DFO MARITIMES REGION SCIENCE REVIEW OF THE PROPOSED MARINE FINFISH AQUACULTURE BOUNDARY AMENDMENT AND NEW SITES, LIVERPOOL BAY, QUEENS COUNTY, NOVA SCOTIA

Context

Kelly Cove Salmon Ltd. has submitted applications to the Province of Nova Scotia to amend their existing Liverpool site (#1205) and to construct and operate two new sites, Mersey Point (#1433) and Brooklyn (#1432), in Liverpool Bay, Queens County, Nova Scotia.

As per the Canada-Nova Scotia Memorandum of Understanding on Aquaculture Development, the Nova Scotia Department of Fisheries and Aquaculture (NSDFA) has forwarded these application to Fisheries and Oceans Canada (DFO) for review and advice in relation to DFO's legislative mandate. The applications were supplemented by information collected by the proponent as required by the *Aquaculture Activities Regulations* (AAR).

To help inform DFO's review of these applications, 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 Act* (SARA) 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 available information, what are the Ecologically and Biologically Significant Areas (EBSAs), Species At Risk (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?

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 make use of the area, and for what duration and when?

Question 5. Which populations of conspecifics are within a geographic range that escapes 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 the *SARA*?

This Science Response Report results from the Science Response Process of February 24–25, 2021, on DFO Maritimes Region Review of the Proposed Marine Finfish Aquaculture Sites and Boundary Amendment, Liverpool Bay, Queens County, Nova Scotia.

Background

Kelly Cove Salmon Ltd. is requesting an amendment to expand the boundaries and increase the production level at their existing Liverpool #1205 site, and to construct and operate two new sites, Mersey Point (#1433) and Brooklyn (#1432), in Liverpool Bay, Queens County, Nova Scotia. The proposed actions will increase the total leased area and production of Atlantic Salmon within the bay. The only other aquaculture activity in the vicinity of the sites is a land-based facility. The location of the sites are shown in Figure 1.

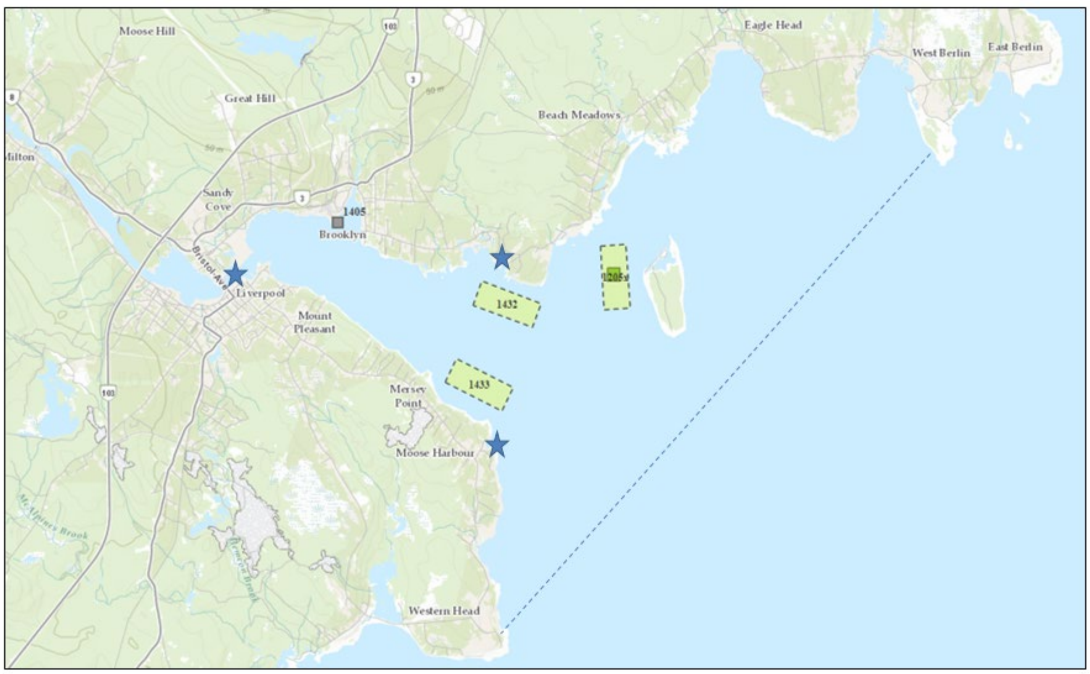

Figure 1. Map of finfish aquaculture site leases in Liverpool Bay, Queens County, Nova Scotia. Light green polygons represent proposed finfish leases requested by Kelly Cove Salmon Ltd. The darker green box denotes the existing #1205 Liverpool site lease. The grey square represents the location of a land-based aquaculture facility. Maps were retrieved from the NSDFA Site Mapping Tool website on August 17, 2020 (NSDFAa). Stars show approximate locations of seasonal lobster holding facilities. The dotted blue line is the approximate 'open boundary' used by Gregory et al. 1993 for Liverpool Bay.

The existing site (#1205) has been in operation since 2002, and was acquired by Kelly Cove Salmon Ltd. in 2011. The current area under lease by site #1205 is approximately 4 hectares (ha) with 14 cages in a 2 x 7 grid configuration. The proposed amendment would increase the area of the site to a total of 40.7 ha. This increase allows for the incorporation of all aquaculture-related gear, above and below the water line, and the addition of six cages to the south of the current grid for a total of 20 cages in a 2 x 10 configuration. The same lease sizes and cage configurations are proposed for the additional sites at Mersey Point and Brooklyn. Liverpool Bay has previously been estimated to have an area of 3590 ha within the ‘open boundary’ shown in Figure 1 (Gregory et al. 1993). Therefore, approximately 3.4% of Liverpool Bay would be occupied by finfish leases with the proposed expansion. The approved production at the existing site 420,000 Atlantic Salmon. The maximum production plan at the proposed sites is 660,000 Atlantic Salmon per site, with a grow-out period of approximately 22 months from stocking. This represents an approximate 370% increase in the number of farmed fish in Liverpool Bay. The site development plan for the bay, with bathymetry, is presented in Figure 2.

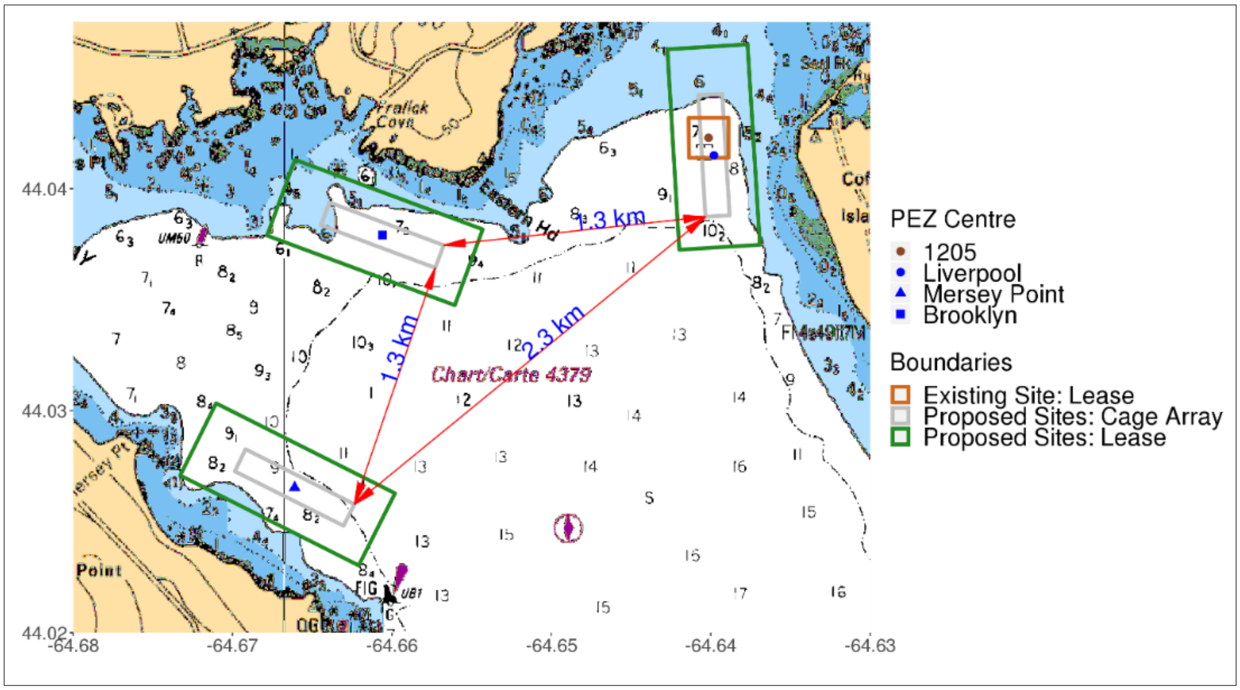

Figure 2. Current (brown) and proposed (green) lease boundaries overlaid on CHS chart #4379 (depths shown in fathoms). Distance between each proposed cage array (grey) is shown. The centers of each lease for predicted exposure zone calculations are also shown.

The sites are located in an area with variable bottom type and ecosystem characteristics (i.e., sand, mud, cobble, boulder, bedrock, shell debris). Proponent-submitted baseline data indicates the seabed beneath the proposed Mersey Point site is characterized by mixed substrates (hard-packed sand, pebbles, cobble, rubble and boulders), while the proposed Brooklyn site is characterized by harder and coarser sediment types only such as bedrock, boulders, and cobble. Baseline data collected at Liverpool while the existing #1205 site was stocked indicated mostly hard-packed sand and shell debris. Prevalent waste feed was also noted at the site center. Sediment sulfide concentration ranges based on Environmental Monitoring Program (EMP) data collected at the existing #1205 site from 2011–2019 are shown in Table 1.

Table 1. Station mean sediment sulfide concentration ranges (measured according to the Environmental Monitoring Program (EMP) Framework for Marine Aquaculture in Nova Scotia, NSDFAb). Records are shown from when the proponent acquired the site. The EMP data was retrieved from Nova Scotia's Open Data Portal on August 17, 2020 (NSDFAb).

Date	Sulfide Concentration Range (µM)	Sample Size (n)*	Production Stage
July 2011	77–3,677	3 stations	Year 1 fish
July 2012	51–5,477	4 stations	Year 2 fish
June 2013	78–551	3 stations	Harvest and fallow
July 2014	53–470	5 stations	Year 1 fish
July 2015	74–11,030	3 stations	Year 2 fish
July 2016	0	1 station	Harvest and fallow
October 2017	220–540	6 stations	Year 1 fish
July 2018	120–2,327	4 stations	Year 2 fish
July 2019	38–110	4 stations	Harvest and fallow

**each station consisted of 3 replicate samples*

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). The sediments beneath the existing site have demonstrated elevated sediment sulfides in the past with concentrations at some stations reaching Hypoxic B (> 3,000 µM) levels in 2011 and 2012, and an Anoxic (> 6,000 µM) level in 2015 based on Hargrave 2010 oxic categories (Appendix A). The location of these stations are shown in Figure 3. Some of the highest sulfide concentrations were observed during production stages of larger fish (i.e., year 2).

Figure 3. Environmental Monitoring Program stations at site #1205 that have exceeded mean sediment sulfide concentrations of 3,000 µM (yellow) and 6,000 µM (red), respectively, overlaid on a Google Earth image of the existing cages. Exceedances occurred in 2011 (triangles), 2012 (circles), and 2015 (stars). The existing #1205 lease boundary is shown in cyan and proposed lease boundary in white.

The Google Earth imagery (Figure 3) depicts net-pens are anchored outside of the currently issued lease but within the proposed #1205 expanded lease boundaries. Available *AAR* data from 2015–2018 indicate that no pest control products (i.e., azamethiphos, hydrogen peroxide, emamectin benzoate) have been used at the existing site. This is consistent with other finfish sites in Nova Scotia. Available information on reported escapes since 2010 indicate there have been no reports of escapes at the existing site (DFO 2020a). Additionally, there have been no reports of entanglements of marine mammals, sea turtles, or other species of concern to this review at the existing site.

Fishing vessel traffic from DFO's Vessel Monitoring System (VMS) database shows that all three sites, including site #1205, are located in an area with active fisheries. Lobster is the predominant commercial benthic invertebrate fishery occurring from late November through May each year. These sites are located within Lobster Fishing Area (LFA) 33, where the stock is considered to be healthy based on determined stock reference points (DFO 2020b), and more specifically within reporting grid 310. Catch and effort data reported by fishermen show that within LFA 33, 5.4% of licenses annually report landings from this grid, which represents 2.4% of total landings for the LFA, on average. Three licensed lobster holding facilities exist within 1 km of the proposed sites at Moose Harbour wharf, Mersey Seafoods wharf, and Fralick Cove (as shown on Figure 1; DFO Resource Management). These facilities consists of holding cages placed in the water adjacent to the wharves and are used by lobster fishers to store catch while waiting for the appropriate market conditions to sell their product. These facilities are only used during the commercial lobster season and are removed from the water during the off-season. The sites are also located within Scallop Fishing Area 29; however, the commercial fishery for scallop is typically further offshore.

Commercial groundfish and pelagic species in the area include Haddock, Atlantic Cod, Hake, Atlantic Halibut, Atlantic Herring, and mackerel. Cod and Haddock in Liverpool Bay are within the 4X5Y Northwest Atlantic Fisheries Organization (NAFO) management unit for these fisheries. The exact stock structure of Cod inshore is unknown; however, 4X5Y Cod is considered in the Critical zone. A review of tagging studies by Fowler (2011) concluded that there may have been several discrete Haddock reproductive populations in the past, many of which were inshore, but currently the remaining populations are offshore. The remaining populations are thought to be highly migratory and may come inshore during warmer months. The 4X5Y Haddock stock was considered in the Healthy zone in 2019 (DFO 2019a). All three proposed sites overlap with identified gillnet fishing activities within the Little Hope Herring fishing area, an area that is > 100,000 ha in size off SWNS from LaHave Islands down to Western Head. Herring spawning is also known to occur within the Little Hope fishing area from September–November based on the spawning condition of Herring landed from the area. The actual locations of Herring spawn on substrate within the Little Hope area is currently undocumented. The area is also noted to be used by juvenile Herring since they typically feed close to shore and fishermen have reported schools near shore (e.g., wharves). Gaspereau were also noted as a commercial fishery in the area (DFO Resource Management). Marine plants such as rockweed and wrack seaweed are also harvested for commercial purposes in the area.

There are Food, Social, and Ceremonial (FSC) fisheries for Lobster and Eel in Liverpool Bay (DFO Resource Management). All three proposed sites were noted to overlap with identified glass eel (pre-elver) fishing and nursery areas through DFO’s Coastal Fisheries Mapping Project (DFO Oceans and Coastal Management Division). Additional information on the size of the area or how specifically juveniles use the coastal habitat around the sites is lacking. Glass eels likely pass through these areas when migrating to streams further into bay and estuary such as the Mersey River, Herring Cove Brook, and Beach Meadows Brook. American Eel populations have been assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) since 2012 and are under consideration for listing under the SARA. Recreational fisheries for groundfish species and mackerel also occur in the area.

DFO database searches also indicated presence of Cusk and Bluefin Tuna in the area (both assessed by COSEWIC as Endangered), crab, and more sessile species such as clam, sea urchin, and whelk. Proponent-submitted baseline data also commonly identified the presence of mussel shells.

The existing and proposed sites are both within the migration pathways and range of the Nova Scotia Southern Upland (SU) wild Atlantic Salmon population. The nearby Mersey and Medway rivers are known Atlantic Salmon rivers. The SU Salmon run in the Medway River in Port Medway Harbour, which is approximately 10–12 km from Liverpool Bay, while the Mersey River is thought to be extirpated. Aquaculture escapees have been found in rivers at distances of up to 200–300 km from the nearest aquaculture site (Morris et al. 2008) and, although the Mersey and Medway rivers are closest in proximity, the majority of salmon rivers in the SU region are within that range. The SU Salmon have been assessed as Endangered by COSEWIC since

2010 and are under consideration for *SARA*-listing. Beginning in 2010, all rivers within Salmon Fishing Area (SFA) 21 were closed to recreational fishing for Atlantic Salmon and there have been no FSC allocations.

