HOW DO WE ENSURE ECOSYSTEMS ARE HEALTHY?

The North Pacific Ocean is home to a spectacular assemblage of more than 10,000 species of marine life. Respecting and protecting this biodiversity is the responsibility of all coastal people, including salmon farmers.

This chapter describes how salmon farm locations are sited and operated in order to minimize potential effects on marine biodiversity arising from the presence of the farm infrastructure, feeding practices and from applying veterinary treatments to farm-raised salmon.

Salmon farmers, with guidance from First Nation advisors, have adopted a four-step approach to minimizing effects on biodiversity:

1. Respect for First Nations Rightsholders – input and guidance on how to protect biodiversity,
2. Prevention - selecting suitability locations for salmon aquaculture – selecting locations with environmental conditions suitable for growing healthy salmon; and careful siting to avoid sensitive and critical habitats,
3. Monitoring – routinely monitor farm footprints for potential impacts to biodiversity, and
4. Mitigation – careful operating practices and alignment of fish production to the capacity of the surrounding environment.

Each of these steps is described in detail in the following sections.

PROTECTING BIODIVERSITY STARTS WITH FARM SITING. HOW ARE FARMS SITED?

IT BEGINS WITH FIRST NATIONS APPROVAL

Today, 100% of farm-raised salmon in BC is grown in partnership with local First Nations (Figure 1). The continued operation of existing sites, and applications to change existing sites or apply for new sites occur through permissions and partnership agreements with Nations. Recognition of Indigenous rights and their holistic use and occupation of their lands is at the forefront of all data collection and siting considerations. Please see Chapter 4 “Caring for Indigenous Stewardship - Connecting with the Original Guardians of the Coast” for more information.

Figure 1. Celebratory speeches given during the opening of Klemtu Spirit Hot Smoked Atlantic Salmon facility
[Klemtu Spirit (klemtuspiritsmokedsalmon.com)](klemtuspiritsmokedsalmon.com). *(4)*

ONLY A FRACTION OF THE COAST IS SUITABLE FOR FARMING SALMON

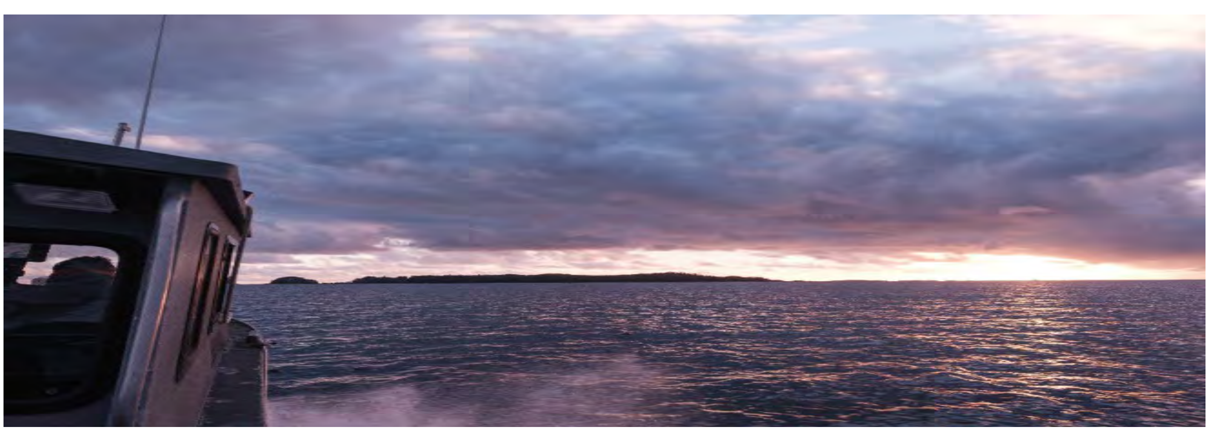
While BC has a large coastline, a relatively small proportion of the nearshore waters are suitable for growing salmon year-round in net pens. This is because salmon are sensitive to changes in water quality and thrive within narrow ranges of temperature and oxygen. Many of the initial farms in BC were located in shallow, protected bays that had limited water mixing and not well suited to growing salmon.

Today, First Nations Rightsholders and salmon farmers discuss where potential farms may be located. Then, oceanographic conditions at potential farm locations are investigated for months or years before advancing an application to develop or modify a site. Information on water temperature, salinity, current speeds, water exchange rates, wave and wind exposure, plankton, and oxygen profiles is collected and assessed to determine if a location is suitable for growing salmon. The goal is to find optimal conditions to grow healthy salmon.

Farm-raised Atlantic salmon grow best in sites where water temperature ranges from 6-16 °C, salinities are close to oceanic levels (33-34‰), and water flows need to be sufficient to supply well oxygenated water (ideally 7 – 10 parts per million oxygen) (5). Farm-raised Chinook salmon have similar requirements.

In BC, ocean currents and winds are arguably the most important physical criteria for site selection to ensure there is adequate water mixing to moderate temperature, provide continual oxygen to the fish in the pens, and prevent water stratification, which can lead to plankton blooms. During summer months, in the presence of plankton blooms, oxygen levels may drop below 5 parts per million and cause extreme stress to salmon in the net pens. This is the leading cause of mortality for farm-raised salmon in BC (see "Chapter 11 – Caring for Fish Health" for more information). These variables are constantly monitored at every salmon farm in BC (Figure 2).

Figure 2. Water quality and plankton monitoring are essential for understanding growing conditions for salmon



.MEETING REGULATORY CONDITIONS FOR NEW SITES

There are many regulations that protect fish, fish habitat and wildlife in BC (see Appendix A). The Department of Fisheries and Oceans (DFO) has specific siting guidelines for marine finfish farms to avoid critical and sensitive habitats and protect biodiversity (see Table 1). Salmon farmers must demonstrate how they meet all of these requirements for any new site application.

All new site applications and amendments in BC require formal applications through Front Counter BC following the Pacific Region Marine Finfish Aquaculture Application guidebook (6). There are three lead government agencies within the application:

- Ministry of Water, Land and Resource Stewardship - responsible for managing Crown land, including the issuance of land tenures. This includes tenures for aquaculture facilities and ancillary uses on land covered by water, upland and foreshore.
- DFO - responsibility includes most aspects of the aquaculture industry including, but not limited to: species cultured, production practices and volumes, fish containment, fish health, sea lice levels, marine mammal and escape mitigation, and fish habitat protection measures.
- Transport Canada - responsible for reviewing and approving applications for the placement of aquaculture containment and/or structures within the navigable waters of Canada.

Table 1. DFO siting guidelines for marine finfish aquaculture in British Columbia. (7)

General Siting Considerations

Management Objective – farms must respect First Nations Rights and Title and have the required permits, tenures and authorizations

- Siting must be consistent with all legislation and agreements governing Indigenous relations
- Provincial land tenure and Navigable Waters Permit
- No siting within Marine Protected Areas, unless exempted within regulations

Potential fish, fish habitat and environmental impacts

Management Objective - farmers must minimize potential impacts to the environment (e.g., seabed) that might result in a negative impact on existing commercial, recreational or aboriginal (CRA) fisheries or important/valued ecosystem components

- Farms should be capable of meeting performance measures for benthic conditions, as identified in the Aquaculture Activities Regulations
- Predicted footprint of increased deposition should be located in water depth of greater than 30 m to mitigate potential impacts to shallow water habitats
- A minimum distance of 10m should be maintained between the bottom of the facility infrastructure (i.e., netting, predator nets etc.) and the seabed to mitigate potential impacts from direct contact
- Placement and operation of the proposed aquaculture facility should not impact Species at Risk Act (SARA) listed species

Potential impacts to existing fishery activities

Management Objective - minimize and/or mitigate potential impacts on existing fisheries. Within this objective, Aboriginal Rights to fish for Food, Social and Ceremonial (FSC) purposes have priority, after conservation, over other uses of the aquatic resource

- Placement and operation of the proposed facility in relation to First Nations' ability to access fish for Food, Social and Ceremonial (FSC) purposes will be evaluated
- Placement and operation of the proposed aquaculture facility in relation to existing commercial, recreational or aboriginal (CRA) fisheries will be evaluated

Fish health and wild-farmed interactions

Management Objective - Minimize and/or mitigate potential risks to the health of wild and farmed stocks resulting from interactions between wild and farmed fish

- Siting of aquaculture facilities will take into consideration potential impacts to the health of wild migratory salmon and other fish stocks
- Aquaculture facilities should be located at least three kilometers from an existing marine finfish facility or operate under coordinated Health Management Plans

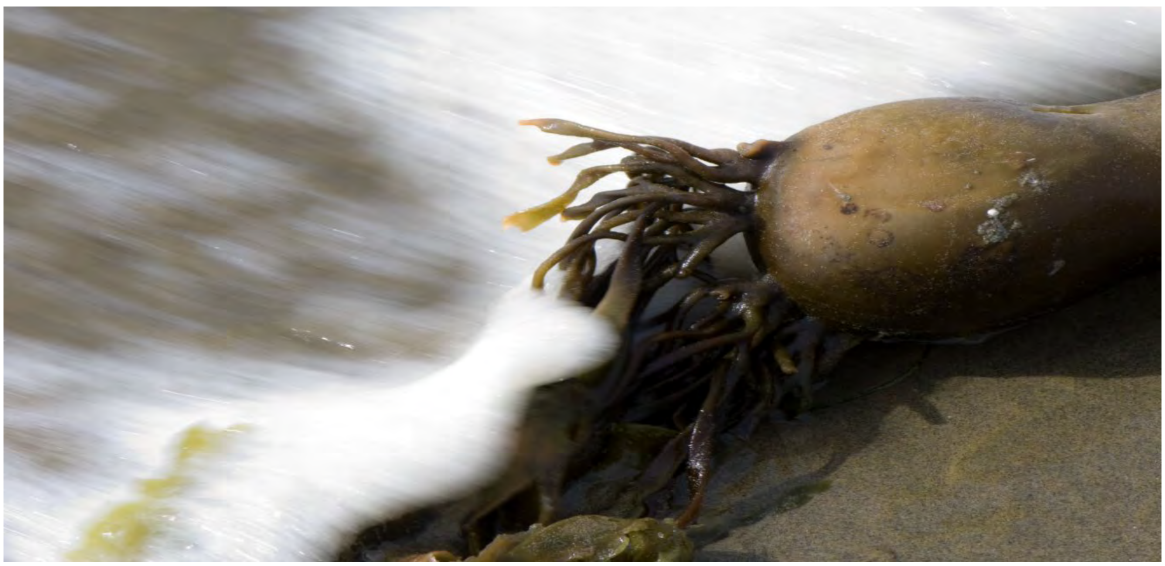


Photo by Brian Kingzett

COLLECTING BASELINE INFORMATION

Detailed environmental information is required for each site application, according to:

- Agreements with First Nations Rightsholders,
- the Guide to the Pacific Marine Finfish Aquaculture Application (6), and
- the Baseline Fish and Fish Habitat of the Aquaculture Activities Regulation (8).

It can take several years to collect all of the necessary baseline information. This includes physical information about the geography of the site and water movements (ocean current flow measurements, bathymetry and seabed habitat mapping).

Comprehensive information is collected to understand the size, location and magnitude of the potential nutrient footprint:

- Water movement data is used to program DEPOMOD, a footprint simulation model, to predict the location and intensity of the depositional footprint beneath the cages,

- o Underwater video of the seafloor within the proposed tenure and along the shoreline is collected and BC Registered Professional Biologists identify organisms and any sensitive or critical habitats encountered,
- o Seafloor sediments are collected and analyzed, and
- o Ultimately, this information is used to demonstrate that the predicted farm nutrient footprint will meet benthic management performance measures set out in the Aquaculture Activities Regulations (9).

Shoreline surveys within the proposed tenure area are completed by BC Registered Professional Biologists. This includes assessments of potential sensitive and critical habitats. Depending upon site conditions, this may include monitoring for northern abalone, eelgrass beds, kelp beds, intertidal clam beds, subtidal clam beds, rockfish and ling cod habitats, and mapping of any high concentrations of glass sponges or complexes within the proposed tenure rearing areas.

The proposed farm infrastructure and anticipated nutrient footprint must be sited to avoid overlapping with sensitive and critical habitats (Figure 3). Additional monitoring may be required if the feature is within the tenure but not within the nutrient footprint.

Photo by Brian Kingzett

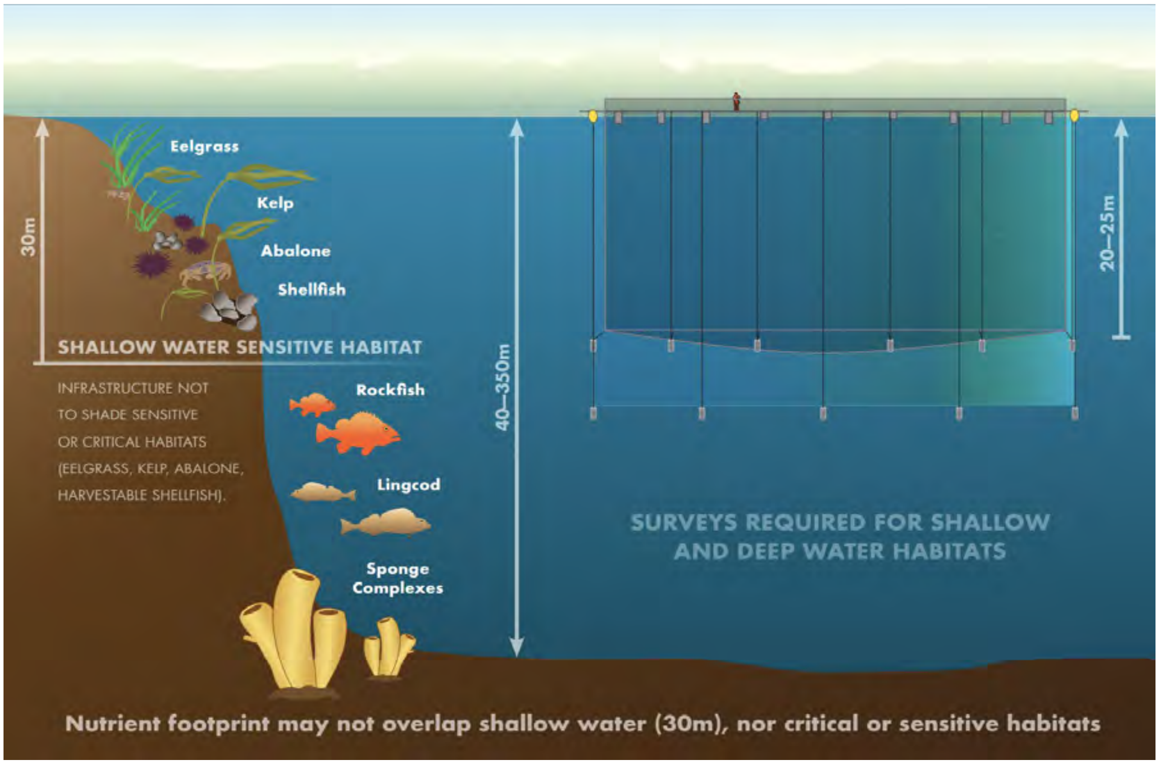


Figure 3. Schematic of potential critical and sensitive habitats and required baseline surveys and siting restrictions.

Information on wild fish and marine mammals must also be provided. This includes:

- Mapping historical Pacific herring spawn and completing standard stream assessments for wild salmonids within a five-kilometer radius of the proposed site (10),
- The application review process considers known salmon migratory routes, holding/rearing/resting areas for salmon, the status of the local Pacific Salmon Conservation Unit, and the location of anadromous salmonid spawning habitat,
- Marine mammal usage of the proposed area must be provided,
- Detailed maps are developed to show the potential placement of farm infrastructure along the seafloor and shoreline, information collected in the environmental surveys, and the results of the DEPOMOD simulations (Figures 4 and 5), and
- Management plans for fish production, fish health, escape prevention and response, and marine mammal interactions are also required in the initial submission to Front Counter BC.

