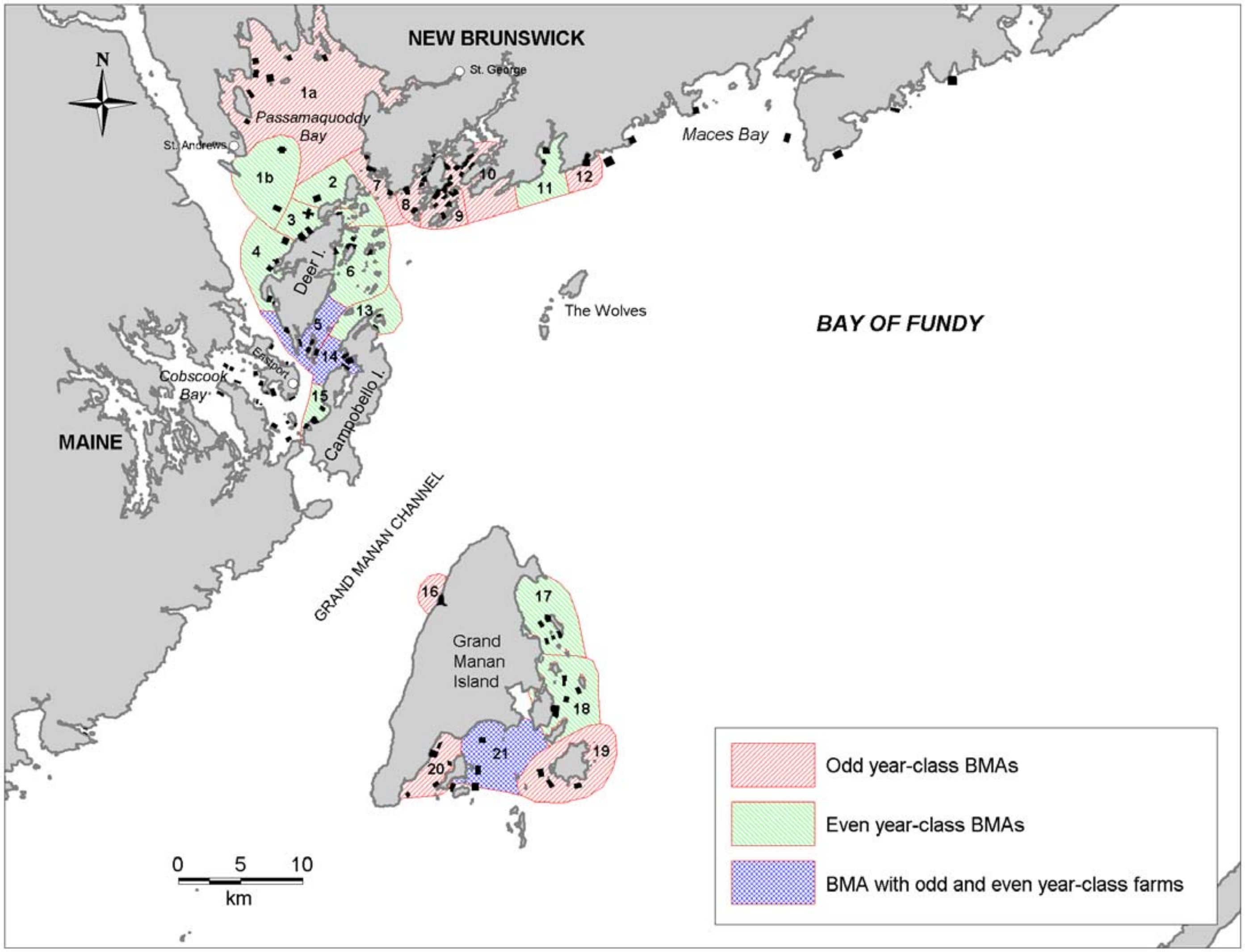

Fig. 1. Map of the southwestern New Brunswick (SWNB) salmon farming region showing salmon farms (small black polygons) and the Bay Management Area (BMA) structure used in 2002-2005. The year-class status is based on 2005 information. The area outside of the designated BMAs (Maces Bay area and eastward) included both odd and even year-class farms.

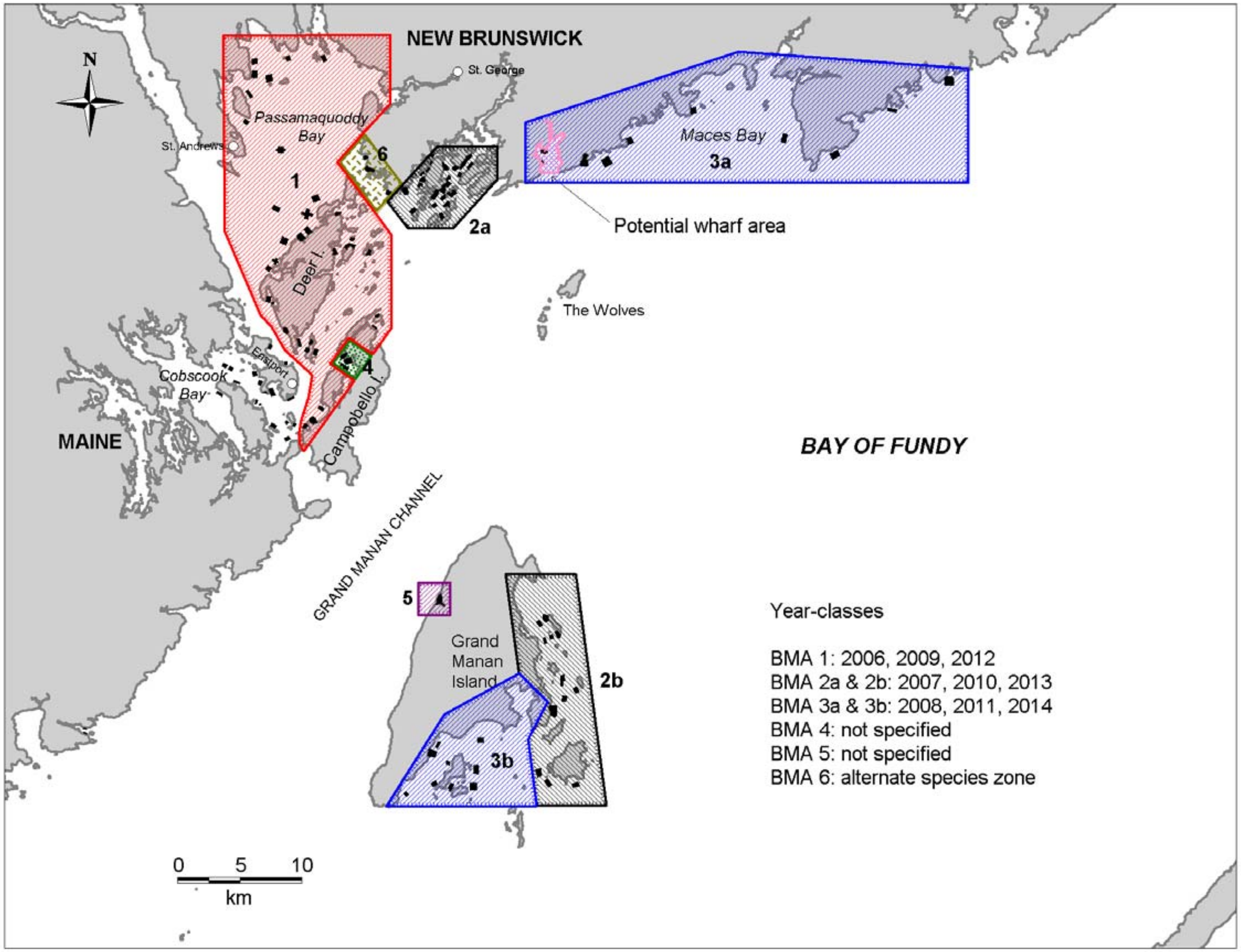

Fig. 2. Map of the SWNB salmon farming region showing salmon farms (small black polygons) and new BMAs implemented in late 2006 (larger colored polygons).

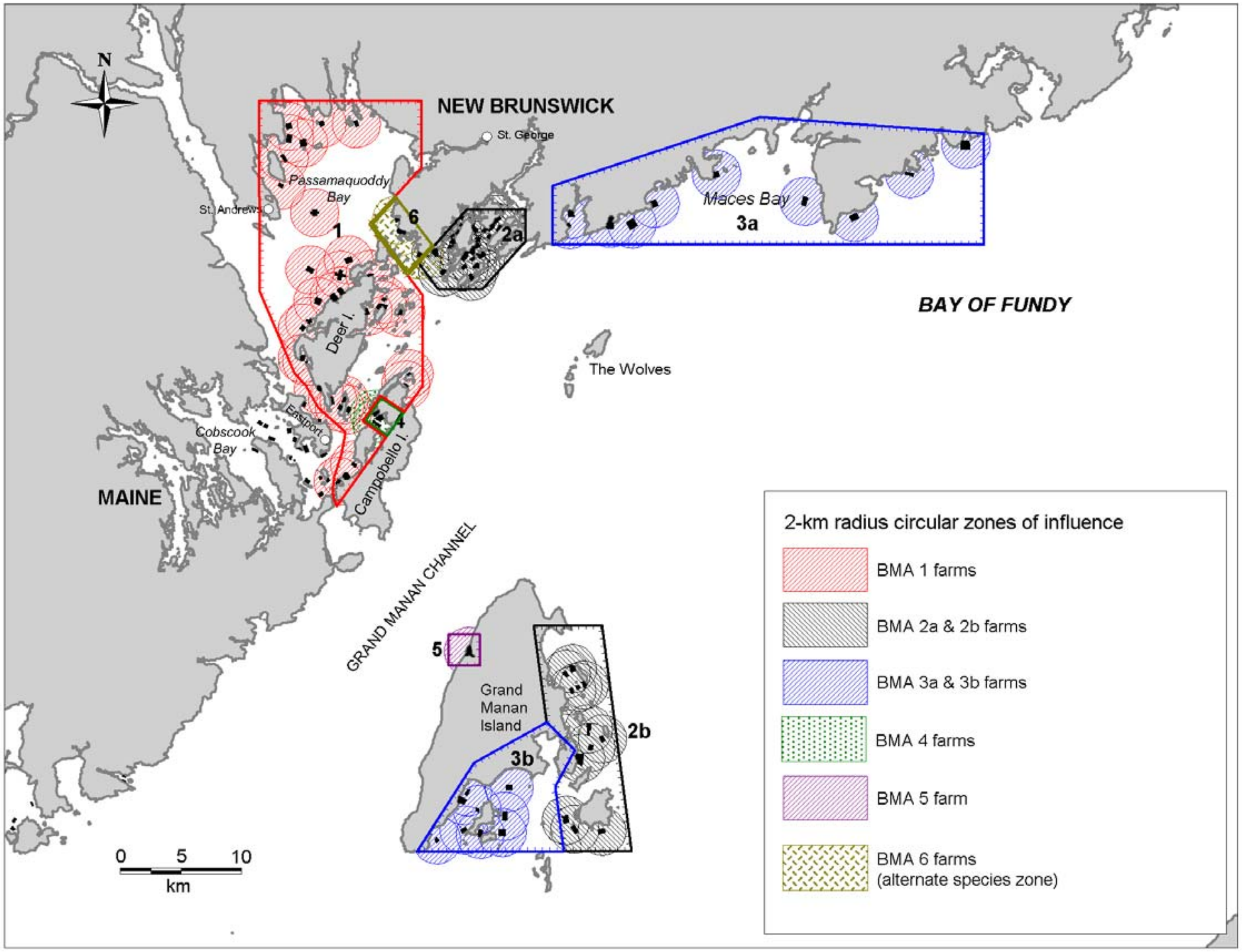

Fig. 3. Map of the SWNB salmon farming region showing salmon farms (small black polygons) and 2-km radius circular zones of influence around the centre of each farm. Also shown are the new BMAs.

