Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat
Maritimes Region
Science Response 2023/042

DFO MARITIMES REGION SCIENCE REVIEW OF THE PROPOSED NEW MARINE FINFISH AQUACULTURE SITE, BEAVER HARBOUR, CHARLOTTE COUNTY, NEW BRUNSWICK

Context

Kelly Cove Salmon Ltd. has submitted an application to the Province of New Brunswick to construct and operate a new site, Rams Head (# MF-0509), in Beaver Harbour, Charlotte County, New Brunswick.

As per the Canada-New Brunswick Memorandum of Understanding on Aquaculture Development, the New Brunswick Department of Agriculture, Aquaculture and Fisheries (NBDAAF) has forwarded this application to Fisheries and Oceans Canada (DFO) for review and advice in relation to DFO's legislative mandate. The application was supplemented by information collected by the proponent as required by the *Aquaculture Activities Regulations (AAR)*.

To help inform DFO's review of this application, the Regional Aquaculture Management Office has asked for DFO Science advice on the predicted exposure zones (PEZs) associated with the range of aquaculture activities, and the predicted impacts on susceptible fish and fish habitat, including sensitive Species at Risk (SAR) listed species, susceptible fishery species, and the habitats that support them.

Specifically, the following questions are addressed for each application:

Question 1. Based on available data for the site and scientific information, what is the predicted exposure zone from the use of approved fish health treatment products in the marine environment, and the potential consequences to susceptible species?

Question 2. Based on the available information for each site, what are the Ecologically and Biologically Significant Areas, Species at Risk listed under Schedule 1 of the *Species at Risk Act*, fishery species, Ecologically Significant Species, and their associated habitats that are within the predicted benthic exposure zone and vulnerable to exposure from the deposition of organic matter? How does this compare to the extent of these species and habitats in the surrounding area (i.e., are they common or rare)? What are the anticipated impacts to these sensitive species and habitats from the proposed aquaculture activity?

Question 3. How do the impacts on these species from the proposed aquaculture site compare to impacts from other anthropogenic sources (including existing finfish farms)? Do the zones of influence overlap with these activities and if so, what are the potential consequences?

Question 4. To support the analysis of risk of entanglement with the proposed aquaculture infrastructure, which pelagic aquatic Species at Risk listed under Schedule 1 of the *Species at Risk Act* make use of the area, and for what duration and when?

Question 5. What populations of conspecifics are within a geographic range that escapees are likely to migrate to? What is the size and status trends of those conspecific populations in the escape exposure zone for the proposed site? Are any of these populations listed under Schedule 1 of *Species at Risk Act*?

This Science Response Report results from the Regional Science Response Process of November 29-30, 2021 on DFO Maritimes Region Review of the Proposed New Marine Finfish Aquaculture Site, Beaver Harbour, Charlotte County, New Brunswick.

Background

Kelly Cove Salmon Ltd. is requesting to construct and operate a new marine finfish site, Rams Head (# MF-0509), in Beaver Harbour, Charlotte County, New Brunswick. The proposed site is located in the Bay of Fundy at the mouth of Beaver Harbour in Bay Management Area (BMA) 3a, which also currently encompasses twelve other marine finfish aquaculture leases. The location of the site is shown in Figure 1.

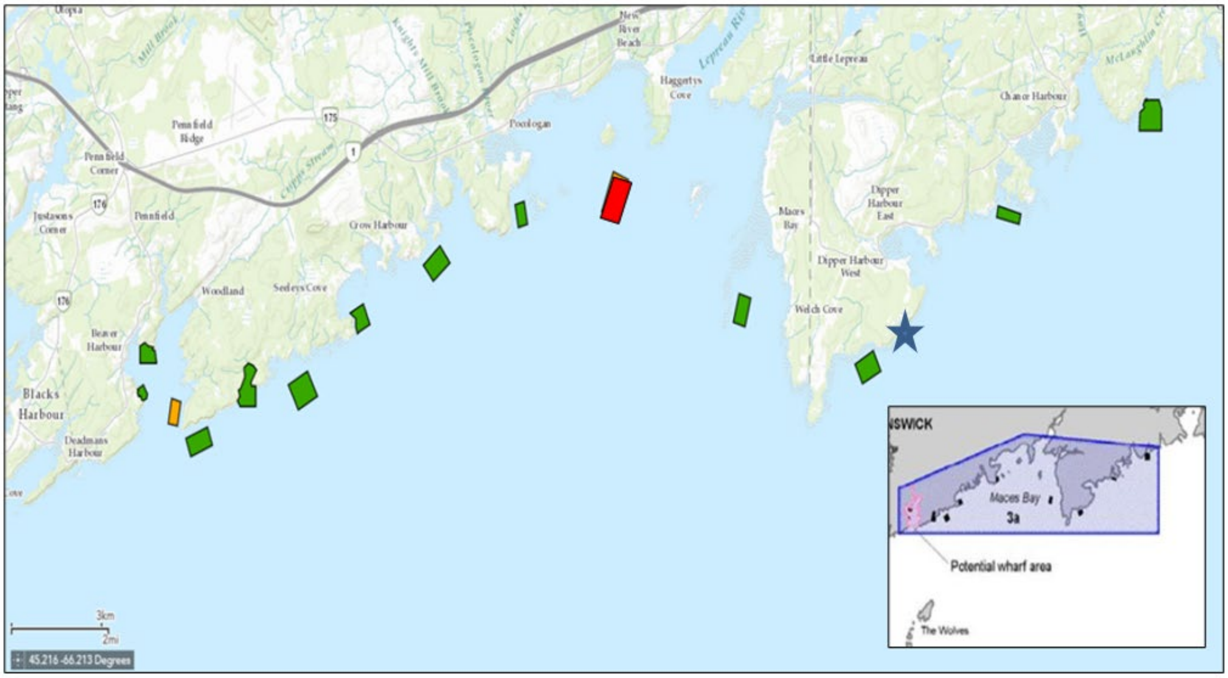

Figure 1. Map of finfish aquaculture site leases in Bay Management Area (BMA) 3a, Bay of Fundy, New Brunswick. The inset picture shows the boundaries of the BMA (Chang et al. 2007). Green polygons represent existing finfish aquaculture sites. The orange polygon represents the focus of this review, proposed site # MF-0509. The red polygon denotes a second proposed site in BMA 3a in Maces Bay, which will be reviewed separately. The base map was retrieved from the New Brunswick Marine Aquaculture Site Mapping Program website on December 9 2021 (NBDAAF).

There are three existing marine finfish leases located within or at the entrance to Beaver Harbour. Those most closely surrounding the proposed # MF-0509 site are located within approximately 400 m (# MF-0508), 800 m (# MF-0012), and 980 m (# MF-0010) (Figure 2). These sites were last stocked in 2011, 2017, and 2011, respectively.

The proposed new site would occupy an area of approximately 18 ha with a 2x8 net-pen array configuration. Although a total of 16 net-pens will be on site, only 15 will be stocked with fish as the remaining net-pen will be used for transfer of fish during well-boat treatments. The proposed production plan is a maximum of 400,000 Atlantic Salmon (*Salmo salar*), with a grow-out period of 18–24 months from stocking. Figure 2 shows the site development plan with bathymetry.

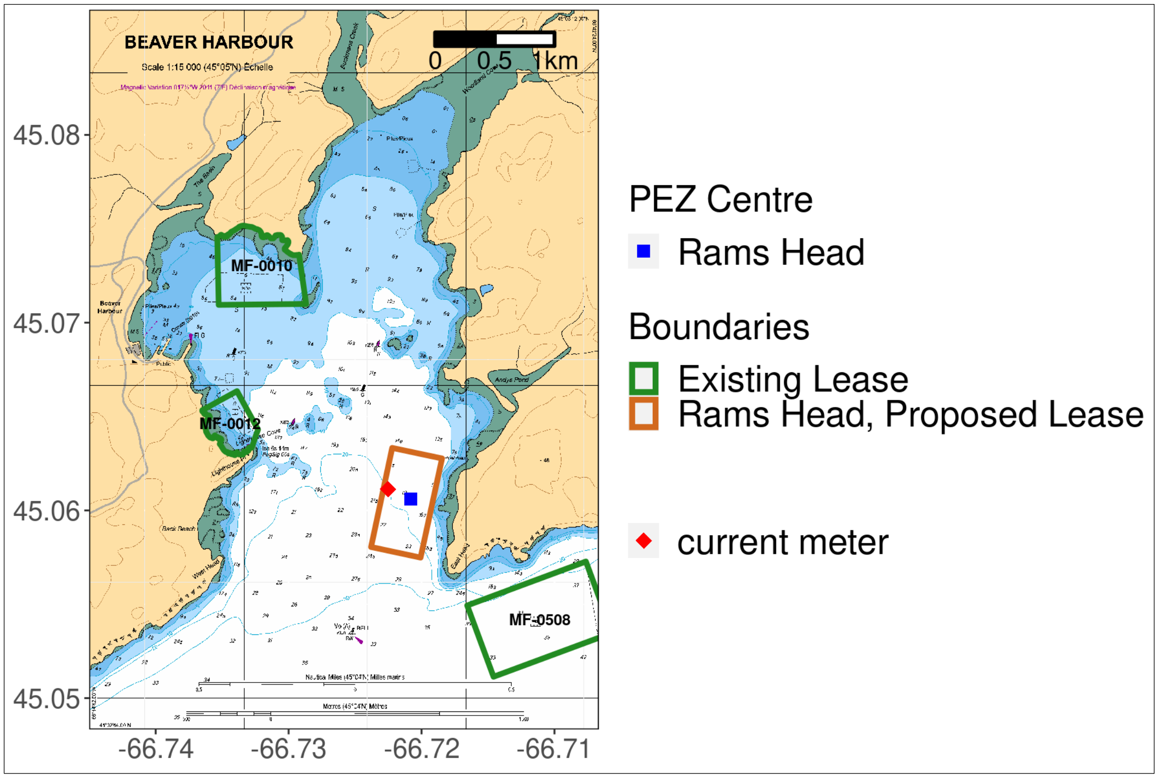

Figure 2. Proposed lease boundaries for # MF-0509 Rams Head (orange) overlaid on CHS chart # 4114 (depth is in meters). Existing finfish aquaculture leases within Beaver Harbour are shown in green. The locations of the proponent-deployed current meter and the center of the proposed cage array for predicted exposure zone (PEZ) calculations are also shown.

Proponent-submitted baseline data collected in 2019 indicates the site is located in an area with variable bottom type and ecosystem characteristics (i.e., mud, silt, sand, gravel, cobble, boulder, and shell debris). The seabed beneath the proposed site was predominantly characterized as having soft, loosely-packed sediments, though still consisting of a mixture of sediment types. Nine out of twenty-eight video stations were classified as 'hard-bottom' during observation, the majority of which were along the northern and eastern boundaries of the proposed site.

These recent observations are consistent with seabed characteristics recorded in DFO diving surveys conducted within Beaver Harbour, as well as some limited historical DFO seabed video surveys conducted in the central portions of the harbour. While a predominant habitat transition from 'hard-bottom' to loosely-packed sediments occurs with increasing depth (at around 15-20 m depths), there are also lateral transitions in predominant bottom type from cobble-boulder dominated areas to gravel-sand dominated areas within shallower depth ranges (5–15 m depth). This occurs from the exposed headlands towards more sheltered areas within the harbour. For the proposed lease area, proponent comments on the northern and eastern boundaries of the site are consistent with DFO diving observations that indicate the fringing subtidal habitat between 5–15 m depth to the east of the lease area, towards and around East Head, is dominated by accumulations of very large boulders with numerous crevices and deep galleries. This type of habitat is particularly difficult to quantitatively survey for lobsters, but it can be presumed to host high local densities (P. Lawton, DFO, pers. comm.).

Linkages between sediment sulfide concentrations and overall sediment conditions, such as oxic state and macrofauna diversity, at aquaculture sites are well documented (Pearson and Rosenberg 1978, Hansen et al. 2001, Wildish et al. 2001, Hargrave et al. 2008). Average sediment sulfide concentrations measured during the baseline survey indicate Oxic A levels based on Hargrave (2010) oxic categories.

The proposed site is located within the Whole of Quoddy Ecologically and Biologically Significant Area (EBSA) included as part of a regional list of coastal EBSAs within the Scotian Shelf Bioregion marine conservation network design process (DFO 2018). The Whole of Quoddy EBSA was identified on the basis of its perceived uniqueness and irreplaceability within the Bay of Fundy given its rich biodiversity, food aggregations, and habitat that are important for many marine species (Buzeta 2014). Within the Whole of Quoddy EBSA, there are some smaller discrete EBSA components (e.g., the Wolves Islands). While there is no discrete “Beaver Harbour” component, there is strong consensus that the Quoddy Region functions as a whole with ecological linkages between the different areas within it (Buzeta and Singh 2008, Buzeta 2014). The Quoddy Region is clearly also acknowledged as a major aquaculture and fisheries area. However, this area contains more hard substrate than generally exists in the Bay of Fundy, and has significant aspects that need to be protected (Buzeta et al. 2003, DFO 2018). DFO (2004) states that EBSAs are intended as a tool for calling attention to an area that has particularly high ecological or biological significance to facilitate provision of a greater-than usual degree of risk aversion in management of activities in such areas.

The proposed # MF-0509 Rams Head site is in an area with active fisheries. Commercial benthic invertebrate fisheries in the area include American Lobster (*Homarus americanus*), Sea Urchin (*Strongylocentrotus droebachiensis*), Atlantic Sea Scallop (*Placopecten magellanicus*), and Softshell Clam (*Mya arenaria*). The proposed site is located within Lobster Fishing Area (LFA) 36, where the stock status is considered to be healthy based on the primary indicator (DFO 2021a). Commercial landings within LFA 36 began a long-term increase in the mid-1990s, and are currently near record highs (DFO 2021a). LFA 36 has a split fishing season, from November through January, and March through June. Beaver Harbour is located specifically within reporting grid 26, which accounts for 0.05% of the total area of the LFA. Catch and effort data reported by fishermen indicate that the grid represented an average of 5.5% of total landings for the LFA over the last five years (2017-2021). The southwest New Brunswick (SWNB) sea urchin fishery operated on a small scale since the 1950s, and was commercially established in 1989. There are 19 license holders in LFA 36 (which covers off the area of interest), including harvesting that occurs in the area adjacent to the proposed site. The proposed site is located within Scallop Production Area (SPA) 6, and more specifically within subarea 6C. Available landings data within 3 km of the proposed site from 2015–2020 represent approximately 0.04% of landings in all of SPA 6, and 0.12% of landings within subarea 6C. While there is no information specific to Clam harvesting in Beaver Harbour, nearshore harvesting occurs throughout Clam Harvest Area 7, which covers the entire New Brunswick shoreline. Clam Harvest Area 7 had the highest reported landings in 2020 of all harvest areas.

Commercial groundfish and pelagic species in the area include Atlantic Cod (*Gadus morhua)*, Pollock (*Pollachius virens*), Haddock (*Melanogrammus aeglefinus*), and Atlantic Herring (*Clupea* *harengus*). This area is included within the NAFO 4X5Y Cod unit and the Western Component (NAFO 4xopqrs5) Pollock unit. A rebuilding plan is in place for the 4X5Y Atlantic Cod stock, as the stock is currently in the Critical zone. There is no directed fishing due to the stocks population size, which was reassessed as Endangered by COSEWIC in 2010 and is pending a listing decision under the *Species at Risk Act*. The 4X5Y Haddock stock biomass is currently considered to be in the Cautious zone (DFO 2021b), but active fishing is still underway. Historical data shows that Beaver Harbour has had active herring weirs, and currently there are two active weirs. However, the 4VWX Herring stock is considered to be in the Critical zone; therefore, current advice is towards a precautionary approach that requires harvesting be kept to an absolute minimum to contribute to rebuilding the stock (DFO 2020a).

There are many Food, Social and Ceremonial (FSC) fisheries in the area. While licenses likely contain various species, the most commonly fished for in this area include Lobster, Scallop, and Clam (DFO Resource Management, F. Page, DFO, pers. comm.). Recreational fisheries in the area include Scallop, Mackerel (*Scomber scombrus*), and various groundfish (DFO Resource Management, pers. comm.).

DFO database searches (Appendix A) also indicated the presence of Northern Shrimp (*Pandalus borealis*), Scallop, Sea Cucumber, Winter Flounder, Witch Flounder, Atlantic Halibut, Cod, Pollock (*Pollachius virens*), Haddock, White Hake (*Urophycis tenuis*), sculpin, skate, squid, and Herring, as well as Rockweed presence all along the shoreline of Beaver Harbour.

Proponent-collected video baseline data identified fauna at all of the 28 survey stations throughout the proposed lease. Predominant observations were shrimp (> 241), anemones (84 *Hormathia* sp., one Northern Cerianthid, and one unidentified), sponges (17 unidentified, two Breadcrumb, and 5–10% Fig Sponge coverage), and Scallop (19). Also noted (in abundance of five or less) were limpet, cockle, quahog, Rock Crab, Hermit Crab, flounder, and eelpout.

The proposed site is likely within the migration pathways of wild Atlantic Salmon. The Bay of Fundy commercial fishery for Atlantic Salmon was closed in 1985 (Amiro 1998), and the recreational fishery for Atlantic Salmon has been prohibited for all rivers located around the Bay of Fundy since 1998 due to conservation concerns. Inner Bay of Fundy (iBoF) Atlantic Salmon have been listed as Endangered under the *Species at Risk Act (SARA)* since 2003. Outer Bay of Fundy (oBoF) and Southern Upland (SU) Atlantic Salmon have both been assessed as Endangered by COSEWIC since 2010, and are currently under consideration by the Minister for listing under *SARA*.

A search of the predicted exposure zones using the DFO Aquatic Species at Risk Map Tool indicates that other Species at Risk (SAR) listed on schedule 1 that may be present in the area include White Shark (*Carcharodon carcharias*), Leatherback Sea Turtle (*Dermochelys coriacea*), North Atlantic Right Whale (*Eubalaena glacialis*), Blue Whale (*Balaenoptera musculus*), and Fin Whale (*Balaenoptera physalus*). According to the map tool, no overlaps with critical habitat were identified for these species. However, it is important to note that these types of tools are typically based on common knowledge of geographic range and habitat preferences and are not necessarily based on actual observation. A key example specific to this review is that, while Atlantic Wolffish (*Anarhichas lupus*) did not appear in the map tool list due to the shallow nature of the search depths, there has been diver observation of Atlantic Wolffish immediately adjacent to the proposed site in relatively shallow waters (A. Cooper, DFO, pers. comm.). This speaks to the limitations of such tools, and also adds Atlantic Wolffish to the list of SAR present in Beaver Harbour specifically in the vicinity of the proposed site.

Additional marine mammals that make use of the area around the proposed site are Harbour Porpoise (*Phocoena phocoena*), Grey Seal (*Halichoerus grypus*), and Harbour Seal (*Phoca vitulina*). Harbour Porpoise are common in the Bay of Fundy year round, and are predominantly found inshore during summer months. Harbour and Grey Seal make use of Beaver Harbour as a haul-out area on rocks that are exposed during low tide.

Beaver Harbour was extensively surveyed between 1989 and 1992 by DFO scuba divers using both transect survey approaches (150 m x 2 m path) and timed collection dives. This work contributed to a broad-scale coastal habitat survey on sensitive fishery areas in relation to the initial phase of regional aquaculture development. A project funded by the province of New Brunswick's Cooperation Agreement on Fisheries and Aquaculture Development surveyed the then active and proposed sites throughout the Fundy Isles, along the New Brunswick (NB) shore to Point Lepreau, and on Grand Manan (Lawton 1992[1], 1993[2]). A long-term annual Lobster settlement monitoring program was established by DFO in Beaver Harbour in 1991 using diver-based suction sampling approaches. Suction sampling allows for the collection of newly-recruited Lobster down to the immediate post-settlement stage (4 mm carapace length [CL]). The DFO annual survey data contributes to the American Lobster Settlement Index (ALSI). First initiated in 1989 in the United States, there are now more than 100 bays throughout the Northeast United States and Atlantic Canada that are surveyed for annual Lobster settlement under the ALSI collaboration. Beaver Harbour has the second longest time series in the program, with data collected from 1991–2021. Over this time period, both diver-based suction sampling and post-larval collectors have been used to quantify recently settled young-of-year and older juvenile Lobster at the end of the larval settlement season (late October in the Bay of Fundy; earlier in southern New England) (Wahle et al. 2010, 2013). Surface-deployed, on-bottom cobble filled collector trays offer another technique to survey annual settlement strength, with the benefit of being able to be deployed over a greater range of bottom types and depths (Wahle et al. 2013). The University of New Brunswick (UNB) has undertaken the post-larval collector deployments annually in Beaver Harbour since 2009 (Remy Rochette, Dept of Biology, UNB, pers. comm.). Sampling locations specifically within Beaver Harbour are shown in Figure 3. This work is part of a much broader academic research program at UNB on lobster fisheries ecology in Atlantic Canada, including new DFO-funded research on fishery recruitment forecasting.

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[1] Lawton, P. 1992. Identification of Lobster Areas in the Vicinity of Proposed, Current, and Possible Future Aquaculture Sites in Southwestern New Brunswick. Interim Report to the New Brunswick Department of Fisheries and Aquaculture. Unpublished report, 76p.

[2] Lawton, P. 1993. Salmon Aquaculture and the Traditional Invertebrate Fisheries of the Fundy Isles Region: Habitat Mapping and Impact Definition. Report to the New Brunswick Department of Fisheries and Aquaculture. Unpublished report, 84p.

