AN EVALUATION OF FISH HABITAT IN BURRARD INLET, BRITISH COLUMBIA.

by

DANA ROCHELLE HAGGARTY

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Department of Zoology

The University of British Columbia
Vancouver, Canada

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Abstract

I investigated fish habitat evaluation methods for Burrard Inlet, British Columbia. Burrard Inlet, contains the Port of Vancouver and is surrounded by Greater Vancouver. Nearshore habitat loss and alteration are major threats to the health of the marine environment in the region. Considerable habitat has already been lost or altered in Burrard Inlet.

To maintain productive fish habitat, two issues must be resolved: what metrics should be used to assess habitat; and at what scale should they be evaluated? I investigated habitat evaluation in four ways: reviewing habitat classification and evaluation methods used in other aquatic situations; investigating the habitat use of juvenile chum (*Oncorhynchus keta*) and chinook (*O. tshawytscha*) salmon; employing community level metrics of habitat; and measuring substrate types along Burrard Inlet's shoreline.

Scale is a critical issue in habitat evaluation. Scales range between very broad, regional classifications, to fine, site-level habitat assessments. An intermediate scale, the landscape, is appropriate to classify and evaluate fish habitat.

I found a greater abundance of chum and chinook in the western basins of the inlet than the eastern basin. At the site level, juvenile chinook tended to use larger substrates such as bedrock and boulders over sand and mud. More chum were found over cobble substrates than mud. Landscape-level metrics such as habitat connectivity, isolation, rarity, and abundance must, however, be considered as juvenile salmonids use a variety of nearshore habitats as they migrate to the sea.

Numerous species of fishes use Burrard Inlet; therefore, community-level metrics such as species diversity and the identification of species assemblages should also be used in habitat evaluation. My data showed separate assemblages of fish are found on gravel-cobble beaches than on sand and mud. Differences in species diversity also existed between some sites.

These habitat evaluation metrics are particularly important in urban situations such as Burrard Inlet. My analysis showed that 44.6% of Burrard Inlet's shoreline has already been altered. The Inner Harbour, at 79.7%, is the most altered basin. Landscape-level habitat evaluation metrics such as habitat diversity, rarity, abundance and connectivity should be used to assess nearshore fish habitats.

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General introduction to fish habitat evaluations

Human alteration of natural habitats is substantial and ever-increasing. It is estimated that humans have altered between one-third and one-half of Earth's land surface (Vitousek *et al.*, 1997). Though human alterations of marine systems are more difficult to quantify, it is evident that use of the coastal zone is substantial. Approximately 60% of the human population lives within 100 km of the coast. Because of this, the loss of nearshore coastal habitats such as estuaries and wetlands is pervasive worldwide (Vitousek *et al.*, 1997). Habitat loss and alteration are considered primary threats to marine biodiversity and the health of the marine environment (Norse, 1993). In addition to supporting marine biodiversity, habitat also plays a significant role in sustaining fisheries (Langston and Auster, 1999).

The Canadian federal government places a high priority on the maintenance of fish habitat. Fish habitat is defined in the Fisheries Act as "spawning grounds and nursery, rearing, food supply and migration area on which fish depend directly or indirectly in order to carry out their life processes" (Department of Fisheries and Oceans, 1986). The goals of the Department of Fisheries and Oceans' policy for the management of fish habitat, enforced by the Fisheries Act, are to conserve, restore and develop fish habitat. The Habitat Protection Policy aims to conserve habitat by preventing a net loss of the productive capacity of habitats (Department of Fisheries and Oceans, 1986).

The loss and alteration of habitat is an important issue in the Georgia Basin region of southwestern British Columbia and Washington State. In a report on the status of the marine environment in the Straight of Georgia, Juan de Fuca Strait, and Puget Sound, the British Columbia-Washington State Marine Science Panel emphasized the importance of preventing further habitat destruction in the Georgia Basin. Estuaries are of particular concern since much of this habitat in the region has already been altered or lost. They also advised that habitat loss should not be allowed in embayments that have already lost over 30 percent of their historic habitat area (British Columbia/Washington, 1994).

Much of the nearshore habitat of Burrard Inlet, found in the Georgia Basin, has already been altered or lost (Macdonald *et al.*, 1990; Precision-Identification, 1997). The maintenance of fish habitat is hindered by several gaps in our knowledge: habitat is inconsistently defined; the habitat requirements of species are not well understood; ways to measure habitat quality are uncertain; and the appropriate scale at which to measure habitat is not defined. How we evaluate habitat quality, and consequently conserve habitat, depends on resolving these issues.

Habitat is an important topic in ecology and has been defined in several different ways (Kramer *et al.*, 1997; Whittaker *et al.*, 1973). In the broadest sense, habitat can refer to areas that are more or less distinct with respect to their suite of abiotic and biotic characteristics (Kramer *et al.*, 1997). Kramer *et al.* (1997) provided riffle and pool habitats as examples of habitat at a coarse scale. At a finer scale, deep and shallow areas within a pool, represented by relatively homogeneous subdivisions of habitat, can be defined as microhabitat (Kramer *et al.*, 1997). Hayes et al. (1996) list several definitions of fish habitat but prefer those which include both biotic and abiotic factors since both are important in determining fish growth and survival. These authors define habitat broadly and view space to be the primary component of fish habitat. Other resources and environmental conditions – physical, chemical and biological variables – modify the utility of this space.

Whittaker *et al.* (1973) define the habitat of a species to be the species' population response, as expressed in a population measure such as growth or biomass, to the many variables of the physical and chemical environment that form spatial gradients in a landscape. They also suggest that habitats are not delimited by areas in which a species could persist, as defined by physiological tolerances, since its interactions with other species may exclude it from some suitable areas. Additionally, environments change and species occur in environments that are, at times, unfavorable. Habitats should therefore be viewed as gradients (Whittaker *et al.*, 1973). If population measurements are taken along a habitat gradient, the species should show a response curve to the gradient such as a bell-shaped or Gaussian curve where the tails taper on each side of the optimum towards ill-defined limits (Whittaker *et al.*, 1973). Because habitats are often gradients of an environmental variable rather than discrete entities they can be difficult to define and classify.

One approach to studying habitat is to identify which habitats are selected by species. Habitat selection is defined as "the non-random use of space resulting from voluntary movements" (Kramer *et al.*, 1997). It is often not possible to measure the demographic processes in the environment or to know the mobility of organisms in relation to the strength and direction of physical forces; therefore, these processes can obscure the role of active habitat selection. Since this is the case in this project I will use the term "habitat use" rather than habitat selection (Kramer *et al.*, 1997). Habitat use also refers to the non-random use of space, but is not necessarily as a result of voluntary movements.

Patterns of habitat use are often investigated by relating the abundance of particular life stages of species of fish to specific environmental variables (Kramer *et al.*, 1997). Kramer et al. (1997) list several factors that can cause the density of fishes to vary among habitats and microhabitats: differential reproduction and mortality, colonization and extinction, involuntary transport and voluntary movements. In this thesis, I investigated habitat use of juvenile chum and chinook salmon using relative abundance in different habitats as one metric of habitat quality.

The variables that are important for habitat use in fishes can be grouped as physical or chemical properties of the water; characteristics of the substratum and other solid objects in the water column; and the presence or absence of other species or individuals (Kramer *et al.*, 1997). Of the many components that make up habitat, I have focused on substrate type.

Substrate is often a strong indicator of habitat type as it correlates well with other aspects of habitat such as algae and invertebrates, as well as physical properties such as exposure and slope. Many fishes show morphological and behavioural adaptations related to substrate, such as flattened bodies adapted to sand and mud habitat, or eel-like bodies suitable for hiding in crevices and interstitial spaces between rocks (Helfman *et al.*, 1997). Substrate can, however, be a difficult habitat variable to investigate for fishes since they are relatively mobile organisms that are able to use a wide variety of substrate types. Ontogenetic habitat shifts are also common in fishes, so that many species use a variety of substrate types throughout their life cycle (Kramer *et al.*, 1997).

Equating substrate with habitat is practical from a management perspective. Substrate is easily identified and measured, is relatively stable throughout time, and can be mapped. Substrate is also a habitat feature that is often altered physically by human activity, particularly in urban situations where shoreline development is high.

This thesis is an investigation of habitat classification and evaluation models that may, in future, be used to assess nearshore fish habitat in Burrard Inlet. It is organized into six chapters. Two general themes exist: 1. what metrics should be used to assess fish habitat; and 2. at what scale should it be assessed?

In Chapter 1, I introduce the physical, social and biological setting of Burrard Inlet. Greater Vancouver, Canada's third largest city, is built on the shores of Burrard Inlet. Burrard Inlet, contains the Port of Vancouver, which is one of the busiest ports in North America. Despite heavy use of the inlet, it is inhabited by several species of plants, algae, invertebrates, fishes, birds and mammals.

Chapter 2 is a comprehensive description of the methods that I used in this thesis.

In the third chapter, I review habitat classification and evaluation models that have been used in other aquatic environments. Habitat classification tends to occur at broad regional scales, while habitat evaluation is often performed at fine site-specific scales. An intermediate level, the landscape scale, is appropriate for combining habitat classifications and evaluation.

Chapter 4 discusses juvenile chum and chinook salmon habitat at three nested scales: Burrard Inlet; basins within the inlet; and sampling sites within each basin. Chum and chinook are the most abundant commercially significant fish species that use Burrard Inlet, mainly as juveniles. Though site-specific habitats must meet the life history requirements of the salmonids, landscape level metrics must be used to evaluate juvenile salmonid habitat quality.

In Chapter 5, I discuss community-level metrics such as species diversity and species assemblages of nearshore fish communities of Burrard Inlet. Habitat in Burrard Inlet should be managed so that it can continue to support a diversity of fish species. Species diversity as well as other characteristics of fish communities such as the presence of sensitive species or life stages should be monitored to ensure that the inlet continues to support healthy communities.

Finally, in Chapter 6, I summarize the main findings of this thesis and provide conclusions and recommendations on evaluating nearshore coastal fish habitat in Burrard Inlet. Conclusions and principles are also applicable to similar coastal situations worldwide.

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Chapter 1

Physical, Biological and Social Description of Burrard Inlet.

Physical Setting: Oceanography and Environment

Burrard Inlet is found on the mainland coast of southwestern British Columbia just north of the estuary of the Fraser River, one of British Columbia's main river system. The mouth of the inlet opens into the Strait of Georgia, the water body between the Coast Mountains and Vancouver Island. Burrard Inlet differs from most inlets along the BC coast in that it lacks a sill at its seaward entrance and the land adjacent to the inlet is of moderate relief rather than steep. In addition, Burrard inlet is relatively shallow, and receives considerable fresh water input from an external source, the Fraser River (Thomson, 1981).

Covering 11,100 hectares (Ha), Burrard Inlet extends 30 km westward from the head at Port Moody Arm to Point Atkinson at the north and Point Grey at the south (Figure 1.1) (Stott and Popple, Draft; Tabata, 1971). The inlet can be divided into five basins: Outer Harbour (5,600 Ha); False Creek (77 Ha); Inner Harbour (also called Vancouver Harbour) (1540 Ha); Central Harbour (890 Ha); and Port Moody Arm (560 Ha) (Stott and Popple, Draft). Burrard Inlet reaches a maximum depth of 100 m in the mid-channel south of Point Atkinson but several very shallow areas exist. Mean depth from the First Narrows to the head at Port Moody Arm is 21 m. Port Moody Arm itself averages a mere 9 m deep (Tabata, 1971; Thomson, 1981).

Near its eastern end, Burrard Inlet is joined by Indian Arm, which extends in a northeastern direction for about 20 km. Indian Arm is a typical fjord with steep sides and average and maximum depths of 120 m and 245 m respectively. A broad shallow sill at the mouth of Indian Arm restricts the exchange of salt water with Burrard Inlet. Indian Arm was not considered in this study.

Tides in the inlet are mixed, mainly semi-diurnal with a strong declination variation over a two-week period. Tide prediction stations are found at both Point Atkinson and Vancouver Harbour (also known as the Inner Harbour) (Canadian-Hydrographic-Service, 1999). There is a slight increase in tidal range east of the Second Narrows, and a delay of the higher high water by approximately 30 minutes in Port Moody relative to the tide station in Vancouver Harbour (Figure 1.1). The mean tidal range is 3.3 m, but tides can range between 0.0 and 5.0 above chart datum.

Strong tidal currents of up to 6 knots exist at both the First and Second Narrows during both the ebb and flood (Canadian-Hydrographic-Service, 1999). These strong currents flush the Inner and Central Harbours as net surface water flow is seaward (Stockner and Cliff, 1979). During the rising tide, the flood current flows into the inlet. Water funnels through the First Narrows at great speeds but drops to 0.5-2.5 knots in the wider space of the Inner Harbour. A counter-clockwise eddy develops to the north of the main flow and a clockwise eddy to the south. Water speeds again climb as the water funnels through the next constriction, Second Narrows, and then drop back to about 1 knot. Again, a counter-clockwise eddy is present at the north, and two clockwise eddies are apparent to the south of the eastward flow. During the falling tide, the water flows seaward and the direction of the eddies reverses. In addition to the tidal currents, currents driven by freshwater runoff and wind exist. Runoff from rivers emptying into the inlet causes a net seaward surface flow (Tabata, 1971).

Temperature and salinity vary seasonally and are affected by conditions in the Strait of Georgia, local runoff levels, influx of water from the Fraser River, the tides and winds. A coinciding thermocline and halocline exists in the inlet. Approximately 5 m of relatively warm, low salinity water lies on top of colder, more saline water. Temperatures are highest in July to early August and may reach up to 20°C in the surface waters of shallow portions of the Outer Harbour and Port Moody Arm. A shallow thermocline exists and water temperature decreases by

5-10°C within 5 m of the surface. Maximum surface temperatures in the Inner and Central Harbours is 15°C. Winter temperatures vary between 6-8°C. Salinity below a depth of 10 m is quite uniform throughout the year at 29-30‰. Surface salinity, on the other hand is quite variable, particularly in the Outer Harbour. Summertime salinity can be as low as 10‰ in the surface waters most strongly affected by the Fraser River freshet at the southwest of the Outer Harbour. Salinity increases in a northerly direction across the basin to 20‰ near the north shore. East of the First Narrows, surface salinity ranges between 20 and 18‰ in the summer and 26 to 20‰ in winter (Thomson, 1981).

Runoff from the North Arm of the Fraser River is the main source of brackish water in the outer portion of the inlet. Fraser River discharge is tied to snow melt and peaks in May and June each year. The North Arm carries about 20% of Fraser discharge, or about 2800 m^3/s in freshet and 160 m^3/s during winter low flow.

The internal catchment area of Burrard Inlet (including Indian Arm) is 98000 ha. The Indian River, at the head of Indian Arm, discharges from Buntzen Lake via the Buntzen Power Plant, and local streams around Burrard Inlet also add freshwater. The Seymour River provides the main local source of freshwater to the inner harbour while the Capilano River provides inflow to the Outer Harbour. The flow of these rivers is closely tied to precipitation and is usually greatest in autumn and winter but rarely exceeds 150 m^3/s, roughly 1% of the maximum discharge of the Fraser River. Numerous other creeks empty into Burrard Inlet and Indian Arm (see Appendix 1). Noons Creek, Lynn Creek, Mosquito Creek, and Mackay Creek are among the larger creeks but still only contribute an order of magnitude less than the Seymour River (Thomson, 1981).

Social Setting

The watershed around Burrard Inlet is one of fastest growing urban areas in North America. The population of Greater Vancouver is roughly 2.0 million, and over 1 million of these people actually reside in Burrard Inlet's drainage basin, mainly concentrated on the foreshore. Eight municipalities border the inlet: the cities of Vancouver, West Vancouver, Burnaby, North Vancouver and Port Moody, the District of North Vancouver, and the villages of Anmore and Belcarra. Intense urban, commercial and industrial activity takes place on the shores of the inlet (Stott and Popple, Draft).

Vancouver's port, situated in Burrard Inlet and operated by the Vancouver Port Authority, is Canada's largest port and principal gateway for trade with the Pacific Rim. In 1999, 71.2 million tonnes of cargo moved through the port making it the busiest North American port in terms of foreign export. It is also the most diversified port along the West Coast of North America as it encompasses container, bulk and general cargo terminals. Coal, grain, sulfur, potash, and wood pulp are the principal commodities exported. Port Vancouver is also an important cruise ship terminal that saw over a million passengers in the year 2000. Thousands of vessels visit the harbour each year. Port activities generate approximately 45 million dollars per year (Vancouver Port, 2001). The urban and industrial development around Burrard Inlet have greatly altered much of the natural shoreline.

The urban/industrial nature of the inlet have led to the discharge and accumulation of a wide range of contaminants in the sediments in Burrard Inlet (Sandwell Inc. and Castor Consultants, 1992). A study by Sandwell Inc. and Castor Consultants Ltd. (1992) showed that concentrations of cadmium and copper in dredged material exceeded the ocean dumping criteria. Histopathological conditions of demersal fishes have been linked to exposure to toxic and carcinogenic chemicals in water and sediment. English sole (*Pleuronectes vetulus*) were collected from seven locations in the inlet and examined for idiopathic liver lesions and epidermal abnormalities (Goyette *et al.*, 1988). A high prevalence (58.8%) of liver lesions was found in English Sole from Port Moody Arm. This may be linked to petroleum refinery waste water and other pollutants or overall quality of sediment or water. A moderate frequency (20.0-30.0%) of lesions was found along the shoreline of the inner harbour; lowest frequencies (8.3-13.3%) were observed in the Outer and Central Harbours (Goyette *et al.*, 1988).

Despite the input of numerous point sources (i.e. permitted industrial and municipal discharges, combined sewer overflows, emergency overflows, storm-water outfalls, landfills, and tributary streams) and non-point sources (marinas and live-aboards, ship repair, fueling facilities, ship loading, anchorages, and fish processing plants and aquaculture), (Bion Research Inc., 1997) water quality is considered to be acceptable, mainly because it is a well flushed system (Stockner and Cliff, 1979; Waters, 1986). Shellfish harvesting is prohibited in the inlet due to high fecal coliform levels resulting from storm and sewer discharges, and swimming at certain locations can be limited in the summer (Waters, 1986). Metal levels are typically below toxic levels though sub-lethal levels of metals may affect processes such as cell division and uptake of carbon in diatoms and dinoflagellates (Waters, 1986). Waters (1986) cautions that the way in which pollution affects all species inhabiting the inlet must be studied before water quality can truly be considered “acceptable”.

The Vancouver Port Authority conducts regular ballast water monitoring to ensure clean water is discharged from vessels visiting the port. Additionally, in 1997, the Port introduced a mandatory mid-ocean ballast exchange program for ships calling on the Port in order to minimize the introduction of non-native species to Canada waters (Vancouver Port, 2001). Ballast water is a possible source of some of the existing non-native species that have already been introduced into the Strait of Georgia (i.e. 64 invertebrates, 22 algal species) (Levings *et al.* 2002).

Due to the high levels of use Burrard Inlet is prone to catastrophic environmental events such as oil, gas or chemical spills (Sandwell Inc., 1991). Two canola oil spills occurred in the winter of 1999-2000, both of which occurred while canola oil was being loaded into ships for export. One-hundred and eighty-one bird casualties in total were collected during and after the first oil spill by the Wildlife Rescue Association, the Stanley Park Zoological Society and by the Canadian Wildlife Service (Personal communication, André Breault, Canadian Wildlife Service). Presumably, a similar number of birds were harmed in the second spill.

The Vancouver Port Authority, Environment Canada, Fisheries and Oceans Canada, BC Ministry of the Environment, Lands and Parks, and Greater Vancouver Regional District have entered into a partnership to form the Burrard Inlet Environmental Action Program (BIEAP). BIEAP's mission is to promote balance between the environment and the economy in Burrard Inlet. BIEAP has taken an ecosystem approach to develop a consolidated management plan for the Burrard Inlet and its entire drainage basin. The management plan aims to be a geographically comprehensive approach to recognize the interrelated nature of all components of an ecosystem – natural environment, humans and human activities, physical, chemical and biological processes – and to place equal emphasis on concerns related to the environment, the economy and the community (Stott and Popple, Draft). Other objectives are to reduce existing contaminant discharge, to control future discharges, to protect and enhance habitat values, and to provide remedial measures for existing environmental impacts (Burrard Inlet Environmental Action Plan, 2001).

Biological setting: Biota of Burrard Inlet

Stockner and Cliff (1979) studied the phytoplankton ecology of Burrard Inlet. Spring phytoplankton blooms, mid-March to early April, were related to the onset of thermal stratification and increased light and nutrient levels. Maximum biomass was reached by mid-May to early June. The authors estimated a mean annual primary production of 350 g $C{\cdot}m^{-2}$ for the inlet. Port Moody Arm was the most productive basin, while the First Narrows showed lowest annual production of the stations sampled. Chlorophyll a levels as well as zooplankton abundance decreased in a seaward direction from a high in Port Moody to a low at Point Atkinson (Stockner and Cliff, 1979). Strong tidal mixing and increased turbidity in the outer inlet caused by the Fraser River plume reduced productivity in the inner and outer harbour (Harrison *et al.*, 1983; Stockner and Cliff, 1979). Additionally, the disparity in the distribution of phytoplankton biomass in the Inner Harbour may have been caused by a net horizontal advection of cells in a seaward direction (Stockner and Cliff, 1979).

Stockner and Cliff (1979) found over 85 taxa of phytoplankton from six major groups: diatoms, dinoflagellates, cryptophytes, silicoflagellates, small chrysophyceans, and euglenophytes. Diatoms and dinoflagellates were dominant. The most abundant species at all stations were *Skeletonema costatum, Chaetoceros spp.*, and *Thalassiosira spp.* (Stockner and Cliff, 1979). Peak zooplankton biomass lagged behind phytoplankton peaks by several weeks. Harrison et al. (1983) explained that dynamic water movements and flushing in the nearshore and estuarine areas of the Strait of Georgia lead to sporadic and massive recruitment of meroplankton. Copepods of the genera *Acartia, Pseudocalanus, Centropages,* and *Epilabidocera* are the more stable components of the nearshore plankton community, though decapod zoea and juveniles as well as barnacle nauplii are also abundant. Extended periods of calm weather can produce large blooms of the larvacean *Oikopleura* (Harrison *et al.*, 1983). Large populations of jellyfish and hydroid medusae (*Aurelia aurita*, *Cyanea capillata*, and *Acquorea acquorea*) in late summer and fall reduce the zooplankton abundance and enable a second peak in phytoplankton abundance in the fall in Burrard Inlet (Stockner and Cliff, 1979). Conditions that concentrate zooplankton, such as physical, chemical and biological gradients, are important for planktivors such as juvenile chum salmon since high densities of prey are required to feed to satiation (Harrison *et al.*, 1983).

Juvenile salmon, particularly chum (*Oncorhynchus keta*) and chinook (*O. tshawytscha*) are abundant in the nearshore areas of Burrard Inlet from early spring to fall (Levy, 1996; Macdonald and Chang, 1993; Naito and Hwang, 2000). Pink salmon, (*O. gorbuscha*) are also abundant in the inlet every second year (Groot *et al.*, 1991; Macdonald and Chang, 1993). Coho salmon (*O. kisutch*) use the nearshore areas of the inlet; however, they are less abundant than either chum or chinook. Sockeye (*O. nerka*), steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) are found with the lowest frequency of all (Levy, 1996; Macdonald and Chang, 1993; Naito and Hwang, 2000). Chum salmon emerge in the spring and migrate from streams to the nearshore and estuarine areas shortly thereafter, sometime between February and October (Healey, 1980). Their peak abundance in the inlet occurs between March and July (Levy, 1996; Macdonald and Chang, 1993). After emergence, juvenile chinook either remain in freshwater for a year or migrate directly to estuaries. Chinook that migrate directly to estuarine nurseries after emergence or after a short freshwater period (60-90 days) are termed ocean-type while those that remain in freshwater for a year are called stream-type (Healey, 1980). Juvenile ocean-type chinook are present in the inlet between April and September with their peak abundance between May and July (Levy, 1996; Macdonald and Chang, 1993). It is commonly stated that the first few months salmon spend at sea is a critical period for the salmon as they experience both high mortality and growth rates (Bax, 1983; Birman, 1969; Fisher and Pearcy, 1989; Godin, 1981; Healey, 1982a; Healey, 1979; Healey, 1980; Healey, 1982b; Karpenko, 1983; Levy and Northcote, 1982; Pearcy *et al.*, 1989; Simenstad and Salo, 1980). These factors are thought to affect the strength of the adult return (Bax, 1983; Healey, 1980; Karpenko, 1987; Peterman, 1978). As the juvenile salmon grow, they move offshore into deeper water and migrate to the Georgia Strait and Pacific Ocean (Healey, 1980).

Adult salmon have been observed returning to spawn in 17 streams that flow into Burrard Inlet (Appendix 2). In addition to naturally spawned fish, there are several hatcheries that release salmon into the inlet (Appendix 3). Most of the chum salmon adult returns are to the Indian River while most chinook adult returns are hatchery fish returning to the Capilano hatchery (Macdonald and Chang, 1993). An average of 20118 chum spawners returned to the Indian River between 1953 and 1997 while an average of 615 chinook returned to spawn in the Capilano between 1971 and 1993 and 106 to the Seymour between 1973-1993 (Appendix 2). In 1999, a total of 639,781 chum and 156,571 chinook fry were released into the inlet (personal communication, G. Bonnell, Fisheries and Oceans Canada) (Appendix 3).

Salmon are not the only fish that use the nearshore areas of the inlet. Renyard (1988) lists 63 species of fishes that have been found in Burrard Inlet. An additional 12 species are listed to be present in the Port Moody Arm (Hanrahan, 1994). Commercially important herring (*Clupea harengus pallasi*), anchovy (*Engaulis mordax mordax*), lingcod (*Ophiodon elongatus*) and other bottom fish such as English sole (*Pleuronectes vetulus*), rock sole (*Lepidopsetta bilineata*) Dover sole (*Microstomus pacificus*), quillback rockfish (*Sebastes maliger*), and kelp greenling (*Hexagrammos decagrammus*) are all present in the inlet (Renyard, 1988). Surf smelt (*Hypomesus pretiosus pretiosus*) spawn on beaches in the outer inlet and are the target of an important recreational fishery (Levy, 1985). Shiner surfperch (*Cymatogaster aggregata*), starry flounder (*Platichthys stellatus*) and staghorn sculpins (*Leptocottus armatus*) are among the most common fishes in the inlet (Renyard, 1988). Many of these species were also caught incidentally in the previous habitat studies that targeted salmon. In addition, Goyette *et al.* (1988) studied the idiopathic liver lesions in English sole and other flatfish in the inlet. Levings (1973) investigated the sediment preferences of the blackbelly eelpout (*Lycodopsis pacifica*). Habitat studies and species inventories were completed at fifty shore units in Burrard Inlet in 1992 and 1993 (ECL Envirowest Consultants, 1992; ECL Envirowest Consultants, 1993). Several species of fish were observed on the subtidal transects from each site and several habitat parameters were recorded, but no conclusions regarding fish habitat were drawn.