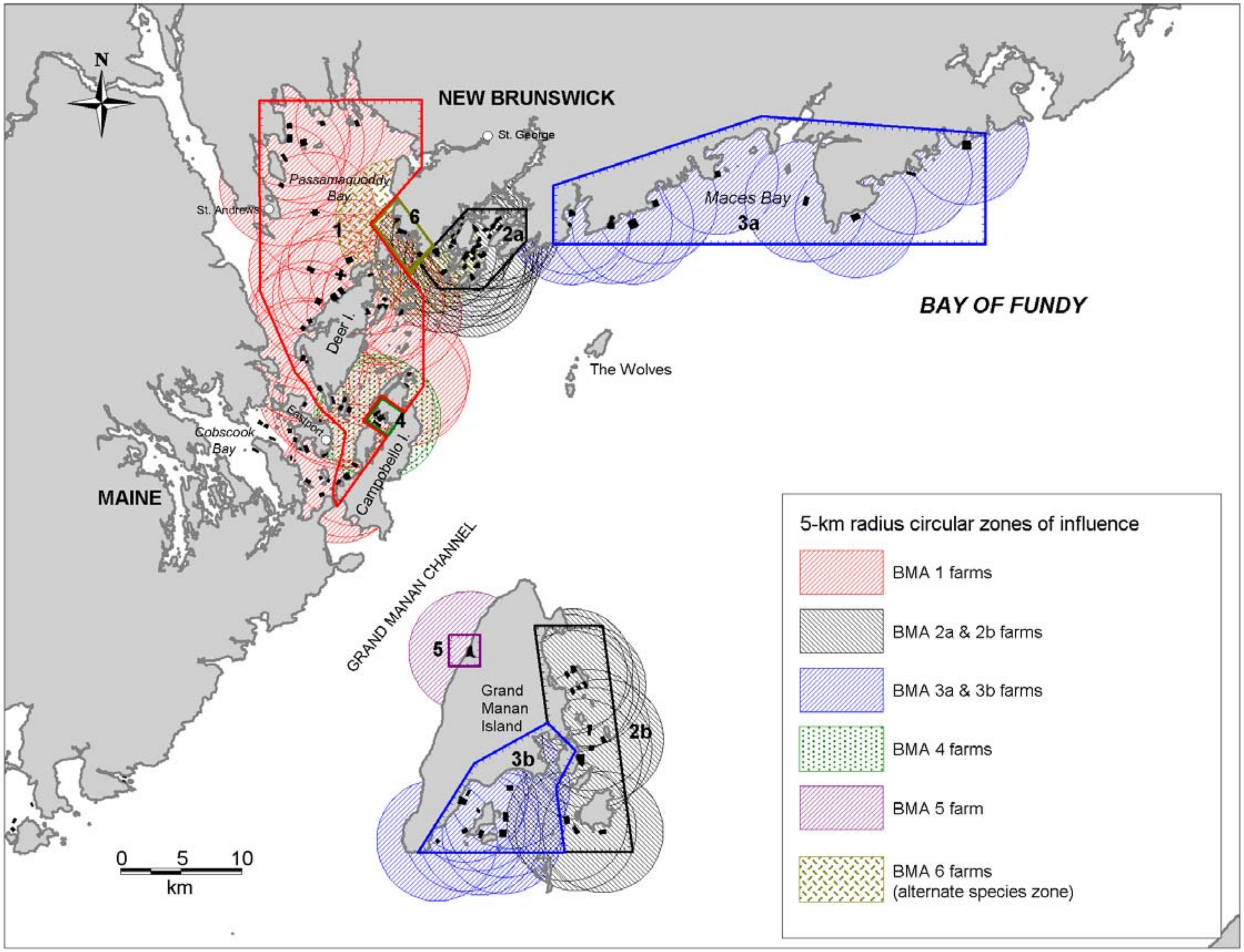

Fig. 4. Map of the SWNB salmon farming region showing salmon farms (small black polygons) and 5-km radius circular zones of influence around the centre of each farm. Also shown are the new BMAs.

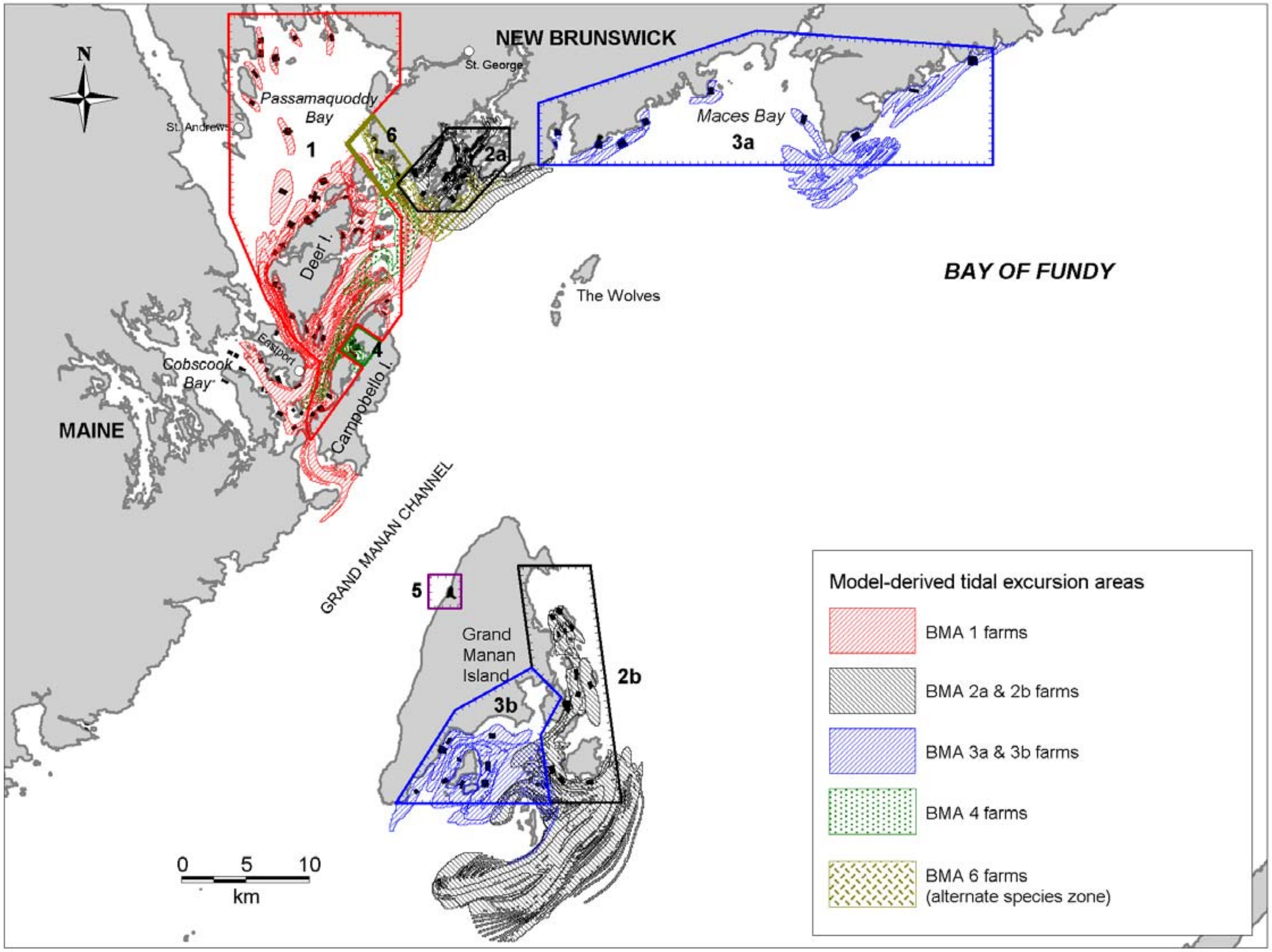

Fig. 5. Map of the SWNB salmon farming region showing salmon farms (small black polygons) and model-derived tidal excursion areas for each farm. Also shown are the new BMAs.

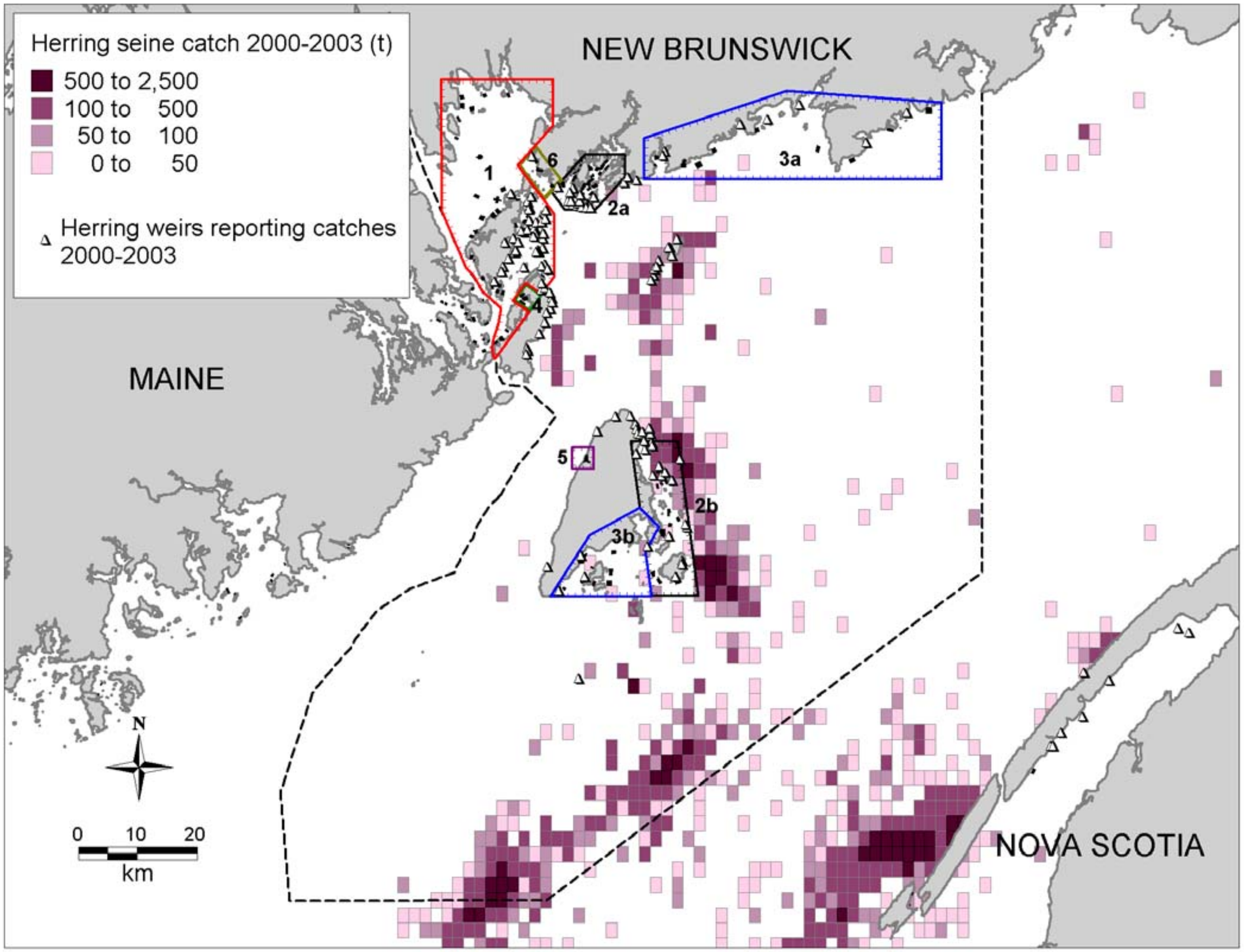

Fig. 6. New BMAs (colored outlines) and herring catches in SWNB. Purse seine catches are totals for 2000-2003 within 1 × 1 minute grid squares. Herring weirs shown are those that reported catches during this period. Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database; M. Power.

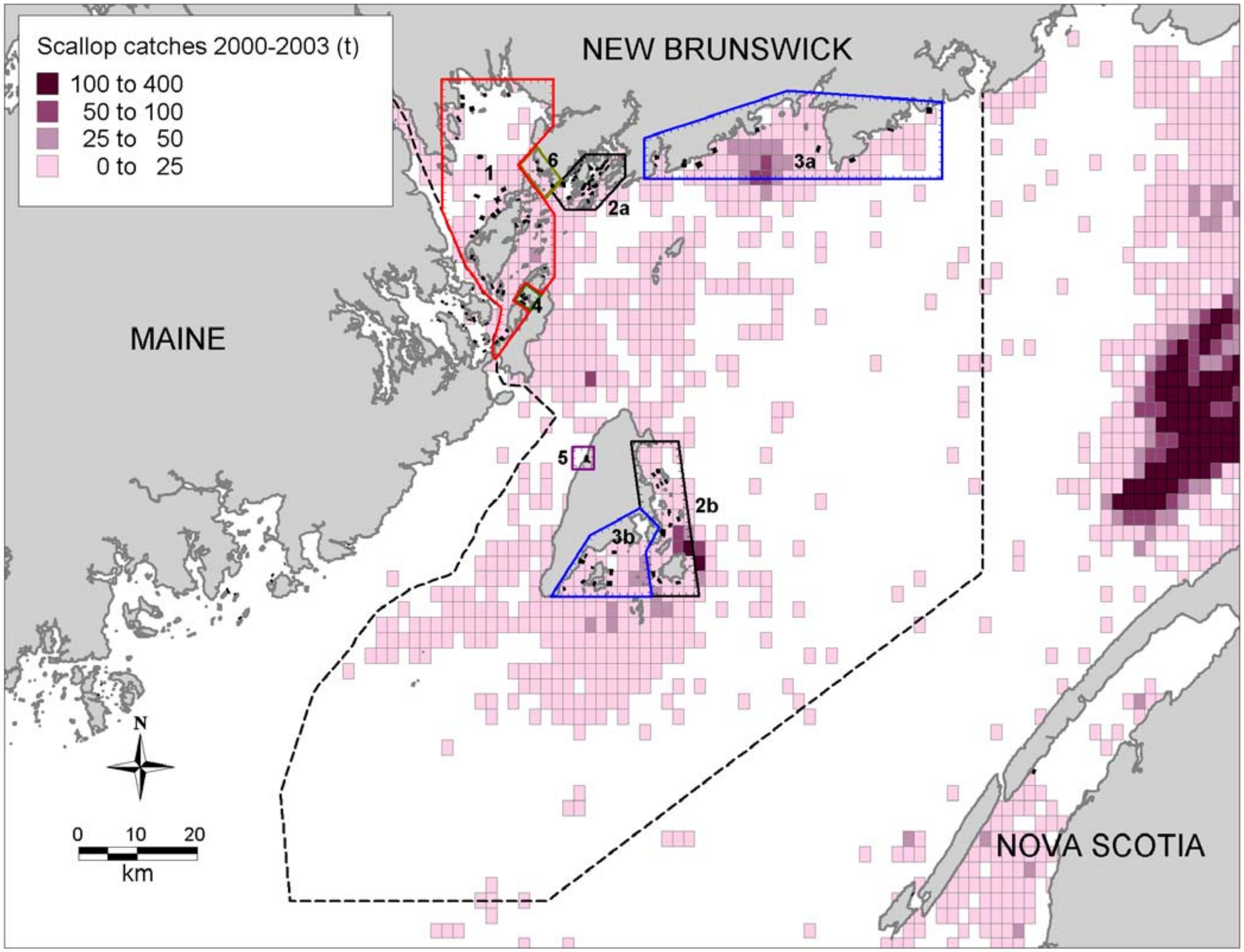

Fig. 7. New BMAs (colored outlines) and sea scallop catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

