ACTIVITIES AND POTENTIAL ENVIRONMENTAL EFFECTS

ASSOCIATED

WITH SHELLFISH AQUACULTURE

IN BAYNES SOUND

A DISCUSSION DOCUMENT

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1.0 INTRODUCTION

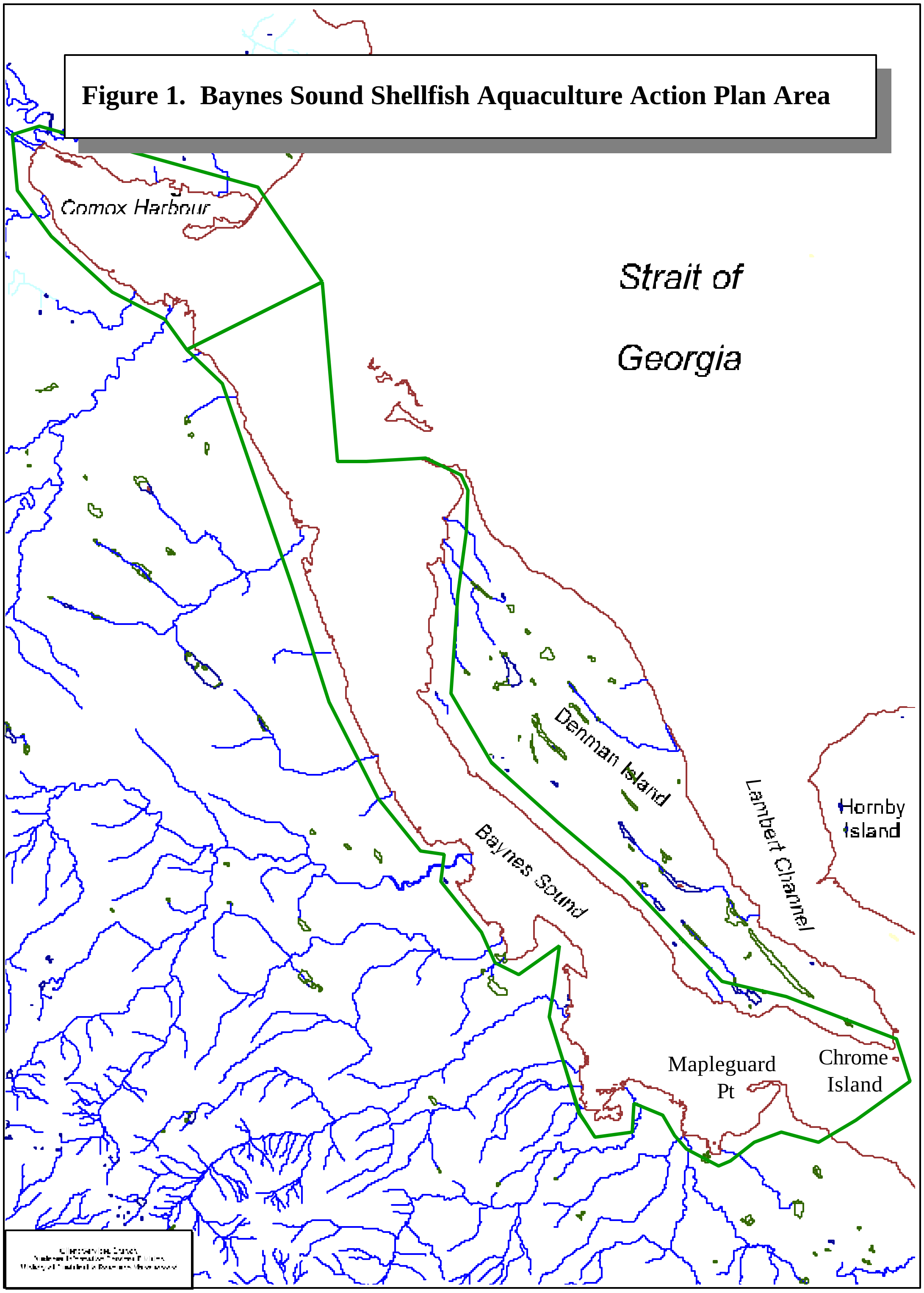
1.1 BACKGROUND

In 1998 the Government of British Columbia announced the Shellfish Development Initiative with the objective of increasing provincial foreshore areas under shellfish aquaculture tenure. Baynes Sound is an important shellfish (oyster and intertidal clam) aquaculture area in the Strait of Georgia, and the shellfish aquaculture industry has expressed interest in obtaining additional lease areas (both intertidal and off-bottom) within Baynes Sound. Concerns have been raised as to the suitability and sustainability of expanding shellfish aquaculture tenures in Baynes Sound due to potential resources use conflicts, environmental and wildlife conflicts, and lack of effective consultation and compliance processes (Baynes Sound Shellfish Aquaculture Action Plan Terms of Reference). In August of 2001 the province of British Columbia suspended processing of new applications for shellfish leases in Baynes Sound and initiated the Baynes Sound Shellfish Aquaculture Action Plan. The plan area includes Baynes Sound north of Chrome Island and Mapleguard Point, including Comox Harbour but excluding Sandy Island Marine Park north of Denman Island (Figure 1). The stated objectives of this planning process are:

1. Identify whether any additional areas within Baynes Sound are suitable for further aquaculture development.
2. Address concerns of upland residents, other fisheries resource users and the aquaculture industry by documenting problem areas and developing management tools where required.
3. Ensure that, if any shellfish aquaculture expansion occurs, that it does so in an environmentally sustainable fashion.

Archipelago Marine Research Ltd. was engaged by the BC Ministry of Sustainable Resource Management to address a component of the Baynes Sound Shellfish Aquaculture Action Plan, namely summarising potential environmental effects of shellfish aquaculture and providing a systematic method for assessing the degree of potential impact. The objective of this component of the planning process is to aid in developing a decision-making framework, based on sustainable development principles, with respect to the possibility of expanding shellfish aquaculture tenures within Baynes Sound.

Figure 1. Baynes Sound Shellfish Aquaculture Action Plan Area



1.2 APPROACH

Our approach to the objectives outlined above involved several steps:

1. Identify key biophysical features of Baynes Sound;
2. Summarise existing environmental overviews for Baynes Sound which outline potential environmental effects of shellfish aquaculture activities;
3. Using the information provided in these reports, develop and document a method to address the degree of potential impact resulting from shellfish aquaculture activities and identify data gaps and research priorities;
4. Conduct an assessment of environmental effects using the proposed methodology and provide an indication of the risk associated with specific effects; and,
5. Provide direction on the use of precautionary, adaptive management principles within a decision oriented, sustainable resource management framework for shellfish aquaculture in Baynes Sound.

It is important to note the scope of this project does *not* include providing specific recommendations on if, or where, expansion of shellfish aquaculture tenures should occur in Baynes Sound. That decision requires consideration of broad range of values and interests. Rather this report is intended to aid in addressing how the potential environmental issues associated with shellfish aquaculture should be addressed within this broader decision-making context.

Three synoptic reports on the environmental interactions of shellfish aquaculture within Baynes Sound were provided to Archipelago by the Ministry of Sustainable Resource Management.

A. A Review of the Impacts of Shellfish Aquaculture Lease Operations on Marine and Shorebird Species in Baynes Sound, British Columbia (Axys *et al.* 2000).
B. Phase 0 Review of the Environmental Impacts of Intertidal Aquaculture in Baynes Sound (Jamieson *et al.* 2001).
C. A Literature Review of Environmental Interactions with Shellfish Aquaculture by the BC Ministry of Agriculture Food and Fisheries (Lasuik 2001).

These reports were reviewed to summarise the potential environmental effects of shellfish aquaculture in Baynes Sound. No new liturature reviews were undertaken. The primary focus of the environmental issue analysis is intertidal oyster (*Crassostrea gigas*) and manila clam (*Tapes phiippinarium*) aquaculture, however activities and potential environmental interactions resulting from off-bottom longline aquaculture (oysters and scallops) are also summarised.

1.3 KEY BIOPHYSICAL FEATURES OF BAYNES SOUND

The overview reports collectively identify a number of biophysical features of Baynes Sound which are key to both ecosystem function and the diverse resource values of the area.

1. Intertidal Flats

Baynes Sound contains large intertidal areas of gravel/sand sediment, including several delta and estuaries. Comox Harbour is one of the largest, low gradient deltic deposits on the east coast of Vancouver Island. Approximately 45% of the shore length of the Baynes Sound

Shellfish Aquaculture Action Plan area is classified as gravel flats or beaches by the BC Land Use Coordination Office (Figure 2) as compared to 25% for the area of the Strait of Georgia north of Nanaimo and Burrard Inlet.

2. **Quantity and Diversity of Estuarine Habitat**
   Baynes Sound, particularly the east coast of Vancouver Island, contains a number of valued estuarine habitats within a relatively small area of coast (Deep Bay, Mud Bay, Fanny Bay, Buckley Bay, and Comox Harbour). Approximately 25% of the shore length of the Baynes Sound Shellfish Aquaculture Plan area is classified as estuary by the BC Land Use Coordination Office as compared to 5% for the area of the Strait of Georgia north of Nanaimo and Burrard Inlet (Figure 2).

