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Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
Science Response 2025/025

DFO NEWFOUNDLAND AND LABRADOR REGION SCIENCE REVIEW OF PROPOSED COLD OCEAN SALMON FINFISH AQUACULTURE FACILITIES IN JUNE COVE, CONNAIGRE BAY, NEWFOUNDLAND

CONTEXT

The Proponent, Cold Ocean Salmon Inc., has submitted an application for an Atlantic Salmon aquaculture licence for one site in Connaigre Bay located on the south coast of Newfoundland. The application was submitted to the Province of Newfoundland and Labrador (NL) and referred to Department of Fisheries and Oceans Canada (DFO) for siting advice. DFO Science has been asked for a review of the predicted exposure zones associated with the new aquaculture activity and the predicted impacts on species and the habitats that support them. In accordance with the *Aquaculture Activities Regulations* (AARs), the Proponent's site application package includes a Baseline Assessment Report.

DFO has implemented a siting framework to promote a consistent approach to aquaculture site reviews. This framework includes four standardized questions the Regional Aquaculture Management Office (RAMO) uses to ensure a comprehensive review of site applications and inform DFO advice to the Province:

1. Based on the available data for the site and scientific information, what is the expected exposure zone from the use of approved fish health treatment products in the marine environment, and the predicted consequences to susceptible species?
2. Based on available data, what are the Ecologically and Biologically Significant Areas (EBSAs); Species at Risk (SAR); fishery species; and 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?
3. 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?
4. Which populations of conspecifics are within a geographic range where escapes are likely to migrate? What are the size and status trends of those conspecific populations in the escape exposure zone for the proposed site? Are any of these populations listed under Schedule 1 of the Species at Risk Act (SARA)?

This Science Response Report results from the regional peer review of September 20–21, 2022, Aquaculture Siting Advice for Provincial Site Licence Applications from Cold Ocean Salmon in Connaigre Bay and Grieg Aquaculture in Placentia Bay. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

BACKGROUND

The Proponent submitted an application to develop and operate a new finfish aquaculture site for the production of Atlantic Salmon (diploid *Salmo salar*; St. John River Strain) in Connaigre Bay. The location of the site is June Cove (Figure 1) and there have been no previous aquaculture activities within the proposed site lease. The June Cove proposed site is located within Bay Management Area (BMA) 6. This BMA has two existing licensed finfish farms, Fish Cove and Rattling Brook, neither of which have been stocked as of the writing of this report. All of the finfish sites within the BMA are operated by Cold Ocean Salmon (the Proponent). This BMA is scheduled to be stocked with finfish year classes from 2021, 2024, and 2027. Additionally, there are two shellfish sites licensed in the BMA, The Pocket and Salmonier Cove. Both of these sites are operated by Connaigre Fish Farms.

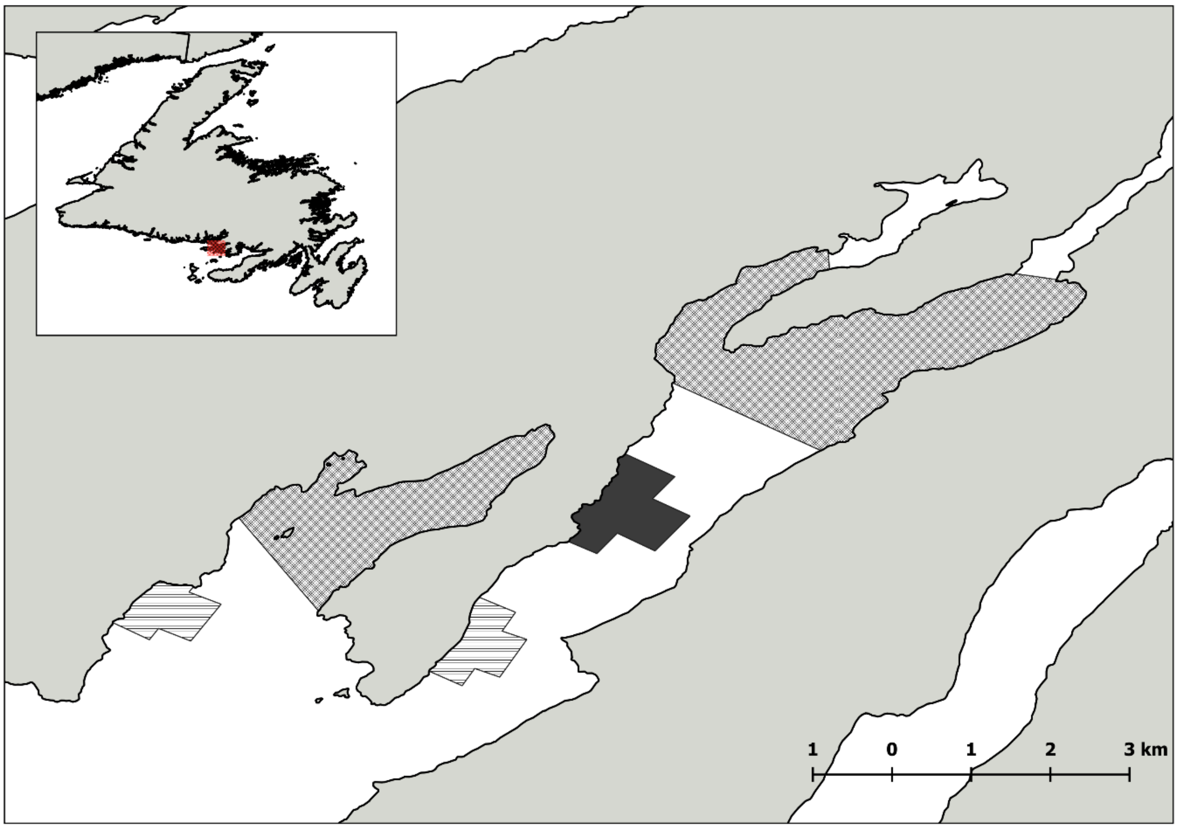

Figure 1: Location of aquaculture sites in Connaigre Bay, NL. The cross hatch areas are existing mussel leases, the horizontal lined areas are existing salmon farms, and the dark grey area is the proposed site lease.

General Description of Site

The baseline environmental report for the June Cove proposed aquaculture site[1], following the *Aquaculture Activities Regulations (AAR) Monitoring Standard* includes the site description, bathymetric survey, visual benthic survey, and fish habitat survey conducted for the entire

[1] Aquaculture Activities Regulations: Baseline Environmental Assessment Report.

proposed lease area. The general description of site section of this Science Response Report is based on the aforementioned information, and other documentation provided by the Proponent.

The proposed lease area (0.69 km^2) is approximately 21.7 km northeast of the town of Seal Cove (by waterway) and approximately 32.6 km northwest of the town of Harbour Breton. The bathymetric survey reports that depth ranges from approximately 7 m to 233 m. While this is the case for the entire lease area polygon, the depths directly beneath the planned cage array area range from 50 m to 160 m.

The fish-habitat survey carried out in 2009 (September; 75 stations less than 100 m) and 2019 (August; 54 stations less than 300 m) at the June Cove site revealed that silt/mud was the most common substrate observed and that the site classification was considered soft (59% of stations surveyed had soft substrates). Soft bottom was indicated when the camera frame sank into the substrate. Attempts were made to collect sediment grabs. No station yielded acceptable sediment for analyses due to insufficient sediment, overfilled sampling, and/or benthic grab not closing. Despite the loss of opportunity for baseline sediment samples (for indicators such as sulphide levels), sediment grabs will be a regulatory requirement for long-term monitoring of this site.

The seabed within the area is uneven and primarily made up of silt and mud. As this site has not previously hosted aquaculture facilities, evidence of benthic indicators for aquaculture activity were not expected. Consistent with this, observations from the benthic survey did not show any indications of aquaculture disturbance such as the presence of *Beggiatoa*-like bacteria, opportunistic polychaete complexes and/or barrenness caused by aquaculture.

No aggregations of commercially important species were observed during the survey. This statement is followed by an important caveat: a visual benthic survey using a drop camera would not be expected to detect aggregations of fish. Presence of certain commercial (and recreational) species is indicated by the presence of fishing activities in the area. The area is used for recreational (Atlantic cod [*Gadus morhua*], scallop [*Placopecten magellanicus* and *Chlamys islandica*], trout [*Salvelinus fontinalis*]) and commercial fisheries (inshore American Lobster [*Homarus americanus*] and inshore Snow Crab [*Chionoecetes opilio*]).

The baseline reports did not contain any observations of lobster in the underwater video surveys. However, lobster are cryptic (especially during the day) and are unlikely to be detected by this type of survey. The baseline assessment did identify suitable lobster habitats at the proposed site. Habitats and substrates identified in the baseline studies of the proposed site (i.e., bedrock, cobble, kelp, mud, and silt) are known as suitable habitat for lobster (Dinning and Rochette 2019). In Newfoundland, lobster commonly frequent shallow depths in the spring and summer months and move into deeper waters in the fall.

There is a fishery for Snow Crab in Connaigre Bay and they were identified in the underwater video survey within the proposed lease area (Goulet et al. 2022). The habitat range of Snow Crab spans from nearshore coastal waters to the edges of the continental shelf breaks. Snow Crab are typically found in water ranging from -0.5 to 3°C and loosely conform to a depth range of about 50 to 500 m, although occurrence outside these ranges does occur and distributions can reflect localized habitat characteristics (Mullowney et al. 2014, 2018). Habitat use follows a general pattern of distributions occurring in shallow, cold, and coarse-bottomed habitats during early ontogeny and deeper, warm, softer-bottomed habitats during later ontogeny, with vertical exchanges for some groups of crab, particularly large males, during seasonal breeding migrations (Mullowney et al. 2018).

The Snow Crab life cycle features a release of larvae in spring followed by a pelagic larval period before settlement to benthos in the fall (Comeau et al. 1999, Sainte-Marie 1993).

Compared to other marine benthic invertebrates, the Snow Crab planktonic phase is long and allows for potentially broad dispersal of larvae by currents.

Krill (*Meganyctiphanes norvegica*) were the most numerous fauna, with krill swarms present at 44 of the 129 stations. Shrimp (*Pandalus borealis*) were also commonly found. Arrow worms were the second most abundant organism with presence at 48 of the stations. Within the survey area, scallops, Acadian Redfish (*Sebastes fasciatus*), and Snow Crab were noted. A few soft corals (*Gersemia spp* and unidentified species) were noted at 4 of the stations. DFO's Research Vessel (RV) survey does not sample the shallow coastal waters of Connaigre Bay. Corals and sponges have however been observed in adjacent offshore areas in DFO RV surveys and are shown in Figure 2. These, in combination with the few observations at the site, indicate that corals and sponges are present in the general area.

No species identified as at risk by Canada's *Species at Risk Act* (SARA) were observed during the survey. Because the DFO RV surveys do not occur as far inshore as Connaigre Bay, they cannot provide a record of Species at Risk (SAR) directly in the proposed site area, however based on general distribution maps, DFO RV survey data, and/or DFO marine mammal sightings/survey data in general, the following SAR can potentially occur in the application site: Blue Whale (*Balaenoptera musculus*), Fin Whale (*Balaenoptera physalus*), Northern Bottlenose Whale (*Hyperoodon ampullatus*), North Atlantic Right Whale (*Eubalaena glacialis*), Sowerby's Beaked Whale (*Mesoplodon bidens*), Harbour Porpoise (*Phocoena phocoena*), Leatherback Sea Turtle (*Dermochelys coriacea*), Loggerhead Sea Turtle (*Caretta caretta*), Northern Wolffish (*Anarhichas denticulatus*), Spotted Wolffish (*Anarhichas minor*), Atlantic Wolffish (*Anarhichas lupus*), American Eel (*Anguilla rostrata*), the Newfoundland population of the Banded Killifish (*Fundulus diaphanus*), and White Shark (*Carcharodon carcharias*). White Shark have been tracked into the south coast of Newfoundland through satellite telemetry and are increasing in frequency (Bastien et al. 2020).

The SARA-listed marine fish species at risk (MFSAR) Northern Wolffish, Spotted Wolffish, and Atlantic Wolffish can be found along the south coast of Newfoundland. Atlantic Wolffish is the most commonly found wolffish species in coastal shallow Newfoundland waters, while Spotted and Northern Wolffish are less frequent in inshore waters and tend to be found at greater depths. Atlantic Wolffish eggs have been observed on boulders and rocky crevices at depths <40 m (late summer-fall).

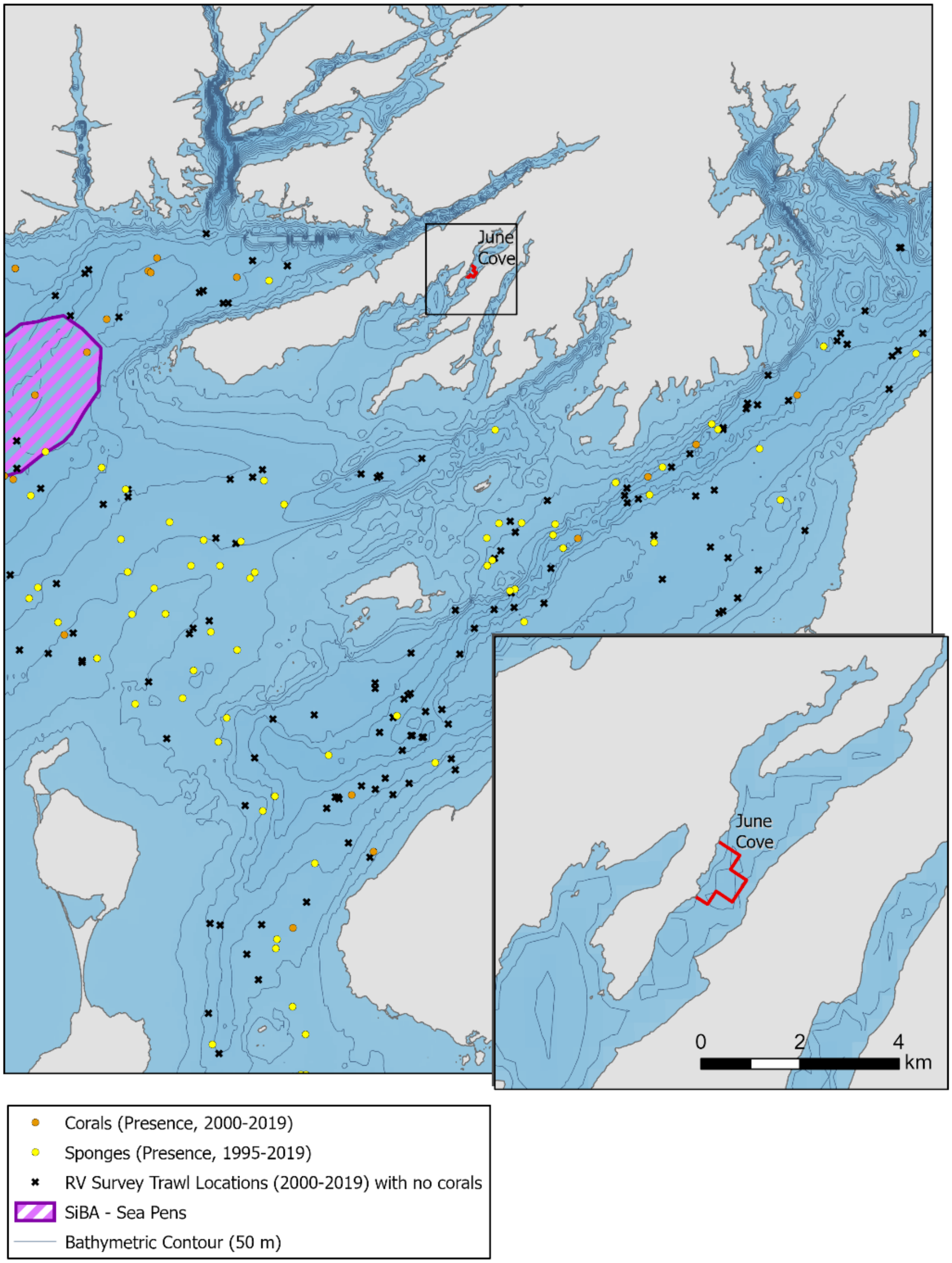

Figure 2: Set locations of DFO's spring RV survey data from 2000–19 (for corals) and 1995–2019 (for sponges) indicating presence of corals (orange circles) and sponges (yellow circles). Sets that lacked corals and sponges are indicated with a black "x". Significant benthic areas containing sea pen corals are indicated by purple hatched polygons.