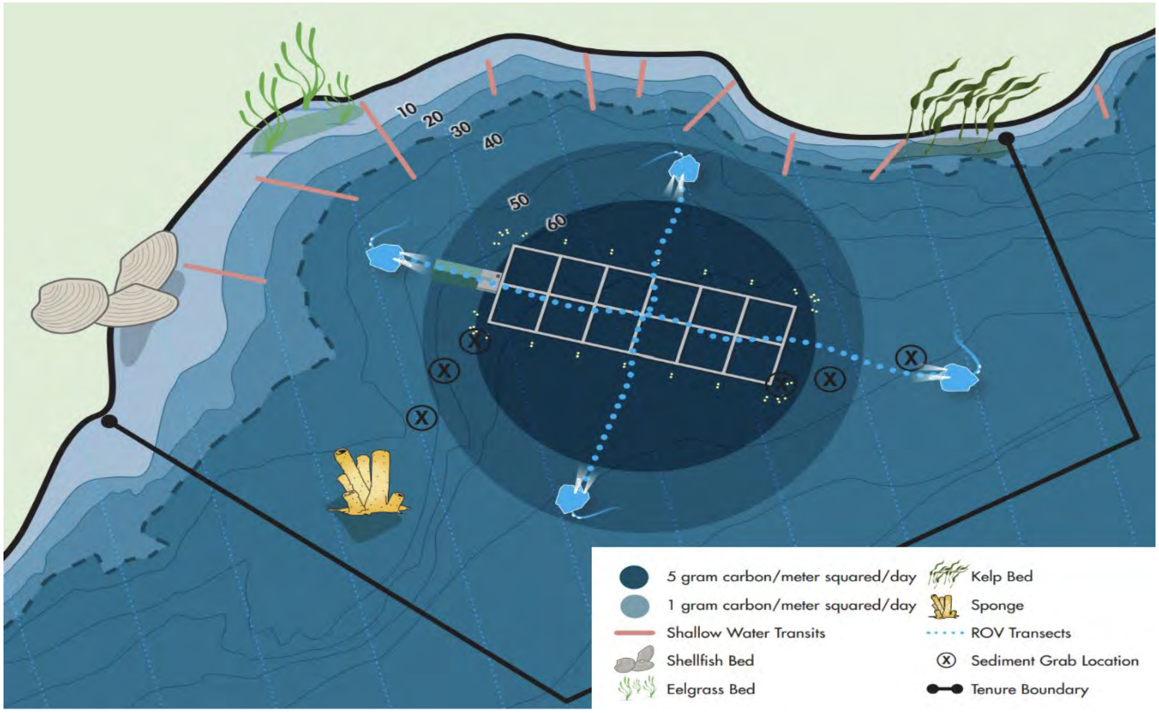


Figure 4. Depiction of proposed cage array, seafloor surveys and predicted nutrient footprint as estimated by the footprint simulation model DEPOMOD.

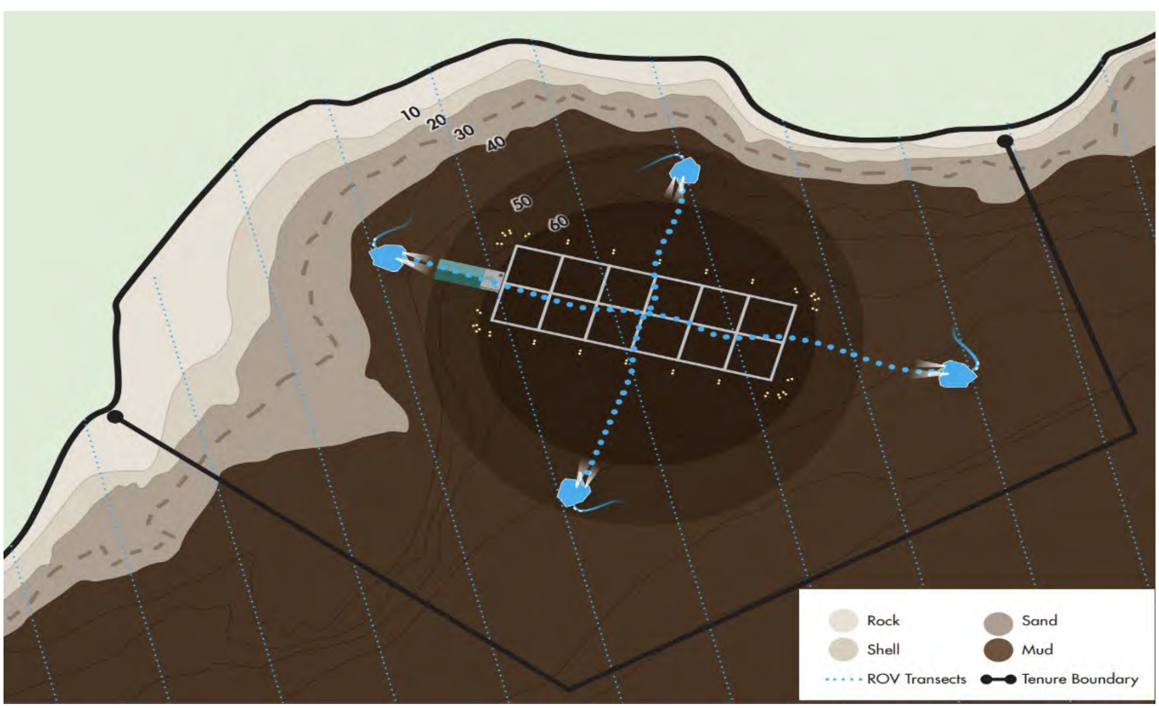


Figure 5. Depiction of seafloor habitats.

WHAT IS THE FOOTPRINT SIMULATION MODEL DEPOMOD?

DFO has management thresholds limiting both the size and intensity of the nutrient footprint of farms (9). Since 2004, DFO has required that all farmers use the simulation model DEPOMOD to estimate the dimensions of the nutrient footprint when the farm is using the maximum amount of feed during a production cycle (typically just before harvest) (11). The model is also used to predict the 'average' footprint for the entire production cycle.

The DEPOMOD model uses inputs on the size of the operation, location, feed inputs, and environmental data like current speed and direction and bathymetry, to track particles and predict the deposition of carbon and total solids and the impacts of that deposition on the benthic environment.

DFO considers a deposition rate of 5 grams of carbon/ meter^2/day of seafloor to be a threshold of significant impact. For any new farm or significant amendment, DFO will not allow the 5-gram carbon contour to overlap shallow water (less than 30 meters depth) (Figure 6). A carbon flux less than 1-gram of carbon has been shown to indicate a healthy and diverse benthic community (11); however, shoreline surveys are required if it overlaps with shallow water.

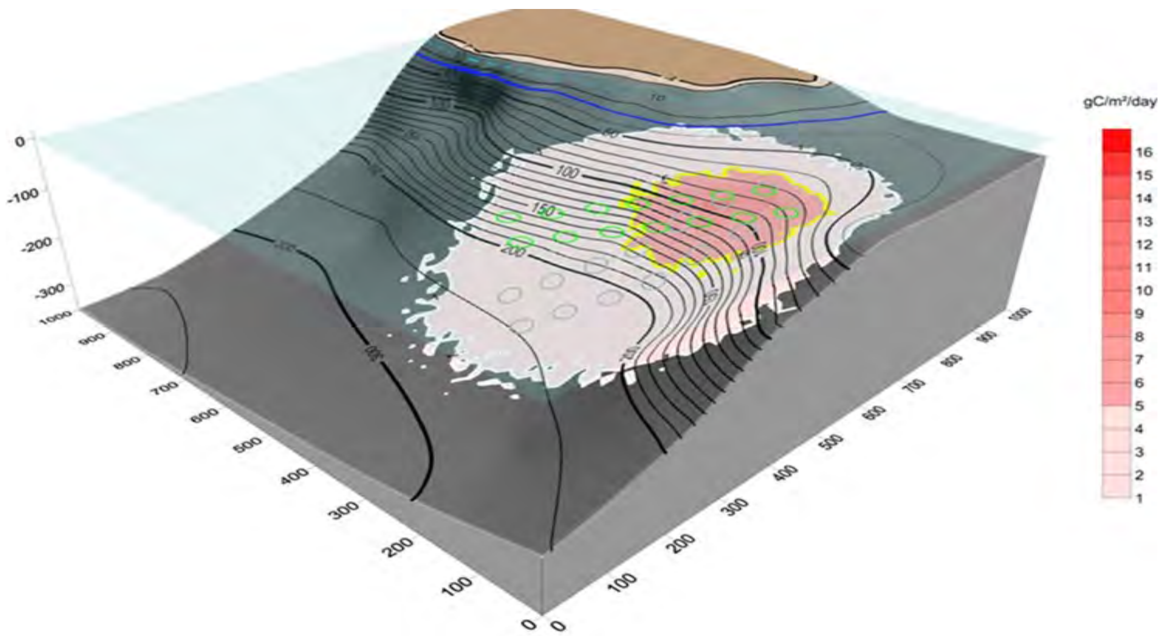
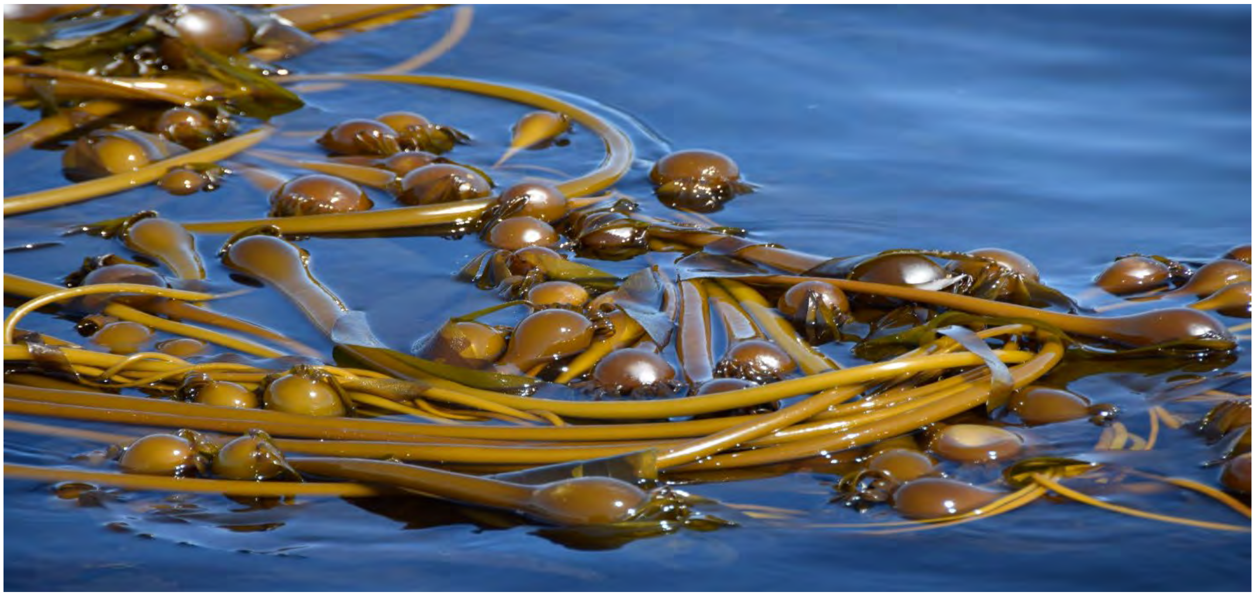


Figure 6. Example of DEPOMOD footprint simulation model.

Note: Farm cages shown as green circles. The shore is shown as brown. Black contours depict depth in meters. The predicted deposition of carbon (grams/m^2/day) is shown in the colored footprint, according to the legend bar on the right of the figure. The 5 gram carbon/m^2/day contour is outlined in yellow. The sensitive shallow water 30m depth contour is shown in dark blue. Note that the 5 gram carbon/m^2/day contour does not overlap shallow water. The majority of the footprint is closer to 1 gram carbon/m2/day, indicating a minimally impacted benthic environment.

EVALUATING A NEW SITE APPLICATION



The three agencies evaluate each application according to their mandates.

- DFO assesses each application according to the siting guideline themes, acts and regulations, and their Pathway of Effects for Finfish and Shellfish Aquaculture with consideration for mitigation measures (Appendix B) (12). If DFO considers the potential impacts to be unacceptable, the application may be declined.
- Transport Canada reviews infrastructure and locational details according to Navigation Protection Act rules. They also review environmental assessment information.
- The BC government assesses the infrastructure and intended use of the site for consistency with local land use bylaws and zoning, land use plans and marine plans, and checks for potential conflicts with the riparian rights of other upland owners and eelgrass meadows and kelp beds. They also have set back distances from First Nations reserves, parks and conservancies and salmon-bearing streams.
- All three agencies consult with local First Nations.

PROTECTING BIODIVERSITY - WHAT IS IN THE FARM FOOTPRINT?

The farm 'footprint' consists of three classes of substances managed under the Aquaculture Activities Regulation(9):

1. Biochemical oxygen-demanding matter (BOD) – nutrients released by uneaten feed and fish fecal material, and fouling debris that is removed from nets to maintain water flow,
2. Medicines – antimicrobials that are prescribed by licensed veterinarians, and
3. Pesticides – sea lice medicines that are prescribed by licensed veterinarians (Figure 7).

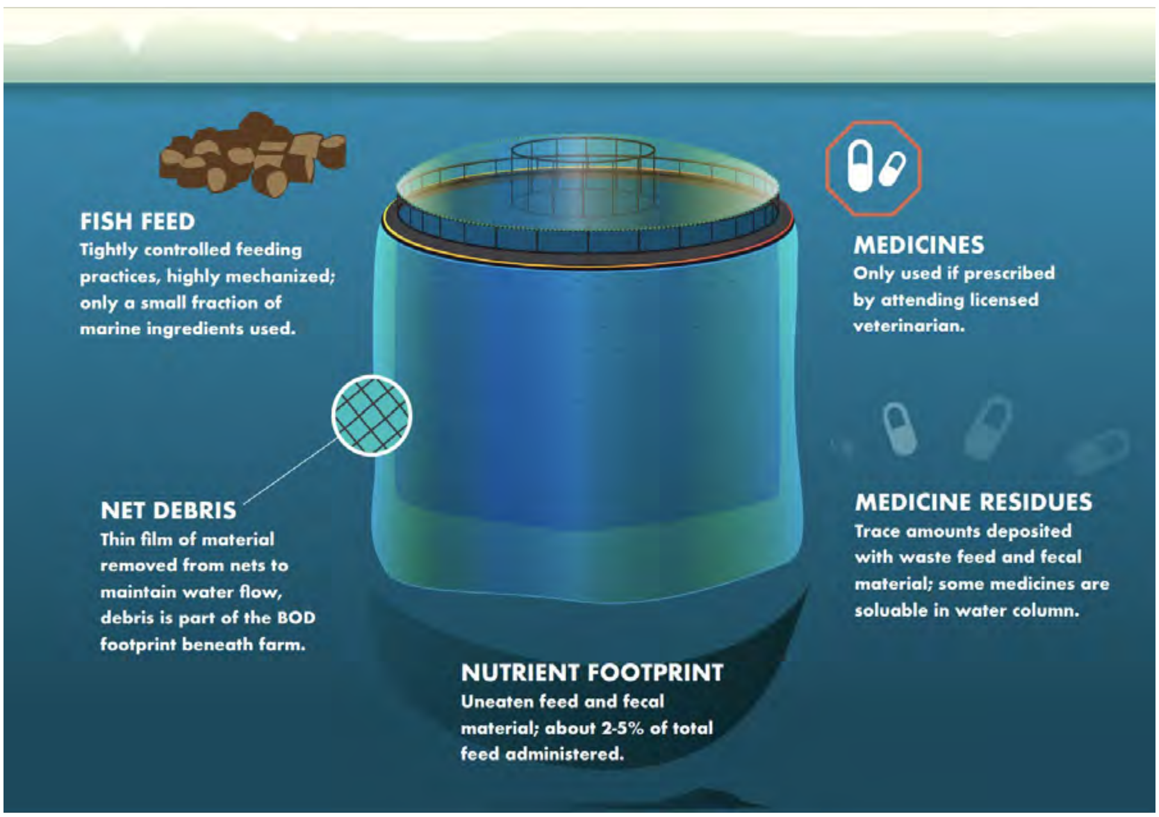
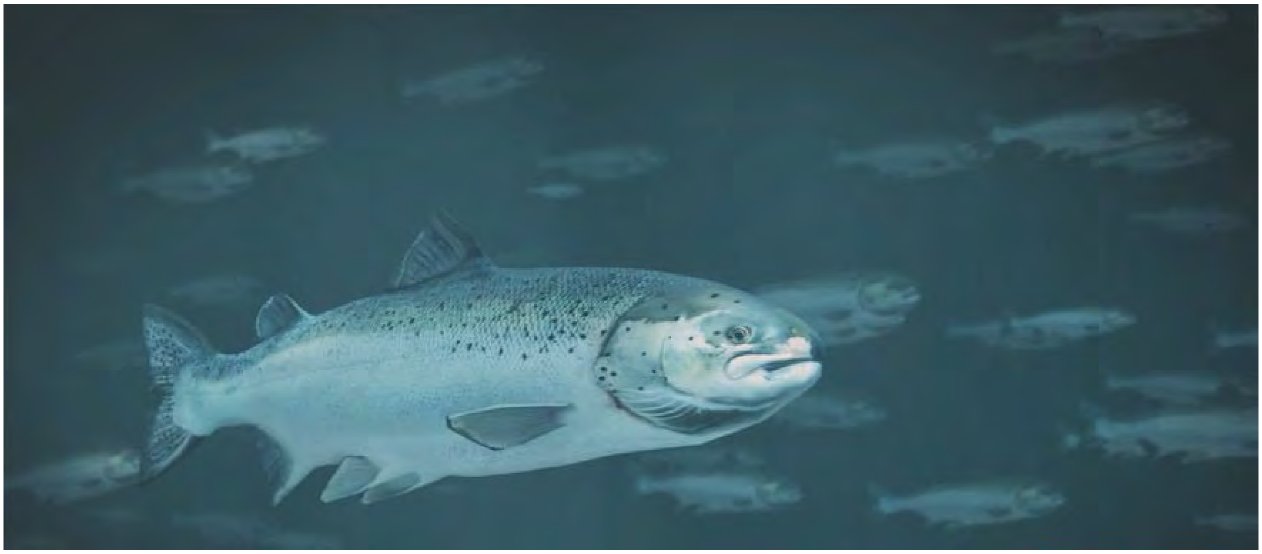


Figure 7. Schematic of inputs and outputs from cages at salmon farms in BC.
See "Chapter 7 – Caring for the Environment – Feed Sustainability", "Chapter 10 – Caring for Wild Salmon – Sea Lice Management", and "Chapter 11 – Caring for Fish Health" for more information on feeding practices and the use of medicines at sea sites.