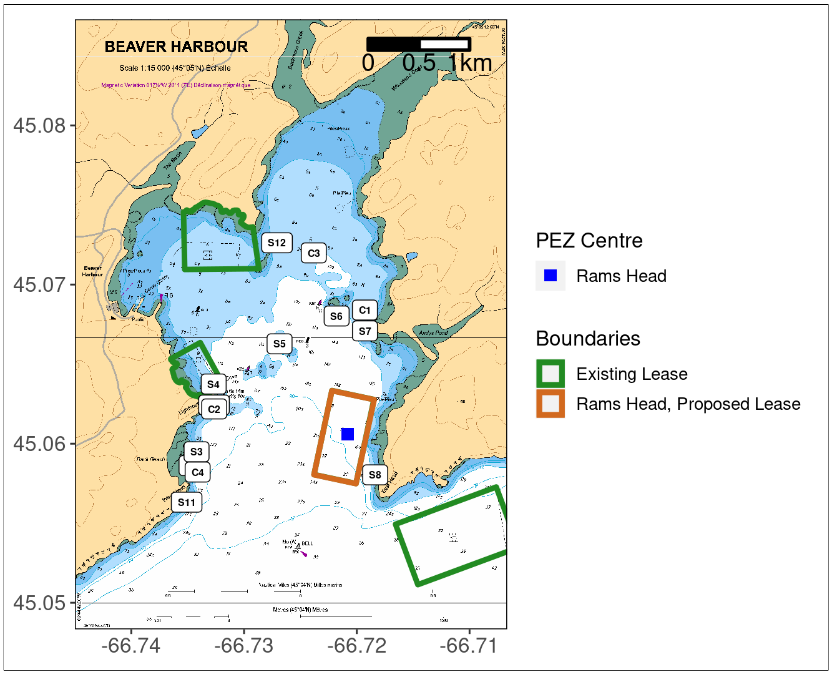

Figure 3. Locations of annual DFO suction sampling (Sxx) and University of New Brunswick post-larval collector deployments (Cx) between West Head and East Head, Beaver Harbour overlaid on CHS chart # 4115 (depth is in meters). Not all locations are surveyed annually.

Other human activities within 5 km of the proposed site represent a combination of land- and marine-based sources, and have the potential to influence the marine ecosystem of Beaver Harbour and surrounding area. These include human-derived nutrient loading and pollution, fishing, vessel traffic (commercial and recreational), and the addition of hardened shoreline structures (e.g., sea walls, jetties, breakwaters, etc.).

Key oceanographic, farm infrastructure and grow-out characteristics of the new site considered in the following analyses are summarized in Table 1.

Table 1. Key oceanographic, farm infrastructure and grow-out characteristics of the proposed site. Information sources are the proponent's development plan and baseline data reports. Note: n/a = not applicable (i.e., no relevant additional information to include).

Characteristic	Rams Head # MF-0509	Additional Information
Maximum tidal range (m)	7.5	• Range does not include surges in sea level. • Large tide at Letang Harbour NB – elevation above chart datum (CHS chart # 4115)
Depth of tenure (m)	10.0 – 23.0	• Relative to vertical chart datum (lowest normal tide). • approximately 20 m at center of cage array.

Characteristic	Rams Head # MF-0509	Additional Information
Current speed (cm/s)		
• **Surface**	0.1 – 26.6	• Surface currents measured at 17 m from bottom.
• **Midwater**	0.2 – 24.6	• Midwater currents measured at 11 m from bottom.
• **Bottom**	0.1 – 22.9	• Bottom currents measured at 4 m from bottom.
Salinity (PSU)	30 – 33	• Depth-averaged salinity measured at Prince 5 station.
Temperature (°C)	0.7 – 15.9	• Measured from August 2007–March 2008 and July 2012 – September 2013 at two nearby aquaculture sites (within 1 km).
Dissolved oxygen (mg/L)	3.5 – 13.0	• Typically above 6 mg/L. • Measured from July 2012–September 2013 at nearby aquaculture site (< 0.5 km). • Generally highest in April – May and lowest in September – October.
Substrate type	Mud, silt, sand, gravel, cobble, boulders, shell debris	*n/a*
Net-pen array configuration	2 x 8	• only 15 of the potential 16 net-pens are planned to be stocked.
Individual net-pen circumference (m)	100	*n/a*
Net-pen depth (m)	8	• Predator nets to 9 m.
Grow-out period (months)	18-24 months	*n/a*
Maximum number of fish on site	400,000	*n/a*
Initial stocking number (fish/pen)	26,666	*n/a*
Average harvest weight (kg)	4.5	*n/a*

Characteristic	Rams Head # MF-0509	Additional Information
Maximum biomass (kg)	1,620,000	• Assumes overall 10% mortality.
Maximum stocking density (kg/m^3)	17.0	*n/a*

Sources of Data

Information to support this analysis includes data and information from the proponent, data holdings within DFO, publicly available literature, and registry information from the *Species at Risk Act (SARA)* database. Additionally, supporting information files submitted to DFO for consideration and used in its review are shown in Table 2.

Table 2. Summary table of information files submitted to Fisheries and Oceans Canada and used in the Science Response process.

Description	Filename
Proposed development plan package	1) MF-0509 New Site App. section 1 of 3.pdf 2) MF-0509 Signed Site Development Plans.pdf
Proposed production plan	1) Rams Head DAAF PBS application July_19 (signed).pdf 2) Rams Head DAAF PBS Diagram June_19.pdf
Baseline survey data submission	1) Rams Head Baseline Report June 7_19.pdf
Proponent-collected current meter data	1) Beaver Harbour Raw Direction & Speed Data.xlsx 2) MF-0509 Current Profile Report, April 3, 2019.pdf

The following DFO databases were searched for species records within the predicted exposure zones (PEZs) of the proposed sites and records are in Appendix A:

- Maritimes Research Vessel (RV) Survey
- Industry Survey Database (ISDB)
- The Maritime Fishery Information System (MARFIS)
- Ocean Biodiversity Information System (OBIS)
- Whale Sightings Database (WSDB)
- North Atlantic Right Whale Consortium (NARWC) Sightings Database
- Satellite-based Maps of Intertidal Vegetation and Rockweed Presence

Site Description

The water temperature and salinity at the proposed # MF-0509 site are expected to vary on at least tidal and seasonal time scales, and are expected to fall approximately within the observed limits indicated above (Table 1). These limits are likely to change with time due to large scale climate change.

The depth relative to chart datum ranges from approximately 10 m on the eastern side to 23 m at the southwestern corner of the proposed lease (Figure 2). Depths adjacent to the southern boundary of the lease can be greater than 25 m and depths to the immediate east of the lease site exhibit a shallowing toward the nearby intertidal which is approximately 100 m from the lease edge. The intertidal bathymetry is available from the Government of New Brunswick lidar data repository (GeoNB), but was not examined for this assessment.

The wave information provided in the proponent's report is from Jonesport, Maine and is not considered representative of the # MF-0509 site as the buoy is located in open water at depths of 182 m. Therefore, data was obtained from the MSC50 Wind and Wave Climate Hindcast model (Swail et al. 2006) to provide a wave summary for this review. Data were obtained for the grid point 45°N, 66.7°W, which is approximately 10 km offshore of the proposed lease site and the closest grid point (MSC50 hindcast data received on July 12 2021). More detailed analyses of the wave data can be found in Appendix B. The data indicate that the most frequent waves travel from the south-southeast with amplitudes less than 1 m. There is a seasonal variation in the wave field with the largest waves typically occurring in the winter months and amplitudes greater than 4 m possible. Since the predicted waves are at a depth of approximately 60 m, it is anticipated that wave amplitudes will increase as they travel towards the proposed site, due to the shallowing depths. Furthermore, due to the location of the proposed site and the predicted direction of the waves, it is unlikely that the waves will be damped as the bay provides little sheltering.

Current meter data were collected by the proponent from October 9, 2018 to November 19, 2018 near the proposed western lease boundary in approximately 22 m of water (Figure 2). Observations in the current speed data demonstrate there is not significant vertical variation (Table 1). Over the 41-day period that current speeds were measured, the most frequently observed current speeds were between 4.0–6.0 cm/s, with more than 80% of measurements below 10 cm/s. Throughout the water column, the majority of the flow was towards the north, east, and south; there was little observed flow in the westward direction. Current speeds vary due to complexities of the coastline, bathymetry, and seasonal influences that are not captured in the provided current meter data, as the data are from a single location for a limited time period. Preliminary hydrodynamic model results indicate that maximum current speeds can vary seasonally by a factor of 2 and vary spatially by a factor of 4 over length scales of a few hundred meters.

Based on the depth profiles of current speed data, temperature, and salinity at the site, stratification is expected to be weak. Therefore, estimates of exposure zones at the proposed site do not need to consider stratification influences with respect to water current speed selection.

Benthic Predicted Exposure Zones and Interactions

The benthic-PEZ is a first-order estimate of the size and location of benthic areas that may be exposed to the deposit of waste feed and feces released from a site, which can result in organic loading. Additionally, it is assumed that the PE associated with the release of in-feed drugs is also indicated by the potential deposition area of medicated waste feed and feces. Both organic loading and the deposit of in-feed drugs can result in direct habitat and infaunal species impacts on the benthic community and seafloor. These predicted exposure zones are precautionary overestimates used as a tool for identifying, albeit at a larger spatial scale, areas of potential overlap with species and habitats that are sensitive to these exposures.

Benthic Predicted Exposure Zone

The dominant factors that will affect estimations of benthic exposure are farm layout, feeding practices, and oceanographic conditions such as the bathymetry and water currents. Benthic exposure can also occur in relation to the use of bath pesticides, if used, particularly at sites over or near shallow depths such as the proposed site. However, this will be considered in the Pelagic-PEZ and Interactions section of this review.

A first-order estimate of the spatial extent of the benthic-PEZ related to organic effluent and in-feed drugs from the proposed # MF-0509 Rams Head site was calculated. Sinking rates of different particulate materials released from farmed fish (i.e., waste feed and feces) vary, although the distribution of the sinking speeds amongst the released particles is poorly characterized. Therefore, the minimum sinking rate for each category of particle (Table 3), along with the maximum depth within 500 m of the proposed site, and maximum observed mid-water current speed in the proponent's record were used. The fish and, therefore, the release of waste feed and feces are within the 8 m surface layer. Since these particles sink from the net-pens to the seabed, a mid-water current speed was selected as representative.

Table 3. First order estimates of the potential horizontal distances travelled by sinking particles such as waste feed pellets, fish feces, and in-feed drugs and pesticides released from the fish farm (settling rates obtained from literature; Findlay and Watling 1994, Chen et al. 1999, Cromey et al. 2002, Chen et al. 2003, Sutherland et al. 2006, Law et al. 2014, Bannister et al. 2016, Law et al. 2016, Skoien et al. 2016).

Particle type	# MF-0509 Rams Head (maximum depth within 500 may m = 42.5 m			
	Min. sinking rate (cm/s)	Max. observed current (cm/s)	Horizontal distance travelled (m)	PEZ radius (m)
Feed	5.3	24.6	197	375
Feces	0.3	24.6	3485	3663
Fines and Flocs	0.1	24.6	10,455	10,633

A PEZ is a circular zone centered over the middle of the proposed net-pen array and represents the outer limit for potential exposure. The maximum distance from the centre to the edge of the proposed cage-array was added to the maximum possible horizontal distance travelled by a particle (feed, feces, or fines) to obtain the PEZ radius. Although represented by a circle, the benthic footprint is more likely a curved ellipse with a shape that is dependent on local current flow.

The benthic-PEZ does not provide an estimate of the intensity of organic loading within the site, and the zones do not imply that everywhere within the zone has the same exposure risk. The intensity of exposure is expected to be highest near the net-pen arrays and decrease as distance from the net-pens increases, except in areas of anticipated overlaps where cumulative exposures may occur. The feed-PEZ is anticipated to have the greatest intensity of impacts and is conservatively a circle centered on the net-pen array as seen in Figure 4.

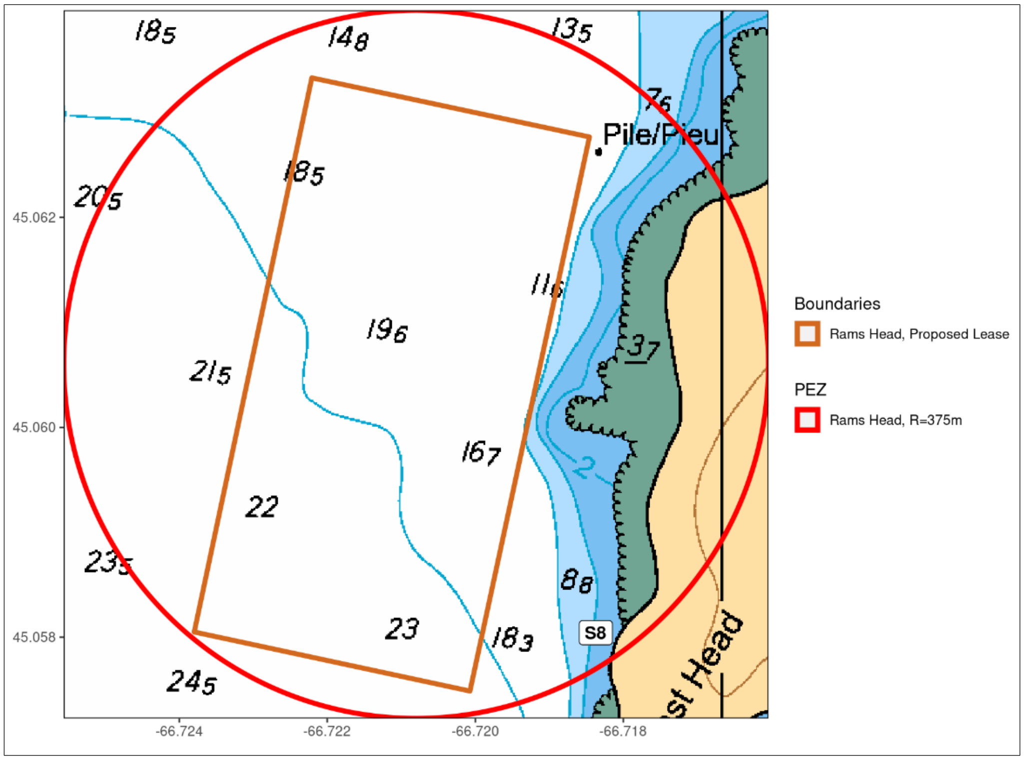

Figure 4. The benthic-Predicted Exposure Zone (PEZ) for the # MF-0509 Rams Head proposed site using the waste feed minimum sinking rate is shown in red overlaid on Canadian Hydrographic Service chart # 4115 (depth is in meters). Seabed survey locations at which early benthic settlement stages of Lobster have been sampled within the benthic-PEZ are also shown. Fisheries and Oceans Canada suction sampling and University of New Brunswick post-larval collector deployments are indicated as Sxx and Cx, respectively.

Based on the feed-PEZ, no overlaps are predicted with the benthic deposition zones of nearby existing leases where smothering and oxic-state changes would occur due to organic loading. However, the spatial extent of the PEZs based on feces provides a better indication of the full area that could be exposed to any in-feed drugs used (Figure 5).

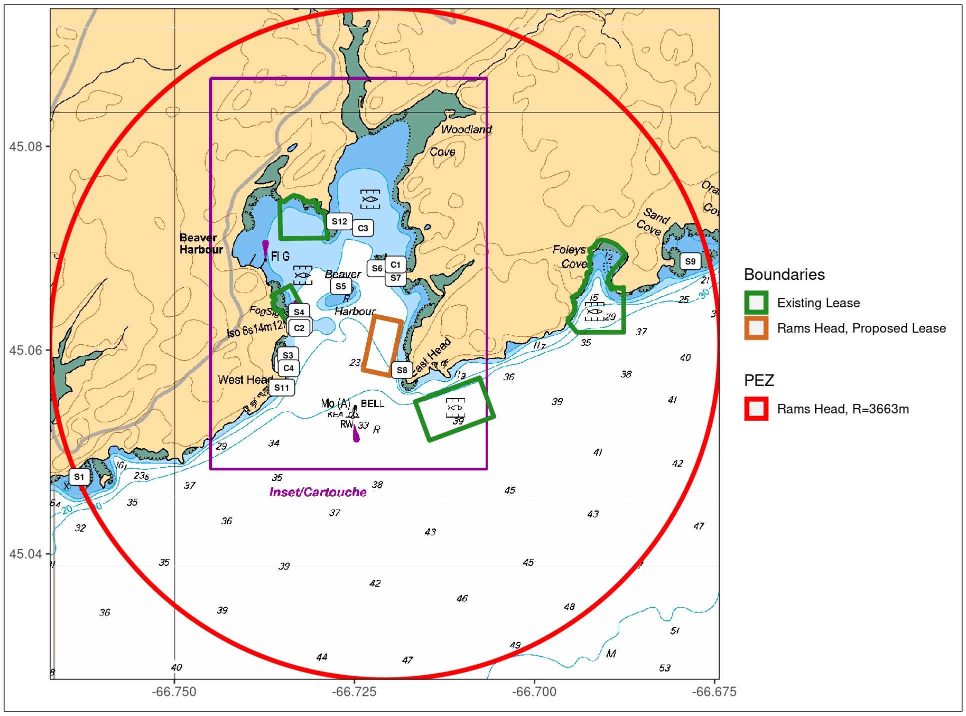

Figure 5. The benthic- Predicted Exposure Zone (PEZ) for the # MF-0509 Rams Head proposed site using the feces minimum sinking rate is shown in red overlaid on CHS chart # 4115 (depth is in meters). Seabed survey locations at which early benthic settlement stages of Lobster have been sampled within the benthic-PEZ are also shown. Fisheries and Oceans Canada suction sampling and University of New Brunswick post-larval collector deployments are indicated as Sxx and Cx, respectively.

It is important to note that, although not done for the purposes of this review, assuming a similar benthic feces-PEZ for the existing leases near the proposed # MF-0509 Rams Head site predicts overlaps in areas of feces deposition, if stocked simultaneously.

The wave amplitudes and periods in combination with the depths in the vicinity of the proposed site suggest that waves could, at times, touch the bottom and induce redistribution of bottom deposits. Current- and wave-induced bottom resuspension is not explicitly considered for these first-order estimates of exposure. However, waste particles are unlikely to extend beyond the benthic-PEZ estimated for fines and flocs. The overall potential impacts of redistribution and flocculant deposition is unknown, but they are not anticipated to occur at levels where significant changes are predicted.

The total benthic area impacted within Beaver Harbour is expected to increase based on the proposed addition in lease area and production at the proposed # MF-0509 Rams Head site.

The existing sites in Beaver Harbour have not been in production since the *AAR* requirement to report the use of in-feed drugs came into effect in 2015, with the exception of # MF-0012 temporarily in 2017.

Susceptible Species Interactions

Species are considered to be susceptible within the benthic-PEZ if they are sessile at any life stage and are sensitive to low oxygen levels, smothering, or exposure to in-feed drugs, if used. This may include species such as crustaceans and bivalves during particular life stages.

Specific consideration was also given to the presence of certain sensitive sessile species, such as sponges, corals, and eelgrass, and critical habitat for *SARA*-listed species in the baseline survey data, scientific literature, and Departmental biological data holdings. When the available data are limited, consideration as to whether the benthic substrate type is suitable for the growth of these species was considered.

Although industry and internal holdings are limited in their abilities to observe all susceptible species in the coastal zone, available data indicate that Lobster, crabs, shrimp, Scallop, clams, Horse Mussels, sea urchins, sponges, and anemones are present within the benthic-PEZ and may be susceptible to the deposition of organic matter and/or in-feed drugs.

As described in the background section of this review, there have been significant Lobster survey efforts in Beaver Harbour over the past 30 years. Initial regional dive surveys conducted in the early 1990s reported Beaver Harbour as having some of the highest Lobster densities in the region (Lawton 1992[1], 1993[2]). In terms of relative abundance, collection dives at Beaver Harbour exceeded 30 Lobsters per 60 minute search effort, and individual survey unit densities were as high as 30 Lobsters per 100 m^2 within the transect surveys. Lobster sizes sampled ranged from < 20 mm CL to > 140 mm CL, with the highest frequency in the 20 to 59 mm CL juvenile range.

Experience from other regional coastal Lobster habitat surveys where repeated surveys have been undertaken, such as in nearby Maces Bay, show that coastal habitat use by Lobster can show consistent patterns over several decades (P. Lawton, DFO, pers. comm.). Specific to Beaver Harbour, both suction sampling and collector tray surveys confirm a 30 plus year settlement signal with high local levels of Lobster (Figure 6).

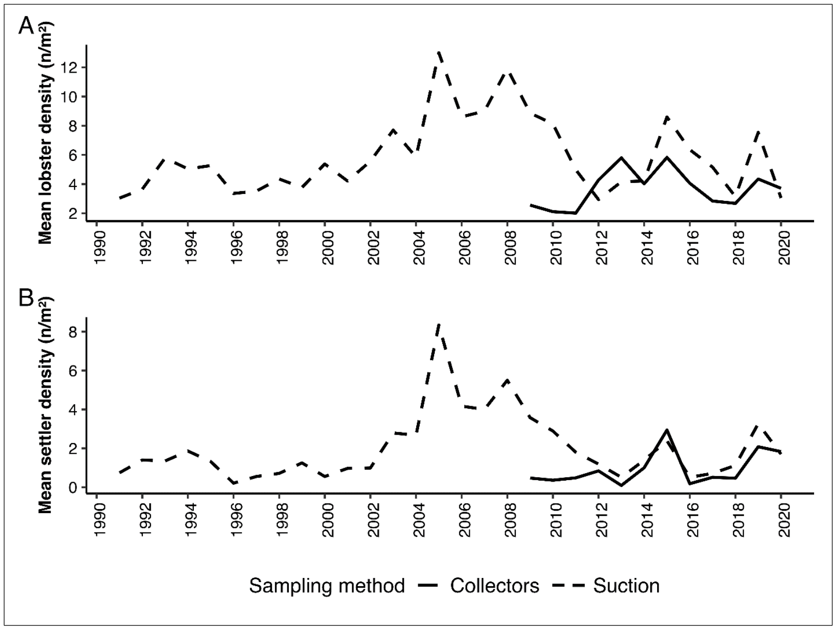

Figure 6. (A) Lobster densities at Beaver Harbour from annual Fisheries and Oceans Canada (DFO) suction sampling surveys (1991-2020; 4 mm - 90 mm carapace length [CL] overall size range; number of 0.25 m^2 quadrats sampled annually ranged from 24 to 69), and University of New Brunswick (UNB) post-larval collector surveys (2009-2020; 4 mm - 54 mm CL overall size range; number of 0.56 m^2 collectors sampled annually ranged from 12 to 28). (B) Lobster settler densities at Beaver Harbour from the DFO suction sampling, and UNB post-larval collector surveys (4 mm – 13 mm CL size range for each time series; sample sizes same as in A).