Oceanographic, farm infrastructure, and grow-out information for the proposed June Cove site is summarized in Table 1.

Table 1: Oceanographic, farm infrastructure, and grow-out information for the proposed June Cove site. All information was extracted from the reports provided by the Proponent for the site licence applications.

Characteristic	June Cove		
(2) Dimension [m]	1,191 x 913		
(1) Area [ha]	69.9		
(2) Predominant substrate type	Soft bottom		
(1) Net-pen array configuration	2 x 6		
(1) Individual net-pen circumference/depth [m]	150 / 20		
(1) Net-pen volume [m^3]	429,720		
(2) Depth under the lease area [m]	0 – 233		
Depth under the cage array [m]	50 – 160		
(1) Current measurement period	10-Oct-2019 to 18-Nov-2019		
Current speed [cm/s]	Depth [m}	Speed [cm/s]	
		Mean	Max
	16	5.4	26.3
	54	4.3	20.1
	94	2.3	8.6
Current measurement type	16–94 m current profiler		
(1) Grow-out period [month]	18–24		
(1) Maximum number of fish on site	1,000,000		
(1) Initial stocking number [fish/pen]	83,333		
(1) Initial stocking weight [kg]	0.25		
(1) Average planned harvest weight [kg]	5.3		
(1) Expected maximum biomass [kg]	4,770,000		
(1) Maximum stocking density [kg/m^3]	12		

[1] Values taken from “Aquaculture License Application” document and rounded to the nearest cm/s (i.e., significant figure)
[2] AAR Baseline Report Cold Ocean Salmon Inc.

ANALYSIS AND RESPONSE

Sources of Data

Information to support this analysis includes data and information provided by the Proponent, holdings within DFO, publicly available literature, and registry information from the SARA database. The DFO multispecies RV Survey database was referenced to supplement commercial fisheries information provided in the Proponent’s submissions. Supporting information files submitted to DFO for consideration and used in its review are shown in Table 2.

Table 2: Summary table of files submitted to DFO.

Description	File Name
Proposed development plan package Baseline survey data submission	1. June Cove Application Package 2. June Cove AAR Baseline Video Files

Temperature Conditions

Temperature information collected by the Proponent shows that in 2008, temperature varied between 0°C (winter) and 18°C (summer) at 3 m depth with some variability during summer. At 20 m depth, water temperature ranged between 0°C (winter) to 16°C (summer) with numerous short-term changes in summer (as high as 10°C of change in a very short period of the order of a few days).

Current Analysis

DFO has collected ocean current data approximately 2 km south of the proposed site for the period of April 2013 to May 2014. The data were collected using a current profiler moored at 77 m depth (Ratsimandresy et al. 2019).

A subsample of measured ocean current data was provided by the Proponent at the time of review. The Proponent used current profilers moored at ~100 m depth. These measured currents between 10 October–18 November 2019. Because the deepest location within the lease area is 233 m and 160 m within the cage array, the available data from the Proponent do not capture the full water column nor do they capture temporal variability (either seasonal or annual). More data were requested but not provided in time for the review.

The 1-year current data measured near the proposed site, by Ratsimandresy et al. 2019, characterize the ocean currents at June Cove. Measurements were taken up to 77 m depth and inform on the upper layer conditions (but not the deeper region). These data show that maximum currents over 40 cm/s can be observed in the upper layer (top 20 m) without any specific seasonal pattern. This is due to the surface layer's response to strong winds that occur all year long in the region (Donnet et al. 2018). Currents in Connaigre Bay show monthly variability: for example, in 2013–14, the upper 20 m presented a lower median current speed in spring/summer and higher speed in fall (Figure 3). High maximum current speeds were observed in summer or fall and the lowest speeds in winter or early spring.

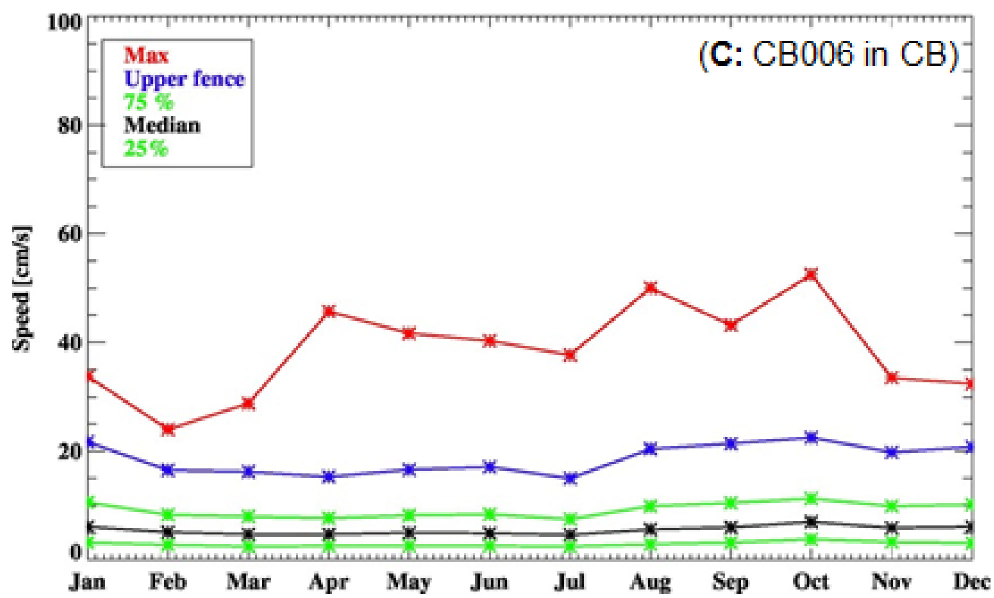

Figure 3: Monthly variability of the current speed in the upper layer for a station in Connaigre Bay. 25%, median, and 75% represent the 25, 50, and 75 percentiles, upper fence is the value as described in the methodology on summary statistics and Max is the maximum recorded current speed. (Ratsimandresy et al. 2019).

The data collected by the Proponent show vertical stratification (of current speed; Figure 4). Median current speed slightly decreases with depth; however, higher maximum currents were observed near the surface and at around 46 m.

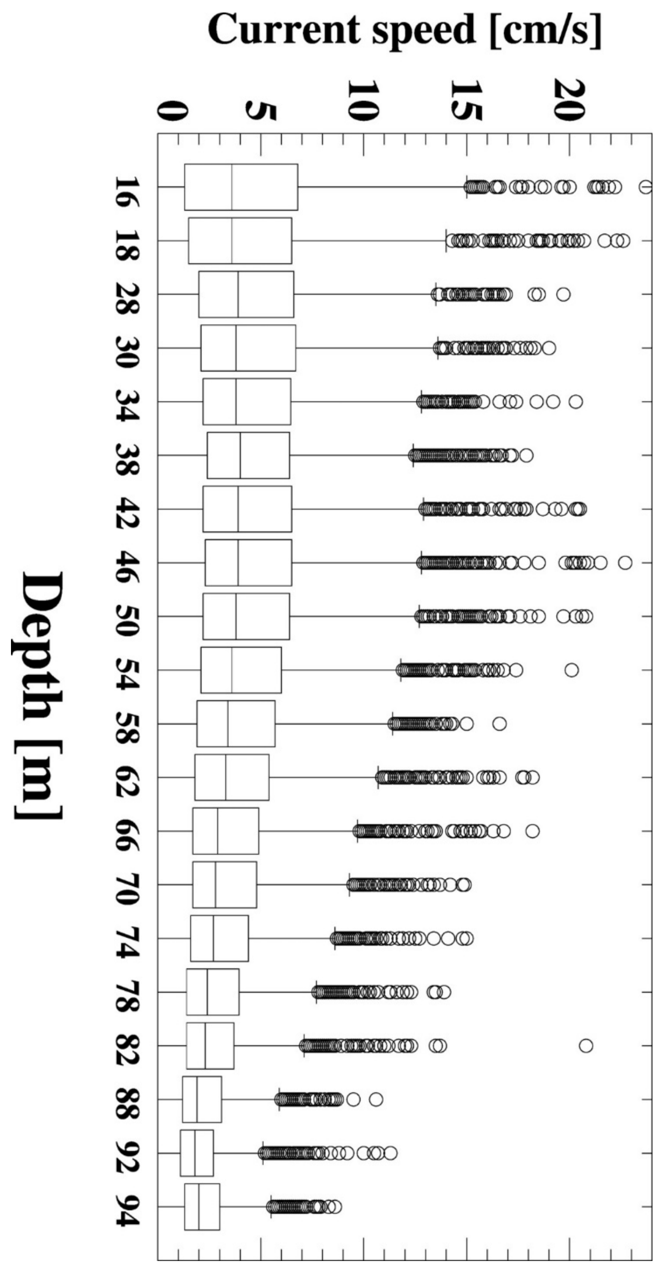

Figure 4: Boxplot of current speed at June Cove for the period of 10 Oct 2018 to 18 Nov 2019 for various depths. The boxplot provides information on median and interquartile range (IQR) of data, current speeds above the upper fence (values above 1.5xIQR from the third quartile) are represented with open circles.

Benthic Predicted Exposure Zone

Predicted exposure zones (known as PEZs) are tools for identifying, albeit at a broad spatial scale, areas of potential exposure for sensitive species and habitats (Page et al. 2023).

The Benthic Predicted Exposure Zone (benthic-PEZ) is an estimate of the size and location of benthic area that may be exposed to the deposit of waste feed and feces released from a site, which can result in organic loading. The PEZ potentially exposed to the deposit of medicated waste feed is known as the waste feed-PEZ, and feces is the fecal-PEZ. The benthos may also be exposed to pesticides released into the water, particularly at shallow depths, however, this impact is addressed through the calculation of the Pelagic Predicted Exposure Zone (pelagic-PEZ). Dominant factors that affect benthic-PEZ are farm layout, feeding practices, and oceanographic conditions (i.e., bathymetry and water currents).

The benthic-PEZ calculation is carried out with as conservative approach as can be achieved while retaining its simplicity. It is calculated by first computing the transport distance (ocean current speed multiplied by the period of sinking of the particles, feed, and feces individually), and adding half the length of the cage array. Key assumptions for the model include: constant settling velocity of the particles, constant ocean current speed during the particle descent, constant depth (i.e., flat bathymetry), and no resuspension mechanism. The parameters used are: slow sinking velocities (the minimum sinking rate obtained from the literature), fast water currents (the maximum persisting water current speed observed at the site during the sinking or dilution period of particles), and deep bottom topography (the maximum depth over the lease area). The sinking rates for different particulate materials released from farmed fish (i.e., waste feed and feces) vary, although little is known about the distribution of the sinking speeds in relation to the characteristics of the released particles. The rates were obtained from literature values (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).

Since the release of waste particles is considered to happen at the bottom of the cages, the available ocean currents just below the cage depth (~46 m) were selected for the calculation of maximum current speed during the sinking period. The selected minimum sinking rate for each category and the corresponding maximum current speed as well as the first-order estimates of the spatial extent of the benthic-PEZ related to organic effluent and in-feed drugs from the proposed June Cove site are given in Table 3.

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

June Cove				
Particle type	Min. sinking rate [cm/s]	Sinking period [h]	Max. calculated current speed during sinking period [cm/s]	PEZ radius [km]
Feed	5.3	1.2	20.2	1.1
Feces	0.3	21.6	9.6	7.7
Fines and Flocs	0.1	64.7	6.4	15

The benthic-PEZ is represented by a circular zone centered on the middle of the proposed cage array and represents the outer limit for potential exposure; however, the benthic footprint is more likely a curved ellipse with a major axis length scale due to current directionality. The zones were estimated by adding the horizontal transport distance to the length of the proposed net-pen array. The spatial extent of exposure is illustrated in Figure 5.

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 with distance. The waste feed-PEZ is anticipated to have the greatest intensity of exposure given that it happens closer to the net-pens.

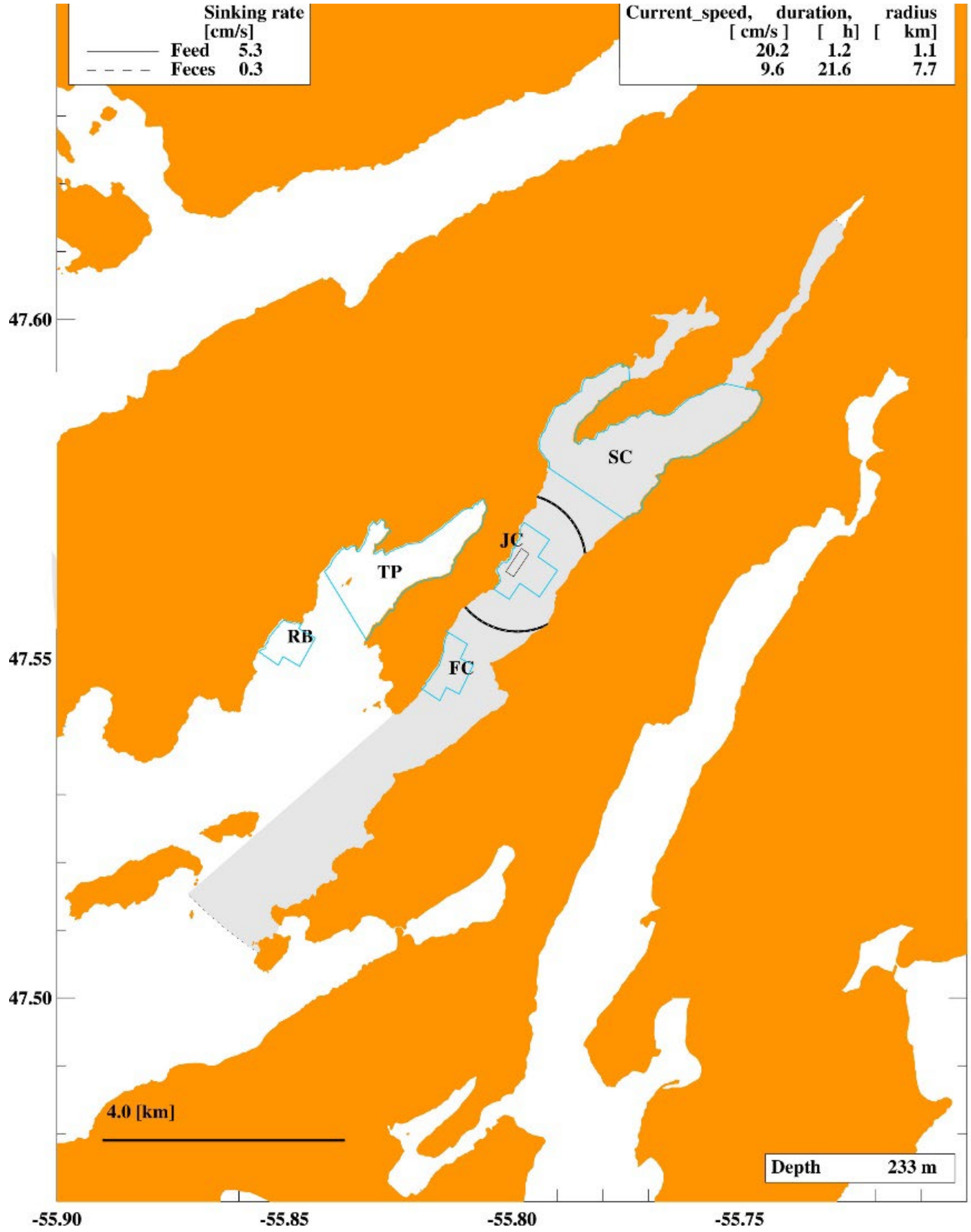

Figure 5: Benthic-PEZ for the proposed June Cove site. Net-pen arrays (dark grey lines) within lease boundaries (light blue polygons) are shown. Bold black circle delimits the waste feed-PEZ and shaded grey areas the fecal-PEZ. Rattling Brook (RB) and Fish Cove (FC) are existing finfish licenses, The Pocket (TP) and Salmonier Cove Connaigre Bay (SC) are shellfish licenses.