Species at risk that may be present in the area according to DFO's Aquatic Species at Risk Map include White Shark, Northern Wolffish, Spotted Wolffish, Leatherback Sea Turtle, North Atlantic Right Whale, Blue Whale, and Fin Whale. No overlaps between the proposed aquaculture sites and Critical Habitat for these species were identified (DFO 2019b).

Additionally, no DFO Ecologically and Biologically Significant Areas (EBSA) or Ecologically Significant Species (ESS) have been identified as having the potential to overlap with the proposed aquaculture activities. There is anecdotal information that suggests eelgrass (an ESS) could be present in Liverpool Bay, including documented eelgrass presence in neighbouring bays and along the south shore of Nova Scotia; however, satellite images from 2012 and 2016 and drone images from 2017 of Liverpool Bay does not indicate the presence of eelgrass. Furthermore, proponent-submitted baseline data collected at each site in 2019 did not indicate the presence of eelgrass. While this does not preclude the possibility of small patches existing in sheltered areas with suitable habitat, eelgrass is unlikely to occur in significant aggregations within the vicinity of the sites based on available data.

A provincially-designated nature reserve is located on Coffin Island, approximately 250 m from the proposed #1205 site and within 5 km of all three proposed sites. Other human activities, that represent a combination of land- and marine-based sources that have the potential to influence the Liverpool Bay marine ecosystem, also occur within 5 km of the existing and proposed sites. These include other industrial activities, the presence of land-based contaminated sites near the coastline, boat traffic, commercial fishing activities, and nutrient loading.

Key oceanographic, farm infrastructure and grow-out characteristics of the existing sites and proposed expansion considered in the following analyses are summarized in Table 2.

Table 2. Key oceanographic, farm infrastructure and grow-out characteristics of the existing and proposed site. Information sources are the proponent's development plan and baseline data reports, as well as the wind and wave conditions report for Liverpool Bay (CMAR 2020). Information not available for the existing site at the time of this review is indicated by n/a.

Characteristic	Liverpool	Mersey Point	Brooklyn	Additional Information
Tidal range (m)	2.1	2.1	2.1	• Same at existing site. • Range does not include surges in sea level.
Depth of tenure (m)	7.0–20.0	8.0–21.0	4.0–20.0	• 7.0–14.0 m at existing site. • Relative to vertical chart datum (lowest normal tide).
Current speed (cm/s)				• Same at existing site.

Characteristic	Liverpool	Mersey Point	Brooklyn	Additional Information
• **Surface**	0.1–52.5	0.1–29.7	0.1–37.3	• Surface currents measured at 14–16 m from bottom.
• **Midwater**	0.2–53.7	0.1–21.6	0.0–20.2	• Midwater currents measured at 8–9 m from bottom.
• **Bottom**	0.0–43.3 Dominant flow directionality to N-NW.	0.0–23.4 Dominant flow directionality to SE-NW.	0.1–18.2 Dominant flow directionality to NW.	• Bottom currents measured at 3–4 m from bottom. • Current speeds measured at the Liverpool site include a storm event.
Maximum 10-year significant wave height (m)	3.24 (S)	2.95 (ESE)	3.42 (SSE)	• Same at existing site.
Salinity (PSU)	30–32	30–32	30–32	• Same at existing site. • Length of measurement unknown.
Temperature (°C)	-0.4–19.9	-0.4–19.9	-0.4–19.9	• Same at existing site. • Measured from May 2014–November 2018.
Dissolved oxygen (mg/L)	4.35–14.3	4.35–14.3	4.35–14.3	• Same at existing site. • Typically above 6 mg/L. • Measured from June 2014–June 2018.
Substrate type	Mainly hard-packed sand and shell debris	Mix of hard-packed sand, pebbles, cobble, rubble, boulders	Mainly bedrock, cobble, boulders	• Same at existing site.
Net-pen array configuration	2 x 10	2 x 10	2 x 10	• 2 x 7 at existing site.
Individual net-pen	100	100	100	• Same at existing site.

Characteristic	Liverpool	Mersey Point	Brooklyn	Additional Information
circumference (m)				
Net-pen depth (m)	9	8	8	• Same at existing site. • Predator nets to 9–10 m.
Grow-out period (months)	< 22 months	< 22 months	< 22 months	• Same at existing site.
Maximum number of fish on site	660,000	660,000	660,000	• 420,000 at existing site.
Initial stocking number (fish/pen)	33,000	33,000	33,000	• 30,000 at existing site.
Average harvest weight (kg)	5.5	5.5	5.5	• Same at existing site.
Expected maximum biomass (kg)	3,630,000	3,630,000	3,630,000	• 2,310,000 at existing site. • Assumes fish grown to 5.5 kg.
Maximum stocking density (kg/m^3)	25.0	25.0	25.0	• n/a for existing site.

Sources of Data

Information to support this analysis includes data and information from the proponent, data holdings within DFO, publically available literature, and registry information from the SARA database. Additionally, supporting information files submitted to DFO for consideration and used in its review are shown in Table 3.

Table 3. Summary table of information files submitted to DFO.

Description	Filename
Proposed development plan package Baseline survey data submission	1) Liverpool Bay Package_FINAL_4Mar19.pdf

Description	Filename
Proponent-collected raw current meter data	1) Liverpool 2010 Raw Direction & Speed Data.xlsx 2) Mersey Point 2012 Raw Direction & Speed Data.xlsx 3) Brooklyn 2019 Raw Direction & Speed Data.xlsx

The following DFO databases were searched for species records within the Predicted Exposure Zones (PEZs) of the proposed sites and records are in Appendix B:

- Ecosystem Research Vessel (RV) Survey
- Industry Survey Database (ISDB)
- Maritime Fishery Information System (MARFIS)
- Whale Sightings Database

Site Description

The physical characteristics of the existing and proposed sites are reasonably expected to be similar given the close proximity to one another (Figure 2). The water temperature and salinity at the proposed sites are expected to have some variation on tidal time scales, but larger variations on wind-driven and seasonal time scales. Values are expected to fall within the ranges indicated above (Table 2). Temperature records provided in the baseline submission report a maximum low temperature that is above the required -0.7 °C for “superchill” events; however, a die-off event that occurred in March 2019 at the existing #1205 site was suspected to have been related to cold ocean temperatures.

Near-shore bathymetry information in the vicinity of the proposed sites to supplement information submitted by the proponent is lacking in Departmental and public data holdings. Proponent collected bathymetry data shows a depth range between 4 and 21 m within the proposed leases, with the most shallow depths at the Brooklyn site. In comparison to the existing #1205 lease, the proposed expansion will shift the northern and southern portions of the lease closer to slightly shallower and deeper waters, respectively.

The wave information provided in the proponent’s report is from an open ocean buoy located 215 km south-southwest of Liverpool Bay, and is not considered representative of the waves experienced at the proposed sites. A wind and wave conditions report for the proposed sites indicate that the sites are particularly vulnerable to waves from the east and southeast that will travel directly into the bay (CMAR 2020). Wave modelling for Liverpool Bay (CMAR 2020) predicts reasonably large maximum significant wave heights (Table 2), although more typical wave heights are likely to be less.

Current meter deployments occurred in September–October 2010 and 2012 at the Liverpool and Mersey Point sites, respectively, and January–February 2019 at the Brooklyn site. The difference in timing likely accounts for the differences in maximum observed current speeds

(Table 2), particularly at the Liverpool site where the highest maximum current speed was observed between the three sites. It was confirmed that Hurricane Earl passed through during that deployment on September 4, 2010. This presents a unique opportunity to consider the potential spatial extent of exposure in both ‘typical’ and ‘storm’ conditions, and demonstrates that current speeds vary with complexities of seasonal, wind, and storm influences that may or may not be captured in the records. Based on proximity of the sites, it is reasonable to assume that, at any given time, current speeds at all three sites would be similar.

Over the 32–37 day period that current speeds were measured at the proposed sites, average current speeds did not vary significantly with depth. Depth-averaged current speeds were consistent between sites with a range between 5.05 and 5.34 cm/s, and 52–71% of observed current speeds were from 2–8 cm/s at all depths and all sites. Current speeds > 16 cm/s were only observed approximately 2% of the time. Therefore, current dynamics at these sites are considered to be “low energy” with respect to marine finfish farming, with the periodic occurrence of large waves and storm events.

Based on the depth profiles of current speed data, temperature, and salinity at the site, stratification is expected to be weak. Therefore, exposure predictions do not need to consider stratification influences.

Benthic Predicted Exposure Zones and Interactions

Benthic Predicted Exposure Zone

The benthic-PEZ is an early screening step in a triage-based approach. A precautionary first-order estimate is used to determine the size and location of areas that may be exposed to a substance introduced into or released from a site. It is used to broadly assess the potential for impacts on the benthic community and seafloor from the deposit of waste feed and feces, which can result in organic loading and direct habitat and infaunal species impacts. Additionally, it is assumed that the PEZ associated with the release of in-feed drugs is dominated by the deposition of medicated feed waste and feces. These predicted exposure zones are precautionary overestimates and are considered sufficient for identifying, albeit at a larger spatial scale, the potential for impacts from the proposed activity.

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, particularly at sites over or near shallow depths such as all three proposed sites; however, this will be considered in the Pelagic-PEZ and Interactions section of this review.

First-order estimates of the spatial extent of the benthic-PEZ related to organic effluent and in-feed drugs from the proposed Liverpool, Mersey Point, and Brooklyn sites were 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 4), along with the maximum site depth 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 surface layer. Since these particles sink from the net-pens to the seabed, a mid-water current speed was selected as representative.

Table 4. First order benthic-Predicted Exposure Zone (PEZ) estimates of the potential horizontal distances travelled by sinking particles such as waste feed pellets, fish feces and in-feed drugs released from the fish farm (settling rates obtained from literature; Findlay and Watling 1994, Chen et al. 1999, Chen et al. 2003, Cromey et al. 2002, Sutherland et al. 2006, Law et al. 2014, Bannister et al. 2016, Law et al. 2016, Skoien et al. 2016).

Particle Type	Min. Sinking Rate (cm/s)	Max. Observed Current (cm/s)	Horizontal Distance Travelled (m)	PEZ Radius
LIVERPOOL				
Feed	5.3	53.7 *No storm - 20.3*	203 *No storm: 77*	515 *No storm: 389*
Feces	0.3	53.7 *No storm - 20.3*	3,580 *No storm: 1,353*	3,892 *No storm: 1,665*
Fines and Flocs	0.1	53.7 *No storm: 20.3*	10,740 *No storm: 4,060*	11,052 *No storm: 4,372*
MERSEY POINT				
Feed	5.3	21.6	86	398
Feces	0.3	21.6	1,512	1,825
Fines and Flocs	0.1	21.6	4,536	4,849
BROOKLYN				
Feed	5.3	20.2	76	389
Feces	0.3	20.2	1,347	1,659
Fines and Flocs	0.1	20.2	4,040	4,353

A PEZ is a circular zone centered on the middle of the proposed cage array and represent the outer limit for potential exposure; however, the benthic footprint is more likely a curved ellipse with a major axis length scale due to current directionality. The zones for each site were estimated by adding the horizontal transport distance to the longest length scale of the proposed net-pen array.

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. The waste feed-PEZ is anticipated to have the greatest intensity of exposure, and is conservatively a circle centered on the net-pen array. The spatial extent of exposure has been estimated for the Liverpool site using the maximum observed current speed both including and excluding the storm event on September 4, 2010 (Figure 4).

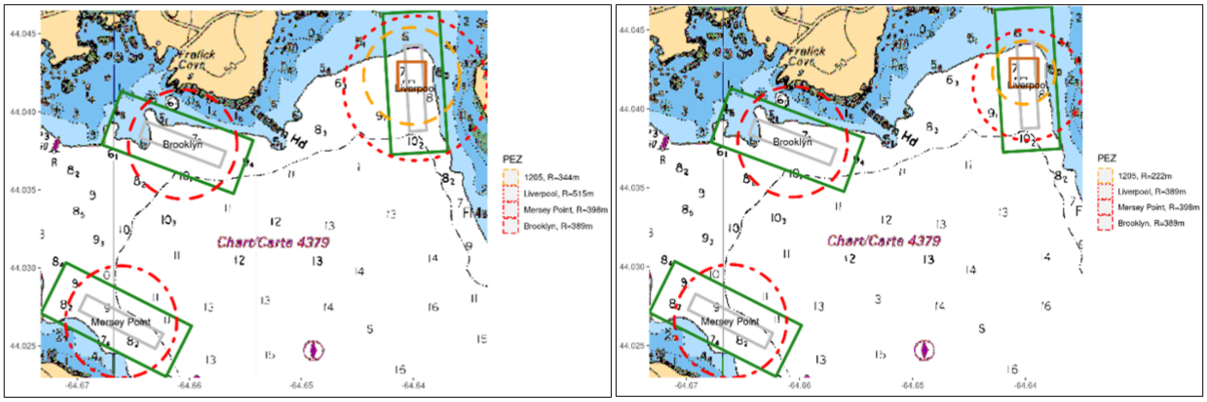

Figure 4. Benthic-Predicted Exposure Zones (PEZs) for the Liverpool (left: including storm event, right: excluding storm event), Mersey Point and Brooklyn proposed sites using the waste feed minimum sinking rate are shown in red overlaid on CHS chart #4379 (depths shown in fathoms). Net-pen arrays (grey) and lease boundaries (green) are shown. The existing #1205 Liverpool lease boundary and estimated benthic-PEZ are also indicated in brown and orange, respectively.

Based on the waste feed-PEZs, there are no overlaps between the benthic deposition zones where smothering and oxic-state changes are anticipated to occur due to organic loading (Figure 4). 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).

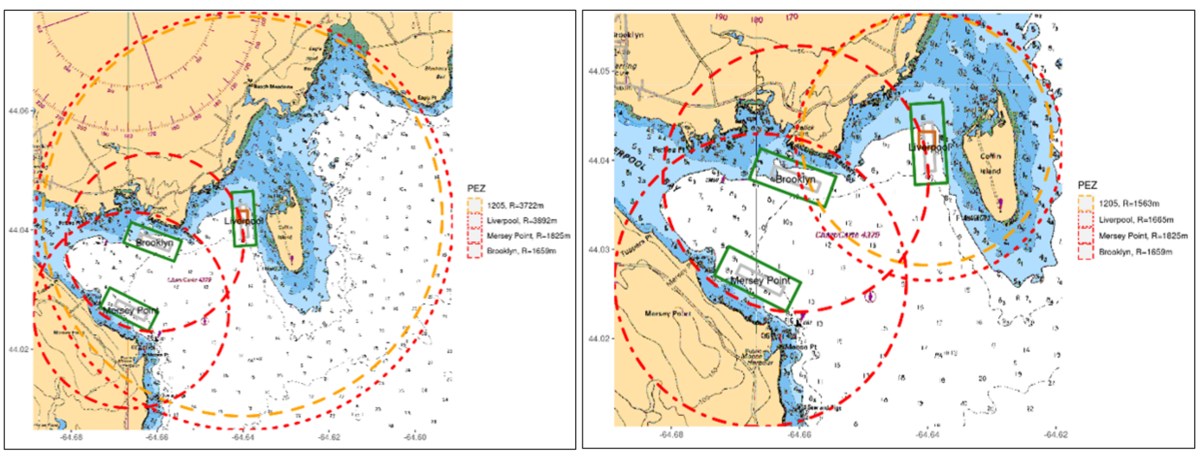

Figure 5. Benthic-Predicted Exposure Zones (PEZs) for the Liverpool (left: including storm event, right: excluding storm event), Mersey Point and Brooklyn proposed sites using the feces minimum sinking rate are shown in red overlaid on CHS chart #4379 (depths shown in fathoms). Cage arrays (grey) and lease boundaries (green) are shown. The existing #1205 Liverpool lease boundary and estimated benthic-PEZ are also indicated in brown and orange, respectively.

Overlaps in areas of feces deposition are predicted when the maximum current speed, both including and excluding the storm event captured in the Liverpool current meter record, is used (Figure 5). It is important to note that, although not done for the purposes of this review, using the maximum observed current speed during the storm event from the Liverpool current meter record to estimate PEZs for the Mersey Point and Brooklyn sites would result in much larger PEZs for those sites and encompass some areas that are not covered in Figures 4 and 5.