In addition to fishes, invertebrates, birds, and marine mammals all utilize Burrard Inlet. Most invertebrate surveys in the inlet have studied particular communities at localized sites such as Maplewood mudflats (Levings and McDaniel, 1974; Paish, 1975; Zogaris, 1980), the Port Moody shoreline (Hanrahan, 1994) or the Kitsilano foreshore (Millen and Donaldson, 1994). Data on invertebrates were also collected in intertidal and subtidal surveys in the inlet (ECL Envirowest Consultants, 1992; ECL Envirowest Consultants, 1993). Divers noted the occurrence of anemones, barnacles, clams, tubeworms, crabs, cucumbers, sea stars and shrimps in an extensive biophysical inventory of the Burrard Inlet (Foreshore, 1996b). These data were recorded on a series of biophysical maps (Foreshore, 1996a). Burd and Brinkhurst (1990) sampled the infauna at 28 subtidal stations throughout the inlet and identified species from the following groups: polychaeta, oligochaeta, bivalvia, aplacophora, scaphopoda, isopoda, cumacea, decapoda, mysidacea, amphipoda, sipunculida, nemertea, holothuroidea, and ophiuroidea. They found the species richness of infauna in the inner harbour to be similar to other nearshore areas in British Columbia but that of the eastern harbour (Port Moody Arm) to be lower. They speculated that the low species richness of Port Moody Arm was due to anthropogenic factors (Burd and Brinkhurst, 1990).

Numerous species of birds utilize the inlet. Over 83,000 birds representing 53 species have been recorded at Maplewood mudflats. Eighty-four percent of these sightings were waterbirds: loons, grebes, cormorants, geese, dabbling ducks, diving ducks, gulls, coots, and alcids; 8% were marsh and shorebirds: great blue heron, sandpipers, plovers; 7% were songbirds

(Paish, 1975). Raptors such as the bald eagle and osprey are also present in Burrard Inlet (Hanrahan, 1994).

Several mammals are known to use the foreshore areas of Burrard Inlet: river otters, black-tail deer, black bears, coyotes, raccoons, Douglas squirrel, American mink, red fox, Norway rat, and unidentified species of bats, voles, and mouse (Hanrahan, 1994; Zogaris, 1980). Harbour seals are the most common marine mammal in the inlet, though grey whales and false killer whales are occasionally observed (Hanrahan, 1994).

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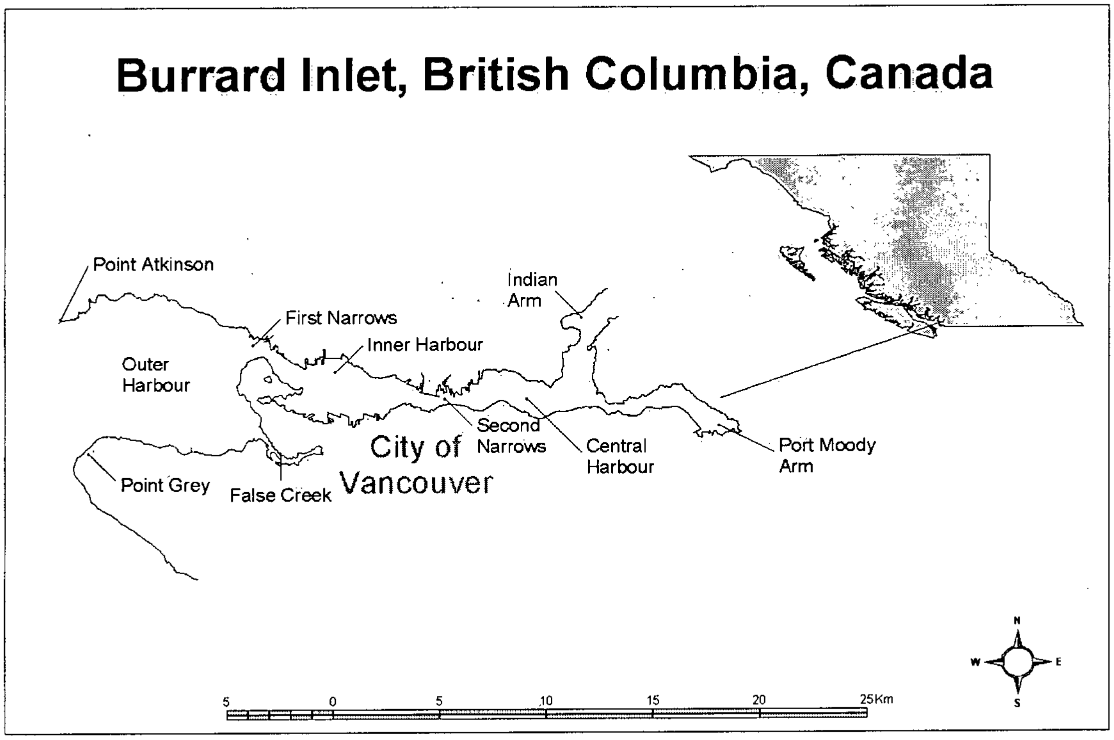

Figure 1.1 Location and geographical features of Burrard Inlet, British Columbia.

Chapter 2

Methods

Defining Spatial Scales

In this study I examine fish habitat in Burrard Inlet at three nested spatial scales. The broadest scale is that of the entire inlet, from Point Atkinson and Point Grey to the end of the Port Moody Arm, minus Indian Arm (Figure 1.1). Despite the fact that the Indian River, at the head of Indian Arm, is a major source of both freshwater and salmonids, Indian Arm was not included in this study because of the physical differences between it and Burrard Inlet.

The next level is the Basin level. I consider three basins in Burrard Inlet: Outer Inlet, Inner Harbour, and Central Harbour. In this study, the Outer Inlet includes all waters west of the First Narrows, including False Creek. This basin is heavily influenced by runoff from the Fraser River (Thomson, 1981) and the constriction at the First Narrows may act as a barrier between the Outer and Inner basins. The Inner Harbour falls between the First and Second Narrows (Figure 2.1). Likewise, the Second Narrows may be a barrier between the Inner and Central Harbours. The Central Harbour starts at the Second Narrows and extends eastward to the end of the Port Moody Arm since no clear division point exists between these Basins.

The third spatial scale is the site level. Sampling sites, distributed throughout the inlet and among the basins are described below. Sampling sites are further subdivided into shore units by substrate type.

Subsequent evaluation of habitat at the whole inlet scale was based on a synthetic evaluation of all the data gathered during this study and others reviewed. Evaluation at the basin scale was based partly on statistical analysis of data collected during this study but with reference to other data sources. Evaluation of habitat at the site scale was based entirely on data gathered at specific sites during this study.

Review of Habitat Classification and Evaluation

To develop a model for habitat assessment in Burrard Inlet, I performed a literature review of habitat classification and evaluation methods. My focus was on models that attempt to evaluate habitat rather than those using habitat parameters as a means of predicting fish populations. I classified the models into categories by their operational spatial scales ranging from a broad, regional scale to the finer, site-level scale. An intermediate scale is the landscape level. This classification matches the nesting of spatial scales that I selected for habitat evaluation in Burrard Inlet.

Near Shore Substrate Delineation

To determine the percentage of the various substrate or habitat types available in the entire Inlet, I subdivided the shoreline into reaches of similar substrates using aerial photographs at the scale of 1:2000 (McElhanney, 1997), the biophysical inventory mapping system for the inlet (1:4,000) (Foreshore, 1996), and Canadian Hydrographic Service nautical charts 3494, 3495, 3496 (1:10,000) and 3311 (1:40,000) (Canadian Hydrographic Service 1993; *ibid.* 1998a; 1998b; 1998c). I mainly determined the substrate types from the biophysical inventory maps, and used the photographs and charts for corroboration. The extent of each reach was determined from the aerial photos and the reach delineations were transferred to the nautical charts using the low-low water line on the nautical charts as a reference line. I then measured the reaches with a Scalex Plan Wheel map-reader. Substrate types identified and measured were Seawall (built structure extending to or beyond the low-low water line); dock (shorelines bordered by docks or marinas including floats); riprap; rubble; bedrock; boulder; cobble; gravel; sand; mud; and combinations of these types.

I grouped the reaches into the following categories (modified from Dethier 1990):

- Mixed fines: mud, sand, mud-sand, mud-gravel, sand-gravel;
- Unconsolidated: cobble, gravel, cobble-gravel, cobble-sand, boulder-cobble-gravel-sand;
- Consolidated: bedrock, boulder, bedrock-boulder, bedrock-sand, bedrock-boulder-cobble-sand;
- Dock: dock-riprap, dock-cobble-mud, dock-rubble, dock-mud;
- Riprap: riprap, riprap-rubble, rubble;
- Seawall: constructed shoreline to the low-low water line.

I summed the length of each shoreline type for the entire inlet and each Basin: Outer Harbour, Inner Harbour, and Central Harbour. I also calculated the total unaltered versus artificial substrate. I considered mixed fines, unconsolidated, and consolidated shoreline types to be unaltered, though this assumption may not be completely accurate since some of these areas may have also been modified or restored. Riprap, Dock, and Seawall are of anthropogenic, or artificial origin.

Field Sampling: Site Scale

I chose seven sampling locations along Burrard Inlet's shoreline. The sites were distributed between West Vancouver and the end of Port Moody Arm and between the North and South shores of the inlet (Figure 2.1). Two sites were in the Outer Harbour, three in the Inner Harbour, and four in the Central Harbour. Sites were chosen for a combination of accessibility and representation of the substrate types present in the Inlet (Table 2.1). Maplewood Mudflats and Rocky Point were chosen because they are the two of the main mudflats in the inlet. Each substrate type was represented by a minimum of two sites.

I divided each site into shore units of like-substrate type. A shore unit is defined as:

> A section of coastline that is continuous and homogeneous in the along shore direction (i.e. parallel to the high tide line) in terms of morphology (i.e. form) and sediment type (i.e. material).. The shore unit extends from the top of the coastal cliff or the landward limit of marine processes to the 20 m depth below low water (Howes *et al.*, 1994).

Although I used this definition as a guideline, my sampling was limited to the intertidal zone and depths of approximately 4 m.

Site Description

I determined the Geographic Position at the center of each sampling site using a Garmin GPS 76 unit, and measured the length and slope of each shore unit (Table 2.2). I described the sampling sites at low tide during the first two weeks in July of 1999, following the protocol in Williams (1989). I divided each sampling site into shore units based on their substrate type. The boundary of the shore unit was sometimes very obvious, e.g., a sand beach abutting riprap. At other times it was more subjective, for example when gravel graded into cobble and large boulders or when a dominant substrate type contained islands of another substrate. For each shore unit, I estimated the percent cover of different sizes of substrate, algae and invertebrates by means of 10 randomly assigned 0.5m x 0.5m quadrats each with 20 point-intercept locations. I randomly assigned the position of the quadrats by establishing a 1m X 1m grid on the shore unit and choosing quadrat locations on the grid using a random number table. I identified and recorded the substrate type and biota under each of the twenty points on the quadrat. Since twenty points were used, each point is assigned a value equivalent to 5% of the quadrat. The quadrat was also scanned for any species or substrate types that were missed in the survey. If any were found they were also recorded and assigned a value of >1%. At extremely large sites, such as Maplewood Mudflats, I surveyed a 50 m X 50 m sub-section from the area where I beach seined.

Although the biota were identified to species whenever possible, I grouped them into the following categories for analysis, algae, barnacles (not identified to species), and other animals. Algae were further divided into overstory – any kelps of the order *Laminariales* and species of the genera *Sargassum, Mazzaella* and *Chondracanthus*; understory – *Ulva, Fucus, Enteromorpha, Mastocarpus,* and *Porphyra*; and turf – green filamentous algae, *Cladophora*, unidentified little red blades, green algae or diatom films. Mussels (*Mytilus*) were the most common species observed in the "other animal" category along with the genera *Littorina* and *Mopalia*.

Because the substrate and biota data were collected as percent cover, I used the arcsine transformation to calculate 95% confidence intervals (Zar, 1996). I then plotted the data (Figures 2.2 and 2.3) to check that I had assigned the shore units correctly, i.e. that the substrate type and biota of the same type of shore units were more similar to each other than they were to different types of shore units. I renamed two shore units based on these measurements: Barnett Riprap became Barnett Boulder, and Third Beach Cobble/Sand joined Third Beach Sand.

Water temperature and salinity were measured at each sampling site on each sampling day. I measured salinity with a refractometer. I measured water visibility or clarity during snorkeling by measuring the horizontal point-of-disappearance of a sechi disk attached to a graduated rope. In all comparisons, the vertical visibility was found to be the same as the horizontal visibility. In comparing sites according to temperature and salinity, I ranked the temperature and salinity data by weekly time period to eliminate seasonal differences and performed Analyses of Variance on the temperature, salinity, and visibility data to test for any differences between sites. All statistical tests were performed with Systat 8.0 unless otherwise stated using a significance level of 5% ($\alpha = 0.05$).

Fish Sampling

I beach seined, snorkeled and made observations from shore to assess juvenile salmonid habitat use between sites and substrate types. Methods varied between sampling locations because not all of the methods could be used at every site (Table 2.3). Two beach seining locations exist at New Brighton and Barnett Marine.

Beach Seining

I beach seined using a 15 m-long beach seine with 3 mm and 18 mm mesh in the bunt and wings respectively. My assistant and I conducted the beach seines by wading out to chest height, dragging the net parallel to shore until the length of the net was parallel to shore, and then returning to shore. The lead line, was kept on the bottom throughout the set. We performed two sets per sampling trip. Although we tried to keep the area swept constant, it depended on the profile of the beach. The area of each set was not calculated. All fish were put in a holding bucket, identified to species (Hart, 1973; Pollard *et al.*, 1997), counted, and moved into a second bucket of water. Both buckets contained battery-powered aerators. Sampling was without replacement and we attempted to seine different parts of the beach on each pass. All of the fish were returned to the water after the last set was made. Temperature, salinity, time of day and tide height were also recorded. I summed the catch in the two sets for all of the analyses.

Snorkel Surveys

I conducted snorkel surveys at five main sites: West Vancouver, Third Beach, Portside Park, New Brighton and Barnett Marine. My assistant and I swam transects parallel to the shore and to each other, swimming in one direction with the current if there was one. Depth of the area surveyed ranged between less than a meter and 3 m. Swimming on our sides at the surface of the water allowed us to view the surface, water column and bottom easily. We collected the following information for each observation: number (estimated or counted), species, the fish's position in water column, water depth (estimated), substrate type, and behaviour. Groups of fish numbering fewer than 20 could usually be counted individually; however, larger schools of fish had to be estimated. The scale we used was 1-20, 40, 50, 75, 100, 200, 200-1000, >1000 fish. All surveys were done at high tide when the water visibility was greatest.

I standardized the snorkel counts by an approximation of the area searched with the following formula: n = number of salmon observed / length of shore unit (m) x water visibility (m).

Shore Observations

We recorded observations of fish from shore by walking a transect parallel to the shoreline. Moving slowly to minimize the degree to which we startled the fish, we waded up to waist deep along beaches, walked along the riprap and at the edge of docks and piers while leaning over to see the fish. We were unable to make observations from shore in the rain or on extremely dark days due to poor visibility and high reflectance off the surface. My assistant and I each covered separate areas simultaneously. We recorded the same information as for the snorkeling surveys.

I totaled the number of chum observed per shore unit per site and divided it by the length of the shore unit to determine an estimate of fish density.

During the first two weeks of April in the year 2000 I recorded observations of juvenile salmon from shore in Coal Harbour, in the southwest corner of the inner harbour, using the same methodology as for the shore observations in 1999. During this survey, however, I also used binoculars to observe the fish more closely. In addition to the numbers of fish seen, I also noted the occurrence of flotsam and oil, as well as the direction of water currents.

I tested for differences between the presence and absence of schools of salmon under areas of flotsam with the Chi-square test. I hypothesized that there would be no difference in the presence or absence of schools of salmon found under the flotsam areas.

Analysis

Since the abundance of chinook and chum decreased throughout the sampling period, I eliminated seasonal differences in abundance by ranking the catches per site or substrate type in each weekly time period and conducted statistical analyses based on the ranks. I used an Analysis of Variance to test for differences in chum and chinook rank abundance between sites and between substrate types for all three data sets: beach seines, snorkel and shore observations. I used the Bonferroni adjustment for post-hoc pairwise comparisons.

To analyze the community data from the beach seining, I used the program Primer to calculate the species diversity of each site with the Brillouin index, H, the appropriate index used for nonrandom samples that may not be representative of the community, such as those collected by seining (Brower *et al.*, 1989). Brillouin's H is defined as:

$$H = (\log N! - \Sigma \log n_i !) / N$$

where N = the total number of individuals in all species, and n_i = the number of individuals per species. I then compared H between sites using an ANOVA (Brower *et al.*, 1989).

I also analyzed the data for species-substrate preferences. I also used the program PC-ORD to perform a Two Way Species Indicator Analysis (TWINSPAN), a hierarchical classification method. TWINSPAN simultaneously clusters the sites and species into groupings based on the species present at each site (Gauch and Whittaker, 1981). Groups of sites are identified on the basis of similar species composition, as are groups of species that tend to found together.

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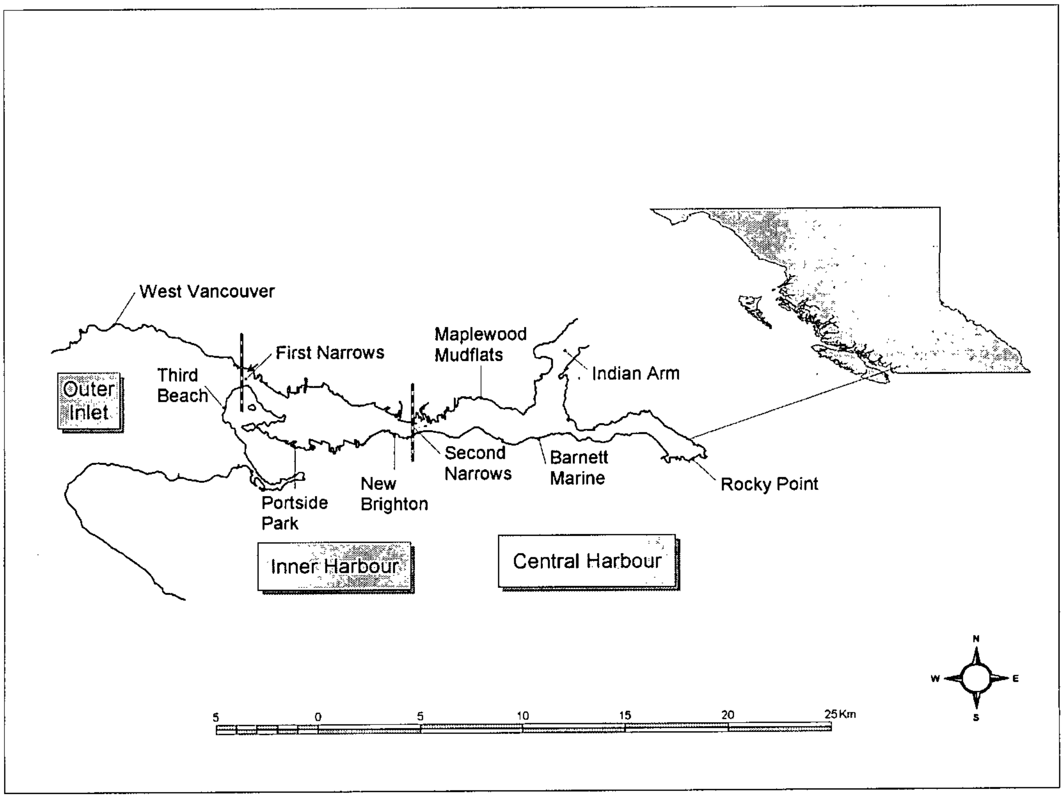

Figure 2.1. Burrard Inlet sampling sites and basins.

Table 2.1. Sampling site substrate types.

Basin (# of substrates)	**Site**	**Shore Unit**						
		Mud	Sand/ gravel	Cobble	Boulder	Bedrock	Riprap	Dock/ pier
Outer	W-Van Lab		X	X	X	X	X	X
(6 types)	Third Beach		X		X	X		
Inner	Portside Park		X	X			X	X
(4 types)	New Brighton		X	X			X	X
Central (5 types)	Maplewood Mudflat	X						
	Barnett Marine		X	X	X			X
	Rocky Point	X						

Table 2.2. Geographic Position of sampling sites and length and slope of shore units.

Site Shore Unit	Latitude Length (m)	Longitude Slope (°)
West Vancouver Lab	N 49°20'24.7"	W 123°14'00.0"
Bedrock	47	16
Boulder	16	6
Cobble/sand	50	6
Pier	133	0
Riprap	110	41
Third Beach	N 49°18'10.4"	W 123°09'23.7"
Boulder/shelf	210	4
Cobble/sand	86	2
Sand	50+	2
Portside Park	N 49°17'10.3"	W 123°06'11.5"
Cobble/sand	90	8
Gravel/sand	25	8
Pier	60	0
Riprap	138	25
New Brighton	N 49°17'26.9"	W 123°02'14.0"
Cobble (E)	60	7
Cobble (W)	63	9
Pier	45	0
Riprap	130	24
Barnett Marine	N 49°17'26.4"	W 122°55'17.3"
Cobble	115	2
Cobble/rubble	50	4
Pier	56	0
Riprap	43	7
Sand	184	4
Maplewood Mudflat	N 49°18'21.8"	W 122°59'59.5"
Mud	50+	2
Rocky Point	N 49°16'49.0"	W 122°50'52.4"
Mud	50+	1

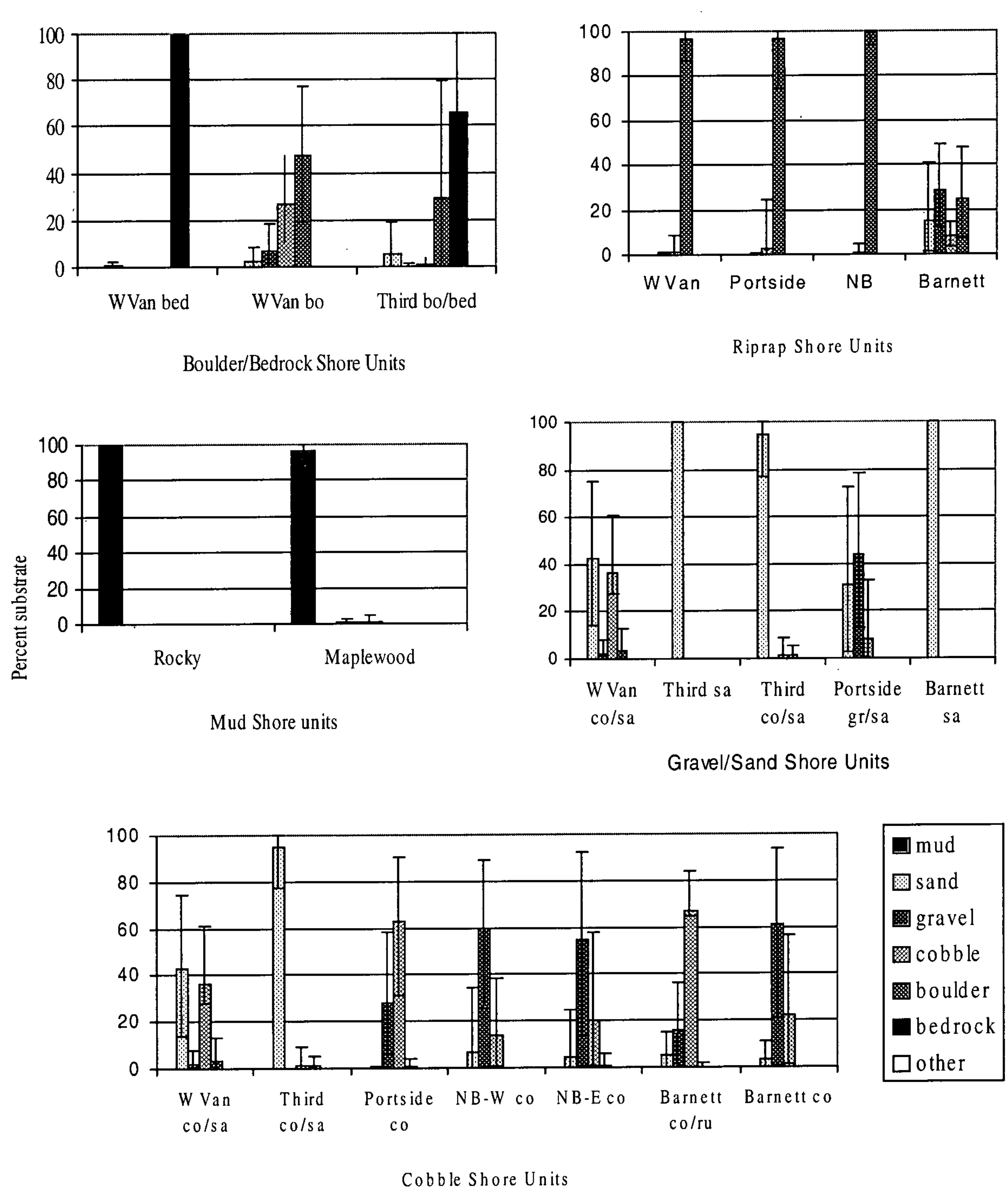

Figure 2.2. Percent substrate type of each shore unit. Error bars are 95% confidence intervals. sa=sand, gr=gravel, co=cobble, bo=boulder, bed=bedrock.

