Preliminary Analysis of Coastal Marine Resource Use and the Development of Open Ocean Aquaculture in the Bay of Fundy

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PRELIMINARY ANALYSIS OF COASTAL MARINE RESOURCE USE AND THE DEVELOPMENT OF OPEN OCEAN AQUACULTURE IN THE BAY OF FUNDY

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ABSTRACT

Chang, B.D., Page, F.H., and Hill, B.W.H. 2005. Preliminary analysis of coastal marine resource use and the development of open ocean aquaculture in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2585: iv + 36 p.

The New Brunswick finfish aquaculture industry is concentrated in the southwestern portion of the province, in the lower Bay of Fundy. Within this area there are few nearshore locations remaining for new aquaculture operations. Open ocean (offshore or exposed) aquaculture may be the only option to allow expansion of the finfish aquaculture industry. In order to assist both the aquaculture industry and coastal zone managers, we conducted a preliminary analysis of coastal zone management issues related to the feasibility of open ocean farms in the Bay of Fundy. We gathered existing geo-referenced information on oceanographic conditions, salmon aquaculture, commercial fisheries, species at risk, ecologically sensitive areas, shipping, and other activities. The information was gathered from scientific publications, other publications, websites, and interviews with government employees. For some important activities, such as the lobster fishery, and some species at risk, such as the endangered inner Bay of Fundy wild salmon, there is very little geo-referenced data available on the locations of essential areas. The preliminary analysis indicates that, while some degree of conflict may occur over much of the Bay of Fundy, there may be some areas where open ocean aquaculture could take place, with relatively little conflict. However, more detailed investigations and consultations are recommended in order to confirm existing data, to gather data where it is lacking, and to examine the potential for aquaculture to coexist with any existing uses or activities.

RÉSUMÉ

Chang, B.D., Page, F.H., and Hill, B.W.H. 2005. Preliminary analysis of coastal marine resource use and the development of open ocean aquaculture in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2585: iv + 36 p.

Au Nouveau-Brunswick, l'industrie de la pisciculture est concentrée dans la partie sud-ouest de la province, à l'embouchure de la baie de Fundy. On y retrouve très peu de zones propices à de nouvelles concessions aquacoles proches des côtes. L'aquaculture en eau libre ou en pleine mer est peut-être la seule possibilité d'expansion de la pisciculture. Dans le but d'aider autant l'industrie aquacole que les gestionnaires de la zone côtière, nous avons fait une analyse préliminaire des questions de gestion qu'il faut examiner pour déterminer la faisabilité de l'aquaculture en pleine mer dans la baie de Fundy. Nous avons rassemblé des données à référence géographique qui existent déjà sur les conditions océanographiques, la salmoniculture, les pêches commerciales, les espèces en péril, les zones écosensibles, le transport maritime et d'autres activités. L'information a été puisée dans des publications scientifiques ou autres, divers sites Web et à partir d'entrevues de fonctionnaires. Dans le cas de certaines activités importantes, telle la pêche du homard, et de certaines espèces en voie de disparition, comme le saumon sauvage du fond de la baie de Fundy, il existe très peu de données à référence géographique sur les emplacements exacts de zones essentielles. Une première analyse indique que, malgré la présence de certains conflits dans presque toute la baie de Fundy, il pourrait y avoir des secteurs

où l'aquaculture en pleine mer serait possible et provoquerait relativement peu de conflits. Nous recommandons toutefois la tenue d'enquêtes et de consultations plus approfondies afin de confirmer la validité des données existantes, de recueillir des données dans les domaines où elles font défaut et de déterminer pour chaque endroit choisi s'il est possible que l'aquaculture coexiste avec d'autres utilisations ou activités déjà en place.

INTRODUCTION

The Atlantic salmon (*Salmo salar*) aquaculture industry of southwestern New Brunswick has grown rapidly since the first farm harvested 6 t in 1979 (Chang 2003). Production in 2003 was estimated as 33,100 t, with a value of Can$179 million (Statistics Canada 2004). Most of the existing farms are located in relatively shallow and sheltered inshore locations (Chang 2003). There are few or no remaining inshore sheltered sites for further expansion of the industry. There have also been suggestions that it may be desirable to remove some inshore sites in order to improve fish health or environmental management in some bays (e.g. Fisheries and Oceans Canada 2003). Accordingly, the industry is looking at the potential for farming in open ocean (i.e. exposed or offshore) locations in order to maintain current production levels and to allow future growth. Various projects have begun to examine the feasibility of open ocean aquaculture in other parts of the world and there has been a series of conferences held on this subject (e.g. Bridger and Costa-Pierce 2003). 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).

The intent of this study was to assist the aquaculture industry, stakeholders and coastal zone managers in identifying potential open ocean aquaculture sites in the Bay of Fundy. In order to identify potential sites, we need to look at both physical constraints (such as water temperature, currents and waves) and potential conflicts with other activities and issues. We gathered existing information on other activities and issues in the Bay of Fundy from primary publications, other publications, unpublished data, websites, and interviews with some government experts. Useful compilations of existing resource and ecological information for the Bay of Fundy were found in Buzeta et al. (2003), Eastern Charlotte Waterways Inc. (1998) and MacKay et al. (1978-1979). We mapped the available information in a Geographic Information System (MapInfo Professional® 7.0), identified information gaps and looked for areas of minimal existing use or ecological significance as an indicator of the potential for open ocean aquaculture.

THE PHYSICAL ENVIRONMENT

The Bay of Fundy (Fig. 1) is noted for its large tides, ranging from about 4 m near its mouth to more than 12 m in Minas Basin at its head (McGuire 1977). The surface area of the Bay of Fundy (Canadian waters) is approximately 15,300 km^2. Most of the offshore area has depths of 50-200 m and the maximum depth is about 220 m.

Current speed may be one physical constraint limiting where open ocean aquaculture operations could be located. A study of 20 nearshore salmon farms in southwestern New Brunswick found mean current speeds of 0.03-0.18 $m \cdot s^{-1}$ and maximum speeds up to 0.42 $m \cdot s^{-1}$ (Peterson et al. 2001). Three new farms approved in southwestern New Brunswick since 2003 have been in more exposed sites, with mean current speeds of 0.15-0.26 $m \cdot s^{-1}$ and maximum current speeds of 0.34-0.73 $m \cdot s^{-1}$ (New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA), pers. comm.). Marine salmon farms in Scotland and Ireland generally have mean current speeds of 0.01-0.10 $m \cdot s^{-1}$ and maximum speeds of 0.15-0.60 $m \cdot s^{-1}$; but at sites with extreme current regimes, means can reach 0.21 $m \cdot s^{-1}$ and maxima 1.40 $m \cdot s^{-1}$, although such sites are difficult to manage and report poor growth (Black and MacDougall 2002). Other reports suggest that ebb and flood tidal currents of 0.1-0.6 $m \cdot s^{-1}$ are best for marine fish farming, while currents exceeding 1 $m \cdot s^{-1}$ are not recommended (Beveridge 1987).

The New Brunswick study by Peterson et al. (2001) found that the average relative swimming speed for Atlantic salmon in cages was 0.44 $m \cdot s^{-1}$, with no significant difference between fish in their first summer (average length 0.3 m) and fish in their second summer (average length 0.5 m). A study by Petrell and Jones (2000) of some fish farms in British Columbia (average current speed: ~0.1 $m \cdot s^{-1}$) found that the average swimming speed of Atlantic salmon was 0.68 $m \cdot s^{-1}$ and the range of values (0.3-1.0 $m \cdot s^{-1}$) did not correlate with fish size (range: ~1.0-5.5 kg). A laboratory study of pre-spawning Atlantic salmon (mean length 0.37 m) in seawater (9.5°C) indicated a maximum sustained swimming speed (critical swimming speed) of 0.96 $m \cdot s^{-1}$ (2.6 body lengths per second), which was lowered to 0.82 $m \cdot s^{-1}$ when the fish had a high level of sea lice infection (Wagner et al. 2003). These findings suggest that sites where current speeds exceed 1 $m \cdot s^{-1}$ for extended periods may not be suitable for growing salmon, which would appear to support the findings cited in the previous paragraph. Caged fish may be able to withstand short periods of time at higher currents, but may have to expend considerable energy to maintain position, thus reducing growth and production.

The available information on water currents for the Bay of Fundy includes drifter data (e.g. Chevrier 1959), current meter records (e.g. Forrester 1959, MacGuire 1977; Fig. 2a,b) and circulation models (e.g. Greenberg et al. 2005; Fig. 3). The current meter and circulation model data are of most relevance to the engineering and near-field effluent dispersal considerations for open ocean aquaculture since it indicates the current speed and duration. The drifter data is useful for estimating the residual surface circulation and longer-term transport of surface borne substances. In the spirit of the preliminary nature of this report, we give a brief flavor for the major characteristics indicated by these data. We do not give a detailed review and analyses of the existing data. The information probably underestimates the current speeds and the spatial extent of high speed areas since the current meter data is often of short duration (<24 h) and the model does not include forcing by multiple tidal constituents, wind or density gradients. Figures 2a, b show the predominate ebb and flood direction and speed of currents at several locations within the Bay of Fundy. Figure 3 shows the amount of time (fraction of a tidal cycle) that current speeds are greater than 1 $m \cdot s^{-1}$ (approximately 2 knots), as estimated by the Greenberg at al. (2005) 3-dimensional M_2 tidal circulation model. Both sources of information indicate that in most open ocean areas of the Bay of Fundy, current speeds are less than 1 $m \cdot s^{-1}$ for most of the time. However, in some areas such as southeast and northwest of Grand Manan and in parts of the central and inner Bay of Fundy, current speeds often exceed 1 $m \cdot s^{-1}$ for a considerable portion of a tidal cycle.

There is also some limited information available on the wave climate within the Bay of Fundy (e.g. Neu and Vandall 1976; Trites and Garrett 1983). The surface wave field consists of swell and chop or wind waves. In general wave heights are about two times larger in the open Gulf of Maine than in the Bay of Fundy and the waves within the open Bay of Fundy are about three times as large as in the protected Passamaquoddy Bay. In the Bay of Fundy, the largest wave heights are about 6-8 m and the 100-yr wave height is estimated to be about 10 m. The most frequent wave periods are 4-6 s. About 30% of the waves (the swell) have a period of about 8-15 s and propagate into the Bay of Fundy from the Gulf of Maine.

Another physical constraint on aquaculture may be the winter seawater temperature. The lower lethal temperature for Atlantic salmon is about -0.7°C (Saunders et al. 1975). Satellite remote sensing data (available at the Fisheries and Oceans Canada, Ocean Sciences Division website: http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/remotesensing.html) shows that the sea surface temperatures in parts of the Bay of Fundy, especially in the inner bay, will fall below 0°C most winters, with the extent of the area below 0°C varying between years (Fig. 4a). This means that parts of the inner bay are at high risk for cage culture, at least for salmonids, during the winter, while a larger area carries a lower, but not insignificant, risk. For example, near-surface (~1 m) water temperatures at the Prince 5 monitoring station (located a few kilometres northeast of Campobello Island) frequently drop below 1°C and have occasionally dropped below 0°C (Fig. 4b).

The residual water circulation pattern for the Bay of Fundy indicates a counterclockwise gyre east of Grand Manan Island (Godin 1968; see Fig. 1). This gyre is thought to be a major contributing factor to the annual occurrence of toxic algal blooms (especially *Alexandrium fundyense*) in this area (Martin and White 1988). *Alexandrium* blooms have been implicated as the cause of mortalities of farmed salmon southwestern New Brunswick, as well as in southeastern Nova Scotia (Cembella et al. 2002) and the Faroe Islands (Mortensen 1985).

THE EXISTING MARINE FINFISH AQUACULTURE INDUSTRY IN SOUTHWESTERN NEW BRUNSWICK

In 2004 there were 97 licensed marine finfish aquaculture sites in New Brunswick, all located in the southwestern part of the province near the mouth of the Bay of Fundy (NBDAFA, pers. comm.; see Fig. 5). Most of the New Brunswick sites are located within 1 km of the shore. Most are located in relatively shallow water, with and average depth of approximately 15 m (Chang 2003), and all except one located at less than 30 m depth. There were seven licensed marine finfish sites located along the Nova Scotia shore of the Bay of Fundy in 2004 (Nova Scotia Department of Agriculture and Fisheries 2004). There were also several finfish farms in the adjacent waters of Cobscook Bay, Maine (Maine Department of Marine Resources 2004).

For fish health purposes, the concept of using a zone of potential influence around each farm, based on the size of the tidal excursion, is being used in Norway and Scotland (Norwegian Animal Health Authority 2002; JGIWG 2000). These zones are used to designate management areas and disease control areas: farms with overlapping tidal excursion areas are generally considered to be within the same management area. In the lower Bay of Fundy, the tidal excursion areas for inshore salmon farm sites can be roughly estimated as a circle with a radius of 5 km around the centre of the farm (Fig. 5).

The Marine Aquaculture Site Allocation Policy for New Brunswick (NBDAFA 2000a, b), includes the establishment of "Controlled Growth Areas" and "Exclusion Areas" (Fig. 5). Within these areas, no new finfish aquaculture sites are being permitted at this time.

SHIP TRAFFIC

Open ocean aquaculture must avoid areas of known heavy boat traffic and anchorages. There are designated traffic lanes for large ships travelling between the southeastern entrance to the Bay of Fundy and the Port of Saint John. These lanes are used by about 800 vessels annually, most of which are oil tankers (Transport Canada 2004). In July 2003, these traffic lanes were shifted slightly eastward in order to reduce the potential for collisions with right whales (Fig. 6). In addition, a whale sanctuary area was designated to coincide with an area east of Grand Manan Island where right whales have been most frequently observed (Fisheries and Oceans Canada 2004a). Ships are asked to avoid this area, if possible, but if they are within this area, they are requested to decrease speed, post lookouts, manoeuvre around marine mammal activity, and report any marine mammal sightings or collisions.