All survey sampling locations within Beaver Harbour, as well as two outer coast sampling locations (S1, S9), fall within the benthic-PEZ determined for feces (Figure 5), and one survey location (S8) on the fringing rocky habitat directly adjacent to the proposed site falls within the waste feed benthic-PEZ (Figure 4). Additionally, while detailed surveys have not been conducted directly within the proposed lease area, it can be anticipated that juvenile Lobsters initially settling in the adjacent rocky habitat would eventually migrate out onto the deeper habitats within the lease area, and also that juvenile (and adult) Lobsters from other areas would likely migrate into this area seasonally (P. Lawton, DFO, pers. comm.). This means there is direct evidence that highly productive recruitment and juvenile Lobster habitat in Beaver Harbour is at risk of exposure to both waste feed and feces deposition from the proposed aquaculture activities.

While Lobster recruitment and habitat use is not particularly unique to Beaver Harbour for this area, anecdotal dive survey observations from hundreds of locations in the Bay of Fundy along the NB coast suggest restrictions in the availability of this type of preferential hard-bottom recruitment habitat (P. Lawton, DFO, pers. comm.). The degree to which alterations in the benthic habitat due to increased organic matter deposition will impact juvenile Lobster habitat conditions and abundance is unknown.

Exposure to in-feed pest control drugs such as emamectin benzoate and ivermectin through deposition of medicated waste feed and/or fecal excretion will have impacts on Lobster within Beaver Harbour, if used. (Daoud et al. 2018, DFO 2021c). In-feed drugs are not used continuously, but they are persistent in sediments following the end of a treatment period, which may lead to prolonged exposures for benthic species and a potential cumulative effect of multi-chemical usage (DFO 2021c, Strachan et al. 2021). While the exact mechanism of exposure is unknown (e.g., direct consumption, exoskeleton contact, low concentration water exposure, etc.), both emamectin benzoate and ivermectin have been shown in laboratory studies to have toxic effects on juvenile Lobster, including premature moulting, reduced growth rates, and mortality (Burridge et al. 2000, Waddy et al. 2002, Burridge et al. 2008, Daoud et al. 2018, Mill et al. 2021).

Exposure to in-feed drugs will also have impacts on other non-target marine crustaceans in Beaver Harbour. As part of an overall program to assess the utility of surface-deployed post-larval collectors at 72 locations from Rhode Island to Newfoundland, Hunt et al. (2017) examined the occurrence of decapod crustaceans and fishes that either settle into or migrate into the collector trays during summer deployment periods of several months. Catches were examined from 12 shallow (5–18 m depth) collector sites in the lower Bay of Fundy, including three sites in Beaver Harbour sampled in 2008–2009. Nine decapod crustacean taxa were identified, including Hermit Crabs, Rock and Jonah Crabs, Green Crabs, and North Atlantic Spider Crabs. DFO suction sampling surveys also document similar decapod crab species in the samples. Shrimp were the most abundant fauna identified during the proponent’s baseline survey. Individuals were not identified to the species level; however, shrimp species in the area commonly observed during DFO diving for lobster settlement surveys include *Pandalus montagui (*Striped Shrimp*)* and *Crangon septemspinosa* (Sand Shrimp). Additionally, database records of *Pandalus borealis (*Northern Shrimp*)* were found within the pelagic-PEZ (Appendix A). In general, there is not a lot of toxicity data on benthic exposure of crabs and shrimp to emamectin benzoate and ivermectin (Hamoutene et al. 2022), but recent studies provide indications of deleterious effects of emamectin benzoate on *Pandalus platyceros* (Pacific Spot Prawn) (Mill et al. 2021).

Bivalves such as scallops, clams, and Horse Mussels (*Modiolus modiolus*) were also documented within the benthic-PEZ. Horse Mussels provide an ecosystem engineering role in the formation of biogenic habitat conducive to occupation by a wide range of taxa including echinoderms, marine worms, bivalves, gastropods, chitons, holothurians, and ascidans. Elsewhere in the Bay of Fundy, Horse Mussels are found in discrete biogenic habitat formations termed bioherms (Wilson et al. 2021). Protection of these biogenic habitats is a conservation priority within regional marine conservation network planning (DFO 2018). Horse Mussel aggregations have recently been identified within other parts of the Fundy Isles region (Mireault et al.[3] unpublished manuscript). While not present at high local densities sufficient to be classified as Horse Mussel beds, Horse Mussels within the fringing subtidal rocky habitat in Beaver Harbour, and elsewhere along the NB coastline, contribute to the EBSA designation. Bivalves within the benthic-PEZ are susceptible to increased sedimentation and the potential for smothering. In addition, bivalves in the vicinity of net-pens elsewhere have been shown to have measurable quantities of in-feed drugs such as emamectin benzoate. However, available hazard information primarily based on acute exposures does not indicate a high level of risk (Burridge et al. 2011, Strachan et al. 2021).

Sea urchins, sponges, and anemones were other species with a sessile nature that were identified within the benthic-PEZ and are susceptible to smothering. Sea urchins are often present in the shallower areas at the depths suction sampling occurs (5-15 m). While Sea urchins within the benthic-PEZ may be susceptible to smothering, they may also thrive around aquaculture sites, as they can access some of the food and organic waste that is deposited, and can absorb pigments into their gonads. Similarly, sponges and anemones may also thrive around aquaculture sites since they capture food from the water column. Sponges, in particular, may actually help to remove waste from the water column and have been advocated for use in integrated multi-trophic aquaculture farms (Gökalp et al. 2021). However, they are also considered “sensitive and susceptible to anthropogenic activities, including direct (e.g., removal or damage) and indirect (e.g., smothering by sedimentation) fishing impacts” (DFO 2010a). Sponges identified by the proponent during the baseline survey include breadcrumb sponges, fig sponges, and unidentified sponges. Certain sponges can also be considered vulnerable marine ecosystems (VMEs) when present at specific densities (Murillo et al. 2011). The concentration of significance at which point sponges are considered habitat-forming are specific for each area and taxa, and are unknown for this area. It is known, however, that breadcrumb sponges in particular are not unique to the area. Identified anemones include *Hormathia* sp., Northern Cerianthid, and unidentified anemones. *Hormathia* sp. was the most abundant of the anemones identified in the underwater benthic habitat video. While there is little information specifically on *Hormathia* sp. abundance and distribution in the Bay of Fundy, they are known to be quite common on the Scotian Shelf and Slope, and are not particularly unique to Beaver Harbour. Cerianthid anemones, however, are less common and also considered VMEs when present at specific habitat-forming densities (Murillo et al. 2011, Kenchington 2014). Cerianthids can be important even at low densities (1–3 individuals/m^2) as they are larger and would not form tight aggregations due to the need to space out their tentacles. Only one Cerianthid was identified during the proponent-submitted baseline survey throughout the proposed lease; it is unknown whether more exist throughout the larger benthic-PEZ.

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[3] Mireault, C.A., Lawton, P., and Devillers, R. High-resolution spatial distribution modelling of two benthic biogenic species in coastal waters of the Bay of Fundy, Canada. Unpublished manuscript.

Pelagic Predicted Exposure Zones and Interactions

The pelagic-PEZ is a first-order estimate of the size and location of pelagic areas that may be exposed to potentially toxic levels of registered pesticides, if used. Additionally, there may be shallow benthic areas with the potential for exposure. The release of pest control products from a site can result in direct impacts on susceptible species in both the water column and on the seafloor. These predicted exposure zones are precautionary overestimates used as a tool for identifying areas of potential overlap, albeit at a larger spatial scale, with species and habitats that are sensitive to these exposures.

Pelagic Predicted Exposure Zones for Pesticides

The two pesticides available for use in bath treatments (e.g., tarp bath and well-boat) are azamethiphos and hydrogen peroxide. The pelagic-PEZ is calculated assuming use of tarp bath treatments, regardless of whether all net-pens would meet the Pest Management Regulatory Agency (PMRA) treatment conditions for application, given the larger exposure zone anticipated to result from a tarp treatment versus a well-boat treatment.

The size of the PEZ depends on the decay and/or dilution rate of the pesticide, the target treatment concentration, a chosen concentration threshold, and choice of horizontal water current depth. PMRA has assessed that the two registered pesticides (hydrogen peroxide and azamethiphos), and their breakdown products, are expected to remain in suspension since they do not bind with organics or sediments and do not accumulate in organisms tissues. Their half-lives are days to weeks, which influences their persistence in the environment at concentrations considered to be toxic (PMRA 2014, 2016a,b, 2017).

Since the application of tarp bath treatments occurs in the surface waters, the maximum near-surface current speed is used in the calculation of the pelagic-PEZ, and is assumed to persist throughout the duration of the dilution or decay scale (Figure 7).

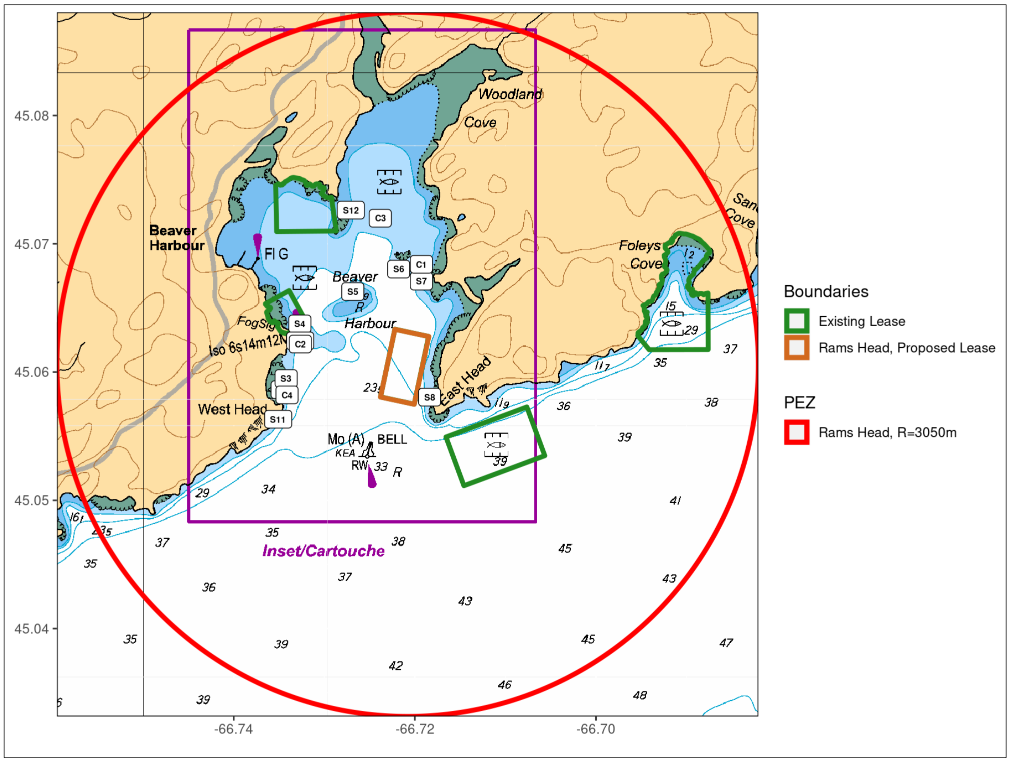

Figure 7. The pelagic-Predicted Exposure Zones (PEZ) for the # MF-0509 Rams Head proposed site is shown in red overlaid on Canadian Hydrographic Service chart # 4115 (depth is in meters). Seabed survey locations at which early benthic settlement stages of Lobster have been sampled within the pelagic-PEZ are also shown. Fisheries and Oceans Canada suction sampling and University of New Brunswick post-larval collector deployments are indicated as Sxx and Cx, respectively.

For both azamethiphos and hydrogen peroxide, the decay rate of the active ingredient is low compared to the dilution rate. Hence a dilution time scale was used to calculate the pelagic-PEZ. The pelagic-PEZ is estimated using toxicity information of azamethiphos, considered the most toxic at the times of registration of the two pesticides (PMRA 2014, 2016a,b, 2017). A three-hour dilution time scale was used to estimate the time required for the maximum azamethiphos target treatment concentration of 100 µg/L to dilute to the PMRA environmental effects threshold of 1 µg/L (DFO 2013a).

The dilution time scale, and hence the size of the pelagic-PEZ, increases as the ratio of the treatment concentration to the threshold concentration increases. The values of threshold concentrations for both bath pesticides have recently been discussed in a Canadian Science Advisory Secretariat (CSAS) peer review process (DFO 2021c, Hamoutene et al. 2022), and they will continue to be reviewed within DFO. Recent literature indicates that hydrogen peroxide is not as benign as initially assumed (Bechmann et al. 2019, Escobar-Lux and Samuelsen 2020, Escobar-Lux et al. 2020, Mill et al. 2021) and may remain above suggested threshold concentrations for longer than azamethiphos. The threshold values for azamethiphos discussed in Hamoutene et al. (2022) and available internationally (SEPA 2019) are lower than the threshold used in this modelling exercise. If new thresholds are adopted, generation of new PEZs for azamethiphos and hydrogen peroxide may be necessary in the future.

The pelagic-PEZ is estimated by adding the horizontal distance travelled to the longest length scale of the proposed net-pen array. For the duration of the dilution time scale, there are concentrations within the pelagic-PEZ above the specific threshold. Not all areas within the pelagic-PEZ have the same exposure risk. The exposure concentration is expected to be highest near the net-pen arrays and decrease as the distance from the net-pens increases, except for in areas of anticipated overlaps where cumulative exposures may occur.

If treatment is used at more than one site in Beaver Harbour simultaneously, exposure overlaps associated with pesticide releases are predicted when assuming similar exposure areas for nearby sites. The proposed addition of another site and additional net-pens in Beaver Harbour may also increase exposure time of susceptible species to pesticides within the area.

Exposures are expected to primarily occur in the pelagic zone; however, areas within the pelagic-PEZ where the bathymetry is less than 10 m may also be at risk of exposure to toxic pesticide concentrations. For azamethiphos, the PMRA restriction on its use at shallow sites (i.e., no application to tarped net pens in water depths ≤ 10 m) may also be applicable to some net-pens at certain phases of the tide.

The existing sites in Beaver Harbour have not been in production since the *AAR* requirement to report the use of pesticides came into effect in 2015, with the exception of # MF-0012 temporarily in 2017.

Susceptible Species Interactions

Species were considered to be susceptible within the pelagic-PEZ if they are known to have sensitivities to pesticide exposures, should treatment be required. Specific consideration was given to the potential for interactions with crustaceans due to their higher relative susceptibility to the pesticides used in aquaculture. Although industry and internal holdings are limited in their ability to observe all susceptible species in the coastal zone, available data indicate that lobsters, crabs, and shrimp are present within the pelagic-PEZ for pesticides.

Azamethiphos is toxic to non-target crustaceans while in the environment, including all larval, juvenile, and adult life stages of lobster (Burridge 2013, PMRA 2016b, 2017). Acute toxicity tests indicate lethality can occur at concentrations that are below the target treatment concentration for azamethiphos over a range of exposure times (Parsons et al. 2020, DFO 2021c, Hamoutene et al. 2022). A recent study of acute toxicity tests with hydrogen peroxide have also documented delayed lethal effects (24h post exposure) on all stages of larval lobster at concentrations that are much lower than recommended treatment concentrations for hydrogen peroxide after only one hour of exposure time (Escobar-Lux et al. 2020). Although dilution is a factor for the use of pelagic pesticides, active ingredients such as azamethiphos and hydrogen peroxide have proven to be more stable in the formulations used which contain additives and, therefore, may lead to prolonged exposures for non-target crustaceans (Strachan et al. 2021).

This is of concern given that while there have been inter-annual changes in Lobster settlement strength (Figure 6), there is now a 30 year plus database of information confirming that Beaver Harbour is a very significant regional Lobster habitat. Consistently, during DFO and UNB Lobster surveys at locations that are within the pelagic-PEZ (Figure 7), recently settled Lobsters (4-5 mm CL) have been recorded in the samples. The finding of very recently settled Lobsters in a sampling location strongly infers that pelagic larval stages would have been in the overlying water column in the preceding weeks to months, as Lobsters do not move significantly over the seabed until at least the year following settlement, and potentially later (Lawton and Lavalli 1995). Based on the historical data, it can be suggested that Lobster larvae, including the fourth larval stage that settles to the seabed, are likely present within Beaver Harbour between July and October, possibly even into November due to climate change shifts in the overall timing of post-larval settlement. This seasonality directly aligns with the months of highest reported treatment use at farms in New Brunswick from 2016–2018 (Chang et al. 2021).

Additionally, Beaver Harbour consists of productive juvenile and adult Lobster habitat, which is also at risk of exposure to toxic concentrations of pesticides that may come into contact with the seabed in the shallow water areas of the pelagic-PEZ. After settlement in October, juvenile Lobsters will be present on the seabed in Beaver Harbour for some time since Lobsters do not move significantly until at least the year following settlement (Lawton and Lavalli 1995). Initial regional dive surveys conducted in the early 1990's reported Beaver Harbour as having some of the highest Lobster densities in the region (Lawton 1992[1], 1993[2]), with the highest frequency of size ranges in the 20–59 mm CL juvenile category. Overall size distributions observed included those of adult Lobsters ranging up to > 140 mm CL. All life stages of Lobster, including adults, are anticipated to be present during the summer months. A seasonal movement is also likely for adult Lobster, as they move to the deeper offshore waters during the coldest months to maintain ideal temperatures, though some will maintain residence over the winter time.

Several other decapod crustaceans have been identified in the area. Shrimp were the most abundant fauna identified during the proponent's baseline survey. Individuals were not identified to the species level; however, shrimp species reported in the area include Striped Shrimp, Sand Shrimp, and Northern Shrimp. Recent acute toxicity studies for both hydrogen peroxide and azamethiphos have documented morbidity and mortality effects on a variety of shrimp species, including Sand Shrimp, Northern Shrimp, and Spot Prawn (Bechmann et al. 2019, Escobar-Lux and Samuelsen 2020, Mill et al. 2021, Hamoutene et al. 2022). Crab species such as Hermit, Rock, Jonah, Green, and North Atlantic Spider crabs were documented during collector tray surveys in Beaver Harbour at shallow sites within the pelagic-PEZ (Hunt et al. 2017). Any crabs that are in shallow areas are at risk of exposure to pesticides that come into contact with the seabed. While there are limited toxicity studies directly related to crabs (Hamoutene et al. 2022), predicted impacts are similar to those of Lobster and shrimp given the targeted mode of action of these substances.

Genetic Interactions

The proposed lease is physically located within the oBoF Designatable Unit (DU) of wild Atlantic Salmon and Salmon Fishing Area (SFA) 23. Across their reported range, escaped Atlantic Salmon have been detected in rivers at distances up to approximately 900 km from the nearest aquaculture site (Jensen 2013), although dispersal distances of 200–300 km are more typical (Morris et al. 2008). Thus, rivers in the iBoF (SFA 22 and 23) and SU (SFA 21 and 22) DUs, many of which are within 200 km of the lease site, could be impacted by escaped farmed Salmon. OBoF and SU Atlantic Salmon population levels remain critically low and have been assessed as Endangered by COSEWIC since 2010. The iBoF DU is listed as Endangered under Schedule 1 of the *Species at Risk Act*. All three groups of Atlantic Salmon are considered to be biologically unique and extirpation of any of them would constitute an irreplaceable loss of Atlantic Salmon biodiversity (Gibson et al. 2011).

Escapes have been identified as an ongoing threat to the genetic integrity and persistence of wild Atlantic Salmon populations (Forseth et al. 2017, Bradbury et al. 2020a and 2020b, Glover et al. 2020). Escapes of Atlantic Salmon from finfish aquaculture sites occur regularly, including in Atlantic Canada (Glover et al. 2017, Keyser et al. 2018, Diserud et al. 2019), and the true number of fish that escape are estimated to significantly exceed the number reported (Skilbrei et al. 2015, Mahlum et al. 2020, Føre and Thorvaldsen 2021). Escaped Atlantic Salmon have been found in Canadian rivers at distances of up to 200–300 km from the nearest aquaculture site (Morris et al. 2008), and escapees may continue to pose a threat to wild Salmon for several years after escape (Aronsen et al. 2020). Recent genetic studies have documented widespread hybridization between wild Atlantic Salmon and aquaculture escapees across the natural range of wild Salmon, notably in Scotland (Gilbey et al. 2021), Norway (Karlsson et al. 2016) and Newfoundland (Wringe et al. 2018, Sylvester et al. 2019). These interactions can occur over large areas and escapees can represent a significant portion of a population's annual production (Glover et al. 2013, Heino et al. 2015, Glover et al. 2017, Sylvester et al. 2018, Wringe et al. 2018). Across the North Atlantic, the magnitude of genetic impacts on wild populations due to escaped farmed Atlantic Salmon has been correlated with the biomass of farmed Salmon in net-pens and the distance between net-pens and rivers, as well as the size of wild populations (Keyser et al. 2018).