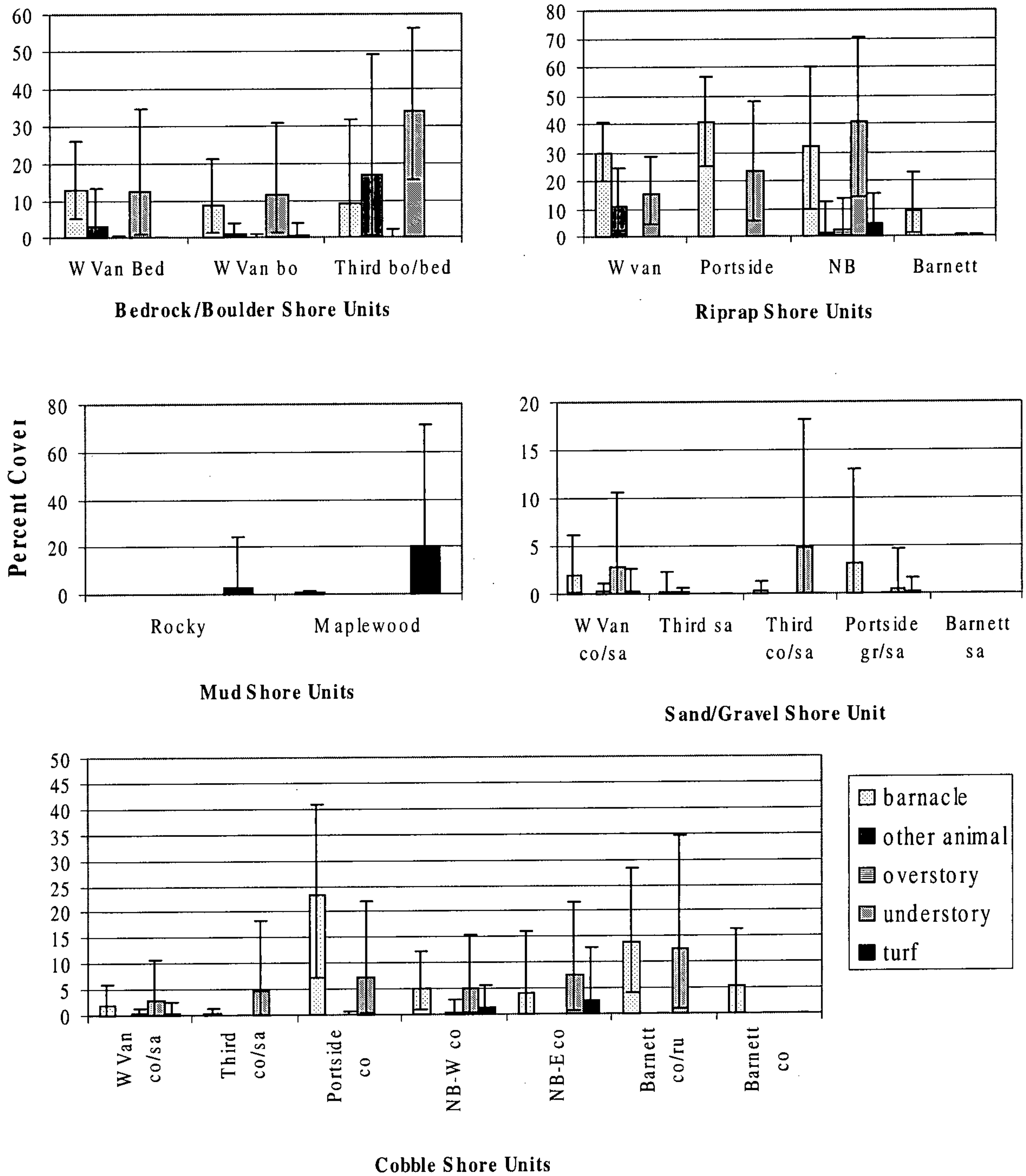

Figure 2.3. Percent cover of biota for each shore unit. Error bars are 95% confidence intervals. sa=sand, gr=gravel, co=cobble, bo=boulder, bed=bedrock. Note that the scales differ.

Table 2.3. Methods used per sampling site.

Site	Beach Seine	Snorkel Survey	Shore Observations
Outer Inlet			
West Van	X	X	X
Third Beach	X	X	
Inner Harbour			
Portside	X	X	X
New Brighton		X	X
West	X		
East	X		
Central Harbour			
Maplewood	X		
Barnett		X	X
Sand	X		
Cobble	X		
Rocky Point	X		
Total	9	5	4

Chapter 3

Fish Habitat Classification and Evaluation Models .

Introduction

Fish habitat in lakes, streams, estuaries and coastal environments has been classified and evaluated in several different ways. Habitat classification systems use a set of rules or procedures to identify, delimit or describe habitats while fish-habitat models aim to describe the relationship between habitat variables and fish properties (Robinson and Levings, 1995). Since habitat models attempt to relate habitat to critical fish properties, the relative value of habitats can be assessed. Habitat classification is descriptive but does not place values on the respective habitats. The approaches vary in their use of physical (e.g. Instream Flow Incremental Methodology) or biological criteria (e.g. Index of Biotic Integrity), from single parameter models (i.e. Probability Density Function models) to multivariate and aggregated indices (e.g. Habitat Suitability Index), and from qualitative (subjective) to quantitative (objective). Habitat classification and evaluation models all have strengths and weaknesses related to the type and number of criteria used and their qualitative versus quantitative nature. Robinson and Levings (1995) provide a thorough overview of habitat classification and evaluation models.

Methods of classifying and evaluating habitat are important management tools but are also important for scientific understanding of biological interactions. The scale of the habitat classification system or model influences the decisions that can be drawn from it. Habitat information at the broadest scale may be useful for management or planning, but may not adequately explain the biology. Conversely, ecologists tend to work at a finer, site-level scale since environmental noise often increases with increasing scale and masks the behaviour of the system of interest (Lewis *et al.*, 1996). A compromise between these two extremes is necessary to achieve proper management as well as adequate understanding of habitats. Such compromises can be reached with the landscape level approach.

The operational scale of habitat classifications and models varies from a broad, regional scale, to a finer site-level scale. Most coastal habitat classification systems fall at the broadest scale, or regional level (Day and Roff, 2000; Dethier, 1990; Zacharias *et al.*, 1998). Many examples are also available from the other end of the spectrum, the site level. Habitat Suitability Index (HSI) models fall into this finer category. The landscape level links the broader and finer scales through meaningful intermediates. Landscape level studies can be divided into hierarchical or multiple scale studies, those which have detailed information over a wide spatial area such that the scale is internally consistent, and those which use assumptions to extrapolate conclusions to wider areas. I will describe a selection of habitat classification and evaluation models at each of these three scales and compare the conclusions that can be drawn from each. I will also discuss Landscape Ecology, a field of Ecology that explores ecological effects of spatial patterns, and some of its key concepts that should be applied to habitat evaluation.

Regional Level

Two examples of broad scale habitat classification systems are the BC Marine Ecological Classification system and the Washington State Marine and Estuarine Habitat Classification System.

The British Columbia government devised a hierarchical marine classification system, the BC Marine Ecological Classification (BC MEC). It encompasses over 453,000 km^2 of coastline and is the most extensive marine classification system that has been attempted for the Pacific coast of Canada. Marine areas of British Columbia are divided into “ecozones,” “ecoprovinces,” “ecoregions,” “ecosections,” and “ecounits.” The ecounit level is the smallest scale (1:250,000) and was developed to clarify the boundaries of the larger divisions and to be used in coastal planning and marine protected area planning. Ecounits were based on a broad categorization of the following attributes: wave exposure, depth, relief, currents, and substrate (Table 3.1) (Zacharias *et al.*, 1998).

The Washington State Habitat Classification System is also hierarchical. The first level of classification is the "system" level: Marine versus Estuarine. These areas are generally separated by salinity, >30 ‰ for marine and <30 ‰ for estuarine, although the author states that transition areas with salinity generally higher than 25 ‰, such as Puget Sound, are difficult to categorize as either marine or estuarine. The two "systems" are divided into the "subsystems" intertidal and subtidal and finally into habitat "class" based on substrate, energy and modifiers (backshore, eulittoral, shallow, and deep) (Table 3.2).

A feature of this system which distinguished it from the BC system is the inclusion of biological information. Dominant or diagnostic species are listed for each habitat type if they are known. The following criteria were used to choose dominant and diagnostic species:

- The species (plant or animal) most abundant at the end of the growing season;
- Numerical and biomass measures;
- The most "obvious" species in the habitat, but not if these are widely distributed among different habitats;
- The species with highest "fidelity" to one habitat type-preferably restricted to one habitat type, even if not necessarily abundant (Dethier, 1990).

In addition to the diagnostic species, common plant and animal species are listed for each habitat type.

Recently, Washington State has combined this methodology with the BC shore-zone mapping system (Howes *et al.*, 1994) to produce an extensive shore-zone mapping inventory for Washington State (Berry *et al.*, 2001).

An advantage of the BC MEC and as well as the physical components of the Washington State classification, is that they can be used to classify habitats at broad spatial scales (whole coasts) based on generally available physical oceanographic and geographic parameters. These parameters tend to be collected at a coarser grain than biological data (Day and Roff, 2000). Though it is convenient from a management perspective to classify large spatial areas, these systems may not adequately address the biological properties of certain areas. For instance the data used to create the BC MEC ecounits, particularly substrate, depth, and relief, are too coarse and do not accurately describe the habitat. In an analysis of the BC MEC for the Central Coast area of British Columbia, it was found that the photic depth category (Table 2.1) missed 72% of actual photic-zone areas because they were too small to map at a scale of 1:250,000. Consequently, many biologically important areas were missed. (Ardron *et al.*, 2001).

The Marine and Estuarine Habitat Classification for Washington State avoids some of the problems of the BC MEC in that it includes biological criteria and has been mapped at a more detailed scale (1:24,000) than the BC MEC. It therefore requires considerably more information, but gives a better representation of the biological features of coastal habitat.

A problem associated with all classification systems, particularly those at broader scales, is that the boundaries of some habitats are poorly defined (Robinson and Levings, 1995). The division between estuarine and marine systems in the Washington State classification is one example of the fuzzy boundaries that are created when attributes that are gradients (like salinity) are arbitrarily divided into broad categories.

Site Level

Habitat Suitability Indices (HSI), Instream Flow Incremental Methodology (IFIM), and Habitat Affinity Indices (HAI) are all similar, site-level habitat assessment methods. The central assumption of this type of modeling is that the importance of a geographical area can be characterized by estimating the habitat requirements of a species and by quantifying the amount of habitat in an area that meets those requirements (Monaco and Christensen, 1997). Table 3.3. summarizes these models.

Models such as HSI can provide a basis for identifying the habitat features at a site that appear to limit fish production (Stoneman *et al.*, 1996). A set of suitability index (SI) curves that describe the presumed relationship between the habitat attributes or environmental variables and their suitability for a particular species (or lifestage) are determined. The SI curves are constructed using quantified field and laboratory data on the effects of each habitat variable (e.g. temperature, dissolved oxygen, substrate, and cover) on the growth, survival or biomass of the species by life stage. The increments of growth, survival or biomass plotted on the y-axis are directly converted into a score between 0.0 (unsuitable) and 1.0 (optimal). The SI curves are then aggregated into an overall Habitat Suitability Index (HSI) for the site (Raleigh *et al.*, 1986).

Rubec *et al.* (1998) combined HSI and a Geographic Information System (GIS) to model fish habitat in Florida estuaries. Each habitat parameter (temperature, salinity, depth, and substrate) was mapped on a different map layer and an HSI algorithm was used to calculate the composite index (Rubec *et al.*, 1998).

Instream Flow Incremental Methodology (IFIM) is similar to HSI, however it focuses on changes in usable habitat for stream-dwelling organisms under various flow regimes. Habitat value is determined based on water depth, water velocity, substrate size, and sometimes cover (Bovee and Cochnauer, 1977; Raleigh *et al.*, 1986; Stalnaker *et al.*, 1995). Probability-of-use curves (equivalent to SI curves and scaled from 0 to 1.0) for various life stages of each species for each habitat variable are developed based on three assumptions (Bovee and Cochnauer, 1977):

- i) Individuals of a species will tend to select areas the in the stream with the most favorable hydraulic conditions;
- ii) Probability-of-use will decrease for less favorable areas; and
- iii) Individuals will leave an area before the conditions become lethal.

Physical Habitat Simulation System (PHABSIM) uses an hydraulic model to determine habitat characteristics under different flows and the probability-of-use curves to calculate an index of habitat value (weighted useable area) at different flows (Raleigh *et al.*, 1986). Instream Flow Incremental Methodology does, however, attempt to take account for scale issues by considering both macro and microhabitat characteristics and by accumulating site specific assessment, or microhabitat, into a broad scale measure with the weighted useable area.

The Habitat Affinity Index (HAI) rates habitats in a similar manner. Rather than developing suitability curves, however, species catch rates and simultaneous habitat/environmental measurements are used to define species habitat affinities quantitatively. Habitats of interest must be previously defined. The HAI compares species concentrations in a specific habitat to the relative availability of the given habitat throughout a larger area (Monaco and Christensen, 1997). The HAI values range from –1 to +1, with –1 representing complete avoidance of a particular habitat, 0 representing no affinity or indifference to a particular habitat, and +1 representing an exclusive affinity to a particular habitat (Monaco and Christensen, 1997). Conceivably, the affinities could be aggregated into an overall index as is done for the HSI and HAI could be used quite effectively on its own or in conjunction with other habitat classification systems.

These three systems provide detailed information about habitat use by particular species, or even life stages of particular species. These systems can be useful in identifying the habitat features at a site that appear to limit fish production. Additionally, information regarding why a particular site receives a low score can be just as useful as the score itself (Stoneman *et al.*, 1996).

There are, nevertheless, some problems associated with application of these site specific systems. First, it can be computationally difficult to aggregate the SI curves into an aggregated index (Terrell *et al.*, 1995). When more than one species or lifestage is included, computations become even more challenging. Although how the indices are aggregated is a critical step in the development of the model, Burgman *et al.* (2001) state that equations used are often either arbitrary or not adequately explained. Furthermore, the uncertainty of the models are rarely formalized and models are infrequently tested for validity (Burgman *et al.*, 2001). The models are also static in nature and, therefore, have difficulty in describing dynamic systems (Terrell *et al.*, 1995).

In addition, the models have considerable data requirements. Detailed information on habitat parameters as well as fish use needs to be gathered at the site level, particularly for the HAI. The models also often suffer from a lack of transferability between sites (Faush *et al.*, 1988; Imhof *et al.*, 1996; Terrell *et al.*, 1995). Therefore, the habitat model for one area cannot necessarily be extrapolated to another. This means that intensive sampling must be carried out over a large area if interested in large spatial scales. Although this may increase biological understanding, it is probably impractical from a management perspective.

Landscape Level

The landscape level lies between the broad, regional scale and the finer, site scale. Three examples (Fish Habitat Classification Model for Severn Sound, the Fraser River Estuary Classification, and the Prince Rupert Harbour Foreshore Habitat Classification) attempt, with varying success, to combine habitat classification and habitat evaluation. Habitat at a scale greater than the site is classified and ranked and it's fish habitat value is assessed. Although these three models operate at a landscape scale, greater emphasis could be placed on landscape-level issues that will be discussed in the following section.

Minns *et al.* (1999) developed a "Fish Habitat Classification Model for Littoral Areas of Severn Sound, Georgian Bay, Ontario." This system classifies nearshore fish habitat as Red (high value), Yellow (medium value), and Green (low value). This complex modeling exercise, summarized in Figure 3.1, builds on several years of habitat research and two extensive databases: the Severn Sound Littoral Zone Physical Database, and the Severn Sound Freshwater Species Habitat Requirement Database. This modeling work was enabled through the use of Geographic Information Systems (GIS).

The physical habitat database resulted from intensive field sampling and contains the following information for most of Severn Sound's shoreline: bottom substrate; emergent and submerged vegetation composition and cover; shoreline material; depth contours; and other point features such as docks. These data are managed as separate themes in a GIS. The fish habitat requirement database contains habitat information of all fish species that are found in the littoral areas of the sound. These two databases were used to rate littoral habitats for fishes using "defensible methods" software, developed for assessing site-specific developments in nearshore habitats of the Great Lakes (Minns *et al.*, 1995). The resulting fish habitat classification model was then tested and validated with a survey of fish communities and habitat characteristics (Randall *et al.*, 1998; Valere, 1996).

A rarity analysis, wetlands identification and expert information augmented the classifications. Numerous categories of habitat resulted from this process so a non-parametric statistical approach called Classification and Regression Tree analysis (CART) was used assign habitats to the final three classes: Red, Yellow, Green (Minns *et al.*, 1999).

Details of this modeling procedure are given in Minns *et al.* (1995 & 1999). Though the authors state that this system is both defensible and repeatable, the methodology is extremely difficult to follow. Reproducing this system in a different environment, such as nearshore ocean or estuarine environments, would be difficult. It would require intensive fish and habitat sampling, in-depth life history and habitat information about all species, and the development or expansion of the "defensible methods" software.

None-the-less, interesting conclusions can be drawn from this work. Models are limited by the quality of data used in their creation. This model incorporated detailed habitat and fish information, therefore strong conclusions about habitat quality could be reached.

Models must also be tested. Testing of the fish habitat suitability ratings against catch data that were not used in the development of the model helped to validated it. The model was further verified for accuracy with expert opinion and the overlay of identified wetlands.

The rarity analysis is one of the most important aspect of this model since habitat patches were considered in relation to other habitats within the landscape. As a result of this analysis, rare habitats with low or medium value ratings were reassigned as high value (Minns *et al.*, 1999).

Another important aspect of this model is that it considered the entire community of nearshore fishes, not just commercially important ones. Community dynamics were taken into consideration by grouping fishes into trophic guilds and thermal groups.

The statistical methodology (CART) that was used to reduce the number of habitat suitability ratings to 3 discrete categories is one component of this model that could be used in other situations. A statistical method to define discrete categories from relatively continuous habitat is very useful since habitats are usually gradients environmental variables rather than discrete units (Dethier, 1990; Robinson and Levings, 1995).

The Fraser River Estuary Habitat Classification is a habitat inventory and classification system of the North Arm of the Fraser River that was completed in 1986. It was then expanded in 1990 to include other areas of the lower Fraser River. The habitat classification was primarily driven by an assessment of juvenile salmon requirements, with emphasis on riparian vegetation and marsh areas (Archipelago, 1999). As in the Severn Sound classification, habitat is grouped into three classes: Red (highly productive habitat); Yellow (moderately productive habitat); and Green (low productivity habitat). Definitions of these three categories are shown in Table 3.4.

As is apparent from Table 3.4, the criteria for this classification are far less formalized than those used in the Severn Sound Classification. The classification criteria are also not transparent. Despite several attempts, I was not able to find any additional information that led to the classification of the habitats. Although this three-tiered classification scheme is convenient from a management perspective, it has been highly criticized for it's subjective classifications and is, therefore, harder to defend on scientific grounds. In addition, habitat, particularly in an estuary, is not static. Habitat re-evaluations need to be performed but this has not been done (Kistritz, 1996). Another serious limitation to this system is the emphasis placed on juvenile salmonids rather than community or ecosystem-level attributes.

Foreshore habitat in Prince Rupert harbour was classified as part of a management plan for the harbour (Archipelago, 1999). Three steps were taken: habitat inventory, foreshore classification, and development conditions and criteria (Archipelago, 1999). The intertidal habitat inventory used a combination of techniques:

- An intertidal vegetation inventory using airborne multi-spectral (CASI) imaging;
- Ground-truthing observations to assist with interpreting CASI survey;
- Oblique aerial video imagery of intertidal shoreline
- Colour air photos
- Ground and boat observations (Archipelago, 1999).

Aerial video and air photos were used to identify shore units, or areas with similar morphology, substrate, and physical processes, following the BC shore-zone classification (Howes *et al.*, 1994). The BC shore-zone system identifies 34 shore types that can be generalized into:

- rock shorelines;
- combinations of rock and sediment shorelines;
- sediment shorelines;
- estuary shorelines;
- man-made shorelines (Archipelago, 1999).

The shore units from the Prince Rupert shoreline were entered into an Access database and into a geographic information system. Both physical and biological features (vegetation, substrate, wave exposure) were used in this classification.

Each shore unit was evaluated for its habitat value using the "ecological" and "other" criteria listed in Table 3.5. The shore unit valuations were then used to assign overall values to shoreline. As in the previous two systems, the shoreline was classified as Red (high habitat value), Yellow (moderate habitat value) and Green (low habitat value) in a manner outlined in Table 3.6. This classification is intended to guide management decisions.

Although this system is much more transparent and more defensible than the Fraser River Estuary classification, the investigators still had to make some large assumptions about habitat quality. For instance, sites with existing habitat compensation were accorded high habitat value. However, there is no guarantee that the habitat compensation project successfully created productive habitat. Although some broad assumptions were made in this classification system, it is less data intensive and probably easier to understand than the Severn Sound example.

Landscape Ecology

An interest in large-scale spatial dynamics and the ecological effects of spatial patterns has led to the formation of Landscape Ecology. Landscape Ecology is "the study of processes occurring across spatially heterogeneous mosaics and the biotic responses to the resulting patterns" (Robbins and Bell, 1994). A landscape is a matrix of habitats or patches whose identity, scale and spatial extent are determined by the individuals that exploit it (Knight and Morris, 1996; Robbins and Bell, 1994). There are three main components to landscape: (1) structure, or the spatial relationships among distinct elements; (2) function, the interactions among spatial elements; and (3) change, temporal alterations in the structure and function of landscape mosaics. Landscape Ecology therefore allows questions concerning processes which influence ecological heterogeneity to be addressed in spatially explicit terms (Robbins and Bell, 1994). As the name implies, the principles and concepts of Landscape Ecology were originally developed for terrestrial applications; however, they are applicable to marine and aquatic situations (Kuiper, 1998; Robbins and Bell, 1994; Shreffler and Thom, 1994; Simenstad and Cordell, 2000). Several metrics or indices to assess landscapes have been developed.

- Landscape diversity: a measure of the proportion of the landscape exhibiting different elements. It is similar to species diversity.
- Landscape dominance or rarity: the proportion of the different types of habitats compared to the other elements in the landscape.
- Complexity: commonly a measure of patch size and shape, based on the ratio of patch perimeter to area.
- Patch isolation: the distance between an individual patch and its nearest neighbors.
- Contiguity: a measure of patch aggregation or dispersion (Robbins and Bell, 1994).

Contiguity and patch isolation are two components of what is sometimes called connectivity (Shreffler and Thom, 1994; Simenstad and Cordell, 2000).

Conclusion

The management of fish habitat has traditionally focussed on site-level strategies (Imhof *et al.*, 1996). Habitat classification, on the other hand, often takes place at regional scales. There are limitations at both extremes, the site and regional levels, as they are either impractical for management or lack biological meaning. Examining habitat characteristics using a larger context, such as the watershed, are becoming more popular in freshwater environments since habitat changes at the site level are often a result of changes at the reach or watershed scale (Imhof *et al.*, 1996). Littoral habitat in lakes, estuaries and coastal environments have also recently been examined at a landscape scale. This requires either very detailed information (as detailed as for the site-level investigations) over large spatial areas (i.e. Severn Sound and Washington State Shore-zones) or that assumptions and extrapolations be made. If the latter happens, assumptions and evaluation criteria must be transparent as in the Prince Rupert Harbour example and not opaque as in the Fraser River Estuary example. Regardless of the method used, it is imperative that the proper scale be selected for habitat assessments both from a management perspective and for the biological understanding of habitats.

Evaluating habitats at the landscape scale also allows us to broaden our perspective. Some of the landscape-level models I have reviewed use some landscape ecology principles, such as the rarity analysis in Minns *et al.* (1999). However, we must move to incorporate more landscape-level metrics in habitat assessments. Of particular importance are habitat diversity, dominance, rarity, complexity and connectivity. Taking a broader view of habitat also requires that we look past commercially significant species. Langston and Auster (1999) explain that two traditionally identified functional roles of habitat are to maintain biodiversity and to sustain fisheries. We must, therefore, begin to view fish and fish habitat as components of regional biodiversity.

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Table 3.1. Attributes and classification for ecounits (Zacharias *et al.*, 1998).

Attribute	Class	Description
Wave exposure	High:	Fetch> 500 km. Ocean swell
	Medium	Fetch 50-500 km. Some swell
	Low	Fetch <50 km. Protected
Depth	Photic	0-20 m
	Shallow	20-200 m
	Moderate	200-1,000 m
	Abyssal	>1,000 m
Relief	High	Abundant cover and diversity of habitats
	Low	Smooth or gently undulating bottom
Currents	High	Maximum currents >3 knots (1.54 m/s)
	Low	Maximum currents <3 knots (1.54 m/s)
Substrate	Hard	Bedrock, boulders, cobble, and some sand/gravel
	Sand	Sand, gravel/sand, and some mud
	Mud	Mud, sandy mud
	Unknown	Not sampled

Table 3.2. Outline of Washington State Marine and Estuarine Classification System (Dethier, 1990).

System	**Marine**	**Marine**	**Estuarine**	**Estuarine**
Subsystem	**Intertidal**	**Subtidal**	**Intertidal**	**Subtidal**
Classes				
Consolidated	Rock • Exposed • Partially exposed • Semi-protected Boulders • Exposed • Partially exposed • Semi-protected Hardpan	Bedrock and boulders • Moderate to high energy • Low energy	Bedrock • Open Hardpan Mixed-coarse • Open	Bedrock-boulder • Open
Unconsolidated	Cobble • Partially exposed Mixed-coarse • Semi-protected to protected Gravel • Partially exposed • Semi-protected Sand • Exposed and partially exposed • Semi-protected Mixed-fine • Semi-protected and protected Mud • Protected Organic (e.g. wood, debris)	Cobble • High energy • Mixed-coarse • Moderate to high energy Gravel • High energy Mixed-fine • High energy • Moderate energy • Low energy Mud and mixed fine • Low energy Organic	Gravel • Open • Partly enclosed, Eulittoral Sand • Open • Partly enclosed, Eulittoral • Lagoon Mixed-fine • Partly enclosed • Lagoon Mixed-fine and mud • Partly enclosed, Eulittoral • Lagoon • Channel-slough Mud • Partly enclosed and enclosed Organic • Partly enclosed, backshore	Cobble • Open Mixed-coarse • Open Sand • Open • Partly enclosed Mixed-fines • Open Mud • Open • Partly enclosed Sand and mud • Channel Organic
Artificial Reef	(e.g. oyster, worm)			

Table 3.3. Steps for site level habitat models.

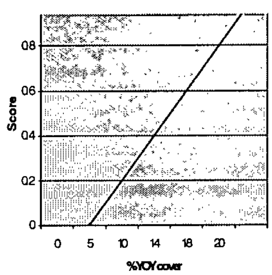
Steps	Habitat Suitability Index HSI	Instream Flow Incremental Methodology IFIM	Habitat Affinity Index HAI
1.	Choose Habitat Parameters: • temperature • salinity • depth • substrate • vegetation • other?	Flow Parameters Pre-chosen: • depth • velocity • substrate • cover	Define Habitats
2.	Create Suitability Index (SI) Curves for each parameter and life stage 	Create Probability-of-use curves for each parameter and life stage Value = 0 to 1	Measure catch rates and habitat simultaneously
3.	Calculate aggregated index = HSI Model Value = 0 to 1	Use PHABSIM (Physical Habitat Simulation System) to create index Value = Product of values of individual probability of use curves. Weighted Useable Area (WUA) = Sum of Values for Stream Reach.	Calculate Habitat Affinity Index: **HAI= (p-r)/r** if p< or = r, or **HAI=(p-r)/(1-r)** if p> or = r, **p=** proportion of species collected in specific habitat **r=** proportion of area that the habitat comprises in the study area Value = -1 to +1

Table 3.4. Habitat Classification Definitions used in the Fraser River Estuary (FREMP, 1996)

Code	Habitat description 1994	Estuary Management Plan Definitions, 1994	Habitat description, 1996	Refined Definitions 1996
Red	Highly productive	No development permitted unless mitigation can be applied to ensure that no alteration or alienation to existing habitats will occur.	Shoreline areas having highly productive habitat features and/or areas where habitat compensation has been previously constructed to offset habitat impacts.	Development may occur provided that mitigation is applied through site location and/or design to avoid impacts on habitat features of the area. Habitat compensation is not an option. The only circumstances whereby exception to the above guideline can be considered are where the project is specifically undertaken in the interest of public health and safety. Even in these cases, alternative siting and design mitigation will be pursued to the maximum extent possible.
Yellow	Moderately productive	Development permitted subject to satisfactory mitigation and/or compensation	Shoreline areas having moderately productive habitat features	Development may occur provided that mitigation and/or compensation measures are incorporated into the project design to ensure that there is NO NET LOSS of productive capacity as a result of the project. Mitigation options should be pursued to the maximum extent possible prior to consideration of compensation for unavoidable impacts on habitat features.
Green	Low productivity	Development permitted subject to environmentally sound design and timing restrictions	Shoreline areas with low productivity or lacking habitat features	Development may occur provided that reasonable efforts are made to mitigate environmental impacts through appropriate location and design. Habitat compensation will not be a condition of approval.