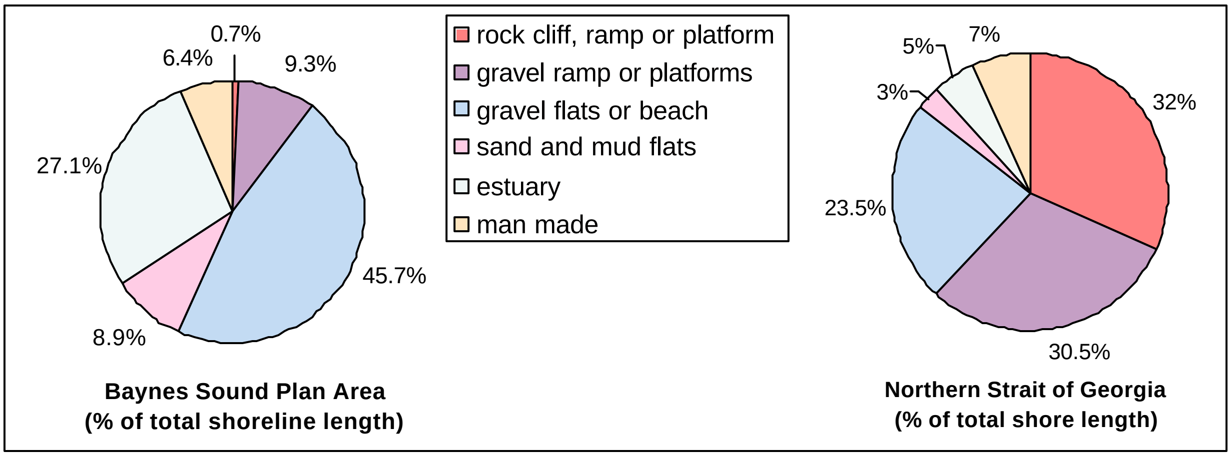


Figure 2. Summary of Shore Types in Baynes Sound and the Northern Strait of Georgia (the BC Land Use Coordination Office Physical Shore Classification for the St. of Georgia).

3. **Significance for Marine and Shorebirds**
   Baynes Sound is recognised as an important overwintering area for waterfowl and shorebirds as well as a summer moulting area for seaducks (Axys *et al.* 2000). At various times of the year the area has nationally and globally significant numbers of several waterfowl, shorebird and gull species.
4. **Herring Spawning**
   Baynes Sound, Lambert Channel and Comox Bar are significant herring spawning areas. Since the mid-1980's Lambert Channel has been the main herring spawning grounds in the Strait of Georgia.
5. **Salmon Spawning and Juvenile Rearing**
   There are 15 salmon bearing streams (14 on Vancouver Island, one on Denman Island) draining to Baynes Sound. Coho, chum and cutthroat trout are the most widely distributed species. The Courtenay River supports a major spawning run of chinook salmon. The estuaries of Baynes Sound are considered significant rearing habitats for juvenile salmon, in particular chinook and chum salmon.
6. **Bivalve Productivity**
   Baynes Sound is an important bivalve (intertidal clams and oysters) growing area and produces significant quantities of both wild and cultured bivalves. The bivalve community is a mixture of native and exotic species. Baynes Sound produces 39% of British Columbia's cultured oyster production and 55% of the provincial landed value for cultured clams.

None of these biophysical features are unique to Baynes Sound, however the combination of these features within the sound is regionally significant and an ecosystem approach to the environmental management of Baynes Sound should recognise this significance and attempt to manage human activities in a manner which sustains ecological function.

1.4 SHELLFISH AQUACULTURE TENURES

A. Intertidal Tenures

Eight intertidal habitat types were mapped in Baynes Sound (Howes and Thomson 1983) as part of a previous foreshore planning process for Baynes Sound. Definitions for each intertidal habitat are provided in Appendix Table 1. The Baynes Sound Aquaculture Action Plan is using these habitat types as the basis for analysing the extent of intertidal tenure area and clam netting area in Baynes Sound (B. Carswell, BC MAFF, pers. comm.) Tables 1 and 2 summarises the results of this analysis. The extent of intertidal tenures (Table 1) is provided for the study area with Comox Harbour both included and excluded. Comox Harbour contains large areas of tidal flats but few shellfish tenures, primarily due to water quality concerns (e.g. faecal coliforms in excess of shellfish growing water quality standards). Maps showing tenure areas and intertidal areas under clam netting have been produced under other components of the Baynes Sound Aquaculture Action Plan. Much of the area under intertidal tenures in Baynes Sound ranges in vertical elevation from +2.5 to 0.0m relative to hydrographic chart datum, the lower portion of the intertidal zone, which is the preferred growing range for both oysters and manila clams.

Table 2 summarises the area of intertidal habitats in Baynes Sound under clam netting, based on air photos taken at extreme low tide in June 2001 and interpreted by the BC Ministry of Agriculture, Fisheries and Food (B. Carswell, pers. comm.). This information indicates that 3 to %% of the intertidal zone is currently under clam netting. In certain habitats (e.g. rock platform with beach, common on the west side of Denman Island) up to 9.5% of the habitat is covered by clam netting. Almost all of the clam netted area is between +1.0 and +2.5m vertical elevation, the preferred growing area for manila clams.

B. Off-Bottom Tenures

Most off-bottom tenures in Baynes Sound are used for the culture of oysters for the half shell market. Oysters are grown in trays suspended in the water column from small rafts grouped as longlines and anchored at both ends of the longline assembly. In some cases rafts are not used and trays are hung directly from longlines. A total of 61.2 ha of Baynes Sound is occupied by off-bottom shellfish tenures (J. Truscott, BC MSRM, pers. comm.). This represents about 1.5% of Baynes Sound proper and 1.2% of the Baynes Sound Aquaculture Action Plan area.

Table 1. Summary of Baynes Sound tenure areas by intertidal habitat type
(B. Carswell, pers. comm.)

Shoreline Type	Intertidal Area (ha)		Tenure Area		
	Plan Area	Ex. Comox Harbour	(ha)	% of Intertidal Area	
				Plan Area	Ex. Comox Harbour
Delta	539.5	539.5	196.5	36.4%	36.4%
Rock platform w/ beach	203.9	203.9	110.1	54.0	54.0
Mixed beach	342.9	342.9	119.6	34.9	34.9
Tidal flats	971.8	115.0	47.1	4.8	41.0
Rock platform	53.9	53.9	18.6	34.5	34.5
Anthropogenic	2.1	2.1	1.0	47.6	47.6
Coarse beach	13.7	25.5	0.0	0.0	0.0
Sand beach	87.6	247.5	0.0	0.0	0.0
Total	**2215.4**	**1530.3**	**492.9**	**22.2%**	**32.2%**

Table 2. Summary of Baynes Sound intertidal habitats under clam netting
(B. Carswell, pers. comm.)

Shoreline Type	Intertidal Area (ha)		Area under Clam Netting		
	Plan Area	Ex. Comox Harbour	Total Area (ha)	% of Intertidal Area	
				Plan Area	Ex. Comox Harbour
Delta	539.5	539.5	32.0	6.0%	6.0%
Rock Platform w/ beach	203.9	203.9	19.1	9.4	9.4
Mixed Beach	342.9	342.9	20.9	6.1	6.1
Tidal Flats	971.8	115.0	2.8	0.3	2.4
Rock Platform	53.9	53.9	1.9	3.8	3.8
Anthropogenic	2.1	2.1	0.03	1.4	1.4
Coarse Beach	13.7	25.5	0	0	0
Sand Beach	87.6	247.5	0	0	0
Total	**2215.4**	**1530.3**	**76.73**	**3.5%**	**5.0%**

2.0 SHELLFISH AQUACULTURE ACTIVITIES AND POTENTIAL ENVIRONMENTAL EFFECTS

The overview reports referenced in Section 1.2 provide detailed information on current aquaculture practices in Baynes Sound and identify a number of potential[1] environmental effects associated with these activities. Tables 3 and 4 summarise this information for both intertidal and off-bottom shellfish aquaculture. The tables list activities undertaken during different components of oyster and clam culture cycles and identify potential environmental effects provided in the overview reports. Activities specific to intertidal clam and oyster culture are noted in Table 3; activities specific to off-bottom culture are provided in Table 4. These effects have been organised into general descriptive categories in order to facilitate the subsequent environmental issue analysis.

For intertidal culture, seven potential environmental effects are listed on Table 3. Activities which do not occur in British Columbia or Baynes Sound (e.g. gravelling intertidal areas, use of pesticides, mechanical harvesting) are not considered in this summary or the subsequent environmental issue analysis (Section 3).