There are designated anchorage areas just outside Saint John Harbour, at the nearby Canaport facility, and near the Wolves (Fig. 6). There are two regular ferry runs that cross the offshore area: Saint John to Digby and Blacks Harbour to Grand Manan. In addition there are other frequently used vessel routes, which are less well defined: gypsum carriers following the Nova Scotia shore of the Bay of Fundy going to and from Hantsport (in the inner Bay of Fundy); and freighters proceeding along the New England shore toward Eastport (Maine), Bayside (New Brunswick), and Saint John (Canadian Coast Guard, Fundy Traffic, Saint John, pers. comm.). There is also much small boat traffic, including many fishing vessels. An example of radar fixes of all boat traffic during July-August 2000 shows that much of the Bay of Fundy is traversed by boats of some kind (Fig. 7).

COMMERCIAL FISHERIES

Geographically referenced catch data was obtained for some fisheries from the Fisheries and Oceans Canada, Maritime Science, Virtual Data Centre. This information is based on logbook data provided by fishermen. We have used the available data on the five species or species groups having the highest commercial value during this period and for which geographically referenced data is available: groundfish (all species combined), herring (*Clupea harengus harengus*), scallops (*Placopecten magellanicus*), sea urchins (*Strongylocentrotus droebachiensis*), and crabs (rock and Jonah; *Cancer borealis* and *C. irroratus*). We binned the geo-referenced data for the years 2000 to 2003 into a grid comprised of 2 km by 2 km squares covering the Bay of Fundy. For each species group, we ranked the grid squares in order of catch volume (weight), and then mapped the top ranking squares which, when combined, represented 50%, 75%, 90%, and 100% of the total reported catch (Fig. 8-12). Figure 13 is a composite map for all of these species, derived by amalgamating the areas shown in Fig. 8-12.

There is also geo-referenced data from an annual summer groundfish survey conducted by Fisheries and Oceans Canada scientists. Figure 14 shows the data for 2000-2003, indicating where the most abundant five species of groundfish (dogfish, cod, haddock, pollock and silver hake) were caught and the total amounts caught in each grid square.

A traditional fixed-gear fishery in southwestern New Brunswick and Nova Scotia is the herring weir fishery. The existing aquaculture site allocation policy in New Brunswick (NBDAFA

2000a) includes an objective to ensure a viable herring weir industry in southwestern New Brunswick. Specific actions to ensure this objective include the establishment of Exclusion Areas, where no new aquaculture farms are allowed (Fig. 5), and the requirement for a minimum separation distance of 300 m between an aquaculture site and a licensed herring weir (NBDAFA 2000b). The locations of weirs which reported catches in 2002 and 2003 (M. Power, pers. comm.) are included in the Fig. 9. Also included in Fig. 9 is a 5-km radius zone of potential sensitivity around each weir.

The most valuable fishery in the Bay of Fundy at present (based on landed value) is for lobster (*Homarus americanus*). Unfortunately, geographically referenced catch data is not available for this species. Recently, however, a requirement for reporting the geographic location of catches (within 10-min squares) has been included in lobster fishing licenses, so some geographic data should be available in the future. Some data on fishing locations for lobster in southwestern New Brunswick (Charlotte County) were found in various sources: Wilder (1960); MacKay et al. (1977-78); Eastern Charlotte Waterways Inc.(1998); and interviews with Fisheries and Oceans Canada and Canadian Coast Guard personnel (Fig. 15). This information is mostly for the inshore fishery, which was the primary fishery in the past. In recent years, however, there has been increasing effort further offshore, to the offshore limits of each Lobster Fishing Area (Fig. 15).

As can be seen in the maps, the area covered by all grid squares in which landings were reported covers most of the Bay of Fundy. Prohibiting aquaculture in all offshore waters used for fishing would, in effect, prevent the development of offshore aquaculture. There are, however, uncertainties regarding how much aquaculture actually does interfere with fishing. There can be a physical impediment to fishing caused by the presence of salmon cages and mooring lines if a farm exists over fishing grounds. The extent of this impediment would depend on the size of the farm and the type of mooring system used. It is not clear how far other potential impacts of aquaculture on fish and fisheries (such as effluent discharges to the water column and sea floor, noise disturbance, boat traffic, etc,) extend. Experience in southwestern New Brunswick shows that, at least in some cases, intensive fishing activity can occur in relatively close proximity to finfish aquaculture. Nevertheless, it is probably advisable to avoid proposing initial open ocean aquaculture operations in the most productive fishing areas. It may, however, be possible to have aquaculture operations in some less productive fishing areas, without causing significant impact on the fisheries. This raises the question of how much of the less productive fishery areas should be made available for finfish aquaculture. For example, would it be acceptable to allow aquaculture in the least productive 10%, 25% or even 50% of fishing areas?

It would also be advisable to avoid situating aquaculture in areas which are known to be critical habitats, such as the important spawning or nursery areas, for important commercial species. Information on groundfish spawning areas in the Bay of Fundy has been compiled by Graham et al. (2002). Herring spawning areas were obtained from Power et al. (2002) and M. Power (pers. comm.). Information on lobster spawning areas is reported in Campbell (1986, 1990) and Eastern Charlotte Waterways Inc. (1998). Figure 16 shows the locations of both current and historical spawning areas for these species. If it is accepted that current spawning areas of important species should be protected and that aquaculture operations situated in close proximity to such areas could affect spawning success, then open ocean aquaculture should avoid these areas. A more debatable issue may be whether aquaculture operations should be prohibited in close proximity to historical (but not currently used) spawning areas. Historical spawning areas may be necessary for the recovery of currently depressed stocks, so if historical spawning areas are not protected, then recovery of these stocks may not occur.

OTHER SPECIES

It is not just the commercially exploited species which must be included within the coastal zone management analysis. For example, marine mammals, especially whales, are an important aspect of the growing ecotourism industry in the lower Bay of Fundy. Furthermore, the Canadian Species at Risk Act (Fisheries and Oceans Canada 2004b) provides for the protection of endangered species such as the right whale (*Eubalaena glacialis*). Information on locations of sightings of right whales in the Bay of Fundy is reported in Brown et al. (2001) and is shown in Fig. 17. As mentioned previously, a whale sanctuary area has been designated east of Grand Manan Island in order to protect the areas where right whales have most frequently been sighted, and this area should therefore probably be considered off limits to aquaculture development.

Information on areas where other cetacean species occur in the Bay of Fundy is shown in Fig. 18. This includes data on minke whales (*Balaenoptera acutorostrata*), fin whales (*B. physalus*), white-sided dolphins (*Lagenorphynchus acutus*), and harbour porpoise (*Phocoena phocoena*) in Charlotte County, southwestern New Brunswick and in the Digby Neck area of Nova Scotia (Eastern Charlotte Waterways Inc.1998; Gaskin 1983; Trippel et al. 1996; Stephenson et al. 1999).

Two species of seals occur in the Bay of Fundy: harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*). The locations of seal haul-outs have been identified by Stobo and Fowler (1994) and Eastern Charlotte Waterways, Inc. (1998; see Fig. 18). Since seals are known predators of farmed salmon, the locating of a fish farm in close proximity to a seal haul-out will increase the risk of salmon escaping through holes in nets caused by seal attacks.

Populations of wild inner Bay of Fundy Atlantic salmon (*Salmo salar*) have declined severely since 1989 and are now considered "endangered" (Fisheries and Oceans Canada 2004b). Indications are that low marine survival has been one of the main factors in this decline. It also appears that these stocks remain within the Bay of Fundy for much of the year (Amiro 2003). Although interactions with farmed salmon, especially escapees from cages, are sometimes implicated in the decline of these stocks, there is a lack of scientific evidence to confirm that this is the case for the Bay of Fundy (Fisheries and Oceans Canada 1999). Nevertheless, due to the endangered status of these stocks, there could be demands to prevent or limit salmon farming in essential habitats for inner Bay of Fundy salmon. Unfortunately, there is a lack of information on specific areas of the Bay of Fundy which may be essential to these stocks. Amiro et al. (2003) mapped potential marine habitat for inner Bay of Fundy salmon based on temperature preferences of this species (Fig. 19). This analysis indicated that suitable habitat was limited to the outer Bay of Fundy in August-September, but that acceptable habitat was present in most of the bay in other months. A study which captured wild Atlantic salmon post-smolts by surface trawl in the Bay of Fundy in late May to mid-June of 2001-2003 found that the majority of the salmon were caught in the outer Bay of Fundy and off southwest Nova Scotia (Lacroix and Knox

2005; Fig. 20) within a portion of the high preference temperature area. The study also indicates that the wild and hatchery salmon are found in the same offshore areas.

Some populations of seabirds may also require protection. Figure 21 shows the locations of designated Important Bird Areas (IBAs) within the Bay of Fundy (Important Bird Areas of Canada 2004). IBAs are sites providing essential habitat for one or more species of birds. These may include threatened species, endemic species, species representative of a biome, or highly exceptional concentrations of birds. There currently are some nearshore aquaculture sites operating within some IBAs. This may indicate some ability for coexistence of aquaculture and IBAs, but it would be preferable to avoid placing open ocean aquaculture sites within designated IBAs.

OTHER AREAS REQUIRING PROTECTION

A Marine Protected Area (MPA) has been proposed at the Musquash estuary (Singh et al. 2000). While this is mainly an inshore area (Fig. 21), the placement of a large aquaculture site in close proximity to an MPA would likely raise objections, since there may be advection of farm effluents into the MPA.

WHERE COULD YOU LOCATE OPEN OCEAN AQUACULTURE?

When layers of all of the identified geo-referenced concerns are overlapped, it is clear that there are virtually no areas in the Bay of Fundy where there are absolutely no usages (Fig. 22). However, the presence of a potential usage should not necessarily preclude the possibility of aquaculture. Rather than only allowing open ocean aquaculture where there are absolutely no potential usage overlaps, the challenge for coastal zone managers is to reduce conflict within these overlap areas to a minimum, to balance any potential detrimental impacts on existing activities or uses with the potential economic, social and environmental benefits of having open ocean aquaculture.

Some of the layers we have included in Fig. 22 are activities or uses which may be able to co-exist with aquaculture, at least to some degree. For example, aquaculture currently co-exists with some fishing activity and also exists in some areas which have some risk of low winter temperatures. We suggest that the maps should be examined in stages, with the first stage including only those layers where it is agreed that absolutely no aquaculture activity should be allowed: for example, the most productive fishing areas (including herring weirs), current spawning areas for important commercial species, critical habitat for species-at-risk (e.g. right whales, inner Bay of Fundy wild salmon), important shipping channels and anchorages, protected areas, areas at high risk of having below 0°C water temperatures and areas at high risk due to predicted high current velocities (Fig. 23).

Figure 23 does not exclude open ocean aquaculture from the less productive fishing areas (lowest 50% of grid squares in terms of landings), historical spawning areas which are not currently active, right whale sighting areas outside of the whale sanctuary area, and areas with lower risk of below 0°C water temperature (i.e. where below 0°C temperatures occur, but only in much colder than average years). We have also not yet included activities such as recreational boating and ecotourism. When we examine Fig. 23, we can see that there are some areas where there appear to be no overlaps (at least for those activities and issues included in this figure) and where we might tentatively suggest that open ocean aquaculture could occur, subject to further analyses and stakeholder consultations regarding those activities and issues not shown or not clearly understood.

Another important factor to consider in determining how many open ocean aquaculture sites could be allowed is how close together such sites should be allowed to be. In the inshore areas of southwest New Brunswick, the current policy stipulates a minimum separation distance of 300 m between finfish aquaculture sites (NBDAFA 2000b). In these inshore areas, the magnitude of water currents means that the tidal excursions can be roughly approximated by a circular area of 5-km radius (Fig. 5). In open ocean areas of the Bay of Fundy, the sparse available data suggests that water currents are stronger than in inshore areas and that a 10-km radius tidal excursion area may be more appropriate. The concept of using a separation distance equivalent to one tidal excursion to control spread of disease has been adopted in Norway and Scotland (Norwegian Animal Health Authority 2002; JGIWG 2000). One possible scenario for open ocean sites is to have only one large site per management area. This would mean that individual sites must be at least 10 km apart, but preferably at least 20 km apart, so that there is no overlap of tidal excursion areas of adjacent farms. This obviously limits the number of potential sites, but it is likely that such sites would be very large. An alternative scenario would be to allow a few sites within one management area. This would mean that the management area for these sites would be quite large (at least 10 km around all farms) and that all farms within the management area would need to coordinate activities.

As stated in the introduction to this report, the intent of compiling this preliminary set of maps was to assist the aquaculture industry, coastal zone managers and stakeholders in their deliberations concerning the development potential for open ocean aquaculture in the Bay of Fundy. When looking at the potential site locations we have indicated in Fig. 23, it is essential to remember that there are issues and activities which are not included, e.g. issues for which we have no geo-referenced data, such as lobster fishing areas and critical habitats for wild salmon, as well as other issues we excluded from Fig. 23, such as historical spawning areas, less productive fishing areas, and recreational activities. There is also the need to confirm the fishing data with the fishing industry. Another important issue is the need to have more information on water currents and waves at the potential sites to ensure that these sites are suitable, both for the cages and the fish. The results of further analyses of any of these factors may mean that some or all of the locations we have suggested may not be acceptable.

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Croix Estuary Project); C. Taggart (Dalhousie University); and C. Bridger (Bridger & Associates).

