# DFO MARITIMES REGION REVIEW OF THE PROPOSED MARINE FINFISH AQUACULTURE BOUNDARY AMENDMENT, WHYCOCOMAGH BAY, BRAS D'OR LAKES, NOVA SCOTIA

## Context

We'koqma'q First Nation has made an application to the Province of Nova Scotia to amend their existing sites (#0814, 0845, and 0600) in Whycocomagh Bay, Bras d'Or Lakes, 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 this application to Fisheries and Oceans Canada (DFO) for review and advice in relation to DFO's legislative mandate. The application was supplemented by information collected by the proponent as required by the *Aquaculture Activities Regulations (AAR)*.

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

Specifically, the following questions are addressed in this report:

**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 Ecologically and Biologically Significant Areas (EBSAs), SAR, fishery species, Ecologically Significant Species (ESS), and associated habitats 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 in the area (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 salmonids are within a geographic range that escapes are likely to migrate to? What is the size and status trends of those populations in the escape exposure zone for the proposed site? Are any of these populations listed under Schedule 1 of *SARA*?

**Question 6.** The existing sites have been known to experience benthic and pelagic oxygen issues in the past. Given the proposed approach to managing this site and the increased numbers of fish to be cultivated in this area (i.e., 1,000,000 fish), what is the oxygen demand for the area and what does this mean for the balance of oxygen in the area (i.e., will the demand for oxygen exceed the supply of oxygen)?

This Science Response Report results from the Regional Science Response Process of December 1–2, 2020, on the DFO Maritimes Region Review of the Proposed Marine Finfish Aquaculture Boundary Amendment, Whycocomagh Bay, Bras d'Or Lakes, Nova Scotia.

## Background

We'koqma'q First Nation is requesting an amendment to combine three existing Rainbow Trout (*Oncorhynchus mykiss*) sites (#0814, 0845, and 0600) into one lease under #0814x. The proposed amalgamation under site #0814x will also be accompanied by an increase in total leased area. The proposed #0814x site is located in Whycocomagh Bay, Bras d'Or Lakes, Nova Scotia, southwest of the village of Whycocomagh and Indian Island. The proponent's overall development plan for Whycocomagh Bay also includes the addition of two new proposed sites within the bay, #1430 North Aberdeen and #1431 South Aberdeen, which will be reviewed separately from site #0814x. The location of the proposed #0814x site, and proximity to the North (#1430) and South (#1431) Aberdeen sites, is shown in Figure 1.


*Figure 1. Map of finfish aquaculture site leases in Whycocomagh Bay, Bras d'Or Lakes, Nova Scotia. Light green polygons represent proposed finfish leases requested by We'koqma'q First Nation. Site #0814x is circled in red, and the others represent the North and South Aberdeen proposed new sites. Maps were retrieved from the NSDFA Site Mapping Tool website on March 23, 2020 (NSDFAa). The star denotes an approximate location of a mid-bay sill.*

The existing sites (#0814, 0845, and 0600) have been in operation since 1992–1993 under various ownership. All three sites were inactive from 2001 until 2011, when they were transferred to We'koqma'q First Nation. The current combined area under lease by these three sites is 4.35 ha, and the proposed amendment would increase the area of the site to 75 ha (including a navigational corridor), which represents a 1624% increase in total leased area (NSDFAa). The proposed lease infrastructure is 6 arrays of 8 net-pens; however, the site configuration will not be static. The intent is for the stocked net-pen arrays to be variables in location within the lease boundaries to allow for fallowing of sections, based on results from environmental monitoring, while other sections within the lease are stocked. Figure 2 shows the site development plan with bathymetry.

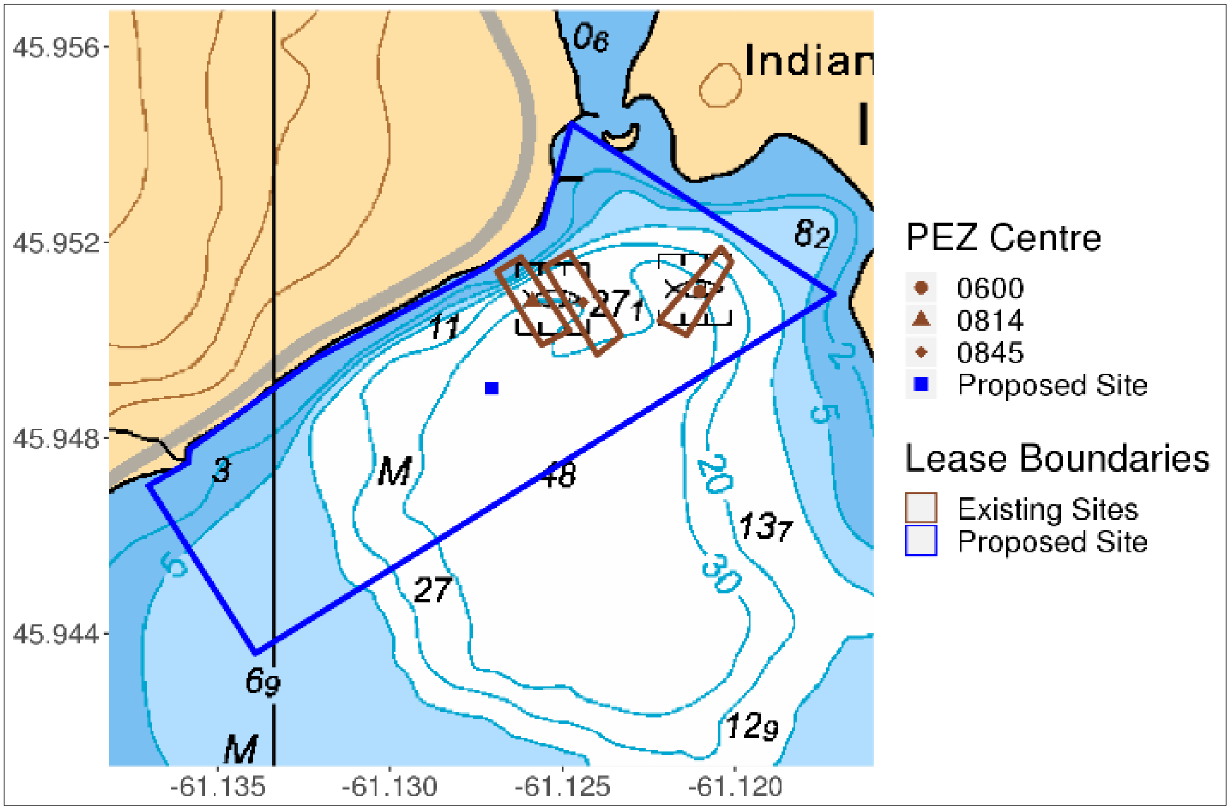


*Figure 2. Current (brown) and proposed (blue) lease boundaries overlaid on CHS chart #4278. The centers of each lease for predicted exposure zone calculations are also shown.*

Proposed site #0814x is located in a depositional area with a relatively homogenous bottom type. Baseline data collected in May 2020, submitted by the proponent (supplementary to the original baseline data), denotes the seabed consists of easily disturbed, black to brown mud. Several stations throughout the proposed lease had presence of waste feed and some feces, off-gassing, and Beggiatoa-like bacteria. Average sediment sulfide concentrations based on raw Environmental Monitoring Program (EMP) data from 2012–2019 for the existing #0814, 0845, and 0600 sites are shown in Table 1. Baseline conditions of proposed site #0814x from May 2020 are also shown.

*Table 1. Average sediment sulfide concentrations at existing sites #0814, 0845, and 0600 based on level I sampling (and level II, if required by the Environmental Monitoring Program Framework for Marine Aquaculture in Nova Scotia, NSDFAb). Years where information is not available or data not collected are indicated by n/a.*

| Year | Average sediment sulfide concentration (µM) |
|---|---|
| **2012** | 0814—2793 (level I)<br>0845—*n/a*<br>0600—*n/a* |
| **2013** | 0814—722 (level I)<br>0845—1581 (level I)<br>0600—*n/a* |
| **2014** | 0814—4681 (level I) / 7944 (level II)<br>0845—*n/a*<br>0600—2583 (level I) / 2620 (level II) |
| **2015** | 0814—3037 (level I)<br>0845—*n/a*<br>0600—2284 (level I) |
| **2016** | 0814—2397 (level I)<br>0845—1890 (level I)<br>0600—3481 (level I) |
| **2017** | 0814—1326 (level I)<br>0845—1244 (level I)<br>0600—1830 (level I) |
| **2018** | 0814—2311 (level I)<br>0845—*n/a*<br>0600—2129 (level I) |
| **2019** | 0814—4631 (level I) / 3524 (level II)<br>0845—4380 (level I) / 3735 (level II)<br>0600—4103 (level I) / 4554 (level II) |
| **2020 (baseline)** | 0814x—489 |

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 all three existing sites have demonstrated elevated sediment sulfides in the past, with average sulfide concentrations reaching Hypoxic B levels in 2014, 2015, 2016, and 2019, and an Anoxic level in 2014 based on Hargrave (2010) oxic categories (Appendix A). Individual sediment sampling locations that have historically reached the Hypoxic B and Anoxic levels can be seen in Figure 3.

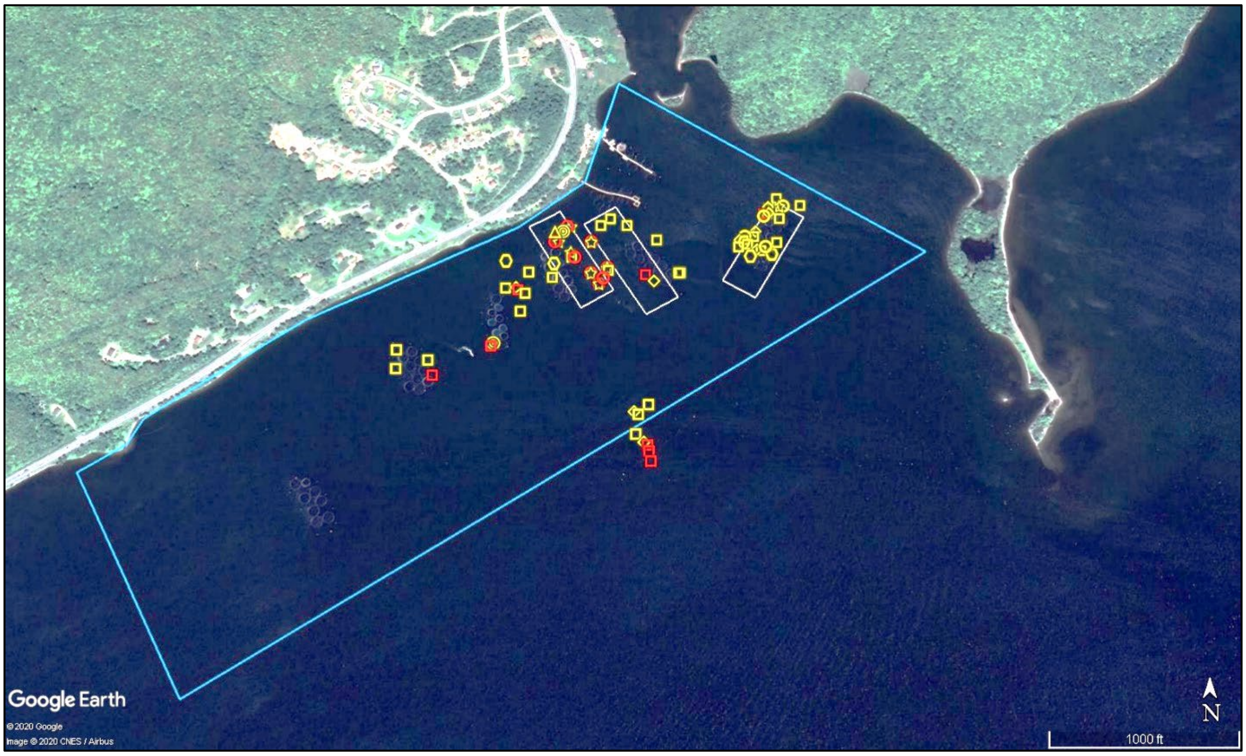


*Figure 3. Sediment sampling locations from #0814, 0845, and 0600 that have reached sediment sulfide concentrations of 3000 µM (yellow) and 6000 µM (red), respectively, overlaid on a Google Earth image of the existing net-pens. This was observed in 2012 (triangles), 2014 (circles), 2015 (stars), 2016 (hexagons), 2018 (bullseye), and 2019 (squares). The blue polygon is the new proposed #0814x lease and the white polygons are existing lease boundaries.*

The Google Earth imagery above depicts net-pens located west of the three currently-issued leases but within the proposed #0814x lease boundaries; however, the EMP station locations to the south indicate net-pens may have been located outside of the proposed boundaries. The staggered and complex nature of stocking throughout the year, due to factors such as ice cover and grow-out periods of 5–10 months, also make it challenging to know how many fish have historically been on site, as well as the number of fish that will be on site in the future at any given time throughout the year. The maximum number of Rainbow Trout anticipated to be on the #0814x site at any one time is 720,000 based on the proposed maximum number of fish per net-pen. This number appears to be greater than prior annual stocking levels. 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. The existing sites within Whycocomagh Bay have experienced oxygen issues in the past, including reported kills of on-site farmed fish.