These potential effects are:

1. Behavioural Disturbance
2. Habitat Modification
3. Changes to Sediment Process
4. Changes in Temperature/Salinity Regime
5. Changes to Benthic Community Composition
6. Loss of Foraging Habitat
7. Direct Mortality

For off-bottom culture five potential environmental effects are listed on Table 4:

1. Behavioural Disturbance
2. Habitat Modification
3. Changes to Benthic Community Composition
4. Loss of Foraging Habitat
5. Direct Mortality

[1] The term potential is used throughout this report to describe environmental effects associated with shellfish aquaculture in Baynes Sound as the listed environmental effects are not necessarily demonstrated to occur in Baynes Sound, nor do these effects necessarily negatively impact the Baynes Sound ecosystem. Jamieson *et al*. 2001 point out that "Little scientific information exists on the environmental effects of shellfish aquaculture as currently practised in British Columbia' and that studies available "are relatively few and limited in scope and rigour". For these reasons this report considers the effects described in the overview studies as reasonable, potential outcomes resulting from the associated shellfish aquaculture activities.

Table 3. Intertidal oyster/clam culture activities and potential environmental effects

GROWTH CYCLE PHASE	ACTIVITY	POTENTIAL EFFECT
Site Preparation	Noise Human Activity	• Behavioural Disturbance (particularly birds)
	Removal of Larger Sediments (clam planting)	• Habitat Modification
	Building Vexar or Rock Berm Enclosures	• Habitat Modification • Changes to Sediment Processes
	Stream Channelisation	• Habitat Modification • Changes to Sediment Processes • Changes to Temp./Salinity Regime
	Vehicle Access	• Behavioural Disturbance (particularly birds) • Habitat Modification (compaction)
	Gravelling (Clams)	**Not Done in Baynes Sound**
Grow-out Cycle	Clam Seed	• Changes to Benthic Community Composition
	Oyster Cultch	• Habitat Modification
	Use of Protective Netting (clams)	• Changes to Sediment Processes • Changes to Benthic Community Composition • Loss of Foraging Habitat (birds, macroinvertebrates, fish) • Bird/Fish mortality (entanglement)
	Predator Control –Removals or Culls	• Direct Bird/Invertebrate Mortality
	Application of Pesticides	**Not done in British Columbia**
Harvesting	Noise	• Behavioural Disturbance (particularly birds)
	Lights	• Behavioural Disturbance (particularly birds)
	Human Activity	• Behavioural Disturbance (particularly birds)
	Vehicle Access	• Behavioural Disturbance (particularly birds) • Habitat Modification (compaction)
	Hand Harvesting	• Habitat Modification • Changes to Benthic Community Composition
	Mechanical Harvesting	**Not Done in British Columbia**

Table 4. Off- bottom culture activities and potential environmental effects

GROW-OUT CYCLE PHASE	ACTIVITY	EFFECT
Site Preparation	Noise Human Activity	• Behavioural Disturbance (particularly birds)
	Anchoring Structures	• Habitat Modification
	Float and Longline Array	• Habitat Modification • Behavioural Disturbance (particularly birds)
	Boat/Vessel Access	• Behavioural Disturbance (particularly birds)
Grow-out Cycle	Bivalve feeding (Faeces and pseudofaeces production)	• Benthic Habitat Modification • Changes to Benthic Community Composition
	Predator Control – Removals and Culls	• Direct Mortality (Birds)
Harvesting	Noise	• Behavioural Disturbance (particularly birds)
	Human Activity	• Behavioural Disturbance (particularly birds)
	Boat Access	• Behavioural Disturbance (particularly birds)

3.0 A METHOD FOR ASSESSING THE SIGNIFICANCE OF POTENTIAL IMPACTS

The overview reports identify a number of general ecosystem interactions related to shellfish aquaculture. These interactions can be broadly categorised by the following ecosystem components:

1. Marine and Shorebirds
2. Physical Features and Processes
3. Benthic Communities
4. Fish Communities

These general categories of ecosystem interactions relate directly to the key biophysical features identified for Baynes Sound (Section 1.3) and can also be viewed as "Valued Ecosystem Components" (VECs) for Baynes Sound in an environmental assessment context (See Figure 3). Note that there is considerable overlap among these interactions. For example use of protective netting over seeded clam beds has the potential to alter substrate sediment composition (physical features and processes) which in turn changes benthic community composition and possibly affects juvenile chum salmon foraging.

The assessment method outlined in Figure 3 is a generalised format for environmental assessment under the Canadian Environmental Assessment Act (CEAA). This is a step wise qualitative approach which relies on a structured process, use of defined assessment criteria and expert knowledge to assess ecosystem interactions. Expert systems can be used to address processes and interrelationships that cannot be precisely defined and are a tool for decision-making in a context of uncertainty.

The key components of the process are:

1. Identification of Valued Ecosystem Components (e.g. Section 1.3);
2. List of potential effects (e.g. Tables 3 and 4);
3. Identification of interaction with Valued Ecosystem Components (Tables 5 and 6);
4. Evaluation of significance of the effects on Valued Ecosystem Components (Tables 5 and 6).

The latter two components are qualitative in nature and rely on the expert knowledge systems which use generally accepted ecological hypotheses and/or information available within the scientific literature, but not necessarily for the specific study area. This qualitative evaluation may also identify data gaps which can be subsequently addressed by ecological studies carried out, depending on the significance of the data gap, prior to approval of a project or concurrent with project development as part of a structured monitoring program.

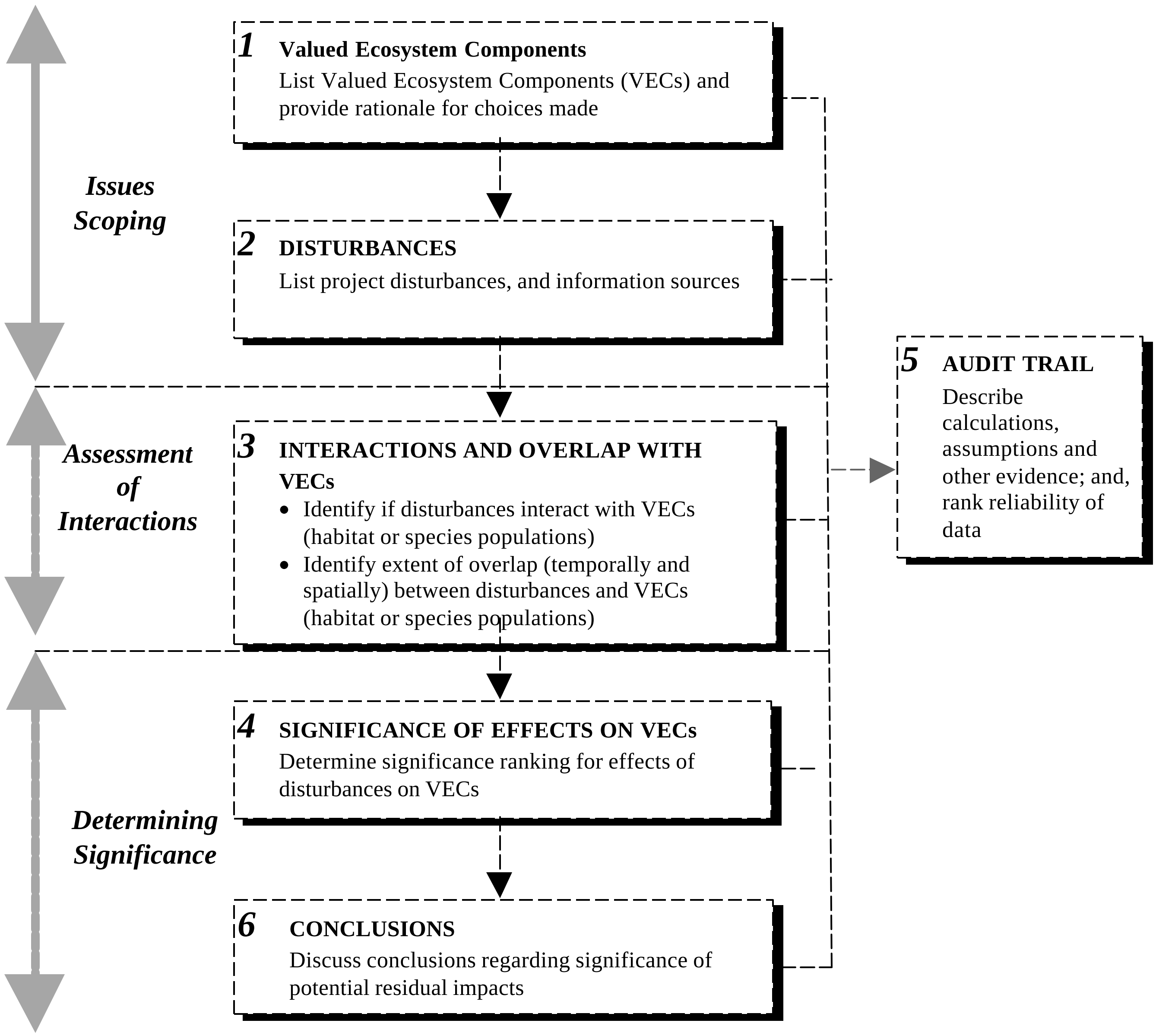


Figure 3. A qualitative approach to initial impact assessment (adapted from Duval and Vonk 1994)

Expert knowledge assessment methods must be:

1. **Transparent –** It must be easy to understand how the significance of a specific effect is assessed. It should be easy for others to understand and apply the methodology,
2. **Adaptive** –It must be possible to easily incorporate changes and updates (*e.g.*, incorporation of new scientific, local and or traditional knowledge or data) and,
3. **Robust –** The methodology should yield reproducible results if different people apply the same methodology to the same ecosystem interaction.

