POTENTIAL IMPACTS TO WILD FISH POPULATIONS AND HABITAT IN THE VICINITY OF A PROPOSED FINFISH AQUACULTURE SITE IN SHOAL BAY, HALIFAX COUNTY, NOVA SCOTIA

Context

On April 17, 2012, Fisheries and Oceans Canada's (DFO) Habitat Management Division, Maritimes Region, requested that DFO Science provide advice on three issues pertaining to a proposed finfish aquaculture site in Shoal Bay, Nova Scotia (NS), in order to determine if it is likely to result in negative impacts to fish and fish habitat: the potential for organic enrichment, the potential impacts to wild salmon populations, and the potential uses of habitat by commercially important species and the presence of critical or valuable habitat for these species.

The request for advice is to support Habitat Management's review of an aquaculture project proposal pursuant to the *Canadian Environmental Assessment Act*. As part of the federal Environmental Assessment (EA) process, DFO may provide advice to Transport Canada regarding any impacts that fall under DFO's mandate. In addition, DFO may provide advice to the Nova Scotia Department of Fisheries and Aquaculture on the proposed aquaculture development. The Canadian Environmental Assessment Registry reference number 12-01-66202 can be referred to for more information regarding the EA of this proposed development project.

Specifically, Habitat Management asked the following questions with respect to:

Organic Enrichment

1) When running DEPOMOD with resuspension off, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Shoal Bay based on a stocking level of 500,000 fish at the
   i) maximum daily feed rate?
   ii) average daily feed rate?

2) When running DEPOMOD with resuspension on, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Shoal Bay based on a stocking level of 500,000 fish at the
   i) maximum daily feed rate?
   ii) average daily feed rate?

3) At what daily feed rate would the deposition rate of 5 g C m^{-2} d^{-1} be exceeded at the site and what level of stocking would that support when running DEPOMOD with
   i) resuspension off?
   ii) resuspension on?

Wild Salmon Populations

4) What wild salmon populations (and their lifecycle stages) are known to be or are potentially present in the vicinity of the proposed finfish aquaculture sites at Shoal Bay, Nova Scotia and what is their relative abundance?

5) During which times of the year and for what duration would wild salmon be expected to be in the vicinity of the proposed aquaculture site?

6) What freshwater habitat found within the range of the Southern Uplands designatable unit is currently used by wild salmon as spawning habitat?

Fish Habitat and Other Fish Populations

7) Based on the type of habitat (as shown in the benthic video) and the site depths and locations (shown on attached map), what are the potential uses of that habitat by lobster, crab, groundfish, clams, scallops, sea urchin, and any other commercially important species?

8) Within the general vicinity of the proposed aquaculture sites, are there species that are not listed in the attached table that are particularly important for fisheries resources, and is there any critical or valuable habitat for these species in the area?

This Science Response Report results from the Science Special Response Process of May 2012 on the Review of the Potential Impacts to Wild Fish Populations and Habitat in the Vicinity of a Proposed Finfish Aquaculture Site in Shoal Bay, Nova Scotia. A meeting to review this Science Response was held on June 14, 2012.

Analysis and Response

Organic Enrichment

DEPOMOD (version 2) software was used to predict the near-field deposition of organic solid wastes released from the proposed salmon aquaculture site (Figure 1 and Appendix 1). DEPOMOD is a commercially available computer model (Cromey et al. 2000, 2002) that was developed in Scotland. It has been used to predict the benthic impacts of salmon farming in British Columbia (Chamberlain and Stucchi 2007; Chamberlain et al. 2005). Studies on the use of DEPOMOD have also been conducted at some existing and proposed salmon farms in southwestern New Brunswick (NB) and Nova Scotia (DFO 2009; DFO 2011a; DFO 2011 b; DFO 2012a; Page et al. 2009).

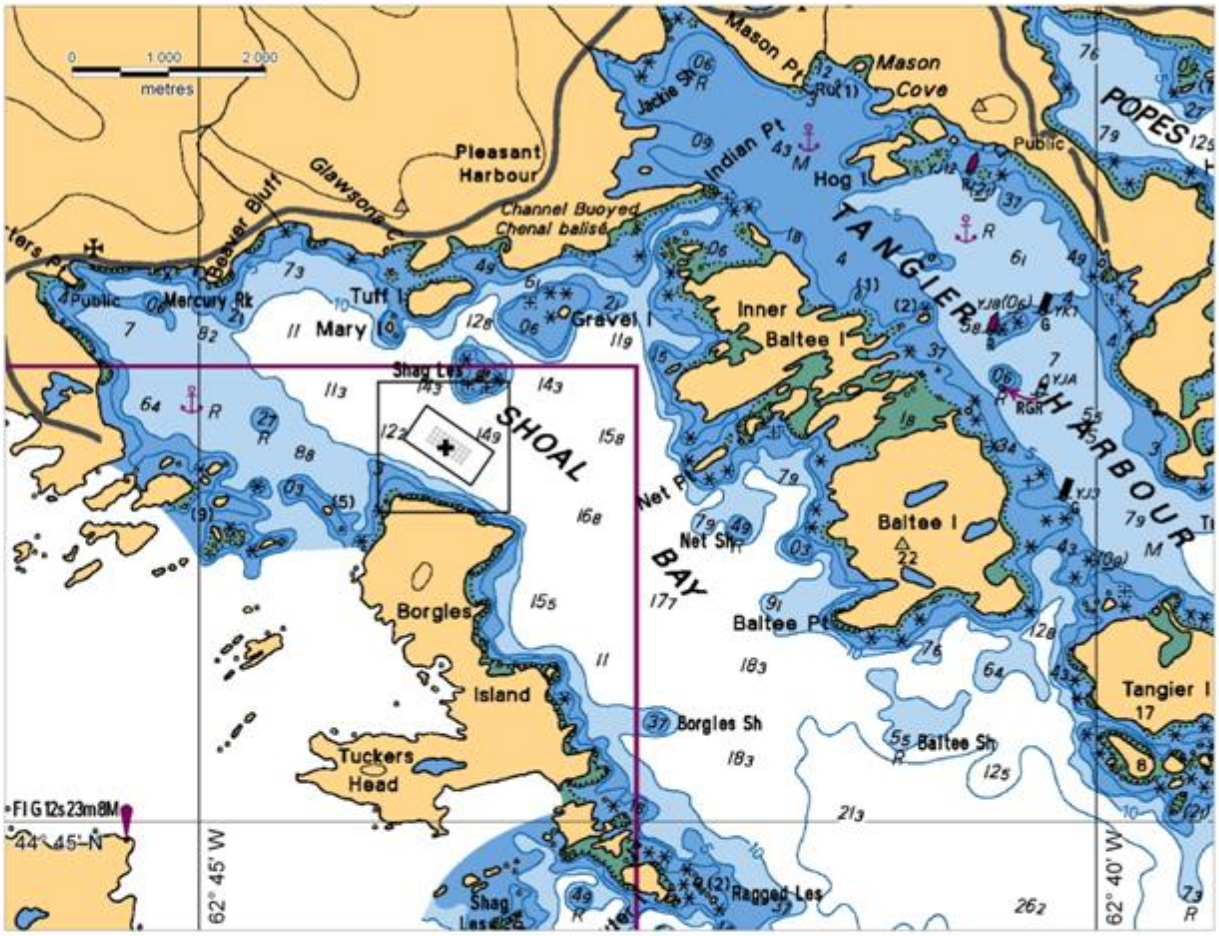

Figure 1. Map of the Shoal Bay, Nova Scotia area showing the location of the proposed site #1370. The square represents the extent of the DEPOMOD domain. The polygon within the square is the lease boundary. The cross (near the site centre) indicates the location of the current meter deployment. The background map is Canadian Hydrographic Service chart 4236: Taylors Head to Shut-in Island (2001).

Using cage locations and dimensions, feed rates per cage, current velocity data, bathymetry, feed wastage rates, and feed/fecal particle sinking rates, DEPOMOD predicts the spatial distribution of organic carbon deposition on the seafloor in the vicinity of the site (in grams carbon per m^2 per day [g C m^{-2} d^{-1}]) resulting from estimates of waste feed and feces produced by farmed fish in cages. These deposition rates can be related to benthic classifications for fish farms in NB and NS, based on sediment sulfide concentrations (NBDENV 2006; NSDFA 2011), using Appendix 1: Table 1.2 (based on information in Hargrave et al. 2008 and Hargrave 2010).

The following documentation describes the outputs from the DEPOMOD runs that were completed in relation to the proposed aquaculture site. Detailed information pertaining to the methodology and data inputs used in the DEPOMOD runs is located within Appendix 1.

Following the completion of the DEPOMOD runs, the proponent requested a small adjustment to the lease boundaries. Information on this adjustment and its potential consequences is included in Appendix 2.

Current Velocity

Current rose diagrams for the proposed site are shown in Appendix 1: Figure 1.1. Currents were predominantly to the west and east near the surface and to the west-northwest and east-southeast at mid-depth and near the bottom.

Current speed data are shown in Appendix 1: Figure1.2 and Table1.6. Current speeds were low, and there was little variation in the minimum, mean, and maximum speeds among the three depth layers. The percentage of near bottom records greater than the DEPOMOD resuspension threshold of 9.5 cm s^{-1} was low, 12%.

Carbon Deposition Rates

Mass balance calculations for the DEPOMOD predictions are shown in Appendix 1: Table 1.7. For both maximum and average feed rates, all waste particles remained within the model domain with resuspension off. With resuspension on, 77% of particles remained within the model domain using the maximum feed rate, and 52% with the average feed rate.

Contour plots of the DEPOMOD predicted carbon deposition rates are shown in Appendix 1: Figure 1.3 (maximum feed rate) and Figure 1.4 (average feed rate). The areas of the contours are shown in Appendix 1: Table 1.8 (maximum feed rate) and Table 1.9 (average feed rate). Parameters for the linear relationship between the feed rate and highest predicted deposition rate within the DEPOMOD domain are shown in Appendix 1: Table 1.10 and stocking rates that would maintain the carbon deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the DEPOMOD domain are shown in Appendix 1: Table 1.11.

Resuspension off

With resuspension off, DEPOMOD predicted large areas with elevated carbon deposition rates when using the proposed maximum feed rate: 41,800 m^2 with carbon deposition rates >5 g C m^{-2} d^{-1} and 16,700 m^2 with anoxic conditions (>10 g C m^{-2} d^{-1}). Using the proposed average feed rate, the area with deposition rates >5 g C m^{-2} d^{-1} was reduced to 3,300 m^2 and there were no areas with anoxic conditions.

The highest predicted deposition rate within the DEPOMOD domain using the proposed maximum feed rate was 23.8 g C m^{-2} d^{-1}, three times higher than when using the proposed average feed rate, 7.8 g C m^{-2} d^{-1}.

The estimated feed rate that would maintain the predicted deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the DEPOMOD domain (derived from the linear relationship between the feed rate and the highest predicted deposition rate within the DEPOMOD domain) was 65 kg d^{-1} per cage (assuming the same number of cages). During the period of maximum feeding (when fish biomass is highest), this feed rate would support a stocking rate of 3,200 fish per cage (compared to proposed stocking of 15,150 fish per cage).

Resuspension on

With resuspension on, there was some reduction in the amount of waste deposition within the model domain, using both maximum and average feed rates. When using the proposed maximum feed rate, there was 34,200 m^2 with carbon deposition rates >5 g C m^{-2} d^{-1} and 9,800 m^2 with anoxic conditions (>10 g C m^{-2} d^{-1}). Using the proposed average feed rate, there were no areas with deposition rates >5 g C m^{-2} d^{-1}.

The highest predicted deposition rates within the DEPOMOD domain were slightly lower than with resuspension off: using the proposed maximum feed rate, it was 21.5 g C m^{-2} d^{-1}, and when using the proposed average feed rate, 5.6 g C m^{-2} d^{-1}.

The estimated feed rate that would maintain the predicted deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the DEPOMOD domain (derived from the linear relationship between the feed rate and the highest predicted deposition rate within the DEPOMOD domain) was 91 kg d^{-1} per cage (assuming the same number of cages). During the period of maximum feeding (when fish biomass is highest), this feed rate would support a stocking rate of 4,400 fish per cage (compared to proposed stocking of 15,150 fish per cage).

The resuspension module was validated at some Scottish salmon farms (Cromey et al. 2002) where average near-bottom current speeds were low (3.6 - 6.2 cm s^{-1}). However, at a British Columbia farm, where the average near-bottom current speed was higher (7.9 cm s^{-1}), the resuspension module was found to overestimate the transport of particles away from farms (Chamberlain and Stucchi 2007); this also appears to be the case at some sites in NB where DEPOMOD has been tested, except where current speeds are very low (Chang et al. *in prep*). This suggests that DEPOMOD predictions with resuspension on should be used with caution, as it is not known if the threshold resuspension current speed of 9.5 cm s^{-1} (near bottom), as well as the default consolidation time of 4 days, are appropriate for the conditions at the farm examined in this study. The average near-bottom current speed at the Shoal Bay site (5.3 cm s^{-1}) was within the range of average near-bottom current speeds in the Cromey et al. (2002) Scottish sites.

Summary

When running DEPOMOD with resuspension off, the area of sensitivity for organic enrichment (i.e., the area where DEPOMOD predicts that the carbon deposition rate will exceed 5 g C m^{-2} d^{-1}) predicted for the proposed aquaculture site at Shoal Bay based on a stocking level of 500,000 fish at i) the maximum daily feed rate is 41,800 m^2 and at ii) the average daily feed rate is 3,300 m^2 relative to a proposed aquaculture site area of 18,000 m^2.

When running DEPOMOD with resuspension on, the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Shoal Bay based on a stocking level of 500,000 fish at i) the maximum daily feed rate is 34,200 m^2 and at ii) the average daily feed rate is 0 m^2 relative to a proposed aquaculture site area of 18000 m^2.

With resuspension off, the deposition rate of 5 g C m^{-2} d^{-1} would be exceeded at the site (in any cell within the DEPOMOD domain) at a feed rate of 65 kg d^{-1} per cage and a stocking level of 3,200 fish per cage (assuming the same number of cages).

With resuspension on, the deposition rate of 5 g C m^{-2} d^{-1} would be exceeded at the site (in any cell within the DEPOMOD domain) at a feed rate of 91 kg d^{-1} per cage and a stocking level of 4,400 fish per cage (assuming the same number of cages).

Note that DEPOMOD is a predictive tool, and limitations of the results (as described in DFO 2012a) should be taken into account.

Wild Salmon Interactions

Atlantic salmon show high, but not complete, fidelity to their natal river. Consequently, rivers in close geographic proximity are treated as uniform units for management and assessment purposes. When evaluating the extinction risk of Atlantic salmon in Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), identified four of these geographic groups or designatable units (DU) for evaluation (Figure 2). The proposed aquaculture site is located within the Southern Upland DU of Atlantic salmon. Southern Upland Atlantic salmon were assessed as Endangered by COSEWIC in November 2010 (COSEWIC 2010).

All of the concerns related to interactions between wild Atlantic salmon and marine aquaculture identified previously by DFO Maritimes Science in a review of aquaculture sites proposed for Shelburne Harbour (DFO 2012b) would be applicable to the review of the proposed Shoal Bay site. To avoid repetition, this response focuses on information that is of particular relevance for Shoal Bay, as well as new information provided in the recent Recovery Potential Assessment (RPA) for Southern Upland Atlantic salmon.

The genetic and phylogenetic characteristics of Southern Upland Atlantic salmon, the minimal historical gene flow between the Southern Upland and surrounding regions, and the evidence for local adaptation to environmental conditions in the Southern Upland region support the view that Southern Upland salmon are a distinct group from other groups of Atlantic salmon populations.

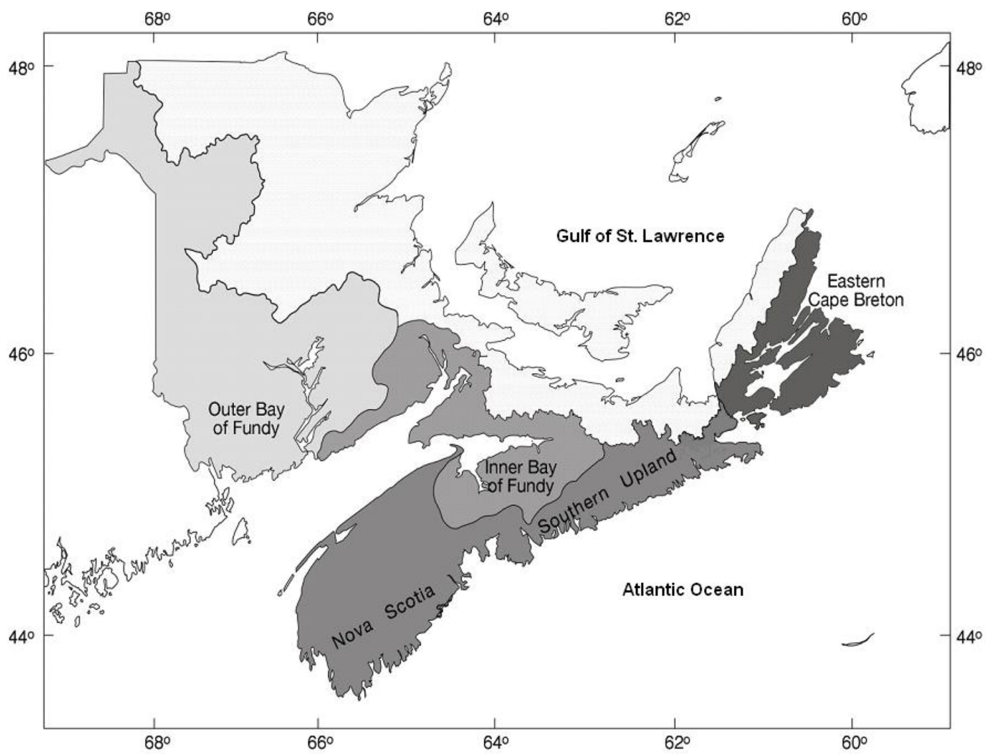

Figure 2. Map showing the major salmon areas of the Maritimes Region.[1]

[1] Map based on a version from Gibson et al. (2010).