Direct genetic (i.e., reproductive) interaction between escapee and wild Atlantic Salmon can have negative impacts on the wild population (Glover et al. 2012, 2017). Both experimental and field studies have demonstrated decreased survival of hybrids in the wild (Fleming et al. 2000, McGinnity et al. 2003, Sylvester et al. 2019), and recent modeling indicates that population declines and loss of genetic diversity are likely when the percentage of escapees in a river relative to wild population size exceeds 10% annually (Castellani et al. 2015, 2018, Sylvester et al. 2019, Bradbury et al. 2020a). Recently, several modelling approaches have been used to estimate the impact of aquaculture production and escapees on wild Atlantic Salmon populations, as follows:

1. Propagule pressure
2. Individual-Based Salmon Eco-Genetic Model
3. Spatial dispersal of escapees

Propagule Pressure

Propagule pressure has been adapted from invasive species research where it represents the intensity of human-mediated species introductions. Propagule pressure has been used previously (e.g., Keyser et al. 2018) to quantify the intensity of aquaculture production on a river-by-river level assessment, where it was found to correlate with both numbers of escapees and levels of hybridization. Propagule pressure is calculated separately for each river and uses geographical coordinates of all farms and river mouths, farm-level production (i.e., number of fish stocked), and a distance function for each farm to each river (Keyser et al. 2018). This model makes no assumptions about Salmon behaviour or mortality and, therefore, represents a geographical relationship between all farms and rivers. Propagule pressure was calculated for both the current stocking levels, as well as with the proposed Beaver Harbour site in operation (Keyser et al. 2018; see methods in Appendix C). With the proposed expansion, while those rivers in proximity to the expansion site will see the greatest increase, the propagule pressure experienced by nearly all rivers in the Maritimes Region will rise (Figure 8). Propagule pressure for rivers within 200 km of the proposed sites will increase by an average of approximately 1.2%, those within 100 km by an average of approximately 1.38%, and those within 50 km by an average of approximately 1.44% (Figure 8). The percent change in propagule pressure that would be brought about by the establishment of the Beaver Harbour facility is a direct reflection of scale of existing aquaculture production in the area; the Passamquoddy Bay and Southwest New Brunswick region is the area with the majority of the aquaculture activity in the Canadian Maritimes Provinces, and it is responsible for approximately two thirds of the Atlantic Salmon production in the area in 2020. However, given the findings of Keyser et al. (2018) that propagule pressure correlates with both numbers of escapees and levels of hybridization, any increases are expected to result in further impacts on wild populations and may hinder future recovery efforts.

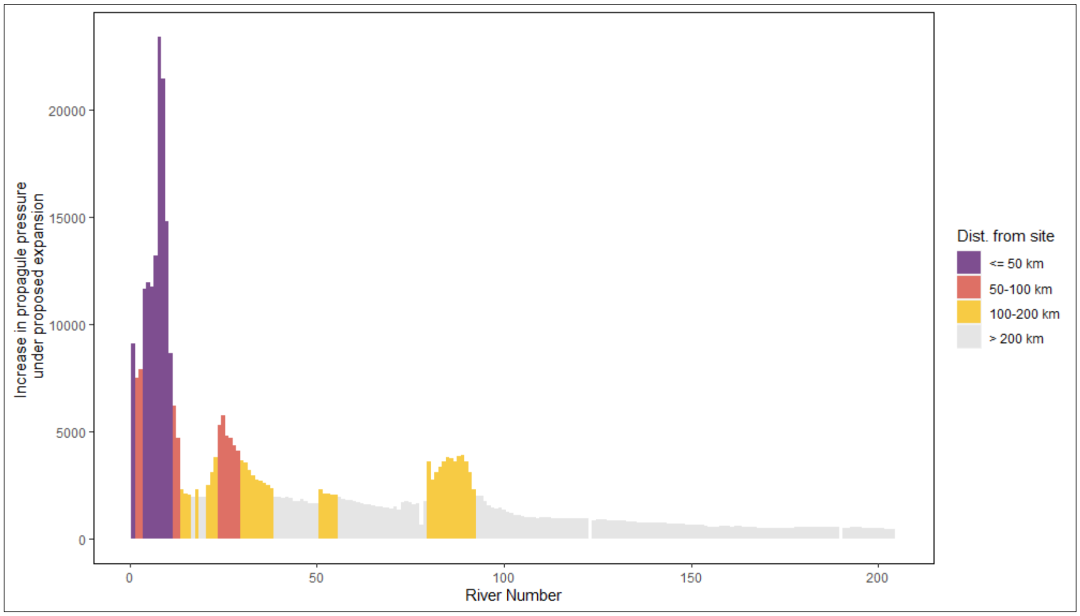

Figure 8. Increase in propagule pressure for select rivers within the Maritimes Region. Propagule pressure was calculated as per Keyser et al. (2018). The proposed expansion is located between the Magaudavic (River Number 7; approximately 30.3 km) and Pocologan rivers (River Number 8; approximately 17.1 km). Rivers are plotted west to east around the coast from the St. Croix River in Charlotte County (River 1), NB to the Salmon River in Victoria County in NS (River 204). Rivers are coloured by categorical distance from the proposed Beaver Habour site. River names and corresponding river numbers are given in Supplementary Table C1 in Appendix C.

Individual-Based Salmon Eco-Genetic Model

To assess demographic and genetic impacts of aquaculture escapees on wild Salmon populations, the Individual-Based Salmon Eco-Genetic Model (IBSEM; Castellani et al. 2015) used by Bradbury et al. (2020a) in Newfoundland was adapted for the current context. The model is summarized elsewhere in detail (Castellani et al. 2015, 2018, Sylvester et al. 2019, Bradbury et al. 2020a) but, briefly, it models changes in abundance, genotype, and individual size in response to the introduction of domesticated individuals. The model considers the duration of invasion by farm escapees, wild population size, number of invaders, environmental conditions, individual size, genotypic and phenotypic and fitness differences between individuals of farm and wild origin. Simulations show the impact on abundance and genetic change during the invasion period, as well as after the invasion has been “turned off”, to assess the potential for recovery in these two measures. The IBSEM was re-parameterized to simulate the Tobique River for environmental and life-history data. The Tobique River was chosen because it is the river in the Maritimes Region for which the most parameters for IBSEM were available. Other values to parameterize the model were taken from the best available data from the literature across the range of Atlantic Salmon. Invasions of 1–100% of the wild population per year were modelled and the results were compared to a zero-percent invasion baseline.

In agreement with what was found by Bradbury et al. (2020a) for Newfoundland, the number of returning spawners was found to decline during the invasion period, but then returned relatively quickly to the zero-percent invasion baseline during the recovery period at proportions of escapees between 2.5 and 10% of the wild population per year (see Figure C1, Appendix C). Above 10% escapees per year, the number of returning spawners declined during the invasion period, and were either slow to return, or did not fully return to the zero-invasion baseline during the 100 year recovery period (see Figures C1 and C2, Appendix C). The magnitude of decline in abundance was found to increase with the proportion of escapees entering rivers, and declines were continuous while invasions were occurring.

Within the model, wild individuals have genetic values approaching one, and farmed individuals values approaching zero. Therefore, if the population genetic average declines, this indicates the population is becoming genetically more “farm-like”. Like for the abundance above, if the average genetic value falls below the 95% confidence interval of the zero-percent invasion baseline, a genetic impact has been observed (Bradbury et al. 2020a). Compared to demographic impacts, genetic impacts were found to occur at a lower proportion of escapees, and to require a longer time to recover (if at all). At 2.5% or greater of escapees, compared to the wild population, genetic impacts were detected during the invasion period (see Figure C3 and C4, Appendix C). At levels of 7.5% and above, genetic impacts never fully recovered back to levels observed in the zero-percent invasion baseline during the 100-year recovery period (Figure C3 and C4, Appendix C). Like demographic impacts, genetic impacts were also shown to increase with the proportion of escapees entering rivers, and the genetic impacts increased while invasions were occurring.

Two thresholds of proportion of escapees in rivers were chosen, one representing lower impact, and a higher threshold above which the IBSEM simulations suggest lasting demographic and genetic impacts are likely. The IBSEM simulations suggest that at percentages of invasion of 5% or less, demographic and genetic recovery was likely within 100 years of escapes stopping. A more conservative proportion of escapees in rivers of 4% was chosen for the lower threshold, consistent with those that have been previously used in a CSAS aquaculture siting review (DFO in press). An upper threshold of 10% was chosen because the IBSEM simulations suggest that populations experiencing this or greater levels of invasion were likely to suffer lasting demographic and genetic impacts even if escapes stopped (see Figures C1-C4, Appendix C). Between these two thresholds, the IBSEM results suggested that during the simulated 100 year recovery period following the cessation of escapes, demographic recovery was likely, but genetic recovery may not fully occur (Figures C1 and C3, Appendix C). This upper threshold is also consistent with that of another CSAS aquaculture siting review (DFO in press).

Spatial Dispersal of Escapees

Dispersal of escapees from aquaculture facilities was modelled using the model of Johannsson et al. (2017), as described in Bradbury et al. (2020a). Briefly, this model incorporates the best information on local levels of aquaculture production, rates of escape, survival, behaviour, environment, and size of wild populations. The model output is the proportion of escapees (as a function of wild population size estimates) within a given river. Previous estimates from this model have been shown to be consistent with observed levels of hybridization (Bradbury et al. 2020a). Salmon populations in all rivers are assumed to be at 5% of the conservation egg requirement (CER; Gibson and Claytor 2012), a value that is consistent with the best available estimates (DFO 2020b), and percentages of escapees are calculated relative to these values. At current production levels, that is without the proposed Beaver Harbour site in operation, the dispersal model predicts that a large number of rivers in the Maritimes Region are expected to be above both thresholds (Figure 9). This includes rivers in the oBoF, iBoF and SU DUs, as far east as far as Pennant River, near Halifax (Figure 9).

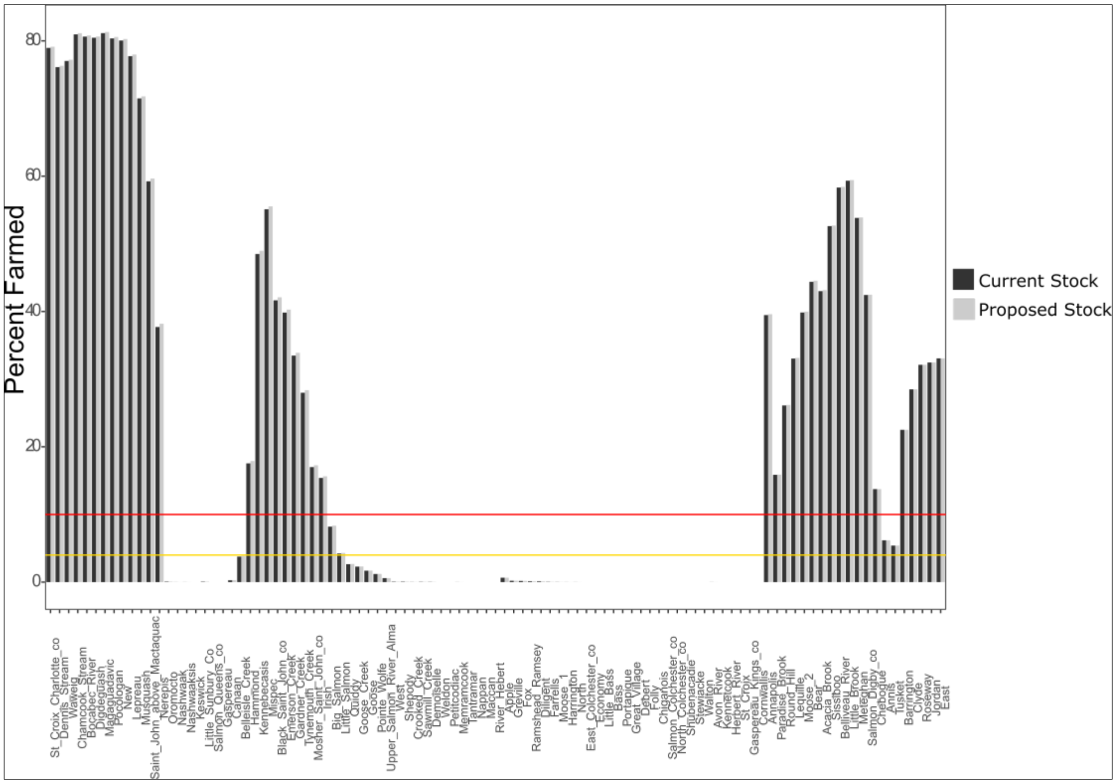

Figure 9. Predicted percent farmed Salmon in selected rivers, arranged west to east, within the OBOF, IBOF and SU DUs. Rivers displayed such that those within 200 km of the proposed Beaver Harbour site are included (refer to Figure 8). Expected proportions under current stocking numbers are shown in black. Expected proportions with the proposed Beaver Harbour site in operation are shown in grey. The horizontal yellow and red lines are the 4% and 10% thresholds. The proposed expansion is located between the Magaguadavic and Pocologan Rivers. Salmon populations in all rivers are assumed to be at 5% of the conservation egg requirement.

Compared to current production, the dispersal model predicts that the proposed expansion would result in an increase of about 1% in the number of escaped farmed Salmon entering rivers. With the proposed new site in operation, most of the rivers within 200 km on either side of the proposed Beaver Harbour site would see an increase in the proportion of farmed Salmon (Figure 9). That said, based on wild populations at 5% of the CER, and because of the existing scale of the aquaculture industry in the area, most rivers in the vicinity of the proposed Beaver Harbour site are predicted to already be above the 4 and 10% thresholds. Thus, the proposed Beaver Harbour site is not predicted to result in rivers changing thresholds (Figure 9). However, because the IBSEM model suggests that demographic and genetic impacts will increase with the proportion of escapees entering rivers, for all rivers in which the dispersal model predicted increases in percentage of escapees, greater impacts on the wild populations are likely. Increases in escapees may also hinder any future recovery efforts.

One of the closest rivers to the proposed Beaver Harbour site is the Magaguadavic, which is also the site of a fishway that has been monitored annually by the Atlantic Salmon Federation since at least 1992. Between 1992 and 2019, escaped farmed Salmon have been found in the fishway, and reproduction of escaped females has been documented in this river (Carr et al. 1997). Since 2000, about 80.9% of Salmon at the fishway have been farm escapees. This compares favourably to the dispersal model that predicts, at current production, the percentage of escapees in the Magaguadavic is 81.1%. While only a single location, this is the best information available on the number of escapees that enter rivers in proximity to the proposed Beaver Harbour site, and suggests the dispersal model results are reasonable.

Consideration of Potential Genetic Impacts and Local Population Conservation Status

Keyser et al. (2018) found that the number of aquaculture escapees and their genetic impact was positively correlated with propagule pressure. The IBSEM results shown here, and in Bradbury et al. (2020a), indicate that both the genetic and demographic impact of aquaculture escapees increases with their proportion in rivers. Given that both propagule pressure and proportion of escapees in rivers will increase with the proposed addition of a site in Beaver Harbour, it is likely the genetic and demographic impact from escapees impact will also increase as a result of the expansion.

Additionally, it is important to note that even where the direct genetic impacts of hybridization or introgression between wild and escapee Salmon does not occur, impacts on the wild population are still possible. A recent review has highlighted the potential for ecological interactions, including competition, predation, and introduction of disease or parasites, to change the selective landscape, resulting in changes to fitness-related allele frequencies (Bradbury et al. 2020b). Ecological interactions may also lead to reduced wild Atlantic Salmon population size and consequently reduce their genetic diversity. Reduced population size and genetic diversity would in turn lead to increased susceptibility to genetic drift and impact of stochastic events.

For the purpose of regional monitoring, DFO uses index rivers as proxy for the status of the DUs in which they are located (DFO 2020b). The index populations for the oBoF DU and SFA 23 are the Saint John River (above Mactaquac Dam) and the Nashwaak River (a tributary of the Saint John, downstream of the Mactaquac Dam). The Saint John and Nashwaak rivers are located approximately 65 and 192 km, respectively, from the proposed site. In 2018, the returns to these rivers were low, and the predicted egg depositions were the lowest on record at 1% and 2% of the CER for the Saint John River and Nashwaak River.

The index river for the SU DU and SFA 21 that is closest to the proposed site is the LaHave River. Annual adult counts have occurred on the LaHave since 1970 at the Morgan Falls fishway (representing 51% of the total Salmon rearing habitat of LaHave River). In 2019, monitoring efforts indicated that adult salmon returns to Morgan Falls were among the lowest returns on record, at 4% of the CER (DFO 2020c). The total counts at the Morgan Falls fishway have been below 250 individuals since 2012, with fewer than 100 returning Salmon in four of those years (DFO 2020c). Recreational angling data from 1984–2008 indicate similar, if not more severe, declines in other SU rivers (Gibson et al. 2009a) prior to the complete closure of Atlantic Salmon angling for all rivers in SFAs 20 and 21 in 2010. For the LaHave River, the proposed expansion would be expected to increase the propagule pressure by about 0.75%, which is not unexpected given its distance from the proposed site. At about 394 km from the proposed Beaver Harbour site, the LaHave river is outside the modelled dispersal distance, thus the dispersal model predicts no change in the proportion of escapees.

Aquaculture has been identified a threat to recovery of the SU (DFO 2013b), oBoF (DFO 2014a) and iBoF (Amiro et al. 2008) Atlantic Salmon populations. Based on the critically low levels of

Salmon in these DUs (including the *SARA*-listed iBoF), minimizing impacts to wild Salmon is crucial. To minimize the impacts, mitigation measures that decrease the likelihood of a breach of containment are important, including physical containment and biocontainment measures. These have been reviewed as part of a 2013 CSAS peer review meeting specific to the use of European origin fish, but they are equally applicable to all marine finfish aquaculture (DFO 2013c, Benfey 2015, Bridger et al. 2015).

The models used suggest that due to the scale of the existing aquaculture industry in the region, many rivers are already well above the thresholds at which demographic and genetic impacts may already be occurring (Castellani et al. 2015). The model-predicted increases in propagule pressure and escapees, while small, are an increase above the already high background levels. This suggests the impacts on the wild Atlantic Salmon populations in the oBoF, iBoF and SU DUs will be greater, than at present, with the proposed Beaver Harbour aquaculture site in operation.

Pest and Pathogen Interactions

Cultured fish may acquire endemic diseases and/or parasites, such as sea lice, from wild fish or from other farmed fish in the area (DFO 2014b). Density-dependent transmission is observed in many host-pathogen systems, including sea lice on salmonid farms (Frazer et al. 2012, Kristoffersen et al. 2013). This can pose a significant health risk to farmed and wild fish when pathogen or parasite loads exceed certain levels, which may be reached faster with more hosts in an area (Krkošek 2010).

NBDAAF established six aquaculture Bay Management Areas (BMAs) in the Bay of Fundy in 2006 to allow for a coordinated approach to the management of fish health. The goal of these boundaries are to provide water separation based on considerations including proximity between farms, pathogen spreading dynamics, and current speeds that will disperse and dilute pelagic particles released from these farm sites (Chang et al. 2007, DFO 2010b). The proposed site is located in BMA 3a (Figure 1).

Sea lice has historically been a concern for finfish farms in New Brunswick. The existing sites in Beaver Harbour have not been in production for a full grow-out cycle since implementation of the requirement to report the use of pest control products under the *AAR*. Annual Sea Lice Management Reports from BMA 3a do indicate sea lice issues resulting in the use of pest control products and other treatment types during the last stocked production cycle (Table 4).

Table 4. Summary table of information reported in New Brunswick Annual Sea Lice Management Reports by Atlantic Canada Fish Farmers Association (ACFFA) during the most recent production cycle (2017-2019 for Bay Management Area [BMA] 3a) (accessed on June 14 2021).

Year & production stage	Maximum # of adult female lice per fish in BMA 3a	Treatment description as reported by ACFFA
2017 – smolt stocked	approximately 8 (December)	Treated with in-feed products primarily. Several fall bath treatments primarily with Salmosan.
2018 – second year fish	approximately 29 (October)	There were nine warm water treatments and six water pressure treatments. Starting in early

Year & production stage	Maximum # of adult female lice per fish in BMA 3a	Treatment description as reported by ACFFA
		September, seven bath treatments with Salmosan.
2019 – pre-market/harvest fish	approximately 16 (March)	There were no bath treatments.

Linking back to historical trends may not be a predictor of future disease outbreaks, as production within the bay and BMA increases or as other influencing factors change, and the exact level of sea lice abundance per site is unknown. The addition of another site and more farmed fish towards the western end of the BMA could lead to increased risk of pathogen and sea lice outbreaks to levels that require treatment. The addition of farmed fish to an area can reasonably be expected to amplify both endemic pathogens and pests in that area, due to the increase in the number of host fish. However, the impact on wild susceptible fish species will depend on the duration and extent of their exposure to the proposed site, the increased concentration of pathogens and parasites, and their relative susceptibility to infection and disease within the environmental conditions found in the area, which may vary among DUs.

The limited available data on Atlantic Salmon migration in this area suggest that wild iBoF post-smolts do migrate near the area, while oBoF post-smolts do not (Lacroix 2013). It is unknown if SU Atlantic Salmon post-smolts, or if adult Atlantic Salmon that return to the Bay of Fundy, migrate near this area. Exact proportions and residence time of wild Atlantic Salmon near aquaculture sites or within areas of exposure to pests and pathogens generated and/or amplified by sites in the Bay of Fundy is unknown; however, Atlantic Salmon residency near the proposed site appears transient. It is anticipated that the exposure time at the proposed site will result in a low risk of infection, particularly in adult Salmon. Any sea lice that may be transferred to adults returning to this area will drop off and die once the adults enter freshwater. The limited data available to date indicate that there is no evidence of pathogen transfer from open net-pens to wild Atlantic Salmon in the Bay of Fundy (Teffer et al. 2020). It should be noted that escaped farmed Salmon may also serve as a vector of pathogens to wild Salmon in the marine and freshwater ecosystems (e.g., spawning grounds), though the risk that escapees pose to wild Salmon for the transfer of pathogens remains unknown.

Physical Interactions

Potential interactions associated with the placement of infrastructure at aquaculture sites include entanglement of wild species (e.g., marine mammals, turtles, sharks), loss of access to habitat, and displacement of traditional fishing activities.

SARA-listed marine mammal, sea turtle, and shark species potentially within the area include North Atlantic Right Whale, Blue Whale, Fin Whale, Leatherback Sea Turtle, and White Shark. North Atlantic Right Whale, Blue Whale and Fin Whale frequent both offshore and coastal waters, particularly to feed and mate. The likelihood of these species being in close proximity to the site infrastructure is considered low given the relatively shallow water depths within and near the proposed lease area. Leatherback Sea Turtles have a wide geographic range within Canada and can be found in coastal, shelf, and offshore waters. The Bay of Fundy, however, is not considered important habitat for Leatherback Sea Turtles, and it hosts relatively few foraging Leatherback Sea Turtles during the summer and fall. White Sharks occur in water depths ranging from just below the surface to greater than 1,100 m and across a large geographic area within Atlantic Canadian waters. Available tracking information from tagging studies conducted throughout 2021 did not detect any tagged fish, including White Shark, at the existing # MF-0012 site (unstocked) in Beaver Harbour. However, at least 20 White Sharks were detected at nearby aquaculture sites between Seeley's Cove and Maces Bay, indicating that White Sharks do migrate near this area (M. Trudel, DFO, pers. comm.). However, the transient nature of this species makes it unlikely that infrastructure at the proposed # MF-0509 site will have a significant effect on the White Shark population. To date, there have been no reports of White Shark entanglements in marine finfish aquaculture gear in Atlantic Canada.

