

Review of Marine Finfish Aquaculture Benthic Fish Habitat Monitoring Programs

Submitted to:

Fisheries and Oceans Canada
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Table of Contents

1	INTRODUCTION.....	1
1.1	Background	1
1.2	Objectives	1
2	METHODOLOGY	1
3	RESULTS TABLES.....	2
3.1	Canadian Jurisdictions.....	2
	Newfoundland & Labrador Region.....	2
	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)	5
	Pacific Region	13
3.2	International Jurisdictions.....	19
	Scotland.....	19
	Norway	29
	United States (Maine)	33
	Australia (South Australia)	38
4	CONCLUSION	41
5	REFERENCES.....	47



1 Introduction

1.1 Background

Habitat Protection Division (HPD) of Fisheries and Oceans, Canada (DFO) is responsible for the conservation and protection of fish habitat pursuant to the habitat protection provisions of the *Fisheries Act*. As such, HPD must assess the potential impact of proposed development projects on fish and fish habitat. Specifically, HPD must identify the fish habitat potentially impacted by a proposed project and determine whether a harmful alteration, disruption or destruction (HADD) of fish habitat is likely as a result of the project.

Like other development projects, HPD must assess the potential impacts of finfish aquaculture sites on fish and fish habitat. The highest risk to fish habitat from finfish aquaculture sites is due to the potential accumulation of organic waste (excess feed and feces) on benthic habitat during site operations. HPD's assessment of the risk to fish habitat due to waste accumulation considers site biophysical conditions (i.e., substrate type, productivity, flushing rate, etc.), site set-up and operations (e.g., feed management). Data collected by the proponent, including visual observations and benthic samples, is used by HPD to conduct its assessment. The information collected during the site assessment and review process is also used for post-operation monitoring to verify habitat impact predictions and/or to determine whether additional mitigative or management measures, including an Authorization under Section 35(2) of the *Fisheries Act* for a HADD of fish habitat, are necessary.

1.2 Objectives

The objective of this report is to summarize current national and international approaches and methodology for benthic fish habitat monitoring associated with **marine finfish aquaculture** operations. This information is to focus on regions with similar oceanographic conditions (i.e., hard substrate, seasonally cold ocean). It will be used to inform HPD and the Finfish Aquaculture Habitat Management Committee (FAHMC) to facilitate updating and revising the existing Newfoundland Region Finfish Aquaculture Fish Habitat Monitoring Program.

2 Methodology

The study involves a review of publically-available documentation, especially that available from various Internet sources. Information collection was guided according to the following methodology:

- The focus of the study will be on marine finfish aquaculture in Canadian jurisdictions (Newfoundland & Labrador Region; Pacific Region and Maritimes Region) and international jurisdictions with similar oceanographic conditions. The international jurisdictions investigated included Scotland, Norway, United States (Maine), and Australia (Southern Australia).
- The focus of this report is on hard bottom substrates. However, soft substrate monitoring programs may be included based on methodology (statistical design, timing).
- Results of this investigation are provided in the tables below.



3 Results Tables

3.1 Canadian Jurisdictions

Monitoring Program Component	Newfoundland & Labrador Region
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> • Proactive – The purpose of the monitoring is to verify impact predictions and adaptive management/mitigate to avoid a HADD (Pers Comm, HPD).
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> • Assess benthic fish habitat condition in cage area and effectiveness of one year fallow mitigation measure: use of indicators to assess the health of benthic habitat
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> • Provincial Aquaculture Cage Culture application includes site layout development/production plans, water/site quality, baseline benthic sampling, and stakeholder consultation information. • Community-Based Coastal Resource Inventory (GIS tool identify fisheries-related resources in the area of a proposed aquaculture facility (DFO, 2009) • DFA/DFO ‘Benthic Environment Monitoring Index’ for Baseline and Part 2 Monitoring Data • Siting conditions (<30m depth, 1 km site separation, 1 year fallow, etc.)
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<p>Finfish Aquaculture – Farm Monitoring Report for Fish Habitat assesses benthic conditions pre and post fallow (DFO, 2010a).</p> <ul style="list-style-type: none"> • Part 1 (at beginning of fallow period) to be completed between two weeks before and after fallowing starts • Part 2 completed four to eight weeks before end of fallow period • Video and benthic sampling (redox and sulphide) • Completed every rotation cycle until a “steady state” is attained; if no change in production or species farmed and monitoring indicates no HADD for two consecutive fallow periods then, monitoring report once every second rotation period or once every six years • No grab sampling within 6 months of a disease outbreak. If disease outbreak within 6 months of the start of the fallow period, only Part II is completed, and only after a minimum six month fallow period. <p>Baseline Monitoring (Department of Fisheries and Aquaculture Cage Culture application form)</p>
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<p>Finfish Aquaculture – Farm Monitoring Report for Fish Habitat:</p> <ul style="list-style-type: none"> • Video and sediment samples for both Part I and Part II (Part II may not be required if Part I indicated no accumulation of organic material from the farm.). <ul style="list-style-type: none"> ○ Clock method: each cage edge. ○ Description of images on video (e.g., substrate type). • Sediment collection: each cage where video identifies soft sediments: 2 samples/cage for cages located at the end and outside of an array; 1 sample/cage for all other cages (DFO, 2010a).



Monitoring Program Component	Newfoundland & Labrador Region																	
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	Finfish Aquaculture – Farm Monitoring Report for Fish Habitat: <ul style="list-style-type: none"> Sediment samples: only one (inside cages) or two (outside cages) sample stations per cage required for each of Part I and Part II. Three grabs per sample stations, one subsample each grab for redox and sulphide testing (DFO, 2010a). 																	
Sampling Methods and Tools (e.g., Eckman grab)	<ul style="list-style-type: none"> Fallow monitoring (video, Eh, sulphides) Sediment sampling: Eckman grab Video Sampling: ROV, drop/cable camera, or scuba divers with hand held video camera(s) (DFO, 2010a) 																	
Ecological Components (e.g., soft substrate sulphide levels)	<ul style="list-style-type: none"> Benthic community structure/diversity based upon oxygen availability as determined by redox and sulphide levels. 																	
Biological Indicators (e.g., <i>Beggiatoa</i>);	<ul style="list-style-type: none"> Soft substrate measure redox potential and sulphide levels, sediment color, water depth. Hard substrate indicators (organic deposition, <i>Beggiatoa</i>, opportunistic polychaete complex (Pers Comm, HPD). 																	
Thresholds and criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)	<p><i>The Finfish Aquaculture – Farm Monitoring Report for Fish Habitat:</i> if the results of the sediment sample analysis for Part I monitoring indicates a minimum 25% decrease in redox and/or a minimum 25% increase in sulphide levels when compared to original background levels (or if there is no pre-farm background data), or if there are hypoxic conditions, Part II Monitoring is required. Mitigative measures are required if Part II monitoring results indicate that benthic conditions: are not within 25% of pre-farm conditions (i.e., for redox and sulphides); or, if no pre-farm data, are not within 25% of two offsite monitoring stations that are approximately 50 m away (DFO, 2010a).</p> <table border="1" style="width: 100%; text-align: center;"> <thead> <tr> <th style="background-color: #d3d3d3;">Sediment Condition</th> <th style="background-color: #d3d3d3;">Redox</th> <th style="background-color: #d3d3d3;">Sulphides</th> </tr> </thead> <tbody> <tr> <td style="background-color: #00b050; color: white;">Oxic 1</td> <td style="background-color: #00b050; color: white;">> +100</td> <td style="background-color: #00b050; color: white;">< 300</td> </tr> <tr> <td style="background-color: #00b050; color: white;">Oxic 2</td> <td style="background-color: #00b050; color: white;">0 to 100</td> <td style="background-color: #00b050; color: white;">300 to 1300</td> </tr> <tr> <td style="background-color: #ffff00; color: black;">Hypoxic</td> <td style="background-color: #ffff00; color: black;">0 to -100</td> <td style="background-color: #ffff00; color: black;">1300 to 6000</td> </tr> <tr> <td style="background-color: #ff0000; color: white;">Anoxic</td> <td style="background-color: #ff0000; color: white;">< -100</td> <td style="background-color: #ff0000; color: white;">> 6000</td> </tr> </tbody> </table> <p>(Source: DFO, 2010)</p>			Sediment Condition	Redox	Sulphides	Oxic 1	> +100	< 300	Oxic 2	0 to 100	300 to 1300	Hypoxic	0 to -100	1300 to 6000	Anoxic	< -100	> 6000
Sediment Condition	Redox	Sulphides																
Oxic 1	> +100	< 300																
Oxic 2	0 to 100	300 to 1300																
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Anoxic	< -100	> 6000																



Monitoring Program Component	Newfoundland & Labrador Region
Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., <i>Fisheries Act</i> Authorizations, practices, other approaches)	<ul style="list-style-type: none">• Increase rotation period, duration or frequency• Move cages within lease boundary• Reduce biomass adjust feed management program• Move farm site to a more suitable area (DFO, 2010a). • If unable to implement additional mitigation then apply for a <i>Fisheries Act</i> section 35(2) Authorization for HADD. There has been no authorization to date in Newfoundland and Labrador Region. <i>Fisheries Act</i> Authorizations and related management tools:<ul style="list-style-type: none">○ Authorizations○ Letters of Credit○ Compensation



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> • New Brunswick: Proactive and Nova Scotia (from a DFO perspective)
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> • Benthic impact assessment: use of indicators to assess the health of benthic habitat
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> • Baseline assessments are also undertaken by the Province of New Brunswick to assess initial site conditions (NB, 2006A) • DFO-HPD Marine Finfish Aquaculture Decision Support System (DSS): a screening tool used by HPD to assess site suitability when evaluating environmental data included in marine lease applications. It is based on a “traffic light” method, scoring answers to questions assessing the state environmental variables. It includes site variables such as tidal amplitude, sulphide criteria, redox criteria, etc. (Doucette <i>et al.</i>, 2002). • The Province of Nova Scotia Environmental Monitoring Program (DFA, 2006;DFA, 2007): <ul style="list-style-type: none"> ○ Implemented by Nova Scotia Department of Fisheries and Aquaculture (consulting with Nova Scotia Aquaculture Environmental Coordinating Committee, and managing with regulatory partners) ○ Conducted baseline data collection of finfish sites and reference sites to assess pre-aquaculture conditions, to asses bay-scale effects and to characterize risk of each aquaculture development. ○ Finfish (i.e., larger and more productive aquaculture sites) are considered higher risk. It is coupled with site Remediation Plans (if required) and is shifting to operational phase and also working to generally improve understanding of aquaculture-environment interactions. Level 2 sampling compares to historical results.
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<p>New Brunswick (NB, 2006A)</p> <ul style="list-style-type: none"> • Tier 1 monitoring – conducted once annually, between August 1 and October 31 • Tier 2 monitoring – conducted once, within 20 days after Tier 1 or Tier 2, if average sediment sulphide concentration measured in Tier 1 or Tier 2 is $\geq 3000 \mu\text{M}$. • Tier 3 monitoring – conducted once annually, between March 1 and May 31, if average sediment sulphide concentration measured in Tier 1 is $\geq 4500 \mu\text{M}$. <p>The Department of the Environment may require additional environmental monitoring.</p> <p>Nova Scotia (DFA, 2006)</p> <ul style="list-style-type: none"> • Baseline monitoring (from 2003 to 2007), then shifting to the operational phase.



