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Use of a GIS for decision support in coastal zone management in the southwestern New Brunswick portion of the Bay of Fundy

B.D. Chang[1], F.H. Page[1], R.J. Losier[1], and D.A. Greenberg[2]

[1] St. Andrews Biological Station, Maritimes Region, Fisheries and Oceans Canada
[2] Bedford Institute of Oceanography, Maritimes Region, Fisheries and Oceans Canada

Abstract

The southwestern New Brunswick (SWNB) portion of the lower Bay of Fundy is the location of considerable human activity in its marine waters despite a relatively low human population. Traditionally, fisheries have been the dominant activity in marine waters. Commercial shipping has also been of importance since the earliest days of European settlement. More recently, salmon aquaculture and marine recreational activities have become important, and there is new interest in the energy sector (tidal power generation and liquefied natural gas terminals). The area is also used by endangered species, such as the northern right whale and wild Atlantic salmon. Our first involvement with the use of GIS was for fish health management in the salmon aquaculture industry in SWNB. We used a circulation model and GIS to predict the water-borne spread of diseases, such as infectious salmon anemia, among salmon farms. This work was later used in the delineation of Aquaculture Bay Management Areas for the SWNB salmon farming industry. We also used GIS to conduct a preliminary analysis to determine potential locations for offshore aquaculture in the Bay of Fundy. Using GIS enabled us to overlay available geo-referenced information on activities, resources, and other issues to determine where overlaps occur, and where the potential for locating offshore aquaculture would likely cause the least negative interaction and potential for conflict. We can also use GIS with oceanographic data and models to predict which areas are technically best suited for certain activities, such as aquaculture or tidal power. The presentation will highlight some of our applications and experiences with taking this approach to Decision Support.

Keywords: coastal zone management, aquaculture, decision support

Contact author B.D. Chang: Fisheries and Oceans Canada, Biological Station, 529 Brandy Cove Road, St. Andrews, NB, Canada E5B 2L9 [tel: +1 506 529 5907, fax: +1 506 529 5862, email: changb@mar.dfo-mpo.gc.ca]

Introduction

The Coastal Ocean Research Section at the St. Andrews Biological Station, in collaboration with colleagues at the Bedford Institute of Oceanography, has been involved in the application of GIS to issues in the southwestern New Brunswick (SWNB) area of the lower Bay of Fundy since 2001. In this report, we summarize our GIS-related activities to date.

The Bay of Fundy is an extension of the Gulf of Maine, between the provinces of New Brunswick and Nova Scotia (Fig. 1). The Bay of Fundy is characterized by large tides: the maximum tidal range in Passamaquoddy Bay in SWNB is 8.3 m, while the tidal range can exceed 16 m in the Minas Basin at the head of the Bay of Fundy (Trites 1983). The SWNB marine area is characterized by a wide variety of physical and biological features (Thomas 1983).

Although the SWNB area has a relatively low population, considerable activity occurs in its marine waters. Fishing has been the dominant activity in marine waters since before European settlement. Ship-building was important in the past, and considerable commercial shipping continues to occur. More recently, aquaculture and marine recreational activities have become important. There are now proposals for liquefied natural gas (LNG) terminals and tidal power in the area.

Application of GIS to predict water-borne disease transmission among fish farms

Our first involvement in using GIS was related to the management of the disease infectious salmon anemia (ISA) in salmon farms in SWNB. In 2001, we were approached by the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) to provide advice on the potential fish health risk resulting from the approval of some new farms in the southern Grand Manan Island area. Prior to 2001, there were 7 farms in this area: 6 farms were odd year-class farms (smolts were transferred to sea cages in odd years) and one farm was even year-class. In 2001, five new odd year-class farms were approved in this area. Previously, the one even year-class farm was relatively isolated from the other farms, but the addition of the new farms would decrease the separation distance between different year-class farms.

The Norwegian and Scottish experience with ISA suggested that water-borne disease spread was an important risk factor, and that the highest risk was at the scale of one tidal excursion around infected farms (JGIWG 2000; Norwegian Animal Health Authority 2002). The practice of multi-year-class farming within sites and bays was also identified as an important risk factor (McGeachy and Moore 2003).

In Norway, control zones were established around ISA-infected farms. A control zone was defined as a circular zone with a radius of at least one tidal excursion, but not less than 5 km (Norwegian Animal Health Authority 2002). If 5-km radius circular zones are drawn around farms in the southern Grand Manan Island area, considerable influences among farms are indicated (Fig. 2), suggesting that they should all be considered to be within one management zone, with all stocked fish in the same year-class. We subsequently examined if 5-km radius circular zones were appropriate for defining tidal excursion areas of farms in SWNB.

Our approach to this issue was to use a tidal circulation model that had been developed for the Gulf of Maine – Bay of Fundy area (Greenberg et al. 2005) and customize it for the specific area of interest (the SWNB salmon farming area). We used the model to predict the tidal excursion area of each fish farm in the area of interest. We then used GIS software (MapInfo) to determine the overlaps of each tidal excursion area with other farms and with other farms' tidal excursion areas.

Using the model, 36 particles were released from a square grid (200 × 200 m) located at the approximate centre of the farm. The model particles were maintained at 1 m depth, tracked at approximately 2 second intervals, and recorded at 20 min intervals for one tidal excursion (12.4 h). The releases were repeated at hourly intervals for a total of 12 releases, in order to represent particles released over the tidal cycle. A polygon was then drawn around all of the particle tracks, to represent one tidal excursion area. Details of the methodology have been previously reported (Page et al 2005; Chang et al. 2005a). Fig. 3 shows the particle tracks and the tidal excursion area for one farm in the southern Grand Manan Island area.

Fig. 4 shows the tidal excursion areas of all farms in the southern Grand Manan Island area before and after the new farms were added in 2001. The model-predicted tidal excursion areas were not circular, and were generally much smaller than the 5-km radius circular zones. The overlap analyses using the model-derived tidal excursion areas show that in 2000, the even year-class farm was somewhat isolated from the others, but the addition of the new farms in 2001 reduced the degree of isolation. Also, prior to 2001, the White Head Island farms were isolated from the other southern Grand Manan Island farms, but the addition of the new farms decreased this isolation.

Development of a new Aquaculture Bay Management Area structure for SWNB

In 2000, the province and industry had introduced an Aquaculture Bay Management Area (ABMA) structure (NBDAFA 2000). The SWNB farming area was divided into 21 (increased to 22 in 2001) ABMAs (Fig. 5). Within each ABMA, all farms were to become single year-class farms, with all farms in the same ABMA having the same year-class of fish and common management standards and practices. Although oceanography was indicated as one of the factors used in developing this ABMA structure, there was relatively little oceanographic data available at the time.

One of the main reasons for implementing ABMAs was to address the ISA problem; however, ISA continued to be a problem for the industry in the early 2000s. One factor may have been that the structure introduced in 2000-2001 had too many ABMAs. If the Norwegian and Scottish recommendations were followed, there should be little or no overlap of tidal excursion areas between farms in different ABMAs. Using our circulation model, we predicted tidal excursion areas for all farms in SWNB, and then determined the overlaps between the tidal excursion areas and farms, as well as the overlaps among tidal excursion areas.