All basins within the Bras d'Or Lakes, including Whycocomagh Bay, are part of the Bras d'Or Lakes Ecologically and Biologically Significant Area (EBSA). The Bras d'Or Lakes EBSA is a unique inland sea of special importance for Atlantic Herring, Atlantic Cod, Sea Urchin, and eelgrass (DFO 2006). Given the significant heterogeneity of ecosystems within the Bras d'Or Lakes, bays were evaluated separately. While Whycocomagh Bay is a unique area of the Lakes, it does not have the habitat diversity or qualities to support a diverse and productive biota, and the enclosed nature of Whycocomagh Bay further limits the impact that it has on the Bras d'Or Lakes ecosystem as a whole (DFO 2006). For these reasons, Whycocomagh Bay was ranked as the second least significant EBSA of the Lakes. Regardless, DFO (2004) states that EBSAs are intended as a tool for calling attention to an area that has particularly high ecological or biological significance to facilitate provision of a greater-than-usual degree of risk aversion in management of activities in such areas.

Biological surveys conducted in the Bras d'Or Lakes of fish, algae, copepods, polychaetes, and foraminifera show Whycocomagh Bay as one of two areas with the least variety of species (Parker et al. 2007). Currently, Whycocomagh Bay also has limited fisheries. The existing leases have operated for over a decade in the area. Lobster, Oyster, Scallop, and Rock Crab are the most significant commercial benthic invertebrate species in the Bras d'Or Lakes. Of these species, only wild oyster production has been significant in Whycocomagh Bay (Parker et al. 2007), but oysters have been over fished in their native habitats within the Lakes and only small wild pockets still exist (Lambert 2002). Commercial groundfish and pelagic fisheries within the Bras d'Or Lakes have included Winter Flounder, Atlantic Cod, and Atlantic Herring. Of these species, trawl surveys conducted from 1952–2000 identified Atlantic Cod and Winter Flounder in Whycocomagh Bay (Parker et al. 2007). The Winter Flounder fishery ended in 1992 and directed fisheries for 4VsW and 4Vn Atlantic Cod were both closed in 1993 due to the depleted status of the stocks (Fanning et al. 2003, DFO 2002). The Skye River estuary in Whycocomagh Bay supports limited recreational fisheries for American Eel, Mackerel, and Smelt. Traditional ecological knowledge (TEK) data compiled in 2017 by the Unama'ki Institute of Natural Resources (UINR) indicates the area is important for American Eel, Atlantic Salmon, Atlantic Herring, Mackerel, Atlantic Cod, Smelt, Oyster, Painted and Snapping Turtle, and otter trapping (Oceans Management, personal communication), and the majority of these populations have declined (CEPI 2006).

American Eel is currently assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and is under consideration for listing under the *Species at Risk Act* (*SARA*). Eastern Cape Breton (ECB) Atlantic Salmon occupy rivers in Eastern Cape Breton that drain into the Bras d'Or Lakes (DFO 2014a) and are located in Salmon Fishing Area (SFA) 21. According to TEK, wild salmon in the area have declined in numbers and size (CEPI 2006, Parker et al. 2007). The ECB Atlantic Salmon were assessed as Endangered by COSEWIC in 2010. In 2019, all rivers within SFA 19 were closed to salmon fishing all year, with the exception of the Middle, Baddeck, and North rivers. These three rivers were open to catch-and-release angling during certain times of the year. Food, Social, and Ceremonial (FSC) allocations were available to First Nations on these three rivers; however, FSC harvest was discouraged where rivers are not expected to exceed their conservation egg requirement in a 2019–2020 Atlantic Salmon, Plamu, Conservation Harvesting Plan, and no harvest of returning salmon was reported by Indigenous communities in ECB (DFO 2020a).

Rainbow Trout are an introduced species to the Atlantic coast. Historically, escape events totaling over one million individuals from commercial Rainbow Trout aquaculture operations in the Bras d'Or Lakes have been recorded. These escapees were observed to have formed a feral, reproducing population in the late 1980s (Sabean 1983 cited in Alexander et al. 1986), which still exists today. There have been escape events at the current existing sites. Available information on reported escapes in recent years indicates single escape events in 2017 and 2018, and multiple events in 2019, with numbers ranging from hundreds to tens of thousands.

The proponent's submission indicates that Grey Seal and Harbor Seal are the only marine mammals known to transit Whycocomagh Bay. Submitted baseline video monitoring at the proposed #0814x site denotes echinoderms such as Sea Star as the main observed macrofaunal species. This is consistent with knowledge that echinoderms have been the dominant invertebrate biomass collected during surveys of the Bras d'Or Lakes (Tremblay 2004).

Whycocomagh Bay is noted for its high salt marsh concentration within the Bras d'Or Lakes (Hastings et al. 2014). These wetland habitats support a number of important ecological functions, and they host a diversity of species not typically found in other habitats (Parker et al. 2007). Eelgrass is known to have historically provided important spawning grounds for herring (Denny et al. 1998) and may also have a significant contribution to the productivity of the Bras d'Or Lakes. Eelgrass is designated as an Ecologically Significant Species (ESS) because of the numerous ecological functions it provides, including habitat for fish and their prey. Video surveys conducted in 2007, when the sites had not been in operation since 2001, showed both extensive and patchy eelgrass beds in parts of Whycocomagh Bay (Vandermeulen 2016). Little is known about the present abundance and distribution of eelgrass in Whycocomagh Bay and in the broader Bras d'Or Lakes; however, proponent-submitted baseline data collected in May 2020 indicated the presence of eelgrass within the proposed lease at 4 out of 21 stations surveyed.

Other human activities with potential impacts on habitats and species in the area include a sewage treatment plant, recreational activities (e.g., pleasure boating, kayaking), a marina, additional proposed finfish farm leases, and oyster leases. Land-based inputs from the sub-watershed stem from forestry and agricultural activities, parks and trails (and other tourism), abandoned mines, transmission lines, suspected contaminated sites, and an increasing population and road density (Parker et al. 2007, Province of Nova Scotia, 2020). A 900-m section of Nova Scotia Highway 105 is immediately adjacent to the site, with only a 10–20 m wide land buffer between the highway and the shoreline boundary of the proposed site.

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 sites and proposed expansion. Some information for the existing sites was not available at the time of this review (indicated by n/a).*

| Characteristic | Existing sites | Proposed site | Additional Information | Source |
|---|---|---|---|---|
| **Tidal range (m)** | 0.57 | 0.57 | • Range does not include surges in sea level. | • Drozdowski et al. 2014 |
| **Depth of tenure (m)** | 1.8–35.0 | 1.8–48.0 | • Relative to vertical chart datum (lowest normal tide).<br>• Proponent submission shows net-pens over 14–27 m depth.<br>• Centre of proposed lease = 35 m.<br>• PEZ calculation depth = 48 m. | • CHS chart #4278 (2016)<br>• Proponent submission |

| Characteristic | Existing sites | Proposed site | Additional Information | Source |
|---|---|---|---|---|
| **Current speed (m/s)** | | | • Surface currents measured at 32 m above the bottom.<br>• Midwater currents measured at 17 and 22 m above the bottom.<br>• Bottom currents measured at 12 m above the bottom.<br>• Near-bottom and midwater currents do not have dominant directions. Near-surface currents have a tendency for a small northerly dominance. | • Proponent submission (35-day record) |
| • **Surface** | *n/a* | 0.0–0.184 | | |
| • **Midwater** | *n/a* | 0.0–0.063 | | |
| • **Bottom** | *n/a* | 0.0–0.035 | | |
| **Salinity (PSU)** | 8.8–23.2 | 8.8–23.2 | • A lower salinity surface layer is present in spring (8.8–17 PSU). | • Proponent submission<br>• Strain et al. 2001, DFO data 2014 & 2020 (**Appendix B**) |
| **Temperature (°C)** | -0.6–22.6 | -0.6–22.6 | • Ice cover experienced in winter months (maximum in early March). | • Proponent submission (data collected by NSDFA 2016–2018)<br>• Strain et al. 2001, DFO data 2014 & 2020 (**Appendix B**) |
| **Dissolved oxygen (mg/L)** | 3.5–5.6 | 0–13.6 | • Anoxic below 25 m depth.<br>• Oxygen at existing sites estimated to be within surface values based on leases being in shallower waters. | • Strain et al. 2001, DFO data 2014 & 2020 (**Appendix B**) |
| **Substrate type** | Mud | Mud | - | • Proponent submission |

| Characteristic | Existing sites | Proposed site | Additional Information | Source |
|---|---|---|---|---|
| **Net-pen array configuration** | n/a | 2 x 4 array<br>6 arrays | • Site configuration of 6 arrays will not be static within lease boundaries. | • Proponent submission |
| **Individual net-pen circumference (m)** | 60 | 60 | - | • Proponent submission |
| **Net-pen depth (m)** | 6 | 6 | - | • Proponent submission |
| **Grow-out period (months)** | 5–10 | 5–10 | - | • Proponent submission |
| **Maximum number of fish on site** | *n/a* | 720,000 | • Annual production plan. | • Proponent submission |
| **Initial stocking number (fish/pen)** | *n/a* | 15,000 | - | • Proponent submission |
| **Average harvest weight (kg)** | 2.0 | 2.0 | - | • Proponent submission |
| **Expected maximum biomass (kg)** | *n/a* | 1,500,000 | • Assumes growth of fish to approximately 2 kg. | • Proponent submission |
| **Net-pen volume ($m^3$)** | *n/a* | 1700 | -- | • Proponent submission |
| **Maximum stocking density ($kg/m^3$)** | *n/a* | 18.0 | -- | • Proponent submission |

## Sources of Data

Information to support this analysis includes data and information from the proponent, data holdings within DFO, publically available literature, and information from the SARA registry. 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 | 1) AQ0814 – Boundary Amendment Dev. Plan (DFO).pdf |
| Proponent-collected raw current meter data | 1) Whycocomagh Basin – Current Stats.xlsx |
| Baseline survey data submission | 1) Waycobah new lease coords and maps with depths.xlsx<br>2) 2018_Waycobah Amendment Data Baseline Results.xlsx<br>3) Data for Organix 0814 Amendment.xlsx<br>4) NS-0814 – 2020 Enhanced Baseline Report June_6_20.pdf |
| EMP data – in addition to data retrieved from NS Open Data Portal for 2012–2015 and 2017, (NSDFAc) | 1) 20200721 DFO Information Request—2016 Data.xlsx<br>2) 2018 EMP Data Whycocomagh Bay 0814.xlsx<br>3) EMP Level I 0600_0814_0845_Oct 16_19.xlsx<br>4) EMP Level I 0600_0814_0845_Oct 22_19.xlsx<br>5) EMP Level I 0600_0814_0845_Oct 24_19.xlsx<br>6) EMP Level II 0845_dec 2_19.xlsx<br>7) EMP Level II 0600_0814_dec 4_19.xlsx<br>8) EMP Level II 0814_dec 5_19.xlsx<br>9) NS0814 – 2020 Level 3 EMP Report June_6_20.pdf |
| Historical stocking information | 1) 2012–2015 stocking info Waycobah sites 0814 0600 0845.xlsx<br>2) Historical stocking 0814 0845 0600 for submission to NSDFA.XLSX |

The following DFO databases were searched for species records within the Predicted Exposure Zones (PEZs) of the proposed site #0814x and returned no records:

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

## Site Description

Whycocomagh Bay is separated from the remainder of St. Patrick's Channel to the east by a shallow sill (approximately 12 m deep) at Little Narrows. A mid-bay sill (approximately 7 m deep) that further separates a pair of deep basins (40 and 48 m) also exists closer to the

#0814x site (Figure 1). The #0814x site is located in the western portion of the bay near the 48 m deep basin, in an area that displays both shallow and deep characteristics.

The sills at Little Narrows and mid-bay effectively isolate the deep areas of the bay from the rest of the Bras d'Or Lakes and restrict flushing. This bathymetric isolation means there is no direct horizontal connection to other deepwater areas, and this isolation has resulted in an environment of limited mixing and the longest flushing time (approximately two years) in the Lakes. Slow water exchange facilitates the hypoxic and anoxic characteristics of these water bodies below the surface layer (Petrie and Bugden 2002, Gurbutt and Petrie 1995, Gurbutt et al. 1993). The deep basin of the western half of Whycocomagh Bay is typically anoxic below 25 m, a characteristic that is naturally occurring and appears consistent over time (Krauel 1975, Strain and Yeats 2002).

The proposed amalgamation and expansion at the #0814x site will shift the southern portion of the site closer to the deep anoxic 48 m basin (Figure 2) and encompass a broader range of water depths than the existing sites (Figure 2; Table 2). This deep anoxic water has periodically been known to be pushed into the shallower waters during phenomena such as large storm events, although the exact mechanism is not well understood.

In general, additional information on physical characteristics in the vicinity of the #0814x site to supplement the information submitted by the proponent is lacking in Departmental and public data holdings. The scarcity of the data is shown in Appendix B. The water temperature and salinity at the #0814x site are expected to have minimal variation on tidal time scales, but larger variations on wind-driven and seasonal time scales. Values are expected to fall within the ranges indicated in Table 2.

The wave information provided by the proponent from the eastern end of Whycocomagh Bay near North Aberdeen is not considered representative of the #0814x site. The data were collected from a more exposed site approximately 9 km away. Wave amplitudes at the site are anticipated to be less than the reported maximum height of 1.08 m due to the sheltered location of the site from wind and waves on all sides, except the southeast.

Current meters were deployed by the proponent over a 35-day period in the center of the southern portion of the lease in 35 m of water. The median current speed was 1.5 cm/s, with a trend of decreasing current speeds with increasing depths (Table 2). This indicates the overall current dynamics at #0814x are "low energy" with respect to marine fish farming. Current speeds vary with complexities of the coastline, bathymetry, seasonal, and wind influences that may not be captured in the record.