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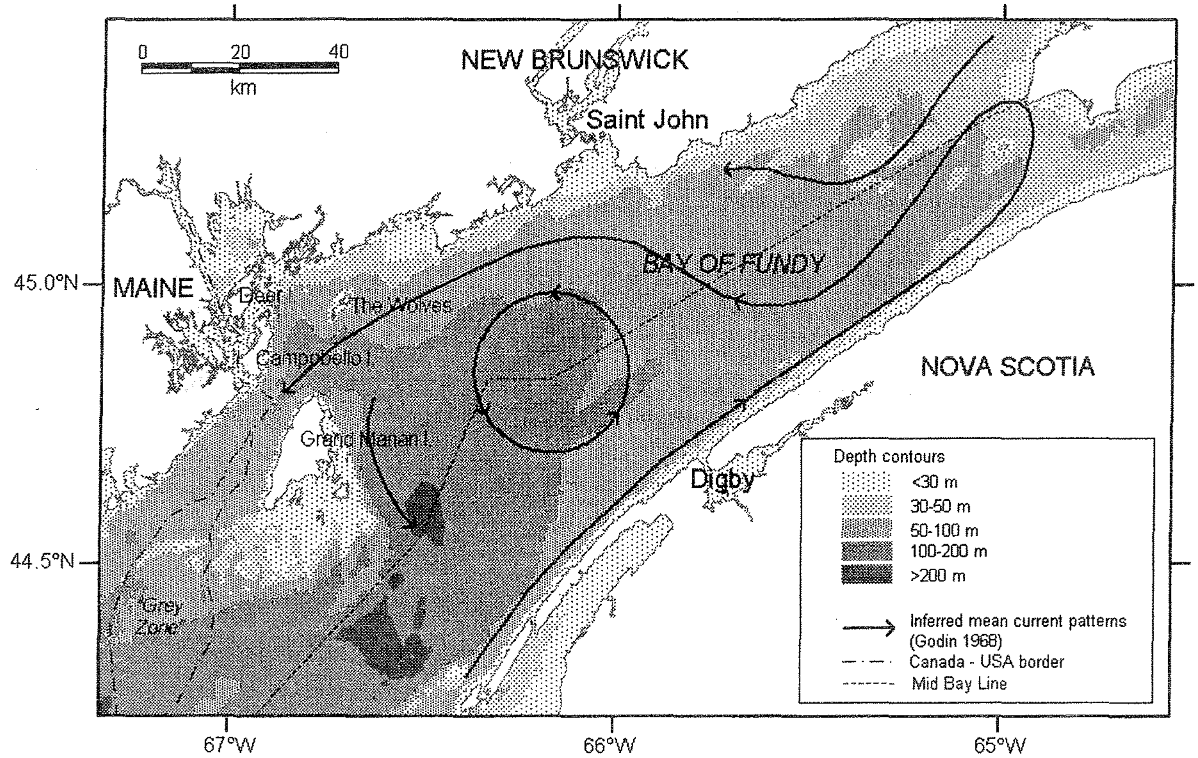

Fig. 1. Map of Bay Fundy showing depth contours and residual water circulation patterns. The "Grey zone" is a section of the Canada-USA boundary that is currently in dispute. Depth contours are from the U.S. Geological Survey (http://pubs.usgs.gov/of/of98-801/bathy/data.htm).

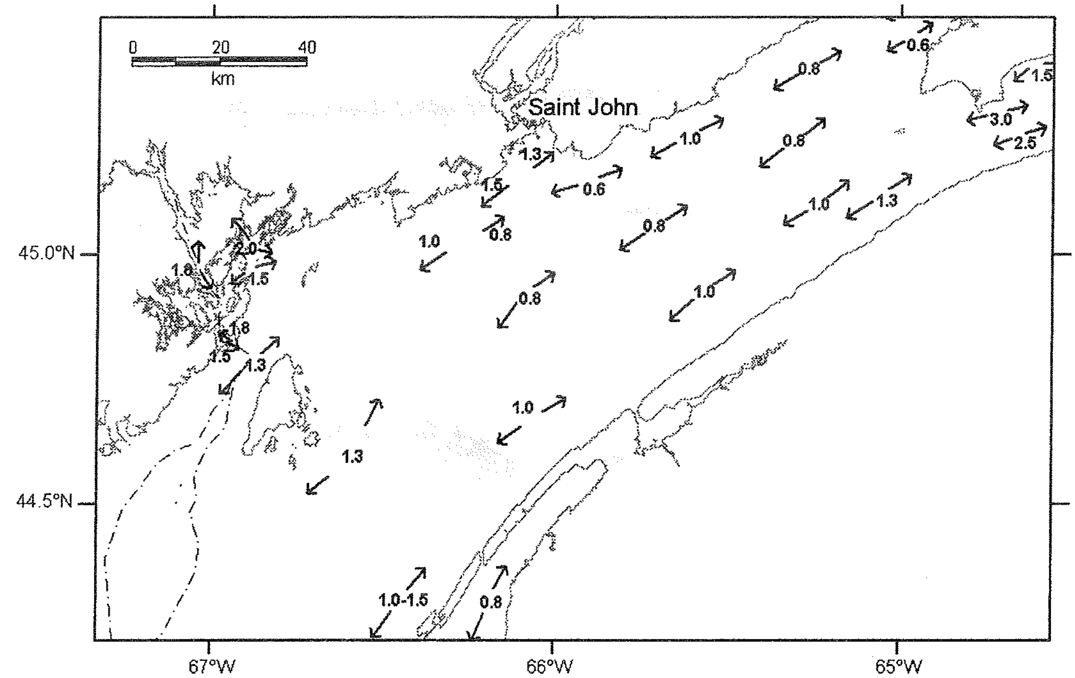

Fig. 2a. Ebb and flood tidal currents (arrows) in the Bay of Fundy, redrawn from MacGuire (1977), based on a compilation of existing information. Numbers are current speeds ($m \cdot s^{-1}$).

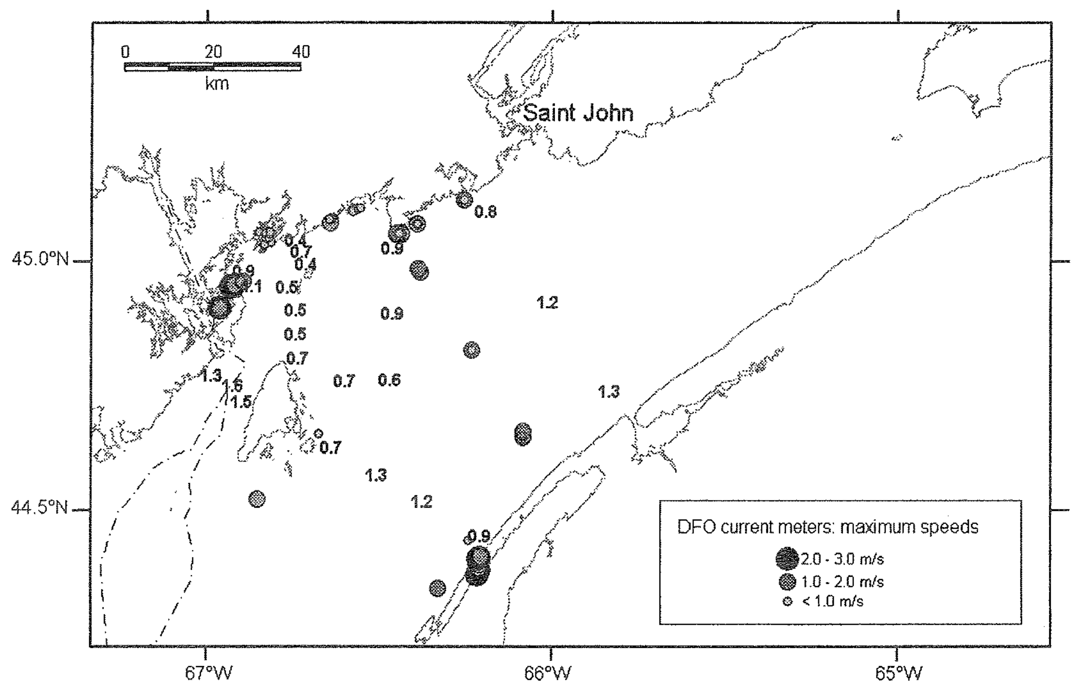

Fig. 2b. Current meter data for the lower Bay of Fundy. Circles represent maximum current speeds from Fisheries and Oceans Canada (DFO) current meters (Information source: DFO Maritimes Region, Ocean Sciences Division). Numbers are estimated maximum tidal current speeds ($m \cdot s^{-1}$) for a mean tide, as determined by Forrester (1959). The maximum currents persist about 1 h each tidal cycle.

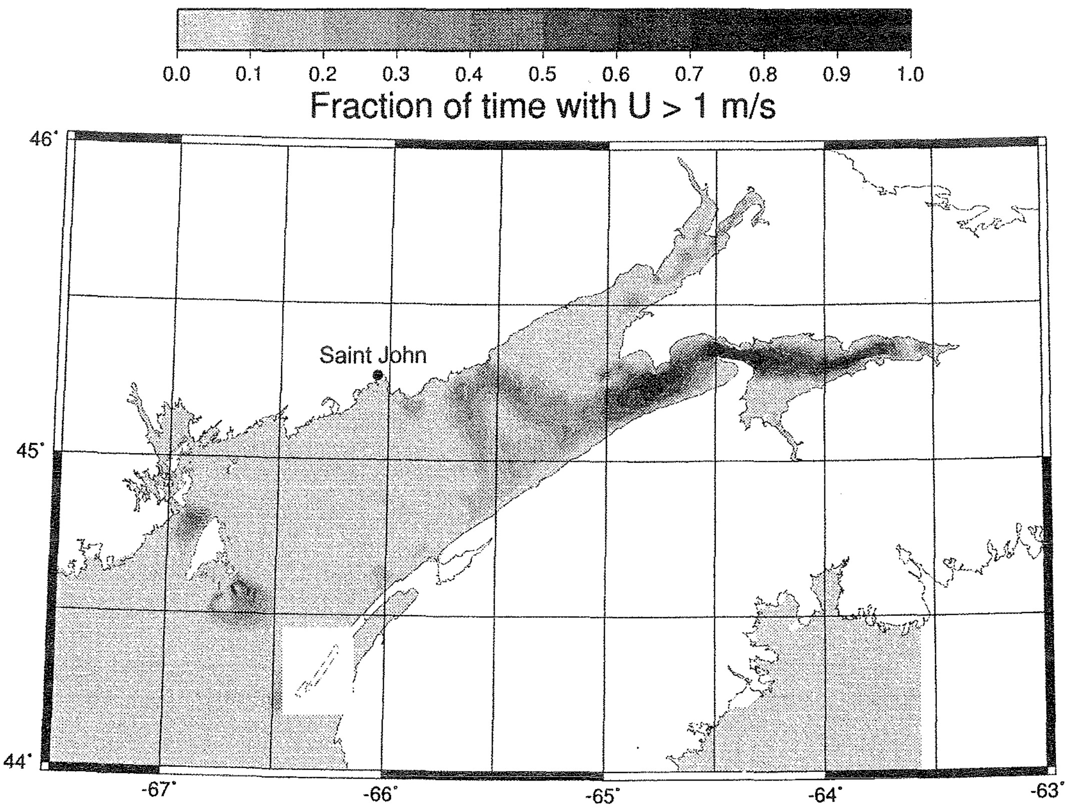

Fig. 3. Fraction of the M_2 tidal cycle (12.42 h) when the current speed (U), as predicted by a 3-dimensional particle tracking model (Greenberg et al. 2005), is greater than 1 $m{\cdot}s^{-1}$. Maps provided by: D.A. Greenberg and J.D. Chaffey (Fisheries and Oceans Canada, Maritimes Region).

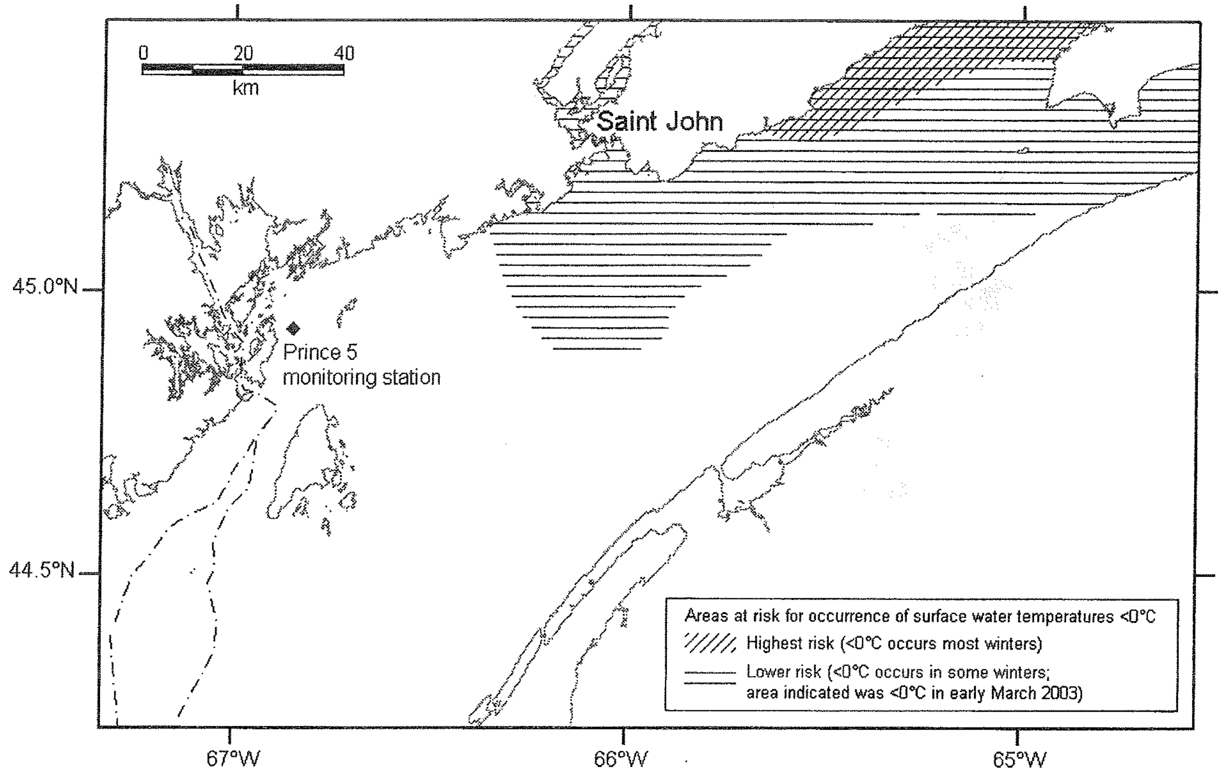

Fig. 4a. Areas of the Bay of Fundy where winter surface water temperatures are likely to fall below 0°C, based on satellite imagery for 1998-2003. Information source: Fisheries and Oceans Canada, Ocean Sciences Division (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/remotesensing.html).