When COSEWIC designates aquatic species as threatened or endangered, DFO, as the responsible jurisdiction under the *Species at Risk Act* (SARA), is required to undertake a number of actions, including completion of an RPA. DFO Science conducted a peer-review of the RPA for the Southern DU of Atlantic salmon on May 22-25, 2012. Results of the RPA have been used to inform this Science Response.

Status of the Southern Upland DU of Atlantic Salmon

The available indices suggest that abundance of Atlantic salmon is very low in the Southern Upland DU and declining from levels observed in the 1980s. Relative abundance is informative both in terms of comparison to historical abundance and tolerance to threats that could affect populations. Annual adult abundance data from four rivers show declines of 88% to 99% from observed abundance in the 1980s, a pattern consistent with trends in the recreational catch. Region-wide comparisons of juvenile density data from more than 50 rivers indicate significant ongoing declines between 2000 and 2008/2009 and provide evidence for river-specific extirpations. In 2008/2009, juvenile Atlantic salmon were found in 22 of 54 surveyed rivers within the DU, but were not found in 4 rivers where they had been found in 2000 (Figure 3; Gibson et al. 2010). River acidification has significantly contributed to reduced abundance or extirpation of populations from many rivers in the region during the last century. In addition to ongoing effects of acidification, contemporary declines in non-acidified rivers indicate that other factors (including invasive fish species; dams, water diversion and permanent structures; illegal fishing and poaching; marine ecosystem changes; and salmonid aquaculture) are now though to be impacting populations. Threats to populations were identified in the RPA, and when populations are low and declining, as is clear for salmon populations from this area, these threats would increase the potential for extirpation if not mitigated.

The St. Mary's River (Figure 3: 61), which is within 100 km of the proposed sites, has declined from about 1,000 salmon in the mid-1990s to less than 400 since 2005 (Gibson et al. 2010). The LaHave River (Figure 3: 26), although somewhat distant, had returns of 4,000 to 5,000 salmon during the 1980s and now has returns less than 1,000 salmon. These returns are in comparison to a spawning requirement of about 2,000 salmon (Gibson et al. 2010).

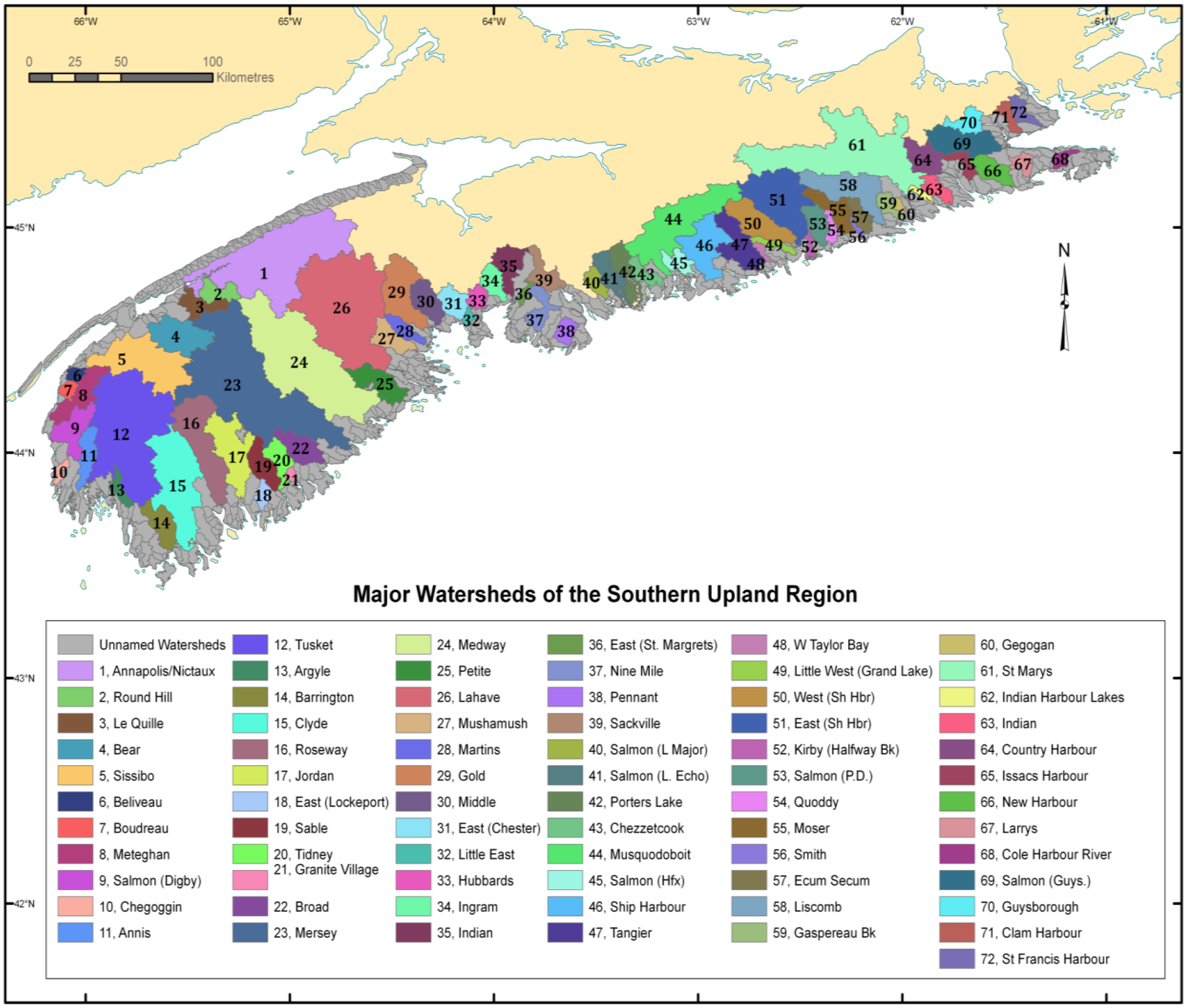

Figure 3. Major watersheds of the Southern Upland of Nova Scotia.

Juvenile Atlantic salmon have been observed in electrofishing surveys in several rivers within 25 – 50 km of the proposed aquaculture site (Figure 4). Rivers within 50 – 100 km of the proposed site had appreciable declines in juvenile density from 2000 to 2008.

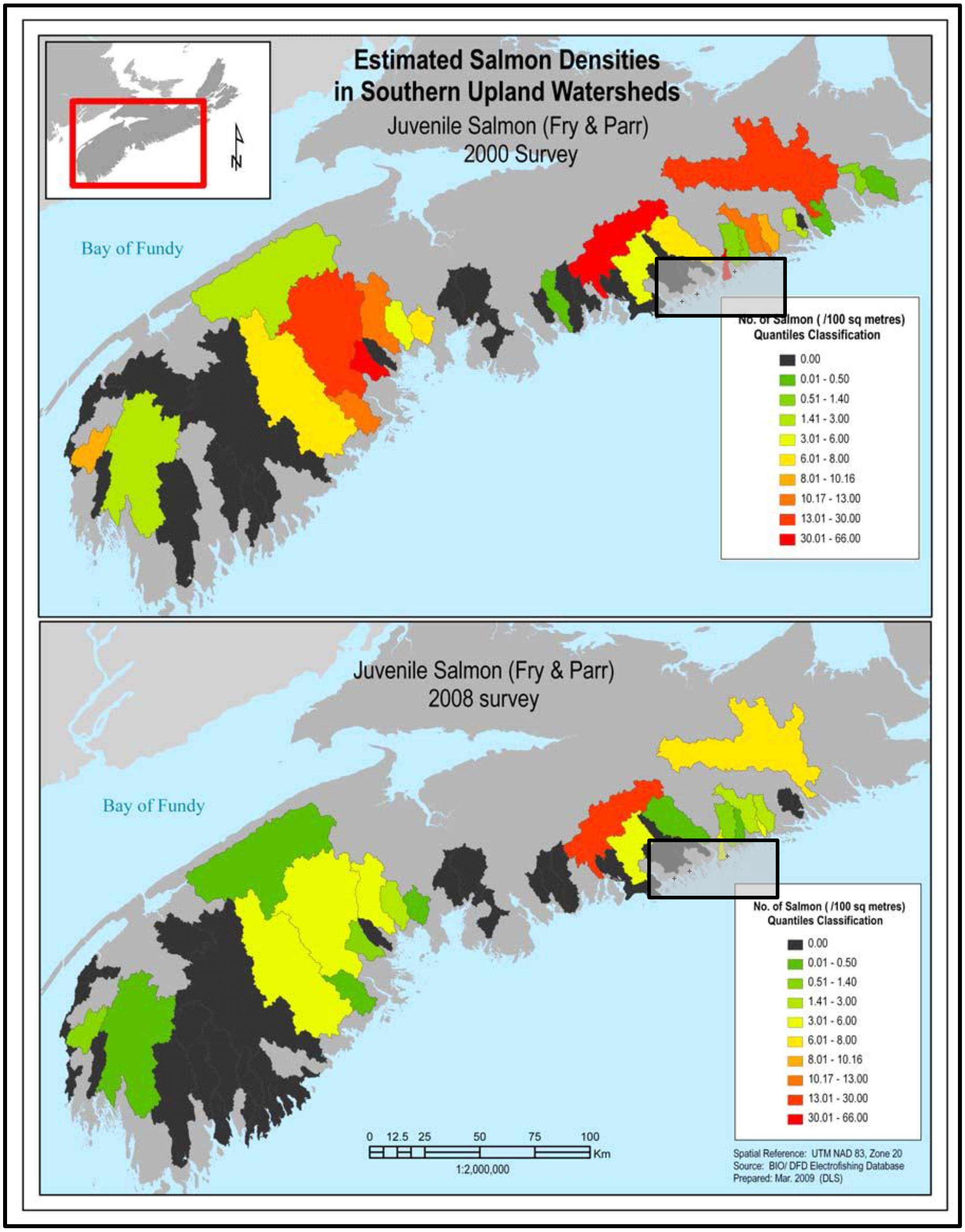

Figure 4. A comparison of the mean juvenile densities (all age classes combined) in watersheds throughout the Southern Upland in 2000 and 2008. Watersheds in which no salmon were captured are shown in black (Gibson et al. 2010). The box shows the general area of the proposed sites.

In addition to Southern Upland Atlantic salmon, tag return data reported in Ritter (1989) also indicated that salmon from other areas, including rivers of the Bay of Fundy and southwestern NS, migrated near shore and were captured on the eastern shore during the study period, mostly between the early 1970s and mid-1980s (Table 1; Figure 5).

Table 1. River of release and number of recaptures on the eastern shore of Nova Scotia from the various Atlantic salmon tagging programs carried out over the period 1964-1997[2]. These data represent a simple extraction from the salmon tagging database to provide a perspective on salmon tag recoveries in the area, and are not a definitive summary of tagging data.

River of release	***Total number recovered 1964-1997***
Nova Scotia	
East River Sheet Harbour	269
LaHave River	16
Liscomb River	615
Medway River	10
Middle River	1
Musquodoboit River	18
St. Mary's River	198
West River Sheet Harbour	63
New Brunswick	
Big Salmon River	1
Saint John River Mactaquac	44
Saint John River	11
St. Croix River	1
Tobique River	1

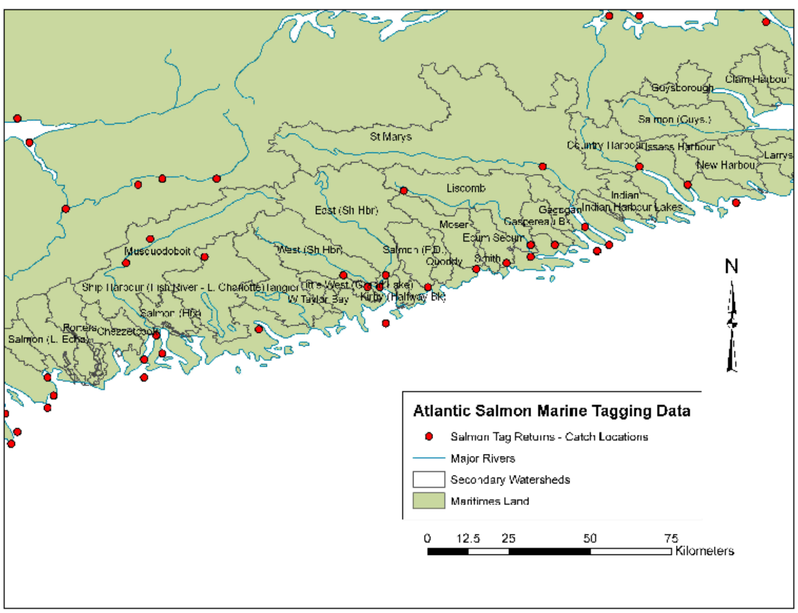

Figure 5. Atlantic salmon tag recaptures on the eastern shore of Nova Scotia for fish tagged and released in a number of tagging programs over the years 1964-97.

[2] Data provided by T. Horsman and J. Gibson; Data extracted from the salmon tagging database, Population Ecology Division, Science Branch, Fisheries and Oceans, Bedford Institute of Oceanography, March 2012.

Freshwater Habitat Use

Southern Upland Atlantic salmon are anadromous fish, meaning that while they are obligated to reproduce in fresh water, most spend part of their lives in the ocean to feed and grow. They are iterparous, meaning that they can spawn several times before they die. After spawning for the first time, some individuals may spawn again in consecutive years, while others may spawn in alternate years and others may switch between alternate and consecutive repeat spawning. Spawning typically occurs in November. After spawning, adults (known as “kelts”) may return to the sea or may remain in fresh water until the following spring. Although the proportion of kelts remaining in fresh water is not well studied, a recent (2010/11) acoustic tagging study on the St. Mary’s River indicates that the proportion of salmon over-wintering in fresh water is likely very high.

The distribution and range of Southern Upland salmon has been partially evaluated using region-wide electrofishing surveys for juvenile Atlantic salmon, the most recent of which occurred in the Southern Upland in 2008 and 2009. A total of 151 sites were surveyed in 54 rivers, with between 1 and 12 sites fished per river. Salmon juveniles were found in 22 of the 54 rivers surveyed (Figure 4). It is assumed that spawning is occurring, at a minimum, in rivers where juveniles were found. However, not all rivers were sampled. At the low population sizes of Southern Upland Atlantic salmon at present, freshwater habitats are unlikely to be limiting recovery in rivers with a large proportion of accessible area. Unfortunately, impassable dams and highly acidic water have reduced freshwater habitat availability by approximately 40% for this area. The question of whether available habitat will become limiting as populations increase depends on the productive capacity of freshwater habitats as well as the mortality rates experienced by Atlantic salmon in the marine environment.

West River, Sheet Harbour, is within 25 kilometers of the proposed Shoal Bay site. Recovery efforts are underway on this river. Liming has reduced the acidity of much of the main branch of the West River, resulting in an improvement in the quality of habitat. There is ongoing monitoring to track the liming effort on the fish population and, although returns are low, some preliminary work to evaluate the smolt production in the river and the effects of the liming is encouraging but has not been documented in the published literature (Ferguson and Hinks 2007). Other projects to improve freshwater access and quality are also ongoing in the Southern Upland region.

Estuarine Habitat Use

Recent research using acoustic tagging suggests that Southern Upland Atlantic salmon populations do not make extended use of estuarine environments, either as smolts or as kelts. The range of residence times observed for Southern Upland salmon is 1 to 8 days per km of habitat for smolts in estuaries and 3 to 32 days from release to open ocean for kelts. Depth information from the tagged kelts indicated that they were located predominantly near the surface but made occasional forays to the bottom. It has been hypothesized that such behaviour could be associated with feeding and searching for prey, or could be an adaptation to the physiological stresses of re-entering sea water (Hubley et al. 2008). The use of particular habitat types within estuaries by smolts, adults and kelts is relatively unknown for Southern Upland populations, but habitat availability is not thought to be limiting.

Marine Habitat Use

Marine distribution patterns for Southern Upland Atlantic salmon has been investigated using historical tagging programs of smolts and adults combined with reported recaptures by commercial and recreational fisheries.