Additional marine mammals that make use of the area, and may be at risk of potential entanglement, include Harbour Porpoise, Grey Seal, and Harbour Seal. There are locations of known seal haul-out areas in Beaver Harbour that may be compromised by the continued addition of aquaculture site infrastructure.

The proposed increase in total leased area within Beaver Harbour may result in a loss of access to habitat used by wild Atlantic Salmon populations during various life history stages. Tagging studies have shown that oBoF post-smolts are distant migrants, leaving the Bay of Fundy early and reaching the Gulf of Maine before mid-June (Marshall 2014). However, the majority of iBoF post-smolts are coastal migrants, or residents of the Bay of Fundy, and utilize a migration corridor within 14 km along the New Brunswick coast and off the east coast of Grand Manan Island through to September (Marshall 2014). Historical Atlantic Salmon landings from commercial fisheries indicate that the Bay of Fundy is an important staging area for returning adults, and iBoF adults may reuse the coastal New Brunswick corridor (used by post-smolts) to return to their natal rivers (Marshall 2014). Limited information suggests that reconditioning kelts similarly use this migratory corridor (Marshall 2014). Interaction with the proposed infrastructure and wild Atlantic Salmon is anticipated to be minimal.

Diver observation of the presence of Atlantic Wolffish directly adjacent to the proposed lease boundary indicates the potential for loss of access to habitat used by the species. Although the full extent of presence and use of the area by Atlantic Wolffish is unknown, preferred habitat is typically in much deeper waters and trenches.

There is no information available on Cod and Pollock specifically in Beaver Harbour. However, both species are known to aggregate by size, with some in-shore areas functioning as nursing grounds. While Herring are migratory, it is believed that juveniles stay inshore and use these coastal areas as habitat year round for feeding and as nursery habitat (Reid et al. 1999). Weir fishers have indicated that the presence of active aquaculture sites impacts Herring migration along the coastal areas; however, studies in the Bay of Fundy indicate that Herring have been seen schooling around aquaculture farms, rather than avoiding them (S. Robinson, DFO, pers. comm.).

The proposed addition of an aquaculture site and increase in total leased area within Beaver Harbour may result in physical displacement of active traditional fishing activities in the area such as for Lobster, Sea Urchin, Scallop, Clam, Herring, Mackerel, and a number of groundfish species.

The exact magnitude of exposure and physical interactions between fish and infrastructure at the proposed # MF-0509 site is unknown. However, an addition of a new site to Beaver Harbour suggests a larger potential for interactions with finfish aquaculture infrastructure than currently exists in Beaver Harbour, should these species be present.

Comparison of Potential Anthropogenic Impacts

The entire area of interest surrounding the proposed aquaculture site (# MF-0509) is influenced by human activity (Figure 10). There is a high degree of spatial overlap among all aquaculture sites, as well as with all other human activities occurring in the area of interest (defined as a 5 km radius centered on the proposed lease). The number of activities that overlap the proposed lease is high, with approximately 83% of the area of interest being influenced by four or more co-occurring human activities in any given grid cell (Figure 11). Most human activities are concentrated in the central area of the harbour (Figure 10). Human derived pollution covers the largest spatial area, followed by commercial fishing activities, vessel traffic, and finfish aquaculture.

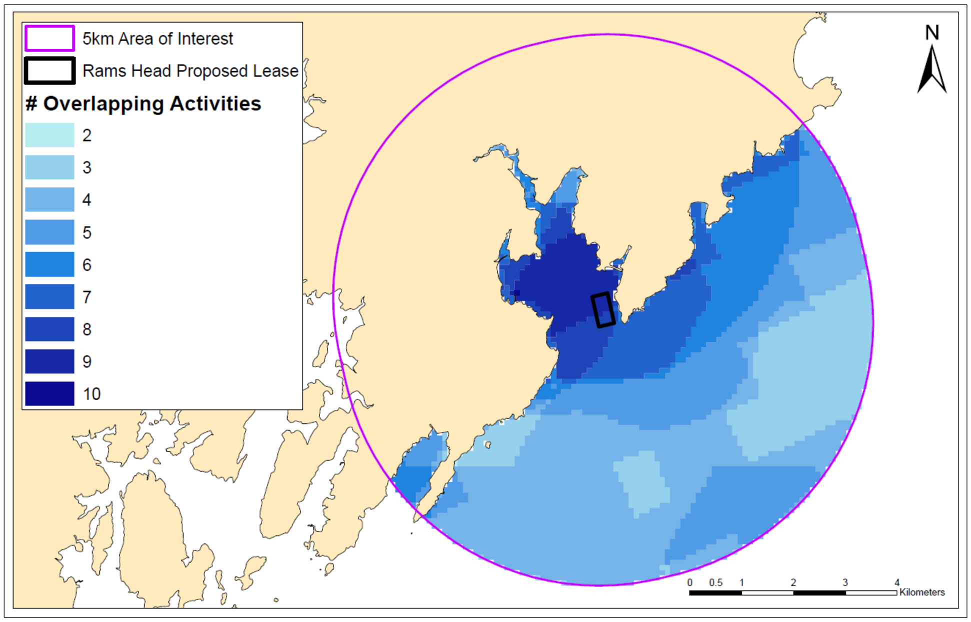

Figure 10. Number of overlapping human activities in each 0.01 km^2 grid cell. The proposed lease boundary is represented by the black rectangle.

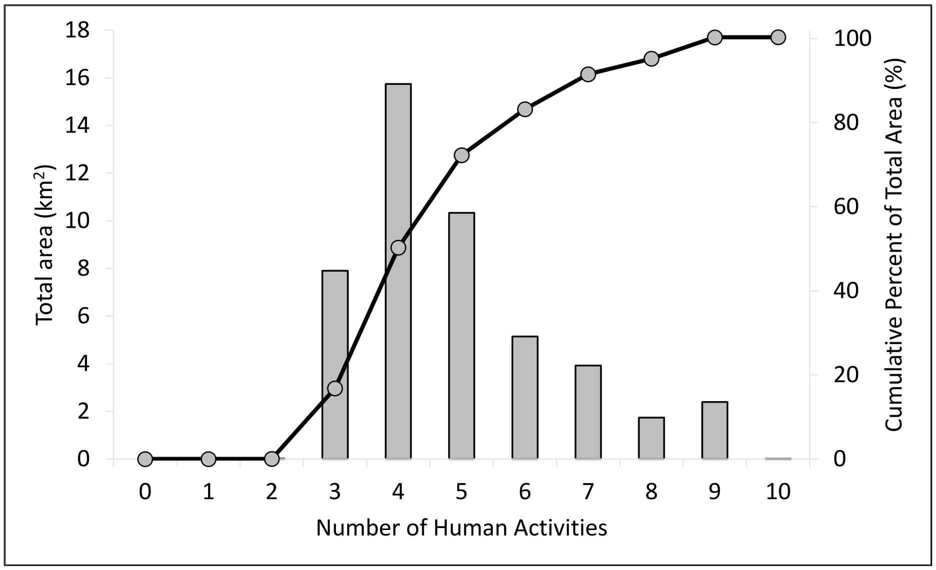

Figure 11. Total area (km^2; grey bars), and the cumulative percentage of the total area (%; black line, grey circles), in all grid cells with the corresponding number of human activities.

Relative cumulative impact scores in Beaver Harbour ranged from 0 to 21.7 (Figure 12); higher numbers indicate areas where cumulative impacts from overlapping human activities are more likely to occur. Despite the central harbour area having the greatest number of overlapping human uses (Figure 10), the highest cumulative impact scores occurred at the mouth of the harbour/southward of the lease boundary and eastward along the coastline (dark red areas in Figure 12). These areas consist of mixed shelf, soft shelf, and soft shallow benthic habitat types, that have spatial overlaps with activities to which they are highly vulnerable (nutrient input, groundfish bottom longline fishing, human derived pollution), activities with very high intensities at these locations (finfish aquaculture, vessel traffic, lobster fishing), or both at the same time (groundfish bottom trawl fishing). Appendix D provides methodology details of this analysis.

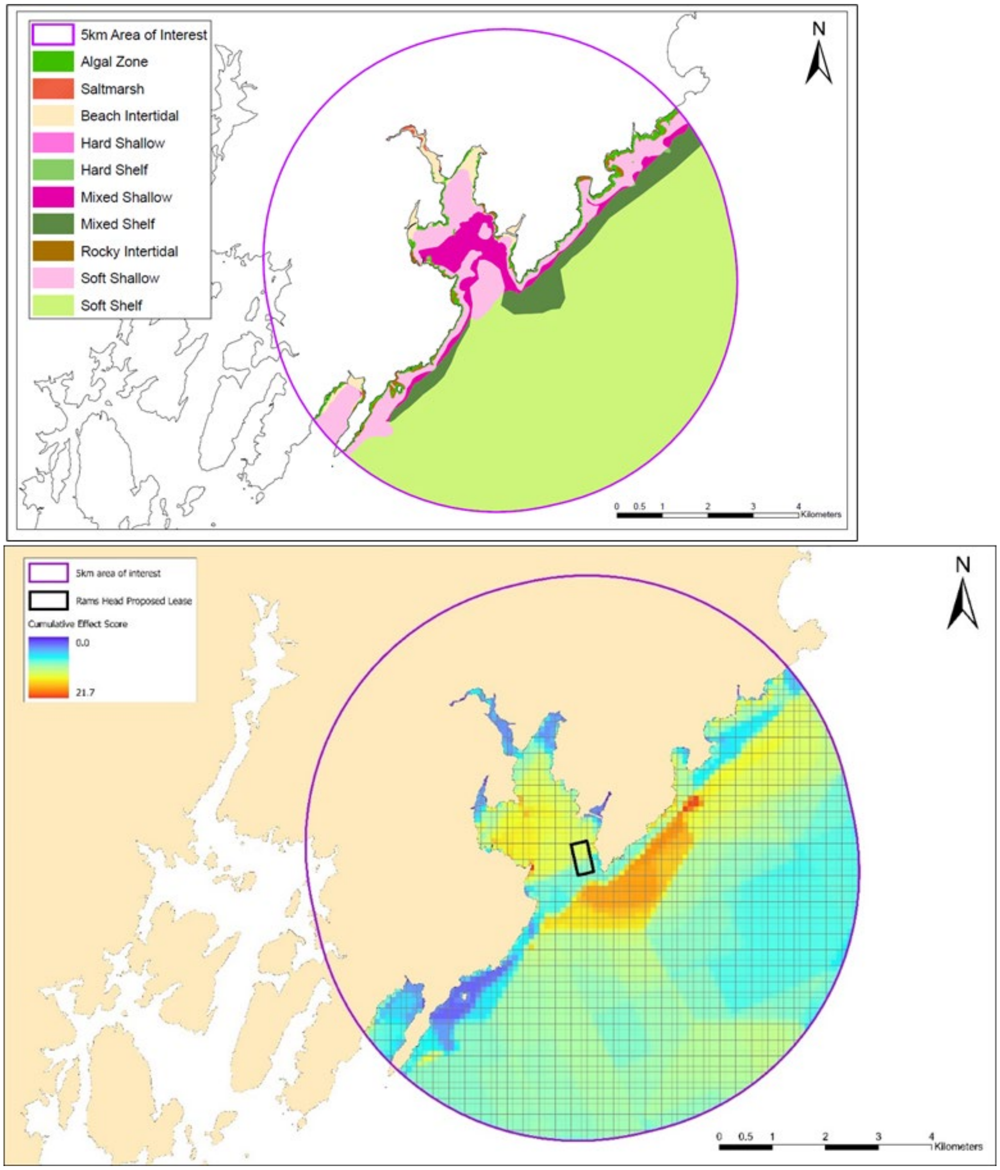

Figure 12. ***Top:*** *Map of habitat classes for Beaver Harbour. The habitat class for shallow pelagic waters are layered on top of the benthic habitat classes within the GIS model and are thus not visible in the map.* ***Bottom:*** *Cumulative impact map for Beaver Harbour. Cooler colours denote lower potential impact; warmer colours indicate higher potential impact. The proposed lease boundary is outlined in black.*

Individually, fishing (three types together comprise approximately 60% of total score), followed by human-derived pollution, vessel traffic, and finfish aquaculture, respectively, made the largest percentage contribution to the total cumulative impact score (Figure 13). While finfish aquaculture contributes <10% to the total impact score (Figure 13), the area around the proposed lease has high and very high relative cumulative impact scores (of which finfish aquaculture is a contributor); the overlap between finfish aquaculture and fishing activities in Beaver Harbour suggests potentially significant impacts on benthic habitats in these areas.

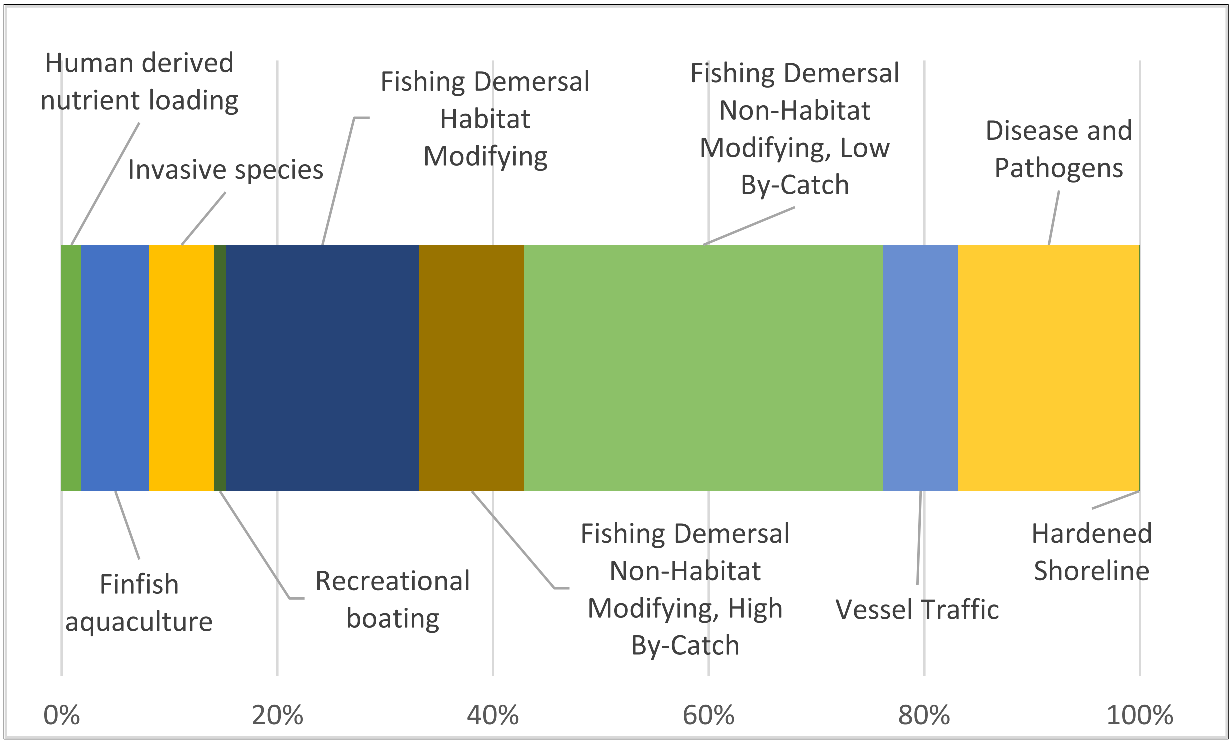

Figure 13. Percent contribution to cumulative impact scores of 10 human activities summed across all habitats. Hardened shoreline value is <0.1% of the total cumulative impact score.

The stressors linked to human activities in the marine environment can be grouped into three main categories: physical (direct alteration to habitats), chemical (effects on water and sediment quality), and biological (changes to non-target species). All human activities considered within this analysis have been linked to more than one stressor, and 8 of these 10 activities have influences across all three categories (Table 5).

Stressors common to finfish aquaculture, commercial fishing activities, vessel traffic, and human derived pollution suggest increases in benthic disturbance and changes to water and sediment quality (Table 5). Increases in biomass removal through incidental mortality may also occur as a result of the cumulative impact of finfish aquaculture, vessel traffic, and commercial fishing (Table 5).

Table 5. Comparison of stressors associated with human activities identified in this analysis. Stressors linked to finfish aquaculture, recreational boating, and land-based activities were summarized from Ban et al. (2010). Stressors linked to hardened shoreline summarized from Perkins et al. (2015), while those linked to invasive species were summarized from Therriault and Herborg (2007). Physical stressors result in direct alteration to habitats; chemical stressors impact water and sediment quality; biological stressors affect changes to non-target species. A dash (-)= not applicable.

		Human activities									
		Marine				**Fishing**			**Land based**		
Stressors		**Finfish aqua-culture**	**Invasive species**	**Vessel traffic**[a]	**Recreational boating**[b]	**Fishing – groundfish**[c]	**Fishing – scallop**	**Fishing – lobster**	**Nutrient loading**[d]	**Human derived pollution**[e]	**Hardened shoreline**
Physical	Benthic disturbance	X	-	X	X	X	X	X	X	X	X
	Collisions	-	-	X	X	X	X	X	-	-	-
	Change in currents/circulation	X	X	-	X	-	-	-	-	-	X
	Light	X	-	X	X	-	-	-	-	X	-
	Marine debris	-	-	-	X	X	X	X	-	X	-
	Noise	X	-	X	X	X	X	X	-	-	-
Chemical	Bacteria	X	-	-	X	X	X	X	X	X	-
	Contaminants	X	-	-	X	X	X	X	-	X	-
	Nutrients	X	-	-	X	X	X	X	X	X	X
	Oil/waste	X	-	-	X	X	X	X	X	X	-
	Organic waste	X	-	-	X	X	X	X	X	X	-
	Sediment transport (turbidity)	X	-	X	X	X	X	X	X	X	X

Stressors		Human activities									
		Marine				Fishing			Land based		
		Finfish aqua-culture	Invasive species	Vessel traffic [a]	Recreational boating [b]	Fishing – groundfish [c]	Fishing – scallop	Fishing – lobster	Nutrient loading [d]	Human derived pollution [e]	Hardened shoreline
Biological	Changes in behaviour (predator or prey)	X	X	-	X	-	-	-	-	-	X
	Biomass removal (incidental mortality)	X	X	X	X	X	X	X	-	-	X
	Diseases, pathogens, and/or parasites	X	-	-	-	-	-	-	-	X	-
	Genetic interactions	X	-	-	-	-	-	-	-	-	X
	Invasive species	X	X	X	X	-	-	-	-	-	X

Most relevant stressor categories from Ban et al. (2010): [a] large boat traffic; [b] combined stressors from small docks, ramps, wharves, fishing vessel, and pleasure boating activity; [c] bottom trawling; [d] agriculture; [e] human settlements.

Cumulative impacts on coastal sediment quality may result from the overlap in marine aquaculture, and groundfish and scallop fishing activity. Sediment plumes created from commercial fishing activities such as bottom trawling and dredging impact local benthic habitat through smothering of benthic communities and increased organic enrichment (reviewed in Fuller et al. 2008). The addition of increased feed and waste products from the production of fish at the proposed site and other nearby marine aquaculture facilities, in combination with these other marine-based sources, suggests a high potential for alterations to the composition, vegetative cover, biomass, and structure of soft sedimentary marine benthic habitats in close proximity to the finfish net pens (DFO 2003,2010b, Cullain et al. 2018).

Both small and large vessels contribute to reduced water quality through pollution, due to leakage of fuels and oils, antifouling paints (containing copper), and inputs of grey water and human waste (sewage effluents) (Leon and Warnken 2008, Tornero and Hanke 2016). Fecal coliform counts, used herein to estimate human derived pollution in coastal waters, has been associated with reduced water clarity and decreased oxygen in coastal ecosystems (Arasamuthu et al. 2017). Anthropogenic nitrogen loading can also impact water quality through increases in chlorophyll *a* concentrations, promotion of nuisance/toxic algae and macroalgae, and reduced dissolved oxygen concentrations (Bricker et al. 2008). These symptoms occur along a continuum that is determined by the magnitude of nitrogen loads, water residence time, and tidal exchange. In addition to contributing to bacterial contamination of Beaver Harbour, the addition of more finfish aquaculture will likely add to the existing anthropogenic total nitrogen loading in the bay (McIver et al. 2018, Kelly et al. 2021), which may also contribute to reduced water quality.

It is well understood that bottom contact fishing gear affects benthic habitat structure, can damage structural epibenthic species, reduces the biomass and diversity of benthic organisms, and causes loss of habitat for other benthic or demersal species (Watling and Norse 1998, Gordon et al. 2002, Henry et al. 2006, Kenchington et al. 2006). Varying in severity by gear type, benthic damage occurs when trawls, longlines, and/or traps contact the bottom, and especially when they are dragged along the seafloor (Fuller et al. 2008, Donaldson et al. 2010). The movement of vessels in shallow waters causes benthic disturbance and destruction due to anchoring and dragging, which are a particular threat to submerged macrophytes (Bishop 2008; Lewin et al. 2019). Finfish aquaculture, through addition or removal of physical structures (ropes, buoys, anchors, etc.) and biological components (fish, fouling organisms), also has the potential to cause disturbance to the benthos (DFO 2010b). The spatial overlap of finfish aquaculture and commercial fishing activities suggests increased benthic disturbance in these areas.