The data we provided was a major input into the process which resulted in 5 large ABMAs which contained the majority of farms, plus a few smaller ABMAs to include the few remaining farms (Fig. 6). The new ABMA framework results in a large drop in the number of overlaps of tidal excursion areas with farm sites in other ABMAs (Table 1 top). Of the 4 remaining overlaps, three involved farms in ABMA 6, which has been designated for non-salmonids only. The fourth case involved the overlap of a tidal excursion area of a farm in ABMA 1 with farm sites in ABMA 4; the latter ABMA has now been incorporated into ABMA 1. There is also a large drop in the numbers of overlaps of tidal excursion areas with tidal excursion areas originating from other ABMAs (Table 1 bottom).

We also looked at overlaps between ABMAs and the most important fishing activities occurring in SWNB. Geo-referenced fishing catch data (to the nearest minute of latitude and longitude) were available for most of the important fisheries in SWNB, except for the lobster fishery. Considerable fishing activity occurs within the ABMA boundaries, especially for those fisheries that occur mainly near the coast, such as sea urchins, sea scallops and herring weirs (Fig. 7 and Table 2). Groundfish are caught mainly in offshore areas, with only a very small percentage of the catch occurring within the ABMAs.

For lobster, for which we had no geo-referenced catch data, we looked at the bottom subtrate type, as a predictor of the suitability of an area for juvenile lobsters. Shallow cobble/gravel and rocky subtrates are considered to be preferred over mud bottom (Harding 1992; Lawton 1993). Our analysis showed that a considerable amount of the preferred juvenile lobster habitat occurs within the ABMAs (Fig. 8 and Table 3).

Open ocean aquaculture potential, based on a preliminary analysis of marine resource use in the Bay of Fundy

In 2003, an industry-government project was initiated to examine the feasibility of open ocean aquaculture in the Bay of Fundy (Bridger and Beers Neal 2004). Open ocean aquaculture is defined as fish culture in exposed or offshore areas. The interest in open ocean aquaculture is due to the shortage of new sites for aquaculture development in nearshore or protected areas (Chang 2003). Furthermore, there is the preception that open ocean sites would have fewer user conflict issues. We subsequently undertook a GIS resource study to look at the potential for open ocean aquaculture. In this preliminary analysis, we collected readily available information on resources and activities in open ocean areas, as well as the suitability of such areas for raising fish. The main sources of data were: Fisheries and Oceans Canada; Canadian Coast Guard; New Brunswick Department of Agriculture and Aquaculture; Eastern Charlotte Waterways Inc.; Buzeta et al. (2003); Graham et al. (2002); MacKay et al. (1978-1979); Lacroix and Knox (2005). See Chang et al. (2005c) for a complete list of data sources.

An initial overlay of activities, which included all reported fishing activity, as well as historic and current spawning areas, major shipping lanes and anchorages, aquaculture sites, and cetacean areas, indicated that there were no areas where there were no potential conflicts (Fig. 9; see Chang et al. 2005c for details). If we eliminated less productive fishing areas and historic (but not current) spawning areas, some potential areas for offshore aquaculture are indicated (Fig. 10). However, it is essential that further work be done to determine if these potential sites are indeed free of conflicts. We know that some important activities, such as lobster fishing and critical habitats for the endangered stocks of inner Bay of Fundy salmon, were not adequately included in our analysis due to lack of available data.

Developing issues

Some developing issues in the Bay of Fundy which will likely require GIS analyses are tidal power and liquefied natural gas (LNG) terminals. While the potential for tidal power is greatest near the head of the Bay of Fundy, where tides are higher, there is interest in tidal power in the SWNB area, as well as in adjacent areas of Maine. Work is ongoing to look for potential sites, from the viewpoint of tides and currents, as well as possible conflicts with existing activities such as fishing, aquaculture, and ecotourism.

An LNG terminal is currently under construction at the Canaport facility at Saint John, New Brunswick. There are also three proposals for LNG terminals on the Maine coast of Passamaquoddy Bay. The Saint John facility is located in an existing industrial port facility, and the LNG tankers would use existing designated traffic lanes. The three Maine proposals are located in areas with relatively little industrial development, and would require ships to transit through waters that are used by fishing, aquaculture, and ecotourism activities.

Some final considerations

We must emphasize that the analyses presented are our first efforts in this direction. Work is underway to refine and enhance these initial efforts. It must also be noted that the presence of an overlap in the GIS analysis does not necessarily mean that there is a conflict or problem. This work has proven to be an effective communications tool for decision-makers and clients.

Acknowledgements

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Table 1. Numbers of overlaps of farm tidal excursion areas with other farm sites (top) and with other farms' tidal excursion areas (bottom) in ABMA frameworks implemented in 2001 and 2006. Excludes overlaps of a tidal excursion area with its originating farm site or with the originating tidal excursion area.

		Total number of farms whose zones of influence overlap the site boundaries of:		
BMA framework	No. of farms	Any other farms in SWNB	Any other farms in the same ABMA	Any farms in other ABMAs
2001	94	70	68	20
2006	94	70	69	4

		Total number of farms whose zones of influence overlap the zones of influence of:		
BMA framework	No. of farms	Any other farms in SWNB	Any other farms in the same ABMA	Any farms in other ABMAs
2001	94	81	79	58
2006	94	81	81	32

Table 2. Commercial fisheries catches within ABMAs, 2000-2003. Data shown are for the most important fisheries in SWNB for which geo-referenced catch data is available. Top table: catches (t) within each ABMA. 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).

ABMA	No. of farms in ABMA	Total catches 2000-2003 (t)				
		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 ABMAs	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

ABMA	No. of farms in ABMA (% of total)	Total catches 2000-2003 as % of total SWNB catch				
		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 ABMAs	100.0	51.9	7.2	48.7	85.6	2.8

Table 3. Areas of seafloor habitat types (for depths <60 m) within ABMAs. Top table: areas (km^2) within each ABMA. Bottom table: same data expressed as percentages of the SWNB totals.

ABMA	No. of farms in ABMA	Marine area of ABMA (km^2)	Seafloor type <60 m depth within each ABMA (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 ABMAs	94	637.9	431.8	77.7	32.0
All SWNB	94	637.9	1 165.0	100.0	130.7

ABMA	No. of farms in ABMA (% of total)	Marine area of ABMA (% of all ABMAs)	Seafloor type <60 m depth within each ABMA (% 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 ABMAs	100.0	100.0	37.1	77.7	24.5