Current- and wave-induced bottom resuspension is not explicitly considered for these first-order estimates of exposure. The large maximum significant wave heights predicted by modelled wave dynamics at the proposed sites and the shallow water depths suggest that material deposited on the seabed will be resuspended and shifted around by these extreme waves during storm events. Studies in nearby Jordan Bay have shown that waves do generate sediment resuspension and greater dispersal of particulates (Law and Hill 2019); hence, it is not unreasonable to assume similar results from wave action in Liverpool Bay. Waste particles are unlikely to extend beyond the benthic-PEZs estimated for fines and flocs, particularly when considering the spatial extent of particulates predicted from the Liverpool site which captures the full extent of transport during these storm events. The overall potential impacts of redistribution and flocculant deposition is unknown, but are not anticipated to occur at levels where significant exposures are predicted.

Sediment sulfide concentrations in certain locations at the existing site have reached Hypoxic B and Anoxic oxic categories under current levels of production (Table 1; Figure 3), and these levels may increase as the total benthic footprint within the bay increases with the proposed expansion and addition of two new sites. The resuspension and transport of accumulated material on the bottom due to the periodic occurrence of large waves and storm events in Liverpool Bay likely contribute to the seabed beneath the proposed sites being periodically reset, and predicted exposures and interactions may therefore be transient.

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 either low oxygen levels, smothering, loss of access to the site, or exposure to in-feed drugs, if used. This includes species such as crustaceans and bivalves. 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, crab, clam, mussels, sea urchin, and whelk are present within the benthic-PEZ.

Studies have demonstrated the correlation of Lobster presence points (as indicated by Lobster traps) with the presence of rock and gravel substrate within Liverpool Bay. The most suitable habitat within Liverpool Bay appears to be closer to the shoreline and in proximity to the Liverpool, Mersey Point, and Brooklyn proposed sites, with a slightly higher probability of presence near the Liverpool and Brooklyn as compared to the Mersey Point site (McKee et al. 2020). However, preliminary results from a DFO Lobster tagging study in Liverpool Bay show that Lobster travel throughout most areas of the bay (Figure 6).

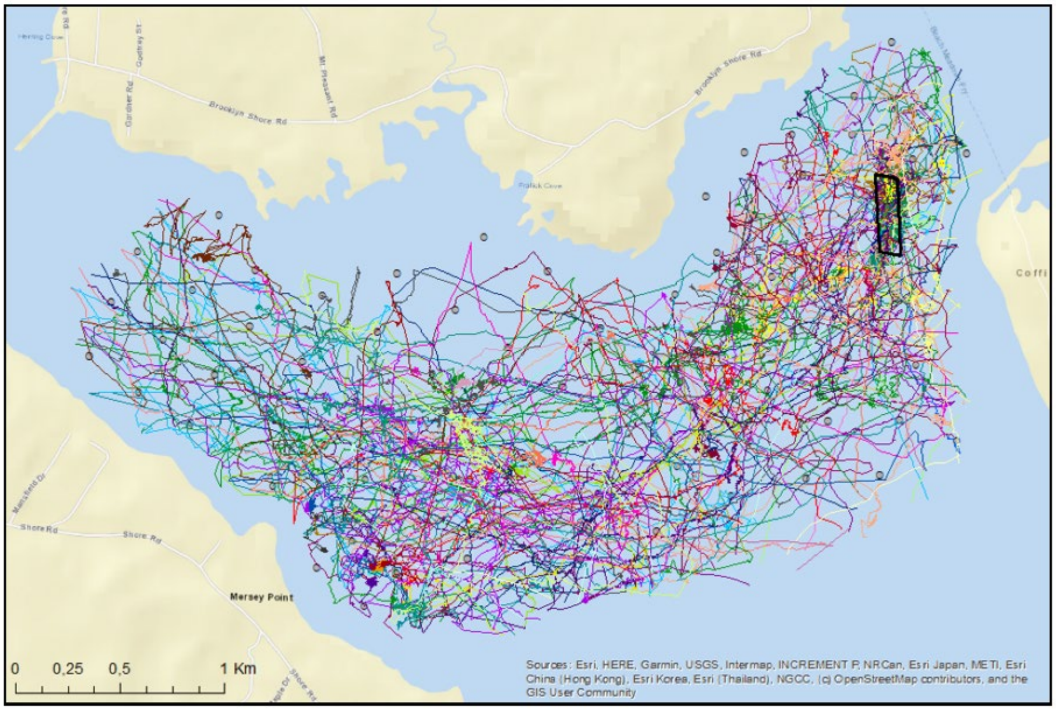

Figure 6. Movement of 50 lobsters tagged in Liverpool Bay in 2019. The black polygon represents the existing lease.

Areas of bottom habitat at the proposed aquaculture sites may also be highly suitable for settlement of larval lobster given the preferential selection for hard-bottom substrates. Increased sedimentation associated with the proposed aquaculture activities may preclude the settlement of larval lobster. Bivalves such as clams and mussels are also sensitive to siltation and the potential for smothering due to excess deposition that exists within the benthic-PEZ, particularly given their sessile nature. The potential for smothering also exists for the other sessile species in the area such as sea urchin and whelk. Given the periodic occurrence of large waves and storm events that contribute to the seabed being periodically reset, the accumulation of depositional material on the seabed may not be sufficient to result in smothering.

In-feed anti-sea lice drugs, such as Emamectin Benzoate (EB), have been shown in lab studies to have lethal toxic effects to crustaceans and can induce sub-lethal effects, including premature moulting (Burridge et al. 2000, Waddy et al. 2002, Burridge et al. 2008). If sea lice becomes an issue and anti-sea lice drugs are used, this may be of particular concern given the presence of Lobster within the benthic-PEZs. Bivalves in the vicinity of net pens have also been shown to have measureable quantities of in-feed drugs such as EB. Currently, hazard information is primarily based on acute exposures; however, it does not indicate a high level of risk (Burridge et al. 2011).

While the potential for exposures to organic matter and in-feed drugs (if used) already exist at the current #1205 Liverpool site, it is anticipated to increase as the individual and cumulative benthic-PEZs increase with the proposed expansion.

Pelagic Predicted Exposure Zones and Interactions

Pelagic Predicted Exposure Zones for Pesticides

The pelagic-PEZ is an early screening step in a triage-based approach. A precautionary first-order estimate is used to determine the size and location of areas that may be exposed to a substance introduced into or released from a site. It is used to broadly assess the potential for impacts on susceptible species from the use of registered pesticides used in finfish aquaculture, if required. These predicted exposure zones are precautionary overestimates and are considered sufficient for identifying, albeit at a larger spatial scale, the potential for impacts from the proposed activity.

The two pesticides available for use in bath treatments (e.g., tarp bath and well-boat) are azamethiphos and hydrogen peroxide. The size of the pelagic-PEZ depends on the decay and/or dilution rate of the pesticide, a chosen concentration threshold, and choice of horizontal water current speed. The PEZ is estimated using toxicity information of azamethiphos, the most toxic of the pesticides registered for use in Canada. Health Canada's Pest Management Regulatory Agency (PMRA) has assessed that neither of the two registered pesticides (hydrogen peroxide and azamethiphos), nor 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, suggesting they will not persist in the environment at concentrations considered to be toxic (PMRA 2014, PMRA 2016a, PMRA 2016b, PMRA 2017).

The pelagic-PEZ for azamethiphos was calculated assuming the maximum near-surface current speed persists throughout the dilution or decay scale (Figure 7). The spatial extent of exposure has been estimated for the Liverpool site using the maximum observed current speed both including and excluding the storm event on September 4, 2010. A 3-hour duration 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).

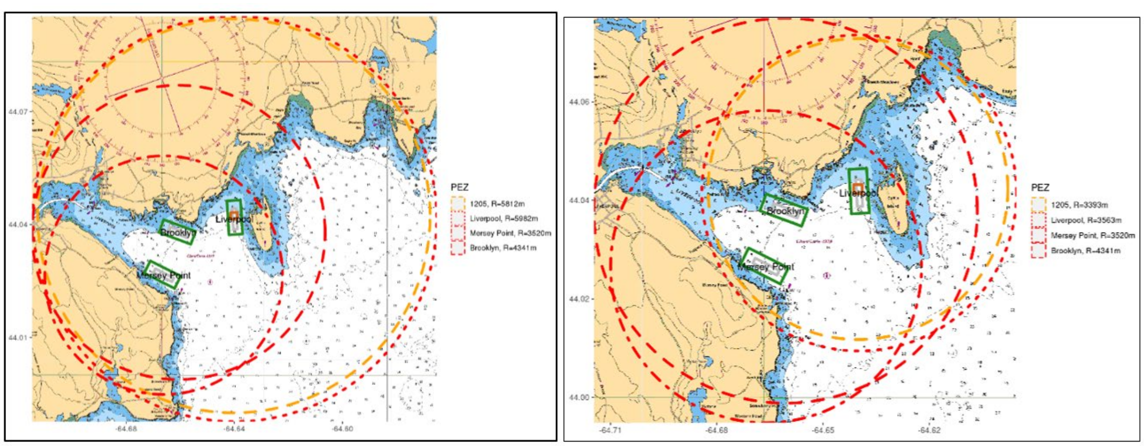

Figure 7. Pelagic-PEZs for the Liverpool (left: including storm event, right: excluding storm event), Mersey Point and Brooklyn proposed sites are shown in red overlaid on CHS chart #4379 (depths shown in fathoms). Net-pen arrays (grey) and lease boundaries (green) are shown. The existing #1205 Liverpool lease boundary and estimated benthic-PEZ are also indicated in brown and orange, respectively.

The near-surface current speed was used since the application of tarp bath treatments occurs in the surface waters. The pelagic-PEZ was calculated assuming the use of tarp bath treatments, regardless of whether all cages would meet the PMRA treatment conditions for application, given the larger exposure zone anticipated to result from a tarp treatment versus a well boat.

The pelagic-PEZ was estimated by adding the horizontal transport distance to the longest length scale of the proposed net-pen array. The pelagic-PEZ does not quantify the intensity or duration of exposure, nor include a frequency of exposure. The zones do not imply that areas within the pelagic-PEZ have the same exposure risk. The intensity of exposure 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.

The exposure is 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. The PMRA restriction on the use of azamethiphos at shallow sites (i.e., no application to tarped net pens in water depths ≤ 10 m) may be applicable to some net-pens.

If treatment is used at more than one site simultaneously, exposure overlaps associated with pesticide releases from the proposed sites are predicted when the maximum current speed, both including and excluding the storm event captured in the Liverpool current meter record, is used (Figure 7). However, it is recognized that estimates of exposure associated with storm scenarios would be a large overestimate since it is unlikely tarp applications would be used during a storm event.

The proposed addition of 6 net pens at the existing site may increase exposure time to azamethiphos within the pelagic-PEZ if the entire site requires treatment. This is based on the number of tarped net pens that can be treated simultaneously (no more than two) according to PMRA restrictions. This potential increase in exposure time is further amplified if sea lice were to become an issue within the bay at all three sites by the overall proposed addition of 46 net pens within the bay.

Since 2015, *AAR* reporting regarding the application of pesticides indicates that the existing #1205 Liverpool site has not required the use of pesticides such as azamethiphos.

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 Lobster and crab are present within the pelagic-PEZs for azamethiphos.

Azamethiphos tarp bath treatments are reported to pose risk levels that are below the established Level of Concern (LOC) for marine fish, marine mammals, and algae, but they are above the LOC for pelagic and benthic invertebrates. While in the environment, azamethiphos is toxic to non-target crustaceans, including all life stages of Lobster (PMRA 2016b, PMRA 2017, Burridge 2013).

Little is known about the larval Lobster dispersal or retention along the South shore of Nova Scotia. Miller (1997) examined larval distribution along the south shore of Nova Scotia from Sambro to Jordan Bay. Lower abundances of larval Lobster were found at study locations to the east of Port I'Hebert, including Liverpool Bay, as compared to western study areas. When present, Lobster larvae are likely in the water column from July through September, with the highest abundances from mid-July to mid-August (Tremblay and Sharp 1987, Miller 1997). A seasonal movement is also likely for adult lobster, with Lobster moving to the deeper offshore waters during the coldest months to maintain ideal temperatures and returning in proximity to the proposed sites as inshore bottom waters warm during the summer months. When they are present, they appear to travel throughout most areas of the bay (Figure 6).

The presence of Lobster holding facilities within 1 km of the proposed sites (Figure 1) means that the PMRA restriction concerning the use of pesticides within 1 km of any active licensed Lobster holding facilities may be applicable at certain times. These facilities are active during the commercial Lobster fishing season, which occurs from late November through May.

Should anti-sea lice pesticides be used at any of these three sites, overlaps with shallow hard-bottom areas that are suitable settlement habitat for post-larval juvenile and adult Lobsters are predicted, with higher probability of interaction from July through September. Additionally, the PMRA restriction is expected to be applicable from late November through May during the commercial Lobster season based on overlaps with these facilities. Timing and method of treatment is an important consideration that can reduce the potential for impacts on non-target crustaceans.

Genetic Interactions

The proposed leases are within the range of the SU wild Atlantic Salmon population and SFA 21. The SU Atlantic Salmon population levels remain critically low and have been assessed as Endangered by COSEWIC since 2010. The SU population of Atlantic Salmon is considered to be biologically unique, and its extirpation 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. 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 escapees are estimated to significantly exceed the number reported (Skilbrei et al. 2015, Mahlum et al. 2021, Føre and Thorvaldsen 2021). Escaped Atlantic Salmon have been found in 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 Atlantic Salmon, notably in Norway (Karlsson et al. 2016) and Newfoundland (Sylvester et al. 2019, Wringe et al. 2018). These interactions can occur over large areas, and escapees can represent a significant portion of a population's annual production (Glover et al. 2013, Glover et al. 2017, Heino et al. 2015, 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) interactions between escapees and wild Atlantic Salmon can have negative impacts on the wild population (Glover et al. 2012). 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. 2020b). Recently, several modelling approaches have been used to estimate the impact of aquaculture production and escapees on wild Atlantic Salmon populations:

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 the proposed expansion scenario (Keyser et al. 2018, see methods in Appendix C). With the proposed expansion, rivers in proximity to the expansion site will see the greatest increase; however, the propagule pressure experienced by nearly all rivers in the Maritimes Region will rise (Figure 8). Propagule pressure for rivers within 100 km of the proposed sites will increase by an average of approximately 17%, those within 50 km by an average of approximately 55%, and the largest increase will be approximately 107% for the Mersey River (Figure 8). Although, the Atlantic Salmon population in the Mersey River is considered extirpated, increases in escapees may hinder any future recovery efforts.