This information indicates that different life stages may transiently occupy similar habitats, and their overall direction of movement could be in opposite directions, potentially leading to a relatively ubiquitous distribution from NS to the Labrador Sea and West Greenland throughout most of the year. Tagging data suggest that Southern Upland Atlantic salmon are widely distributed in coastal marine habitats throughout their first year, particularly during the summer months, and coastal areas of NS do not cease to become salmon habitat during winter. Given the variability expressed in run-timing, both within and among populations, there is likely to be similar variability in the movement of Southern Upland Atlantic salmon along the near-shore environments of the Northeast Atlantic, meaning that marine distribution (and therefore habitat use) cannot be clearly delineated on a seasonal basis.

Information from the Recreational Salmon Fishery

There are 15 scheduled[3] salmon rivers within 50 km (distance measured in straight lines from aquaculture site to the mouth of each river) of the proposed sites, many of which continue to sustain populations of Atlantic salmon (Gibson et al. 2010). Nine of the noted rivers discharge into the coastal zone within 25 km of the proposed aquaculture site: Salmon River (Halifax); Ship Harbour River; Tangier River; Taylor Bay Brook ; Little West (Grand Lake); West River, Sheet Harbour; East River, Sheet Harbour; Kirby River; and Halfway Brook; (Figure 3: numbers 45 to 52, respectively). There are a further 6 rivers within 50 km of the proposal area boundaries. The most significant of these based on angling data are the Musquodoboit (Figure 3: 44), Moser (Figure 3: 55), and Ecum Secum (Figure 3: 57) rivers.

Information on Atlantic Salmon from the Past Commercial Salmon Fishery

According to Dunfield (1974), in 1971, there were 75 trap nets and 18 fixed gill nets licensed to fish for Atlantic salmon on the eastern shore of NS, approximately from Country Harbour River to Cole Harbour, Fisheries Statistical Districts (FSD) 16 to 20 (Figure 6). Salmon “berths” (“berth” was a term used for the fixed site location for commercial salmon fishing gear) were located in traditional migration routes to capture mature or maturing Atlantic salmon on their return to rivers to spawn. The berth locations were near shore and at the entrance to some of the rivers; for example, the berths in the Musquodoboit Harbour area were located in the prolonged harbour, well inside the headlands (Appendix 3). As noted in DFO 2011a, Atlantic salmon smolt, post-smolt and kelts (post-spawned adult fish) would be expected to use the coastal zone for “feeding grounds in support of growth, maturation, and postspawning reconditioning”.

Commercial salmon landings in the immediate proximity of the proposed aquaculture site (FSD 19) during 1981-1984 ranged from 250 to 1,400 kg over the 4 years. Earlier landings were reported in Cutting (1984) who documented commercial and recreational catch data for the

[3] Rivers with well known runs of Atlantic salmon that were actively fished for recreation were often managed by applying restrictions on fishing to protect salmon stocks by a variety of means from a series of closures to within-season limits to fishing. Restricting fishing for part of the season to fly fishing only was called scheduling.

parts of NS that included the eastern shore. For a point of reference, the commercial catch during the period 1967-1983 in FSD 19 ranged from approximately 300 to 2,700 kg. Commercial salmon catches recorded for directed salmon fisheries for the eastern shore, exclusive of bycatch in other fisheries, ranged from 1,200 to 3,600 kg during the period 1949-1965 (Allen and Lindsey 1967).

Regulation changes and reductions in salmon abundance caused many fishermen to cease fishing. During the period 1981-1984, about 22 of the fixed salmon berth locations were still being operated from Country Harbour east to near Cole Harbour in the west (FSD 17, 19-20), primarily trap nets (Appendix 3: Figures 3.1-3.5). The commercial salmon fishery was closed in NS after the curtailed 1984 season. During the last 4 years of the fishery (1981-1984), 2,700 kg of salmon on average was reported as harvested, indicating that although populations were lower than they had been previously, many fish were still migrating through the near coastal zone of the eastern shore (Swetnam and Bernard 1982; O'Neil and Bernard 1983; O'Neil, et al. 1984; O'Neil et al. 1985). One berth location was in close proximity (within 3 km) to the proposed aquaculture site, indicating that the cage site would be placed where adult salmon were known to occur (Appendix 3: Figure 3.1). It is likely that the salmon captured in commercial fishing berths were on their migration to their natal river to spawn.

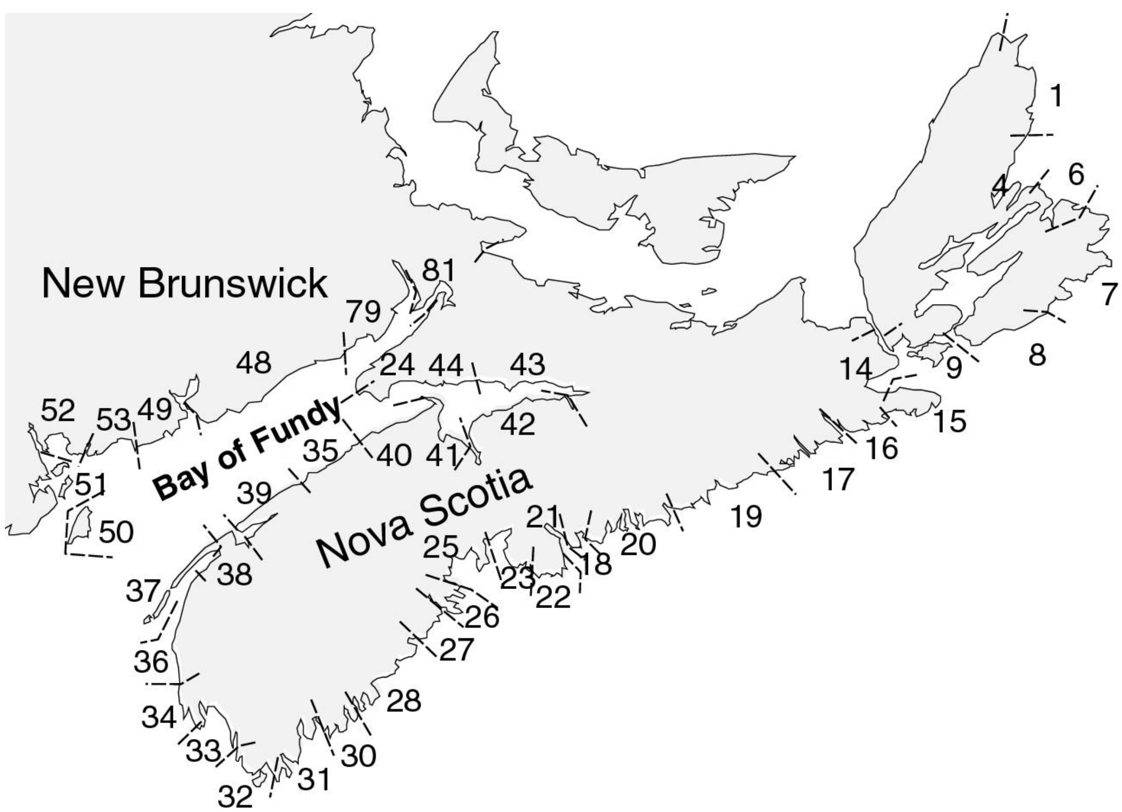

Figure 6. Fisheries Statistical Districts.

Fish Habitat and Other Fish Populations

A list of fishery resources was provided by Habitat Management Division for the review of the proposed aquaculture sites (Table 2).

Table 2. List of species assessed by DFO Habitat Management Division for potential impacts from the proposed aquaculture site at Shoal Bay, Halifax County, Nova Scotia.

SPECIES ASSESSED
Aquatic Vegetation
Kelp
Eelgrass
Algae
Rockweed
Crustaceans
Lobster
Rock Crab
Echinoderms
Sea Urchin
Mollusks
Scallop
Clam
Mussels
Pelagics
Herring
Mackerel
Bluefin Tuna
Groundfish (Demersal)
Haddock
Atlantic Cod
Cusk
Pollock
Flounder
Diadramous
Atlantic Salmon
Gaspereaux
Shad
American Eel
Smelt
Marine Mammals and Reptiles
Harbour Porpoise - Northwest Atlantic Population
Atlantic Walrus - Atlantic Population
Seal
Aquatic Species at Risk (SARA Schedule 1)
Leatherback Sea Turtle - Endangered
North Atlantic Right Whale - Endangered
Blue Whale - Endangered
White Shark - Atlantic Population - Endangered

Diadromous Species

Gaspereau (Alewife and blueback herring)

Gaspereau include both alewife and blueback herring; both species are present in some watersheds, while only alewife are present in some. Several rivers on the Eastern shore of

Nova Scotia (Halifax and Guysborough counties) house populations of gaspereau and commercial fisheries are active in some (Table 3). Fishing occurs in both tidal and non-tidal waters.

Table 3. List of drainage basins in Halifax and Guysborough counties, Nova Scotia, that have authorized gaspereau fisheries and where recent logbook reports have indicated a fishery is active.

River/Water Body
Beaver
Chezzecook
Country Harbour
Ecum Secum
Guysborough
Liscomb
Marie Joseph
Musquodoboit
Newcombe Brook
Neils Harbour
Port Dufferin
Rocky Run, Porters Lake
Saint Mary's
Salmon, Guysborough Co.
Salmon, Halifax Co.
Ship Harbour, Lake Charlotte
Tangier
Three Fathom Harbour
West River, Sheet Harbour

Large eel fishing occurs in both tidal and non-tidal waters (Figures 7a and 7b). Elver fishing occurs near or at the head of tide. Eels should be assumed to be present in the near shore and non-tidal waters lying adjacent to (and in some cases within) any marine finfish grow-out sites that are proposed or existing within the coastal areas of Halifax and Guysborough Counties. Elver fisheries are authorized for several drainage basins lying within Halifax and Guysborough counties (Table 4). All other water bodies could be fished for large eels.

Potentially important ecological attributes include: migration routes of recruiting elvers, and sea-going adults; alteration of habitat within the immediate vicinity of the aquaculture grow-out sites for marine-phase yellow eels.

Table 4. List of drainage basins in Halifax and Guysborough counties, Nova Scotia, that have authorized juvenile American eel (elver) licenses.

River Name
Chezzetcook River
Moser River
East River, Sheet Harbour
West River, Sheet Harbour
Salmon River, Port Dufferin
The Ponds, Spry Harbour
Liscomb River
Geggogin Brook
Gaspereau Brook
St. Mary's River
Salmon River
Country Harbour River
Spanish Bay Brook
The brook flowing from Indian Harbour Lake at Port Hilford

Catch and effort for both the large and small eel fisheries occurring in Halifax and Guysborough counties have generally been low relative to other eel fishing areas in the Maritimes Region. This is because many of the waterbodies throughout this area are 'fallow', i.e., no fishing, for extended periods of time as they are thought to help maintain the reproductive potential of American eel, a panmictic species consisting of a single stock. Fallow (fishing) areas are recognized within the National (Draft) American Eel Management Plan as having significant conservation value.

Other Diadromous Species

Striped bass would be expected to occur in the area but in low numbers as there are no native populations along the eastern shore of NS. Migrants or feeding fish would be from elsewhere in NS and more distant populations.

Atlantic whitefish are endangered (Schedule 1 of SARA) and the only existing population occurs in the Petite Rivière, Lunenburg County, NS (DFO 2006). The former range for the species may have extended to the eastern shore of NS. There are no reports of Atlantic whitefish populations on the eastern shore. The marine migration phase of the whitefish is thought to be limited in range, so it is unlikely fish from the south shore of NS would occur in the area of the proposed sites.

Limited numbers of Atlantic sturgeon have been reported on the eastern shore of NS. There are no Atlantic sturgeon populations there, and any sturgeon found there are those on a feeding migration. The likelihood that sturgeon would occur in the area of the proposed aquaculture site would be low.

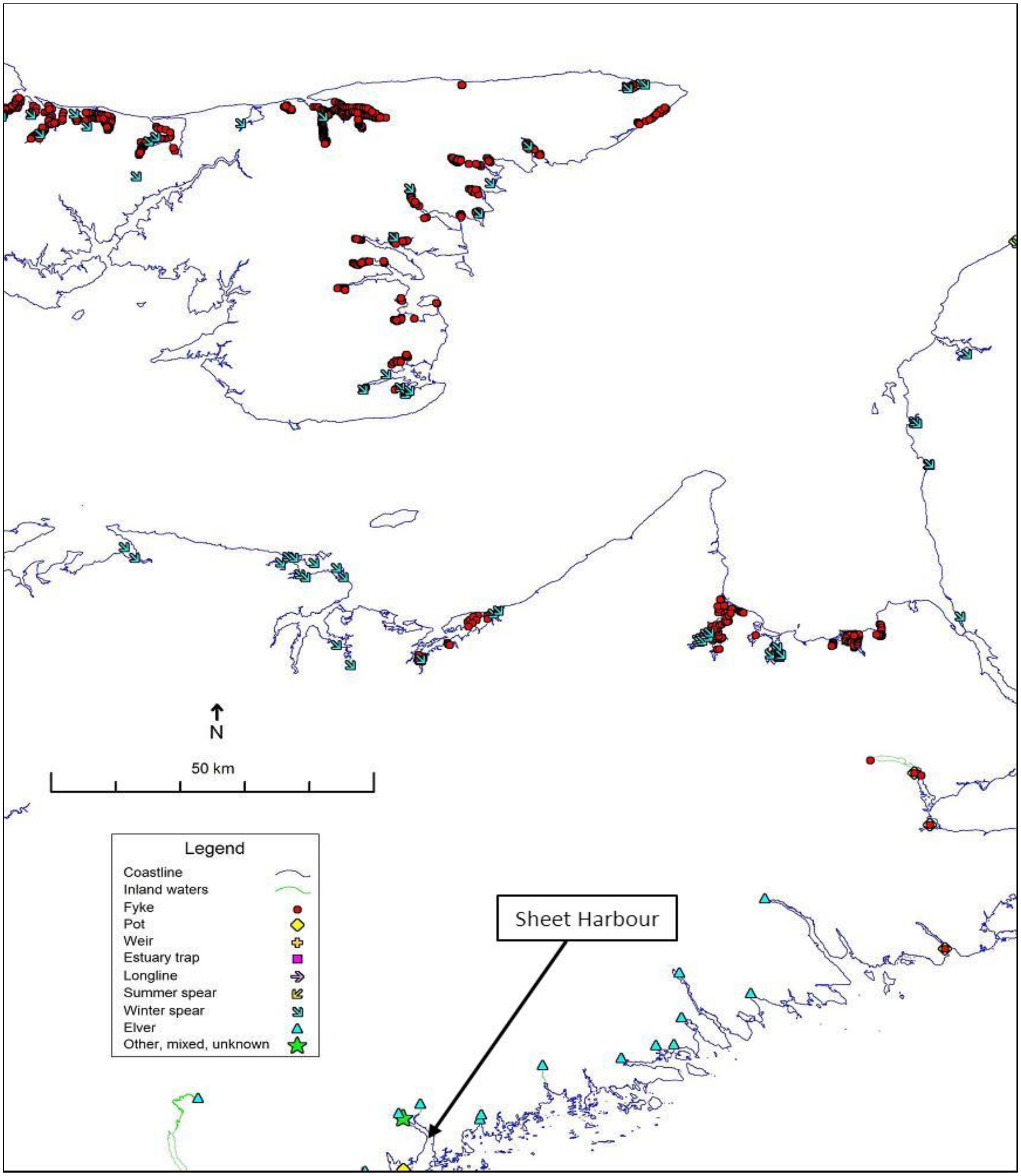

Figure 7a. Locations of eel fishing in Block U in 2006 - winter 2010 (Southern Gulf) and 2005 - 2007 (Scotia-Fundy). Source: David Cairns, DFO Gulf Region, unpublished data. Includes the area of the Eastern Shore of NS from Country Harbour (lower right) to Sheet Harbour (lowermost).