Based on the depth profiles of current speed data, temperature, and salinity at the site, stratification is expected to be significant; therefore, estimates of exposure zones at the proposed site #0814x should consider stratification influences with respect to water current speed selection.

## 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 and pesticides is dominated by the deposition of medicated feed waste and feces.

These predicted exposure zones are precautionary overestimates to determine whether the scoping area of concern warrants further refinement of the spatial extent, intensity, and/or duration of anticipated interactions. Otherwise, the PEZ analysis is 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 for site #0814x are farm layout, stocking densities, feeding practices, and oceanographic conditions, such as the bathymetry, water currents, and stratification. The low flushing rate of Whycocomagh Bay makes it particularly sensitive to deleterious substance inputs, as they cannot be quickly dispersed by water movement (Parker et al. 2007). Benthic exposure can also occur in relation to bath pesticides, if they were to be used, particularly at sites over or near shallow depths such as #0814x. This will be considered in the Pelagic Predicted Exposure Zones and Interactions section of this review.

A first-order estimate of the spatial extent of the benthic-PEZ related to organic effluent and in-feed drugs and pesticides from the #0814x site was calculated. Limited available data suggest that sinking rates of Rainbow Trout feed and feces are within similar ranges to that of Atlantic Salmon. Sinking rates of different particulate materials released from farmed fish (i.e., waste feed and feces) vary, and the distribution of 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 the release of waste feed and feces, are within the 6 m 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 estimates of the potential horizontal distances travelled by sinking particles, such as waste feed pellets, fish feces and in-feed drugs and pesticides released from the fish farm (settling rates obtained from literature; Findlay and Watling 1994, Chen et al. 1999, Cromey et al. 2002, Chen et al. 2003, Sutherland et al. 2006, Law et al. 2014, Bannister et al. 2016, Law et al. 2016, Skoien et al. 2016).*

| Particle type | Benthic-PEZ | | | |
|---|---|---|---|---|
| | Min. Sinking Rate (cm/s) | Max. Observed Current (cm/s) | Horizontal Distance Travelled (m) | PEZ Radius (m) |
| **Feed** | 5.3 | 6.3 | 57 | 860 |
| **Feces** | 0.3 | 6.3 | 1,008 | 1,811 |
| **Fines and Flocs** | 0.1 | 6.3 | 3,024 | 3,827 |

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 feed-PEZ is anticipated to have the greatest intensity of impacts and is conservatively a circle centered on the lease boundaries as seen in Figure 4.

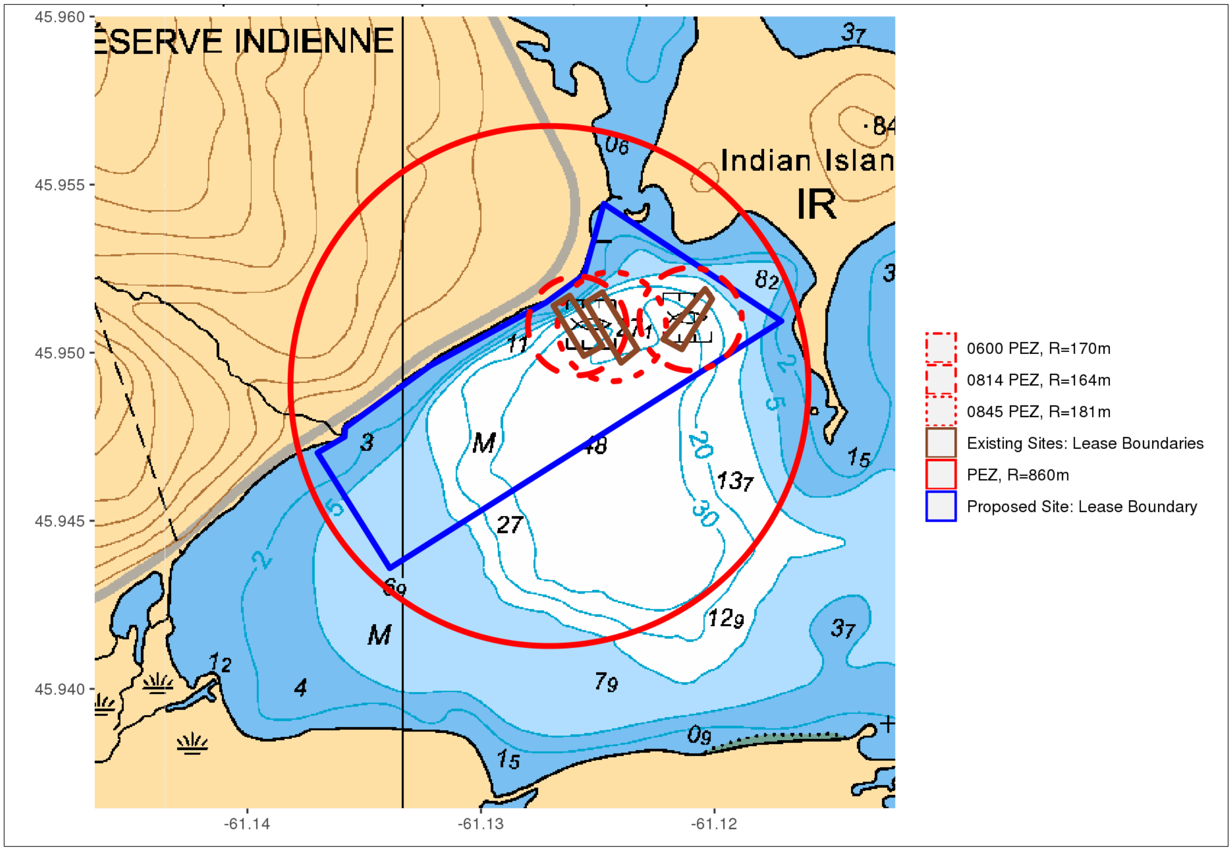


*Figure 4. First-order estimation of the benthic-PEZ for #0814x using the waste feed minimum sinking rate overlaid on CHS chart #4278.*

The locations of the net-pens within the proposed lease are unknown given the proponent's intent to move the net-pen arrays around within the lease boundaries. Therefore, a precautionary approach was taken in estimating the PEZ by adding the horizontal transport distance to the longest length scale of the proposed lease (i.e., half the length of the lease), as compared to the length scale of the net-pen arrays and centering the PEZ on the lease.

Current- and wave-induced bottom resuspension, is not considered in the first order estimates of exposure zones; however, waste particles are unlikely to extend beyond the benthic-PEZ estimated for fines and flocs. While some areas of the lease are shallow enough that the 6 m nets may be very near or touching the bottom, the proponent has stated that the net-pens will only be over water depths of at least 14 m. Therefore, any redistribution of fines and flocs are not anticipated to be caused by the net-pen infrastructure in this way.

Using the same current meter record, the PEZs for the existing sites have also been estimated (Figure 4). The benthic-PEZ for the proposed #0814x site is larger than those of the existing sites since the proposed lease is located over a larger area and encompasses some deeper waters. Furthermore, the benthic impact of the proposed site is anticipated to be larger than the combined benthic impacts of the existing sites since there are multiple net-pen arrays, and there may be increased numbers of fish on site at the same time than typically on site in the past.

Given the location of the additional proposed finfish sites #1430 Aberdeen North and #1431 Aberdeen South in the eastern end of the bay and the water circulation within the region, an overlap between the benthic organic deposition zones associated with the farms is not expected.

In the existing locations, average sediment sulfide concentrations at all three sites #0814, 0845, and 0600 have reached Hypoxic and Anoxic oxic categories (Figure A1; Appendix A). It is not known whether the EMP station locations that have previously reached sulfide concentrations ≥ 3000 and 6000 µM will be beneath the proposed net-pen arrays given the proposed non-stationary nature of the arrays within the lease. However, areas of the seabed that have reached these levels during production occupy a large proportion of the proposed lease. This suggests that, in combination with the presence of offgassing, Beggiatoa-like bacteria, and waste feed and feces at baseline stations throughout the lease, the ability of the benthic environment within the proposed lease to handle increased inputs of organic matter is of concern. Since 2015, *AAR* reporting indicates that the existing #0814, 0845, and 0600 sites have not used in-feed drugs or pesticides.

## 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 and pesticides should treatment be required. 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.

Departmental holdings of biological data from Whycocomagh Bay are sparse, and database searches of the PEZs returned no records. The ability to delineate present-day spatial overlaps between species distributions and the benthic-PEZ for site #0814x is limited; however, available information indicates that wild oysters and eelgrass are present within the benthic-PEZ.

Oyster beds have been known to exist in Whycocomagh Bay, but present-day distributions within the bay are unknown. Two American Oyster leases are located outside of the benthic-PEZ to the south and east of site #0814x. These sites are not currently in production due to a parasitic disease known as Multinucleate Sphere Unknown X (MSX); however, when in production, these sites may have been established upon existing wild beds. Given their sessile nature, oysters are sensitive to increased siltation, which could result in smothering due to excess deposition that exists within the benthic-PEZ. According to TEK, increased silt deposition has contributed to the decline of oysters in other areas of the Bras d'Or Lakes (CEPI 2006). Bivalves in the vicinity of net-pens elsewhere have also been shown to have measureable quantities of in-feed pesticides such as Emamectin Benzoate (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 PEZ does encompass areas along the shoreline that meet the depth criteria, most water depths within the benthic-PEZ are outside of the preferred habitat range for oysters in the area (i.e., mostly < 2 m, although some found up to 11 m; Mackenzie et al. 1997). Additionally, the predominantly soft substrate type in the area is likely not suitable given that oyster larvae typically require coarser-grained habitats for settlement. For these reasons, wild oysters are not anticipated to be present in significant aggregations within the benthic-PEZ.

Currently, there are a lack of available data representing present-day eelgrass distribution within the benthic-PEZ; however, video surveys conducted in the western end of Whycocomagh Bay in 2007 (Vandermeulen 2016) indicated potential spatial overlap between areas of patchy and continuous eelgrass coverage and the benthic-PEZs for all particle types (i.e., feed, feces, and fines and flocs). The distribution of eelgrass in the area in 2007 (Figure 5) depicts an environment that had been without aquaculture activities and inputs since 2001. Eelgrass habitat is subject to natural temporal and spatial variability, and it is unknown if distribution has changed since these data were collected. However, proponent-submitted baseline data collected in May 2020 identified the presence of eelgrass at 4 out of 21 locations sampled throughout the proposed lease (Figure 5). These stations were located in nearshore areas within the benthic feed-PEZ and were characterized as having between 5–30% eelgrass density. While available distribution data are insufficient for determining the scale of potential interactions, any overlap between eelgrass habitat and the benthic-PEZ is of concern given the importance of eelgrass as an ESS in Atlantic Canada.

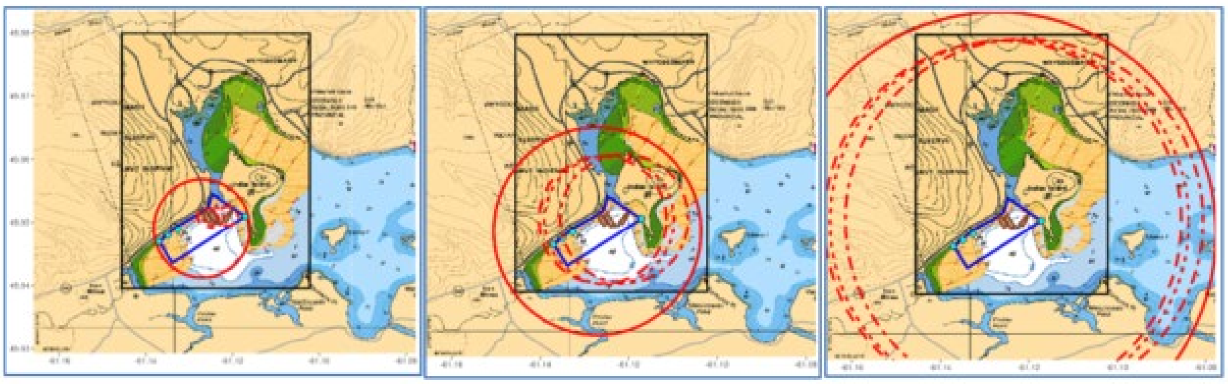

*Figure 5. Map of eelgrass coverage in 2007 in the western end of Whycocomagh Bay (Vandermeulen 2016) overlaid on CHS chart #4278. Dark and light green represent areas of continuous and patchy eelgrass coverage, respectively. The existing leases (brown) and proposed lease (blue) are shown. The benthic-PEZs for feed (A), feces (B), and fines and flocs (C) are shown in dotted and solid red circles for the existing and proposed sites, respectively. Locations of baseline stations where eelgrass was present are shown in cyan.*

The physical conditions of this region of the Bras d'Or Lakes are suboptimal for eelgrass. Optimal salinity for eelgrass growth ranges from 20–26 psu, although it can tolerate lower values for short periods (DFO 2009). As indicated in Table 2, salinity at the site ranges from 8.8 to 23.2 psu with a lower range in surface waters in spring (8.8 to 17 psu). It is likely that the salinity regime would contribute to reduced growth rates and spatial fragmentation. Additionally, Whycocomagh Bay experiences ice cover in winter, which can further contribute to spatial fragmentation through scouring. Aside from these physical factors, the presence of the invasive European Green Crab, which is known to cause widespread damage to eelgrass habitat, has been documented in the Bras d'Or Lakes (Vercaemer and Sephton 2016). Even in the absence of anthropogenic activities, such as aquaculture, it is likely that eelgrass in this area is subject to multiple stressors, and it would be expected to exhibit high spatial and temporal variability when compared to areas with more suitable conditions.