WHAT IS IN THE NUTRIENT FOOTPRINT?



The nutrient footprint at a farm is created by the deposition of fish feces, minor amounts of fish feed, and biofouling material from net cleaning on the seafloor directly beneath and adjacent to the farms. This "BOD benthic footprint" is unique to each farm as it is dependent upon local currents, water depth, prevailing winds, bottom substrate, and farming practices.

The size, location and intensity of the "BOD benthic footprint" has been regulated in British Columbia since 2002 (initially the BC Waste Management Act, Finfish Aquaculture Waste Control Regulation) (13); and subsequently through DFO site aquaculture license conditions and the Aquaculture Activities Regulation.

Nets are maintained with small cleaning units that routinely remove thin skims of growth off the fibers to maintain water flow for the salmon (Figure 8). Any nutrients that fall to the seafloor are included in the thresholds administered in the Aquaculture Activities Regulation.

Trace elements such as copper and zinc are also found in uneaten feed and feces. At some farms, copper is used as a net antifoulant, although the majority of the BC sector has discontinued this practice.

The nutrient footprint (i.e., BOD benthic footprint) is *one of the primary drivers* determining where farms can be located, how many fish can be grown, and the length of the fallow period between crops. Individual farms and company fish production schedules rely on sustainable seafloor performance.

Figure 8. View of net scrubber in pen.
Routine net cleaning prevents biofilm build up on nets and maintains water flow for salmon.

WHAT HAPPENS TO MEDICINES USED ON SITES?

Veterinarians may prescribe treatments for fish. The use of antimicrobials (antibiotics) at BC salmon farms is strictly controlled in BC:

- Only products that are registered under the Pest Control Products Act (regulated by the Pest Management Regulatory Agency) and the Food and Drugs Act (regulated by the Veterinary Drugs Directorate of Health Canada) can be used (14), and only under the authority and supervision of a licensed veterinarian (Figure 9).
- The Aquaculture Activities Regulations requires that veterinarians consider using other non-chemical viable alternative measures. Where no alternative measures would be effective, the use of chemical products may be approved.
- Licensed veterinarians consider a variety of information, including fish behaviour, environmental conditions, laboratory tests, site records and information from monthly site visits and from an ongoing dialogue with site managers, to determine the appropriate prescription for maintaining the health of farmed fish (see "Chapter 11 – Caring for Fish Health" for more information).
- Unlike other agri-food sectors, antimicrobial use in salmon farming is only for clinical disease, there are no prophylactic treatments, and usage is tracked and publicly reported (15).
- All medications used at sites must be reported through the Aquaculture Activities Regulation(16).
- The two main antimicrobials used in BC are florfenicol and oxytetracycline. Both are broad-spectrum (effective against a variety of organisms) and administered as medicated feeds for short periods of time (example, 10 days).
- Florfenicol is primarily used to treat "yellow mouth" (also known as "mouth rot") infections caused by Tenacibaculum maritimum at sites with newly stocked Atlantic salmon (see "Chapter 11 – Caring for Fish Health" for more information). Once fish are larger than 500 grams, they are not generally susceptible to yellow mouth; therefore, florfenicol is typically administered for several weeks every two to three years at Atlantic salmon farm sites depending upon production cycles. On average, florfenicol was administered at 47.8% of marine sites each year from 2016 to 2021 (Figure 10).

Only products that are registered under the Pest Control Products Act (regulated by the Pest Management Regulatory Agency) and the Food and Drugs Act (regulated by the Veterinary Drugs Directorate of Health Canada) can be used at BC salmon farms, and only under the authority and supervision of a licensed veterinarian.

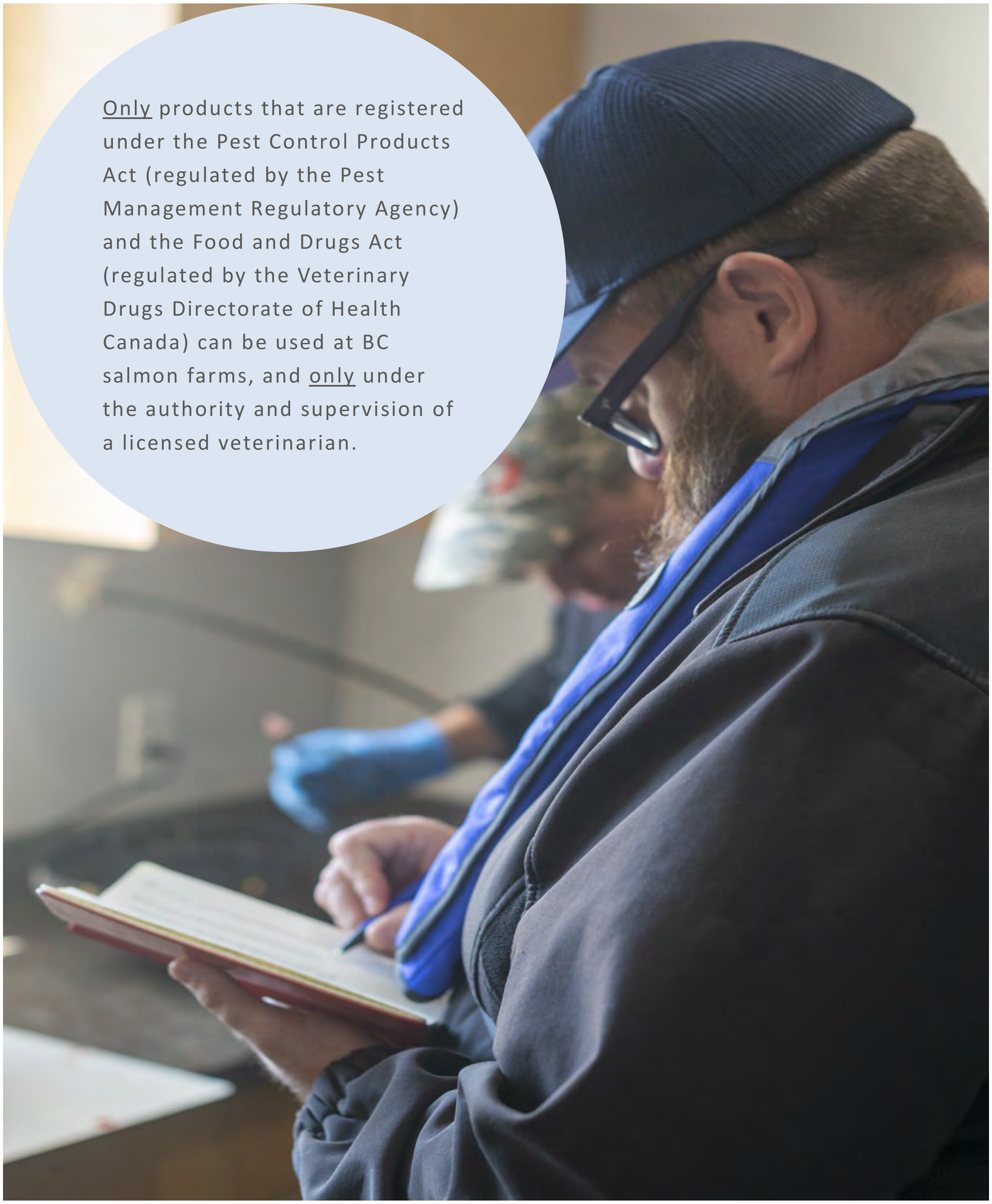


Figure 9. Licensed veterinarian completing a fish health check at a newly stocked Atlantic salmon farm.

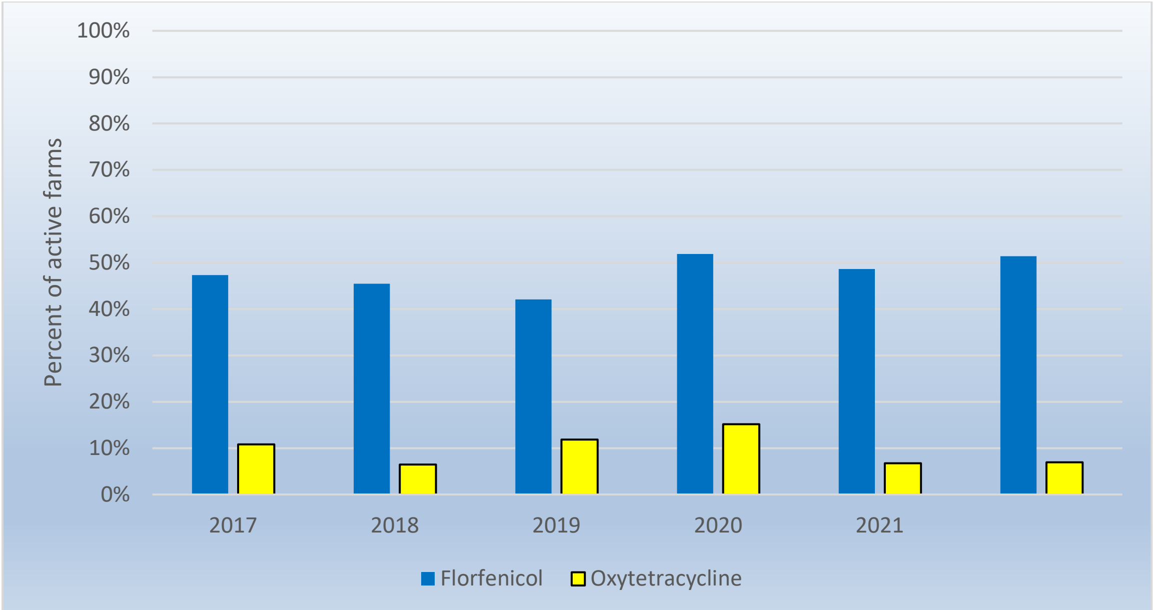


Figure 10. Percentage of active salmon farms in BC where florfenicol and oxytetracycline antimicrobial treatments were administered 2016 to 2021.
Data source: National Aquaculture Public Reporting Data (16)

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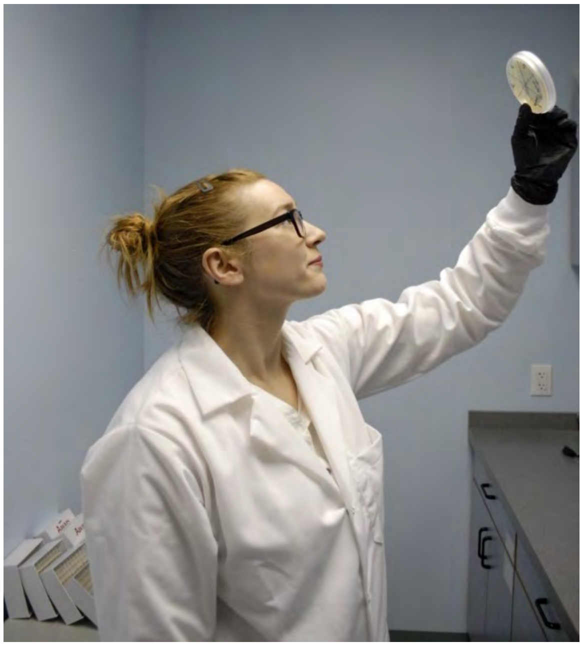
Oxytetracycline is used to control certain gram-negative bacteria that cause infections in salmonids (e.g., furunculosis, Vibrio, salmonid piscirickettsiosis (SRS), and bacterial kidney disease (BKD)). On average, from 2016 to 2021, oxytetracycline was administered at 9.7% of the sea sites (Figure 10). Erythromycin, an injectable antimicrobial, is rarely used in BC – it was used twice from 2016 to 2021, to treat bacterial kidney disease in broodstock fish not destined for consumption by consumers.

Very few farms used more than one antimicrobial in the same year (one to four farms/year out of an average of 75 operating farms/year) between 2016 and 2021. Vaccination of fish in freshwater, and improved vaccine efficacy have greatly reduced the need for antimicrobial treatments for several diseases (*Aeromonas salmonicida* (Furunculosis), *Vibrio anguillarum*, and *Moritella viscosa* (winter ulcer).

Fate in the Environment

The antimicrobials are delivered to salmon via food pellets. Residues may be released into the environment as either: dissolved within the water column, or within fish waste, or uneaten feed pellets.



Florfenicol is water soluble and breaks down in the presence of water (hydrolysis) and light (photolysis) thus limiting its persistence in the environment. Florfenicol is estimated to have a half-life (the time it takes to decrease to 50% of the original concentration) of 4.5 days in the sediment beneath farms (17), while oxytetracycline is around 150 days (18). Although oxytetracycline persists longer in the environment, it is considered to degrade rapidly in seawater (19), and its antimicrobial activity decreases once bound to the sediments (14). Oxytetracycline has low toxicity to crustaceans as it can be used to safely treat bacterial infections in crustaceans such as lobsters (20).

In a recent study of ten salmon farms in Canada, florfenicol was not detected in the sediments at any site, confirming that the antimicrobial disperses rapidly and is not readily absorbed into the seafloor, while oxytetracycline was detected within the enriched organic footprint of the farms (3).

Between 2019 and 2022 additional monitoring for florfenicol was completed for Aquaculture Stewardship Council certification in British Columbia. Samples during this monitoring were taken at stations 25m outside the 1g C/day DEPOMOD contour and at two reference stations. In all cases samples have been below the laboratory's detectable limit (2.0 -5.0 ppb). A key describing chemical concentrations is presented in Table 2. See Appendix C for descriptions of exposure and ecotoxicity in the marine environment.

Table 2. Description of chemical concentrations.

Solutions (mass per volume)		Solids (mass per mass)		Parts per notation	Example
g/L	mg/mL	g/Kg	mg/g	Parts per thousand; ‰	1 second in 17 minutes
mg/L	µg/mL	mg/Kg	µg/g	Parts per million; ppm	1 second in 11.5 days
µg/L	ng/mL	µg/Kg	ng/g	Parts per billion; ppb	1 second in 32 years
ng/L	pg/mL	ng/Kg	pg/g	Parts per trillion; ppt	1 second in 31,700 years

Both florfenicol (21, 22), and oxytetracycline have low toxicity (20), however rather than toxicity, most of the concern around the use antimicrobials is the potential for the development of antimicrobial resistance in fish, non-target organisms, the bacterial community, and even humans. The development of antimicrobial resistance is complex and depends on numerous factors such as:

- the type of bacteria present,
- the environmental conditions (ocean currents, seafloor bottom type) (Figure 11),
- the concentration of exposure to antimicrobials, and
- the duration of exposure to antimicrobials (in BC, fish receive medicated feed for short durations, typically ten days).

Researchers found that concentrations of oxytetracycline used within many aquaculture operations do not pose a high risk of causing major changes in sediment bacterial community structures, however the influence of local, site specific conditions warrants further investigation (23).

There are no environmental quality standards or threshold values for oxytetracycline deposition in Canada. Studies have developed Predicted No Effect Concentrations (PNEC) based on development of antibacterial resistance (which is more sensitive than traditional toxicity-based results). However, these values have either been derived for water or freshwater sediment exposures, and may not be appropriate for marine sediments, especially given the influence of sediment type and characteristics on the fate of oxytetracycline.