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)
<p>Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”</p>	<p>New Brunswick (NB, 2006A)</p> <p>Tier 2 Monitoring</p> <ul style="list-style-type: none">• Video recording: 50 m transect showing seafloor conditions (starting from the cage edge, including the end of the 50 m transect line towed by the diver, at the end of each transect; no transect direction specified); diver collection of core samples; each core or grab sample will be video recorded before analysis onboard the vessel. Seafloor observations at cage edge and furthest from the cage, as well as at the reference areas, will be recorded. <p>Transects</p> <ul style="list-style-type: none">• The number of transects and sediment samples will be identical for all sites despite the number of fish present during monitoring.• One transect at each of 4 corner cages and one transect at the centre cage.• The transects will be from the cage edge to underneath and beyond the cage. <p>Sediment Samples</p> <ul style="list-style-type: none">• Sediment samples (1 set of 3 samples per position) at: each of 4 corner cages (at cage edge); at the centre cage (at cage edge); and, at 3 reference areas (up to 100 m away, in similar substrate types as samples collected at cage edges). <p>Tier 1 and Tier 3 Monitoring</p> <p><i>Transects and Sediment Samples</i></p> <p>Transects</p> <ul style="list-style-type: none">• Linear current (uni-/bi-directional) with high current speeds (>5 cm/s for 75% of a 12.5 hour tide cycle)<ul style="list-style-type: none">○ Transects are positioned at cages along outside of cage configuration.○ If no cages present, then no transects will be laid.○ If more than one transect on same side of site, transects will be located at separate cages, beginning from cages with highest to lowest biomass of cages at that side,○ First two transects, at opposite sides of site, aligned with prevailing water current pattern○ Third and fourth transects(if required) located at right angles to prevailing water current pattern, on sides of site where there are no previous transects<ul style="list-style-type: none">▪ Third transect: (if required) located at the shoreward side of site, space permitting▪ Fourth transect: (if required) located at side of site furthest from shore, space permitting○ More transects (if required), will be parallel to previous first or second transect, then continuing around the site with the remaining transects.• Curving current (eddies/ follows shoreline, uni/ multi-directional) with low current speeds (< 5 cm/s for 25% of a 12.5 hr tide cycle)



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)
	<ul style="list-style-type: none"> ○ Transects are positioned at cages along outside of cage configuration. ○ If no cages present, then no transects will be laid. ○ If more than one transect on same side of site, transects will be located at separate cages, beginning from cages with highest to lowest biomass of cages at that side, ○ First two transect, at right angles to each other, one transect at shoreward side of site (space permitting), and one transect aligned to general directional trend of shore ○ Third and fourth transects (if required), on opposite side of site to first two transects <ul style="list-style-type: none"> ▪ Third transect (if required) aligned to general trend of shore ▪ Fourth transect (if required) at side of site furthest from shore ○ More transects (if required), will be parallel to first or second transect, then continuing around the site with the remaining transects. <p>Sediment Samples</p> <ul style="list-style-type: none"> • 1 set of 3 samples per position, collected in close proximity to each other in similar substrate types, at cage edge: each of 4 corner cages and at the centre cage. • If no cages at site, samples taken from same position as most recent Tier 1 or 3 monitoring <p>For site depths <30.5 m (at site centre at mean low tide), one transect and three sediment samples are required for each 100,000 fish (or part thereof) present onsite during monitoring (minimum of two transects and six sediment samples at sites with 1 to 200,000 fish; for site where there are zero fish, no transects are required but 6 sediment samples are required).</p> <p>For site depths >30.5 m (at site centre at mean low tide), no transects are required, and three sediment samples are required for each 100,000 fish (or part thereof) present onsite during monitoring (minimum of six sediment samples at sites with <200,001 fish).</p> <p>Nova Scotia (DFA, 2006)</p> <ul style="list-style-type: none"> • Monitoring is conducted at lease sites and at reference stations • Video, water quality testing and benthic sediment analysis
<p>Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)</p>	<p>New Brunswick (NB, 2006A)</p> <p><i>Tier 1 Monitoring (once annually, between August 1 and October 31)</i></p> <p><i>Transects</i></p> <p>Depends on numbers of fish present and water depth:</p> <ul style="list-style-type: none"> • If water depth at site center is <30.5 m (at mean low tide) then no transects required if no fish present, 2 transects required when between 1-200,000 fish present, and 1 additional transect for each additional 100,000 (or part thereof) fish; and,



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)
	<ul style="list-style-type: none">• Water depth at site center at mean low tide > 30.5 m, no transects. <p><i>Sediment Samples</i> Depends on numbers of fish present when monitoring is conducted: (1) minimum of 6 sediment samples when 0 to 200,000 fish present and 3 additional samples for each additional (or part thereof) 100,000 fish.</p> <p><i>Video Recording</i></p> <ul style="list-style-type: none">• Video recording of each transect and each core sample. <p><i>Tier 2 Monitoring (conducted once, with 20 days after Tier 1 or Tier 2 if average sediment sulphide observed in Tier 1 or 2 is $\geq 3000 \mu\text{M}$)</i></p> <p><i>Transects</i></p> <ul style="list-style-type: none">• 5 transects (1 at each of 4 corner cages and 1 at centre cage) <p><i>Sediment Samples</i> 24 samples (3 samples per sample location: 5 cage locations and 3 reference locations)</p> <p><i>Video Recording</i> Video recording of: each transect (i.e., 5 recordings); seafloor observations at each transect end at cage edge and furthest from cage edge (2); each core sample collection (24); bottom of cages at which samples are collected (5); each core sample before analysis on vessel (24); and, reference areas (3).</p> <p><i>Tier 3 Monitoring (once annually, between March 1 and May 31, if average sediment sulphide observed in Tier 1 is $\geq 4500 \mu\text{M}$.</i></p> <p>As noted in Tier 1 Monitoring (above)</p> <p>Nova Scotia (DFA, 2006)</p> <ul style="list-style-type: none">• Increased risk requires increased monitoring.• All sites tested but sites with larger production are given higher priority.• Repeat sampling and (if required) remediation is done at sites of potential concern.



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)
<p>Sampling Methods and Tools (e.g., Eckman grab)</p>	<p>New Brunswick (NB, 2006A)</p> <p><i>Transects</i> Includes video recording by SCUBA diver</p> <p><i>Sediment Sampling</i> Core samples by diver at site center at mean low tide < 30.5 m</p> <ul style="list-style-type: none"> • Clear core tubes, approximately 30 cm long x 5 cm diameter • Tape-covered holes (for redox measurement of top 2 cm while core is contained in core tube); • Diver push core into sediment (as deeply as possible) to a maximum depth of 10 cm, cap it and not disturb sediment-water interface. <p>Grab or core samples by surface-deployed equipment at site centre > 30.5 m</p> <ul style="list-style-type: none"> • Gravity corer, weighing at least 20 kg, with a core tube similar to hand-held core tubes but with a plastic “egg catcher” at the core tube opening to prevent sediment loss during ascent (for silt/clay sediments) • Heavy grab with opening on top to allow access for analysis of top 2 cm of the sample (for all other sediments) • Three grabs/cores collected per sampling location <p><i>Video Recording</i> Unspecified equipment, recording by SCUBA diver, other recordings (e.g., of sediment samples before analysis on vessel)</p> <p>Nova Scotia (DFA, 2006)</p> <p><i>Video, sediment sampling or water analysis methods or tools not identified</i></p> <p>Repeat sampling may be conducted at sites of potential concern. Sites with larger production are higher priority but all sites in production are tested.</p>
<p>Ecological Components (e.g., soft substrate sulphide levels)</p>	<p>New Brunswick (NB, 2006A)</p> <p><i>Transects/Video Monitoring</i></p> <ul style="list-style-type: none"> • Tier 1 and 3 - seafloor conditions along 50 m transects, seafloor conditions under cages (where samples are collected), seafloor observations at each transect end (approximate sediment thickness, sediment colour, sediment consistency; sediment surface consolidation, relative amount of gas bubbles present; % <i>Beggiatoa</i> coverage, presence of feed; presence of feces; macrofauna/flora - relative abundance of polychaetes, molluscs, echinoderms and crustaceans; indication of species that are in relative abundance; and, presence of detritus and fouling organisms, including mussel shells, unattached algae, etc.)



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)										
	<ul style="list-style-type: none"> Tier 2 - seafloor conditions along 50 m transects; seafloor observations at each transect end/reference locations (as per Tier 1) <p><i>Sediment Samples (soft bottom)</i></p> <ul style="list-style-type: none"> Soft substrates - sulphide levels and redox. Sediment sulphide measurements are relied upon as the key indicator of the condition of sediments (FAO, 2009). <p>Nova Scotia (DFA, 2006)</p> <ul style="list-style-type: none"> Qualitative measures (video and sediment observations) <ul style="list-style-type: none"> Sediment colour Microbial and algal (plant) presence (i.e., sulphur bacteria, benthic micro-algae, shallow-site macro-algae, cyanobacteria films) Macrofaunal (animal) assemblage (various infauna and epifauna; large burrowers/animals, tube-dwellers) Quantitative measures (sediment analysis focus): Total dissolved sulphide, and redox potential as indirect indicators of aerobic versus anaerobic conditions in benthic sediment, percent organic content as an indicator organic loading, and percent porosity (sediment water content) to indicate recent deposition at the sediment surface. 										
<p>Biological Indicators (e.g., <i>Beggiatoa</i>)</p>	<p>New Brunswick (NB, 2006A)</p> <ul style="list-style-type: none"> <i>Beggiatoa</i> (i.e., % <i>Beggiatoa</i> coverage: 50-100 %; 25-5%; 10-25%; 0-10%) in seafloor observations for Tier 1, 2 and 3 monitoring <p>Nova Scotia (DFA, 2006)</p> <ul style="list-style-type: none"> Microbial and algal (plant) presence (i.e., sulphur bacteria, benthic micro-algae, shallow-site macro-algae, cyanobacteria films) Macrofaunal (animal) assemblage (various infauna and epifauna; large burrowers/animals, tube-dwellers) 										
<p>Thresholds and criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)</p>	<p>New Brunswick (NB, 2006A)</p> <ul style="list-style-type: none"> Tier 2 monitoring conducted if average sediment sulphide concentration noted in Tier 1 or Tier 2 is $\geq 3000 \mu\text{M}$. Tier 3 monitoring conducted if average sediment sulphide concentration noted in Tier 1 is $\geq 4500 \mu\text{M}$. <p>The Environmental Effects Management Framework (EEM) involves increasing monitoring based on severity of the measured effect. In terms of monitoring (Tier 1, 2 and/or 3), the following is required for the specified sulphide levels:</p> <table border="1" data-bbox="512 1222 1974 1408"> <thead> <tr> <th data-bbox="512 1222 877 1284">Site Classification</th> <th data-bbox="877 1222 1528 1284">Sediment Condition</th> <th data-bbox="1528 1222 1974 1284">Tiered EEM (See New Brunswick SOP)</th> </tr> </thead> <tbody> <tr> <td data-bbox="512 1284 877 1346">Oxic A</td> <td data-bbox="877 1284 1528 1346">Sulphide < 750 µM</td> <td data-bbox="1528 1284 1974 1408" rowspan="2">TIER 1 EEM</td> </tr> <tr> <td data-bbox="512 1346 877 1408">Oxic B</td> <td data-bbox="877 1346 1528 1408">Sulphide = 750 to 1500 µM</td> </tr> </tbody> </table>			Site Classification	Sediment Condition	Tiered EEM (See New Brunswick SOP)	Oxic A	Sulphide < 750 µM	TIER 1 EEM	Oxic B	Sulphide = 750 to 1500 µM
Site Classification	Sediment Condition	Tiered EEM (See New Brunswick SOP)									
Oxic A	Sulphide < 750 µM	TIER 1 EEM									
Oxic B	Sulphide = 750 to 1500 µM										



Monitoring Program Component **Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)**

Hypoxic A	Sulphide = 1500 to 3000 µM	TIER 1 EEM
Hypoxic B	Sulphide = 3000 to 4500 µM	TIER 1, 2 EEM
Hypoxic C	Sulphide = 4500 to 6000 µM	TIER 1,2,3 EEM
Anoxic	Sulphide > 6000 µM	TIER 1,2,3 EEM

Source: NB, 2006b

An Authorization is likely required for Hypoxic C sites (sulphide levels of 4500 to 6000 µM) and anoxic sites (sulphide levels >6000 µM; NB, 2006b)

Nova Scotia (DFA, 2006)

- Repeat sampling and (if required) remediation is done at sites of potential concern. The following table identifies environmental quality definitions for Nova Scotia’s marine aquaculture monitoring; however, it does not identify management actions.