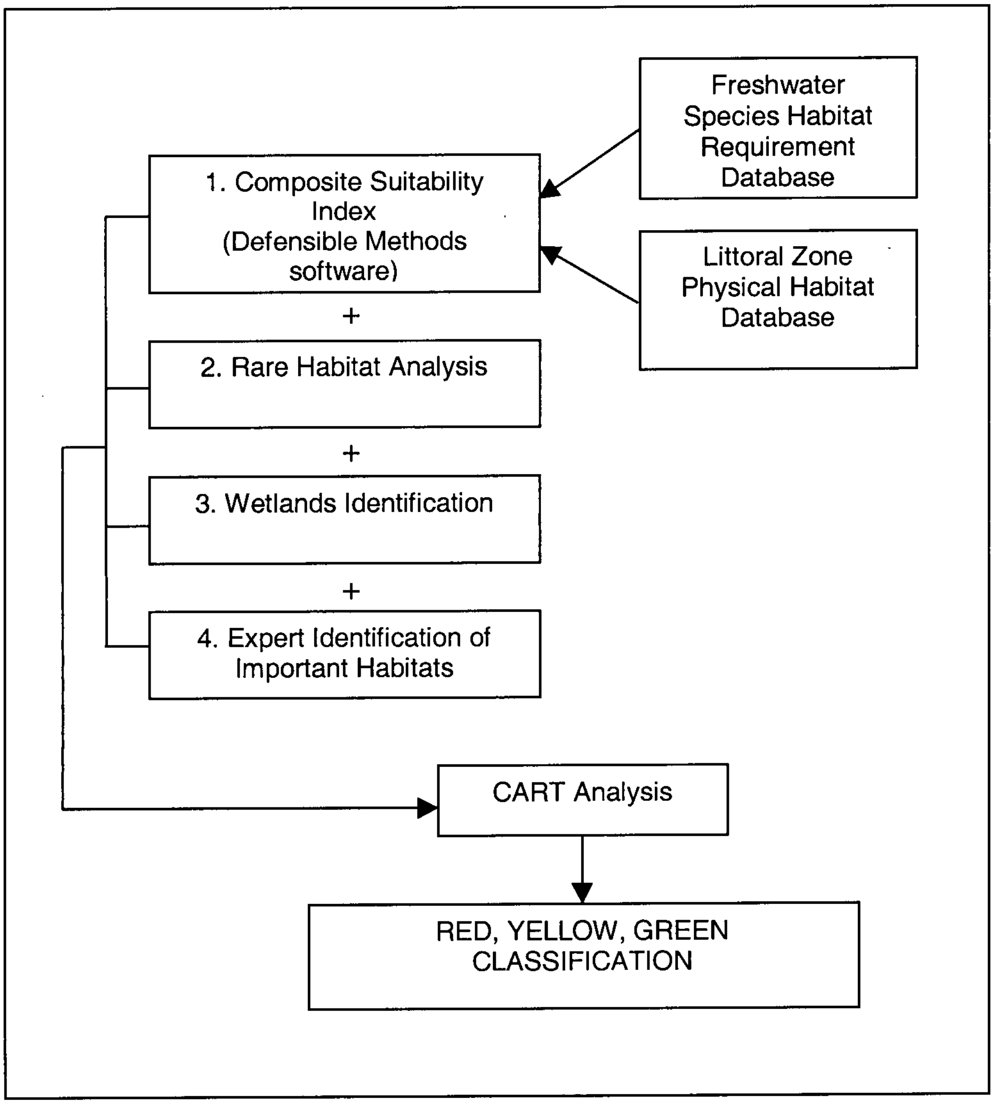


Figure 3.1. Flow chart of Severn Sound habitat classification model.

Table 3.5. Criteria used to classify shore units in Prince Rupert Harbour (Archipelago, 1999).

Ecological Criteria	Other Criteria
Habitat sensitivity • Sensitive • Not sensitive Rare or uncommon habitats • Locally uncommon • Provincially rare • Not rare or uncommon Habitat complexity • Low • Medium • High Fisheries Resource value • High • Medium • Low	Degree of modification • High • Medium • Low Presence of existing habitat compensation • Present • Not Present Restoration potential • High priority • Lower priority • Unknown

Table 3.6. Criteria for red, yellow and green coding of shore units in Prince Rupert Harbour.

Foreshore Code	Criteria
Red (high value)	• Sensitive or rare/uncommon habitat • High habitat complexity and or fisheries resource value • Existing compensation site • High priority restoration site
Yellow (medium value)	• No sensitive or rare/uncommon habitat or species • Moderate complexity or fisheries resource value • Lower priority restoration site
Green (low value)	• Low complexity and low fisheries resource values

Chapter 4

Determining Scales and Evaluating Juvenile Chum and Chinook Salmon Habitat in Burrard Inlet.

Abstract

Nearshore habitat loss and alteration are the main threats to the health of the marine environment in the Georgia Basin despite the no-net loss of productive fish habitat policy of the Department of Fisheries and Oceans. One problem with maintaining productive fish habitat concerns the choice of the appropriate scale at which to assess habitat. I studied the habitat use of chum (*Oncorhynchus keta*) and chinook (*Oncorhynchus tshawytscha*) salmon in Burrard Inlet at three nested scales: the entire inlet; basins within the inlet; and sites within each basin. I sampled juvenile chum and chinook using different substrate types by beach seining, snorkeling and by observing chum from the shore. I also performed an analysis of the different nearshore substrate types found along Burrard Inlet's entire shoreline. Juvenile chum and chinook use nearshore habitats in Burrard Inlet from early spring to late summer. The abundance the two species among the basins in the inlet corresponds to the strength of the runs of the nearby rivers and streams. More fish are therefore found at the western end of the inlet than the east. At the level of the site, juvenile chinook tended to use larger substrates such as bedrock, boulders and cobble than sand or mud. More juvenile chum were also found over cobble and gravel substrates than sand or mud. Juvenile salmon habitat can not, however, be solely assessed at the level of the site. Landscape-level metrics such as habitat connectivity, isolation, rarity, and abundance must be considered as juvenile salmonids must use a variety of nearshore habitats as they migrate to the sea. These habitat evaluation metrics are particularly important in urban situations such as Burrard Inlet that have already undergone considerable habitat alterations. My analysis showed that 44.6% of Burrard Inlet's shoreline has already been altered. The Inner Harbour, at 79.7%, is the basin where most of the alteration has occurred.

Introduction

The conservation of fish habitat is an important topic in North America. The productive capacity of fish habitat is protected by Canada's Fisheries Act; essential fish habitat is protected by the Sustainable Fisheries Act in the United States. Both acts acknowledge the important role that habitat plays in sustaining fisheries. Habitat loss or alteration is also considered to be a major threat to marine biodiversity (British Columbia/Washington, 1994; Norse, 1993).

Despite the importance of habitat, methods of identifying and evaluating fish habitat are fraught with difficulty. Three questions regarding fish habitat evaluation must be resolved: What metrics should be used to measure population processes affected by habitat; which habitat characteristics should be measured to assess habitat quality; and at what scale should habitat and populations be measured at (Hayes *et al.*, 1996; Kocik and Ferreri, 1998; Langston and Auster, 1999; Simenstad and Cordell, 2000)?

I studied juvenile chum (*Oncorhynchus keta*) and chinook (*O. tshawytscha*) habitat use in Burrard Inlet, British Columbia. Juvenile chum and chinook are abundant in the nearshore areas of Burrard Inlet from early spring to fall (Levy, 1996; Macdonald and Chang, 1993; Naito and Hwang, 2000). Chum salmon emerge in the spring and migrate to the nearshore and estuarine areas shortly thereafter, between February and October (Healey, 1980). Their peak abundance in the inlet occurs between March and July (Levy, 1996; Macdonald and Chang, 1993). Juvenile ocean-type chinook are present in the inlet between April and September with their peak abundance between May and July (Levy, 1996; Macdonald and Chang, 1993). As the juvenile salmon grow, they move offshore into deeper water and migrate to the Georgia Strait and Pacific Ocean (Healey, 1980).

I used the abundance of fish as the population metric to assess quality. Patterns of habitat use are often investigated by relating the abundance of the particular life stage of fish to specific environmental variables (Kramer *et al.*, 1997). Kramer *et al.* (1997) lists several factors that can cause the density of fishes to vary among habitats and microhabitats: differential reproduction and mortality, colonization and extinction, involuntary transport and voluntary movements. Greater abundance of fish in certain habitats can therefore be used as a metric to indicate greater habitat quality.

I identified substrate type as the primary habitat component. Substrate is a strong indicator of habitat type since it correlates well with other aspects of habitat such as algae and invertebrates, as well as physical properties such as exposure and slope. Equating substrate with habitat is also practical from a management perspective. Substrate is easily identified and measured, is relatively stable throughout time, and can be mapped. Substrate is also a habitat feature that is often altered physically by human activity, particularly in urban situations where shoreline development is high. For instance, much of the nearshore habitat in Burrard Inlet, one of Greater Vancouver's two main waterways, has already been altered or lost (Macdonald *et al.*, 1990; Precision-Identification, 1997).

Past studies of fish habitat in Burrard Inlet also focussed on the abundance of salmonids with respect to substrate type (Levy, 1996; Macdonald and Chang, 1993; Naito and Hwang, 2000; Nelles, 1978) . These studies concentrated on cobble, gravel, and sand beaches since beach seining is a common method of sampling juvenile salmon, and because gravel beaches are considered to be one of the most natural substrate types in the inlet (Macdonald and Chang, 1993). A considerable amount of the inlet's shoreline is, however, made up of other substrate types. Additional natural substrate types include boulders, bedrock, mudflats, and sand beaches. Manmade or altered substrate types that are also common in the inlet include riprap, rubble, and shoreline with docks, floats, piers, marinas, and seawalls. In addition to cobble, gravel and sand beaches, I also studied salmonid habitat use of mudflats, boulder and bedrock areas and constructed shoreline types such as riprap, rubble and piers.

Previous studies have approached habitat from a site scale. Though several sites were sampled in some studies i.e. (Levy, 1996; Naito and Hwang, 2000) fish habitat has not been investigated or evaluated on the scale of the entire inlet. In this study, I take a landscape approach and consider habitat at three nested geographic scales: the entire Inlet; by basin; and by site.

A landscape is a matrix of habitats or patches whose identity, scale and spatial extent are determined by the individuals that exploit it (Knight and Morris, 1996; Robbins and Bell, 1994). In addition to the quality and quantity of habitats, the spatial relationship between habitats has long been accepted as an important aspect of overall habitat suitability and productive capacity in wildlife management. Determining the appropriate scale at which to study habitat by considering how organisms move between habitats is also important in fisheries management and ecology (Kocik and Ferreri, 1998). Knight and Morris (1996) explain that the ecological and evolutionary significance of habitats to individuals must be included among the criteria that ecologists use to identify habitats.

Applying landscape ecology principles to the study of habitat is particularly appropriate for juvenile salmon since they are dependent on landscape rather than site-specific attributes (Kocik and Ferreri, 1998; Simenstad and Cordell, 2000). Salmon interact with the changing habitats along the entire estuarine gradient and indeed the entire fresh water-ocean continuum. Therefore, salmon respond "to the organization of patches, corridors, and matrix of habitats through which they move and interact as a part of the 'trophic relay' to the ocean" (Simenstad and Cordell, 2000).

Several metrics or indices to assess landscapes have been developed. Landscape diversity is a measure of the proportion of the landscape exhibiting different elements. Landscape dominance or rarity considers the proportion of the different types compared to the other elements in the landscape. Landscape complexity, can be measured based on the ratio of patch perimeter to area. Patch isolation, or the distance between an individual patch and its nearest neighbors; and contiguity, a measure of patch aggregation or dispersion, are two components of what is sometimes called connectivity (Robbins and Bell, 1994); (Shreffler and Thom, 1994; Simenstad and Cordell, 2000). Simenstad and Cordell (2000) discuss some additional landscape-scale metrics appropriate to the assessment of estuarine habitat function for anadromous salmonids: length of uninterrupted (e.g. vegetated) edge or habitat fragmentation; lengths or network dimensions of entrapment zones (e.g. tidal/current fronts) for neuston and other prey; and continuity between estuarine and undisturbed upland habitat (buffer width and extent). Many of these metrics apply to the assessment of juvenile chum and chinook habitat in Burrard Inlet.

In this study, I examined fish habitat in Burrard Inlet at three nested spatial scales: the entire Inlet; basins within the inlet; and sites within each basin. I sampled juvenile chum and chinook in different substrate types by beach seining, snorkeling and observing chum from shore. I also performed an analysis of the different nearshore substrate types found along Burrard Inlet's entire shoreline. Although site-specific habitat assessments are important, juvenile salmonid habitat must be viewed within a larger context and using landscape-level metrics.

Methods

Defining Spatial Scales

The broadest scale is that of the entire inlet, minus Indian Arm. Despite the fact that the Indian River, at the head of Indian Arm, is a major source of both freshwater and salmonids, Indian Arm itself was not included in this study because of the substantial physical differences between it and Burrard Inlet.

The next level is the Basin level. I consider three basins in Burrard Inlet: Outer Inlet, Inner Harbour, and Central Harbour (Figure 4.1). In this study, the Outer Inlet includes all waters west of the First Narrows, including False Creek. This basin is heavily influenced by runoff from the Fraser River (Thomson, 1981) and the constriction at the First Narrows may act as a barrier to fish movement between the Outer and Inner basins. The Inner Harbour falls between the First and Second Narrows. Like First Narrows, the Second Narrows may be a barrier between the Inner and Central Harbours. The Central Harbour starts at the Second Narrows and goes east to the end of the Port Moody Arm since no clear division point exists between these Basins.

The third spatial scale is the site level. Sampling sites, distributed throughout the inlet and among the basins are described below. Sampling sites are further subdivided into shore units based on substrate type.

Evaluation of habitat at the whole inlet scale was based on a synthesis of all the data gathered during this study and others reviewed. Evaluation at the basin scale was based partly on statistical analysis of data collected during this study but with reference to other data sources. Evaluation of habitat at the site scale was based entirely on data gathered at specific sites during this study.

Nearshore Substrate Delineation

To determine the percentage of the various substrate or habitat types available in the entire Inlet, I broke the shoreline into reaches of similar substrates using aerial photographs at the scale of 1:2000 (McElhanney, 1997), the inlet's biophysical inventory mapping system (1:4,000) (Foreshore, 1996), and Canadian Hydrographic Service nautical charts 3494, 3495, 3496 (1:10,000) and 3311 (1:40,000) (Canadian Hydrographic Service 1993; *ibid.* 1998a; 1998b; 1998c). I mainly determined the substrate types from the biophysical inventory maps, and used the photographs and charts for corroboration. The extent of each reach was determined from the aerial photos and the reach delineations were transferred to the nautical charts using the low-low water line on the nautical charts as a reference line. I then measured the reaches with a Scalex Plan Wheel map-reader. Substrate types identified and measured were seawall, dock (shorelines bordered by docks or marinas), riprap, rubble, bedrock, boulder, cobble, gravel, sand, mud, and combinations of these types. I grouped the reaches into the categories shown in Table 4.1, modified from those used in Dethier (1990). I determined the length of each shoreline type for the entire inlet and each Basin. I also calculated the total unaltered versus artificial substrate.

Field Sampling: Site Scale

I studied salmonid habitat use at seven sampling locations along Burrard Inlet's shoreline. The sites were distributed between West Vancouver and the end of Port Moody Arm and between the North and South shores of the inlet (Figure 4.1). Sites were chosen for a combination of accessibility and representation of the substrate types present in the Inlet. I divided each site into shore units with the following substrate types: mud, sand, gravel, cobble, boulder, bedrock, riprap, and dock/pier as defined by (Williams, 1989a). Although the shore units were delineated visually, I tested the accuracy of the divisions by measuring the substrate and biota of ten randomly assigned quadrats within each shore unit (see Chapter 3).

Physical Measurements

I took water temperature with a thermometer and measured salinity with a refractometer at each site every time it was sampled. I measured water visibility or clarity while snorkeling by measuring the horizontal point-of-disappearance of a sechi disk attached to a graduated rope. In comparing sites according to temperature and salinity, I ranked the temperature and salinity data by weekly time period to eliminate seasonal differences and performed analyses of variance on the coded data. All statistical tests were performed with Systat 8.0 using a significance level of 5% ($\alpha = 0.05$).

Juvenile Chum and Chinook Habitat Use

I beach seined, snorkeled and made observations from shore to assess juvenile salmonid habitat use between sites and substrate types. Not all of the methods could be used at every site, therefore the methods varied between sampling locations as shown in Table 4.2. Two beach seining locations exist at New Brighton and Barnett Marine.

I beach seined using a 15 m-long beach seine with 3 mm and 18 mm mesh in the bunt and wings respectively. My assistant and I conducted the beach seines by wading out to chest height, dragging the net parallel to shore until the length of the net was parallel to shore, and then returning to shore. The lead line, was kept on the bottom throughout the set. Although we tried to keep the area swept constant, it depended on the profile of the beach. The area of each set was not calculated. All fish were put in a holding bucket, identified to species using Pollard *et al.* (1997), counted, and moved into a second bucket of water. Both buckets contained battery-powered aerators. We performed two satisfactory sets per sampling trip. Sampling was without replacement and we seined different parts of the beach on each pass whenever possible. All of the fish were returned to the water after the last set was made. I summed the catch in the two sets for all of the analyses.

During the snorkel surveys, my assistant and I swam transects the length of the site, parallel to the shore and to each other, swimming in the direction of the current. Depth of the area surveyed ranged between less than a meter and 3 m. Swimming on our sides at the surface of the water allowed us to view the surface, water column and bottom easily. All surveys were done at high tide when the water visibility was greatest. We collected the following information for each observation: number, species, the fish's position in water column, depth (estimated), substrate type, and behaviour. Groups of fish less than 20 could usually be counted individually; however, larger schools of fish had to be estimated with the following scale: 40, 50, 75, 100, 200, 200-1000, >1000 fish. I standardized the snorkel counts by an approximation of the area searched per shore unit with the following formula: n = number of salmon observed / (length of shore unit (m) x water visibility (m)).

We also recorded observations of fish along a parallel transect during the shore observations. Moving slowly to minimize the degree to which we startled the fish, we waded up to waist deep along beaches, walked along the riprap and at the edge of docks and piers while leaning over to see the fish. We were unable to make observations from shore in the rain or on extremely dark days due to poor visibility and reflectance levels of the surface. We recorded the same information as for the snorkeling surveys. I totaled the number of chum observed per shore unit per site and divided it by the length of the shore unit to estimate fish density.

Using the same shore surveying methodology, I recorded the abundance and distribution of juvenile salmon from shore in Coal Harbour, in the southwest corner of the inner harbour, during the first two weeks of April in the year 2000. In addition to the number and behaviour of fish seen, I also noted the occurrence of flotsam and oil, as well as the direction of water currents. I tested for differences between the presence and absence of schools of salmon under areas of flotsam with the Chi-square test. I hypothesized that there would be no difference in the presence or absence of schools of salmon found under the flotsam areas.

Since the abundance of chinook and chum decreased throughout the sampling period, I eliminated seasonal differences in abundance by ranking the catches per site or substrate type in each weekly time period and conducted statistical analyses based on the ranks. I used an Analysis of Variance to test for differences in chum and chinook rank abundance between basins and between substrate types for all three data sets: beach seines, snorkel and shore observations. I used the Bonferroni adjustment for post-hoc pair-wise comparisons.

Results

Nearshore Substrate Delineation

The total linear distance of each substrate category along the low-low water line of Burrard Inlet is 113.6 kilometers (Table 4.2). Overall, about 55% of the shoreline is natural substrates and 45% anthropogenic. Among the natural substrates, unconsolidated, the category with the greatest mix of substrate types, makes up the most common category in the entire inlet (22.2%, Table 4.2). Mixed Fines follows close behind at 20.9%. Although unconsolidated substrate was well distributed throughout the inlet, mixed fines were found mainly in three very large areas: Maplewood Mudflats, Port Moody Mudflats, and Spanish Banks sand flat. Natural consolidated substrate occupied only 12.4% of the shoreline.

The Riprap category was the most common anthropogenic substrate. It placed third overall at 16.5% but it is underestimated as sections of riprap shoreline which have docks or floats in front of them were classified as "dock". If these sections had been placed in the "riprap" category, the overall percentage of riprap would climb to 27.0% and it would be the most common shoreline type in the entire inlet. Seawall and dock, the two remaining anthropogenic substrates, occupied almost as much shoreline as riprap.

The amount of anthropogenic versus natural shoreline types in Burrard Inlet differs greatly between basins. The Inner Harbour, at nearly 80% altered, has the most modified shoreline. False Creek, which is included in the Outer Inlet, is the only comparable area with an equally modified shoreline (80%). By comparison, less than a third of the Outer Inlet (27.0%) and Central Harbour (27.8%) are modified.

Percentages of the other substrate categories also vary between basins. Most of the consolidated shoreline is found in the Outer Harbour. The Inner Harbour has very low levels of both mixed fines (0.7%) and consolidated substrate (7.6%), as well as the lowest percentage of unconsolidated substrates (12.0%). Both the Outer Inlet and Central Harbour have a high proportion of mixed fines though it tends to be made up of sand in the Outer Inlet and Mud in the Central Harbour.

The substrates sampled at the site level are reflective of the substrate distribution at the basin level (Table 4.3). "Seawall" was the only category not present at any of the sites. This omission is only of potential significance for the Inner Harbour where its overall percentage is 35.5%. Other categories that were not represented at the site level are also found at low frequencies throughout the basin. For instance, there were no mixed fines in the Inner Harbour sites and no consolidated in either the Inner or Central Harbours. The only sites containing consolidated substrates were found in the Outer Inlet where most bedrock occurs. Apart from seawall, mixed fines, and consolidated, all other categories are represented at sites in each basin.

Greater detail such as the length, substrate type and category, and generalized location of each shore segment is presented in Appendix 7.

Physical Measurements

Water temperature in the inlet increased by 3 or 4 degrees over the sampling period of April 19-June 25 (Table 4.4). Likewise, salinity decreased approximately 12‰ throughout the sampling season. Salinity and water temperature are negatively correlated with a Pearson correlation value of –0.607. Summertime salinity levels in Burrard Inlet are similar to those in the southern Strait of Georgia that are also affected by the Fraser River freshet. Though summertime water temperatures in Burrard Inlet are higher than most of the Strait of Georgia, they are comparable to other protected waters such as Departure Bay (Thomson, 1981).

The largest difference in salinity occurred at the sites in the Outer Inlet, West Vancouver and Third Beach, where the runoff from the Fraser River has the greatest effect. Neither salinity ($F_{6,43}$=2.099, p=0.073); nor temperature ($F_{6,37}$=0.909, p=0.499) varied significantly between sampling sites when the effect of time was removed. Though not significant, New Brighton tended to have higher salinity and lower water temperatures, likely due to increased water mixing occurring at the Second Narrows. The opposite was true at the mud flat sites, Maplewood Mudflats and Rocky Point, where salinity tended to be lower and temperature higher than at other sites in the inlet.

Visibility also decreased throughout the sampling season and varied significantly between sites ($F_{4,40}$=5.577, p=0.001). Water clarity seemed to be related to plankton blooms as well as the Fraser River freshet (Stockner and Cliff, 1979). Visibility at the outer sites dropped off more quickly than at the Inner Harbour sites. A Bonferroni, post-hoc pair-wise comparison test showed that water visibility was lower at both sites in the Outer Inlet, Third Beach and West Vancouver (p=0.001; p=0.007), than at New Brighton, the site with the greatest visibility.

Juvenile Chum and Chinook Habitat Use

I performed a total of 147 beach seines on 9 beaches, 31 snorkel surveys at 5 sites, and twenty shore observation surveys at 4 sites (Table 4.5). Water visibility needed to be greater than a meter to do a snorkeling survey, so an unequal number of surveys per site resulted. Below a meter in visibility, salmonids could simply stay out of the diver's range of vision. Chum were the only fish frequently observed from shore since they tend to swim close to the surface. In both the shore observations and snorkel surveys, I observed that juvenile chum and chinook salmon behaved differently and occupied different parts of the water column. Chum were almost always within 10 cm of the surface of the water, whereas chinook tended to be in the middle of the water column. Chum also schooled in larger groups than chinook. Chinook tended to be found alone or in small groups of less than 10 fish. Although I did catch a few salmon smolts, data discussed in this paper refer only to chum and chinook fry.

Inlet level

Numerous juvenile salmonids use the nearshore areas of Burrard Inlet in the spring and summer. Salmon are produced in local streams surrounding the inlet and Indian Arm, as well as in major river systems to the North and South of the Inlet. Due to its geographic proximity and the strength of its salmon runs, the Fraser River, directly south of the inlet, can be expected to contribute many juvenile salmonids to Burrard Inlet, particularly the Outer Inlet. The number of salmon spawning in Fraser River dwarfs the number spawning in the streams emptying directly into the inlet (Table 4.6). Some additional juvenile salmonids are also produced in the Squamish River in Howe Sound, located directly north of Burrard Inlet. In addition to naturally produced fish, there is a hatchery on the Capilano River, which empties into the Outer Inlet, as well as several community hatcheries in the Central Basin. In 1999, a total of 639,781 chum and 156,571 chinook fry were released into the inlet from hatcheries (personal communication, G. Bonnell, Fisheries and Oceans Canada) (Appendix 3). I expected that a combination of internally and externally produced salmonids would lead to greater abundance of chum and chinook at the western end of the inlet than at the east.

The highest catches of chum occurred in late April and of chinook in May (Figure 4.2). Numbers of both salmonids decreased toward the end of the sampling period and were near zero by mid-to-late June. I caught far fewer juvenile chinook than chum salmon reflecting the greater number of chum spawners returning to the rivers and streams surrounding Burrard Inlet, particularly the strong chum run of the Indian River, at the head of Indian Arm, as well as the greater chum abundance from the lower Fraser River (Table 4.6).