The structured process outlined in Figure 3 and provision for an audit trail, including provision of assumptions and references, are essential to meet the these key criteria.

Table 5 (See Section 4.3.3) is a matrix identifying interactions between key ecosystem components and the potential environmental effects identified in Tables 3 and 4. The significance of these interactions are evaluated based on three criteria; severity, duration and extent of impact. These are generally accepted criteria for assessing the significance of environmental impacts (CEAA 1997, BC/Washington Marine Science Panel 1994, Duval and Vonk 1994, Emmett *et al*. 1999, Jamieson and Levings 2001).

The following definitions of these criteria and associated rating levels have been adapted from proposed methodology to identify Marine Sensitive Areas with respect to impacts resulting from coastal logging activities (Emmett *et al*. 1999).

1. Severity

A measure of the degree of harm, without consideration of duration or geographical extent, rated as follows:

Low

- No threats to reproductive cycle, critical food supply or vital habitats
- Minor impacts to other environmental factors

Medium

- Displacement of non-reproductive activity
- Loss of non critical food supply
- Reduction of ambient environmental quality
- Reduction in habitat complexity/diversity/productivity

High

- Interruption of reproductive life cycle
- Loss of critical food supply
- Loss of complex or vital habitat
- Large scale mortality or species loss

2. Duration

Duration can be defined in two ways: (A) The time between the initial effect and recovery with recovery defined as a return to pre-disturbance levels. In this case duration of impact is the sum of the period of operation and the time from cessation of operations to full recovery. (B) Duration can also be defined as recovery time, the time required to recovery from disturbances once operations have ceased. This is probably a more appropriate definition for shellfish aquaculture activity as it provides a direct assessment of the ability of the ecosystem to revert to pre-operational conditions. Duration is rated as follows:

Short term	<2 years
Medium term	2-15 years
Long term	>15 years

These criteria are adapted from the BC/Washington Marine Science Panel (1994) study of the status of environmental quality of the Strait of Georgia and Puget Sound. Short term is based on recovery occurring within a single life cycle of many organisms, over 1-3 life cycles for medium term, and over many life cycles for long term. As the life cycles of nearshore organisms are highly variable (days to tens of years), these criteria should be considered a general guideline.

3. Extent:

The geographic distribution of the stress, rated according to the following criteria:

Site Specific

- Impact or disturbance is restricted to the site at which the activity is occurring.

Local

- Impact or disturbance extends up to 1km beyond the boundaries of site at which the activity is occurring.

Regional

- Impact or disturbance extends further than 1km beyond the immediate boundaries of the event.

In general, impacts are considered significant if:

- *severity* ranks high,
- *duration* is long term, and severity is medium or high
- *extent of impact* is regional, and severity is medium or high

These three criteria can be defined slightly differently (see Appendix Table 2) however the criteria provided above appear most appropriate for the qualitative evaluation of the environmental interactions of shellfish aquaculture activities.

4.0 ANALYSIS OF ENVIRONMENTAL INTERACTIONS

4.1 SCREENING OF MARINE AND SHOREBIRD INTERACTIONS

Both Axys *et al.*2000 and Jamieson *et al.* 2001 identify a large number of bird species which utilise Baynes Sound habitats. In order to address ecosystem interactions with shellfish aquaculture it is necessary to focus on bird species that both use Baynes Sound in a significant manner *as well as* potentially interact with shellfish aquaculture operations. This screening of marine and shorebird species is conducted in Appendix Table 3. The criteria used to list species for inclusion in this table are:

1. the species is documented for Baynes Sound and is listed provincially as species of special concern (from Axys *et al.* 2000 or Jamieson *et al.* 2001)
2. the species is documented for Baynes Sound and its use of the area is considered globally or nationally significant (Axys *et al.* 2000, Jamieson *et al.* 2001)
3. the species is documented for Baynes Sound and significant interactions with shellfish aquaculture are anticipated (e.g. white wing scoters).

Species from this list which are judged to have moderate to high interactions with shellfish aquaculture are considered in greater detail in the environmental interaction assessment (Tables 5 and 6).

For intertidal culture these species are:

- Black Turnstone
- Surf Scoter
- White wing scoter

For suspended culture these species are:

- Surf Scoter
- White wing scoter
- Brant Geese
- Western Grebe

4.2 SCREENING OF SALMONID USE OF NEARSHORE HABITATS

Jamieson *et al.* 2001 point out that substrate modification (primarily by use of protective netting in clam beds) has the potential to alter benthic communities composition, possibly reducing epibenthic organisms such as harpacticoid copepods which are a key prey item for juvenile chum salmon. As with bird interactions, it is important to screen salmonid use of intertidal habitats to develop an understanding of which salmonid species may be impacted by shellfish aquaculture. Appendix Table 4 summarises use of nearshore habitats by the various salmonid species as well as the feeding habits of each species during the estuarine or nearshore rearing phase. From this table it is evident that juvenile chum salmon have the most potential for environmental interactions with shellfish aquaculture, both through their use of overlapping intertidal habitats and a feeding ecology which relies heavily on epibenthic organisms. Juvenile chinook use similar habitats (particularly estuaries), but their diet is more opportunistic and consists of a variety of infaunal, epifaunal and planktonic organisms. Pink fry have a short nearshore residency during the same time period as chum fry, but are primarily planktonic feeders. Coho and sockeye move to marine habitats as larger, older fish (after one or two years residency in freshwater) and move quite rapidly from shallow nearshore habitats. Therefore chum fry and, to a lesser extent, chinook fry have some potential to interact with intertidal shellfish aquaculture operations and these are the species considered in Tables 5 and 6.

4.3 ASSESSMENT OF THE SIGNIFICANCE OF ENVIRONMENTAL INTERACTIONS

4.3.1 General

Ideally the analysis of environmental interactions, using methods described in Section 3.0, should be carried out by a group with diverse scientific expertise in marine and shorebird ecology, coastal physical processes, nearshore benthic community biology and fish community ecology. In this report the assessment is the author's alone, and it is acknowledged that this assessment would benefit from a broader range of scientific expertise. However this assessment is intended to provide a structured basis for the analysis of the significance of environmental interactions and to focus discussion on specific activities or effects where uncertainty or varying opinions may exist.

Table 5 assesses the significance of potential environmental effects of intertidal aquaculture using the three assessment criteria severity, duration and extent. The accompanying footnotes provide the rationale (or audit trail) for the evaluation ratings given for each potential effect. Table 6 provides the same assessment for off-bottom longline culture.

Most potential effects were considered to be of low to moderate severity, short to medium term duration (rated as recovery time following cessation of operations) and site specific or local in extent. Using the assessment framework provided in Section 3.0, these effects would not be considered of major significance and are best described as subtle (difficult to document quantitatively) and variable (site specific factors and/or natural environmental variation may have a greater influence than the specific activity under consideration). In many cases there is some uncertainty as to the severity rating provided for a specific activity. Research and monitoring initiatives will help to address this uncertainty, however subtle and variable effects are inherently difficult to assess quantitatively.

Specific activities and effects considered to be potentially significant are described in Section 4.3.4.

4.3.2 Use of Predator Netting in Clam Culture

There are two distinct environmental issues associated with the use of predator nets in clam culture. First, potential changes in sedimentation processes which may lead to changes in benthic community composition and subsequent foraging species for birds and fish. Second, physically blocking access to birds such as scoters to prey (clams), which is the intended effect of the predator net.

With respect to the first issue, the studies available for review (Simonstad and Fresh 1995, Spencer 1996, 1998), suggest that there is considerable variation between sites in sedimentation effects of clam netting and that recovery is quite rapid once the netting has been removed. If further research is undertaken to document the sedimentation/benthic community effects of clam netting, this work should account for culture cycle activities in Baynes Sound, whereby the netting is removed once or twice per year to harvest clams by raking or hand turning the substrate. If sedimentation is occurring it is quite plausible that any effect is offset by harvesting activities. In addition, it should be recognised that seasonal algae (*Ulva*, *Porphyra* and *Enteromorpha*) which grows on clam nets in spring and summer affords structural habitat and foraging opportunities for algal grazers. Assessment of benthic community effects of clam netting should incorporate an assessment of the seasonal algal community.

The assessment of the potential impact resulting from protecting cultured manila clams from species such as scoters should incorporate the following factors:

(A) the contribution of manila clams to scoter diet relative to other bivalve species and

(B) an analysis of how many clams are protected from scoter predation relative to the number of accessible manila clams in the Baynes Sound area.