Currently there is no known evidence of harm to the surrounding marine environment due to the use of antimicrobials in salmon farming in BC. While antibiotic resistant genes (ARGs) have been detected in the vicinity of aquaculture sites in eastern Canada, the impact of these genes, which are found naturally throughout the marine environment, remains unknown.

A suggested Predicted No Effect Concentration (PNEC) for development of antimicrobial resistance is 10,000 ppb dry weight (2), which is ~100 times greater than the available measured concentrations in sediment in BC (3).

Recent data have shown that Atlantic salmon farms in the Bay of Fundy are host to vibrant microbial communities, and that these communities differ in structure depending on their distance from farm sites (24). Within these communities, as well as in microbial communities from reference sites and sites near wastewater treatment outflows, there was detection of ARGs.

These results highlight that ARGs are common in the marine environment, and that their concentrations in microbial communities can vary widely, over a million times (six orders of magnitude). However, the patterns and association of ARGs with antimicrobial drugs (e.g., florfenicol and oxytetracycline) were not consistent, and the implications for potential transmission to other organisms is yet unknown. Further research into this topic is ongoing.

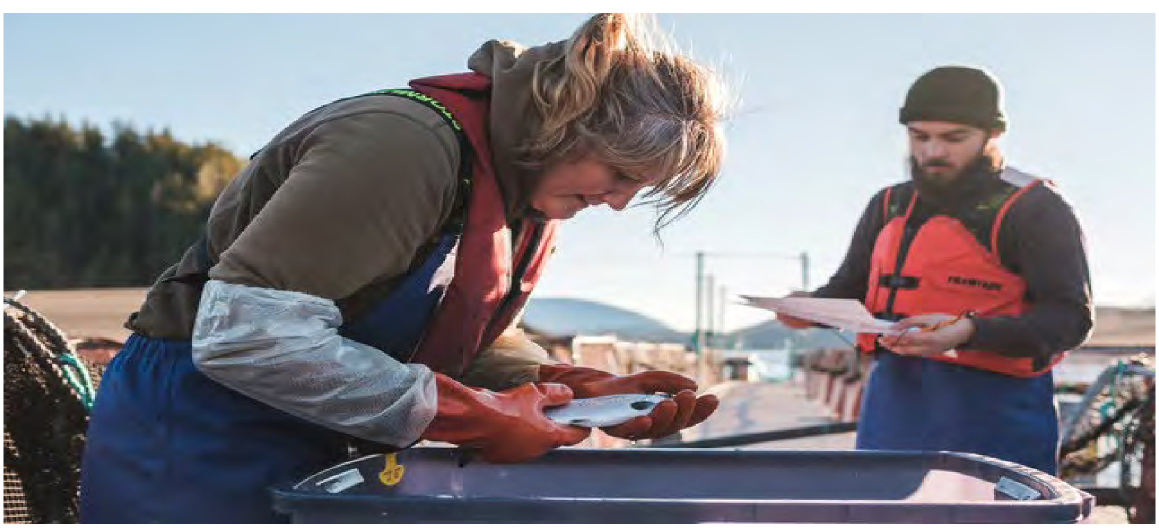
Figure 11. Underwater view of monitoring transect crossing into shallower nearshore water.

Note: Many salmon farms in BC have rocky bottoms with fast currents and little evidence of nutrient accumulation.

WHAT HAPPENS TO SEA LICE TREATMENT MEDICINES IN THE ENVIRONMENT?

Sea lice treatments generally occur at Atlantic salmon farms during the spring juvenile wild salmon outmigration window (March 1 – June 30). There are four methods veterinarians can prescribe to remove sea lice in BC: water jets (mechanical delousers), freshwater baths (Figure 12), emamectin benzoate (SLICE® - classified as an in-feed drug) and hydrogen peroxide (Interox®Paramove®50 – classified as a pesticide).

Figure 12. Sea lice are routinely removed in freshwater baths within the hold of the AquaTromØy vessel.
Note: The vessel has onboard reverse osmosis equipment that generates freshwater from seawater.



The use of chemical medicines to manage sea lice is strictly controlled in BC:

- Only products that are registered under the Pest Control Products Act (regulated by the Pest Management Regulatory Agency) and the Food and Drugs Act (regulated by the Veterinary Drugs Directorate of Health Canada) can be used (14), and only under the authority and supervision of a licensed veterinarian.
- Before the use of pest control products, the Aquaculture Activities Regulations requires that other non-chemical viable alternative measures be considered. Where no alternative measures would be effective, the use of chemical products may be approved.
- These products may only be used under the authority and supervision of a registered veterinarian, and their usage must be reported through the Aquaculture Activities Regulation (Source: Government of Canada, National Aquaculture Public Reporting Data) (16).
- The use of pesticides must follow the application details within the registered product label, while the determination of the appropriate prescription for the use of drugs is determined by the veterinarian.
- The prescribing veterinarian's decision is informed by trends in sea lice counts and site-specific aspects (i.e., life stage of farmed fish, environmental conditions, prior treatments, and conditions of license), and dialogue with site managers.
- The use of hydrogen peroxide in BC also requires a Pesticide Use Permit regulated by BC Integrated Pest Management Act (Source: Integrated Pest Management Act) (25).

Medicinal chemical treatments of sea lice at BC salmon farms are summarized in Figure 13. On average, SLICE® was administered to fish at 52% of sites and 22% of the sites administered Interox®Paramove®50 hydrogen peroxide treatments. No farm-raised Chinook salmon were treated for sea lice.

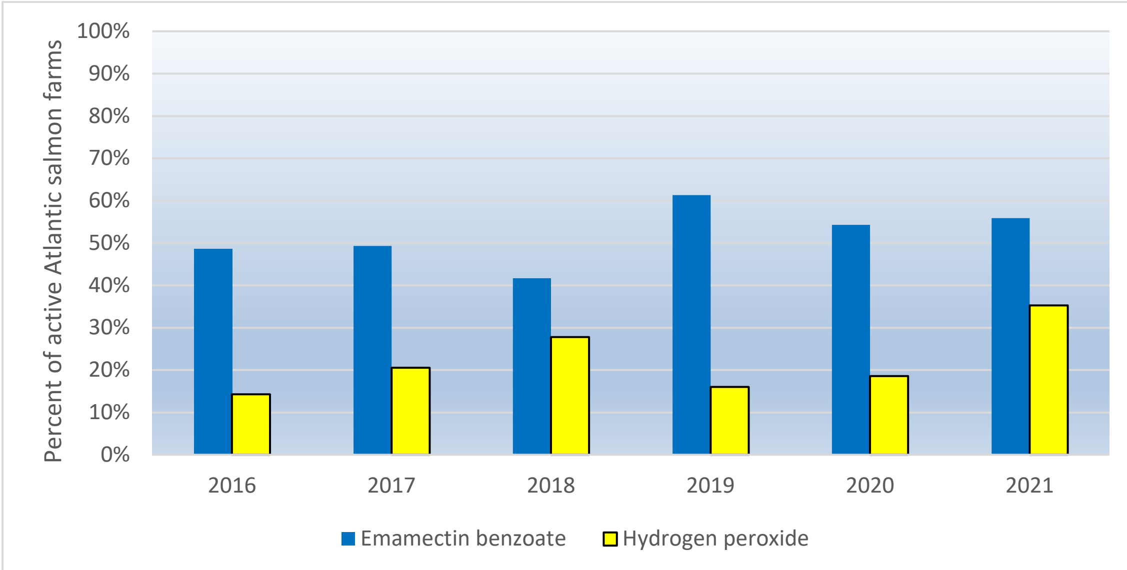


Figure 13. Percentage of active salmon farms in BC where sea lice treatments, Emamectin benzoate (SLICE®) and hydrogen peroxide (Interox Paramove® 50), were administered 2016 to 2021.
Data source: [National Aquaculture Public Reporting Data](#) (16)

EMAMECTIN BENZOATE (SLICE®)

Emamectin benzoate, also known as SLICE®, is added to fish feed for a short duration (typically seven days) to control all stages of sea-lice (motile and non-motile). SLICE® can offer protection against sea lice infestation for up to 60 days because it is slowly metabolized and excreted by treated fish. It is administered at ultralow doses (50 ppb), totaling on average 26 kg of active ingredient used for the entire BC salmon farming sector from 2016 - 2021 (16).

On average, BC Atlantic salmon farms treat 1.2 times per crop of fish (i.e., it is administered for about 1 week of the typical 72 to 96 week production cycle). The concentration of emamectin benzoate in medicated feed pellets ranges from 1 to 25 ppm; the most common dosage is 10 ppm (26).

SLICE® can enter the environment through fish waste and uneaten medicated feed. It has low water solubility (does not dissolve readily in seawater) and binds tightly with seafloor sediments (27) and is considered to be an immobile chemical that will not readily move into the environment (28). SLICE® has a reported environmental half-life (time it takes to reduce to 50% of the original concentration) between 100 and >400 days (29) (30).

The environmental concern with the use of SLICE® centers around the potential exposure to sea floor organisms including non-target crustaceans (e.g., crabs, shrimp and prawns) (31). Once SLICE® enters the environment there are three potential avenues of exposure for marine organisms:

- the dissolved fraction in the water column,
- direct consumption of medicated feed pellets or fish waste, or
- exposure to what is bound to the sediments.

Researchers have reported that American lobsters (32, 33), BC spot prawns (26), and BC Dungeness crab (34) avoid feed pellets that contain SLICE®. Given the general avoidance for feed pellets and preference for other food items, it is unlikely that the wild lobsters would ingest a sufficient amount of medicated pellets to cause the adverse effects observed in these laboratory studies which utilize force-feeding (31).

Photo by Brian Kingzett

For toxicity to be realized:

- an **organism has to be exposed** to the potential toxicant in its habitat, **AND**
- the potential toxicant has to be in a form that is **available for uptake**, **AND**
- the uptake (dose) of the contaminant has to be **at a level that causes toxicity** to the particular organism.

Researchers have reported that American lobsters, BC spot prawns, and BC Dungeness crab avoid feed pellets that contain SLICE®.

Photo by Brian Kingzett

In BC, a researcher found that BC spot prawns were able to detect and avoid medicated pellets containing low concentrations of emamectin benzoate (i.e., concentrations at the lowest range of doses used in feed pellets, and about one tenth the dose typically used in feed pellets) (26). No increased mortality or molting was observed with feeding spot prawns, even with feed pellets containing 4X the maximum potential dose used at salmon farms (26).

In a laboratory trial, BC spot prawns did not exhibit increased molting or mortality when directly fed pellets containing 4X the maximum medicated dose in feed pellets used at salmon farms.

Given that SLICE® has low water solubility and binds tightly with seafloor sediments, the likelihood that the therapeutant would be found in the water column around farm sites is very low (35). In 2011, an assessment of the fate of SLICE® near salmon farms in BC completed for the Canadian Science Advisory Secretariat (CSAS) reported ultra-low water column concentrations of 0.0006 parts per billion (ppb) emamectin benzoate within 50 meters of net pens one day after a SLICE® treatment, falling to below the method limit of quantification of the laboratory equipment for measuring water concentrations (0.000006 ppb) at a distance of 150 meters (36).

The main exposure pathway for organisms to SLICE® released in the environment appears to be through contact with sediments. Three studies in BC found low concentrations of emamectin benzoate in sediments near salmon farms, ranging from 0.07 to 35 ppb, with the majority below 1 ppb (3, 26, 36).

Figure 14. Deepwater video transect within farm nutrient footprint, food and fecal material are rarely seen in abundance.

In BC, reported concentrations of emamectin benzoate in sediments near salmon farms range from less than 0.07 ppb to 35 ppb, with the majority below 1 ppb. In laboratory trials, BC spot prawns have exhibited negative effects when exposed to sediments containing higher concentrations than what has been found near salmon farms in BC.

A laboratory-based examination of BC spot prawns reported negative effects following an 8-day exposure to sediment containing more than 100 ppb (wet weight) emamectin benzoate (37), however increased mortality was not observed at much higher sediment concentrations (1,200 and 4,800 ppb) (38). A second laboratory study found elevated mortality after thirty days of exposure to sediments containing 735 ppb (26). Molting was not affected in either study. These concentrations are higher than anything reported in sediments at salmon farms in BC (36).

With respect to crustaceans dwelling *within* the sediments beneath farms, in 2010, a laboratory-based examination of the Canadian west coast crustacean *Eohaustorius estuarius* reported that sediment concentrations of 185 ppb emamectin benzoate (wet weight of sediments) were toxic after 10 days of exposure (39). This sediment concentration is 5X higher than what has been observed in sediments near salmon farms in BC.

Toxicological studies examining the impact of emamectin benzoate on species other than the ones described above have been completed by researchers from other parts of the world; however, these might not be of direct relevance to resident species found in the coastal areas of Canada.

HYDROGEN PEROXIDE (INTEROX® PARAMOVE®50)

Figure 15. View of specialty vessel equipped with live wells in the hull where Interox®Paramove®50 treatments are performed.
Farm-raised fish are pumped into and out of the vessel for treatment.

Hydrogen peroxide (Interox®, Paramove®50) is used in sea lice treatment baths to cause pre-adult and mature lice to detach from the host fish. Atlantic salmon farmers have vessels with live wells that are designed to administer the treatment (Figure 15). Due to the capacity of the vessels, it takes multiple days to treat all the pens.

As hydrogen peroxide is water soluble and administered in the upper water-column it does not tend to be detectable in the sediment (40, 41). It is expected to remain in the water column for a short time following release and will rapidly disperse and degrade into its components of water and oxygen (42), and it is considered as non-persistent in the environment (14).

Hydrogen peroxide has a registered dosage of 1.2 – 1.8 g/L (42), and studies with tracker dyes have shown that concentrations of dye are reduced by a thousand times (three orders of magnitude) within 3 to 5 hours post release from a treatment tarp by dilution alone (43), suggesting that the combined actions of dilution and degradation of released hydrogen peroxide will quickly diminish concentrations.

The Pest Management Regulatory Agency (PMRA) has assessed potential impacts of the use of hydrogen peroxide on non-target species and concluded that "*the long-term use of hydrogen peroxide, taking cumulative impacts into consideration, is expected to not pose risks of concern to non-target marine organisms such as mammals, crustaceans, birds, adult lobsters, lobster larvae, copepods or fish." (42).*

For more information, please see the Registration Decision RD2016-18, Hydrogen Peroxide (44).

MEETING REGULATORY CONDITIONS FOR THE NUTRIENT FOOTPRINT

Seafloor monitoring occurs within 30 days of maximum fish tonnage at each site, in order to monitor the maximum nutrient footprint at each farm. Third-party BC Registered professional biologists are retained to complete the monitoring according to the requirements of the Aquaculture Activities Regulation (9). The type of survey depends upon the seafloor characteristics; defined as either "soft bottom" (where a sediment grab can be used) or "hard bottom" (where an underwater camera must be used).

In 2002, the BC Ministry of Environment set environmental thresholds for the farm nutrient footprint at "soft bottom" sites and prescribed underwater video monitoring methods for "hard bottom" sites where sediment grab samples were not obtainable (13). The thresholds were developed by studying thousands of organisms that live on the sea floor and their response to organic deposition from farms (45, 46). Two relatively easily measured chemical indicators, total free sulfides and oxygen reduction potential, were linked to enrichment responses of organisms within the nutrient footprint (47). The utility of using total free sulfide sediment concentrations as a proxy for environmental health was evaluated and reconfirmed by DFO in 2005 (48). In the case of "hard-bottom sites" which are monitored by underwater video, only minimal amounts of nutrient-enrichment-indicating worms and bacteria can be present. In 2010, DFO adopted the standards during the development of the British Columbia Aquaculture Regulatory Program and subsequent development of the Aquaculture Activities Regulations.

SOFT BOTTOM SEAFLOOR MONITORING

Based upon detailed environmental studies, a near-field threshold was set 30 meters from the cages for farms with "soft bottom" seafloors to ensure that nutrients released from farms would not significantly impact the variety of organisms associated with the sea floor habitat.

The threshold was set at the boundary between when sediments are well oxygenated (i.e., oxic) and the beginning of conditions when oxygen is less available (i.e., hypoxia) as defined by benthic scientists (45). A second threshold, about 125 meters from the cages, ensures that oxygen levels are near background conditions (i.e., oxic).

Soft bottom monitoring requires the collection of sediment from the ocean floor using a grab sampler at a distance 30m from the pen system and 125m from the pen system (Figures 16 and 17).

Sediment is collected from these locations on transects that follow the dominant and sub-dominant currents and consider the predicted nutrient footprint from DEPOMOD simulations, which is where the nutrients would most likely be deposited. Cage arrays longer than 200 meters that are perpendicular to the ocean currents require additional transects. Multiple grabs are collected from each station and tested for total free sulfide concentration and oxidation-reduction potential.