Calculation of the fecal-PEZ uses a similar method but uses the maximum current speed for the period of sinking of fecal particles (Table 3). The spatial extent of the fecal-PEZ provides an indication of the full area that could be exposed to any in-feed drugs used. The benthic-PEZ associated with the feed (waste feed-PEZ) and feces particles (fecal-PEZ) covers the region outside the lease area with the latter reaching farther distance.

The Proponent used the 2-D mode of AquaModel to analyze the waste deposition around the June Cove site. It is a program which helps predict the environmental impacts and operations of fish farms in nearshore and open ocean environments. In order to run the model, it needs information on ocean currents (from one-point measurement or a hydrodynamic model), surface irradiance, water temperature, concentration of dissolved oxygen, dissolved inorganic nitrogen, as well as cellular nitrogen in phytoplankton and zooplankton. AquaModel-predicted depositional contours (1 g C m^{-2} d^{-1} and greater), as provided through the AAR baseline reporting, do not exceed the proposed lease boundaries and are generally confined to water deeper than 30 m. The contours are mostly centered around the cage array but extend further away from the array to the southwest (i.e., the direction of the predominant current) and to the east (i.e., into deeper water). On the western side of the array, some patchy deposition occurs in the shallower depths (close to the 20 m isobath). The PEZ estimates for feed and fecal particles released from the site are of the order of 1.1 and 7.7 km, respectively, around the center of the proposed site. The waste feed-PEZ particles reach the island south of the site and the fecal-PEZ can impact the shoreline of the islands west and north of the site. The result of the AquaModel falls within the benthic-PEZ.

Current- and wave-induced bottom resuspension is not explicitly considered for these first-order estimates of exposure. Maximum current speed at 94 m depth was 8.6 cm/s; however, should bottom currents with speeds over 9.5 cm/s be observed at the site (the critical value for resuspension for the deposition model DEPOMOD, Chamberlain and Stucchi 2007), then there will be potential for sediment resuspension. The potential impacts of redistribution and flocculant deposition are unknown.

The presented benthic-PEZ does not show any overlap with exposed zones from other previously proposed sites in the region. A combined analysis would be necessary should multiple sites in BMA 6 be simultaneously active. For the interpretation of the PEZ, one needs to consider that PEZ analyses provide estimates only, which are sensitive to data input. The results should be interpreted as an order of magnitude.

Susceptible Species Interactions

Species are considered susceptible within the benthic-PEZ if they are sessile at any life stage and are sensitive to low oxygen levels, smothering, loss of access to the site, or exposure to in-feed drugs (DFO 2022a, 2022b). This includes any species that spends time on the benthos (and has limited vagility), during any life stage. Expansion of aquaculture development at the proposed site increases the risk of anoxic or hypoxic conditions that could potentially impact benthic species (this includes important commercial species such as American Lobster, Snow Crab, and scallop) in the lease area (and benthic-PEZ). This may also impact eggs of fish species.

Special consideration must be given when there is evidence of certain highly sensitive sessile species (such as sponges and corals), and critical habitat (such as eelgrass; DFO 2009) for SARA-listed species in the baseline survey, 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 is considered instead.

In this case the site consists primarily of silt/mud substrate with a reported low presence of habitat forming organisms (coral and kelp), highlighting an environment not as susceptible to the physical effects of deposits as other sites with a higher abundance of coral, kelp, and other sensitive species.

The presence of commercial species within the benthic-PEZ lends to the potential for these species to be affected by the deposition of feces/medicated feed. The Proponent's Fish Health and Biosecurity Management Plan indicates that the usage of chemical treatments will be prescribed only in cases when the series of alternative treatments (cleaner fish, the installation of sea lice skirts, functional feeds, mechanical or thermal treatments) fail to keep parasite infestation under control. The drugs listed are emamectin benzoate (EMB, an in-feed treatment known commercially as SLICE®), as well as approved pesticides (azamethiphos and hydrogen peroxide; discussed in the pelagic-PEZ section).

In a review of 4 years of publicly available data (2016–19) on chemical usage at salmon sites in NL, results show that sequential chemical treatments are the prevalent approach, EMB with azamethiphos being the most used combination with a decrease in ivermectin usage. There was no usage of teflubenzuron in NL as per the consulted dataset. Relatively high rates of usage of EMB per fish biomass were noted (Hamoutene et al. 2022).

Exposure to in-feed pest control drug EMB through deposition of medicated waste feed and/or fecal excretion is documented to have impacts on crustaceans (e.g., Burridge et al. 2000, Waddy et al. 2002, Burridge et al. 2008, Hamoutene et al. 2023b). These studies report deleterious effects on lobsters (adults and larvae) as well as shrimp species, with less data on crabs. Their presence within the lease area with potential benthic deposits (Figure 5) suggests a potential risk associated with the usage of medicated feed (EMB, ivermectin, or teflubenzuron).

How in-feed drugs impact bottom dwelling fish is unknown, but species such as wolffish would be potentially exposed to contaminated seabed within the PEZ. Although the fish habitat survey and benthic video sampling did not detect MFSAR, it is likely that Atlantic Wolffish are present in the vicinity of the proposed aquaculture site. Thus, the accumulation of waste materials from the cages has the potential to negatively impact benthic habitats (e.g., habitat degradation, mortality of prey species) used by wolffish, for any such habitats within the benthic-PEZ (e.g., nesting sites, feeding grounds).

Wolffish tend to be found in low densities, have low mobility, and a solitary lifestyle. The three wolffish species are widespread in Canadian waters, and each is considered as a single Designatable Unit (DU). Under the scenario of single DUs, and life history traits as described above, the anticipated impacts to these species and habitats will be low and limited to the surrounding areas of the proposed aquaculture activities. Otherwise, if evidence of local populations can be established, then the potential for spatial erosion of those populations should be assessed.

Pelagic Predicted Exposure Zone

The Pelagic Predicted Exposure Zone (pelagic-PEZ) is computed to provide an order of magnitude of the potential pelagic area where interactions between registered pesticides used in finfish aquaculture and susceptible species are likely. It is a conservative estimate used to determine the spatial pelagic area that may be exposed to a potentially harmful substance.

The two Health Canada authorized pesticides available for use in bath treatments, tarp bath and well-boat, are azamethiphos and hydrogen peroxide (Pest Management Regulatory Agency [PMRA]). The pelagic-PEZ is calculated conservatively, assuming use of tarp bath treatment, regardless of whether all cages would meet the PMRA treatment conditions for application, given the larger exposure zone anticipated to result from the tarp treatment versus a well-boat. Tarp baths involve enclosing the salmon net-pens with tarps and adding bath treatment medicine, where the well-boat method is a more contained environment; fish are pumped into well-boats containing the pesticide (Shen et al. 2019).

The size of the pelagic-PEZ depends on the decay and/or dilution rate of the pesticide, a chosen concentration threshold, and choice of horizontal water current speed. Health Canada's PMRA has assessed that the pesticides and their breakdown products are expected to remain in suspension since they do not bind with organics or sediments and do not accumulate in organisms' tissues. The half-lives of the pesticides range from days to weeks, suggesting that they can persist in the environment at toxic concentrations for some time (PMRA 2014, 2016a, 2016b, 2017).

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

The dilution time scale, and hence the size of the pelagic-PEZ, increases as the ratio of the treatment to the threshold concentration increases. The values of threshold concentrations for both bath pesticides were recently discussed in a Canadian Science Advisory Secretariat (CSAS) meeting (Hamoutene et al. 2022), and will continue to be reviewed within DFO. Recent literature indicates that hydrogen peroxide is not as benign as initially assumed (Bechmann et al. 2019, Escobar-Lux and Samuelsen 2020, Escobar-Lux et al. 2020, Mill et al. 2022) and may remain above suggested threshold concentrations. The threshold values for azamethiphos discussed in Hamoutene et al. (2022, 2023a) and available internationally (SEPA 1999) are lower than the threshold used in this modelling exercise. When new thresholds are adopted, new pelagic-PEZs for azamethiphos and hydrogen peroxide will be generated for site applications.

The tarp bath treatments occur in the surface layer thus near-surface currents would be more appropriate to be used in the calculation of the pelagic-PEZ. However, the shallowest current data available from the Proponent were at 16 m depth, therefore, the time series of ocean currents at that depth was considered. The pelagic-PEZ is calculated by first computing the maximum persisting current speed during the period of dilution and multiplying it by the dilution period (three-hour). The estimate was generated by adding the horizontal transport distance to the length of the proposed net-pen array.

The pelagic-PEZ does not quantify the intensity or duration of exposure, nor does it include a frequency of exposure. The zones do not imply that areas within the pelagic-PEZ have the same exposure risk. The intensity of exposure is expected to be highest near the net-pen arrays and decrease as the distance from the net-pens increases.

As shown in Table 4, treatment particles can reach a distance of 2.2 km away from the center of the cage array during the three-hour dilution period. The pelagic-PEZ for the proposed June Cove site is illustrated in Figure 6. The exposure is expected to primarily occur in the pelagic zone; however, since it reaches areas near the shoreline, shallow areas (less than 10 m depth) may also be at risk of exposure to toxic pesticide concentrations.

Table 4: First order pelagic-PEZ estimates associated to the potential horizontal distances travelled by non-sinking particles for a dilution period of 3 h.

Dilution period [h]	Max. calculated speed during dilution period [cm/s]	PEZ radius [km]
3	17.7	2.2

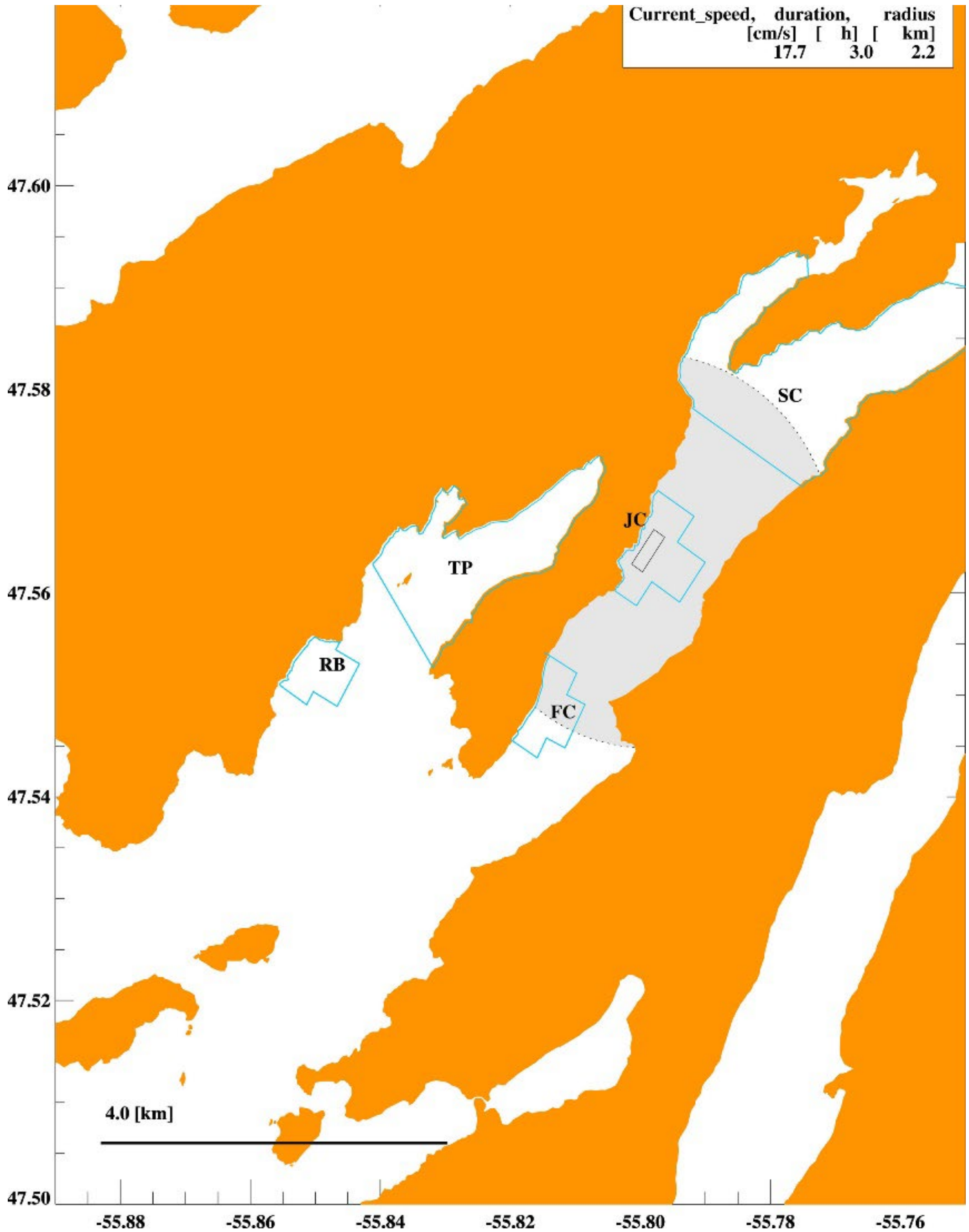

Figure 6: Pelagic-PEZ (shaded grey area) for the proposed June Cove site. Net-pen arrays (grey lines) within lease boundaries (light blue polygons) are shown. Rattling Brook (RB) and Fish Cove (FC) are existing finfish licenses, The Pocket (TP) and Salmonier Cove Connaigre Bay (SC) are shellfish licenses.

Susceptible Species Interactions

Species are considered susceptible within the pelagic-PEZ if they are known to have sensitivities to pesticide exposures. Specific consideration must be given to the potential for interactions with crustaceans due to their higher relative susceptibility to the pesticides used. Survey data indicate, as stated above, that shrimp, crabs, and krill are present within the pelagic-PEZ for pesticides. Due to their cryptic nature, American Lobster are difficult to detect via the survey, however due to the suitable habitat (i.e., bedrock, cobble, kelp, mud and silt) and presence of a commercial fishery, they are expected to also occupy the PEZ.

Azamethiphos is known to be toxic to crustaceans (e.g., Burridge 2013, PMRA 2016b, 2017). Recent acute toxicity studies have included hydrogen peroxide and azamethiphos and have documented morbidity and mortality effects on a variety of shrimp species (Bechmann et al. 2019, Escobar-Lux and Samuelsen 2020, Mill et al. 2022, Hamoutene et al. 2023b). This risk might be more prevalent for the pelagic stages of the crustacean lifecycle but there is also a risk of exposure to benthic stages (newly settled instars, juveniles, or adults) to toxic concentrations of pesticides that may come into contact with the seabed in the shallow areas of the pelagic-PEZ.

While there are limited toxicity studies directly related to crabs (Hamoutene et al. 2023b), predicted impacts are similar to those on lobster and shrimp given the targeted mode of action of substances like azamethiphos. In addition, tests for both pesticides have documented delayed effects on crustaceans (shrimp and lobster larvae) at concentrations that are lower than recommended treatment concentrations (Bechmann et al. 2019, Escobar-Lux and Samuelsen 2020, Escobar-Lux et al. 2020, Parsons et al. 2020). Although dilution is a factor for the use of pelagic pesticides, active ingredients such as azamethiphos and hydrogen peroxide are proven to be more stable in the formulations used which contain additives, and therefore may lead to prolonged exposures for non-target crustaceans.