This is a difficult topic, particularly if attempts are made to address it in a quantitative fashion. It is also important to recognise that results of such research may be highly dynamic over short time frames. The manila clam was introduced to the Strait of Georgia in the 1940's (Bourne 1982) and was likely not present in significant quantities in Baynes Sound until the 1950's. This species is thus relatively new in the Strait of Georgia ecosystem. The rapid expansion of varnish clams (*Nuttallia obscurata*), another introduced species, throughout the 1990's may provide new foraging opportunities for bivalve feeders. The longlines and rafts used in off-bottom culture are ideal structural habitats for mussels, another important forage species for diving ducks such as scoters.

4.3.3 Off-Bottom (Longline and Raft) Culture

Unlike cultured salmon, bivalves are not fed artificial diets and therefore excess feed does not accumulate under growout sites. However, in depositional environments, faeces and pseudofeces may accumulate underneath dense aggregations of cultured bivalves. This is particularly true of mussel culture operations as mussels produce large quantities of pseudofeces, suspended material which is filtered from the water column and held together with mucus but not actually ingested. This organic material can deposit on the bottom and impact benthic substrates. It is less likely to occur with cultured oysters or scallops which do not produce the similar quantities of pseudofeces. Monitoring (visual inspections or grab samples) is likely the best approach to documenting existing conditions in Baynes Sound. Proper siting (e.g. areas with coarser bottom sediments and no critical biophysical features such as eelgrass or geoduck beds), and appropriate spacing between longlines or raft arrays is an approach to avoiding or mitigating any potential impacts of off-bottom culture on benthic substrates.

4.3.4 Potentially Significant Impacts

The following activities and associated effects were considered to have potentially significant impacts on the biophysical features of Baynes Sound, primarily due to high severity ratings:

For *intertidal culture* these activities are**:**

A. Stream channelisation and associated biophysical impacts

Estuaries and deltas are recognised as environmentally sensitive areas primarily because they are formed by complex interactions of physical processes (exposure, sedimentation and freshwater input) and these habitats will have very slow recovery rates if these processes are disturbed. Estuaries and deltas are also highly dynamic and are often impacted significantly by episodic natural events such as flooding or changes to upland use. Shellfish tenures can also be significantly impacted by these episodic events, and this is often the rationale for stream channalisation. Preventative or restoration management initiatives aimed to both conserve estuary ecosystem function and provide protection of shellfish tenures from episodic impacts should be encouraged.

B. Vehicle use in areas with perennial vegetation, particularly marsh grasses
Brackish marshes fringe many of the estuaries, delta and gravel flat habitats in Baynes Sound. These are perennial plants which require a well drained substrate and seasonal freshwater flows. Vehicle use in these areas will compact the substrate and alter soil drainage, potentially resulting in long term loss of important habitat. Best management practices for vehicle use in the intertidal zone should focus on

- reducing overall use;
- avoiding areas of soft substrate and perennial vegetation;
- encourage use of dedicated, harder substrate routes which are less susceptible to compaction.

C. Clam harvesting during periods of finfish beach spawning.
As mentioned in Table 5, beach spawning by species such as sand lance, surf smelt and rock sole is poorly documented in British Columbia. In Washington State these species tend to spawn on sand/gravel beaches in late fall and winter. Harvesting activity during the period of egg incubation could severely impact spawning success. A first step to addressing this potential impact is to document if and where these species spawn in Baynes Sound. If these areas include shellfish tenures, potential impacts can be mitigated by monitoring and harvest closures during periods when spawn is present.

For *Off-Bottom Culture* potentially significant impacts include*:*

A. Sediment impacts to valued benthic features such as geoduck or eelgrass beds
This potential impact is best managed through proper site selection and modification of culture practices (see Section 4.3.1 above).

4.3.5 Potentially Positive Effects of Shellfish Aquaculture Activities

Human activities have the potential to effect ecosystem interactions in a variety of ways, both positively and negatively. Environmental assessment analysis tends to focus on the identification and evaluation of potentially negative environmental effects. However there are a number of potentially positive effects of bivalve aquaculture including:

1. **Coastal Stewardship**

   Water Quality- Shellfish growing water standards are extremely restrictive with respect to faecal coliform levels. Sound watershed management is key to conserving shellfish growing water quality and initiatives to conserve shellfish growing water standards have secondary effects of reducing chemical contaminant and sediment inputs. *Shoreline Management –* shellfish growers have a direct interest in initiatives which protect stream and shoreline integrity. In a coastal stewardship context, measures which provide protection to lease areas and which co-currently conserve or enhance ecological features and functions should be encouraged and supported.

2. **Improved Water Quality and Sediment Productivity.**
   Bivalve feeding removes suspended phytoplankton and sediment from the water column, potentially reducing turbidity in eutrophic areas and recycling nutrients from the water column to sediments. Recent experimental studies (Peterson and Heck 2001) suggest that this process can increase the productivity of seagrass beds and that the habitat structure provided by bivalves, particularly oysters, increased epiphytic grazers resulting in a reduction in epiphyte growth on seagrasses.
3. **Improved Sediment Quality**
   Harvesting activity, particularly clam harvesting, provides periodic resuspension of fine sediments and organic material, potentially resulting in a reduction in anaerobic benthic communities which tend to have lower biodiversity. Hand harvesting is a highly localised and small scale activity, therefore significant impacts to water quality are not expected to result from these activities.
4. **Predation Refuges**
   A large proportion of the clam population can be consumed by predators such as scoters at sizes (<20mm) which preclude any significant contribution to reproductive output. Clam netting provides adequate protection from predators and could enable a larger biomass of clams (20-35mm) to spawn prior to harvest, contributing to clam populations in adjacent, unnetted areas.
5. **Structural Habitat Features**
   Intertidal oyster beds and associated epiphytes provide structural habitat for a diverse invertebrate and fish communities (Ferraro and Cole 2001, Hosack *et al.* 2001). Off-bottom longline and raft gear provide complex three dimensional habitat for suspension feeders such as mussels, tube worms and shrimp which, in turn, are important food sources for grazing fish and associated birds.

Table 5. Intertidal Oyster/Clam Culture - Environmental Issue Analysis

Ecosystem Interaction	Activity	Associated Disturbance	Potential Effect	Significance of Interaction		
				Severity	Duration	Extent
Marine and Shorebirds	**Noise** (inc. predator control) **Lights** **Human Activity**	**Behavioural** (e.g. resting, roosting disturbance)	May disrupt resting, roosting, or foraging activities, much of the disturbance occurs in winter at night during low tides (harvesting).	Medium[1]	Short Term	Local
	Predator Exclusion Nets	**Loss of Foraging Habitat**	Physical exclusion may result in more energy expended to forage, or reduction in important foraging habitat.	Low to Medium?[2]	Short Term	Site Specific
		Changes to Benthic Community	May impact foraging opportunities for birds and other animals, results from changes in sediment processes and composition.	Low to Medium?[3]	Short/Medium Term	Site Specific
	Intensive Bivalve Monoculture	**Changes to Benthic Community**	Reduction in species diversity, and consequent foraging opportunities for various bird species.	Low[4] Medium	Medium Term	Site Specific
	Predator Control	**Direct mortality**	Direct impact on population, must be carried out under permit.	Medium[5]	Short Term	Local
Alternation of Physical Features and Processes	**Site Clearing** **Raking at Harvest**	**Habitat Modification** **Changes in sediment processes**	Removes larger cobbles and boulders, generating more uniform substrate (clam culture). Alters patchy habitat to more uniform habitat. May increase rate of fine sediment deposition.	Low Medium[6]	Medium Term	Site Specific
	Vehicle Access	**Habitat Modification**	Substrate compaction, changes to runoff patterns, loss of vegetation, particularly in marsh areas.	**High**[7] Medium	Medium	Site Specific
	Use of Predator Exclusion Netting	**Habitat Modification**	May increase sedimentation rate, resulting in the deposition of finer sediments.	Low to Medium?[3]	Short Term	Site Specific
	Perimeter Berms/Vexar Fences	**Habitat Modification**	May impact sediment transport, resulting in increased sediment deposition. Creates linear corridors of larger substrate, altering patchy habitat to more uniform habitat.	Low to Medium[8]	Medium Term	Site Specific Local[9]
	Stream Channelisation	**Habitat Modification** **Changes in sediment processes**	May alter input of fluvial (stream) sediments to the foreshore. Creates linear corridors of larger substrate, altering patchy habitat to more uniform habitat.	**High**[10] Medium	Medium to **Long Term**	Local
	Stream Channelisation	**Changes to Temperature/Salinity Regime**	Altering freshwater flows to the foreshore may impact benthic community structure and ecological function.	Medium[10]	Short Term	Local

Table 5 (continued). Intertidal Oyster/Clam Culture - Environmental Issue Analysis