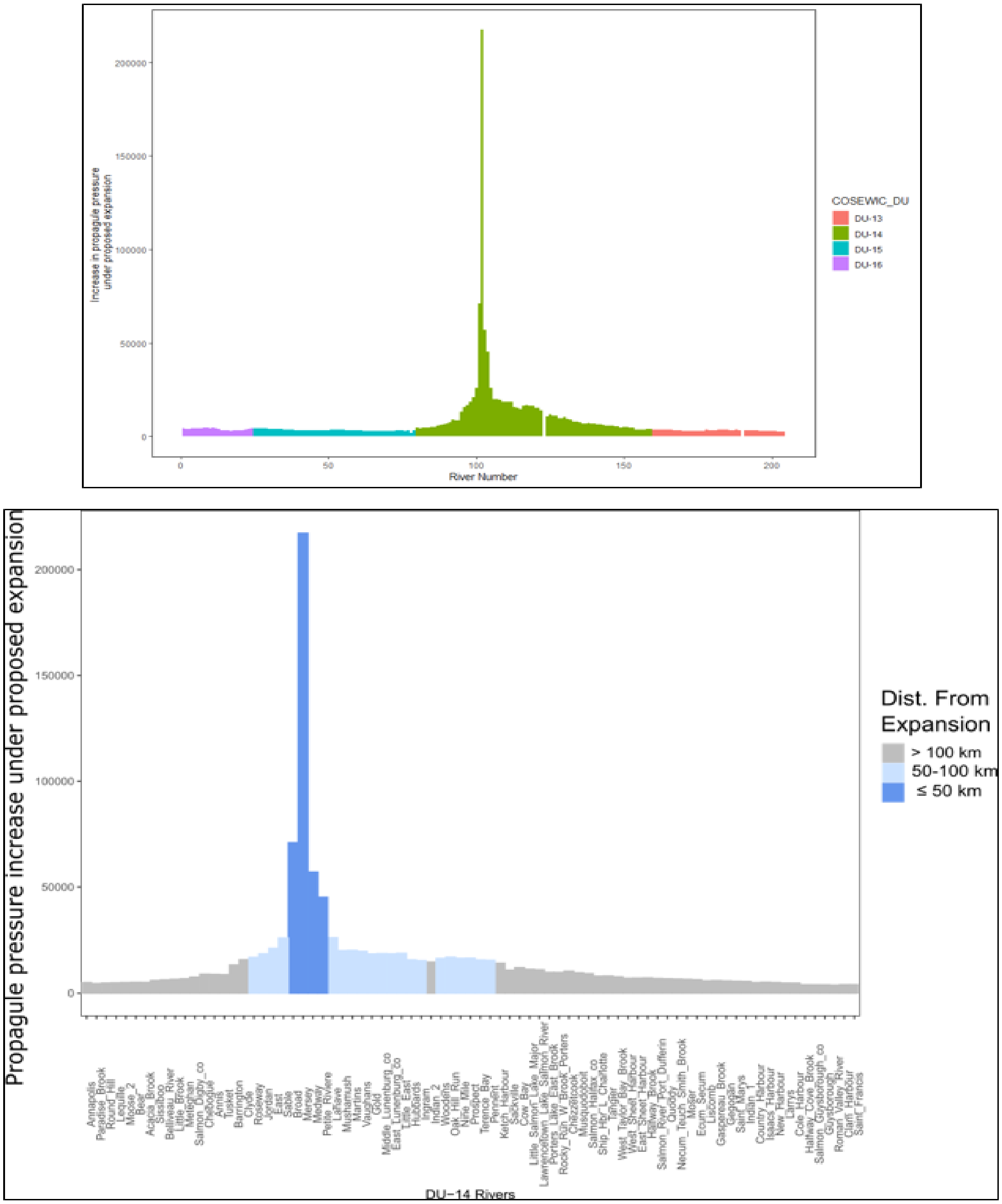

Figure 8. Top: Increase in propagule pressure for select rivers within the Maritimes Region. Propagule pressure was calculated as per Keyser et al. (2018). The proposed expansion is located approximately 10 km from the mouth of the Mersey River, number 102. Rivers are plotted west to east around the 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 Designateable Unit (DU). Bottom: Increase in propagule pressure under the proposed expansion for select rivers within the Southern Uplands DU (DU-14). Rivers plotted are a subset of those in the top panel and correspond to river numbers 80 to 159. Colours indicate distance from the proposed expansion.

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. (2020b) was adapted for this review. The IBSEM models changes in abundance, genotype, and individual size in response to the introduction of domesticated individuals (Castellani et al. 2015, 2018, Sylvester et al. 2019, Bradbury et al. 2020b). It 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 since it has the most parameters available for the IBSEM. Other values to parameterize the model were taken from across the global 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.

As in Bradbury et al. (2020b), the number of returning spawners declined during the invasion period, but returned to the zero-percent invasion baseline relatively quickly 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 1, and farmed individuals values approaching 0. Therefore, if the population genetic average declines, this indicates the population is becoming genetically more "farm-like". As with abundance, 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. 2020b). Compared to demographic impacts, genetic impacts were found to occur at a lower proportion of escapees, and require a longer time to recover (if at all). Genetic impacts were detected during the invasion period when the level of escapees were 2.5% or greater compared to the wild population (see Figure C3 and Figure 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.

A lower and higher impact threshold of 4% and 10%, respectively, was chosen for the proportion of escapees. The IBSEM simulations suggest that at invasion percentages of 5% or less demographic and genetic recovery was likely within 100 years of escapes stopping, while lasting demographic and genetic impacts are likely in populations experiencing influx levels at or above 10% 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 (Figure C1 and Figure C3, Appendix C). The lower and upper threshold have both been used in previous siting reviews (DFO unpublished manuscript)[1].

Spatial Dispersal of Escapees

Dispersal of escapees from aquaculture facilities was modelled using Johannsson et al. (2017), as described in Bradbury et al. (2020b). This model incorporates 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. 2020b). Salmon populations in all rivers are assumed to be at 5% of the conservation egg requirement (Gibson and Claytor 2012), a value that is consistent with the best available estimates (DFO 2020c), and percentages of escapees are calculated relative to these values. At current production levels, the dispersal model predicts that a large number of rivers in the Maritimes Region are expected to be above both thresholds (Figure 9). Within the Southern Uplands DU, except for the Annis and Tusket rivers, all rivers to the west of Liverpool Bay are currently predicted to be above the upper 10% threshold, while all rivers to the east as far as Pennant River, near Halifax, are above the 4% threshold (Figure 9).

[1] DFO. 2021. Review Of The Marine Harvest Atlantic Canada Inc. Aquaculture Siting Baseline Assessments For The South Coast Of Newfoundland. Manuscript in preparation.

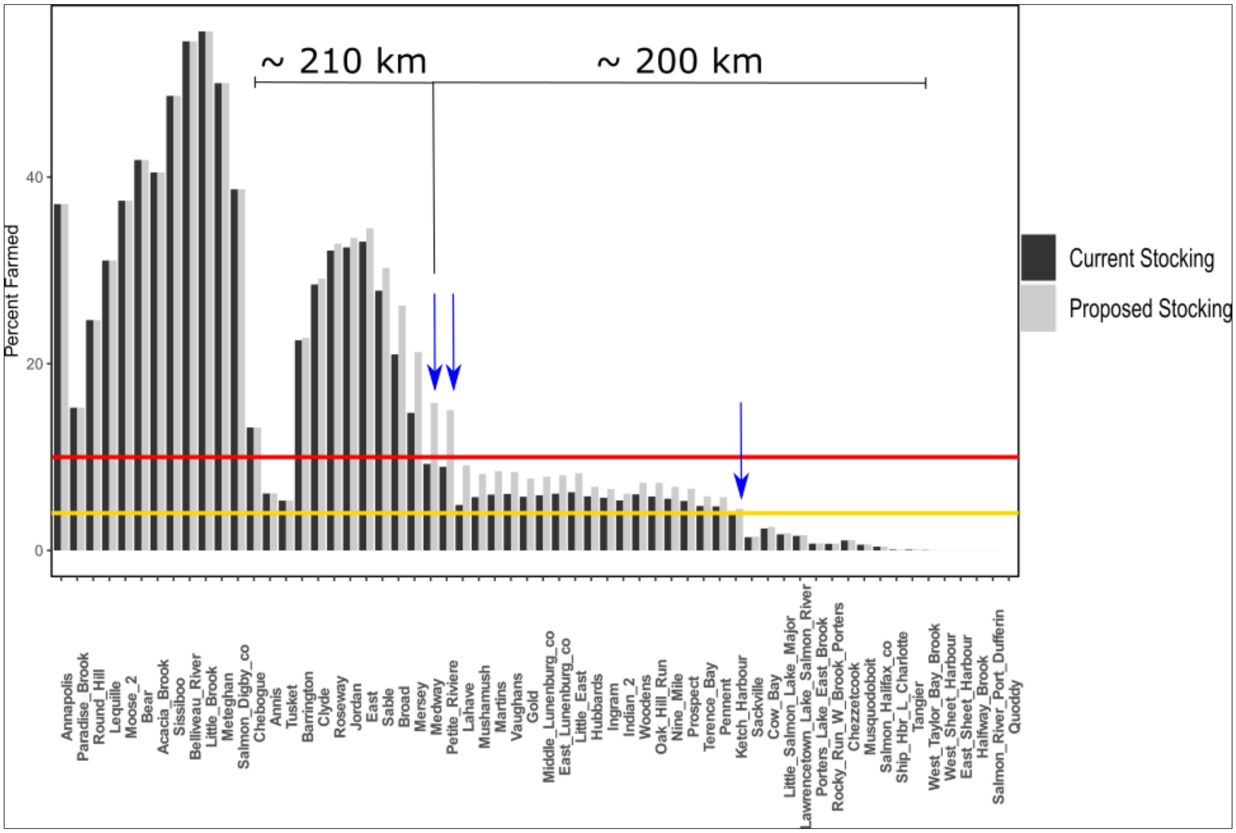

Figure 9. Predicted percent farmed salmon in selected rivers, arranged west to east, within the Southern Uplands DU. Rivers from the border of with the Inner Bay of Fundy DU in the east, to the Quoddy River to the west are shown (Numbers 80–40 in Figure 8). Expected proportions under current stocking numbers. are shown in black. Expected proportions with the proposed expansion in Liverpool Bay operational are shown in grey. The horizontal yellow and red lines are the 4% and 10% thresholds, respectively. The proposed expansion is located approximately 10 km from the mouth of the Mersey River and is predicted to result in the Mersey, Medway and Ketch Harbour rivers (blue arrows) moving into higher risk thresholds. Distances from the proposed expansion site are shown by scale bars.

Compared to current production, the dispersal model predicts that the proposed expansion would result in an increase in the proportion of escapees in most rivers within 200 km on either side of the proposed Liverpool Bay expansion sites (Figure 9). Based on wild populations at 5% of the CER, the proportion of escapees in Mersey and Medway Rivers would increase beyond the 10% threshold, while the proportion in Ketch Harbour River would increase from being below the lower risk threshold to above the 4% threshold (Figures 9). Given the IBSEM model suggests that demographic and genetic impacts will increase with the proportion of escapees entering rivers, greater impacts to wild populations are expected in rivers where the dispersal model predicted increases in the percentage of escapees. Furthermore, increases in escapees may hinder future recovery efforts in rivers, such as Mersey River, where Atlantic Salmon are considered extirpated.

Summary of Genetic Results

Keyser et al. (2018) found that the number of aquaculture escapees and their genetic impact was positively correlated with propagule pressure, while the IBSEM results shown here, and in Bradbury et al. (2020b), 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 Liverpool Bay expansion, it is likely the genetic and demographic impact from escapees impact will also increase as a result of the expansion.

Additionally, impacts on wild Atlantic Salmon population are possible in the absence of direct genetic impacts of hybridization or introgression between wild and escapee salmon. Bradbury et al. (2020a) 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. Ecological interactions can 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.

The closest rivers to the proposed sites are the Mersey and Medway. Southern Upland Atlantic Salmon were present in the Medway River during electrofishing surveys conducted by DFO in 2008. Salmon were not detected in the Mersey River during the survey, and the population is considered to be extirpated. Increases in escapees may hinder future recovery efforts in the Mersey and other SU rivers. In SFA 21, the index population for Atlantic Salmon assessment activities is the LaHave River, which is located approximately 40 km from the existing and proposed sites. The LaHave River watershed is one of the largest in SFA 21, and annual adult counts have occurred 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 conservation egg requirement (DFO 2020c). The total counts at the Morgan Falls fishway have been below 250 individuals since 2012, with fewer than 100 returning salmon in 4 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 19% and the dispersal model predicts the proportion escapees would nearly double from 4.87 to 9.11%. While the LaHave River would remain below the 10% upper threshold, the IBSEM model indicated demographic and genetic impacts generally increased with proportion of escapees.

Given the low levels of SU Atlantic Salmon and the proximity of the proposed sites to salmon rivers, impacts to wild salmon should be minimized to the lowest possible level. Mitigation measures that decrease the likelihood of a containment breach (e.g., physical and containment and biocontainment measures) should be considered (DFO 2013, Benfey 2015, Bridger et al. 2015).

While the risks to SU Atlantic Salmon already exist at the current lease, these risks are expected to be at least proportional to the intensity of the activities themselves. Therefore, the risks to the wild Salmon population will be greater with the proposed increases in the number of farmed Salmon within Liverpool Bay between the Liverpool, Mersey Point, and Brooklyn sites.

Pest and Pathogen Interactions

Cultured fish may acquire endemic diseases and/or sea lice infestations from wild fish or from other farmed fish in the area (DFO 2014). Given density-dependent transmission is observed in many host-pathogen systems, including sea lice on salmonid farms (Kristoffersen et al. 2013, Frazer et al. 2012), this can pose a significant health risk to farmed and wild fish when present at certain host density threshold levels (Krkošek 2010).

Since 2015, available *AAR* data confirm that no pest control products have been used at the existing site in Liverpool Bay. However, the sea lice abundance at the sites is unknown and the historical use of approved drugs and pesticides may not be a predictor of future disease outbreaks as production within the bay increases or as other influencing factors change. 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. The impact on wild susceptible fish species will depend on the duration and extent of their exposure to the farm, the increased concentration of pathogens and parasites, and their relative susceptibility to infection and disease within the environmental conditions found in Liverpool Bay.

Physical Interactions

Bycatch or entanglement of wild species (e.g., wild fish, marine mammals, turtles, sharks) associated with the placement of infrastructure are also potential interactions associated with aquaculture sites.

The proposed increase in total leased area within Liverpool Bay may result in a loss of access to habitat used by wild populations during various life history stages. Overlaps between the proposed sites and herring spawning grounds were identified; however, the spawning area was defined using the spawning condition of landed herring rather than the presence of non-motile spawn on the substrate. Additionally, this habitat is not unique to the proposed lease areas or to Liverpool Bay given the size of the Little Hope fishing area and related spawning area.

Overlaps between the proposed sites and nursery habitat for juvenile American Eel were also identified. The size and uniqueness of the nursery habitat, as well as habitat use is unknown.

All near-shore areas along the North American coast with suitable surface temperatures and high prey densities are likely to be the primary feeding and staging grounds for immature wild salmon destined to return as spawners to rivers in the SU region (Thorstad et al. 2011). Additionally, limited data from a post-spawn adults (kelts) tracking study on LaHave River suggest that coastal habitats in the vicinity of their natal river are important for consecutive spawning adult Atlantic Salmon while reconditioning between spawning events (Hubley et al. 2008).

The proposed increase in total leased area may result in Lobster being inaccessible to the traditional Lobster fishery in Liverpool Bay. Preliminary results from a DFO Lobster tagging study in Liverpool Bay have found that individuals tagged under the existing Liverpool #1205 site did not stay beneath the site and individuals tagged at reference locations did not go under the site (Figure 6; McKindsey and Robinson, DFO, pers. comm.). While the site was fallowed during the first year of sampling in Liverpool Bay, data were collected in 2020 when the site was stocked and are currently being analyzed. The results of this study will provide information on the behavior of Lobster beneath fish cages.

Potential *SARA*-listed marine mammal and sea turtle species within the area include North Atlantic Right Whale, Blue Whale, Fin Whale, and Leatherback Sea Turtle (DFO 2019b). 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 the proposed lease areas. Leatherback Sea Turtle is the most common sea turtle recorded in Nova Scotian coastal waters; they inhabit both offshore and coastal waters, but have a median sightings water depth of over 100 m.

White Shark, Spotted Wolffish, and Northern Wolffish are also SAR identified in the area. Tracking data from August–October 2019 detected the presence of at least 15 distinct White Shark in Liverpool Bay directly around the proposed aquaculture sites (Trudel and McKindsey, DFO, pers. comm). To date, there have been no reports of White Shark entanglements in marine finfish aquaculture gear in Atlantic Canada. Additionally, both wolffish species are unlikely to be near the proposed sites, as their preferred habitat is in much deeper waters and trenches.

There have been no entanglement reports of wild species at the existing #1205 Liverpool site. The magnitude of exposure and physical interactions between fish and infrastructure at the proposed Liverpool, Mersey Point, and Brooklyn sites are unknown; however, if present, the increase in total leased area and infrastructure from the proposed expansion suggests a greater potential for interactions between these species and the infrastructure associated with the footprint of the existing site.

Potential Cumulative Interactions

The entire area of interest surrounding the three proposed finfish aquaculture sites in Liverpool Bay is influenced by human activity (Figure 10; Table 5).