Exposure to pesticides could threaten commercial lobster and Snow Crab at all life stages (throughout the pelagic-PEZ). Concern about pesticide exposure for lobster is greatest at shallow sites with lower dispersion patterns and higher juvenile lobster prevalence (Lawton and Lavalli 1995).

Due to risks to seabed crustaceans, the PMRA guidelines restrict azamethiphos usage at shallow sites (i.e., no application to tarped net pens in water depths ≤10 m). In addition, any crabs that are in shallow areas are at risk of exposure to pesticides that come into contact with the seabed. A better understanding of the pelagic-PEZ concentrations and timing of dispersion in shallow areas of the bay remains a priority to better characterize risk.

It was noted that pesticides may have negative impacts on commercial crustaceans even in non-lethal exposure events. Behavioural changes, including reduced female reproductive success, have been reported after lobster exposure to sub-lethal doses of sea lice pesticides (Burridge 2013). Research conducted in New Brunswick also found that sub-lethal pesticide exposure resulted in higher shipping mortality for lobsters, raising market concerns (Couillard and Burridge 2015). A recent study found no impact of salmon aquaculture on lobster abundance through an eight year before-after-control study at a production site in the Bay of Fundy (Grant et al. 2019).

There are few studies on the potential effects of pesticides on mussels. An earlier study conducted in 2007 shows that azamethiphos can modulate haemocyte function and immune defense in *Mytilus edulis* at environmentally relevant concentrations after only a few hours (Canty et al. 2007). More recent work on exposure with the giant mussel *Choromytilus chorus* larvae suggest that azamethiphos can modulate the transcriptome signatures related to early development (Núñez-Acuña 2022).

Bivalve mollusks important from a fishery and aquaculture perspective in the area may be affected within the pelagic-PEZ. For example, other areas where aquaculture operations exist have shown evidence of lower meat to shell ratios (lower meat quality) and thinner shells in scallop (Wiber et al. 2012).

The potential threats of pesticides as they disperse throughout the water currents on large pelagic fish are unknown. However, there are concerns that the use of invertebrate pesticides targeting sea lice at aquaculture sites may kill off copepods and other invertebrates that are the prey of many pelagic species and early life stage organisms.

Physical Interactions

Groundfish Species Interactions

There is evidence from multiple studies in both Newfoundland and elsewhere showing that the presence of Atlantic Salmon aquaculture is likely to alter the spatial distribution of wild fish with many types of gadoids, including Atlantic cod, being attracted to finfish aquaculture sites by their excess feed (Dempster et al. 2009, McAllister et al. 2021). Work by Goodbrand et al. (2013) in Fortune Bay, NL found that an acoustic index of the biomass of biological organisms in the water column was two to three times higher in bays with aquaculture sites compared to those without. Further, work by McAllister et al. (2021) collected juvenile and adult cod and Redfish that were present at aquaculture sites in Fortune Bay, NL, and, using stable isotope and terrestrial-based fatty acid analysis, found evidence suggesting that juvenile cod were receiving an energy subsidy from the farm. The data for adult cod and Redfish suggested that they were not receiving an energy subsidy. In Norway, Atlantic cod and other gadoids were often found aggregated in the water column directly adjacent to and below aquaculture nets (Uglem et al. 2014, Callier et al. 2018). The fish biomass aggregated around aquaculture sites included a mix of gadoids including cod and was generally on the order of 10s of tonnes of fish.

Fish aggregating adjacent to the nets potentially represents a vertical shift in the spatial distribution of cod as the maximum depth of the proposed aquaculture nets is 37 m while Lawson and Rose (2000) found that the median depth of cod was 60 m in April and as high as 38 m in October. Shifts in the vertical distribution of cod may alter the temperature regimes they are exposed to which could have metabolic effects on the cod as metabolic processes tend to increase at higher temperatures (to some maximum temperature at which point metabolic rates slow and may end in death) which could alter growth rates (Baudron et al. 2014, Gillooly et al. 2001).

Cod are known to consume aquaculture feed (Dempster et al. 2009, McAllister et al. 2021), and this has the potential to affect the quality and taste of cod; there have been anecdotal reports by Newfoundland harvesters of cod from bays with aquaculture facilities having soft flesh and undesirable flavour. Changes in distribution due to cod being attracted to cages may also impact the availability of cod to harvesters. Aggregations of cod around aquaculture activities may also increase density-dependent impacts on the local population (e.g., increased predation, cannibalism) which may have implications for natural mortality on this stock. This is of particular concern for Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps cod as the stock is currently in the Critical Zone and is experiencing high natural mortality.

There is a potential that larval cod could be transported by local currents into the proposed salmon pen from surrounding areas which would have increased predator densities due to the presence of farmed fish in the pens and juvenile and adult fish that are attracted to the pens. Larval fish experience extremely high mortality rates and even small changes in their growth and mortality rates (e.g., due to reduced availability of prey and/or increased predation) can have tenfold or greater effects on their recruitment (Houde 1987).

Pelagic Species Interactions

Pelagic species data in Connaigre Bay are moderately limited; there is a lack of biomass estimates for Capelin (*Mallotus villosus*), mackerel (*Scomber scombrus*), and herring

(*Clupea harengus*). Though biomass data for Capelin are not available, it is known that Capelin are seasonally abundant in Connaigre Bay from the spring through fall, initially as spawning adults, and then later as eggs and larvae. There may also be overwintering populations of juvenile Capelin in the bay (Bourne et at. 2018). Though biomass data for mackerel in the Connaigre Bay are not available, it is known that mackerel use Newfoundland waters seasonally during summer and fall.

Aquaculture facilities promote the growth of phytoplankton and potentially zooplankton (Suikkanen et al. 2013) through eutrophication due to increased nutrient loads (Bonsdorff et al. 1997, Callier et al. 2018). Increasing nutrient loading rates to Newfoundland's coastal bays in combination with climate change has the potential to lead to coastal eutrophication and the formation of coastal hypoxic zones (Justić et al. 1996, Laurent et al. 2018). These zones are known to impact benthic productivity and could affect the survival of the eggs and larvae of pelagic fish, depending on the water column structure of hypoxic zones and the vertical distribution of eggs and larvae (Breitburg et al. 2003, Adamack et al. 2012).

The presence of elevated phytoplankton and zooplankton concentrations may serve to aggregate pelagic fish such as herring in bays with salmon farms. Additionally, any lighting used at the aquaculture facility (e.g., for navigation or security purposes) may act to concentrate zooplankton, larval fish, and adult herring to the waters surrounding the facility (Stickney 1970). Use of lighting at night, particularly when larvae are abundant, may expose larval herring and Capelin to increased predation rates as they are drawn to the lights (Stickney 1970, Keenan et al. 2007) which are also areas with higher predator concentrations (both wild fish and farmed salmon).

The aggregation of both piscivorous fish and small pelagic forage species is likely to result in increased mortality rates of the latter (versus their spatial distribution when not aggregated by attraction to salmon farms). Effects are likely to be greater on herring than Capelin and mackerel as herring may be present year-round in coastal waters (Bourne et al. 2018) while Capelin spend much of their lives in deeper offshore waters (Mowbray et al. 2019) and mackerel migrate to Newfoundland waters on a seasonal basis (Parsons and Hodder 1970). However, all three species have the potential for increased predation pressure on early life-stage individuals if they pass through waters occupied by fish farms. Work on farmed Atlantic Salmon in British Columbia (BC) has shown predation incidence rates of 0.14% (Hay et al. 2004, Johannes and Hay 2006).

Aggregation of fish by aquaculture facilities may also promote the spread of disease and parasites to and from wild fish stocks .The development of new sites has the potential to increase the ease of spread of diseases between aquaculture sites as it shortens the travel distance/time between sites for wild fish who may move frequently between farm sites (Uglem et al. 2009). The spread of disease is of particular concern as there have been more than 50 incidents of infectious salmon anemia in Newfoundland waters since 2012[2] although 18 of the outbreaks involved strains that were not known to cause disease. However, the impact on wild susceptible fish species will depend on the duration and extent of their exposure to the proposed site, the increased concentration of pathogens and parasites, and their relative susceptibility to infection and disease within the environmental conditions found in the area.

Due to the positioning of the proposed cages adjacent to coastline, the relative position of the water column occupied by pelagic forage fish, and their high relative abundance in the ecosystem, it is likely that they will move past or interact with salmon aquaculture cages during their production cycles. Some research indicates infectious salmon anemia (ISA) virus is able to propagate in Atlantic herring and they may be an asymptomatic carrier of the virus (Nylund et al.

[2] Canadian Food Inspection Agency. Locations infected with infectious salmon anaemia.

2002). Herring are known to move between bays and offshore areas, traveling tens or hundreds of kilometres (Wheeler and Winters 1984).

Recent work by Bouwmeester et al. (2021) identified several potential means by which farmed fish populations may affect the disease dynamics of wild fish stocks. Specifically, farmed fish may co-introduce parasites to the new environment which may infect conspecifics and may or may not infect other wild species, potentially leading to emerging disease. Farmed fish may play host to parasites from wild host species, with the potential to amplify parasite numbers and increase the frequency of parasite infections in wild hosts when the parasite infections spill back to wild populations. Finally, the presence of farmed fish has the potential to alter the transmission of parasites between wild host species, potentially altering wildlife disease dynamics. Collectively, these effects of farmed fish populations have the potential to degrade fish health in an ecosystem through increased rates of disease and parasitism.

Salmonid Species Interactions

There are 55 Atlantic Salmon rivers along the southwest coast of Newfoundland (43 in Salmon Fishing Area [SFA] 11, 12 in SFA 12), three of which have been monitored in recent decades. Connaigre Bay is in SFA 11. Atlantic Salmon returns to Little River averaged 235 salmon annually (range: 47–801) from 1987–2016 but did not exceed ten fish annually from 2017–20 (DFO 2022c). Over the previous three generations (2006–20), adult Atlantic Salmon returns to Little River have declined by 98%. Total returns to Conne River ranged from 8,047–10,671 salmon from 1986–88 and have been on a declining trajectory ever since. Consecutive record low adult Atlantic Salmon returns to Conne River were recorded from 2017–20 (DFO 2022c) and did not exceed 710 salmon each year. In 2021, total returns to Conne River were the second lowest in the time series, 71% below the previous generation average (2015–20), and 85% below the previous three generation average (2004–20). Atlantic Salmon returns to Garnish River (Fortune Bay) have been monitored since 2015 and averaged 445 salmon annually from 2015–21 (range: 155–885). Since 2015–16, all three populations have been consistently assessed in the Critical Zone.

There have been longstanding population declines of wild salmon in southern Newfoundland (SFA 11), that are counter to other regions of the province. This trend is against a backdrop of continued escape events, documented hybridization with escapees, reported disease outbreaks, and increased need for sea lice control measures, all of which have documented negative impacts on wild salmon populations. Two of the rivers where smolts are counted and marine survival is estimated are in SFA 11 (Conne River and Garnish River) and both show poor marine survival in recent years (<3% since 2018 and <1% in 2020) relative to the other three populations DFO monitors in a similar fashion (DFO 2022c). At Western Arm Brook, Campbellton River, and Rocky River, mean marine survival rates over the past 10 years range from ~5–9% across rivers.

Both past commercial salmon catch data and tag returns indicate that salmon from all over the south coast and Atlantic Canada are present in the region of southern Newfoundland. Reddin and Lear (1990) describe the tag returns from the commercial fishery. Salmon tagged in locations like St. Lawrence (1973), Placentia Bay (1975), and throughout the east coast were recaptured across the south coast (e.g., Burgeo, Port aux Basques) and throughout the Maritimes (Reddin and Lear 1990). This is further substantiated by the historical data on commercial and recreational catches in southern Newfoundland (May and Lear 1971, Lear 1973, Reddin and Short 1981, Ash and O'Connell 1987). Recent genetic data from the St Pierre-Miquelon mixed stock fishery analysis (ICES WGNAS 2020 Report) was dominated by contributions from Gulf and Gaspe Peninsula regions and had a smaller contribution from the northeast coast of Newfoundland. It is likely that individuals from southern Newfoundland populations, and from elsewhere, migrate through this area on a regular basis and will be exposed to cage sites both as migrating smolts and returning adults. Pathogens and parasites can potentially be transmitted to migrating fish and represent a significant source of potential impact.

Pests and Pathogens

Marine finfish aquaculture conducted in net pens have no barriers to pathogen and pest exchange with the environment. Water flows freely through the net pens and potential pathogens may come in contact both with wild fish and other farmed fish populations (Johansen et al. 2011).

A substantial and growing body of research (Dionne et al. 2007, 2009, Tonteri et al. 2010, Consuegra et al. 2011, Kjaerner-Semb et al. 2016, Pritchard et al. 2018, Zueva et al. 2018, Lehnert et al. 2020) indicates that wild salmon populations are adapted to common pathogens and that the introduction of new pathogens could drive population decline. Several recent studies in Europe clearly document evidence supporting the transfer of pathogens from aquaculture to wild salmon (Garseth et al. 2013, Madhun et al. 2015, 2018, Nylund et al. 2019).

Information about pests and pathogens on salmon farms in NL is limited to regulatory and licensing public reporting requirements. The Government of NL licensing requirements for incident reporting are outlined in its ‘Aquaculture Operator Incident Reporting Guidelines’, and state reporting requirements for abnormal mortality, disease events, and suspected or confirmed escapes. Aquaculture operators fulfill these requirements with industry statements posted on the Newfoundland Aquaculture Industry Association (NAIA) website. Further to this, as a condition of licensing, aggregated monthly sea lice abundance numbers must be reported publicly, and the website is used to satisfy this requirement.

The Government of NL Aquatic Animal Health Division published a one-page aquatic animal health summary[3] providing a brief description of the audits and site visits on aquaculture leases in NL. The summary included diseases, Canadian Food Inspection Agency (CFIA) reportable viruses, and parasites identified during the aquatic animal health inspections conducted in 2015, plus a list of 20 diseases historically detected in NL wild and farmed finfish.

Reportable diseases

Of significant importance to aquatic animal health are reportable diseases. Individuals, organizations, and businesses who own or work with aquatic animals and know of or suspect a reportable disease is required by law to notify the CFIA. To date, two such diseases have been reported in finfish in Newfoundland: infectious salmon anemia virus (ISA; total of 25 entries) and viral hemorrhagic septicemia (VHS; total of 3 entries; CFIA 2021a, 2021b).

ISA is considered endemic in Atlantic Canada and is commonly detected in marine Atlantic Salmon aquaculture at levels not known to cause disease (non-virulent; DFO 2020a). There has been at least one confirmed case of virulent or non-virulent infection annually between 2012–21 in Newfoundland Atlantic Salmon (CFIA 2021a). This includes the recent positive detection of ISA in two fish on an Atlantic Salmon farm along the south coast of Newfoundland that required removal of fishes raised in the same cage to mitigate the risk of viral spread (ASF 2020).

Infections with VHS virus (VHSV) have been reported in over 80 species including Salmoniformes (salmon, trout, whitefish; Garver and Hawley 2021). Despite VHSV’s capacity to infect a broad range of hosts, not all species are universally susceptible to all genotypes of VHSV (Garver and Hawley 2021). In Newfoundland since 2013, some Atlantic herring have

[3] Aquatic Animal Health Division, Government of Newfoundland and Labrador website (accessed Jan 6, 2023).

been confirmed to be infected with VHSV in at least one instance in each of three years (2016, 2019, and 2020) and there have been no detections reported in Atlantic Salmon (CFIA 2021b). Due to the positioning of the proposed cages, the relative position of the water column occupied by herring, and the relative abundance of herring in the ecosystem, it is likely that wild herring will swim past or interact with cages during the production cycle and potentially increase the transmission of the virus.