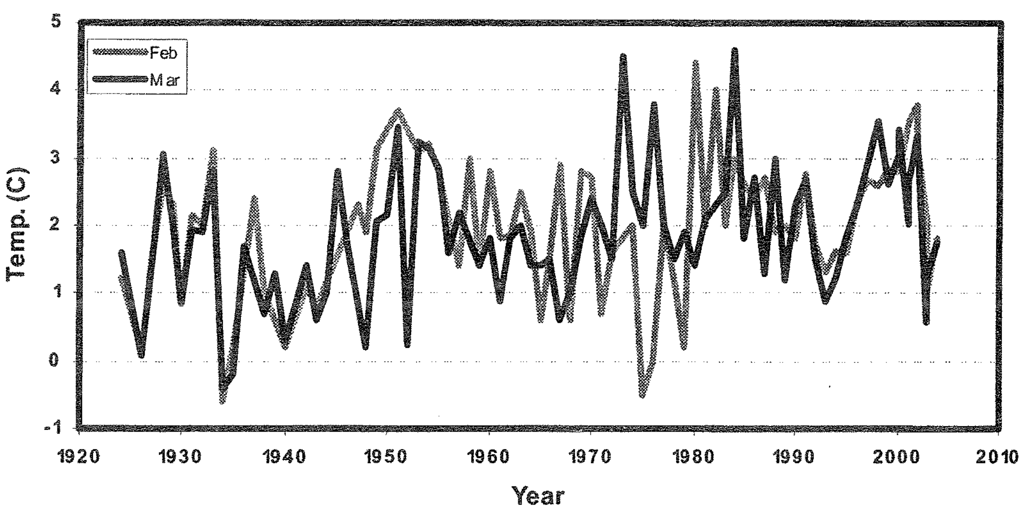

Fig. 4b. Near surface (~1 m depth) winter water temperatures at the Prince 5 monitoring station (see Fig. 4a) located in about 90-100 m of water. Water temperatures were measured once or twice a month. Information source: Fisheries and Oceans Canada, St. Andrews Biological Station.

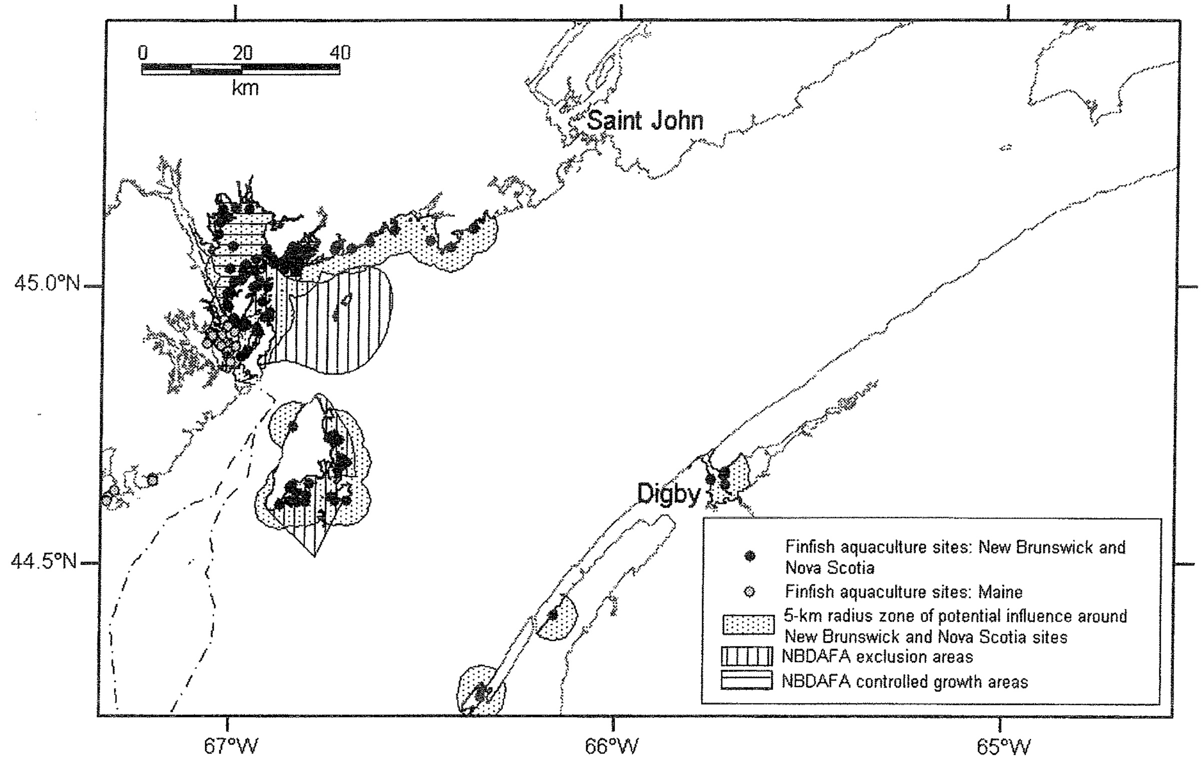

Fig. 5. Locations of marine finfish aquaculture farms in the Bay of Fundy in 2004. Potential zones of influence are shown around Canadian farms (as estimated by a 5-km radius circular area). Also shown are Controlled Growth and Exclusion Areas in New Brunswick; no new finfish aquaculture sites are currently allowed in these areas. Information sources: New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) (2000b, pers. comm.), Nova Scotia Department of Agriculture and Fisheries (2004), Maine Department of Marine Resources (2004).

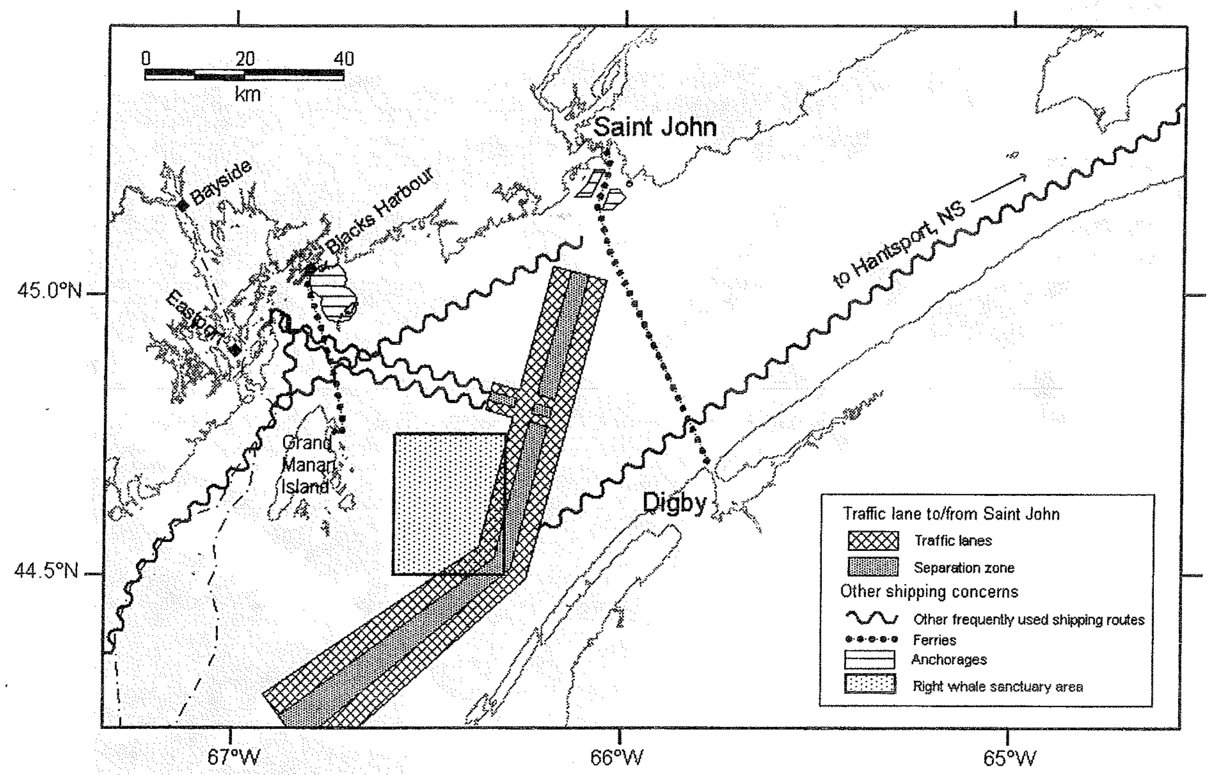

Fig. 6. Main shipping routes, anchorages and related information for the Bay of Fundy. The traffice lanes to/from Saint John are those in effect since July 2003. Information sources: Canadian Hydrographic Service nautical charts 4011 (Approaches to Bay of Fundy) and 4016 (Approaches to Saint John); Canadian Coast Guard, Fundy Traffic, Saint John (pers. comm.); Transport Canada (2004); Fisheries and Oceans Canada (2004a).

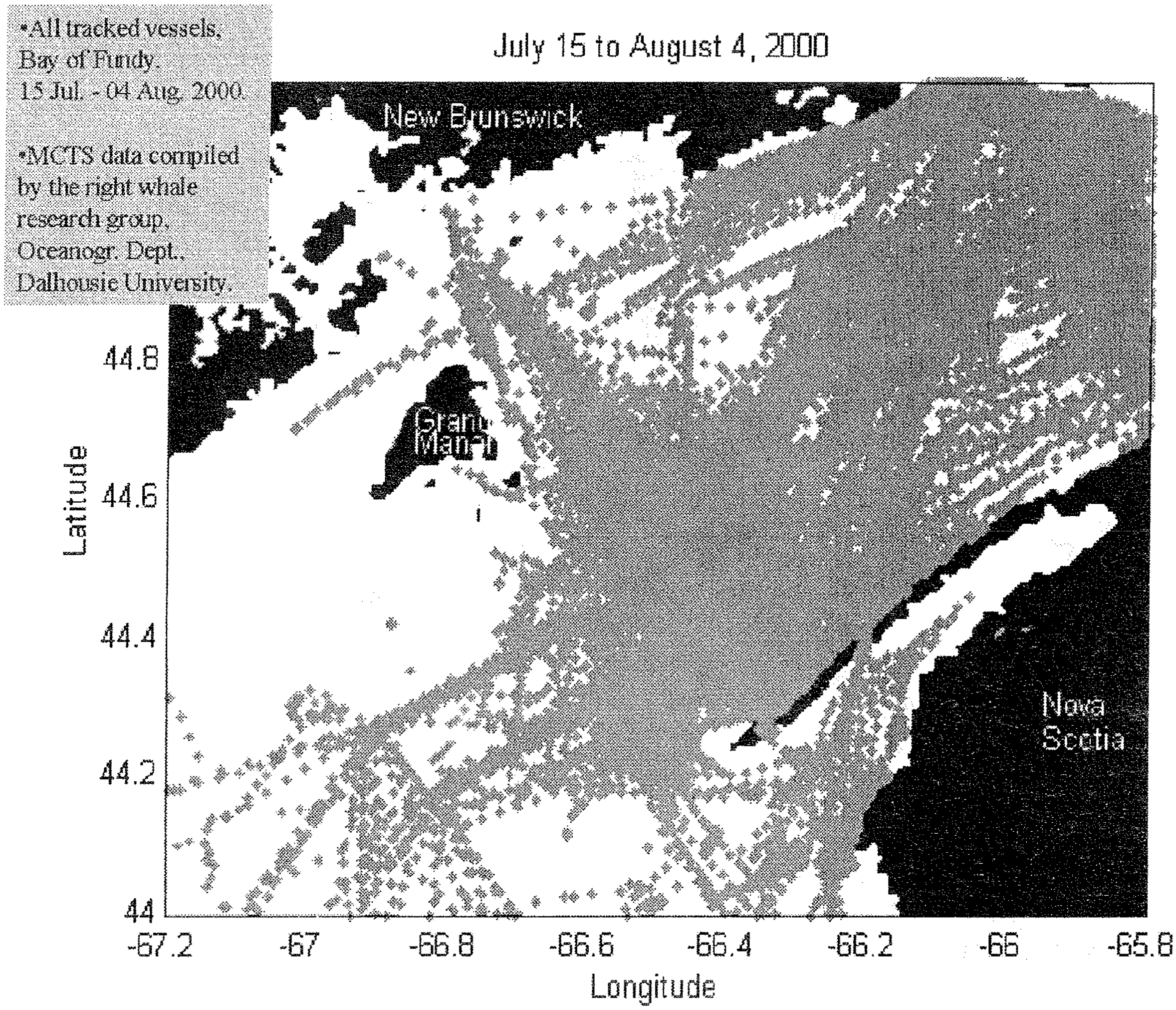

Fig. 7. Locations of all tracked vessels (grey symbols) in the lower Bay of Fundy for the period 15 July to 4 August 2000. Map provided by: C. Taggart, Oceanography Department, Dalhousie University, based on data provided by Marine Communications and Traffic Services (MCTS), Canadian Coast Guard, Saint John, NB.

