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Phase 0 Review of the Environmental Impacts of Intertidal Shellfish Aquaculture in Baynes Sound

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ABSTRACT

Shellfish aquaculture has taken place in coastal British Columbia (BC) since the early 1900s, and Baynes Sound has developed into one of the major production areas for cultured shellfish in BC. There are few scientific studies of the environmental impact of shellfish aquaculture; the most notable management issues centre around land-use conflicts with upland owners, recreational harvesters, wild harvesters, other recreational activities, and navigation. Recently, Simenstad and Fresh (1995) published on the ecosystem concerns regarding intertidal bivalve bottom culture practices . The existing and planned expanded scale of this aquaculture in Baynes Sound has raised concerns among Department of Fisheries and Oceans (DFO) and BC Ministry of Water, Land and Air Protection resource managers, particularly in.

Here, we present a Phase 0 habitat review of Baynes Sound intertidal shellfish aquaculture to provide a baseline with which to advise on alternative management options and to identify where information is lacking. The review: 1) covers the existing scientific literature on the potential environmental impacts of intertidal bottom culture aquaculture on coastal ecosystem processes, specifically relating to fish and fish habitat in the Pacific north-east; 2) describes intertidal bottom culture operations and their potential impacts in Baynes Sound; 3) assesses the need for monitoring and/or a cumulative effects study related to the planned increase of leased area in the intertidal zone of Baynes Sound; 4) identifies gaps in the understanding of ecosystem impacts of extensive, intensive intertidal bottom bivalve aquaculture; and 5) makes recommendations for future research in support of advice on ecosystem-based intertidal bivalve aquaculture management.

We have gathered all information, but have found that studies are relatively few and those available were limited in scope and rigour. The literature is fragmented in its relevance, and much available information has not been scientifically reviewed and published. Views expressed are thus more hypothesis-generating than definitive, which warrants a need for rigorous testing and evaluation.

RÉSUME

La conchyliculture sur la côte de la Colombie-Britannique (C.-B.) remonte au début des années 1900, et la baie Baynes est devenue l'une des principales régions productrices de mollusques cultivés de la province. Peu d'études scientifiques se sont penchées sur l'impact environnemental de la conchyliculture; les questions litigieuses de gestion les plus marquantes concernent les conflits au sujet de l'utilisation des terrains, les propriétaires du littoral, les pêcheurs récréatifs, les pêcheurs commerciaux, d'autres activités récréatives et la navigation. Une publication récente (1995) de Simenstad et Fresh fait état des préoccupations pour l'écosystème reliées aux pratiques de la conchyliculture sur le fond en zone intertidale. L'échelle à laquelle se pratique actuellement l'aquaculture dans la baie Baynes et son expansion prévue inquiètent particulièrement les gestionnaires des ressources du MPO et du ministère de la Protection des eaux, des terres et de l'air de la Colombie-Britannique.

Nous présentons la Phase 0 d'un examen de l'habitat dans lequel se pratique la conchyliculture en zone intertidale dans la baie Baynes qui servira à étayer la prestation de conseils sur des options de gestion de rechange et à cerner les lacunes dans l'information. L'examen consiste à: 1) étudier la documentation scientifique sur les impacts potentiels de l'aquaculture sur le fond en zone intertidale sur les processus écosystémiques côtiers, concernant précisément le poisson et son habitat dans le Pacifique Nord-Est; à 2) décrire les opérations de culture sur le fond en zone intertidale et leurs impacts potentiels dans la baie Baynes; à 3) évaluer le besoin d'exercer une surveillance et/ou d'étudier les effets cumulatifs reliés à l'agrandissement prévu de la superficie louée dans la zone intertidale de la baie Baynes; à 4) établir les connaissances qui manquent pour mieux comprendre les impacts, sur l'écosystème, de la conchyliculture intensive et étendue sur le fond en zone intertidale et à 5) recommander des sujets de recherches futures pour appuyer la prestation de conseils sur la gestion de la conchyliculture en zone intertidale fondée sur l'écosystème.

Nous avons recueilli toute l'information, mais avons constaté que les études sont relativement peu nombreuses, manquent de rigueur et ont une portée limitée. Les documents n'ont pas tous la même pertinence, et une grande partie de l'information disponible n'a pas été revue par des scientifiques ni publiée. Par conséquent, nous énonçons plutôt des hypothèses que des certitudes, ce qui justifie la tenue d'expériences et d'évaluations rigoureuses.

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INTRODUCTION

Shellfish aquaculture has taken place in coastal British Columbia (BC) since the early 1900s, and Baynes Sound is one of the major production areas in the province, with 45% of the total production of clams and oysters, the majority produced on 380 hectares of leased intertidal zone (AXYS et al. 2000).

Baynes Sound falls within the Regional District of Comox Strathcona and includes the foreshore of the City of Courtenay and the Town of Comox. During the past decade, population growth and accompanying changes in regional land use have created marine stressors in a number of environmental areas. For example, in the early 1990s, increases in non-point source pollution from failing septic systems, agricultural runoff, marine mammals and to a lesser extent birds, municipal wastewater and stormwater runoff, and boater waste have lead to increased faecal coliform counts. However, significant improvements have recently been made by the local community, growers and government agencies to address this issue. Land-use conflicts in the intertidal zone occur among shellfish growers, recreational users, and local residents, and there are also increasing concerns by upland landowners that bivalve culture is adversely affecting the local ecosystems, relative abundances of native species, and the monetary value of their upland properties. They are claiming of both ecological change and inappropriate activities in intertidal areas. Groups around the north half of the Strait of Georgia have recently united in a common association to address these issues. Increased pressure to establish ecologically appropriate controls on this industry seems likely to occur.

There have been few scientific studies of the environmental impact of shellfish aquaculture in the Pacific north-east. The majority of aquaculture studies have focussed on the effects of netpen finfish farms, and of the few studies on shellfish aquaculture, most have revolved around off-bottom culture techniques (WGEIM 2000). Because of the dependence of shellfish aquaculture production on high water quality, it has been assumed as having few environmental impacts. The most notable management issues to date have centred around land use conflicts with adjacent upland owners, recreational harvesters, wild harvesters, other recreational activities, and navigation (deFur and Rader 1995).

Ecosystem concerns have been published regarding intertidal bivalve bottom culture practices (e.g. Simenstad and Fresh 1995), and the scale of existing and planned expansion of this industry in BC has raised concerns among both DFO and BC Ministry of Water, Land and Air Protection (WLAP) [formerly the BC Ministry of Environment, Lands and Parks (MELP)] resource managers, particularly in Baynes Sound. Operational activities in Baynes Sound including the delineation of lease areas through the use of Vexar® netting and berms, the use of predator exclusion nets on beach surfaces, modifying substrate and sedimentation characteristics, the repeated tilling of beach surfaces for the thinning and harvest of stock, and the channelisation of estuaries, can all have either direct or indirect environmental impacts.

Elsewhere, these practices have impacted the biodiversity and productivity of the intertidal by altering the compositions of benthic intertidal communities, and excluded some species from foraging areas, reduced the sizes of some finfish spawning, nursery and rearing habitats, and altered the natural coastal hydrography (Simenstad and Fresh 1995). In Baynes Sound, these impacts could be affecting the growth and survival of transient fish and wildlife, such as juvenile chinook, coho, chum, pink and steelhead salmon; herring; and, migratory waterfowl and local shorebirds. Little scientific information exists on the environmental effects of shellfish aquaculture in BC as it is currently practised. This lack of knowledge hampers DFO habitat and fisheries managers to evaluate the potential adverse impacts on fish and fish habitat of new aquaculture proposals or those submitted for farm expansions.

In November 1998, the British Columbia Assets and Land Corporation (BCAL) and Ministry of Agriculture, Food and Fisheries (MAFF) introduced the Shellfish Development Initiative, with the goal of increasing the diversification and stability of coastal and First Nations' economies through the expansion of the shellfish aquaculture industry. The 10-year plan allows a doubling of the farmed area by roughly 10% per year. Thirty-three proposals for expansion of existing shellfish tenures in Baynes Sound were referred to DFO by BCAL in December 1999. Twenty of the 33 required a Subsection 5(1) *Navigable Waters Protection Act* (NWPA) approval, relating to significant impacts to navigation, thus requiring a *Canadian Environmental Assessment Act* (CEAA) screening review. CEAA can also be triggered by NWPA subsection 6(4) or by the *Fisheries Act* subsection 35(2) relating to the harmful alteration, disruption or destruction of fish habitat (HADD). Environmental assessments of the 20 proposals have been, or are being, conducted by the Habitat Management Division (HMD) of DFO. In the absence of previous scientific study of this issue, HMD requested assistance in conducting these reviews. To date, eight of the 20 proposals requiring CEAA screening have been approved. Although HMD had concerns that the projects could add to the cumulative effects in the Sound, it concluded that they would not likely cause significant environmental effects based on the adaptive management approach outlined in the Aquaculture Site Referral Process: Interim Operational – Policy Guidelines (DFO, February 2001). The Interim Policy states that "In such cases, based on the information available at the time of the screening, if it cannot be concluded that the project will likely cause cumulative effects, such effects will not be considered for purposes of preventing a project from proceeding pursuant to s. 20 of CEAA". The Canadian Wildlife Service (CWS) and WLAP expressed concerns about the proposed shellfish lease expansion and the potential impacts on species they are mandated to manage. Given the relatively large number of existing aquaculture leases already present, the cumulative effects of the proposed leases for Baynes Sound must be considered.

The objectives of this paper are to:

1. Review the scientific literature on environmental impacts of intertidal bottom culture on coastal ecosystem processes, specifically relating to fish and fish habitat;
2. Describe the current practices of intertidal bottom culture operations and their potential impacts in Baynes Sound;
3. Assess the need for monitoring and/or a cumulative effects study related to the planned increase in leased area in the intertidal zone of Baynes Sound;
4. Identify gaps in the understanding of ecosystem impacts of extensive, intensive intertidal bottom bivalve aquaculture; and
5. Make recommendations for future research support of ecosystem-based intertidal bivalve aquaculture management.

Like Simenstad and Fresh's (1995) review of aquaculture impacts of intertidal shellfish culture in Washington State, we recognise that the economics and job opportunities associated with aquaculture are often considered acceptable trade-offs for some ecological change. However, the nature of both the ecological changes and their scales arising from existing or proposed activities need to be considered so that the pros and cons of existing and proposed shellfish aquaculture activities can be appropriately assessed. To date, scientific assessment of the impacts of intertidal aquaculture in the bays and estuaries of British Columbia has not been done. Different resource management agencies and citizen groups are now expressing concern that this is an essential component of appropriate marine nearshore stewardship.

What we are presenting here is a Phase 0 habitat review of Baynes Sound intertidal shellfish aquaculture, defined as the following: "a Phase 0 study involves collection of all relevant information on the target species or issue, and from similar species or issues elsewhere, in order to provide a baseline with which to advise on alternative management options and to identify where information is lacking." (Perry et al. 1999). The next step is a Phase 1 study, which if fiscal resources are provided, will involve surveys and more detailed descriptions where the objective is the collection of data required to fill in the information gaps identified in the Phase 0 report, and to explore alternative management options. This phased approach, developed for potential new fisheries, is, we suggest, also relevant to evaluation of previously unassessed habitat impacts.

We have tried to bring together available information for this study, but have found that studies are relatively few and those available limited in scope and rigour. The literature is fragmented, and much of it has not been scientifically reviewed and published. New research suggested below may be more hypothesis-generating than definitive, as baseline information still needs to be gathered and assessed.

DESCRIPTION OF BAYNES SOUND

PHYSIOGRAPHY

The following description defines the boundary of Baynes Sound (Figure 1): the study area is inclusive of the area bounded on the north by a straight line drawn between Cape Lazo on Vancouver Island and Longbreak Point at the northern tip of Denman Island. The southern boundary is a straight line drawn between Mapleguard Point on Vancouver Island and Chrome Island just off the southern tip of Denman Island. The study area extends beyond the area considered on shellfish aquaculture impacts on marine and shorebirds (AXYS et al. 2000) (i.e. north of Union Point) to include the valuable bird habitat of Comox Harbour, and associated land use impacts (contamination, etc.).

The study area is located within the Nanaimo Lowland Ecosection of the Georgia Depression Ecoprovince (Ward et al. 1998). Most of the Vancouver Island portion of the area is located in the Coastal Western Hemlock biogeoclimatic classification zone. The southern portion of the study area on Vancouver Island around Deep Bay, and all of Denman Island are located in the slightly warmer and drier Coastal Douglas-fir biogeoclimatic classification zone (Meidinger and Pojar 1991).

Baynes Sound consists of over 9000 ha of shallow coastal channel fringed by protected bays, open foreshore, tidal estuaries, inshore marshes and adjacent forests. Comox Harbour, which bounds Baynes Sound on the north, is one of the largest low gradient deltaic deposits on the east coast of Vancouver Island. The shoreline has a great diversity of habitat ranging from hundreds-of-metres-wide intertidal mud and sand flats to rocky shorelines bounding deep water. The surficial geology of the area is predominantly glacial marine, overlain in some areas by fluvial or organic deposits. The unconsolidated sands, gravels and tills dominate most of the beaches except on Denman Island and some of the headlands where exposed bedrock forms a significant portion of the coastline.

Foreshore mapping of the study area (Figure 2) outlines the contrast in the physical shoreline properties between Vancouver Island and the western shore of Denman Island (Howes and Thomson 1983). Vancouver Island is characterised primarily by shore units of beaches, interspersed with low-gradient deltas and tidal flats with nearshore widths extending up to 1000m. The northern tip of Denman Island also has beaches and deltas with nearshore widths up to 500m, but the majority of the western shore is characterised by rock platforms with mixed sand-cobble beach veneer.

The following description of the oceanography of Baynes Sound (except where referenced otherwise) is based primarily on the summary by Morris et al. (1979) of surveys carried out during the 1960s. The primary factors controlling the physical oceanography of the Sound are tides, currents and freshwater. The tides are semi-diurnal, with low waters occurring during daylight or near midnight in the summer and winter months, respectively. The tidal range at the northern end of Baynes Sound is greater than in the south by approximately 0.3 m. On the flood tide, northeasterly currents transport waters from the Strait of Georgia into the northern end of the sound, while the ebb tide is characterised by a greater outflow at the southern entrance. Thus, the net circulation of flow through Baynes Sound is from north to south. Freshwater input is predominantly from the Courtenay River in the north, with smaller streams having only a localised effect (Waldie 1952). The freshwater runoff drives the net outflow of surface waters, superimposed on regular tidal activity with occasional modifications by wind-driven currents. The deepwater currents in Baynes Sound are also presumed to flow towards the south, with a total exchange of bottom water taking place approximately every two months. The waters in Baynes Sound are relatively well protected from wave action by Goose Spit, Denman Island, and the smaller islands extending from the northern tip of Denman Island. This protection helps contribute to the vertical stratification of the waters. There are seasonal variations in density, salinity, temperature and dissolved oxygen coinciding with higher summer temperatures, and inputs of freshwater from heavy winter runoff and spring snowmelt.

SENSITIVE ECOSYSTEMS AND PROTECTED AREAS

The east coast of Vancouver Island and the adjacent Gulf Islands form a unique ecological region (Coastal Douglas-fir Biogeoclimatic Zone) in Canada, supporting many rare species of plants and animals, and plant communities. Less than eight percent of this area still supports rare and fragile ecosystems. These natural ecosystems are biologically diverse, supporting a large variety of plant and animal species, and they provide wildlife corridors and linkages. They provide specialised habitat for many rare species that are only known to occur in specific ecosystems. Intense development pressures has resulted in habitat fragmentation, degradation, and loss. The Sensitive Ecosystems Inventory (SEI) project has identified the remaining fragments of natural ecosystems on Eastern Vancouver Island and the adjacent Gulf Islands (Ward et al. 1998). The purpose of this SEI project was to identify, map and evaluate remnants of rare and fragile ecosystems, and to encourage land-use decisions that will ensure the continued integrity of these ecosystem types. Of the seven sensitive ecosystem types that have been identified, three are present along the coast of Baynes Sound including wetlands, riparian and coastal bluff (Figures 3a, 3b, 3c).

Baynes Sound is internationally recognised as important for migratory waterbirds. It has been ranked as the most important wetland complex on Vancouver Island by two of the foremost conservation agencies, the Pacific Estuary Conservation Program (PECP) and the Pacific Coast Joint Venture (PCJV). PECP is a co-operative project funded by Nature Trust of BC, Ducks Unlimited Canada, Wildlife Habitat Canada, MELP, DFO and CWS. PCJV is an international initiative represented by the US Fish and Wildlife Service, Oregon Department of Fish and Game, CWS, Ducks Unlimited, Inc., Ducks Unlimited Canada, the Nature Trust of BC, MELP, California Department of Fish and Game, the Nature Conservancy, and the Washington Department of Fish and Wildlife. The boundaries they used for the region for the most part are those of the Important Bird Area nomination (Booth 2001). Conservation values of Baynes Sound have long been recognised. Since 1973, MELP has actively pursued the protection of the productive estuaries, wetlands, and foreshore habitats within Baynes Sound. These efforts have resulted in Green Belt designations securing property along the south and west portions, Section 6A and DL 30 in Fanny Bay. In 1974, to elevate the importance of Baynes Sound as a wildlife area, MELP was granted a Notation of Interest Map Reserve over the intertidal foreshore from Maple Guard Point to Buckley Bay. A decade later, international recognition was gained when a series of biophysical studies (led by Environment Canada and MELP) identified Baynes Sound as "critical" habitat for waterfowl.

There are presently five small legislated protected areas (total marine area = 91.7 ha, i.e. <1 km^2) within Baynes Sound (Figure 4) (Jamieson and Lessard 2000). The Rosewall Creek Unit of the Qualicum National Wildlife Area (undetermined marine area) was established by CWS in 1974 for the conservation of essential habitat for migratory birds, and is subject to regulations defined by the *Canada Wildlife Act*. From 1991 to 1996, MELP established Wildlife Reserves at Deep Bay (12.9 ha), Rosewall Creek (Mud Bay) (27 ha), Fanny Bay (51.7 ha), and the Comox/Courtenay River Estuary (undetermined marine area) for the preservation of estuarine habitat and management of waterfowl resources. However, there are no specific provisions under the BC *Land Act* with respect to the management of the Wildlife Reserves (Jamieson and Lessard, 2000), and no management plans have been developed for these Wildlife Reserves.

Although not legislated protected areas, there are also two Recreational Shellfish Reserves established by MAFF: UREP 0284188 (est. 1968), which is 14.2 ha of intertidal area; and UREP 1405271 (est. 1991), which is 120 ha of deepwater. These areas preclude shellfish tenures or commercial harvesting. There is also UREP 1404487 (est. 1988), 277 ha of foreshore held by

BC Parks surrounding Sandy Islets Marine Park. This is traditionally an area of First Nations clam harvest and continues to be an important area for recreational and First Nation harvest of shellfish.

INTERTIDAL VEGETATION

Intertidal vegetation in Baynes Sound consists of a mixture of red, brown and green algae, with eelgrass beds in the mid-lower zones and marsh vegetation in higher areas. The most important mid-to-lower intertidal vegetation is eelgrass (*Zostera marina, Z. japonicus*), which provides critical habitat for young fish, invertebrates and other species and stabilises shorelines. It also helps to increase water clarity and reduce erosion by reducing wave energy and trapping loose sediments. The areal extent of eelgrass beds (*Zostera spp.*) in Baynes Sound, which includes a substantial admixture of macroalgae, is estimated to be around 500 ha; Comox Harbour is estimated to have an additional 500 ha of primarily eelgrass beds (Romaine et al. 1976, 1981, 1983). Figure 4 presents the eelgrass occurrence from a 1995 survey of eelgrass beds interpreted from 1:6000 scale aerial photographs (Durance 1996).

WILD BIVALVES

Intertidal bivalves of Baynes Sound form a rich mixture of native and exotic species, with relative distributions and abundance on each beach determined primarily by the area available at each tidal elevation and the substrate type (Figure 5). For the purposes of this review, the major species are divided into epifaunal (species that live on the substrate or attached to solid structures above the substrate) and infaunal (species that live buried in the substrate) components. The epifaunal bivalve community is dominated by two major species groups, mussels (family Mytilidae) and oysters (family Ostreaidae). The infaunal component is dominated by clams of various families, including the Veneridae, Psammobiidae, Myidae, Cardiidae, Mactridae and Tellinidae.

The most common oyster species in Baynes Sound is the "introduced" Pacific oyster, *Crassostrea gigas*. Oysters are found attached to rocks and pilings in the intertidal, as well as loose on the substrate, either singly or in clusters. Much of the intertidal area of Baynes Sound (about ⅓ of the total intertidal area, and a much larger, but unmeasured, percentage of suitable manila clam habitat) is under tenure for aquaculture, and a considerable portion of the oyster stock results from regularly seeding. There are, however, large numbers of oysters on non-tenured ground, resulting from spawning events in the Sound.

The native Olympia oyster, *Ostrea conchaphila*, is found in Baynes Sound at much lower densities than Pacifics. It is the only oyster species native to British Columbia. It was utilised as a commercial species for a brief period early in the 1900s (Gillespie 1999). Quayle (1988) listed Comox Harbour as one of several sites that supported commercially exploited populations of the Olympia oyster. The harbour has not been examined recently for Olympia oyster populations, but Olympia oysters are considered extremely rare throughout Georgia Strait, and only a single specimen was located at Royston, where this species used to be abundant, during intertidal surveys undertaken in 2001 (G. Gillespie, pers. observation). The Olympia oyster was given

"Special Concern" status in 2000 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2001).

Blue mussels, *Mytilus* spp., are common on rocks and pilings, or attached to small pieces of hard substrate over much of Baynes Sound. The species of blue mussel native to BC is the foolish mussel, *Mytilus trossulus*. The exact proportions of mussel species in the Strait of Georgia are unclear and may be changing over time due to possible hybridisation with introduced blue mussel species, *Mytilus edulis* and *Mytilus galloprovincialis*, that were either introduced for culture or arrived in BC as fouling organisms.

The infaunal community is made up of numerous species, with dominant taxa being determined largely by tidal elevations and substrate characteristics. The bivalve found at the highest elevations is the exotic varnish, or dark mahogany, clam, *Nuttallia obscurata*. This species has been recorded from BC since the early 1990s, has quickly expanded its distribution to include the entire Georgia Strait, and is expanding into Puget Sound, Johnstone Strait and the west coast of Vancouver Island (Gillespie, et al. 1999). Varnish clams are primarily found at intertidal elevations above other bivalves but overlap with species found lower in the intertidal.

The next zone of the intertidal is dominated by the exotic Manila clam, *Venerupis philippinarum*. This species was accidentally introduced to BC with Japanese oyster seed in the 1930s, and subsequently spread throughout Georgia Strait, into Johnstone Strait, up the west coast of Vancouver Island and into the Central Coast to nearly 53ºN (Quayle and Bourne 1972; Bourne 1982; Gillespie and Bourne 2000). Manila clams achieved commercial significance in the late 1980s, and currently are the most important commercial wild-harvest clam species in BC.

The distribution of Manila clams overlaps with that of the native littleneck clam, *Protothaca staminea*. This species is found from the mid-intertidal to subtidal depths, is of minor importance in commercial fisheries and is targeted, along with Manilas, in the recreational fishery. Also prominent in this zone is the exotic eastern softshell clam, *Mya arenaria*. This species was deliberately introduced into California in the late 1800s, and subsequently invaded northward, eventually finding its way into the Queen Charlotte Islands and southeastern Alaska (Quayle 1964; Gillespie and Bourne 1998).

The lower intertidal is dominated by littleneck and butter clams, *Saxidomus gigantea*. The latter was the primary commercial species in BC until the development of the live steamer (littleneck clams) market in the 1980s. Butter clams extend from the lower intertidal to at least 40 m depth (Bernard 1983). Horse clams, primarily the fat gaper, *Tresus capax* but also the Pacific gaper, *Tresus nutallii*, are found in the lower intertidal, with the bulk of populations occurring subtidally. The commercially important geoduck, *Panopea abrupta*, although recorded intertidally in other areas of Georgia Strait, is found only subtidally in Baynes Sound.

Other species of infaunal bivalves are found at relatively lower densities. The heart or basket cockle, *Clinocardium nuttallii*, is found on soft substrates and in eelgrass beds at lower tidal levels. A number of *Macoma* species are found, depending on substrate characteristics. The white sand macoma, *Macoma secta*, is found in sandy substrates; the bentnose macoma, *Macoma nasuta*, is found in mud or silt; and the pointed macoma, *Macoma inquinata*, and Baltic macoma,

Macoma balthica, are found in substrates of mixed sand, gravel and mud. Minor clam species that are likely present in the Sound include the rough diplodon, *Diplodonta impolita*; the thin-shelled littleneck, *Protothaca tenerrima*; and the arctic hiatella, *Hiatella arctica*.

The nature of the intertidal habitat in Baynes Sound is such that any stretch of intertidal with mixed substrates will support populations of varnish, Manila, littleneck and butter clams, depending upon the elevation examined. A single day's sampling at the unharvested beach fronting Royston yielded 14 species: blue mussels, Pacific and Olympia oysters, varnish, Manila, littleneck, butter, softshell, horse and butter clams, Baltic, bentnose and pointed macomas and cockles.

The beach area at Seal Island on the north end of Denman Island is the single most productive butter clam beach in southern coastal BC (Quayle and Bourne 1972; Kingzett and Bourne 1998). This may be because it represents the largest area of low subtidal in Baynes Sound. The lower beach is dominated by butter, littleneck and horse clams, with higher tidal elevations supporting populations of littleneck, Manila and, more recently, varnish clams (G. Gillespie, pers. observation).

Most beaches in Baynes Sound support Manila, littleneck, butter and varnish clam populations, with relative abundances determined largely by relative areas at appropriate tidal elevations. Beaches with extensive areas of bedrock and boulder or cobble cover may be dominated by epifaunal mussels and oysters, while beaches with sand and mud substrates will support more softshell clams, macomas and cockles.

SALMONIDS AND PACIFIC HERRING

A minimum of 23 creeks and rivers drain into Baynes Sound, providing spawning and rearing habitat for coho (*Oncorhynchus kisutch*), chum (*O. keta*), chinook (*O. tshawytscha*), pink (*O. gorbuscha*), sockeye (*O. nerka*), coastal cutthroat (*O. clarki*) and steelhead (*O. mykiss*). The intertidal zone of Baynes Sound is utilised as a juvenile rearing area at various times of the year (Healey 1980). The largest system is the Courtenay River, which is formed by the joining of the Puntledge and Tsolum Rivers. The total Sound watershed covers an area of 859 km^2. Small creeks and rivers which drain into Baynes Sound include the Cruikshank, Brown, Tsable Rivers; Hart, Hindoo, Cowie, Cougar Smith, Wilfred (Coal), Waterloo, Rosewall, McNaughton, and Sandy Creeks; plus, numerous other unnamed streams (Figure 6). Millions of wild salmon juveniles are produced within these watercourses. As well, the Puntledge River hatchery releases approximately 10 million juvenile salmon annually into the Courtenay River estuary and Baynes Sound, including 1.5 million chinook, 3 million pinks, 4.5 million chum and 700,000 coho. Table 1 lists the species reported in the DFO/ BC Fisheries FISS (Fish Information Summary System) database for the Baynes Sound watersheds.

The estuaries in Baynes Sound also fulfil important habitat requirements for several life stages of the six salmonid species. The nutrient rich estuaries provide excellent rearing grounds for adult cutthroat, and coho, along with chum and chinook juveniles. Furthermore, the intertidal zone and waters of Baynes Sound are recognised as productive Pacific herring (*Clupea harengus pallasi*) spawning and nursery habitat on the BC coast (Hay and McCarter 2001). Eggs are deposited on intertidal and subtidal marine vegetation in Baynes Sound and Lambert Channel, and hatched larvae from both areas disperse into the stratified waters of the Sound to rear in the adjacent waters of protected bays and inlets (Haegele and Schweigert 1985; Robinson 1989). Figure 7 presents the habitat sensitivity map for Baynes Sound based on cumulative herring spawn data since 1928. The areas of Metcalf and Deep Bays to the south, and the coastal region north of Union Bay and surrounding Longbreak Point have been classified as vital spawning grounds, with areas in between specified as having major or high spawning classification (Hay and McCarter 2001).

BIRD HABITAT AND USAGE

The following summary synthesises Canadian Wildlife Service (CWS) studies of migratory bird abundance and describes use of habitats within the Comox Harbour – Baynes Sound area (the 'subject area').