Sea lice

Salmon lice are small, naturally occurring ectoparasites that can pose a significant health risk to farmed and wild Atlantic Salmon when present at certain host density threshold levels (Krkosek 2010). The prevalence and abundance of *Lepeophtheirus salmonis*, the most common sea lice infesting farmed Atlantic Salmon (Saksida et al. 2015), vary based on the origin of fish (i.e., farmed versus wild). Sea lice can spread from farm to farm and from farmed to wild salmon; the effects of sea lice infestation on wild salmon population productivity and the consequent control management for salmon aquaculture have been the subject of many studies in recent decades (Brooks 2009, Krkošek et al. 2011, Torrissen et al. 2013).

Wild salmon smolt survival can be impacted by exposure to sea lice. Migrating smolts have been shown to have reduced one sea-winter returns to natal rivers and a shift in relationships between ocean climate and returns. Rivers showed lesser returns in years following high lice levels on nearby salmon farms (Shephard and Gargan 2021). The magnitude of wild population decline in years of sea lice outbreaks in salmon farms has been reported to be between 12–50% (Shephard and Gargan 2017, Thorstad and Finstad 2018). Moreover, prophylactically treating migrating smolts for sea lice resulted in a 55 times higher likelihood of survival (Bøhn et al. 2020). Although no data exists on sea lice-induced mortality in Connaigre Bay, the addition of 1,000,000 farmed fish to the bay can reasonably be expected to amplify both endemic pathogens and sea lice in the area, due to the increased abundance of host fish.

Aquaculture Escapees

Genetic studies over the last decade have documented widespread hybridization between wild salmon and aquaculture escapees both in southern Newfoundland and the Maritimes (Holborn et al. 2022, Keyser et al. 2018, Sylvester et al. 2019, Wringe et al. 2018). The magnitude of genetic impacts due to escaped farmed Atlantic Salmon on wild populations has been correlated with the biomass of farmed salmon in nearby cages. Recent work in the region suggests that smaller populations in accessible rivers may be most at risk (Sylvester et al. 2019). In southern Newfoundland, the precocial maturation of male wild-farm hybrid parr has been documented, likely fast-tracking introgression (i.e., transfer of genetic material from farmed escapees to wild populations) and subsequent genetic impacts (Holborn et al. 2022). Overall, research over the last decade indicates that genetic impacts of farmed escaped salmon are present in southern Newfoundland, though significant uncertainty exists as to the magnitude. In the context of site evaluation, the use of European origin salmon or individuals with European ancestry adds significant uncertainty and could elevate the potential impact of escapees on wild populations (Bradbury et al. 2022).

The distribution of escapees in the wild under the proposed production regime (existing and proposed expansion) were modelled using a spatial model of dispersal and survival (Bradbury et al. 2020). Model predictions for individual rivers were evaluated against a 10% threshold for the proportion of escapees relative to wild population size, above which demographic decline and genetic changes have been predicted in wild populations (Bradbury et al. 2020). Wild population sizes were estimated based on habitat area and corrected for recent population declines through comparison with recent data. For the adjacent Bay d'Espoir region, an 80% decline was used following counting fence trends in the region. For the rest of DU 4b (west of

Garnish) a 60% decline correction was applied based on angling statistics. The number of expected escapees per unit production was estimated using both Norwegian (2011–21) and Newfoundland data on licensed maximum production and escape events as ~0.2 escapees per tonne production and compared with a corrected value (i.e., 0.4) for unreported escape events following Skilbrei et al. (2015). The model accounts for periods of fallowing and production losses as stated by the Proponent, and assumes a 5 kg harvest weight.

June Cove is in the Southern Newfoundland West DU and closest to known salmon rivers in Bay d'Espoir and Bay de l'Eau. The recent detection of significant (exceeding 10%) European ancestry in 21% of samples (n=189) of escaped smolts from a freshwater site in Long Pond in 2021 elevates the uncertainty and risk to wild populations from this activity. Escapee dispersal simulations suggest that there would be a 2% increase in the number of escapees present in the region associated with the proposed site. Overall, 53% to 60% of salmon rivers in the Southern Newfoundland West DU are predicted to exceed 10% escapees (i.e., 0.2 or 0.4 escapees per tonne, Figure 7). The maximum values for the proportion of escapees are predicted to occur within rivers in the head of Bay d'Espoir, including Conne River, where predictions suggest the percentage of escapees are 37–54% depending on the level of escapees (i.e., 0.2 or 0.4 escapees per tonne, Figure 7). The majority of escapees from the proposed site (i.e., 60%) are predicted to occur in five rivers in Bay d'Espoir and Fortune Bay. At the Regional (i.e., DU) level, the proportion of escapees exceeds the cautionary threshold of 10% and is predicted to be 11% and 20% at 0.2 and 0.4 escapees per tonne production, respectively. This is consistent with significant genetic impacts present in the region.

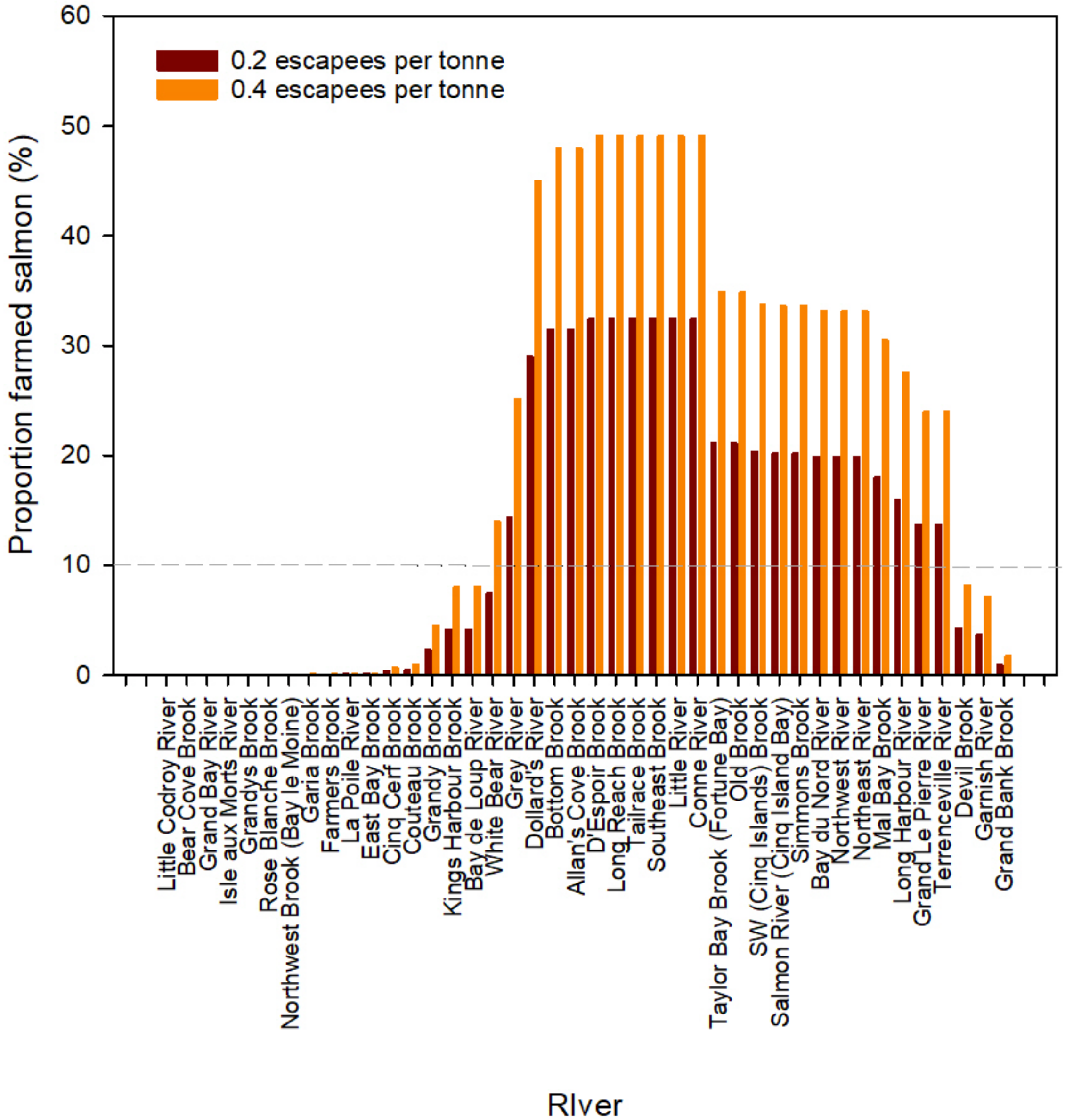

Figure 7: Predicted proportion of escaped farmed salmon in rivers of southern Newfoundland relative to wild population size with the inclusion of the June Cove site. Brown bars indicate simulations using 0.2 escapees per tonne production and orange bars indicate 0.4 escapees per tonne production, see text and Bradbury et al. 2020 for details. The horizontal dashed line represents 10% threshold above which demographic and genetic impacts are predicted.

The proposed plan for this site does not include any evaluation of containment success through an escapee monitoring and/or provision for an escapee traceability program. Without these components, there are no data to evaluate containment success. The use of counting fences to monitor for escapees is included for other sites and it is unclear why similar requirements were not made here, particularly given the detection of European ancestry (see below). Furthermore, a traceability program to identify a farmed fish via genetic markers from a tissue sample would be important and has recently been implemented in Norway. There also remains significant uncertainty as to the presence and magnitude of indirect genetic or ecological impacts resulting from both existing sites and the proposed site.

European ancestry

Recent analysis has used population genomics to explore the presence of European introgression into North American farmed and wild Atlantic Salmon (Bradbury et al. 2022). This study demonstrated that both contained and escaped farmed salmon sampled in Atlantic Canada had a portion of their DNA attributable to recent interbreeding with European-origin domestic salmon. In addition, two escaped farmed salmon were detected with 100% European ancestry (Bradbury et al. 2022). In NL, European genes were detected in wild salmon sampled in areas around aquaculture sites (e.g., Conne River), indicating the source to be aquaculture escapees with European genes that have interbred with wild Atlantic Salmon. These results demonstrate that even though diploid European salmon have never been approved for use in Canada, individuals of full and partial European ancestry have been in use over the last decade, and that some of these individuals have escaped and hybridized in the wild (Bradbury et al. 2022).

Recent analysis of samples of salmon which escaped from the Proponent's Long Pond (net pen nursery) site in southern Newfoundland in the summer of 2021 indicate evidence of significant European ancestry. Overall, 21% of the 189 fish analyzed displayed more than 10% European ancestry. European salmon have been shown to differ significantly from North American salmon across a variety of important genes and traits (Lehnert et al. 2019, 2020), thus this observation significantly elevates the risk to wild salmon populations if individuals escape and interbreed, as has been demonstrated (Bradbury et al. 2022). In other jurisdictions (e.g., Maine), pre-screening of fish for European ancestry prior to transfer to sea cages is required and such efforts could be used to mitigate these impacts in southern Newfoundland as well. DFO has developed a new screening tool of genomic markers chosen to provide accurate identification of European ancestry.

Cleaner Fish Escapees

Cleaner fish such as wrasse and Common Lumpfish (*Cyclopterus lumpus*) are increasingly used in aquaculture as a biological control for sea lice in other countries, such as Norway (Blanco Gonzalez and de Boer 2017) and Ireland (Bolton-Warberg 2018). In Atlantic Canada, the industry has begun using Common Lumpfish as cleaner fish in salmon aquaculture. The Proponent includes this in their application for the proposed site. However, as with Atlantic Salmon, research suggests genetic interactions between escaped cleaner fish and wild populations warrant consideration as negative impacts are likely (Blanco Gonzalez et al. 2019, Faust et al. 2018, 2021). DFO-NL spring multispecies surveys in Subdivision 3Ps indicated declines in Lumpfish abundance of about 58% between 1996 and 2014 (Simpson et al. 2016). Accordingly, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated Common Lumpfish as Threatened in Canadian waters in 2017 (COSEWIC 2017). Although Lumpfish in Canadian waters were assessed as a single DU (COSEWIC 2017), recent genetic analysis (Ian Bradbury, pers. comm.) suggests the presence of a distinct northern population which includes southern Newfoundland, and further structuring within that group around the island of Newfoundland. There remains considerable uncertainty with regards to the potential impact of the proposed expansion on local Common Lumpfish populations. However, given the status of this species in the region, and evidence of negative genetic impacts of cleaner fish on wild populations elsewhere, the potential exists for negative interactions in southern Newfoundland.

Entanglements

Entanglement of megafauna (e.g., wild fish, marine mammals, turtles, and sharks) associated with the placement of infrastructure is another potential interaction associated with aquaculture sites. Entanglement can cause drowning, direct injury from ropes and nets, fatigue, and starvation. Interactions that result in the death of megafauna have reduced dramatically over the past two decades due to improved anti-predator netting, improved anchoring, and the prompt removal of attractants, such as dead fish (DFO 2022d).

Whales

There is a lack of information regarding the distribution of marine mammals in the aquaculture lease area under review as few scientific surveys have been completed in the coastal, sheltered area of Connaigre Bay. In this situation, Local and Traditional Ecological Knowledge collected from consultations would be valuable to assess the potential for entanglements. There is overlap with the distribution of several species of whales (Blue Whale, Fin Whale, Humpback Whale, Minke Whale, Sei Whale, North Atlantic Right Whale, Sperm Whale), several species of dolphins, and Harbour Porpoise. Based on opportunistic and systematic sightings data, these cetaceans can occur in Newfoundland waters year-round with seasonal peaks in abundance occurring typically in summer and fall.

Data on cetacean entanglement associated with aquaculture infrastructure are largely not available in Canada. BC provides data on marine mammal fatalities at marine finish aquaculture sites from 1990 to 2022 (DFO 2022d). From 1990 to 2015, there were two reports of cetacean fatalities that included one Harbour Porpoise and one Humpback Whale found dead at an aquaculture site, but cause of death was unknown. Between 2016 and 2021, there were five reported Humpback Whale entanglements at aquaculture sites in BC, and two of these entanglements were fatal. DFO (2022d) noted that Humpback Whales, like other baleen whales, are more prone to entanglement because they do not use echolocation for navigation and have become more numerous in BC coastal waters in recent years. In Newfoundland there have not been any reported cetacean entanglements with finfish aquaculture net pens to date; however, in 2018 a Humpback Whale was entangled in a gillnet deployed to capture escaped farmed salmon in Hermitage Bay. It was freed later the same day.

Seals

Seal species such as Harbour Seals (*Phoca vitulina*) and Grey Seals (*Halichoerus grypus*) occur in Connaigre Bay regularly and may have haul-outs in the lease area, particularly near islands and rocks. Compared to cetaceans and sea turtles, the risk of entanglement may be higher for pinniped species that may be attracted to the cage netting for potential prey. Harbour Seals occur year-round while Grey Seals are seasonal visitors that arrive in late spring and depart in late fall.

Similar to cetaceans, data on pinniped entanglement associated with aquaculture infrastructure are largely not available in Canada. In BC, the most common marine mammal fatalities at aquaculture sites were Harbour Seal and California Sea Lion (*Zalophus californianus*); however, the vast majority are authorized fatalities that were permitted prior to March 2020. DFO (2022d) publicly provided data on marine mammal fatalities (authorized and accidental) for 2011–22. Over that period, 78 authorized fatalities and 50 accidental drownings were reported for Harbour Seal. In Newfoundland, there have not been any reported pinniped entanglements with finfish aquaculture net pens to date.

Turtles

Leatherback and Loggerhead Sea Turtles are known to frequent Newfoundland waters during summer and fall to forage, but do not nest in Canada. Leatherback Sea Turtles can be found to frequent inshore waters, with nearby Placentia Bay being identified as containing important habitat for the species (DFO 2012, Wells et al. 2019). Loggerhead Sea Turtles typically occur offshore along the continental shelf break and beyond, from Georges Bank to the southern Grand Banks in summer (DFO 2020b) and are not expected to occur in the proposed aquaculture lease area. In Newfoundland there have not been any reported turtle entanglements with finfish aquaculture net pens to date. While entanglement and subsequent drowning are concerns, the risk of entanglement is considered low at the proposed site.