Ecosystem Interaction	Activity	Associated Disturbance	Potential Effect	Significance of Interaction		
				Severity	**Duration**	**Extent**
Benthic Communities	**Use of Protective Netting**	**Changes to benthic community composition**	Removal or exclusion of larger predators may effect benthic community composition and diversity. Change in sediment composition may impact benthic species composition/diversity. Netting provides attachment for seasonal algae such as *Ulva, Porphrya.*	Low to Medium?[3]	Medium	Site Specific
	Harvesting/ Raking	**Changes to benthic community composition**	Sediment turnover may increase predation and/or change sediment composition. Removal of algal vegetation (which may only be present as a result of protective netting).	Low	Short Term	Site Specific
	Clam seeding	**Changes to benthic communities**	Intense clam culture may effect species composition/diversity.	Low[11] Medium	Short to Medium Term	Site Specific
Fish Communities	**Predator Exclusion Nets** (salmon)	**Changes in Benthic Communities**	May impact foraging opportunities for juvenile salmon (particularly chum), resulting from changes in sediment processes and composition shift from epibenthic (harpacticoids) to infaunal communities.	Low to Medium?[3]	Short to Medium Term	Site Specific
	Site Clearing Raking at Harvest Predator Exclusion Nets (Beach spawning species)	**Habitat Modification**	Several species of fish (sand lance, smelt) spawn on intertidal gravel beaches. Finer sediments and harvesting activity may negatively impact these habitats.	**High**?[12]	Short to Medium Term	Site specific
	Site Clearing Raking at Harvest (herring spawning)	**Habitat Modification**	Herring spawn primarily on vegetation (eelgrass, kelps, rockweed, red and green algae). Removal may negatively impact spawning habitat, activities which favour algal growth (clam netting, berms) may enhance spawning habitat	Low to Medium[13]	Short to Medium Term	Site specific

[1] Rating related to potential decrease in ambient environmental quality. Awareness and best management practices can reduce potential impacts; CWS can provide guidance on most sensitive species.

[2] This issue is primarily related to scoter predation on bivalves and black turnstone foraging, uncertain as to degree of impact.

[3] Site specific variation in potential impacts is expected depending on exposure and nature of substrate (Simenstad and Fresh 1995), Studies in Britain demonstrate changes in sediments and benthic community composition with recovery within one year after harvesting.

[4] Different species may benefit or be negatively impacted by such a change. Not identified as an issue of concern for any specific bird species.

[5] Would be a significant concern if unregulated and uncontrolled, although not considered a significant issue in Baynes Sound (*Axys et al. 2000*). A predator control reporting requirement would aid in quantifying the issue.

[6] Potential loss of microhabitat complexity, raking is often accompanied by building cobble/boulder berms, see Footnote 8 below

[7] Rated high in areas with perennial vegetation, particularly marsh grasses. Vehicle routing on the intertidal zone should be minimised and avoid softer substrates and vegetated areas.

[8] Potential loss of microhabitat complexity but accompanied by increased macrohabitat features (e.g. cobble/boulder berms). Severity cannot be readily accessed but not considered high. Greatest concern relates to potential impact to sediment processes. Berms should not be built higher than required to retain oyster clutch on the tenure area.

[9] If sediment transport is effected, the extent of the effect is considered local rather than site specific

[10] Channelisation of stream outflow in estuarine habitats will impact complex biological and physical interactions such as sediment dynamics, salinity regimes, vegetation and juvenile salmon access to estuarine habitats.

[11] Different species may benefit or be negatively impacted by such a change. There is considerable uncertainty as to this potential effect with respect to clam and oyster culture and some data support a positive impact on benthic community composition, particularly from oyster culture (See Section 4.3.5)

[12] Several species of fish (sand lance, smelt, rock sole) spawn on sand/gravel beaches during winter months (Penttila 1995). These spawning areas are poorly documented in BC. Harvesting activities and/or major changes in substrate composition may significantly impact incubating eggs.

[13] Removal of larger cobbles and boulders will reduce available substrate for algal vegetation, incorporating this material into berms and use of predation netting may enhance algal vegetation. Activities can be structured to avoid impacts to areas with incubating eggs as herring spawn is readily visible and spawning period is well documented (March/early April).

Table 6. Off-Bottom Oyster/Scallop Culture - Environmental Issue Analysis

Ecosystem Interaction	Activity	Associated Disturbance	Potential Effect	Significance of Effect		
				Severity	Duration	Extent
Marine and Shorebirds	**Noise** (inc. predator control) **Lights** **Human Activity**	**Behavioural** (e.g. resting, roosting disturbance)	May disrupt resting, roosting, foraging activities.	Medium[14]	Short Term	Local
	Predator Exclusion Nets	**Direct mortality**	Birds may be entangled in perimeter barrier nets if used.	Medium [15]	Medium Term	Site Specific
	Predator Control	**Direct mortality**	Direct impact on population, must be carried out under permit.	Medium[16]	Medium Term	Site Specific
Alternation of Physical Features and Processes	**Bivalve feeding**	**Habitat Modification**	May increase rate of fine organic sediment deposition, resulting in accumulation of organic, sediments	Medium[17]	Medium Term	Local
Benthic Communities (inc. plants)	**Bivalve feeding**	**Changes to benthic community composition**	Change in sediment composition; may impact benthic species composition/diversity, potential to impact valued benthic resources such as geoducks	**High**[18] Medium	Medium Term	Local
	Siting of floats, rafts	**Changes to benthic plant community**	Some potential to impact plant communities due to shading, not generally an issue with longline structures	Low[19]	Medium Term	Site Specific
Fish Communities	**Siting of floats, rafts**	**Changes to pelagic fish community**	Longlines provide habitat structure for pelagic fish grazers (e.g. pile, striped perch)	Low[20]	Short Term	Local

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[14] Severity rating is related to potential decrease in ambient environmental quality. Awareness and best management practices can reduce potential impacts. Potential disturbance to resting and roosting is a concern with species such as Brant Geese and Western Grebe. Sites should be selected with consideration for traditional areas used by these species.
[15] Predator nets are not generally used in longline culture operations. Issue is mostly related to off -bottom mussel culture, which currently does not occur in Baynes Sound.
[16] See note 5, Table 5.
[17] Potential impacts can be mitigated by proper site selection (adequate flushing , avoiding areas with valued benthic resources). Monitoring of benthic sedimentation and occasional fallowing are possible adaptive management measures
[18] High severity rating relates to the potential to impact valued, longer lived benthic resources such as geoducks. See note 16 above re mitigative measures
[19] Most longline systems are in deeper water (>20m) with minimal benthic algal vegetation, proper site selection should mitigate this potential impact.
[20] Generally regarded as a beneficial effect (e.g. rearing habitat for juvenile rockfish). Most fish species using longline structures (pile perch, striped perch) graze on sessile invertebrates on longlines and anchor lines, rather then species such as juvenile salmon.

5.0 DECISION-MAKING IN A WORLD OF UNCERTAINTY

5.1 Baynes Sound and Shellfish Aquaculture Tenure Area

As shown in Section 1.4 (Table 1) 30-50% of the intertidal area of certain habitats in Baynes Sound are currently under shellfish aquaculture tenures. The most suitable oyster and clam growing area is at the mid to lower tidal range (+2.5m to 0.0m vertical elevation relative to chart datum). Thus it is likely that a larger proportion of certain habitats (delta, rock platform with beach, mixed beach), within the tidal range suitable for shellfish culture, is currently under shellfish aquaculture tenures.

A much smaller area of these habitats (0 - 9.4%) is covered by clam netting (Table 2), and this netting is used on specific habitats (sand/gravel beaches and flats) at a suitable tidal elevation (+2.5m to 1.0m) for manila clam culture. Because manila clams grow over a narrow tidal range, the netted area will likely remain a small portion of the overall intertidal habitat area, however there is the potential to cover a significant proportion of manila clam growing area with netting.

A major focus of the Baynes Sound Aquaculture Action Plan is addressing the potential for expanding shellfish aquaculture tenures in the plan area. From an environmental perspective the following questions might be asked:

1. Will increasing the area of intertidal shellfish tenure in Baynes Sound increase the significance of ecosystem interactions by increasing the severity of effects for specific activities?
2. Will the extent of potential impacts, although site specific, be unacceptably large due too the increased amount of area under tenure?

The overview reports point out that we do not have the information to answer these questions definitively. Focused research will help to understand and quantify ecological interactions in a manner which will lead to more certainty as to the significance of the environmental interactions associated with shellfish aquaculture. However extensive studies or environmental monitoring may not be able to answer this question in the quantitative manner desired by land use managers including specific scenarios with various increments (e.g. 5%, 10% etc.) of increased tenure.

5.2 CHANGING CONTEXTS FOR DECISION MAKING

Resource managers and planners have always been compelled to make decisions on complex issues with the potential to impact ecosystem function. Heightened public concern, the poor success of many resource management approaches (particularly in fisheries management), and the rapid growth of scientific knowledge and associated technologies has resulted in increased emphasis on precautionary approaches to environmental and resource management. Unfortunately the context for applying the precautionary approach is often unclear and decision-making is frequently stalled rather that facilitated due to uncertainty as to how to apply the precautionary approach.