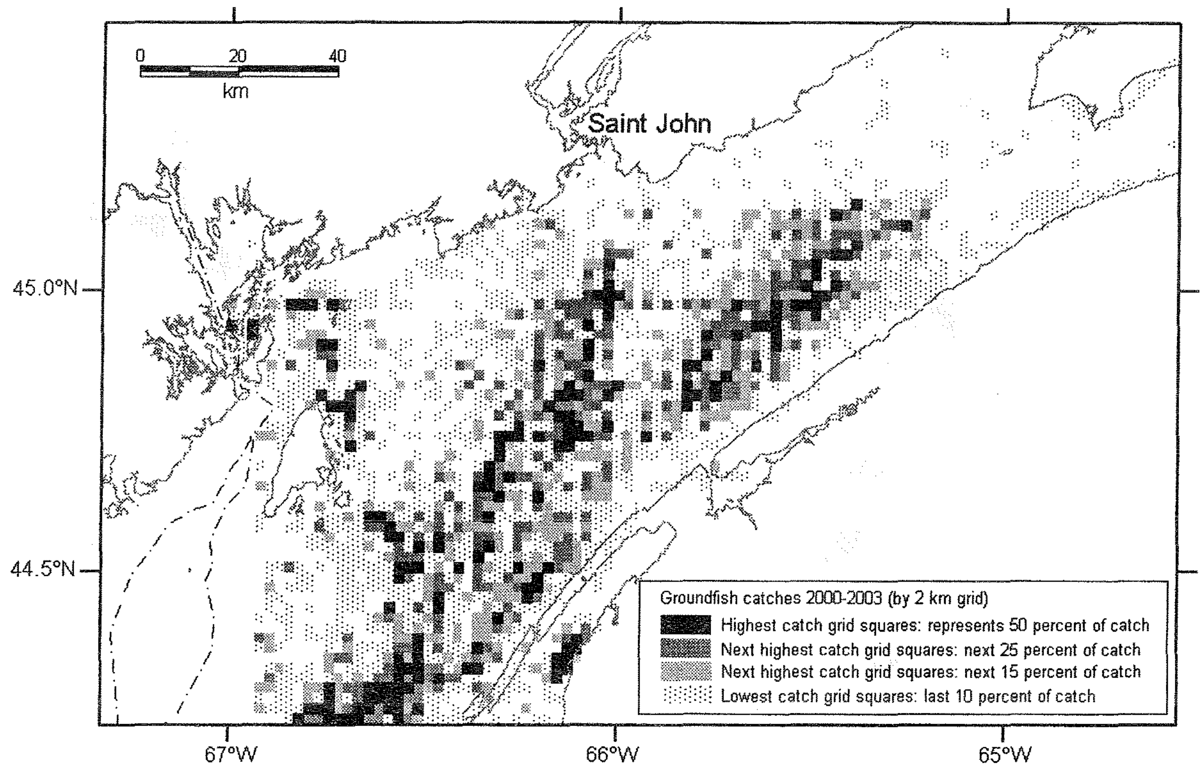

Fig. 8. Geo-referenced groundfish catch data (all species combined) for the Bay of Fundy, 2000-2003 combined. Information source: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre.

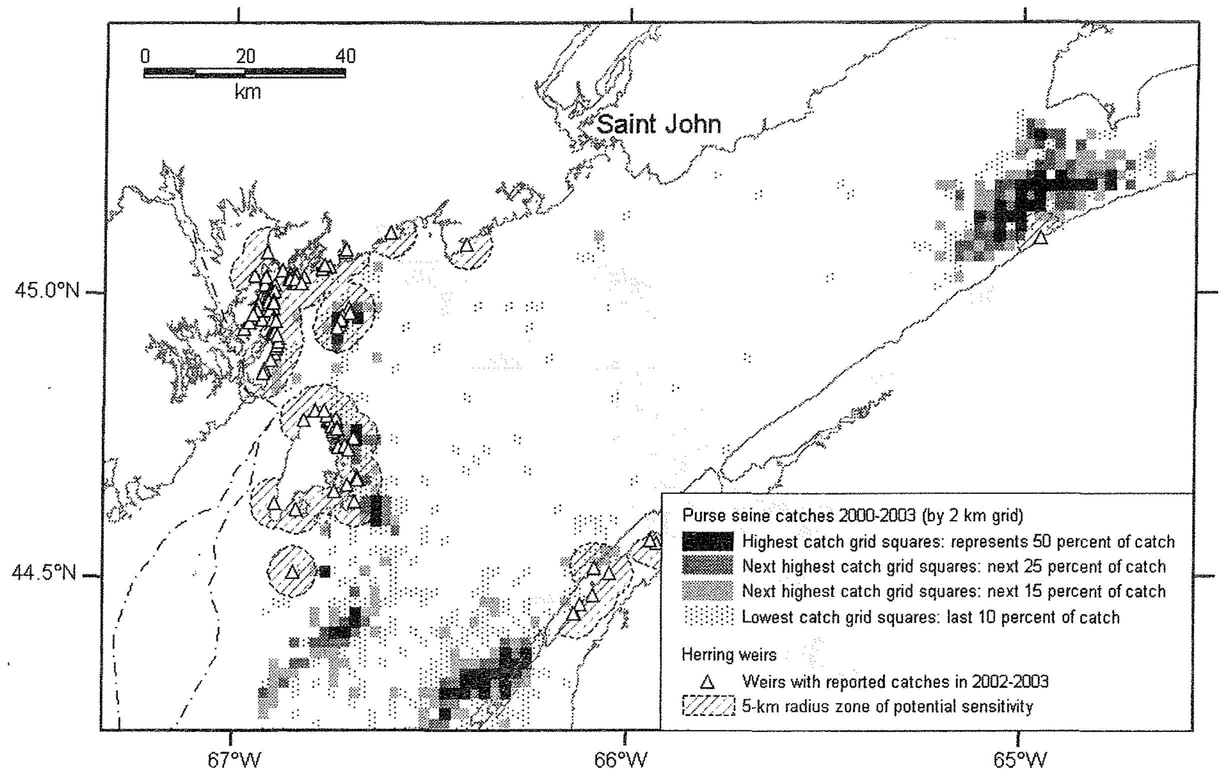

Fig. 9. Geo-referenced herring purse seine catch data for the Bay of Fundy, 2000-2003 combined. Also shown are locations of herring weirs which caught fish during 2002 and 2003 and 5-km radius zones of potential sensitivity around the weirs. Information sources: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre; M.J. Power (pers. comm.).

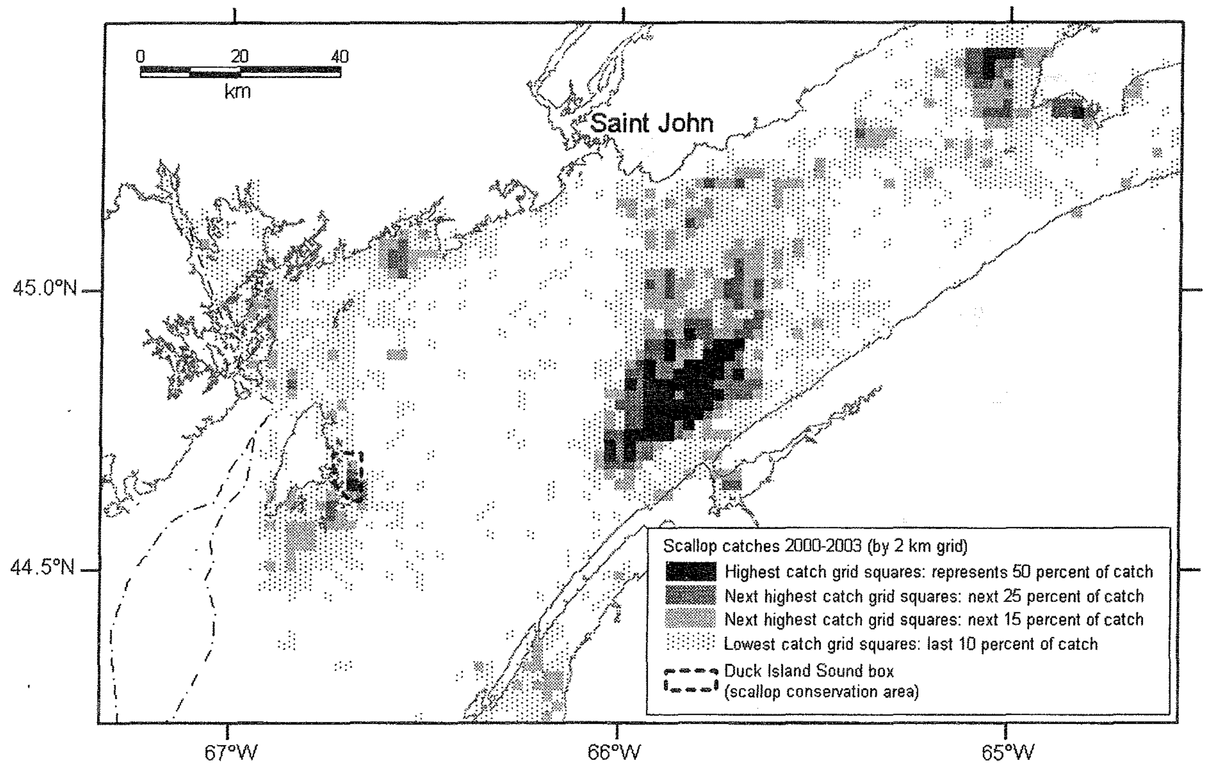

Fig. 10. Geo-referenced scallop catch data for the Bay of Fundy, 2000-2003 combined. Also shown is the Duck Island Sound Box, within which scallop fishing is limited for conservation purposes. Information source: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre.

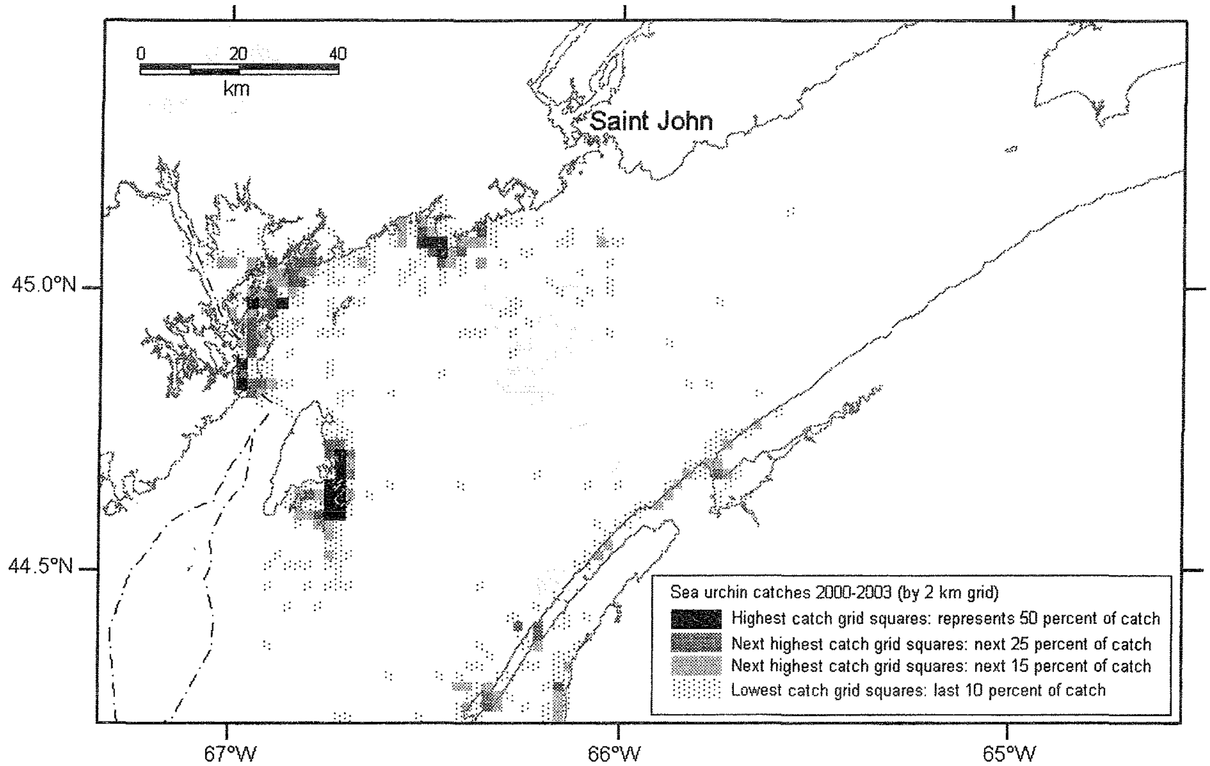

Fig. 11. Geo-referenced sea urchin catch data for the Bay of Fundy, 2000-2003 combined. Information source: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre.