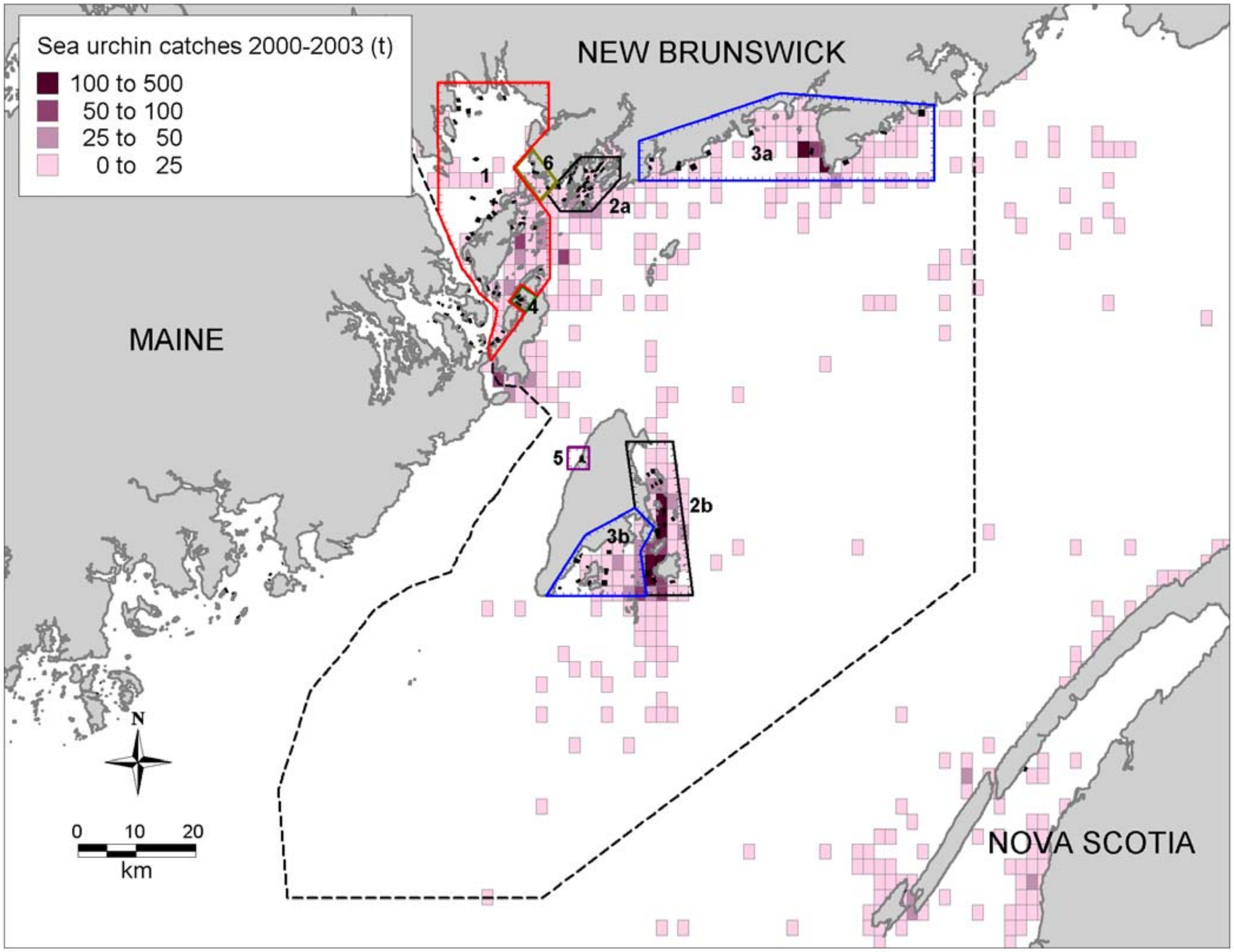

Fig. 8. New BMAs (colored outlines) and sea urchin catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

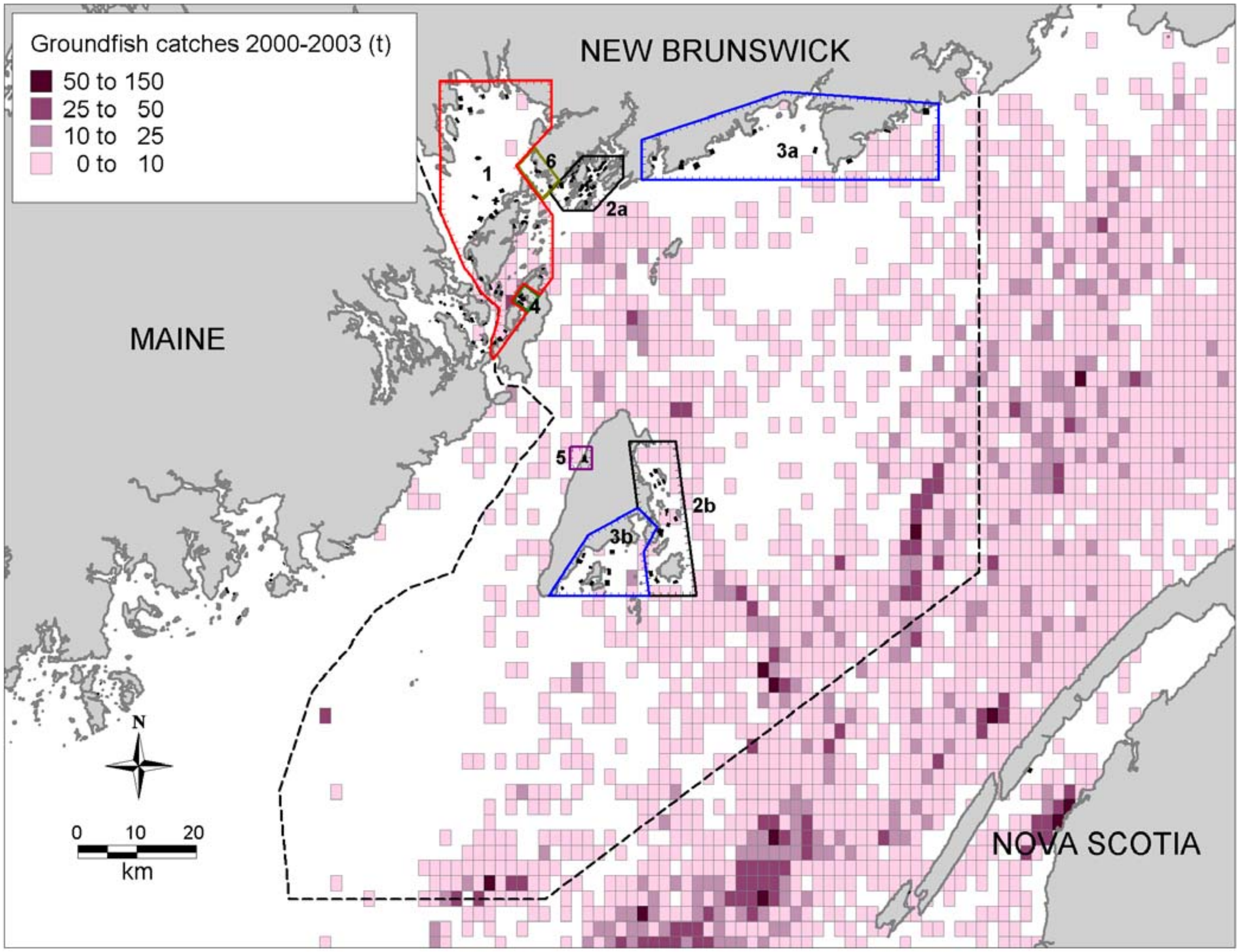

Fig. 9. New BMAs (colored outlines) and groundfish catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

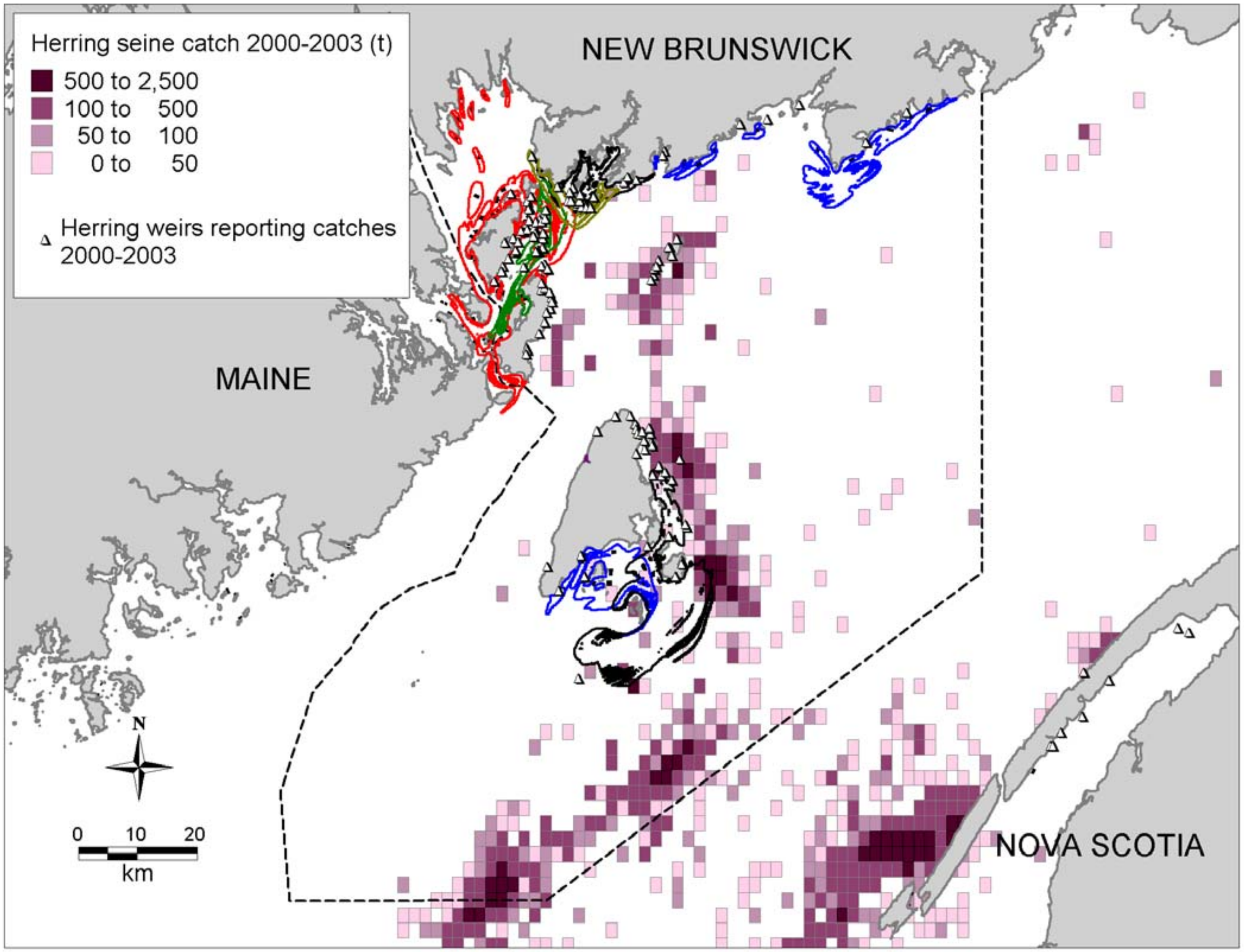

Fig. 10. Model-derived tidal excursion areas and herring catches in SWNB. Purse seine catches are totals for 2000-2003 within 1 × 1 minute grid squares. Herring weirs shown are those that reported catches during this period. Combined model-derived tidal excursion areas for all farms in each new BMA are shown as colored outlines (from Fig. 6). Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database; M. Power.