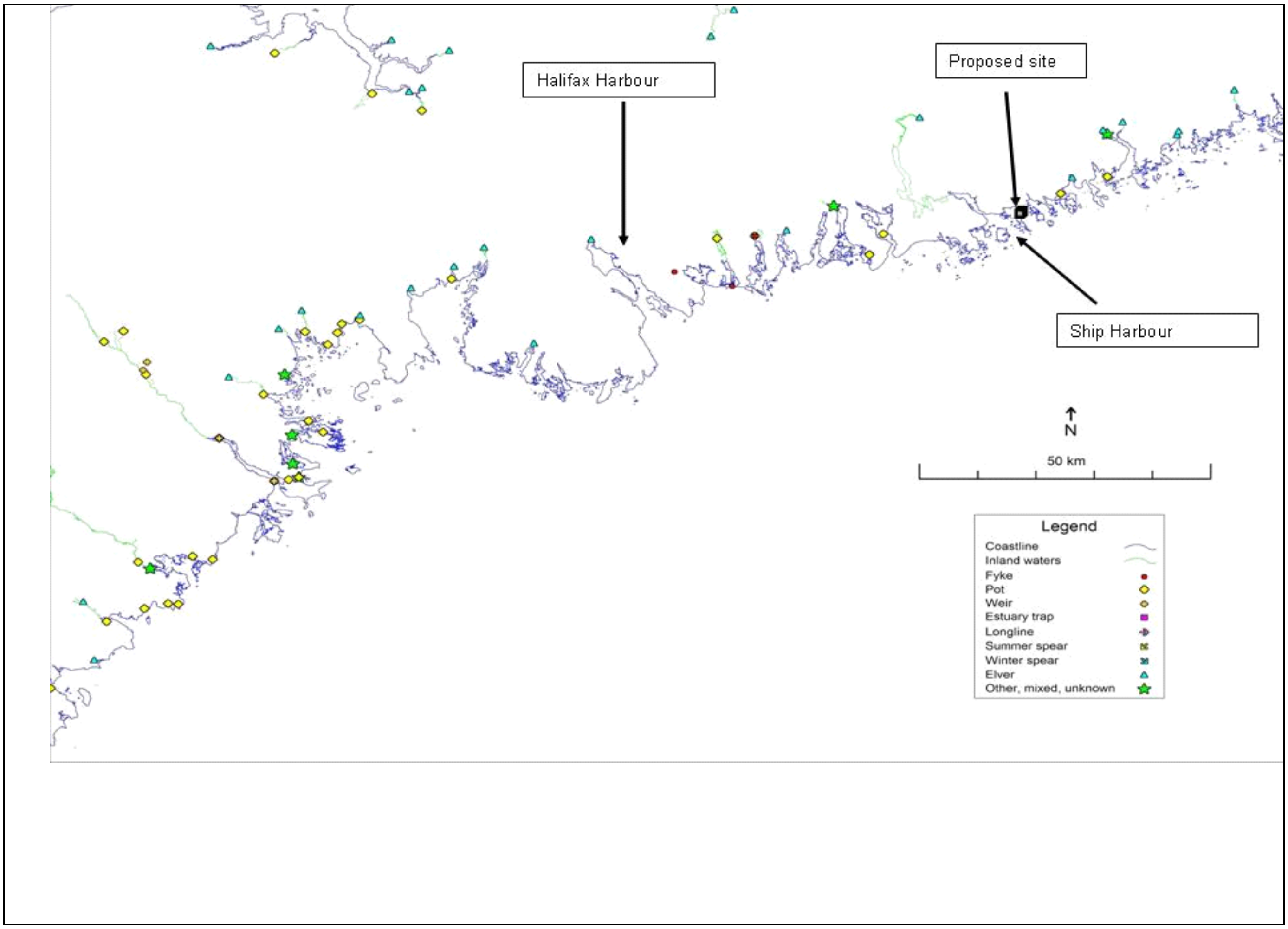

Figure 7b. Locations of eel fishing in Block U in 2006 - winter 2010 (Southern Gulf) and 2005 - 2007 (Scotia-Fundy). Source: David Cairns, DFO Gulf Region, unpublished data. Includes the area of the Atlantic coast of NS from Sheet Harbour to west of Halifax. The approximate area of the proposed aquaculture site is indicated.

Lobster

Lobster stocks along the eastern shore, (Lobster Fishing Area [LFA] 28-32), although supporting one of the areas' largest fisheries, are thought to be considerably smaller than those of Sydney Bight and southwest NS based on respective landing statistics (McCullough et al. 2005). In recent years, lobster landings and catch per unit effort (CPUE) have been increasing along the eastern shore of NS. Landings in LFA 32 (includes Shoal Bay) in 2010 were more than double the median landings from 1985-2004 and CPUE has increased as well, though not to the extent of LFAs 29, 30 and 31 (DFO 2011c). Lobster fishing season in area LFA 32 takes place from April 19 to June 20th of each year (DFO 2011c).

Habitat Characteristics

The geology and geomorphology of the coastline largely determine lobster habitat characteristics, along with the axis of orientation of the coastline (orientation to prevailing winds) and its degree of complexity (presence of islands, shallows and bays). The general region is very complex topographically with many islands and this topographic complexity continues into the subtidal (Greenlaw et al. 2012). Generally, the area has been divided into areas of exposed bedrock with patches of sediment or areas with a thicker layer of fine sediment cover. However, there will be much finer scale areas of bedrock with patches of sediment that have been classified as fine substrate, and vice versa (Figure 8). The islands on either side of Shoal Bay enclose the area almost like an inlet, causing sediment to deposit in the channel or basin that forms in the area between the islands. This pattern is repeated for many “inlets” in the region including Outer Ship Harbour, Tangier Harbour, Popes Harbour, Spry Bay, Mushaboom Harbour and Outer Sheet Harbour.

Greenlaw et al. (2012) suggest that the underlying surficial sediment of the proposed aquaculture site is likely to be mud, sandy mud or sand, which is further supported by underwater substrate video footage that was taken at the site. Although the bottom video was of low quality, it does indicate that bottom habitat at Shoal Bay primarily consists of silt and clay with some sand/pebble ripple.The area generally has a thin layer of this sediment type covering bedrock. It is unknown how thick the underlying sediment layer is in general, but it is expected to be variable depending how deep the area is in comparison to the surrounding topography and current patterns. The area of fine sediment is surrounded by exposed bedrock with patches of sediment, at shallower depths.

Hudon (1994) suggested that lobster generally like more exposed areas with a rectilinear shoreline as opposed to complex embayments generally characterized by muddy bottoms. However, this general assertion does not mean that muddy bottoms are not important in certain areas, or for certain life history stages and events. Lobsters can excavate burrows in mud bottoms, which may be used as shelter; mud bottoms may be used more extensively at certain times of the year, such as during spring and fall migrations. Although the April 11, 2012, videos are of a mixed quality and preclude a quantitative analysis of habitat use, it is clear there are many burrows present; however, it is unclear what species created or may be using these. No occupant was visible in most burrows, but a two-clawed decapod (possibly a juvenile lobster) was evident in one. Sampling by self-contained underwater breathing apparatus (SCUBA) would likely be required to get firm information on what is occupying the burrow. Another major issue with the video survey is the fact that it was conducted in April. Observations by DFO scientists in similarly fine-sediment dominated seabed in other areas of the Maritimes have yielded observations of significant habitat usage during late Spring to early Fall (Lawton *pers. comm*. 2012). There would need to be more seasonally-appropriate survey activity undertaken to fully document habitat potential for lobsters.

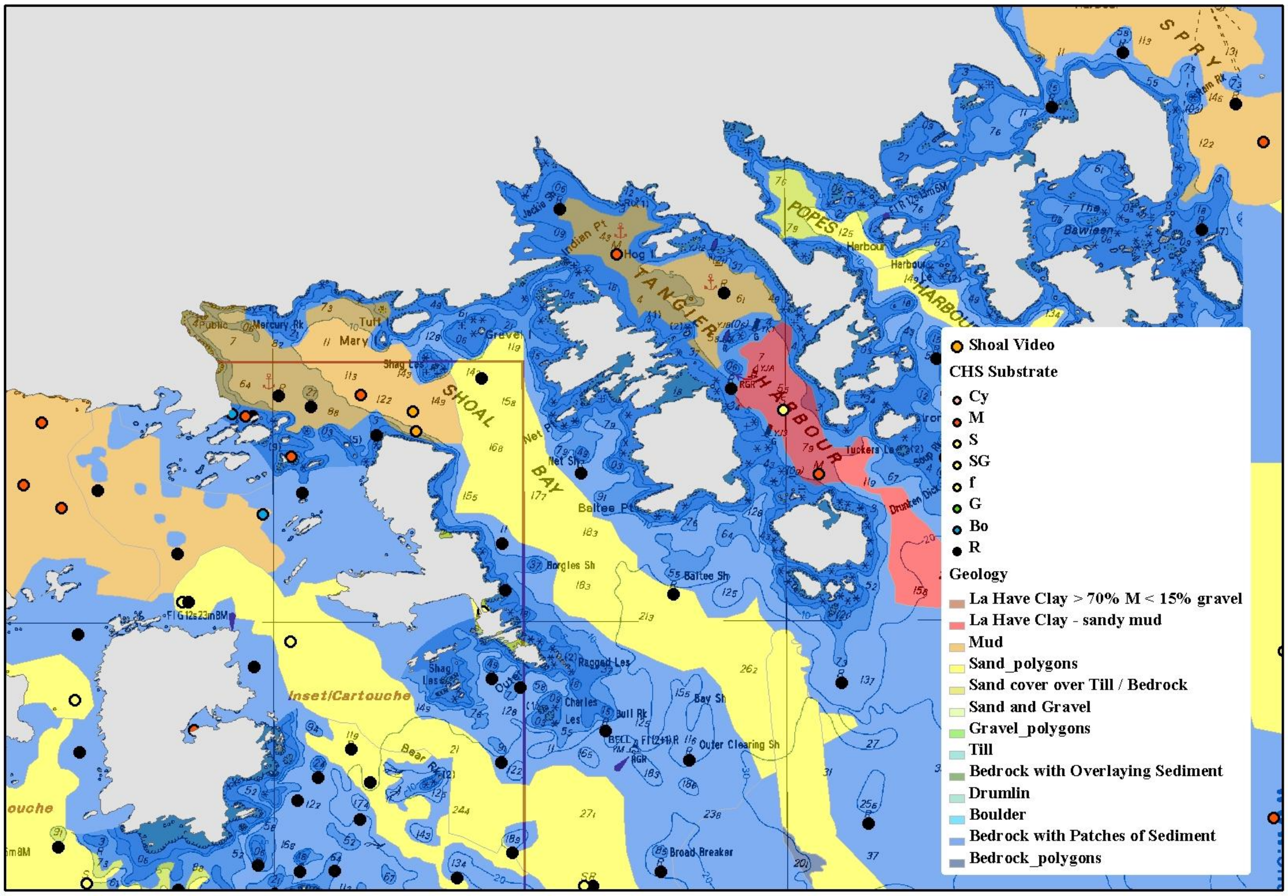

Figure 8. Underlying surficial substrate classification in the vicinity of the proposed aquaculture site. A digital elevation model created using CHS soundings and substrate characterisations digitized from CHS maps was used to create the layer for this area. Confidence for this interpretation is 7/10.

Planktonic Lobsters

There are few studies of the distribution of lobster larvae on the eastern shore of NS. One study in Jeddore Harbour (LFA 32), reported that stage I lobster larvae were present from July until the end of September, but peaked in the first three weeks of August (Dibacco and Pringle 1992). This study suggested that flushing of larvae from the inner harbor to the outer harbour can occur. It is likely that a range of dispersal/retention patterns occur depending on location and seasonal winds. Physical-biological models to evaluate dispersal/retention are in development.

In most years, the highest abundances would be expected from mid-July to mid-August (Tremblay and Sharp 1987; Miller 1997). Field studies in different areas indicate that the vertical distribution of lobster larvae varies with time of day and larvae stage. It is highly likely that lobster larvae are found from July to late September over a large part of Shoal Bay; however, it is not possible to determine the relative abundance of larvae within the areas of the proposed aquaculture sites. To determine this, a field study of the seasonal distribution of planktonic lobster larvae would be needed.

A field study evaluating the maturity of female lobsters in Tangier, NS took place biweekly between May and June of 2010 (526 lobsters) and 2011 (864 lobsters) during the lobster spring fishing season. Berried lobsters (carrying eggs) are mature females that were always found and varied between 26% (2010) to 17% (2011) (Silva *pers. comm*. 2012). All berried females would have released their larvae in the same summer. Studies such as this could also be used as an indicator of upcoming presence of lobster larvae in the vicinity of the proposed site.

Newly Settled Lobsters

During the postlarval stage, lobsters leave the surface waters and begin to settle on the ocean bottom. They prefer substrates that provide shelter, in particular hard bottom with cobbles. Once post-larvae find suitable habitat, they tend to remain near the shelter to avoid predation. Based upon the underwater bottom video footage and sediment classification in the area of the proposed aquaculture site (Greenlaw et al. 2012), the bottom habitat appears to be of low quality for the settlement of lobsters. The possibility that there are some patches of cobble that would provide shelter for settled lobster can not be eliminated; however, the overall habitat appears to be of low quality with respect to initial settlement.

Adolescents and Adults

The population size of lobster around Shoal Bay is not well known, but fishery landings are the best available proxy as they are presumed to reflect of abundance in heavily exploited lobster fisheries (Tremblay and Claytor 2009). In recent years, the lobster fishery landings have been increasing in eastern NS. Landings from the lobster fishery in LFA 32 are derived from mandatory reporting logs completed by commercial fishermen. Fishermen report their daily catch in weight, their daily effort (number of traps hauled), and the location. In Shoal Bay, a portion of landings come from both Grids 326 and 327 and the proposed aquaculture site is located within Grids 326 and 327 (Figure 9 and Table 5).

Between 2006 and 2011, landings within Grids 326 and 327 accounted for 13- 21 % of landings reported for LFA 32 and Grids 326 and 327 had an average respective ranking of 5.7 and 3.2 out of the 8 Grids in LFA 32. Based upon available information, it is not possible to estimate the proportion of lobster landings of Grids 326 and 327 that may come from the areas surrounding the proposed aquaculture sites, since lobsters are not uniformly distributed throughout the grid.

As many studies have indicated that lobsters move to shallower, warmer waters in summer, it can be generalized that similar inshore bays in southeast NS likely have elevated concentrations in summer; however, no specific density estimates of lobster within the proposed area exist.

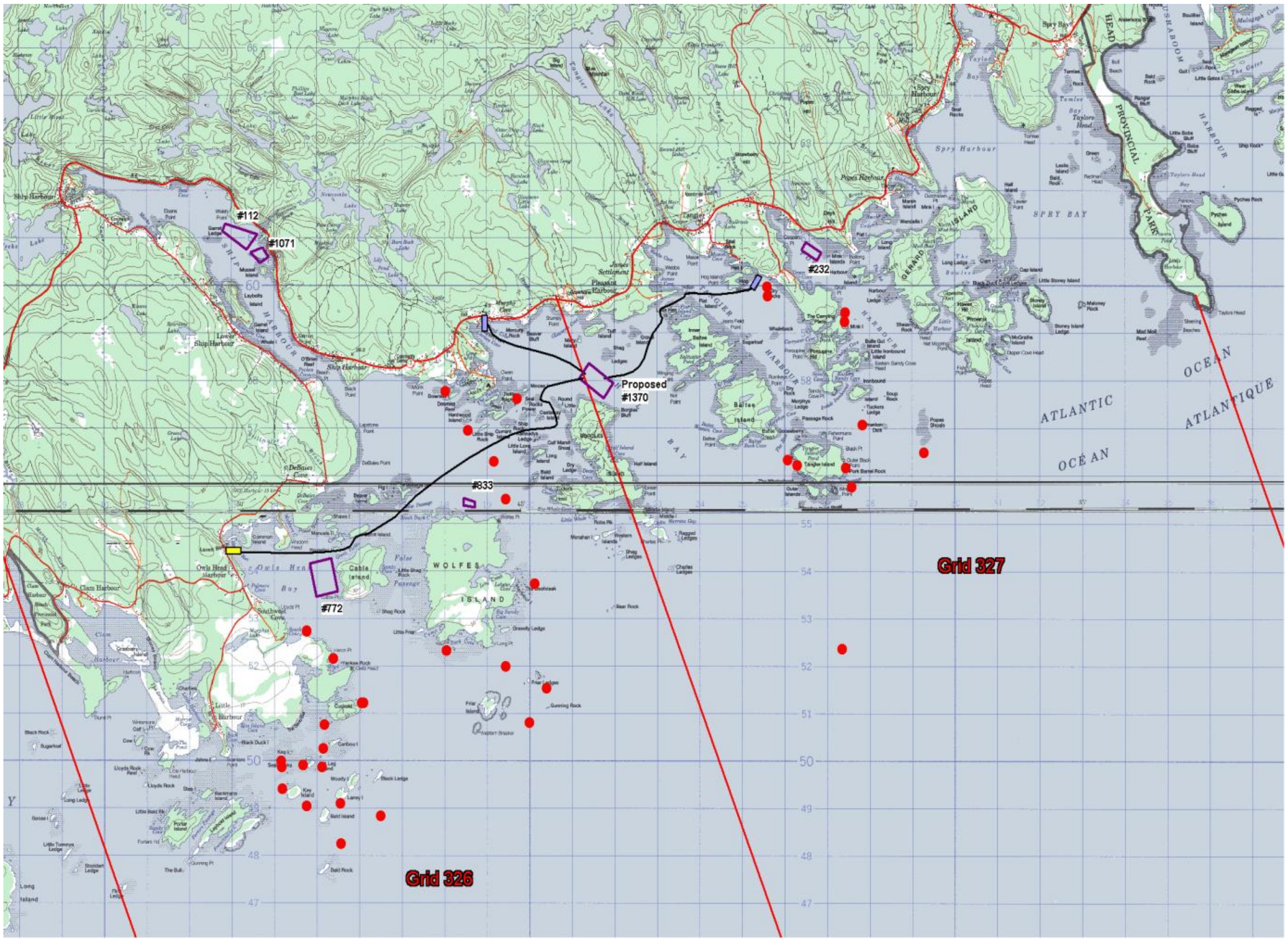

Figure 9. Approximate aquaculture site locations in relation to the Lobster Fishing Area 32 commercial lobster fishermen logbook grids (red lines) and the SARA sampling locations (red dots).

Table 5. Estimated lobster landings in tonnes (t) from mandatory reporting logs. Landings are presented by year (for 2006-2011 calendar years) for Grids 326 and 327 located in LFA 32 (refer to Figure 9 for grid locations). The ranks from high (1) to low (8), and proportion of Grids 326 and 327 landings relative to LFA 32, are also presented by year.