1980 – 1981 Surveys: Baynes Sound – Comox Harbour area

Baynes Sound – Comox Harbour area is an important staging and wintering area for a wide variety of migratory bird species (Dawe et al. 1998). CWS's interest in the subject area extends over thirty years (see Trethewey 1979, Vermeer and Butler 1989). Designated as an Important Bird Area (IBA), the area includes the Courtenay River estuary to Deep Bay and Mapleguard Point, approximately 35 kilometres to the southeast (Booth 2001). Maximum single day counts recorded during 1980 –1981 surveys found globally significant populations of Pacific Loons, Western Grebes, Brant, Black Turnstones, Mew Gulls, Thayer's Gulls, and Glaucous-winged Gulls (Dawe et al. 1998). Table 2 presents the species and seasons at which they are present in the area; the approximate percentage of the population that uses this habitat; the significance at the global, continental, or national level; and the provincial status for the Baynes Sound IBA (from Booth 2001). Provincial status is ranked according to indigenous species considered to be extirpated, endangered or threatened (red-list), species considered to be vulnerable (blue-list), or indigenous species vulnerable during times of seasonal concentration e.g. breeding colonies (yellow-list).

Bird use of habitats within the Baynes Sound – Comox Harbour study area was not directly studied by Dawe et al. (1998). Shorelines were divided into units from which birds counts were recorded (shoreline vegetation characteristics were obtained from existing information). Refer to Figures 8-16 for location of shorezone units within the study area. The most heavily utilised shoreline units were:

- Unit 23 (near Roy Creek and the Trent River) and Unit 28 (just north of Union Point); these units recorded the highest numbers of birds. The totals of all the birds viewed in both of these units were approximately 12% higher than any other unit. Over the study period, the total for unit 23 included approximately 24,000 ducks (mostly diving ducks), 11,000 Western Grebes, and 11,000 gulls. The total for unit 28 was augmented by more than 19,000 ducks (mostly diving ducks).
- Unit 47 (Metcalf Bay on Denman Island) ranked third in total bird use and Unit 41 (Wildfred Creek to Mud Bay) ranked fourth.

The locations having the lowest bird use were around shorezone Units 32 to 35, 15, 16, 2 and 8.

The number of bird-use days for the Baynes Sound – Comox Harbour area was highest in winter, second in autumn and spring, and lowest during summer (Dawe et al. 1998). It should be noted that this assessment was after aquaculture had been established in much of Baynes Sound, so how it might reflect pre-aquaculture usage by birds is unknown. As the focus of this manuscript relates to the effects of intertidal aquaculture upon ecosystem components, the use of the subject area by migratory birds referenced herein will be those that are more likely to be found utilising nearshore habitats. Loons, grebes, cormorants, and gulls are typically found in deep water areas, but are included in Table 3, as habitat use by these species will extend seasonally into shallow water areas.

It is important to note that Table 3 highlights only some of the pertinent aspects of the survey findings. For example, seasonal use (or lack thereof) of shorezone units by different species has not been included. Although the Pacific Loon was the most abundant bird within the loon species group, the Common Loon was the most abundant within this group in autumn. Other aspects of this survey worth noting are that:

- counts are likely conservative; actual numbers of birds were probably greater than the numbers recorded for the study. For example, night time surveys were not conducted, yet low tides during the winter months are at night;
- for certain species, numbers were recorded at higher taxonomic units; for example, in some instances, Greater Scaup and Lesser Scaup were recorded simply as Scaup species.

The following are further details of the Dawe et al. (1998) study that are not reflected in Table 3:

Loons: on February 21, 1981, a peak number of 1005 Pacific Loons were recorded, 900 of which were viewed from Metcalf Bay. This peak number is noted as being higher than any other one-day count recorded between 1 November and 31 March at six other major estuaries around the Strait of Georgia. A total of 3,028 Common Loon were recorded from most shorezone units; the Deep Bay, Mapleguard Point, and Metcalf Bay areas received the most use. Pacific Loon was the most abundant loon in winter and spring, whereas the Common Loon was the most abundant loon in autumn. Other species included the Yellow-billed Loon and Red-throated Loon.

Grebes: a total of 96,142 Western Grebes (provincially red-listed) were identified, making them the most abundant species in this study. Habitat use in autumn and spring centred primarily around units 23 and 28, while winter usage was associated more around units 40-47. A Christmas Bird Count of 15,174 birds from Deep Bay was recorded on December 27, 1983 *(*Campbell et al. 1990*)*. Horned Grebe ranked second in abundance; Pied-billed Grebe and Eared Grebe were also recorded.

Cormorants: the Pelagic Cormorant is provincially yellow-listed, the Double-crested is blue-listed, and the Brandt red-listed. A combined total of 3,975 cormorants were observed.

Herons: the Great Blue Heron, a provincially blue-listed species, was the only heron species observed, and favoured Unit 21 and adjacent units during autumn, spring and summer. Unit 48 (Henry Bay) received highest use during winter.

Swans: the Trumpeter Swan is provincially blue-listed, and the Tundra Swan yellow-listed. Most swans were observed in winter (80% of bird use days). Comox Harbour is an important wintering area for Trumpeter Swans; in 1978-1979 a maximum of 271 birds was reported by MeKelvey (Trethewey 1979) and an all-time North American high Christmas Bird Count of 712 swans was made on the Comox count of December 16, 1984.

Geese: four species of geese were recorded for a combined total of 20,328 birds. Brant totalled 19,168 birds (94% of all geese), but were present only in spring. Areas of highest use were Units 23-25, with less use around Units 28, 36, 41, 45, 47, and 48. Canada Geese, a White-fronted Goose, and Snow Geese were also observed.

Dabbling Ducks: a combined total of 72,436 dabbling ducks was observed. Dabbling ducks were seen on every survey but counts varied by season; numbers were highest during autumn and spring migrations. Highest numbers of dabbling ducks occurred near Millard Creek in Comox Harbour. American Widgeon, Mallard, Northern Pintail, Green-winged Teal, Blue-winged Teal, Northern Shoveler, Eurasian Widgeon, Cinnamon Teal, and Gadwall were observed.

Diving Ducks: a combined total of 238,678 birds (34% of all birds) were recorded, most during autumn and winter. The three species of scoters – White-winged, Surf (provincially blue-listed), and Black - together accounted for 46% of all diving ducks.

The most numerous diving duck and third most abundant species in the study was the White-winged Scoter with a total of 47,666; preferred locations for this species were from the entrance of Comox Harbour south (units 23 to 48). For the Surf Scoter, higher use was recorded towards the southern end of the study area: Unit 39 and south, and from Units 48 and 47. Surf Scoters used more of the north side of the inner harbour and the area around Goose Spit (Units 1 to 11) than White-winged Scoter, especially in autumn and winter. Black Scoter use of Baynes Sound was concentrated in fewer locations than the other two scoter species. Units 13, 45, and 46 were used primarily during autumn, with more dispersion over units during winter; Units 23, 28, and 40-47 were used during spring, while concentration around Units 22 and 28 was observed during summer.

Greater and Lesser Scaup were likely underrepresented because a total of 11,001 birds were recorded simply as Scaup species.

Highest numbers of Harlequin Duck (3% of all diving ducks) (provincially yellow-listed) were recorded south of Gartely Point and between Union Bay and Buckley Bay. The waterfront west of Comox (Unit 14) and Deep Bay (Unit 45) recorded high counts in spring. During fall, birds were most numerous near Mud Bay (Unit 41).

Common Goldeneyes (3% of all diving ducks) used Metcalf Bay (Unit 47) mostly in the winter; the area north of Union Point (Units 27 and 28), and a stretch of Comox waterfront towards Robb Bluff received higher use during spring. 73% of the Barrow's Goldeneyes seen during spring were at units 27 and 28.

8,959 Bufflehead were recorded, being observed at every location surveyed, with numbers varying between seasons.

Three species of mergansers were observed: the Common Merganser, Red-breasted Merganser, and Hooded Merganser. Other divers observed included Oldsquaw (now referred to as Long-tailed Duck), Canvasback, Ring-necked Duck, and Ruddy Duck.

Rails, Coots and Cranes: most American Coots were observed in autumn (56% of bird-use days); two peaks occurred: 112 birds on October 25, 1980, and 103 birds on 22 November 22, 1980.

Shorebirds: 40,004 shorebirds (6% of all birds) from 19 species were seen during the study: Black Turnstone, Dunlin, Sanderling, Killdeer, Black-bellied Plover, Western Sandpiper, Greater Yellowlegs, Spotted Sandpiper, Long-billed Dowitcher, Short-billed Dowitcher, Least Sandpiper, Lesser Yellowlegs, Surfbird, Black Oystercatcher, Common Snipe, Whimbrel, Lesser Golden-Plover, Semipalmated Plover, and Ruddy Turnstone.

Black Turnstone and Dunlin were the most abundant shorebird species recorded. Baynes Sound supports the largest numbers of wintering Black Turnstones in the province *(Campbell et al. 1990).* In this study, the highest count was 3093 seen on 29 November 1980; 3000 of these were at one roost on log booms north of Union Point (Unit 28). 3560 Black Turnstones were recorded in the 1982 Comox Christmas count *(*Paulson 1993*).* Sanderling was the third most abundant, accounting for 4% of all shorebirds.

Gulls: a total of 124,967 gulls were observed (18% of all birds). The Glaucous-winged Gull, accounting for 44% of all gulls, was the most abundant, followed by the Mew Gull and Bonaparte's Gull. Largest aggregations were around Mud Bay (unit 41), with Trent River (unit 23) having the second largest count. Herring Gull, Thayer's Gull, California Gull, Glaucous Gull, Ring-billed Gull, Western Gull and Franklin's Gull were also observed.

Alcids: of the three species recorded – Common Murre, Marbled Murrelet (red-listed), and Pigeon Guillemot - the Common Murre (red-listed) made up 59% of all observations. High use areas for the Common Murre during winter included Goose Spit (Unit 3) and Rosewall Creek (Unit 43).

1990 – 1991 Surveys: Fanny Bay – Little Bay Surveys

Dawe et al. (1995) conducted weekly surveys between 10 September 1990 and 25 August 1991 in the Fanny Bay – Little Bay wetlands area of Baynes Sound. Over this study period, 123 species of birds were identified, and a total 27,001 birds were recorded. It was estimated that a minimum of 4,099 birds depended on the Fanny Bay wetlands for some aspect of their life history. The study area was divided into 7 Units that reflected the major habitat types (Table 4).

Based on the classification scheme above, Dawe et al. (1995) determined that the intertidal flats received the highest bird use (50%), followed by intertidal marsh north (17%), intertidal marsh east (13%), subtidal habitat (8%), forest (6%), and intertidal marsh south (4%); the freshwater marsh ranked lowest in habitat use overall (1%). Table 5 is a partial summary of the results of the study.

Loons: Common Loons were most frequent in autumn (54%) and spring (29%); Pacific Loons were also observed.

Grebes: four species of grebes - Western, Horned, Red-necked, and Pied-billed - were recorded for a total of 510 birds. Western Grebes utilised primarily one distinct area within the subtidal habitat unit.

Cormorants: three species of cormorants (Pelagic, Double-crested, and Brant) were observed for a total of 383 birds. The Pelagic Cormorant was most abundant, and utilised mostly intertidal habitat. It is important to note that 54% of all cormorants were reported as 'cormorant species'.

Herons: the Great Blue Heron, of which 106 were counted (this was the only heron species recorded), utilised all seven habitat units, with the intertidal marsh north and intertidal marsh south receiving heaviest use. A colony of approximately 16 nests was observed in the forest habitat unit.

Swans: Trumpeter Swans (142) were recorded during the survey, with habitat use varying by season, though a small portion of the intertidal marsh north was utilised over the entire year. Most swans were observed during winter.

Geese: the Canada Goose was the only goose species observed, of which 148 were counted. Habitat use changed with season: in winter, intertidal marsh east was the only habitat used while in spring, intertidal marsh north was preferred.

Dabbling Ducks: nine species (American Wigeon, Green-winged Teal, Mallard, Northern Pintail, Wood Duck, Gadwall, Northern Shoveler, Eurasian Wigeon, and Blue-winged Teal) were recorded for a total of 5,951 birds. The intertidal marsh east was used most by dabbling ducks during autumn, with use shifting to the intertidal marsh north thereafter. However, American Wigeon preferred intertidal marsh north followed by intertidal flats, and in the autumn, intertidal marsh south was preferred.

Diving Ducks: twelve species (Greater Scaup, Lesser Scaup, White-winged Scoter, Surf Scoter, Black Scoter, Common Goldeneye, Barrow's Goldeneye, Common Merganser, Hooded Merganser, Red-breasted Merganser, Harlequin Duck, and Long-tailed Duck (Oldsquaw) were recorded for a combined total of 11,821 birds (44% of all birds). These ducks were seen in all seven habitats, with highest numbers in intertidal flats in all seasons. Scoters (all 3 species) were found primarily in intertidal flats habitat, followed by subtidal habitat. Common and

Barrow's Goldeneyes preferred intertidal flats. Harlequin Ducks utilised intertidal flats habitat 86% of the time, with the remainder spent in the subtidal zone.

Shorebirds: seven species (Dunlin, Western Sandpiper, Killdeer, Greater Yellowlegs, Pectoral Sandpiper, Common Snipe) , for a total of 2,275 birds, used the Fanny Bay wetlands during some part of their life histories. Most shorebirds used intertidal flats, with intertidal marsh east ranking second in usage. Intertidal marsh east attracted the highest number of shorebirds in winter. Dunlin was the most abundant shorebird, and utilised the intertidal flats for 68% of the time during autumn. Intertidal marsh east was most favoured during the winter, utilised 22% of the time.

Gulls and Terns: four species of gulls (Mew Gull, Bonaparte's Gull, Glacuous-winged Gull, and Ring-billed Gull) were recorded for a total of 1542. All habitats were used; overall, the intertidal flats were used most (55%), followed by the intertidal marsh north.

Alcids: two species – Pigeon Guillemot and Marbled Murrelet - were recorded for a total of six birds.

Baynes Sound – Comox Harbour Habitat Assessment /Other Surveys

Bird use of Mud Bay – Rosewall Creek from January through March 1973 and October 1975 through August 1977 was estimated at 9,900 birds (mostly waterbirds, herons, and shorebirds) dependant on this area (Trethewey 1979). R. Davies (MELP, Nanaimo, BC; listed in Trethewey 1979) observed an average of 840 ducks per shoreline mile (522/km) for the Mud Bay – Rosewall Creek – Deep Bay area and an average of 290 ducks per shoreline mile (180/km) for the area north from Mud Bay to Gartley Point during an aerial survey of Baynes Sound conducted in January 1977 (Trethewey 1979). In addition, large numbers of Black Brant (Davies et al. unpublished) and one flock of 4,800 Western Grebes (N. Dawe pers. comm.) were seen (Trethewey 1979). The wintering distributions of diving ducks, based on the results of 10 Christmas Bird Counts, suggests different habitat preferences (Table 6) among the species (Savard 1987).

For the seven habitats identified in the Trent River Delta and Estuary, 38,593 birds were recorded; 124 species were identified, with an average of 35 species using the area weekly (Brooks et al. 1994). With respect to habitat use, of the seven types identified (Intertidal Flats, High Salt Marsh, Salt Marsh, Forest/Residential, Upper Beach, Riparian, and Cultivated Fields), the Intertidal Zone was utilised the most, with 48% of all birds recorded there (Brooks et al. 1994). Table 7 summarises the one-day maximum numbers of each bird species observed in the Trent River estuary, 1987.

Areas within Baynes Sound are important herring spawning sites (see above), which are heavily used by migratory birds. In some cases, certain bird species will switch their diets and forage almost entirely upon herring eggs. Within the Baynes Sound – Comox Harbour area, herring spawning areas considered most important to migratory birds are: inside Comox Harbour, north around Goose Spit onto Comox Bar; south around Gartley Point for about three km; and a five km stretch of the north-central portion of Baynes Sound from Union Bay south to Hindoo Creek

(Trethewey 1979). One heavy spawning at Qualicum in the spring of 1976 attracted approximately 70,000 waterbirds, 53,000 of which were gulls (Trethewey 1979). Approximately 140,000 birds were recorded congregated at a herring spawn site in the area in spring of 1998 (R. Butler, CWS, pers. comm.).

Some species such as Long-tailed Duck (Oldsquaw) may dive to several hundred feet for food, but most diving duck species feed in water up to 11-15 metres (Mitchell 1952). Thus, all intertidal areas between the high tide line and subtidal areas out to 15 m depth are potentially important feeding areas for diving ducks (Trethewey 1979). At least 80 species of birds use the intertidal portion of Baynes Sound (Trethewey 1979).

A variety of migratory bird species, such as Brant in the Comox Harbour estuary, are known to utilise eelgrass and macroalgae beds for foraging purposes. McKelvey (1981) determined that rhizomes of three-square bulrush (*Scirpus americanus*) were the predominant food of wintering Trumpeter Swans. The most heavily-vegetated portions of the Baynes Sound (from Base Flat to Maplegaurd Point) (see Figures 14-16) and Comox Harbour are the areas which also receive the heaviest known use by birds (Trethewey 1979).

OYSTER AND CLAM WILD HARVESTING AND AQUACULTURE IN BC

BIOLOGY AND ECOLOGY

Manila Clam

The first specimens of manila clams found in Ladysmith Harbour in 1936 (Quayle 1964) and were described as a new species, *Paphia bifurcata* (Quayle 1938). They were inadvertently introduced into British Columbia with seed of the Pacific oyster from Japan (Quayle 1941, 1944; Bourne 1982).

Manila clams achieved significant economic importance in the South Coast (Quayle and Bourne 1972). Landings increased dramatically in the 1980's and peaked in 1988 at 3,909 t (Figure 17). Commercial fishery landings subsequently decreased, and currently vary around 1,000 t/yr. Decreased landings are a result of more restrictive management measures in response to concerns of recruitment overharvesting, decreased opportunity to fish due to toxic algal blooms, faecal contamination and establishment of aquaculture tenures (Webb and Hobbs 1997).

Description

Manila clams are generally longer than they are high, resulting in an oblong profile, as compared to the circular profile of the native littleneck clam (Gillespie and Kronlund 1999). The valves are thick, marked with both radial and concentric sculpture. Maximum size is approximately 75 mm (Quayle 1960; Quayle and Bourne 1972; Gillespie and Kronlund 1999).

Distribution and Habitat

Manila clams quickly spread throughout Georgia Strait, and after introduction into Barkley Sound, spread up the west coast of Vancouver Island (Quayle 1964). Intentional introductions to the North Coast and Queen Charlotte Islands failed to produce sustainable populations (Gillespie and Bourne 1998) and recruitment into the Central Coast is likely from pelagic larvae from northern Vancouver Island, perhaps Quatsino Sound (Bourne 1982).

Manila clams are found in the upper half of the intertidal zone on protected beaches, in mixed substrates of mud, sand and gravel (Quayle 1960). No subtidal populations of Manila clams occur in B.C. (Bernard 1983). Manila clams are shallow in the substrate and are susceptible to extremes of temperature, resulting in catastrophic mortalities ("winter kills"). These occur when low tides coincide with below freezing air temperatures and strong winds (Bower et al. 1986; Bower 1992).

Life History

Sexes are separate and at spawning, gametes are released into the water column, where fertilisation occurs. The planktonic larval period is approximately three to four weeks, depending upon temperature and availability of food, after which larvae settle and take up an infaunal existence. Recruitment is variable due primarily to environmental conditions (Bourne 1982; Quayle and Bourne 1972).

Size at first maturity is 20-25 mm total length (TL) (Holland and Chew 1974). Fecundity increases with size and in Hawaii (Yap 1977), estimates ranged from 432,000 eggs/female at 20 mm TL to 2,350,000 eggs/female at 40 mm TL. In China (Ponurovsky and Yakovlev 1992), 188,000 eggs/female at 19 mm TL to 1,503,000 eggs/female were estimated.

Maximum size of 75 mm TL is achieved after 8-10 years, and maximum age in B.C. has been documented at 14 years (Bourne 1987). Age at recruitment to legal size (38 mm total length [TL]) varies from beach to beach and between areas on a single beach. Growth is greatly affected by tidal elevation and substrate characteristics, and can vary as much between different areas within the same beach as among beaches. Under optimal conditions, Manila clams can reach legal size in approximately 3-4 years in Georgia Strait (Quayle and Bourne 1972; Bourne 1982), 4 years on the west coast of Vancouver Island (Bourne and Farlinger 1982), and 3-4.5 years in the Central Coast (Bourne and Cawdell 1992; Bourne *et al*. 1994; Bourne and Heritage 1997; Heritage *et al*. 1998).

Predators

Moonsnails (*Euspira lewisi,* previously *Polinices lewisii*) and sea stars (*Pisaster* sp.) are occasional predators of Manila clams, although the distribution of Manilas at higher tidal elevations generally provides a refuge from these predators. Manila clams are preyed upon by diving ducks [scaups (*Aythya affinis)* and scoters (*Melanitta fusca*, *M. perspicillata*], that excavate them from the substrate at high tide. Gulls (*Larus glaucescens*) and crows (*Corvus caurinus*) collect them from the beach surface and drop them from flight to break them open.

Parasites and Diseases

Bower *et al*. (1992) examined B.C. Manila clams for disease, parasites and symbionts. No evidence of infectious disease was found, and although many species of parasites and symbionts were documented, none appeared to have pathological effects on their hosts.

Pacific Oyster

Pacific oysters are the only species harvested commercially in BC. They are large oysters, with a maximum length of approximately 300 mm (Harbo 1997). The shell is extremely variable in shape, from long and thin to round and deep, and shell morphology is greatly influenced by environmental conditions.

Distribution and Habitat

Pacific oysters were first introduced to B.C. in Ladysmith Harbour and Fanny Bay in 1912 or 1913 (Bourne and Clayton 1986, Quayle 1988). Natural spawning and dispersal events in 1932 and 1936 began the spread of Pacifics through Georgia Strait. The 1942 spawning is believed to have allowed dispersal of Pacific oysters from Pender Harbour into Pendrell Sound. The combination of "wild" oyster populations and cultured oysters throughout Georgia Strait and in certain locations on the west coast of Vancouver Island now ensure significant natural settlement in these areas in warm-water years.

Life History

Sexes of oysters are separate, though hermaphrodites occasionally occur (Quayle 1988). Sexes may change from year to year, usually in the winter, and changes may be related to environmental conditions. Fecundity is in the range of 50-100 million eggs/female. Breeding can occur within a temperature range of 14-32°C, with the optimum at 23°C. Salinity range required for spawning is between 11-32‰, with the optimum between 20-25‰. Ideal conditions for natural spawning of Pacific oysters occur relatively infrequently, thus, over most of Georgia Strait and the west coast of Vancouver Island spawning and successful settlement occurs only in unusually warm years. A few sites in BC (*e.g.*, Pendrell Sound) have special oceanographic and geographic features that allow relatively regular spawning to occur.

In BC, Pacific oysters usually spawn by June (Quayle 1988). Spawning and fertilisation are external. Once settled, oyster growth varies widely with season, food availability, tidal elevation and substrate characteristics (Quayle 1988). Growth studies are hampered by the inability to determine age in oysters. Oysters grown on hard substrate tend to be round and highly fluted, those grown on softer substrate tend to be smooth, and those grown in mud may be elongated and smooth. In general, growth is greatest between April and October. Quayle (1988) reported growth of spat from under 1 mm diameter in August to approximately 25 mm in November, and 90 mm by October of the following year. Oysters and other bivalves grow rapidly when young and more slowly with age. Reduction of growth rate in Pacific oysters occurs at 4 to 5 years.

Predators

Juvenile oysters are preyed upon by the exotic flatworm *Pseudostylochus ostreopagus*, the exotic oyster drills *Ceratostoma inornatum* and *Urosalpynx cinera*, native drills *Nucella* spp., three species of cancrid crabs (*Cancer magister*, *C. productus* and *C. gracilis*), several species of sea stars (*Pisaster ochraceus*, *P .brevispinis*, *Evasterias troschelli* and *Picnopodium helianthoides*), and black oystercatchers (*Haematopus bachmani*), scaups and scoters (Quayle 1988).

Parasites and Diseases

Pacific oysters host a number of diseases and parasites, though most cause little or no mass mortality (Bower *et al*. 1994). Two diseases that cause mortalities in BC are nocardiosis and Denman Island disease. Nocardiosis is caused by an actinomycete bacterium (*Nocardia* sp.) that is found in western North America from B.C. to California and in Japan (Bower *et al*. 1994). Denman Island disease (*Mikrocytos mackini*) attacks connective tissue cells in the oyster, and can result in fairly large mortalities (ca. 30%). The disease affects primarily older oysters held at low tide levels. Mortality generally occurs in April and May after a 3-4 month period of cooler temperatures (<10°C). The disease is endemic to Georgia Strait and certain locations on Vancouver Island (Bower *et al*. 1994).

THE COMMERCIAL WILD BIVALVE FISHERY

Intertidal clams have long been a traditional food source for First Nations people in BC, and have supported commercial fisheries since the late 1800s (Quayle and Bourne 1972). In the late 1970s, market demand in the commercial fishery shifted from butter clams to live steamer clams, both Manila and native littleneck clams. The intertidal clam fishery currently concentrates on Manila clams, with relatively minor landings of littlenecks, butters and razor clams (Figure 17). There is also interest in developing a fishery for varnish clams (Gillespie *et al*. 1999).

The wild fishery for Manila clams is undertaken at low tide, when harvesters rake or scrape the clams from the substrate. Because low tides from October to March are at night, and this is the time of year of peak bivalve condition, much harvesting is conducted with lights. The wild fishery is managed using a minimum size limit of 38 mm total length (TL), area licensing, licence limitation and time and area closures related to harvest targets based on historic production (Gillespie and Bond 1997). The depuration fishery is managed with TACs based on population estimates from assessment surveys and a sliding scale of harvest rates based on legal density thresholds (Gillespie 2000). The recreational fishery is managed using daily bag limits.

Baynes Sound is a portion of Clam Area D, which also includes clam grounds on Lasqueti Island and historic production from the Parksville and Craig Bay areas (Figure 18). Baynes Sound, as defined for this paper includes Pacific Fisheries Management Subareas 14-8, 14-11, 14-14 and 14-15. Commercial clam landings are reported either by Clam Management Area (plant hails to the Fishery Manager) or Pacific Fisheries Management Area (PFMA, DFO Catch Statistics from sales slips), depending upon the data source used (Tables 8 and 9). In either case, landings are not summarised in a form that readily allows separation of Baynes Sound landings.

Historic production from PFMA 14 decreased in the early 1990s due to increased clam aquaculture on grounds that previously held wild fisheries and loss of harvestable clam stocks due to faecal contamination. The 1997 season was only open for two days. The large number of diggers holding Area D licences resulted in intensive effort on the remaining open areas in the fishery. After licence limitation in 1998, the number of licensed diggers in Area D dropped from over 500 to under 200, allowing for a more manageable fishery. In recent years, plant hails have allowed separation of Baynes Sound production from Area D and PFMA 14 landings. Hailed Manila clam landings for Baynes Sound were 90.7 t in 1996, 48.5 t in 1997, 105.7 t in 1998, 117.5 t in 1999 and 84.8 t in 2000 (R. Webb, DFO, Parksville, pers. comm.).

Limited licensing has increased the annual days of fishing from 3 days per year in 1995-1997 to eight days of harvesting in 1998 and 1999 (Table 8). The overall annual landing has remained fairly consistent, but it now takes longer to harvest due to a decreased daily effort. Recent declines in harvest are believed attributable to loss of productive ground to aquaculture tenures and closures due to faecal contamination and Paralytic Shellfish Poisoning. The effects of intertidal shellfish aquaculture could be more readily assessed were it known how much productive clam ground was under aquaculture tenure and the spatial locations of tenures.

The paper does not address habitat impacts from commercial or recreational harvesting as these have not been documented. However, commercial and recreational harvesters likely do not cause as large an impact as does shellfish farming operations. Both wild harvest and farming involves turning the substrate and removing target species.

Landings increased in 1998 due to increased opportunity in both the wild and depuration fisheries (depuration fisheries - those that occur in faecally-polluted waters), but have decreased since, due to loss of ground to contamination closures, aquaculture tenure expansions, and closures due to conservation measures. This has resulted in a further concentration of fishing in smaller areas, again leading to concerns or recruitment over-harvesting in Area D.

The specific beaches remaining to the commercial fishery in Baynes Sound are:

- A small portion of the south-eastern end of Beach 8 in Deep Bay (all numbered beaches refer to the beach codes in Harbo *et al*. 1997) between tenured grounds and the closure around the Deep Bay wharf.
- A small portion of the north-western portion of Beach 8 above lease number 395.
- A small portion of the extreme south-western end of Beach 7 in Mud Bay.
- The western portion (approximately half) of Beach 96 on Base Flats.
- A portion of Beach 15 at Union Point and the Coal Hills (excluding the closure inside the breakwater at Union Bay).
- The reef at Denman Island light, 0.3 nautical miles north-west of the ferry landing.
- Various locations along Beach 93 south of the contamination closure at Argyle Road.
- The large beach at Tree Island (Beach 1). Most of this beach has a lower tidal elevation than is inhabited by Manila clams. There are large stocks of butter and littleneck clams on the lower beach (Kingzett and Bourne 1998) and populations of Manila clams on the south-eastern portion of the beach in PFMA 14-10.