In addition to contributing to bycatch (Fuller et al. 2008, Donaldson et al. 2010), capture fisheries also contribute to abandoned, lost and discarded (ALD) fishing gear. ALD fishing gear poses entanglement risks to marine life and ALD traps and lines can smother or damage seafloor habitat through physical abrasion (Macfadyen et al. 2009). The benthic zone is a sink for marine debris (Galgani et al. 2000), and the Bay of Fundy is no exception. In an assessment of benthic marine debris using seafloor video footage in the Bay of Fundy, Goodman et al. (2020) documented that most debris was found within 9 km of shore, and that 28% of all debris items were attributed to fishing (ropes, lobster traps, bait bags, etc.). While aquaculture-derived ghost gear has not been studied to the same extent as it has from capture fisheries, lost nets and ropes can result in entanglement of pelagic species, or damage to benthic habitats through smothering or abrasion (GGGI 2021). However, the bulk of anthropogenic litter (e.g., cable ties and fastenings, plastic bottles, floats, pieces of rope) derived from aquaculture is likely smaller plastics (GGGI 2021), which can impact the aesthetics and recreational value of nearby beaches and shorelines (Brouwer et al. 2017). Additional sources of ghost gear and anthropogenic litter from new aquaculture activities may also increase disturbance to the benthos and incidental mortality of vulnerable or sensitive species.

While the magnitude of recreational boating traffic is currently unknown, it is likely highly seasonal, following the typical tourist season for New Brunswick (May to October, with peaks in June to August). Further, the overlap with fishing suggests a constant, year-round pressure from fishing boats. Both small boats and large vessels contribute to the secondary spread of non-native species (Darbyson et al. 2009, Clarke Murray et al. 2011). Aquaculture activity adds or removes physical structures (e.g., ropes, buoys, anchors) that can be colonized by diverse biological assemblages and can affect the local ecosystem (DFO 2010b). The invasive tunicates *Botryllus violaceus, Botryllus schlosseri* and *Ciona intestinalis* are already present in Beaver Harbour (Sephton et al. 2017). These tunicates pose a moderate to high ecological risk to biodiversity, MPAs, and shellfish and finfish aquaculture in Atlantic coastal ecosystems (Therriault and Herborg 2007). The combined effect of high boating traffic and aquaculture structures may contribute to the spread and subsequent establishment of other non-native species already present elsewhere in the Bay of Fundy.

Additional Lobster Monitoring Considerations

The potential for aquaculture site interactions to influence the Lobster settlement signal and the long-term efforts of Lobster recruitment monitoring underway in Beaver Harbour is a significant concern that warrants separate mention.

Beaver Harbour is a key site within the overall ALSI collective of Lobster settlement monitoring locations from Rhode Island to Newfoundland. Scientific analysis has documented the influence of regional weather and oceanographic factors leading to some synchronies in settlement strength across sampling locations (Pershing et al. 2013), and projections of future fishery recruitment levels, including potential climate change impacts (Oppenheim et al. 2019). A current project underway at UNB, funded under DFO’s Sustainable Fisheries Science Fund, aims to further develop Lobster settlement indices and modeling tools to forecast changes to fisheries recruitment in three Lobster fishing regions of eastern Canada. The Beaver Harbour settlement time series is the longest-running (at 30 years in 2020) of the three Canadian Lobster fishery-independent settlement monitoring time series being used in this project. Therefore, minimization of risk factors that could potentially influence the signal, such as aquaculture operations in the area, should be a priority consideration for the overall protection of the dataset and the significant long-term scientific efforts undertaken.

Conclusions

Question 1: Based on available data for the site and scientific information, what is the predicted exposure zone from the use of approved fish health treatment products in the marine environment, and the potential consequences to susceptible species?

- Fish health treatment products, if used, may travel distances of up to approximately 3.6 km from the proposed site. Exposure concentrations are expected to be highest near the net-pen array and decrease as distance from the net-pens increases, except for in areas of anticipated PEZ overlaps with existing leases where cumulative exposures may occur.
- Lobsters, crabs, and shrimp have been identified within the PEZs for fish health treatment products, and are susceptible to potential impacts. In particular, Beaver Harbour is known as a habitat of consistent regional significance for Lobster settlement and post-settlement use.

- In-feed drugs have documented toxic effects on non-target crustaceans, including premature moulting, reduced growth rates, and mortality. If used and deposited on the seabed, there is a risk to juvenile and adult Lobster, crabs, and shrimp.
- Azamethiphos is toxic to larval, juvenile, and adult life stages of Lobster. Recent literature also indicates toxic effects of hydrogen peroxide to larval Lobster. If used, there is a risk to high local densities of larval Lobsters present in the water column throughout the summer and early fall months, and juvenile and adult Lobsters in shallow water areas of the seabed.
- Azamethiphos and hydrogen peroxide have documented morbidity and mortality effects on a variety of shrimp species. If used, there is a risk to shrimp present in the water column, as well as shrimp in shallow water areas of the seabed.

Question 2: Based on available information, what are the Ecologically and Biologically Significant Areas (EBSAs), SAR, fishery species, Ecologically Significant Species (ESS), and their associated habitats that are within the predicted benthic exposure zone and vulnerable to exposure from the deposition of organic matter? How does this compare to the extent of these species and habitats in the surrounding area (i.e., are they common or rare)? What are the anticipated impacts to these sensitive species and habitats from the proposed aquaculture activity?

- Organic matter in the form of waste feed may be deposited on the seabed at distances of up to approximately 375 m from the proposed site.
- Exposure concentrations are expected to be highest near the net-pen array and decrease as distance from the net-pens increases. Overlaps in the areas of organic matter exposure due to waste feed from aquaculture sites within Beaver Harbour are not predicted.
- The proposed site is located within the Whole of Quoddy EBSA, identified on the basis of its perceived uniqueness and irreplaceability within the Bay of Fundy.
- Atlantic Wolffish is a SAR that has been observed in close proximity to the proposed site, within the benthic-PEZ. It is unknown if alterations in the benthic habitat due to increased organic matter will impact Atlantic Wolffish habitat and abundance.
- Bivalves within the PEZ, such as Horse Mussels, scallops, and clams, are susceptible to smothering and the potential for oxic state changes. These species are not regionally unique to Beaver Harbour.
- Sea urchins, sponges, and anemones within the PEZ may be susceptible to smothering but may also thrive given the increased availability of depositional organic matter. Identified species are not regionally unique to Beaver Harbour.

Question 3: How do the impacts on these species from the proposed aquaculture site compare to impacts from other anthropogenic sources (including existing finfish farms)? Do the zones of influence overlap with these activities and if so, what are the potential consequences?

- Despite low human population in the surrounding area, Beaver Harbour is influenced by human-derived activities, such as nutrient loading and pollution, vessel traffic, commercial fishing activities, recreational boating, invasive species, and aquaculture.
- The proposed site is located in an area that is anticipated to have high relative cumulative impacts in the immediate vicinity.

- Cumulative impacts of commercial fishing activities, finfish aquaculture, vessel traffic, and human-derived pollution have the potential to affect water and sediment quality, and increase benthic disturbance and incident mortality of benthic and pelagic species.

Question 4: To support the analysis of risk of entanglement with the proposed aquaculture infrastructure, which pelagic aquatic species at risk make use of the area, and for what duration and when?

- SAR identified by DFO's Aquatic Species at Risk Map as having the potential to be in the vicinity, and that may be at risk of entanglement, are North Atlantic Right Whale, Blue Whale, Fin Whale, Leatherback Sea Turtle, and White Shark.
- Preferred bathymetric ranges suggest these species are unlikely to be present near the site infrastructure, with the exception of White Shark that are likely to migrate near this area, as several have been detected at nearby aquaculture sites.

Question 5: Which populations of salmonids are within a geographic range that escapees are likely to migrate to? What is the size and status trends of those conspecific populations in the escape exposure zone for the proposed site? Are any of these populations listed under Schedule 1 of SARA?

- The proposed lease is located within the oBoF wild Atlantic Salmon DU and SFA 23.
- Atlantic Salmon rivers in the oBoF, iBoF, and SU DUs are within the typical range (200–300 km) that escaped farmed fish are known to disperse.
- OBoF and SU Atlantic Salmon population levels remain critically low and were assessed as Endangered by COSEWIC in 2010; annual assessment activities have shown populations remain low. The iBoF DU is listed as Endangered under Schedule 1 of the *Species at Risk Act*.
- Aquaculture has been identified as a threat to the recovery of all three populations. There will be increased genetic and demographic risks to wild Atlantic Salmon with the proposed increase in the number of farmed Salmon within Beaver Harbour.

Sources of Uncertainty

Predicted Exposure Zones

Results of calculations based on the proponent's data are a subset of the full range of potential calculation outputs. The PEZs are based on current meter data provided by the proponent. The proponent-provided current record is from a single location over a 30-day time window. This means that the first-order estimates assume the current is spatially homogenous and seasonally consistent, and are unlikely fully representative of the temporal and spatial variability that may be of relevance to estimating exposure and deposition zones. Available data are often insufficient for assessing the probability of sediment transport to specific areas within the PEZs.

The state of knowledge in relation to refining the assessment of in-feed drug and pesticide predicted exposure zones and impacts is evolving. In particular, the selection of environmental quality standard values to be used as thresholds is evolving with data input and the choice of appropriate processes for inference. These values will also be guided by the determination of clear management goals to be defined by policy makers. Therefore, at this stage, a detailed assessment of potential pesticide and drug impacts was not conducted.

Species and Habitat Distributions

Coastal areas are generally not adequately sampled on spatial and temporal scales of most relevance to aquaculture (i.e., tens to hundreds of meters and hours to months), and information on these space and time scales is typically not contained within the various data sources available to DFO to evaluate presence/use of species and habitats in those areas. Data based on surveys do not fully sample the area spatially or temporally and additional information on presence and habitat use (i.e., spawning, migration, feeding) must be drawn from larger-scale studies. However, Beaver Harbour is one area in which there have been significant efforts to collect long-term monitoring data on Lobster settlement and habitat use patterns at spatial and temporal scales that align with those of various aquaculture activities.

Many species within these hard bottom habitats have cryptic life-history habits, including occupying the undersides of cobbles and boulders and interstitial spaces between physical substrate elements. Many are also of a small size and so not well documented by seabed video surveys, particularly those involving lower resolution imaging systems, low light illumination, and/or seabed video transects conducted with relatively high speeds over the ground. These challenges make this type of habitat particularly difficult to quantitatively survey for Lobsters but represents high habitat suitability for Lobsters.

Noteworthy with respect to the current review is the finding that over 180 taxa across 11 Phyla may settle into complex cobble-boulder habitat, such as that provided when post-larval Lobster collectors are deployed on the seabed within this coastal region (Wilson 2013). There are uncertainties with respect to the full scope of potential aquaculture interactions and all 180+ taxa.

Farmed-Wild Interactions

Apart from monitored index rivers, information is generally lacking on the size and distribution of wild Atlantic Salmon populations. Improved estimates of wild Atlantic Salmon population size and the presence of escapees in Salmon-bearing rivers within Maritimes Region would improve the assessment of genetic and demographic risk. Significant knowledge gaps also exist regarding disease and sea lice infestation levels in wild and farmed salmonids, and monitoring and reporting of these levels would be informative.

Comparison of Potential Anthropogenic Impacts

Fishing (demersal, non-habitat modifying, low bycatch) made the largest contribution to the cumulative impact score (33%) as a result of its broad spatial coverage; the polygon representing Lobster fishing covers the entire area of interest around the proposed lease which is an artefact of these data being mapped on a 10-minute statistical grid (Serdynska and Coffen-Smout 2017). Since it is unlikely that Lobster fishing actually occurs throughout the entire area of interest, the cumulative impact score for this activity is likely an overestimate. Additionally, estimates of human derived pollution also covered the entire area of interest, having been interpolated from point source measurements of fecal coliform counts which had generally low values (intensities) across the area of interest (Canadian Shellfish Sanitation Program; ECCC 2019), and thus are also likely an overestimate. Impacts from recreational boating are likely underestimated, as the spatial distribution and magnitude/frequency of small vessels is currently unknown.

Many regional- and global-scale human activities that may overlap with local-scale activities were excluded from this analysis due to limits on data availability and/or spatial resolution.

Historical activities that may have legacy effects (e.g., sedimentary contamination), impacts from natural disturbances (e.g., storms, marine heat wave), or episodic activities that can create infrequent but intense disturbances (e.g., oil spill) were not included in the current analysis.

Many of these impacts will vary spatially and temporally (e.g., increased boating traffic related to seasonal fishing or recreational activities, increased influx of nutrient loading or urban runoff in spring due to snow melt, etc.), so may only be of concern at particular times of year. Further, little information is available on the acute vs. chronic effects of these stressors (e.g., noise, light, marine debris, changes in currents/circulation).

The geographic extent of human activities is likely a minimum estimate. Buffer distances used in the analysis may be a conservative estimate, as the original studies on which the estimates were based were not designed to measure maximum detectable distances of human impacts. Also, we assumed that the influence of human activities diffuse equally in all directions, although it is more likely that alongshore currents and river plumes influence the diffusion of impacts, particularly close to the coastline.

Overall, the cumulative impact map should be considered a preliminary and conservative estimate of human uses within the area of interest. Despite the limitations outlined above, this mapping exercise can identify areas of particular concern where a high degree of cumulative impacts from multiple overlapping human activities are to be expected.

Contributors

Name	Affiliation
Andrushchenko, Irene	DFO Science, Maritimes Region
Barrett, Melanie	DFO Science, Maritimes Region
Brager, Lindsay	DFO Science, Maritimes Region
Cooper, Andrew	DFO Science, Maritimes Region
Coulson, Mark	DFO Science, National Capital Region
Debertin, Allan	DFO Science, Maritimes Region
Fitzgerald, Jennifer	DFO Regulatory Review, Fish and Fish Habitat Protection Program, Maritimes Region
Greyson, Phillip	DFO Science, Maritimes Region
Haigh, Susan	DFO Science, Maritimes Region
Hamoutene, Dounia	DFO Science, Maritimes Region
Hogan, Derek	DFO Science, Maritimes Region
Howse, Victoria	DFO Science, Maritimes Region
Kelly, Noreen	DFO Science, Maritimes Region
Law, Brent	DFO Science, Maritimes Region
Lawton, Peter	DFO Science, Maritimes Region
McIntyre, Tara	DFO Science, Maritimes Region
McKellar-Regnier, Catriona	DFO Science, Maritimes Region
McWilliam, Sherisse	DFO Science, Maritimes Region
Murphy, Grace	DFO Science, Maritimes Region
Nasmith, Leslie	DFO Science, Maritimes Region
O’Flaherty-Sproul, Mitchell	DFO Science, Maritimes Region
Page, Fred	DFO Science, Maritimes Region
Parker, Edward	DFO Aquaculture Management, Maritimes Region
Raab, Dustin	DFO Science, Maritimes Region
Sameoto, Jessica	DFO Science, Maritimes Region
Trudel, Marc	DFO Science, Maritimes Region
Wilson, Brittany	DFO Science, Maritimes Region

Name	Affiliation
Wringe, Brendan	DFO Science, Maritimes Region

Approved by

Francine Desharnais
Regional Director of Science
Maritimes Region
Dartmouth, Nova Scotia
Ph. 902-220-8371

Date: January 26, 2023

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Appendix A: Species Database Searches Within the Region of Interest

Regional databases with records from 2002–2018 were queried for information on observed species within the PEZ of the proposed site and associated aquaculture activities. Databases searched include the Maritimes Research Vessel (RV) Survey, Industry Survey Database (ISDB), Maritime Fishery Information System (MARFIS), Ocean Biodiversity Information System (OBIS), Whale Sightings Database (WSDB) and the North Atlantic Right Whale Consortium (NARWC) Sightings Database. Recorded species are listed in Table A1. Sighting effort has not been quantified (i.e., the numbers cannot be used to estimate true species density or abundance for an area). Lack of sightings do not represent species absence in a particular area.

Table A1. Species records presented as combined numbers from all databases queried. Species names are written as returned from database.

Species	Records (databases combined)
Shrimp, *Pandalus borealis*	493
Scallop, sea	87
Winter flounder	49
Greysole/witch	30
Halibut	29
Herring	25
Haddock	22
Cod	15
Flounder, unspecified	9
White hake	5
Sculpin	5
Skate	4
Squid, illex	4
Pollock	3
Sea cucumber	1

Appendix B: Wave Data

Wave data are from the MSC50 Wind and Wave Climate Hindcast (MSC50) which provides hindcasts for 1954–2018 over a 0.1 degree grid for the Canadian Maritimes. The hindcasts were produced using the method discussed in Swail et al. (2006). The closest grid point to the proposed farm site, M6007891, is located at 45°N, 66.7°W which is approximately 10 km offshore from the centre of the cage array (Figure B1). Results for the significant wave height (defined as the average amplitude of the highest 30%), the dominant wave direction (defined as the direction associated with the peak spectral period), and the peak spectral period of the total spectrum are examined here.

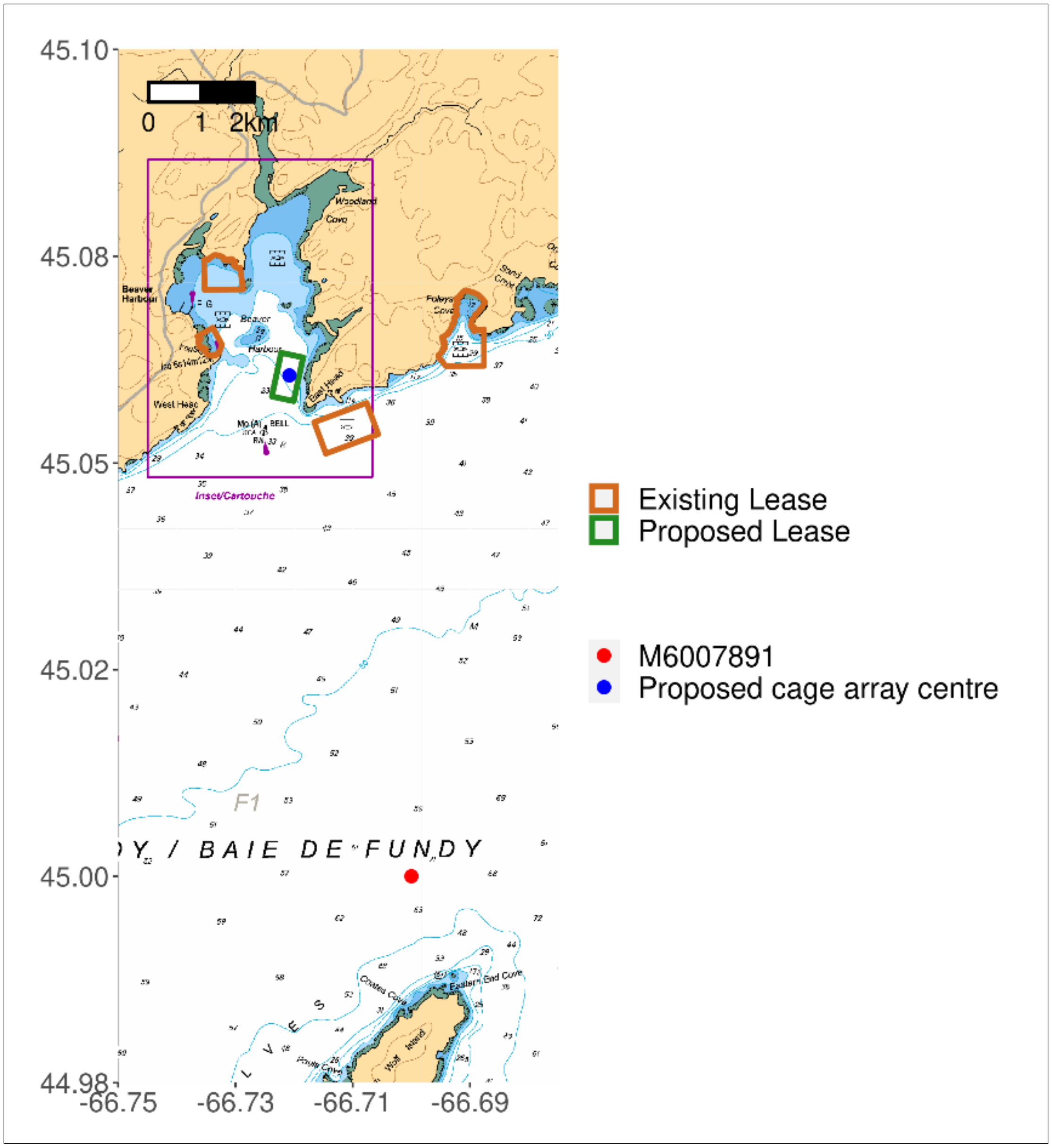

Figure B1. Location of wave data hindcast.

The dominant wave directions are primarily from the northwest and southeast quadrants with the largest waves coming from the south-southeast (Figure B2).