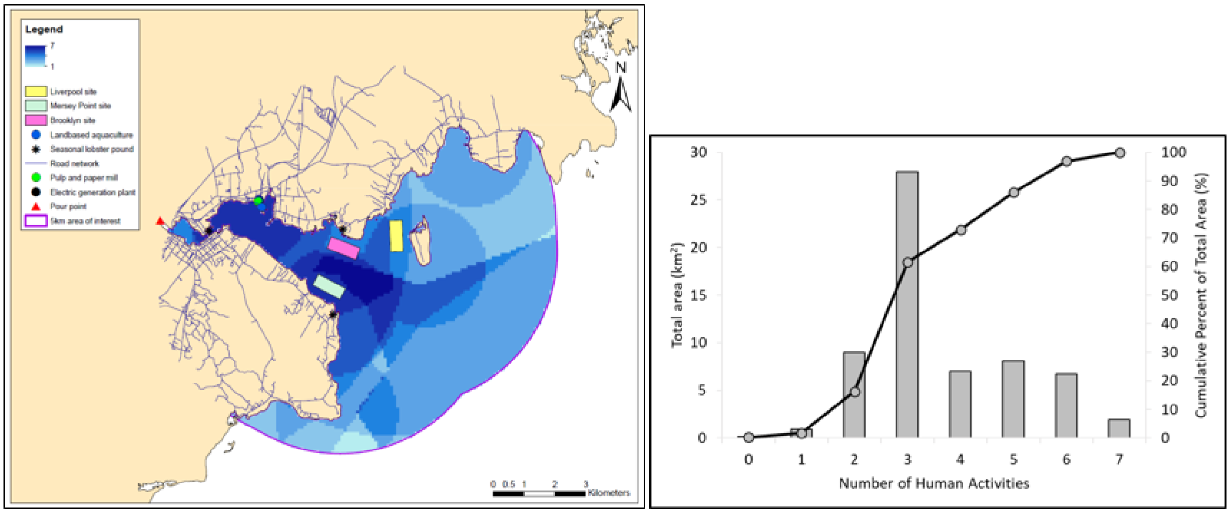

Figure 10. Left: Number of overlapping human activities in each 0.01 km² grid cell within the 5 km area of interest. The existing Liverpool Bay lease boundary amendment is represented by the yellow rectangle. The red triangle is the pour point location (i.e., the location where the Mersey River drains into Liverpool Bay). Locations of seasonal lobster holding facilities are presented for interest, but were not included in the analysis. Right: Total area (km²; grey bars), and the cumulative percent of the total area (%; black line, grey circles), in all grid cells with the corresponding number of human activities.

The larger, widespread estimated PEZ (pelagic-PEZ) associated with marine aquaculture activities results in significant spatial overlap among the existing and proposed lease areas, as well as with all other human activities occurring in the area of interest. The number of overlapping activities is high, with approximately 84% of the area of interest being influenced by three or more co-occurring human activities in any given grid cell (Figure 10).

The greatest degree of overlap and heaviest area of use occurs in the corridor between the proposed Mersey and Brooklyn sites towards the outer bay, followed by the inner bay close to the community of Liverpool (Figure 10). The overlap in human activities also extends to the outer bay and to the limit of the area of interest (i.e., overlap of multiple human activities still occur at 5 km away from the lease areas). Appendix C provides methodology details of this analysis.

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 that have been identified as occurring within Liverpool Bay have been linked to > 1 stressor impact, and five of these activities have influences across all three categories (Table 5).

Finfish aquaculture, boat traffic, Lobster fishing, and nutrient loading activities generate the greatest number of different types of chemical stressors that can affect water and sediment quality (Table 5). Boat traffic is also associated with causing the greatest number of different physical stressors, while finfish aquaculture activities are linked to the greatest proportion of different biological stressors (Table 5). Overall, finfish aquaculture activities and recreational boating may be responsible for the largest proportion of different stressor effects, while contaminated sites and marine plant harvesting may generate the smallest proportion of different stresses on species and habitats in Liverpool Bay (Table 5). The most common stressors linked to the seven human activities are benthic disturbance (physical stressor; 6 of 7 activities), contamination (chemical stressor; 6 of 7 activities), and biomass removal through incidental mortality (biological stressor; all 7 activities) (Table 5).

At present, there is little scientific evidence to be able to weigh the relative magnitude of each stressor effect listed in Table 5. 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.), and may be of concern at particular times of year. Further, little information is available on the acute and chronic effects of these stressors (e.g., noise, light, marine debris, changes in currents/circulation).

Table 5. Comparison of stressors associated with human activities identified in this analysis.

Stressors		Activities						
		Finfish aquaculture	Lobster fishing	Marine plant harvesting	Boat traffic [a]	Nutrient loading [b]	Commercial and industrial [c]	Contaminated sites [d]
Physical (direct alteration to habitats)	Benthic disturbance	X	X	X	X	X	X	-
	Change in temperature	-	-	-	-	X	-	-
	Collisions	-	X	-	X	-	-	-
	Change in currents/circulation	X	-	-	X	-	-	-
	Light	X	-	-	X	-	X	-
	Marine debris	-	X	-	X	X	-	-
	Noise	X	X	-	X	X	X	-
Chemical (water and sediment quality)	Bacteria	X	X	-	X	X	X	-
	Contaminants	X	X	-	X	X	X	X
	Nutrients	X	X	-	X	X	-	-
	Oil/waste	X	X	-	X	X	X	-
	Organic waste	X	X	-	X	X	X	-
	Sediment transport (turbidity)	X	X	-	X	X	X	-
Biological (changes to non-	Changes in behaviour (predator or prey)	X	-	X	X	-	-	X

Stressors		Activities						
		Finfish aquaculture	Lobster fishing	Marine plant harvesting	Boat traffic [a]	Nutrient loading [b]	Commercial and industrial [c]	Contaminated sites [d]
target species)	Biomass removal (incidental mortality)	X	X	X	X	X	X	X
	Diseases and parasites	X	-	-	-	-	-	X
	Genetic interaction	X	-	-	-	-	-	X
	Invasive species	X	-	-	X	X	X	-

[a] combined stressors from small docks, ramps, wharves, fishing vessel, pleasure boating, and kayaking activity categories of Ban et al. (2010)

[b] combined stressors from human settlements and agriculture categories of Ban et al. (2010)

[c] combined stressors from pulp and paper, industry land-based activity categories of Ban et al. (2010)

[d] combined known effects of the majority of contaminants found at the Liverpool Bay contaminated sites (e.g., PCBs, PAHs, PCDD/Fs, and organometalloids) (CCME 1999a, b, 2001a, b, 2010)

Weighing the relative impact of each human activity on a broad spatial scale (e.g., the whole of Liverpool Bay), can be considered by examining the spatial distribution of the activity multiplied by a specific vulnerability score, which estimates the vulnerability to human activities of different habitats known to be present in Liverpool Bay (Kappel et al. 2012; see Appendix D for further explanation). The use of habitats also indirectly captures impacts on associated species. Contaminated sites, followed closely by boating traffic and marine aquaculture, have the greatest (potential) relative impact scores (Figure 11; Table D2 in Appendix D).

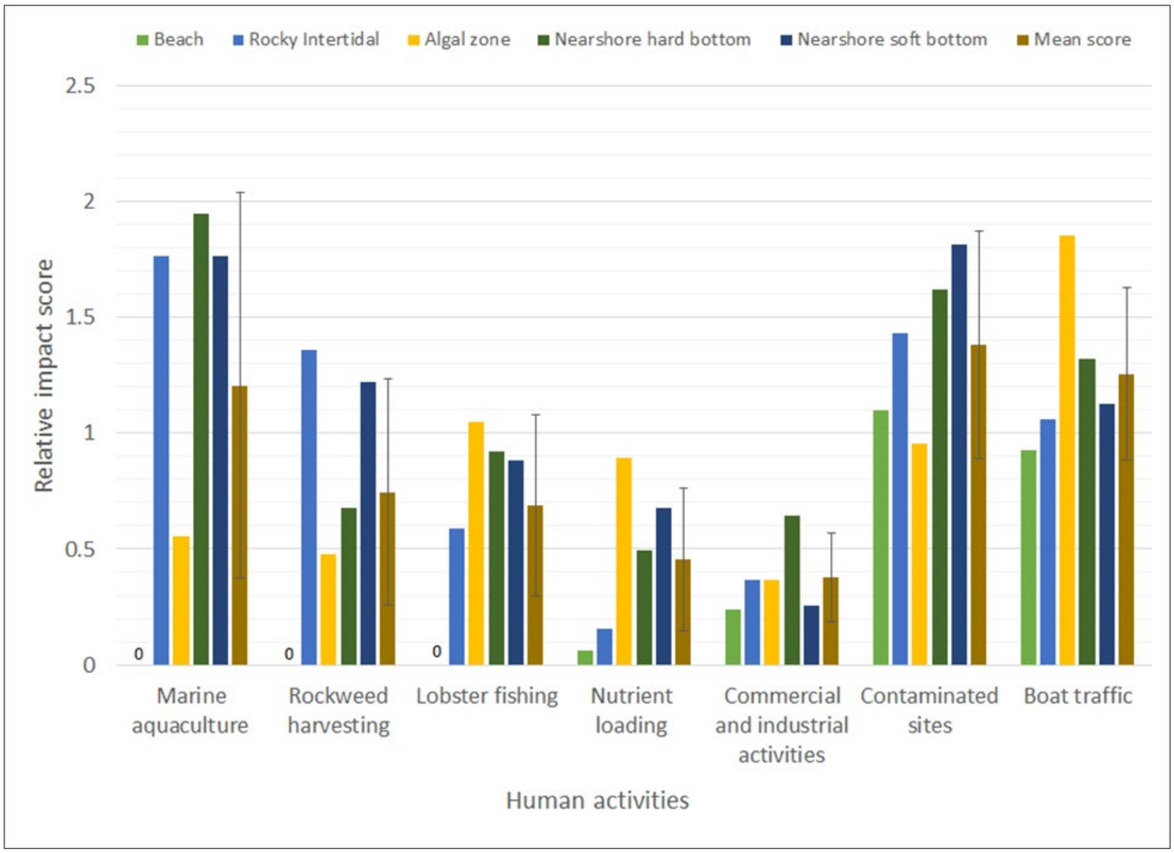

Figure 11. Relative impact score of human activities occurring in Liverpool Bay in 5 different habitat types (beach, rocky intertidal, algal zone, nearshore soft benthic, nearshore hard benthic) plus their mean value. Relative impact score in the vulnerability score multiplied by the proportion of total area in which the human activities occur within the 5 km area of interest. Larger values indicate the potential for more widespread impacts on habitats in Liverpool Bay. Wider error bars indicate more variable vulnerabilities to activities across the 5 different habitat types. See also Table D2 in Appendix D.

High impacts from land-based contaminated sites near the coastline and boating traffic are a result of the high average vulnerability of different marine habitats to these activities, due to the potential of these activities to impact a wide range of trophic levels and a large proportion of biomass. In contrast, high impacts from marine aquaculture are a result of the wide spatial distribution of this activity throughout the area of interest (e.g., highest intensity) despite having a relatively lower mean vulnerability score. This analysis suggests that boating traffic, marine aquaculture, and contaminated sites have the largest potential impacts, and that the cumulative effect of these three activities may have the most significant anthropogenic footprint on the Liverpool Bay ecosystem.

Cumulative impacts on coastal water and sediment quality may result from the overlap in marine aquaculture, boating traffic, and contaminated sites, and to a lesser extent commercial and industrial activities and nutrient loading. While the magnitude of recreational boating traffic is currently unknown, it is likely highly seasonal, following the typical tourist season for Nova Scotia (May–October, with peaks in June–August). Further, as lobster fishing season occurs between November through May, the overlap with fishing vessels suggests a constant, year-round pressure from vessel traffic. While individually the impacts of boating are considered minor, their cumulative impact may result in detrimental effects on species and/or habitats. Small vessels contribute to reduced water quality through pollution due to leakage of fuels and oils, antifouling paints (containing copper), and human waste (sewage effluents) (Leon and Warnken 2008).

The majority of the reported pollutants at the contaminated sites include PCBs, PAHs, PCDD/Fs, and organometalloids. Pelagic species may take up some of these contaminants directly from the water column, while benthic organisms may absorb these substances through contact with the sediments as well as the overlying water (CCME 1999b, 2010). While the ultimate fate for these types of contaminants is the benthos, how much may leach from nearby contaminated soils and groundwater into the water column and marine sediments is unknown (included in this analysis in order to be precautionary). Further, legacy impacts from pollution attributed to land-based industrial activities could also contribute to impacts on water and sediment quality, particularly for localized areas immediately adjacent to the aquaculture leases. Data collected in Liverpool Bay through DFO’s Aquaculture Monitoring and Modelling Program (AMMP) in 2019 showed a clear example of contributions from another industrial source, in which organic matter, sulfides, and trace metals were locally high near the now defunct Bowater Mersey pulp and paper plant further up in the bay in Brooklyn, NS. The plant was closed in 2012 but is still in use for other industrial purposes. The addition of increased feed and waste products from the proposed increase in the production of fish in nearby marine aquaculture facilities, in combination with land- and marine-based pollutant sources, boating traffic, and contaminated sites, suggests a high potential for cumulative effects on water and sediment quality, particularly impacting benthic habitats and associated species.

Boating also contributes to the secondary spread of non-native species (Clarke Murray et al. 2011, Burgin and Hardiman 2011). Aquaculture activity adds or removes physical structures (e.g., ropes, buoys, anchors) that can be colonized by diverse biological assemblages, which can affect the local ecosystem (DFO 2010). The invasive tunicates *Botryllus scholsseri, Botryllus schlosseri* and *Ciona intestinalis* are already present in Liverpool Bay (Sephton et al. 2017); 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 along the NS coastline (e.g., *Botrylloides violaceus*).

The spatial overlap of boat traffic, marine aquaculture sites, and rockweed harvesting, suggests increased benthic disturbance in areas where they may overlap. The presence of finfish aquaculture has been associated with decreased macro-infaunal biomass, and shifts in benthic community structure (Cullain et al. 2018). Marine plant harvesting can directly influence the availability of fish habitat and herbivore driven and detrital food webs through the biomass removal of the plants themselves, but may also indirectly increase the by-catch of plant-associated invertebrates, and alter the behaviours of predators and prey (Vandermuelen 2013, Sharp et al. 2006, Kay 2015). The movement of vessels in shallow waters causes turbulence through propeller action, benthic disturbance and destruction due to anchoring and dragging, which are a particular threat to submerged macrophytes (Bishop 2008, Lewin et al. 2019). Little information was available on the specific areas in which rockweed is harvested in Liverpool Bay (its spatial distribution could only be estimated from the larger lease area); however, if plant harvesting areas occur within or adjacent to aquaculture sites alongside or within the heavy boat use corridors, an increased cumulative impact on algal species and their associated fauna is a likely outcome.

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?*

- The seabed up to approximately 3.8 km from the proposed sites may be exposed to in-feed drugs present in feces, if used.
- Pesticide levels that are toxic to susceptible species may travel up to approximately 4.3 km from the proposed sites, if used.
- Overlaps in the predicted exposure zones from fish health treatment products (both in-feed drugs and bath pesticides) are anticipated, if used at more than one site.
- The intensity of exposure is expected to be highest near the net-pen arrays and decrease as distance from the net-pens increases, except for in areas of anticipated overlaps where cumulative exposures may occur.
- The proposed site locations are likely to result in the benthic environment in shallower areas around the site being exposed to concentrations of pesticides that are toxic to sensitive benthic life stages and species, if present.
- Lobster and crab have been identified within the PEZs of fish health treatment products used at the proposed sites. Adult Lobsters may be exposed to in-feed drugs and toxic concentrations of pesticides in shallower areas around the site. Larval Lobster may also be exposed to toxic concentrations of pesticides.
- The PMRA conditions on use of azamethiphos may apply from November–May, when commercial Lobster holding facilities less than 1 km from the proposed sites are operational.

***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?*

- The total benthic footprint within Liverpool Bay is anticipated to increase, but overlaps in the areas of organic matter exposure due to waste feed are not predicted.
- Lobster, crab, clams, mussels, sea urchin, and whelk have been identified within the benthic-PEZ and are susceptible to deposition of organic matter.
- Bivalves and other sessile species are susceptible to smothering and the potential for oxic state changes. Additionally, increased sedimentation may preclude the settlement of larval Lobster given their preferential selection for harder-bottom substrates.
- Available information suggests these species are not unique to Liverpool Bay.
- Predicted exposures and interactions may be transient as the seabed is periodically reset due to large waves and storm events.