The depuration fishery currently harvests only one beach in Baynes Sound, a 4.1 ha portion of the beach at Gartley Point (Beach 17, Harbo *et al*. 1997). Other depuration beaches in Baynes Sound were:

- Royston, which was harvested for depuration between 1992 and 1995, when it was given a prohibited fishery status due to high faecal coliform counts. It is currently used as an unharvested reference beach for the depuration assessment program (Gillespie2000).
- Mud Bay, which was harvested for depuration between 1993 and 1999 (Gillespie 2000). Most, if not all, of the 16.5 ha that were harvested were removed from the fishery by aquaculture tenure expansions in 2000.

Base Flats, which was fished for depuration in 1994, was re-opened to the wild fishery after water quality reclassification in 1995, when agricultural contamination sources were remediated with the assistance of shellfish growers (Dave Walker, pers.comm.).

OYSTER AND CLAM AQUACULTURE PRODUCTION IN BAYNES SOUND

The most widely cultured species in the Pacific Northwest is the Pacific oyster. Although first introduced from Japan in the early 1910s, significant cultivation did not take place in BC until 1926 (Quayle, 1988). Table 10a shows the volume and value of Pacific oyster production, province-wide, since 1986, and in Baynes Sound since 1993. Historically, intertidal production of Pacific oysters was preferred. However, recent oyster culture trends have been towards deepwater production. The advantages of growing oysters off-bottom in deepwater includes the use of current technology, lower costs and greater productivity. Beaches previously used for oyster production are now often used primarily for clam culture (Anon. 1997).

The farmed production of clams in BC has been formally licensed only since 1991. Table 10b shows the volume and value of clam production in BC and Baynes Sound. The higher value of cultured clams in comparison to oysters is evident in the table, but the higher quality control associated with culture clams also gives them a higher market value than harvested wild clams (Heath 1997).

Bottom culture of oysters

Intertidal oyster culture generally occurs between 0.5 and 2.5 m above Chart datum. Techniques include both bottom (or beach) and near-bottom methods (Quayle 1988; BCSGA 1998).

Since the 1920's, the major species used for bottom culture in Baynes Sound has been the Pacific oyster (Gunn and Saxby 1982). The traditional method used in relatively protected bays is to distribute seed (juvenile oysters or spat), usually attached to pieces of oyster shell (called cultch), on the beach (Quayle 1969, 1988). At seeding, there are optimally from 8 to 15 spat per cultch shell, ranging in size from a few millimetres to more than a centimetre in shell length. After a period of growth, the larger clusters of oysters are manually divided ("cluster busting"). Harvesting by hand picking and placing oysters into onion sacks or cargo nets (for pick up at high tide by skiff) occurs from three to five years after planting. Intertidal tenures are also used by some oyster farmers for hardening or conditioning of oysters from suspended culture (e.g. rafts or longlines) for a period of a few months prior to marketing. Some beach sites with firm substrate may be accessed during low tide by light truck or wide-tired all-terrain vehicles (ATVs) to move seed or harvested product.

On tenures with seasonal wave exposure, coarse (19-25mm mesh) Vexar® fences (20-40 cm above and 0-10 cm below the substrate, held in place by steel re-bar pins) may be placed on the upper edge of (and sometimes around) oyster plots to reduce the loss of product from the plot area by wave action. Rock berms (see below) may also be used for this purpose.

Near-bottom oyster methods

Oyster seed is sometimes nursery-reared in mesh bags, trays or semi-rigid net bags on elevated shelves or racks (e.g. welded re-bar or steel frames) in the intertidal zone, especially in areas where there is a soft or muddy substrate. On firm gravel beaches, the trays or bags may be placed directly on the bottom and secured as necessary with re-bar pins or other anchoring methods. A typical sequence may involve reducing densities of cultch-less or "singles" seed as the oysters grow, using progressively larger-meshed bags or trays (BCSGA 1998). The enclosures, if properly closed, will generally provide protection from predators, such as crabs and starfish.

Intertidal culture of Manila clams

The experimental phase of Manila clam culture began in British Columbia in 1969 and continued until the early 1990's (Bourne 1989, Heath et al. 1992, IEC 1992), using methods developed on the Atlantic coast and in Washington State (Anderson et al. 1982, Toba et al. 1992, Mitchell 1995). These trials demonstrated that it was feasible to improve the production of Manila clams by a combination of seeding and use of protective netting (car cover or seine netting) and beach modification (e.g. berms, contouring, and stream channelisation) at suitable sites. Since 1990, commercial culture of Manila clams has been conducted on a relatively small area , mainly those areas that were tenured for oyster culture prior to September 1990 (Caine and Dickson 1992). Baynes Sound quickly became the leading growing area for Manila clams in BC, with about fifty licensed tenures covering about 280 ha, by 1996. Since 1998, more than half of the farmgate value of cultured shellfish produced in Baynes Sound has been farmed Manila clams (Table 10).

For successful commercial culture of Manila clams, the first step is to choose or modify, where appropriate, a site to obtain the desired physical characteristics for good growth, survival and harvestability of the crop. The most important physical factors are tidal level, substrate type, wave exposure, temperature and salinity. Biological factors that affect clam production are density, biomass, food availability, predation, competition, pests and disease. Pollution and marine biotoxins are factors that may affect the harvestability of clams.

Tenure modifications associated with clam culture

Farmers, after selecting a site, can influence substrate type, beach contour, wave exposure, predation levels, clam densities and competition, pests and disease.

Substrate type and modification

The ideal substrate for Manila clam growth and survival is a stable, loosely packed substrate consisting of gravel, sand, mud and shell (Miller 1982, Toba et al. 1992). Substrate stability is critical because Manila clams cannot survive in a constantly shifting substrate (Kurashige 1942). In unstable areas, the matrix of sediment fines that hold the gravel and sand together may wash away, leaving only an unsuitable, loose deposit of sand and gravel. Substrate stability can be enhanced by use of predator-exclusion netting and berms to lower wave energy.

If an intertidal shellfish tenure lacks adequate natural substrate to support Manila clams, there are methods for substrate modification (Toba et al. 1992, Mitchell 1995) that may be applied under appropriate circumstances, with permission from government agencies (BCAL, DFO). Substrate modification generally involves placing gravel or a combination of gravel and crushed oyster shell onto a soft (mud or mud-sand) or hard (packed cobble) beach area to create a substrate that approaches the ideal substrate for Manila clams (Thompson 1990, 1995; Mitchell 1995). In Baynes Sound, there has been no modification of substrate by gravel addition. This region has the most extensive intertidal flats with gravel/sand/mud substrates in British Columbia that are suitable for clam farming.

Wave exposure and berms

Despite their relative protection from wave action, many Baynes Sound beaches are periodically exposed to storm waves from the south-east or north-west that can shift substrate, clams or oysters. Vexar® fences are often used to hold oysters, but are relatively ineffective in stabilising substrate or preventing clam movements. Protective netting or car cover may assist in stabilising substrate, but waves may scour small Manila clams out of plots in the first few weeks or months after planting (Anderson et al. 1982). Low boulder berms are sometimes placed 50-100m seaward of the clam plots (at or near zero tide level) to protect them from storm damage (BCSGA 1998). Creation of such "improvements" requires approval within the tenure's Shellfish Development Plan by BC Assets and Lands.

Predation and Protective Netting

To reduce clam seed predation by a variety of predators, such as bottom fish, crabs, starfish and sea birds, the technique of placing panels of light-weight, 1.25 cm (0.5") mesh plastic netting (car cover) over seeded natural gravel substrates was developed in Washington (Glock and Chew 1979, Anderson et al. 1982). Some farmers also use old fish farm smoltpen netting to cover their plots. Studies comparing clam recovery in netted and unnetted (control) plots in Washington and BC have shown significantly higher recovery of Manila clams in netted plots (Anderson et al. 1982, Heath et al. 1992, IEC 1992). If protective netting is not used, the spreading of larger clam seed (21 mm shell length) does not necessarily result in better recoveries than use of the smaller seed (3-4 mm) commonly available from shellfish hatcheries (Anderson et al. 1982). Typical survival of 3-4mm seed with netting is 30-57% after two years, compared to 0 to 10% in unprotected plots (Anderson et al. 1982, Toba et al. 1992). BC clam growers generally estimate the mortality rate from 6-9 mm seed through to harvest ranges from 40-50% (BCSGA 1998) even with the use of protective netting.

Population Levels and Competition: Planting Clam Seed

As with other types of farming, appropriate seeding and inventory management on clam farms are critical to economic success. For Manila clam farming, the target initial stocking density is generally 330 to 660 clams m^{-2} or 30 to 60 clams ft^{-2} (Toba et al. 1992, BCSGA 1998). Higher densities (e.g. 800-900 clams m^{-2}), especially when the clams are reaching harvestable yields of 6-7 kg m^{-2}, can lead to reduced growth rates in clam plots, and possibly "stunting" effects, likely due to competition for food (Mitchell 1992). Since natural recruitment of clam seed into netted plots is variable, farmers spread hatchery seed to ensure a desired set. Natural sets, though, may sometimes augment hatchery seed inventories significantly, requiring regular inventory monitoring and management (e.g. tilling and thinning) to prevent over-crowding in clam plots (Toba et al. 1992).

When planting small seed clams, plots are usually prepared in advance. This may involve:

1) removal of wood debris and/or rocks that will interfere with farming techniques; contouring the intertidal; and creating berms and channelising streams that flow through the plots (the latter requires prior DFO approval); and
2) placing plastic netting over the plots (if predation, other than by moon snails, is considered a problem). Netting is typically installed as either car cover net panels usually 4-5m wide by 25-30 m long, with the perimeter having lead line woven through the edge and secured with plastic cable ties, or as smolt netpen panels approximately 15-30m x 15-30m. Panels (single or double layers) are fixed to the substrate by re-bar staples and/or rocks around the edges.

Planting, by sprinkling seed at a predetermined level within marked panel sections, is done on a rising tide on a relatively calm day (waves less than 15 cm high) in water 15-60 cm deep (Toba et al. 1992). When covered by calm water, Manila seed clams can dig into the substrate within minutes under calm conditions.

Maintaining Netted Plots

Netting typically lasts the three-four years of a crop cycle if properly maintained. However, damage to car cover is common (e.g. seam separation, tearing by debris or drift logs), and once the netting is damaged, predators can gain entry, resulting in dramatic loss. Miller (1982) reported that in situations where crabs entered through loose or damaged seams, clam numbers dropped from 550 m^{-2} to 165 m^{-2} over a three-month period. Thus, routine inspection and regular maintenance (e.g. stitching damaged seams) of nets are needed to avoid major losses of cultured clams.

Bio-fouling (macroalgae and mussel/barnacle growth on nets) may restrict water circulation and cause severe reduction in phytoplankton availability. This is most common from spring through fall. If the bio-fouling is significant (i.e. netting becomes clogged), then the fouling organisms must be removed manually. However, it has been suggested that, at some locations, the continual net upkeep may not be economically justifiable (T. Harper, Nanaimo, aquaculturist), as mussels may just reattach and currents may or may not wash the removed algae away.

Harvesting

Clam harvesting is currently done exclusively by hand raking. The netting, if used, is rolled back and the plot is systematically dug. Most harvesting is done by specialists who work year-round for the clam farmers; harvesting occurs at night from October to March because of the diel timing of low tides. Clams below market size (generally less than 35 mm) are left in the plots. When the final harvest is completed on a plot, the area is raked smooth, re-netted and planted with the next crop.

GEOGRAPHICAL AREA CURRENTLY UNDER CULTURE IN BAYNES SOUND

While the total Baynes Sound area currently under tenure for bivalve aquaculture is 538 ha, spread over 194 tenures (W. Heath, pers. comm., July 2001), this value is only meaningful in the context of the area that is currently naturally inhabited at significant densities by relevant bivalve species, and particularly manila clams. Clam species each have different preferred substrate requirements, tolerances to salinities and temperatures, and intertidal height ranges. We could find no summarised information on the total area, spatial patterns of occurrence, and abundance of manila clams in the intertidal zone in Baynes Sound. The habitat preferred by clams is not necessarily that of current leases, since most of these were initially established for oysters. It will only be some fraction of the total intertidal zone: about 1/3 of the intertidal zone is estimated to be in the intertidal height range preferred by manila clams, and of this, only some further fraction will have appropriate substrate characteristics and water conditions for manila clams.

Obtaining this information is important in calculating the ecological impact of bivalve culture. It is important to determine the percentage, e.g., 5, 25, 50, 75 or 95%, of manila clam habitat currently tenured, and the areas over which the different types of impacts associated with clam culture are being applied. Likewise, knowing the spatial pattern of tenures is important, as this can determine whether there are appropriate areas where other natural species may occur in abundance. A substantive series of contiguous tenures is likely to have a different ecological impact than a series of modest sized tenures with appropriately-sized uncultured areas between them, as has been found with urbanisation and agriculture (e.g. Yale Forest Forum 2000).

EXISTING TENURE EXPANSION PROCESS IN BAYNES SOUND

In November 1998, the Province announced the Shellfish Development Initiative, which included a procedure for expansion of existing shellfish tenures and a new application process for obtaining new shellfish tenures. Opportunities for limited tenure expansion were provided to growers that could demonstrate significant utilisation of their existing tenures for shellfish aquaculture.

An outline of the process for obtaining new shellfish tenures is provided in Figure 19. A major new feature of this process is the initial period of community input, including a Community Steering Committee and public meetings. Representation on Community Steering Committees is from a wide range of interests, including First Nations, the shellfish aquaculture industry, provincial agencies (MAFF, BCAL), local government, regional economic development agencies, environmental research groups and clam fishery management boards (Osborne 2000).

The role of the Community Steering Committee is to recommend (a) an acceptable rate of development for shellfish farming for the region (i.e. social acceptability); (b) suitable areas (i.e. capability and suitability for shellfish culture) for accepting new applications (suitability maps) and (c) community criteria for adjudicating tenure applications (i.e. criteria for overlapping applications or exceeding of allowable area). Seven steering committees were established; five of these committees have completed all their tasks. As a result, applications for new shellfish tenures have been accepted in the Powell River, Barkley and Quatsino regions. Nootka-Kyuquot will be opened for applications in the very near future. In Clayoquot Sound, discussions on the number of First Nation shellfish aquaculture reserves are underway. Once these discussions are complete, the area can be opened for applications.

Discussions to establish steering committees for Cortes Island, Quadra-Campbell River, Sechelt, Nanaimo and Southern Gulf Islands are ongoing.

The Comox Valley Shellfish Steering Committee was established in February 2000. The committee voted to hold its activities in abeyance after Denman Island Trustees on the committee advised that no area on the Island Trust area of Baynes Sound would be available without rezoning for shellfish aquaculture.

All applicants must follow the standard procedures for disposition of Crown Land (posting of Form 1, completion of a detailed Shellfish Development Plan that describes the proposed operation, including Schedules of seeding, production and improvements). Following acceptance and payment of a non-refundable administration fee of $500, the applications are referred to a list of agencies, including DFO (for fisheries, habitat and navigable waters concerns); WLAP; local governments (for zoning considerations); and First Nations (aboriginal rights and title issues). Publication requirements, community process, and referral process will determine if there are possible conflicts. Attempts at conflict resolution are made to address concerns before a land use and licensing decision is made. Successful applicants are offered a tenure, to be issued upon payment of an additional $4,500 fee. Figure 20 presents the existing and proposed aquaculture leases in Baynes Sound.

LITERATURE REVIEW OF ENVIRONMENTAL IMPACTS OF SHELLFISH AQUACULTURE

TENURE MODIFICATION IMPACTS ON THE INTERTIDAL ECOSYSTEM

We define disturbance as any physical modification of intertidal or shallow subtidal substrates that results from aquaculture practices (see Simenstad and Fresh 1995). Under this definition, this includes the addition of high densities of cultured animals to natural substrates and indigenous communities, altering sediment structure, modification of population characteristics of indigenous species that are considered deleterious to the efficient culture of the target species, and altering the natural hydrologic and sedimentary regimes. Only the impacts of intertidal bottom culture are considered here. The effects of commercial or recreational harvest impacts on natural bivalve populations have been excluded, even though they can cause extensive disturbance of intertidal communities as well.

Vexar® Fences, Berm Building and Beach Clearing

In comparison to near-bottom and off-bottom methods of culture, in situ bivalves in bottom culture seldom affect the pattern of water flow and sedimentation (Pillay 1992). However, as previously described, berms and vexar® fences are utilised in Baynes Sound for the stabilisation of sediment and retention of stock (Figure 21 and 22). In addition, beach clearing to remove cobble and boulder-sized sediment and driftwood is also practised to maintain ideal substrate conditions for bivalve culture. These modifications alter the natural patterns of waves and currents resulting in impacts on the natural patterns of erosion and sedimentation in the intertidal zone (Pillay 1992). To what degree these impacts have on the coastal ecosystem of Baynes Sound is not known.

Predator Exclusion Netting

One of the most extensive tenure modifications in the intertidal zone of Baynes Sound is the use of predator exclusion nets, which are utilised in Manila clam culture during the on-growing stage to protect stocks from predation by diving ducks, crabs, sea stars and snails. The netting is placed directly on the foreshore surface, and weighted down with lead lines that are attached by rebar (Figure 23-25). Either plastic netting or “car cover”, which is made of polypropylene with a mesh size ranging from 10mm to 20mm, or to a less extent, old netting from smolt net pens are used. If car cover is used, more than one layer of netting may be laid over the substrate, especially during the early phases of culture when the clams are much smaller (Spencer et al. 1996).

Spencer et al. (1996, 1997, 1998) conducted a five-year study of Manila clam culture to assess potential physical and biological disturbances on the benthic community related to clam cultivation. Experimental plots, both with and without clams, were covered with netting, and were compared to control plots without netting. The use of 5 mm mesh netting for the first six months, and a larger mesh size of 10 mm for the remaining two years, had a continuous impact on the local hydrographic regime by reducing flow and increasing sedimentation (Spencer et al. 1996; 1997). Experimental plots treated with netting experienced up to four times the rate of sedimentation, resulting in the raising of netted beds by about 10 cm. The sediment under netted plots, with and without clams, also had higher levels of organic content and phaeopigment. The netting attracted epiphytes, which in turn attracted periwinkles; both contributed to the increase in organic content (Spencer et al. 1996; 1997). Alterations in the abundance of benthic infauna were also attributed to the use of netting via reduced flow, modified substrate conditions, and the exclusion of major predators. There was an increase in the number of species and density under netted plots, and a change in species composition towards domination by deposit feeding worms (Spencer et al. 1996; 1997). A smaller-scale study by Kaiser et al. (1996) reported similar results.

Simenstad et al. (1993) studied the use of predator exclusion netting on epibenthic assemblage structure in Puget Sound, to observe the potential impacts on prey resources of other commercially important juvenile fishes that rear in the intertidal zone during a critical period of their life history. Harpacticoid copepods were utilised as the indicator organism. The varying responses of species composition and density between plots indicated that site-specific factors such as initial grain size structure, tidal elevation, and beach geomorphology may play a larger contribution to epibenthic assemblage structure than was evident between netted and control plots. Similar to the findings of Spencer et al. (1996, 1997), changes to intertidal community structure were also attributed to reductions in mean sediment grain size, increased abundance of algae, and alterations in predation related to the presence of predator exclusion netting (Simenstad et al. 1993).

Bendell-Young et al. (2001) recently attempted to assess the impact of car-cover on intertidal structure and function in Baynes Sound by comparing basic components of species diversity (structure) and cycling of organic matter (function) among three beaches experiencing different farming/harvest intensities: a reference beach used only for recreational harvesting within a provincial park with no car-cover present; and, two commercially-leased beaches that were farmed but at different levels of harvest intensity and net coverage, i.e. partially covered and completely covered. Ecosystem structure was examined through measurement of species richness, abundance and distribution and basic community composition. Ecosystem function was evaluated by among-beach comparisons of surface sediment percent organic matter. Comparison of these indices indicated that intensive farming practices that included seeding and covering of the beach with car-cover decreased species richness and changed the community structure of the intertidal from one comprised of a balance of surface and subsurface species to one comprised primarily of bivalves (Figure 26). Car-cover also increased accumulations of surface sediment organic matter as compared to the reference beach, a finding previously noted by Spencer et al. (1996, 1997).

Predator Removal

In addition to the use of predator exclusion netting, the manual removal and killing of macro invertebrate predators found on lease areas is a common practice in intertidal bivalve aquaculture. Trapping programs can be utilised to limit crabs and sea stars from accessing the intertidal zone (Pillay 1990). In Martha's Vineyard, MA, one local area has a bounty system to monetarily reward fishermen for the removal of predators (Karney, 1995). In Baynes Sound, the invertebrate species subject to removal are Moonsnails, crabs (*Cancer productus, C. magister*), and sea stars *(Pisaster ochraceus, P. brevispinus*). This direct impact on the abundance of certain species of benthic macrofauna can affect the intertidal community structure through the alteration of predator/prey relationships. Caging experiments by Summerson and Peterson (1984) demonstrated that the removal of large, mobile epibenthic predators from unvegetated sandflats resulted in a substantial and significant increase in macrobenthic infauna.

Recent studies by Bendell-Young et al. (2001) and Bendell-Young and Ydenberg, (2001) also demonstrated that predator control has an effect on the abundance and distribution of bivalves (Figure 27 and 28). Three beaches of different shellfish harvest intensity (see above) were compared for species and abundance of bivalves. For the reference beach, non-native Manila and native littleneck are the dominant species, with abundances reaching up to 300 individuals $0.25m^{-2}$, but only at high tidal elevations (Figure 27 and 28). In contrast, on the netted plots, total number of bivalves were more evenly distributed along the intertidal (Figure 27), with Manilas dominating in one beach and Manilas and *Macoma spp*. dominating in the other beach

(Figure 28). That the netted beaches had a fairly even bivalve distribution over tidal elevation, with the Manilas dominating, was not unexpected given the practice of seeding with only Manilas and the removal of other indigenous clam species, specifically native littlenecks, by hand raking.

The high abundance of bivalves at higher tide levels on the reference beach in the absence of predator exclusion nets was somewhat counterintuitive and raises the question as to the actual role of predator exclusion netting in increasing bivalve yield. The location of bivalves on the reference beach is perhaps easier to explain in that unlike the farmed beaches where active predator control occurs, no such practice occurred on the reference beach. As a consequence there was a large Moonsnail population on the reference beach in contrast to the two farmed beaches where this predator was absent (L. Benedell-Young, pers. observation). Moonsnails require water in the substrate to move within the intertidal, and substrate desiccation occurs at higher tidal elevations. At the elevation where Moonsnails can no longer move within the intertidal, bivalves become more abundant. In the study, it was at approximately 2.5 m elevation. In the presence of predator exclusion netting, no such predation pressure on bivalve distribution occurred. It may thus be the removal of Moonsnails and not the presence of predator exclusion netting per se that was the important variable in these studies.

Beach Gravelling

Several studies on the impacts of beach gravelling to enhance hardshell clam habitat have taken place in Puget Sound, Washington. Gravelling either involves the placement of gravel alone, or a mixture of gravel and crushed oyster shell on mud and sand beaches. The addition of coarser sediment serves to increase predator protection and substrate stability, and creates interstitial space to enhance the settlement of juvenile clams in order to increase production (Thompson and Cooke 1991). Although as previously mentioned, gravelling has not taken place in Baynes Sound, aquaculture operators in BC can apply for permission for substrate modification. Permission was given to a farmer in Ladysmith Harbour to add pea gravel over a sandstone substrate to make a substrate for clam culture, but it was never acted on (Rob Russell, DFO, Nanaimo, pers. comm.). Gravelling was done on a clam lease in Nanoose Bay in 1993, and an assessment of the effectiveness of this gravelling project and that of a beach re-contouring project at a clam tenure in Barkley Sound was commissioned by BCMAFF (Mitchell 1995). The study concluded that substrate enhancement by beach contouring and by gravelling are both viable methods for increasing the productive capacity of BC clam tenures for Manila clam seed growth, survival and natural recruitment. This warrants the following review of gravelling impact studies.

Thom et al. (1994) studied the impact of gravelling at two study sites, one characterised by a fine sand and mudflat texture, and the other a broad sand flat. In general, gravelled plots were associated with an increase in secondary productivity, respiration, nutrient flux, and heterotrophy in comparison to control plots. However, there was no major difference between net productivity, and levels of dissolved oxygen and inorganic nitrogen concentrations. For both sand and mudflat sites, there were also significant increases in bivalve density and an increase in vegetation cover of *Ulva* sp. in gravelled plots, probably related to the increased nutrient flux associated with gravelling.

Two studies assessed the impact of beach gravelling on both abundance and diversity of epibenthic organisms. Simenstad et al. (1991) concentrated on gravelling impacts on species subject to predation by juvenile salmon, and found the abundance of harpacticoid copepods and gammarid amphipods was greater on plots of both sand and mudflats subject to gravelling relative to control plots. Thompson (1995) also found an increase in density of both gammarid amphipods and nemertean worms on gravelled plots, in addition to the presence of shore crabs not found in control plots. Conversely, there was a decrease in diversity and abundance of polychaete worm density, which may have been a short-term effect until the breakdown and accumulation of finer material in the substrate occurred. Overall, there were only minor differences in species diversity and abundance between gravelled and control plots. These were associated with changes in texture of gravelled sites and the increase in interstitial space created a more favourable environment for certain species (Thompson 1995).

In the above studies, beach gravelling was not observed to cause a net negative impact on epibenthic species diversity. However, these studies concluded that the enhancement of hardshell (steamer) clam habitat did have an effect on intertidal ecosystems, that the level of impact caused by alterations in substrate texture due to gravelling was related to degree of disturbance in relation to natural conditions (Thom et al. 1994; Simenstad and Fresh 1995).

Beach Tilling and Harvesting

During the 1–3 year harvest cycle of oysters, and the 2-4year harvest cycle of clams, husbandry practices may disturb the benthic environment on a regular basis. Beach tilling or raking associated with transplantation, redistribution or thinning, and harvest of oyster and clam beds directly impacts the intertidal zone. While mechanical harvesting of intertidal grown bivalves is practised in some countries, e.g., through the use of hydraulic dredges towed by boats and tractors (Hall and Harding 1997, Spencer et al. 1998), the use of such machinery has only been experimentally employed in BC (Adkins et al. 1983) and has never been operationally permitted. In Baynes Sound, all harvesting is performed manually by hand raking. Ecosystem impacts related to beach tilling and harvesting focussed on the potential impacts on intertidal vegetation. Although there is supposed to be no interaction between aquaculture leases and eelgrass, overlap of leases and eelgrass beds has occurred (Tamasi et al. 1997), and evidence of oyster on-growing amongst eelgrass has been observed (Figure 29).

Comparisons between mechanical harvesting and hand raking techniques have demonstrated that although the effects of hand raking are much less severe, it does impact the intertidal ecosystem (Peterson et al. 1987, Kaiser et al. in press). In experiments on both sand flat and seagrass bed environments, hand raking did not appear to have a direct, significant impact on the density and species composition of benthic macroinvertebrates in comparison to control plots (Peterson et al. 1987). However, hand raking in seagrass beds resulted in a 25% reduction in seagrass biomass, which subsequently underwent full recovery after one year. Peterson et al. (1987) concluded that through the direct impacts of hand raking on seagrass biomass, indirect changes in the benthic faunal community can occur. In contrast, Kaiser et al. (in press) did observe short-term changes in benthic species composition related to hand raking, but observed recovery occurred within 54 days of disturbance. Limits to disturbance by hand raking were attributed to the leaving of sediment in situ, thus not affecting all animals within the path of the rake (Kaiser et al. in press).

It should be noted that the wild fishery for clams also involves hand raking, and so all clam harvesting involves some ecological impact. On a modest scale, hand raking is unlikely to be too significant ecologically, as the intertidal zone is a dynamic one that is regularly impacted by wave action during storms. The scale and frequency of impacts may be important. Unfortunately, there is little published data that is relevant to either wild harvest or clam aquaculture on hand raking impacts. Bourne et al. (1998) investigated repeated digging effects on sublegal-sized manila clams, and found no significant difference in survival because of repeated digging with rakes. With this technique, the substrate is generally not overturned and juveniles are thus not usually buried under mounds of substrate. Another reason they identified for their lack of significance in survival rates of juveniles with different digging regimes (1,2 or 4 times per year for two years) was experimental design, as in hind-sight, they used large plots to minimise edge effects, but this decreased statistical precision due to fewer replicates.

Impacts from digging include clam removals, the killing and /or injuring of some unharvested clams, and increasing the exposure of others to either predators or adverse environmental conditions, such as desiccation, freezing, or possibly smothering. Smaller clams are likely to be most affected by the latter impact, but comprehensive studies are required to establish the nature and seasonal severity of impacts.