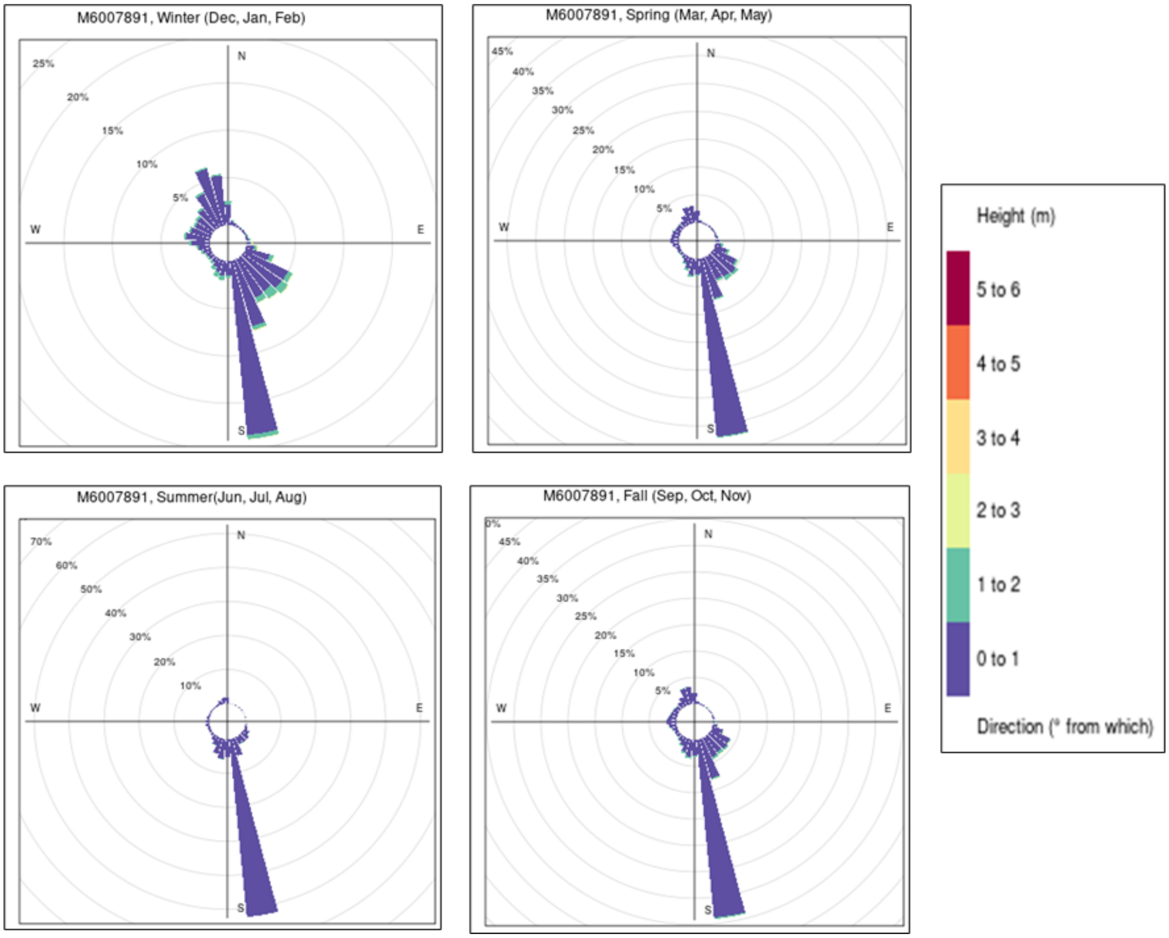

Figure B2. Rose diagram of the predicted significant wave height by season at M6007891.The orientation of a petal in the rose diagram indicates the direction from which the wave originates, the petal length indicates the frequency of waves from the relevant direction, and the colours indicate the magnitude of the wave height.

The majority of the significant wave heights are less than 1 m, though significant wave heights can exceed 4.0 m (Figure B3, left panel). There is a seasonal variation in the significant wave height and dominant direction (Figure B3, left panel and right panel); smaller significant wave heights generally occur during the summer months and a smaller proportion of the waves are from the northwest during the summer months than during other times of the year. Seasonal variations also exists in the peak spectral period of the waves with the median period being greater in the months of May through September than in the months of October through April (Figure B4).

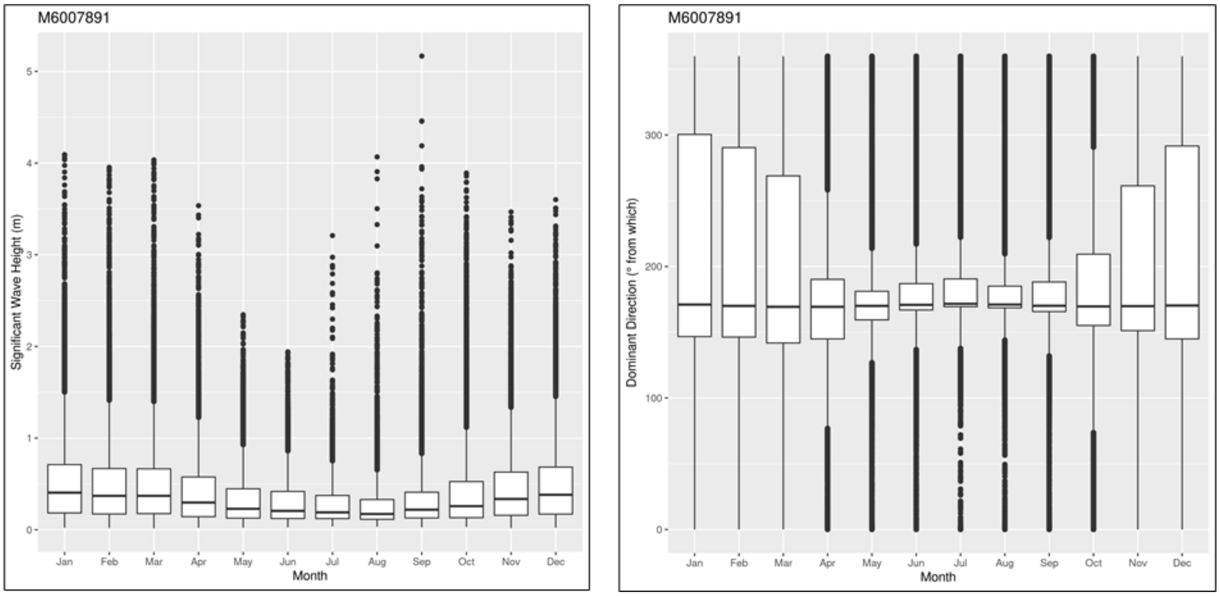

*Figure B3. Plot of statistics of the predicted significant wave height **(left)** and predicted dominant wave direction **(right)** at M6007891 by month of year. Each individual box indicates the 25th (Q1) to the 75th (Q2) percentile with the mean indicated by the bold horizontal line inside the box. The "whiskers", i.e., the vertical lines outside the box, extend downward to Q1-1.5*IQR and upward to Q3+1.5*IQR, where IQR=Q3-Q1. Data that extend past the whiskers are plotted as dots. Wave directions are given in ° from which (i.e., the direction from which the waves are coming).*

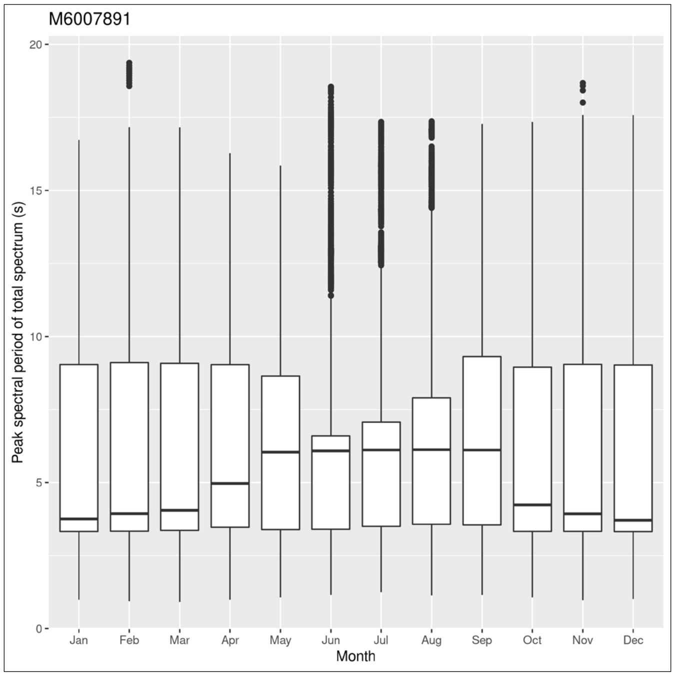

*Figure B4. Plot of statistics of the peak spectral period of the total spectrum at M6007891 by month of year. Each individual box indicates the 25th (Q1) to the 75th (Q2) percentile with the mean indicated by the bold horizontal line inside the box. The "whiskers", i.e., the vertical lines outside the box, extend downward to Q1-1.5*IQR and upward to Q3+1.5*IQR, where IQR=Q3-Q1. Data that extend past the whiskers are plotted as dots.*

There is also inter-annual variation in the significant wave heights with annual maximum significant wave heights varying from 1.919 to 5.167 m with the median maximum being 3.020 m and mean maximum being 3.053 m. The majority of the annual maximum significant wave heights occur in the winter months (Figure B5). Although the majority significant wave heights are less than 1 m, it is expected that significant wave heights at the proposed lease site could be larger than those at M6007891 due to the shallowing of the bathymetric depth. Furthermore, due to the location of the proposed site and the predicted dominant direction of the waves, it is unlikely that the waves from the southwest will be damped as the bay provides little sheltering.

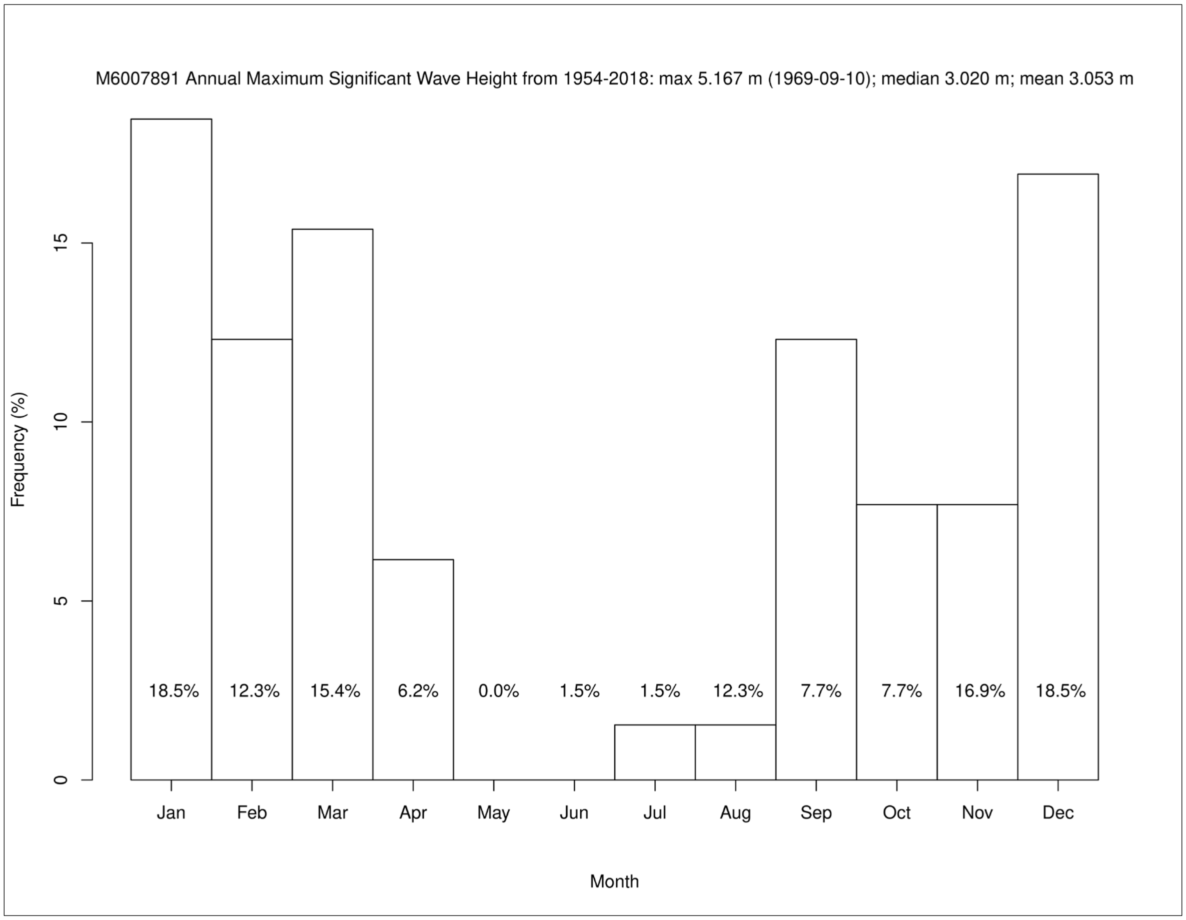

Figure B5. Histogram showing the months in which the annual maximum wave heights at M6007891 occurred. The frequency (in percentage) is the proportion of maximums occurring in a given month. The percentages are the heights of the monthly bars.

Appendix C: Genetic Interactions

Propagule Pressure Details

$$Propagule\ presssure\ for\ a\ given\ river\ (R) = \sum_{i=1}^{S} \frac{F_i}{LCD(S_{i\ to\ R})}$$

Where F_i is the number of fish in the *i*th aquaculture site, S_i, and LCD represents the least-cost distance function between the river R and S_i. For the purposes of risk assessment, the number of fish at each site was set to the greater of the number of fish for which the site was licensed, or the number of fish for which an introduction and transfer permit had been authorized.

IBSEM Details

The model simulated the population in the Tobique River. Gibson et al. (2009a) state that the wild population size required to meet the CER (Elson 1967) for the Tobique is 5,600 returning adults, however to reduce the time required for each simulation to complete, this number was reduced by a factor of 10. The results for a simulated returning spawner population sizes of 5,600 and 560 were compared and the results were found to be qualitatively the same and differed only in scale. The model was allowed to run for 100 years to stabilize, at which point escapees were introduced for 50 years. After the 50 years period of introgression, escapes were ceased, and the population was allowed to recover for 100 years. The proportion of escapees entering the river was simulated between 0 and 100% of the initial wild population, and each scenario was replicated 10 times (Bradbury et al. 2020a). For this document, and in accordance with Bradbury et al. (2020a) we focused on the number of returning spawners, as well as the population allele frequency. Hybridization and introgression from invading escapees was tracked through changes in allele frequency over time. Wild individuals are denoted by allele frequencies approaching 1, and conversely farmed individuals have allele frequencies approaching 0. Thus a shift in overall population allele frequencies away from 1 indicates a greater proportion of escapee, hybrid, and introgressed individuals in the population. Readers are directed to Castellani et al. (2015) and Bradbury et al. (2020a) for further information on the model.

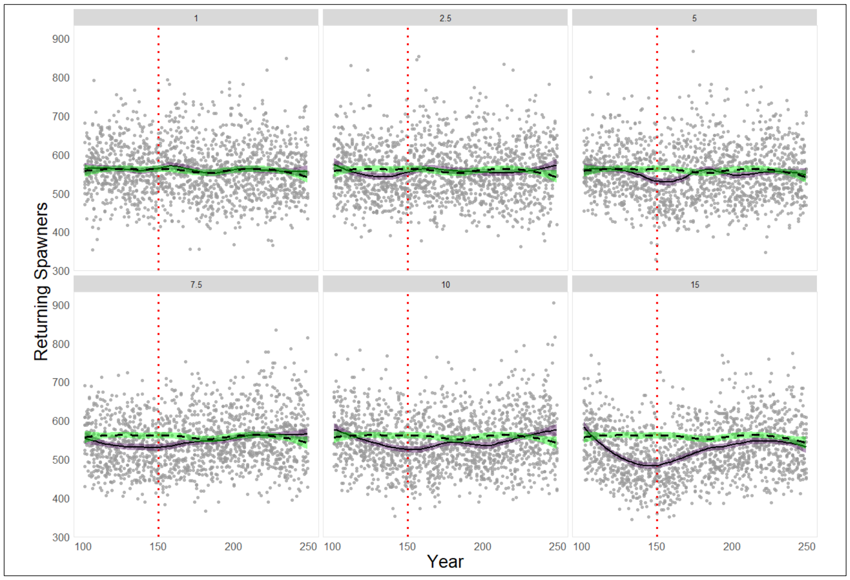

Figure C1. Model-predicted change in the number of returning spawners during and after a 50 year invasion period by escaped farmed salmon. The IBSEM model was allowed to stabilize for 100 years and the invasion begins at year 100. The invasion period is 50 years, and its end point at year 150 is marked by a dashed vertical red line. The results of 10 iterations of the IBSEM model with escapee proportions of 1, 2.5, 5, 7.5, 10 and 15% per year are shown, and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion period. Impacts are said to have occurred when the proportion of returning adults from the invasion scenario (solid horizontal black lines, purple 95% CIs) deviate from the results of the zero-invasion simulation (dashed horizontal black line, green 95% confidence interval CIs). The smoothed lines and associated 95% CI were calculated using a LOESS regression with span of 0.5 with the ggplot2 function geom_smooth.

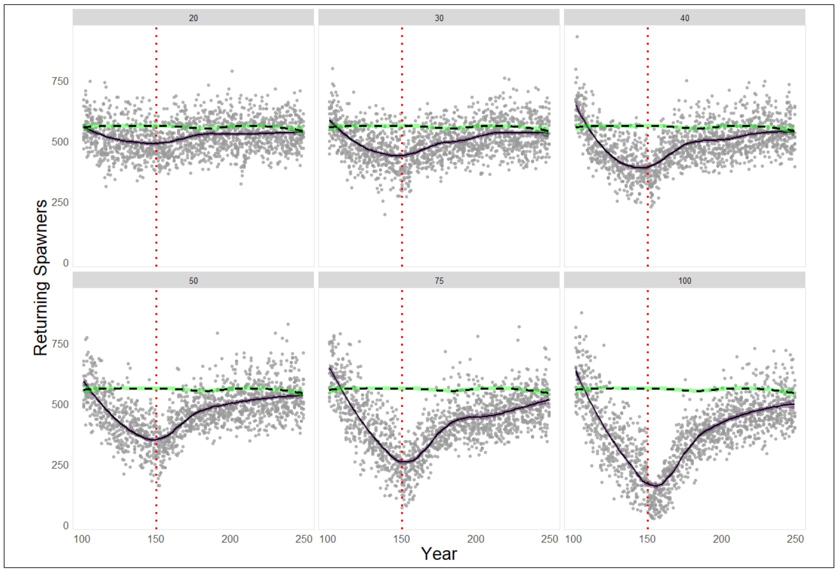

Figure C2. Model-predicted change in the number of returning spawners during and after a 50 year invasion period by escaped farmed salmon. The results of 10 iterations of the IBSEM model with escapee proportions of 20, 30, 40, 50, 75 and 100% per year are shown, and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion period. Refer to Supplementary Figure C3 for more information.

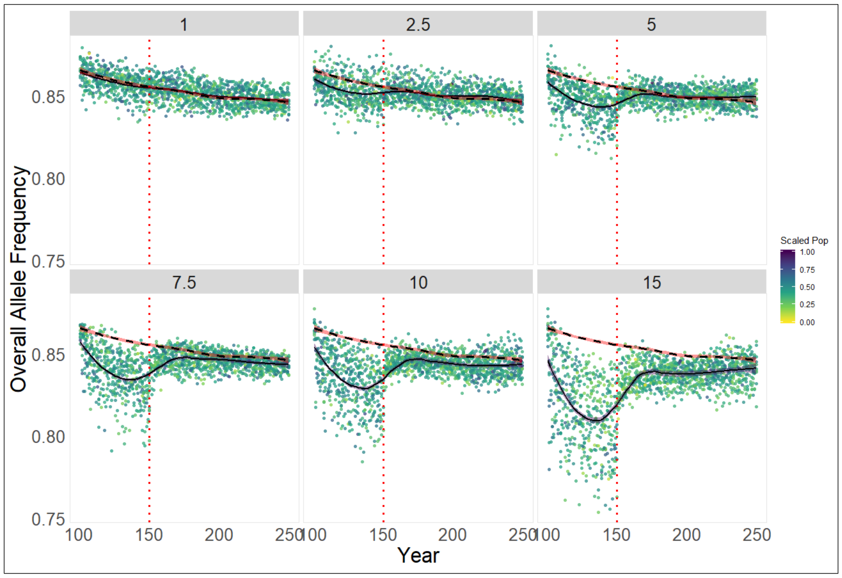

Figure C3. Model-predicted change in allele frequency during and after a 50 year invasion period by farmed salmon. Escapee proportions of 1, 2.5, 5, 7.5, 10, and 15% per year are shown and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion period. Wild populations are characterized by an allele frequency of 1, and farmed populations by an allele frequency of 0. Points are coloured relative to their scaled population size, with 1 being the largest population size observed during the simulation and 0 being the smallest; refer to Figure C1. For the zero-invasion the 95% confidence interval (CI) is shown in red, but all other details are as described in Figure C1.

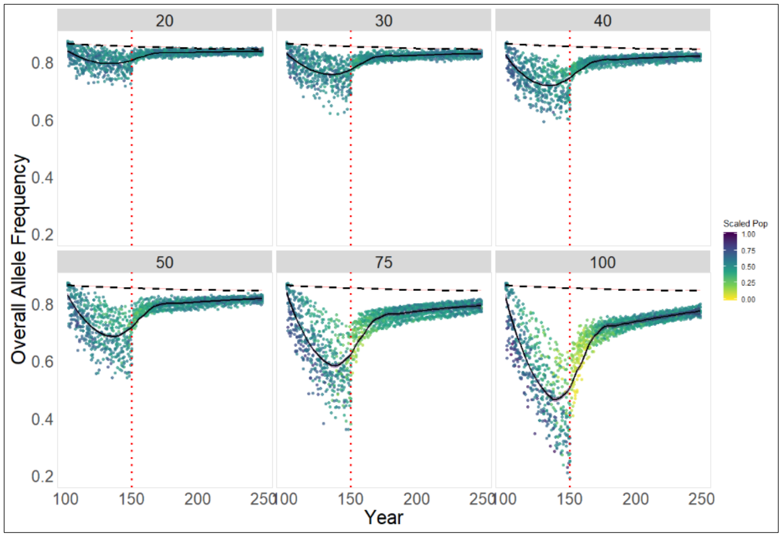

Figure C4. Model-predicted change in allele frequency during and after a 50 year invasion period by farmed salmon. Escapee proportions of 20, 30, 40, 50, 75, and 100% per year are shown and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion period. Wild populations are characterized by an allele frequency of 1, and farmed populations by an allele frequency of 0. Points are coloured relative to their scaled population size, with 1 being the largest population size observed during the simulation and 0 being the smallest; refer to Figure C2. For the zero-invasion the 95% confidence interval (CI) is shown in red, but all other details are as described in Figure C1 and C2.