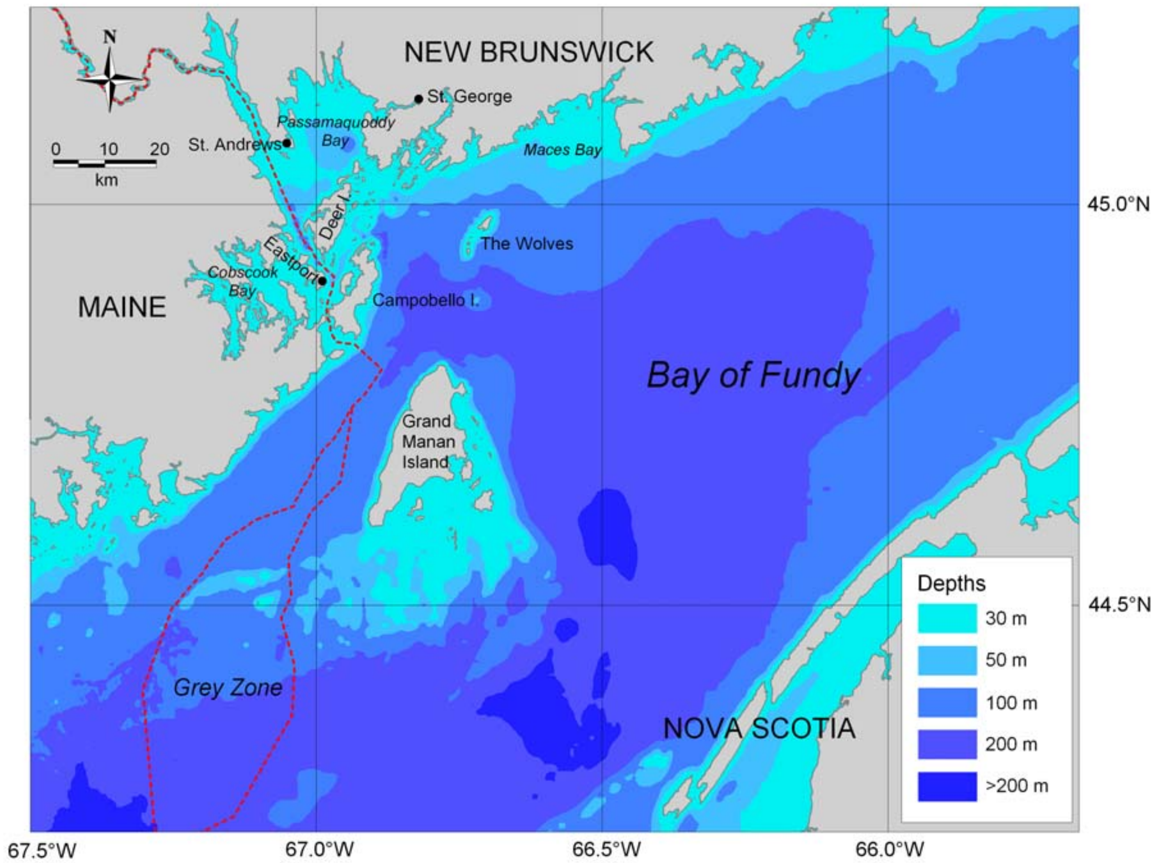


Fig. 1. Map of the lower Bay of Fundy.

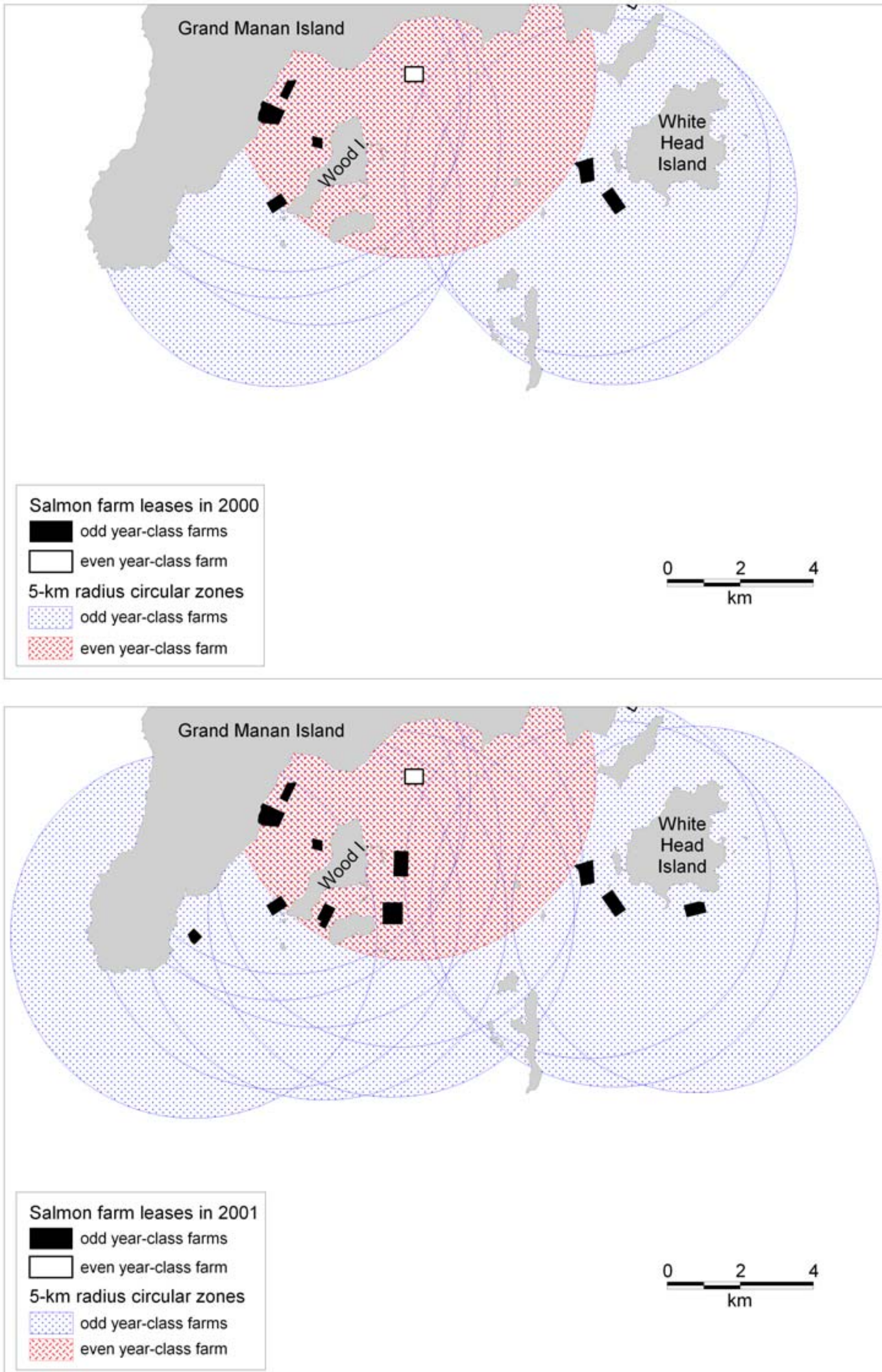


Fig. 2. Circular zones of 5-km radius drawn around fish farms in the southern Grand Manan Island area, 2000 (top) and 2001 (bottom).