Channelisation of Estuaries and Deltas

Estuaries are important ecosystems and provide habitat to a rich diversity of organisms. Estuaries are transitional zones between fresh and salt water sharing characteristics of both environments. The key is the transition from fresh to salt water and the flood and ebb of tides, which changes the water chemistry, sediments, the micro-organisms and the plant and animal communities, such that the system functions in a different way from fresh or salt water habitats. Deltas are the morphological feature formed in estuaries where upland sediment is deposited in coastal areas by streams as they meet the lower energy marine environment. Some of the larger streams that flow into Baynes Sound form deltas, whose morphology is controlled by the supply of sediment from both upstream and longshore transport sources, and dominant tidal flows. As a result, estuaries and deltas are characterised by an unstable network of meandering tidal channels that are constantly changing. Through the relocation or addition of substrate to form fewer or a single channel(s), channelisation can be implemented to stabilise the physical estuarine environment. The effects of locally concentrating stream flow through artificially maintained channels can result in increased erosion and removal of vegetation, altering patterns of sedimentation, temperature, salinity, nutrients and oxygen levels (Bose et al. 1991). Over the long term, the restriction of the lateral movement by tidal channels will limit the downstream supply of these variables to parts of the estuary, while directing sediment farther out than normal. As a result, the overall size and shape of the delta will be altered.

In lease areas located at the mouths of some streams entering Baynes Sound, channelisation of estuaries is occurring that alters the temporal and spatial flow patterns in the intertidal zone (Figure 30-32). This allows the grower to increase the area that can be utilised for culture and reduces the risk of shellfish being washing away during freshets. To what extent these disturbances are occurring and the size of the impact in Baynes Sound is not presently known.

Terrestrial Vehicle and Boat Usage in the Intertidal Zone

Because tidal flats may not always be accessible by boat, terrestrial vehicles are sometimes used to access lease areas (Figure 33 and 34). DeGrave et al. (1998) studied the sediment and benthic macrofauna in vehicle access lanes at an intertidal oyster culture operation. In comparison to control sites, mid-tidal areas subjected to physical disturbance from moderate vehicle traffic experienced alteration in surficial sediment matrix through compaction and displacement, along with a higher abundance of epifaunal decapods at the expense of a reduction in small-bodied crustaceans and shallow, fragile burrowing bivalves. As well, accidental discharge of oil and gasoline from vehicles poses a potential contamination threat to fish and fish habitat in the intertidal zone. Lease areas serviced by boats also have the potential to be similarly impacted, and eelgrass beds can be damaged by propeller wash, the direct cutting action of propellers, and by boat hulls being dragging over vegetated bottoms (Short and Wyllie-Echeverria 1996).

Pesticides

There is no present use of pesticides in BC shellfish aquaculture operations (B. Kingzett, BC Shellfish Growers, pers. comm.) However, chemicals are used in finfish aquaculture to control sea lice (copepods), and their potential use in shellfish culture exists to address yield or quality problems that may be caused by crustaceans. Pesticides are used in bivalve culture in specific areas of coastal Washington, where the pesticide carbaryl (tradename, Sevin®) is used to control local populations of burrowing shrimp that in high densities can destabilise the substrate under oyster beds and result in oyster smothering (Simenstad and Fresh, 1995).

It can be argued that if the use of pesticides for this purpose is required, then the areas tenured are inappropriate for that type of bivalve culture. Even if not used at the outset of culture, managers should be aware of the potential demand for such substances if bivalve culture is approved in areas not particularly suited for profitable bivalve culture without the use of these chemicals.

ECOSYSTEM EFFECTS OF INTERTIDAL BOTTOM CULTURE

INTERTIDAL COMMUNITY RESPONSES TO AQUACULTURE DISTURBANCES

Positive environmental effects attributable to shellfish aquaculture include improvements to water quality by the removal of particulates from the water column by filter-feeders (Phillips et al. 1991). Furthermore, the requirement for good water quality for shellfish culture has lead to greater awareness of water quality issues and improvements in the quality of water flowing into Baynes Sound. Because of the closure of several shellfish growing areas due to faecal contamination in 1994, the Baynes Sound Round Table was formed to work towards reducing levels of non-point source pollution entering the Sound, resulting in a general improvement in water quality (Joughin and Lau 2001).

However, shellfish aquaculture does have the potential to negatively impact intertidal ecosystems in a variety of ways as noted earlier. To date, no studies have addressed the cumulative effect on ecosystems from bivalve culture. The following section attempts to identify the types of impacts that can directly effect intertidal productivity and community structure, and indirectly effect vegetation, fish and wildlife in Baynes Sound. It should be re-emphasised here that most actions by humans have an environmental impact. At issue here is not whether this should occur, as humans are also part of the natural ecosystem and have a right to extract resources to survive, but rather the nature, scale and areal extent of human impacts on the ecosystem. This is particularly important today because we now have the technology and physical capability as a species to effect tremendous change over relatively large areas in a relatively short time. The consequences of inadequately regulated intensive shrimp culture in tropical areas (Bhatta and Bhat 1998, Paez-Osuna et al. 1998, Miller et al. 1999, Flaherty et al. 2000) are an example of our ability to create a large adverse impact over a short time period.

Productivity

The sediment-water interface of aquatic ecosystems is an extremely important zone of nutrient (carbon, nitrogen and phosphorous) flux. In some cases, the sediments form a sink from which nutrients are slowly released. At other times, the sediments can be an important source of nutrients at critical times (Clavero et al. 2000, Yin and Harrison, 2000). This flux can determine amounts of primary productivity on which secondary productivity (i.e. bivalve yield) is based.

Shellfish culture may enhance primary production through an increased rate of nutrient cycling. The consumption of phytoplankton biomass and release of nutrients could increase the ecosystem's capacity for supporting additional primary production (Kaspar et al. 1985). However, intensive production of filter-feeding bivalves might result in a reduction in phytoplankton biomass that would reduce the food supply available to zooplankton, resulting in other alterations to the natural planktonic community (Weston, 1991). Thom et al. (1994) and Thompson (1995) indicated that graveling for enhanced clam production can significantly depress macroalgae cover, enhance chlorophyll-a concentrations, increase benthic respiration rates, and increase nutrient fluxes (particularly PO_4^{3-}, total inorganic N, NO_2^-, and NH_4^+); impacts, though, were quite variable and site-specific.

In addition, predator exclusion nets reduce flows and increase sedimentation and the accumulation of organic content (Spencer et al. 1996; Spencer et al. 1997; Bendell-Young et al. 2001). Exclusion netting provides a substrate for algae, mussels and other sessile species. How this alters the geochemical flux of nutrients of aquatic regions used for shellfish culture remains speculative and unproven. If it is enhanced, marine waters supporting mariculture might pose a threat to shellfish farms by possibly increasing the occurrences of undesirable phytoplankton blooms, particularly those of toxic species (red tides). If the normal flux of nutrients such as nitrogen was restricted at certain times, this could reduce primary productivity and thereby secondary productivity. Hence, from both an ecological as well as from the farmers' perspectives, it is important to consider the impacts of extensive use of intertidal culture practices on the basic geochemical cycling of the key nutrients, i.e., carbon, nitrogen and phosphorous. These impacts may also be incurred through alterations in intertidal hydrography and hence sedimentation due to the use of Vexar® fencing, building of berms, and beach clearing.

Community Structure

Types of aquaculture that provide increased topographic complexity (e.g., suspended culture) result in increased density and species diversity of wild fish in the vicinity of farms. Pile perch (*Rhacochilus vacca*), for example, typically occur in abundance in BC waters only around physical structure in the water column. Epifaunal and epiphytic growth on raft intertidal culture structures (references following refer to suspended culture, although elevated intertidal cultivation might somewhat have the same effect) are a potential food source that can attract other fish and wildlife such as crabs, demersal fishes and marine birds such as oystercatchers (Lopez-Jamar et al. 1984, Weston 1991). Alternatively, aquaculture in Baynes Sound could have potential negative impacts on wild populations by modifying gene pools because of cultured bivalve seed dispersal, increased transmission or transfer of diseases, introductions of species that might alter food webs, and competition for ecological niches (Weston 1991). Alterations in intertidal hydrodynamics through the building of berms, use of Vexar® fencing, beach clearing, and use of car cover netting could also have impacts on benthic recruitment processes (Eckman 1983). Furthermore, high densities of bivalves can reduce larval settlement and survival of other species (Kaiser et al. 1998), and decreases in macrofaunal abundance have been detected in intertidal areas under extensive culture (Castel et al. 1989).

Predator exclusion netting and the removal and destruction of predator species such as birds, snails, crabs, and sea stars can have both a direct and indirect impact on the intertidal community structure. Disturbances to natural patterns of intertidal hydrography by predator exclusion netting can also have indirect impacts on community structure. Both Castel et al. (1989) and Nugues et al. (1996) observed declines in water current velocity directly beneath intertidal oyster trestle culture sites. The associated increases in sedimentation and reductions in oxygen levels were attributed to significant declines in benthic macrofaunal abundance. In contrast, although Spencer et al. (1996) observed increased sedimentation at net-covered clam culture sites, they reported no significant alteration to the diversity of the benthic community. Simenstad and Fresh (1995) reviewed the impacts of predator exclusion netting on epibenthic meiofauna, and found the effects to be site-specific and likely dependent on the inherent levels of natural disturbance. Crustacean abundances, notably harpacticoid copepods and some cumaceans, were typically depressed in comparison to unnetted sites. However, at some netted sites, certain copepodite densities increased at certain times of the year (Simenstad et al. 1993). Similarly, Summerson and Peterson (1984) also observed a significant and substantial increase in benthic infauna related to the direct removal of mobile epibethic predators from unvegetated sand flats.

Bendell-Young et al. (2001) and Bendell-Young and Ydenberg (2001) demonstrated that one consequence of the removal and destruction/exclusion of predator species (e.g., snails, crabs, etc) was to shift the intertidal community from one dominated primarily by epibenthos species to that comprised primarily of clams (Figure 35). A shift to a system dominated by the cultured species is expected. Important ecological questions are thus: "What proportion of the natural ecosystem might be shifted to one of farmed bivalves without a significant disruption in natural ecosystem processes, and is fragmentation of the Baynes Sound ecosystem by aquaculture plots a concern with regards to important processes in the ecosystem?" These questions have not been addressed in the Northeast Pacific, and thus are the fundamental questions that should be addressed in an ecosystem assessment of the environmental impacts of intertidal bivalve culture. The impacts of both current levels of culture, and the proposed expansion on community structure and ecosystem functioning (e.g., nutrient cycling) are unknown and with available knowledge, cannot be easily predicted.

Evaluation of immediate responses by benthic communities to aquaculture substrate modifications such as beach graveling do not exist (Simenstad and Fresh 1995). Data that exist are comparisons of impacted sites with adjacent or nearby "reference" sites.

Simenstad and Fresh (1995) reviewed the literature and concluded that graveling beaches affected interstitial community structure. The main effect was the shifting of the benthic infauna from communities numerically dominated by glycerid, sabellid and nereid polychaetes to ones dominated by bivalves and nemerteans. For epibenthic meiofauna, effects were related to the extent of natural substrate replacement by gravel. If it was all replaced, biodiversity was depressed, but if there was not a total loss of sand and mud, an increase in habitat spatial complexity occurred, since both substrates types would then be present, that increased sediment diversity in the site as a whole.

Chronic low intensity, or infrequent intermediate intensity, intertidal substrate disturbances tend to be within the range of behavioural or ecological adaptability of intertidal species. Spatial distributions within most epibenthic intertidal populations are dynamic because of wave action and meteorological effects (reviewed by Simenstad and Fresh 1995). Meiofaunal species tend to havemultivoltine (i.e. more than two generations per year) turnover rates (Hicks and Coull 1983) that facilitate rapid recolonisation, making the spatial and temporal scales of processes that might affect repopulation particularly important. Hall and Harding (1997) postulated that non-harvested benthic communities, being adapted to periodic disturbance, are likely to recolonize harvested areas rapidly. However, recolonisation rates can vary depending on sediment stability and exposure to wave action and currents, and the scale and degree of disturbance. Disturbance impacts may be limited by adopting a farming cycle of seeding, harvesting and fallowing, depending on the amount of natural disturbance and timing of harvesting in relation to larval recruitment of target and non-target species (Kaiser et al. 1998). However, no studies have investigated these aspects in the context of the particular aquaculture practises currently being employed in Baynes Sound.

Changes in the composition of intertidal invertebrate communities can have an indirect affect on the growth, survival and utilisation of habitats by foraging species. This effect is especially significant if they are a "protected" or "endangered" species (WGEIM, 2000). This is particularly important in the Pacific Northeast where economically-important fishes feed preferentially on specific taxa of intertidal soft-substrate meiofauna and small macrofauna. These include chum, chinook and coho salmon (Groot and Margolis 1991), which all inhabit shallow nearshore habitats during parts of their lifecycles where they feed on epibenthic harpacticoid copepods, gammarid amphipods, cumaceans, and other species. Smelts, sandlances, some flat fish species and sticklebacks also heavily utilise these habitats, as do many sea birds such as sandpipers and Dunlin. The abundance of prey required for growth and reproduction of fish and birds, during at least parts of their life cycles, may also be limited as a result of aquaculture, as many of these only utilise prey species that are associated with specific microhabitats.

Eelgrass Habitat

Eelgrass beds are an important ecosystem component, and the secondary effects of reduced biomass are likely to have implications for fish (such as spawning herring, and juvenile salmonids) and subsequently for relevant foraging migratory birds. Intertidal eelgrass beds are located throughout Baynes Sound, and in some cases are located within shellfish aquaculture lease areas (Tamasi et al. 1997). There are currently no data on the impact of bivalve culture on eelgrass biomass in Baynes Sound. Studies from elsewhere, however, have demonstrated that declines in eelgrass abundance can be related to modifications caused by shellfish aquaculture practices (Peterson et al. 1987, Rumrill and Christy 1996, in Griffin 1997). Dredging, harrowing and levelling activities related to oyster bottom culture have been shown to impact eelgrass habitat by disrupting surface sediments and destroying shoots, leaves, roots and rhizomes. Effects may vary with the length of time the area has been cultured, but can persist for one (Peterson et al. 1987) or two years following farming (Waddell 1964, in Simenstad and Fresh 1995). Studies on the impacts of near-bottom shellfish culture relate declines in eelgrass abundance to shading, altered patterns of sedimentation and erosion, and direct physical disturbance during placement and harvest (Everett et al. 1995).

Juvenile Salmonids

Baynes Sound is an important area for juvenile salmonids to rear and acclimate to salt water. It is well documented that some species of juvenile salmon occupy estuaries and nearshore marine areas for up to three months before going to sea (Healey 1980, Levings 1994). In particular, these habitats are vital to the survival of chinook, chum and coho juveniles (Simenstad 1982), where they go through the smolting process. They can reside in these locations for up to several months. A survey carried out during 2000 in Baynes Sound, utilising beach and purse seines, documented large schools of chinook and chum smolts rearing close to shore during the months of July and August. By the end of August, these fish had grown significantly before migrating out of the area (Jenkins et al. 2001).

Juvenile salmon rely heavily on epibenthic organisms for food in both the estuaries and transition zones along the Pacific coast (Sibert 1979). Analysis of the diet of juvenile chinook in the transition zone around the Campbell River estuary found that numerically, epibenthic organisms comprised up to 96.7% of their diet (Kask et al. 1988). In the Nanaimo River estuary, juvenile chum grew at an average of ~6%/day and consumed mostly epibenthic harpacticoids, many of which are found in high densities in eelgrass and other vegetation (Healey 1979). In the Fraser estuary, over 80% of the total number of food organisms examined in the chum fry stomachs were harpacticoid copepods (Levings and Nishimura 1997).

Epibenthic and benthic organisms are specific to certain habitat types; sediment type and the presence or absence of vegetation such as eelgrass, *Fucus* sp., *Ulva* sp., and *Enteromorpha* sp. are important factors. For example, several species of harpacticoid copepods, that make up much of the diet of juvenile salmon, are only found in eelgrass beds and in association with other vegetation. In Baynes Sound, the beach culture of clams and oysters necessitates the removal of vegetation and substantially modifies the sediments prior to seeding the area with juvenile clams. The construction of berms and installation of predator exclusion nets further alienates these areas and may trap fish as the tide recedes. Habitat modification and the covering of the substrate with predator exclusion nets may thus adversely impact the production of harpacticoid copepods and other important epibenthic organisms, and hence adversely impact the successful feeding of salmon rearing in the area.

Herring Spawning

In Baynes Sound, a significant threat to Pacific herring is the loss or removal of macrophytes (eelgrass, algae) on which they spawn (D. Hay, DFO, pers.comm.). Pacific herring spawning is restricted to the nearshore or tidally active coastal areas of sheltered inlets, sounds and bays. Spawning occurs in the spring from the high tide zone to 20 m subtidal depth, generally within a 150 m wide strip. Eggs are laid primarily on intertidal and subtidal marine vegetation, but can also be deposited on substrate such as silt-free gravels to which the vegetation is attached (Haegele and Schweigert 1985). Aquaculture impacts on herring in Baynes Sound are of considerable concern given the high habitat sensitivity of the area (Hay and McCarter 2001).

Birds

The importance of the subject area for migratory birds, particularly the intertidal habitats, as described in the studies above, raises concerns about the effects of intertidal shellfish aquaculture on bird populations. Diving ducks and shorebirds are particularly vulnerable to potential deleterious effects of aquaculture operations. Below are potential actions by which aquaculture affects bird populations:

(i) Use of predator exclusion netting

The extent to which beach cover (either predator exclusion netting or dense oyster beds) reduces shorebird and seaduck access to the underlying substrates is not known. Protective netting only provides partial exclusion of diving ducks as the birds are able to, and do, excavate clams from under the edges of netting panels (Dave Mitchell, BC Shellfsh Growers, pers. comm). Even if species are able to access the substrate beneath, beach cover may increase the bird’s energetic costs of foraging, or increase the risk of their predation.

Beach cover may alter benthic invertebrate productivity beneath it. Bendell-Young et al. (2001 submitted) reported that species diversity and bivalve abundance is lower on farmed beaches with predator exclusion netting cover.

Washed-up netting may have a significant potential to entangle and kill migratory birds.

(ii) Disturbances to resident, overwinterers, and migrant birds by human activities

Many birds, and particularly those hunted in parts of their range, avoid close proximity to humans. Birds may habituate, move to nearby areas of the beach, or avoid areas of human activity altogether, and this can adversely affect the energetic demands of seaducks, shorebirds, and other migratory birds. The behavioural interactions, and their physiological consequences, between migratory birds and shellfish culture activities needs to be better understood. Because shorebirds generally exhibit high site fidelity, the potential exists for their exclusion from preferred foraging sites where they overlap with aquaculture sites. On the other hand, hundreds of western sandpipers have been observed resting on oyster rafts adjacent to tidal flats during high tide (W. Heath, pers. obs.).

(iii) Habitat alteration and displacement of traditional food sources

The removal by aquaculture growers of snails and other invertebrate resources that serve as food items for waterbirds may affect waterbird abundances and spatial distributions.

(iv) Loss of critical habitat

At present, there is a relative lack of effectively protected bird habitat for this region, and the critical requirements by wildlife are unknown. MELP submitted an application under the Land Act for designation of Baynes Sound as a Wildlife Management Area (WMA) (Clermont 1995); this WMA proposal, however, was rejected (Clermont, MELP, pers. comm.). Presently there are 92 ha of protected marine intertidal in the Baynes Sound/Courtenay River estuary area (Jamieson and Lessard 2000). Establishment of a provincial WMA with intertidal foreshore/estuary habitat at Coal Creek, Little Bay, Rosewall Creek, and Trent River to Millard Creek is being considered, but whether this is likely to occur, exactly how big it might be, and what habitat the WMA might contain are unknown (T. Clermont, MELP, pers. comm.).

Altered foreshore ecology is most likely to affect those birds feeding on benthic invertebrates in the intertidal zone, where the shellfishery, both wild and cultivated, is most active. Species of most concern include several seaduck species common to BC, including the white-winged scoter (*Melanitta fusca*), surf scoter (*Melanitta perspicillata*), harlequin (*Histrionicus histrioncus*), long-tailed duck *(Clangula hyemalis*) common goldeneye (*Bucephala clangula*) Barrow's goldeneye (*Bucephala islandica*) and bufflehead (*Bucephala albeola*). These ducks consume bivalves, snails, crustaceans such as crabs and shrimp, and a variety of other small benthic creatures (e.g., amphipods, isopods). A summary of diet information is given by Vermeer and Ydenberg (1989). The direct removal of potentially marketable clams by avian (and other) predators is without question of greatest immediate interest to wild harvesters and growers. Conversely, the extensive harvest of potentially consumable clams, and the exclusion of birds by nets and other methods, are potential threats to the health of the avian populations that winter in these waters.

Of particular interest are impacts on the scoters. Scoters are bivalve specialists (mussels and clams) that capture prey by diving to the bottom. They thus have access to intertidal areas only at high tide. Foraging, usually restricted to daytime hours, consists of alternating periods of diving and rest, as the bulky prey quickly fill the gizzard to capacity, and some digestion is needed before the stomach can be refilled. The low energy yield of the whole prey, much of which is shell, means that much of the day must be spent either capturing or processing prey. Most prey are encountered in underwater searches along the bottom, and under, in and around rubble and rocks. Mussels must be wrenched from their strong byssal thread attachments, and like some large crabs (cf. Zaklan and Ydenberg 1997), scoters dig clams from the bottom (Glude 1964). A wintering group of scoters continually churns and turns over sediments. Further, Lacroix (2001) showed that surf scoters were a keystone species that removed large quantities of mussels, which provided space for other species of intertidal invertebrates. The exclusion of scoters as predators by the use of exclusion netting may therefore reduce biological diversity in intertidal habitats.

Restricting the access of sea ducks to the substrate by use of exclusion netting benefits the aquaculture industry directly by reducing clam losses and indirectly by forcing them to prey upon surface-dwelling mussels, which are competitors for food eaten by clams. It may thus be that some bivalve predation by sea ducks is beneficial overall to intertidal clam culture, but the relative dietary importance of clams and mussels to sea ducks and how sea ducks are specifically affected by exclusion netting is not known.

CUMULATIVE EFFECTS ISSUES

In order to assess the cumulative effects of any environmental insult, there are numerous factors that must be considered. In order to determine whether an impact has taken place, before-farming baseline conditions must be known and compared with post-farming conditions, or the latter are compared to appropriate reference sites. Because of the dynamic nature of many intertidal areas, it is often unclear as to whether the extent of disturbance from any activity exceeds that to which biological communities might be normally experiencing and to which they are adapted. There must also be an understanding of the disturbances taking place. As pointed out by others (e.g. Sousa 1984, Simenstad and Fresh 1995), disturbances are not unidimensional. Scales include areal extent, intensity (magnitude), local and regional frequency, predictability, and rotation period. It is important to distinguish between the anthropogenic disturbances previously described in this paper, and natural disturbance regimes such as climatic cycles, storm events, and possible impacts of exotic species or outbreaks of disease (Simenstad and Fresh, 1995). There must also be an understanding of the threshold levels, responses, and recovery times of the environmental impact under consideration. The complex interaction of multiple species, habitats and disturbances on the indicator species also need to be understood. These may include not only direct impacts on the intertidal zone, but also indirect, secondary and synergistic effects. For example, anthropogenic factors from land use activities on the surrounding landscape that may contribute secondary impacts to the cumulative effects of intertidal aquaculture in Baynes Sound include:

- changes in water quality from terrestrial land use, increased nutrient loads from fertilisers and pesticide contamination from agriculture, increases in turbidity related to increases in erosion from forestry impacts;
- increased faecal coliform levels from both agriculture and residential septic systems, and also birds and marine mammals, especially sea lions which is a contamination concern in localised areas of the sound, e.g. haulouts in Fanny Bay and Mud Bay in spring during herring season; and

- changes in freshwater input through altered hydrologic regimes from dams and reservoirs, changes in runoff due to altered land cover by forestry and urban development (stormwater runoff) and so on.

ONGOING AND PROPOSED FUTURE RESEARCH

RELEVANT STUDIES AND INFORMATION SOURCES IN BAYNES SOUND

Various government agencies, NGOs, and the shellfish aquaculture industry are either mandated or have recognised the need for integrated resource management to minimise the impacts of human disturbance on marine ecosystems (LUCO 2000, *Oceans Act*). In 1995, the Baynes Sound Round Table on Water Quality (BSRT) was initiated after contamination of shellfish beaches in 1994 lead to widespread closures. The round table is made up of representatives from the shellfish industry, local governments, citizens' groups, non-profit organisations and government agencies, which worked to identify pollution sources and find ways to reduce them through information, education and action. Working towards this goal on behalf of BSRT, the Comox Valley Project Watershed Society (Project Watershed) has initiated a State of the Sound Geographic Information Systems (GIS) Project. The project has just completed Phase 1, collecting a number of inventories and digital data sets to be incorporated into a GIS to aid in the long-term management of Baynes Sound (Joughin and Lau 2001). On a more localised scale, Fisheries and Oceans Canada is working on the Courtenay River Estuary Management Plan (CREMP), to protect the endangered salmon stocks of the Courtenay/Puntledge watershed. Volume 3 of CREMP is an environmental resource inventory that presents the most recent documentation of plant, fish and wildlife descriptions for the estuary (ECL 2000). The Baynes Sound Round Table is taking responsibility for an integrated water quality monitoring program and the preparation and implementation of a co-ordinated environmental emergency response plan for episodic spills in the estuary, as part of CREMP. To improve access to relevant data regarding marine foreshore and estuary habitats in the Strait of Georgia, the DFO Marine Foreshore Fish Habitat Assessment Project produced a spatial database of references including information on Baynes Sound.

OTHER STUDIES ON ENVIRONMENTAL IMPACTS OF SHELLFISH AQUACULTURE

In 2000, the Aquaculture Association of Canada conducted an industry survey of aquaculture-related research and development priorities (AAC 2000). A greater understanding of the interaction between cultured shellfish and the natural environment was identified as a priority, including both wild populations and biofouling organisms. The need for monitoring protocols to measure environmental variables such as currents, oxygen, sedimentation, nutrients, and faecal wastes was identified for the long-term development of an approach towards carrying capacity issues.

Carrying capacity modelling of ecosystem impacts from aquaculture have been developed for finfish (e.g. Hargrave 1994) and shellfish aquaculture (e.g. Gangnery et al. 2001; Smaal et al. 2001), and there are currently three shellfish aquaculture carrying capacity modelling projects taking place on the Pacific coast. However, the Lemmens Inlet Test Study, the Okeover Inlet

Study, and the Productive Capacity Study of Gorge Harbour near Cortes Island are focussing on suspended oyster culture, and not intertidal bottom culture of shellfish at this time (W. Heath and S. Cross, pers.comm.).

CWS is implementing a 4-5 year study, commencing 2001, in Baynes Sound. This study will include weekly surveys in the Sound and in reference areas. Surveys will determine bird abundance, distribution, and seasonal patterns of use. A comparative analysis with previous survey studies will be undertaken. The study will map habitat types, aquaculture sites, habitat productivity, as well as historical changes. To assess the relationship between birds and habitat, radio telemetry will be used to help understand bird movements, time budgets, and habitat use. An important deliverable of this study will be to evaluate the culture industry's impacts, positive and/or negative, on migratory birds.

In addition, CWS, in conjunction with SFU, has submitted applications for research grant from NSERC and the Marine Ecosystem Health Program to evaluate effects of the shellfish industry on scoter populations. The overarching questions in the proposed research include:

(1) Are scoter populations limited by available space or food in winter, which will be reduced as a result of shellfish operations?
(2) What aspects of foraging ecology are potential mechanisms leading to population limitation?

The research approach is proposed to include assessment of scoter distribution and abundance, movements and foraging behaviour, trophic interactions of scoters and intertidal clams, scoter survival rates, and correlates of scoter distribution. The data will be critical for:

(1) Documenting any positive or negative effects of current levels of shellfish aquaculture on scoter populations;
(2) Predicting cumulative and regional effects of proposed industry expansion; and,
(3) Providing recommendations for shellfish industry activities that are most benign for bird populations.

KNOWLEDGE GAPS

McCann (2000) in a recent review on the "diversity-stability debate" concluded that biological diversity is positively related to ecosystem stability. The current scale (almost all of the harvestable bivalve habitat) of intertidal shellfish aquaculture practices, which purposely reduces species richness, can thus be expected to decrease stability of the natural intertidal ecosystem. Like other natural resource-based industries, economic yield depends on an ecosystem that can provide such services as nutrient cycling to maintain its productivity. The marine environment is not as closed as the terrestrial environment, since currents can bring in nutrients and plankton that originated elsewhere. Nevertheless, it has been shown elsewhere (e.g., mussel culture in Spanish rias) that intensive bivalve aquaculture can be conducted at such a large scale that the growth rates of individual cultured bivalves are reduced and that the economic viability of culture operations furthest away from the source of water exchange may be negatively affected.

Current aquaculture practices in Baynes Sound may already be undermining ecosystem integrity, and changes may negatively be affecting bivalve aquaculture.

Regions of the intertidal most suitable for shellfish aquaculture may also be key bird habitat (Vermeer and Butler 1989). Predator exclusion nets restrict access of shore birds and sea ducks to the intertidal region, possibly during key periods of their life histories (e.g., pre and post-breeding, migration). This has the potential to have significant negative consequences to existing populations, particularly to those species for which Baynes Sound has already been identified as particularly important.