Low levels of benthic enrichment can stimulate eelgrass growth; however, higher levels can be detrimental. Deposition of organic material can change sediment biogeochemistry and produce sediment sulfide concentrations that are toxic to eelgrass plants, inhibiting growth, and increasing plant mortality (Vinther and Holmer 2008). Increased sediment anoxia can, in initial stages, cause eelgrass to drastically reduce belowground biomass, reducing anchoring strength, and later stages can induce plant mortality. If in-feed drugs or pesticides are used, the eelgrass beds could be exposed to the active ingredients and may influence the ecosystem associated with the bed. This may include changes to plant health (i.e., photosynthetic capacity, morphology, nutrient stores, etc.) that allow plants to persist in a non-optimal state or may result in plant mortality with bed contraction or complete loss. Eelgrass beds along the coast of Atlantic Canada typically occur in shallow water depths up to 12 m (DFO 2009), though Vandermeulen (2016) noted the presence of the majority of macrophytes in the Bras d'Or Lakes occurring in depths less than 3 m, possibly indicating the result of the suboptimal environmental conditions described above. This depth limitation means that eelgrass is unlikely to be present directly beneath the net-pens, as the proponent's plan suggests net-pens will only be in waters deeper than 14 m. This is consistent with the benthic feed-PEZ where the greatest intensity of organic deposition is expected to occur, encompassing only small areas of eelgrass (Figure 5a). Therefore, interactions within the benthic feed-PEZ will likely have few effects. On the other hand, benthic feces and fines and flocs will be transported further, potentially encompassing a significant portion of the eelgrass habitat identified in 2007 (Figure 5b,c); however, the organic deposition intensity outside of the benthic feed-PEZ is not expected to occur at levels where oxic state or sediment biogeochemistry changes are predicted.

If present in sufficient quantity, suspended particulates will also impact the underwater light climate for eelgrass plants, reducing light availability for photosynthesis. This may be a factor due to the presence of eelgrass habitat within the benthic feces- and fines and flocs-PEZ. Although concentrations and length of suspension are considered in PEZ estimations, reduction in the light climate will have immediate effects on plant physiology and photosynthetic capacity, should it occur (Wong et al. 2021). Prolonged light limitation will affect plant morphology and biomass as plants attempt to maintain carbon balance. Chronic low light will result in mortality and loss of eelgrass plants (Wong et al. 2020, Wong et al. 2021. Notably, no information about background light levels, turbidity, or suspended sediment concentration was available, so it is unknown if or how light availability is affected by the existing level of aquaculture at the site. The light regime may also be affected by the presence of dissolved organic matter of terrestrial origin, which can similarly damage eelgrass health through light reduction. Existing data are also insufficient for assessing the probability of sediment transport to specific areas within the benthic feces- and fines and flocs-PEZ. However, the majority of eelgrass habitat mapped in 2007 is separated from the existing and proposed farm sites by a shallow channel and the adjacent Indian Island, potentially limiting the spread of suspended particulates. Given these knowledge gaps, it is not possible to predict the effects of changes to the light regime on eelgrass habitat.

Predicted impacts from the expansion of aquaculture activities/leases are likely greater than those from the existing leases given the anticipated increase in organic loading over a larger area. Eelgrass in the area may also be particularly vulnerable to additional stressors and/or additional intensity of the same stressors given the frequently observed poor conditions of eelgrass beds in the Bras d'Or Lakes (Vandermeulen 2016). Conversely, given the documented suboptimal environmental conditions at the site, expanded aquaculture activities may not result in a measureable difference in eelgrass health and persistence.

The scale of potential changes to eelgrass in the surrounding area cannot be predicted given the lack of present-day distribution maps, as well as the lack of data representing factors known to affect eelgrass health and distribution, as described above. As a result of this knowledge gap, the spatial overlaps depicted in Figure 5 and associated potential impacts of the proposed site #0814x site expansion are uncertain. Eelgrass is known to be present throughout the Bras d'Or Lakes and is not particularly unique to Whycocomagh Bay itself.

# 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 predict the spatial scale of potential interactions between registered pesticides used in finfish aquaculture and susceptible species. These predicted exposure zones are conservative overestimates to determine whether a larger area of concern warrants further refinement of the spatial extent, intensity and/or duration of anticipated interactions. Otherwise, the PEZ analysis is considered sufficient for identifying, albeit at a larger spatial scale, potential 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 PEZ depends on the decay and/or dilution rate of the pesticide, a chosen concentration threshold, and choice of horizontal water current. The PEZ is estimated using toxicity information of azamethiphos, the most toxic registered pesticide. Health Canada Pest Management Regulatory Agency (HCPMRA) 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 the tissues of organisms. Their half-lives are days to weeks, suggesting they will not persist in the environment at concentrations considered to be toxic (HCPMRA 2014, HCPMRA 2016a, HCPMRA 2016b, HCPMRA 2017).

The pelagic-PEZ for azamethiphos was calculated assuming the maximum near-surface current speed persists throughout the dilution or decay scale (Figure 6). A three-hour duration was used to estimate the time required for the maximum azamethiphos target treatment concentration of 100 µg/L to dilute to the HCPMRA environmental effects threshold of 1 µg/L (DFO 2013).

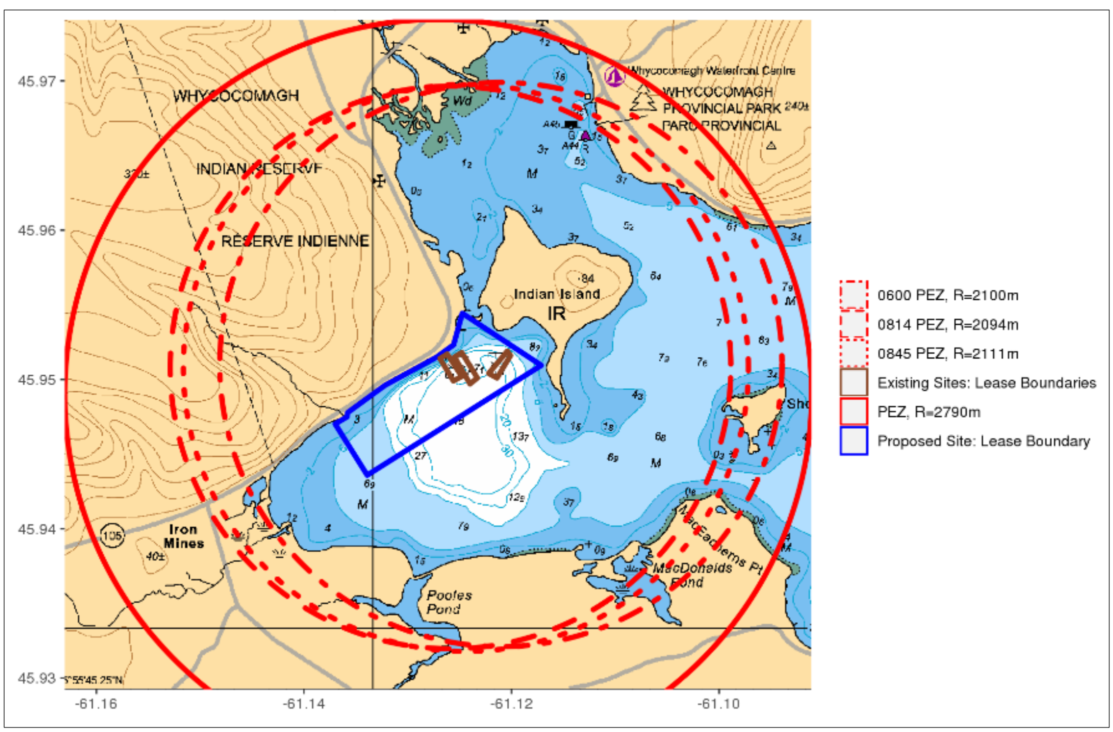


*Figure 6. First-order estimation of the pelagic-PEZ for azamethiphos at site #0814x using the maximum near-surface current speed tracked for three hours overlaid on CHS chart #4278.*

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

Since the location of net-pens within the lease is unknown given the proponent's intent to move the net-pen arrays within the lease boundaries, a precautionary approach was taken in estimating the PEZ. The horizontal transport distance was added to the longest length scale of the proposed lease (i.e., half the length of the lease), rather than the length scale of the net-pen arrays, and the PEZ was centered on the lease.

The zone does not imply that areas within the pelagic-PEZ 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. While some areas of the lease are shallow enough that the HCPMRA restriction for shallow sites (no application to tarped net-pens in water depths ≤10 m) may apply, the proponent has stated that the net-pens will only be over water depths of at least 14 m. The exposure is expected to occur mainly in the pelagic zone, although the bathymetry and water currents at the proposed #0814x site suggest the shallow water (< 10 m) seabed within the pelagic-PEZ may also be at risk of exposure to toxic concentrations released from the proposed site. The low flushing rate of Whycocomagh Bay also makes it particularly sensitive to the input of chemical as they cannot be quickly dispersed by water movement (Parker et al. 2007), and may be more likely to deposit on the seabed and persist.

Using the same current meter record, the PEZs for the existing sites have also been estimated (Figure 6) and indicate that the pelagic-PEZ for the proposed #0814x site is likely larger than those of the current sites. The addition of net-pens to the site may also increase the duration of pesticide exposure 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 HCPMRA application restrictions.

Estimates of cumulative exposures from multiple fish farms and other potential sources of pesticide loading have not been fully assessed in this report. The location of the proposed finfish sites #1430 Aberdeen North and #1431 Aberdeen South in the eastern end of the bay and the approximately 3 km pelagic-PEZ originating from the #0814x proposed site suggest there is unlikely to be exposure overlaps associated with pesticide releases.

Since 2015, *AAR* reporting indicates that the existing sites (#0814, #0845, and #0600) have not used pesticides. Information on historical pesticide use and knowledge of environmental site conditions suggest that the likelihood for azamethiphos treatments is low. This is further discussed in the Pest and Pathogen Interactions section below.

## 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.

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

Departmental holdings of biological data from Whycocomagh Bay are sparse and database searches of the PEZs returned no records. The ability to delineate spatial overlaps between species distributions and the pelagic-PEZ for site #0814x is limited. A 2007 survey identified eelgrass within the pelagic-PEZ. While eelgrass is subject to high spatial and temporal variability, and this distribution may have changed in the subsequent years, proponent-submitted baseline data collected in May 2020 found the presence of eelgrass at 4 out of 21 locations sampled throughout the proposed lease (Figure 7). Though there is no evidence for a direct effect of pelagic pesticides on eelgrass, indirect effects could occur through changes to its associated mesograzer communities. Though available data are insufficient for quantifying the magnitude and likelihood of deleterious effects, the presence of eelgrass within the pelagic-PEZ is of concern given the importance of eelgrass as an ESS in Atlantic Canada.

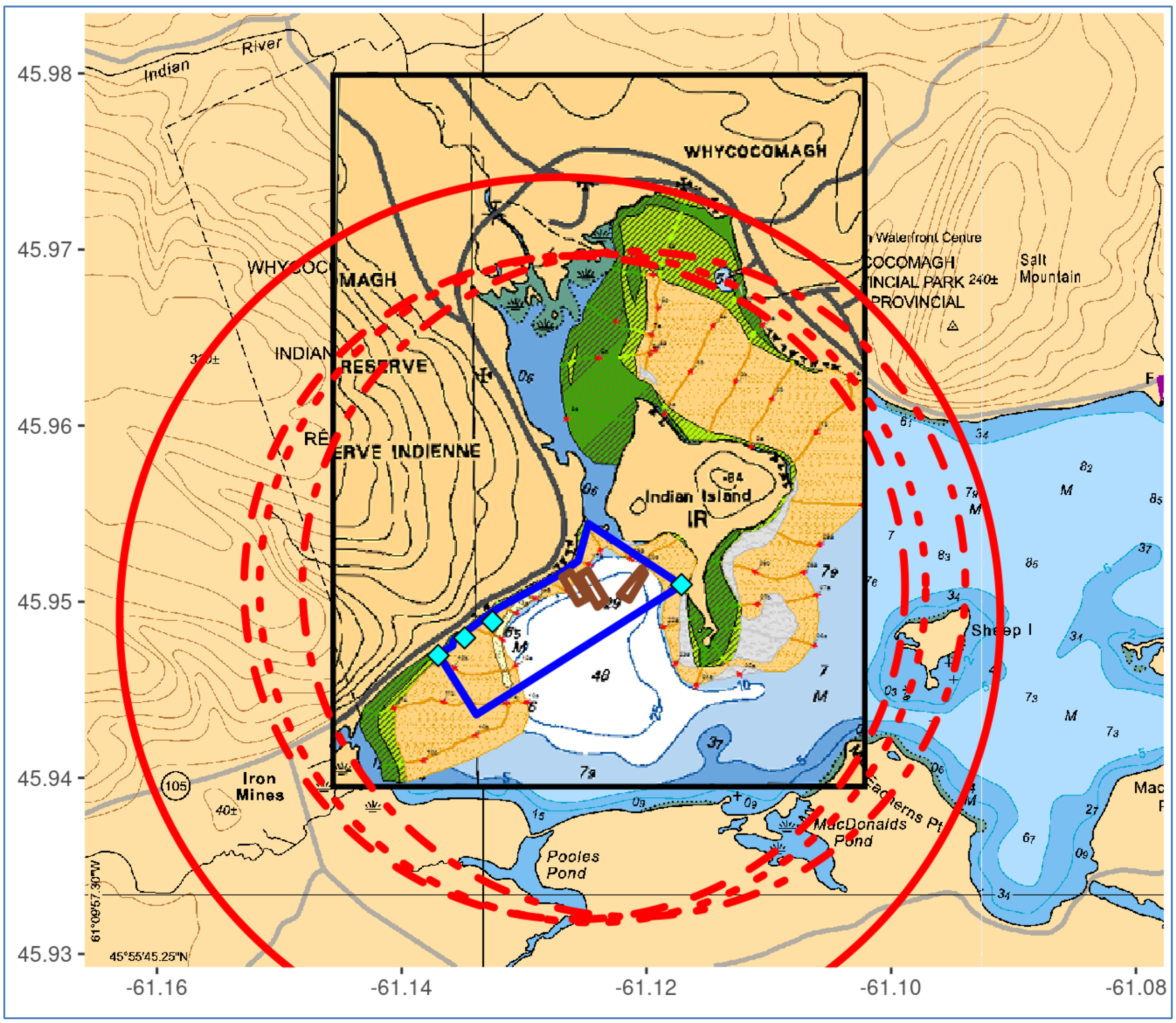


*Figure 7. Map of eelgrass coverage in 2007 in the western end of Whycocomagh Bay (Vandermeulen 2016) overlaid on CHS chart #4278. The area of eelgrass survey coverage is restricted within the black border. Dark and light green represent areas of continuous and patchy eelgrass coverage, respectively. The existing leases are represented by brown polygons and proposed lease by blue polygons. The pelagic-PEZs are shown in dotted and solid red circles for the existing and proposed sites, respectively. Locations of baseline stations where eelgrass was present are shown in cyan.*