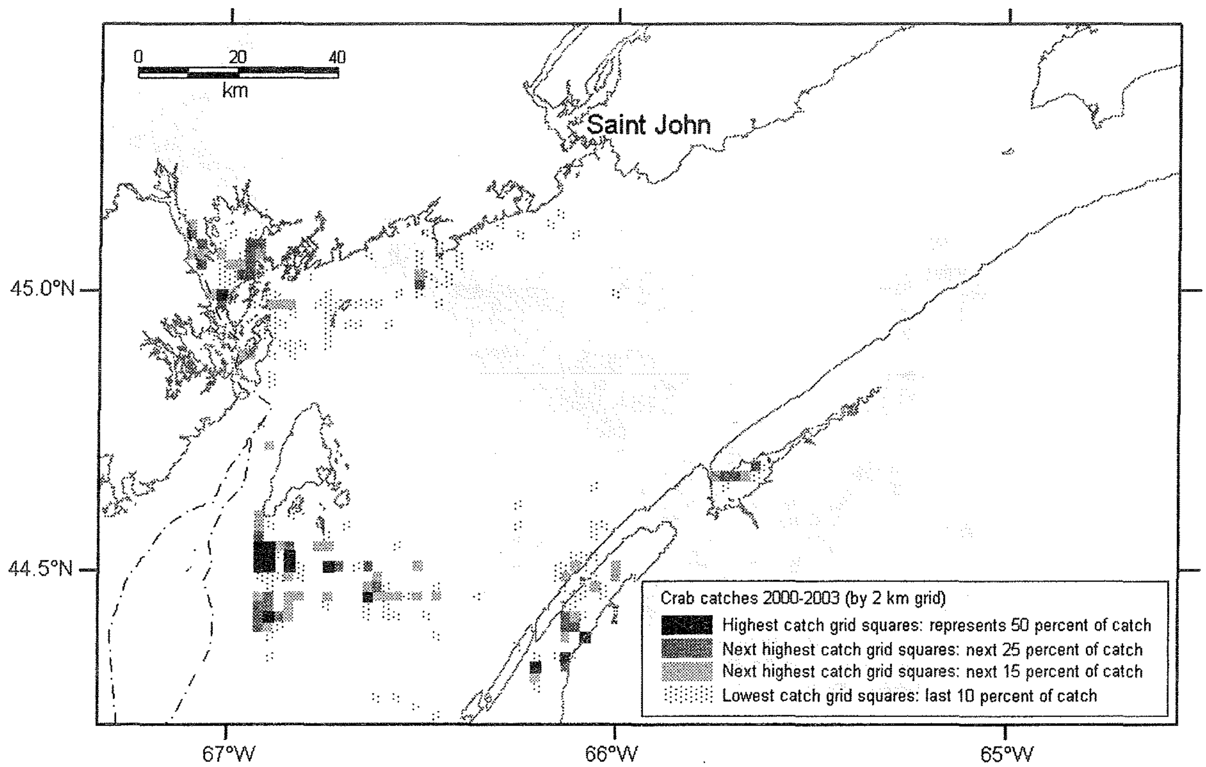

Fig. 12. Geo-referenced crab (rock and Jonah) catch data for the Bay of Fundy, 2000-2003 combined. Information source: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre.

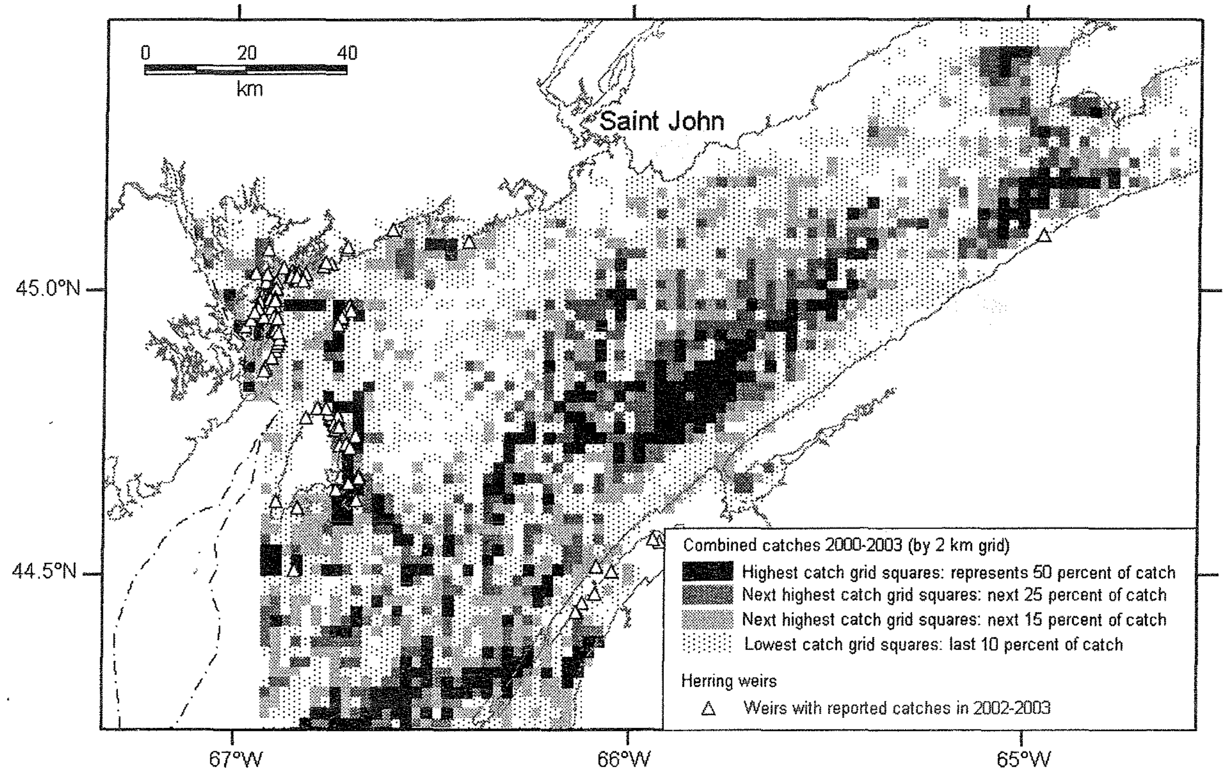

Fig. 13. Combined geo-referenced catch data for groundfish, herring purse seine, scallop, sea urchin, and crabs for the Bay of Fundy, 2000-2003. This figure amalgamates the areas shown in Fig. 7-11. Also shown are active herring weirs.

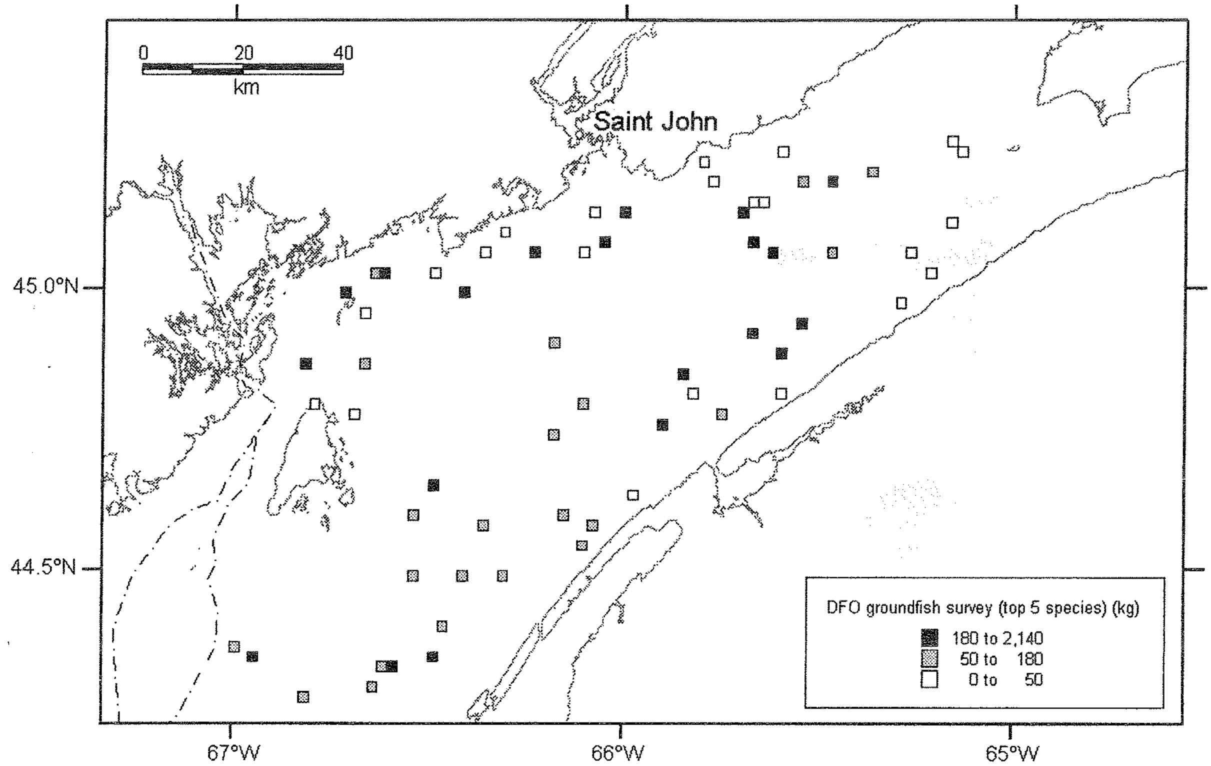

Fig. 14. Groundfish catches from the annual Fisheries and Oceans Canada (DFO) groundfish survey cruises, 2000-2003. The values are the totals of the most abundant five species caught in the surveys (dogfish, cod, haddock, pollock and silver hake). Information source: Fisheries and Oceans Canada, Maritime Science Virtual Data Centre.

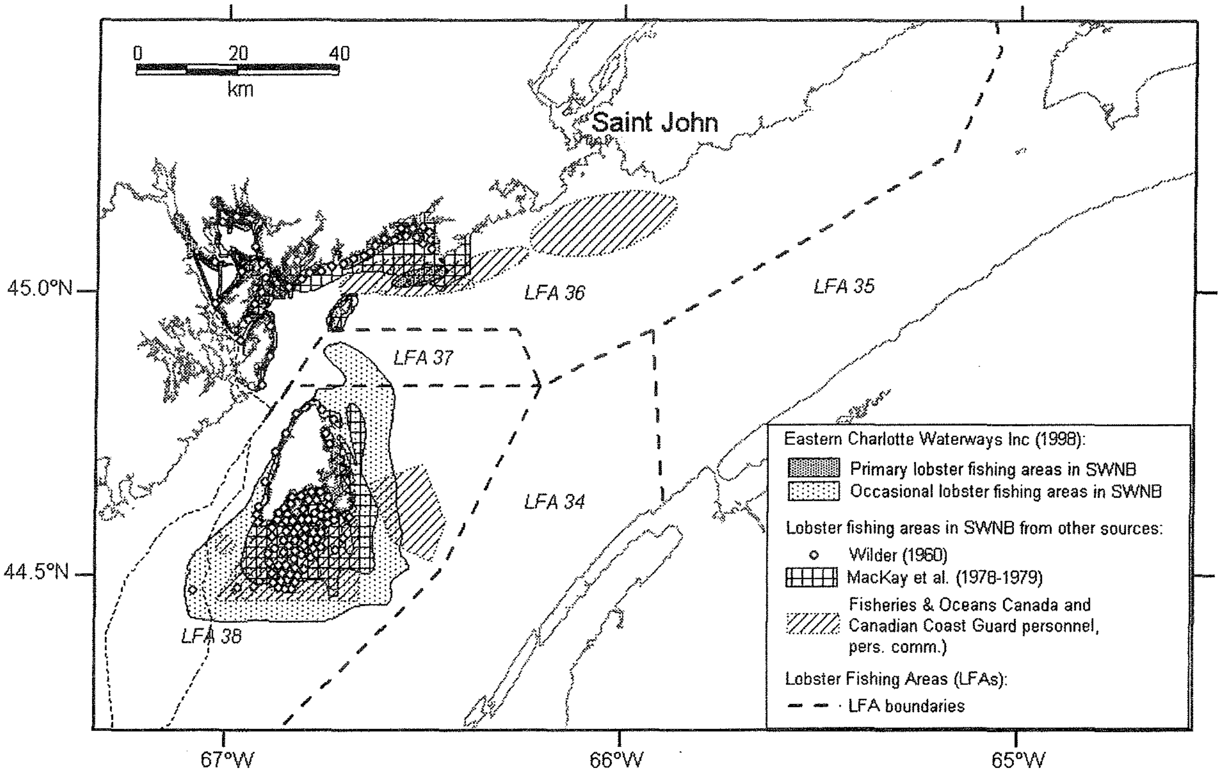

Fig. 15. Lobster fishing areas in the southwestern New Brunswick (SWNB) area of the Bay of Fundy. Also shown are the boundaries of Lobster Fishing Areas (LFAs) in the Bay of Fundy. In recent years, fishing has been extending further offshore, to the limits of each LFA.