Measurement	Qualitative Measures (from video & sediment observations)			Quantitative Measures (from sediment analysis)				Site Classification
	Sediment Colour	Microbial and Algal (Plant) presence	Macrofaunal (Animal) Assemblage	Redox (mV)	Sulphide (µM)	Organic Content (%)	Porosity (%)	
Norm-oxic	Tan to depth of > 0.5 cm	No sulfur bacteria present (also benthic microalgae or macro-algae at shallow sites)	Wide array of infauna and epifauna; may include large burrowers	0 to 300	< 1300	≤ reference*	≤ reference*	Type A
Sub-oxic	Tan to < 0.5 cm and/or patchy black sediments at surface	Patchy or occasional sulfur bacteria and cyanobacterial biofilms	Mixed assemblages of small infauna which may include larger animals	-100 to 0	1300 to 6000	1.5 - 2X reference	1 to 10X reference	Type B



Monitoring Program Component	Maritimes Region – New Brunswick (NB) and Nova Scotia (NS)								
	Anoxic	Surface sediments black	Sulfur bacteria may be widespread	Small infauna or tube-dwellers at shallow sediment depths	< -100	> 6000	> 2X reference	> 10X reference	Type C
Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., Fisheries Act Authorizations, practices, other approaches)	<p><i>*Values compared to reference assume that reference and lease stations would have had similar levels in pre-culture conditions. (Source: Table 1: Environmental Quality Definitions for Nova Scotia Marine Aquaculture Monitoring in DFA, 2006)</i></p> <p>Application Review Process (no Authorizations to date)</p> <ul style="list-style-type: none"> • Letter of Advice (discusses monitoring requirements) • <i>Fisheries Act</i> Authorizations and related management tools (none in DFO-Maritimes because there have been no Authorizations; however, a new <i>Fisheries Act</i> Authorization Framework is in development): <ul style="list-style-type: none"> ○ Authorizations ○ Letters of Credit ○ Compensation <p>New Brunswick</p> <ul style="list-style-type: none"> • The New Brunswick <i>Aquaculture Act</i>, Chapter A-9.2 regulates aquaculture activities (NB, 2008). • Provincial aquaculture licenses are issued by the New Brunswick Department of Agriculture, Fisheries, and Aquaculture (DAFA; NB, 2006b). • The Aquaculture Approvals program (New Brunswick Department of Environment) enforces the provisions of New Brunswick’s Environmental Management Program under the authority of the <i>Water Quality Regulation – Clean Environment Act</i> (NB, 2009; NB, 2006b) • Aquaculture Site Environmental Review Committee reviews Production Plans and evaluates Remediation Plans required by aquaculture site operators with Hypoxic C or Anoxic sites (NB, 2006b). • Standard Operating Practices (SOP) for the Environmental Monitoring of the Marine Finfish Cage Aquaculture Industry in New Brunswick (NB, 2006a) and by DFO through the Fish habitat Protection Provisions of the <i>Fisheries Act</i>. <p>Nova Scotia</p> <ul style="list-style-type: none"> • Nova Scotia’s Department of Fisheries and Aquaculture has online Aquaculture Site Mapping, locating sites by species farmed (DFA, 2010). • Part 5 of Nova Scotia’s <i>Fisheries and Coastal Resources Act</i> discusses requirements for aquaculture licensing (NS, 2008). 								



Monitoring Program Component	Pacific Region
Purpose (i.e., regulatory or proactive?)	<p>Regulatory</p> <ul style="list-style-type: none"> Benthic habitat monitoring (including baseline data collection) is mandated by Provincial (British Columbia) regulations (i.e., Provincial Finfish Aquaculture Waste Control Regulation; FAWCR; BC, 2010). Ensure operation benthic HADD remains within area Authorized under <i>Fisheries Act</i>.
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> Benthic impact assessment: use of indicators to assess the health of benthic habitat
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> DEPOMOD is used to predict the distribution of organic waste deposition (e.g., from feed and feces) on the benthos due to the operation of an aquaculture facility (DFO, 2006). Baseline Inventory (BC, 2010; WLAP, 2002). <ul style="list-style-type: none"> Part I: currents metering Part II: baseline monitoring, includes seabed characterization (with transects), video (or other approved) survey (biophysical features, transects/quadrats), and sediment sampling
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<p>Operational Monitoring (BC, 2010)</p> <p><i>Part I – Hard Bottom Survey</i></p> <ul style="list-style-type: none"> Video surveys (or approved alternative) must be done within 30 days of peak finfish biomass for each production cycle If cages are relocated during a production cycle before monitoring is done, monitoring is must be done within 30 days of the relocation. <p><i>Part II – Sediment Sampling</i></p> <ul style="list-style-type: none"> Sediment grab sampling of soft bottoms must be done within 30 days of peak finfish biomass for each production cycle If cages are relocated during a production cycle before monitoring is done, monitoring is must be done within 30 days of the relocation (Schedule B). If mean sulphide levels at soft-bottom sampling station at or beyond 30 m from the 0 m station exceed 6000 µM or if mean sulphide levels at or beyond the tenure perimeter are greater than the mean reference or baseline level, sulphide sampling must be repeated and sediment biological sampling done in accordance with Schedule B (at sampling stations where the exceedance took place), at least once within 30 days of the exceedance; repeated sulphide and biological sampling must be taken within 7 days of each other). This is subject to section 11(2) of FAWCR, which covers relocation or containment structures in the same tenure and fallowing and possible exemptions to compliance requirements. If a cage is relocated back to a fallow footprint (i.e., to the footprint of a previous cage location that has been left



Monitoring Program Component	Pacific Region
	fallow), monitoring must be done at the perimeter of the cage to confirm pre-stocking criteria prior to stocking the cage.
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<p>Operational Monitoring (BC, 2010)</p> <p><i>Part I – Hard Bottom Survey</i> A video survey (or an approved alternate hard bottom survey) must be conducted if sediment samples cannot be conducted.</p> <ul style="list-style-type: none"> • Megafauna Transect Survey: video megafauna and macrophytes along transects • Macrofauna Quadrat Survey: still images of macrofauna and macrophytes, usually adjacent to the megafauna transects. <ul style="list-style-type: none"> ○ Each transect starts at cage/array perimeter and ends at the tenure perimeter along the prevailing current (one transect for each of two dominant current directions for each containment structure/array). ○ Cages/array less than 60 m apart must be treated as a single array when positioning transects. ○ Transects cannot extend beneath the adjacent cage/array. ○ Alternate transects designs may be acceptable. ○ For each transect there are five macrofauna quadrats at each of the following stations: perimeter of cage or cage array, 30 m from zero metre stations and on the tenure perimeter. ○ At least two reference stations surveyed. ○ More details are available in Part I – Hard Bottom Survey of Schedule B of FAWCR. <p><i>Part II – Sediment Sampling</i></p> <ul style="list-style-type: none"> • Each transect must have a sampling stations at the cage/array perimeter, 30 m from zero metre station and on the tenure perimeter. • Sampling of various parameters (see Ecological Components) must be taken at stations at perimeters of cages/arrays, reference stations during operational monitoring. • Sulphides and redox potential must also be sampled at zero metre stations and perimeter tenures.
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	<p>Operational Monitoring (BC, 2010; WLAP, 2002)</p> <p><i>Part I – Hard Bottom Survey</i></p> <ul style="list-style-type: none"> • Survey must be done within 30 days of: peak finfish biomass for each production cycle; or, a cage relocation if relocated during a production cycle before monitoring is done. • Number of megafauna transects across entire tenure not defined. Therefore, number of samples per year is not defined. (video) • Number of macrofauna quadrats: ~40 (2 transects, but 5 quadrats per sample station with 3 stations for each of 2 transects, plus two reference stations with one transect at each and 5 quadrats per reference station). Alternate transect designs possible. (photographs)



Monitoring Program Component	Pacific Region
	<p><i>Part II — Sediment Sampling</i></p> <ul style="list-style-type: none"> • Number of samples per year not defined. Sampling must be done within 30 days of: peak finfish biomass for each production cycle; or, a cage relocation if relocated during a production cycle before monitoring is done. • From 1 to 5 grab samples are required for various stations, depending on the parameter (see Sample Design for more detail). <ul style="list-style-type: none"> ○ Sulphide and redox levels require three grabs from each station (2 additional grabs for sulphide and redox are required if the sulphide mean of the 3 grabs exceed 1300 µM). ○ ‘TVS or TOC’ and ‘Cu or Zn’ require three grabs at each station at the perimeter of the cage and three grabs at each reference station. SGS require one grab at each station at the perimeter of the cage and one grab at each reference station. ○ “Family richness and abundance of infauna and epifauna” requires 5 grabs at each station, except 3 at each reference station. Note: biological sampling must be done only if a sulphide requirement has not been met.
<p>Sampling Methods and Tools (e.g., Eckman grab)</p>	<p>Operational Monitoring (BC, 2010; WLAP, 2002)</p> <p><i>Part I — Hard Bottom Survey</i></p> <ul style="list-style-type: none"> • Video Survey (unless alternate survey approved) <ul style="list-style-type: none"> <i>Megafauna transect survey</i> <ul style="list-style-type: none"> ○ ROV, cable camera apparatus, or scuba divers ○ Video equipment must produce broadcast-quality images, have supplemental light to maintain light balance, show scale in metres, identification of transect or station recorded, and format of video must be transferable to digital-format storage media. ○ Acceptable transect lines include brightly coloured, weighted, polypropylene ropes (with regularly spaced flagging tape) or measuring tapes. <i>Macrofauna quadrat survey</i> <ul style="list-style-type: none"> ○ Acceptable quadrats include wire frame (1 m x 1 m, with nine 33 cm x 33 cm section) on seabed, wire frame mounted to cable camera or ROV, or laser-delineated frame. <p><i>Part II — Sediment Sampling</i></p> <ul style="list-style-type: none"> • Sediment Sampling (WLAP, 2002) <ul style="list-style-type: none"> ○ Grab sampling (e.g., Petite-Ponar, Ponar, Smith-MacIntyre, or van Veen grab, etc) with 1 to 5 five grabs per sampling station. ○ Any sample size is acceptable for most parameters; however, for “Family richness and abundance of infauna and epifauna” a size of 0.1 m² is required. Note: biological sampling must be done only if a sulphide requirement has not been met.



Monitoring Program Component	Pacific Region
Ecological Components (e.g., soft substrate sulphide levels)	<p>Operational Monitoring (BC, 2010; WLAP, 2002)</p> <p><i>Part I — Hard Bottom Survey</i></p> <ul style="list-style-type: none"> • Video Survey (unless alternate survey approved) <ul style="list-style-type: none"> <i>Megafauna transect survey</i> <ul style="list-style-type: none"> ○ Identification and quantification of abundances of megafauna and macrophytes ○ Definition of extent of observable physical and biological changes (e.g., sediment colour, presence of organic sediments, feed pellets, farm litter or <i>Beggiatoa</i> mats) <i>Macrofauna quadrat survey</i> <ul style="list-style-type: none"> ○ Identification and quantification of abundances of macrofauna and macrophytes <p><i>Part II — Sediment Sampling</i></p> <ul style="list-style-type: none"> • Sediment Sampling <ul style="list-style-type: none"> ○ Sediment sulphide level ○ Redox potential ○ Total volatile solids (TVS) or total organic carbon (TOC) ○ Sediment grain size (SGS; % gravel, sand, silt, mud and clay) ○ Total zinc (at sites where zinc is used in feed formulations) ○ Total copper (at sites where copper is used as an antifouling agent) ○ Sediment colour, odour and texture ○ Family richness and abundance of infauna and epifauna. Note: biological sampling must be done only if a sulphide requirement has not been met. Biota must be identified to at least family level. Individuals of <i>Capitella</i> must be identified. ○ Other contaminants/parameters if required by a director (e.g., pesticides, therapeutic additives, etc.)
Biological Indicators (e.g., <i>Beggiatoa</i>);	<p>Operational Monitoring (BC, 2010; WLAP, 2002)</p> <p><i>Part II — Sediment Sampling</i></p> <p>When biological sediment samples are required (i.e., where a sulphide requirement has not been met), biota must be identified to at least family level. Individuals of <i>Capitella</i> must be identified.</p>
Thresholds and criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)	<p><i>Fisheries Act Authorization:</i></p> <ul style="list-style-type: none"> • An Authorization for a HADD is issued if DEPOMOD predicts a waste deposition greater than 5 g C/m²/day. Compensation habitat must be created as a requirement of the Authorization (BC, 2006). • DFO Pacific Region has thresholds as part of its Authorization approvals process.