Dispersal Model Details

Similar to the calculation of propagule pressure, the number of fish at each site was set to the greater of the number of fish for which the site was licenced, or the number of fish for which an introduction and transfer permit had been authorized. Numbers of fish were converted to harvest biomass using an individual harvest weight of 5 kg, a 25% reduction to account for periods of fallowing, and then multiplying by 0.65, which is a ratio found to convert numbers stocked to numbers harvested in Newfoundland (Bradbury et al. 2020a). A maximum dispersal distance of 200 km was used, and rates of escapees was set at 0.4 fish per tonne. This rate was calculated from the latest published figures from Norway (Føre and Thorvaldsen 2021; Skilbrei et al. 2015), and is within the lower range of rates tested by (Bradbury et al. 2020a). Using the most recent region-wide estimates (DFO 2020c), populations of wild Atlantic Salmon in every river were set at 5% of the number of spawners required to meet the CER. Numbers of spawners and CER values were taken from O'Connell et al. (1997), or estimated using the linear relationship between CER and river axial distance.

Table C1. Rivers and positions included in the dispersal model. River numbers are ordered sequentially from easternmost to westernmost along the coasts of New Brunswick and Nova Scotia.

River Name	River Number	Latitude	Longitude
St. Croix River (Charlotte Co.)	1	-67.17	45.16
Dennis Stream	2	-67.26	45.19
Waweig River	3	-67.14	45.22
Chamcook Stream	4	-67.07	45.13
Bocabec River	5	-66.99	45.18
Digdeguash River	6	-66.96	45.19
Magaguadavic River	7	-66.85	45.12
Pocologan River	8	-66.59	45.12
New River	9	-66.54	45.13
Lepreau River	10	-66.46	45.17
Musquash River	11	-66.25	45.18
Saint John River	12	-66.04	45.25
Nerepis River	13	-66.23	45.36
Oromocto River	14	-66.48	45.86
Nashwaak River	15	-66.63	45.95
Nashwaaksis River	16	-66.66	45.97
Keswick River	17	-66.82	45.99
Little River (Sunbury Co)	18	-66.25	45.97

River Name	River Number	Latitude	Longitude
Salmon River (Queens Co.)	19	-65.85	46.24
Gaspereau River (Queens Co.)	20	-65.85	46.24
Canaan River	21	-65.82	45.89
Belleisle Creek	22	-65.85	45.65
Hammond River	23	-65.90	45.50
Kennebecasis River	24	-66.13	45.31
Mispec River	25	-65.96	45.22
Black River (Saint John Co.)	26	-65.81	45.26
Emerson Creek	27	-65.78	45.26
Gardner Creek	28	-65.72	45.28
Tynemouth Creek	29	-65.65	45.29
Mosher River (Saint John Co.)	30	-65.54	45.34
Irish River	31	-65.53	45.36
Big Salmon River	32	-65.40	45.42
Little Salmon River	33	-65.28	45.47
Quiddy River	34	-65.19	45.49
Goose Creek	35	-65.16	45.51
Goose River	36	-65.09	45.53
Point Wolfe River	37	-65.02	45.55
Upper Salmon River (Alma Par.)	38	-64.96	45.61
West River (Albert Co.)	39	-64.85	45.65
Shepody River	40	-64.67	45.74
Crooked Creek	41	-64.75	45.73
Sawmill Creek	42	-64.71	45.75
Demoiselle Creek	43	-64.59	45.81
Petitcodiac River	45	-64.66	45.96
Memramcook River	46	-64.55	45.87
Tantramar River	47	-64.33	45.86
Nappan River	48	-64.25	45.76

River Name	River Number	Latitude	Longitude
Maccan River	49	-64.26	45.76
River Hebert	50	-64.33	45.75
Apple River	51	-64.80	45.47
Greville River	52	-64.55	45.40
Fox River	53	-64.52	45.40
Ramshead River (Ramsey)	54	-64.47	45.40
Diligent River	55	-64.45	45.39
Farrells River	56	-64.33	45.40
Moose River (Cumberland Co.)	57	-64.19	45.40
Harrington River	58	-64.10	45.41
North River (Cumberland Co.)	59	-64.08	45.41
East River (Colchester Co.)	60	-64.05	45.40
Economy River	61	-63.90	45.38
Little Bass River	62	-63.80	45.40
Bass River	63	-63.78	45.40
Portapique River	64	-63.71	45.39
Great Village River	65	-63.61	45.39
Debert River	66	-63.53	45.39
Folly River	67	-63.53	45.39
Chiganois River	68	-63.42	45.37
Salmon River (Colchester Co.)	69	-63.37	45.36
North River (Colchester Co.)	70	-63.29	45.38
Shubenacadie River	71	-63.48	45.30
Stewiacke River	72	-63.37	45.14
Walton River	73	-64.01	45.23
Avon River	74	-64.22	45.12
Kennetcook River	75	-64.12	45.05
St. Croix River (Hants Co.)	77	-64.13	45.00
Gaspereau River (Kings Co.)	78	-65.85	46.24

River Name	River Number	Latitude	Longitude
Cornwallis River	79	-64.39	45.10
Annapolis River	80	-65.60	44.70
Paradise Brook	81	-65.32	44.83
Round Hill River	82	-65.43	44.77
Lequille River	83	-65.52	44.74
Moose River (Annapolis Co.)	84	-65.61	44.66
Bear River	85	-65.68	44.62
Acacia Brook	86	-65.75	44.59
Sissiboo River	87	-66.01	44.44
Belliveau River	88	-66.08	44.38
Little Brook	89	-66.12	44.30
Meteghan River	90	-66.14	44.22
Salmon River (Digby Co.)	91	-66.17	44.05
Chebogue River	92	-66.08	43.79
Annis River	93	-66.00	43.85
Tusket River	94	-65.98	43.86
Barrington River	95	-65.58	43.56
Clyde River	96	-65.47	43.60
Roseway River	97	-65.34	43.77
Jordan River	98	-65.24	43.80
East River (Shelburne Co.)	99	-65.14	43.74
Sable River	100	-65.05	43.83
Broad River	101	-64.83	43.95
Mersey River	102	-64.73	44.04
Medway River	103	-64.64	44.14
Petite Rivière	104	-64.45	44.23
Lahave River	105	-64.49	44.37
Mushamush River	106	-64.38	44.45
Martins River	107	-64.33	44.49

River Name	River Number	Latitude	Longitude
Vaughans River	108	-64.31	44.52
Gold River	109	-64.33	44.55
Middle River (Lunenburg Co.)	110	-64.29	44.56
East River (Lunenburg Co.)	111	-64.17	44.59
Little East River	112	-64.14	44.57
Hubbards River	113	-64.06	44.64
Ingram River	114	-63.97	44.67
Indian River (Halifax Co.)	115	-63.91	44.69
Woodens River	116	-63.92	44.59
Oak Hill Run	117	-63.85	44.53
Nine Mile River	118	-63.79	44.54
Prospect River	119	-63.76	44.53
Terence Bay River	120	-63.74	44.51
Pennent River	121	-63.63	44.48
Ketch Harbour River	122	-63.55	44.49
Sackville River	124	-63.66	44.73
Cow Bay River	125	-63.45	44.62
Little Salmon River (Lake Major)	126	-63.45	44.68
Lawrencetown Lake (Salmon River)	127	-63.38	44.69
Porters Lake (East Brook)	128	-63.38	44.80
Rocky Run (W. Brook Porters)	129	-63.38	44.81
Chezzetcook River	130	-63.24	44.74
Musquodoboit River	131	-63.14	44.79
Salmon River (Halifax Co.)	132	-63.04	44.78
Ship Hbr. River (L. Charlotte)	133	-62.88	44.81
Tangier River	134	-62.71	44.80
West Taylor Bay Brook	135	-62.62	44.85
West River, Sheet Harbour	136	-62.54	44.92
East River, Sheet Harbour	137	-62.52	44.92

River Name	River Number	Latitude	Longitude
Halfway Brook	138	-62.45	44.87
Salmon River (Port Dufferin)	139	-62.38	44.92
Quoddy River	140	-62.35	44.93
Necum Teuch (Smith Brook)	141	-62.27	44.94
Moser River	142	-62.25	44.97
Ecum Secum River	143	-62.17	44.98
Liscomb River	144	-62.10	45.01
Gaspereaux Brook	145	-65.85	46.24
Gegogan Brook	146	-61.98	45.07
Saint Marys River	147	-61.96	45.10
Indian River (Guysborough Co.)	148	-61.77	45.11
Country Harbour River	149	-61.80	45.24
Isaacs Harbour River	150	-61.67	45.20
New Harbour River	151	-61.46	45.18
Larrys River	152	-61.37	45.22
Cole Harbour River	153	-61.26	45.26
Halfway Cove Brook	154	-61.44	45.35
Salmon River (Guysborough Co.)	155	-61.47	45.36
Guysborough ??	156	-61.49	45.38
Roman Valley River	157	-61.61	45.46
Clam Harbour River	158	-61.35	45.43
Saint Francis River	159	-61.31	45.45
Inhabitants River	160	-61.23	45.61
False Bay Brook	161	-61.01	45.63
River Tillard	162	-60.91	45.66
Grand River	163	-60.63	45.61
Saint Esprit	164	-60.49	45.66
Marie Joseph Brook	165	-60.36	45.69
Framboise River (Giant Lake)	166	-60.36	45.72

River Name	River Number	Latitude	Longitude
Gerratt Brook	167	-59.98	45.92
Lorraine Brook	168	-66.82	45.99
Little Lorraine	169	-59.87	45.96
Mira River	171	-59.97	46.03
MacAskills Brook	172	-59.95	46.16
Northwest Brook (River Ryan)	173	-60.08	46.22
Sydney River	174	-60.23	46.11
Grantmire Brook	175	-60.28	46.16
Frenchvale Brook	176	-60.31	46.15
Aconi Brook	177	-60.35	46.32
MacIntosh Brook	179	-60.52	45.96
Gillies Brook	180	-60.38	46.02
Breac Brook	181	-60.53	45.92
Toms Brook	182	-60.74	45.74
MacNabs Brook	183	-60.72	45.73
George ??	184	-60.83	45.73
Scotts River	185	-60.87	45.75
Black River (Richmond Co.)	186	-61.09	45.69
River Denys	187	-61.09	45.86
MacKinnons Brook	188	-60.90	45.94
Washabuck River	189	-60.87	46.02
Blues Brook	191	-61.14	45.94
Skye River	192	-61.13	45.97
Humes River	193	-60.94	46.05
Middle River (Victoria Co.)	194	-60.90	46.08
Baddeck River	195	-60.86	46.09
North River (Victoria Co.)	196	-60.62	46.30
River Bennett	197	-60.53	46.34
Barachois River	198	-60.53	46.34

River Name	River Number	Latitude	Longitude
Indian Brook	199	-60.53	46.37
Ingonish River	200	-60.43	46.63
Clyburn Brook	201	-60.40	46.66
North Aspy River	202	-60.51	46.91
Wilkie Brook	203	-60.46	46.94
Salmon River (Victoria Co.)	204	-60.49	47.00

Appendix D: Comparison of Potential Anthropogenic Impacts

Identification of Anthropogenic Sources

A visual representation of the pattern of human use can help illustrate the distribution of human activities in the ocean and identify overlaps among them. Spatial data for marine activities within a 5 km radius for the proposed site (hereafter the "area of interest") were collated from a larger inventory of human activities developed for the Maritimes region (Kelly, unpublished data). Human activities that occurred on a "local" scale were selected, defined as those operating over small spatial scales (i.e., < 10 km) or from point-sources that could produce a localized zone of impact, such as marine recreation, aquaculture, or benthic structures. The most recent years of data or up-to-date information were included when possible.

Overlapping of Human Activities

The impact of human activity in the marine environment often extends beyond its immediate occurrence. To estimate the geographical extent of each activity beyond its location of occurrence, a buffer was added that radiated from the point source of the activity. The furthest distance from the activity's origin was determined for the same or most similar activity based on either available data or extensive reviews presented in Ban and Alder (2008), Ban et al. (2010), and/or Clarke Murray et al. (2015) ("buffer radius"; see Table D1).

A GIS approach (ESRI ArcGIS version 10.6.1) was used to map each activity and its associated buffer. The map was then converted to a raster (100 m x 100 m grid). Where activities (and their buffers) overlapped, the values in the grid cell were summed to estimate the total number of overlapping human activities per grid cell.

Table D1. Human activities occurring in the area of interest and buffer radius applied beyond location of activity occurrence. The buffer radius is the furthest extent an activity's impact extends from its origin.

Category	Human activity layer	Layer description	Buffer radius (km)	Relative intensity measure	Data source
Marine	Finfish aquaculture	Rams Head (# MF-0509); Other leases within (#) or adjacent (#) to the area of interest whose buffers overlap, with kernel density decay.	2	Kernel density model	Provincial aquaculture lease data from NB and NS
	Invasive species	Species distribution model layer of 12 invasive species	NA	Invasive species richness	Claudio DiBacco (DFO AIS Program) in Lyons et al. 2020 "Identifying marine invasion hotspots using stacked species distribution models"
	Vessel traffic	Vessel density layer for 'Other' vessel category (vessels of 500 gross tonnage or greater on a domestic voyage that are not cargo, fishing, passenger, or tanker vessels).	NA	Vessel minutes per km^2	Vessel Density Atlas (2019) based on satellite AIS 2017–2018 (DFO internal)

Category	Human activity layer	Layer description	Buffer radius (km)	Relative intensity measure	Data source
	Recreational boating	Locations of marinas, boat launches, and small craft harbours with kernel density decay 2km buffer.	2	Kernel density model	DFO (internal)
Fishing	Demersal, habitat modifying	Polygons representing sum of groundfish trawls and scallop dredging	0	Round weight (kg)	Maritimes Region Fisheries Atlas: Catch Weight Landings Mapping (2014–2018) - Open Government Portal
	Demersal, non-habitat modifying, high bycatch	Polygons representing groundfish bottom longline fishing	0	Round weight (kg)	Maritimes Region Fisheries Atlas: Catch Weight Landings Mapping (2014–2018) - Open Government Portal
	Demersal, non-habitat modifying, low bycatch	Grids with lobster fishing intensity (catch weight standardized to grid size)	0	Catch weight (kg per km^2)	Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid (2012–2014)
Land-based	Human derived pollution	10 year (2009–2018) median fecal coliform counts with IDW interpolation	NA	Median fecal coliform counts (MPN)	Canadian Shellfish Sanitation Program data for NB and NS
	Hardened shorelines	Locations of hardened shoreline structures (riprap, sea walls, groins, jetties, breakwaters, etc.) with the first ocean pixel adjacent to hardened shoreline segments classified as "impacted".	NA	No difference in intensity	Man-made solid classification from the Atlantic Shoreline Classification dataset
	Nutrient loading	Captures activities within the watershed that input nitrogen into the bay, including agriculture, human settlements, wastewater inputs, runoff from roads, buildings, and other impervious surfaces. Buffer radius based on the stream order and a kernel density decay model.	4.22	Magnitude of N loading (kg N/yr)	Nitrogen Loading Model (Kelly et al. in revision)

Estimating Relative Impact Among Human Activities

Human activities in the ocean are presumed to cause stress on marine ecosystems. A literature review was conducted to examine the stressors linked to the 10 different human activities occurring in the area of interest. Stressors linked to finfish aquaculture, recreational boating, vessel traffic, and fishing and land-based activities were summarized from Ban et al. (2010). Stressors linked to hardened shoreline were summarized from Perkins et al. (2015), while those linked to invasive species were summarized from Therriault and Herborg (2007) (Table 5).

The relative impact of human activities on the marine environment depends on their spatial distribution, the intensity of those activities in any particular place, and the vulnerability of the ecosystem component to a particular activity. To estimate the relative impact of human activities on the Beaver Harbour area, we conducted a (additive) cumulative impact mapping (CIM) analysis following previously published studies in British Colombia waters (Ban et al. 2010; Clarke Murray et al. 2015) based on the analytical framework of Halpern et al. (2008). CIM analysis combines the spatial location of human activities and habitats, weighted by their vulnerabilities to each activity. The use of habitats also indirectly captures impacts on associated species. For each 100 m x 100 m grid cell, the cumulative impact score (I_C) is calculated as:

$$I_C = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(D_i * E_j * \mu_{i,j} \right)$$

where D_i is the normalized value (scaled between 0–1) of intensity of human activity i in each grid cell, E_j is the presence or absence of a habitat, and $\mu_{i,j}$ is the vulnerability score (i.e., spatial weighting factors) for activity i and habitat j, n is the number of human activities, and m is the number of habitats. The cumulative impact scores are then summed across all habitats and activities for each grid cell, and the resulting cumulative impact map is displayed in polygon grid cells (Figure 12). For Beaver Harbour, n = 10 activities and m = 11 habitats (Table D1, D2).

Table D2. Coastal habitat classes found in Beaver Harbour.

Habitat class	Habitat class abbreviation	Depth range (m)	Habitat class definition
Beach Intertidal	BITDL	0–2	Sand, pebble/cobble, mixed sediment shoreline habitat within tidal zone
Rocky Intertidal	RITDL	0–2	Bedrock or rocky shoreline habitat within tidal zone
Saltmarsh	SALT	0–2	Marsh (e.g., dominated by *Spartina* spp.) or vegetated estuarine or shoreline habitat within tidal zone
Algal Zone	ALGAL	2–30	Nearshore subtidal habitat dominated by rockweed species
Hard Shallow	HSHLW	2–30	Boulders, continuous bedrock, or discontinuous bedrock substrate, to 30 m depth
Mixed Shallow	MSHLW	2–30	Sand and gravel, mixed sediment, or gravel sediment substrates
Soft Shallow	SSHLW	2–30	Mud, sand and mud, or sand substrates
Hard Shelf	HSHLF	30–200	Boulders, continuous bedrock, or discontinuous bedrock substrate, without algal cover
Mixed Shelf	MSHLF	30–200	Sand and gravel, mixed sediment, or gravel sediment substrates, without algal cover
Soft Shelf	SSHLF	30–200	Mud, sand and mud, or sand substrates, without algal cover

Habitat class	Habitat class abbreviation	Depth range (m)	Habitat class definition
Shallow Pelagic	SP	30–200	Open water habitat where organisms are completely surrounded by water; within the pelagic zone above 200 m in all areas >30 m deep

Spatial data for all 10 previously identified human activities (Table D1) were used to map the impact scores. Commercial fishing activity was organized into three classes to incorporate the effect of different gear types specific to each fishery, which also reflects the available vulnerability scores for these activities. Point-source land-based or marine activities (finfish aquaculture, nutrient loading, recreational boating) were subjected to kernel density decay across their buffers (Table D1; after Clarke Murray et al. 2015).

Total cumulative impact scores were compared for all activities (Figure 13; Table D3). All data preparation and analysis was performed in ArcGIS version 10.6.1 (ESRI). Impact weights (i.e., vulnerabilities) previously generated for the Cape Cod/Southern Gulf of Maine region through an expert elicitation approach (Kappel et al. 2012) were matched to existing human activities and known habitat types occurring in Beaver Harbour (Table D3).

Table D3. Impact weighting (i.e., vulnerability scores) for 10 stressors in 11 habitats present in Beaver Harbour. Ecosystem-vulnerability scores were determined using expert elicitation, as presented in Kappel et al. (2012). Mean (± SD) scores for each stressor across all ecosystems and for each ecosystem across all stressors are reported in the "mean score" column and row, respectively. Habitat abbreviations are given in Table D2.

		Ecosystems											
Human activity	**Associated Stressor**	**BITDL**	**RITDL**	**ALGAL**	**SALT**	**SP**	**HSHLW**	**MSHLW**	**SSHLW**	**HSHLF**	**MSHLF**	**SSHLF**	**Mean score**
Finfish aquaculture	Aquaculture: finfish	0	1.9	0.5	0.9	1.7	2.1	2.0	1.9	3.0	1.8	0.6	1.5 (0.9)
Invasive species	Invasive species	3.6	3.8	3.5	3.5	3.2	3.5	3.8	4.0	4.0	3.7	3.3	3.6 (0.3)
Recreational boating	Tourism: recreational boating	1.4	1.6	2.2	2.0	1.2	2.0	1.9	1.7	1.2	1.0	0.7	1.5 (0.5)
Vessel traffic	Shipping (commercial, cruise, ferry)	0.9	1.2	1.8	0.8	2.7	2.8	1.4	0	3.2	2.5	1.7	1.7 (1.0)
Demersal Habitat Modifying	Fishing Demersal Habitat Modifying	0	0.9	3.1	0.5	2.2	3.5	3.7	3.8	3.5	3.5	3.4	2.5 (1.4)
Demersal, non-habitat modifying, high bycatch	Fish demersal non habitat modifying, high bycatch	0	0.3	2.8	0.8	1.8	2.5	2.6	2.6	3.9	3.7	3.5	2.2 (1.3)
Demersal, non-habitat modifying, low bycatch	Fishing Demersal Non-Habitat Modifying , Low By-Catch	0	1.4	2.5	0.7	2.5	2.2	2.2	2.1	2.3	2.3	2.2	1.8 (0.8)

		Ecosystems											
Human activity	**Associated Stressor**	**BITDL**	**RITDL**	**ALGAL**	**SALT**	**SP**	**HSHLW**	**MSHLW**	**SSHLW**	**HSHLF**	**MSHLF**	**SSHLF**	**Mean score**
Human derived pollution	Diseases or pathogens	1.5	2.9	2.0	1.8	2.8	2.5	2.2	1.8	2.5	4.3	6.1	2.8 (1.3)
Hardened shorelines	Coastal engineering: altered flow dynamics	3.6	4.0	2.5	3.7	1.2	1.2	2.2	3.2	1.4	1.4	1.3	2.3 (1.1)
Nutrient loading	Nutrient input: into oligotrophic waters	0.2	0.5	2.9	2.5	0.4	1.6	2.7	3.7	3.4	3.2	2.9	2.2 (1.3)
Mean score		1.1 (1.4)	1.9 (1.3)	2.4 (0.8)	1.7 (1.2)	2.0 (0.9)	2.4 (0.7)	2.4 (0.8)	2.5 (1.2)	2.8 (1.0)	2.7 (1.1)	2.6 (1.7)	

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Fisheries and Oceans Canada
1 Challenger Drive, P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

E-Mail: DFO.MaritimesCSA-CASMaritimes.MPO@dfo-mpo.gc.ca
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