There is limited literature describing the effects of aquaculture pesticides on seagrasses. Like most aquatic plants, seagrasses concentrate nonessential chemicals in their tissues (Lewis and Devereux 2009). The targeted nature of azamethiphos treatments on crustaceans suggests the diverse mesograzer communities associated with the eelgrass, such as amphipods and isopods, may be impacted (Wong 2018). A loss of grazers could result in higher plant fouling that shades plants and leads to reduced growth or increased mortality. Mesograzers are also an important food source for fish, and a loss of grazers could have cascading trophic effects for fish that use eelgrass beds as nurseries and feeding grounds. Crustacean-specific pesticides could also have an effect on the invasive Green Crab.

Given the potential for wide distribution of pesticides throughout the bay, eelgrass beds, and/or their trophic components could possibly be impacted. The scale of the described changes relative to eelgrass in the surrounding area cannot be quantified given the lack of current distribution maps and lack of data representing macrofauna and epiphytes and the ecological complexity of linkages between eelgrass and its associated faunal communities. Eelgrass is known to be present throughout the Bras d'Or Lakes and is not unique to Whycocomagh Bay itself.

# Oxygen Interactions

## Pelagic

Dissolved oxygen (DO) dynamics in Whycocomagh Bay are complex. Dissolved oxygen levels in the deeper areas can be anoxic at 0 mg/L (Petrie and Bugden 2002), whereas DO in the upper six meters of the water column range from 2.75–5.16 mg/L. Over the entire water column, oxygen extremes of 0 mg/L and 13.58 mg/L have been recorded (DFO[1] unpublished data, Appendix B). The optimal DO level for Rainbow Trout has generally been poorly studied. Research indicates that 5–6 mg/L is the minimum DO concentration to avoid sub-lethal negative effects, such as reduced swimming speeds and growth rates in farmed trout. It also indicates a lethal limit of 2–3 mg/L but that mortality can result from 4 mg/L (Welker et al. 2019).

The oxygen depletion index (Page et al. 2005) provides an indicator of the potential for farmed fish to generate oxygen depletions on scales of a net-pen, farm, or bay, and was applied to the proposed #0814x fish farm at the localized net-pen scale. The index considers fish respiration rates, flushing times, DO levels, and minimum threshold levels for sub-lethal and mortality effects. An index value of 1 indicates the respiration time is equal to the flushing time, under ideal circumstances. A value of 1 may indicate a potentially problematic situation since additional factors that have not considered may be important. Index values less than 1 indicate the potential for DO depletion and consequent impacts. The index was calculated for five different scenarios based on combinations of current speeds, respiration rates, and sub-lethal or mortality-based thresholds. These scenarios are reported in Appendix C.

Using a representative mean current, it is estimated DO depletion will occur at the net-pen scale. The scenarios illustrate that sub-lethal negative effects that impact fish health and growth rates onsite are anticipated due to low DO even in optimal site conditions. Mortality conditions were examined by changing the oxygen threshold and respiration rate (i.e., oxygen consumption rate). Under average current speed and respiration rate conditions, DO levels may be depleted to a level that cause fish mortalities on site. In the absence of currents (as was observed at times in the proponent's current meter record), DO levels within a net-pen at the

[1] DFO. Data collected through the Bras d'Or Lakes Monitoring Program 2014–2020.

#0814x site can be depleted to sub-lethal and mortality levels within less than 5 minutes and 17 minutes, respectively.

Estimations at the individual net-pen scale are anticipated to be exacerbated with each net-pen downstream. Although DO depletion at the site is not anticipated to spread to the bay-scale, it is a compounding factor in a naturally-stressed environment. Ambient DO levels throughout the water column near the site are periodically below the Canadian Council of Ministers of the Environment (CCME 2021) guidelines for DO of 8.0 mg/L in marine and estuarine waters.

In addition, any increased organic deposition from the site that accumulates in the deeper hypoxic and anoxic water will continue to contribute to suppressed oxygen levels as it is decomposed. This anoxic deep-water that is rich in hydrogen sulfide from bacterial activity can periodically be pushed into the shallower waters and impact the net-pens situated near the anoxic hole, resulting in fish-kill events of the farmed fish (Dalhousie University 2017). The DFO monitoring data from 2009–2012 in the Bras d'Or Lakes has shown the occurrence of cold anoxic water being brought up into shallow regions, although the mechanism for this process is still not well understood (Drozdowski et al. 2014). It is not known whether any wild fish have been impacted during these events.

The proponent's mitigation measure of supplementing pure oxygen into the water at the depth of the net-pen is only proposed during times of particularly reduced gas exchange (i.e., during winter ice cover) and appears to be aimed at mitigations for the farmed fish. However, periods of reduced DO levels may not be confined to times of ice cover and may impact wild populations in the vicinity of the site.

## Benthic

An increased sediment oxygen demand is anticipated from the proposed #0814x expansion due to the increased flux of Biochemical Oxygen Demanding (BOD) matter to the seabed and the restricted flushing within the bay. This is a concern as benthic communities respond to both persistent hypoxic effects of low DO concentrations that inhibit respiration, as well as to the direct toxicity of sulfides themselves (Diaz and Rosenberg, 1995, Hargrave et al. 2008). At historical stocking levels, elevated sulfide levels that are reflective of oxygen-poor sediment conditions have been consistently reported during EMP sampling throughout the existing sites (Figure 3).

Bannister et al. (2014) measured benthic oxygen consumption rates associated with sediment collected under fish net-pens and at reference sites. Over a 48-hour period, oxygen consumption rates from sediments collected under net-pens (average of 60 mmol/m$^2$/day) were significantly higher than from reference sites (average of 10 mmol/m$^2$/day).

Based on these numbers, first-order calculations (Appendix C) indicate that if the water immediately above the seabed is not being replaced (as has been observed in the proponent current meter record), benthic respiration could deplete the oxygen within the bottom water layer in less than four days. With low water currents of 1 cm/s, it is estimated that the time to deplete the oxygen in the near-bottom layer is similar to the time to refresh the oxygen. Therefore, the near-bottom oxygen concentration is likely to be low and sensitive to additional oxygen demand from the sediments, water current speeds, vertical mixing within the site boundaries, and advection of low oxygen waters located in the deeper water within and beyond the site.

A range of benthic oxygen consumption rates have been observed between different bottom types, with finer sediments such as mud demonstrating rates that are up to 3 times greater than coarse sediments (Grant et al. 1991). The silty nature of the sediment at the reference site in the Bannister et al. (2014) study is similar to sediment type of Whycocomagh Bay; however, the sediment under the net-pens was coarser compared to that of Whycocomagh Bay. Findings from both studies suggest that oxygen consumption under the net-pens at the Whycocomagh site could be substantially higher than that observed under the net pens in the Bannister et al. (2014) study.

## Escapee Interactions

Interactions between farm escapees and wild populations can be both genetic and ecological. Genetic interactions result from exchange of genetic material (hybridization) and/or the alteration of selection pressures (indirect genetic effects) (Lacroix and Fleming 1998). Ecological interactions can involve the transfer of diseases, predation, or competition for space, food, or mates between wild and escaped farm fish (Lacroix and Fleming 1998). These ecological interactions can result in negative genetic impacts on wild populations (reviewed in Bradbury et al. 2020).

While not native to Eastern Canada, Rainbow Trout have been stocked by the Province of Nova Scotia since the early 1900s, and there is now a successfully reproducing feral population in the Bras d'Or Lakes and the rivers and streams that flow into it (Madden et al. 2010). There are multiple reports of escapes from the existing #0814, 0845, and 0600 aquaculture sites. Madden et al. (2010) noted that since Rainbow Trout aquaculture was introduced to the Bras d'Or Lakes in 1972, large escape events have been associated with an increased popularity of the Rainbow Trout fishery in the area.

Crosses between Atlantic Salmon and Rainbow Trout have not produced any viable offspring (Refstie and Gjedrem 1975, Sutterlin et al. 1977, Blanc and Chevassus 1982). Therefore, direct genetic effects due to interbreeding between escaped Rainbow Trout and the native Atlantic Salmon population is not a concern.

Ecological interactions can occur between escaped Rainbow Trout and native Atlantic Salmon, regardless of life stage. Ecological interactions and deleterious effects on wild salmon from competition from introduced invasive Rainbow Trout are well documented and show that Rainbow Trout have stronger competitive abilities over Atlantic Salmon (Houde et al. 2017, van Zwol et al. 2012a). There is a growing body of evidence linking low marine survival to delayed effects from the physical and biological interactions experienced by juvenile salmon in rivers (Russel et al. 2012, Blanchet et al. 2007). At the individual level, behavioural strategies and dominance hierarchies of salmon have been shown to be strongly disrupted by invasive Rainbow Trout, such that growth trajectories are affected (Blanchet et al. 2007, van Zwol et al. 2012b). Some of these effects were linked to elevated stress hormones in salmon when invasive trout were present (van Zwol et al. 2012c). Rainbow Trout have also been shown to displace Atlantic Salmon out of preferred habitat and into increased competition with other native salmonids, even at low trout densities (Hearn and Kynard 1986, Thibault and Dodson 2013).

These types of ecological interactions have been shown to change the selective landscape, resulting in changes to fitness-related allele frequencies (Bradbury et al. 2020). Ecological interactions can also lead to reduced 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. Given the known ecological interactions between Rainbow Trout and wild Atlantic Salmon, there is no reason to believe that the genetic outcome from interactions with escaped farmed Rainbow Trout would differ from that described in Bradbury et al. (2020).

The above interactions and potential impacts are of particular concern to Eastern Cape Breton (ECB) Atlantic Salmon, which have been assessed as Endangered by COSEWIC since 2010. Eastern Cape Breton salmon support the last remaining recreational fishery and First Nations allocations in DFO Maritimes Region. There are ongoing monitoring efforts in Middle, Baddeck, and Skye rivers, which enter the Bras d'Or Lakes at distances between 2–25 km from the proposed #0814x aquaculture site. Both Middle and Baddeck rivers were below their conservation egg requirement in 2019 and have been for the previous 20 years (DFO 2020b), and the 2018 smolt estimate on Middle River was estimated among the lowest in recent years (albeit with large uncertainty) (DFO 2020b).

In recent years, adult and juvenile Rainbow Trout have been observed in both Middle and Baddeck rivers during DFO assessment unit swim counts for ECB salmon. In 2019, some observations of Rainbow Trout were well upstream of the estuary (> 10 km river distance), and the presence of juvenile trout confirms that natural reproduction is occurring. This heightens concerns about the continued use of diploid Rainbow Trout in both stocking and aquaculture. Gibson et al. (2014) identified commercial salmonid aquaculture as a threat in both the marine and freshwater environment to the recovery potential for ECB Atlantic Salmon. While there are ongoing monitoring efforts and available information specific to the Middle, Baddeck and Skye rivers, all other known ECB salmon rivers are also within 250 km of the proposed #0814x site (Figure 8), a range within which farmed Atlantic Salmon have been documented to travel following escape from aquaculture sites.