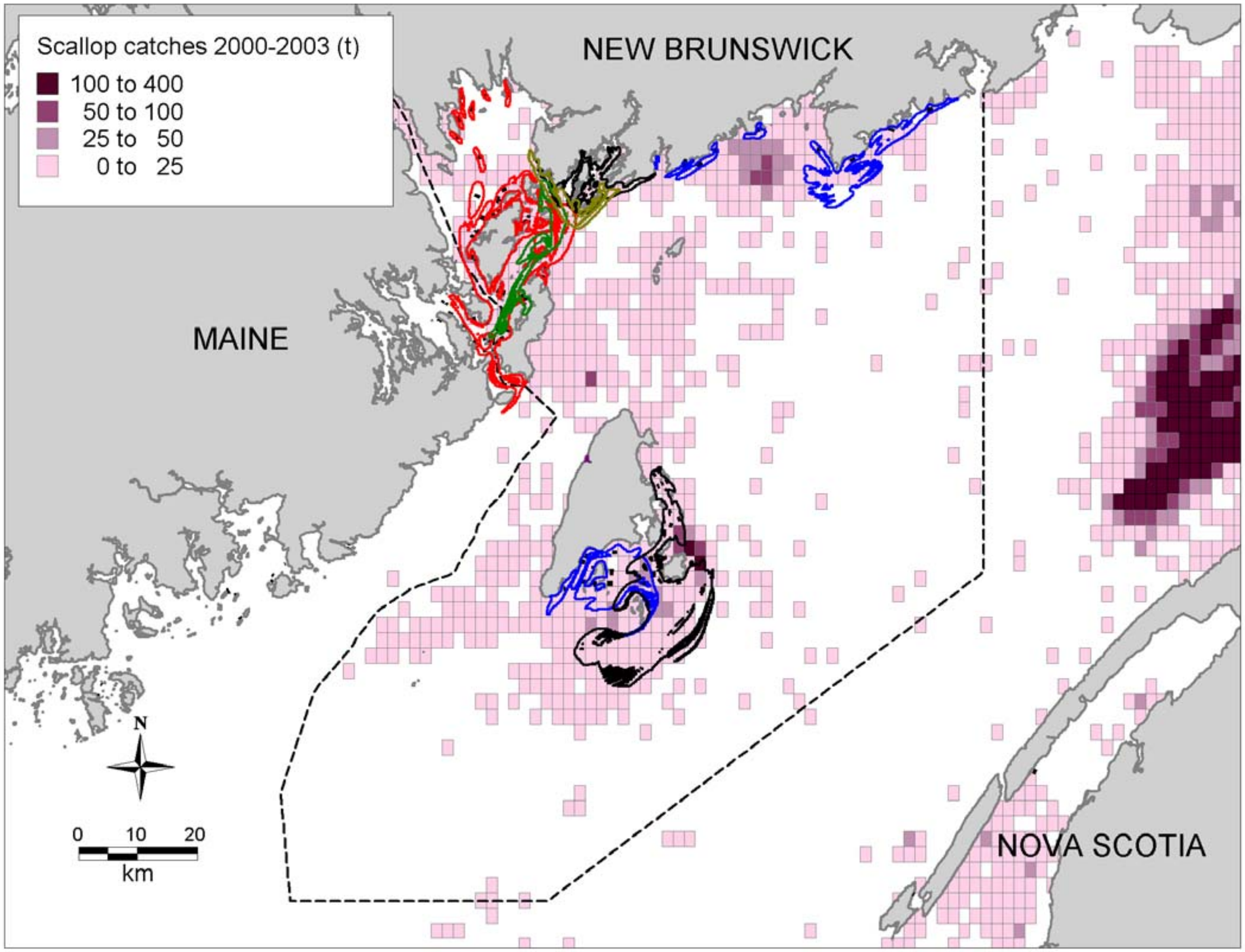

Fig. 11. Model-derived tidal excursion areas and sea scallop catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Combined model-derived tidal excursion areas for all farms in each new BMA are shown as colored outlines (from Fig. 6). Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

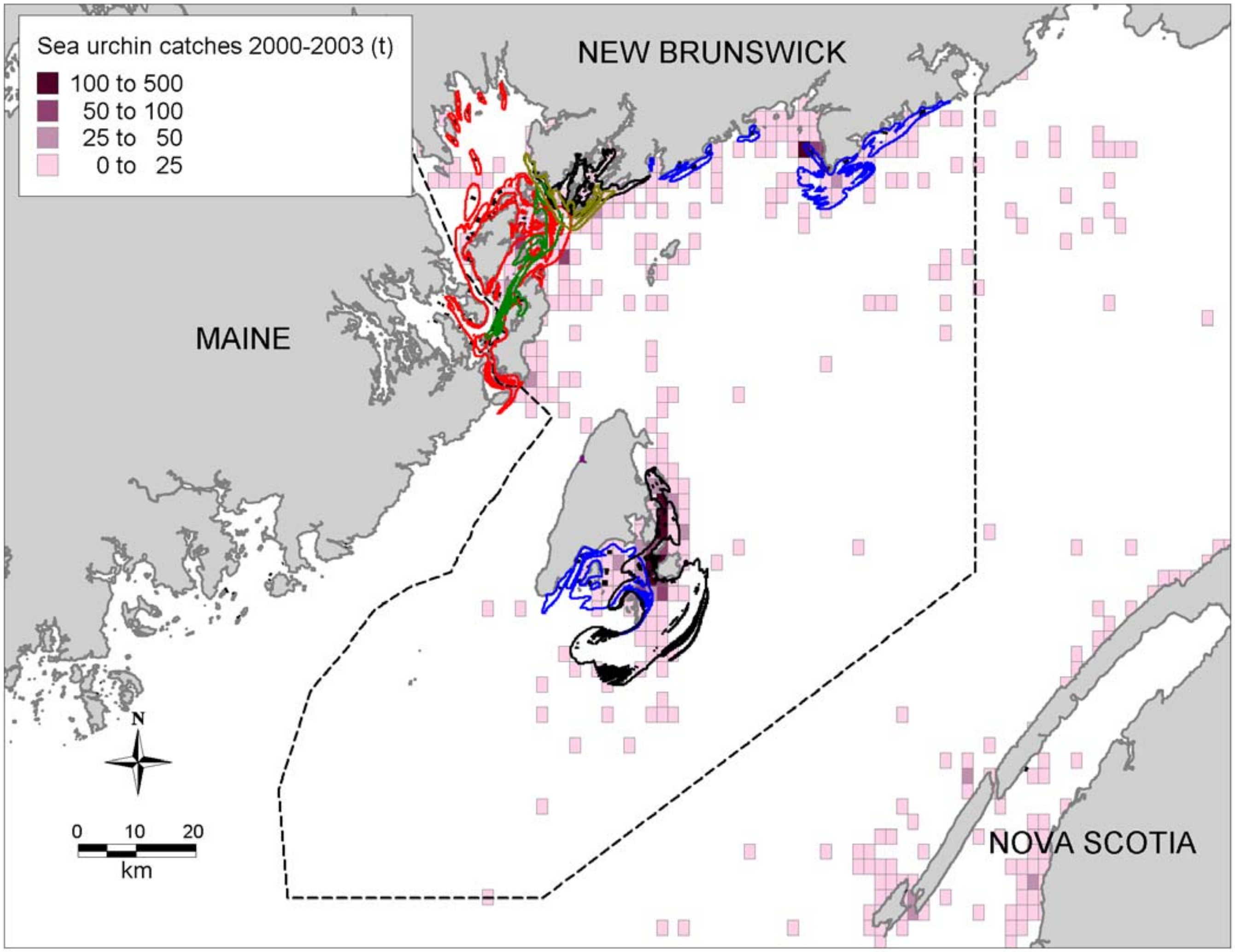

Fig. 12. Model-derived tidal excursion areas and sea urchin catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Combined model-derived tidal excursion areas for all farms in each new BMA are shown as colored outlines (from Fig. 6). Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

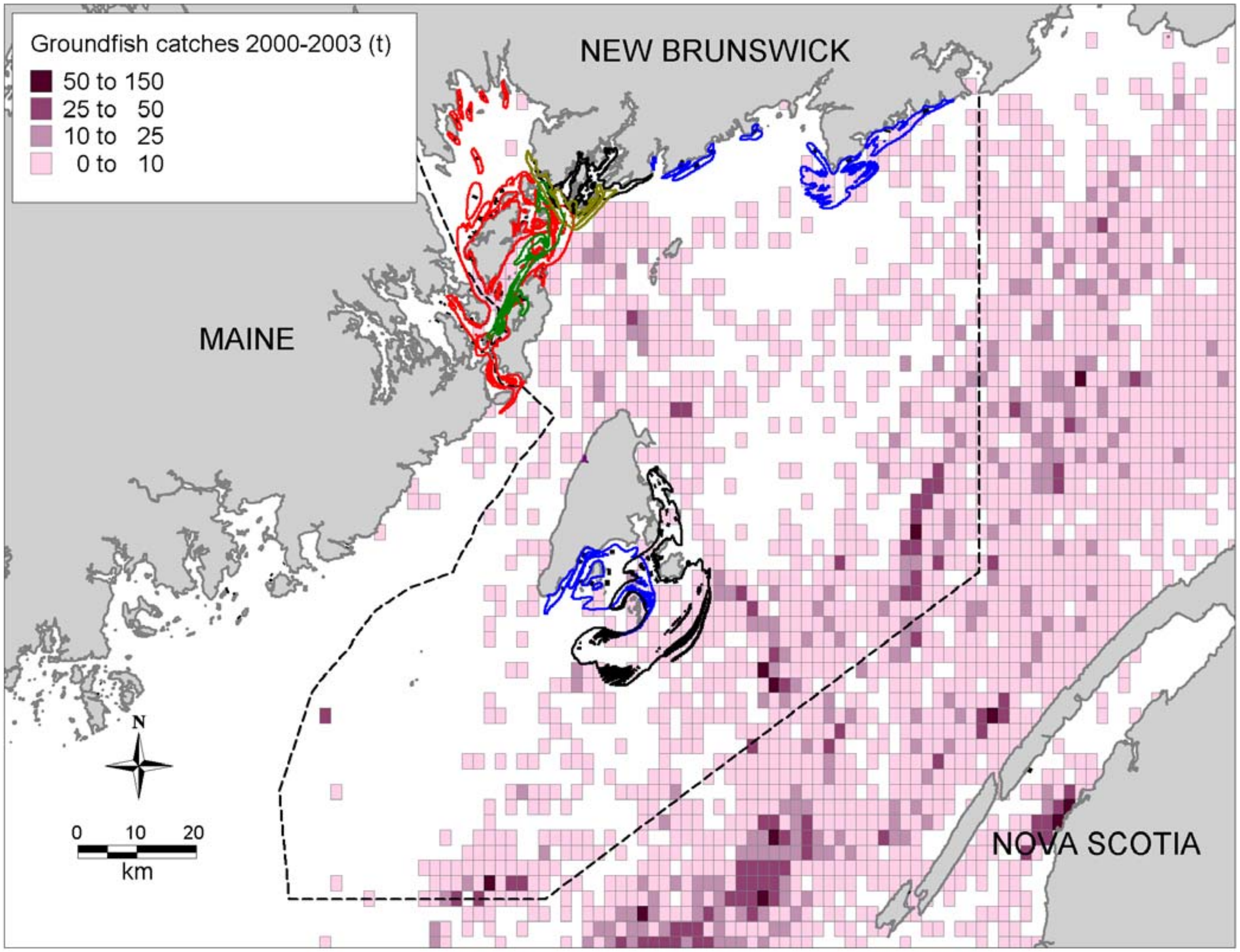

Fig. 13. Model-derived tidal excursion areas and groundfish catches in SWNB. Catches are totals for 2000-2003 within 1 × 1 minute grid squares. Combined model-derived tidal excursion areas for all farms in each new BMA are shown as colored outlines (from Fig. 6). Finfish aquaculture sites are shown as small black polygons. The dotted line defines the SWNB area as used in this report. Data source for fisheries data: Fisheries and Oceans Canada, commercial fisheries landings database.