Basin Level

Catches and observed density of both juvenile chum and chinook in the three basins coincides with the size of the potential sources of salmonids in Burrard Inlet. I observed a significant difference in chum densities among the three basins while snorkeling (Table 4.7). A greater density of chum were observed in the Outer Inlet than in the Central Harbour (p=0.037). The mean density of chum observed in the Inner Harbour was intermediate between the two other basins but did not differ significantly from either. Although not statistically significant, the beach seine catches had the same spatial pattern. I tended to catch more chum in both the Outer Inlet and Inner Harbour than in the Central Harbour ($F_{2,60}$=3.042; p=0.055). There was no difference among basins for the shore observations (Table 4.7).

The spatial trend between western and eastern sites in the inlet observed for chum was even more pronounced for chinook; more chinook were caught in the Outer Inlet and Inner Harbour, particularly Portside Park and West Vancouver, while very few were caught anywhere east of the Second Narrows. No chinook fry were captured at Rocky Point; a single chinook was caught at each of Barnett-sand and Barnett-cobble; and three were found at Maplewood mud. When I aggregated these data by basin, I found significant differences in chinook density and catches among the three basins (Table 4.7). I observed greater densities of chinook by snorkeling in the Outer Inlet than both in the Inner (p=0.004) and Central Harbours (p=0.064). A post-hoc analysis of beach seine catches revealed that catches were higher in both the Outer Inlet and Inner Harbour than in the Central Harbour (p=0.010 and p=0.002 respectively).

Site Level

Although I was unable to find any difference between chum or chinook substrate use within individual sites, I did find significant differences between substrate types when the data from all sites were pooled (Table 4.8). I found significant differences for beach seine catches among substrates for both species with an ANOVA. Post –hoc analysis revealed that significantly more chum were caught on gravel/cobble substrates than over mud (p=0.012). Although not significant, I also tended to catch more chum over gravel/cobble substrates than over sand (p=0.069). Chinook catches showed similar patterns. Greater chinook catches occurred on cobble/sand beaches than on mudflats (p=0.024). There also tended to be more chinook over cobble/sand than over sand (p=0.139). From the beach seining, it appears that both species prefer the larger substrate types.

Although I found no difference in chum observations between substrate types by snorkeling I did find a significant difference in the shore observations (Table 4.9); significantly more chum were observed over cobble than boulders (p=0.023). A wide range of chum densities exists for piers for both the snorkel surveys and shore observations. On a few occasions, I found hundreds to thousands of chum concentrated under small piers. Apart from these instances, chum were rarely observed around piers and I rarely observed very dense concentrations of fish by either snorkeling or shore observation. The low median fish densities (Table 4.9) reflect the low density of fish observed on many occasions; however, a wide range of densities, particularly for chum was observed.

A discrepancy exists in the apparent use of cobble beaches by chum between the shore observations and snorkeling surveys. Cobble beaches were one of the most heavily used substrate types based on the shore observations, while only moderate densities were observed in the snorkel surveys (Table 4.9). It was difficult to see chum on cobble beaches while snorkeling, so they may have been underestimated on this substrate type by snorkeling.

The only significant difference for chinook substrate use from the snorkeling surveys occurred between piers and bedrock (p=0.052). Unlike chum, almost no chinook were observed around piers. I also tended to observe more chinook over bedrock, boulders and riprap than piers, sand and cobble.

In the spring of 2000, I made detailed visual observations of the distribution and abundance of juvenile salmonids in the Coal Harbour area of the Inner Harbour. Although this area is heavily developed with marinas, I observed many juvenile chum and pink salmon, especially around the docks of marinas. Concentrations of juvenile salmonids at first appeared to be associated with concentrations of flotsam, however, only 34 of 61 such areas had salmon concentrations ($X^2 = 0.59$, $p >> 0.05$).

Discussion

I investigated chum and chinook habitat use at three nested scales: Inlet, Basin and Site. By beach seining, snorkeling and making observations from shore, I found that there are differences in the abundance of juvenile chum and chinook salmon among the basins in Burrard Inlet. More chum and chinook were found in the Outer Inlet and Inner Harbour than in the Central Harbour. This pattern corresponds to the size of the spawning populations supplying juvenile salmonids to the inlet. The higher abundance of juvenile salmonids observed in the Outer Inlet probably reflects the combined effect of the streams that empty into Burrard Inlet, particularly the Capilano River flowing into the Outer Harbour, as well as the numerous salmonids produced in the Fraser River.

Although movement patterns of juvenile salmonids are unknown in Burrard Inlet, we can make some inferences from local oceanography. The North Arm of the Fraser River contributes a considerable amount of the brackish water in the Outer Inlet, particularly during the freshet in late spring and early summer (Thomson, 1981) and it is likely transporting juvenile salmon as well. Tidal currents through both constrictions in the inlet, the First and Second Narrows, which separate the three basins, can be greater than 5 knots (Canadian-Hydrographic-Service, 1999). Although the currents reverse directions with the tides, net flow is out of the inlet (Thomson, 1981). The Narrows could therefore pose a significant barrier to movement of salmonids. Certain wind and tide conditions can cause the Fraser River runoff to penetrate into the Inner Harbour, however, water from the Fraser is mainly restricted to the Outer Inlet (Thomson, 1981). The lower salinity and water visibility I found at my sites in the Outer Inlet are reflective of this fact. On flood tides, when water is running into the Inner Harbour, a large clockwise eddy develops in the southern portion of the Outer Harbour and smaller, counter-clockwise eddies develop along the northern shore (Thomson, 1981). It is, therefore, likely that juvenile salmonids found in the nearshore waters would stay in the Outer Inlet. Regardless, some salmon in the Outer Inlet may get pushed through the First Narrows when large flood tides and favorable wind conditions largely break down these eddies (Thomson, 1981). This may be why I often found no difference in chum and chinook abundance between the Outer Inlet and Inner Harbour. A combination of locally produced fish and chum transported from the Fraser River likely led to the higher observations of juvenile chum and chinook in the Outer Inlet and Inner Harbour as compared to the Central Harbour.

I also found that chum and chinook use the different substrates types to varying degrees. At the site level, my beach seining and snorkeling data suggests that chinook use larger substrate types like bedrock, boulders and cobble to a greater extent than sand or mud. Greater densities of chum were also found over cobble-gravel beaches than over mud and sand. The shore observations also showed the greatest densities occurred over cobble beaches and significantly more were observed over cobble than around boulders. I found no differences between substrate types for chum with the snorkeling surveys.

Caution must be used in interpreting the patterns of chinook substrate use that I found. Although it seems that chinook tend to use larger substrate types than over finer sand and mud, I must also consider that overall distribution of chinook as well as the relative availability of the various substrate types in each basin. I found significantly more chinook at the western end of the inlet than to the east. Both mudflat sites are located at the eastern end of the inlet while the outer inlet has the highest amount of consolidated substrates (bedrock and boulders) (31.5% compared to 7.6% and 6.5% for the Inner and Central Harbours respectively). Differences observed in substrate use are, therefore, somewhat confounded with the distribution of substrates. The observed pattern of substrate use may, nevertheless, be biologically significant since there are some sources of juvenile chinook in or near the Central Harbour. Chinook spawn in Lynn Creek, which empties into the eastern end of the Inner Harbour, Seymour River, at the second narrows, and the Indian River, at the head of Indian Arm. In addition, hatchery-reared chinook that are released near the mouth of Indian Arm (34,300 in 1999 (Appendix 2)). Nevertheless, very few were captured at Maplewood mudflats. I also captured few chinook at the sandy shore unit at Third Beach, in the Outer Inlet. The greater use of larger substrates by chinook may be related to the relative structural complexity of the habitats. The abundance of juvenile fishes is often related to structural complexity (Dean *et al.*, 2000). Prey density and diversity is often positively correlated with structural complexity (Crowder and Cooper, 1982). Crowder and Cooper (1982) found that structural complexity reduced the prey capture rate of bluegill sunfish (*Lepomis macrochirus*) that were held in experimental ponds with varying vegetation densities. Carr (1994) found that kelp bass (*Paralabrax clathratus*) recruitment was positively related to the density of giant kelp (*Macrocystis pyrifera*). Lindholm *et al.* (1999) found that juvenile cod (*Gadus morhua)* survival increased with increasing levels of structural complexity.

Despite these significant findings, I did encounter some problems with my fish-sampling methods. Although the snorkel surveys allowed me to sample substrate not amenable to beach seining such as under piers, around docks and over riprap, I do not feel that this technique worked equally well in all habitat types. This is problematic, because biases in the census technique often leads to mistaken estimates of habitat quality, particularly if the sampling method is habitat dependent (Van Horne, 1983). The greatest limitation concerned the relative visibility of juvenile chum while snorkeling in different habitat types. Juvenile chum are silver on their ventral side and have darker, bluish-green dorsal sides. This countershading makes the fish less detectable because the gradient of colour is opposite to the distribution of natural light in the water, making the fish identical to its background. Countershading works best when the fish is viewed from the side (Helfman *et al.*, 1997). For this reason, I found it difficult to see the juvenile chum in open water and over cobble beaches while snorkeling. They were particularly difficult to see on shallow cobble beaches. A combination of countershading, reflections of the cobble on the surface, ripples on the surface, and chum swimming behaviour made them very difficult to observe. They appeared to be using the shallow water and the air-water interface as an abiotic refuge, as do other fishes (Godin, 1997). Although countershading works well in open water, fish do become visible once they are viewed in front of any sort of coloured background, since the visibility of an object underwater depends largely on its contrast with the background (Helfman, 1981). Consequently, chum were much more visible when observed against a background such as boulders or riprap. I therefore felt that the snorkel counts were biased towards substrates such as riprap and boulders and that the counts on cobble beaches were underestimated.

These problems did not exist when I observed the chum from the shore. Since the fish were always observed from above, the same background contrast problems were not encountered. I feel that the observations made from shore were less biased than the snorkel surveys and probably provided a better method for studying juvenile chum in nearshore habitats.

The same problems did not exist for juvenile chinook. They were found to swim deeper in the water column than chum, did not use the air-water interface, and also have larger parr marks making them more visible underwater. I could not, however, observe many chinook from shore and was therefore not able to compare snorkeling results in all habitat types with this sampling technique.

Another problem with the snorkel surveys was the reaction of the fish to the diver. Although juvenile salmon have been observed by snorkeling in streams and are not particularly wary of the diver (Hillman *et al.*, 1992; Rodgers *et al.*, 1992), both juvenile chum and chinook in the nearshore constantly tried to evade the diver. I found that if the water visibility was less than a meter, the fish could just stay out of the diver's sight.

There are also biases associated with beach seining. Rozas and Minello (1997) noted several factors that have been shown to affect the efficiency of seines: bottom type, marsh vegetation and seagrass, sea state, water depth, and even temperature. All of these environmental factors can lead to highly variable catch efficiency (Rozas and Minello, 1997). I found that the quality of the set depended most on the substrate type. Seining on cobble beaches was more difficult than on the sand or gravel as the net had a tendency to become snagged, which could allow fish to escape. Whenever the net was badly snagged I made another set and the data from the spoiled set were discarded. Sea state, vegetation and temperature did not seem to have an effect on the beach seine catches in this study; however, the depth of the water seined may have.

The volume of water swept depends on the profile of the beach and not all beaches sampled had the same profile. Although I tried to hold the depth constant by always sampling as deep as the height of the chest waders; I was not able to do so on very flat beaches due to the weight of the net in shallow water and the softness of the sediment. Populations on very flat beaches and mudflats may therefore be underestimated.

Tide height may have also biased the beach seine data. Most beach seines were performed at mid-tide levels, however, I had to seine at the mudflats and Third Beach at high tide because I was constrained by the softness of the sediment. Rosaz and Minello (1997) also explain that tidal fluctuations can greatly alter density estimates since the rising tide expands the amount of flooded bottom area in a basin. Rangeley and Kramer (1995) found that juvenile pollock (*Pollachius virens*) responded to tidal changes in habitat availability. On rising tides, juvenile pollock switched from schooling in the open habitats without vegetation to dispersing in the algal habitats. On falling tides, pollock schooled rapidly in the open habitat, possibly to avoid stranding (Rangeley and Kramer, 1995). Behavioural changes associated with changes in tide height may have contributed to the lower densities of chum and chinook salmon on the mud flats and at Third Beach.

Controlling for sampling bias across habitat types is a pervasive problem that can confound habitat assessments (Van Horne, 1983). Despite the importance of this limitation, I argue that the identification of the correct scale of sampling is an even more critical issue to resolve. Several other authors have asserted that choosing the appropriate scale of study is an essential, yet commonly overlooked, prerequisite to the assessment of fish habitat (Imhof *et al.*, 1996; Kocik and Ferreri, 1998; Lewis *et al.*, 1996; Simenstad and Cordell, 2000). Kocik and Ferreri (1998) discuss what they term "natural units of scale." They explain that in determining these units, we must not only identify the habitat elements that sustain each life stage, but also consider how the habitat elements are spaced and how the fish move between them. Landscape-level studies can consider such large-scale movements of fish as well as habitat variables and human land use (Lewis *et al.*, 1996). Simenstad and Cordell (2000) recommend that the landscape scale is particularly appropriate for the assessment of juvenile salmonid habitats since it must be considered within the context of the entire freshwater-ocean continuum. Although they focus on restored habitats, their comments are also applicable to the assessment of natural and degraded habitats.

We are still, however, left with the question; how big is a landscape? The scale of a landscape is dependent on the individuals that use it; therefore, the ecological and evolutionary significance of habitats to species must be included in the identification and assessment of habitats (Knight and Morris, 1996). Simenstad and Cordell (2000) discuss the evolutionary and ecological history of Pacific salmon to explain why juvenile salmonid habitats must be assessed at the landscape scale. Both the ecological and evolutionary history of salmon have made them adaptable to many different habitat types. Salmon co-evolved with the emerging coastal habitats that were highly variable due to post-glacial fluctuations in sea level, river flows, geomorphology, and climate. These factors, in addition to overall biogeographic variation, promoted diverse salmonid populations that are adapted to unpredictable regional factors. Each individual salmon must also use a variety of habitats in its life history as they undergo several ontogenetic habitat shifts. Salmon can therefore be viewed as integrators of dynamic habitats in a landscape rather than the product of individual sites (Simenstad and Cordell, 2000).

The appropriate scale to assess juvenile salmonid habitat in Burrard Inlet is dictated by three issues that relate to both the ecology of the animals and the distribution of habitats. First, we must consider the points of origin of the salmon. Next, we must think about how they move through the inlet. Lastly, what habitats do they encounter and do these habitats have the capacity to provide the salmonids with adequate food supply and refuge from predators?

I investigated juvenile chum and chinook habitat at three scales. The largest scale, the Inlet, addresses the first question: where the salmon originate. I actually expanded the inlet scale to include inputs of salmonids from nearby rivers. Upland and watershed effects could also be addressed at this scale. The entire catchment area surrounding Burrard Inlet is probably a reasonable first level planning scale as long as external effects, such as the relationship between the Fraser River and Burrard Inlet are also considered.

Next, we must consider how the salmon are moving through the inlet. As previously discussed this is largely unknown for Burrard Inlet. We do know, however, that as they grow, chum and chinook move offshore, and eventually leave the inlet and enter the Strait of Georgia (Healey, 1980). Migration rates of juvenile chum in Hood Canal have been estimated to be between 3-14 km/day (Bax, 1983; Simenstad and Salo, 1980). In tag-recapture studies, residence time of juvenile chum in Netarts Bay, Oregon, ranged between 5-23 days (Pearcy *et al.*, 1989) and 0-18 days in the Nanaimo River estuary (Healey, 1979). Bax (1983) estimated the average daily loss of tagged hatchery chum, by mortality and emigration, to be between 38-49%. Residence time of tagged chinook in Coos Bay, Oregon was 10 days for the spring run (Fisher and Pearcy, 1989). These migration and residency times from other areas can be used to help identify the necessary scales of investigation required in Burrard Inlet. If a juvenile chum can move 3-14 km/day, and resides in the inlet for somewhere around 20 days, it could travel up to 280 km in that time period and, in theory, use all of Burrard Inlet's shoreline. Habitat therefore must be assessed at the Inlet and Basin scales.

Landscape level habitat metrics should be used to assess habitat at the Inlet and Basin level. Habitat connectivity, which includes measures of patch isolation and contiguity is particularly important to assess for juvenile salmonids (Robbins and Bell, 1994; Simenstad and Cordell, 2000).

Habitat diversity is another important landscape level metric. In this study, I found chum and chinook in all habitats sampled. Salmonids are adapted to using many different habitats (Simenstad and Cordell, 2000) therefore, a diversity of habitat types should be maintained in Burrard Inlet as well as in other areas. Habitat diversity can be measured like species diversity: simply by the richness, or total number, of habitat types; or by also considering rare and dominant types. The dominant shoreline type in the inlet as a whole is riprap at 27%. Some basins, particularly the Outer Harbour and Port Moody Arms have low percentages of riprap, but the Inner Harbour and False Creek have very high proportions of riprap as well as docks and seawalls). Unconsolidated (22%), a very broad category, is the second most abundant category in the inlet. Consolidated substrate is the rarest habitat by percentage in the entire inlet, with most of this type in the Outer Inlet. Mixed fines and consolidated substrate types are the rarest habitat types in the two most altered basins, Inner Harbour and False Creek. Rare habitats in particular need to be considered more valuable than abundant ones and maintained.

Another metric that should be considered is whether the habitats are natural or anthropogenic in origin, or in other words, unaltered or artificial. The Outer Harbour, with 73% of its shoreline unaltered, is the most natural basin. Artificial habitat is most common in False Creek and Inner Harbour, each at nearly 80%. Burrard Inlet, on a whole, is made up of nearly 45% altered habitat with riprap as the dominant shoreline type. The high levels of alteration are not surprising given that the inlet is surrounded by a large city and contains an important port. Furthermore, altered habitats are not necessarily worthless as fish habitat. Although I did not sample along significant seawalls or commercial piers and docks, my sampling showed that riprap and small docks and piers were all used to some extent by chum and chinook. Indeed, high densities of chum salmon were observed around marinas in Coal Harbour. Negative impacts of high rates of habitat alteration do, however, need to be considered. Jennings et al. (1999) studied the cumulative effects of shoreline habitat modification on fish assemblages in 17 Wisconsin lakes. They found that sites with riprap shorelines contained greater species richness of fish than other sites. They attributed this trend to the complex habitat with interstitial spaces provided by the riprap. The authors also studied fish communities at the scale of the entire lake. They found that although riprap increased structural complexity at the scale of the individual site, when viewed at the scale of the whole lake, conversion of the entire shoreline to this one habitat type did not increase overall habitat or species diversity, it caused a reduction (Jennings *et al.*, 1999).

Smaller floats, large docks and piers are common in Burrard Inlet. I did make several observations of chum around small floats and near smaller piers. On a few occasions, I found thousands of juvenile chum under the piers at New Brighton and Barnett Marine Parks. A school of chum was also frequently found just under the West Vancouver dock. The use of overhead cover by fishes is a common phenomenon and there may be a functional advantage to being attracted by shade (Helfman, 1981). Helfman (1981) showed that under appropriate conditions-particularly when the sun is shining, a shaded fish can see an approaching fish up to 2.5 times farther away than it can itself be seen. Under these circumstances a predator approaching a shaded prey will lose all elements of surprise, since the prey will have detected the predator and may be able to avoid attack (Helfman, 1981). Therefore the overhead cover may be providing refuge from predators. The increased visibility provided by the shade may also enhance the chum's feeding opportunities since uncovered zooplankton would be more visible than if the fish were in direct sunlight (Helfman, 1981). Although shading may be important from a behavioural perspective, extensive shading can also reduce the amount of primary productivity. For instance, seagrass beds in Florida have been reduced due to shading by docks (Loflin, 1995).

Though overhead cover, particularly from small structures, may be advantageous to small fishes in certain circumstances, the same may not be true for large, commercial piers. Able and others studied the effect of piers on habitat in the New York-New Jersey Harbor of the Hudson River (Able and Manderson, 1998; Able *et al.*, 1999; Duffy-Anderson and Able, 1999). The growth of juvenile winter flounder and tautogs was found to be lower under large commercial piers in the Hudson River estuary (Able *et al.*, 1999). The authors attributed the decreased growth rates to decreased foraging efficiency due to low light levels under the piers. Growth of caged animals was further shown to decrease along transects running from outside the pier to its center (Duffy-Anderson and Able, 1999). Fish abundance and species richness were also typically low under the piers in the Hudson River (Able and Manderson, 1998). I did not sample under or near any of the large commercial piers found in the Vancouver Harbour. Large commercial piers are likely to be very a different habitat than the smaller, recreational piers that I studied at Portside Park, New Brighton Park, and Barnett Marine Park. Further studies, similar those conducted under Hudson River piers, are required to determine the actual habitat value of piers for juvenile salmon in Vancouver Harbour.

Despite the importance of landscape level habitat evaluation metrics, the value of various habitat types, such as large piers, riprap and natural shorelines, must also be assessed at the site level. In addition to identifying which habitats a juvenile salmonid may encounter, we must also determine if those habitats have the capacity to provide life history needs of the salmon. Simenstad and Cordell (2000) explain that the life history characteristics and episodic occurrence of salmon in estuaries make the study of habitat use difficult. Furthermore, unless water quality or habitat is severely compromised, estuaries can be viable migration routes for juvenile salmonids regardless of their value for enhancing survival (Simenstad and Cordell, 2000). For this reason, metrics other than the relative abundance of fish in various habitat types should be used. Simenstad and Cordell (2000) recommended using measures related to the ecological and physiological responses of juvenile salmonids to assess the habitat value of restored estuaries. Williams (1989b) also recommended assessing habitat by the ecological functions that it may provide, such as migratory routes and holding areas; mating and spawning areas; feeding opportunities, including juvenile rearing areas and adult feeding grounds; and areas of predator refuge.

Simenstad and Cordell (2000) recommended three new categories of site-level metrics of habitat quality: capacity, opportunity and realized function. Capacity metrics include any habitat attributes promoting juvenile salmon production, including conditions that promote foraging, growth, growth efficiencies, and decreased mortality. Examples include productivity measures of availability and quantity of selected invertebrate prey and structural characteristics that provide protection from predators. Opportunity metrics assess the capability of the juvenile salmon to access and benefit from the habitat's capacity. Some examples of opportunity metrics are tidal elevation and flooding; extent of geomorphic features such as tidal channels; and proximity to disturbance. Finally, realized function criteria include direct measures of physiological and behavioural responses attributed to the fish's occupation of the habitat. Survival, residence-time, foraging success and growth rates are all examples. Because of the problems associated with collecting these data, experimental manipulation is usually required (Simenstad and Cordell, 2000).

Simenstad and Cordell (2000) discuss some additional metrics of habitat quality that should be assessed for juvenile salmonids. One of them is lengths or network dimensions of entrapment zones for neuston and other prey caused by features such as tidal/current fronts. Harrison *et al.* (1983) explain that physical, chemical and biological gradients act to concentrate prey. These concentrations may be important for juvenile salmon since it has been shown that they require a high density of prey to feed to satiation (Harrison *et al.*, 1983). Harrison *et al.* (1983) list several examples of biological aggregations caused by gradients: *Neocalanus plumchrus* at the salinity front in the Fraser River Plume; high summer phytoplankton concentrations in areas of high turbulence and nutrients; zooplankton in a tide rip; and zooplankton in the lee wave of the sill of an inlet. My observations of chum from shore suggest that such areas are important for chum. I consistently found a school of chum in the same area in an eddy at the West Vancouver site, and found many schools in protected waters around floats. Oceanographic features must also be considered as habitat.

In additional, water quality must be viewed as a habitat issue for juvenile salmonids. I observed several instances of groups of juvenile salmonids under concentrations of flotsam and oil. I found no difference between the presence or absence of juvenile salmonids under these flotsam concentrations indicating neither an attraction nor avoidance of these areas. Stehr *et al.* (1998) found that juvenile chum and chinook salmon from a contaminated waterway in Washington state showed increased exposure to contaminants than hatchery or reference site fish. Early indications of biological alteration and damage was associated with the increased contamination levels (Stehr *et al.*, 1998).

In conclusion, juvenile salmonid habitats in Burrard Inlet as well as in other similar situations should be assessed at several scales. At the site scale, the actual value of particular substrate or habitat types should be assessed using the metrics proposed by Simenstad and Cordell (2000) rather than simply using relative abundance of fish. It is also critical that salmonid habitat be assessed at the landscape scale of the entire inlet and basins. Data and tools currently exist to evaluate habitat in Burrard Inlet using landscape-level habitat metrics such as connectivity, diversity, abundance, rarity, and isolation. Moreover, properties of the water column, such as currents, eddies, fronts, and water quality, must be considered as important habitat quality issues in addition to substrate type.

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Personal Communications

Gregory Bonnell, Fisheries and Oceans Canada, June 2000.

Table 4.1. Substrate category definitions used in nearshore substrate delineation.

Substrate Category	Definition
Unaltered	
Mixed fines	mud, sand, mud-sand, mud-gravel, sand-gravel
Unconsolidated	cobble, gravel, cobble-gravel, cobble-sand, boulder-cobble-gravel-sand
Consolidated	bedrock, boulder, bedrock-boulder, bedrock-sand, bedrock-boulder-cobble-sand
Artificial	
Dock	dock-riprap, dock-cobble-mud, dock-rubble, dock-mud
Riprap	riprap, riprap-rubble, rubble
Seawall	constructed shoreline to the low-low water line

Table 4.2. Percent shoreline type in Burrard Inlet.

Substrate Category	Burrard Inlet		Outer		Inner		Central	
	meters	%	meters	%	meters	%	meters	%
Mixed Fines	23710	20.9	10980	28.5	280	0.7	12450	32.9
Unconsolidated	25250	22.2	8370	21.8	4460	12.0	12420	32.8
Consolidated	14040	12.4	8720	22.7	2840	7.6	2480	6.5
Total Unaltered		55.4		73.0		20.3		72.2
Dock	15170	13.4	2080	5.4	8350	22.4	4740	12.5
Riprap	18750	16.5	5900	15.3	8120	21.8	4730	12.5
Seawall	16700	14.7	2410	6.3	13220	35.5	1070	2.8
Total Artificial		44.6		27.0		79.7		27.8

Table 4.3. Substrate categories present per sampling site.