Sharks

White Shark move into Canadian waters seasonally, including the south coast of Newfoundland and Connaigre Bay, predominately in shallow waters (<50 m) and mesopelagic depths (200–500 m). The potential attraction and entanglement of large pelagic fish to sea cages (e.g., tunas and sharks) has been documented previously, and an increased presence of White Sharks has been observed along the south coast in recent years. White Sharks are opportunistic predators, feeding on a variety of prey, hence the potential for entanglement of White Sharks to sea cages cannot be disregarded. However, the presence of White Sharks in coastal Newfoundland waters is deemed rare, and the pelagic habitat occupied by the species is extensive (i.e., Ocean Basin scale), suggesting that any impact resulting from the proposed aquaculture activities at species or population levels, and their habitat, is negligible. To date, there have been no reports of White Shark entanglements in marine finfish aquaculture gear in Atlantic Canada.

AAR Guidelines

DFO Science suggests more prescriptive Regional guidelines to be implemented in the AAR, in order to improve the information being provided by the Proponent. These guidelines should include:

- Collection of temperature and salinity profiles at the site of interest during the expected maximum feeding season and for the whole water column, as well as dissolved oxygen (DO) within the upper layer. Collection of ocean current observations at the site of interest, preferably using a current profiler, or, if using single point instruments, at depths representative of the water structure (i.e., water masses) during the expected maximum feeding season for at least 3 months. This would provide the necessary information for a depositional model to be run with reasonable confidence. Ideally, a full year of temperature, salinity, and current profiles collected at the site of interest, would provide a more complete picture and lead to more reliable estimates.
- Provision of a suitable model description including variable input details, justified site-specific depths of current series input (if the model requires such depth to be provided; e.g., DEPOMOD), and the use of a complete range of settling velocities (note: fraction loss on the slowly settling flocs might need to be determined).
- Provision of a climatological representation of temperature conditions that occur at the site of interest, if available, or for the Region where the site is located, to ascertain potential risks of extreme temperature events (e.g., consultation of DFO Marine Environmental Data Section archive).
- Provision of an estimate of oxygen demand from the cage/farm and its environmental availability (e.g., using DO measurements over the course of a year). This would provide a

carrying capacity estimate to frame more robust mitigation measures in case of heat waves/low availability of DO.

- Provision of an estimate for nutrient loading (nitrogen and phosphorous) from the proposed site.
- Provision of a description, which can be based on available literature, of potential site/Region specific risks associated with climate change.

It is also suggested that DFO request, archive, and make available the physical environment data for each site application (including the review) to increase transparency and social acceptance.

SOURCES OF UNCERTAINTY

Oceanographic Data and Model Output

The PEZs are computed based on water current data provided by the Proponent. The Proponent measured the ocean current using a current profiler. However, the instrument was moored at a depth not covering the whole water column found within the lease area and as such, these data are a subsample of the whole collected profile. Further, current measurements were only collected for one part of a season (less than 40 days); this does not allow for the assessment of seasonal variability of the deposition. The first-order PEZ calculation assumes that the current is spatially homogeneous and seasonally consistent. This may affect the estimates of exposure, deposition zones, and intensities over the area of interest and over the period of a year. Validation and sensitivity analysis of the transport and deposition models is ongoing for the NL Region. Uncertainties regarding the estimated deposits can be important; they are unknown for the Proponent’s dispersion results.

In terms of modeling the deposition, the Proponent used AquaModel to examine the near field deposition around an aquaculture farm. The input parameters used by the Proponent to compute deposition are consistent with present scientific understanding of feed and fecal sinking rates, feed wastage rates, fish, net pen size, etc. However, no validation of this model has been carried out in Newfoundland and more studies are required to evaluate its use for Newfoundland deep water conditions.

Potential effects of climate change are not presented; these could be important with respect to mass mortality risks (e.g., summer heat waves, winter superchill events, the susceptibility of the system to the formation of hypoxic zones). It could also be important with respect to potential pest and disease outbreaks (e.g., sea lice).

Cumulative Effects

DFO’s Fisheries and Aquaculture Management (FAM) has been identified by Murray et al. (2020) as an area that would benefit from cumulative effects research and assessment due to its broad application to resource management decisions and policy development. While this science review is focused on the siting of a new aquaculture site in Connaigre Bay, it is important to note that the addition of this site is not happening in isolation. There are numerous other human activities happening in the ecosystem and its surrounding watersheds, including other finfish aquaculture sites, which all have some effect on the ecosystem. Additionally, there are broad-scale processes affecting the ecosystem including global climate change and ocean acidification. The interactions between many of these effects can be multiplicative, which may result in seemingly minor perturbations having disproportionately large impacts on the ecosystem.

Connaigre Bay hosts two small communities, Hermitage-Sandyville and Seal Cove. There are a number of human activities in the bay including a shellfish aquaculture site; commercial and recreational inshore fisheries for lobster, Snow Crab, scallops, and trout; and recreational boating. Connaigre Bay is designated as BMA 6 and the proposed salmon aquaculture site at June Cove would be stocked in conjunction with two existing salmon aquaculture sites (Fish Cove and Rattling Brook). Upcoming BMA 6 year classes will be added to pens in 2024, 2027, and 2030 and will remain in them for 17–19 month grow out periods.

A mussel farm is located adjacent to the proposed June Cove site, near the head of the bay. The mussel farm waters are classified under the Canadian Shellfish Sanitation Program (CSSP). Water classification in the outer areas of the farm are open to harvest, but closed in the upper head of the bay, where there is a stream, as well as cabins and campers. These activities are generally associated with the following pollution sources: regular discharges of sewage, nutrients, and emissions; potential for residual therapeutants; abandoned, lost or otherwise discarded fishing gear (ALDFG); and risk for hydrocarbon spills. Nutrient pollution is a global problem in coastal waters (Cloern 2001, Breitburg et al. 2018) as excess rates of nutrient loading can lead to coastal eutrophication, and in many cases the formation of seasonal or year-round hypoxic and anoxic zones. This is already an issue in some estuaries in the Southern Gulf of St. Lawrence (Thibodeau et al. 2006, Schein et al. 2013). There is the potential for global climate change to exacerbate the effects of coastal eutrophication through higher water temperatures which may strengthen stratification and increase the inflows of freshwater and nutrients to coastal waters (Rabalais et al. 2009). While low levels of eutrophication can be beneficial, potentially leading to increased production of phytoplankton and potentially zooplankton (Cloern 2001, Suikkanen et al. 2013), at higher levels it can be quite destructive to marine ecosystems and can be very costly to deal with (Breitburg et al. 2018).

The level of nutrient loadings from aquaculture facilities requires discussion. In the Åland Archipelago in Finland, 35–40 fish farms producing ~5,000 tonnes of year-1 Rainbow Trout produced nutrient loads comparable to the amount of treated wastewater from a city with ~370,000 people for phosphorous and ~90,000 people for nitrogen (Bonsdorff et al. 1997, Strain and Hargrave 2005). This is in addition to the already existing nutrient loads from sewage discharge, the by-products from fish processing, and existing salmon and shellfish aquaculture facilities in the bay's watersheds.

Estimating/modelling the expected amount of phosphorous and nitrogen, on both a seasonal and annual basis, that will be released by aquaculture farms in a Newfoundland context and examining their potential impacts on oxygen demand is an essential part of understanding the potential impacts of this activity in the Region. To try and avoid the potential for ecological damages from eutrophication and the potential formation of dead zones (volumes of water with low levels of oxygen, typically less than 2–3 mg L-1), conducting a water quality modeling analysis could be considered to determine Connaigre Bay's capacity for additional nutrient loading.

The computed PEZs do not include zones that might be exposed by other previously requested sites in the same BMA. A combined analysis would be necessary should multiple sites in the same BMA be simultaneously active. Although there is some indication of benthic fauna recovery/partial recovery from the fallout of aquaculture activities (Macleod et al. 2004, Lin and Bailey-Brock 2008, Aguado-Giménez et al. 2012, Zhulay et al. 2015), there is also evidence of incomplete (Salvo et al. 2017) or little recovery of benthic diversity even after extended periods of time (Verhoeven et al. 2018). Sediment geochemical recovery in soft bottom areas is another concern for sites whose benthic-PEZ zones overlap spatially. However, the amount of effect magnification is not known and likely varies spatially and temporally.

Intertidal zones near the proposed aquaculture site are expected to be impacted by the proposed site through multiple pathways. As both the benthic- and the pelagic-PEZ include the coastline adjacent to the site, they are expected to be exposed to waste feed, fecal material, and pesticides coming from the aquaculture site. Additionally, the Proponent notes in the proposal that the shorelines adjacent to the aquaculture are likely to receive debris from the facilities (e.g., rope, netting, other gear and debris), despite their efforts to minimize it. While they intend to mitigate this by periodic shoreline clean-ups, this may not result in the removal of debris that settles below the water line.

Other Considerations

Another concern is direct predation on wild fish by farmed salmon which has potential cumulative effects on pelagic stocks in the region. Making some simple assumptions, it is possible to derive an annual estimate of the number of wild fish that could potentially be consumed by farmed salmon in pens. Work from BC (Hay et al. 2004, Johannes and Hay 2006) showed that the incidence of feeding on wild fish by farmed salmon was around 0.14% (typically only one wild fish consumed/event). If we assume salmon feed twice a day on wild fish at the observed incidence rate and there are a million fish in the pens, over a one-year period, the expected consumption of wild fish would be: 1,000,000 farmed salmon × 0.14% incidence rate of wild fish being consumed × 2 feeding period/day × 365 days/yr = 1,022,000 wild fish/yr/million farmed salmon.

We note that this is a rough estimate, and that farmed salmon are supply limited, meaning they are only able to feed on wild fish and invertebrates that are able to enter their pens. The predation and consumption of wild fish and/or shellfish larvae by farmed salmon may be an issue to consider during the regional assessment for herring and potentially other stocks as a new additional source of removals.

The use of eDNA to detect species, in addition to baseline surveys, may be beneficial to detect species which tend to be more cryptic and those that might not be detected by drop camera surveys.

The potential interactions of the proposed site with Aquatic Invasive Species (AIS) have been noted as a topic which should be discussed during aquaculture siting applications reviews.

The Proponent acknowledges the risk of adverse environmental conditions without specifically mentioning the potential effects of climate change and submitted plans to address the potential issues. Those effects could be particularly important and should be considered in all future site applications as well as future science work undertaken by the Department. In particular, effects of and potential for adverse heat waves, oxygen depletion, and winter superchill events should be studied and addressed.

CONCLUSIONS

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

- The benthic predicted exposure zone (benthic-PEZ) associated with the use of in-feed fish health treatment products resulting in potential exposure is within a radius of 1.1 km from the site location for drugs present in feed waste (higher concentration of active ingredients), and 7.7 km for those found in feces waste (lower concentration of active ingredients).
- The pelagic predicted exposure zone (pelagic-PEZ) associated with the use of approved pesticides is within a radius of 2.2 km from the site location.

- Crustaceans are present within the pelagic-PEZ and therefore the sensitivity to drugs and pesticides of larvae in the pelagic environment and juveniles in shallower waters should be carefully considered during the application phase of operations to reduce potential impacts.

Question 2: Based on available data, what are the Ecologically and Biologically Significant Areas (EBSAs); Species At Risk (SAR); fishery species; and 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 associated with the greatest intensity of potential impacts is within a radius of 1.1 km from the site location, while the lightest particles could extend up to 15.0 km from the site. This site has benthic habitats with sessile organisms (including corals and sponges) and a likely presence of fish eggs and larvae for which baseline data on vulnerability and recovery, as well as connectivity within and outside these areas, are lacking.
- Sessile or sedentary benthic taxa present at the site are expected to be vulnerable to aquaculture wastes, as they cannot relocate to another environment when under stress.

Question 3: 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?

- Leatherback Sea Turtles can be found in the area from June to November, suggesting the potential for entanglements from mid-summer to late fall.
- The general area overlaps the distribution of several species of whales, dolphins, porpoises, and sharks including SARA-listed species (Blue Whale, North Atlantic Right Whale, White Shark). The occurrence of cetaceans is generally highest in summer to fall and lowest in winter and spring based on sightings (opportunistic, systematic) and acoustics data. White Shark are present in the area seasonally between June and October, with the highest number of individuals detected in July and August based on tagging and telemetry data. While entanglement and subsequent drowning are the main concerns for cetacean species, such as baleen whales which do not echolocate, the risk of entanglement is considered low at the proposed site.
- The risk of entanglement may be higher for pinniped species, such as Harbour Seals and Grey Seals, that may be attracted to the cage netting for potential prey. Harbour Seals occur year-round while Grey Seals are seasonal visitors that arrive in late spring and depart in late fall.
- In general, the risk of entanglement of White Shark, marine mammals, and sea turtles in the proposed lease area is highest in the summer to fall period and lowest in winter to spring period based on seasonality of occurrence.

Question 4: Which populations of conspecifics are within a geographic range where escapees are likely to migrate? What are the size and status trends of those conspecific populations in the escape exposure zone for the proposed site? Are any of these populations listed under Schedule 1 of the Species At Risk Act (SARA)?

- Individual wild Atlantic Salmon from southern Newfoundland populations, and from elsewhere, migrate through the geographic range where escapees are likely to migrate on a regular basis. Counting fence data and tagging studies in adjacent Bay d'Espoir suggest that wild Atlantic Salmon smolts that migrate to sea in early May are present in the Bay d'Espoir fjord for up to 4–8 weeks.

- COSEWIC (2010) designated the South Newfoundland Atlantic Salmon population as Threatened. There have been longstanding and continuous population declines of wild salmon in southern Newfoundland as compared to other regions of the province. Over the previous three generations (15–16 years), Atlantic Salmon returns to two monitored rivers in Bay d'Espoir declined by 89% or more. Since 2018, estimates of marine survival on monitored rivers in SFA 11 are low compared to other monitored rivers on the island of Newfoundland.
- Although the escapee dispersal simulations suggest that there would be a 2% increase in the number of escapees with the proposed site, more than half of the salmon rivers west of the Burin Peninsula are already experiencing significant genetic and demographic impacts, and these will likely be exacerbated by the approval of the proposed site. Maximum values for the proportion of escapees are predicted to occur within rivers in the head of Bay d'Espoir including the Conne River which continues to be of significant conservation concern. Observations of recent and significant European ancestry in aquaculture salmon in southern Newfoundland further elevate the risk of escapees to wild salmon populations in the region and genetic screening could be utilized to evaluate and reduce this risk.
- There remains significant uncertainty as to the magnitude of indirect genetic and ecological impacts on wild salmon in the region.

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SOURCES OF INFORMATION

Adamack, A.T., Rose, K.A., Breitburg, D.L., Nice, A.J., and Lung, W.-S. 2012. Simulating the effect of hypoxia on bay anchovy egg and larval mortality using coupled watershed, water quality, and individual-based predation models. Mar. Ecol. Prog. Ser. 445: 141–160

Aguado-Giménez, F., Piedecausa, M.A., Gutiérrez, J.M., García-Charton, J.A., Belmonte, A., and García-García, B. 2012. Benthic recovery after fish farming cessation: A “beyond-BACI” approach. Mar. Pollut. Bull. 64(4): 729–738.

ASF. 2020. Mowi forced to empty cage as ISA confirmed at Canada farm site.

Ash, E.G.M., and O'Connell, M.F. 1987. Atlantic salmon fishery in Newfoundland and Labrador, commercial and recreational, 1984. Can. Data Rep. Fish. Aquat. Sci. 658: v + 294 p.

Bannister, R.J., Johnsen, I.A., Hansen, P.K., Kutti, T., and Asplin, L. 2016. Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. ICES J. Mar. Sci. 73(9): 2408–2419.