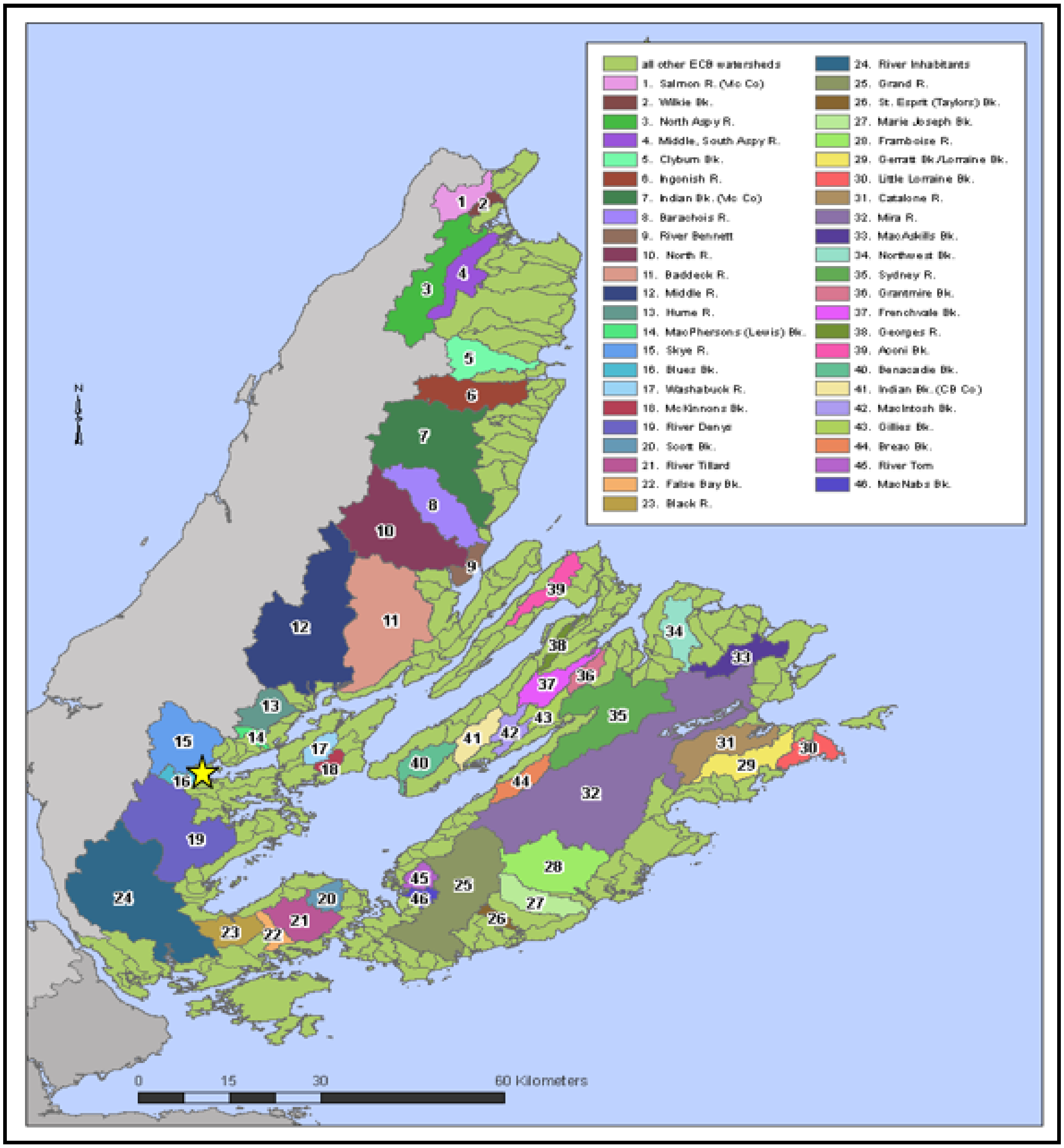


*Figure 8. Location of known major watersheds associated with Eastern Cape Breton Atlantic Salmon rivers (Gibson et al. 2014). The yellow star represents the location of the proposed #0814x aquaculture site expansion.*

The use of sterile fish in marine cage aquaculture has been recommended in Newfoundland (DFO 2016). Additionally, the Province of New Brunswick prescribes the use of sterile triploid Rainbow Trout only in cage aquaculture as part of a process to mitigate risk to wild stocks as outlined in the New Brunswick Rainbow Trout Aquaculture Policy (NBDERD and NBDAAF 2016). Although not specific to Nova Scotia, these examples reinforce the use of sterile salmonids in aquaculture to minimize adverse effects to wild salmon from aquaculture. While sterile Rainbow Trout could still escape and interact with wild salmon populations, they would not contribute to the feral reproducing population of Rainbow Trout in rivers leading into the Bras d'Or Lakes.

While the risks to ECB Atlantic Salmon exist at the current leases, they are expected to be at least proportional to the intensity of the farming activities in the area. Therefore, any increase in the total number of farmed trout in the area associated with the proposed #0814x site will also represent an increased risk to ECB salmon. These concerns also need to be contextualized by other cumulative potential pressures, such as the presence of other introduced salmonids (Brown Trout) and the additional continued stocking of diploid Rainbow Trout in the area for the purpose of sportfishing.

## 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 2014b). 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).

Sea lice development and survival are influenced by salinity and water temperature. Studies have demonstrated that low salinity may prevent sea lice from thriving, as they actively avoid low salinities (< 27 ppt), and that even short-term exposures to low salinity water significantly compromises survival and host infectivity (Bricknell et al. 2006). The proposed #0814x site is located in lower salinity brackish waters, which can be expected to influence the occurrence of sea lice.

The low flushing rate of Whycocomagh Bay may contribute to the occurrences of outbreaks, given that pests and pathogens cannot be quickly dispersed by water movement and, therefore, may persist longer, if present.

Since 2015, available *AAR* data confirm that no pest control products have been used at the existing sites in Whycocomagh Bay. However, 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 is 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 Whycocomagh Bay.

## Physical Interactions

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

Available information indicates that Harbour and Grey Seal are present in Whycocomagh Bay and may be present around the #0814x proposed site. Ice cover in Whycocomagh Bay from mid-December through April is anticipated to limit their presence in the western end of the bay around the site infrastructure during the winter months when they are known to be in the Bras d'Or Lakes for feeding (Parker et al. 2007).

Recreational and Aboriginal fisheries in the area that may experience displacement associated with the placement of infrastructure in the water include American Eel (assessed as Threatened by COSEWIC and under consideration for *SARA* listing), Atlantic Herring, Mackerel, Atlantic Cod, Winter Flounder, Smelt, and Atlantic Salmon. Estuaries associated with rivers containing freshwater habitats are also considered to be important habitat for ECB Atlantic Salmon, as successful migration through these areas is required to complete the life cycle. Traditional Ecological Knowledge also indicates that, in addition to serving as a migratory pathway, the Bras d'Or Lakes also serve as a staging area for returning adults and as an over-wintering area for kelts (DFO 2014a). It is not known what possible impacts the aquaculture site has on use of the area by these fish. To date, there have been no reports of entanglements of wild species at the existing sites.

Shading from aquaculture infrastructure can limit light availability, reducing density, biomass, growth and survival of eelgrass (Rumrill and Poulton 2004, Skinner et al. 2013, Wisehart et al. 2007). Direct shading from net-pens is considered unlikely, as the proponent's submission indicates that net-pens will only be situated at a minimum depth of 14 m. Propeller scarring from boat activity is also anticipated to be low risk, as site infrastructure includes a nearby wharf, precluding the need for boat use in shallow-water eelgrass habitat.

The exact magnitude of exposure and physical interactions of the species above with the #0814x site are unknown. However, the sheer increase in size and infrastructure alone suggest that the proposed site may increase the risk of bycatch, entanglement, physical displacement, and/or destruction to these species and habitats above the risks already posed by the existing sites.

## Potential Cumulative Interactions

The entire area of interest surrounding the #0814x proposed finfish site is influenced by human activity, with most human activities concentrated near the community of Whycocomagh. The larger, widespread PEZ (pelagic-PEZ) of the proposed site results in overlap with most other human activities occurring in the area. The number of overlapping activities is moderate, with the majority (approximately 70%) of the area of interest being influenced by at least two co-occurring human activities (Figure 9). The greatest overlap in co-occurring human activities occurs in northern areas of the bay, particularly between Indian Island and the town of Whycocomagh. Overlap in human activities declines as you move eastward through the bay and away from the point sources of stress. Appendix D provides methodology details of this analysis.

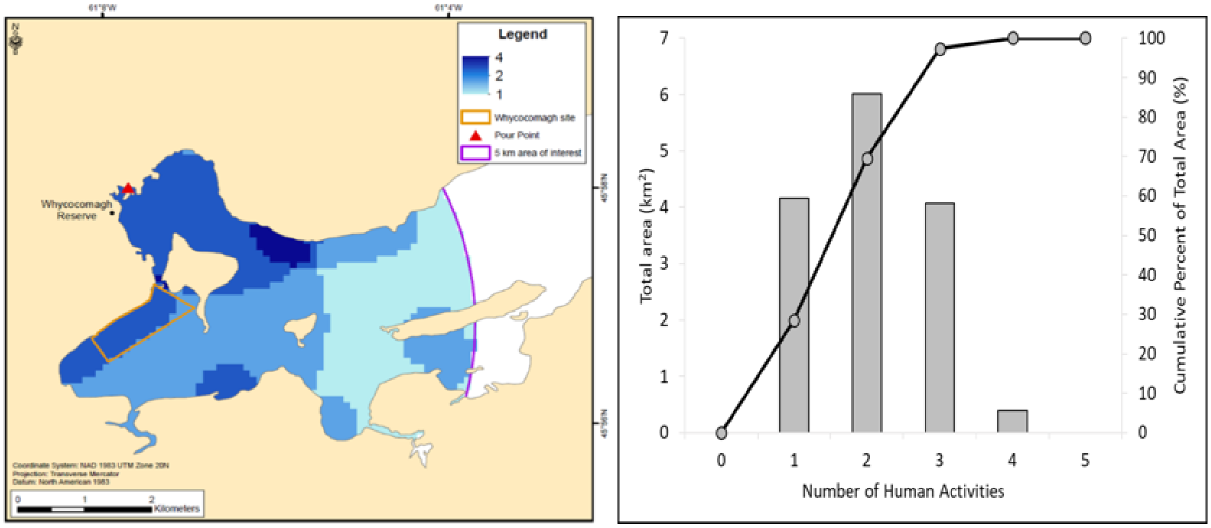


*Figure 9. Left: Number of overlapping human activities in each 0.01 km² grid cell. The #0814x lease boundary amendment is represented by the orange rectangle. The red triangle is the pour point location (i.e., the location where the Skye River drains into the coastal zone). Right: Total area (km²; grey bars), and the cumulative percentage of the total area (%; black line), in all grid cells with the corresponding number of human activities.*

The stressors linked to human activities in the marine environment can be grouped into three main categories: physical (direct alteration to habitats), chemical (effects on water and sediment quality), and biological (changes to non-target species). All human activities considered within this analysis have been linked to > 1 stressor impact, and all activities have influences across all three categories (Table 5).

*Table 5. Comparison of stressors associated with human activities identified in this analysis. Stressors linked to finfish aquaculture, shellfish aquaculture, recreational boating, and land-based activities were summarized from Ban et al. (2010), while those linked to the Trans-Canada highway were summarized from Trombulak and Frissell (2000).*

| Stressors | | Activities | | | | |
|---|---|---|---|---|---|---|
| | | Finfish aquaculture | Shellfish aquaculture | Recreational boating† | Land-based activities* | Highway |
| Physical (direct alteration to habitats) | Benthic disturbance | X | X | X | X | - |
| | Collisions | - | - | X | - | - |
| | Freshwater input/decrease | - | - | - | - | X |
| | Change in currents/circulation | X | X | X | - | - |
| | Light | X | - | X | - | - |
| | Marine debris | - | X | X | X | X |
| | Noise | X | X | X | X | X |
| Chemical (water and sediment quality) | Bacteria | X | - | X | X | - |
| | Contaminants | X | - | X | X | X |
| | Nutrients | X | 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-target species) | Changes in behaviour (predator or prey) | X | X | X | - | - |
| | Biomass removal (incidental mortality) | X | X | X | X | X |
| | Diseases and parasites | X | - | - | - | - |
| | Genetic interactions | X | - | - | - | - |
| | Invasive species | X | X | X | X | - |

**combined stressors from human settlements, onshore mining, and agricultural activity categories to reflect known activities within the Whycocomagh Bay watersheds*
*†combined stressors from small docks, ramps, wharves, pleasure boating, and kayaking activity categories to reflect the known and assumed activities with Whycocomagh Bay*

Overall, finfish aquaculture activities and recreational boating are associated with generating the largest proportion of stressor effects on these ecosystems, followed by land-based inputs and highways, respectively (Table 5). Shellfish aquaculture, while in general could be more impactful than land-based inputs and highways, is unlikely to cause impacts at this time, as oyster culture in the bay is not currently active.

The overlap of finfish aquaculture and recreational boating appear to have the most potential to impact Whycocomagh Bay; however, there is a larger spatial overlap of finfish aquaculture with land-based inputs. The cumulative effect of all three activities (finfish aquaculture, recreational boating, and land-based inputs) likely has the most significant anthropogenic footprint. Given its minimal water circulation and low flushing rate, Whycocomagh Bay may be particularly sensitive to the additive, cumulative, or interactive effects of runoff (excess nutrients and sediment), pollution, and human waste generated from recreational boating activities and land-based inputs, in combination with those generated by finfish aquaculture.

While the magnitude of recreational boating in Whycocomagh Bay is currently unknown, it is likely highly seasonal, following the typical tourist season for Nova Scotia. Individually the impacts of marine tourism and recreational activities are considered minor, but their cumulative impact, often concentrated over short periods of time and in localized areas, may result in detrimental effects on species and/or habitats. Effects may potentially include pollution due to leakage of fuels and oils, and human waste (Leon and Warnken 2008), prop scarring and/or benthic disturbance and destruction due to anchoring (Bishop 2008, Lewin et al. 2019), and the secondary spread of non-native species (Clarke Murray et al. 2011, Burgin and Hardiman 2011). The addition of aquaculture activities in the bay may also compound these inputs. For example, the addition of physical structures at the #0814x site may create more artificial habitats for colonization by invasive tunicates, some of which are already present in Whycocomagh Bay (Sephton et al. 2015). These combined effects may contribute to the spread and subsequent establishment of other non-native species already present elsewhere in the Bras d'Or Lakes.