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?*

- The entire area of interest around the proposed sites is influenced by human activities with significant overlap.
- Human activities include commercial and industrial activities, nutrient loading, presence of land-based contaminated sites near the coastline, boat traffic, Lobster fishing, rockweed harvesting, and marine aquaculture.
- Contaminated sites, boating traffic, and marine aquaculture have the largest potential impacts, and the interactions of these three activities may have the most significant anthropogenic footprint on the Liverpool Bay ecosystem.

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 with the potential for being in the vicinity are North Atlantic Right Whale, Blue Whale, Fin Whale, Leatherback Sea Turtle, White Shark, Spotted Wolffish and Northern Wolffish.
- Preferred bathymetric ranges suggest these species are unlikely to be present near the site infrastructure, with the exception of White Shark, which has been observed in the vicinity of the proposed sites.

Question 5: *Which populations of salmonids are within a geographic range that escapes 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 leases are within the Nova Scotia Southern Upland (SU) region of wild Atlantic Salmon and SFA 21.
- SU Atlantic Salmon population levels remain critically low and have been assessed as Endangered by COSEWIC since 2010.

- The majority of identified watersheds in the Southern Upland region that have historically contained Atlantic Salmon are within the range (200–300 km) that escaped farmed fish could travel.
- There will be increased genetic risks to wild Salmon with the proposed increases in the number of farmed Salmon within Liverpool Bay between the Liverpool, Mersey Point, and Brooklyn sites.

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 predicted exposure zones are based on current meter data provided by the proponent and is from a single location over a 30-day time window. The first-order estimates assume the current is spatially homogenous and seasonally consistent, and the current data are unlikely to represent the temporal and spatial variability needed to estimate exposure and deposition zones. Since the state of knowledge concerning the assessment of potential in-feed drugs and pesticides impacts is evolving, a more 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). 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. Therefore, there is uncertainty as to the exact spatial and temporal distribution of species in the area of the proposed activities, which leads to uncertainty in the full scale of potential interactions of wild species with the proposed activities.

Farmed-Wild Interactions

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 Atlantic salmon, and monitoring and reporting of these levels would be informative.

Potential Cumulative Interactions

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. 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, the influence of human activities was assumed to 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 human activity 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
Barrell, Jeffrey	DFO Science, Gulf Region
Bennett, Lottie	DFO Science, Maritimes Region
Brager, Lindsay **(lead)**	DFO Science, Maritimes Region
Burgetz, Ingrid	DFO Science, National Capital Region
Coulson, Mark	DFO Science, National Capital Region
Finley, Monica	DFO Science, Maritimes Region
Fitzgerald, Jennifer	DFO Regulatory Review, Fish and Fish Habitat Protection Program, Maritimes Region
Gomez, Catalina	DFO Science, Maritimes Region
Haigh, Susan	DFO Science, Maritimes Region
Hardie, David	DFO Science, Maritimes Region
Kelly, Noreen	DFO Science, Maritimes Region
Law, Brent	DFO Science, Maritimes Region
McKindsey, Chris	DFO Science, Quebec Region
Murphy, Grace	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
Pilcher, Scott	DFO Science, National Capital Region

Name	Affiliation
Raab, Dustin	DFO Science, Maritimes Region
Robinson, Shawn	DFO Science, Maritimes Region
Singh, Rabindra	DFO Science, Maritimes Region
Trudel, Marc	DFO Science, Maritimes Region
Worcester, Tana	DFO Science, Maritimes Region
Wringe, Brendan	DFO Science, Maritimes Region
Zisserson, Ben	DFO Science, Maritimes Region

Approved by

Kent Smedbol
Acting/Regional Director of Science, Maritimes Region
Dartmouth, Nova Scotia
Ph. 902-426-3490
Date: August 17, 2021

Sources of Information

Aronsen, T., Ulvan, E.M., Næsje, T.F., and Fiske, P. 2020. Escape history and proportion of farmed Atlantic salmon Salmo salar on the coast and in an adjacent salmon fjord in Norway. Aquaculture Environment Interactions. 12: 371–383.

Ban, N. and Alder, J. 2008. How wild is the ocean? Assessing the intensity of anthropogenic marine activities in British Columbia, Canada. Aquatic Conservation: Marine and Freshwater Ecosystems. 18(1): 55–85.

Ban N.C., Alidina, H.M., and Ardron, J.A. 2010. Cumulative impact mapping: advances, relevance and limitations to marine management and conservation, using Canada's Pacific waters as a case study. Marine Policy, 34(5): 876–886.

Bannister, R. J., Johnsen, I. A., Hansen, P. K., Kutti, T., and Asplin, L. 2016. Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. – CES Journal of Marine Science. 73: 2408–2419.

Benfey, T.J. 2015. Biocontainment Measures to Reduce/mitigate Potential Post-escape Interactions between Cultured European-origin and wild Native Atlantic Salmon in Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/003. v + 28 p.

Bishop, M.J. 2008. Displacement of epifauna from seagrass blades by boat wake. Journal of Experimental Marine Biology and Ecology. 354(1): 111–118.

Bradbury, I.R., Burgetz, I., Coulson, M.W., Verspoor, E., Gilbey, J., Lehnert, S.J., Kess, T., Cross, T.F., Vasemägi, A., Solberg, M.F., Fleming, I.A., and McGinnity, P. 2020a. Beyond hybridization: the genetic impacts of nonreproductive ecological interactions of salmon aquaculture on wild populations. Aquaculture Environment Interactions. 12: 429–445.

Bradbury, I.R., Duffy, S., Lehnert, S.J., Johannsson, R., Fridriksson, J.H., Castellani, M., Burgetz. I., Sylvester, R., Messmer, A., Layton, K., Kelly, N., Dempson, J.B., and Fleming, I.A. 2020b. Model-based Evaluation of the Genetic Impacts of Farm-escaped Atlantic Salmon on Wild Populations. Aquaculture Environment Interactions. 12: 45–49.

Bridger, C.J., Fredriksson, D.W., and Jensen, Ø. 2015. Physical containment approaches to mitigate potential escape of European-origin Atlantic salmon in south coast Newfoundland aquaculture operations. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/072. vi + 54 p.

Burgin, S. and Hardiman, N. 2011. The direct physical, chemical and biotic impacts on Australian coastal waters due to recreational boating. Biodiversity and Conservation. 20(4): 683–701.

Burridge, L.E., Haya, K., Waddy, S.L., and Wade, J. 2000. The lethality of anti-sea lice formulations Salmosan® (azamethiphos) and Excis® (cypermethrin) to stage IV and adult lobsters (*Homarus americanus*) during repeated short-term exposures. Aquaculture. 182: 27–35.

Burridge, L.E., Haya, K., and Waddy, S.L. 2008. The effect of repeated exposure to the organophosphate pesticide, azamethiphos, on survival and spawning in female American lobsters (*Homarus americanus*). Ecotoxicology and Environmental Safety. 69: 411–415.

Burridge, L. 2013. A Review of Potential Environmental Risks Associated with the Use of Pesticides to Treat Atlantic Salmon Against Infestations of Sea Lice in Southwest New Brunswick, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/050. iv + 25 p.

Burridge, L.E., Doe, K.G., and Ernst, W. 2011. Pathway of Effects of Chemical Inputs from the Aquaculture Activities in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/017.

Castellani, M., Heino, M., Gilbey, J., Hitoshi, A., Syåsand, T., and Glover, K.A. 2015. IBSEM: An Individual-Based Atlantic Salmon Population Model. Plos One 10, e0138444.

Castellani, M., Heino, M., Gilbey, J., Araki, H., Svåsand, T., and Glover, K.A. 2018. Modeling Fitness Changes in Wild Atlantic Salmon Populations Faced by Spawning Intrusion of Domesticated Escapees. Evolutionary Applications. 11: 1010–1025.

CCME (Canadian Council of Ministers of the Environment). 1999a. Canadian sediment quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons (PAHs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 1999b. Canadian water quality guidelines for the protection of aquatic life: Polycyclic aromatic hydrocarbons (PAHs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 2001a. Canadian sediment quality guidelines for the protection of aquatic life: Polychlorinated dioxins and furans (PCDD/Fs). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 2001b. Canadian sediment quality guidelines for the protection of aquatic life: Polychlorinated biphenyls (PCBs). Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CCME (Canadian Council of Ministers of the Environment). 2010. Canadian Soil Quality: Guidelines for Carcinogenic and Other Polycyclic Aromatic Hydrocarbons (Environmental and Human Health Effects). Scientific Criteria Document (revised). 216 pp.

Chen, Y.S., Beveridge, M.C.M., and Telfer, T.C. 1999. Settling rate characteristics and nutrient content of the faeces of Atlantic salmon, Salmo salar L. and the implications for modelling of solid waste dispersion. Aquaculture Research. 30: 395–398.

Chen, Y.S., Beveridge, M.C.M., Telfer, T.C., and Roy, W.J. 2003. Nutrient leaching and settling rate characteristics of the faeces of Atlantic salmon (Salmo salar L.) and the implications for modelling of solid waste dispersion. Journal of Applied Ichthyology. 19: 114–117.

Clarke Murray, C., Pakhomov, E.A., and Therriault, T.W. 2011. Recreational boating: a large unregulated vector transporting marine invasive species. Diversity and Distributions. 17(6): 1161–1172.

Clarke Murray, C., Agbayani, S., Alidina, H.M., and Ban, N.C. 2015. Advancing marine cumulative effects mapping: An update in Canada's Pacific waters. Marine Policy. 58: 71–77.

CMAR (Centre for Marine Applied Research). 2020. Exposure Modelling – N.S. Wind and Wave Condition Reports . (Accessed 10 May 2021).

Cromey, C.J., Nickell, T.D., and Black, K.D. 2002. DEPOMOD modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211–239.

Cullain, N., McIver, R., Schmidt, A., Milewski, I., and Lotze, H.K. 2018a. Impacts of organic enrichment from finfish aquaculture on seagrass beds and associated macroinfaunal communities in Atlantic Canada. PeerJ.Preorints 6:e26832v1.

DFO. 2010. Pathways of Effects for Finfish and Shellfish Aquaculture. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/071.

DFO. 2013a. Potential Exposure and Associated Biological Effects from Aquaculture Pest and Pathogen Treatments: Anti-sea Lice Pesticides (Part II). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/049.

DFO. 2013b. Potential Effects Surrounding the Importation of European-Origin Cultured Atlantic Salmon to Atlantic Salmon Populations and Habitats in Newfoundland. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/050.

DFO. 2014. Sea Lice Monitoring and Non-Chemical Measures. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/006.

DFO. 2019a. Stock Status Update of Haddock (Melanogrammus aeglefinus) in NAFO Divisions 4X5Y. DFO Can. Sci. Advis. Sec. Sci. Resp. 2019/016.

DFO. 2019b. Aquatic species at risk map.(Accessed on September 16 2020).

DFO. 2020a. Escape prevention for farmed fish. (Accessed on August 27 2020*)*.

DFO. 2020b. Stock Status Update for American Lobster (Homarus americanus) in Lobster Fishing Area 33 for 2019. DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/047.

DFO. 2020c. Stock Status Update of Atlantic Salmon in Salmon Fishing Areas (SFAs) 19–21 and 23. DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/031.

Diserud, O. H., Fiske, P., Sægrov, H., Urdal, K., Aronsen, T., Lo, H., Barlaup, B. T., Niemela, E., Orell, P., Erkinaro, J., Lund, R. A., Økland, F., Østborg, G. M., Hansen, L. P., and Hindar, K. 2019. Escaped farmed Atlantic salmon in Norwegian rivers during 1989–2013. – ICES Journal of Marine Science. 76(4): 1140–1150.

Elson, P.F. 1967. Effects on Wild Young Salmon of Spraying Ddt over New Brunswick Forests. Journal of the Fisheries Research Board of Canada. 24(4): 731.

Findlay, R.H. and L. Watling. 1994. Toward a process level model to predict the effects of salmon net-pen aquaculture on the benthos. In: Modelling Benthic impacts of organic encrichment from marine aquaculture. Hargrave, B.T.[ed.]. Can. Tech. Rep. Fish. Aquat. Sci. 1949: xi+125p.

Fleming, I. A., Hindar, K., Mjølnerød, I. B., Jonsson, B., Balstad, T., and Lamberg, A. 2000. Lifetime Success and Interactions of Farm Salmon Invading a Native Population. Proceedings of the Royal Society B: Biological Sciences. 267(1452): 1517–1523.

Føre, H.M. and Thorvaldsen, T. 2021. Causal analysis of escape of Atlantic Salmon and rainbow trout from Norwegian fish farms during 2010–2018. Aquaculture. 532: 736002.

Forseth, T., Barlaup, B.T., Finstad, B., Fiske, P., Gjøsæter, H., Falkegård, M., Hindar, A., Mo, T.A., Rikardsen, A.H., Thorstad, E.B., Vøllestad, L.A., and Wennevik, V. 2017. The major threats to Atlantic salmon in Norway. ICES Journal of Marine Science. 74(6): 1496–1513.

Fowler, G.M. 2011. Old and Older Perceptions of the Migrations and Distribution of Haddock, *Melanogrammus aeglefinus*, in Northwest Atlantic Waters from Tagging Conducted in the Bay of Fundy, Georges Bank, Scotian Shelf, and the Southern Gulf of St. Lawrence. Journal of Northwest Atlantic Fishery Science. 43: 137–157.

Frazer N.L., Morton A. and Krkošek M. 2012. Critical thresholds in sea lice epidemics: evidence, sensitivity and subcritical estimation. Proceedings of the Royal Society B: Biological Sciences. 279: 1950–1958.

FCSI (Federal Contaminated Site Inventory). 2020. Federal Contaminated Sites Inventory. (Accessed 20 May 2020).

Gibson, A.J.F., H.D. Bowlby, D.L. Sam, and P.G. Amiro. 2009a. Review of DFO Science information for Atlantic salmon (*Salmo salar*) populations in the Southern Upland region of Nova Scotia. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/081.

Gibson, A.J.F., Jones, R.A., and Bowlby, H.D. 2009b. Equilibrium Analyses of a Population's Response to Recovery Activities: A Case Study with Atlantic Salmon. North American. Journal of Fisheries Management. 29(4): 958–974.

Gibson, A.J.F., Bowlby, H.D., Hardie, D., and O'Reilly, P. 2011. Populations on the Brink: Atlantic Salmon (*Salmo salar*) in the Southern Upland Region of Nova Scotia, Canada. North American. Journal of Fisheries Management. 31: 733–741.

Gibson, A.J.F. and Claytor, R.R. 2012. What is 2.4? Placing Atlantic Salmon Conservation Requirements in the Context of the Precautionary Approach to Fisheries Management in the Maritimes Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/043.

Glover, K.A., Quintela, M., Wennevik, V., Besnier, F., Sorvik, A.G.E., and Skaala, O. 2012. Three Decades of Farmed Escapees in the Wild: A Spatio-Temporal Analysis of Atlantic Salmon Population Genetic Structure throughout Norway. Plos One. 7(8): e43129.

Glover, K.A., Pertoldi, C., Besnier, F., Wennevil, V., Kent, M., and Skaala, Ø. 2013. Atlantic Salmon Populations Invaded by Farmed Escapees: Quantifying Genetic Introgression with a Bayesian Approach and SNPs. BMC Genetics. 14:74.

Glover, K.A., Solberg, M.F., McGinnity, P., Hindar, K., Verspoor, E., Coulson, M.W., Araki, H., Skaala, Ø, and Syåsand, T. 2017. Half a Century of Genetic Interaction Between Farmed and Wild Atlantic Salmon: Status of Knowledge and Unanswered Questions. Fish and Fisheries. 18: 890–927.

Glover, K.A., Wennevik, V., Hindar, K., Skaala, O., Fiske, P., Solberg, M.F., Diserud, O.H., Svasand, T., Karlsson, S., Andersen, L.B., and Grefsrud, E.S. 2020. The future looks like the past: Introgression of domesticated Atlantic salmon escapees in a risk assessment framework. Fish and Fisheries. 21(6): 1077–1091.

Gregory, D., Petrie, B., Jordan, F., and Langille, P. 1993. Oceanographic, geographic and hydrological parameters of Scotia-Fundy and southern Gulf of St. Lawrence inlets Canadian Technical Report of Hydrographic Ocean Sciences. 143: 248.