Substrate Categories	Basin / Site						
	Outer		Inner		Central		
	West Vancouver	Third	Portside Park	New Brighton	Maplewood Mudflat	Barnett Marine	Rocky
Mixed Fines		X			X	X	X
Unconsolidated	X		X	X		X	
Consolidated	X	X					
Riprap	X		X	X		X	
Dock/ pier	X		X	X		X	
Seawall							

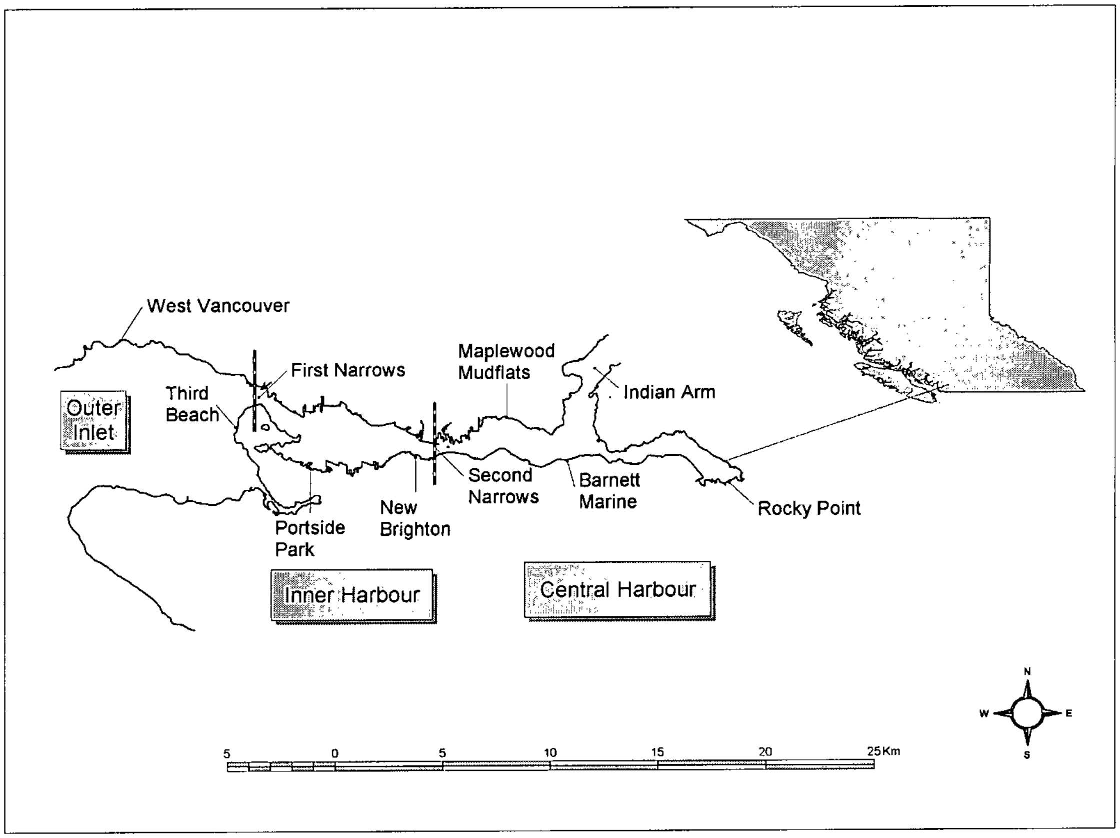

Figure 4.1. Location of Burrard Inlet, British Columbia, showing basins and sampling sites.

Table 4.4. Sampling site physical characteristics.

Site (N)	Mean (± SE)		
	Salinity ‰	Temperature °C	Visibility m
All sites	20.3 (± 0.54)	10.9 (± 0.32)	2.0 (± 0.16)
Outer Inlet			
West Van (4)	20.3 (± 2.78)	9.0 (± 0.50)	1.8 (± 0.55)
Third Beach (4)	19.8 (± 1.436)	10.7 (± 1.67)	1.9 (± 0.39)
Inner Harbour			
Portside (9)	19.3 (± 1.04)	10.3 (± 0.53)	1.7 (± 0.18)
New Brighton (8)	23.9 (± 0.77)	9.9 (± 0.45)	2.8 (± 0.51)
Central Harbour			
Maplewood (4)	18.6 (± 1.91)	13.0 (± 1.58)	NA
Barnett (7)	20.4 (± 0.7)	11.0 (± 0.87)	1.9 (± 0.22)
Rocky Point (6)	19.8 (± 0.79)	13.0 (± 1.23)	NA

Table 4.5. Methods used per sampling site.

Site	Beach Seine	Snorkel Survey	Shore Observations
Outer Inlet			
West Vancouver	X	X	X
Third Beach	X	X	
Inner Harbour			
Portside	X	X	X
New Brighton		X	X
West	X		
East	X		
Central Harbour			
Maplewood	X		
Barnett		X	X
Sand	X		
Cobble	X		
Rocky Point	X		
Total	9	5	4

Table 4.6. Mean adult returns (1953-1998 or available years) of chinook and chum salmonids. Streams and creeks are summed per basin while major rivers are considered individually.

Basin / River	Adult Returns: Chinook	Adult Returns: Chum
Fraser River	110,000*	460,000*
Outer Harbour	637	384
Inner Harbour	19	53
Central Harbour	106	1009
Indian River	113	20,118

*Fraser River estimates are rounded to the nearest 10,000 to reflect unequal sampling effort over the years.

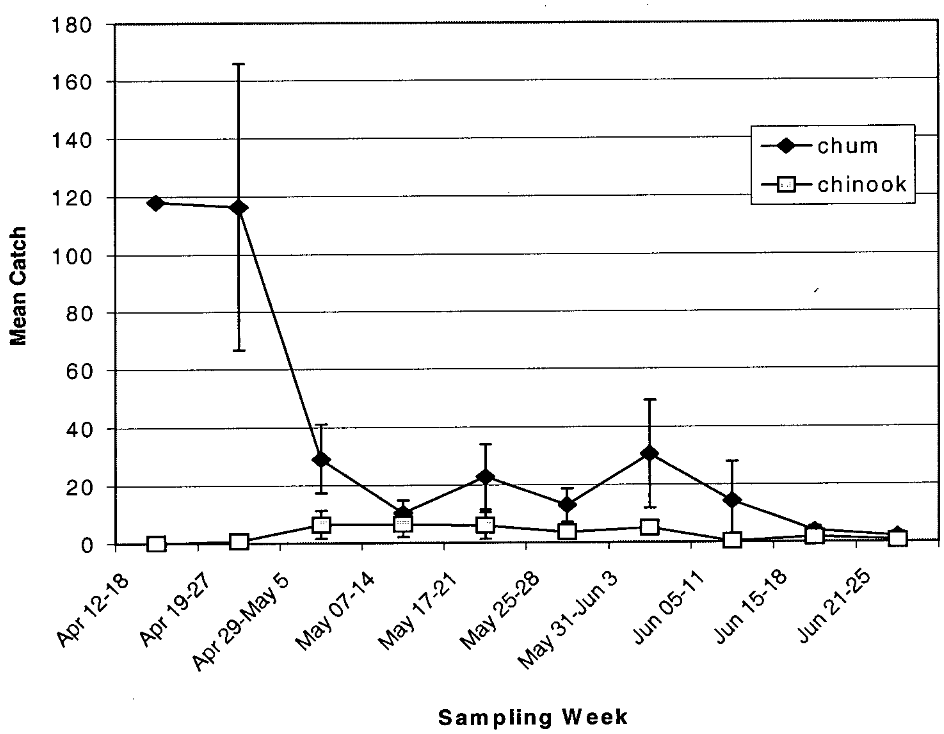

Figure 4.2. Mean chum and chinook catch by beach seine for all sites in Burrard Inlet throughout sampling period. Error bars represent standard error.

Table 4.7. Mean and standard error of rank transformed chum and chinook abundance among basins in Burrard Inlet. Data are aggregated by basin.

	Outer Mean (± SE)	**Inner** Mean (± SE)	**Central** Mean (± SE)	**Significance**
Chum				
Beach Seine	2.714 ± 0.462	3.833 ± 0.384	2.640 ± 0.365	$F_{2,60} = 3.042$ p = 0.055
Snorkel	3.286 ± 0.522	2.333 ± 0.283	1.714 ± 0.264	$F_{2,26} = 3.686$ **p=0.039**
Shore Observations	5.531 ± 0.760	6.357 ± 0.864	4.200 ± 0.588	$F_{2,54} = 2.233$ p = 0.117
Chinook				
Beach Seine	2.429 ± 0.291	2.417 ± 0.324	1.240 ± 0.119	$F_{2,60} = 7.713$ **p = 0.001**
Snorkel	3.571 ± 0.481	1.933 ± 0.200	2.286 ± 0.406	$F_{2,26} = 6.718$ **p = 0.004**

Table 4.8. Median and range of non-transformed catches and mean and standard error of rank transformed beach seine catches of chum and chinook. Overall significance among substrate types, determined by ANOVA, is shown underneath columns for each species.

Substrate	Chum		Chinook	
	Median	Range	Median	Range
Cobble-Sand	9.0	0 – 118	1.5	0 – 35
Gravel-Cobble	6.0	0 – 121	0	0 – 42
Sand	2.5	0 – 82	0.5	0 – 4
Mud	0	0 – 35	0	0 – 3
	Mean	SE	Mean	SE
Cobble-Sand	42.00	34.106	4.38	1.700
Gravel-Cobble	32.22	9.287	4.06	1.623
Sand	9.67	6.659	1.08	0.398
Mud	4.82	3.127	0.27	0.273
Significance	$F_{3,59}=4.753$ **p=0.012**		$F_{3,59}=3.604$ **p=0.024**	

Table 4.9. Median and range of non-transformed densities and mean and standard error of rank transformed snorkel and shore observations for chum and chinook. Overall significance among sites and substrate types, determined by ANOVA on rank transformed data, is shown underneath columns for each species.

Substrate	Snorkel (# fish / m^2) Chinook		Snorkel (# fish / m^2) Chum		Shore (# fish / m) Chum	
	Median	Range	Median	Range	Median	Range
Bedrock	0.01	0 – 0.32	0.00	0 – 0.28	N/A	N/A–
Boulder	0.00	0 – 0.21	0.52	0 – 1.61	0.00	0 – 2.56
Cobble	0.00	0 – 0.37	0.00	0 – 1.87	1.23	0 – 8.21
Cobble/sand	0.00	0 – 0.06	0.00	0 – 0.33	0.02	0 – 0.12
Sand	0.00	0 – 0.00	0.00	0 – 0.13	0.23	0 – 0.16
Pier	0.00	0 – 0.03	0.00	0 – 11.90	0.20	0 – 22.22
Riprap	0.00	0 – 0.51	0.00	0 – 2.79	0.26	0 – 3.15
	Mean	SE	Mean	SE	Mean	SE
Bedrock	11.64	2.36	6.50	1.66	N/A	N/A
Boulder	10.93	2.04	11.79	2.36	3.22	0.57
Cobble	8.40	0.58	8.36	0.65	7.91	1.06
Cobble/sand	7.44	0.86	7.11	1.16	3.20	0.58
Sand	6.86	0.63	7.93	1.57	5.75	0.63
Pier	6.80	0.35	8.59	0.81	5.25	0.97
Riprap	9.59	0.81	8.77	0.79	5.58	0.91
Significance	$F_{6,122}=3.075$ **p=0.008**		$F_{6,122}=1.130$ p=0.349		$F_{5,51}=2.833$ **p=0.025**	

Chapter 5.

Community-Level Metrics to Assess Fish Habitat in Burrard Inlet.

Introduction

Habitat loss and alteration are major threats to marine biodiversity (British Columbia/Washington, 1994; Norse, 1993). Shorelines with over 30% alteration are of particular concern in the Georgia Basin–Puget Sound region (British Columbia/Washington, 1994). There has already been substantial habitat alteration in Burrard Inlet (Macdonald and Chang, 1993; Precision-Identification, 1997). Nearly 45% of Burrard Inlet's shoreline is of anthropogenic origin and the most common shoreline structure in the inlet is riprap (Chapter 4). Considerable portions of the inlet have also been filled-in and therefore lost as fish habitat (Precision-Identification, 1997). Despite habitat loss and alteration, several species of fishes use Burrard Inlet (Macdonald and Chang, 1993; Renyard, 1988). The assessment and evaluation of fish habitat in Burrard Inlet is, therefore, of concern.

Fish habitat is essential for sustaining fisheries and maintaining biodiversity (Langston and Auster, 1999). The role fish habitat plays in sustaining fisheries is usually emphasized over the role it plays in maintaining biodiversity. This is evident in legislation that protects fish habitat in North America: Canada's Fisherirs Act and the Sustainable Fisheries Act in the United States. Although the no-net-loss of productive capacity fish habitats also applies to non-commercial fish species, the limited resources of fish habitat enforcement agencies are commonly focussed on commercial species. Thus, the quality of fish habitat is often assessed at the population level using metrics such as the abundance of commercially important species (Jones *et al.*, 1996). We must, however, begin to view all fish and fish habitats as integral components of regional biodiversity (Langston and Auster, 1999). One approach to incorporating biodiversity into our evaluation of fish habitat is to assess habitat with community-level metrics of habitat quality (Jones *et al.*, 1996). In this study, I discuss the use of species diversity and species assemblages as metrics of fish habitat quality in Burrard Inlet.

The diversity of fish species has been used as one component to assess the health of estuarine and lake habitats (Deegan *et al.*, 1997; Minns *et al.*, 1994). Areas that support a greater diversity of fishes can be considered to be of higher habitat value. Species diversity is an expression of community structure (Brower *et al.*, 1989). Species diversity indices include information on both the number (species richness) as well as the abundance of each species. A community will have high species diversity if many equally or nearly equally abundant species are present. Conversely, a community will have low diversity if very few species or only a few of the species that are present are abundant (Brower *et al.*, 1989). Dahlberg and Odum (1970) list several factors that may regulate species diversity: variety of niches; sizes of niches or niche overlap; stability of environment or climate; rigorousness of environment; succession or geological time; productivity; biomass accumulation; competition; space; length of food chains; and body size.

Species diversity indices are one method to compare relative diversity at sites but they do not consider the identity of the species contributing to the score. Identifying species assemblages is another way to assess the relative value of habitats for different species. Minns *et al.* (1994) provide an example of why it is important to consider the identity of species as well as their biomass or overall diversity. The overall biomass of a very polluted site, Hamilton Harbour, was found to be high but the species contributing to the biomass were non-native carp and alewives, that are both indicators of disturbed freshwater habitats.

In addition to looking for qualitative relationships between species and habitats, statistical clustering tools such as two-way species indicator analysis, or TWINSPAN, can be used to quantitatively predict the occurrence of biological communities based on abiotic data (Zacharias *et al.*, 1999). TWINSPAN clusters species by site, thereby identifying possible communities. These communities can then be related to abiotic data (Zacharias *et al.*, 1999).

I sampled fish communities on sand, mud, cobble/sand and cobble/gravel beaches in Burrard Inlet and used community-level metrics to investigate habitat quality. I compared the fish species diversity among sites and looked for discrete communities of fishes. I expected the different habitat types would support different communities of fishes.

Methods

I chose nine sampling sites along Burrard Inlet's shoreline. The sites were distributed between West Vancouver and the end of Port Moody Arm and between the North and South shores of the inlet (Figure 2.1). There were two beach seining locations at New Brighton (East and West) and Barnett (Cobble and Sand). Four habitats were sampled: 1. mudflats (Rocky Point and Maplewood); 2. sandy beaches (Third Beach and Barnett-Sand); 3. a mixture of cobble and sand (West Vancouver); 4. and cobble-gravel beaches (Portside Park, New Brighton and Barnett-Cobble) (Chapter 2).

I beach seined using a 15 m-long beach seine with 3 mm and 18 mm mesh in the bunt and wings respectively. My assistant and I conducted the beach seines by wading out to chest height, dragging the net parallel to shore until the length of the net was parallel to shore, and then returning to shore. The lead line, was kept on the bottom throughout the set. We performed two sets per sampling trip. Although we tried to keep the area swept constant, it depended on the profile of the beach. The area of each set was not calculated. All fish were put in a holding bucket, identified to species (Hart, 1973; Pollard *et al.*, 1997), counted, and moved into a second bucket of water. Both buckets contained battery-powered aerators. Sampling was without replacement and we attempted to seine different parts of the beach on each pass. All of the fish were returned to the water after the last set was made. Temperature, salinity, time of day and tide height were also recorded.

I summed the catch in the two sets for all of the analyses. I calculated catch-per unit of effort (CPUE) which is the total number of fish caught divided by the number of sampling trips (N). I used the program Primer to calculate the species diversity of each site with the Brillouin Index, *H*, the appropriate index for nonrandom samples collected by seining that may not be representative of the community (Brower *et al.*, 1989). Brillouin's *H* is defined as:

$$H = (\log N! - \Sigma \log n_i !) / N$$

where N = the total number of individuals of all species, and n_i = the number of individuals per species. I then compared H between sites using a one-way ANOVA with a Bonferroni adjusted Post Hoc test (Brower *et al.*, 1989).

I also analyzed the data for species-substrate preferences. I used the program PC-ORD to perform a Two Way Species Indicator Analysis (TWINSPAN), a hierarchical classification method. TWINSPAN simultaneously clusters the sites and species into groupings based on the species present at each site (Gauch and Whittaker, 1981). The results are groups of sites with similar species compositions as well as groups of species that are found together. I further analyzed the site classification from the TWINSPAN analysis by using a chi-square test since I also knew the substrate type found at each site. I tested the null hypothesis that there would be no difference in substrate type between the groups.

Results

I caught a total of 29 species of fish (Table 5.1). The data are presented as a catch per unit of effort (CPUE). The most abundant fish were chum salmon, *Oncorhynchus keta*; chinook salmon, *O. tshawytscha*; shiner surfperch, *Cymatogaster aggregata*; staghorn sculpin, *Leptocottus armatus*; and the starry flounder, *Platichthys stellatus*. Highest catches of shiner surfperch occurred at Third Beach and consisted of spawning adults. I also caught many arrow gobies, *Clevlandia ios*; however, the high number is due to two sampling trips when I caught hundreds of newly recruited gobies at Rocky Point mud flat.

Portside Park and West Vancouver showed the highest species richness and species diversity index values (10-9 and 0.96-0.95 respectively) (Table 5.2). Barnett Cobble had the lowest species diversity (0.310) despite having a species richness of 10. Catches at Barnett Cobble were dominated by chum salmon. Species diversity differed significantly among sites ($F_{8,65}$=2.917, p=0.008). A Bonferroni adjusted Post Hoc test showed that differences existed between the two most diverse sites, Portside Park and West Vancouver, and the least diverse site, Barnett Cobble (p=0.023; p=0.035).

The identity of the species present, which is not taken into account by diversity indices, must also be considered. Chum salmon and staghorn sculpins were found ubiquitously. Shiner surfperch, arrow gobies, starry flounders, English sole (*Pleuronectes vetulus*), speckled sanddabs (*Citharichthys stigmaeus*) and sandlance (*Ammodytes hexapterus*) were found at the mud and sand sites; whereas other sculpins (*Oligocottus maculosus, Oligocottus snyderi, Artedius sp.*), gunnels and cockscombs (*Pholis sp., Apodicthyes flavidus, Anoplarchus sp.*) tended to be found at cobble and gravel sites.

The site results from the two-way species indicator analysis (TWINSPAN) are presented in Tables 5.3; while the fish community results appear in Table 5.4. TWINSPAN divided the data matrix at five levels. In a test of hierarchical classification programs, Gauch and Whittaker (1981) found that the first two levels of division, and sometimes the third, were near the true divisions for the data they tested. They found that any remaining divisions resulted from small dissimilarities which primarily reflect noise, or stochastic variation, rather than data structure (Gauch and Whittaker, 1981). For this reason, I only considered the first two levels of divisions.

TWINSPAN first divided the sampling sites into two groups: 1 and 2 on Table 5.3. Both of these groups were further subdivided into at the second level (A and B). Although the sites were classified purely according to the species found at them, I also analyzed the groupings with respect to substrate type. I conducted a Chi-square test to determine if substrate types differed among the classes. No difference was found in substrate type for level 1A. This grouping represents fish that were found at all sites. I did however find significant differences between substrate types for the remaining three levels (Table 5.3). These correspond to species found mainly on cobble-gravel, sand and mud respectively.

TWINSPAN divided the species into four groups: 1A, fish found at all sites but mostly found on cobble and gravel; 1B, predominantly on cobble and gravel; 2A, sand and mud sites; 2B, all sites but mostly at muddy sites (Table 5.4). High concordance exists between these clusters and life history characteristics of the fishes. For instance, sandlance and flatfishes are more commonly found over sandy bottoms than many sculpins, such as tidepool and buffalo sculpins, which tend to prefer rocky substrates (Hart, 1973).

Discussion

While the most commonly used indicators of habitat value are population-level indicators (Jones *et al.*, 1996); habitat can also be measured and managed at the community level. When management objectives address community-level concerns, indicators such as species diversity, species richness and genetic diversity should instead be used (Jones *et al.*, 1996). Species diversity is often considered to be a more sensitive and reliable index of environmental health than are individual indicator organisms (Dahlberg and Odum, 1970). For example, Wolter (2001) found that species number, diversity, and the abundance of intolerant fish species were inversely correlated with the degree of artificial shoreline structures such as riprap in German waterways.

In this study, I calculated the diversity of fish species as a community-level indicator of habitat quality. Community and population-level measures (Chapter 4) do correspond at some sites. West Vancouver and Portside Park have the highest species diversity index values as well as some of the highest catch rates of juvenile chum and chinook. Maplewood Mudflats shows both a low catch of chum and chinook and a low species diversity index. Conversely, Barnett-Cobble and New Brighton-West had high catches of chum salmon; while, both these sites had relatively low species diversity.

Although the comparison of species diversity at different sites can be useful, caution must be used when interpreting these data since species diversity is scale dependent. Van Horne (1983) explains that a common strategy used to manage habitat is to maximize species diversity which is assumed to be correlated with habitat diversity. Van Horne (1983) cautions that scale must always be considered when looking at species diversity since strategies designed to maximize α-diversity (diversity at a smaller scale) may not produce maximum levels of β-diversity (diversity on a larger scale). The species that are present at the various sampling sites, even those with relatively low diversity, are still contributing significantly to the overall biodiversity of the inlet.

Although diversity indices provide information on the numerical structure of populations, qualitative information about species composition is also important. Both quantitative (fish production) and qualitative (species composition as well as diversity) components of habitat productive capacity should be assessed (Randall *et al.*, 1998). In a study to determine the effect of habitat degradation on fish species composition and biomass in the Great Lakes, Randall *et al.* (1993) found the greatest biomass of fish at the most degraded sites. This increased biomass was positively correlated with eutrophication. Species composition of the communities at these sites was also negatively altered. Conversely, the least degraded sites showed the highest species richness and lowest proportion of exotic species. Quantitative and qualitative measures of habitat quality, therefore, yielded very different results.

In this study, some species, such as chum salmon and adult staghorn sculpins, were found ubiquitously, while other species were only found in certain habitat types. Juvenile shiner surfperch, arrow gobies, juvenile staghorn sculpins, sandlance and most flatfishes were only caught at the sand and mud sites while most other sculpins, gunnels and cockscombs were only caught at cobble/gravel sites. These habitat associations concur with known life history and habitat requirements of these species and probably represent community groupings.

A quantitative procedure to examine these community associations is with TWINSPAN. The TWINSPAN analysis showed that three or four species assemblages can be identified: a generalist group; one relating to cobble/gravel sites; one group to sand-mud; and a last group, with only one species, that is found in greatest abundance on mud but also present on other substrates. This analysis provides evidence that different communities of fishes are present at different types of beaches in Burrard Inlet. It also provides more information about the nature of the fish communities present than do species diversity indices. Biodiversity, or "the sum total of all biotic variation from the level of genes to ecosystems," is a multidimensional concept that cannot be reduced to a single number (Purvis and Hector, 2000).

Other characteristics of species can also be demonstrative. For instance, Randall et al. (1993) compared exotic versus native species. Wolter (2001) compared the proportion of endangered to common species. Eaton (1998) compared demersal fish communities at degraded and reference sites in Puget Sound in an attempt to develop a biocriteria tool for assessing the condition of water resources. Biocriteria are characteristics of populations and communities that are used as ecological metrics of biological assemblages. Examples include total fish biomass; flatfish biomass; abundance and biomass of certain species; mean individual weights and lengths of certain species; categories of tolerant and sensitive species (or species stages); species richness, dominance and evenness (Eaton, 1998). Although Eaton notes some problems with the study design, he did find consistent patterns between the three years of the study. One interesting finding was how the fishes grouped into tolerant and sensitive categories. English sole, sand sole, common sculpins (especially staghorn sculpin), adult bay gobies, juvenile Pacific tomcod, snake pricklebacks, and shiner surfperch were all found to be tolerant species. Sensitive species were starry flounders (particularly large ones), cartilaginous fishes, and juvenile bay gobies.

Eaton's study (1998) points out the importance of not only identifying the various species but also the lifestage or size of the individuals. In some cases, juveniles may be more sensitive than adults. I caught thousands of juvenile arrow gobies at Rocky Point mud flat. Juvenile shiner surfperch and staghorn sculpins were also numerous at this site. Rocky Point seems to be an important juvenile rearing ground as more juvenile fishes were caught there than at any other site. Rearing grounds, as well as spawning areas, such as Third Beach for shiner surfperch, should be identified and maintained.

Eaton (1998) also found the condition of individual fishes to be indicative of habitat quality. I found many small starry flounders with external skin lesions or tumors and very few large ones at Third Beach. Though further research is required, this could be indicative of a problem at or near this site.

Metrics of individual fitness as well as community-level metrics are particularly important in urbanized areas such as Burrard Inlet. Although I did not sample along riprap, seawalls or commercial piers and docks for this study, I did sample the fish communities at sites in the three different basins in Burrard Inlet. In Chapter 4, I showed that levels of habitat alteration vary among the basins. The Outer Inlet, with 73% of its shoreline unaltered, is the most natural basin, followed closely by the Central Harbour at 72%. Conversely, only 20% of the

Inner Harbour's shoreline is unaltered. Burrard Inlet, on a whole, is made up of nearly 45% altered habitat and riprap is the dominant shoreline type.

Negative impacts of habitat alteration, particularly at high rates, have been shown to affect species diversity. Jennings et al. (1999) studied the cumulative effects of shoreline habitat modification on fish assemblages in 17 Wisconsin lakes. They found that sites with riprap shorelines contained greater species richness than other sites. They attributed this trend to the complex habitat with interstitial spaces provided by the riprap. However, the authors also studied fish communities at the scale of the entire lake. They found that although riprap increased structural complexity of an individual site, when the whole lake was considered, the conversion of the entire shoreline to this one habitat type decreased overall habitat diversity and reduced species diversity (Jennings *et al.*, 1999).

In a separate study by Wolter (2001), 19 waterways in Germany were examined to evaluate their conservation value for fishes. Although the abundance of some eurytopic fishes was positively correlated with artificial embankments such as riprap and sheet pile, Wolter found that species richness and diversity, as well as the abundance of threatened and specialized fishes, was negatively correlated with these altered habitats. Further, the highest species richness was found in the most natural waterway and the mean number of species was significantly higher in waterways with predominantly natural shorelines.