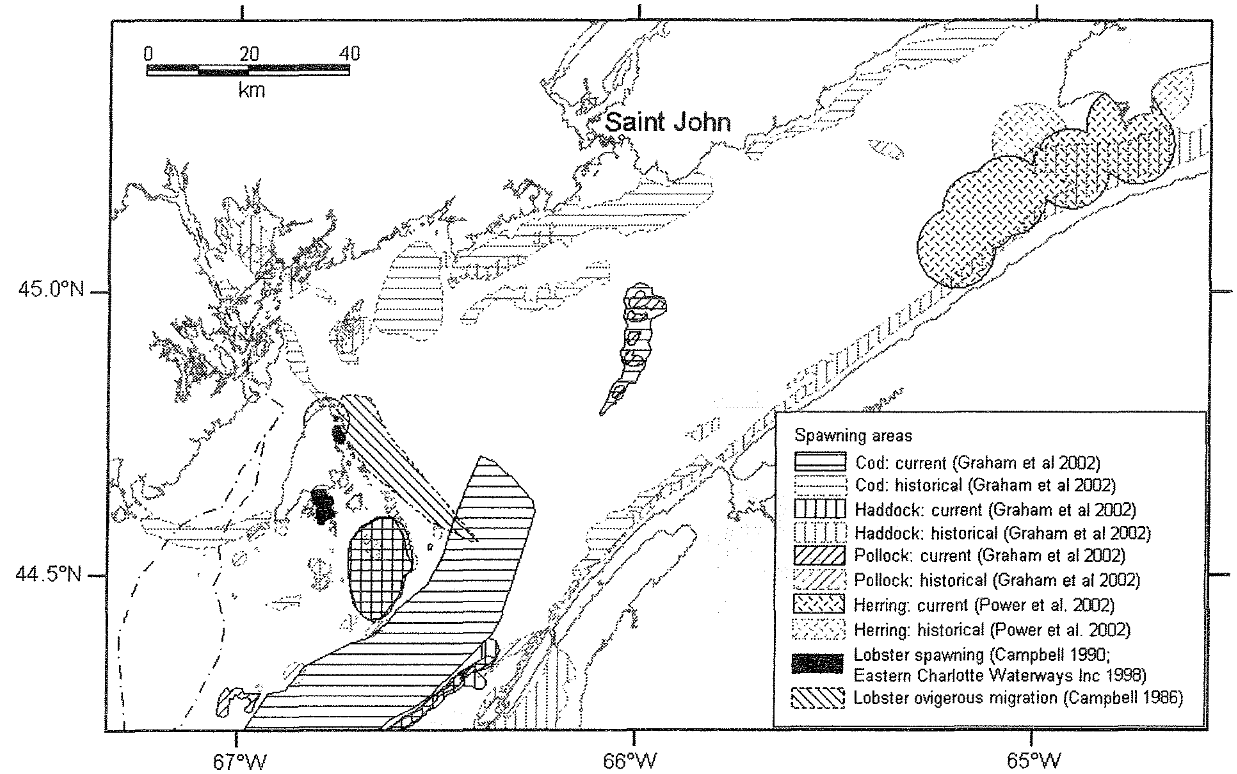

Fig. 16. Spawning areas (current and historical) for major groundfish species, herring, and lobsters in the Bay of Fundy. Spawning areas were redrawn from the information sources indicated in the legend.

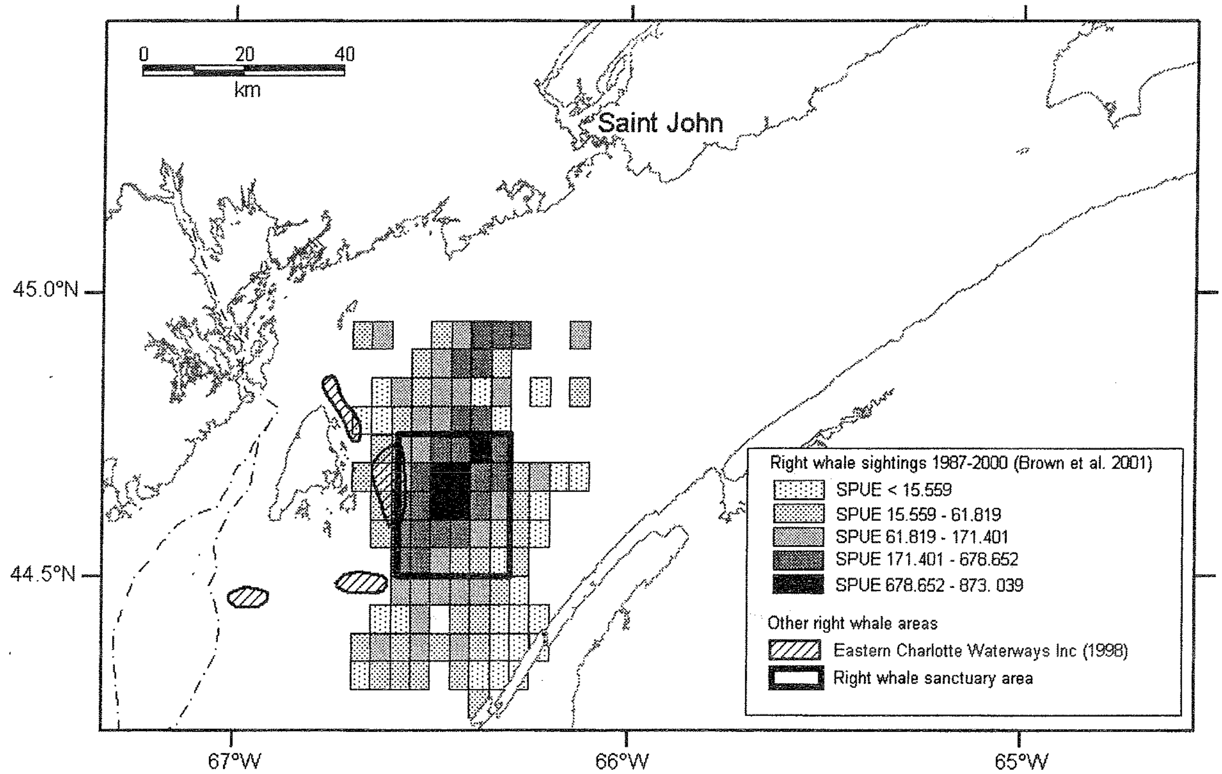

Fig. 17. Right whale sighting locations in the Bay of Fundy. SPUE = sightings per unit effort. Information sources: Brown et al. (2001); Eastern Charlotte Waterways Inc. (1998).

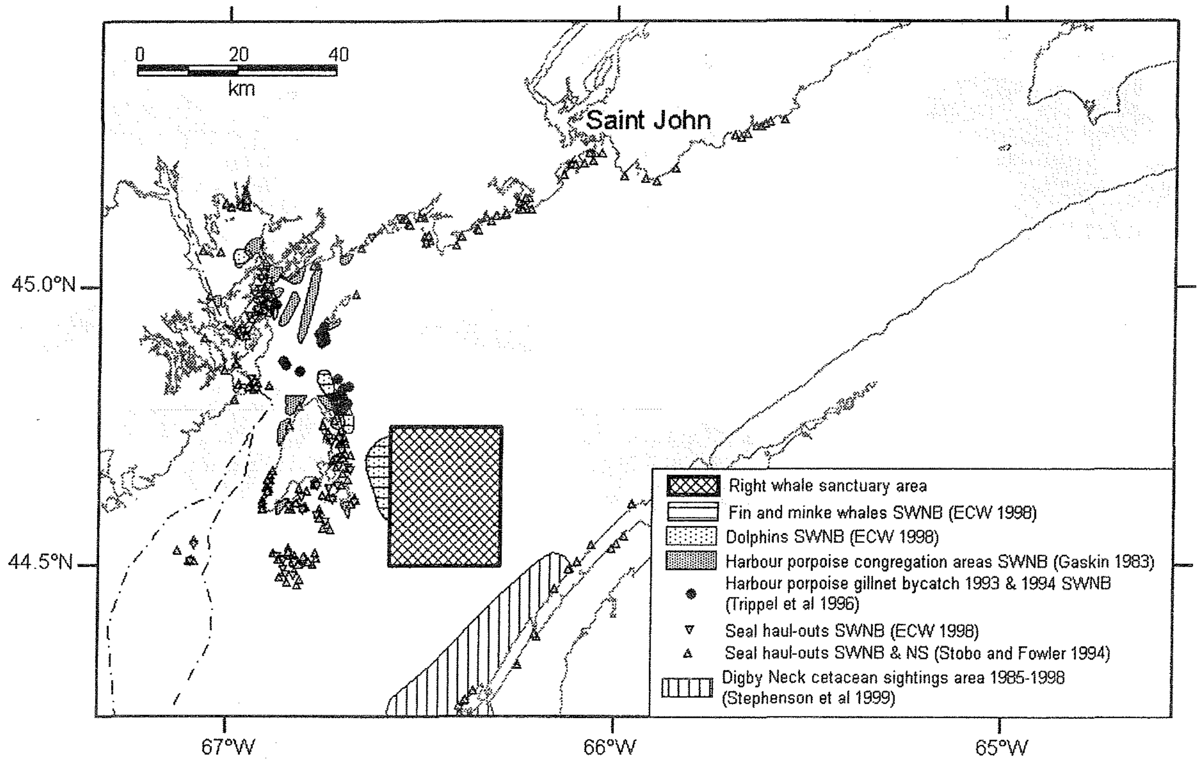

Fig. 18. Location data for other marine mammals in the Bay of Fundy. SWNB = southwestern New Brunswick; NS = Nova Scotia; ECW = Eastern Charlotte Waterways Inc.

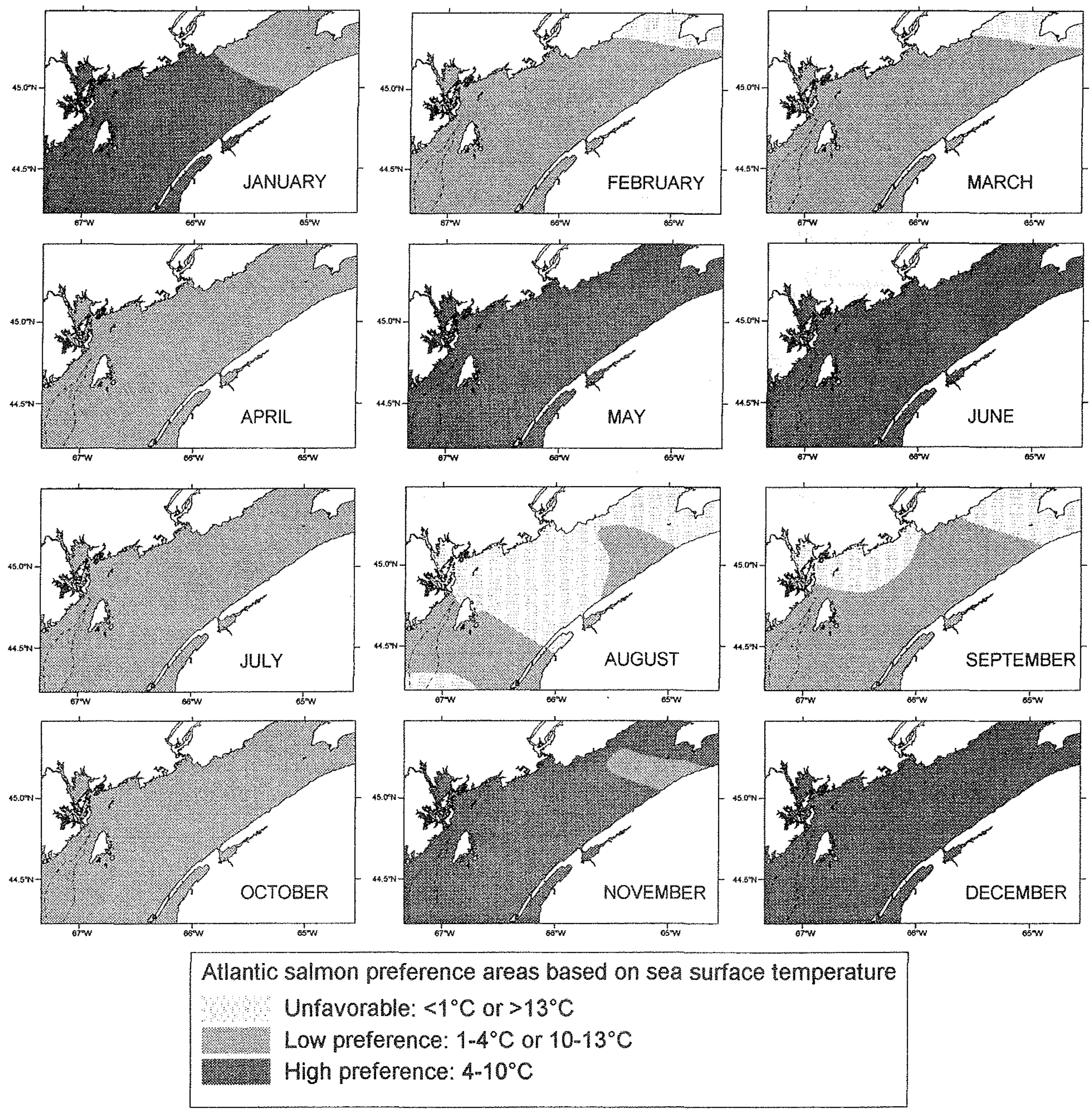

Fig. 19. Potential marine habitat for inner Bay of Fundy salmon based on temperature preference. Figures redrawn from Amiro et al. (2003).