Hansen, P.K., Ervik, A., Schaanning, M., Johannessen, P., Aure, J., Jahnsen, T., and Stigebrandt, A. 2001. Regulating the local environmental impact of intensive, marine fish farming. II. The monitoring programme of the MOM system (Modelling-Ongrowing fish farms-Monitoring). Aquaculture. 194: 75–92.

Hargrave, B.T., Holmer, M., and Newcombe, C.P. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin. 56: 810–824.

Hargrave, B.T. 2010. Empirical relationships describing benthic impacts of salmon aquaculture. Aquaculture Environment Interactions. 1: 33–46.

Heino, M., Svåsand, T., Wennevik, V., and Glover, K.A. 2015. Genetic Introgression of Farmed Salmon in Native Populations: Quantifying the Relative Influence of Population Size and Frequency of Escapees. Aquaculture Environment Interactions. 6:185–190.

Hubley, P.B., Amiro, P.G., Gibson, A.J.F., Lacroix, G.L., and Reddin, A.M. 2008. Survival and behaviour of migrating Atlantic salmon (Salmo salar L.) kelts in river, estuarine and coastal habitat. ICES Journal of Marine Science. 65: 1626-1634.

Jóhannsson, R., Guðjónsson, S., Steinarsson, A., and Friðriksson, J. 2017. Áhættumat vegan mögulegrar erfðablöndunar milli eldislaxa og náttúrulegra laxastofna á Íslandi. Marine and Freshwater Research Institute, Reykjavik

Kappel, C.V., Halpern, B.S., Selkoe, K.A., and Cooke, R.M. 2012. Eliciting Expert Knowledge of Ecosystem Vulnerability to Human Stressors to Support Comprehensive Ocean Management. In: Perera A., Drew C., Johnson C. (eds) Expert Knowledge and Its Application in Landscape Ecology. Springer, New York, NY.

Karlsson, S., Diserud, O.H., Fiske, P., and Hindar, K. 2016. Widespread genetic introgression of escaped farmed Atlantic salmon in wild salmon populations. ICES J. Mar. Sci. 73(10): 2488–2498.

Kay, I. 2015. Canopy and community structure of rockweed beds in Nova Scotia and New Brunswick: regional variation and effects of commercial harvest and proximity to aquaculture. MSc thesis, Dalhousie university, 228 p.

Keyser, F., Wringe, B.F., Jeffrey, .N.W., Dempson, J.B., Duffy, S., and Bradbury, I.R. 2018. Predicting the Impacts of Escaped Farmed Atlantic Salmon on Wild Salmon Populations. Canadian Journal of Fisheries Aquatic Science. 75: 506–512.

Kristoffersen, A.B., Rees, E.E., Stryhn, H., Ibarra, R., Campisto, J.-L., Revie, C.W., and St-Hilaire, S. 2013. Understanding sources of sea lice for salmon farms in Chile. Preventative Veterinary Medicine. 111: 165–175.

Krkošek, M. 2010. Host Density Thresholds and Disease Control for Fisheries and Aquaculture. Aquaculture Environment Interactions. 1: 21–32.

Law, B.A, Hill, P.S., Maier, I., Milligan, T.G. and Page, F. 2014. Size, settling velocity and density of small suspended particles at an active salmon aquaculture site. Aquaculture Environment Interactions. 6: 29–42.

Law, B.A., Hill, P.S., Milligan, T.G., and Zions, V.S. 2016. Erodibility of aquaculture waste from different bottom substrates. Aquaculture Environment Interactions. 8: 575–584.

Law, B.A. and Hill, P.S. 2019. Spatial and temporal variation in cumulative mass eroded and organic matter percentage in surface sediments near areas of active salmon aquaculture. Aquaculture Environment Interactions. 11: 305–320.

Leon, L.M. and Warnken, J. 2008. Copper and sewage inputs from recreational vessels at popular anchor sites in a semi-enclosed Bay (Qld, Australia): estimates of potential annual loads. Marine Pollution Bulletin. *57*(6-12): 838–845.

Lewin, W.C., Weltersbach, M.S., Ferter, K., Hyder, K., Mugerza, E., Prellezo, R., Radford, Z., Zarauz, L., and Strehlow, H.V. 2019. Potential environmental impacts of recreational fishing on marine fish stocks and ecosystems. Reviews in Fisheries Science & Aquaculture. *27*(3): 287–330.

Mahlum, S., Vollset, K.W., Barlaup, B.T., Skoglund, H., and Velle, G. 2021. Salmon on the lam: Drivers of escaped farmed fish abundance in rivers. Journal of Applied Ecology. 58(3): 550–561.

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J., and Cross, T. 2003. Fitness Reduction and Potential Extinction of Wild Populations of Atlantic Salmon, *Salmo salar*, as a Result of Interactions with Escaped Farm Salmon. Proceedings of the Royal Society B: Biological Sciences. 270: 2443–2450.

McKee, A., Grant, J., and Barrell, J. 2020. Mapping American lobster (*Homarus americanus*) habitat for use in marine spatial planning. Can. J. Fish. Aquat. Sci. Accepted Manuscript.

Miller, R.J. 1997. Spatial differences in the productivity of American lobster in Nova Scotia. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1613–1618.

Morris, M.R.J., Fraser, D.J., Heggelin, A.J., Whoriskey, F.G., Carr, J.W., O'Neil, S.F., and Hutchings, J.A. 2008. Prevalence and recurrence of escaped farmed Atlantic salmon (Salmo salar) in eastern North American rivers. Canadian Journal of Fisheries and Aquatic Sciences 65(12): 2807–2826.

NSDFAa (Nova Scotia Department of Fisheries and Aquaculture). Site Mapping Tool. (Accessed on August 17,2020*).*

NSDFAb (Nova Scotia Department of Fisheries and Aquaculture).Environmental Monitoring Program Data. (Accessed 20 May 2021)

O'Connell, M.F., Reddin, D.G., Amiro, P.G., Caron, F., Marshall, T.L., Chaput, G., Mullins, C.C., Locke, A., O'Neill, S.F., and Cairns, D.K., 1997. Estimates of conservation spawner requirements for Atlantic Salmon (Salmo salar L.) for Canada. DFO Canadian Stock Assessment Secretariat. Research Document 97/100.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology: An Annual Review. 16: 229–311.

PMRA. 2014. Hydrogen Peroxide, Proposed Registration Document, PRD2014-11, Pesticide Management Regulatory Agency, Health Canada.

PMRA. 2016a. Hydrogen Peroxide, Registration Decision, PRD2016-18, Pesticide Management Regulatory Agency, Health Canada.

PMRA. 2016b. Azamethiphos, Proposed Registration Document, PRD2016-25. Pesticide Management Regulatory Agency, Health Canada.

PMRA. 2017. Azamethiphos, Registration Decision, PRD2017-13. Pesticide Management Regulatory Agency, Health Canada.

Sephton, D., Vercaemer, B., Silva, A., Stiles, L., Harris, M., and Godin, K. 2017. Biofouling monitoring for Aquatic Invasive Species (AIS) in DFO Maritimes Region (Atlantic shore of Nova Scotia and southwest New Brunswick): May–November, 2012– 2015. Can. Tech. Rep. Fish. Aquat. Sci. 3158.

Sharp, G.J, Ugarte, R., and Semple, R. 2006. The ecological impact of marine plant harvesting in the Canadian Maritimes, implications for coastal zone management. ScienceAsia 32. 1: 77–86.

Skilbrei, O.T., Heino M., and Svåsand, T. 2015. Using simulated escape events to assess the annual numbers and destinies of escaped farmed Atlantic salmon of different life stages from farm sites in Norway. ICES Journal of Marine Science. 72(2): 670–685.

Skøien, K.R., Aas, T.S., Alver, M.O., Romarheim, O.H., and Alfredsen, J.A. 2016. Intrinsic settling rate and spatial diffusion properties of extruded fish feed pellets. Aquaculture Engineering. 74: 30–37.

Sutherland, T.F., Amos, C.F., Ridley, C., Droppo, I.G., and Peterson, S.A. 2006. The settling behaviour and benthic transport of fish feed pellets under steady flows. Estuaries and Coasts. 29: 810–819.

Sylvester, E.V.A., Wringe, B.F., Duffy, S.J., Hamilton, L.C., Fleming, I.A., and Bradbury, I.R. 2018. Migration Effort and Wild Population Size Influence the Prevalence of Hybridization Between Escaped Farmed and Wild Atlantic Salmon. Aquaculture Environment Interaction.10: 401–411.

Sylvester, E.V.A., Wringe, B.F., Duffy, S.J., Hamilton, L.C., Fleming, I.A., Castellani, M., Bentzen, P., and Bradbury, I.R. 2019. Estimating the Relative Fitness of Escaped Farmed Salmon Offspring in the Wild and Modeling the Consequences of Invasion for Wild Populations. Evolutionary Applications. 12(4): 705–717.

Thorstad, E.B., Whorisky, R., Rikardsen, A.H., and Aarestrup, K. 2011. Aquatic nomads: the life and migrations of the Atlantic salmon. *In*: O. Aas, S. Einum, A, Klemetsen, and J. Skurdal [eds.] Atlantic Salmon Ecology. Blackwell Publishing Limited, Oxford, UK. pp. 1–32.

Tremblay, D. and Sharp, G.J. 1987. Lobster larval abundances in Lobster Bay, Yarmouth Co., Nova Scotia - 1983. Proceedings of the Nova Scotian Institute of Science. 38: 43-53.

Vandermeulen, H. 2013. Information to Support Assessment of Stock Status of Commercially Harvested Species of Marine Plants in Nova Scotia: Irish Moss, Rockweed And Kelp. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/042. vi + 50 p.

Waddy, S.L., Burridge, L.E., Hamilton, M.N., Mercer, S.M., Aiken, D.E., and Haya, K. 2002. Emamectin benzoate induces molting in American lobster, *Homarus americanus*. Canadian Journal of Fisheries and Aquatic Sciences. 59: 1096–1099.

Wildish D.J., Hargrave B.T., and Pohle G. 2001. Cost-effective monitoring of organic enrichment resulting from salmon mariculture. ICES Journal of Marine Sciences. 58: 469–476.

Wringe, B.F., Jeffery, N.W., Stanley, R.R.E., Hamilton, L.C., Anderson, E.C., Fleming, I.A., Grant, C., Dempson, B., Veinott, G., Duffy, S.J., and Bradbury, I.R. 2018. Extensive Hybridization Following a Large Escape of Domesticated Atlantic Salmon in the Northwest Atlantic. Communications Biology. 1:108.

Appendix A: Organic Enrichment Interactions

Benthic condition[a]	Geochemical status[b]	Oxygen stress[c]	Sediment condition[d]	Geochemical category[e]	Macrofauna diversity[f]	Oxic category[g]	'Free' S (μM)	Eh_{NHE} (mV)
Normal	Oxic	Pre-hypoxic	Very good	Normal	High	Oxic A	100	225
							150	200
							250	175
							400	150
							625	125
						Oxic A/B threshold	**750**	**100**
Normal	Post-oxic	Aperiodic	Good	Oxic	Good	Oxic B	875	75
							1250	25
						Oxic B/ hypoxic A threshold	**1500**	**0**
Transitory	Sulfidic	Moderate	Less good	Hypoxic	Moderate	Hypoxic A	1750	−25
							2500	−75
						Hypoxic A/B threshold	**3000**	**−100**
Polluted	Sulfidic	Severe	Bad	Hypoxic	Poor	Hypoxic B	4000	−150
							5000	−175
						Anoxic threshold	**6000**	**−185**
Grossly polluted	Methanic	Persistent anoxia	Very bad	Anoxic	Bad	Anoxic	7000	−195
							8500	−200
							10000	−210

[a]Pearson & Rosenberg (1978), [b]Berner (1981), [c]Diaz & Rosenberg (1995), [d]Hansen et al. (2001), [e]Wildish et al. (2001), [f]Rosenberg et al. (2004), [g]Hargrave et al. (2008a)

Figure A1. Nomenclature for gradients in benthic organic enrichment from Hargrave (2010).

Appendix B: Species Database Searches within the Region of Interest

Regional databases with records from 2002–2018 were queried for information on observed species within the PEZs of the proposed sites and associated aquaculture activities. Databases searched include the Ecosystem Research Vessel (RV) Survey, Industry Survey Database (ISDB), Maritime Fishery Information System (MARFIS), and the Whale Sightings Database. Recorded species are listed in Table B1. 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 B1. Species records presented as combined numbers from all databases queried. Species names are written as returned from database.

	Records (databases combined)		
Species	**Liverpool**	**Mersey**	**Brooklyn**
American Lobster	20	21	20
Sea Raven	3	2	2
Longhorn Sculpin	2	4	3
Toad Crab	2	2	2
Atlantic Cod	-	1	1
Mackerel	1,461	2,018	1,443
Herring	125	161	101
Ocean Quahaug	72	206	75
Cusk	16	-	-
Halibut	16	-	-
Catfish	8	-	-
Cod (Atlantic)	8	1	-
Haddock	8	-	-
Monkfish	8	-	-
Pollock	8	-	-
White Hake	8	-	-
Clam, Propellor	7	8	7
Tuna, Bluefin	6	4	2
Strongylocentrotus droebachiensis	-	2	1
Whelk	-	2	1

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 ith 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

Gibson et al. (2009b) state that the wild population size required to meet the conservation egg requirement (Elson 1967) 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. 2020b). In accordance with (Bradbury et al. 2020b), this analysis 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. 2020b) for further information on the model.

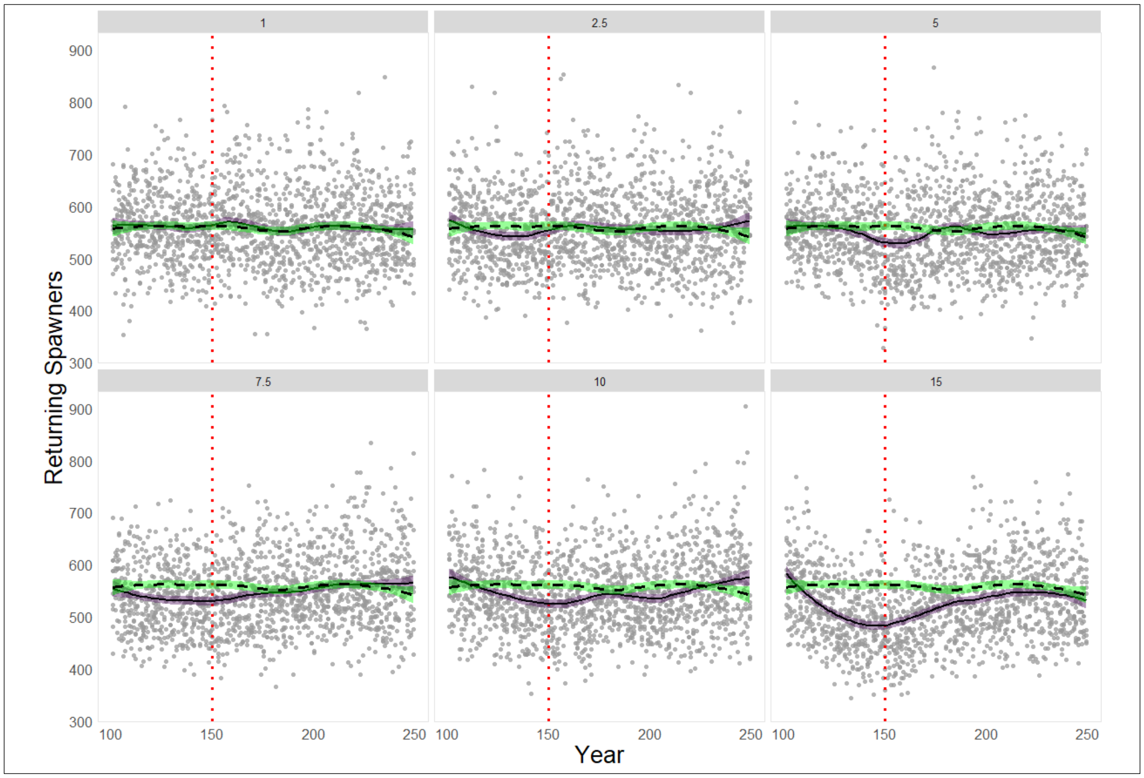

Figure C1. Model-predicted change in the number of returning spawners during and after a 50 year invasion period by escaped farmed salmon. The IBSEM model was allowed to stabilize for 100 years and the invasion begins at year 100. The invasion period is 50 years, and its end point at year 150 is marked 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.