Large commercial piers are another significant shoreline structure in Burrard Inlet. The effect of piers on fish habitat in the New York-New Jersey Harbour of the Hudson River have been examined by several investigators. Able *et al.* (1999) found the growth of juvenile winter flounder and tautogs to be lower under large commercial piers. They attributed decreased growth rates to decreased foraging efficiency due to low light levels under the piers. Duffy-Anderson and Able (1999) showed the growth of caged animals decreased along transects running from outside the pier to its center. Finally, Able and Manderson (1998) report that fish abundance and species richness were also typically low under the piers in the Hudson River.

However, the relationship between species diversity and altered habitats found in Wisconsin Lakes (Jennings *et al.*, 1999), German waterways (Wolter, 2001), and the Hudson River Estuary (Able and Manderson, 1998; Able *et al.*, 1999; Duffy-Anderson and Able, 1999) were not supported in this study. Species diversity was highest at Portside Park, in the most altered basin. Though the only statistically significant difference occurred between the least diverse site, Barnett Cobble, and the most diverse sites, Portside Park and West Vancouver, overall patterns of diversity can be looked at. Despite the fact that the Inner Harbour is much more altered than the Central Harbour, species diversity was high at Portside Park and New Brighton but relatively low at Barnett, Rocky Point and Maplewood Mudflats. These results may be explained by the fact that all of the sites used for this beach seining study were of natural habitat types. I suggest future studies be completed to investigate subtidal fish habitat use of altered habitat types such as riprap and commercial piers. Comparisons of species diversity in the different basins and habitats of Burrard Inlet are necessary to identify any effects of habitat alteration on fish communities.

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Table 5.1. Catch Per Unit of Effort (CPUE) of species caught by beach seine at each site in Burrard Inlet, April-June, 1999. N=number of sampling trips.

Species	West Vancouver	Third Beach	Portside Park	New Brighton E	New Brighton W	Maplewood Mud	Barnett-Cobble	Barnett-Sand	Rocky Point
N	9	6	10	8	7	5	8	6	7
Chum	41.7	2.5	31.6	16.6	33.7	9.6	37.5	17.3	0.7
Chinook	7.8	2.0	11.6	0.4	1.9	0.6	0.1	0.2	0
Coho	0.3	0.2	0.9	1.6	0	0	0	0	0
Salmon smolt	0.4	0.2	1.6	4.5	3.6	0	0.1	0	0.1
Sockeye	0.3	0	0	0	0	0	0	0	0
Cutthroat	0.1	0	0	0	0	0	0	0	0
Starry flounder	2.0	34.7	0.8	0.4	0.1	0.2	0	0.5	1.9
English sole	0.1	0.3	0	0	0	0	0	0	0
Speckled sanddab	0.2	0	0	0	0	0	0	0	0
Flatfish (juvenile)	3.0	0	0.1	0	0	0	0	0	0
Tidepool sculpin	0	0	2.5	2.6	1.1	0	0.3	0	0
Fluffy sculpin	0	0	0.3	1.0	0	0	0.1	0	0
Staghorn sculpin	1.6	2.2	3.6	0.8	0.1	4.2	1.1	8.7	20.4
Buffalo sculpin	0	0	0	0.4	0	0	0	0	0
Roughead sculpin	0	0	0	0.8	0.4	0	0	0	0
Smoothead sculpin	0	0	0	0	0.1	0	0	0	0
Baby sculpins	0	0	0	0.9	0.3	0	0.5	0	0
Shiner surfperch	32.6	157.0	3.7	0	0	0	0.1	0	7.7
Kelp surfperch	0.2	0	0	0	0	0	0	0	0
Crescent gunnel	0	0	0	0	0.1	0	0	0	0
Saddleback gunnel	0	0	0.1	0	0.3	0	0	0	0
Cockscomb	0	0	0	0	0	0	0.1	0	0
Penpoint	0	0	0.2	0	0	0	0	0	0
Pipefish	0	0.2	0	0.1	0	0	0	0	0
Arrow goby	0	0	0	0	0	0.2	0	0.2	289.7
Stickleback	3.0	0	0.2	0.3	0	0.2	0.6	0.3	0
Lingcod	0.2	0	0.5	0	0.9	0	0	0	0
Sandlance	0	4.2	0	0	0	0	0	2.0	0
Surf smelt	0	0.5	0	0	0	0	0	0	0

Table 5.2. Species richness and species diversity by site.

Site	Substrate	N	Species Richness	Species Diversity Brillouin Index (H)	
				Mean	SE
Portside	Cobble/gravel/sand	10	15	0.965	0.131
West Vancouver	Cobble/sand	9	15	0.954	0.155
New Brighton E	Gravel	8	13	0.828	0.100
Third Beach	Sand	6	11	0.655	0.141
New Brighton W	Gravel	7	12	0.641	0.159
Barnett Sand	Sand	6	7	0.577	0.113
Rocky Point	Mud	7	6	0.539	0.133
Maplewood Mud	Mud	5	6	0.372	0.143
Barnett Cobble	Cobble	8	10	0.310	0.149

Table 5.3. TWINSPAN site clusters.

	% Substrate Type Per Cluster Level			
Substrate	**1A**	**1B**	**2A**	**2B**
Cobble-Sand	20	0	27	0
Cobble-Gravel	63	92	18	8
Sand	7	0	55	30
Mud	10	8	0	62
X^2	5.25	8.63	13.73	21.0
Significance (3 df)	0.154	**0.034**	**0.003**	**0.0001**

Table 5.4. TWINSPAN Species clusters.

Cluster/ Species	Substrate Type
Cluster 1A	On all substrates but with greater abundance on Cobble/Gravel
Chinook	
Juvenile Flatfish	
Saddleback Gunnel	
Lingcod	
Chum	
Stickleback	
Cluster 1B	Mostly on Cobble/ Gravel
Fluffy Sculpin	
Buffalo Sculpin	
Roughhead Sculpin	
Juvenile Sculpin	
Tidepool Sculpin	
Salmon Smolt	
Smoothhead Sculpin	
Kelp Surfperch	
Crescent Gunnel	
Coho	
Sockeye	
Cutthroat Trout	
Cockscomb	
Cluster 2A	Mostly on Sand/Mud
Penpoint Gunnel	
Pipefish	
English Sole	
Shiner Surfperch	
Starry Flounder	
Speckled Sanddab	
Smelt	
Arrow Goby	
Sandlance	
Cluster 2B	On all substrates, but most abundant on mud
Staghorn Sculpin	

Chapter 6

Conclusions and Recommendations

Human alteration of the Earth is substantial and is ever-increasing with our growing population. It is estimated that between one-third and one-half of the land surface of Earth have already been transformed by human action. Much of this alteration has been concentrated in the coastal zone since up to 60% of the human population is concentrated within 100 km of the coast (Vitousek *et al.*, 1997). Though limiting our use of natural systems by preserving certain areas is one strategy to conserve biodiversity (Redford and Richter, 1999), we also have to learn how to live and use natural systems without destroying biodiversity. Understanding the effects of human alteration of habitats and landscapes in urban situations is especially pertinent. Despite the heavy urban, industrial, and commercial use of Burrard Inlet and its surrounding areas, rich communities and seemingly healthy populations of wildlife exist. Careful planning and management of human activities in Burrard Inlet will hopefully allow the persistence of a healthy environment.

Holling and Meffe (1996) discuss a paradigm used in the management of natural systems that they term "command and control." They explain that as problems are perceived, solutions for their control are developed and implemented. Problems are assumed to be well-bounded, clearly defined, relatively simple, and linear. In reality, problems we encounter while attempting to manage natural systems are complex, nonlinear, poorly understood, and subject to temporal and spatial scales. Given this incongruity, this management paradigm usually fails. Holling and Meffe (1996) state: "A frequent, perhaps universal result of command and control as applied to natural resource management is reduction of the range of natural variation of systems – their structure, function, or both – in an attempt to increase their predictability or stability." It is also observed that this reduction of variation through time or space often leads to a loss of system resilience (Holling and Meffe, 1996). They argue that management of natural resources should, instead, strive to retain critical types and ranges of natural variation in ecosystems. Existing processes and variables should be maintained rather than changing and controlling them, thereby maintaining ecosystem resilience; natural processes, structure and function; and species diversity (Holling and Meffe, 1996).

The command and control paradigm is also apparent in shoreline habitat management. Methods of slope stabilization such as seawalls and riprap are used to control natural erosion processes and to allow permanent human use of nearshore areas. Conversion of shoreline habitats in American lakes as well as in German waterways, lead to a decrease in species diversity and changes in species composition (Jennings *et al.*, 1999; Wolter, 2001). I have shown that much of Burrard Inlet's shoreline has undergone similar alterations. Nearly 45% of Burrard Inlet's shoreline has been altered and the most common substrate type is riprap. How this alteration affects the ecological communities and wildlife populations inhabiting the inlet is, however, still unknown.

Studies of habitat use, as well as habitat evaluation methods, are biased by our perspective and values and limited by our understanding of the ecology of natural systems. Points of bias include the temporal and spatial scales chosen for study and management; the identification of the important habitat variables; and the assumptions and values used to choose metrics of habitat quality.

In this thesis, I provided information on the physical, social and biotic environments of Burrard Inlet. I researched habitat classification and evaluation models. I investigated juvenile chum and chinook habitat at three nested scales. Finally, I studied nearshore fish communities found on cobble, gravel, sand, and mud beaches. Throughout this thesis, I have discussed metrics that could be used to assess fish habitat and appropriate scales of evaluation. These lines of investigation have brought me to several conclusions. I offer the following recommendations for the management of fish habitat in Burrard Inlet:

1. Habitat assessments are dependent upon scale. Habitat in Burrard Inlet should be assessed and managed at three scales: The scale of the entire Inlet, including it's watershed and significant external inputs; the scale of the basin; and site-level habitat characteristics. The Severn Sound (Minns *et al.*, 1999) and Prince Rupert Harbour (Archipelago, 1999) habitat classification and evaluation models are two models that could be adapted to meet the management needs of Burrard Inlet.
2. Fish habitat should first be considered at the two broadest scales using landscape level habitat metrics. Critical metrics include habitat diversity, abundance and rarity; habitat connectivity and isolation; and natural versus anthropogenic substrates types. These metrics should be applied to the entire inlet as well as within each basin. For instance, natural habitat types should be maintained in each basin. These metrics are not only important for juvenile salmonids but also to maintain appropriate habitats for the different fish communities found in the inlet. Tools and data currently exist to perform these types of assessments.
3. Habitat should secondarily be assessed at a site level. Do the habitats that fish encounter meet the requirements of their entire life history? With respect to juvenile salmonids, I recommend that further work using capacity, opportunity and realized function be performed (Simenstad and Cordell, 2000). Studies should include the direct measurement of physiological and behavioural responses, such as survival, residence-time, foraging success and growth rates attributed to the fish's occupation of the habitat. Additionally, movement patterns of juvenile salmonids in Burrard Inlet

should be studied to identify critical habitats and to investigate the effects of habitat isolation and connectivity.

4. Community-level metrics should also be assessed. Species diversity measurements and fish community identification in additional habitats, particularly altered habitats, should be performed. A comparison of these metrics among the three basins in the inlet would help us to understand the cumulative effects of urbanization and development on fish communities.
5. Important fish habitats in the inlet should be identified and maintained. Examples include areas of high diversity such as Portside Park and West Vancouver, rearing habitats such as Rocky Point, and spawning areas such as Third Beach.
6. Research should be done to determine tolerant and intolerant fish species or life stages of species in Burrard Inlet.
7. Growth, biomass and health assessments should be performed on certain indicator species such as flatfishes.
8. Water and sediment quality should be considered integral components of physical habitat.
9. Oceanographic features such as water currents, fronts, and eddies should be considered as habitat, particularly for juvenile salmonids.
10. A formal monitoring system of fish populations and communities should be developed to assess and monitor the health of the Burrard Inlet ecosystem.

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Appendix 1. Streams, Creeks and Tributaries of Burrard Inlet and Indian Arm.

Flows into:	Municipality	Stream	Classification	Fish Species
Howe Sound	West Vancouver	Eagle Creek	Salmon Spawning	
Howe Sound	West Vancouver	Nelson Creek	Salmon Spawning	
Howe Sound	West Vancouver	Larson Creek	Named	
Outer Inlet	West Vancouver	Brothers Creek	Salmon Spawning	
Outer Inlet	West Vancouver	Cypress Creek	Salmon Spawning	
?	West Vancouver	Wood Creek	Named	
?	West Vancouver	Willow Creek	Named	
?	West Vancouver	Godman Creek	Named	
?	West Vancouver	Turner Creek	Named	
?	West Vancouver	Cave Creek	Named	
Outer Inlet	West Vancouver	Westmount Creek	Named	
?	West Vancouver	Pipe Creek	Named	
Outer Inlet	West Vancouver	Rogers Creek	Named	
Outer Inlet	West Vancouver	Marr Creek	Named	
Outer Inlet	West Vancouver	McDonald Creek	Named	
Outer Inlet	West Vancouver	Lawson Creek	Named	
Outer Inlet	West Vancouver	Vinson Creek	Named	
Outer Inlet	West Vancouver	Hadden Creek	Named	
Capilano River	West Vancouver/ DNV	Houlgate Creek	Named	
Outer Inlet	West Vancouver	Capilano River	Salmon Spawning/ Fish Bearing	CO, CH, CM, PI, CT,ST, DV
Outer Inlet	West Vancouver	Holyburn Creek	?	
Inner Harbour	Vancouver	Beaver Creek	Unclassified	
Outer Inlet	Vancouver	Spanish Creek	Unclassified	
Central Harbour	Burnaby	Rainbow Creek	Fish Bearing	
Central Harbour	Burnaby	Berry Point Creek	Nutrient	
Central Harbour	Burnaby	Capitol Creek	Nutrient	
Central Harbour	Burnaby	Squatters Creek	Nutrient	
Central Harbour	Burnaby	Heron Creek	Nutrient	
Central Harbour	Burnaby	Dynamite Creek	Nutrient	
Central Harbour	Burnaby	Kask's Camp Creek	Nutrient	
Central Harbour	Burnaby	Thluck Way Tun Creek	Fish Bearing	
Port Moody Arm	Burnaby	Simon Creek	Fish Bearing	
Port Moody Arm	Burnaby	Nicholson Creek	Fish Bearing	
Port Moody Arm	Burnaby	Submarine Creek	Fish Bearing	
Port Moody Arm	Burnaby	Crab Creek	Nutrient	
Port Moody Arm	Burnaby	Cougar Creek	Nutrient	
Port Moody Arm	Burnaby	Aliceville Creek	Nutrient	
Port Moody Arm	Port Moody	Barnett Stream A	D	
Port Moody Arm	Port Moody	Barnett Stream B	B	
Port Moody Arm	Port Moody	Barnett Stream C	B	
Port Moody Arm	Port Moody	Barnett Stream D	B	
Port Moody Arm	Port Moody	Stoney Creek	A	
Port Moody Arm	Port Moody	South Schoolhouse Creek	A	
S Schoolhouse	Port Moody	Melrose Creek	A	

S Schoolhouse	Port Moody	Unnamed Tributary	B	
S Schoolhouse	Port Moody	Unnamed Tributary	B	
"Chines" Creek	Port Moody	Ottley Creek	B	
"Chines" Creek	Port Moody	Axford Creek	B	
"Chines" Creek	Port Moody	Kyle Creek	B	
"Chines" Creek	Port Moody	Hachely Creek	B	
"Chines" Creek	Port Moody	West Sundial Creek	D	
"Chines" Creek	Port Moody	East Sundial Creek	D	
"Chines" Creek	Port Moody	Goulet Creek	A	
Port Moody Arm	Port Moody	Slaughterhouse Creek	see tributaries	
Slaughterhouse Creek	Port Moody	Williams Creek	B	
Slaughterhouse Creek	Port Moody	Elginhouse Creek	B	
Slaughterhouse Creek	Port Moody	Correl Brool	A	
Slaughterhouse Creek	Port Moody	Dallas Creek	A	
Port Moody Arm	Port Moody	Pigeon Creek	A	
Port Moody Arm	Port Moody	Suter Brook	A	
Port Moody Arm	Port Moody	Noons Creek	A	
Port Moody Arm	Port Moody	Hutchinson Creek	A	
Port Moody Arm	Port Moody	Turner Creek	D	
Port Moody Arm	Port Moody	Wilkes Creek	D	
Port Moody Arm	Port Moody	Hett Creek	D	
Port Moody Arm	Port Moody	Pleasantside Creek	B	
Port Moody Arm	Port Moody	Mossom Creek	A	
Mossom Creek	Port Moody	April Creek	B	
Mossom Creek	Port Moody	Unnamed Tributary	B	
Port Moody Arm	Port Moody	North Schoolhouse Creek	A	
Port Moody Arm	Port Moody	Imperial Creek	A	
Port Moody Arm	Port Moody	Ioco Creek	D	
Port Moody Arm	Port Moody	Unnamed Ioco Creek A	B	
Port Moody Arm	Port Moody	Burrard Thermal Creek	B	
Port Moody Arm	Port Moody	Unnamed Belcarra Creek A	B	
Port Moody Arm	Port Moody	Unnamed Belcarra Creek B	B	
Port Moody Arm	Port Moody	Unnamed Belcarra Creek C	B	
Indian Arm	Port Moody	Unnamed Belcarra Creek D	B	
Bedwell Bay, Indian Arm	Port Moody	Ray Creek	A	
Bedwell Bay, Indian Arm	Port Moody	Anmore Creek	A	
Indian Arm	DNV	Allan Creek	Non-fish bearing*	
Indian Arm	DNV	Sunshine Creek	Non-fish bearing*	
Indian Arm	DNV	Scott Goldie Creek	Fish Bearing	SC
Indian Arm	DNV	Percy Creek	Non-fish bearing*	
Indian Arm	DNV	Myddleton Creek	Non-fish bearing*	
Indian Arm	DNV	Oster Creek	Non-fish bearing*	

Indian Arm	DNV	Word Creek	Non-fish bearing*	
Deep Cove	DNV	Francois Creek	Non-fish bearing*	
Deep Cove	DNV	Cleopatra Creek	Non-fish bearing*	
Deep Cove	DNV	Cove Creek	Non-fish bearing*	
Deep Cove	DNV	Matthews Brook	Non-fish bearing*	
Deep Cove	DNV	Panorama Creek	Non-fish bearing*	
Deep Cove	DNV	Gallant Creek	Fish Bearing	CT
Deep Cove	DNV	Unnamed Creek	Nutrient	
Deep Cove	DNV	Parkside Creek	Fish Bearing	CT, ST
Indian Arm	DNV	Unnamed Creek	Nutrient	
Indian Arm	DNV	Unnamed Creek	Nutrient	
Central Harbour	DNV	Roche Point Creek	Non-fish bearing*	
Central Harbour	DNV	Taylor Creek	Fish Bearing	CT
Central Harbour	DNV	Thomas Creek	Non-fish bearing*	
Thomas Cr.	DNV	Unnamed Tributary	Nutrient	
Central Harbour	DNV	Range Creek	Non-fish bearing*	
Central Harbour	DNV	McCartney Creek	Fish Bearing	CM, CO, CT
McCartney Cr.	DNV	Trillium Creek	Fish Bearing	CT
McCartney Cr.	DNV	Woods Creek	Nutrient	
McCartney Cr.	DNV	Mountain Creek	Nutrient	
Central Harbour	DNV	Blueridge Creek	Fish Bearing	CO, CT
Central Harbour	DNV	Seymore River	Fish Bearing	CM, ST, CH, CT, SO, DV
Seymore River	DNV	Maplewood Creek	Fish Bearing	CT, CM, CT
Seymore River	DNV	Boulder Creek	Nutrient	
Seymore River	DNV	Mystery Creek	Nutrient	
Seymore River	DNV	Canyon Creek	Non-fish bearing	
Inner Harbour	North Vancouver, DNV	Lynn Creek	Fish Bearing	CO, CH, CM, PI, CT, ST, DV
Lynn Cr.	DNV	Hoskins Creek	Fish Bearing	CO, CH,
Lynn Cr.	DNV	Pierard Creek	Fish Bearing	CT
Lynn Cr.	DNV	Thames Creek	Fish Bearing	CT
Lynn Cr.	DNV	Coleman Creek	Fish Bearing	CT, CO
Lynn Cr.	DNV	Hastings Creek	Fish Bearing	CO, CH, SC, DV, ST, CT
Lynn Cr.	DNV	Dyer Creek	Fish Bearing	CT
Lynn Cr.	DNV	Dunell Creek	Nutrient	
Lynn Cr.	DNV	Kilmer Creek	Fish Bearing	ST
Lynn Cr.	DNV	Keith Creek	Fish Bearing	CO, CT, ST, SC
Inner Harbour	North Vancouver, DNV	Mosquito Creek	Fish Bearing	CO, CT, ST,
Mosquito Cr.	North Vancouver, DNV	Mission Creek	Fish Bearing	CT
Mosquito Cr.	North Vancouver, DNV	Thain Creek	Fish Bearing	CT
Mosquito Cr.	DNV	Lower Mission Creek	Nutrient	
Mosquito Cr.	North Vancouver, DNV	Wagg Creek	Fish Bearing	CO, CT
Wagg Cr.	DNV	St. Martins Creek	Non-fish bearing*	
Inner Harbour	North Vancouver, DNV	MacKay Creek	Fish Bearing	CO, CH, CT, PI, ST

Inner Harbour	North Vancouver	Moodyville Creek	Non-fish bearing*	
Indian Arm		Indian River	Salmon Spawning	CH, CO, CM, PI, SO
Indian Arm		Bishop Creek	Unclassified	
Indian Arm		Clementine Creek	Unclassified	
Indian Arm		Coldwell Creek	Unclassified	
Indian Arm		Elsay Creek	Unclassified	
Indian Arm		Francis Creek	Unclassified	
Indian Arm		Grand Creek	Unclassified	
Indian Arm		Holmden Creek	Unclassified	
Indian Arm		Lighthall Creek	Unclassified	
Indian Arm		Shone Creek	Unclassified	
Indian Arm		Underhill Creek	Unclassified	
Indian Arm		Wigwam Creek	Unclassified	
Indian Arm		Windermere Creek	Fish Bearing	CT

Fish Species Codes: SC=Sculpin, CO=Coho, CH=Chinook, CM=Chum, PI=Pink, SO=Sockeye, CT=Cutthroat, ST=Stealhead, DV=Dolly Varden.
*No fish were found with the present sampling effort, however, fish may be present. Further sampling is required.

West Vancouver: Is currently working on developing a classification system. 4 creeks are designated as salmon spawning streams. An additional 15 are streams are "named" but are not classified (Personal Communication, L. Richard).

District of North Vancouver (DNV): Streams are classified as fish bearing, non-fish bearing and nutrient providing based on some loose survey work done in 1993. This should only be considered as a preliminary indicator as to whether or not fish have been spotted in particular locations. They note that streams on the map that do not indicate the presence of fish on them only implies that fish were not found at the time the data were collected. Further sampling is required to further assess this fact. Additionally, the nutrient providing streams are considered to be as important as fish bearing streams. (District of North Vancouver 1999) (Personal Communication, K. Bennett; www.dnv.org). The District of North Vancouver may also have some hydrology information for some streams; however, I was not able to access it from the website.

City of North Vancouver: Streams are classified as fish bearing or non-fish bearing. Most streams are shared with the District of North-Vancouver. Classification is consistent between the municipalities (Personal Communication, M. Hunter).

Port Moody: Streams in Port Moody were classified as part of the Port Moody ESA Management Strategy in June of 2000 (Robertson, Ltd. et al. 2000). Port Moody's classification system and definitions correspond to the Fish Protection Act

Port Moody Stream Classification Definitions

Class	Definition
A	Watercourses inhabited by salmonids and/or rare or endangered fish species, or potentially inhabited by such fish with access enhancement (e.g. removal of culverts).
B	Watercourses that are a significant (as defined in MELP 1999) source or a potentially significant source of food and nutrients to downstream fish populations. These watersheds are characterized by no fish presence and no reasonable potential for fish presence through flow or access enhancement.
C	Watercourses that provide an insignificant contribution of food or nutrients to downstream areas supporting or potentially fish populations.
D	Unknown but potentially fish bearing.

Belcarra and Anmore: It appears as though streams in these two townships were classified in the Port Moody Study as well.

Burnaby: The City of Burnaby is also in the process of classifying streams. Streams will be classified as Class A, fish bearing or potentially fish bearing with access enhancements; and Class B, significant food and nutrient as in the Fish Protection Act. Only the lower reaches of the streams classified as A are fish bearing as the road and escarpment make the headwaters inaccessible to fish (Personal Communication, R. Wark).

Vancouver: Almost all of the streams feeding into Burrard Inlet in the City of Vancouver have been lost (Precision-Identification 1997). The map Wild, Threatened, Endangered and Lost Streams of the Lower Fraser Valley (Precision-Identification 1997) shows that at least 24 streams feeding into the Outer Harbour, Inner Harbour and False Creek have been lost in Vancouver. These streams were turned into sewers and culverts (personal communication, J. Addiss, S. McTaggart). The streams that do still exist are in parks and are under the management of the Parks board. They are not classified by the park board (Personal Communication, K. Davis-Johnson).

Indian Arm: Although some of the streams leading into Indian Arm are classified by Port Moody or the District of North Vancouver, many of the Northern Streams are not classified. Neither BC Parks nor the Tsleil Waututh First Nation has conducted a comprehensive stream inventory or classification (Personal Communication, D. Abberly and T. Ang). I searched for all of the "unclassified" streams around Indian Arm on the Fish Information Summary System (FISS) database and found only 1 entry which I included on the Table 1. FISS can be accessed at: http://www.bcfisheries.gov.bc.ca/fishinv/fiss.html

Literature Cited

District of North Vancouver, G. I. S. D. (1999). Fish Species Map. District of North Vancouver, District of North Vancouver.

Precision-Identification, B. C. (1997). Wild, threatened, endangered and lost steams of the Lower Fraser Valley Summary Report. Vancouver, Fraser River Action Plan.

Robertson, E. S. L., C. R. E. S. Ltd., et al. (2000). City of Port Moody ESA Management Strategy. Phase 2: Development of Management Recommendations. City of Port Moody.