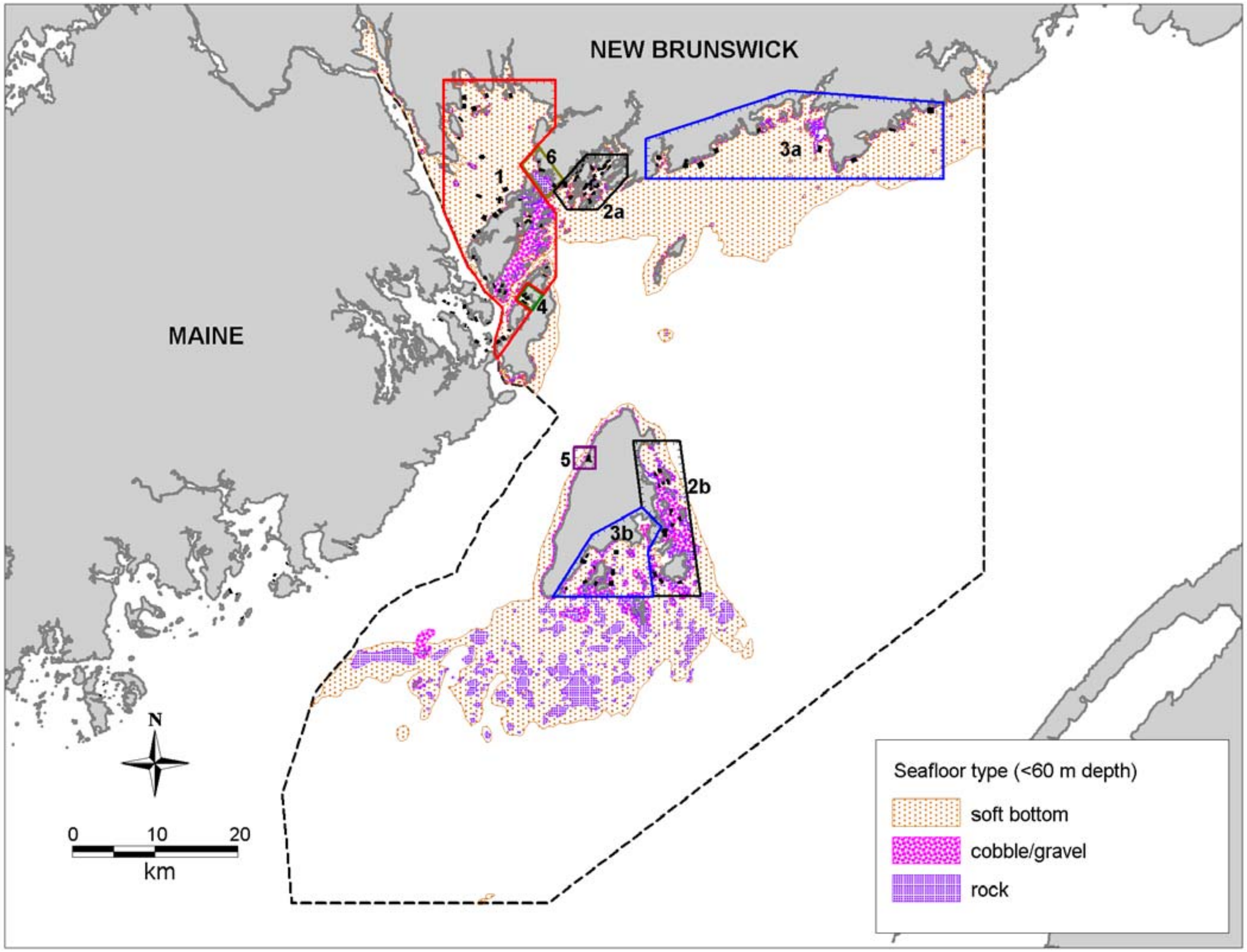

Fig. 14. Seafloor habitat types in SWNB, for depths of less than 60 m, as an indication of juvenile lobster habitat. Also shown are new BMAs (colored outlines). The dotted line defines the SWNB area as used in this report.

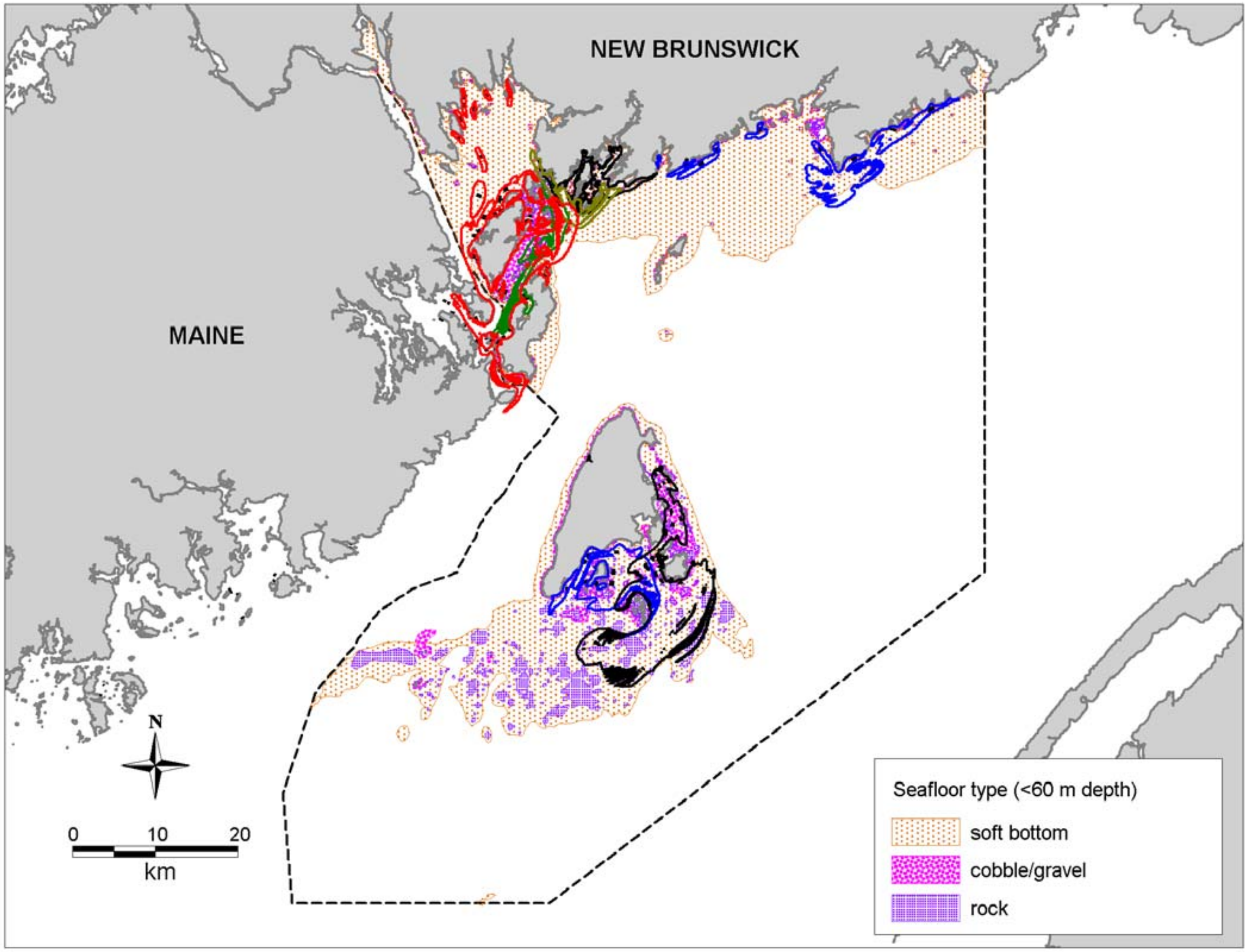

Fig. 15. Seafloor habitat types in SWNB, for depths of less than 60 m, as an indication of juvenile lobster habitat. Also shown are combined model-derived tidal excursion areas for all farms in each new BMA (colored outlines, from Fig. 6). The dotted line defines the SWNB area as used in this report.

WATER CIRCULATION AND MANAGEMENT OF INFECTIOUS SALMON ANEMIA IN THE SALMON AQUACULTURE INDUSTRY IN THE EASTERN MAINLAND AREA OF SOUTHWESTERN NEW BRUNSWICK

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INTRODUCTION

The objective of this project was to examine the potential for water-borne spread of fish diseases, such as infectious salmon anemia (ISA), among fish farms located along the eastern mainland shore of southwestern New Brunswick (SWNB), from Beaver Harbour to Haleys Cove. We did this by estimating the zone of influence (due to water exchange) around each farm and then looking at the overlaps of each zone of influence with farm sites and with the zones of influence of other farms. The zones of influence were estimated using a simple method, drawing circular areas around each farm, and a more complex method, using a water circulation model to estimate the tidal excursion area of each farm. The methodology used in this study was originally developed 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). This approach was subsequently applied to the other salmon farming areas in SWNB (with the exception of the area covered in the present report): southern Deer Island, Campobello Island, and adjacent Cobscook Bay, Maine (Chang et al. 2005a); Letete Passage, Back Bay, Bliss Harbour, and Lime Kiln Bay (Chang et al. 2005b); the eastern Grand Manan Island area (Chang et al. 2006a); and Passamaquoddy Bay (Chang et al. 2006b).

METHODS

The site boundaries for fish farms in SWNB were provided by the New Brunswick Department of Agriculture and Aquaculture (NBDAA), and were entered into a Geographic Information System (MapInfo Professional® 8.0). There are 10 salmon farms located along the eastern mainland shore of SWNB, including farm MF-494 (Haleys Cove) which was approved in 2006, but has not yet started operating (Fig. 1). Simple estimates of the zone of influence or water exchange around each farm were made by drawing 2-km and 5-km radius circles 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 centre of a site, the circle was centred over the location of the fish cage cluster. These circular areas were drawn using the MapInfo buffer tool. The maximum possible area of a 2-km radius circular zone of influence (i.e. if there were no land areas within a 2-km radius of the farm centre) was 12.6 km^2; for a 5-km radius circular zone of influence the maximum possible area was 78.5 km^2.

More precise estimates of the zones of influence or water exchange around farms were made using a three-dimensional tidal circulation and particle tracking model (Greenberg et al. 2005) that was customized to our geographic domain of interest. The geographic domain of the model included the entire Bay of Fundy and Gulf of Maine. The model estimated 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 was run, a depth profile of the current was calculated at each corner of every triangle every 2.07 s. The circulation model was fully non-linear, had 21 sigma depth levels (reduced in water shallower than 10 m), and had variable horizontal resolution (minimum approximately 50 m). This feature of the finite-element model made 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 was relatively coarse in the middle of the Gulf of Maine and quite fine in the salmon farming areas of SWNB. The model also simulated wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing using multiple tidal constituents, internal water density and surface winds as current driving forces, the customized model for the SWNB area was run using only boundary forcing by the principal lunar semi-diurnal tidal constituent (M_2).

Using the model, 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). Particles were released simultaneously from 36 points spaced equidistantly within a 200 × 200 m grid, except in the case of farm MF-012, where due to the small size of this site, only 21 grid release points were used. The particles were released and maintained at 1 m below the sea surface. Each particle was tracked and its position recorded 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, particles were released from every grid point at hourly intervals over a 12-h period (for a total of 36 × 12 = 432 particle tracks from most farms) in order to represent particles released throughout an entire tidal cycle. For farm MF-010 there were only 431 particle tracks, because one particle hit the shore less than 20 min after release (prior to its first recorded position). Because farm MF-012 had only 21 grid release points, there were only 252 particle tracks for this site.

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 visited by at least one particle track 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.

We then examined 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 zone of influence (as estimated by 2-km and 5-km radius circular area and by a model-derived tidal excursion area). We also determined which farms had overlapping zones of influence. With the model-derived tidal excursion areas, we were able to quantitatively measure the intensity of overlaps. We did this by determining the number of model particles that overlapped each farm site and each tidal excursion area.

RESULTS

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS USING 2-KM AND 5-KM RADIUS CIRCULAR ZONES OF INFLUENCE

Fig. 1 shows the 2-km and 5-km radius circular zones of influence of all farms in the study area. The 2-km radius zones suggest some connectivity among the five westernmost farms, but none among the other farms. The 5-km radius zones suggest a chain of connectivity linking all farms in the study area. The areas of the 2-km radius zones of influence ranged from 4.6-11.4 km^2 (average 8.1 km^2), while the 5-km radius zones ranged from 26.4-59.0 km^2 (average 46.4 km^2) (Table 1).

The presence or absence of overlaps of 2-km radius zones of influence with farm sites and the overlaps among 2-km radius zones of influence are shown in Table 2a. In all instances, where one farm's 2-km radius zone of influence overlapped a second farm's site, the second farm's 2-km radius zone of influence also overlapped the first farm's site. The 2-km radius zones of influence overlapped an average of 1.4 farm sites (including the originating farm site). For 6 of the 10 farms, the 2-km radius zones of influence did not overlap any other farm site, while for the other four farms, one other farm site was overlapped (in addition to the originating farm site). The number of overlaps among 2-km radius zones averaged 1.8 per farm (including the overlap of each 2-km radius zone with itself). There were no overlaps with farm sites or 2-km radius zones of influence of farms located outside the study area.

The presence or absence of overlaps of 5-km radius zones of influence with farm sites is shown in Table 2b. There was only one instance where one farm's 5-km radius zone of influence overlapped a second farm's site, but the second farm's 5-km radius zone of influence did not overlap the first farm's site: the 5-km zone of farm MF-012 overlapped farm site MF-496, but the 5-km zone of farm MF-496 did not overlap farm site MF-012. This occurred because the zones were based on 5-km circles drawn around a point located at the center of each farm site; in this instance, the centre points of these two farms were slightly greater than 5 km apart, but part of the site boundaries of the larger farm, MF-496, extended to within 5 km of the centre of farm MF-012, while the site boundaries of farm MF-012 did not extend to within 5-km of the centre of farm MF-496. The 5-km radius zones of influence overlapped an average of 2.9 farm sites (including the originating farm site). The number of overlaps among 5-km radius zones averaged 4.6 per farm (including the overlap of each 5-km radius zone with itself). There were no overlaps with farm sites or 5-km radius zones of influence of farms located outside the study area.