Monitoring Program Component	Pacific Region
	<p><i>Soft Bottom (BC, 2010; WLAP, 2003):</i></p> <ul style="list-style-type: none"> • At or beyond 30 m from the zero-metre station on a soft bottom, sulphide levels must not be greater than 6000 µm • Mean taxon richness at a sampling station at/beyond tenure perimeter should not be statistically significantly different than mean reference or baseline taxon richness; • Mean total abundance at a sampling station at/beyond tenure perimeter should not be statistically significantly different than mean reference or baseline total abundance. If these standards are exceeded, a remedial action plan is required and must be implemented. • Sulphides on soft bottom triggers <ul style="list-style-type: none"> ○ Stations at or beyond 30 m from the zero-metre station: <ul style="list-style-type: none"> ▪ If at all stations mean sulphide results are not significantly (above baseline) >1300 µM then pre-stocking requirements are met; no additional monitoring required; reporting of monitoring results are required. ▪ If at one or more stations sulphide results are significantly >1300 µM but not significantly > 6000 µM then pre-stocking requirements must be met; pre-stocking monitoring required; reporting required. ▪ If at one or more stations sulphide results are significantly >6000 µM then pre-stocking requirements must be met; pre-stocking monitoring required; sulphide monitoring must be repeated and biological monitoring conducted; biological samples must be analyzed; reporting of monitoring results are required; remedial action plan must be prepared, submitted and implemented. ○ Stations at or beyond the tenure perimeter: <ul style="list-style-type: none"> ▪ If, at all stations, mean sulphide is not significantly > reference /baseline sulphide then pre-stocking requirements are met; no additional monitoring required; reporting of monitoring results are required. ▪ If, at one or more stations, sulphide results are significantly > mean reference or baseline sulphide reading then pre-stocking requirements must be met; pre-stocking monitoring required; sulphide monitoring must be repeated and biological monitoring conducted; biological samples must be analyzed; reporting of monitoring results are required; remedial action plan must be prepared, submitted and implemented. <p><i>Hard Bottom Site Standards (BC, 2010)</i></p> <ul style="list-style-type: none"> • There are no hard bottom site standards listed in FAWCR (WLAP. 2003). • DFO Pacific Region also has video/sampling requirements associated with sulphide levels as part of its Authorization approvals process.
<p>Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., Fisheries Act Authorizations, practices, other approaches)</p>	<ul style="list-style-type: none"> • DEPOMOD as regulatory tool to determine FA Authorization requirements by identifying distribution of deposition from an aquaculture site (The BC. Pacific Forum, 2007). • <i>DFO Marine Fish Habitat Information Requirements (HIR) for Finfish Aquaculture Projects</i> provides general guidance about the basic information requirements for documenting marine species and fish habitat at a proposed finfish aquaculture site. DFO reviews information submitted in its assessment of a potential HADD (DFO, 2004).



Monitoring Program Component	Pacific Region
	<p><i>Application Review Process</i></p> <ul style="list-style-type: none">• Letter of Advice (discusses monitoring requirements)• <i>Fisheries Act</i> Authorizations and related management tools (none in DFO-HF because there have been no Authorizations):<ul style="list-style-type: none">○ Authorizations○ Letters of Credit○ Compensation• Note: if compensation is required for impacted habitat under Section 35(2) of the <i>Fisheries Act</i>, the applicant must conduct monitoring of compensation habitat (The B.C. Pacific Forum, 2007).• British Columbia's Ministry of Water, Land and Air Protection (WLAP) has two a guidance documents that support FAWCR:<ul style="list-style-type: none">○ <i>Protocols for Marine Environmental Monitoring</i> (WLAP, 2002).○ <i>Guidance Document for the British Columbia Finfish Aquaculture Waste Control Regulation</i> (WLAP, 2003).• The Fisheries and Aquaculture Licensing and Compliance Branch of the Ministry of Agriculture and Lands issues licenses for Finfish aquaculture facilities, and administers the Aquaculture Regulation under British Columbia's <i>Fisheries Act</i>, which includes requirements for monitoring (MAL, 2010).



3.2 International Jurisdictions

Monitoring Program Component	Scotland
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> Regulatory (required at all marine sites; FAO, 2009)
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> Benthic impact assessment/ use of indicators to assess health of benthic habitat/benthos.
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> Site-specific, DEPOMOD models the diameter of AZE and locations of sampling stations (FAO, 2009). <p>Anti-parasite Chemicals</p> <ul style="list-style-type: none"> Two modelling approaches (SEPA, 2010a): <ul style="list-style-type: none"> Modelling anti-parasite chemicals (bath treatments) <ul style="list-style-type: none"> Short-term model (mixing zone approach; considers mean current speed and distance of site from shore) Longer term dispersion model (multiple releases of treatment chemical per treatment); when substances might still be present in toxic concentrations after 72 hours Modelling anti-parasite chemicals (feed and deposition of waste feed and faeces) <ul style="list-style-type: none"> For anti-parasite chemicals – DEPOMOD V1.5 & V2.0, AUTODEPOMOD 1.0.1/ DEPOMOD V3.0) For maximum biomass and for anti-parasite chemicals – AUTODEPOMOD 2.0.1 (Incorporating DEPOMOD v3.0) <p>Sediment sampling for anti-parasite chemicals is included in all Benthic Sediment Sampling procedures.</p> <ul style="list-style-type: none"> If in-feed Treatment Residues (Slice, Calicide) is included in license and used with 24 months (or current growing cycle), collect sediment samples in the last 12 months of production at the same time as the benthic survey, if possible (Slice: sample between 80 and 169 days after treatment stops; Calicide: between 10 and 30 days after treatment stops. If timings of peak biomass do not coincide with in-feed sampling window: contact Scottish Environmental Protection Agency (SEPA) Marine Science. Sampling: at the cage edge and 100 m from the cage edge along the main current direction. Additional sampling may be required. Sampling stations: at cage edge (0 m along main current direction), at 100 m station (100 m along main current direction), and a supplementary station (if required). In-feed Residues: 3 grab samples (to 5 cm depth) at each sampling station. Cores should be representative of undisturbed sediment. <p>Baseline Monitoring (SEPA, 2010b)</p> <ul style="list-style-type: none"> Done prior to Controlled Activities Regulation (CAR) license application for new site or modified site, from May to October (if possible)



Monitoring Program Component	Scotland
	<p><i>Baseline Survey, Benthic – Standard</i></p> <ul style="list-style-type: none">• Conducted at proposed new sites• With maximum biomass applied for <1000 tonnes• Sediment samples from 2 stations (separated by at least 100 m) near the proposed cage location and current direction, and at 2 reference stations outside the proposed or actual leased area (500 to 1000 m from leased area – locations of similar exposure, depth, and sediment type, and not influenced by discharges or other aquaculture sites)• Visual seabed survey may be provided as an alternative for farms of <500 tonnes where there is no intention to apply for chemo-therapeutants.• Additional data may be required (e.g., visual survey) if site may impact a natural heritage area or have other environmental concerns <p><i>Baseline Survey, Benthic – Extended</i></p> <ul style="list-style-type: none">• Conducted at proposed new sites• With maximum biomass applied for is ≥ 1000 tonnes• In new sites and where tonnage applied for is <1000 tonnes, additional data may be required (e.g., visual survey) if site may impact a natural heritage area or have other environmental concerns.• Sediment sampling along two transects<ul style="list-style-type: none">○ Transect 1: along predominant current direction from proposed cage group location, with sample stations at centre of the proposed cages site, at 50 m from the centre and at 100 m from the centre○ Transect 2 – along reciprocal direction away from the cage group (opposite direction to Transect 1), with sample stations at centre of the proposed cages site, at 50 m from the centre and at 100 m from the centre○ Transects should be placed at right angles to each other if the predominant current direction is not clear.○ Sampling stations should be, with sample stations at 25 m and 50 m from the cages.• Sediment samples should be taken at 2 reference stations outside the proposed or actual leased area (500 to 1000 m from leased area – locations of similar exposure, depth, and sediment type, and not influenced by discharges or other aquaculture sites. <p><i>Baseline Survey, Visual – Standard</i></p> <ul style="list-style-type: none">• No sediment sampling.• Conducted at proposed new sites not located in or near areas with statutory natural heritage designations• Conducted at modifications to sites as per threshold criteria• New sites with no cages<ul style="list-style-type: none">○ Transect along the centre line of the longest access of the proposed cage grid extended to the longest modeled extent of the allowable zone of effect (AZE) on either end of the cage group.○ If widest point is >200 m, then second transect required there from one side of the AZE to the other



Monitoring Program Component	Scotland
	<ul style="list-style-type: none"> • Modified sites <ul style="list-style-type: none"> ○ Transect along line of longest transect distance of the AZE, from end of modified cage group or location of proposed cage group to the AZE boundary. ○ If the widest point is >200 m, then second transect required there from one side of the AZE to the other <p><i>Baseline Survey, Visual - Site-Specific:</i></p> <ul style="list-style-type: none"> • No sediment sampling • Conducted at proposed new sites and modifications to existing sites located in or near areas with statutory natural heritage designations • Conducted as per threshold criteria • New sites with no cages <ul style="list-style-type: none"> ○ Transect along centre line of longest access of the proposed cage grid (extended to longest modeled extent of AZE on either end of cage group) ○ If the widest point is >200 m, then second transect required there from one side of AZE to the other. • Modified sites <ul style="list-style-type: none"> ○ Transect along line of longest transect distance of AZE, from end of modified cage group or location of proposed cage group to AZE boundary ○ If the widest point is >200 m, then second transect required there from one side of AZE to the other. ○ If there are obvious changes in chart features (e.g., indicating reefs or subsea cliffs) within or near the proposed AZE, then additional survey transects must be done to survey the seabed between these features and the cage groups.
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<p>Benthic Sediment Sampling and Visual Survey</p> <ul style="list-style-type: none"> • Once every two years since peak production usually occurs once per production cycle (FAO, 2009). • For all benthic sediment sampling and types of visual surveys (SEPA, 2010b): <ul style="list-style-type: none"> ○ During date when peak biomass is first reached to one month after peak biomass ○ Survey conducted between May 1st and October 31st (ideally).
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<p>Benthic Sediment Sampling (SEPA, 2010b)</p> <ul style="list-style-type: none"> • Benthic infauna and chemistry. Natural variations in faunal samples require taking reference samples. If no benthic sample possible, then video survey may be used. • Also, additional data required (e.g., visual survey) if site may impact a natural heritage area or have other environmental concerns. <p><i>Monitoring Survey, Benthic – Standard</i></p> <ul style="list-style-type: none"> • Conducted in accordance with license or for application to increase biomass up to 1000 tonnes • Additional monitoring may be required where sites are stocked on rotational basis with other sites and/or have extended stocking or fallowing activities.



Monitoring Program Component	Scotland
	<ul style="list-style-type: none">• Sediment samples from 2 stations along predominant current direction, and at 2 reference stations (500 to 1000 m from leased area – locations of similar exposure, depth, and sediment type, and not influenced by discharges or other aquaculture sites – use a SEPA recommended location if one is provided)• Sampling stations at edge (within 5 m) of cage group and the edge of the AZE (currently 25m from the cage edge).• If more than one cage group (with >100 m separation) sampling stations will be taken off each cage group.• Discuss with SEPA for alternative if transect cross location of seabed over which there previously was a cage <p><i>Monitoring Survey, Benthic – Extended</i></p> <ul style="list-style-type: none">• Conducted in accordance with license or for application to increase biomass ≥ 1000 tonnes at existing sites• Sampling along two transects<ul style="list-style-type: none">○ Transect 1: along predominant current direction from centre of cage group, with sample stations at cage, edge, at 25m and 50m from the cages○ Transect 2 – along reciprocal direction away from the cage group, with sample stations at 25m and 50m from the cages.• If more than one cage group (with >100 m separation) sampling stations will be taken off each cage group.• Discuss with SEPA for alternative if transect cross location of seabed over which there previously was a cage• Sampling must be taken from 2 reference stations <p><i>Monitoring Survey, Benthic – Site Specific</i></p> <ul style="list-style-type: none">• Conducted in accordance with license <p>The SEPA fish farm manual identifies two alternatives: <i>The AutoDEPOMOD output identifies two transect directions, the primary transect should be used where possible; in the event that sampling is not possible along this transect due to sea bed conditions, the secondary transect should be used. Samples should be obtained from 4 stations lying along one of the survey transects and at 2 reference stations remote from the cage location.</i></p> <p><i>Sampling stations shall be:</i></p> <ul style="list-style-type: none">○ <i>At the edge (within 5 m) of the cage group;</i>○ <i>At the edge of the Allowable Zone of Effects (AZE);</i>○ <i>At a station that is a distance 10m beyond the edge of AZE;</i>○ <i>At a station that is a distance 10m short of the edge of the AZE; and</i>○ <i>At 2 reference stations remote from the cage location.</i> <p>OR</p>