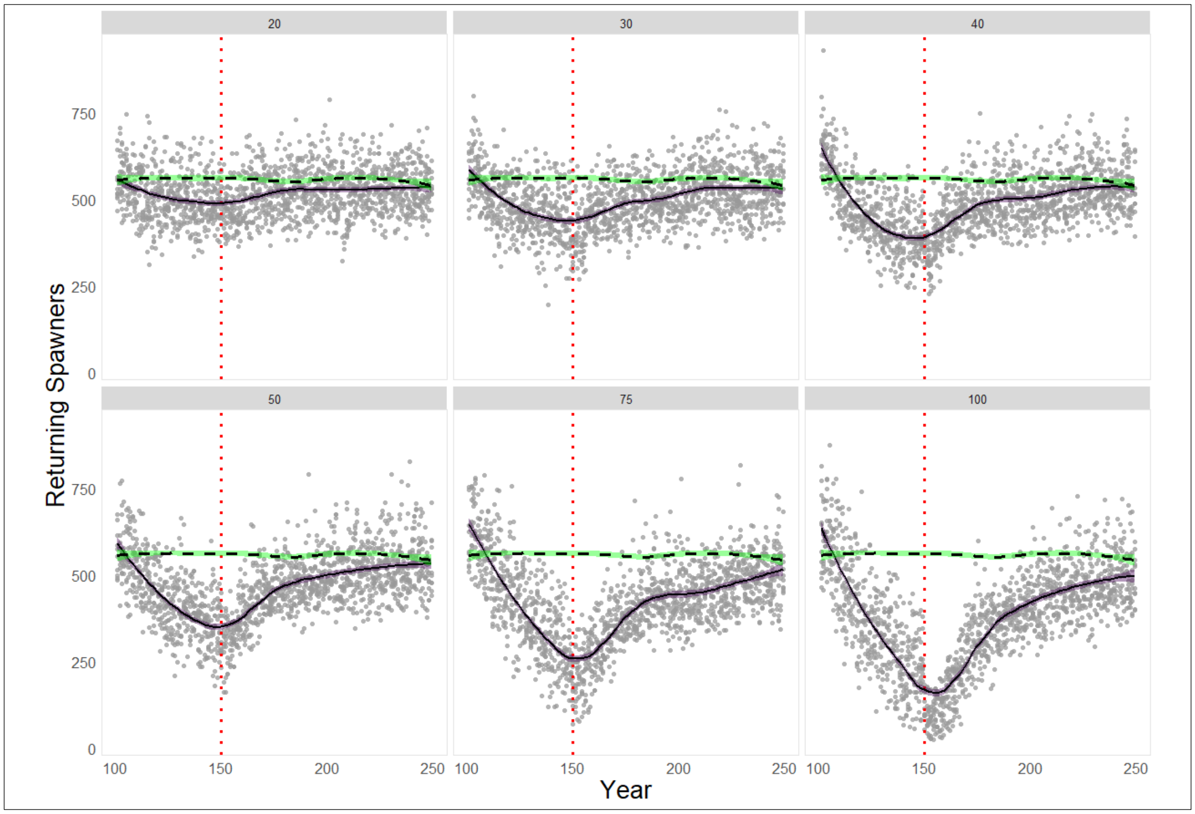

Figure C2. Model-predicted change in the number of returning spawners during and after a 50 year invasion period by escaped farmed salmon. The results of 10 iterations of the IBSEM model with escapee proportions of 20, 30, 40, 50, 75, and 100% per year are shown, and numbers at the top of each panel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

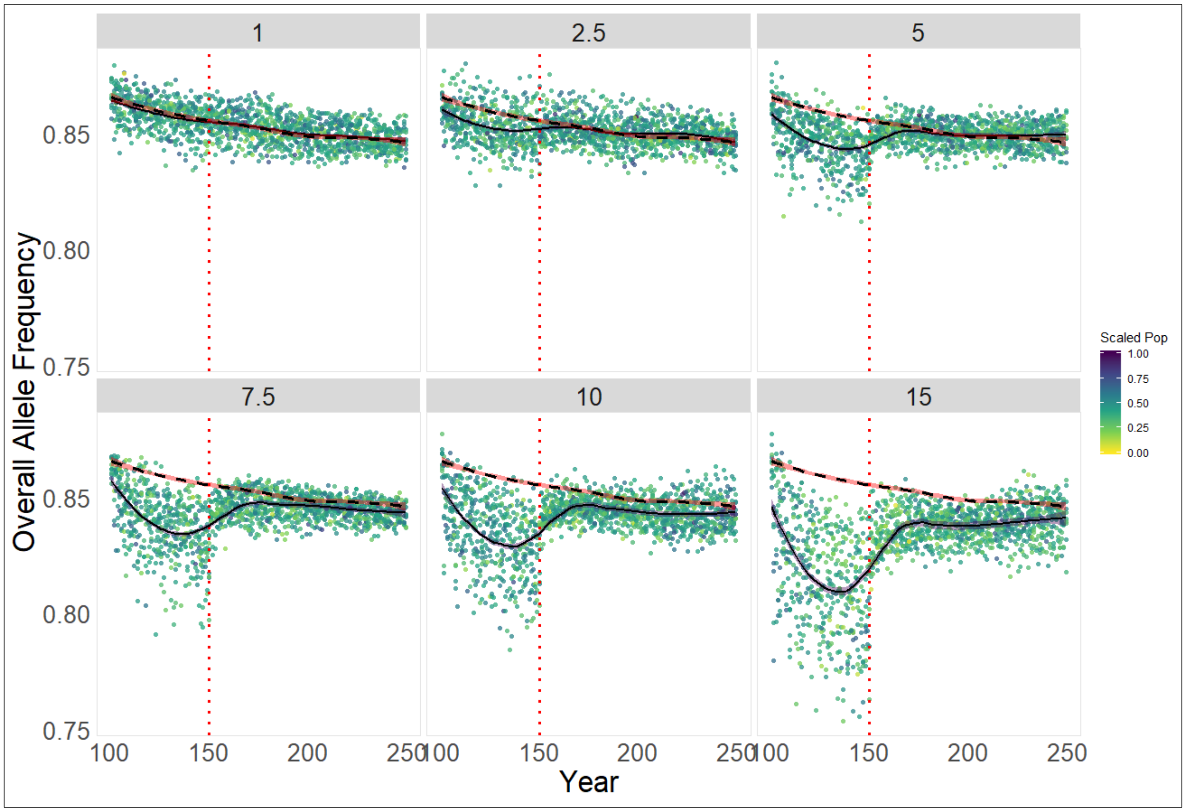

Figure C3. Model-predicted change in allele frequency during and after a 50 year invasion period by farmed salmon. Escapee proportions of 1, 2.5, 5, 7.5, 10, and 15% per year are shown and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion 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.

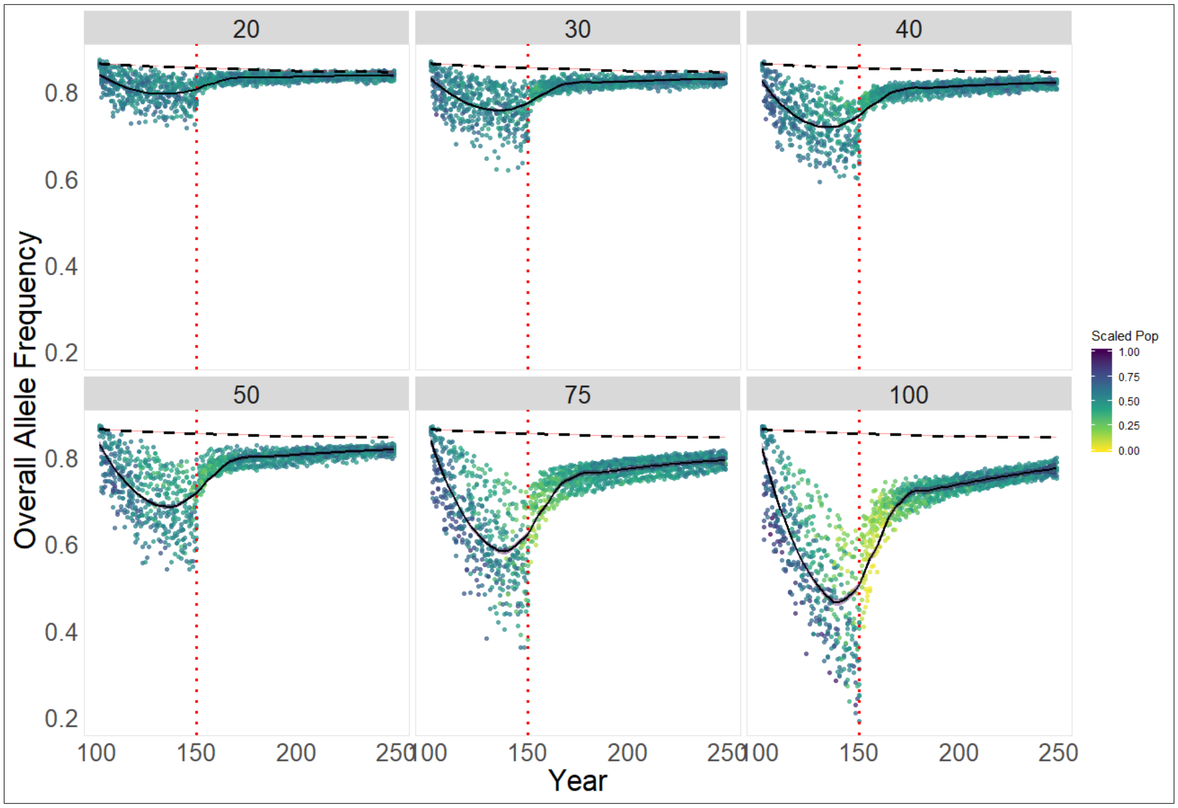

Figure C4. Model-predicted change in allele frequency during and after a 50 year invasion period by farmed salmon. Escapee proportions of 20, 30, 40, 50, 75, and 100% per year are shown and numbers at the top of each panel indicate the percentage of escapees entering the river each year during the invasion 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

Similarly 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. 2020). 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. 2020b). Using the most recent region-wide estimates (DFO 2020c), populations of wild 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.

Appendix D: Cumulative Occurrence of Human Activities

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 three sites (hereafter the "area of interest") were collated from a larger inventory of human activities developed for the Maritimes region (N. Kelly, DFO, pers. comm.). We selected human activities that occurred on a "local" scale, 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 Occurrence of Human Activities

The impact of human activity in the marine environment often extends beyond its immediate occurrence. A "zone of influence" was used to estimate the actual footprint of the stressor(s) (assumed to be) caused by an activity. To estimate the geographical extent of each activity beyond its location of occurrence, we added a buffer 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 (m)
Marine	Finfish aquaculture	Pelagic PEZ model for 3-hr pesticides, based on maximum current speeds.	Brooklyn: 4,341
			Mersey Point: 3,520
			Liverpool: 5,982
	Boat traffic	Small craft harbours and boat launches (point sources) captures activity from kayaking, recreational boating, fishing tours.	2,000
		Polygon containing the locations of all fishing vessel traffic in 2019 as reported in DFO's Vessel Monitoring System (VMS) database.	0
Fishing	Lobster fishing	Potential locations of traps based on VMS fishing vessel traffic polygon, restricted to the outer bay only.	0

Category	Human activity layer	Layer description	Buffer radius (m)
	Marine plant harvesting‡	Polygon of merged boundaries for two rockweed harvesting leases in the Bay.	0
Land-based	Commercial and industrial activities	Captures inputs from point sources (electrical generation plant, Bowater-Mersey pulp & paper mill, Port Mersey commercial park); outer buffer radius based on the furthest sediment sampling sites containing elevated chemical concentrations as measured by DFO's Aquaculture Marine Monitoring Program (AMMP) in 2019.	1,136
	Contaminated sites†	Four sites within 50 m of coastline with impacts of organic pollutants (e.g., PAHs, PCBs, PCDD/Fs, organometalloids) to soil, sediment, and/or groundwater.	2,000
	Nutrient loading	Captures activities within the watershed that input nitrogen into the bay, including on-shore aquaculture, agriculture, human settlements, wastewater inputs, runoff from roads, buildings, and other impervious surfaces. Layer is centered on the pour point of the Mersey River draining into Liverpool Bay, with a buffer radius based on the stream order of the river (after Clarke Murray et al. 2015).	8,170

† Federal Contaminated Sites Inventory (FCSI)

‡ Province of Nova Scotia marine aquaculture site mapping tool

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 7 different human activities occurring in the area of interest. Stressor effects linked to fin-fish aquaculture, lobster fishing, boat traffic, nutrient loading, and commercial and industrial activities were summarized from Ban et al. (2010; Table S4), contaminated sites summarized from CCME (1999a, 1999b, 2001a, 2001b, 2010), and marine plant harvesting were summarized from Vandermuelen (2013), Sharp et al (2006), and Kay (2015).

The relative impact of human activities on the marine environment depends on the spatial distribution of activities, the intensity of those activities in any particular place, and the vulnerability of the ecosystem component to a particular activity. To compare the relative impacts among human activities occurring in Liverpool Bay (e.g., at the bay scale), stressor-habitat vulnerability scores previously generated for the Cape Cod/Southern Gulf of Maine through an expert elicitation approach (Kappel et al. 2012) were matched to existing human activities and known habitat types occurring in Liverpool Bay. Habitat types in Liverpool Bay included beach, rocky intertidal, algal zone, nearshore hard bottom, and nearshore soft bottom. Human activities in Liverpool Bay were matched to the closest stressor category, based on the predominant stressor linked to that activity (Table D2). The mean (± SD) vulnerability score was then calculated across 5 habitats for each of 7 human activities (Table D2). The proportion of total area over which each activity occurs within the area of interest was used as a measure of intensity for each activity. The proportional area value was then multiplied by the mean vulnerability score to generate an overall relative impact score (± propagated SD error) for each human activity (Table D2; Figure 11).

Table D2. Mean (±SD) relative impact score for seven human activities occurring in Liverpool Bay. Relative impact score calculated as the product of the mean vulnerability score (±SD) and the proportion of total area over which each activity occurs within the area of interest. Mean vulnerability scores are calculated using individual activity-habitat vulnerability scores (from Kappel et al. 2012) for 5 different habitat types in Liverpool Bay (beach, rocky intertidal, eelgrass, algal habitat, nearshore soft benthic, nearshore hard benthic).

Human activity category	Matching activity category from Kappel et al. (2012)	Mean vulnerability score (± SD)	Proportion of total area	Relative impact score (± SD)
Marine aquaculture	Aquaculture: finfish (predators)	1.30 (0.89)	0.93	1.21 (0.83)
Rockweed harvesting	Aquaculture: marine plants	1.10 (0.72)	0.68	0.75 (0.49)
Lobster fishing	Fishing: demersal, non-destructive, low bycatch	1.64 (0.93)	0.42	0.69 (0.39)
Nutrient loading	Nutrient input: into oligotrophic waters	1.48 (1.01)	0.31	0.46 (0.31)
Commercial and industrial activities	Pollution input: inorganic	2.04 (1.07)	0.18	0.38 (0.19)
Contaminated sites	Pollution input: organic	2.90 (1.02)	0.48	1.38 (0.49)
Boat traffic	Tourism: recreational boating	1.90 (0.56)	0.66	1.26 (0.37)

This Report is Available from the:

Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
1 Challenger Drive, P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2

E-Mail: MaritimesRAP.XMAR@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-3769
ISBN 978-0-660-45072-8 Cat. No. Fs70-7/2022-039E-PDF

Correct Citation for this Publication:

DFO. 2022. DFO Maritimes Region Science Review of the Proposed Marine Finfish Aquaculture Boundary Amendment and New Sites, Liverpool Bay, Queens County, Nova Scotia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2022/039.

Aussi disponible en français :

MPO. 2022. Examen scientifique par la région des Maritimes du MPO de la modification proposée des limites de la pisciculture marine et des nouveaux sites dans la baie de Liverpool, comté de Queens, en Nouvelle-Écosse. Secr. can. des avis sci. du MPO, Rép. des Sci. 2022/039.