We know it is also important fish habitat. Studies are therefore needed to ensure that bivalve culture activities are not at cross-purposes to finfish stock enhancement activities, with the combined result being a wasting of scarce resources.

We suggest consideration be given to addressing the following scientific issues as soon as possible (arbitrary order):

i) Interactions between the different species of birds and car-cover (on foraging, effects of fouled nets etc);

ii) Predator relationships, particularly with respect to non-commercial invertebrates (e.g. sea stars) - general interactions, the effectiveness of predator removal, the effects of predator removal on the ecosystem, disposal of the predators & its effects, etc.;

iii) Impacts of aquaculture related 'traffic' - trucks and ATVs on the beach and through the saltmarshes and eelgrass, boats (e.g. through eelgrass) and foot-traffic;

iv) Interactions between car cover and the subsequent trapping of sediments, and the particular impacts on invertebrate species on which fish (in particular salmonids) feed;

v) The overall scale, or percentage, of Baynes Sound habitats that has been alienated or modified by intertidal aquaculture practices. The socially desirable level is obviously a balancing of competing values, but the ecosystem consequences associated with an increasing percentage of alienated habitat should be documented and understood by all; and

vi) The cumulative ecosystem effects of deepwater sites, especially when considered along with intertidal culture in Baynes Sound (e.g. the impacts on birds from overall aquaculture-related activity), as the area under suspended culture is also being simultaneously expanded. This could perhaps be associated with a carrying capacity assessment of bivalve aquaculture in the intertidal zone in Baynes Sound.

RECOMMENDATIONS

1. A multi-agency research initiative, involving Environment Canada avian researchers, DFO marine invertebrate and fish experts, the Geological Survey of Canada and Canadian Hydrographic Service, WLAP wildlife managers, and BCMAFF aquaculture managers, should be established as soon as possible to identify both the nature of existing and potential future impacts and, where necessary, how they can be minimised.

Intertidal bivalve culture, because of its intensity and its habitat modifications, has an environmental impact. At issue is the scale of this impact on the natural system, and whether shellfish culture expansion would have an unacceptable ecological impact on the overall ecosystem. There are no studies that address these issues. Avian species in particular are frequently alienated from habitats by human activity, including shellfish aquaculture. These adverse effects may also influence enhanced salmon stocks. Similarly, coastal geological processes may be being affected by landscape modifications.

2. An effective network of protected areas in Baynes Sound that exclude shellfish culture should be established. The network should include sensitive habitats and key bird habitat.

The lack of aquaculture impact studies in Baynes Sound renders opinions on ecological effects of aquaculture speculative. However, lack of data should not mean that resource management decisions should not be made. Potential risks are unknown but possibly substantial. Decisions should be made in line with DFO's adoption of a precautionary approach in ecosystem management. One decision might be that an effective network of protected areas be established that preclude aquaculture. Protected areas of an appropriate scale are essential to serve as both reference sites for future research studies and as "insurance" areas to ensure that elements of the natural ecosystem are being conserved. Adaptive management would be required, since what constitutes an "effective network" of appropriate marine protected areas is not presently known.

3. The significance of Baynes Sound in the Georgia Basin ecosystem appears not to have been recognised by resource managers to date. Potential adverse impacts from intertidal shellfish aquaculture in this broader context need to be identified and mitigative actions, where appropriate, implemented. Ocean management in Baynes Sound should be considering intertidal aquaculture both as an economic asset and as an ecological disturbance that may be negatively influencing important ecosystem processes (i.e., productivities of other important species).

Areas with a broad intertidal zone are often associated with estuaries because of the riverine discharge of sediments. However, in parts of the Strait of Georgia and Puget Sound, they are also associated with past glacial deposits of sedimentary material. The Baynes Sound area is the largest such latter area in the Strait. It has a unique natural ecosystem with a large number of intertidal invertebrates that make it an important avian staging area during migrations. This critical ecosystem role, needs to be reflected in management plans.

4. With increasing bivalve culture in Baynes Sound, the overall carrying capacity of the system with respect to phytoplankton production and its removal by filter-feeders needs investigation, both with respect to annual and /seasonal fluctuations.

Trying to culture more individuals than the ecosystem can support would benefit neither the aquaculture industry nor other ecosystem elements. At some locations, mussel culture in Europe has exceeded carrying capacity. Scientific information is required to determine the Sound's carrying capacity for culture in relation to other important species and ecological processes.

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Table 1. Species reported in the DFO/ BCF FISS (Fish Information Summary System) database for the Baynes Sound watersheds

Gazetted Name	**ACT**	**CH**	**CM**	**CO**	**CT**	**DV**	**KO**	**PK**	**RB**	**SK**	**ST**
Sandy Creek	x		x	x							
McNaughton Creek	x		x	x	x						x
Rosewall Creek	x		x	x	x						x
Waterloo Creek	x		x	x	x						x
Wilfred Creek	x		x	x	x			x			x
Cowie Creek			x	x	x			x	x		x
Tsable River			x	x	x			x	x		x
Hindoo Creek	x			x							
Hart Creek			x	x	x						x
Trent River	x		x	x	x			x	x		x
Roy Creek	x		x	x	x						
Millard Creek	x		x	x	x			x			x
Courtenay River	x	x	x	x	x	x	x	x	x	x	x
Brooklyn Creek				x							

<u>Species Codes</u>
ACT – anadromous cutthroat trout (*Oncorhynchus clarki*, formerly *Salmo clarki*)
CH – chinook salmon (*O. tshawytscha*)
CM – chum salmon (*O. keta*)
CO – coho salmon (*O. kisutch*)
CT – cutthroat trout, general (*O. clarki*, formerly *Salmo clarki*)
DV – Dolly Varden char (*Salvelinus malma*)
KO – kokanee (*O. nerka*)
PK – pink salmon (*O. gorbuscha*)
RB – rainbow trout (*O. mykiss,* formerly *Salmo gairdneri)*)
SK – sockeye salmon (*O. nerka*)
ST – steelhead trout (*O. mykiss,* formerly *Salmo gairdneri*)

Table 2. Species of birds, season at which they are present in the area, the approximate percentage of the population, the significance at the global, continental, or national level, and the provincial status for the Baynes Sound IBA
(from Booth 2001).

Species/Groups Meeting IBA Criteria	**Season[1]**	**Number[2] (1 day peak)**	**Approximate % of Population[3]**	**Significance[6]**	**Provincial Ranking[4]**	**National Ranking[5]**
Pacific Loon	W	1,005	2.0 (NA)	G		
Western Grebe	W	10,356	8.6 (W)	G	Red	
Great Blue Heron (ssp. Fannini)	S	136	1.4 (NA)	C	Blue	
Pelagic Cormorant	B/W	141 pairs, 263	2.0 (CDN)	N		SC
Brant	SM	5,291	4.0 (NA)	G		
Trumpeter Swan (Pacific population)	W	179	1.1 (NA)	C	Blue	
Mew Gull	W/SM	1,256	2.5 (NA)	G		
Glaucaus-winged Gull	W	6,250	3.5 (NA)	G		
Thayer's Gull	W	257	2.6 (NA)	G		
Black Turnstone	W	3,093	4.0 (W)	G		

1 W=Winter, S=Summer, B=Breeding, SM=Spring Migration
2 Numbers: Bird numbers from BSC (2001)
3 Importance: Percentages from the BSC (2001); W - % of world population, NA - % of North American population (of species if G, or of subspecies/flyway etc if C); CDN - % of Canadian population
4 Red = threatened or endangered, Blue = vulnerable
5 SC = Species of Concern
6 G = global (1% of global population or 1% of North American population); C = Continental (1% of subspecies or flyway population); N = National (1% of Canadian population)

Table 3. 1980 – 1981 Migratory Bird Surveys – Partial Summary of Results for the Baynes Sound / Comox Harbour area.
(from Dawe et al. 1998)

Species Group	Number of Bird Species within each Group	Principle Species[1]	Peak Number[2]	Cumulative Total[3] and % of Group Total[4]	Shorezone Unit(s) with most Birds[5]
Loons	4	PALO	1005	4779 (59%)	43-47
Grebes	5	WEGR	10,356	96142 (94%)	40-47
Cormorants	3	PECO	263	2893 (73%)	47
Herons	1	GBHE	136	2359 (100%)	21,48
Swans	2	TRUS	179	1089 (~100%)	16-22,37-44,47
Geese	4	BRAN	5291	19168 (94%)	23-25,28,36,41-45,47,48
Dabbling Duck	9	AMWI MALL	2254 2001	33109 (46%) 31560 (44%)	21 21
Diving Ducks	16	WWSC SUSC GRSC	2436 1847 2265	47666 (20%) 30777 ((13%) 27313 (11%)	12-13,23-48 31-11,23,39-48 13,1936-45,47-48
Shorebirds	19	BLTU DUNL	3093 2020	12504 (31%) 10560 (26%)	28 48
Rails, Coots and Cranes	3	AMCO	112	844	13-20
Gulls	10	GWGU MEGU BOGU	6250 1256 1301	54908 (44%) 14114 (11%) 13281 (11%)	23,41 21-23,41-43 19-23,39-43
Alcids	3	COMU	138	822 (59%)	

[1]See Appendices for bird check-list.
[2]Single day peak numbers for principle species
[3]Cumulative total (ie total number) for principle species over study period
[4] Principle species proportion (%) within species group
[5]Shorezone bird counts for principle species

Table 4. Habitat classification for the Fanny Bay / Little Bay study area (from Dawe et al. 1995)

Habitat Unit	Name	Habitat description
1	Subtidal	Subtidal and deep water marine areas beyond entrance to Fanny Bay
2	Intertidal Flats	Primarily unvegetated intertidal mud and sand flats with some green algae. *Salicornia* grows along the high fringe and *Fucus* in rocky areas.
3	Intertidal Marsh North	Upper intertidal marsh with *Distichlis spicata*, *Scirpus maritimus*, *Salicornia Virginica* and *Triglochin maritimum*. Estuarine brackish marsh with *Carex lyngbyei*, *Scirpus americanus*, *Agrostis spp*. and *Deschampsia spp*.
4	Freshwater Marsh	Cattail *(Typha latifolia)* marsh adjacent to a sedge marsh, grasslands, woodland swamp of Skunk Cabbage, Red Alder, Cottonwood and *Spirea spp*.
5	Intertidal Marsh East	A wet grassy meadow in transition (since 1988) to a brackish intertidal marsh community that includes a sedge marsh with *Carex obnupta*, *Eleocharis palustris* and *Scirpus maritimum*.
6	Intertidal Marsh South	Estuarine marsh habitat made brackish by springs feeding into Little Bay.
7	Forest	Second growth forest with stands of Red Alder, Cottonwood, Douglas Fir, Western Red Cedar and Big-leaf Maple; Salmonberry, Sword Fern and Skunk Cabbage dominate the understorey. The unit includes grassland, creek and woodland swamp habitats.

Table 5. 1990 - 1991 Migratory Bird Surveys – Partial Summary of Results for the Fanny Bay /Little Bay wetlands, Vancouver Island
(from Dawe et al. 1995)

Species Group	Number of Bird Species within each Group	Principle Species[1]	Peak Number[2]	Cumulative Total[3] and % of Group Total[4]	Principle Habitat Unit(s) Utilized[5]
Loons	2	COLO	11	76 (84%)	1,2
Grebes	4	WEGR	60	428 (84%)	1
Cormorants	3	PECO	15	96(25%)	2
		DCCO	17	77 (20%)	2
Herons	1	GBHE	10	106 (100%)	3,6
Swans	1	TRUS	22	142(100%)	3
Geese	1	CAGO	22	142 (100%)	2
Dabbling Duck	9	AMWI	374	2252 (38%)	3,2,6
		GWTE	210	1630 (27%)	5,3
		MALL	151	1291 (22%)	2,3,6
Diving Ducks	12	SCAUP[6]	550	5372 (45%)	2,1,3
		WWSC	140	2429 (21%)	2,1,3
		SUSC	135	1178 (10%)	2,1
Shorebirds	19	DUNL	220	732 (32%)	2,5
		WESA	280	430 (19%)	3,5
Gulls	4	MEGU	56	559 (36%)	2,3
		BOGU	87	298(19%)	2,1,6
Alcids	2	PIGU	-	4 (67%)	1,2

[1]See Appendices for bird check-list.
[2]Single day peak numbers for principle species
[3]Cumulative total (i.e. total number) for principle species over study period
[4] Principle species proportion (%) within species group
[5]see Table 4 for definitions of habitat units
[6]Scaup species were reported primarily as ‘Scaup species’

Table 6. Average number of diving ducks (± SE), shorebirds, and offshore species seen between 1978 and 1985 in ten Christmas Bird Counts[1] conducted annually for Deep Bay and Comox. The shorebirds listed were associated with rocky shores, whereas the pelagics were associated with deeper water areas. (n=8)
(from Savard 1987)

Species	Deep Bay	Comox
Ring-necked Duck	3 ± 2	4 ± 1
Canvasback	-	5 ± 2
Greater Scaup	1359 ± 138	804 ± 113
Lesser Scaup	22 ± 15	31 ± 6
Common Goldeneye	441 ± 37	394 ± 36
Barrow's Goldeneye	54 ±10	79 ± 11
Bufflehead	459 ±38	378 ± 28
Oldsquaw	59 ± 19	157 ± 25
Harlequin Duck	400 ± 73	235 ± 31
White-winged Scoter	1535 ± 122	1081 ± 92
Surf Scoter	1296 ± 126	1090 ± 94
Black Scoter	602 ± 87	434 ± 68
Hooded Merganser	9 ± 2	10 ± 3
Common Merganser	86 ± 7	194 ± 64
Red-breasted Merganser	49 ± 6	124 ± 23
Ruddy Duck	0	-
American Black Oystercatcher	12 ± 4	0
Black Turnstone	204 ± 60	794 ± 467
Surfbird	0	1 ± 1
Rock Sandpiper	0	0
Western Grebe	4926 ± 1632	1655 ± 1632
Common Murre	58 ± 19	58 ± 966
Pigeon Guillemot	5 ± 1	3 ± 2
Marbled Murrelet	4 ± 1	6 ± 3
Ancient Murrelet	0	0

[1]Source: American Birds 1976-86, Vols. 29(4), 30(4), 31(4), 32(4), 33(4), 34(4), 35(4), 36(4), 37(4), 38(4), 39(4).

Table 7. Summing of one-day maximum numbers of each bird species observed in the Trent River estuary, 1987. Numbers in parenthesis are species totals for each group (from Brooks et al. 1994)

Species		Numbers of Birds
Loons (3)		19
Grebes (3)		33
Cormorants (2)		10
Swans (1)		9
Geese (2)		478
Ducks		
Dabblers (6)	779	
Divers (13)	908	
Total Ducks (19)		1687
Gulls and Terns (7)		1563
Alcids (1)		3
Herons (1)		10
Shorebirds (13)		1469
Raptors (9)		59
Woodpeckers (4)		13
Passerines (52)		1744
Others (7)		
Ring-necked Pheasant		1
Sandhill Crane		4
Rock Dove		3
Band-tailed Pigeon		22
Vaux's Swift		11
Rufous Hummingbird		9
Belted Kingfisher		6
	Total	**7153**
Total Number of Species 124		

Table 8. Wild Clam Landings (t), days fished and number of licenses fished for Clam Area D*, 1990-2000. Landings data from plant hails.
† = license limitation in effect

Year	Manilas and Littlenecks	Butters	Total	Days Fished	No. of Licenses
1990	454	n/a	n/a	29	516
1991	354	n/a	n/a	12	598
1992	315	n/a	n/a	10	436
1993	227	n/a	n/a	6	533
1994	272	n/a	n/a	6	568
1995	159	n/a	n/a	3	714
1996	162	n/a	n/a	4	405
1997	71	19	90	2	503
1998	173	18	191	8	196†
1999	147	14	161	8	174†
2000	111	14	125	5	181†

Table 9. Wild Clam Landings (t) from PFMA 14*, 1985-1999. Data from sales slips.

Year	Manilas	Littlenecks	Mixed Steamers	Butters	Total
1985	297.4	53.5	36.9	38.7	426.5
1986	375.4	104.4	19.9	30.8	530.5
1987	898.7	66.6	5.8	33.5	1,004.6
1988	749.2	24.4	6.0	9.8	789.4
1989	441.4	23.4	1.8	7.8	474.4
1990	313.8	85.6	45.3	42.9	487.6
1991	252.6	53.7	5.9	32.8	345.0
1992	258.0	27.8	1.1	29.5	316.4
1993	312.0	53.6	2.1	9.1	376.8
1994	322.3	35.6	0.5	9.1	367.5
1995	220.4	15.5	0.0	6.0	241.9
1996	122.6	0.9	0.0	3.5	127.0
1997	170.4	4.3	0.4	25.2	200.3
1998	196.9	9.1	1.0	7.2	214.2
1999	130.1	9.5	2.0	12.9	154.5

* Note: Wild clam harvest statistical areas are not coincident with the Baynes Sound study area. Data in Tables 8 and 9 may include beaches outside of the study area.

Table 10. DFO – BC Fisheries Aquaculture Production Statistics 1986-1999 (http://www.ncr.dfo.ca/communic/statistics/aquacult/Aqua_E.htm; BC Fisheries 2001).
A. Cultured Oyster Production in British Columbia and Baynes Sound.
B. Cultured Clam Production in British Columbia and Baynes Sound. na = not available

A.

Year	British Columbia		Baynes Sound	
	Volume (t)	Value ($\$10^{-3}$)	Volume (t)	Value ($\$10^{-3}$)
1986	2864	2515	na	na
1987	3482	2548	na	na
1988	3701	2726	na	na
1989	3721	2938	na	na
1990	4076	3200	na	na
1991	4482	3465	na	na
1992	4484	3572	na	na
1993	4758	4000	1230	857
1994	4990	4566	1722	1263
1995	5260	5355	1713	1750
1996	5480	5659	1618	1686
1997	3650	3917	1656	1896
1998	5500	4900	1659	1692
1999	5800	6000	1842	2123

B.

Year	British Columbia		Baynes Sound	
	Volume (t)	Value ($\$10^{-3}$)	Volume (t)	Value ($\$10^{-3}$)
1986	7	14	na	na
1987	25	43	na	na
1988	30	59	na	na
1989	31	96	na	na
1990	47	130	na	na
1991	169	556	na	na
1992	308	1003	na	na
1993	347	1162	154	528
1994	542	1894	333	1066
1995	885	3885	356	1337
1996	979	4427	383	1626
1997	649	2902	389	1730
1998	704	3619	362	1782
1999	900	3800	463	2516