DFO will not permit farmers to restock the site unless total free sulfide concentrations are below 1,300 μM 30-meters from the cage array, and below 700 μM at 125 meters from the cages.

Figure 16. View of grab sampler and seafloor sediments.

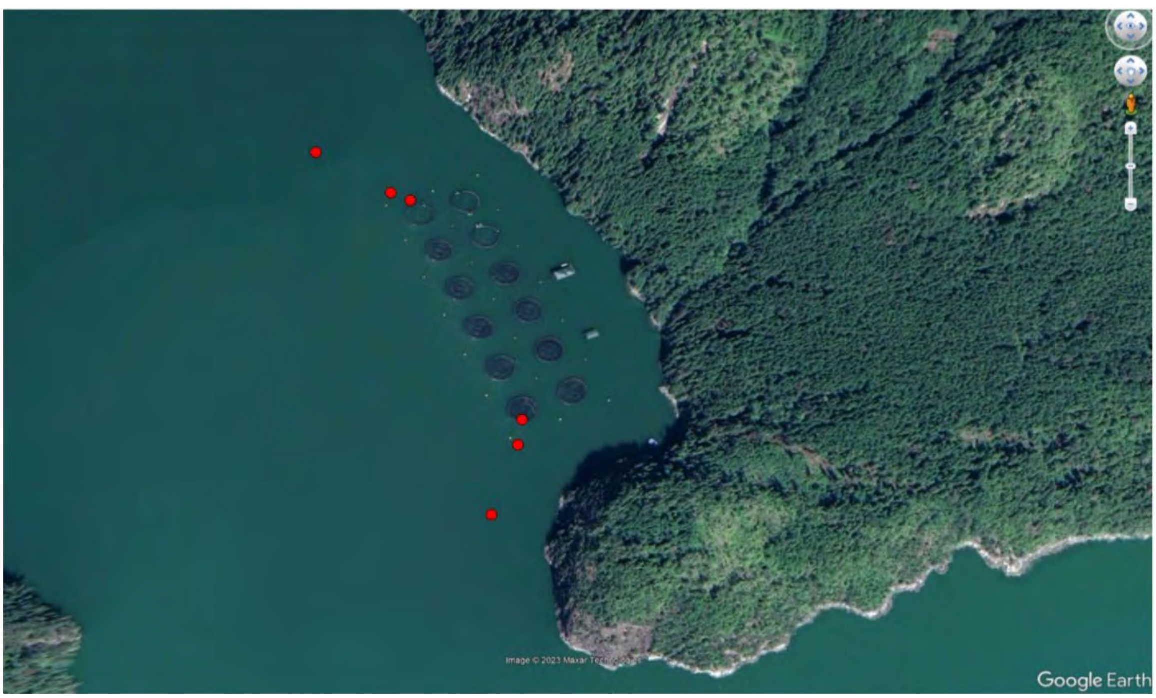


Figure 17. A typical two-transect monitoring survey design for a soft-bottomed site.
Grab samples are collected at cage edge, 30 meters and 125 meters from the array along dominant and sub-dominant current directions. Note that cage arrays longer than 200 meters require more than two transects if perpendicular to the current flow.

HARD BOTTOM SEAFLOOR MONITORING

Hard bottom monitoring requires the collection video of the ocean floor from the edge of the pen system out to a distance that is 140 m from the pen system. Video is collected using a remotely operated underwater vehicle (ROV) (Figures 18 and 19) along two to four individual transects depending on the orientation and length of the pen array (Figure 20).

Each transect video is divided into 4-meter-long segments. Organisms in each segment along with the substrate type in each segment are identified and counted by biologists. The amount of substrate covered by nutrient enrichment indicators (worm complexes and indicator bacteria) is estimated for each video segment.

DFO will not allow farmers to restock the site with fish until the amount of indicator worm and bacteria complexes are not greater than 10% in at least three of the six video segments between 100 and 124 meters from the containment array.

Additional monitoring may occur if requested by First Nations partners, DFO, or if companies are seeking a deeper understanding of the seafloor performance.

Figure 18. View of remotely operated underwater vehicle camera used to monitor “hard bottom” sites.

Figure 19. View of rocky habitat beneath a salmon farm. Image captured by underwater ROV.

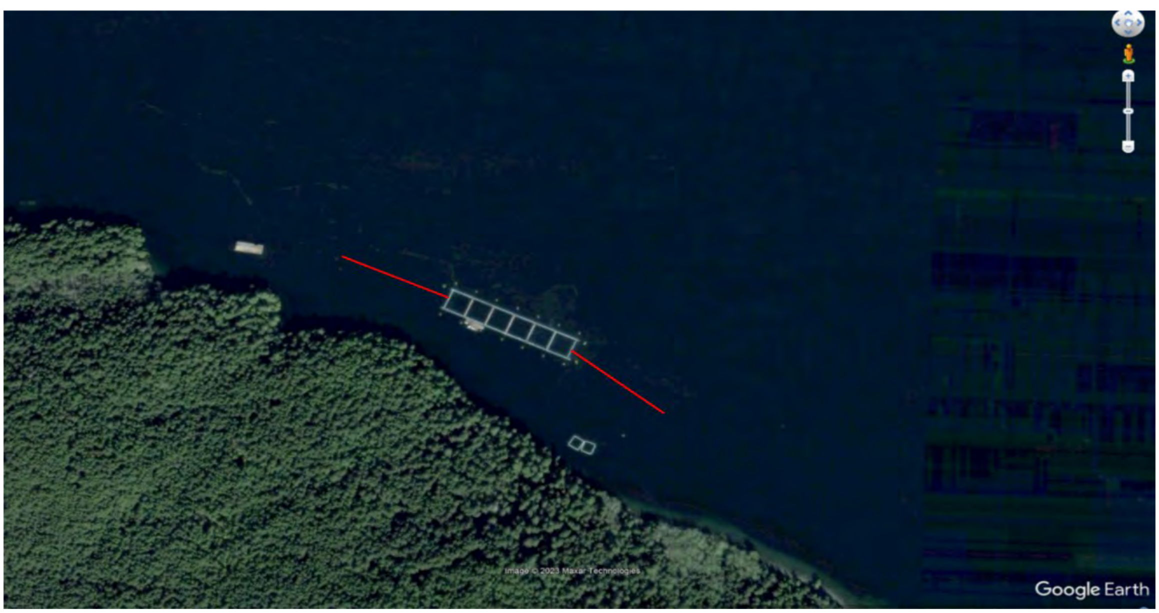


Figure 20. A typical two-transect underwater video survey design for monitoring a hard-bottomed site.
Note that cage arrays longer than 200 meters require additional transects.

Benthic monitoring results are very encouraging, with 86% of the sites over the last decade demonstrating a limited nutrient footprint on the seafloor that does not accumulate and is quick to recover.

DO FARMS MEET REGULATORY REQUIREMENTS?

The nutrient footprint has been monitored for more than 20 years in British Columbia. A summary of operational monitoring results is available online through DFO (49).

From 2011 to 2022 there were 592 regulatory surveys at salmon farms in British Columbia (Figure 21). The majority of surveys (86%) met the seafloor compliance thresholds, and no additional monitoring has been required prior to fish re-entry into the site. Sites that exceeded performance thresholds were required to complete an additional survey, after a fallow period, showing the site met the fish entry criteria before fish could be re-entered at the site.

To ensure the accuracy of the industry provided monitoring reports DFO completes random audits of the conditions of the ocean bottom at finfish aquaculture sites during the required peak biomass sampling window (30 days before or after peak biomass). Between 2011 and 2022 DFO completed 138 audits of industry monitoring and found similar results during 93% of those audits (50).

Photo by Brian Kingzett

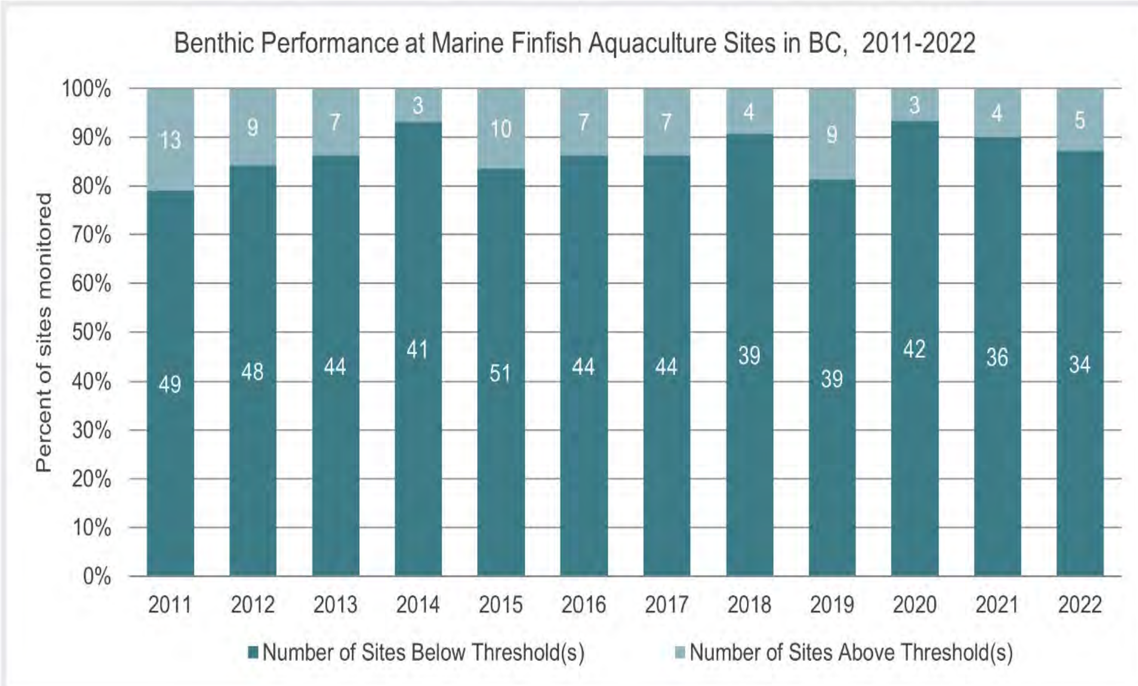
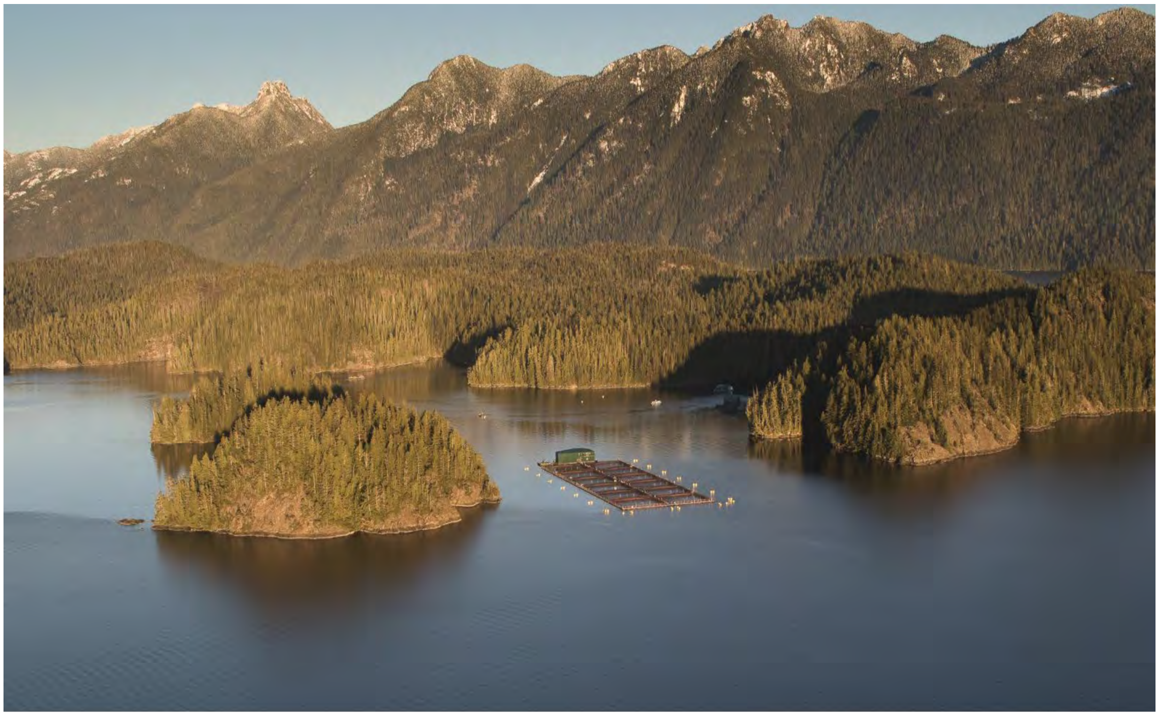


Figure 21. Benthic monitoring results at BC finfish aquaculture sites (2011 to 2022).
Data Source: [Benthic performance at marine finfish aquaculture sites in BC]

WHAT HAPPENS IF A FARM NUTRIENT FOOTPRINT EXCEEDS FEDERAL REGULATIONS?

If a threshold(s) is not met the farm must be left fallow until another survey is completed to ensure the thresholds are met. The benthic performance thresholds (soft or hard bottom) have been designed to limit the size and intensity of the BOD footprint, and make sure the seafloor recovers between crops.

> The Aquaculture Activities Regulation encourages farmers to have as light a footprint as possible; farms that have a heavier footprint will have a slower recovery timeline and cannot be restocked until sustainability thresholds have been met.



THIRD-PARTY AUDITS AND TRANSPARENCY

Seafloor monitoring results are available on the DFO website (49) and company websites with Aquaculture Stewardship Council (ASC) certification (51).

MITIGATION: HOW DO SALMON FARMERS MINIMIZE THE NUTRIENT FOOTPRINT?

Two decades of sea floor monitoring have helped farmers adapt production to optimize benthic performance and maintain the best growing conditions for fish. The deposition of nutrients and organic matter, as fish fecal matter and uneaten feed is now about 5% of the administered feed. (52). Further advancements in camera assisted feeding control and acoustic registration of lost feed pellets have likely reduced feed loss to about 3% (53) (11) (Figure 22).

Figure 22. View of feed camera within fish pen.

The regulatory framework has been effective to limit the size and location of the BOD benthic footprint, as well as make certain that sea floor recovery occurs between crop cycles. Companies have restructured to improve benthic performance, including:

- Reducing production at low-capacity sites,
- Repositioning cages to improve flushing,
- Closing non-sustainable sites,
- Improving fish feeding strategies (see "Chapter 7 – Caring for the Environment – Feed Sustainability"), and
- Shifting production to sites with higher capacity to assimilate nutrients (54).

HOW BIG ARE THE NUTRIENT FOOTPRINTS?

The "BOD nutrient footprints" typically center around the cage arrays and can be detectable about 30 – 300 meters from the cages (55). The majority of nutrients fall within 150 meters of the cages (56) and changes in organisms within the footprint are mainly found in this area. Based upon modeling estimates, a small amount (about 3%) of the particulate organic material is dispersed by currents more than 2 km away from the cages (57). This reflects the patchiness of the seafloor, which is often comprised of a complex mixture of rocky outcrops, mud, sand, cobbles, and broken shell (Figure 23). Tidal currents and local bathymetry affect how far nutrients may be transported. In general, feed is heavier than fecal material and tends to settle closer to the pens.

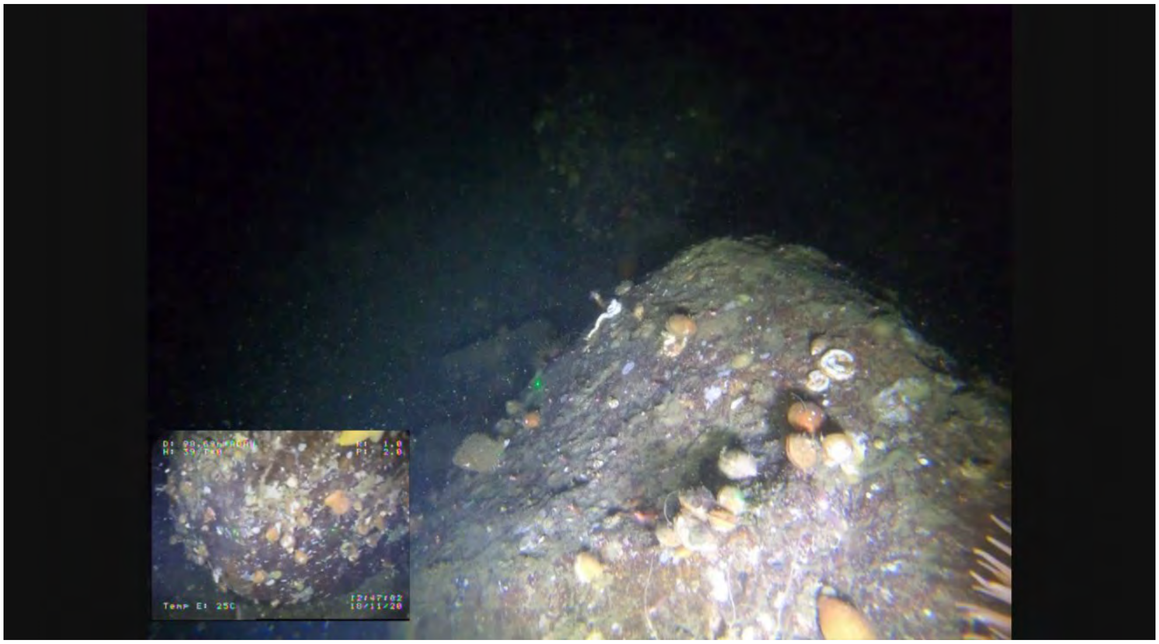


Figure 23. View of rocky habitat within the farm nutrient footprint.
Image captured by underwater ROV at peak biomass (maximum fish tonnage and maximum feeding).