Bastien, G., Barkley, A., Chappus, J., Heath, V., Popov, S., Smith, R., Tran, T., Currier, S., Fernandez, D.C., Okpara, P., Owen, V., Franks, B., Hueter, R., Madigan, D.J., Fischer, C., McBride, B., and Hussey, N.E. 2020. Inconspicuous, recovering, or northward shift: status and management of the white shark (*Carcharodon carcharias*) in Atlantic Canada. Can. J. Fish. Aquat. Sci. 77(10): 1666–1677.

Baudron, A.R., Needle, C.L., Rijnsdorp, A.D., and Marshall, C.T. 2013. Warming temperatures and smaller body sizes: synchronous changes in growth of North Sea fishes. Global Change Biol. 20(4): 1023–1031.

Bechmann, R.K., Arnberg, M., Gomiero, A., Westerlund, S., Lyng, E., Berry, M., Agustsson, T., Jager, T., and Burridge, L.E. 2019. Gill damage and delayed mortality of Northern shrimp (*Pandalus borealis*) after short time exposure to anti-parasitic veterinary medicine containing hydrogen peroxide. Ecotoxicol. Environ. Safe. 180: 473–482.

Blanco Gonzalez, E., and de Boer, F. 2017. The development of the Norwegian wrasse fishery and the use of wrasses as cleaner fish in the salmon aquaculture industry. Fish. Sci. 83: 661–670.

Blanco Gonzalez, E., Espeland, S.H., Jentoft, S., Hansen, M.M., Robalo, J.I., Stenseth, N.C., and Jorde, P.E. 2019. Interbreeding between local and translocated populations of a cleaner fish in an experimental mesocosm predicts risk of disrupted local adaptation. Ecol. Evol. 9(11): 6665–6677.

Bøhn, T., Gjelland, K.O., Serra-Llinares, R.M., Finstad, B., Primicerio, R., Nilsen, R., Karlsen, Ø., Sandvik, A.D., Skilbrei, O.T., Elvik, K.M.S., Skaala, Ø., and Bjørn, P.A. 2020. Timing is everything: Survival of Atlantic salmon *Salmo salar* postsmolts during events of high salmon lice densities. J. Appl. Ecol. 57(6): 1149–1160.

Bolton-Warberg, M. 2018. An overview of cleaner fish use in Ireland. J. Fish Dis. 41(6): 935–939.

Bonsdorff, E., Blomqvist, E.M., Mattila, J., and Norkko, A. 1997. Coastal eutrophication: Causes, consequences and perspectives in the Archipelago areas of the northern Baltic Sea. Estuar. Coast. Shelf Sci. 44 (Supplement 1): 63–72.

Bourne, C., Mowbray, F., Squires, B., and Koen-Alonso, M. 2018. 2017 Assessment of Newfoundland east and south coast Atlantic herring (*Clupea harengus*) stock complexes. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/026. v + 45 p.

Bouwmeester, M.M., Goedknegt, M.A., Poulin, R., and Thieltges, D.W. 2021. Collateral diseases: Aquaculture impacts on wildlife infections. J. Appl. Ecol. 58(3): 453–464.

Bradbury, I.R., Duffy, S., Lehnert, S.J., Jóhannsson, R., Fridriksson, J.H., Castellani, M., Burgetz, I., Sylvester, E., Messmer, A., Layton, K., Kelly, N., Dempson, J.B., and Fleming, I.A. 2020. Model-based evaluation of the genetic impacts of farm-escaped Atlantic salmon on wild populations. Aquacult. Environ. Interact. 12: 45–59.

Bradbury, I.R., Lehnert, S.J., Kess, T., Van Wyngaarden, M., Duffy, S., Messmer, A.M., Wringe, B., Karoliussen, S., Dempson, J.B., Fleming, I.A., Solberg, M.F., Glover, K.A., and Bentzen, P. 2022. Genomic evidence of recent European introgression into North American farmed and wild Atlantic salmon. Evol. Appl.15(9): 1436–1448.

Breitburg, D.L., Adamack, A., Rose, K.A., Kolesar, S.E., Decker, B., Purcell, J.E., Keister, J.E., and Cowan, J.H. 2003. The pattern and influence of low dissolved oxygen in the Patuxent River, a seasonally hypoxic estuary. Estuaries. 26(2): 280–297.

Breitburg, D., Levin, L.A., Oschlies, A., Grégoire, M., Chavez, F.P., Conley, D.J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K., Jacinto, G.S., Limburg, K.E., Montes, I., Navqi, S.W.A., Pitcher, G.C., Rabalais, N.N., Roman, M.R., Rose, K.A., Seibel, B.A., Telszewski, M., Yasuhara, M., and Zhang, J. 2018. Declining oxygen in the global ocean and coastal waters. Science. 359(6371): 11 p.

Brooks, K.M. 2009. Considerations in developing an integrated pest management programme for control of sea lice on farmed salmon in Pacific Canada. J. Fish Dis. 32(1): 59–73.

Burridge, L. 2013. A review of potential environmental risks associated with the use of pesticides to treat Atlantic salmon against infestation of sea lice in southwest New Brunswick, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/050. iv + 25 p.

Burridge, L.E., Haya, K., Waddy, S.L., and Wade, J. 2000. The lethality of anti-sea lice formulations Salmosan® (Azamethiphos) and Excis® (Cypermethrin) to stage IV and adult lobsters (*Homarus americanus*) during repeated short-term exposures. Aquaculture. 182(1–2): 27–35.

Burridge, L.E., Haya, K., and Waddy, S.L. 2008. The effect of repeated exposure to azamethiphos on survival and spawning in female American lobsters (*Homarus americanus*). Ecotoxicol. Environ. Safe. 69(3): 411–415.

Callier, M.D., Byron, C.J., Bengtson, D.A., Cranford, P.J., Cross, S.F., Focken, U., Jansen, H.M., Kamermans, P., Kiessling, A., Landry, T., O'Beirn, F., Petersson, E., Rheault ,R.B., Strand, Ø., Sundell, K., Svåsand, T., Wikfors, G.H., and McKindsey, C.W. 2018. Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Rev. Aquacult. 10(4): 924–949.

Canty, M.N, Hagger, J.A., Moore, R.T.B., Cooper, L., and Galloway, T.S. 2007. Sublethal impact of short term exposure to the organophosphate pesticide azamethiphos in the marine mollusc *Mytilus edulis*. Mar. Pollut. Bull. 54(4): 396–402.

CFIA. 2021a. Locations infected with infectious salmon anaemia.

CFIA. 2021b. Viral Hemorrhagic Septicemia (VHS).

Chamberlain, J., and Stucchi, D. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. Aquaculture. 272(1–4): 296−311.

Chen, Y.-S., Beveridge, M.C.M., and Telfer, T.C. 1999. Settling rate characteristics and nutrient content of the faeces of Atlantic salmon, *Salmo salar* L. and the implications for modelling of solid waste dispersion. Aquacult. Res. 30(5): 395–398.

Chen, Y.-S., Beveridge, M.C.M., Telfer, T.C., and Roy, W.J. 2003. Nutrient leaching and settling rate characteristics of the faeces of Atlantic salmon (*Salmo salar* L.) and the implications for modelling of solid waste dispersion. J. Appl. Ichthyol. 19(2): 114–117.

Cloern, J.E. 2001. Our Evolving Conceptual Model of the Coastal Eutrophication Problem. Mar. Ecol. Prog. Ser. 210: 223–253.

Comeau, M., Starr, M., Conan, G. Y., Robichaud, G., and Therriault, J.-C. 1999. Fecundity and duration of egg incubation for multiparous female snow crabs (*Chionoectes opilio*) in the fjord of Bonne Bay, Newfoundland. Can. J. Fish. Aquat. Sci. 56(6):1088–1095.

Consuegra, S., de Eyto, E., McGinnity, P., Stet, R.J.M., and Jordan, W.C. 2011. Contrasting responses to selection in class I and class IIα major histocompatibility-linked markers in salmon. Heredity. 107: 143–154.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon Salmo salar (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 p.

COSEWIC. 2017. COSEWIC assessment and status report on the Lumpfish Cyclopterus lumpus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 78 p.

Couillard, C.M., and Burridge, L.E. 2015. Sublethal exposure to azamethiphos causes neurotoxicity, altered energy allocation and high mortality during simulated live transport in American lobster. Ecotoxicol. Environ. Safe. 115: 291–299.

Cromey, C.J., Nickell, T.D., and Black, K.D. 2002. DEPOMOD–modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture. 214(1–4): 211−239.

Dempster, T., Uglem, I., Sánchez-Jerez, P., Fernández-Jover, D., Bayle-Sempere, J., Nilsen, R., and Bjørn, P.A. 2009. Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect. Mar. Ecol. Prog. Ser. 385: 1–14.

DFO. 2009. Does eelgrass (*Zostera marina*) meet the criteria as an ecologically significant species? DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/018.

DFO. 2012. Using Satellite Tracking Data to Define Important Habitat for Leatherback Turtles in Atlantic Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/036.

DFO. 2013. Guidelines on Defining Potential Exposure and Associated Biological Effects from Aquaculture Pest and Pathogen Treatments: Anti-Sea Lice Bath Treatments in the Bay of Fundy, New Brunswick. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/070.

DFO. 2020a. Disease (ISA) Outbreak at MOWI Salmon Farm in Newfoundland and Labrador.

DFO. 2020b. Recovery Strategy for the Loggerhead Sea Turtle (*Caretta caretta*) in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. vi + 35 p.

DFO. 2022a. Review Of The Marine Harvest Atlantic Canada Inc. Aquaculture Siting Baseline Assessments For The South Coast Of Newfoundland. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/02.

DFO. 2022b. DFO Newfoundland and Labrador Region Science Review of Five Proposed Grieg Aquaculture Marine Finfish Aquaculture Facilities in Placentia Bay, Newfoundland. DFO Can. Sci. Advis. Sec. Sci. Resp. 2022/019.

DFO. 2022c. Stock Assessment of Newfoundland and Labrador Atlantic Salmon in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/031.

DFO. 2022d. Marine mammal (megafauna) fatalities at marine finfish aquaculture facilities in British Columbia. Date updated: 2022-05-31.

Dinning, K.M., and Rochette, R. 2019. Evidence that mud seafloor serves as recruitment habitat for settling and early benthic phase of the American lobster *Homarus americanus* H. (Decapoda: Astacidea: Nephropidae). J. Crustacean Biol. 39(5): 594–601.

Dionne, M., Miller, K.M., Dodson, J.J., Caron, F., and Bernatchez, L. 2007. Clinal variation in MHC diversity with temperature: evidence for the role of host–pathogen interaction on local adaptation in Atlantic salmon. Evolution. 61(9): 2154–2164.

Dionne, M., Miller, K.M., Dodson, J.J., and Bernatchez, L. 2009. MHC standing genetic variation and pathogen resistance in wild Atlantic salmon. Philos. Trans. R. Soc. London, Ser. B. 364: 1555–1565.

Donnet, S., Ratsimandresy, A.W., Goulet, P., Doody, C., Burke, S., and Cross, S. 2018. Coast of Bays Metrics: Geography, Hydrology and Physical Oceanography of an Aquaculture Area of the South Coast of Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/076. x + 109 p.

Escobar-Lux, R.H., and Samuelsen, O.B. 2020. The Acute and Delayed Mortality of the Northern Krill (*Meganyctiphanes norvegica*) When Exposed to Hydrogen Peroxide. Bull. Environ. Contam. Toxicol. 105(5): 705–710.

Escobar-Lux, R.H., Parsons, A.E., Samuelsen, O.B., and Agnalt, A.-L. 2020. Short-term exposure to hydrogen peroxide induces mortality and alters exploratory behavior of European lobster (*Homarus gammarus*). Ecotoxicol. Environ. Safe. 204: 111111.

Faust, E., Halvorsen, K.T., Andersen, P., Knutsen, H., and André, C. 2018. Cleaner fish escape salmon farms and hybridize with local wrasse populations. R. Soc. Open Sci. 5(3): 171752.

Faust, E., Jansson, E., André, C., Halvorsen, K.T., Dahle, G., Knutsen, H., Quintela, M, and Glover, K.A. 2021. Not that clean: Aquaculture-mediated translocation of cleaner fish has led to hybridization on the northern edge of the species' range. Evol. Appl. 14(6): 1572–1587.

Findlay, R.H., and Watling, L. 1994. Toward a process level model to predict the effects of salmon net-pen aquaculture on the benthos. *In* Modelling Benthic Impacts of Organic Enrichment from Marine Aquaculture. Edited by B.T. Hargrave. Can. Tech. Rep. Fish. Aquat. Sci. 1949: xi + 125 p.

Garseth, Å.H., Ekrem, T., and Biering, E. 2013. Phylogenetic Evidence of Long Distance Dispersal and Transmission of Piscine Reovirus (PRV) between Farmed and Wild Atlantic Salmon. PLoS ONE. 8(12): e82202.

Garver, K.A., and Hawley, L.M. 2021. Characterization of viral haemorrhagic septicaemia virus (VHSV) to inform pathogen transfer risk assessments in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/064. v + 24 p.

Gillooly, J.F., Brown, J.H., West, G.B., Savage, V.M., and Charnov, E.L. 2001. Effects of Size and Temperature on Metabolic Rate. Science. 293(5538): 2248–2251.

Goodbrand, L., Abrahams, M.V., and Rose, G.A. 2013. Sea cage aquaculture affects distribution of wild fish at large spatial scales. Can. J. Fish. Aquat. Sci. 70(9): 1289–1295.

Goulet, P., Mullowney, D., Ratsimandresy, A., Kingsbury, M, and Hamoutene, D. 2022. Species Distribution Modelling for snow crab (*Chionoecetes opilio*) potential habitat in Connaigre Bay Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 3517: vii + 36 p.

Grant, J., Simone, M., and Daggett, T. 2019. Long-term studies of lobster abundance at a salmon aquaculture site, eastern Canada. Can. J. Fish. Aquat. Sci. 76(7): 1096–1102.

Hamoutene, D., Oldford, V., and Donnet, S. 2022. Drug and pesticide usage for sea lice treatment in salmon aquaculture sites in a Canadian province from 2016 to 2019. Sci. Rep. 12(4475): 1–15.

Hamoutene, D., Marteinson, S., Kingsbury, M., and McTavish, K. 2023a. Species sensitivity distributions for two widely used anti-sea lice chemotherapeutants in the salmon aquaculture industry. Sci. Total Environ. 857(2): 159574.

Hamoutene, D., Ryall, E., Porter, E., Page, F.H., Wickens, K., Wong, D., Martell, L., Burridge, L., Villeneuve, J., Miller, C. 2023b. Discussion of Environmental Quality Standards (EQS) and their development for the monitoring of impacts from the use of pesticides and drugs at marine aquaculture sites. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/066. vii + 117 p.

Hay, D.E., Bravender, B.A., Gillis, D.J., and Black, E.A. 2004. An Investigation into the Consumption of Wild Food Organisms, and the Possible Effects of Lights on Predation, by Caged Atlantic Salmon in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2662: vi + 35 p.

Holborn, M.K., Crowley, S.E., Duffy, S.J., Messmer, A.M., Kess, T., Dempson, J.B., Wringe, B.F., Fleming, I.A., Bentzen, P, and Bradbury, I.R. 2022. Precocial male maturation contributes to the introgression of farmed Atlantic salmon into wild populations. Aquacult. Environ. Interact. 14: 205–218.

Houde, E.D. 1987. Fish early life dynamics and recruitment variability. *In* American Fisheries Society Symposium Series. Edited by R.D. Hoyt. Am. Fish. Soc. 2: 17–29.

ICES. 2020. Working Group on North Atlantic Salmon (WGNAS). ICES Scientific Reports. 2(21): 358 p.

Johannes, M.R.S., and Hay, D.E. 2006. Trophic interactions and consumption of wild fish and plankton by cage-reared salmon in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2634: vii + 22 p.

Johansen, L.-H., Jensen, I., Mikkelsen, H., Bjørn, P.A., Jansen, P.A., and Bergh, Ø. 2011. Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. Aquaculture. 315(3–4): 167–186.