Monitoring Program Component	Scotland
	<p><i>The highly resuspensive conditions, indicated by the current speeds at this site, prevent AutoDEPOMOD from identifying suitable sampling stations; consequently, samples should be obtained from 4 stations lying along one of the survey transects specified in Table A-1, and at 2 reference stations remote from the cage location. The primary transect (number 1 in Table A-1) should be used where possible; in the event that sampling is not possible along this transect due to sea bed conditions, the secondary transect (number 2 in Table A-1) should be used.</i></p> <p><i>Sampling stations shall be:</i></p> <ul style="list-style-type: none">○ <i>At the edge (within 5m) of the cage group;</i>○ <i>At a station 25m from cage group;</i>○ <i>At a station 50m from cage group;</i>○ <i>At a station 100m from cage group;</i>○ <i>At 2 reference stations remote from the cage location.</i> <ul style="list-style-type: none">● Discuss with SEPA for alternative if transect cross location of seabed over which there previously was a cage● Sampling must be taken from 2 reference stations <p>Visual Survey (SEPA, 2010b) Video and photographs to collect information on the benthic community (habitat and species) may be necessary. Data is used both for the CAR license application and to support Planning Consent and EIA. Visual surveys are needed for new sites, when sites are subject to expansion to natural heritage areas, where there is insufficient information in the seabed around the site to make a conservation assessment (e.g., no previous video surveys or previous video survey is greater than 6 years old). They may not be required for minor facility expansions or where existing data shows no habitats or species of special interest. Information required for CAR license should be sufficient for information for applications for SEPA Planning Consents or EIA. The SEPA fish farm manual includes a decision tree to identify when visual survey is required. If no benthic sample possible, then video survey may be used.</p> <p><i>Monitoring Survey, Visual</i></p> <ul style="list-style-type: none">● Hard-bottom substrate sites● Conducted at existing sites <500 tonnes (history of minimal impact)● At any sites where more detailed visual data required (e.g., sites affecting natural heritage designations, or other conservation or environmental concerns)● Transect along predominant current direction. A 50 m weighted line (with station number marked at 5 m intervals on the line) is run straight along the seabed, out from the cage edge at right angles



Monitoring Program Component	Scotland
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	<ul style="list-style-type: none">The scope of visual survey for CAR license requirements are proportional to farm size, its allowable zone of effects and likely impact to surrounding benthic environment (SEPA, 2010b). <p>Benthic Sediment Samples (SEPA, 2010b)</p> <p><i>Grabs</i></p> <ul style="list-style-type: none">per cage or cage group (if cage separation >100 m), plus 2 reference stations: 4 stations (Monitoring Survey, Benthic – Standard); 7 sample stations (Monitoring Survey, Benthic – Extended);6 stations including two reference stations (Monitoring Survey, Benthic – Site Specific)<ul style="list-style-type: none">Minimum grab size 0.02 m²:<ul style="list-style-type: none">5 samples per sampling station (biological analysis)2 samples per sampling station (chemical analysis); or,Grab size 0.1 m²:<ul style="list-style-type: none">2 samples per sampling station (biological analysis)2 samples per sampling station (chemical analysis) <p>Video Survey (SEPA, 2010b)</p> <p><i>Monitoring Survey, Visual</i></p> <ul style="list-style-type: none">One 50-m transect, visual records made at stations marked every 5 meters (i.e., 10 stations)
Sampling Methods and Tools (e.g., Eckman grab)	<p>Benthic Sediment Samples (SEPA, 2010b)</p> <ul style="list-style-type: none">Van Veen or similar grab with flaps on top for access and visual examination (minimum grab size 0.02 m²), 5 samples per sampling site (for biological analysis) and 2 samples per site chemical analysis. If grabs on 0.1 m² are used, 2 samples for biology and 2 samples for chemistry are required. Samples for chemical and physio-chemical parameters should be obtained from separate grab from samples for other uses.Sampling equipment must be washed out between collection of each sample; any on-site disinfection policy must be followed by sample collectors. <p>Video Survey (SEPA, 2010b)</p> <ul style="list-style-type: none">Visual survey techniques involving video (in colour and DVD format) or photographs (in colour and CD/DVD format)Diver or remotely operated system<ul style="list-style-type: none">Survey to proceed from one end, to the other of transect line at moderate speed, pausing at each tag, and then view should pan to the surface and show surrounding land topographyVideo should be taken high enough from the seabed to allow for proper illumination and focus to show seabed features, including epifauna and habitat type (distance and close-ups).Modify visual sampling to determine the extent of habitats or species of natural heritage interest where



Monitoring Program Component	Scotland
	<p>observed.</p> <ul style="list-style-type: none"> • Drop down/towed video <ul style="list-style-type: none"> ○ Plan the transect route via GIS/GPS systems (expect that vessels will drift slightly from the precise route). ○ Discrete video captures along transect is acceptable where conditions prevent continuous capture. However, the transect must be surveyed in full, and continues location of or camera position or boat is needed for assessment. ○ Tow the camera above the seabed (so images are clearly visible) and set down periodically for clear images. Careful placement of the camera is required for good footage of difficult habitat (e.g., dense kelp, maerl, brittlestar beds). If survey conditions do not allow for adequate camera control, the survey may need to be abandoned and re-done during slack water or when there is an improvement of conditions. ○ Modify visual sampling to determine the extent of habitats or species of natural heritage interest where observed. ○ Geo-reference still photographs from drop down video. • Still Photographs <ul style="list-style-type: none"> ○ Photographs should be taken at each station along transect (clearly showing the tag number). To show ○ Correct focus and illumination (natural light is inadequate) is required to clearly show seabed features, including epifauna and habitat type. ○ A written record of observations along the transect line should be kept by divers. ○ Photograph
<p>Ecological components (e.g., soft substrate sulphide levels)</p>	<p>Benthic Sediment Samples</p> <ul style="list-style-type: none"> • Parameters evaluated in sediment include: particle size, redox potential and as required, copper and zinc levels. Samples are also taken to analyze SLICE or Calicide (anti-parasite compounds), sediment description (e.g., colour, consistency, texture, etc.), sediment chemistry (e.g., organic carbon content, loss of ignition, zinc, copper), faunal summary (various biological indices e.g., Number of taxa, Abundance, Margalef's Richness, Pielou's Evenness, S-Wiener Diversity $H' \log 2$, Number of Enrichment Polychaete Species, Abundance of Enrichment Polychaetes (m^2), macrobenthos, and Infaunal Trophic Index) (FAO, 2009; SEPA, 2010b). <p>Video Surveys (SEPA, 2010b):</p> <ul style="list-style-type: none"> • Key species and habitats (including abundance and frequency). Where observed, video monitoring should be modified to describe extent of features. • Substrate type • SEPA and Scottish National Heritage may request more detailed information and further work if required (especially in conservation or environmental sensitive areas). SEPA and Scottish National Heritage information may change and proponents should check with them before conducting field work or lab analysis.



Monitoring Program Component	Scotland
Biological Indicators (e.g., <i>Beggiatoa</i>);	<ul style="list-style-type: none">• Goal is to determine if there are sufficient “sediment re-worker species” to support increases in biomass or use of medicines, macrobenthos/fauna, various biological indices (e.g., Number of taxa, Abundance, Margalef’s Richness, Pielou’s Evenness, S-Wiener Diversity $H' \log 2$, Number of Enrichment Polychaete Species, Abundance of Enrichment Polychaetes (m^2), macrobenthos, and Infaunal Trophic Index) (FAO, 2009; SEPA, 2010b)
Thresholds and criteria (e.g., if 3000 μm sulphide then Section.35(2) Fisheries Act authorization)	<ul style="list-style-type: none">• Environmental Impact Assessment (EIA) applies to all marine farm developments above 100 tonnes biomass or covering an area of 0.1 ha or more. The full EIA process may not be required but scoping at least must be done at these levels. EIA may still be required below this level (e.g., depending on perceived environmental impact) (FAO, 2009)• SEPA fish farm manual notes (SEPA, 2010b):<ul style="list-style-type: none">○ For new sites, Standard Baseline Visual Survey or a Site Specific Baseline Visual Survey if site to be located in or will affect a natural heritage area,○ For site modifications, SEPA will already have data (e.g., monitoring required as part of CAR license, and SEPA’s audit monitoring, to enable identification on conservation features under and round cage group up to at least edge of allowable zone of effects and usually to at least 25 m beyond this.○ Threshold triggering requests for further information are based on: increased area and length of transect. Modifications result in an increased AZE. Small increases may be of little concern because existing data would give good indication that the seabed will be similar, but increasing the distance decreases the confidence that this is still true, resulting in need for additional data collection.<p><i>Scenario 1 AZE Area:</i> if new AZE is in area subject to low current speeds and has a reasonably uniform shape around cages, then there will be a significantly smaller extension of area over new sea bed than in site with uni-directional current. No new visual survey will be required if there is information on the seabed unless the threshold area ($40,000 m^3$)¹ is exceeded.</p><p><i>Scenario 2 AZE Length:</i> A survey is required even if area threshold (above) is not exceed if the AZE is significantly skewed in one direction, with its longest length greater than 200 m.</p><p>Therefore:</p><ol style="list-style-type: none">1) Appropriate visual survey is required if threshold area $>40,000 m^3$;2) Appropriate visual survey is required if the longest transect $>200 m$; and,3) Visual survey is not required if modified AZE $<60 m$ (irrespective of threshold area).<p>Proponents should seek further guidance from SEPA or Scottish Natural Heritage if modification scenarios are different from above.</p>

¹ Threshold area = (Area of sea bed covered by modified cages) minus (area of sea bed of the existing cages and AZE)



Monitoring Program Component	Scotland
	<ul style="list-style-type: none"> ○ The SEPA manual notes that the Infaunal Trophic Index has potential for setting standards: <ul style="list-style-type: none"> ▪ Index Value of 60 to 100 represents Community 'Normal' ▪ Index Value of 30 to 60 represents Community 'Changed' ▪ Index Value of < 30 represents Community 'Degraded'
<p>Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., Fisheries Act Authorizations, practices, other approaches)</p>	<ul style="list-style-type: none"> • Registration of Fish Farming and Shellfish Farming Businesses Amendment (Scotland) Order (2002): all aquaculture companies must register within two weeks of site operation (FAO, 2009). • Locally, EIA is translated into a Planning Advice Note (PAN) No 58 (specifically deals with aquaculture development) (FAO, 2009). • Legislation requires 1) application for siting and 2) application to discharge waste. Aquaculture development is regulated under the EU Water Framework Directive as The Water Environment (Controlled Activities) (Scotland) Regulations 2005. A CAR license from SEPA is required for each farm. The license allows for discharge of feed, faecal and dissolved fish-generated wastes, and regulates maximum biomass (marine) or production (freshwater) allowed, infrastructure requirements, site-specific monitoring requirements (FAO, 2009). • Legislative drivers that require collection of benthic information describing conservation features include: Council Directive 92/43/EEC (Habitats Directive); Council Directive 79/409/EEC (Birds Directive); Nature Conservation (Scotland) Act 2004 (FAO, 2009; SEPA, 2010b). • Environmental impact assessment (EIA) is integral to determining most marine finfish applications. EU Directive on Environmental Assessment (85/337/EC) as amended by Directive 97/11/EC seeks to ensure that a formal Environmental Impact Statement addresses potential effects, when a marine aquaculture development is likely to have significant effects. The amended directive was brought into force by the Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations 1999 (FAO, 2009). • The SEPA fish farm manual provides a detailed description of EIA requirements, and all monitoring requirements. It is posted on the internet, at http://www.sepa.org.uk/water/water_regulation/regimes/aquaculture/marine_aquaculture/fish_farm_manual.aspx. • SEPA Marine Science staff follow quality control protocols (e.g., the epibiota ring test: internet-based, photographic epibiota identification system developed by Joint Nature Conservation Committee and National Marine Biology Analytical Quality Control; SEPA, 2010b) • SEPA conducts audit monitoring targeting higher risk areas (e.g., based on farm size, local hydrography or natural heritage). This includes additional monitoring than the required self-monitoring: <p><i>“underwater camera, benthic faunal community assessment, sediment chemistry (redox, sulphide levels, copper and zinc levels and analysis for the full suite of medicines), particle size analysis, visual assessment of sediment structure, presence of feed pellets and Beggiatoa growth. Samples are collected near the cages, at the edge of the AZE and at reference sites”</i></p> <p>SEPA conducts benthic sediment monitoring to assess license use, and environmental impacts from chemical</p>



Monitoring Program Component	Scotland
	<p>therapeutants, and to validate DEPOMOD predictions. Samples collected from selected site are analyzed for cypermethrin, azamethiphos, teflubenzuron, emamectin benzoate and deltamethrin and any other compounds as required (e.g., ivermectin) (SEPA, 2010b.)</p> <ul style="list-style-type: none">• Monitoring results are compared with published Environmental Quality Standards within an AZE to determine if facility has passed or failed SEPA consent (FAO, 2009).• Failure to maintain the environmental quality standards may result in sanctions applied by regulatory body: reduction or removal of consent to discharge wastes, resulting in cease of facility operations; and, regulator taking the facility operator to court, resulting in fines. There are no specific policy on sanctions (FAO, 2009).• Strategic Framework for Aquaculture, developed in conjunction with industry and stakeholders (Scottish Executive, 2003):<ul style="list-style-type: none">○ SEPA must safeguard water quality and condition of seabed under aquaculture facilities.○ <i>Control of Pollution Act 1974</i> (regulates consent for effluent discharge from aquaculture sites)○ Industry Code of Best Practice by 2004• SEPA has published a guide to the CAR regulations (SEPA, 2008).• <i>Aquaculture and Fisheries (Scotland) Act 2007 (asp 12)</i> – Part I includes fish farms (section 8, monitoring) (OPSI, 2007).