A typical salmon farm produces 1 to 1.5 million pounds of salmon per hectare every two years in a cage array that is about 4 hectares in size. This is an incredibly efficient method of animal farming. Consider Canadian beef, which produces between 236 – 600 pounds per hectare per year (1).

IS THERE STILL LIFE UNDERNEATH A FARM?

Yes, it is generally accepted in the scientific community that low levels of organic enrichment can enhance benthic communities, while higher levels lead to negative community level impacts either directly from increased toxic sulfide concentrations, or through a reduction in dissolved oxygen levels (58). Regulated thresholds consider both sulfide and oxygen concentrations along the seafloor.

Undisturbed seafloor areas in coastal British Columbia have on average about 52 species of organisms that live in the sediments; the 30-meter near-field threshold of 1,300 μM total free sulfide has about 50% of that diversity (59). This means that farmers must ensure that the nutrient footprint is close to the farm with a high enough diversity to recover very quickly (Figure 24).

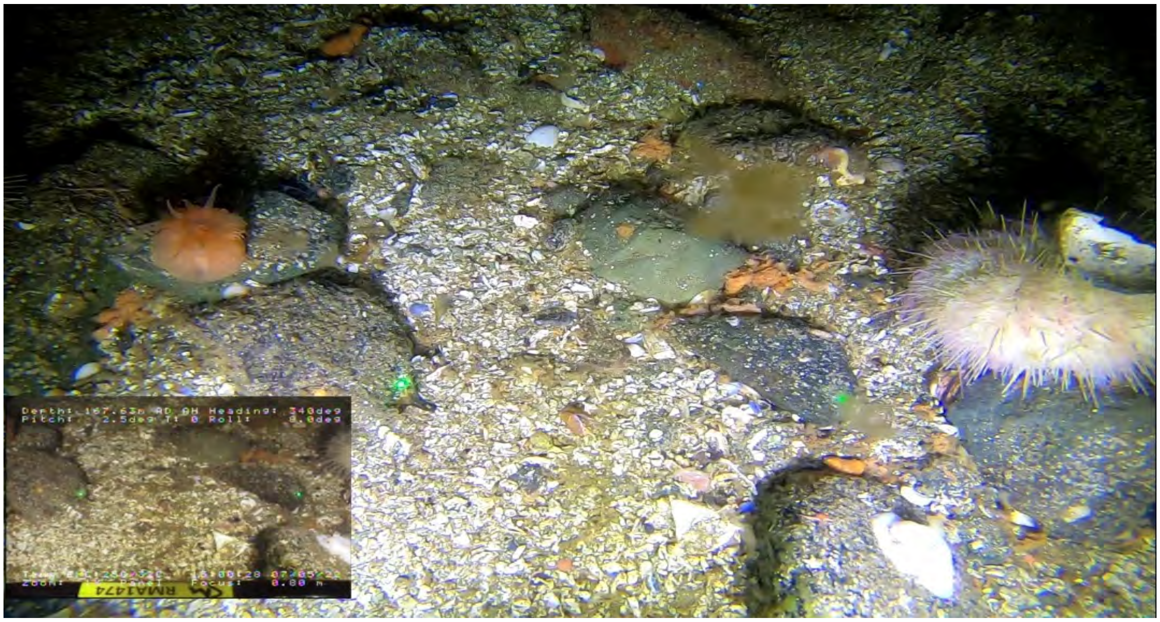


Figure 24. View of patchy seafloor habitat consisting of cobble, gravel and broken shell within the farm nutrient footprint.
Image captured by underwater ROV at peak biomass (maximum fish tonnage and maximum feeding).

HOW LONG DOES IT TAKE THE SEAFLOOR TO RECOVER FROM A FARM?

Nutrients are released from farms in "pulses" following the stocking-growing-harvesting-fallow cycle of each site. While variable, recovery generally occurs in two overlapping steps:

- Chemical recovery - aided by opportunistic organisms that consume the excess feed and fecal material, and
- Biological recovery – organisms that naturally lived within the footprint area begin to return as chemical recovery occurs; this follows the natural spawning cycle of the organisms (60). At some farms, biological recovery begins as soon as harvesting begins (60).

Some of the first salmon farms in British Columbia were located in areas with slow current speeds and highly depositional environments not well suited to farming. The worst-case scenario, Centre Cove, Kyuquot Sound, was estimated to require a 15-year recovery (61). Sites with high impact and long recovery timelines are clearly not environmentally nor economically sustainable. Over the years all farms with slow recovery have been phased out of production.

Today, most sites take less than three months of fallow to meet re-stocking thresholds and 86% of sites do not require additional surveys prior to re-stocking. The farm fallow period is an important part of taking care of the sea floor. It ensures that the benthic habitat can rest and recover between crops and gives farm staff time to get the site ready for the next fish.

Maintaining the health of the sea floor is a critical part of the six-year production plans for salmon farmers. Today most sites take less than three months to meet pre-stocking thresholds.

DO FARMS IMPACT WATER QUALITY?

BC waters are naturally rich in nutrients (62) originating from the many rivers and streams that flow to the ocean. Additionally, there is frequent nutrient upwelling, bringing nutrient-rich deep waters towards the near-shore surface (62). Warm, sunny summers with low winds can create the ideal conditions for plankton blooms in BC.

The promotion of a harmful algal blooms by the addition of nutrients discharged from salmon farms is feasible but unlikely to occur in the Pacific Northwest because the natural nutrient load is already very high. This is similar to other salmon farming regions in the world. For example, a 2012 study quantified the loading of nitrate from Norwegian salmon farms and found that it was <15% of the natural loading rate from deep water upwelling, suggesting the contribution from aquaculture is within safe limits (53).

Estimates for the amount of dissolved N that are predicted to be released from aquaculture vary between 35 – 120 kg of dissolved nitrogen per metric tonne of salmon produced (53), however this value has continually been decreased owing to improvements in feeding and reduction in food conversion ratios (ratio of the weight of feed added to the weight of fish produced, see "Chapter 7 – Caring for the Environment – Feed Sustainability".

Another approach to limit nutrient loading into the environment that is actively being explored is integrated multitrophic aquaculture (IMTA). IMTA is seen as a means of making aquaculture more sustainable and profitable, as the integration of other aquatic species from different, lower trophic levels (e.g., seaweed, sea cucumbers, mussels) may reduce the waste generated (as these species use waste as their source of nutrients), while providing ecosystem services (e.g., filtration, oxygen production) in addition to being harvested themselves. Further research into the best IMTA practices may lead to increased sustainability in salmon aquaculture.

Photo by Cascadia Seaweed

FUTURE GOALS

Salmon farming, with guidance from First Nations advisors, will continue to minimize potential impacts to biodiversity through prevention, monitoring, and mitigation. This includes adherence to the many federal and provincial laws and regulations that protect fish, fish habitat and wildlife in BC. In addition, ongoing and future research into additional vaccines and veterinary tools to support fish health programs, and continued innovations in feed and feeding practices may further improve the sustainability of the sector.

REFERENCES

1. Canadian Roundtable for Sustainable Beef (CRSB). 2016. National Beef Sustainability Assessment and Strategy summary report. Calgary, AB: : Canadian Roundtable for Sustainable Beef https://crsb.ca/wp-content/uploads/2021/12/Assessment-and-Strategy_summary_report_2016.pdf
2. O'Reilly A, Smith P. 2001. Use of indirect conductimetry to establish predictive no effect concentrations of oxytetracycline and oxolinic acid in aquatic sediments. Aquaculture.196(1):13-26.https://doi.org/10.1016/S0044-8486(00)00569-X
3. Kingsbury MV, Hamoutene D, Kraska P, Lacoursière-Roussel A, Page F, Coyle T, et al. 2023. Relationship between in feed drugs, antibiotics and organic enrichment in marine sediments at Canadian Atlantic salmon aquaculture sites. Marine Pollution Bulletin.188:114654.https://doi.org/10.1016/j.marpolbul.2023.114654
4. Kitasoo Xai'xais Nation. 2023. Klemtu Spirit: Kitasoo/Xai'Xais First Nation; [Available from: https://klemtuspiritsmokedsalmon.com/.
5. FAO. 2009. *Salmo salar*. Text by Text by Jones MEacbVCaMN: FAO.https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/en/en_atlanticsalmon.htm
6. Anon. 2017. Guide to the Pacific Marine Finfish Aquaculture Application. Government of British Columbia and Canada.https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/pacific_marine_finfish_aquaculture_application_guide.pdf
7. Fisheries and Oceans Canada. 2016. DFO siting guidelines for marine finfish aquaculture in British Columbia Ottawa: Government of Canada; [Available from: https://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/site-guide-direct-eng.html.
8. Canada FaO. 2018. Aquaculture Monitoring Standard - 2018. Ottawa: Government of Canada.https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-ann7-eng.htm
9. Fisheries and Oceans Canada. 2018. Aquaculture Activities Regulations guidance document. Ottawa: Government of Candada; Sept. 9, 2018. Contract No.: March 2024.https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/aar-raa-gd-eng.htm#purpose
10. BC Fisheries Information Services Branch. 2001. Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Standards and Procedures. Victoria, BC: Resources Inventory Committee, Province of British Columbia.https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/recce2c.pdf#:~:text=The%20reconnaissance%20is%20a%20sample-based%20survey%20covering%20whole,of%20habitat%20sensitivity%20and%20capability%20for%20fish%20production.
11. Chamberlain J, Stucchi D, Lu L, Levings C. 2005. The suitability of DEPOMOD for use in the management of finfish aquaculture sites, with particular reference to Pacific Region. Fisheries & Oceans Canada, Science, Canadian Science Advisory Secretariat. Report No.: 1499-3848.https://www.researchgate.net/profile/Lin-Lu-

17/publication/280091630_The_suitability_of_DEPOMOD_for_use_in_the_management_of_finfish_aquaculture_sites_with_particular_reference_to_Pacific_Region/links/55a7f38008ae481aa7f56437/The-suitability-of-DEPOMOD-for-use-in-the-management-of-finfish-aquaculture-sites-with-particular-reference-to-Pacific-Region.pdf

12. Fisheries and Oceans Canada. 2019. Framework for Aquaculture Risk Management (FARM). Ottawa: Government of Canada. 23 p.https://www.dfo-mpo.gc.ca/aquaculture/consultations/farm-cgra/farm-cgra-eng.html

13. "Point in Time" Regulation Content Environmental Management Act Finfish Aquaculture Waste Control Regulation, (2012).

14. Fisheries and Oceans Canada. 2021. Advice to inform the development of a drug and pesticide post-deposit marine finfish aquaculture monitoring program in support of the Aquaculture Activities Regulations. Ottawa, Ont.: Fisheries and Oceans Canada, Ecosystems nd Ocean Science. Report No.: 978-0-660-38356-9.https://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2021/2021_013-eng.html

15. Morrison DB, Saksida S. 2013. Trends in antimicrobial use in Marine Harvest Canada farmed salmon production in British Columbia (2003-2011). Can Vet J.54(12):1160-1163,

16. Open Government. 2024. National Aquaculture Public Reporting Data Ottawa: Government of Canada; [Available from: https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383.

17. Armstrong SM, Hargrave BT, Haya K. 2005. Antibiotic Use in Finfish Aquaculture: Modes of Action, Environmental Fate,and Microbial Resistance. In: Hargrave BT, editor. Environmental Effects of Marine Finfish Aquaculture. Berlin, Heidelberg: Springer Berlin Heidelberg. p. 341-357.https://doi.org/10.1007/b136017

18. Brooks B, Maul J, Belden J. 2008. Antibiotics in aquatic and terrestrial ecosystems. Encyclopedia of Ecology:210-217,

19. Samuelsen OB. 1989. Degradation of oxytetracycline in seawater at two different temperatures and light intensities, and the persistence of oxytetracycline in the sediment from a fish farm. Aquaculture.83(1):7-16.https://doi.org/10.1016/0044-8486(89)90056-2

20. Bayer RC, Daniel PC. 1987. Safety and efficacy of oxytetracycline for control of gaffkemia in the American lobster (Homarus americanus). Fisheries Research.5(1):71-81.https://doi.org/10.1016/0165-7836(87)90016-6

21. Florencio T, Carraschi SP, Cruz Cd, da Silva AF, Marques AM, Pitelli RA. 2014. Neotropical bioindicators of ecotoxicity and environmental risk of drugs with aquaculture interest. Boletim do Instituto de Pesca.40(4):569-576,

22. Basti D, Bouchard D, Lichtenwalner A. 2011. Safety of Florfenicol in the Adult Lobster (Homarus americanus). Journal of Zoo and Wildlife Medicine.42(1):131-133, 3, https://doi.org/10.1638/2010-0023.1

23. Suga N, Ogo M, Suzuki S. 2013. Risk assessment of oxytetracycline in water phase to major sediment bacterial community: A water-sediment microcosm study. Environmental Toxicology and Pharmacology.36(1):142-148.https://doi.org/10.1016/j.etap.2013.03.013

24. Murphy GM, Robinson SMC. 2022. Review of Antibiotic Resistance Genes (ARGs) in Salmon Aquaculture and Empirical Data on Spatial and Seasonal Trends in the Bay of

Fundy. Ottawa ON Fisheries and Oceans Canada. Available from: https://publications.gc.ca/collections/collection_2023/mpo-dfo/fs70-5/Fs70-5-2022-061-eng.pdf.

25. Integrated Pest Management Act, [SBC 2003] CHAPTER 58 (2003).

26. Park A. 2013. The biological effects of emamectin benzoate (SLICE®) on spot prawn (Pandalus platyceros). University of Vicrtoria.http://dspace.library.uvic.ca/bitstream/handle/1828/4530/Park_Ashley_MSc_2013.pdf

27. Bright D, Dionne S. 2004. Use of emamectin benzoate in the Canadian finfish aquaculture industry: a review of environmental fate and effects. UMA Engineering,.https://www.watershed-watch.org/publications/files/EnvCan-ReviewofSlice.pdf

28. Mushtaq M, Feely WF, Syintsakos LR, Wislocki PG. 1996. Immobility of Emamectin Benzoate in Soils. Journal of Agricultural and Food Chemistry.44(3):940-944.10.1021/jf950474v

29. Benskin JP, Ikonomou MG, Surridge BD, Dubetz C, Klaassen E. 2016. Biodegradation potential of aquaculture chemotherapeutants in marine sediments. Aquaculture Research.47(2):482-497.https://doi.org/10.1111/are.12509

30. Strachan F, Kennedy CJ. 2021. The environmental fate and effects of anti-sea lice chemotherapeutants used in salmon aquaculture. Aquaculture.544:737079.https://doi.org/10.1016/j.aquaculture.2021.737079

31. Waddy SL, Mercer SM, Hamilton-Gibson MN, Aiken DE, Burridge LE. 2007. Feeding response of female American lobsters, Homarus americanus, to SLICE®-medicated salmon feed. Aquaculture.269(1):123-129.https://doi.org/10.1016/j.aquaculture.2007.04.060

32. Burridge LE, Hamilton N, Waddy SL, Haya K, Mercer SM, Greenhalgh R, et al. 2004. Acute toxicity of emamectin benzoate (SLICE™) in fish feed to American lobster, Homarus americanus. Aquaculture Research.35(8):713-722.https://doi.org/10.1111/j.1365-2109.2004.01093.x

33. Waddy SL, Merritt VA, Hamilton-Gibson MN, Aiken DE. 2010. Effect of emamectin benzoate on the molt cycle of ovigerous American lobsters Homarus americanus is influenced by the dosing regimen. Aquatic Biology.11(1):47-52, https://www.int-res.com/abstracts/ab/v11/n1/p47-52

34. Aggelen GCv, Linssen M, Endris R, editors. 2003. Toxicity of emamectin benzoate in commercial fish feed to adults of the spot prawn and dungeness crab. Oceans 2003 Celebrating the Past Teaming Toward the Future (IEEE Cat No03CH37492); 2003 22-26 Sept. 2003

35. Fish Farm Advisory Group. 1999. Emamectin Benzoate, An Environmental Risk Assessment. Scottish Environment Protection Agency,.