COLOR FIGURES AVAILABLE ON INTERNET

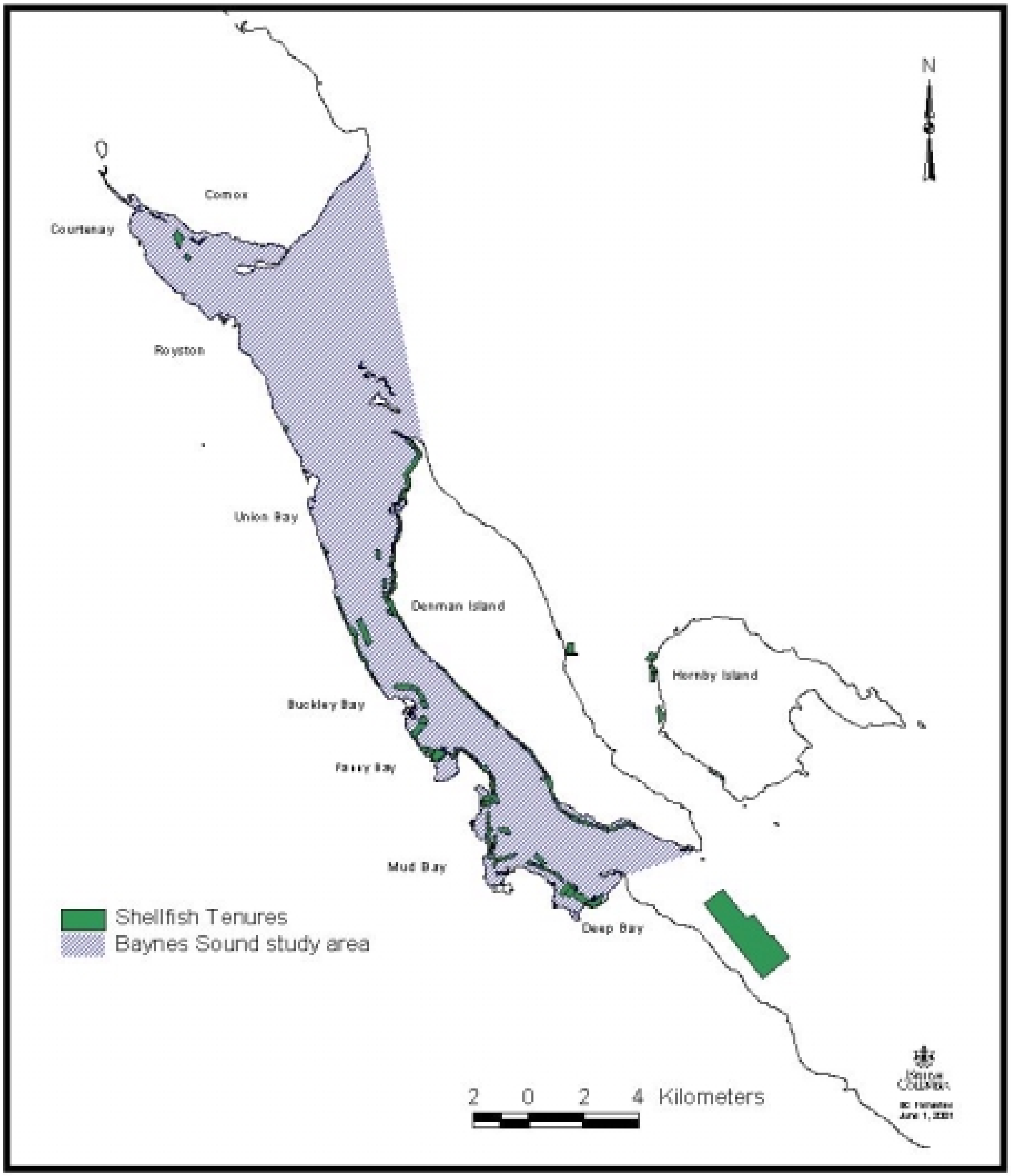


Figure 1: Baynes Sound Study Area

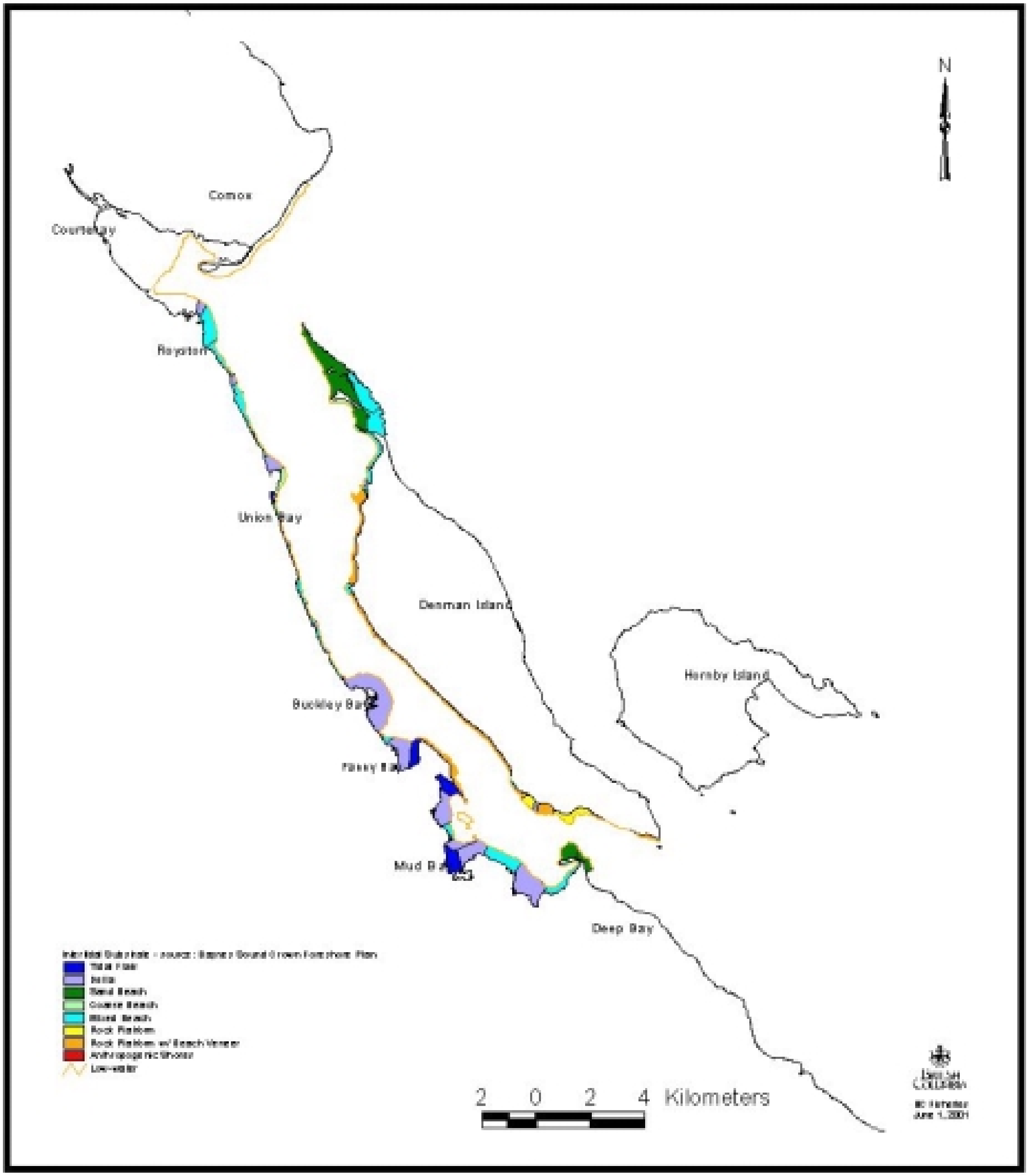


Figure 2: Baynes Sound Intertidal Substrate Classification

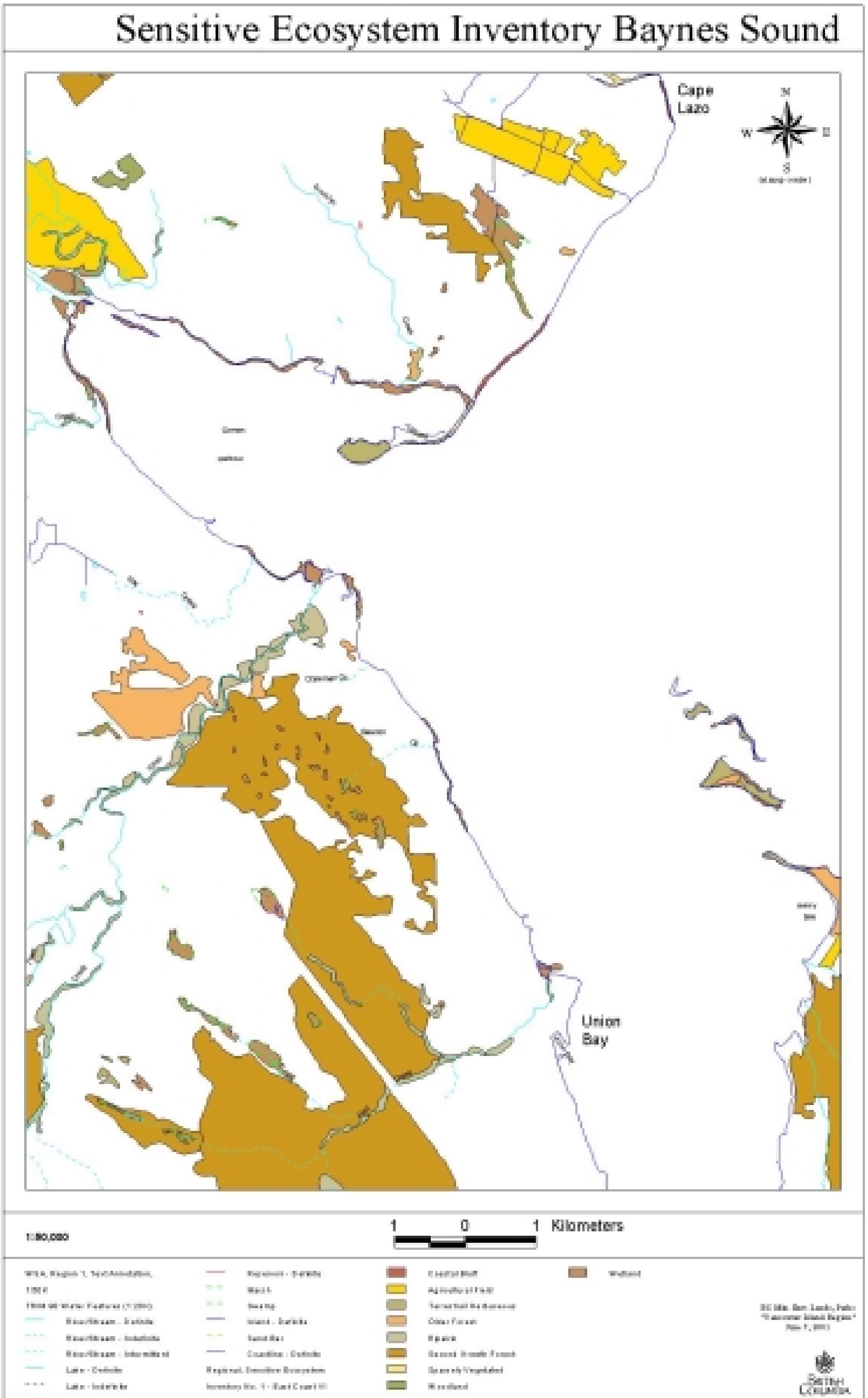


Figure 3a: Sensitive Ecosystem Inventory of Baynes Sound

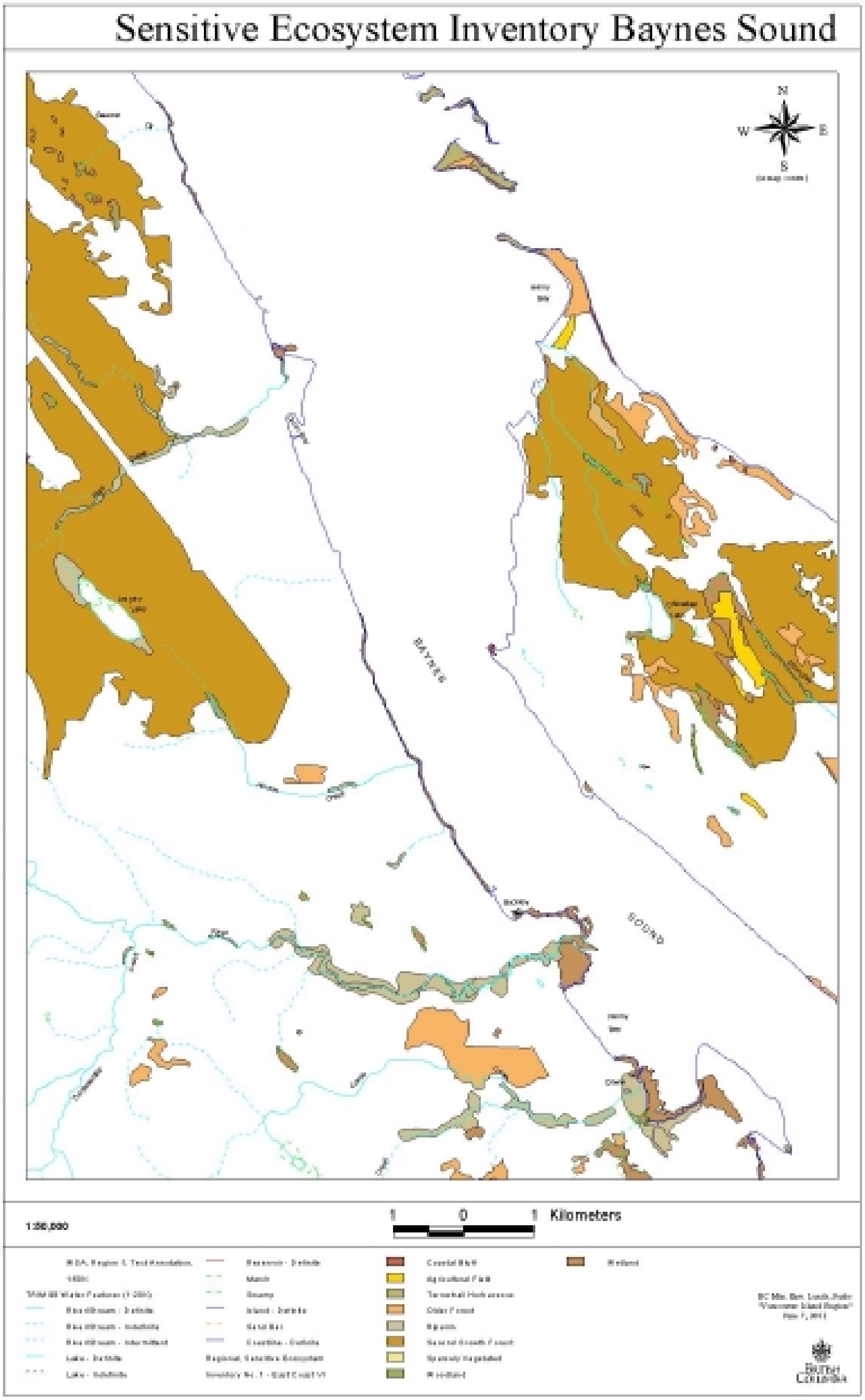


Figure 3b: Sensitive Ecosystem Inventory of Baynes Sound

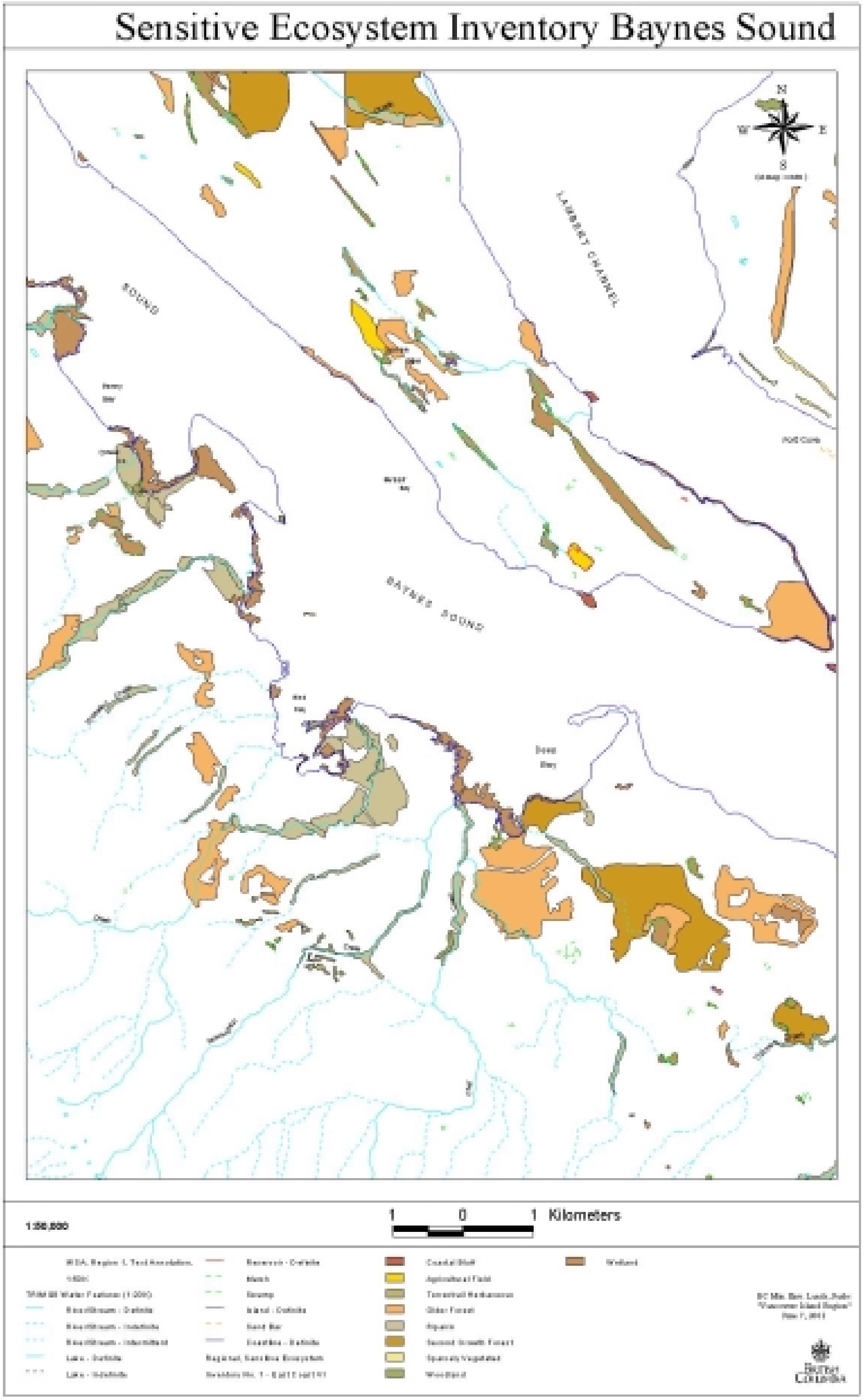


Figure 3c: Sensitive Ecosystem Inventory of Baynes Sound

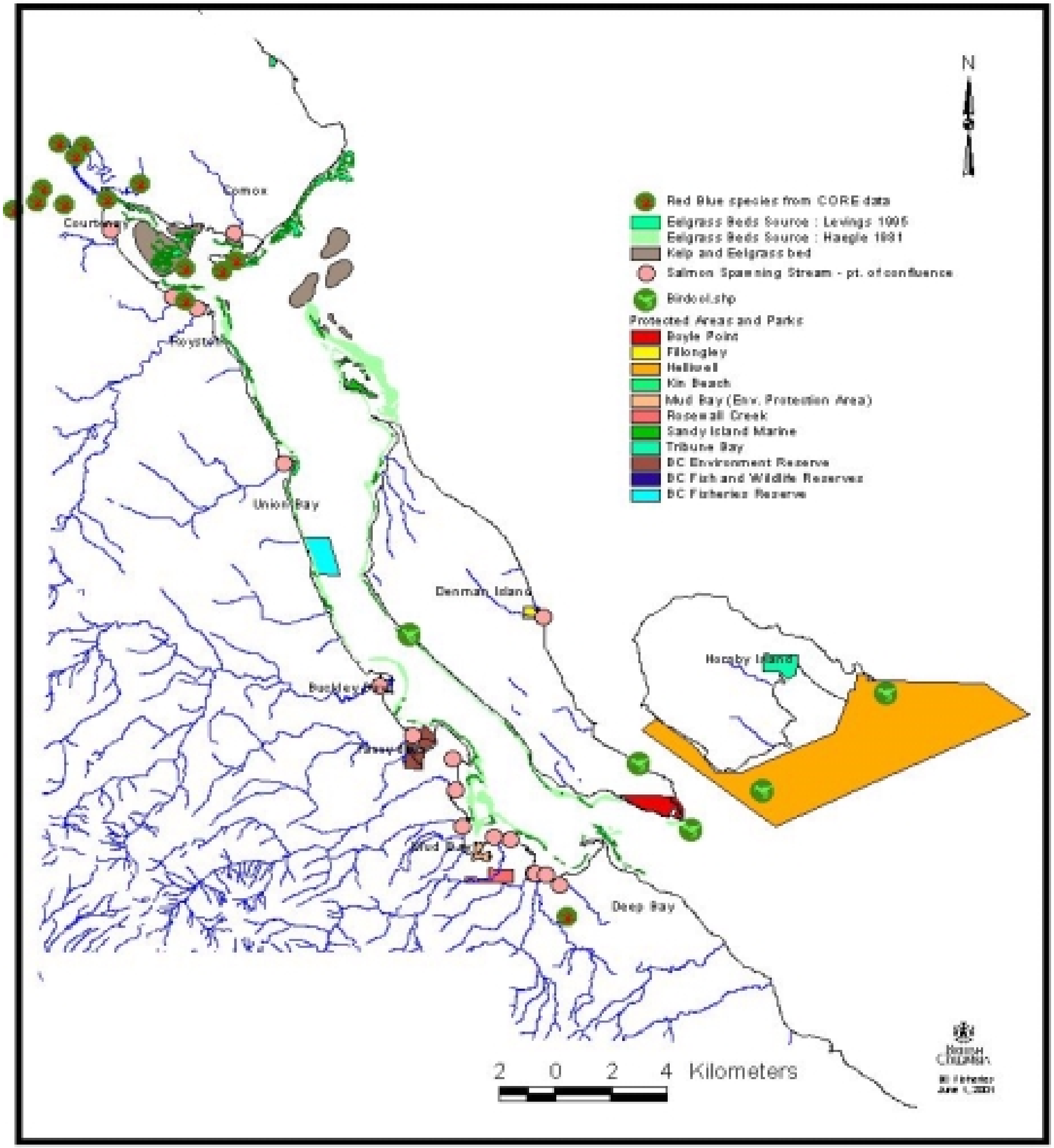


Figure 4: Baynes Sound Protected Areas and Natural Resources

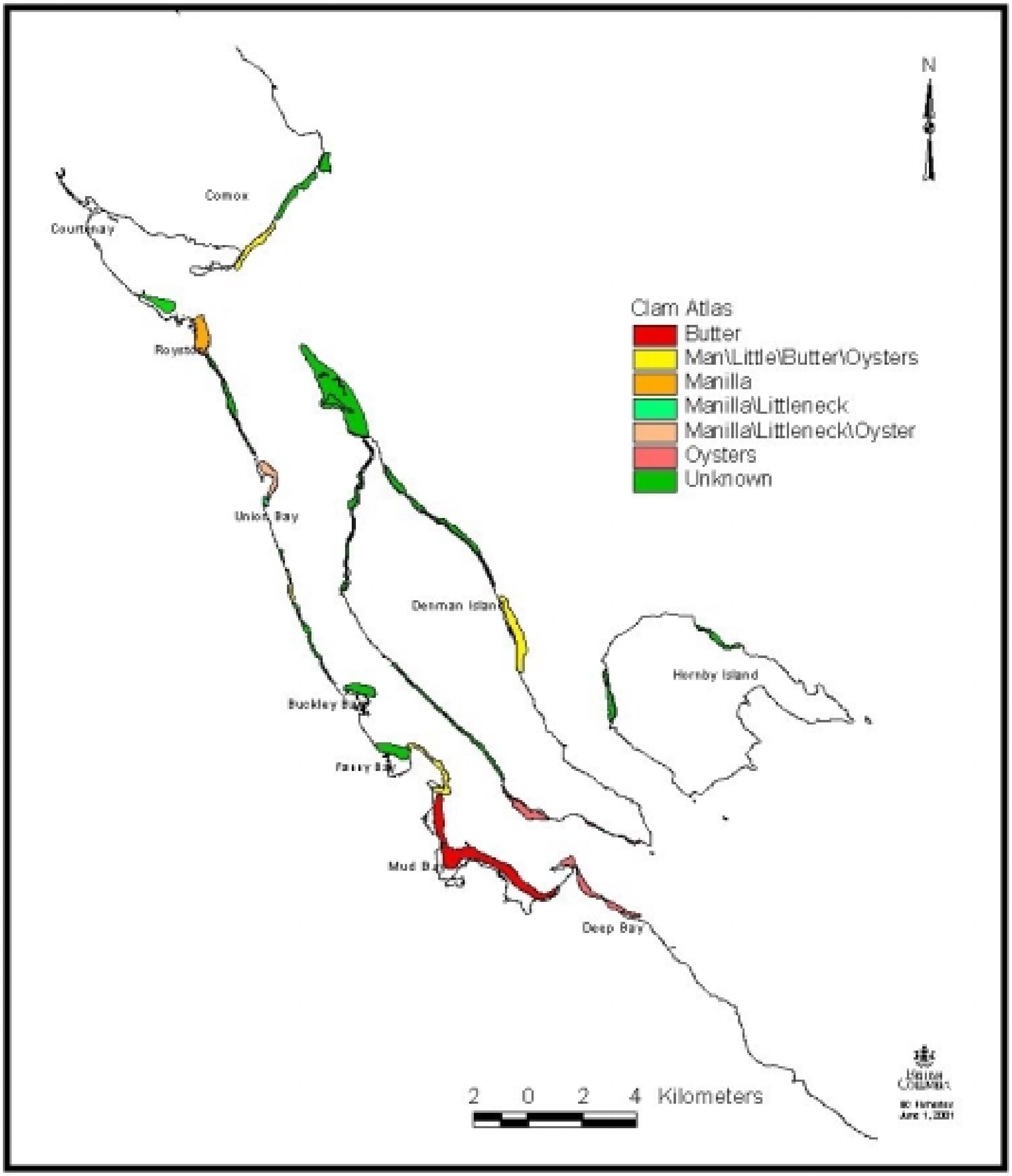


Figure 5: Baynes Sound Clam Atlas Data

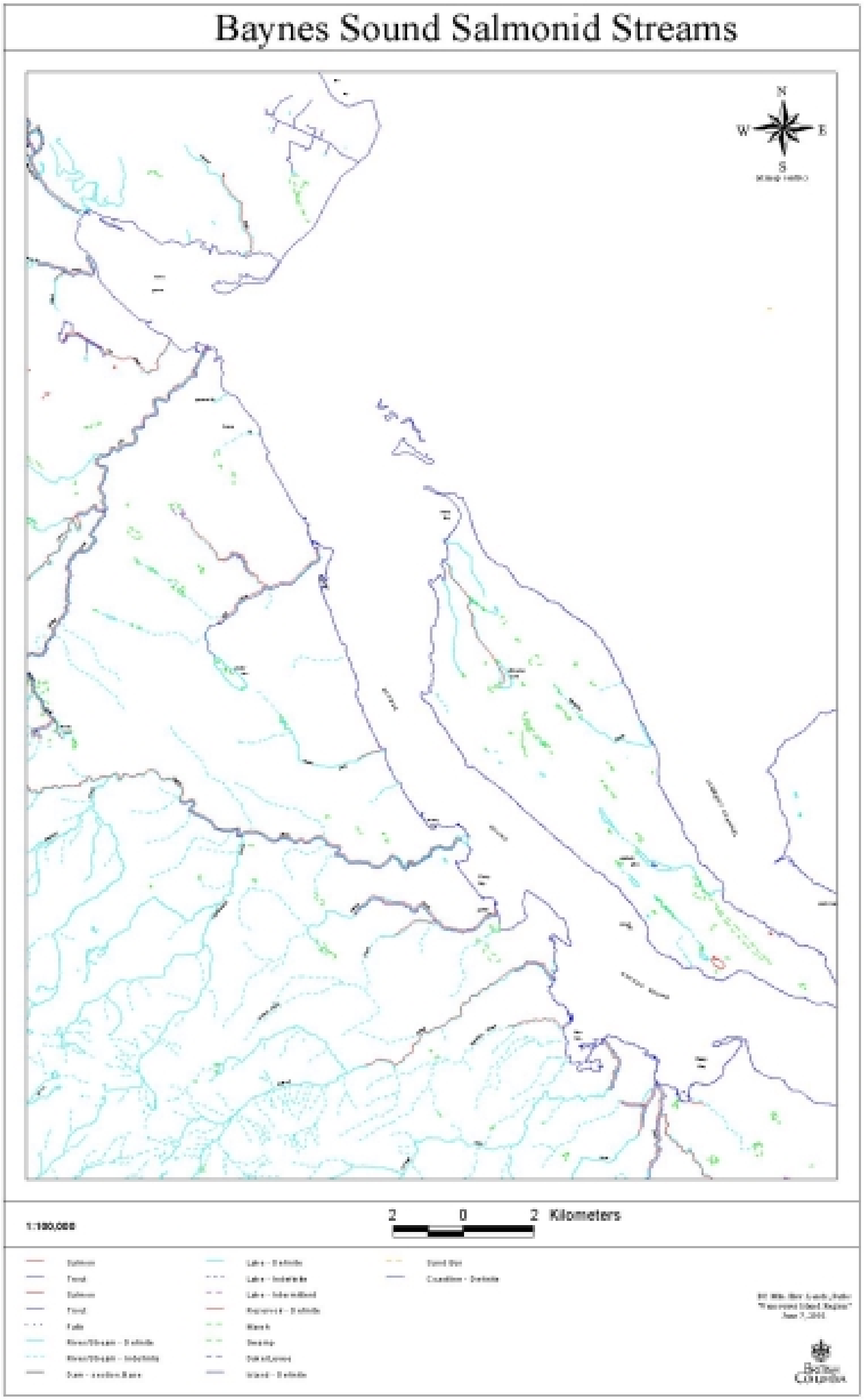
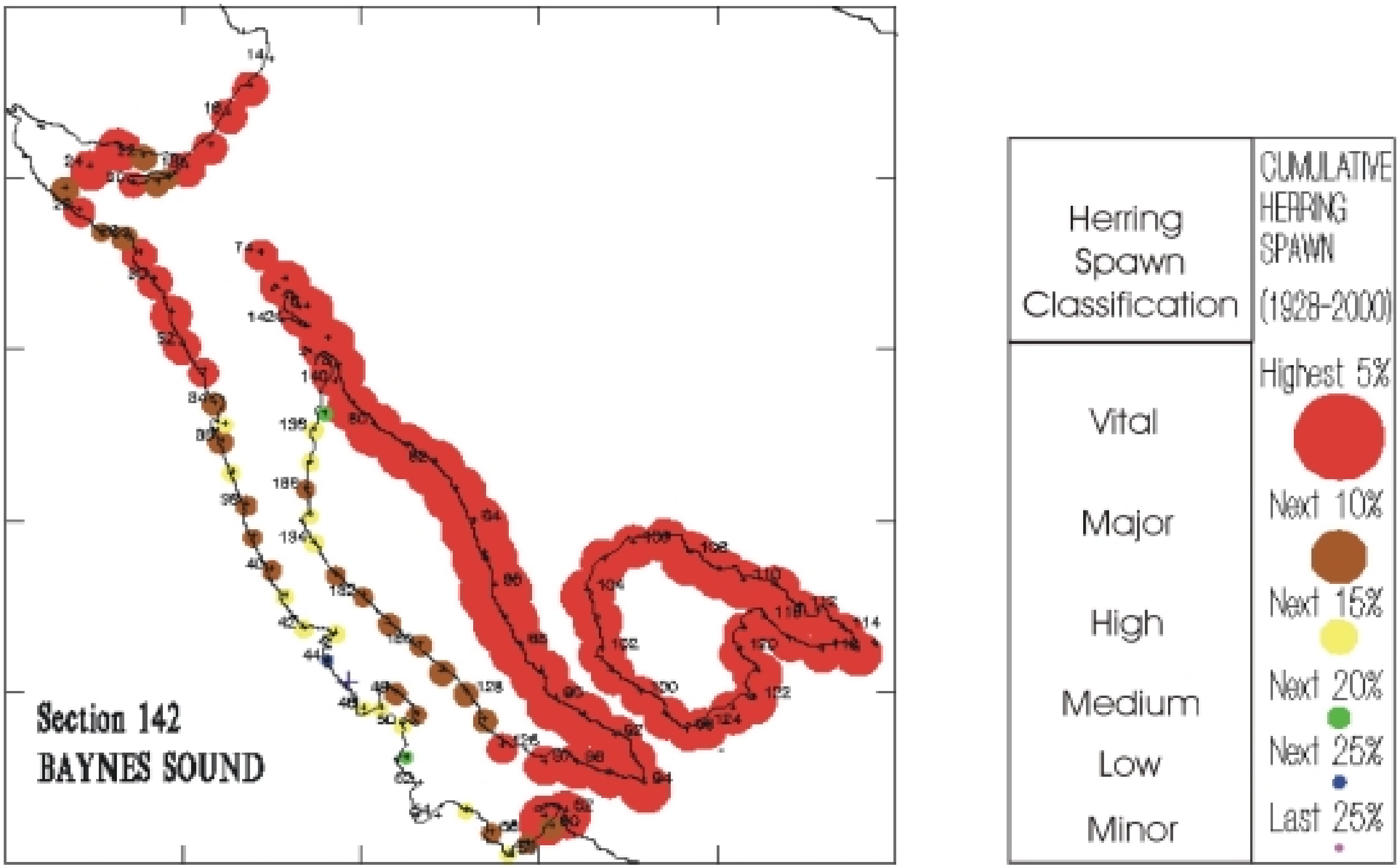


Figure 6: Salmonid streams draining into Baynes Sound



(after Hay and McCarter 2001)