Monitoring Program Component	Norway
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> Regulatory
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> Benthic impact assessment/ use of indicators to assess health of benthic habitat
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> Modelling of organic matter deposition and nutrient or chemical dispersal. Site-based <i>Modelling-Ongrowing -Monitoring (MoM) system for fish farms</i>. The degree of exploitation and impact determine the degree of monitoring, either Investigation B (local and intermediate zones) or C (intermediate and regional zones), which increase in complexity and monitoring frequency). Impacts assessment criteria are applied to three zones (local, immediate and regional). Norway also considers water column impacts by modelling nutrient release and reduction in ambient water oxygen levels. MoM has been tested and validated in over 200 investigations in Norway (FAO, 2009).
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<ul style="list-style-type: none"> Monitoring for organic sediment loading conducted every month, every two months or every third month. This depends on the determined degree of exploitation (FAO, 2009) <p>MoM Monitoring – Investigation B (Local and intermediate) (FAO, 2009)</p> <ul style="list-style-type: none"> Degree of Exploitation (determined by applying a scoring system; see Threshold and Criteria) results in different monitoring frequencies for the complete B investigation: <ul style="list-style-type: none"> Degree of Exploitation1 – Every second Year Degree of Exploitation 2 – Every Year Degree of Exploitation 3 – Twice a year (spring and autumn) <p>MoM Monitoring – Investigation C (Intermediate and Regional) (FAO, 2009)</p> <ul style="list-style-type: none"> Sampling frequency determined by local authority (County Governor Department of Environmental Affairs)
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<ul style="list-style-type: none"> Specific spatial design was not determined. However, sampling methodology is based on Norwegian Standards (NS9410 Environmental Monitoring of Marine Fish Farms; NS-EN ISO 16665:2005 for sampling/processing marine soft-bottom macrofauna) available for purchase from Standard.no (see Mitigative and Management Measures or Tools) MoM Monitoring (FAO, 2009) <ul style="list-style-type: none"> Investigation B applies to the local zone and intermediate (near and under the farm). Investigation C applies to the intermediate and regional zones. The transect runs from local to intermediate and regional zones.



Monitoring Program Component	Norway
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	<ul style="list-style-type: none"> The numbers of sample stations, samples, or transects were not determined. However, sampling methodology is based on Norwegian Standards available for purchase from Standard.no (see Mitigative and Management Measures or Tools)
Sampling Methods and Tools (e.g., Eckman grab)	<p>MoM B Investigation (FAO, 2009)</p> <ul style="list-style-type: none"> All sampling can be taken from a small boat (even in rough weather conditions) – under and near the farm. No laboratory analysis is required. Macro infauna – Quantitative sediment assessment after 1mm sieve (presence/absence) pH and redox – Measurements at 1 cm depth; electrodes inserted into sediment immediately after grab sampling. Colour – subjective visual sediment assessment Odour and consistency – subjective olfactory sediment assessment Gas ebullition – quantitative sediment assessment (presence/absence of gas bubbles) Sludge layer thickness – transparent core (top layer of overlying sludge) <p>MoM C Investigation (FAO, 2009)</p> <ul style="list-style-type: none"> Measures long-term changes to sediment by transect running from local through intermediate and regional zones, performed according to Norwegian Standards: <ul style="list-style-type: none"> NS9410 (Environmental Monitoring of Marine Fish Farms), based on the MoM monitoring programme. NS-EN ISO 16665:2005 (for sampling/processing marine soft-bottom macrofauna; replaces NS9423 for sampling benthic infauna) – grab (or box core); macrofauna (animals retained on a 0,5 mm to 1,0 mm mesh screen) (Standard.no, 2010a) Standards available for purchase from Standard.no (see Mitigative and Management Measures or Tools)
Ecological components (e.g., soft substrate sulphide levels)	<ul style="list-style-type: none"> Benthic community pH and redox Benthic fauna/macro infauna Total organic content Particle size Sensory sediment variables (colour, odour and consistency, gas ebullition, sludge layer thickness) Oxygen content of the water column Parameters meant to be sensitive enough to detect subtle impacts and based on organic-enriched sediment ecology. (FAO, 2009)
Biological Indicators (e.g., <i>Beggiatoa</i>);	<ul style="list-style-type: none"> MoM C Investigation: benthic fauna (animals retained on a 0,5 mm to 1,0 mm mesh screen) (FAO, 2009; Standard.no, 2010a)



Monitoring Program Component	Norway
<p>Thresholds and Criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)</p>	<ul style="list-style-type: none"> • MoM B Investigation (FAO, 2009) <ul style="list-style-type: none"> ○ Scoring is applied to each parameter to determine environment quality standards (Environmental Conditions, ECs). ○ Degree of site exploitation determined by set environmental quality standards (by combining the results of the three sets of variables: presence of macro infauna; pH and redox; and, sediment sensory variables) <ul style="list-style-type: none"> ▪ Presence of macro infauna: <ul style="list-style-type: none"> • Presence=0; absence=1 • Mean sample score: ≤0.5 EC 1-3 (acceptable); >0.5 EC 4 (not acceptable) ▪ pH and redox <ul style="list-style-type: none"> • Mean sample score: ≤1=EC 1; >1 to ≤2=EC 2; >2 to ≤3=EC 3 (acceptable); >3=EC 4 (not acceptable) ▪ Sediment sensory variables <ul style="list-style-type: none"> • Colour: None, light grey, brown=0; dark brown, black=2 • Odour and consistency: no smell=0; slight smell=2; strong smell=4 • Gas ebullition: Absent=0; Present=4 • Sludge layer thickness: 0-2cm=0; 2-4cm=1; 4-6cm=2; 6-8cm=3; >8cm=4 • Combined scores gives EC; mean score represents EC as for ph and redox ○ EC 1, 2 and 3 are acceptable conditions. EC 4 is not acceptable. Degree of Exploitation (1, 2 or 3) is determined by the EC level. ○ Degree of Exploitation results in different monitoring frequencies (see Timing of Data Collection): <ul style="list-style-type: none"> ▪ Degree of Exploitation 1 – Every second Year ▪ Degree of Exploitation 2 – Every Year ▪ Degree of Exploitation 3 – Twice a year (spring and autumn) ○ If site “not acceptable,” proponent can implement mitigative measures. ○ Past mitigation: relocation to more-exposed sites with greater flushing; NYTEK regulations developed to mitigate increased fish escapes since cages were not designed for more-exposed sites; Now, more often utilized mitigation options: lowering production and fallowing. • MoM C Investigation (FAO, 2009) – Environmental quality standards set by Norwegian Pollution Control Authority and according to Norwegian Standard 9410 (standard sold by Standard.no, see next row).
<p>Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., Fisheries Act Authorizations, practices, other approaches)</p>	<ul style="list-style-type: none"> • <i>Aquaculture Act (2006)</i> <ul style="list-style-type: none"> ○ Describes licensing process (section 5) ○ Promotes industry competitiveness in sustainable development framework. ○ Requires proponents to monitor/document condition of environment, at the time of facility establishment, operation and abandonment (Chapter 3, section 11; NMFCA, 2005). • Aquaculture Operation Regulations (Ministry of Fisheries and Coastal Affairs) <ul style="list-style-type: none"> ○ Measurements of oxygen saturation, temperature and salinity should be done as needed based on risk



Monitoring Program Component	Norway
	<p>assessments (Section 23).</p> <ul style="list-style-type: none">○ Regulations for sustainable and competitive development, good aquaculture animal health, and good fish welfare (NFSA, 2009).• <i>Salmon Allocation Decree</i> discusses discuses authorizations related to breeding salmon, trout and rainbow trout. It also discusses criteria for operation of aquaculture and mariculture of salmon, trout and rainbow trout (FAOLEX, 2010a.). The full text of the <i>Salmon Allocation Decree</i> is available in Norwegian at http://faolex.fao.org/docs/texts/nor66429.doc (accessed March 2010).• There are efforts to develop environmental monitoring and localizing (MOMO) as a comprehensive system for regulation of environmental impact and site adaptations, see report on environmentally sustainable aquaculture (NDF, 2009).• Standard.no sells NS9410 Norwegian Standard for Environmental Monitoring of Marine Fish Farms (approximately CDN \$100) and NS-EN ISO 16665:2005, standard for sampling/processing marine soft-bottom macrofauna (approximately CDN \$75) (Standard.no, 2010b)• NYTEK regulations cover issues relating to fish containment/escapement (FAO, 2009)



Monitoring Program Component	United States (Maine)
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> • Regulatory • NOTE: There are numerous states in USA involved in aquaculture. The focus is on Maine.
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> • Benthic impact assessment
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> • Inflow/outflow (effluent) waters monitored under NPDES General Permit for Discharges from Aquaculture and Aquariums (General Permit): this includes quarterly grab samples to analyze for settleable solids (FAO, 2009).
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<p>Sediment and Benthic Monitoring (FAO, 2009)</p> <ul style="list-style-type: none"> • Carried out at same time as video monitoring • April to May and August to October – redox potential; sulphide; anoxic sediment, gas formation and <i>Beggiatoa</i> • Minimum once each 5yrs in August/October – azoic conditions and infauna (both may also be required if warning levels exceeded) <ul style="list-style-type: none"> ◦ When taxa measured – Sediment grain size, TOC • Once every 2 years – copper and zinc: total metal (measured when fish biomass is at maximum) • Within month of use – Medications used (including primary metabolites) <p>Video (or photographic) Monitoring (FAO, 2009)</p> <ul style="list-style-type: none"> • Twice per year (spring and autumn) – sediment type and colour, erosional or depositional areas, flora and fauna, presence of feed pellets, presence and appearance of <i>Beggiatoa</i> mats, presence of black sediments, out-gassing • Spring monitoring may be waived if there no exceedences in autumn monitoring.
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<p>Sediment and Benthic Monitoring (FAO, 2009 and MDEP, 2003)</p> <ul style="list-style-type: none"> • Sampling for all parameters taken as same locations. • Minimum of four stations along transect – two on each side of cage array: one 30 m from the cage array (in mixing zone), and one within the mixing zone where greatest benthic impact observed or 5 m from pen if no difference in impacts) • At each station, a minimum of three samples taken perpendicular to transect spaced at distances reflecting and within the lateral extent of greatest benthic impact • If grab samples used for sediment analysis subsamples, maximum 25% of sample should be removed <p>Video (or photographic) Monitoring (FAO, 2009)</p> <ul style="list-style-type: none"> • 60-m transects under cages from edge of cages: up-current; downcurrent. • Images should cover 1 m² of sea floor.