36. DFO. 2012. Assessment of the Fate of Emamectin Benzoate, the Active Ingredient in SLICE®, near Aquaculture Facilities in British Columbia and its Effect on Spot Prawns (*Pandalus platyceros*). Nanaimo, BC: Centre for Science Advice (CSA) Pacific Region Fisheries and

Oceans Canada. Report No.: 1919-5087 https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/346389.pdf

37. Veldhoen N, Ikonomou MG, Buday C, Jordan J, Rehaume V, Cabecinha M, et al. 2012. Biological effects of the anti-parasitic chemotherapeutant emamectin benzoate on a non-target crustacean, the spot prawn (Pandalus platyceros Brandt, 1851) under laboratory conditions. Aquatic Toxicology.108:94-105.https://doi.org/10.1016/j.aquatox.2011.10.015

38. DFO. 2015. Proceedings of the Pacific regional peer review on the assessment of the fate of emamectin benzoate, the active ingredient in SLICE®, near aquaculture facilities in British Columbia and its effect on the Pacific Spot Prawn (Pandalus platyceros); October 18-19, 2011.https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs70-4-2015-057-eng.pdf

39. Kuo J-n, Buday C, van Aggelen G, Ikonomou MG, Pasternak J. 2010. Acute toxicity of emamectin benzoate and its desmethyl metabolite to Eohaustorius estuarius. Environmental Toxicology and Chemistry.29(8):1816-1820.https://doi.org/10.1002/etc.209

40. Burridge L, Weis JS, Cabello F, Pizarro J, Bostick K. 2010. Chemical use in salmon aquaculture: A review of current practices and possible environmental effects. Aquaculture.306(1):7-23.https://doi.org/10.1016/j.aquaculture.2010.05.020

41. Munn S, Allanou R, Aschberger K, Berthault F, De Bruijn J, Musset C, et al. 2003. European Union Risk Assessment Report. Hydrogen Peroxide. Luxembourg:: European Chemicals Bureau Institute for Health and Consumer Protection.https://publications.jrc.ec.europa.eu/repository/handle/JRC26024

42. Pest Management Regulatory Agency (PMRA). 2016. Registration decision RD2016-18 : Hydrogen peroxide. Ottawa, ON: Pest Management Regulatory Agency. Report No.: 1925-0940.https://publications.gc.ca/collections/collection_2016/sc-hc/H113-25-2016-18-eng.pdf

43. Ernst W, Jackman P, Doe K, Page F, Julien G, MacKay K, Sutherland T. 2001. Dispersion and Toxicity to Non-target Aquatic Organisms of Pesticides Used to Treat Sea Lice on Salmon in Net Pen Enclosures. Marine Pollution Bulletin.42(6):432-443.https://doi.org/10.1016/S0025-326X(00)00177-6

44. Canada H. 2016. PMRA (RD2016-18) Hydrogen Peroxide Ottawa: Government of Canada; [Available from: https://www.canada.ca/en/health-canada/corporate/request-publication-form.html?title=PMRA%20(RD2016-18)%20Hydrogen%20Peroxide.

45. Wildish D, Pohle G, Hargrave B, Sutherland T, Anderson R. 2005. Benthic monitoring methods for habitat management of finfish mariculture in Canada. Fisheries and Oceans Canada Canadian Science Advisory Secretariat. Report No.: 1499-3848.https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=810eb2096ed2244edcd79359083bf5a033cd9325

46. DFO. 2014. Potential impacts of finfish aquaculture on hard bottom substrates and development of a standardized monitoring protocol. St. John's, NL: Canadian Science Advisory Secretariat. Report No.: 1919-5087.https://publications.gc.ca/site/eng/474009/publication.html

47. Brooks KM. 2001. An evaluation of the relationship between salmon farm biomass, organic inputs to sediments, physicochemical changes associated with those inputs and the

infaunal response–with emphasis on total sediment sulfides, total volatile solids, and oxidation-reduction potential as surrogate endpoints for biological monitoring Final Report. BC Ministry of Environment.

48. DFO. 2005. Assessment of Finfish Cage Aquaculture in the Marine Environment. Ottawa, Ont. Report No.: 1480-4913

49. Fisheries and Oceans Canada. 2023. Benthic performance at marine finfish aquaculture sites in BC. Ottawa: Government of Canada.https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/benth/index-eng.html

50. Open Government. 2023. Results of DFO benthic audits of British Columbia marine finfish aquaculture sites Ottawa: Government of Canada; [Available from: https://open.canada.ca/data/en/dataset/c1a54a0c-4eb0-4b50-be1f-01aee632527e.

51. Grieg Seafood British Columbia. 2024. Reporting & Compliance: Greig Seafood ASA; [Available from: https://griegseafood.com/gsf-british-columbia-reporting.

52. Folkedal O, Macaulay G, Fosseidengen JE, Mikkelsen G, Myrland J, Søvegjarto B, et al. 2022. Deployment of hydroacoustic feeding control in salmon sea-cages; biological and technical considerations. Aquaculture.561:738700.https://doi.org/10.1016/j.aquaculture.2022.738700

53. Wang X, Olsen LM, Reitan KI, Olsen Y. 2012. Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture. Aquaculture Environment Interactions.2(3):267-283,

54. Backman DC, DeDominicis SL, Johnstone R. 2009. Operational decisions in response to a performance-based regulation to reduce organic waste impacts near Atlantic salmon farms in British Columbia, Canada. Journal of Cleaner Production.17(3):374-379.https://doi.org/10.1016/j.jclepro.2008.08.019

55. Hamoutene D, Hua K, Lacoursière-Roussel A, Page F, Baillie SM, Brager L, et al. 2021. Assessing trace-elements as indicators of marine finfish aquaculture across three distinct Canadian coastal regions. Marine Pollution Bulletin.169:112557.https://doi.org/10.1016/j.marpolbul.2021.112557

56. Chamberlain J, Stucchi D. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. Aquaculture.272(1):296-311.https://doi.org/10.1016/j.aquaculture.2007.08.051

57. Bannister RJ, Johnsen IA, Hansen PK, Kutti T, Asplin L. 2016. Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. ICES Journal of Marine Science.73(9):2408-2419.10.1093/icesjms/fsw027

58. Hargrave BT, Holmer M, Newcombe CP. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin.56(5):810-824.https://doi.org/10.1016/j.marpolbul.2008.02.006

59. Hargrave B. 2010. Empirical relationships describing benthic impacts of salmon aquaculture. Aquaculture Environment Interactions.1(1):33-46,

60. Brooks KM, Stierns AR, Mahnken CVW, Blackburn DB. 2003. Chemical and biological remediation of the benthos near Atlantic salmon farms. Aquaculture.219(1):355-377.https://doi.org/10.1016/S0044-8486(02)00528-8

61. Obee N. 2009. Chemical and Biological Remediation of Marine Sediments at a Fallowed Salmon Farm, Centre Cove, Kyuquot Sound, . B.C. Environmental Protection, BC Ministry of Environment.https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/aquaculture/remediation_aquaculture.pdf

62. Peña MA, Fine I, Callendar W. 2019. Interannual variability in primary production and shelf-offshore transport of nutrients along the northeast Pacific Ocean margin. Deep Sea Research Part II: Topical Studies in Oceanography.169-170:104637.https://doi.org/10.1016/j.dsr2.2019.104637

63. Ianni C, Bignasca A, Magi E, Rivaro P. 2010. Metal bioavailability in marine sediments measured by chemical extraction and enzymatic mobilization. Microchemical Journal.96(2):308-316.https://doi.org/10.1016/j.microc.2010.05.003

APPENDICES

APPENDIX A. ACTS AND REGULATIONS PROTECTING FISH, FISH HABITAT AND WILDLIFE IN BC

Fisheries Act https://laws-lois.justice.gc.ca/eng/acts/F-14/

Pacific Aquaculture Regulation https://laws.justice.gc.ca/eng/regulations/SOR-2010-270/FullText.html

Aquaculture Activities Regulation https://laws.justice.gc.ca/eng/regulations/SOR-2015-177/page-1.html

Species at Risk Act https://laws.justice.gc.ca/eng/acts/S-15.3/page-1.html

Coastal Fisheries Protection Act https://laws.justice.gc.ca/eng/acts/C-33/index.html

Canada National Marine Conservation Areas Act Canada National Marine Conservation Areas Act (justice.gc.ca)

Canada National Parks Act Canada National Parks Act (justice.gc.ca)

Canada Wildlife Act & Regulations Canada Wildlife Act (justice.gc.ca)

Park Act & Regulations Parks Canada Agency's Forward Regulatory Plan: April 1, 2022 – March 31, 2024

Migratory Birds Convention Act Birds protected under the Migratory Birds Convention Act - Canada.ca

Oceans Act https://laws.justice.gc.ca/eng/acts/O-2.4/rpdc.html

Health of Animals Act https://laws-lois.justice.gc.ca/eng/acts/H-3.3/

Food and Drugs Act https://laws-lois.justice.gc.ca/eng/acts/F-27/page-2.html#h-234115

Pest Control Products Act https://laws-lois.justice.gc.ca/eng/acts/P-9.01/

Navigation Protection Act https://tc.canada.ca/en/corporate-services/acts-regulations/navigation-protection-act-rs-1985-c-n-22

BC Land Act https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96245_01

BC Environmental Management Act https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/03053_01

BC Fisheries Act https://www.bclaws.gov.bc.ca/civix/document/id/consol26/consol26/00_96149_01

Protected Areas of British Columbia Act Protected Areas of British Columbia Act (gov.bc.ca)

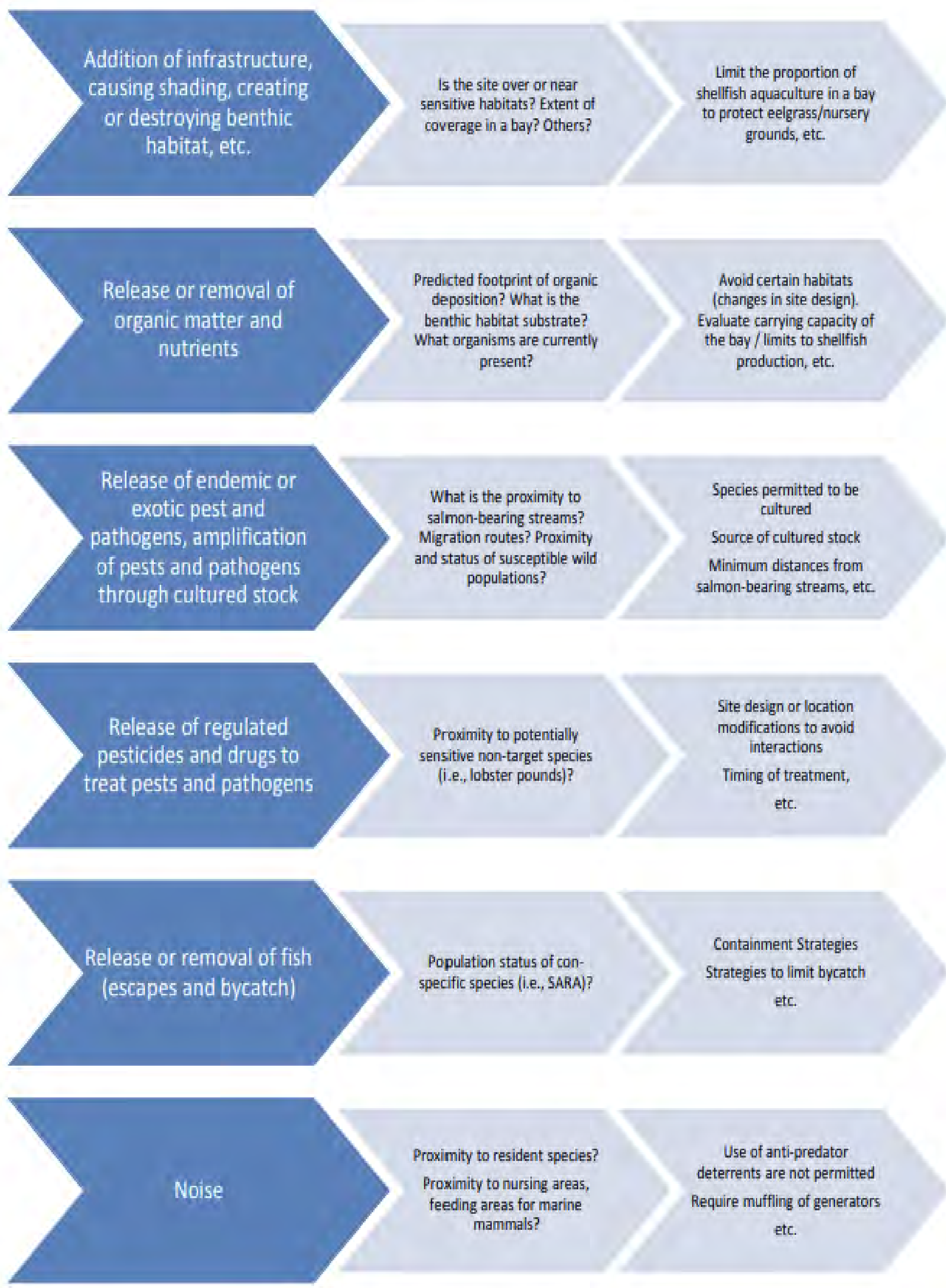
Ecological Reserve Act & Regulation Ecological Reserve Act (gov.bc.ca)

BC Wildlife Act & Regulations Wildlife Act (gov.bc.ca)

BC Integrated Pest Management Act https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/00_03058_01

Veterinary Drugs Act Veterinary Drugs Act (gov.bc.ca)

APPENDIX B. DFO AQUACULTURE PATHWAY OF EFFECTS



Key considerations and examples of potential stressors and risk mitigation options to avoid or limit effects on fish, fish populations and habitat. DFO source, Framework for Aquaculture Risk Management (12).

APPENDIX C. UNDERSTANDING CHEMICAL EXPOSURE AND ECOTOXICITY

Exposure

Once a chemical is in the environment, it has the potential to interact with organisms that live in that environment, this is termed exposure. The degree of exposure is often determined by the route through which the contaminant enters the organism. The route of uptake is important for determining whether adverse effects are likely to occur. With respect to exposure to aquaculture associated chemicals, two potential routes of exposure may occur. These include direct consumption of salmon feed and or contaminated sediments, or through passive contact with sediment and water.

Exposure via the water is unlikely given the rapid dissipation by ocean currents and the soluble nature of the antimicrobials florfenicol and oxytetracycline, and the sea lice treatment medicine Interox®Paramove®50. Conversely, the sea lice treatment medicine SLICE®, which is administered in the feed, has low water solubility meaning it will stay bound to particles. Dietary ingestion of fish feed has been shown to be limited in many species, especially when other food sources are available. Studies have repeatedly shown that lobsters, BC spot prawns and Dungeness crabs avoid eating feed pellets containing SLICE®. Uneaten pellets are likely to be incorporated into the sediments, making sediment exposures particularly relevant.