Justić, D., Rabalais, N., and Turner, R.E. 1996. Effects of Climate Change on Hypoxia in Coastal Waters: A Doubled Co2 Scenario for the Northern Gulf of Mexico. Limnol. Oceanogr. 41(5): 992–1003.

Keenan, S.F., Benfield, M.C., and Blackburn, J.K. 2007. Importance of the artificial light field around offshore petroleum platforms for the associated fish community. Mar. Ecol. Prog. Ser. 331: 219–231.

Keyser, F., Wringe, B.F., Jeffery, N.W., Dempson, J.B., Duffy, S., and Bradbury, I.R. 2018. Predicting the impacts of escaped farmed Atlantic salmon on wild salmon populations. Can. J. Fish. Aquat. Sci. 75(4): 1–7.

Kjærner-Semb, E., Ayllon, F., Furmanek, T., Wennevik, V., Dahle, G., Niemelä, E., Ozerov, M., Vähä, J.P., Glover, K.A., Rubin, C.J., Wargelius, A., and Edvardsen, R.B. 2016. Atlantic salmon populations reveal adaptive divergence of immune related genes - a duplicated genome under selection. BMC Genomics. 17(610): 1–12.

Krkošek, M. 2010. Host density thresholds and disease control for fisheries and aquaculture. Aquacult. Environ. Interact. 1: 21–32.

Krkošek, M., Connors, B.M., Morton, A., Lewis, M.A., Dill, L.M., and Hilborn, R. 2011. Effects of parasites from salmon farms on productivity of wild salmon. PNAS. 108(35): 14700–14704.

Laurent, A., Fennel, K., Ko, D.S., and Lehrter, J. 2018. Climate Change Projected to Exacerbate Impacts of Coastal Eutrophication in the Northern Gulf of Mexico. J. Geophys. Res.: Oceans.123(5): 3408–3426.

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

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

Lawson, G.L., and Rose, G.A. 2000. Small-scale spatial and temporal patterns in spawning of Atlantic cod (*Gadus morhua*) in coastal Newfoundland waters. Can. J. Fish. Aquat. Sci. 57(5): 1011–1024.

Lawton, P., and Lavalli, K.L. 1995. Postlarval, Juvenile, Adolescent, and Adult Ecology. *In*: Biology of the Lobster *Homarus americanus*. Edited by J.R. Factor. Academic Press. San Diego, California. pp. 47–88.

Lear, W.H. 1973. Size and age composition of the 1971 Newfoundland-Labrador commercial salmon catch. Fish. Res. Board Can. Tech. Rep. 392. 43 p.

Lehnert, S.J., Bentzen, P., Kess, T., Lien, S., Horne, J.B., Clément, M., and Bradbury, I.R. 2019. Chromosome polymorphisms track trans-Atlantic divergence and secondary contact in Atlantic salmon. Mol. Ecol. 28(8): 2074–2087.

Lehnert, S.J., Kess, T., Bentzen, P., Clément, M., and Bradbury, I.R. 2020. Divergent and linked selection shape patterns of genomic differentiation between European and North American Atlantic salmon (*Salmo salar*). Mol. Ecol. 29(12): 2160–2175.

Lin, D.T., and Bailey-Brock, J.H. 2008. Partial recovery of infaunal communities during a fallow period at an open-ocean aquaculture. Mar. Ecol. Prog. Ser. 371: 65–72.

Macleod, C.K., Crawford, C.M., and Moltschaniwskyj, N.A. 2004. Assessment of long term change in sediment condition after organic enrichment: defining recovery. Mar. Pollut. Bull. 49(1–2): 79–88.

Madhun, A.S., Karlsbakk, E., Isachsen, C.H., Omdal, L.M., Eide Sørvik, A.G., Skaala, Ø., Barlaup, B.T., and Glover, K.A. 2015. Potential disease interaction reinforced: double-virus-infected escaped farmed Atlantic salmon, *Salmo salar* L., recaptured in a nearby river. J. Fish Dis. 38(2): 209–219.

Madhun, A.S., Isachsen, C.H., Omdal, L.M., Einen, A.C.B., Mæhle, S., Wennevik, V., Niemelä, E., Svåsand, T., and Karlsbakk, E. 2018. Prevalence of piscine orthoreovirus and salmonid alphavirus in sea-caught returning adult Atlantic salmon (*Salmo salar* L.) in northern Norway. J. Fish Dis. 41(5): 797–803.

May, A.W., and Lear, W.H. 1971. Digest of Canadian Atlantic salmon catch statistics. Fish. Res. Board Can. Tech. Rep. 270: 106 p.

McAllister, L.T., Van Leeuwen, T.E., Hanlon, J.M., Morris, C.J., Potter, J., Wells, J., and Abrahams, M. 2021. Sea cage aquaculture may provide an energetic subsidy to wild juvenile cod in coastal bays of southern Newfoundland, Canada. Mar. Ecol. Prog. Ser. 674: 241–255.

Mill, K., Sahota, C., Hayek, K., and Kennedy, C.J. 2022. Effects of sea louse chemotherapeutants on early life stages of the spot prawn (*Pandalus platyceros*). Aquacult. Res. 53(1): 109–124.

Mowbray, F.K., Bourne, C., Murphy, H., Adamack, A., Lewis, K., Varkey, D., and Regular, P. 2019. Assessment of Capelin (*Mallotus villosus*) in SA2 + Div. 3KL in 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/068. iv + 34 p.

Mullowney, D.R.J., Dawe, E.G., Colbourne, E.B., and Rose, G.A. 2014. A review of factors contributing to the decline of Newfoundland and Labrador snow crab (*Chionoecetes opilio*). Rev. Fish Biol. Fish. 24: 639–657.

Mullowney, D.R., Morris, C., Dawe, E., Zagorsky, I., and Goryanina, S. 2018. Dynamics of snow crab (*Chionoecetes opilio*) movement and migration along the Newfoundland and Labrador and Eastern Barents Sea continental shelves. Rev. Fish Biol. Fish. 28: 435–459.

Murray, C., Hannah, L., and Locke, A. 2020. A Review of Cumulative Effects Research and Assessment in Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3357: vii + 51 p.

Núñez-Acuña, G., Fernandez, C., Sanhueza-Guevara, S., and Gallardo-Escárate, C. 2022. Transcriptome profiling of the early developmental stages in the giant mussel *Choromytilus chorus* exposed to delousing drugs. Mar. Genomics. 65: 100970.

Nylund, A., Devoid, M., Mullins, J., and Plarre, H. 2002. Herring (*Clupea harengus*): A host for infectious salmon anemia virus (ISAV). Bull. Euro. Assoc. Fish Path. 22(5): 311–318.

Nylund, A., Brattespe, J., Plarre, H., Kambestad, M., and Karlsen, M. 2019. Wild and farmed salmon (*Salmo salar*) as reservoirs for infectious salmon anaemia virus, and the importance of horizontal- and vertical transmission. PLoS ONE. 14(4): e0215478.

Page, F., Haigh, S., and O'Flaherty-Sproul, M. 2023. Potential Exposure Zones for Proposed Newfoundland Marine Finfish Salmon Aquaculture Sites: Initial First Order Triage Scoping Calculations and Consistency Comparisons. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/071. iv + 80 p.

Parsons, L.S., and Hodder, V.M. 1970. Occurrence of Juvenile and Spawning Atlantic Mackerel in Southeastern Newfoundland Coastal Waters. J. Fish. Res. Board Can. 27(11): 2097–2100.

Parsons, A., Escobar-Lux, R.H., Sævik, P., Samuelsen, O.B., and Agnalt, A.-L. 2020. The impact of anti-sea lice pesticides, azamethiphos and deltamethrin, on European lobster (*Homarus gammarus*) larvae in the Norwegian marine environment. Environ. Pollut. 264: 114725.

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

PMRA. 2016a. Registration Decision RD 2016-18, Hydrogen Peroxide. Products Consultation Document. Pesticide Management Regulatory Agency, Health Canada.

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

PMRA. 2017. Registration Decision RD2017-13, Azamethiphos. Products Consultation Document. Pesticide Management Regulatory Agency, Health Canada.

Pritchard, V.L., Mäkinen, H., Vähä, J.-P., Erkinaro, J., Orell, P., and Primmer, C.R. 2018. Genomic signatures of fine-scale local selection in Atlantic salmon suggest involvement of sexual maturation, energy homeostasis and immune defence-related genes. Mol. Ecol. 27(11): 2560–2575.

Rabalais, N.N., Turner, R.E., Díaz, R.J., and Justić, D. 2009. Global change and eutrophication of coastal waters. ICES J. Mar. Sci. 66(7): 1528–1537.

Ratsimandresy, A.W., Donnet, S., Snook, S., and Goulet, P. 2019. Analysis of the variability of the ocean currents in the Coast of Bays area. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/008. viii + 59 p.

Reddin, D.G., and Lear, W.H. 1990. Summary of marine tagging studies of Atlantic salmon (*Salmo salar* L.) in the Northwest Atlantic area. Can. Tech. Rep. Fish. Aquat. Sci. 1737: iv + 115 p.

Reddin, D.G., and Short, P.B. 1981. The 1976 Newfoundland and Labrador Atlantic salmon commercial landings. Can. Tech. Rep. Fish. Aquat. Sci. 1007: iv + 105 p.

Sainte-Marie, B. 1993. Reproductive Cycle and Fecundity of Primiparous and Multiparous Female Snow Crab, *Chionoecetes opilio*, in the Northwest Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 50(10): 2147–2156.

Saksida, S., Bricknell, I., Robinson, S., and Jones, S. 2015. Population ecology and epidemiology of sea lice in Canadian waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/004. v + 34 p.

Salvo, F., Mersereau, J., Hamoutene, D., Belley, R., and Dufour, S.C. 2017. Spatial and temporal changes in epibenthic communities at deep, hard bottom aquaculture sites in Newfoundland. Ecol. Indic. 76: 207–218.

Schein, A., Courtenay, S.C., Kidd, K.A., Campbell, K.A., and van den Heuvel, M.R. 2013. Food web structure within an estuary of the southern Gulf of St. Lawrence undergoing eutrophication. Can. J. Fish. Aquat. Sci. 70(12): 1805–1812.

SEPA. 1999. Emamectin Benzoate, An Environmental Risk Assessment. Scottish Environmental Protection Agency. SEPA Board Paper 65/99: 23 p.

Shen, Y., Greco, M., and Faltinsen, O.M. 2019. Numerical study of a well boat operating at a fish farm in current. J. Fluids Struct. 84: 77–96.

Shephard, S., and Gargan, P. 2017. Quantifying the contribution of sea lice from aquaculture to declining annual returns in a wild Atlantic salmon population. Aquacult. Environ. Interact. 9: 181–192.

Shephard, S., and Gargan, P. 2021. Wild Atlantic salmon exposed to sea lice from aquaculture show reduced marine survival and modified response to ocean climate. ICES J. Mar. Sci. 78(1): 368–376.

Simpson, M.R., Gauthier, J., Benoît, H.P., MacDonald, D., Hedges, K., Collins, R., Mello, L., and Miri, C. 2016. A pre-COSEWIC assessment of the Common Lumpfish (*Cyclopterus lumpus*, Linnaeus 1758) in Canadian Atlantic and Arctic waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/068. v + 135 p.

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

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

Stickney, A.P. 1970. Factors influencing the attraction of Atlantic herring *Clupea harengus harengus*, to artificial lights. Fish. Bull. 68(1): 73–85.

Strain, P.M., and Hargrave, B.T. 2005. Salmon Aquaculture, Nutrient Fluxes and Ecosystem Processes in Southwestern New Brunswick. *In*: Hargrave, B.T. (Ed.). Environmental Effects of Marine Finfish Aquaculture. Handbook of Environmental Chemistry, vol 5M. Springer, Berlin, Heidelberg. 29–57.

Suikkanen, S., Pulina, S., Engström-Öst, J., Lehtiniemi, M., Lehtinen, S., and Brutemark, A. 2013. Climate Change and Eutrophication Induced Shifts in Northern Summer Plankton Communities. PLOS ONE. 8(6): e66475.

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

Sylvester, E.V.A., Wringe, B.F., Duffy, S.J., Hamilton, L.C., Fleming, I.A., Castellani, M., Bentzen, P., and Bradbury, I.R. 2019. Estimating the relative fitness of escaped farmed salmon offspring in the wild and modelling the consequences of invasion for wild populations. Evol. Appl. 12(4): 705–717.

Thibodeau, B., de Vernal, A., and Mucci, A. 2006. Recent eutrophication and consequent hypoxia in the bottom waters of the Lower St. Lawrence Estuary: Micropaleontological and geochemical evidence. Mar. Geol. 231(1–4): 37–50.

Thorstad, E.B., and Finstad, B. 2018. Impacts of salmon lice emanating from salmon farms on wild Atlantic salmon and sea trout. NINA Report. 1449: 1–22.

Tonteri, A., Vasemägi, A., Lumme, J., and Primmer, C.R. 2010. Beyond MHC: signals of elevated selection pressure on Atlantic salmon (*Salmo salar*) immune-relevant loci. Mol. Ecol. 19(7): 1273–1282.

Torrissen, O., Jones, S., Asche, F., Guttormsen, A., Skilbrei, O.T., Nilsen, F., Horsberg, T.E., and Jackson, D. 2013. Salmon lice – impact on wild salmonids and salmon aquaculture. J. Fish Dis. 36(3): 171–194.

Uglem, I., Karlsen, Ø., Sanchez-Jerez, P., and Sæther, B.-S. 2014. Impacts of wild fishes attracted to open-cage salmonid farms in Norway. Aquacult. Environ. Interact. 6(1): 91–103.

Verhoeven, J.T.P., Salvo, F., Knight, R., Hamoutene, D., and Dufour, S.C. 2018 Temporal Bacterial Surveillance of Salmon Aquaculture Sites Indicates a Long Lasting Benthic Impact With Minimal Recovery. Front. Microbiol. 9: 3054.

Waddy, S.L., Burridge, L.E., Hamilton, M.N., Mercer, S.M., Aiken, D.E., and Haya, K. 2002. Emamectin benzoate induces molting in American lobster, *Homarus americanus*. Can. J. Fish. Aquat. Sci. 59(7): 1096–1099.

Wells, N., Tucker, K., Allard, K., Warren, M., Olson, S., Gullage, L., Pretty, C., Sutton-Pande, V., and Clarke, K. 2019. Re-evaluation of the Placentia Bay-Grand Banks Area of the Newfoundland and Labrador Shelves Bioregion to Identify and Describe Ecologically and Biologically Significant Areas. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/049. viii + 151 p.

Wheeler, J.P., and Winters, G.H. 1984. Homing of Atlantic herring (*Clupea harengus harengus*) in Newfoundland Waters as Indicated by Tagging Data. Can. J. Fish. Aquat. Sci. 41(1): 108–117.

Wiber, M.G, Young, S., and Wilson, L. 2012. Impact of Aquaculture on Commercial Fisheries: Fisherman's Local Ecological Knowledge. Human Ecol. 40: 29–40.

Wringe, B.F., Jeffery, N.W., Stanley, R.R.E., Hamilton, L.C., Anderson, E.C., Fleming, I.A., Grant, C., Dempson, J.B., Veinott, G., Duffy, S.J., and Bradbury, I.R. 2018. Extensive hybridization following a large escape of domesticated Atlantic Salmon in the Northwest Atlantic. Commun. Biol. 1(108): 1–9.

Zhulay, I., Reiss, K., and Reiss, H. 2015. Effects of aquaculture fallowing on the recovery of macrofauna communities. Mar. Pollut. Bull. 97(1–2): 381–390.

Zueva, K.J., Lumme, J., Veselov, A.E., Kent, M.P., and Primmer, C.R. 2018. Genomic signatures of parasite-driven natural selection in north European Atlantic salmon (*Salmo salar*). Mar. Genomics. 39: 26–38.

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