Figure 7: Herring spawn habitat sensitivity map

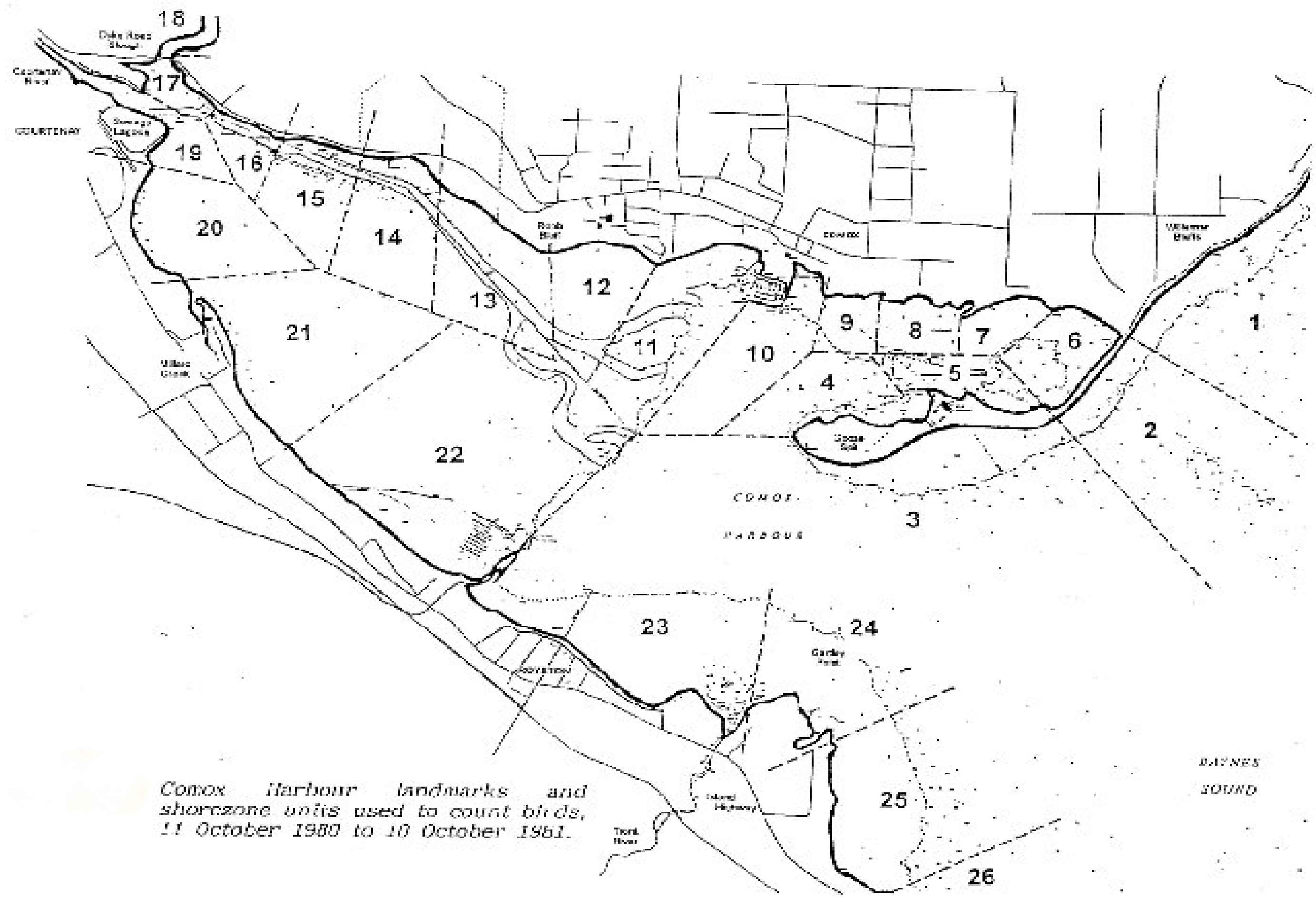
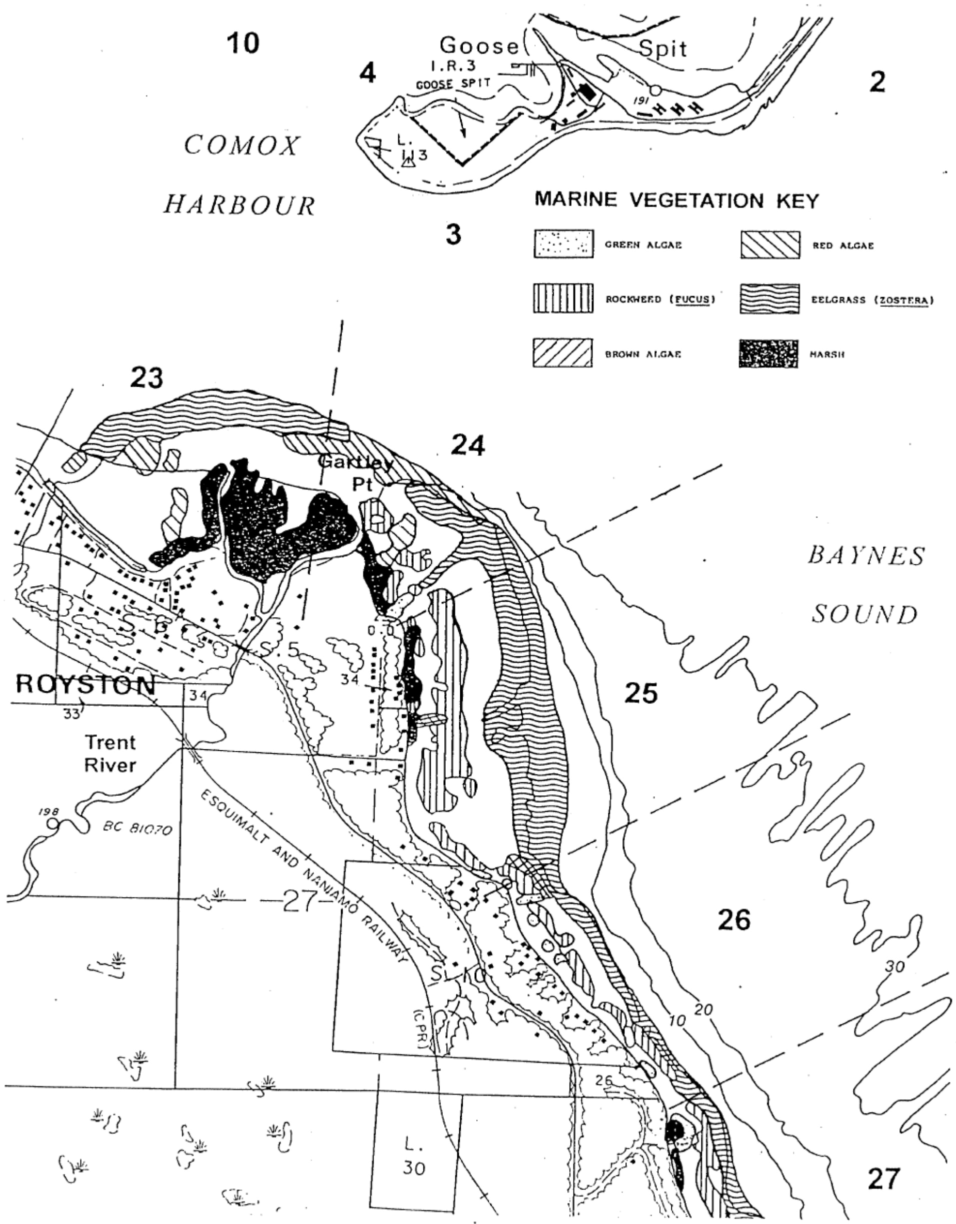
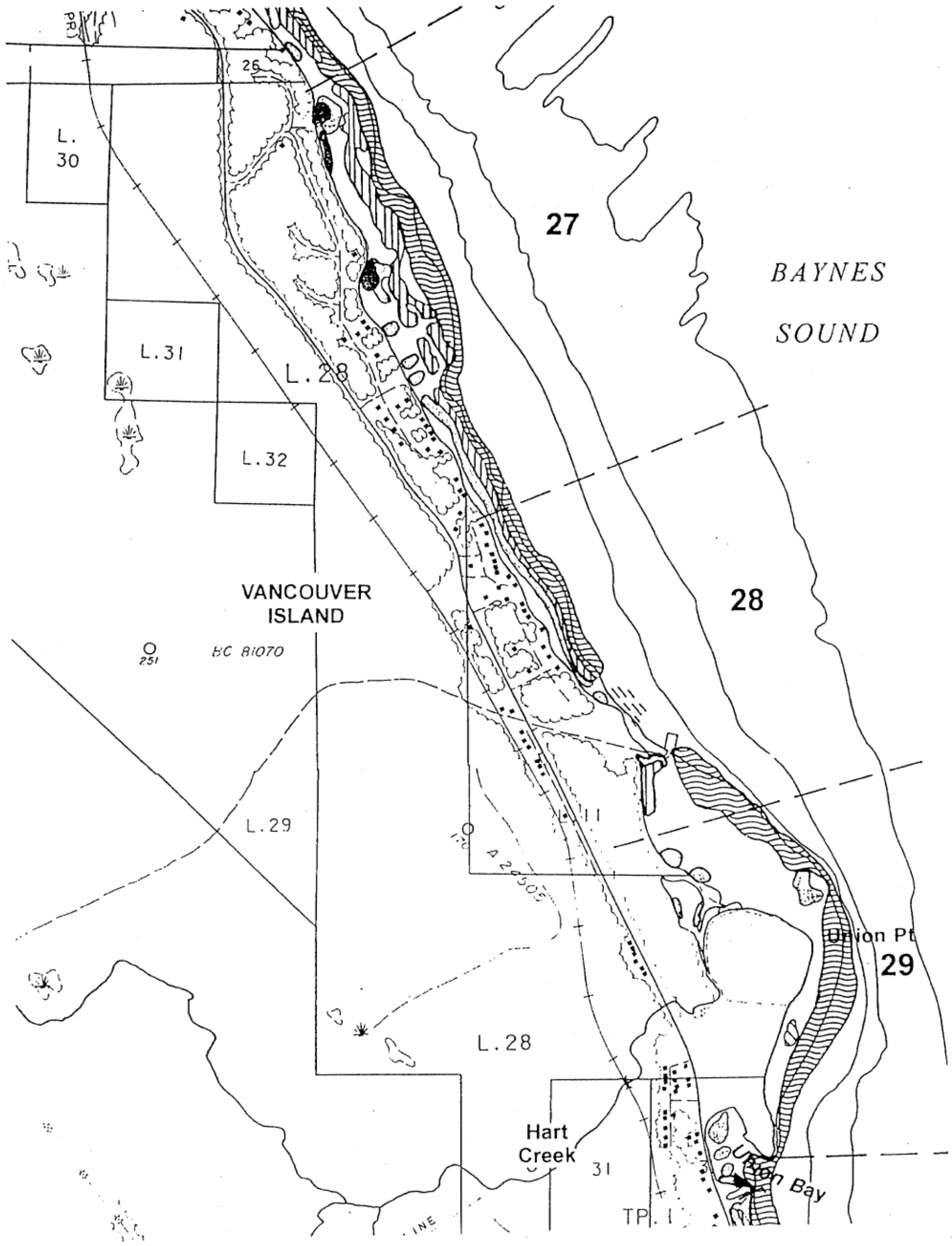


Figure 8: Comox Harbour landmarks and shorezone units
(from Dawe et al. 1998)



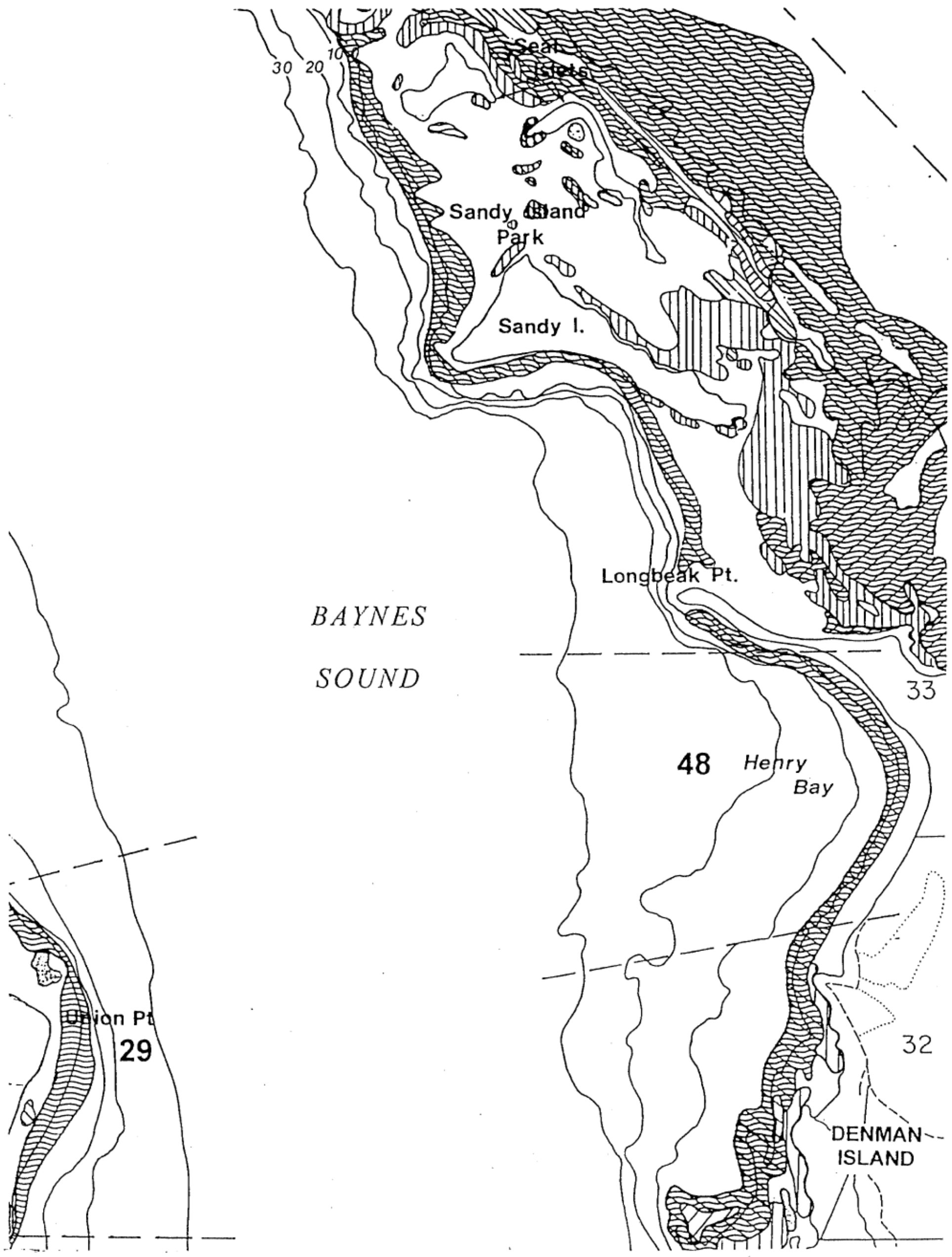
Shorezone units and foreshore vegetation around Gartley Point. For details about vegetation mapping, see Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 9: Shorezone units and foreshore vegetation around Garley Point (from Dawe et al. 1998)



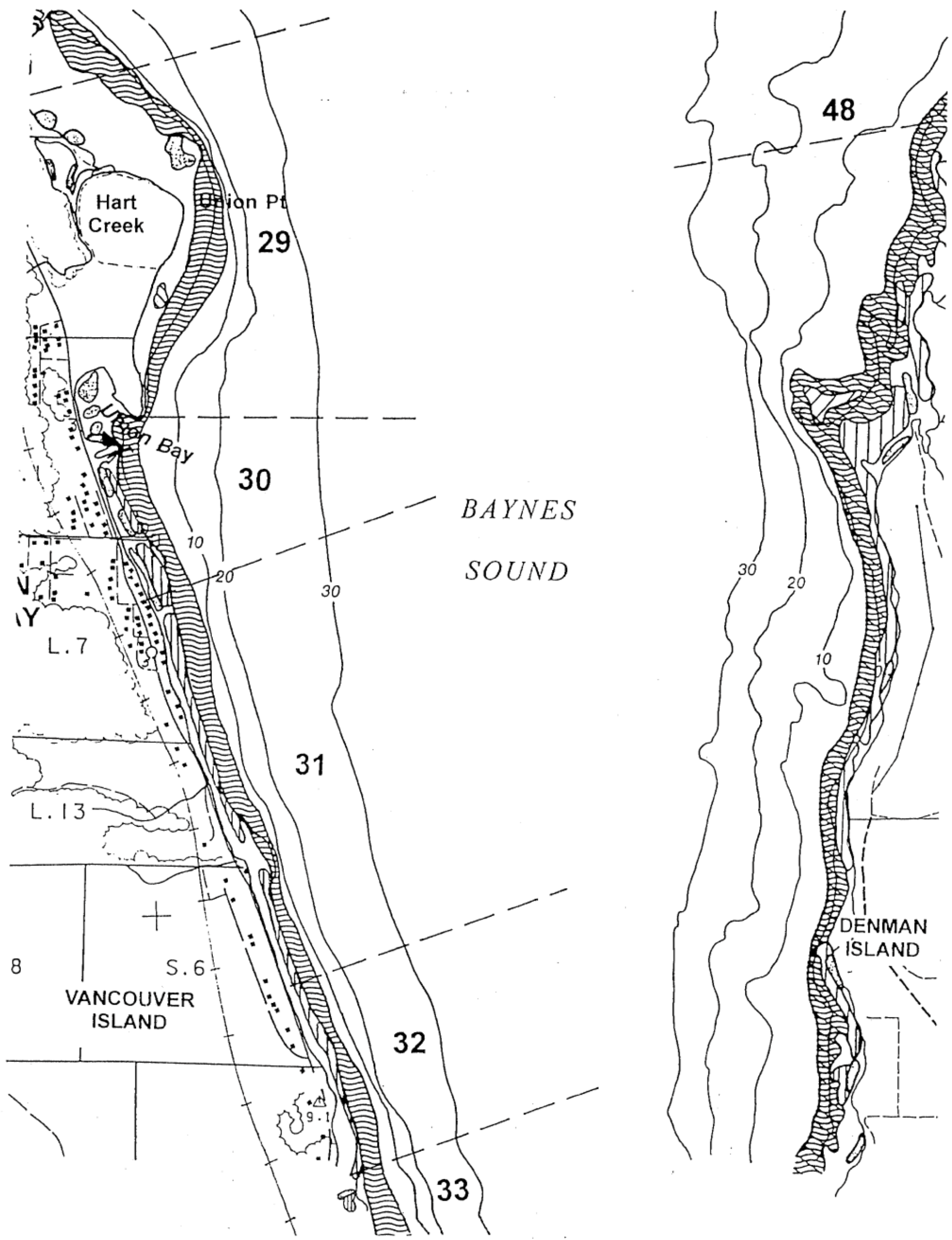
Shorezone units and foreshore vegetation, Beacon Creek to Union Point. For key to vegetation, see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 10: Shorezone units and foreshore vegetation, Beacon Creek to Union Point (from Dawe et al. 1998)



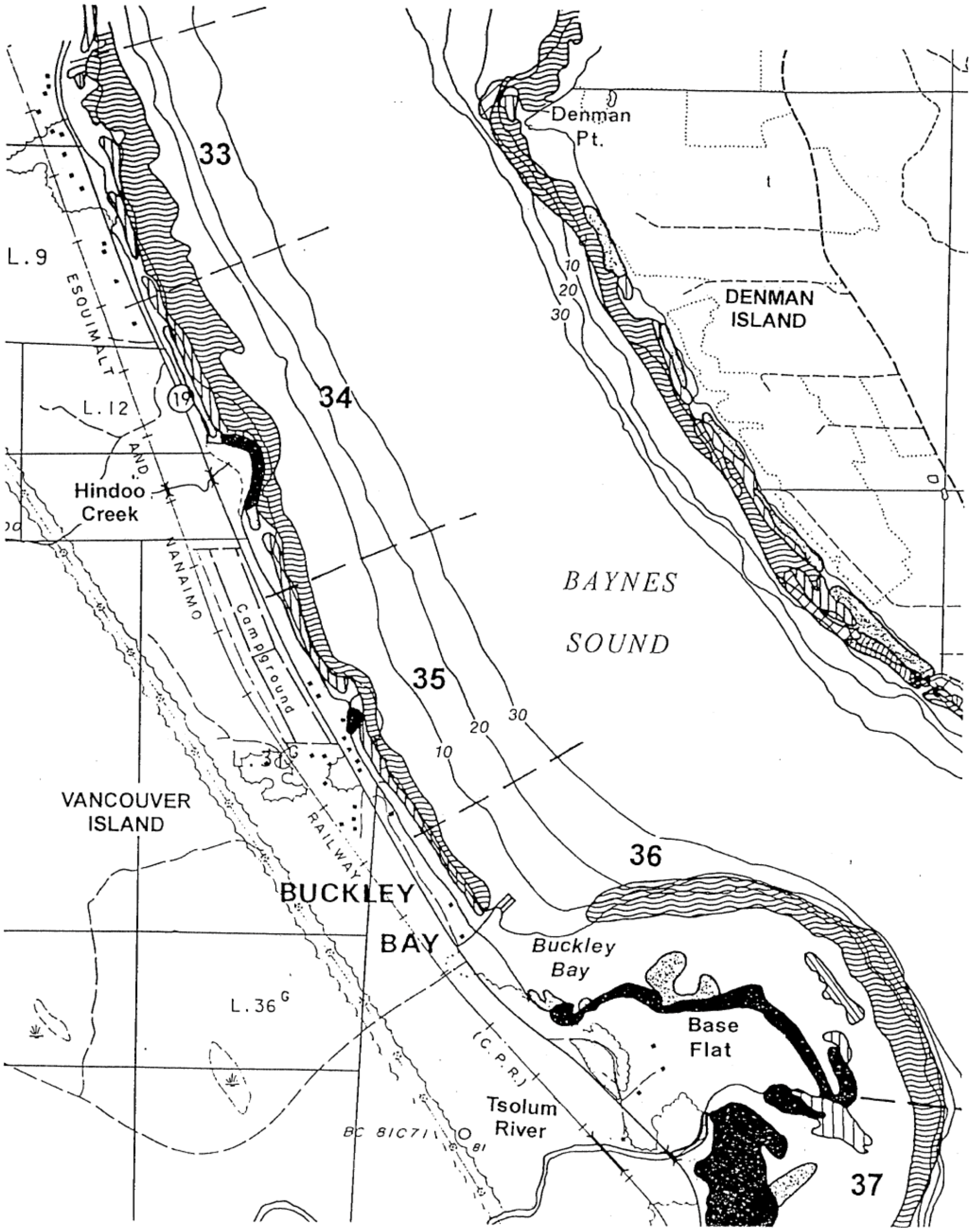
Shorezone units and foreshore vegetation near Henry Bay, Denman Island. For key to vegetation, see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 11: Shorezone units and foreshore vegetation near Henry Bay, Denman Island (from Dawe et al. 1998)



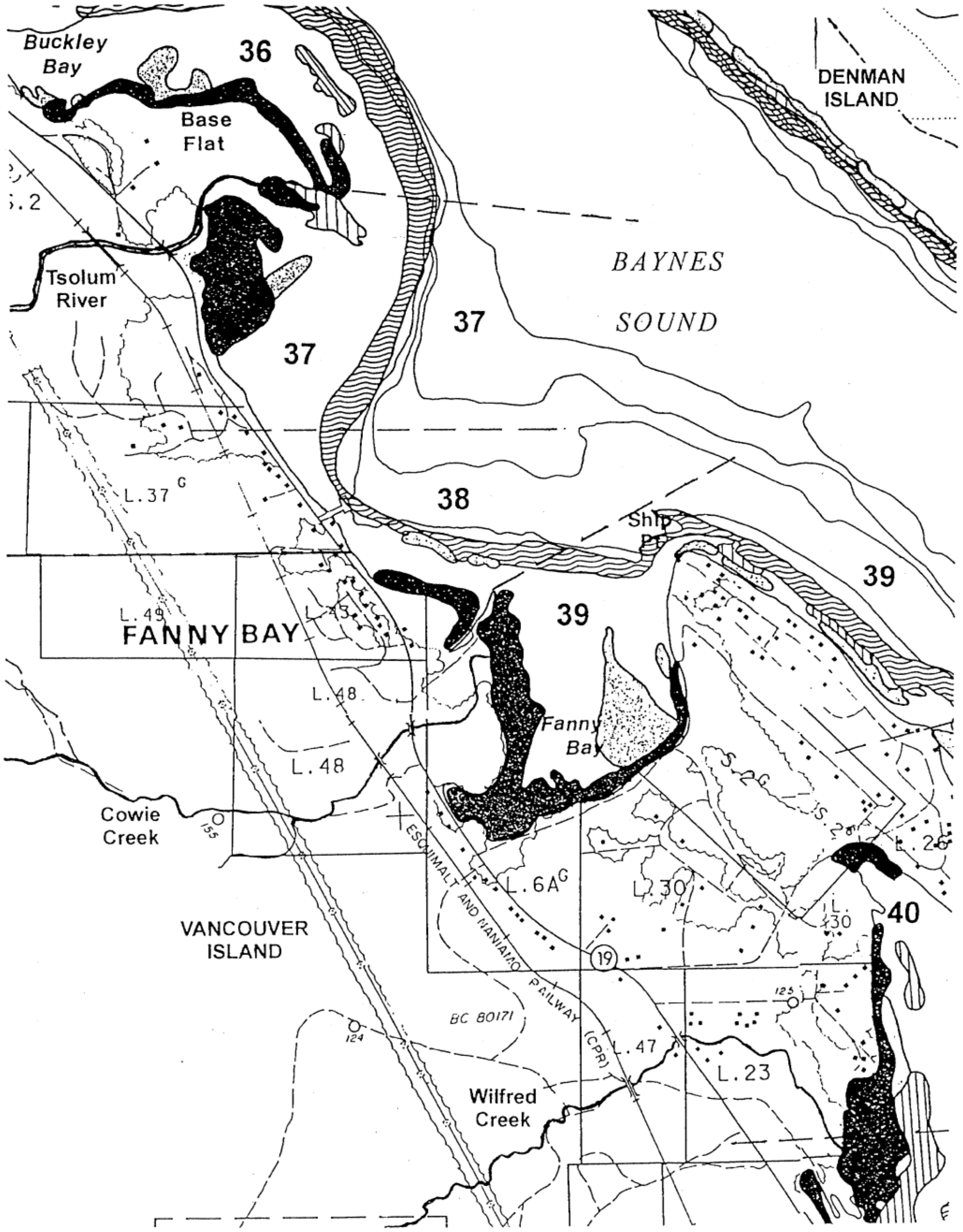
Shorezone units and foreshore vegetation near Union Bay. For key to vegetation, see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 12: Shorezone units and foreshore vegetation near Union Bay (from Dawe et al. 1998)



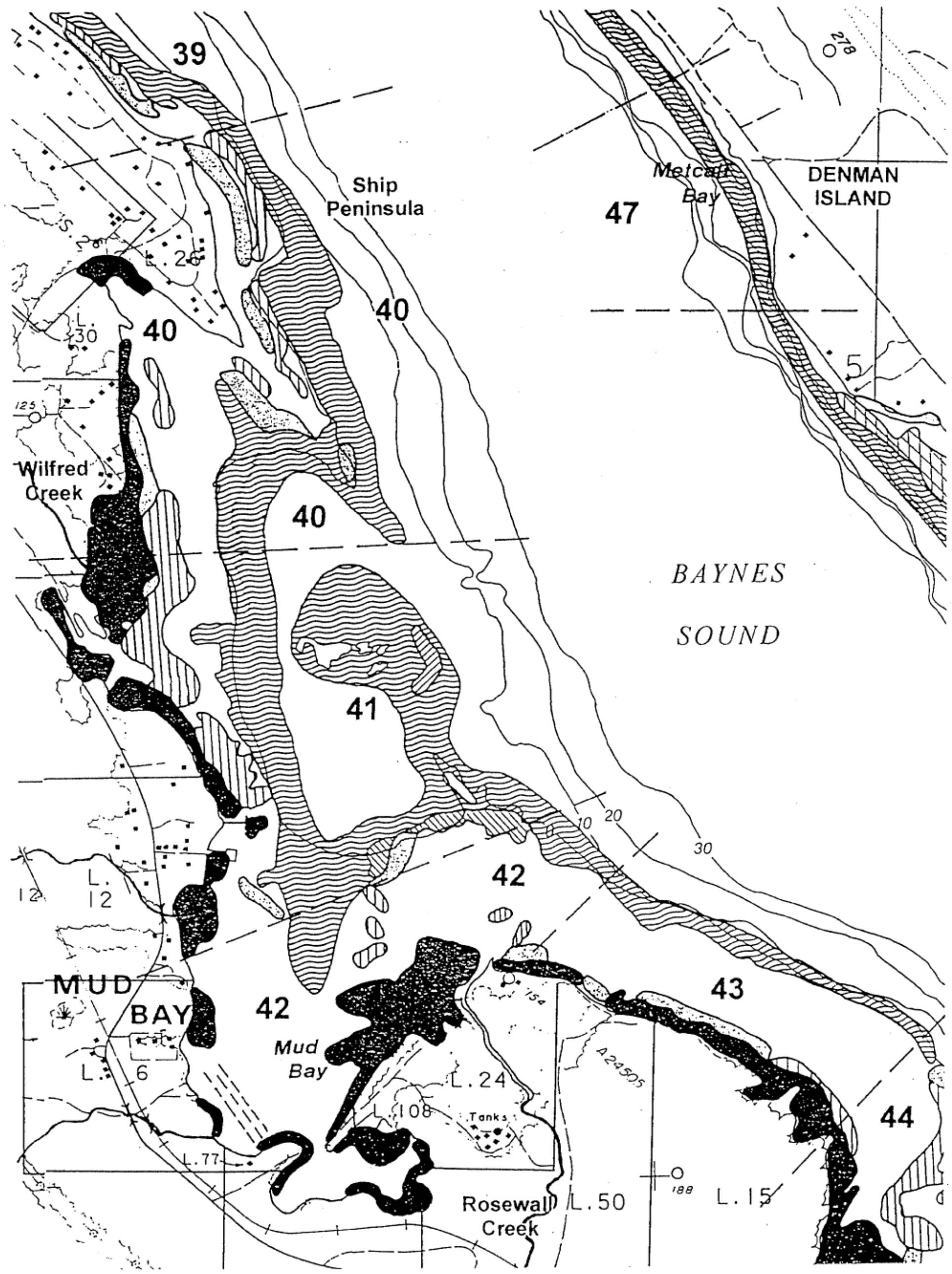
Shorezone units and foreshore vegetation, Hindoo Creek to Buckley Bay. For key to vegetation see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 13: Shorezone units and foreshore vegetation, Hindoo Creek to Buckley Bay (from Dawe et al. 1998)



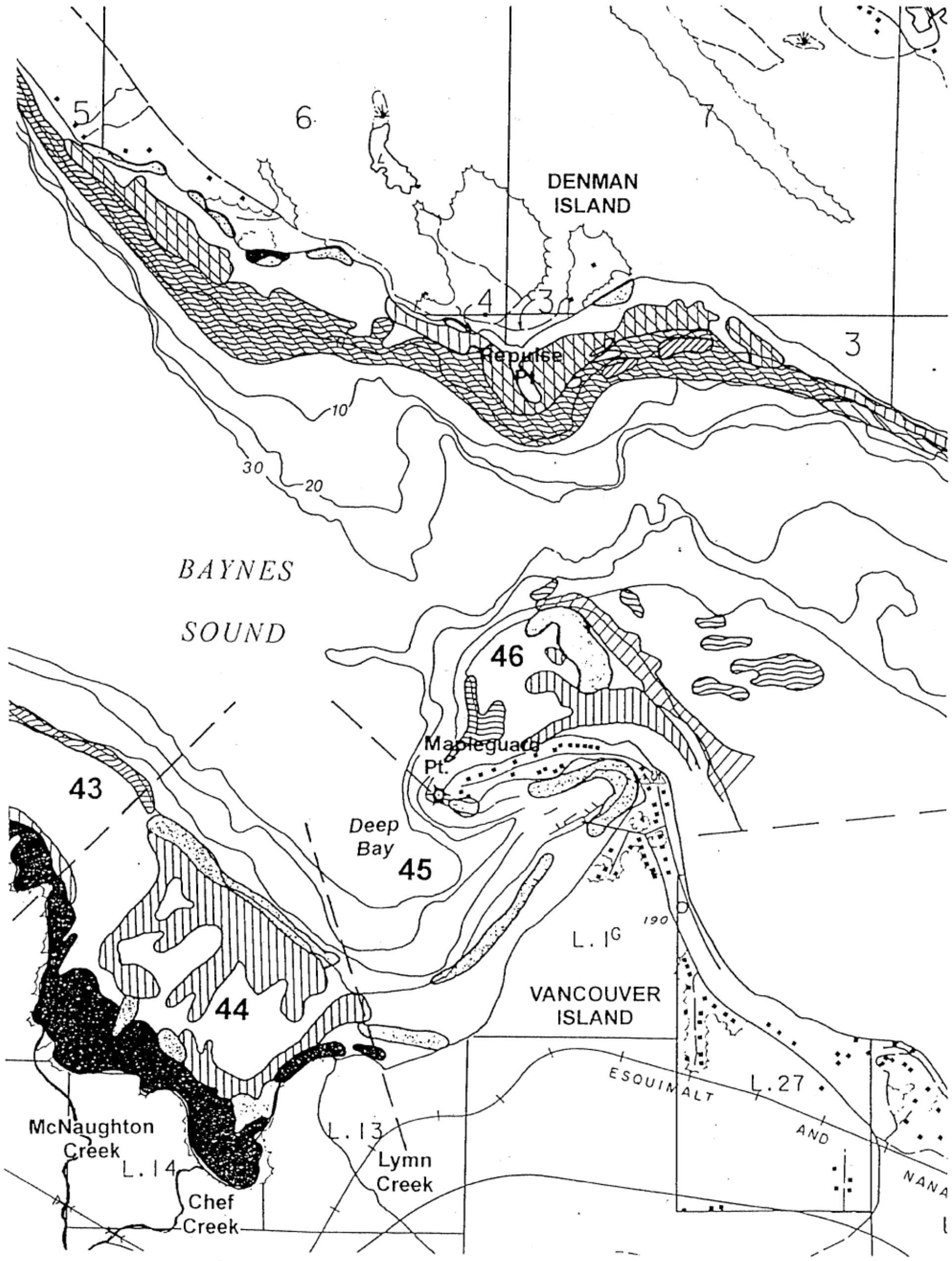
Shorezone units and foreshore vegetation, Tsolum River to Ship Peninsula. For key to vegetation, see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 14: Shorezone units and foreshore vegetation, Tsolum River to Ship Peninsula (from Dawe et al. 1998)



Shorezone units and foreshore vegetation, Ship Peninsula to Rosewall Creek. For key to vegetation, see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).