Monitoring Program Component	United States (Maine)
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	<p>Sediment and Benthic Monitoring</p> <ul style="list-style-type: none"> • 12 samples: 4 sampling stations, 3 samples per station (see Timing of Data Collection for frequency of sampling for each parameter) <p>Video (or photographic) monitoring</p> <ul style="list-style-type: none"> • 4 transects (upcurrent and downcurrent; twice per year) • Continuous color video monitoring; if still camera, one photograph at least every 10 meters (MDEP, 2003)
Sampling Methods and Tools (e.g., Eckman grab)	<p>Sediment and Benthic Monitoring – cores/grab samples (FAO, 2009)</p> <ul style="list-style-type: none"> • Cores of top 3 cm (for redox and sulphide) • Single cores, ≥ 10cm (4 inches), to depth of 15 or to resistance with samples sieved through 1.0 mm sieve (for azoic conditions, infauna species) • Cores of top 2 cm (for total metal – copper and zinc) <p>Video (or Photographic) Monitoring (FAO, 2009 and MDEP, 2003)</p> <ul style="list-style-type: none"> • Divers (up to 85 feet); at greater depth: a video camera mounted on a tethered sled, a tethered drop still/video camera (or equivalent) along each transect • GPS to locate beginning/end of each transect
Ecological Components (e.g., soft substrate sulphide levels)	<p>Sediment and Benthic Monitoring (FAO, 2009 and MDEP, 2003)</p> <ul style="list-style-type: none"> • Redox • Sulphide • Anoxic sediment, gas formation and <i>Beggiatoa</i> • Azoic conditions • Infauna (Taxa measurements must include presence, absolute and relative abundance and Shannon-Weiner Diversity Index) • Sediment grain size • Total organic carbon • Copper – total metal • Zinc – total metal • Medications used (included: analysis for primary metabolites) <p>Video (or Photographic) Monitoring (FAO, 2009 and MDEP, 2003) (requirement for spring monitoring may be waived if the previous autumn monitoring showed no exceedances of warning levels)</p> <ul style="list-style-type: none"> • Sediment type and colour • Erosional or depositional areas • Flora and fauna (presence) • Feed pellets (presence) and other anthropogenic debris



Monitoring Program Component	United States (Maine)			
	<ul style="list-style-type: none"> • Appearance of <i>Beggiatoa</i> mats • Presence of black sediments • Presence of “pimpled” sediment • Out-gassing • Document location of any nets located on the bottom 			
Biological Indicators (e.g., <i>Beggiatoa</i>)	<ul style="list-style-type: none"> • <i>Beggiatoa</i> (relative abundance: abundant, frequently present within video; common, seen occasionally during video or existing in patches; rare, only seen once or in a few places during dive.) Flora, fauna/infauna, taxa richness (MDEP, 2003; FAO, 2009). • Main Department of Environmental Protection permit: discharges must not resulting in harmful alga blooms (e.g., <i>Alexandrium</i>, <i>Dinophysis</i>, <i>Prorocentrum</i>, <i>Pseudonitzschia</i>, <i>Phaeocystis</i>, <i>Enteromorpha</i>, <i>Ulva</i>, <i>Aureococcus</i>, etc. (Sowles, 2003). 			
Thresholds and criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)	Sediment Warning Levels			
	Determinand	Sediment mixing zone (or < 30 m of cages)		Beyond sediment mixing zone (≥ 30 m from cages)
		Warning Level	Impact limit	Impact limit
	Redox potential	Mean 100 – 0 mV nhe [normal hydrogen electrode]	Mean < 100 mV nhe	Report level
	Sulfide	Mean 1300-6 000 µM	Mean > 6 000 µM	Report level
	<i>Beggiatoa</i> coverage	≥ 25 % photo coverage	≥ 50 % photo coverage	Compelling evidence (see note)
	Anoxic sediments	≥ 25 % photo coverage	≥ 50 % photo coverage	Compelling evidence (see note)
	Pollution tolerant taxa	No. individuals in single taxa > 70 %	Report information	None specified.



Monitoring Program Component	United States (Maine)			
	Pollution sensitive taxa	> 50 % reduction in mean abundance of taxa not identified as pollution tolerant ⁹	Report information	SB Classification receiving waters – Significant reduction in mean number of listed taxa as compared to mean baseline or reference site SC Classification receiving waters – unsuitable for any species of indigenous fish, or structure and function of resident biological community is not maintained
	Taxa richness	> 25 % reduction in total number of all taxa compared to mean baseline or reference site	Report information	SB Classification receiving waters – Significant reduction in mean number of listed taxa as compared to mean baseline or reference site SC Classification receiving waters – unsuitable for any species of indigenous fish, or structure and function of resident biological community is not maintained
	Azoic conditions	> 50 % reduction in total abundance compared to mean baseline or ref site	Absence of fauna	None specified.
<p>Source: Table 26, 508 Part 1 – Reviews and synthesis (FAO, 2009)</p> <p>Note: Compelling evidence includes photo or video documentation, diver observations, or sediment analyses indicating impact limits achieved.</p> <ul style="list-style-type: none"> • <i>Beggiatoa</i> must not cover more than 50% of bottom (under cage) and must not cover more than 25% of the bottom within 30 meters (Sowles, 2003). 				



Monitoring Program Component	United States (Maine)
Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., Fisheries Act Authorizations, practices, other approaches)	<ul style="list-style-type: none">• In the United States, all aquaculture facilities within 4.8 km (three miles) of the coast are subject to state regulations and all activities are required to be registered with the appropriate department (FAO, 2009).• Federal and state regulations controlling wastewater discharge and water quality<ul style="list-style-type: none">○ Federal:<ul style="list-style-type: none">▪ US EPA (FAO, 2009)<ul style="list-style-type: none">• Conducts regulatory enforcement• <i>Federal Water Pollution Control Act</i> regulates discharge to inter-state waters – requires permit under the National Pollutant Discharge Elimination System (NPDES) programme (includes monitoring and reporting requirements)• Concentrated Aquatic Animal Production (CAAP) programme and Effluent Limitations Guidelines (ELGs): provide performance standards for aquatic animal production• Coastal Water Quality Monitoring Programme – monitors coastal systems/coordinates monitoring with other agencies▪ <i>Clean Water Act</i> allows alteration of natural environment but requires maintenance of “chemical, physical, and biological integrity”; requires permits for finfish aquaculture○ Maine:<ul style="list-style-type: none">▪ Permit required from Department of Environmental Protection - monitoring under direct control of State of Maine – “General Permit for Atlantic Salmon Aquaculture”; includes water monitoring, and video/photographic monitoring of seafloor (Sowles, 2003; MDEP, 2003).



Monitoring Program Component	Australia (South Australia)
Purpose (i.e., regulatory or proactive?)	<ul style="list-style-type: none"> • Regulatory • NOTE: there are several states in Australia involved in aquaculture. The focus is on South Australia.
Function (i.e., assess benthic habitat condition)	<ul style="list-style-type: none"> • Benthic impact assessment in sub-tidal area (National Aquaculture Legislation Overview: Australia (FAO, 2010a).
Prediction Tool or Method (e.g., DEPOMOD, other tools) and siting criteria/tools	<ul style="list-style-type: none"> • No information found
Timing of Data Collection (i.e., peak biomass; when/why is monitoring being done)	<ul style="list-style-type: none"> • Colour recording of sea floor, at least once per reporting year, at approximately same time each year
Sample Design – Spatial (i.e., radial, transects) “How are they doing it?”	<p>Aquaculture in State Waters (as defined by <i>Harbors and Navigation Act 1993</i>) (GSA, 2009)</p> <ul style="list-style-type: none"> • Video monitoring <ul style="list-style-type: none"> ○ Minimum three transects <ul style="list-style-type: none"> ▪ Close as practicable to side of sea cage, along direction of prevailing current(downcurrent) for 150 m ▪ Close as practicable to opposite side of sea cage, along opposite direction of prevailing current (upcurrent) for 150 m ▪ Offsite transect (same transect video recorded each year)– outside license area at midpoint of prevailing downcurrent boundary of license area, along right angle to the boundary for 150 m ○ Continuous recording (no breaks) ○ Each transect requires minimum 30 second 360° pan of above water horizon at start and finish ○ Minimum 2 m width of sea floor visible at all times ○ Video must be at 45° angle to sea floor; always focused on sea floor ○ Footage: steady and slow pace of 2 to 4 seconds per metre.
Intensity (i.e., approximate of number of samples per year)/ Statistical Merit (i.e., determination of significance)	<p>Video monitoring (GSA, 2009)</p> <ul style="list-style-type: none"> • Once per reporting year, minimum three transects • Written records (transect/cage location; for each 10 m of transect of various parameters)



Monitoring Program Component	Australia (South Australia)
Sampling Methods and Tools (e.g., Eckman grab)	Video monitoring (GSA, 2009) <ul style="list-style-type: none"> • Correct data and time stamp always visible • Footage: steady, and slow pace of 2 to 4 seconds per metre. • Video must be of sufficient quality to assess benthic environment • Adequate lighting to show benthic flora and fauna colours (lighting level equivalent to that of two high-intensity underwater metal halide 10 watt lamps) • Written records describing video
Ecological Components (e.g., soft substrate sulphide levels)	Aquaculture in State Waters (as defined by <i>Harbors and Navigation Act 1993</i>) (GSA, 2009) <ul style="list-style-type: none"> • Level of bioturbation in sediment • Undulation • Natural organic waste • Aquaculture waste (including waste baitfish, pellets); • Sand colour • Macroalgal cover • Seagrass cover • Microbial mats (e.g., <i>Beggiatoa sp.</i>) • Blue-green algal mats • Sponge cover • The presence of: holothurians (sea cucumbers), ascidians (sea squirts), razor fish (<i>Pinna sp.</i>), scallops, crabs, gastropods, fish, seahorses and sea dragons.
Biological Indicators (e.g., <i>Beggiatoa</i>);	<ul style="list-style-type: none"> • Macroalgal cover • Seagrass cover • Microbial mats (e.g., <i>Beggiatoa sp.</i>) • Blue-green algal mats • Sponge cover • The presence of: holothurians (sea cucumbers), ascidians (sea squirts), razor fish (<i>Pinna sp.</i>), scallops, crabs, gastropods, fish, seahorses and sea dragons (GSA, 2009).
Thresholds and criteria (e.g., if 3000 µm sulphide then Section.35(2) Fisheries Act authorization)	Environment Protection (Water Quality) Policy (2003) prohibits discharge or deposition of pollutants into waters resulting in a variety of effects, including (FAO, 2010a): <ul style="list-style-type: none"> • Loss of sea grass or other native aquatic vegetation • Reduced numbers of native species of aquatic animals or insects • Increased numbers of non-native species of aquatic animals or insects • Various water quality changes • Aquaculture Regulations (2005) require that aquaculture waste (definition includes waste generated during carrying out aquaculture, but not that from living organisms) does not result in unsightly/offensive conditions in the licensed



Monitoring Program Component	Australia (South Australia)
	<p>area. Also, no waste can leave the license area; if so, it must be recovered as soon as possible (FAO, 2010a).</p>
<p>Mitigative and Management Measures or Tools (regulatory or administrative tools; e.g., <i>Fisheries Act</i> Authorizations, practices, other approaches)</p>	<ul style="list-style-type: none"> • States/territorial governments have primary aquaculture responsibility up to 3 nautical miles limit (inland and coastal waters); Australian Government is responsible of management of marine water from 3 to 200 nautical mile limits (FAO, 2010b). • Statutory marine aquaculture planning (regional aquaculture plans subject to environmental assessment and zoning: leading tenders are invited for lease zones; conditional licenses specify management/monitoring requirements (FAO, 2009). • State legislation: <i>Aquaculture Act (2001)</i>, responsible authority, Department of Primary Industries, Resources (FAO, 2009). Act covers granting of aquaculture license, covers decisions of license conditions and lease terms/conditions, establishes an Aquaculture Advisory Committee, preparation of aquaculture policies – Aquaculture Environmental Management Framework Policy (2004) establishes environmental assessment , monitoring and management framework Primary Industries and Resources South Australia (PIRSA) assesses aquaculture licenses to meet policy objectives and license application will be reviewed by the environment Protection Authority; Aquaculture Regulations (2005) under the Aquaculture Act (2001) covers license environmental monitoring/reporting requirements licensees (FAO, 2010a). • Environment Protection (Water Quality) Policy (2003) under <i>South Australian Environmental Protection Act (2003)</i>: state-wide approach to water quality protection (FAO, 2010a). • There are various policies relating to specific zones and general aquaculture policies (PIRSA, 2009a). • Risk-based management approach focuses management and monitoring on key environmental concerns for land-based aquaculture activities (coastal and inland). Risk (low, medium and high) is based on how water is discharged and feed input (FAO, 2009). • Commonwealth legislation: <i>Environment Protection and Biodiversity Conservation Act 1999</i> (for protection of the environment and the biodiversity conservation) (FAO, 2010b; FAOLEX, 2010b). • (National) Australian Aquaculture Code of Conduct – to maintain ecologic and economical sustainability for aquaculture industry. National Aquaculture Legislation Overview: Australia, (FAO, 2010a; PIRSA, 2009b).



4 Conclusion

Table 4.1 summarizes the monitoring program components for each of the three Canadian jurisdictions and the four international jurisdictions.

Purpose

- Proactive in Newfoundland and Labrador Region and Maritimes Region
- Regulatory in all remaining jurisdictions

Function

- Monitoring conducted for benthic impact assessment in all jurisdictions

Prediction Tool or Method

- DEPOMOD is used in Pacific Region and Scotland
- Several other tools are used (siting/assessment tools, license application, anti-parasite and MoM modelling, baseline assessment, inflow/outflow monitoring)

Timing of Data Collection

- Based on fallowing period, sulphide levels, peak biomass, cage relocations, scoring (environmental condition/degree of exploitation), timing of sampling of other parameters, and time of year (spring/fall)

Sample Design – Spatial

- Newfoundland and Labrador Region is the only jurisdiction doing video monitoring via clock method; all others use a transect method
- All jurisdictions do sediment sampling (generally along transects)
- South Australia does not do sediment sampling

Intensity

- Sediment sampling was variable ranging from 1 to 8 stations. However, more might be possible since number of stations could be dependent on site size, and number/density of cages or cage arrays. Grabs per station ranged from 3 to 7.
- Video sampling ranges to clock-method under cages to transects of varying lengths. Pacific Regions also recorded quadrats; Scotland specifically observes 10 stations along a 50-m transect, and South Australia describes each 10 m of a transect.