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

Figure 2 shows the model-derived tidal excursion areas (all hourly releases from each farm combined) of all farms in the study area. Figure 3 shows the individual tidal excursion areas of each farm, including the relative density of particle tracks present in 100 × 100 m grid cells. The tidal excursion areas were smaller than either the 2-km radius or the 5-km zones of influence, ranging from 0.2-11.4 km^2 (average 5.8 km^2) (Table 1), and were generally elongated in shape. The presence or absence of overlaps of tidal excursion areas with farm sites and the overlaps among model-derived tidal excursion areas is shown in Table 2c. Brief descriptions of the tidal excursion areas of each farm follow, in order of farm location from west to east.

The tidal excursion areas of the two farms in Beaver Harbour (MF-010 and MF-012) were very small (0.2 km^2) and somewhat elongated in the north-south direction. These tidal excursion areas did not overlap each other and did not overlap any other farm sites or tidal excursion areas.

The tidal excursion area of farm MF-378 in Foleys Cove was also small (1.5 km^2), extending along the coast west to the mouth of Beaver Harbour and a lesser distance east. This tidal excursion did not overlap any other farm's site or tidal excursion area, but did come very close to the farm site and tidal excursion area of MF-496.

Farm MF-496 had a tidal excursion area of 3.1 km^2, which extended along the shore west almost to Beaver Harbour and east almost to Maces Bay. The tidal excursion area did not overlap any other farm sites, but did come very close to farm sites MF-378 and MF-400. All 432 particles overlapped the tidal excursion area of MF-400, and also came very close to that of MF-378.

The tidal excursion area of farm MF-400 was 2.3 km^2, extending west to overlap the farm site and tidal excursion area of MF-496, and north into Seeleys Cove. The overlap with farm site MF-496 involved 109 particles (25%), while the overlap with this farm's tidal excursion area involved 303 particles (70%).

The tidal excursion area of farm MF-412 was small (1.9 km^2) and did not overlap any other farm's site or tidal excursion area.

The tidal excursion area of farm MF-404 was larger (11.4 km^2) and extended mostly south and east past Point Lepreau. This tidal excursion area did not overlap any other farm's site, but 270 particles (63%) released from this farm overlapped the tidal excursion area of farm MF-501.

The tidal excursion area of farm MF-501 was the largest in the study area (24.6 km^2) and extended mostly west and south past Point Lepreau. This tidal excursion area did not overlap any other farm's site, but 363 particles (84%) overlapped the tidal excursion area of farm MF-404.

The tidal excursion area of farm MF-495 (4.8 km^2) extended west to the mouth of Dipper Harbour and east to the mouth of Little Dipper Harbour. This tidal excursion area did not overlap any other farm's site, but 194 particles (45%) overlapped the tidal excursion area of farm MF-494.

The tidal excursion area of farm MF-494 (8.0 km^2) was almost 12 km long, extending west to the mouth of Dipper Harbour and east to Little Musquash Cove. This tidal excursion area did not overlap any other farm's site, but 74 particles (17%) released from this farm overlapped the tidal excursion area of farm MF-495.

The tidal excursion areas overlapped an average of 1.1 farm sites (including the originating farm site). Only one farm's tidal excursion area overlapped another farm's site (the tidal excursion area of farm MF-400 overlapped site MF-496). This is slightly less than the average numbers of overlaps of 2-km circular zones of influence with farm sites, and considerably less than the average numbers of overlaps of 5-km radius zones with farm sites (Table 3).

The tidal excursion areas overlapped an average of 1.6 tidal excursion areas (including each tidal excursion area's overlap with itself). There were four farms whose tidal excursion areas did not overlap any other farm's tidal excursion area, while six farms' tidal excursion areas overlapped one other tidal excursion area. This was slightly less than the average numbers of overlaps among 2-km radius circular zones of influence, and considerably less than the average numbers of overlaps among 5-km radius zones (Table 3).

None of the tidal excursion areas overlapped the sites or tidal excursion areas of farms located outside the study area.

DISCUSSION

The simple approach using 2-km radius circular zones of influence to estimate water exchange areas predicts connectivity among the five westernmost farms in the study area, but not among the other farms, while using 5-km radius zones predicts a chain of connectivity linking all farms in the study area. The model tidal excursion areas are slightly smaller than the 2-km radius circular zones of influence, and considerably smaller than the 5-km radius zones, and are not circular. Consequently, the model tidal excursion areas predict slightly fewer overlaps with other farms (and their zones of influence) than do the 2-km radius circular zones, and considerably fewer overlaps than do the 5-km radius zones (Table 3). The only overlaps of model-derived tidal excursion areas with farm sites involved the tidal excursion area of farm MF-400 with site MF-496, and the tidal excursion area of farm MF-404 with site MF-501. The overlaps among tidal excursion areas indicated just a few linkages among farms: MF-496 with MF-400, MF-404 with MF-501, and MF-495 with MF-494. These results suggest that there is some risk of water-borne disease transmission among at least some of the farms located within the eastern mainland area of SWNB. Because none of the estimated zones of influence of farms in this area overlapped with farm sites (or their zones of influence) located in other areas of SWNB, it is unlikely that there could be water-borne disease transmission between farms in the eastern mainland area and farms in other areas.

It must be noted that the tidal excursion areas 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 the SWNB 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 and increasing the predicted connectivity among some of the farms.

ACKNOWLEDGEMENTS

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We thank G. Smith (NBDAA, St. George) for providing information on farm site boundaries and J.D. Chaffey (DFO, Bedford Institute of Oceanography) for providing assistance with the circulation model development.

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Table 1. Areas of estimated zones of influence of finfish farms in the eastern mainland area of southwestern New Brunswick (SWNB). Zones of influence were estimated by three methods: 2-km and 5-km radius circular zones (excluding land and water areas cut off from the originating farm site by land) and model-derived tidal excursion areas. Farms are listed in order of their locations, from west to east. The combined zones of influence (formed by merging all of the individual zones) are smaller than the sums of the individual farms' zones of influence, because of overlaps between some of the individual farm's zones.

Farm site	2-km radius zone of influence (km^2)	5-km radius zone of influence (km^2)	Model tidal excursion area (km^2)
MF-012	6.0	34.8	0.2
MF-010	4.6	26.4	0.2
MF-378	6.8	46.8	1.5
MF-496	9.5	53.5	3.1
MF-400	8.6	44.9	2.3
MF-412	9.6	52.4	1.9
MF-404	11.4	59.0	11.4
MF-501	7.6	57.2	24.6
MF-495	8.7	45.2	4.8
MF-494	8.2	44.2	8.0
Mean ± SD	8.1 ± 2.0	46.4 ± 10.0	5.8 ± 7.5
Totals	81.0	464.4	58.0
Combined	70.7	259.8	49.0

Table 2a. Overlaps (indicated by shaded squares) of 2-km radius zones of influence of finfish farms in the eastern mainland area of SWNB. Top: overlaps of 2-km radius zones of influence with finfish farm sites. Bottom: overlaps among 2-km radius zones of influence. Farms are listed in order of their locations, from west to east.

Overlaps of originating farms' 2-km zones of influence with receiving farm sites		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	■	■								
	MF-010	■	■								
	MF-378			■	■						
	MF-496			■	■						
	MF-400					■					
	MF-412						■				
	MF-404							■			
	MF-501								■		
	MF-495									■	
	MF-494										■

Overlaps among 2-km zones of influence		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	■	■	■							
	MF-010	■	■								
	MF-378	■		■	■						
	MF-496			■	■	■					
	MF-400				■	■					
	MF-412						■				
	MF-404							■			
	MF-501								■		
	MF-495									■	
	MF-494										■

Table 2b. Overlaps (indicated by shaded squares) of 5-km radius zones of influence of finfish farms in the eastern mainland area of SWNB. Top: overlaps of 5-km radius zones of influence with finfish farm sites. Bottom: overlaps among 5-km radius zones of influence. Farms are listed in order of their locations, from west to east.

Overlaps of originating farms' 5-km zones of influence with receiving farm sites		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	■	■	■							
	MF-010	■	■	■	■						
	MF-378	■	■	■	■	■					
	MF-496	■	■	■	■	■					
	MF-400			■	■	■					
	MF-412						■				
	MF-404							■	■		
	MF-501							■	■		
	MF-495									■	■
	MF-494									■	■

Overlaps among 5-km zones of influence		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	■	■	■	■	■					
	MF-010	■	■	■	■	■					
	MF-378	■	■	■	■	■	■				
	MF-496	■	■	■	■	■	■				
	MF-400	■	■	■	■	■	■				
	MF-412			■	■	■	■	■			
	MF-404						■	■	■	■	
	MF-501							■	■	■	
	MF-495							■	■	■	■
	MF-494									■	■

Table 2c. Overlaps (indicated by shaded squares) of model-derived tidal excursion areas of finfish farms in the eastern mainland area of SWNB. The numbers within the shaded squares represent the number of particle tracks from the originating farm which overlap the receiving farm site or tidal excursion area. Top: overlaps of tidal excursion areas with finfish farm sites. Bottom: overlaps among tidal excursion areas. Farms are listed in order of their locations, from west to east.

Overlaps of originating farms' tidal excursion areas with receiving farm sites		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	252									
	MF-010		431								
	MF-378			432							
	MF-496				432	109					
	MF-400					432					
	MF-412						432				
	MF-404							432			
	MF-501								432		
	MF-495									432	
	MF-494										432

Overlaps among model-derived tidal excursion areas		**Originating farm**									
		MF-012	MF-010	MF-378	MF-496	MF-400	MF-412	MF-404	MF-501	MF-495	MF-494
Receiving farm	MF-012	252									
	MF-010		431								
	MF-378			432							
	MF-496				432	303					
	MF-400				432	432					
	MF-412						432				
	MF-404							432	363		
	MF-501							270	432		
	MF-495									432	74
	MF-494									194	432

Table 3. Summary table of the numbers of overlaps between estimated zones of influence and finfish farms in the eastern mainland area of SWNB, and the numbers of overlaps among the zones of influence. Zones of influence around farms were estimated using three methods: 2-km and 5-km radius circular zones and model-derived tidal excursion areas. Numbers include the overlap of each zone of influence with its originating farm and the overlap of each zone of influence with itself.

Estimation method	Number of overlaps (Mean ± SD)
Overlaps of zones of influence with finfish farm sites	
2-km radius zones	1.4 ± 0.5
5-km radius zones	2.9 ± 1.3
Model-derived tidal excursion areas	1.1 ± 0.3
Overlaps among zones of influence	
2-km radius zones	1.8 ± 0.9
5-km radius zones	4.6 ± 1.3
Model-derived tidal excursion areas	1.6 ± 0.5

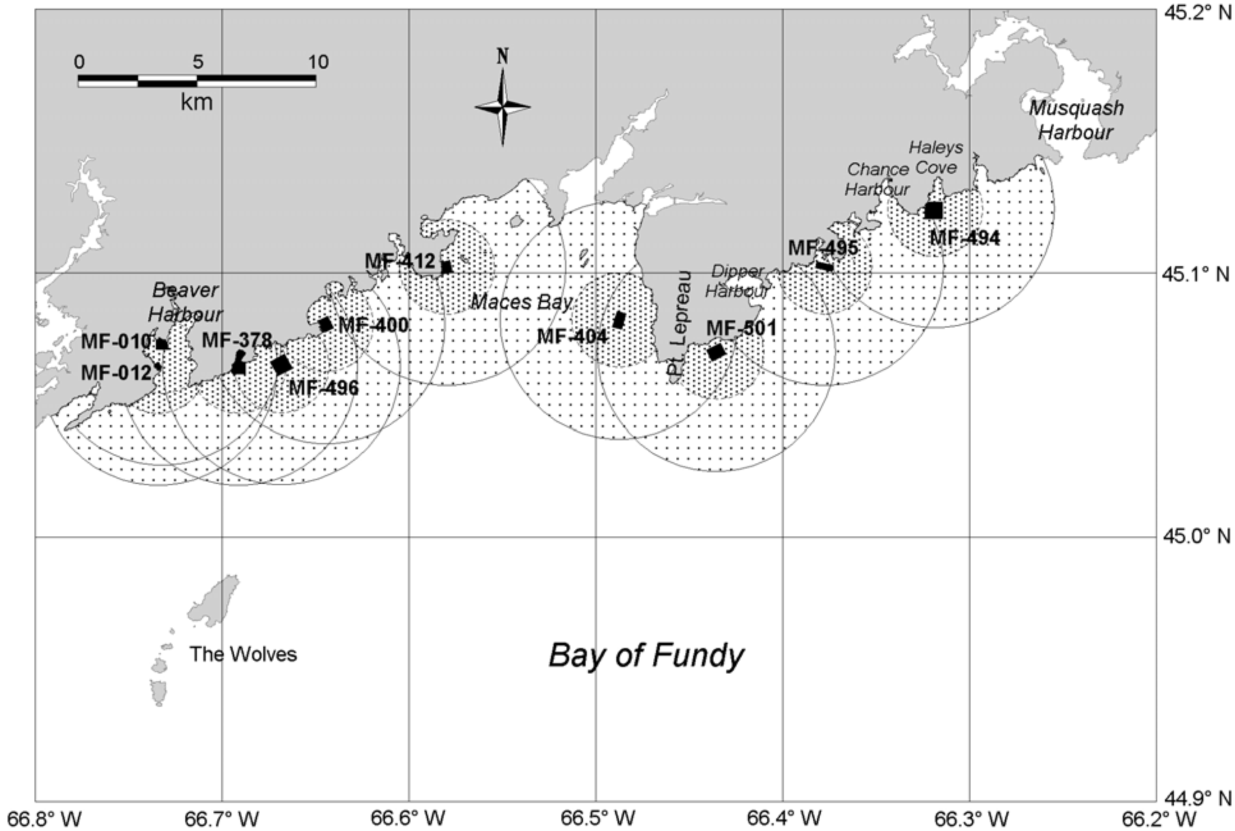


Fig. 1. Map of the eastern mainland area of SWNB, showing finfish farms (small black polygons) and circular zones of influence around farms: 2-km radius (darker shading) and 5-km radius (lighter shading).