Figure 15: Shorezone units and foreshore vegetation, Ship Peninsula to Rosewall Creek (from Dawe et al. 1998)



. *Shorezone units and foreshore vegetation near Mapleguard Point. For key to vegetation see Figure 5 and Appendix III (modified from Baynes Sound Crown Foreshore Plan, B.C. Ministry of Environment and Environment Canada Lands Directorate).*

Figure 16: Shorezone units and foreshore vegetation near Mapleguard Point (from Dawe et al. 1998)

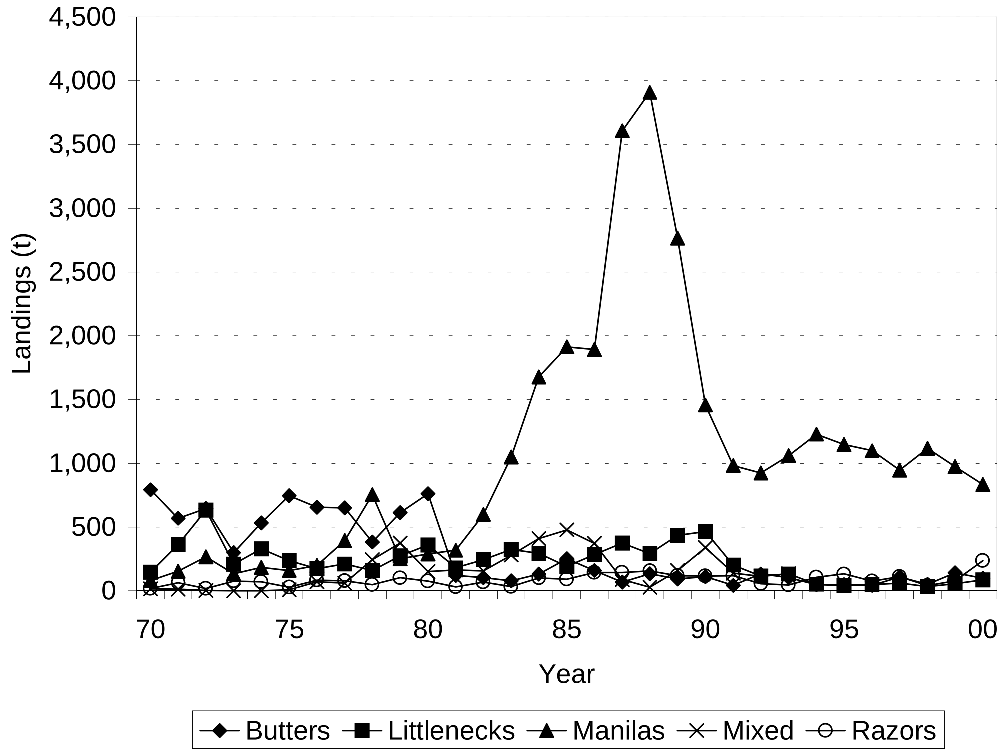


Figure 17. Annual landings (t) of intertidal clams from commercial clam fisheries in BC (1999 and 2000 statistics are preliminary)

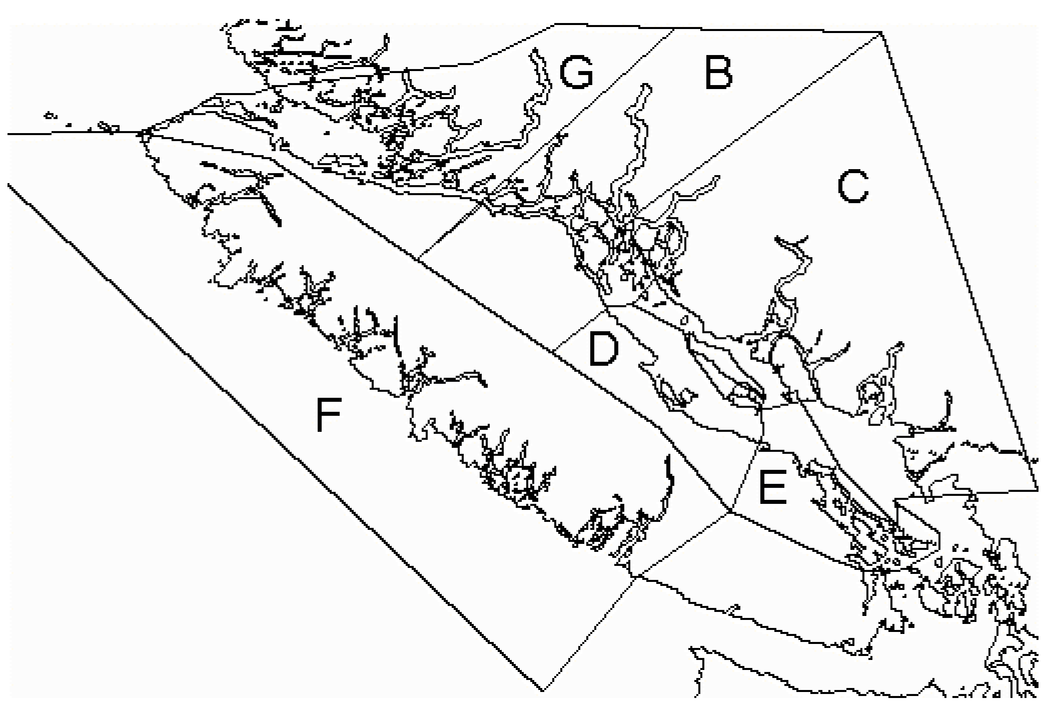


Figure 18. Clam Management Areas in southern coastal British Columbia.

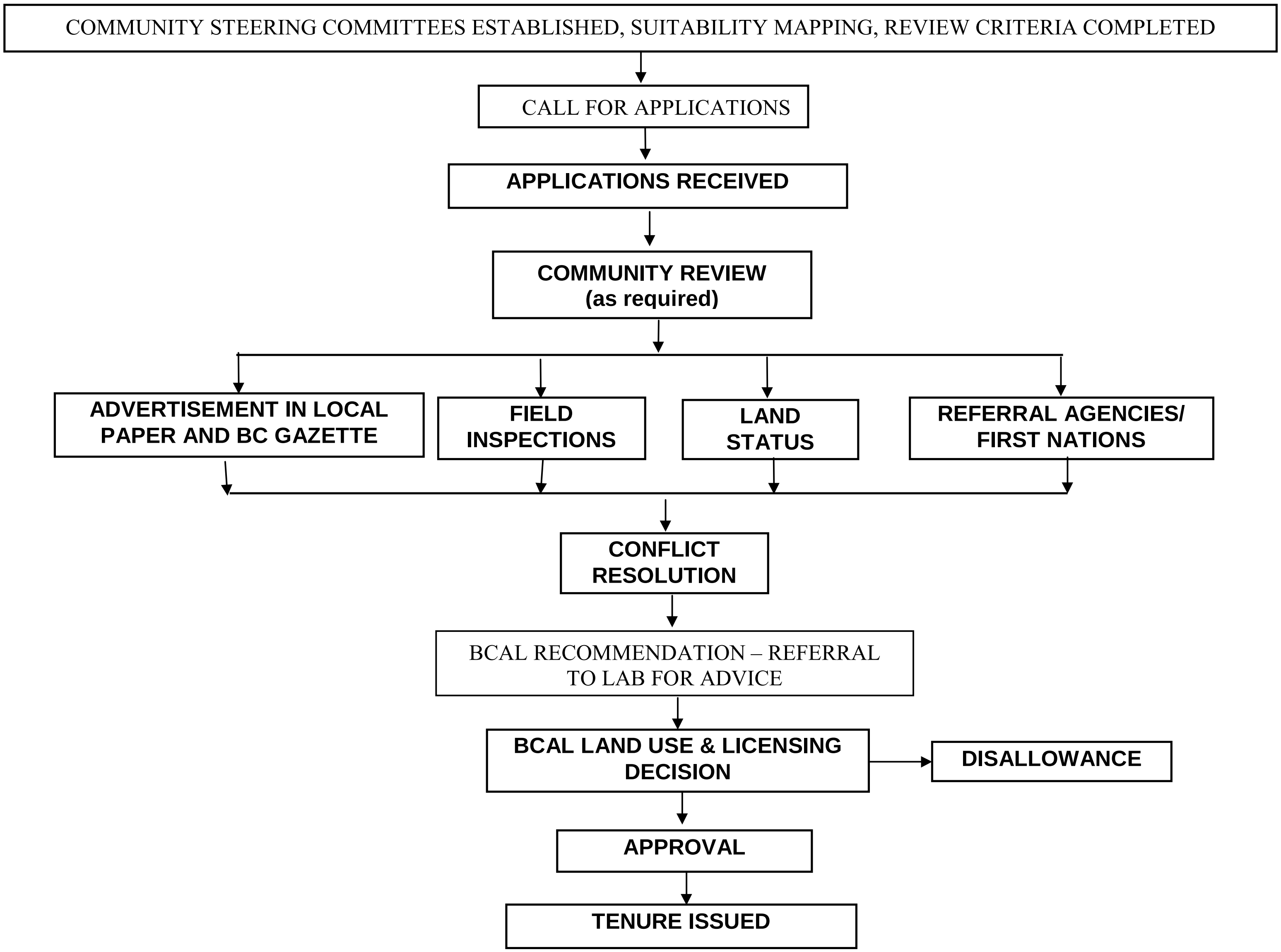


Figure 19: BCAL Guide to Shellfish Aquaculture Application Process

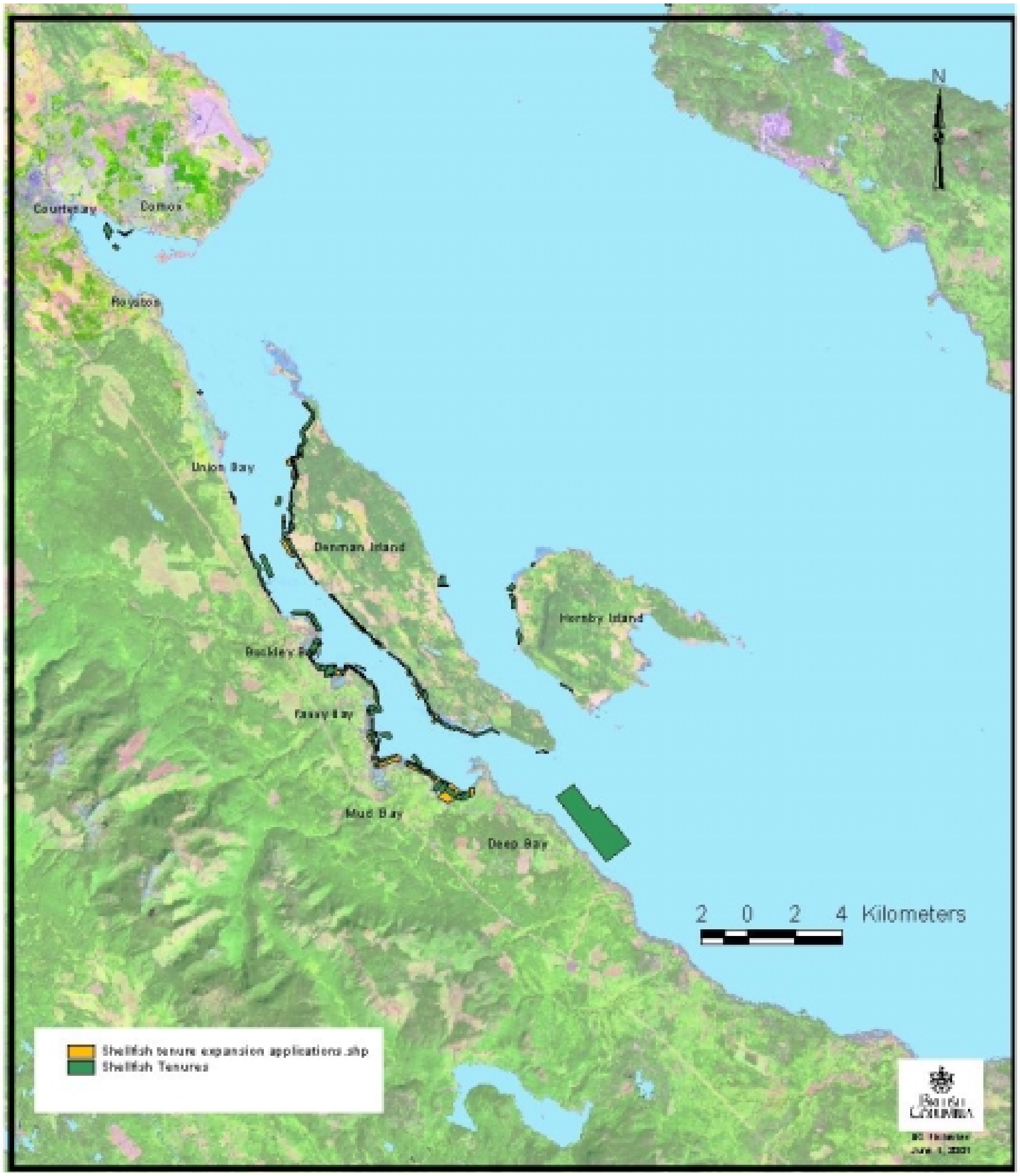


Figure 20: Baynes Sound Shellfish Tenures and Expansion Applications

Figure 21: Vexar fence boundary around lease area, Denman Island

Figure 22: Berms built on lease areas and intertidal terrestrial vehicle usage, Denman Island

Figure 23: Predator exclusion netting on beach surface

Figure 24: Aerial view of predator exclusion netting on beach surface

Figure 25: Biofouling on smolt pen predator exclusion net

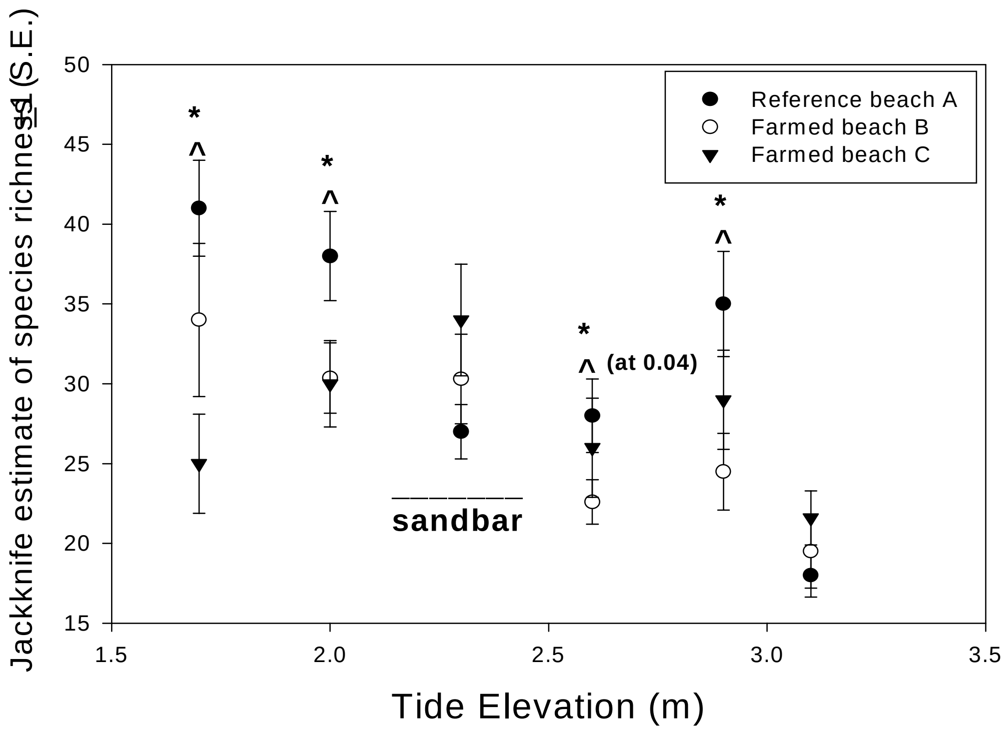


Figure 26: Comparison of species richness between cultured and control plots (Bendall-Young et al. 2001)

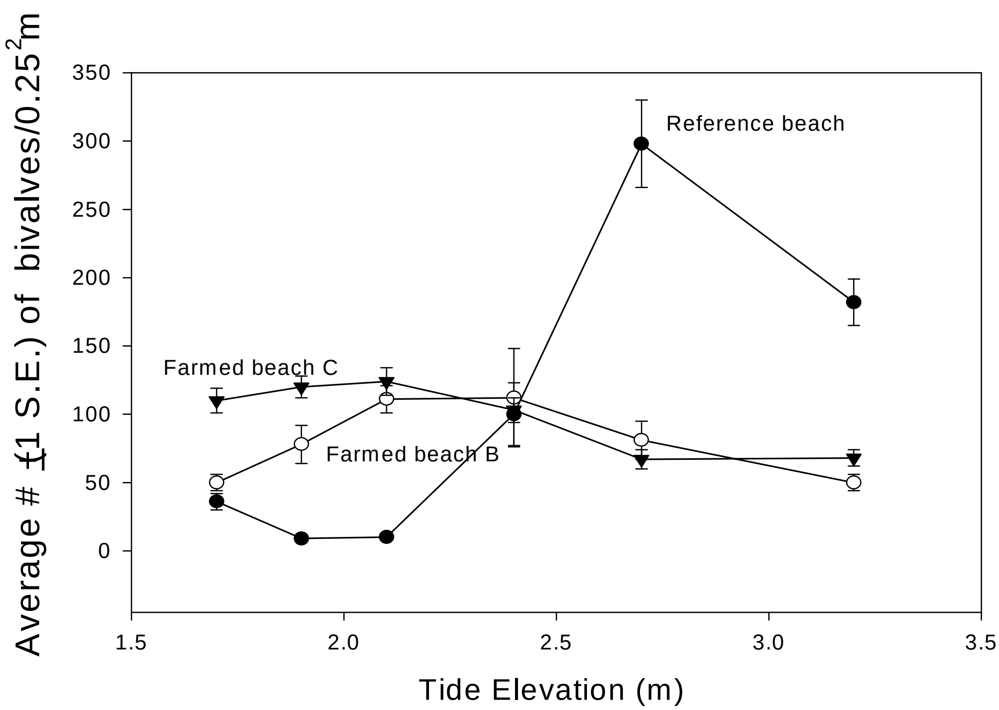


Figure 27: Comparison of bivalve abundance between cultured and control plots (Bendall-Young et al. 2001)

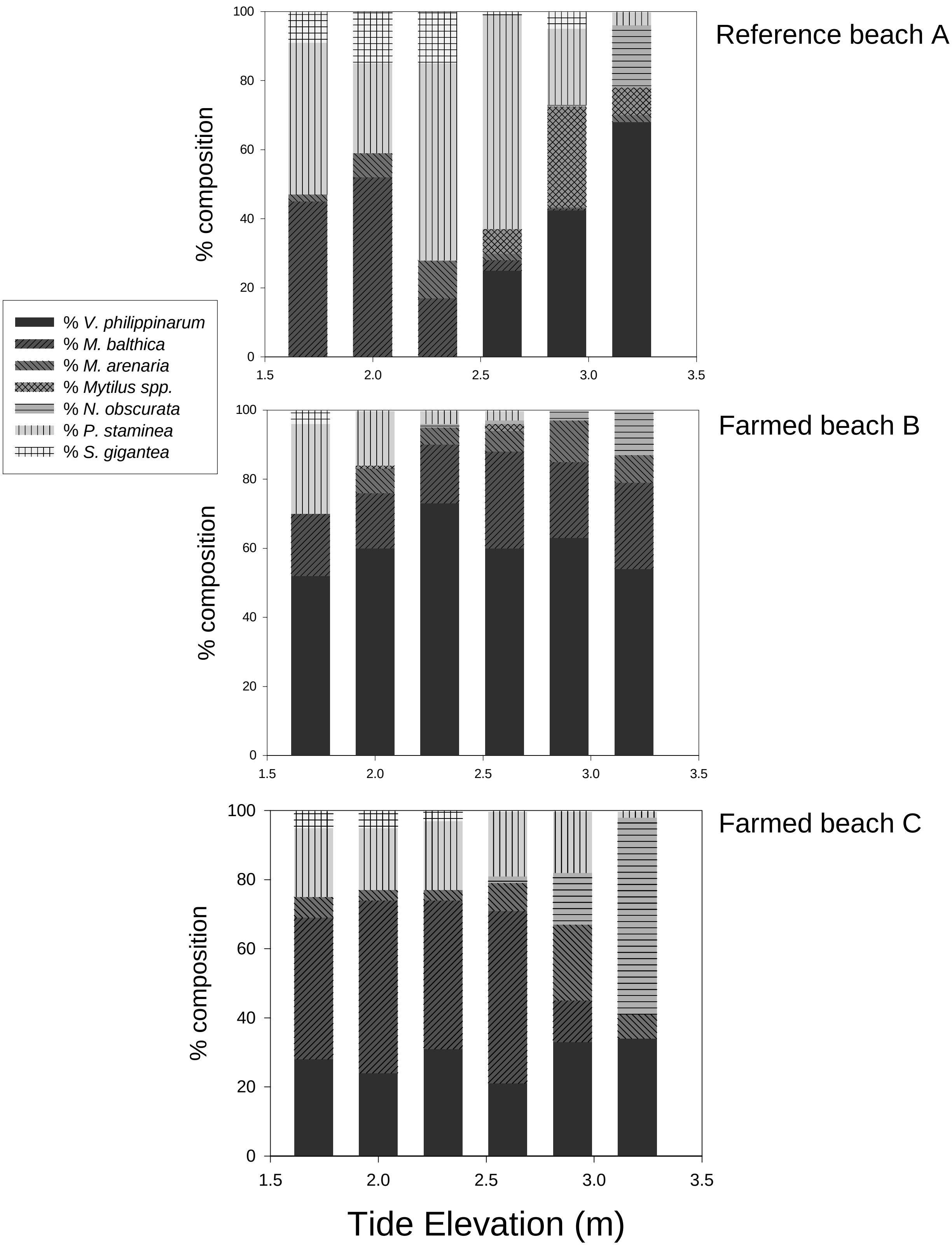


Figure 28: Comparison of bivalve distribution between cultured and control plots (Bendall-Young et al. 2001)

Figure 29: Oyster on-growing in eelgrass bed

Figure 30: Channelisation of estuary at Henry Bay

Figure 31: Estuary channelisation at Wilfred (Coal) Creek

Figure 32: Gabions used for estuary channelisation at Wilfred (Coal) Creek

Figure 33: Truck usage in intertidal zone, Denman Island

Figure 34: Boat beached during low tide at Henry Bay

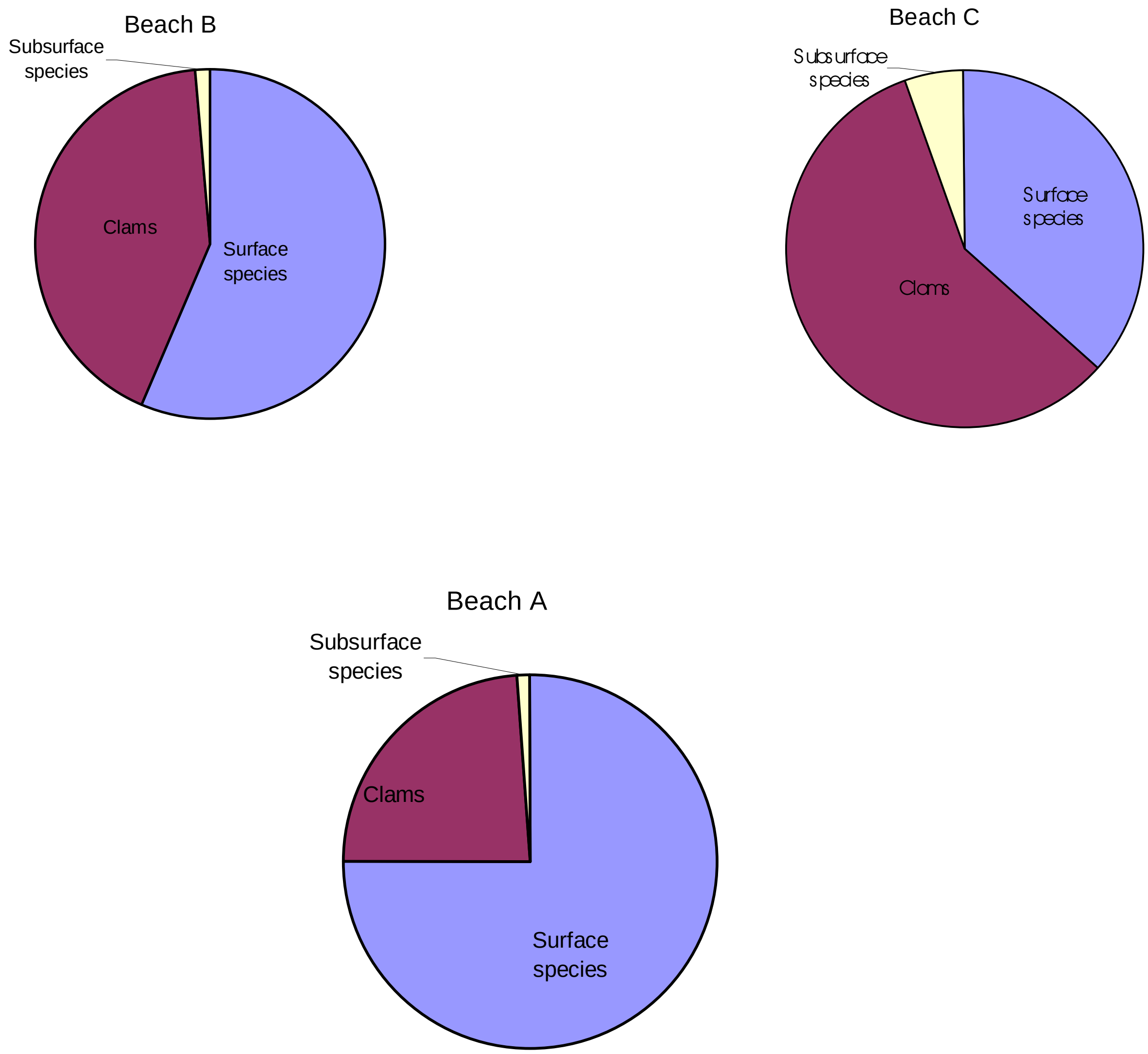


Figure 35: Comparison of intertidal community structure between cultured and control plots (Bendell-Young et al. 2001)

APPENDIX 1: BIRD CHECK-LIST

Species Code	Species Name	Scientific Name
PALO	Pacific Loon	*Gavia pacifica*
COLO	Common Loon	*Gavia immer*
WEGR	Western Grebe	*Aechmophorus occidentalis*
DCCO	Double-crested Cormorant	*Phalacrocorax auritus*
PECO	Pelagic Cormorant	*Phalacrocorax pelagicus*
GBHE	Great Blue Heron	*Ardea herodias*
TRUS	Trumpeter Swan	*Cygnus buccinator*
BRAN	Brant	*Branta bernicla*
CAGO	Canada Goose	*Branta canadensis*
GWTE	Green-winged Teal	*Anas crecca*
MALL	Mallard	*Anas platyrhyncos*
AMWI	American Wigeon	*Anas americana*
GRSC	Greater Scaup	*Aythya marila*
SUSC	Surf Scoter	*Melanitta perspicillata*
WWSC	White-winged Scoter	*Melanitta fusca*
AMCO	American Coot	*Fulica americana*
RUTU	Ruddy Turnstone	*Arenaria interpres*
BLTU	Black Turnstone	*Arenaria melanocephala*
WESA	Western Sandpiper	*Calidris mauri*
DUNL	Dunlin	*Calidris alpina*
BOGU	Bonaparte's Gull	*Larus philadelphia*
MEGU	Mew Gull	*Larus canus*
GWGU	Glaucous-winged Gull	*Larus occidentalis*
COMU	Common Murre	*Uria aalga*
PIGU	Pigeon Guillemot	*Cepphus columba*