Runoff and sediment erosion impacting water quality due to human land use is already ranked as a high threat for the surrounding two watersheds that drain into Whycocomagh Bay (Sterling et al. 2014). While the extent of the total spatial overlap is small, the direct occurrence of the #0814x site immediately adjacent to the highway may lead to periodic and intense, yet localized, deposition and/or water quality issues. This could result in cumulative stress on benthic species and habitats, if occurring at the same time as pesticide/drug application or restocking of fish in pens in close proximity to the road during times of the year when road runoff peaks. The proposed increase in finfish aquaculture within the bay is also expected to increase sedimentation, leading to the potential for additive sediment and nutrient inputs at least in the immediate area surrounding the #0814x site. Excess nutrients from land runoff contribute sources of nitrogen (N) to Whycocomagh Bay (Williamson et al. 2017, Nagel et al. 2018), and the addition of more finfish aquaculture to Whycocomagh Bay will also add to the existing anthropogenic total N loading in the bay, which may increase the risk of eutrophication.

Sources of sewage pollution in Whycocomagh Bay include malfunctioning sewage or treatment systems, residential septic tanks and fields, and outhouses (EDM 2008). As of February 2019, Environment and Climate Change Canada (ECCC) ordered the closure of all shellfish harvesting in Whycocomagh and in sections along the coastline adjacent to the town, citing a sanitary pollution source (ECCC 2020). These sections overlap with the location of the proposed #0814x lease and point to human sewage effluent being present in the area. In addition to contributing to bacterial contamination of the bay, such inputs may also exacerbate the reduced oxygen concentrations experienced in Whycocomagh Bay, for which finfish aquaculture is also a contributor.

While many of these cumulative interactions are likely to have already been occurring with the presence of the existing #0814, 0845, and 0600 finfish sites, the addition of more farm infrastructure, more fish, and more operational boating activity are anticipated to further intensify interactions with the other human activities in the bay.

The scope of this review does not specifically weigh the relative magnitude of each stressor effect listed above. Many of these impacts will vary spatially and temporally, and information available on the acute versus chronic effects of these stressors is complex. Ongoing work is being completed on how such impacts accumulate and interact to produce cumulative effects, and it is an area of ongoing research and analysis within DFO.

## 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 benthic-PEZ from the use of in-feed fish health treatment and the pelagic-PEZ from the use of approved bath pesticides are within a radius of 860 and 2790 m from the center of the proposed site, respectively. The intensity of exposure is expected to be highest near the net-pen arrays and decrease as distance from the net-pens increases.
- The proposed site location is likely to result in the benthic environment in shallower areas around the site being exposed to concentrations of drugs and pesticides that are toxic to sensitive benthic life stages and species, if present.
- The addition of net-pens may lead to an increase in duration of exposure to pesticides at toxic levels if the site in its entirety requires treatment.
- The low flushing rate of Whycocomagh Bay makes it particularly sensitive to chemical inputs that are passive and persistent, if used.
- Available information suggests that there is little evidence of species that are directly susceptible to fish health treatment products within the benthic- and pelagic-PEZ.
- Since 2015, *AAR* reporting indicates the existing sites have not used fish health treatment products. This may in part be related to the low occurrence of sea lice due to environmental conditions at the site.

***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 benthic-PEZ from deposition of organic matter due to waste feed is within a radius of 860 m from the centre of the proposed site. The intensity of exposure is expected to be highest near the net-pen arrays and decrease as distance from the net-pens increases.
- The low flushing rate of Whycocomagh Bay makes it particularly sensitive to deleterious substance inputs.
- Whycocomagh Bay is part of the Bras d’Or Lakes EBSA; however, ranked as the second least significant basin given its limited habitat diversity and ability to support a diverse and productive biota.
- Eelgrass has been identified within the benthic-PEZs related to all particle types. Interactions between eelgrass and deposition of waste feed are anticipated to have few effects. Feces and fines and flocs will be transported further and potentially encompass a significant portion of the eelgrass habitat; however, deposition is not anticipated to occur at levels where oxic state or sediment biogeochemistry changes are predicted.
- Eelgrass habitat may experience a reduction in the light climate due to suspended feces and fines and flocs. It is not possible to predict the likelihood or magnitude of effects or changes

to the light regime on eelgrass habitat due to the lack of existing data on current light levels and on sediment transport.

- Significant spatial and temporal variability in eelgrass distribution and condition is expected due to natural factors within the region that are suboptimal for eelgrass.
- Eelgrass habitat is not unique to Whycocomagh Bay within the Bras d'Or Lakes.

***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 site is influenced by human activities with significant overlap.
- Overlaps in predicted exposure zones from the proposed aquaculture activities at site #0814x and new sites #1430 North and #1431 South Aberdeen are not anticipated.
- Stressors such as invasive species, increased water quality issues, and reduced oxygen that stem from the activities associated with finfish aquaculture, recreational boating, and land-based inputs are anticipated to have the largest cumulative effects in Whycocomagh Bay.
- The significance of these potential cumulative interactions has not been assessed.

***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?*

- Species within Whycocomagh Bay include wild Atlantic Salmon, Harbour and Grey Seal, American Eel, Atlantic Herring, Mackerel, Atlantic Cod, and Smelt.
- Ice cover in the western end of Whycocomagh Bay is anticipated to limit the presence of Harbour and Grey Seal around the site infrastructure during the winter months when they are known to be present in the Bras d'Or Lakes for feeding.
- Eastern Cape Breton Atlantic Salmon that use the area during various stages of their life cycle and/or as a migratory pathway may experience displacement due to the significant increase in total leased area and site infrastructure. It is not known what magnitude of impact this may have.

***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?*

- All ECB Atlantic Salmon rivers are within potential dispersal distances of Rainbow Trout escapees The ECB salmon populations are assessed as Endangered by COSEWIC and are the last remaining recreational fishery and First Nations allocations in the Maritimes Region.
- There is no evidence of direct genetic interactions between Rainbow Trout and Atlantic Salmon. Therefore, direct genetic effects due to interbreeding between escaped Rainbow Trout and the native Atlantic Salmon population is not a concern.
- Ecological interactions and deleterious effects on wild salmon from competition from introduced invasive Rainbow Trout are well documented. There is evidence that these types of ecological interactions can lead to indirect genetic effects that ultimately reduce Atlantic Salmon population size and, consequently, reduce their genetic diversity.

- While the risks to ECB Atlantic Salmon already exist at the current leases, any increase in the total number of farmed trout in the area associated with the proposed #0814x site will also represent an increased risk to ECB salmon

***Question 6.*** *The existing sites have been known to experience benthic and pelagic oxygen issues in the past. Given the proposed approach to managing this site and the increased numbers of fish to be cultivated in this area, does science have a sense of the oxygen demand for the area and what this means for the balance of oxygen in the area (i.e., will the demand for oxygen exceed the supply of oxygen)?*

- Dissolved oxygen depletion within the net-pens is estimated to reach levels that may cause sub-lethal effects to the farmed fish, and mortality conditions may also be feasible at certain times.
- Near-bottom DO levels are likely to be low and sensitive to factors such as additional organic matter inputs that cause increased benthic oxygen demand, water current speeds, vertical mixing, and advection of the hypoxic and anoxic, deep waters within and beyond the site.
- This anoxic, deep water can periodically be pushed into the shallower waters and impact the farmed fish, as well as any wild populations in the vicinity.
- These predicted net-pen scale effects are compounding factors that are likely to exacerbate the hypoxic and anoxic conditions that already occur in Whycocomagh Bay.

# Sources of Uncertainty

## Predicted Exposure Zones and Oxygen Estimates

Results of calculations based on the proponent's data are a subset of the full range of potential calculation outputs. The PEZs are based on current meter data provided by the proponent. The minimal availability of additional oceanographic data for Whycocomagh Bay contributes to uncertainty in the representativeness of the current meter record and dependent analyses. The proponent-provided current record is from a single location over a 30-day time window. This means that the precautionary scoping PEZ estimates do not account for seasonal and spatial variation in the currents, they and are unlikely to be fully representative of the temporal and spatial variability that may be of relevance to estimating exposure and deposition zones. All oxygen considerations are subject to uncertainty in several factors including the variability of water currents and flushing, oxygen concentrations, and oxygen consumption (by fish and the seabed). Available current meter data did not include information on near-bottom (i.e., within 1 m of seabed) currents, which may contribute to uncertainties in simple seabed oxygen estimations. Additionally, the mechanism and impacts surrounding the periodic upwelling of anoxic, contaminant-rich water within Whycocomagh Bay are not well understood. The state of knowledge in relation to refining the assessment of the potential for in-feed drugs and pesticides impacts is evolving. Therefore, 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. Survey based data do not fully sample the area spatially or temporally and, therefore, additional information on presence and habitat use (i.e., spawning, migration, feeding) are drawn from larger-scale studies. Therefore, there is uncertainty as to the distribution of species in the area of the existing site and proposed expansion.

### 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 the 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. The sensitivity of many wild species to the potential effects of aquaculture operations are also largely unknown.

### Potential Cumulative Interactions

Human activity maps should be considered a preliminary and conservative estimate of human uses within the area of interest. 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 also not included. Buffer distances used in the analysis may be a conservative estimate. Assumptions that the influence of human activities diffuse equally in all directions was also used, although it is more likely that alongshore currents and river plumes influence the diffusion of impacts, particularly close to the coastline. While there is evidence that different interaction types (e.g., synergistic, antagonistic) are common, more research is required to determine the types and magnitude of interactions between key activities. Moreover, there is currently not enough information to know what effects all included human activities in the area may have on different components of the marine environment, or their appropriate decay of impacts.

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# 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. (2008)

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

# Appendix B: Physical Data

Additional information on physical characteristics (temperature, salinity, dissolved oxygen) of the area surrounding site #0814x in Whycocomagh Bay was obtained from the following sources (locations shown in Figure B1):

- Strain et al. (2001) stationary oxygen measurements recorded from 1995–1997 in spring, summer and fall (six stations)
- DFO unpublished data collected through the Bras d'Or Lakes Monitoring Program
  - vertical profile data from May 2014 (three stations)
  - near-bottom time series data from November 2014–May 2015 (two stations)
  - vertical profile data from March 2020 (one station)


*Figure B1. Location information for available dissolved oxygen data in Whycocomagh Bay used in this review. Anchors represent station locations, and the orange polygon represents the proposed #0814x site boundaries.*

The data shown in the above figure (Figure B1) illustrate the spatial sparsity of available data and the data shown below (Figures B2 and B3) highlight the temporal sparsity in the records available for an overall understanding of the area and the consequent uncertainties in variability.

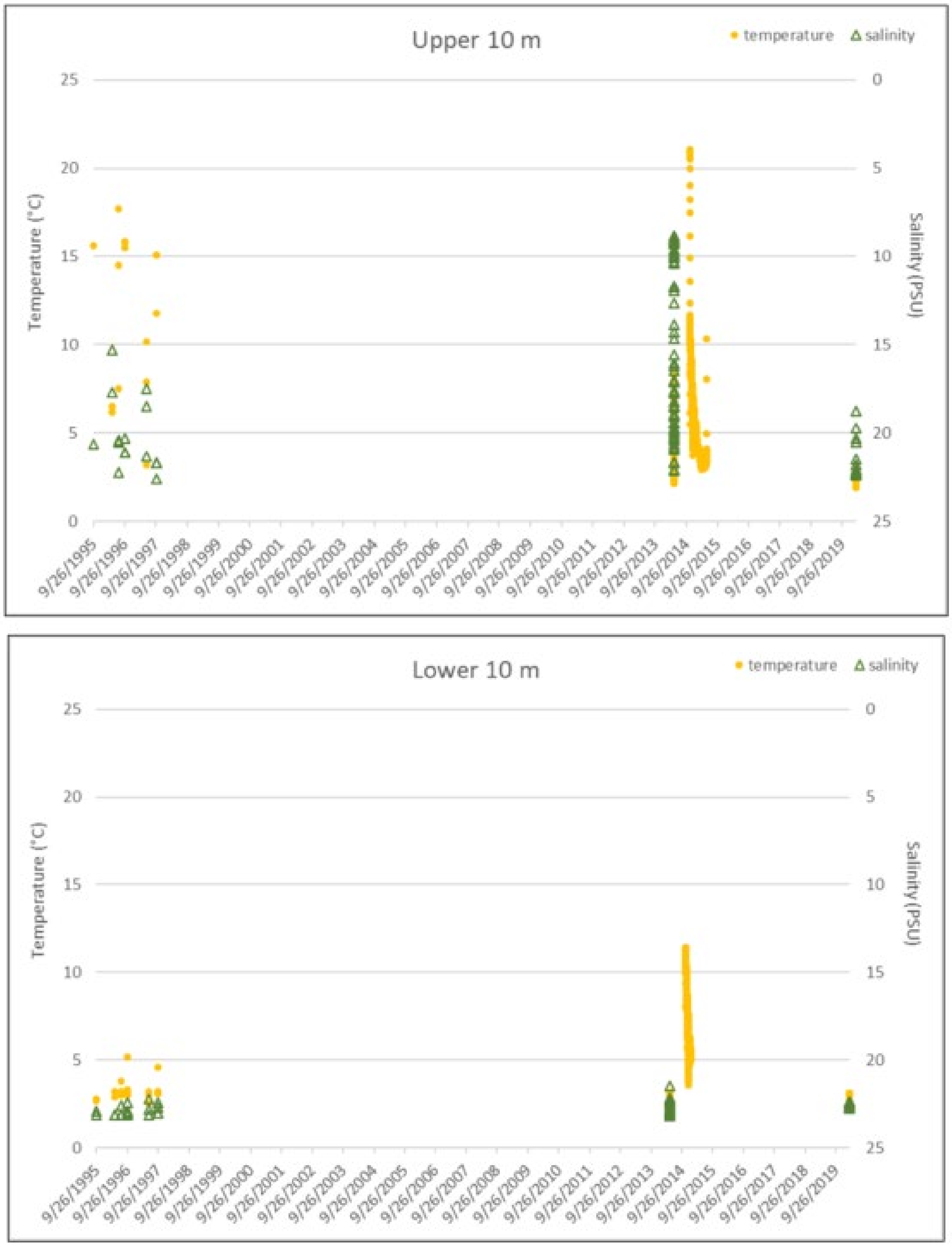


*Figure B2. Temperature (yellow) and salinity (green) records available over time at locations near the proposed #0814x site. Data have been divided into near-surface waters in the upper 10 m (top panel) and water depths below 10 m (bottom panel).*