Principle 16 of the 1992 Rio Declaration on Environment and Development states “In order to protect the environment, the precautionary approach shall be applied by States according to their capability. Where there are threats of *serious* or *irreversible* damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

In other words when significant impacts (as assessed by methods such as those outlined in Section 3.0) are anticipated, measures to prevent environmental degradation should be applied even though these impacts are not proven with certainty by scientific studies and data. This statement does not imply that no activity should proceed until full scientific certainty is available, which is often how the precautionary principle is interpreted.

Two important points should be recognised with respect to this principle.

1. It specifically refers to serious (i.e. severe) and irreversible (long term) damage.

2. In science, particularly ecological science, full scientific certainty is usually not achievable, rather acceptance or rejection of specific hypotheses are usually based on accepted levels of probability of occurrence.

In this context Canadian federal government has just released a discussion paper which provides a Canadian perspective on the precautionary approach and invited public comment (http:www.dfo-mpo.gc.ca/cppa/HTML/discussion_e.htm).

Management processes must now recognise uncertainty as part of the decision-making process. Scientific knowledge can help reduce uncertainty with respect to specific impacts but our growing knowledge of large scale environmental processes (global warming, climate change, ozone depletion) also adds uncertainty to the decision-making equation. There are three key considerations in assessing the risk of environmental damage resulting from human activities.

1. The significance of the impact (i.e. severity, duration and extent);

2. The probability of occurrence;

3. The degree of uncertainty regarding the assessment of the above two factors.

5.2 A QUALITATIVE RISK ASSESSMENT FRAMEWORK

Figure 4 outlines a qualitative approach to risk assessment using significance of impact and probability of occurrence as key criteria. Increased uncertainty with respect to either of these factors should be accounted for by assigning a higher ranking with increased uncertainty. This matrix points out the importance of adaptive management approaches to managing risks of lesser significance and/or low probability of occurrence.

Figure 4. A qualitative approach to assessing environmental risk.

Probability of Occurrence	Significance of Risk	
	Lower → Higher	
Lower ↓	**Reduced management focus**	**Apply Precautionary Principle and Manage Adaptively** Focus monitoring and decision thresholds on probability of occurrence (e.g. Managing Exotic Introductions)
Higher	**Manage Adaptively** Focus monitoring and decision thresholds on significance of impact (e.g. Environmental Effects Monitoring, including appropriate reference monitoring)	**Apply Precautionary Principle**

Most of the potential impacts identified in Tables 5 and 6 for shellfish aquaculture are considered to be of low to moderate significance, primarily based on the degree of severity of impact. Most of these impacts are also potentially reversible on a short to medium term time frame upon cessation of the specific activity. This suggests that an adaptive management approach, focusing on monitoring the significance of potential impacts, is an important component of environmental risk management for shellfish aquaculture in Baynes Sound.

Adaptive management relies on a number of key factors:

1. **Effective Co-management** – the strategic planning and information requirements of adaptive management require effective participation by government, industry and other communities of interest in the management process.
2. **Transparency** – the rationale for decision thresholds and monitoring requirements must be readily understood by all communities of interest. Ideally they should be developed and applied collaboratively.
3. **Prior Determination of Decision or Performance Thresholds** - many management decisions will be based on information resulting from monitoring or scientific investigations and thresholds should be determined in advance of implementing a monitoring program.
4. **Embracing Uncertainty and Change** – Decision-making is supported by inputs from ongoing monitoring systems. Inevitably, the resulting information base is incomplete with change and uncertainty being continuing conditions of adaptive resource management as a result. In comparison to aquaculture, change is likely a more frequent event in wild fisheries management. However, in both cases it should be regarded as a key component of effective, sustainable management.
5. **Appropriate Monitoring and Information** – adaptive management processes rely on information as the basis for decision-making. Designing and conducting appropriate monitoring programs are key to effective adaptive management.
6. **Time Horizon, Continuous Learning and Adaptation**. The development and implementation of an instrument such as the Baynes Sound Shellfish Aquaculture Action

Plan must be based on an application time horizon of decades. It is only by using such a time horizon that the success of systems of continuous learning and adaptation can be demonstrated and the linked well-being of the Baynes Sound ecosystem and dependent people/communities can be assured.

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APPENDIX TABLES

Appendix Table 1. Description of Baynes Sound intertidal shore types. (from Howes and Thompson 1983)

SHORE TYPE	DESCRIPTION
Anthropogenic Shores	Man-made or man-modified features including docks, boat ramps, marine, and ferry terminals as well as areas where material has been moved (dredged) or deposited (e.g., rip-rap, breakwater, coal slag pile).
Rock Platform	A level or gently sloping bedrock surface. Rock platforms in the study area have low gradients (slopes $<5^o$) with local relief less than 1m. They are usually devoid of sediment (<20% cover). Intertidal widths range from 10 - 20m (intermediate) to >50m (very broad).
Rock Platform with Beach Veneer	Rock platforms overlain by beach sediments less than 1m thick. Beach materials are variable and consist of mixtures of sand and gravels. The degree of beach cover varies spatially and seasonally but usually ranges from 20 to 60%. Intertidal width ranges from 20 - 50m (broad) to >50m (very broad).
Delta	An accumulation of silt, sand, and gravels deposited at the mouth of a river or stream. Deltas in this study area have low gradients (slopes $<5^o$), are fan-shaped and dissected by single or multiple river channels. Approximately one-third of the deltas have salt marshes in their upper intertidal zone. The supratidal zone of several of the units are made up of raised deltas (i.e., delta deposits that are no longer forming). Intertidal width ranges from 20 - 50m (broad) to >50m (very broad).
Tidal Flats	A flat surface slopes ($<5^o$) made up mixtures of mud and sand. Tidal flats in the area are found in sheltered bays; salt marshes sometimes occur within the upper intertidal zone of the flat. Intertidal widths are very broad (>50m).
Sand Beach	A beach composed primarily of sand particles but may contain up to 20% coarse materials (pebbles, cobbles and boulders). Minor amounts of shell hash and wood particles may be associated with the clastic sediments. Intertidal widths range from 20 - 50m (broad) to >50m (very broad).
Mixed Beach	A beach composed of poorly sorted mixtures of sand and gravels (pebble, cobble, and boulder). Intertidal widths range from 10 - 20m (intermediate) to > 50m (very broad).
Coarse Beach	A beach composed of gravel-sized materials (pebbles, cobbles and boulders) which may have a minor portion of sand (<20%). Intertidal widths vary from 0 - 10m (narrow) to >50m (very broad).

Appendix Table 2. Alternative method for evaluating significance of environmental impacts. Impacts are evaluated and ranked using a systematic methodology with respect to magnitude, spatial extent, and duration of impact. Impacts are then assessed as either "Significant" or "Not Significant". The definitions employed in this study are presented below.

Major Impact	An impact is rated major if it is judged to result in a 10%, or greater, change in the carrying capacity of the environment, size of an animal, population, size of a resource harvest, or in an attribute of another VEC.
Moderate Impact	An impact is rated moderate if it is judged to result in a 1% to 10% change in the carrying capacity of the environment, size of an animal population, size of a resource harvest, or in an attribute of another VEC.
Minor Impact	An impact is rated minor if it is judged to result in a less than 1% change in the carrying capacity of the environment, size of an animal population, size of a resource harvest, or in an attribute of another VEC.
Negligible Impact	Negligible impacts are those that have essentially no effects.
Regional Impact	A regional impact is an interaction that is judged to have an impact at the regional level. For the purposes of this report, regional impacts are those that extend beyond the boundaries of the exercise areas.
Local Impact	A local impact is an interaction that is judged to have an impact at the local level. For the purposes of this report, local impacts are those that extend beyond a 1-km radius, but do not extend beyond the boundaries of the exercise areas.
Sub-Local Impact	A sub-local impact extends only to 1 km or less around the activity.
Long-Term Impact	Long-term impacts last for more than 5 years.
Medium-Term Impact	Medium-term impacts last for periods of 1 to 5 years.
Short-Term Impacts	Short-term impacts last for less than 1 year.
Significant	Significant means that the impact is either major, moderate, minor with a medium-term or long-term impact, or minor with a regional impact.
Not Significant	Not Significant means that the impact is negligible, minor with a short-term impact, or minor with a local or sub-local impact.