Season	Landings (t) by Grid		Grid 326		Grid 327	
	Grid 326	Grid 327	Rank out of 8 by landings for LFA 32	Proportion of LFA 32 landings (%)	Rank out of 8 by landings for LFA 32	Proportion of LFA 32 landings (%)
2006	33.3	40.7	5	6%	4	7%
2007	23.0	56.0	8	4%	3	9%
2008	56.1	71.5	6	8%	4	10%
2009	66.0	93.4	5	8%	3	11%
2010	53.8	69.5	6	8%	2	11%
2011	72.2	79.7	4	10%	3	11%

Additional Fishery Resources

Limited information is available on potential habitat use, critical or valuable habitat related to crab, groundfish, clams, scallops, sea urchin and any other important species within the general vicinity of the proposed aquaculture site.

Ocean quahog prefer areas composed primarily of medium to fine grain sand (Cargnelli et al. 1999). Although the possibility that some patches of preferred ocean quohog habitat occurs in the vicinity of the site cannot be eliminated, based upon the underwater bottom video footage and sediment classification in the area of the proposed aquaculture site (Greenlaw et al. 2012), the bottom habitat appears to be of low quality for ocean quohog.

Given the ongoing ground fish moratorium in the Shoal Bay area, limited up-to-date commercial fishing data is available; however, DFO conducted a sentinel ground fish survey in the vicinity of the proposed aquaculture site in 2006. Although this survey does not provide groundfish abundance estimates specific to the site location, several groundfish species were sampled within the vicinity of the proposed aquaculture site, including: striped wolffish, spotted wolffish (SARA status is Threatened), cusk (assessed as Threatened by COSEWIC), American plaice, barndoor skate, thorny skate, Atlantic cod, longhorn sculpin, redfish, white hake and silver hake.

DFO also collected bycatch information for LFA 32 during SARA sampling in 2010 (Table 6 and 7). Although this survey does not provide species abundance estimates specific to the site location, several species were sampled with the vicinity of the proposed aquaculture site including: Jonah crab, rock crab, green crab, hermit crab, sculpin, longhorn sculpin, cod, winter flounder, lumpfish, tomcod (Atlantic), starfish, and white perch (Pezzack, *pers. comm.* 2012).

Table 6. Species caught in the lobster traps expressed as kg per 100 kg of lobsters landed. The retained catch represents species legally retained for use as bait. Lobster discards represent under size, berried females and v-notched females.

kg /100kg lobsters landed	**Total in Traps**	**Discard**	**Retained**
Lobster	179	79	100
			Bait
Jonah crab	4.96	0.95	4.02
Sculpin	2.36	0.00	2.36
Longhorn sculpin	1.34	1.34	
Rock crab	1.10	0.55	0.55
Green crab	0.95	0.95	
Cod	0.87	0.87	
Winter flounder	0.71	0.71	
Hermit crab	0.32	0.32	
Lumpfish	0.32	0.32	
Tomcod (Atlantic)	0.16	0.16	
Starfish	0.08	0.08	
White perch	0.08	0.08	
Total	192	85	107

Table 7. The species caught in the lobster traps expressed as % of the total weight of the catch in the lobster trap (all species)

Lobster	93.1%
Jonah crab	2.58%
Sculpin	1.23%
Longhorn sculpin	0.70%
Rock crab	0.57%
Green crab	0.49%
Cod	0.45%
Winter flounder	0.37%
Hermit crab	0.16%
Lumpfish	0.16%
Tomcod (Atlantic)	0.08%
Starfish	0.04%
White perch	0.04%

There is a small commercial scallop fishery in south eastern NS. Logbook data for this fishery does not indicate that scallop fishing occurs inside of Shoal Bay (Figure 10); however, the MARFIS database only contains logbook data from 2001 to the present. Sea scallops are generally found in seabed areas with firm sand, gravel, shells and cobble substrate and the proposed site has a predominately mud, sandy mud or sand bottom. While it is probable that scallops are present within the vicinity of the proposed aquaculture site, distribution date or density estimates do not currently exist.

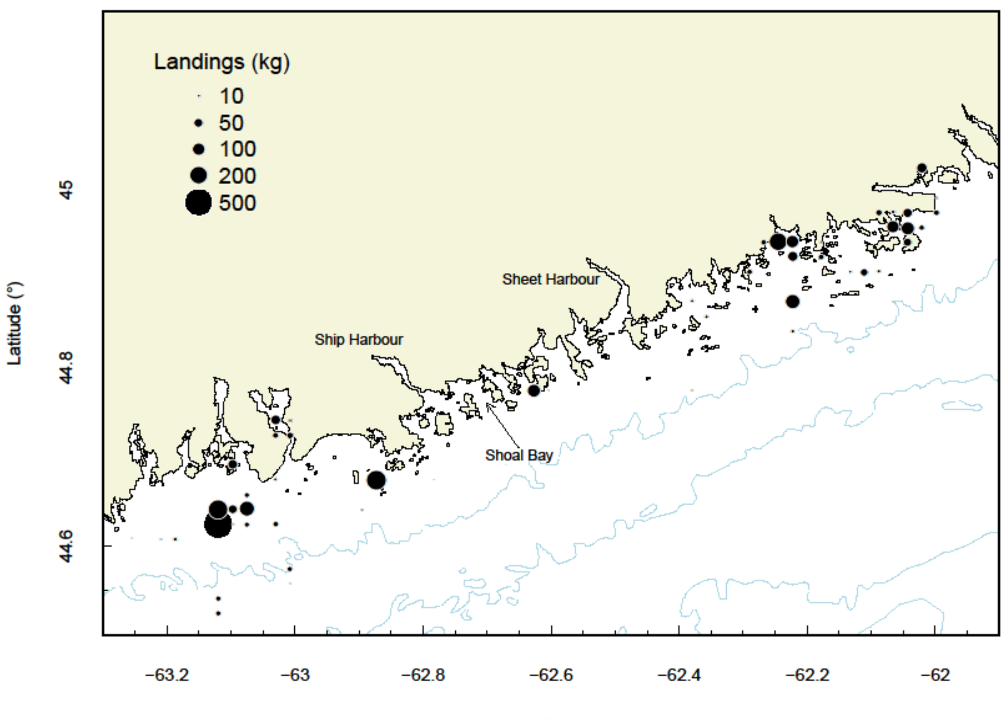

Figure 10. Reported scallop landings from logbook data from October 2002 to January 2012. Landings are aggregated by one minute square.

Herring spawn primarily during the fall in the shallow inshore waters of the bays and inlets located along the coast of Halifax County. It has been reported that herring spawn in areas from Peggy's Cove to Pennant Point, off Chebucto Head, and from Lawrencetown to Jeddore, with no spawning locations listed in the easternmost regions of Halifax County, including the Shoal Bay area (Trippel *unpublished report*). However, in an earlier study Crawford (1978) reports that spawning does occur further east, with spawning areas indicated within 8 km of the proposed aquaculture site around the Owl's head and Tangier Island areas.

Based on Traditional Ecological Knowledge (TEK), Trippel (*unpublished report*) also identified a large area between East Head and Taylor Head, including Shoal Bay, as a possible juvenile haddock area. TEK indicated that these juvenile haddock areas were once more extensive and contained more juveniles.

Other Considerations

Although, this review is focused on providing advice on the proposed finfish aquaculture site in Shoal Bay, it is important to note that the Shoal Bay site is one of three sites which are proposed by Snow Island Salmon Ltd. (a subsidary of Loch Duart) for the eastern shore of Nova Scotia. The additional sites are proposed for Spry Harbour and Beaver Harbour, which are 10 km and 30 km from the Shoal Bay site, respectively. Given the close proximity of the three sites to one another, there may be interactions between them. Therefore, the potential cumulative effects of all three of these sites should be considered, potentially within the area-based assessment proposed for the eastern shore (2012-2013).

Conclusions

Organic Enrichment

With resuspension off and using the proposed maximum feed rate, DEPOMOD predicted a large area (41,800 m^2) with deposition rates >5 g C m^{-2} d^{-1}, including 16,700 m^2 with deposition rates >10 g C m^{-2} d^{-1} (deposition rates that could potentially lead to sediment anoxia, based on the Hargrave et al. (2008) and Hargrave (2010) relationships). Using the proposed average feed rate (and resuspension off), there were some areas with elevated impacts (3,300 m^2 with deposition rates >5 g C m^{-2} d^{-1}), but none with deposition rates >10 g C m^{-2} d^{-1}.

With resuspension on, DEPOMOD predicted some reduction in the amount of deposition within the model domain, but there were still large areas with elevated deposition rates using the maximum feed rate.

Considerable reduction in feed and stocking rates would be required to keep deposition rates ≤5 g C m^{-2} d^{-1} at all grid cells within the model domain at the time of maximum feeding (highest fish biomass) at the site, based on the DEPOMOD prediction with resuspension off or on.

The above conclusions are based on the assumption that the current meter record is representative of the area of interest and that the predicted deposition rates are related to sediment sulfide concentrations and sediment oxygen concentrations as indicated by Hargrave (2010).

Wild Salmon Interactions

The proposed aquaculture site is location in the Southern Upland DU of Atlantic Salmon. The Southern Upland of Atlantic Salmon was assessed as Endangered by COSEWIC in November 2010. All of the concerns related to interactions between wild Atlantic salmon and marine aquaculture identified previously by DFO Maritimes Science in a review of aquaculture sites proposed for Shelburne Harbour (DFO 2012b) would be applicable to the review of the proposed Shoal Bay site.

The available indices suggest that abundance of Atlantic salmon is very low in the Southern Upland DU and declining from levels observed in the 1980s. Relative abundance is informative both in terms of comparison to historical abundance and tolerance to threats that could affect populations. Annual adult abundance data from four rivers show declines of 88% to 99% from observed abundance in the 1980s. Region-wide comparisons of juvenile density data from more than 50 rivers indicate significant ongoing declines between 2000 and 2008/2009 and provide evidence for river-specific extirpations. In addition to ongoing effects of acidification, contemporary declines in non-acidified rivers indicate that other factors (including invasive fish species; dams, water diversion and permanent structures; illegal fishing and poaching; marine ecosystem changes; and salmonid aquaculture) are also thought to be impacting populations. Threats to populations were identified in the RPA, and when populations are low and declining, as is clear for salmon populations from this area, these threats would increase the potential for extirpation if not mitigated.

The distribution and range of Southern Upland Atlantic salmon has been evaluated using region-wide electrofishing surveys for juvenile Atlantic salmon, the most recent of which occurred in the Southern Upland in 2008 and 2009. Salmon juveniles were found in 21 of the 54 rivers surveyed, including several rivers within 25 – 50 km of the proposed aquaculture site. It is assumed that spawning is occurring, at a minimum, in rivers where juveniles were found.

Recent research using acoustic tagging suggests that Southern Upland Atlantic salmon populations do not make extended use of estuarine environments, either as smolts or as kelts. The range of residence times observed for Southern Upland salmon is 1 to 8 days per km of habitat for smolts in estuaries and 3 to 32 days from release to open ocean for kelts. Depth information from the tagged kelts indicated that they were located predominantly near the surface but made occasional forays to the bottom. It has been hypothesized that such behaviour could be associated with feeding and searching for prey, or could be an adaptation to the physiological stresses of re-entering sea water. The use of particular habitat types within estuaries by smolts, adults and kelts is relatively unknown for Southern Upland populations, but habitat availability is not thought to be limiting.

Tagging data suggest that Southern Upland Atlantic salmon are widely distributed in coastal marine habitats throughout their first year, particularly during the summer months, and coastal areas of NS do not cease to become salmon habitat during winter. Given the variability expressed in run-timing, both within and among populations, similar variability is likely to exist in movement of Southern Upland Atlantic salmon along the near-shore environments of the Northeast Atlantic, meaning that marine distribution (and therefore habitat use) cannot be clearly delineated on a seasonal basis.

An RPA for the Southern Upland DU of Atlantic salmon was conducted in May 2012. Conservation and recovery efforts for Atlantic salmon already underway on the eastern shore of NS may be reducing the risk of extirpations and should be considered during an assessment of proposed developments.

Fish Habitat and Other Fish Populations

Several rivers on the eastern shore of NS (Halifax and Guysborough counties), including some close to the proposed aquaculture site, have populations of gaspareau, and commercial fisheries are active in some. Fishing occurs in both tidal and non-tidal waters.

Adult American eel occurs in both tidal and non-tidal waters in the vicinity of the site. American eel elver fishing occurs near, or at the head of tide. Eels should be assumed to be present in the near shore and non-tidal waters lying adjacent to (and in some cases within) any aquaculture sites that are proposed or existing within the coastal areas of Halifax and Guysborough Counties. For eels, potentially affected attributes include: migration routes of recruiting elvers, and sea-going adults; alteration of habitat within the immediate vicinity of the aquaculture grow-out site for marine-phase yellow eels.

The likelihood that sturgeon would occur in the area of the proposed aquaculture development would be low. The marine migration phase of the whitefish is thought to be limited in range, so it is unlikely fish from the south shore of NS would occur in the area of the proposed aquaculture site. Striped bass would be expected to occur in the area but in low numbers as there are no native populations along the eastern shore of NS.

It is highly likely that lobster larvae are found from July to late September over a large part of Shoal Bay; however, it is not possible to determine the relative abundance of larvae within the area of the proposed aquaculture site. To address this question, field studies of the distribution of planktonic larvae are required. The identification of berried (ovigerous) female lobsters in the area during and after fishing season would also help address this question.

The underlying surficial sediment of the proposed aquaculture site is likely to be mud, sandy mud or sand. There were many burrows observed in the video footage, but it was unclear what species created or may be using these. The possibility that there are some patches of cobble that would provide shelter for settled lobster cannot be eliminated; however, based upon the underwater bottom video footage and sediment classification in the area of the proposed aquaculture site, the bottom habitat appears to be of low quality for the settlement of lobsters.

The population size of lobster around Shoal Bay is not well known, but lobster fisheries landing have been increasing in eastern NS in recent years. Although adolescent and adult lobsters are likely present in the vicinity of the site at various times of the year, based upon available information, it is not possible to estimate the proportion of lobster landings that may come from this area since lobsters are not uniformly distributed. To determine the importance of the areas to adolescent and adult lobsters relative to surrounding areas, further studies would be required.

Although the possibility that some patches of preferred ocean quohog habitat occurs in the vicinity of the site cannot be eliminated, based upon the underwater bottom video footage and sediment classification in the area of the proposed aquaculture site, the bottom habitat appears to be of low quality for ocean quohog.

There is a small commercial scallop fishery in south eastern NS. While it is probable that scallops are present within the vicinity of the proposed aquaculture site, distribution data or density estimates do not currently exist. Sea scallops are generally found in seabed areas with firm sand, gravel, shells and cobble substrate and, based upon the underwater bottom video footage and sediment classification in the area, the bottom habitat appears to be of low quality for scallop.

Due to the existing groundfish moratorium, up-to-date commercial fishing data is largely unavailable in the vicinity of the proposed aquaculture site; however, surveys and bycatch data has noted the presence of numerous fish and invertebrate species including: striped wolffish, spotted wolffish (SARA status is Threatened), cusk (assessed as Threatened by COSEWIC), American plaice, winter flounder, barndoor skate, thorny skate, lumpfish, tomcod (Atlantic), Atlantic cod, longhorn sculpin, redfish, white hake, silver hake, white perch, Jonah crab, rock crab, green crab, hermit crab, and starfish.

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Appendices

Appendix 1: Methodology, Input Data, DEPOMOD Inputs and Results

Methodology

Cage locations and sizes, proposed feed rates (per week), and current velocity data were provided by the proponent. Current velocity data were collected by the Nova Scotia Department of Fisheries and Aquaculture using a 600 kHz RDI Sentinel Acoustic Doppler Current Profiler (ADCP), moored on the seafloor within the lease boundary. The location, time, and duration of the current meter deployment are shown in Table 1.1 (Appendix 1). The meter deployment was prior to the farm beginning operations. The ADCP measured current speed and direction at 1-m depth intervals throughout the water column. Information on calibration of the ADCP was not provided.

DEPOMOD (version 2) was used to predict carbon deposition rates, using the scenario of a continuous release of food; this is the scenario typically used for proposed or operational farms (Cromey et al. 2000). The model predicts deposition rates within domain and grid cell sizes defined by the user. The domain size for this study was 1000 × 1000 m and the grid cell size was 10 × 10 m. DEPOMOD allows the user to define separate major and minor grids; however, in this study, only one grid was used for the entire domain.

DEPOMOD includes a sediment resuspension module, which has the option to have resuspension turned on or off. The model was first run with resuspension turned off, and then with resuspension on. The threshold (critical shear stress) for resuspension in DEPOMOD is fixed in the software at a near-bottom current speed of approximately 9.5 cm s^{-1}. Resuspension only affects unconsolidated particles. The model was run using the default particle consolidation time of 4 days; this assumes that particles sitting on the bottom for ≥4 days are consolidated into the bottom sediment matrix.

The model was run for 2 loops of the current meter record, as recommended in the DEPOMOD manual in order to achieve a steady state solution (Cromey et al. 2000). The output selected was carbon flux, in g m^{-2} yr^{-1} (at the centre of each grid cell). The carbon flux values were converted to g m^{-2} d^{-1}.