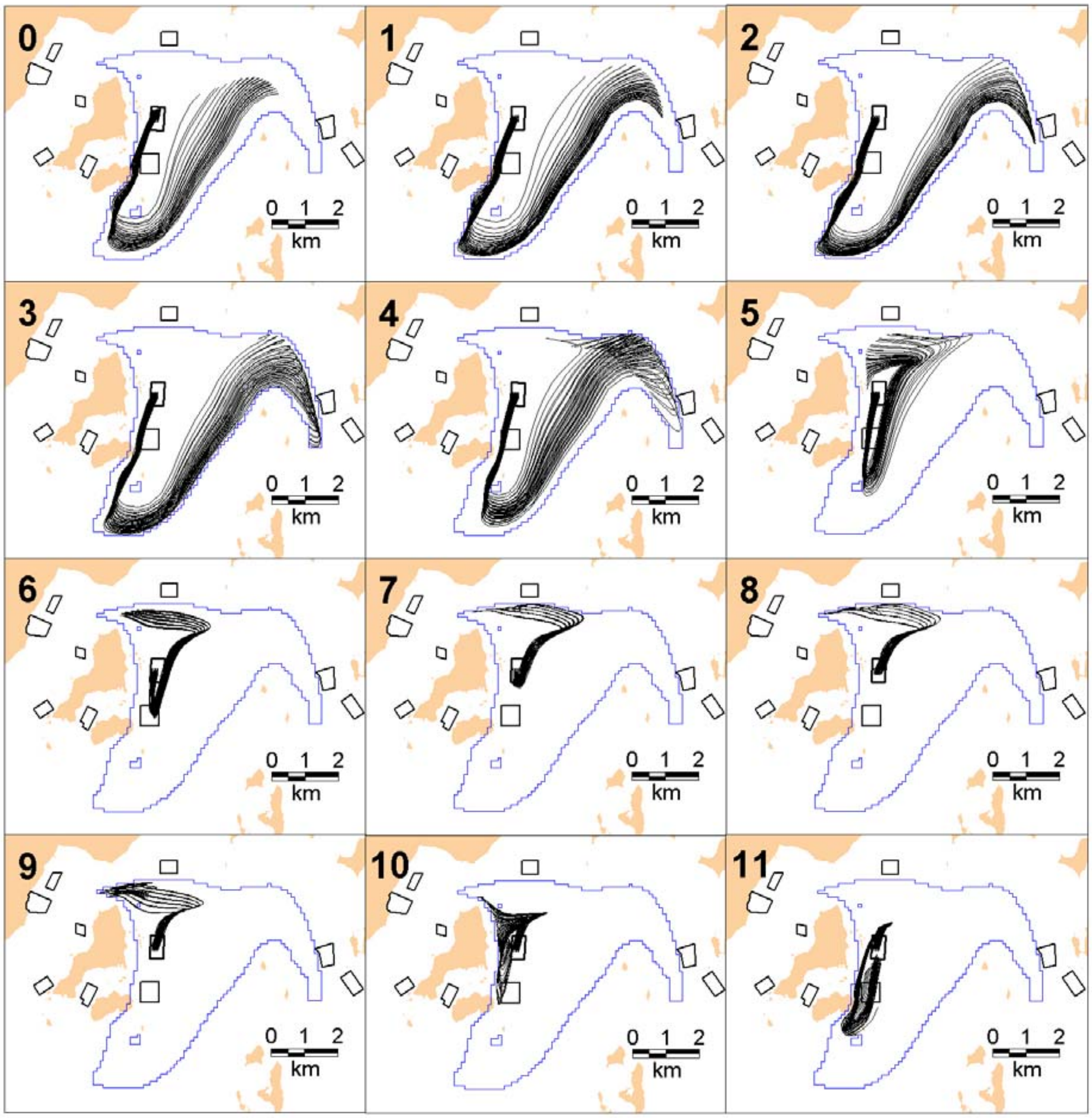
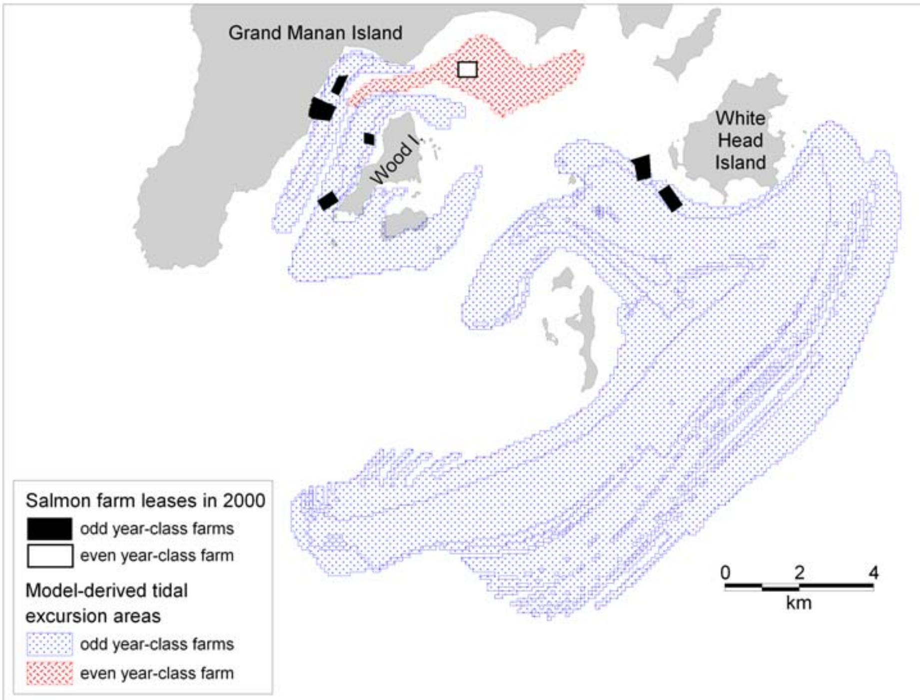


Fig. 3. Model particle tracks for hourly releases 0 to 11 from a fish farm in the southern Grand Manan Island area (from Chang et al. 2005a). Each release consists of 36 particle tracks, released from a square grid within the farm site, and tracked for one tidal excursion (12.4 h) or until the particle hit the shore if that happened first. Finfish farms are shown as small white polygons. The larger blue polygon is the outline of the tidal excursion area.



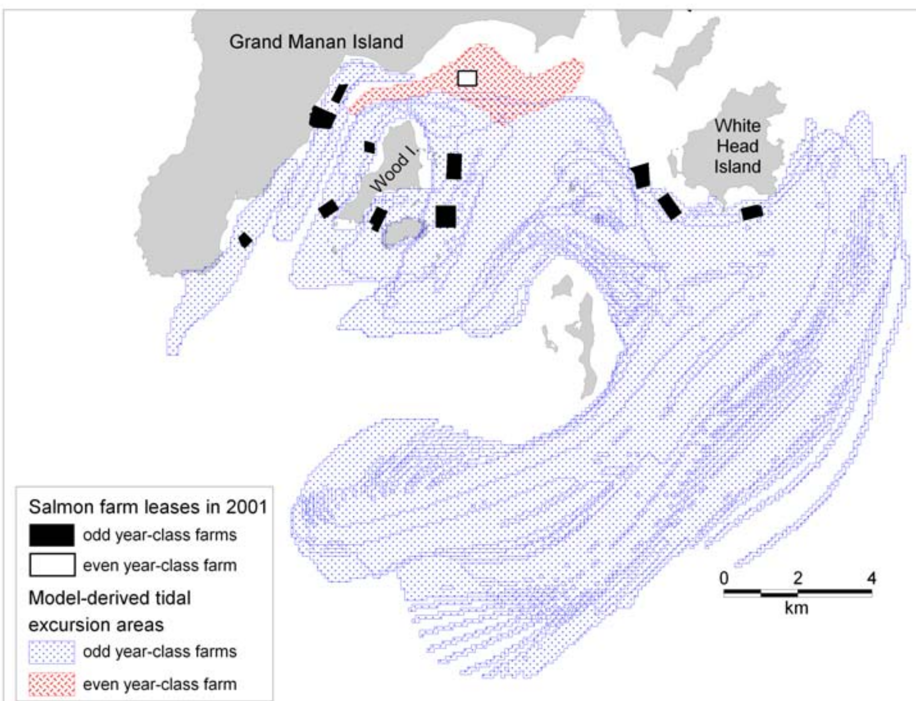


Fig. 4. Model-derived tidal excursion areas of salmon farms in southern Grand Manan, 2000 (top) and 2001 (bottom).