Sampling Methods and Tools

- Sediment sampling typically included core or grab sampling
- Video surveys use scuba divers, or remote monitoring equipment (e.g., ROV or drop/tow cable).



- Other tools used include fallow monitoring, repeat sampling (if there is remediation), prioritizing higher production sites, and use of lighting

Ecological Components

- Primarily benthic community structure/ diversity (e.g., fauna, flora, key species or habitat, etc.), and redox/sulphide or other qualitative/quantitative sediment measures

Biological Indicators

- *Beggiatoa* used Newfoundland and Labrador Region, Maritimes Region (Nova Scotia), USA (Maine) and Australia South Australia)
- Other indicators included redox/sulphide, algae/flora/sea grass, fauna/macrofauna, sponge, biota to family level, and biological indices.

Thresholds and Criteria

- Based on change from baseline or reference conditions (e.g., sulphide/redox), qualitative criteria (e.g., sediment colour or smell), deposition levels defined by DEPOMOD, scoring to determine environmental conditions/level of exploitation, abundances of sensitive/tolerant species (including % *Beggiatoa* coverage) or native/non-native species, water quality, and waste discharge or impacts

Mitigative and Management Measures or Tools

- In Canada, only Pacific Region has had Authorizations.
- In Canada, an environmental assessment is required under the Canadian *Environmental Assessment Act* (CEAA; DFO, 2008)
- Various legislative tools, permits licenses and policies
- Management tools include changing rotation period, adjusting biomass, use of a site mapping tool, applying sanctions, comparison to published environmental quality standards, risk-based management approach and enforcement.



Table 4.1: Summary of monitoring program components in each jurisdiction

Monitoring Program Component	Newfoundland & Labrador Region	Maritimes Region	Pacific Region	Scotland	Norway	USA (Maine)	Australia (South Australia)
Purpose	•Proactive	•Proactive	•Regulatory	•Regulatory	•Regulatory	•Regulatory	•Regulatory
Function	•Benthic assessment	•Benthic assessment	•Benthic assessment	•Benthic assessment	•Benthic assessment	•Benthic assessment	•Benthic assessment
Prediction Tool or Method	<ul style="list-style-type: none"> •Provincial Aquaculture Cage Culture application •CCRI (GIS assessment tool) •Benthic Environment Monitoring Index (baseline/part 2 monitoring) •Siting conditions 	<ul style="list-style-type: none"> •Baseline monitoring •DSS (site screening tool) •NS - EMP 	<ul style="list-style-type: none"> •DEPOMOD •Baseline monitoring 	<ul style="list-style-type: none"> •DEPOMOD •Anti-parasite modelling/sampling •Baseline monitoring 	•Modelling/Site-based MoM system	•NPDES General Permit for Discharges from Aquaculture and Aquariums (inflow/outflow monitoring)	•No information found
Timing of Data Collection	•Two parts: pre-fallow (between 2 weeks before/after fallow start); fallow (4-8 weeks before fallow end)	<ul style="list-style-type: none"> •NB: Tier 1 monitoring – 1x/year (Aug. 1-Oct 31); Tier 2 monitoring – once, within 20 days after Tier 1 or 2 (based Tier 1 or 2 sulphide); Tier 3 - 1x/year (based on Tier 1 sulphide) •NS: no timing determined 	<ul style="list-style-type: none"> •Sediment/Video: Within 30 days of peak biomass or relocation of cage if during production cycle •Sediment: if sulphide levels met, if cage moved back to fallow area 	•Within 30 days of peak biomass, once every 2 years, May 1 to Oct 31	<ul style="list-style-type: none"> •MoM B, depends of degree of exploitation, determine by scoring; 1x/2years, 1x/year, or 2x/year •MoM C – set by local authority 	<ul style="list-style-type: none"> •Sediment (spring/fall; min. 1x/5 years in Aug/Oct for azoic conditions/ infauna and sediment grain size/TOC when taxa measured) •Video (spring and fall, spring may be waived) 	•Video of seafloor (at least 1x / reporting year, same time each year)



Monitoring Program Component	Newfoundland & Labrador Region	Maritimes Region	Pacific Region	Scotland	Norway	USA (Maine)	Australia (South Australia)
Sample Design – Spatial	<ul style="list-style-type: none"> •Video (clock-method) •Sediment samples (no transects) 	<ul style="list-style-type: none"> •NB: 3 tiers with transects, video, and sediment sampling •NS: monitoring with transects, video, sediment samples, water quality 	<ul style="list-style-type: none"> •Video (megafauna transect), Photographs (macrofauna quadrat), transects and quadrats •Sediment samples 	<ul style="list-style-type: none"> •Benthic sediment (base on current, transects) •Video (transects) 	<ul style="list-style-type: none"> •Specify design not determined, based on Norwegian Standards •MoM B – local/intermediate zones •MoM C – intermediate/ regional zones 	<ul style="list-style-type: none"> •Sampling at same location for all parameters •Sediment (station as along transects) •Video (transects) 	<ul style="list-style-type: none"> •Video (transects)
Intensity	<ul style="list-style-type: none"> •1-2 stations/cage (for each of Part I or II) •3 grabs/station 	<ul style="list-style-type: none"> •NB: Tier 1&3, -# of transects (with video) based on fish biomass; Tier 2, 5 transects (with video), 24 samples (8 stations, 3 samples/station) •NS - risk determines monitoring, repeat sampling if remediation 	<ul style="list-style-type: none"> •# megafauna transects: not specified •Macrofauna quadrats: ~40 (alternate designs possible) •Sediment: total number not specified (up to 5 grabs/station) 	<ul style="list-style-type: none"> •Sediment 2-5 grabs/station (biological), 2 grabs (chemical); # stations dependent on monitoring level/ and #/density of cage arrays •Video: 50-m transect with 10 stations 	<ul style="list-style-type: none"> •Specify intensity not determined, based on Norwegian Standards 	<ul style="list-style-type: none"> •Sediment 12 samples: 4 stations, 3 samples/ station •Video (4 60-m transects; continuous color video, or still photographs every 10 m) 	<ul style="list-style-type: none"> •Video (1x/year, minimum 3 transects, written records for each 10 m)
Sampling Methods and Tools	<ul style="list-style-type: none"> •Fallow monitoring •Sediment (grab) •Video (ROV, drop/cable camera, or diver) 	<ul style="list-style-type: none"> •NB – Sediment core/grab, video (by diver) •NS – repeat sampling if remediation, higher priority given to higher production sites 	<ul style="list-style-type: none"> •Sediment (grab) •Video (ROV, cable, diver) 	<ul style="list-style-type: none"> •Sediment (grab) •Video (diver, remote system), drop cable/towed video, still photographs 	<ul style="list-style-type: none"> •Sediment (grab) •Other methodology not specified (e.g., if video is conducted during transects) •Based on Norwegian 	<ul style="list-style-type: none"> •Sediment (grab/core) •Video or Photographic (diver, <85 feet depth; tethered sled/tethered drop/still camera, >85 	<ul style="list-style-type: none"> •Video (slow/steady pace, sufficient quality for benthic assessment, adequate lighting, written records)



Monitoring Program Component	Newfoundland & Labrador Region	Maritimes Region	Pacific Region	Scotland	Norway	USA (Maine)	Australia (South Australia)
					standards	feet)	
Ecological Components	<ul style="list-style-type: none"> •Benthic community structure/ diversity •Redox/ sulphide 	<ul style="list-style-type: none"> •NB – Benthic community structure/ diversity, redox/sulphide • NS - Benthic community structure/ diversity, redox/sulphide, % organic content, porosity 	<ul style="list-style-type: none"> •Benthic community structure/diversity •Redox/sulphide, various qualitative and quantitative sediment measures 	<ul style="list-style-type: none"> •Benthic community structure/diversity •Redox/sulphide, various qualitative and quantitative sediment measures •Key species/ habitats •Substrate type 	<ul style="list-style-type: none"> •Benthic community structure/ diversity •Redox/sulphide, various qualitative and quantitative sediment measures •Water column O₂ content 	<ul style="list-style-type: none"> •Benthic community structure/ diversity •Redox/ sulphide, various qualitative and quantitative sediment measures •Presence: feed pellets, nets on bottom, human-made debris •Medications 	<ul style="list-style-type: none"> •Benthic community structure/ diversity •Level of bioturbation in sediment •Undulation •Natural organic waste •Aquaculture waste (including waste baitfish, pellets) •Sand colour
Biological Indicators	<ul style="list-style-type: none"> •Redox/ sulphide •organic deposition, <i>Beggiatoa</i>, opportunistic polychaete 	<ul style="list-style-type: none"> •NB: <i>Beggiatoa</i> •NS: Microbes, algae, macrofauna 	<ul style="list-style-type: none"> •Biota identified to family level •<i>Capitella</i> 	<ul style="list-style-type: none"> •Determination if sufficient “sediment re-worker” species •Macrobenthos/ fauna •Various biological indices 	<ul style="list-style-type: none"> •Benthic fauna (MoM C) 	<ul style="list-style-type: none"> •<i>Beggiatoa</i> •Flora, fauna/infauna, taxa richness •No harmful algal blooms from discharges 	<ul style="list-style-type: none"> •Macroalgal, sea grass, sponge cover •Microbial (e.g., <i>Beggiatoa</i> sp.) and Blue-green algal mats •Presence of various fauna
Thresholds and Criteria	<ul style="list-style-type: none"> •> 25% change in sulphide/ redox or if anoxic conditions •Mitigation required >25% change 	<ul style="list-style-type: none"> •NB: sulphides •NB: qualitative (sediment colour, microbes/plants, macrofauna); quantitative (redox, sulphide, 	<ul style="list-style-type: none"> •Authorization required if DEPOMOD predicts waste deposition >5 g C/m²/day •Taxon richness •Sulphides 	<ul style="list-style-type: none"> •EIA is site >100 tonnes or ≥0.1 ha •Trigger for further information based on increases to AZE area/length 	<ul style="list-style-type: none"> •Scoring applied to each parameter to determine degree of site exploitation, which determines 	<ul style="list-style-type: none"> •Sediment (sulphide/ redox, % <i>Beggiatoa</i> coverage, pollution tolerant/ sensitive taxa, 	<ul style="list-style-type: none"> •Changes in abundance to native/non-native species •Water quality changes •Aquaculture waste not to result in



Monitoring Program Component	Newfoundland & Labrador Region	Maritimes Region	Pacific Region	Scotland	Norway	USA (Maine)	Australia (South Australia)
		organic content, porosity)			monitoring requirements or if mitigation required (MoM B) • MoM C – standards by local authority and NS 9410.	taxa richness, azoic conditions)	unsightly/ offensive conditions • No waste to leave licensed area; if so, prompt recovery
Mitigative and Management Measures or Tools	<ul style="list-style-type: none"> • Change rotation period • Move cages in boundary • Reduce biomass/adjust feed • Application Review Process: No Authorizations to date • Environmental assessment required under CEAA 	<ul style="list-style-type: none"> • Application Review Process: No Authorizations • Environmental assessment required under CEAA • NB: provincial acts/regulation s/license, ASERC reviews (Production/R emediation Plans), SOP for marine finfish aquaculture monitoring • NS: Aquaculture Site Mapping tool, provincial act 	<ul style="list-style-type: none"> • DEPOMOD • Application Review Process: Authorizations (and compensation) • FAWCR and support documents • Aquaculture licenses • Environmental assessment required under CEAA 	<ul style="list-style-type: none"> • Legislative tools, sanctions • Guide to CAR regulations • EIA/planning advice • SEPA fish farm manual (online) • SEPA Marine Science follows QC procedures • SEPA audit monitoring • Monitoring compared to published environmental quality standards • Strategic Framework for Aquaculture 	<ul style="list-style-type: none"> • Various legislation • Development of regulation system (MOMO) • Norwegian Standards 	<ul style="list-style-type: none"> • State and federal regulations • State permitting for Atlantic Salmon Aquaculture • USEPA: enforcement, monitors via Coastal Water Quality Monitoring Programme, provides performance standards for aquatic animal production 	<ul style="list-style-type: none"> • State and Commonwealth legislation • Various policies • Risk-based management approach • National Australian Aquaculture Code of Conduct



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