Contour plots of the predicted carbon deposition rates at the centre of each grid cell were produced using MapInfo Vertical Mapper (version 3.1.1) software. The interpolation technique was Rectangular; the contouring software recommends this technique when data points are evenly distributed, as in DEPOMOD outputs. Default values for cell size and search radius were used. The contour intervals were defined by the carbon deposition rates corresponding to the sediment classifications in Table 1.2 (Appendix 1). Deposition rates <0.3 g C m^{-2} d^{-1} were considered to be background levels; this was the carbon deposition rate at control sites in southwestern NB reported by Hargrave (1994).

Mass balance calculations compared the DEPOMOD predicted total rate of waste production by the farm (waste feed and feces) with the predicted rate of waste deposition on the seafloor within the model domain. The total rate of waste production was calculated as the total feed rate (all cages combined) multiplied by the rate of waste production per unit of feed. The waste production rate per unit of feed was calculated by DEPOMOD based on the input feed characteristics. Using the feed characteristics in Table 1.3 (Appendix 1) the model estimated the waste production rate per unit of feed (waste feed plus feces) to be 0.044 kg C per kg feed. The total rate of waste deposition within the model domain was calculated as the sum of the predicted waste deposition rates in all grid cells. The waste deposition rate in each grid cell was calculated as the estimated deposition rate at each grid point (in g C m^{-2} d^{-1}) multiplied by the size of each grid cell (100 m^2).

In cases where the predicted carbon deposition rate exceeded 5 g C m^{-2} d^{-1} in any of the grid cells within the DEPOMOD domain, there was interest in determining the highest feed rate that would result in the carbon deposition rates in all grid cells being maintained below this value. In DEPOMOD, the relationship between the feed rate and the highest predicted carbon deposition rate (in any grid cell) is linear:

$$D_{Max} = a + bF$$

where D_{Max} is the highest predicted carbon deposition rate (g C m^{-2} d^{-1}) of all grid cells in the DEPOMOD domain, F is the feed rate (kg d^{-1} per cage), a is the deposition rate when there is no feed, and b is the rate of deposition per unit of feed. The values for a and b for any site can be determined by plotting the feed rate versus the maximum predicted carbon deposition rate for two or more feed rates at each site. F_{D5}, the feed rate that would result in $D_{Max} = 5$ g C m^{-2} d^{-1} can then be estimated from the relationship. S_{D5}, the highest number of fish per cage which will maintain $D_{Max} \leq 5$ g C m^{-2} d^{-1}, can then be calculated as

$$S_{D5} = \frac{F_{D5}}{F_{Max}} S_{Proposed}$$

where F_{Max} is the proposed maximum feed rate (in kg d^{-1} per cage), and $S_{Proposed}$ is the proposed number of fish per cage.

Input Data

Production information for the proposed farm is given in Table 1.4 (Appendix 1). It is proposed to stock a total of 500,000 smolts in 33 cages. The site will have 36 cages, but 3 cages will be empty at any one time, although it will not always be the same cages empty: fish will be rotated among cages during net changes, approximately every 6-7 weeks. DEPOMOD was run for the 33 cages that are initially to be stocked, using the proposed maximum and average feed rates per cage. No rotation of fish among cages was considered.

For current velocity input, hourly records (the default time step) were extracted for three depth layers (the number of layers recommended by Cromey et al. 2002) from the raw current meter datafiles, after the datafiles were checked for errors. The three depth layers were: near surface, mid-depth, and near bottom (Appendix 1: Table 1.5).

Bathymetry data were obtained from the Canadian Hydrographic Service (CHS). The data indicate that the seafloor in the vicinity of the site is relatively flat, with an average depth (relative to chart datum, lowest normal tide) within the lease area of 14.1 m (range: 12.5 - 15.2 m). A grid of depth values corresponding to the centre of each DEPOMOD grid cell was created by interpolation from the CHS data.

The mean tidal height (mean water level above chart datum) was set at 1.2 m above chart datum in the DEPOMOD main input dialog screen, using CHS data from the nearest reference or secondary port (Murphy Cove, NS). Mean water level data can be found in the latest edition of the Canadian Tide and Current Tables, Volume 1 (Atlantic Coast and Bay of Fundy).

Other DEPOMOD input values used are shown in Table 1.3 (Appendix 1). In most cases, these were values recommended for British Columbia (Stucchi and Chamberlain 2005) or default values.

DEPOMOD Inputs and Results

Table 1.1. Location, dates, and duration of the current meter deployment at the Shoal Bay salmon aquaculture site.

Location	Deploy-ment	Latitude	Longitude	Start date	End date	Duration (days)
Shoal Bay (#1370)	492	44.77483°N	62.72709°W	19 May 2011	29 Jun 2011	41

Table 1.2 Site classifications for fish farms in New Brunswick (NBDENV 2006) and Nova Scotia (NSDFA 2011) based on sediment sulfide concentrations, with equivalent carbon deposition rates (based on Hargrave et al. 2008 and Hargrave 2010).

Site classification: New Brunswick	Site classification: Nova Scotia	Sediment sulfide concentration (μM)	Carbon deposition rate (DEPOMOD) (g C m^{-2} d^{-1})
Oxic A	Oxic A	<750	<1.0
Oxic B	Oxic B	750–1 500	1.0–2.0
Hypoxic A	Hypoxic A	1 500–3 000	2.0–5.0
Hypoxic B Hypoxic C	Hypoxic B	3 000–4 500 4 500–6 000	5.0–7.5 7.5–10.0
Anoxic	Anoxic	>6 000	>10.0

Table 1.3. DEPOMOD input parameter values.

Parameter	Value
Grid generation module (values set by user)	
Grid cell dimensions (major and minor grids)	10 × 10 m
Number of major grid cells	99 × 99
Number of minor grid cells	98 × 98
Particle tracking module	
Material type	Carbon
Food release type	Continuous release of food
Particle information (see Stucchi and Chamberlain 2005)	
Food water content	10%
Food digestibility	90%
Food wasted as % of food fed	3%
Carbon as % of feed pellets (dry weight)	57%
Carbon as % of feces (dry weight)	33%
Settling velocity of feed pellets (mean ± SD)	11.0 cm s^{-1}
Settling velocity of feces (mean ± SD)	3.2 ± 1.1 cm s^{-1}
Current velocity data (see Cromey et al. 2002)	
Current velocity layers	3: near surface, mid-depth, near bottom
Current velocity time step (default value)	3,600 s (1 h)
Turbulence model (default values)	
Random walk model	Yes
Dispersion coefficient (x)	0.100 m^{-2} s^{-1}
Dispersion coefficient (y)	0.100 m^{-2} s^{-1}
Dispersion coefficient (z)	0.001 m^{-2} s^{-1}
Particle trajectory model (default values)	
Number of particles released (for each particle type, per cage, at every time step)	10
Trajectory evaluation accuracy (model time step)	High (60 s)
Resuspension module	
Number of loops to run model for (Cromey et al. 2000)	2
Consolidation time of particles (default value)	4 d
Critical erosion threshold (non-adjustable)	9.5 cm s^{-1}

Table 1.4. Production information for a proposed salmon aquaculture site at Shoal Bay (#1370).

Parameter	Value
Total number of fish	500 000
Lease area	18.0 ha
Number of cages holding fish	33
Cage circumference	72 m
Cage diameter	23 m
Cage net depth (below water surface)	9 m
Number of fish per cage	15 150
Average feed rate per cage	102 kg d^{-1}
Maximum feed rate per cage	311 kg d^{-1}

Table 1.5. Depth layers of current velocity data used in DEPOMOD runs at the proposed Shoal Bay salmon aquaculture site. The average water depth is the average distance from the water surface to the seafloor at the current meter deployment location, based on Canadian Hydrographic Service bathymetry and tide data.

Site	Average water depth at current meter (m)	Depth layer	Number of hourly records	Location of depth layer
Shoal Bay (#1370)	15.2	Near surface	981	12.6 m above bottom
		Mid-depth	981	7.6 m above bottom
		Near bottom	981	2.6 m above bottom

Table 1.6. Summary of current speed data from current meter deployments at the proposed Shoal Bay salmon aquaculture site. The values shown are based on hourly current speed records (see Table 1.1). A near bottom current speed ~9.5 cm s^{-1} corresponds to the critical shear stress threshold for resuspension in DEPOMOD.

Depth layer	Current speed (cm s^{-1}) Minimum	Mean	Maximum	% of near bottom records >9.5 cm s^{-1}
Near surface	0.5	6.1	22.4	
Mid-depth	0.6	5.2	20.4	
Near bottom	0.6	5.3	22.0	12

Table 1.7. DEPOMOD mass balance calculations for wastes released from the Shoal Bay site and the amount of wastes deposited on seafloor within the model domain (1 × 1 km), using proposed maximum and average feed rates, with resuspension off and on.

Total feed rate (kg d^{-1})	Waste produced per kg feed (kg)	Total waste produced (kg C d^{-1})	% of waste falling within DEPOMOD domain	
			Resuspension off	Resuspension on
10 263 (maximum)	0.044	452	100	77
3 366 (average)	0.044	148	100	52

Table 1.8. DEPOMOD predictions of contour areas for ranges of carbon deposition rates at the proposed Shoal Bay salmon aquaculture site, using the proposed ***maximum*** *feed rate (311 kg d^{-1} per cage), with resuspension off and on. Oxic A areas exclude areas with background deposition rates (<0.3 g C m^{-2} d^{-1}).*

Site classification	Carbon deposition rate (g C m^{-2} d^{-1})	Contour area (m^2) (maximum feed rate)		Change due to resuspension	
		Resuspension off	Resuspension on	Area (m^2)	% change
Oxic A	0.3-1.0	10 200	6 400	-3 800	-37
Oxic B	1.0-2.0	5 100	3 800	-1 300	-25
Hypoxic A	2.0-5.0	7 000	10 900	3 900	56
Hypoxic B	5.0-7.5	10 300	15 500	5 200	50
Hypoxic C	7.5-10.0	14 800	8 900	-5 900	-40
Anoxic	>10.0	16 700	9 800	-6 900	-41
>5 g C m^{-2} d^{-1}	*>5.0*	*41 800*	*34 200*	*-7 600*	*-18*

*Table 1.9. DEPOMOD predictions of contour areas for ranges of carbon deposition rates at the proposed Shoal Bay salmon aquaculture site, using the proposed **average** feed rate (102 kg d^{-1} per cage), with resuspension off and on. Oxic A areas exclude areas with background deposition rates (<0.3 g C m^{-2} d^{-1}).*

		Contour area (m^2) (average feed rate)		Change due to resuspension	
Site classification	Carbon deposition rate (g C m^{-2} d^{-1})	Resuspension off	Resuspension on	Area (m^2)	% change
Oxic A	0.3-1.0	8 900	11 600	2 700	30
Oxic B	1.0-2.0	7 300	21 800	14 500	199
Hypoxic A	2.0-5.0	35 000	13 000	-22 000	-63
Hypoxic B	5.0-7.5	3 300	0	-3 300	-100
Hypoxic C	7.5-10.0	0	0	0	0
Anoxic	>10.0	0	0	0	0
>5 g C m^{-2} d^{-1}	*>5.0*	*3 300*	*0*	*-3 300*	*-100*

Table 1.10. Linear relationships between the feed rate (kg d^{-1} per cage) and the highest predicted carbon deposition rate (g C m^{-2} d^{-1}) within the Shoal Bay DEPOMOD domain. Also shown is the feed rate that would result in a highest deposition rate of 5 g C m^{-2} d^{-1} based on the relationships. The relationships were derived from the predicted highest deposition rates at 3 feed rates: maximum, average, and mid-way through the first year.

Site	Resuspension	Slope (*b*)	y-axis intercept (*a*)	r^2	Feed rate (kg d^{-1} per cage) resulting in a highest predicted deposition rate of 5 g C m^{-2} d^{-1}
Shoal Bay (#1370)	Off	0.077	-0.038	1.0	65
Shoal Bay (#1370)	On	0.075	-1.76	1.0	91

Table 1.11. Maximum feed and stockings rate to maintain the predicted carbon deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the Shoal Bay DEPOMOD domain.

Site	Resus-pension	Proposed stocking rate (number of fish per cage)	Highest predicted deposition rate using proposed maximum feed rate (g C m^{-2} d^{-1})	Feed rate (kg d^{-1} per cage) to maintain deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells	Number of fish per cage to maintain deposition rate ≤5 g C m^{-2} d^{-1} at time of maximum feeding
Shoal Bay (#1370)	Off	15 150	23.8	65	3 200
	On	15 150	21.5	91	4 400

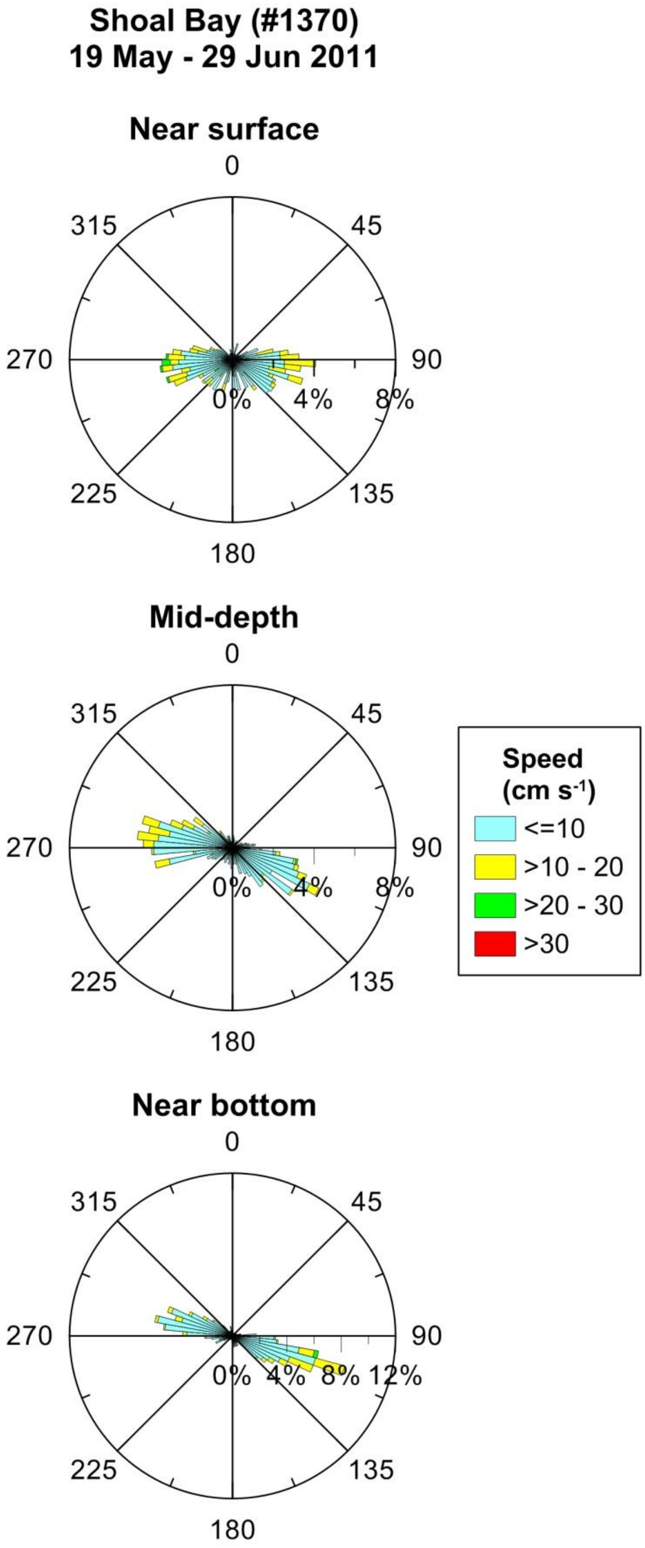

Figure 1.1. Current rose diagrams for the ADCP current meter deployment at the proposed Shoal Bay salmon aquaculture site (#1370). Data shown are based on hourly records at three depth layers: near-surface (top), mid-depth (middle), and near-bottom (bottom).

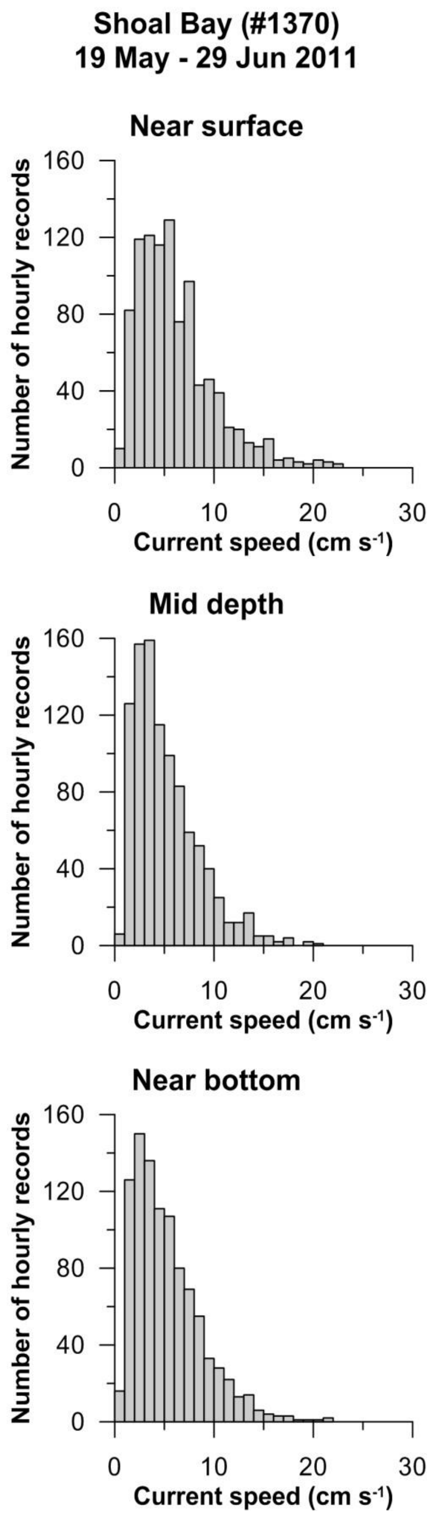

Figure 1.2. Current speed histograms for the ADCP current meter deployment at the proposed Shoal Bay salmon aquaculture site (#1370). Data are shown based on hourly records at three depth layers: near-surface (top), mid-depth (middle), and near-bottom (bottom).