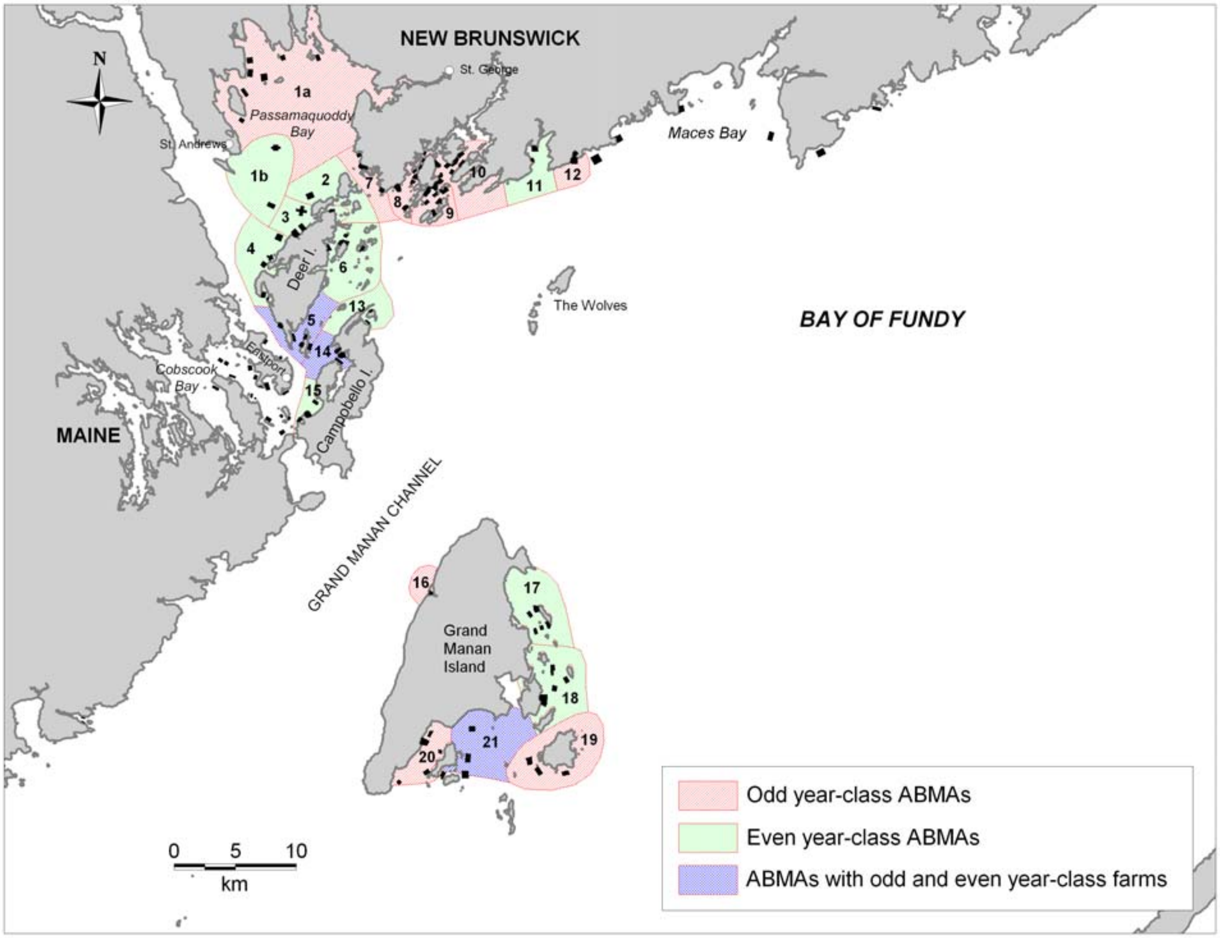


Fig. 5. Map of SWNB showing finfish aquaculture farms in 2005 (small black polygons) and Aquaculture Bay Management Areas (ABMAs) used in 2001-2005. The year-class status is based on 2005 information. Information on farm locations, year-class status, and ABMAs provided by the New Brunswick Department of Agriculture and Aquaculture.

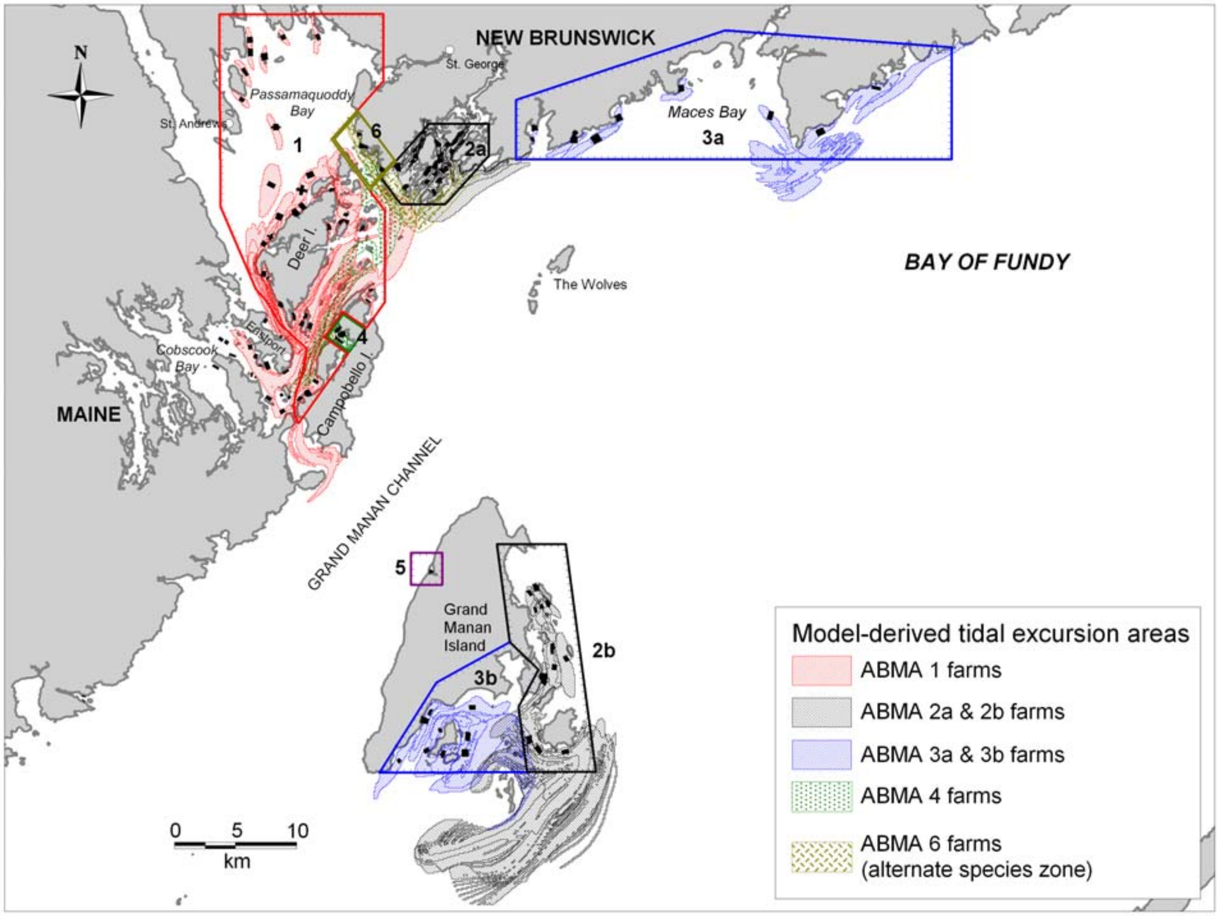
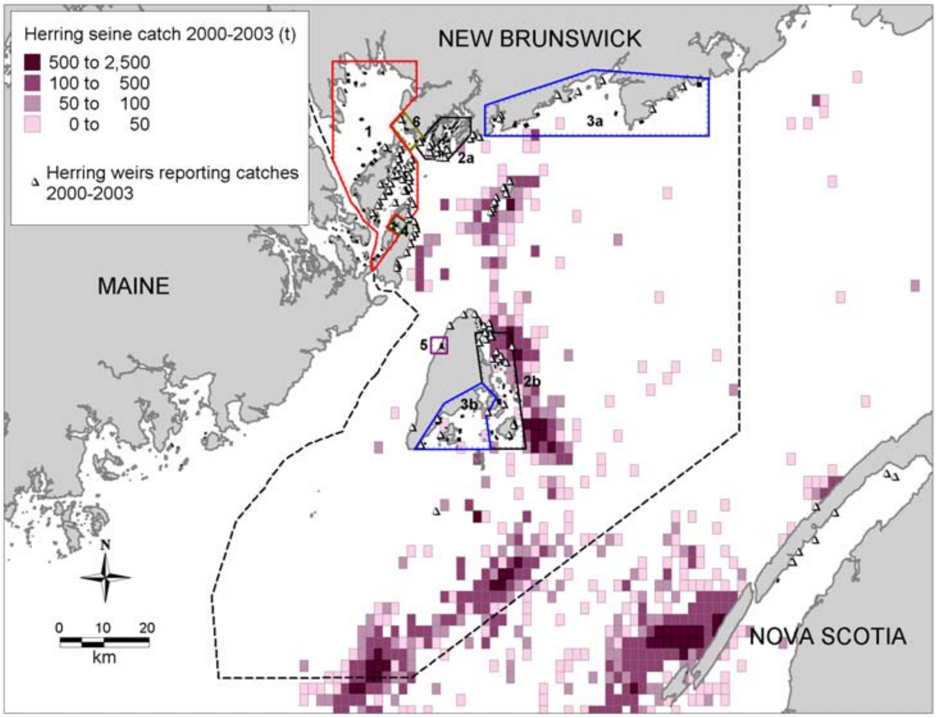