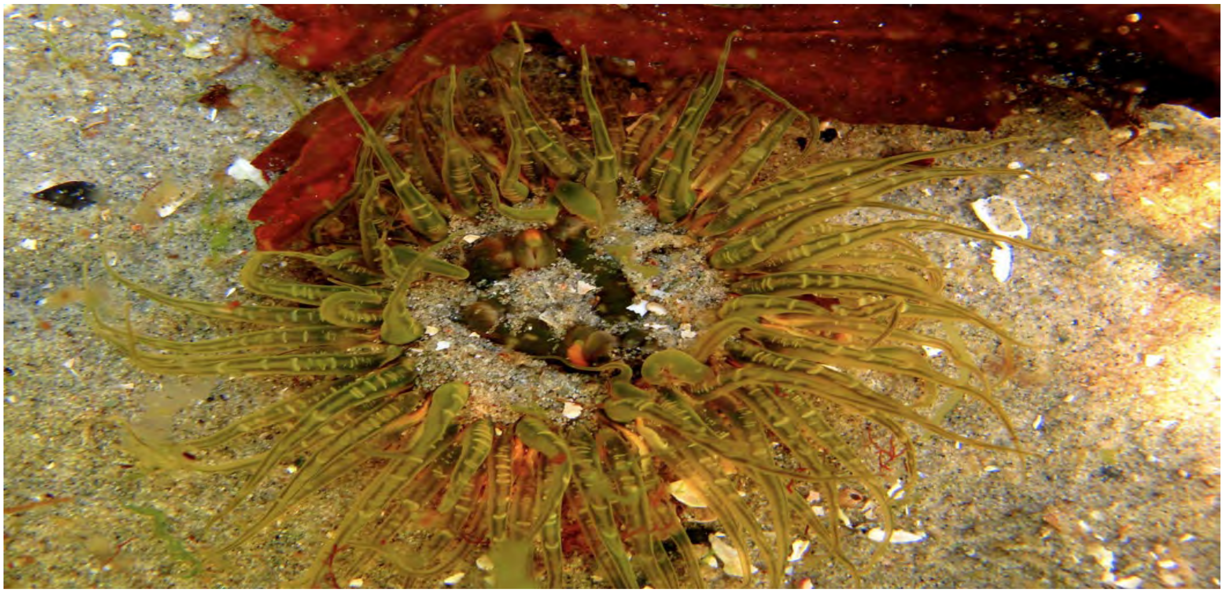
The bulk measurement of a contaminant in a sediment is not always a good predictor of potential effects. This is because the bulk measurement does not reflect the 'bioavailability' of that contaminant within the sediment. Bioavailability may be defined as the maximum amount of a contaminant which is available in the gut environment of an organism(63). Chemicals that have strong binding affinity for sediments like SLICE®, have lower bioavailability to organisms. Bioavailability in sediments is very complex, and is specific to the species, chemical, and environment. The bioavailability reflects the actual exposure of an organism and will dictate whether adverse impacts are observed.

Toxicity

For toxicity to be realized:

- an **organism has to be exposed** to the potential toxicant in its habitat, AND
- the potential toxicant has to be in a form that is **available for uptake**, AND
- the uptake (dose) of the contaminant has to be **at a level that causes toxicity** to the particular organism.

Understanding the toxicity of a compound to an organism in a laboratory test helps to understand the hazard associated with that compound and can inform risk assessments.



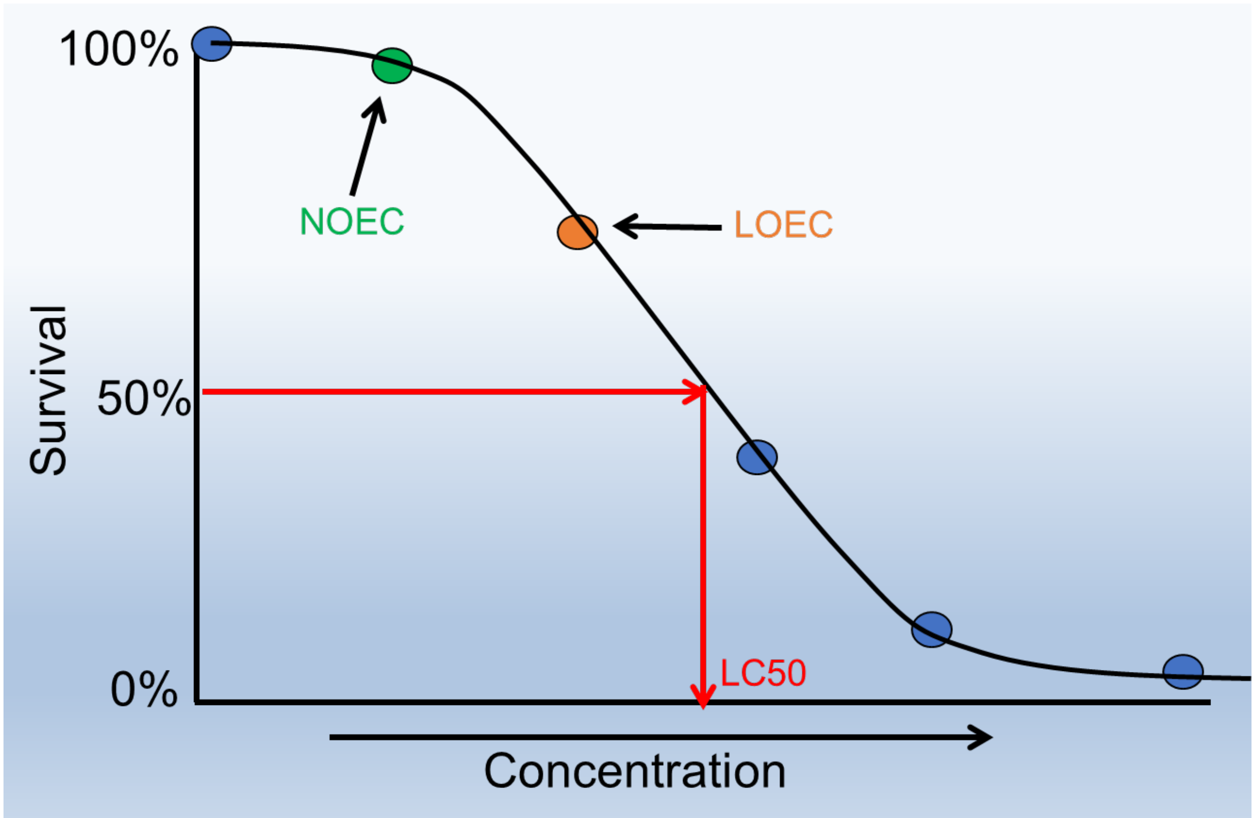
Many laboratory toxicity tests are designed to determine the hazard a specific toxicant has on a specific organism – that is to determine how much exposure is required (both the concentration and duration) in order for the organism to begin experiencing harmful effects. The toxicity tests may be:

- acute (high range of concentrations, short duration) or
- chronic (low range of concentration, long duration) in design, and
- tend to employ the early, most vulnerable life stage of an organism.

Depending on the biology and traits of the test organism, the toxicity test may be conducted in the water or sediment phase. The choice of exposure matrix (e.g., water or sediment) is also informed by the usage patterns and environmental fate of the test chemical. For example, for a chemical like emamectin benzoate a sediment toxicity test would be most appropriate because that chemical partitions to and persists in sediments. On the other hand, hydrogen peroxide does not reach or persist in sediments, and as such a water born exposure would be most appropriate.

Sediments are spiked with known concentrations of chemicals, either alone or in combination, to establish definitive cause-and-effect relationships between chemicals and biological responses.

At the end of the test period, the response of the test organism is examined in relation to a biological end point (e.g., survival, reproduction, growth). An example of the results from a typical toxicity study is shown in the figure below.



Example of a typical result from a toxicity test. The figure shows with increasing concentration (moving left to right), there is a decrease in survival. Each point along the curve represents a different concentration that was tested. The green circle is the last treatment concentration that has a response that is not statistically different from the control, this is termed the No Observed Effect Concentration (NOEC). The orange point is the lowest concentration that is significantly different from the control, this is termed the Lowest Observed Effect Concentration (LOEC). From the relationship between the concentration and the response, the concentration which is lethal to 50% of the population (LC50) can be mathematically determined.

These laboratory tests are very useful for generating data that can be used to compare the sensitivity of different organisms or comparing the response of the same species to different toxicants. However, it can be difficult to compare between different studies owing to differences in methodology (e.g., different sediment types, exposure durations), and especially if analytical determination of the test concentrations was not performed. Because of this, the results from each study must be considered within the context of their own objective, and in order to be used for other objectives, such as developing regulatory thresholds, their **reliability** (e.g., Did the study measure its concentrations? Did it employ appropriate experimental controls?) and **relevance** (e.g., Was the study performed with a species and life stage likely to be found in the area of interest? Was the exposure duration appropriate based on the environmental fate of the compound) must be evaluated. Differences in the reliability and relevance of studies are considered through a weight of evidence approach, where more reliable and relevant studies are given more weight when considering all available data.

Laboratory tests have limitations, in particular they cannot recreate everything that happens in the field environment. In the field there are numerous interactions and processes that act together to change the exposure and the response of organisms. In laboratory tests, these variables are tightly controlled, and the exposures are generally constant. As such, results from laboratory tests tend to be conservative compared to what would be observed in the field.

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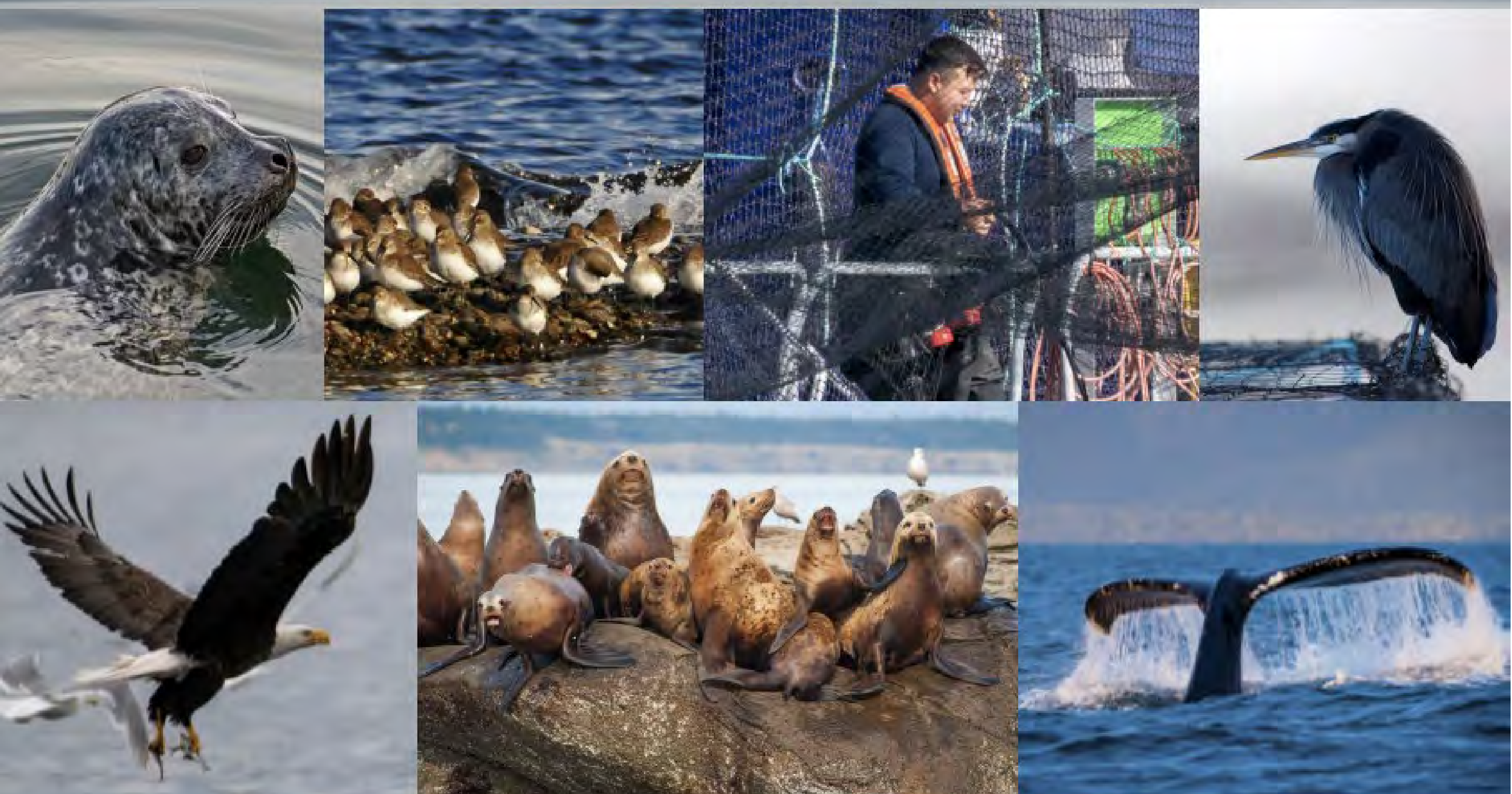
CHAPTER 9

CARING FOR THE ENVIRONMENT

MINIMIZING WILDLIFE INTERACTIONS



This document describes measures salmon farmers take to minimize interactions with wildlife and provides important statistics on wildlife interactions at farms in British Columbia

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Citation: BC Salmon Farmers Association. 2024. Caring for the environment -minimizing wildlife interactions *in* Modern Salmon Farming in BC: A Review. BC Salmon Farmers Association, Campbell River, British Columbia. 29 pages. available at www.bcsalmonfarmers.ca

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CHAPTER HIGHLIGHTS - MINIMIZING WILDLIFE INTERACTIONS

Interactions between wildlife and salmon farms occur in a variety of ways. The majority of these interactions are harmonious, consisting of viewing each other from a safe distance. On occasion, wildlife comes into close proximity to farms. Care must be taken to ensure wildlife, people and infrastructure are not harmed during these events.

Farmers focus on preventing interactions by minimizing both attractants and the ability for wildlife to access farm infrastructure. If these measures do not work, non-lethal deterrents (authorized by DFO) may be used to encourage wildlife to avoid the farm. Underwater acoustical deterrents are not permitted in BC.

From 2011 to 2022, there were 431 megafauna mortalities at salmon farms in BC. Almost all (98%) were California sea lions and harbour seals, reflecting increasing population growth in both species. In 2012, BC salmon farmers implemented a sector-wide management policy for seals and sea lions that included the implementation of mandatory prevention measures and a "no-kill" policy. Innovations in infrastructure and staff training have significantly reduced mortalities at farms. From 2013 to 2022, there were, on average, 10 mortalities per year at salmon farms in BC, which is approximately one mortality per seven operating farms yearly.

Sea lion and seal population growth will continue to challenge salmon farmers, given that salmon is naturally a part of the diet of these very intelligent animals. Salmon farmers are working with seal/sea lion biologists to further develop non-harmful deterrents and exclusionary infrastructure.

Six humpback whales interacted with salmon farms in BC from 2011 to 2022. An additional two interactions occurred with farms: one in 2008 and another 2009. Of the eight entangled humpback whales over the thirteen year period (2008 to 2022), five were successfully released unharmed (24). Unfortunately, the other three did not survive. The entanglements accounted for less than six per cent of all entanglements in B.C.

These events were related to mooring lines or nets located under farms. Operational changes to mooring lines were made after 2018 to reduce these interactions. DFO whale experts and regulatory personnel provide guidance/instruction to farmers in the event of an entanglement.

There have been no reported mortalities of sharks, turtles, otters, porpoises or dolphins at BC salmon farming operations.

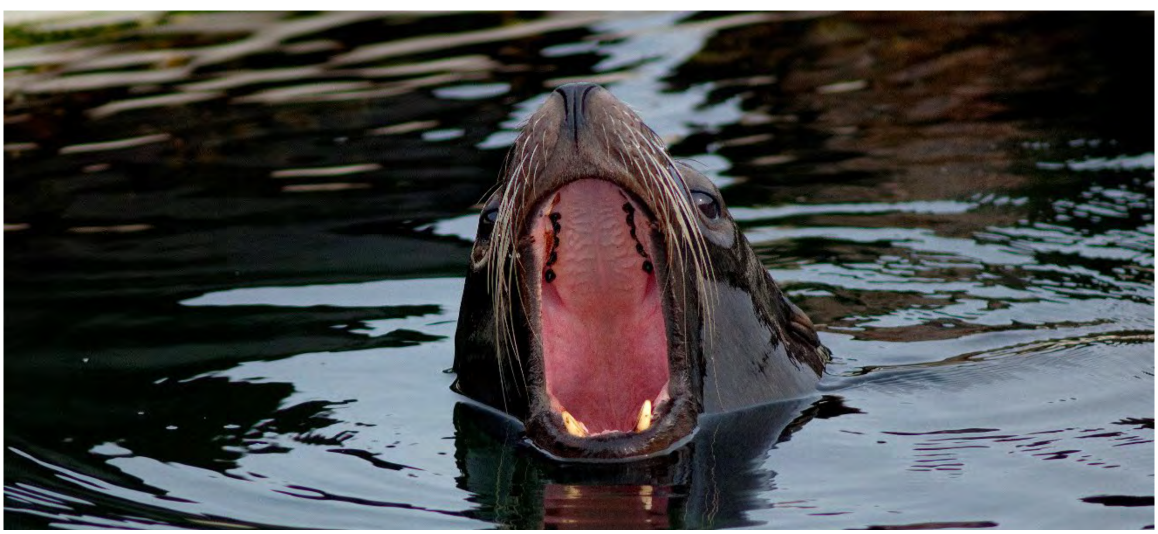

Photo by Brian Kingzett

TABLE OF CONTENTS