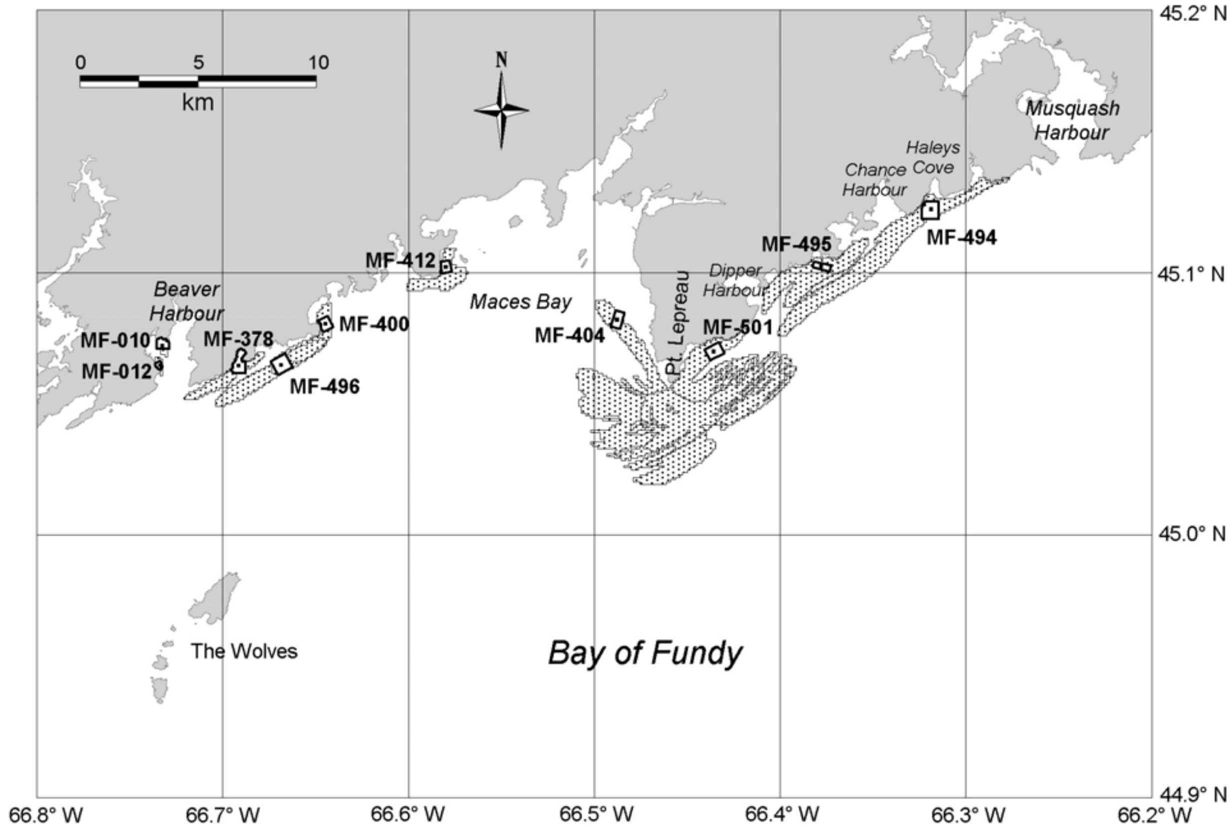


Fig. 2. Map of the eastern mainland area of SWNB, showing finfish farms (white polygons), the starting grids for model particle releases (small black squares within farm sites), and model-derived tidal excursion areas of these farms (larger, shaded polygons).

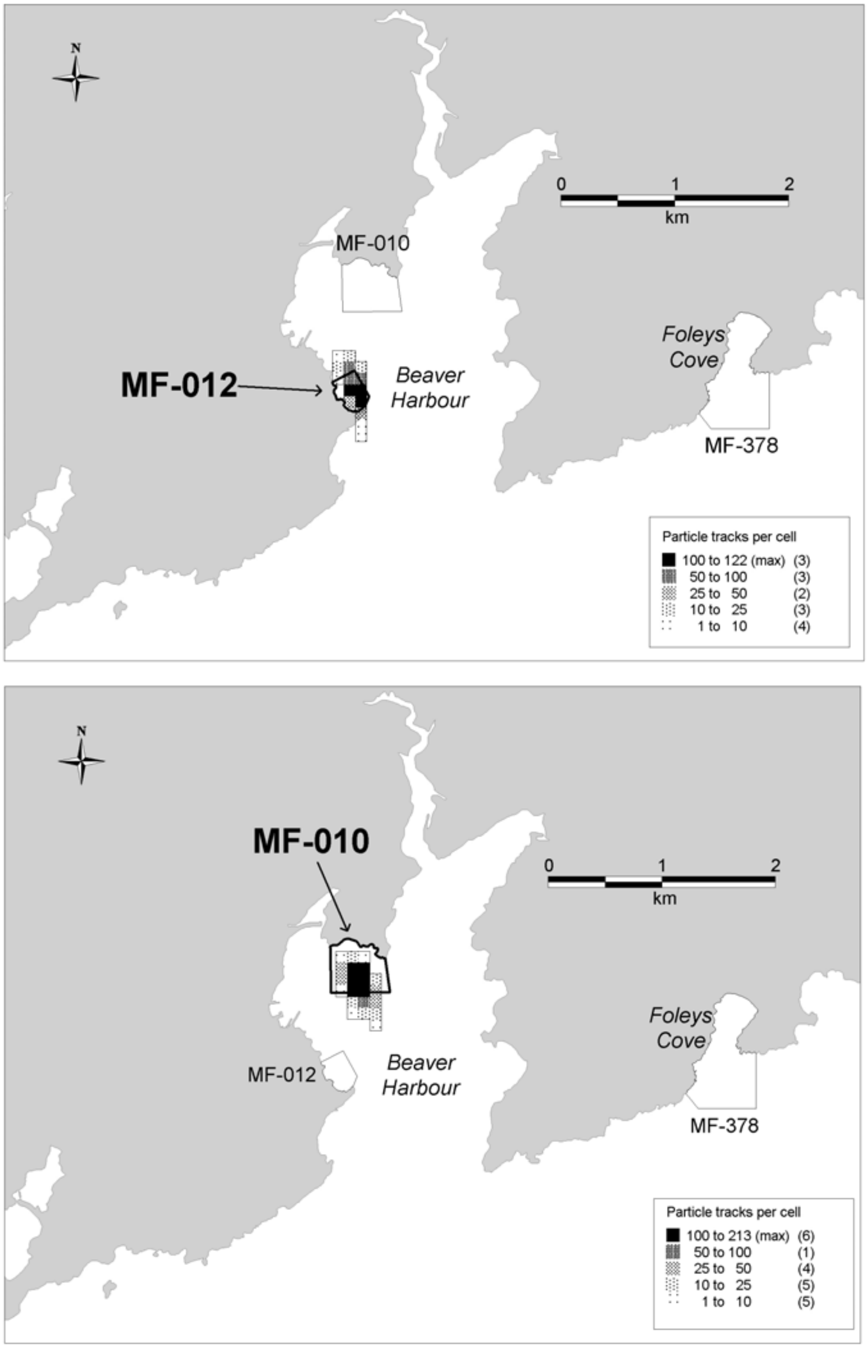
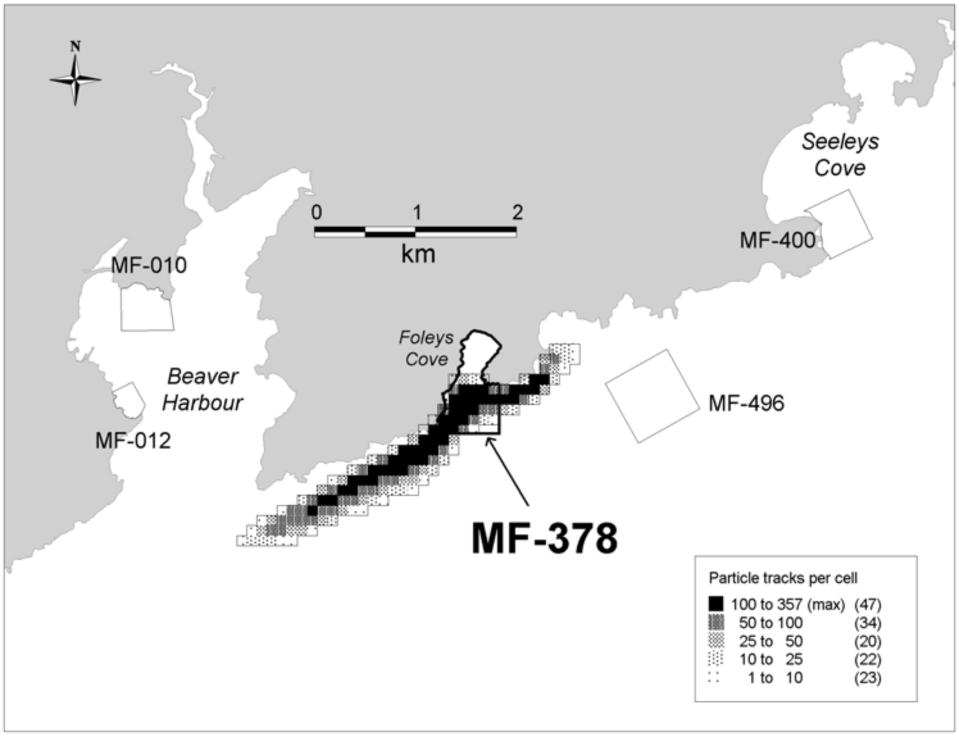


Fig. 3. Model-derived tidal excursion areas for each finfish farm in the eastern mainland area of SWNB. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell (see legend). Thirty-six particles were released from each farm (except 21 for farm MF-012) at hourly intervals over a 12-h period (see text for details). 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 white polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts. The maps are presented in order of farm locations, from west to east.



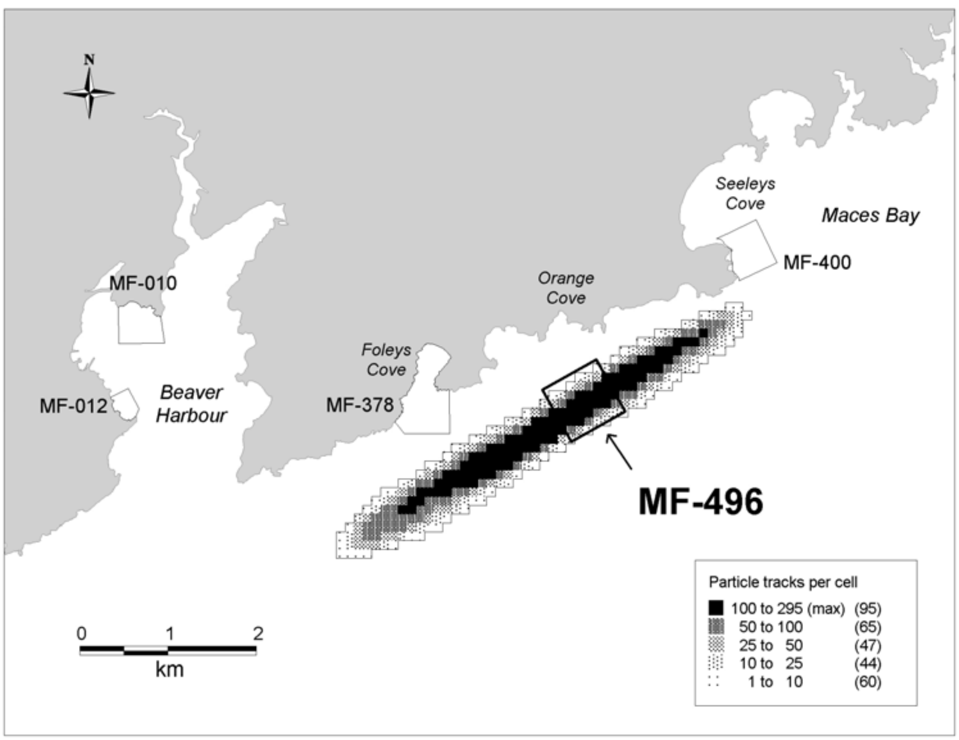
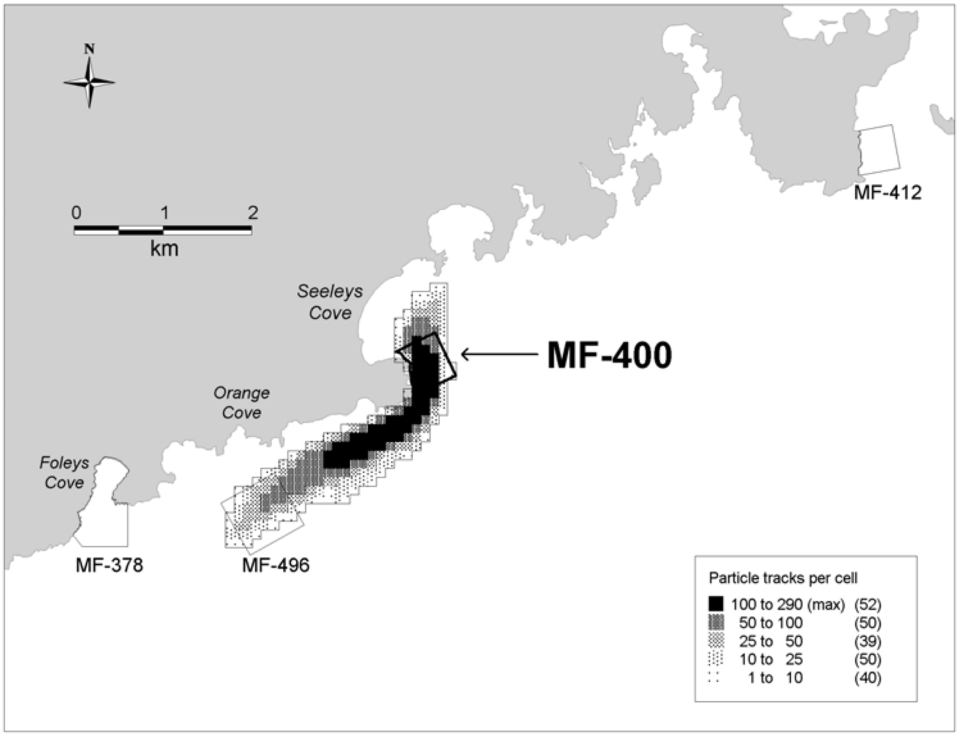