Fig. 6. Map of the SWNB showing finfish farms in 2006 (small black polygons), Aquaculture Bay Management Areas (ABMAs) implemented starting in 2006, and model-derived tidal excursion areas of all farms. Tidal excursion areas are shown as larger stippled polygons; finfish farms are shown as small black polygons; ABMAs are indicated by thick outlines. Information on farm locations and ABMAs provided by the New Brunswick Department of Agriculture and Aquaculture.



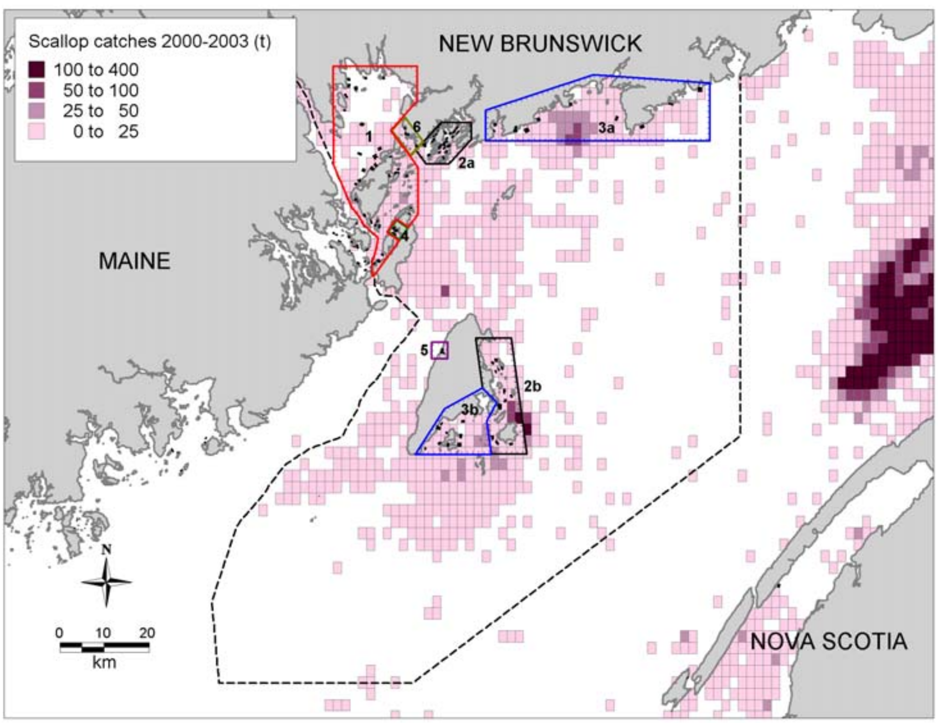
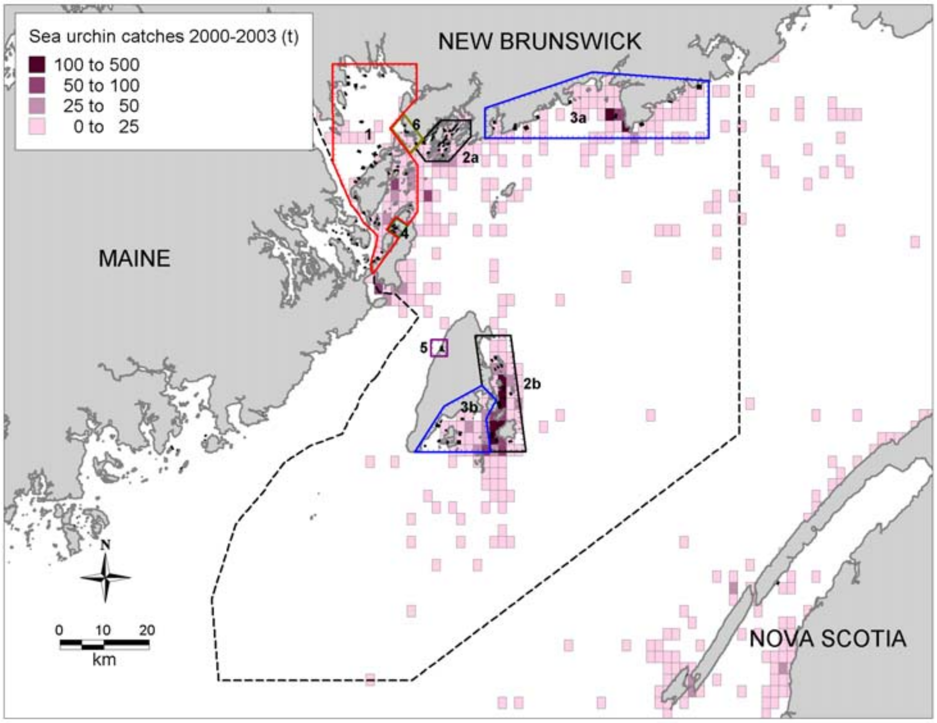


Fig. 7. Aquaculture Bay Management Areas (solid lines) and catches of herring (top) and sea scallops (bottom) for 2000-2003 (from Chang et al. 2007). The dotted line defines the SWNB area. Data for U.S.A. waters are incomplete. Data source for catch data: Fisheries and Oceans Canada.