Appendix Table 3. Screening of interactions of significant bird species and shellfish aquaculture in Baynes Sound.
Significant is defined as provincial listed species, species of global or national significance (in bold text) as defined by Axys (2000) or species with clearly defined interactions with shellfish aquaculture (e.g. WW Scoters)

Common Name	Scientific Name	Provincial Listing and Reason		Life Cycle Requisite in Baynes Sound	Interaction with Shellfish aquaculture
Pacific Loon	*Gavia pacifica*	No	N/A	Non-breeding, Overwintering,	**Low-** Disturbance and possibility of entanglement in suspended culture protective netting (particularly mussels)
Western Grebe	*Aechmophorus occidentalis*	Red	Small breeding population restricted to three freshwater sites in the interior,	Nonbreeding, primarily spring, autumn, winter Listing not associated with BS	Low intertidal **Low to moderate – suspended culture** Disturbance of Daytime Roosting/night feeding activity Occupation of staging areas by longline float arrays
Great Blue Heron	*Ardea herodias fannini*	Blue	Population declines reported, vulnerable to pollution, disturbance and habitat loss	Non breeding, year round, feeding- Listing not associated with BS as no breeding colonies reported	**Low** - Disturbance of feeding activity
Brant	*Branta bernicla*	Yellow	Large concentrations of migrates in only a few areas (e.g. Parksville/Qualicum) , potential loss of some staging areas due to harassment and/or loss of feeding beaches	Spring migration, feeding adjacent to Parksville/Qualicum Listing is associated with BS life cycle requisite	**Low – intertidal** **Moderate – suspended culture** **Disturbance of feeding activity** Occupation of staging areas by longline float arrays
Marbled Murrelet	*Brachyramphus marmoratus*	Red	Declines in breeding areas due to loss of breeding habitat in coastal old growth forests	Overwintering – listing not associated with BS	No evident interactions
Long-tailed Duck/ Oldsquaw	*Clangula hyemalis*	Blue	Small breeding populations in restricted area	Overwintering – listing not associated with BS	No evident interactions
Trumpeter Swan	*Cygnus buccinator*	Blue	Small but expanding breeding population in BC, threats such as human disturbance and degradation of habitats are present but not a major concern	Overwintering in upper estuary and upland Feed on herring spawn in spring Listing not associated with BS	No evident interactions
Tundra Swan	*Cygnus columbianus*	Yellow	Wintering populations are restricted to a few key areas (interior lakes and rivers) and abundance is relatively low	Overwintering but in upper estuary and upland Listing not associated with BS	No evident interactions

Appendix Table 3. (continued)

Common Name	Scientific Name	Provincial Listing	Reason for Provincial Listing	Life Cycle Requisite in Baynes Sound	Interaction with Shellfish aquaculture
Sandhill Crane	*Grus canadensis*	Blue	Wetland degradation and logging around nesting sites, vulnerable to disturbance and habitat destruction, restricted wintering sites in BC	Overwintering in upper estuary and upland ??? Listing not associated with BS	No evident interactions
Harlequin Duck	*Histrionicus histrionicus*	Yellow	Potential loss of wintering habitats due to development in coastal areas, logging and other activities may impact breeding habitat.	Concentration of wintering and molting in Baynes Sound region. In general associated with rocky intertidal habitats or deeper water Listing is associated with life history requisite in BS	General Disturbance Occupation of staging areas by longline float arrays?
Bald Eagle	*Haliaeetus leucocephalus*	Yellow	Locally threatened only by disturbance, population is healthy and increasing	Feeding in habitats occupied by leases Listing not associated with BS	**Low**- May perch and roost on longline structures
Short-billed dowitcher	*Limnodromus griseus*	Blue	Only two small breeding populations known in NW BC that are widely separated, one breeding ground in QC is threatened. Migrants vulnerable to oil spills	Forage in intertidal mudflats Listing not associated with BS	**Low** – mudflats are not preferred lease areas
Black Turnstone	*Arenaria melanocephala*	Not Listed	N/A	Forage on both rocky shores and gravel beaches and flats	**Low to moderate** – disturbance and overlap of intertidal lease sites and foraging habitat (clam netting)
Ring-billed Gull	*Larus delawarensis*	Yellow	Population small but increasing, only potential threat is disturbance at colonies	Spring/fall and summer, present in coastal bays and inlets Listing not associated with BS	**Low** - May perch and roost on aquaculture structures
California Gull	*Larus californicus*	Blue	Population is small in BC but increasing, susceptible to human disturbance and environmental fluctuations in breeding colonies	Spring/fall migrant or year round, present in coastal bays and estuaries Listing not associated with BS	**Low** - May perch and roost on aquaculture structures
Mew Gull	*Larus canus*	Not Listed	N/A	Aquaculture in BS in spring to feed on herring spawn	**Low** - May perch and roost on aquaculture structures
Thayer's Gull	*Larus thayeri*	Not Listed	N/A	Aquaculture in BS in spring to feed on herring spawn	**Low** - May perch and roost on aquaculture structures
Glaucous-winged Gull	*Larus glauescens*	Not Listed	N/A	Aquaculture in BS in spring to feed on herring spawn	**Low** - May perch and roost on aquaculture structures

Appendix Table 3. (continued)

Common Name	Scientific Name	Provincial Listing	Reason for Provincial Listing	Life Cycle Requisite in Baynes Sound	Interaction with Shellfish aquaculture
Surf Scoter	*Melanitta perspicillata*	Blue	Few known nesting sites in BC, in winter and spring very large concentrations of birds congregation on coast are susceptible to oil spills	Overwintering, feeding areas, including herring spawn Listing not associated with BS	**Moderate to high** –particularly feeding on bivalves, however less foraging of infaunal bivalves (clams) than WWS , use of predator exclusion nets (clam and mussels)
White winged scoter	*Melanitta fusca*	Not Listed	N/A	Overwintering, feeding areas, including herring spawn	**High** –particularly feeding on intertidal clams, use of predator exclusion nets (clam and mussels)
Double-crested Cormorant	*Phalacrocorax auritus*	Blue	Small numbers of breeding colonies mainly in the Strait of Georgia with breeding pairs declining due to primarily nest predation by Glaucous-winged Gulls	Feeding in habitats occupied by leases Listing not associated with BS	**Low**- May perch and roost on longline structure, possibility of entangement in suspended culture protective netting (mussels)
Brandt's Cormorant	*Phalacrocorax penicillatus*	Red	Small breeding populations with colonies threatened by human disturbance, oil spills and gill-net entanglement	Feeding in habitats occupied by leases Listing not associated with BS	**Low**- May perch and roost on longline structure, possibility of entanglement in suspended culture protective netting (mussels)
Pelagic Cormorant	*Phalacrocorax pelagicus pelagicus*	Yellow	The population and breeding sites are declining, threats are human disturbance, oils spills, gill-net entanglement. A potential threat is conflict with salmon farms	Feeding in habitats occupied by leases Listing not associated with BS	**Low**- May perch and roost on longline structure, possibility of entangement in suspended culture protective netting (mussels)
Ancient Murrelet	*Synthliboramphus antiquus*	Blue	Predation by introduced animals such as rats and raccoons are causing decline in colonies mainly on Langara Is, Lyell Is.	Fall/winter, Listing not associated with BS	None evident
Common Murre	*Uria aalge*	Red	One colony on Triangle Island comprises 95% of the population, very susceptible to oil spills and inshore gill net drownings.	Fall/winter Listing not associated with BS	**Low**- May perch and roost on longline structure, possibility of entanglement in suspended culture protective netting (mussels)- May perch and roost on longline structure, possibility of entanglement in suspended culture protective netting (mussels)
American Golden-plover	*Pluvialis dominica*	Blue	Population size is small and known to breed in only one area, but likely to be more widespread. Main threat is random environmental events.	Spring/fall migrant, feeds primarily in upland but intertidal habitats are used Listing not associated with BS	**Low** – Feeding in gravel flats

Appendix Table 4. Summary of juvenile salmon use of estuary and nearshore habitats.

Salmonid Species	Use of estuarine and nearshore habitats by juveniles	Foraging Habit
Sockeye	• Enter the ocean as yearlings (1+) • Generally don't spend much time in estuaries, though a minor portion of downstream migration of sockeye in the Fraser R are fry which then spend up to 5 months in sloughs and marshes	**Planktonic** Copepods, amphipods, insects; also euphausiids, fish larvae
Chum	• Second only to chinook in dependence on estuaries for juvenile habitat • Often mingle with pink fry of similar size and age during early sea life • Spend up to 3 weeks rearing in estuaries (e.g. Fraser, Nanaimo R) where they occupy tidal creeks and sloughs high in the delta areas, then slowly more to deeper areas further from shore. • Prey supporting chum fry in estuarine habitats are primarily detritus based, so prime rearing areas are high in carbon input from freshwater sources	**Epibenthic** Harpacticoid copepods, gammarid amphipods
Pink	• Large runs from Fraser R are transported across open water by plumes of riverine water to protected areas where they feed and grow 2-3 months before migrating to open ocean • No significant estuary residence but early fry tend to follow shorelines and remain for periods in very shallow nearshore areas	**Primarily planktonic** Small copepods, invertebrate and fish eggs and larvae, larvaceans, insects, amphipods, euphausiids
Chinook	• Most southern stocks migrate to marine waters (estuaries) within 3 months of emergence from spawning gravel, • spending several months rearing to about 70mm length in estuaries	**Opportunistic** initially epibenthic (chironomids, mysids) then planktonic (small fish, pelagic amphipods, crab megalops; adult insects)
Coho	• Typically spend a year (or more) in freshwater after emergence from spawning gravel • Migrate to marine waters as 1+ smolts with no significant estuary residence	**Primarily pelagic** (planktonic and small fish) Marine invertebrates, small fish, amphipods, crab megalops
Sea run Cutthroat	• To be done, most migrate to sea at 2+ and prey on larger items s/a shrimp and small fish	