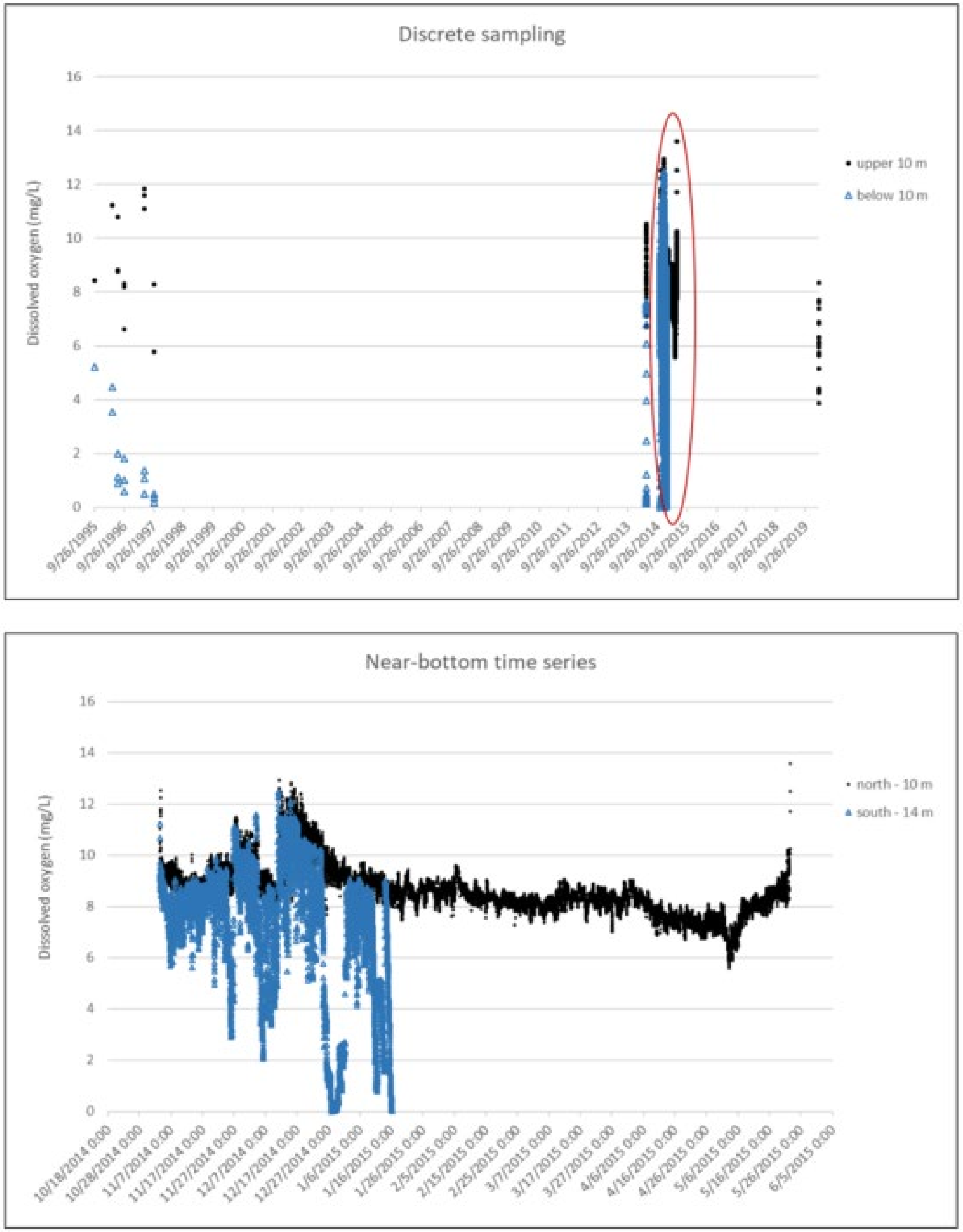


*Figure B3. Dissolved oxygen (mg/L) data available at locations near the proposed #0814x site. Circled data in the top panel represent the time-series data collected near the site and shown in the bottom panel. The south side instrument stopped working on January 16, 2015.*

# Appendix C: Oxygen Calculations

## Pelagic

The oxygen depletion index (Page et al. 2005) is an indicator of the potential for farmed fish to generate oxygen depletions on scales of a net-pen, farm or bay. The oxygen depletion index ($I_{\mathrm{DO}}$) is defined as the ratio of the time required to reduce the oxygen concentration to a specified threshold with no flushing, $T_{\mathrm{thres}}(s)$, and the appropriate flushing time, $T_{\mathrm{fl}}\ (s)$:

$$I_{\mathrm{DO}} = \frac{T_{\mathrm{thres}}}{T_{\mathrm{fl}}}$$

with

$$T_{\mathrm{thres}} = \frac{C_0 - C_{\mathrm{thres}}}{\frac{R}{3600}\,\frac{\rho_{\mathrm{fish}}}{1000}}$$

where $C_0$ is the concentration of dissolved oxygen away from the farm (mg/L), $C_{\mathrm{thres}}$ is the minimum required concentration (mg/L), $R$ is the respiration rate of the fish per volume of water (mg/kg/hr), and $\rho_{\mathrm{fish}}$ is the fish net-pen stocking density (kg/m$^3$) (Page et al. 2005). Here, the flushing rate is calculated as

$$T_{\mathrm{fl}} = \frac{D_{\mathrm{cage}}}{U}$$

where $D_{\mathrm{cage}}$is the fish cage diameter (m) and $U$ is the ambient current speed (m/s). An index value of 1 means that the respiration time is equal to the flushing time, under ideal circumstances. Index values less than 1 indicate the potential for oxygen depletion and consequent impacts.

For Whycocomagh, the oxygen depletion index for a fish net-pen was calculated for various scenarios (Table C1) using a range of parameter values obtained from data submitted by the proponent, collected by DFO, and extracted from the literature. Data collected by DFO suggest that the composition of Dissolved Oxygen (DO) in Whycocomagh is complex. Deeper areas can be perfectly anoxic (i.e., DO concentration of 0 mg/L). In the top six meters of the water column, the DO concentration ranged from 2.75–5.16 mg/L with a mean of 4.29 mg/L. Over the entire water column, oxygen extremes of 0 mg/L and 13.05 mg/L have been recorded. Current speeds were estimated from the data submitted by the proponent: in the upper six meters of the water column, the current speed varied between 0–18.4 cm/s and had an average of 3.16 cm/s. Rainbow Trout consume DO at an average rate ranging from 213 to 233 mg/kg/hr with values as low as 108.6 and as high as 362.8 (Kindschi et al. 1991, Taguchi and Liao 2011, Svendsen et al. 2012). The optimal DO concentration for Rainbow Trout is poorly studied. Raleigh et al. (1984) reported that the optimal DO concentration is at least 7 mg/L at temperatures of 15°C or less. For temperatures greater than 15°C, the optimal DO concentration is at least 9 mg/L. Rainbow Trout will avoid water with DO concentrations less than 5 mg/L, and levels approximately 3 mg/L and less are known to be lethal (Raleigh et al. 1984). Newer research indicates that, in order to avoid negative effects, farmed trout require a minimum DO concentration of 5–6 mg/L; the lethal limit is 2–3mg /L and mortality can occur at 4 mg/L (Welker et al. 2019).

*Table C1. Oxygen depletion index calculations at the proposed #0814x site for five scenarios. Current speed ranges are based on the proponent's data for the upper six meters of the water column and DO levels on DFO data also for the upper six meters of the water column. Respiration rates for Rainbow Trout are taken from the literature (Kindschi et al. 1991, Taguchi and Liao 2011, Svendsen et al. 2012).*

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|
| **Current speeds** 0–18.6 cm/s | 18.6 | 3.16 (mean) | 3.16 (mean) | 0 | 0 |
| **Ambient DO levels** 2.75–5.16 mg/L | 5.16 | 5.16 | 5.16 | 5.16 | 5.16 |
| **Respiration rates** 108.6–362.8 mg/kg/hour | 108.6 | 108.6 | 223 (mean) | 108.6 | 223 (mean) |
| **Sub-lethal threshold DO** 5–6 mg/L | 5 | 5 | - | 5 | - |
| **Mortality threshold DO** 2–4 mg/L | - | - | 4 | - | 4 |
| **Oxygen depletion index value** | 2.84 | 0.49 | 1.72 | n/a | n/a |

## Benthic

To assess the potential impact of a fish farm on benthic oxygen levels, it is assumed that a benthic oxygen consumption rate of 60 mmol·m-2·$d^{-1}$ (1,343.46 ml·m-2·$d^{-1}$) is representative of conditions under a fish net-pen and 10 mmol·m-2·$d^{-1}$ is a representative reference rate. Thus, a farming operation could increase benthic oxygen consumption by about 50 mmol·m-2·$d^{-1}$. Assuming the water within the first 1 m above the sediment has an ambient dissolved oxygen concentration of 5 ml·$L^{-1}$ (5,000 ml·$m^{-3}$) and the water is not moving, i.e., the water is not replaced, the benthic respiration would deplete the oxygen within the bottom 1 m of water under the net-pens within about 3.7 d. If the ambient dissolved oxygen concentration was lower than 5 ml·$L^{-1}$ or if the depletion was to a threshold rather than zero, this time would be shorter. For example, if the threshold were 4 ml·$L^{-1}$, the depletion time would be less than 1 day (0.7 d). However, since the water under the net-pens is moving, oxygen is being replenished at the same time as it is being consumed. For a representative bottom current speed and farm length of 1 cm·$s^{-1}$ and 1,000 m, respectively, the time for a parcel of water to transit the site is about 1.2 d. Thus, the time to deplete the oxygen in the near-bottom layer is of the same order of magnitude as the time to refresh the oxygen. Therefore, the near-bottom oxygen concentration could be low and is sensitive to oxygen demand, water current speed, vertical mixing within the site, and horizontal advection of low oxygen waters located in the deeper water within and beyond the site.

# Appendix D: Cumulative Occurrence of Human Activities

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 of site #0814x (hereafter the “area of interest”) were collated from a larger inventory of human activities developed for the Maritimes Region (Province of Nova Scotia 2021). Human activities that occurred on a “local” scale were selected, defined as those operating over small spatial scales (i.e., < 10 km) or from point-sources that could produce a localized zone of impact, such as marine recreation, aquaculture, or benthic structures. The most recent years of data or up-to-date information were included when possible.

The impact of human activity in the marine environment often extends beyond their 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, a buffer was added that radiated from the point source of the activity. The furthest distance from the activity’s origin was determined for the same or most similar activity based on extensive reviews presented in Ban and Alder (2008), Ban et al. (2010), and/or Clarke Murray et al. (2015) (“buffer radius”; see Table D1). The radius for the proposed finfish site was taken from the pelagic-PEZ, as it also overlaps with the benthic-PEZ and, therefore, represents the maximum occurrence of both benthic and pelagic stressors.

The zone of influence of land-based activities on coastal environments is more difficult to determine than for activities that occur directly in marine waters. Land-based human activities occurring in the watersheds surrounding Whycocomagh Bay are described earlier in the document. To estimate a zone of influence for the potential effects of runoff and pollution from these land-based sources, the location pour point of the Skye River draining into Whycocomagh Bay within the area of interest was used, and the buffer radius was based on the stream order of the river (after Clarke Murray et al. 2015). While the majority of effects of roads within the watershed are included from the pour-point buffer, there are several sections of the bay where the Trans-Canada Highway comes in very close proximity to the shoreline; runoff from this source would drain directly into Whycocomagh Bay, instead of first flowing through the watershed. Using information from Forman and Deblinger (2000), the effects resulting from the close proximity of the highway were estimated along sections of the shoreline where the highway is ≤ 30 m away and by setting a rectangular buffer extending 500 m into the bay from the shoreline.

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.*

| Activity category | Activity | Buffer radius (m) |
|---|---|---|
| Aquaculture | Finfish sites | 2,790 |
| | Shellfish sites | 500 |
| Boat traffic | Recreational (boating, kayaking)* | 2,000 |
| Land | Wastewater inputs and runoff from land-use (i.e., industry, agriculture, urban cover, roads) | 5,873 |
| | Trans-Canada Highway | 500 |

*impact of small docks, ramps, wharves contained within this buffer as well

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