Fig. 3 continued.



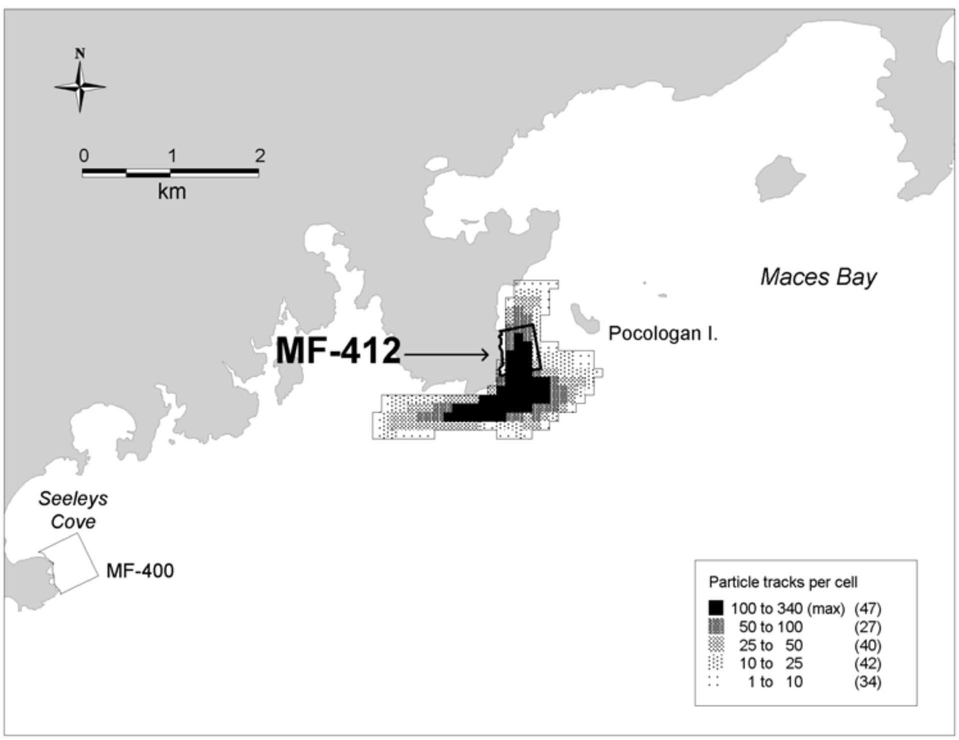


Fig. 3 continued.

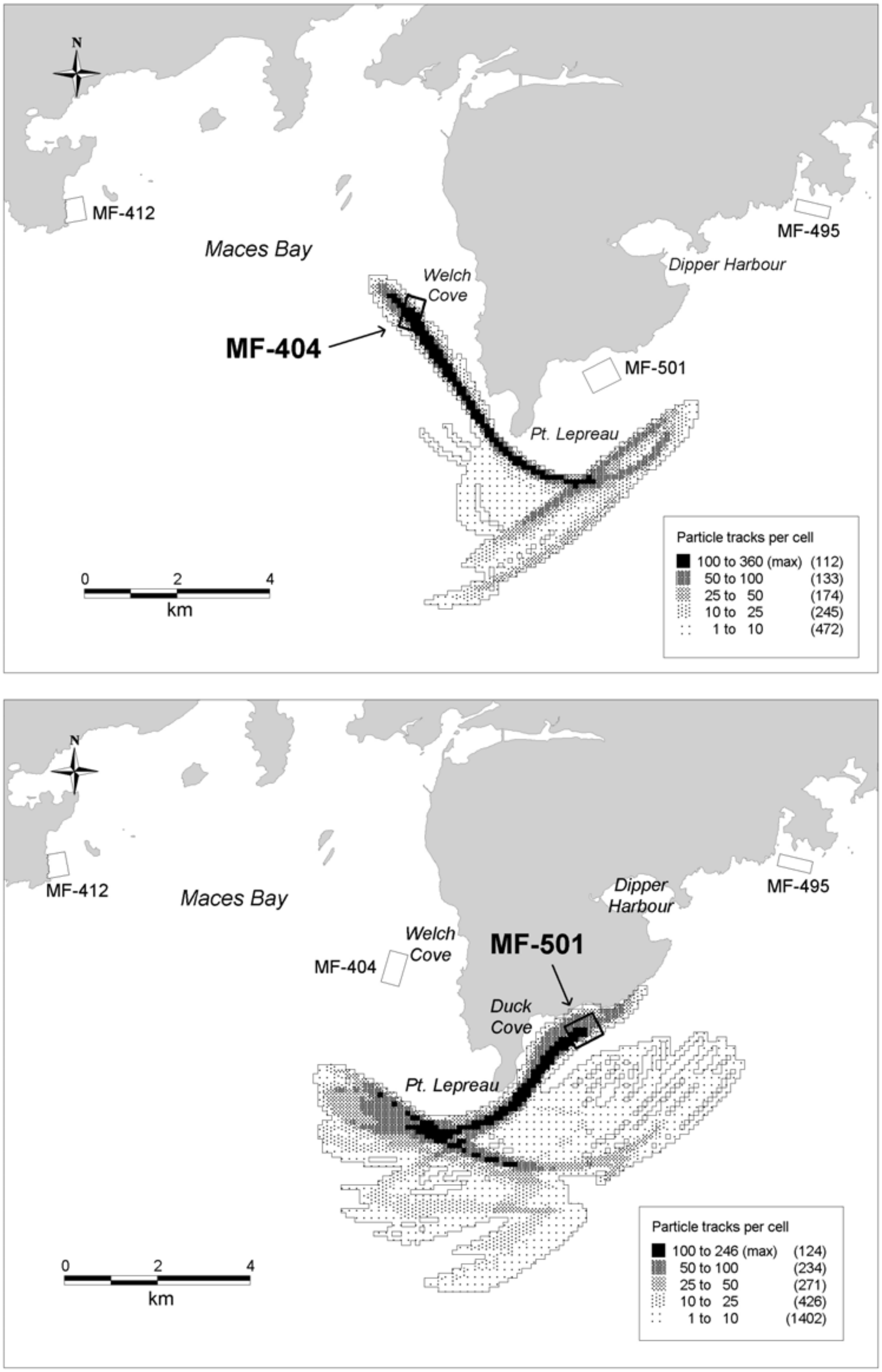
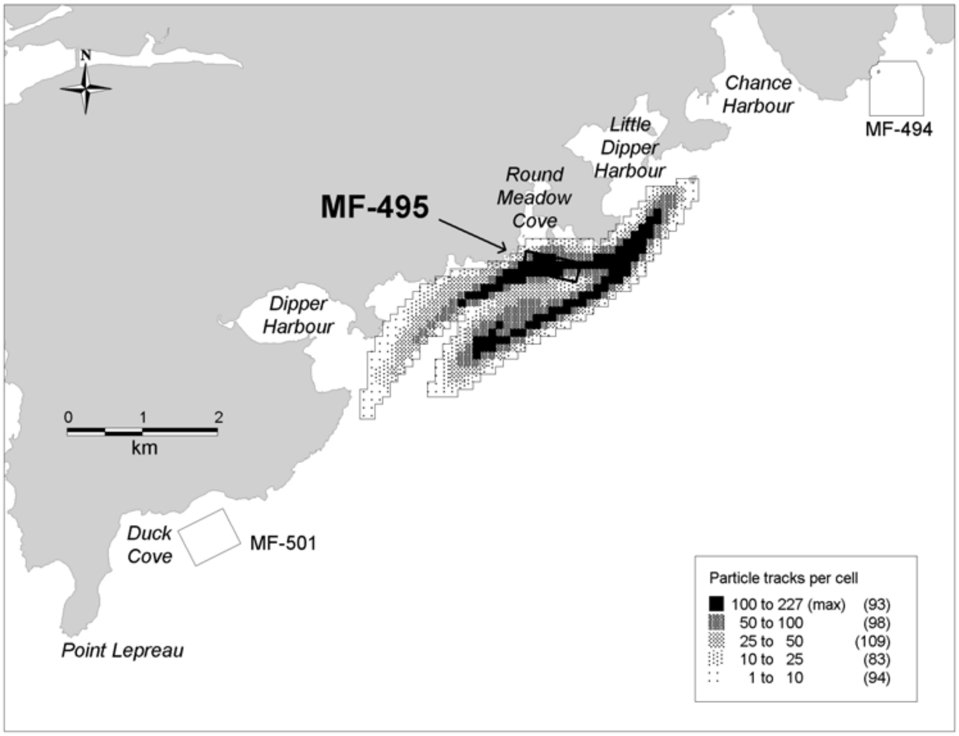


Fig. 3 continued.



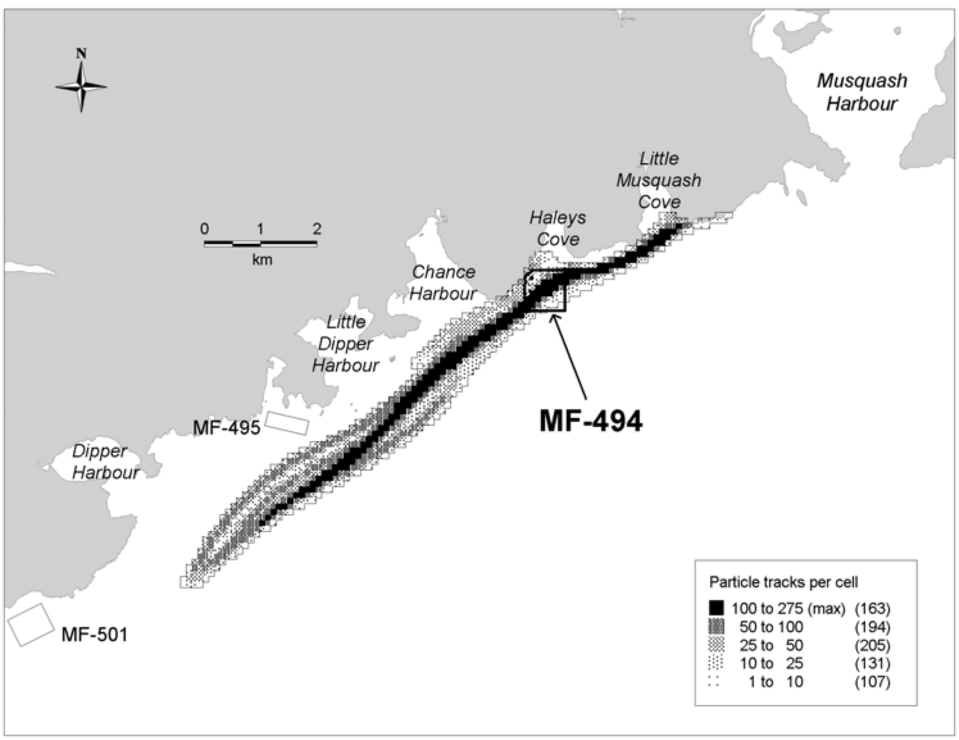


Fig. 3 concluded.