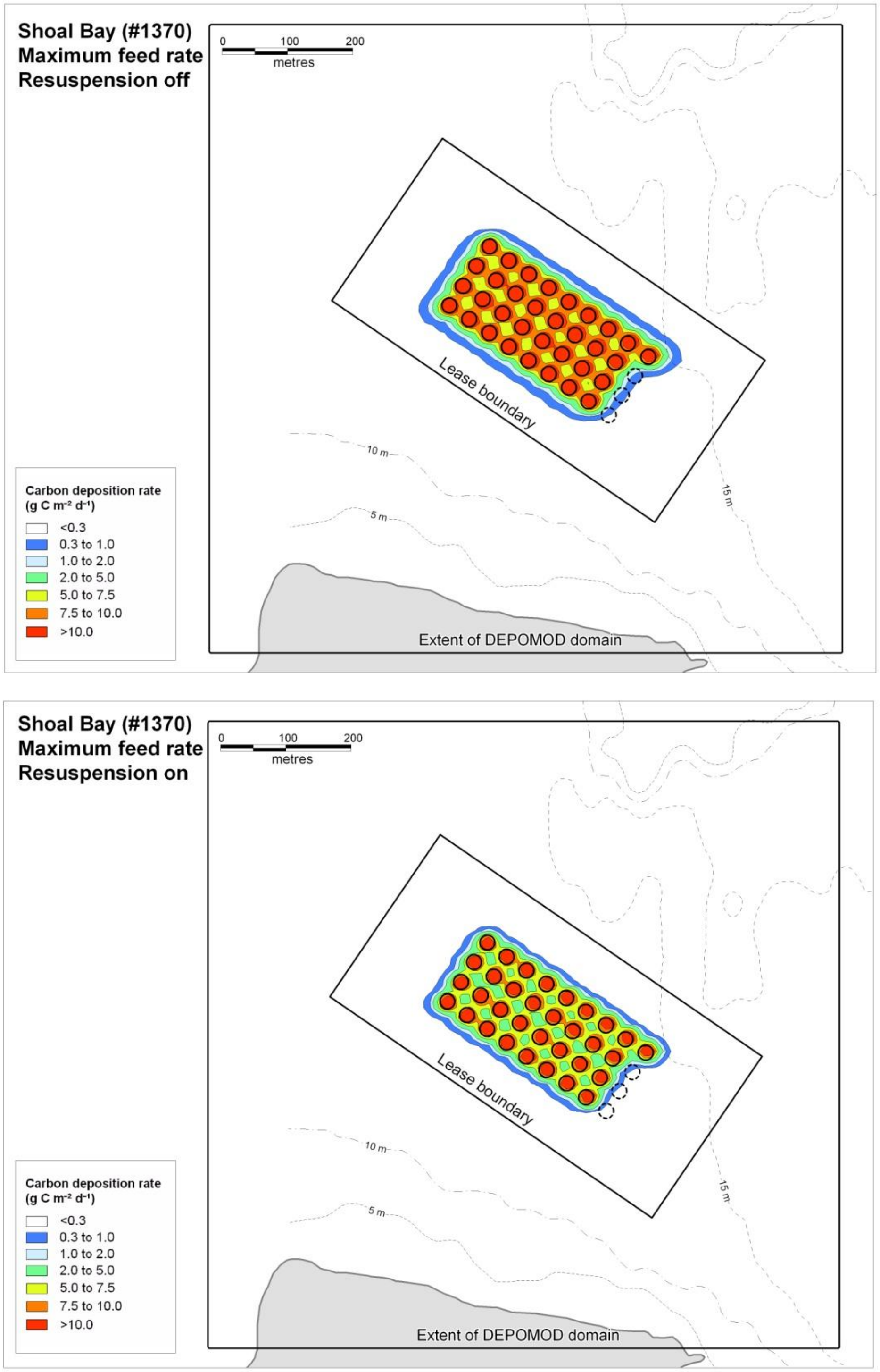

*Figure 1.3. Contour plots of DEPOMOD predicted carbon deposition rates at the proposed Shoal Bay salmon aquaculture site (#1370), with a total of 500,000 fish in 33 cages, using the proposed **maximum** feed rate (311 kg d^{-1} per cage), with resuspension off (top) and on (bottom).*

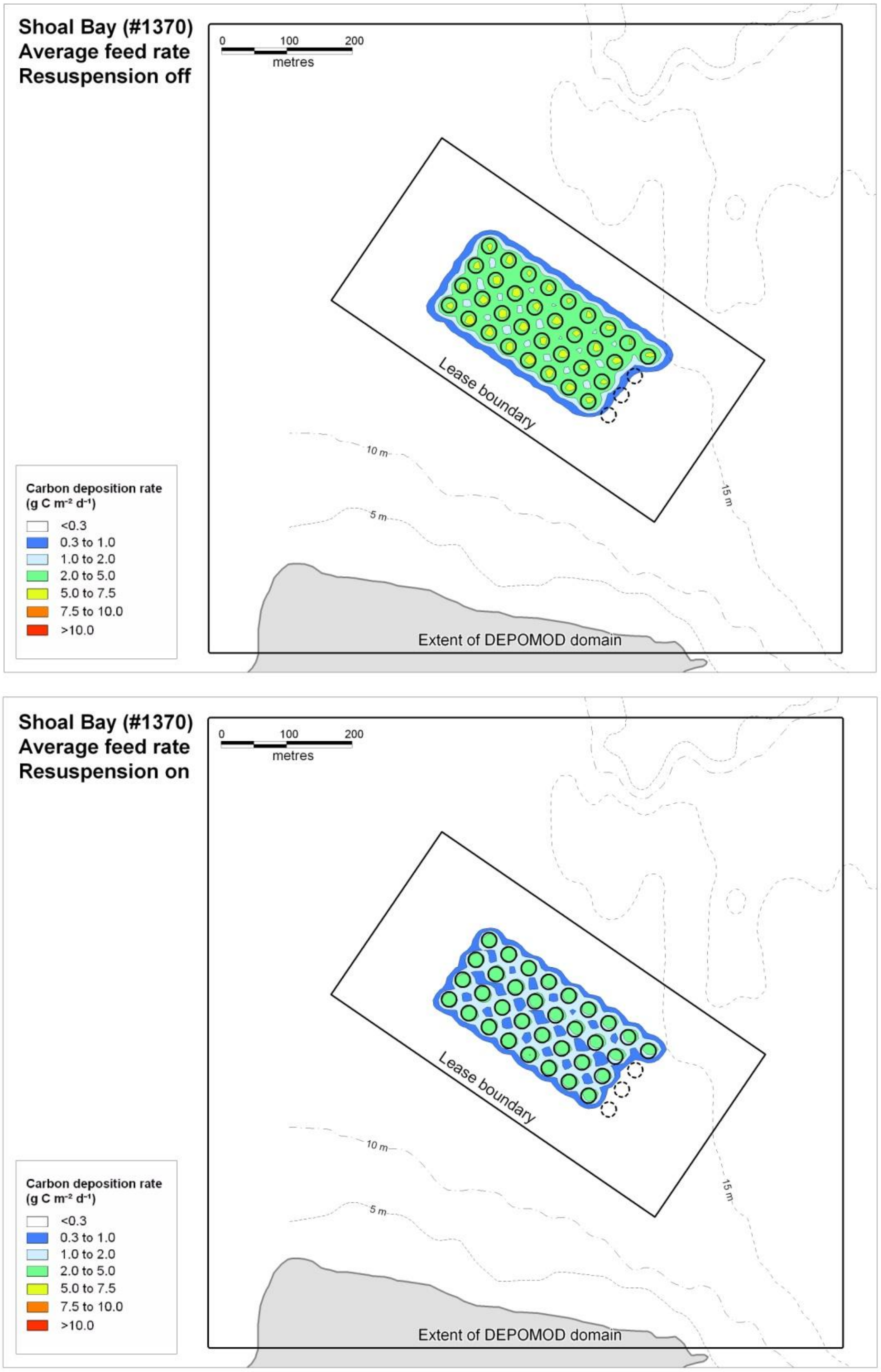

*Figure 1.4. Contour plots of DEPOMOD predicted carbon deposition rates at the proposed Shoal Bay salmon aquaculture site (#1370), with a total of 500,000 fish in 33 cages, using the proposed **average** feed rate (102 kg d^{-1} per cage), with resuspension off (top) and on (bottom).*

Appendix 2: Proposed Revision to Site Boundaries

On 23 March 2012, DFO Science was advised that the proponent had proposed a slight shift in the lease boundaries (Figure 1.). The new boundaries largely overlap the original boundaries. The bathymetry within the new boundaries is similar to that in the original boundaries: the seafloor is relatively flat, and the average depth is slightly less within the new boundaries (13.7 m below chart datum, compared to 14.1 m within the original boundaries).

Because the change in depth was small, and since DEPOMOD runs would use the same current velocity and feed data, it was felt that re-running the model was not required. The extent of areas with elevated impacts and the maximum deposition rates would not differ significantly from the original model results. The only difference would be the exact locations of the impacted areas, which would reflect the small shift in cage locations.

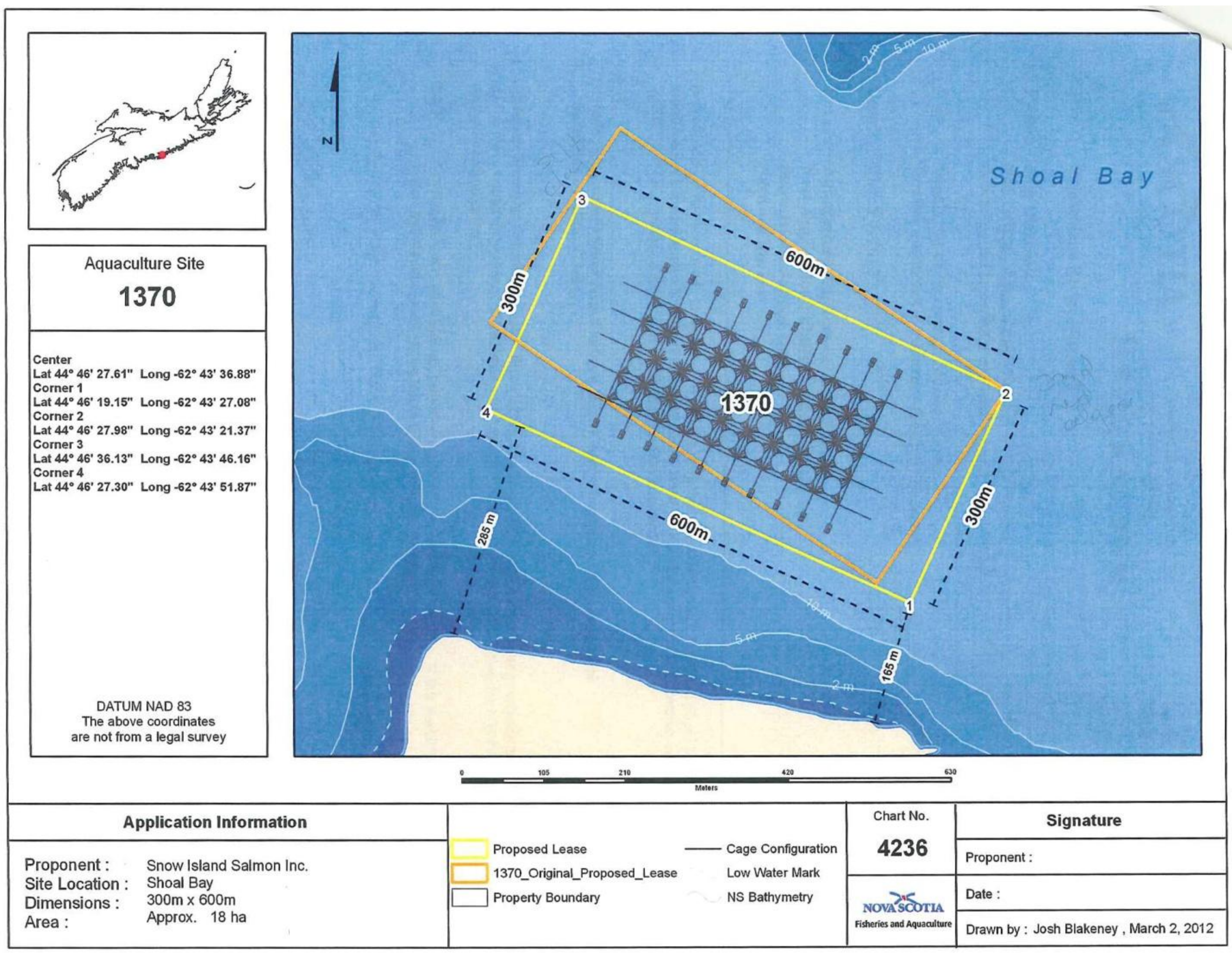

Figure. 2.1. Map showing revised (yellow line) and original (orange line) boundaries for the proposed Shoal Bay salmon aquaculture site. The cage locations are for the revised boundaries.

Appendix 3. Atlantic Salmon "Berth" Locations on the Eastern Shore of Nova Scotia

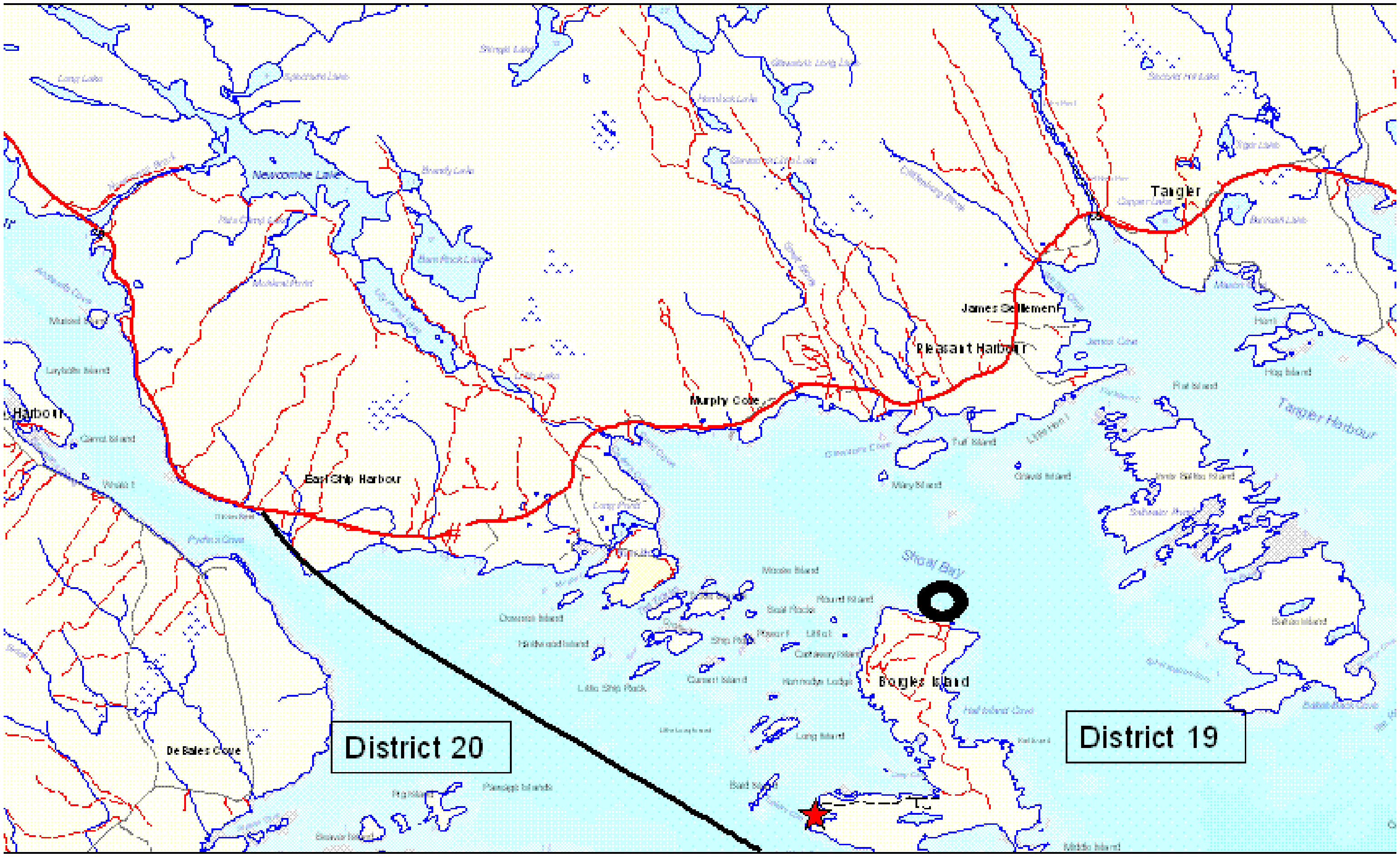

Figure 3.1. Atlantic salmon "berth" locations, where commercial Atlantic salmon fixed harvest gear were located (red stars) on the Eastern Shore of Nova Scotia, from Ship Harbour in the west to Popes Harbour in the east (part of Fisheries Statistical District 19 and 20). The approximate location the proposed aquaculture site is identified as an open circle.