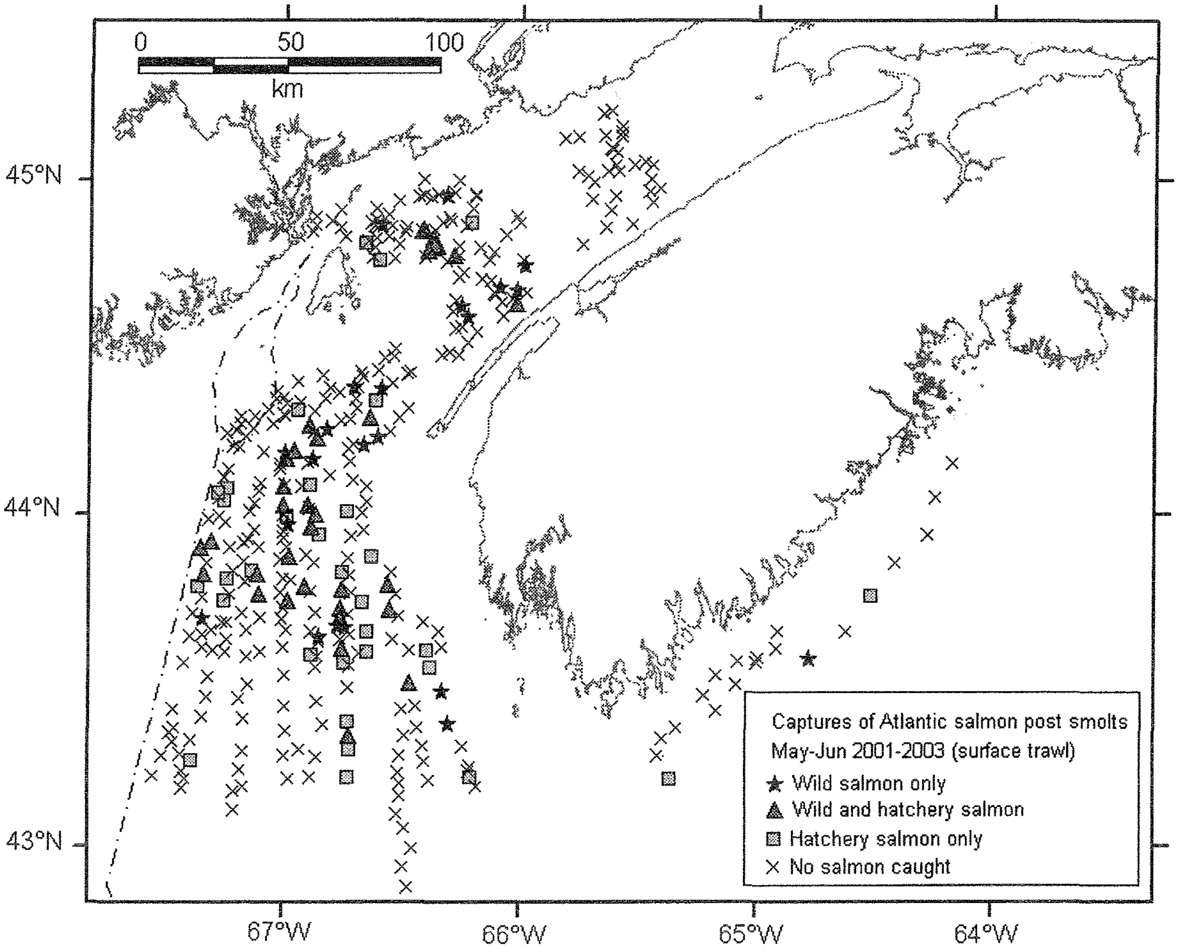

Fig. 20. Atlantic salmon post-smolts captured in the Bay of Fundy area by surface trawl in late May to mid-June 2001-2003. Information source: Lacroix and Knox (2005).

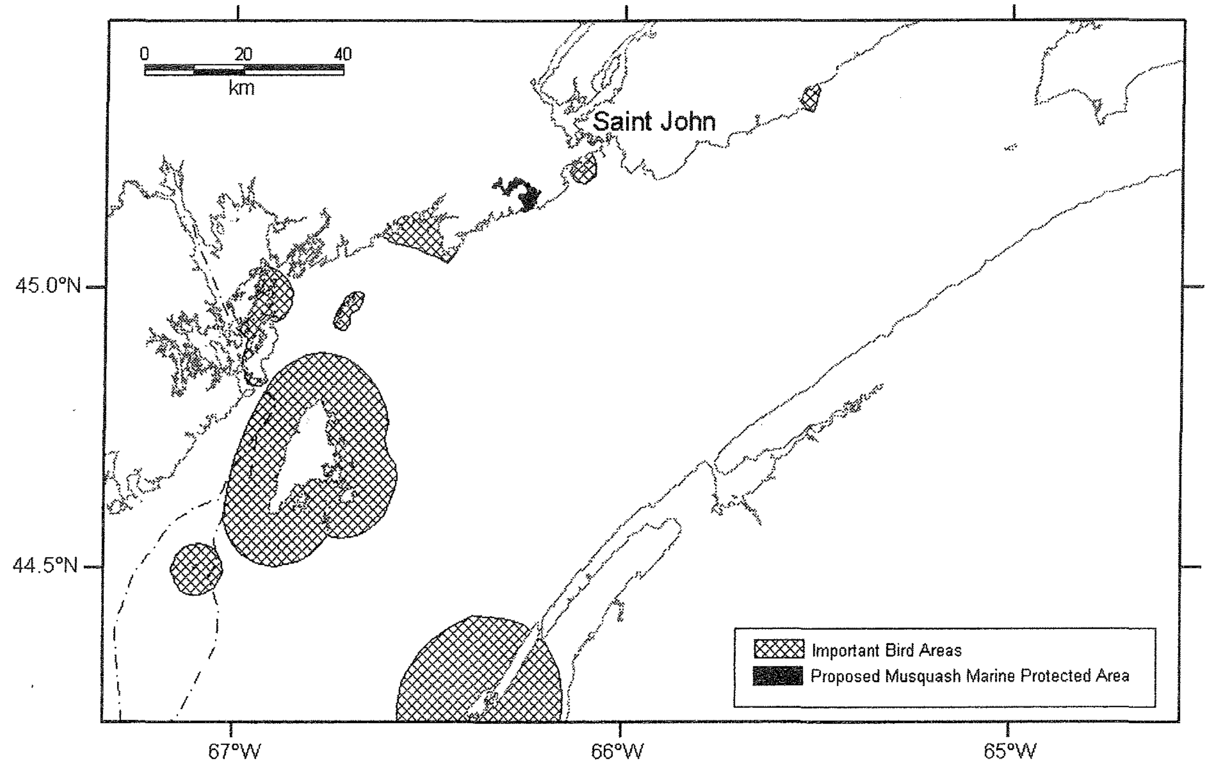

Fig. 21. Important Bird Areas and the proposed Musquash Marine Protected Area. Information sources: Important Bird Areas of Canada (2004); Singh et al. (2000).

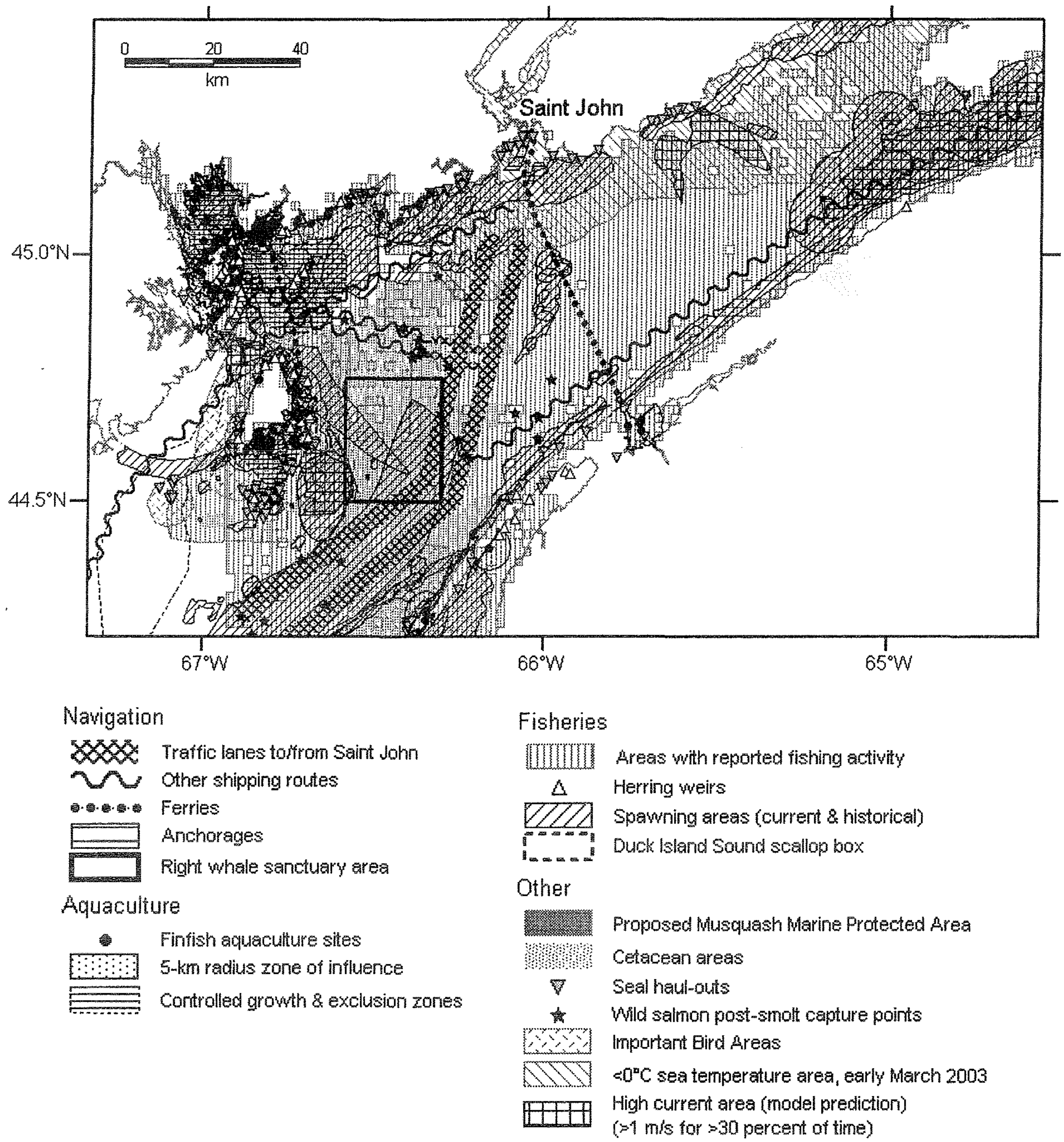

Fig. 22. Geographic overlap of activities and issues in the Bay of Fundy. See text and previous figures for details and information sources.

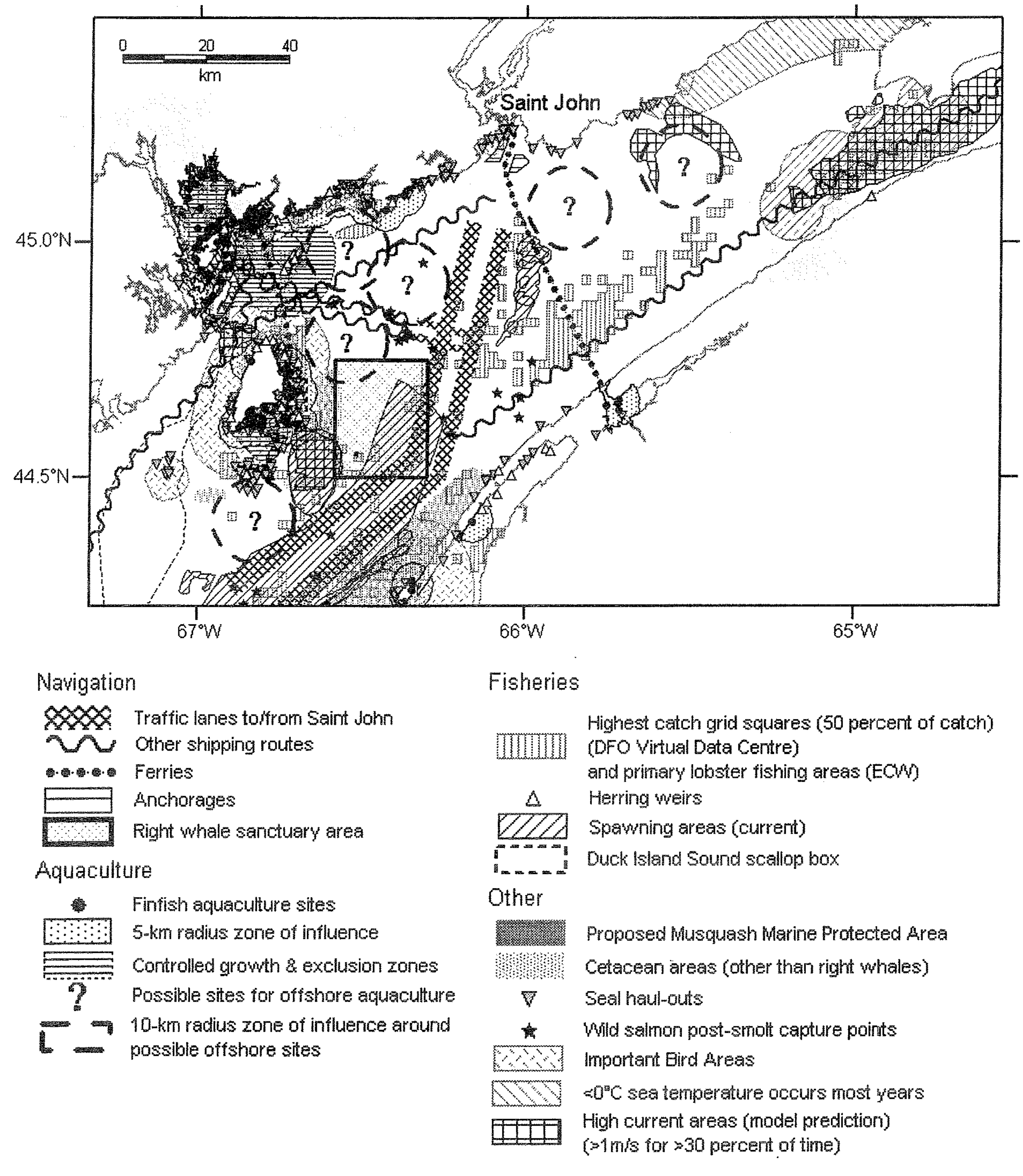

Fig. 23. Potential locations for offshore aquaculture in the Bay of Fundy, based on preliminary analyses. Further analysis is required to confirm the suitability of any of the possible offshore aquaculture sites. See text and previous figures for details and information sources.