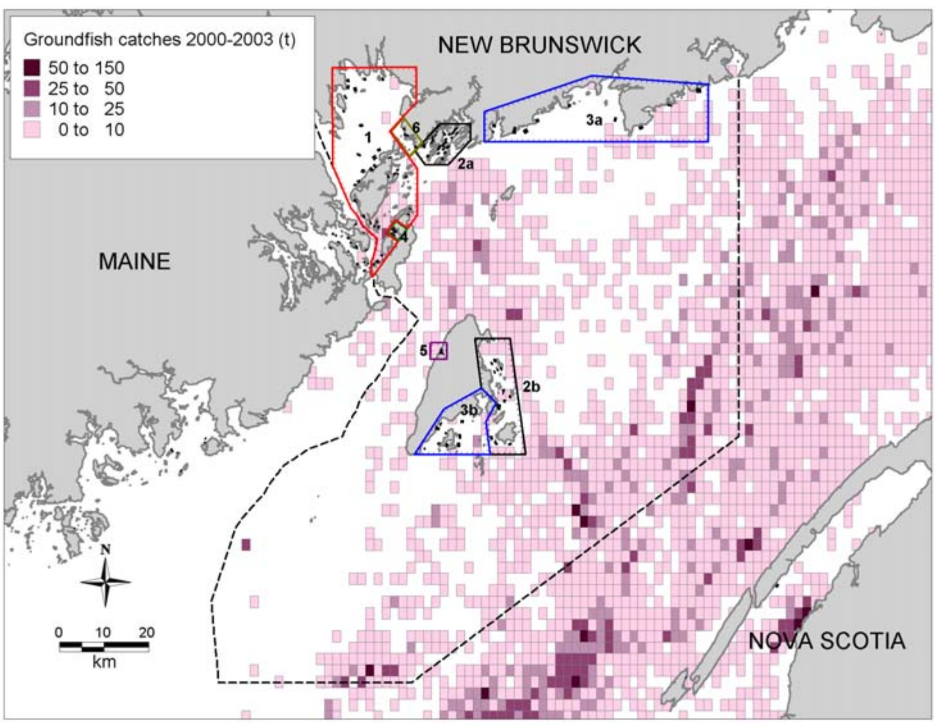


Fig. 7 (continued). Aquaculture Bay Management Areas (solid lines) and catches of sea urchins (top) and groundfish (bottom) for 2000-2003.

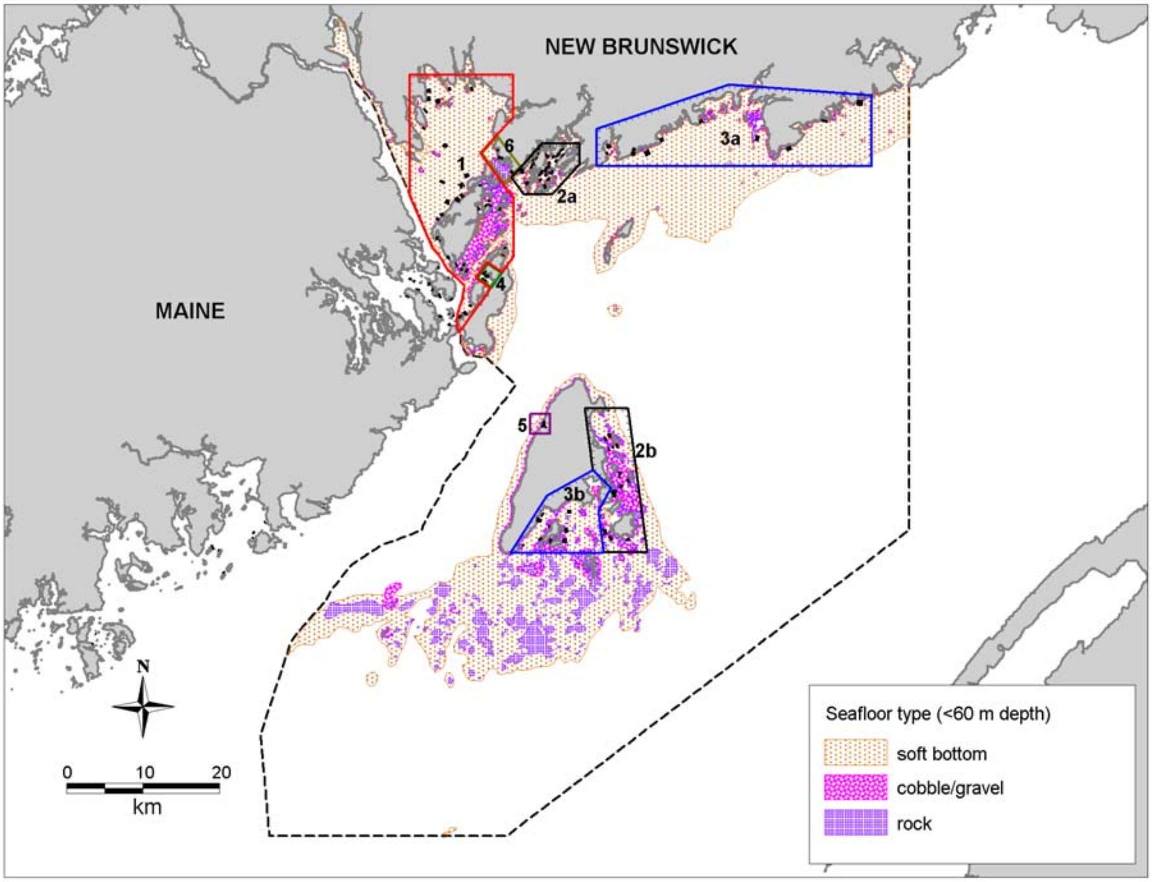


Fig. 8. Aquaculture Bay Management Areas (solid lines) and seafloor habitats for depths less than 60 m (from Chang et al. 2007). The seafloor types are an indication of juvenile lobster habitat. The dotted line defines the SWNB area.