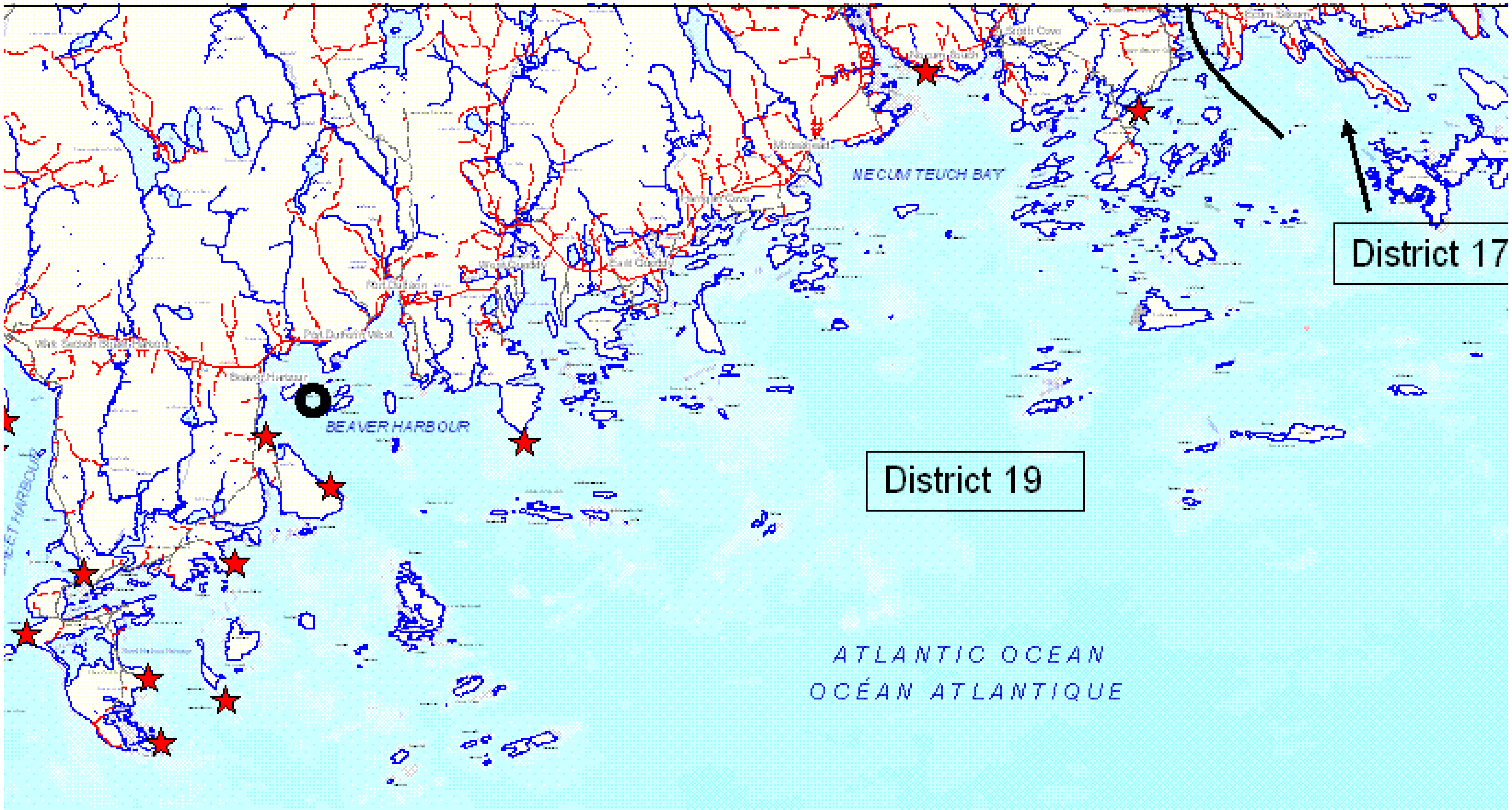

Figure 3.2. Atlantic salmon "berth" locations, where commercial Atlantic salmon fixed harvest gear (red stars) were located on the Eastern Shore of Nova Scotia, from Sheet Harbour in the west to Ecum Secum in the east (part of Fisheries Statistical District 19). The approximate location of an additional proposed aquaculture site in Beaver Harbour is identified with an open circle.

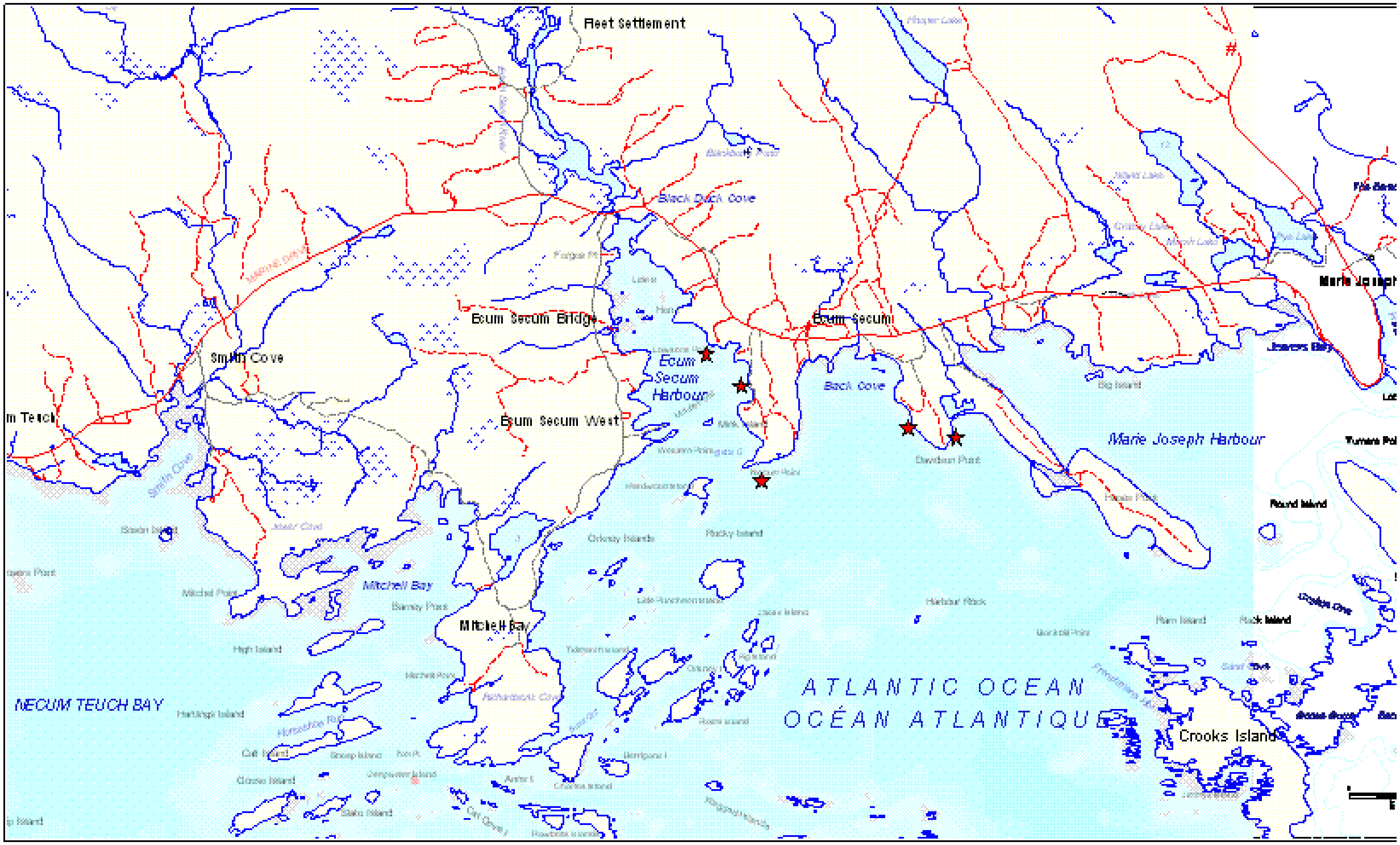

Figure 3.3. Atlantic salmon "berth" locations, where commercial Atlantic salmon fixed harvest gear was located (red stars) on the Eastern Shore of Nova Scotia, from Necum Teuch Bay in the west to Marie Joseph in the east (part of Fisheries Statistical District 17).

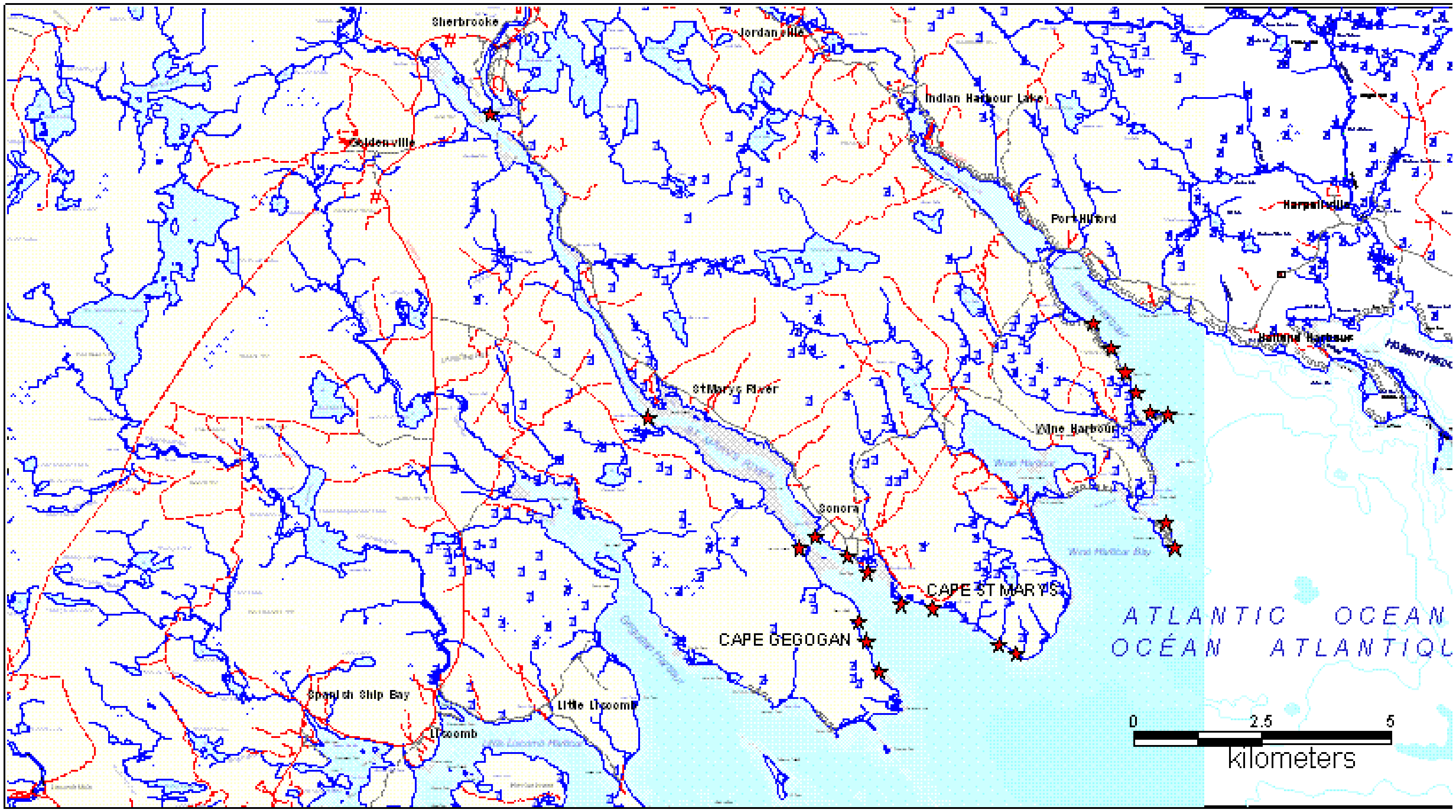

Figure 3.4. Atlantic salmon "berth" locations, where commercial Atlantic salmon fixed harvest gear was located (red stars) on the Eastern Shore of Nova Scotia, from Little Liscomb in the west to Holland Harbour in the east (part of Fisheries Statistical District 17).

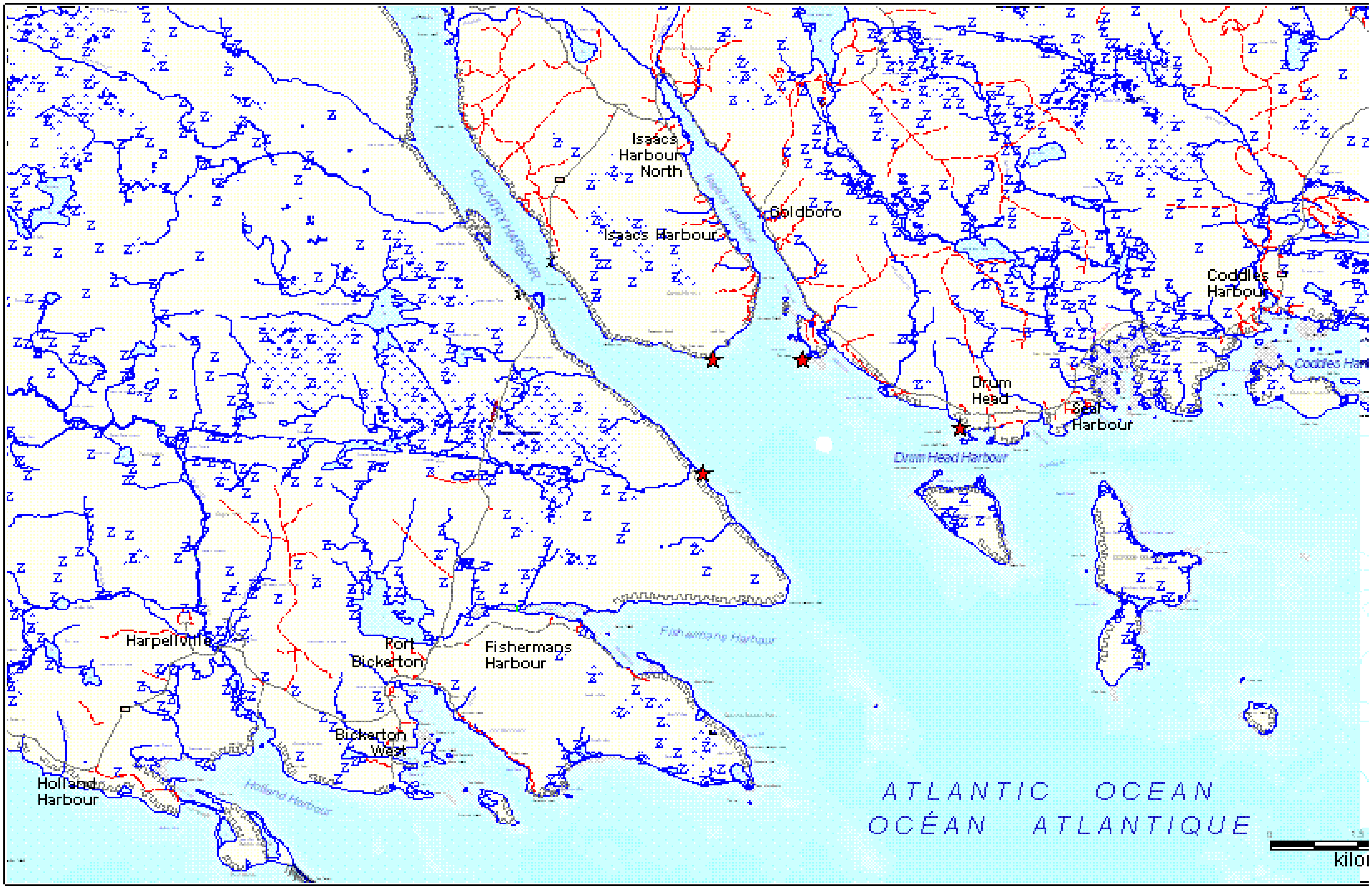

Figure 3.5. Atlantic salmon "berth" locations, where commercial Atlantic salmon fixed harvest gear was located (red stars) on the Eastern Shore of Nova Scotia, in the Country Harbour area (part of Fisheries Statistical District 17).

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