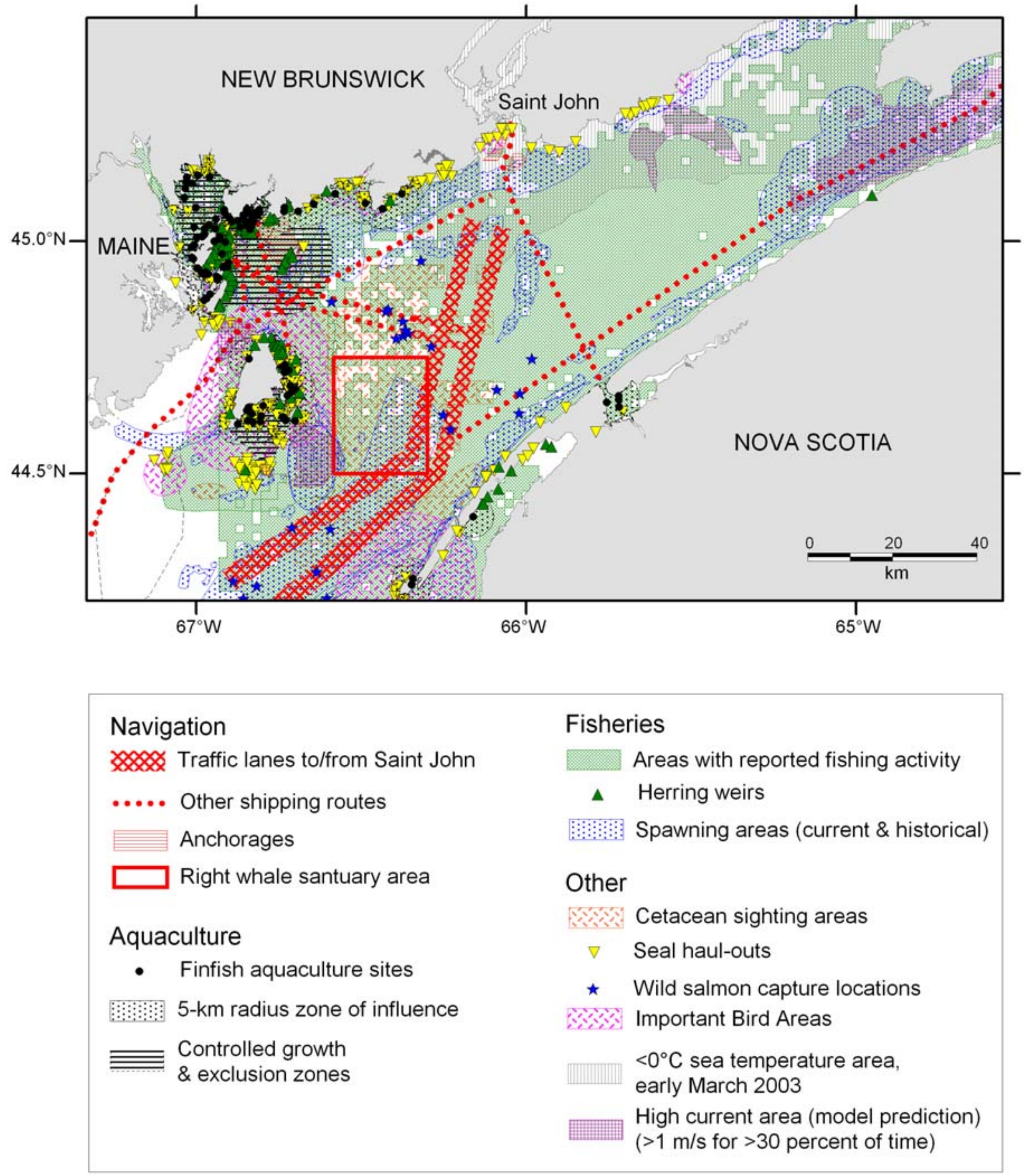


Fig. 9. Geographic overlaps of activities and issues in the Bay of Fundy (modified from Chang et al. 2005c).

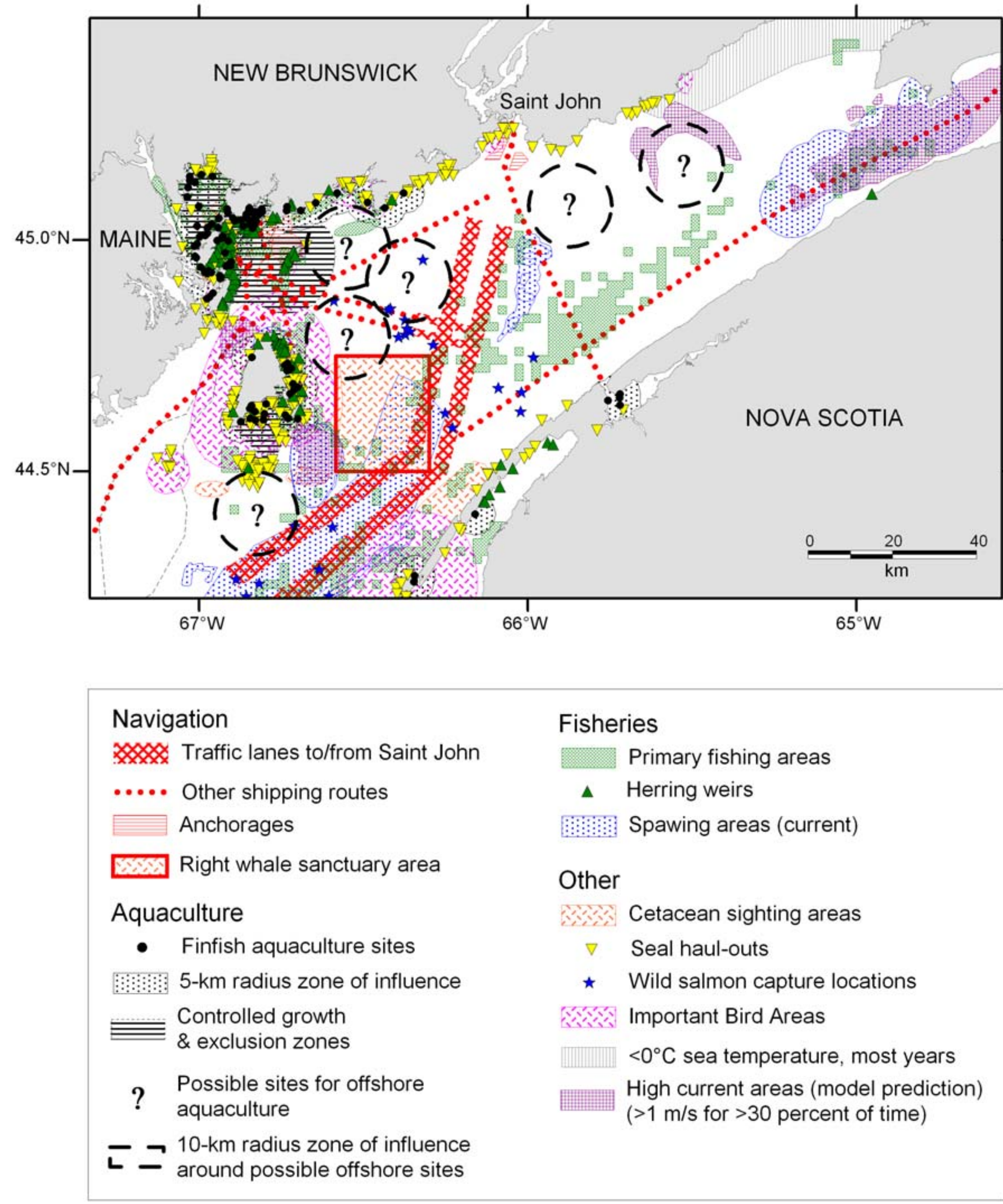


Fig. 10. Potential locations for offshore aquaculture in the Bay of Fundy, based on preliminary analyses (modified from Chang et al. 2005c). Further analysis is required to confirm the suitability of any of the indicated potential offshore aquaculture sites.