Websites:

www.gis.dnv.org

http://www.bcfisheries.gov.bc.ca/fishinv/fiss.html

Personal Communications:

Contact Person	Municipality	Phone
Jeff Addiss	Vancouver	873-7353
Steve McTaggart	Vancouver	873-7356
Kate Davis-Johnson	Vancouver Parks Board	257-8400
Robyn Wark	Burnaby	294-7297
Rick Saunier	Port Moody	469-4572
Michael Hunter	North Vancouver	985-7761
Ken Bennett	District of North Vancouver	990-2445
Laura Lee Richard	West Vancouver	925-7000
Doug Abberly	Tsleil Waututh First Nation	929-3454
Tom Ang	Indian Arm Provincial Park	924-2231

Appendix 2. Salmon Spawning Returns In Burrard Inlet, 1953-1998 (Pers.Com. G. Bonnell)

RAB Code	90-0300-000-000-000-000			90-0320-000-000-000-000		90-0500-000-000-000-000				
Gazetted Name	NOONS CREEK			MOSSOM CREEK		INDIAN RIVER				
Local Name	(blank)			(blank)		BURRARD RIVER				
Year	Chinook	Chum	Coho	Chum	Coho	Chinook	Chum	Coho	Pink	Sockeye
1953							1500	1500	100000	
1954							35000	1500	200	
1955							3500	3500	75000	
1956							1500	1500		
1957							3500	1500	125000	
1958							15000	750		
1959							35000	1500	125000	
1960							4000	1500		
1961							2500	3500	400	
1962							3500	400		
1963							3000	1500	200000	
1964							5000	3500		
1965							3500	400	35000	
1966							3500	1500	75	
1967							3500	1500	7500	
1968							15000	750		
1969							15000	400	7500	25
1970							15000	750		25
1971							7500	750	35000	25
1972							35000	400		
1973							35000	750	35000	
1974							7500	750		
1975							15000	200	35000	75
1976							20000	200		
1977						25	14000	500	22000	25
1978						6	7000	150		7
1979						180	7500	280	22000	12
1980						50	15000	300		25
1981						20	17500	800	40000	8
1982						50	24000	450		
1983						70	26000	700	24000	16
1984			300	60	10	100	30000	600		12
1985			300	275		200	30000	500	10000	24
1986			186			82	32000	1200		
1987			62	376		50	31000	375	35000	12
1988			110	750	1	100	30000	700		
1989			400	500	50	375	14000	800	38000	
1990			175			245	43000	450		
1991		6	8	435	12	106	24000	350	103000	
1992		20	20	1000		120	36000	400		
1993	1	50	350	600	30	142	33000	510	135000	
1994		50		350			60000			
1995		19		126			42000			
1996		45		300			40000			
1997		40		250			60800			
1998										
Sum of Count	1	230	1911	5022	103	1921	905300	39565	1209675	291
Mean		32.8571	191.1	418.5	20.6	113	20117.8	965	52594.6	22.3846

RAB Code	90-0690-000-000-000-000		90-0700-000-000-000-000					90-0700-100-000-000-000	
Gazetted Name	MCCARTNEY CREEK		SEYMOUR RIVER					MAPLEWOOD CREEK	
Local Name	MCCARTNEY CREEK		SEYMOUR RIVER					(blank)	
Year	Chum	Coho	Chinook	Chum	Coho	Pink	Sockeye	Chum	Coho
1953				750	1500	1500			
1954				3500	1500	25			
1955				200	3500	400			
1956				200	1500				
1957				200	3500	75			
1958				200	400				
1959				75	1500	7500			
1960				25	1500				
1961				25	400	400			
1962				25	1500				
1963				75	1500	400			
1964				25	750				
1965				25	400	200			
1966				25	1500				
1967				25	400	400			
1968				25	1500				
1969					1500	25			
1970					1500				
1971				25	3500	200			
1972				750	1500				
1973				25	1500	25			
1974					3500				
1975				25	1500	200			
1976			6		1000	100			
1977			20	150	3000	100			
1978			17	220	5000				
1979			150	300	4500	250			
1980			250	250	9000				
1981			50	800	8500	1000			
1982		22	250	200	8500		2		
1983		13	300	500	14000	1000		6	21
1984		39	280	600	13000			14	240
1985		22	35	170	6500			27	110
1986	7	11	150	400	7800			1	29
1987		76		6800	3150	1200			
1988			12	300	4700				
1989		7	102	150	4650	275		4	3
1990			52	409	5950			9	5
1991		3	85	2240	4300	2780		125	3
1992		8	25	175	3500			50	15
1993		5	14	376	4100	775		27	16
1994	2			800					
1995				463				79	
1996									
1997									
1998		34							
Sum of Count	9	240	1798	21528	148500	18830	2	342	442
Mean	4.5	20.6	105.765	552	3621.95	855.909	2	34.2	49.1111

RAB Code	90-0800-000-000-000-000				90-0800-020-000-000-000			90-0860-000-000-000-000	
Gazetted Name	LYNN CREEK				HASTINGS CREEK			MACKAY CREEK	
Local Name	LYNN CREEK				(blank)			MCKAY CREEK	
Year	Chinook	Chum	Coho	Pink	Chinook	Chum	Coho	Chum	Coho
1953		25	75	25					25
1954		200	75						25
1955		25	200	25					25
1956			75						25
1957		25	200	25					25
1958		75	75						25
1959		75	25	25					
1960		25	25						
1961		25	25	25					
1962		25	25						
1963		25	25	25					
1964		25	25						
1965		25	25	25					
1966		25	25						
1967		25	25						
1968		25	25						
1969			200						
1970			75						
1971			75						
1972		400	400						
1973		25	75						
1974		25	75						
1975			75						
1976			30						
1977			60				16		
1978		6	85				12		8
1979	4	10	42	26			50	4	18
1980	10		250				175	4	12
1981	4	10	120				85	6	25
1982	6		121				78		16
1983	6		175				16		16
1984		16	185				32		32
1985	7		215		6		175		106
1986							67		
1987		36	127				27		87
1988		7	350				38	4	40
1989	7	19	254				36		27
1990	27		175				11		
1991	16	17	68			2	9	3	12
1992	25	6	100				10	12	60
1993	31	50	220				5	20	75
1994		12						5	
1995		32							
1996									
1997									
1998									
Sum of Count	143	1321	4502	201	6	2	842	58	684
Mean	13	44.0333	112.55	25.125	6	2	49.5294	7.25	34.2

RAB Code	90-0900-000-000-000-000					90-0900-010-000-000-000			
Gazetted Name	CAPILANO RIVER					BROTHERS CREEK			
Local Name	CAPILANO RIVER					BROTHERS CREEK			
Year	Chinook	Chum	Coho	Pink	Sockeye	Chinook	Chum	Coho	Pink
1953		750	3500	1500					
1954		3500	3500	75					
1955		400	4998	400	4				
1956		25	1840						
1957		200	5100	75					
1958		400	3745						
1959		75	2730	25					
1960		25	3614						
1961		25	2114	25					
1962		25	2636						
1963		75	2071	100					
1964		25	2622						
1965		25	750	25					
1966		25	3500						
1967		25	1500						
1968		200	1500						
1969		200	1500	25					
1970		75	3500						
1971	44	75		25					
1972	38	700		7					
1973	165	1100		150					
1974	93	1500							
1975	767	400		200					
1976	1102	40			2				
1977		150		30			55	12	
1978	492	250					48	66	
1979	3000	280		200		13	38	54	
1980	2839	200				20	65	85	
1981	1330	400		450		12	160	110	35
1982	463	100				18	56	194	
1983	1133	500		70	3	27	124	186	64
1984	32	205	370			17	97	183	
1985	164	50	460	200		93	117	253	
1986	19	287	182			27	36	112	
1987		180	350	375		7	16	37	
1988	95	65	650			15	17	37	
1989	72	37	600			33	64	137	
1990									
1991	67	39	650	53		16	111	26	27
1992	320	50	2400			5	130	75	
1993	56	163	1571			3		62	23
1994		30					100		
1995		39					76		
1996									
1997							60		
1998									
Sum of Count	12291	12915	57953	4010	9	306	1370	1629	149
Mean	614.55	307.5	2146.41	200.5	3	21.8571	76.1111	101.813	37.25

RAB Code	90-0988-000-000-000-000		90-0990-000-000-000-000		90-1500-030-000-000-000
Gazetted Name	EAGLE CREEK		NELSON CREEK		CENTRE CREEK
Local Name	EAGLE HARBOUR CREEK		NELSON CREEK		CENTRE CREEK
Year	Chum	Coho	Chum	Coho	Chum
1953			400		
1954			750		
1955			25		
1956			25		
1957			25		
1958			25		
1959					
1960					
1961					
1962					
1963					
1964					
1965					
1966					
1967					
1968					
1969					
1970	25		75		
1971	15		30		
1972	25		75		
1973	6		35		
1974	25		25		
1975					
1976			4		
1977					
1978					
1979	6		50		
1980			6		
1981		6	6		
1982					
1983					
1984	3	7	3		
1985		4			
1986	15				
1987					
1988		18			
1989		14			
1990		3		6	3
1991	1	5			
1992					
1993					
1994					
1995					
1996					
1997					
1998					
Sum of Count	121	57	1559	6	3
Mean	13.4444	8.14286	97.4375	6	3

RAB Code	90-1500-040-000-000-000		90-1580-000-000-000-000	
Gazetted Name	MANNION CREEK		FLUME CREEK	
Local Name	COTTON CREEK		FLUME CREEK	Sum of
Year	Chum	Coho	Chum	Count
1953				12003
1954				15104
1955				12157
1956				5646
1957				11407
1958				6903
1959				13989
1960				7174
1961				5025
1962				6198
1963				6259
1964				5436
1965				3465
1966				7066
1967				4367
1968				5243
1969	500			5919
1970	200			7420
1971	100			6060
1972	250		25	6142
1973	750		75	5904
1974	75		25	7317
1975	400			5542
1976	125			4385
1977	750			6320
1978	90			8272
1979	175			11149
1980	150			15296
1981	300			15390
1982	50	65	2	12125
1983	400		6	20549
1984	350			17689
1985	393			11092
1986	150			11279
1987	800			15255
1988	75			8411
1989	214		25	8719
1990				8640
1991	54			12703
1992	10			8968
1993	5			9590
1994	3		10	2956
1995				2684
1996				1996
1997				2057
1998				2032
Sum of Count	6369	65	168	298430
Mean	254.76	65	24	

Appendix 3. Hatchery Releases in Burrard Inlet, 1998-1999. (Pers. Com, G. Bonnell)

Species / **Release stage**	**1998**	**1999**
Chinook		
Seapen 0+	192500	156571
Smolt 0+	690599	589580
Chum		
Fed FW	488572	482573
Seapen	28467	95669
Unfed	205742	60912
Coho		
Fed Fall	11000	1950
Fed Spring	223357	327203
Seapen	17280	30482
Smolt	655995	631394
Pink		
Unfed	128639	0
Cutthroat		
Fed fry	75	0
Smolt	1164	1753
Steelhead		
Fed Fry	46859	27020
Smolt SR 2	29083	4853
Smolt Wr 1+	0	34724
Smolt Wr 2+	16964	7607

Appendix 4. Previous studies of Biota in Burrard Inlet

These reports are found in the Burrard Inlet Environmental Action Plan library.

<u>Source I</u>

Bion Research Inc. (1994). Fish habitat and fish food production in Burrard Inlet, Interim Report. Prepared for the Department of Fisheries and Oceans, Vancouver.

Bion Research Inc. (1995). Fish habitat and food production in Burrard Inlet, technical appendix. Prepared for Department of Fisheries and Oceans, Vancouver.

Levy, D. A. (1996). Juvenile salmon utilization of Burrard Inlet foreshore habitats. Prepared for the Department of Fisheries and Oceans, New Westminster.

Fish Species Sampled

Table 1. Summary of salmonid species sampling by Bion, March 09-October 07, 1994.

	Chum	Pink	Chinook	Coho	Sockeye	Cutthroat	Steelhead
# Captured	4571	3813	3761	8	15	9	0
% of total catch	16.6	13.9	13.7	0.1	0.1	0.1	
Mean Size (FL)	38.8 mm	32.8 mm	41.6mm				
Stomach contents identified?	Y	Y	Y	N	N	N	
Other Info.							

Sampling Sites and Methods

Seven primary sites were sampled for fish repeatedly between March 09 and October 07, 1994, and another seven sites were sampled once or twice in the spring. Fish were caught using a 30 m long Beach Seine with 0.25 inch meshed net deployed from a Zodiac at mid to high tide. Three replicate seines were taken at each site on most sampling trip. See Appendix 2 for sampling dates and times.

Habitat Information Collected

Abiotic Parameters: Exposure, slope, aspect, Ash free weight, substrate class (%): mud, sand, gravel, cobble, boulder, bedrock, anthropomorphic substrate; water temperature (C), dissolved oxygen (mg/L), turbidity (mg/L), salinity (ppt), conductivity (mS), pH,

Biotic Parameters: Organic matter (%): wood, Fucus, Laminaria, Mytilus, Ulva, Balanus, Enteromorpha, Nereocystis, other; Invertebrate sampling (total #/replicate and Weight (g)): Intertidal epibenthic sled sampler, diver-operated sub-tidal sled sampler, a plankton pump, fucus basket sampler.

Source II

Naito, B. G., and Hwang, J. (2000). Timing and distribution of juvenile salmonids in Burrard Inlet: February to August 1992. Canadian Data Report of Fisheries and Aquatic Sciences, 1069.

Fish Species Sampled

Table 2. Summary of salmonid species sampling by Naito et al., February 25-August 26, 1992.

	Chum	**Pink**	**Chinook**	**Coho**	**Sockeye**	**Cutthroat**	**Steelhead**
# Caught	12647	11494	573	406	42	20	12
% of total catch	50.2	45.6	2.3	1.6	0.17	0.01	0.004
Mean Size Range (mm)*	35-83 (48.3)**	34-87 (51.5)**	40-117 (80.8)**	63-127	75-94	139-300	120-159
Stomach Contents identified?	N	N	N	N	N	N	N
Other Info.	P/A of tags indicating hatchery fish						

- *subsamples of 30 fish were taken to be measured.
- ** Mean lengths as calculated in Levy (1996).

Sampling Sites and Methods

10 sites were sampled once a week from Feb. 25-May 12 and bi-weekly from May 12 until August 26, 1992. See Appendix 2 for sampling dates and times. A 30 m beach seine deployed from a boat was used to collect the fish.

Habitat Information Collected

Abiotic Parameters: Aspect, wave environment, substrate, slope, surface temperature,
Biotic Parameters: P/A of non-salmonid species. No data on inverts or algae.

Source III

Macdonald, J. S., and Chang, B. D. (1993). Seasonal use by fish of nearshore areas in an urbanized inlet in Southwestern British Columbia. *Northwest Science*, 67(2), 63-77.

Fish Species Sampled

Table 4. Summary of salmonid species sampling by Macdonald and Chang, February 04-November 30, 1983.

	Chum	Pink	Chinook	Coho	Sockeye	Cutthroat	Steelhead
# Caught	1185	0	58	15	2	0	5
% of total catch	29.1		1.4	0.3	.004		.001
Mean Size Range (mm)	34-78		60-120				
Stomach Contents identified?	Y		Y	Y			
Other Info.							

Other fish species caught (from most to least common)

(The number of fish caught per site is not presented in this paper.)
Pacific sandlance, threespine stickleback, English sole, speckled sanddab, pipefish, starry flounder, tidepool sculpin, staghorn sculpin, kelp greenling, tube-snout, surf smelt, buffalo sculpin, pile perch, steelhead, sharpnose sculpin, tomcod, shiner perch, penpoint gunnel, crescent gunnel, sockeye, herring, rock sole, butter sole, eulachon, anchovy.

Sampling Sites and Times and Methods

Three sites in West Vancouver were sampled in 13 trips between February 4-November 30, 1983. A 13.8 m beach seine was deployed from an inflatable boat.

Habitat Information Collected

Abiotic Parameters: Surface water temperature, general site characteristics.

Biotic Parameters: none.

Source IV

ECL Envirowest Consultants. (1992). Biophysical surveys of twenty Burrard Inlet shore units utilizing Department of Fisheries and Oceans description and assessment procedures. Burrard Inlet Environmental Action Program, New Westminster.

ECL Envirowest Consultants. (1993). Habitat mapping of thirty Burrard Inlet Shore units. Burrard Inlet Action Program, New Westminster.

Fish Species Sampled

No Salmon

Other fish species observed

Sculpins, gunnels, flatfish, rockfish, lingcod, greenlings, surf perches, ratfish, spiny lumpsucker, pipefish, gobbies, poachers, and eelpouts. The numbers of fish observed per transect was quite low (2 or 3 fish) unless a group of schooling fish was observed to increase the numbers to 12-16. Fish count information is available in the source.

Sampling Sites and Methods
20 sites surveyed in 1992, and 30 more in 1993. In 1992, intertidal surveys, conducted at daylight low tides, as well as subtidal diving surveys (1 transect/site) were completed, but only diving surveys were done in 1993. In 1993 two transect lines per site were surveyed. The diving transects were videotaped both years and still photos of the intertidal areas of the shore units were taken in 1992. See Appendix 5 for sample sites and locations.

Habitat Information Collected
Abiotic Parameters: Latitude/Longitude, time, weather, wave environment, fetch, sediment transport, substrate type, slope, tide height.

Biotic Parameters: Algae (mostly %, some count), Invertebrates (%, Estimated # per section, or total count), written description of zone characteristics: backshore, intertidal, subtidal.

Source V

Goyette, D., and Thomas, M. (1987). Vancouver Harbour Benthic Environmental Quality Studies May 1985 to September 1986-Relative Species Abundance and Distribution, Trawl Catch. *87-03*, Environment Canada Environmental Protection, Vancouver.

Fish Species Sampled
No salmon were sampled in this survey.

Other fish species caught (from most to least common)
English Sole, rex sole, f;athead sole, hybrid sole, rock sole, dover sole, starry flounder, Pacific sanddab, Pacific cod, hake, pollack, shiner perch, midshipman, greenlings, ratfish, eelpouts.

Sampling Sites and Times and Methods
12 sites were sampled in total but one is outside Burrard Inlet. The survey took place in May and October 1985, and January and May, 1986. A otter trawl (3.8 cm mesh and 5.8 m throat), towed for approximately 0.9 km was used to collect specimens.

Habitat Information Collected
Abiotic Parameters: trawl depth, trawl time,

Biotic Parameters: crab and shrimp species caught in trawls also identified and counted.

Source VI

Foreshore Technologies Inc. (1996). Report on the subtidal biophysical inventory of Burrard Inlet. *P-1659*, Prepared for: Burrard Inlet Environmental Action Program, New Westminster.

Fish Species Sampled
No fish were sampled.

Sampling Sites and Times and Methods
A diver was towed on a sled along the shore at depths of 3, 8 or 15 meters below chart datum. An approximate distance of 400 kilometers of longshore transects completed in this study. was Visual observations of biota and substrate to be mapped were called out on a two-way communication system and recorded along with the diver's geographical position.

Habitat Information Collected
Abiotic Parameters: substrate types: Anthropogenic-metal, concrete, rubble, sunken logs, structural wood; Unconsolidated-boulder, cobble, sand, mud; bedrock.

Biotic Parameters: Biota mapped were: bull kelp, eel grass, laminarians, Fucus, red algae, green algae, anemones, barnacles, clams, tubeworms, crabs, cucumbers, sea stars, shrimps, mussels., and sea urchin aggregations.

Information Source VII

Burd, B. J., and Brinkhurst, R. O. (1990). Vancouver Harbour and Burrard Inlet benthic infaunal sampling program. *Canadian Technical Report of Hydrography and Ocean Sciences* **122**, Department of Fisheries and Oceans, Sidney.

Fish Species Sampled
No fish species were sampled.

Sampling Sites and Methods
Infauna was sampled at 28 stations throughout the inlet between October 26 to 30, 1987. Samples (2 replicates per site) were taken with a 23 cm ponar grab. A sediment core was taken and then the grabs were filtered through a 0.3 mm screen. Samples were sorted and identified in the lab.

Appendix 5. Site cross referencing of the data sets described above: I, Bion; II, Naito et al.; III, Macdonald and Chang; IV, ECL Envirowest; V Goyette and Thomas. The number in brackets indicates the number of replicates taken at each site.

Site/location	I	II	III	IV	V	Other
Dundarave: NW-shore, outer BI	X(43)	X(15)			X(1)	
Sunset Beach: Mouth of False Creek	X(41)	X(16)		X(2)		
Mackay Creek: N-Shore, inner BI	X(41)					
Maplewood: N-shore, central harbour	X(41)			X(2)		(1, 2, 3)
Coal Harbour: S-shore, inner harbour	X(41)	X(17)		X(2)	X(4)	
Portside: S-shore, inner harbour	X(51)	X(18)		X(2)		
New Brighton: S-shore, inner harbour	X(42)	X(18)		X(2)		
Caulfiel: N-shore, outer BI	X(8)			X(2)		
Cypress: N-shore, outer BI	X(4)		X			
Pilot Cove: N-shore, outer BI	X(1)					
Sandy Cove: n-shore, outer BI	X(3)					
Cates Park: Mouth of Indian Arm	X(1)	X(17)			X (1)	
Jericho: S outer BI	X(8)	X(15)				
Second beach: SE outer BI, Stanley Park	X(3)			X(2)		
Ambleside: N-shore outer BI		X(3)		X(2)		
Woodlands: Mid-Indian Arm		X(15)				
Moody Arm West: Mouth of Port Moody		X(16)				(4)
Moody Arm East: Head of Port Moody		X(15)				(4)
Starboat Cove: NW outer BI			X			
West Van Lab: NW outer BI			X			
Altamount: NW outer BI				X(2)		
Capilano R. (W): N outer BI				X(2)		
Mosquito C. (E): N inner harbour				X(2)		
Lynn C. (W): N Inner harbour				X(2)		
Seymour R. (W): N central harbour				X(2)		
Big John C. (EW): N central harbour				X(2)		
Goodwin Johnson: S central harbour				X(2)		
Coastal Containers: S inner harbour				X(2)		
Brockton Point: S inner harbour				X(2)		
False Creek (N): end of False Creek				X(2)		
False Creek (S): Center of False Creek				X(2)		
Kitsilano Point: S outer BI				X(2)		(5)
Spanish Bank: S outer BI				X(2)		
Calamity Point: N inner harbour				X(2)		
Fullerton Fill: N inner harbour				X(2)		
Van. Dry Dock: N inner harbour				X(2)		
Pioneer Grain Term: N inner harbour				X(2)		
Burrard Band: N central harbour				X(2)		
Noble towing N central harbour				X(2)		
Roche Point: N central harbour				X(2)		
DollartonMouth of Indian Arm				X(2)		
Deep Cove: Indian Arm				X(2)		
Brighton Beach: Indian Arm				X(2)		
Shone Creek: Indian Arm				X(2)		
Croker Creek: Indian Arm				X(2)		
Bishop Creek: Indian Arm				X(2)		
Clemintine Creek: Indian Arm				X(2)		
Wigwam Inn: Indian Arm				X(2)		
Farrer Cove: Indian Arm				X(2)		
Bedwell Bay: Indian Arm				X(2)		

Belcarra Bay: Indian Arm				X(2)		(6, 7)
Dockrill Point: N Port Moody Arm				X(2)		
Sunnyside: N Port Moody Arm				X(2)		
Old Orchard Park: N Port Moody Arm				X(2)		
General Chemical: S Port Moody Arm				X(2)		
Texaco: S central harbour				X(2)		
Berry Point: S central harbour				X(2)		
Second Narrows Park: S central harbour				X(2)		
Columbia Containers: S inner harbour				X(2)		
Heliport: S inner harbour				X(2)		
Deadman Island: S inner harbour				X(2)		
Burnaby Shoal: S inner harbour				X(2)		
Pacific Environment Inst.: NW outer BI					X(4)	
Burrard Yarrows: N Inner harbour					X(4)	
Chevron: Mid central harbour					X(1)	
Boulder Rock: Mouth of Indian Arm					X(1)	
Ioco: N Port Moody Arm					X(2)	
Port Moody: Mid Port Moody Arm					X(4)	
Sterling: S inner harbour					X(3)	
Centre: S inner Harbour					X(2)	

1.Howard Paish and Associates Ltd., "An ecological assessment of the Seymour-Maplewood foreshore area" (Department of the Environment Canada, 1975).
2.C. D. Levings, N. G. McDaniel, "Invertebrates at the Maplewood Mudflats, a rare habitat in Vancouver Harbour" Fisheriees Research Board of Canada Manuscript Report Series *1314* (Pacific Environment Institute, 1974).
3.S. Zogaris, "Maplewood flats upland and basin: wildlife habitat significance" (Western Canada Wilderness Committee and Vancouver Natural History Society, 1980).
4.C. Hanrahan, "Wildlife inventory of the shoreline park system, Port Moody, B.C." (Burke Mountain Naturalists, 1994).
5.S. Millen, S. Donaldson, "Kitsilano shoreline marine biological survey of the intertidal zone 1993-1994" (Point Grey Natural Foreshore and Waterfowl Sanctuary Protective Society Burrard Inlet Environmental Action Program, 1994).
6.C. Hardon, et al., "Belcarra Regional Park intertidal and subtidal biophysical inventory" *3* (Greater Vancouver Regional District, 1985).
Sandwell Inc., "A risk analysis of tanker traffic movements within the Port of Vancouver, Vol. 2, characterization of the port and its environs" (Vancouver Port Corporation, 1991).

Appendix 6. Partially Annotated Bibliography of Burrard Inlet Data Sources

This is a list of sources that contain information on biophysical aspects of the Burrard Inlet. The documents containing some information about fish are marked with an asterisk*.

Arduino, S. (1995). Fish and wildlife source review for the Burrard Inlet area. Burrard Inlet Environmental Action Program, Vancouver.
This is a bibliography of information on fish and wildlife in Burrard Inlet. Some Compensation reports are listed in this bibliography. Available from BIEAP office.

Austin, B., MacBride, L., and Walker, D. (1995). Adopt a shoreline quadrat study. Burrard Inlet Environmental Action Program, Vancouver.
This describes the preliminary volunteer intertidal data collection program. 8 sites were studied. Not terribly quantitative. A second year's data is also available (Gehlen, 1995).

Barreca, J. (1984). Intertidal baseline study of Figurehead Point, Vancouver, British Columbia, 15-16 May 1984. Vancouver Natural history Society, Vancouver.
Data from the transects and core samples are available. The complete report is at the BIEAP office.

*Bion Research Inc. (1994). Fish habitat and fish food production in Burrard Inlet, Interim Report. Prepared for the Department of Fisheries and Oceans, Vancouver.
Some preliminary data is included in this report.

*Bion Research Inc. (1995). Fish habitat and food production in Burrard Inlet, technical appendix. Prepared for Department of Fisheries and Oceans, Vancouver.
This contract was never completed but most of the data gathered are available. The remaining stomach content data may be available from Sandy Leposki. David Levy may also have some of the rest of the data. See also Levy (1996).

Bion Research Inc. (1997). Burrard Inlet Point Source Discharge Inventory. Burrard Inlet Environmental Action Program, Vancouver.

Burd, B. J., and Brinkhurst, R. O. (1990). Vancouver Harbour and Burrard Inlet benthic infaunal sampling program. *122*, Department of Fisheries and Oceans, Sidney.
Benthic infauna were sampled at 28 stations in the Harbour from October 26=30, 1987. Only the infauna was sampled in this study.

*Coast River Environmental Services Ltd. (1997). Fourth annual (1997) post-construction monitoring report for the Rivtow Marine Ltd. compensation site at 101 Victoria Avenue, Vancouver. Coast River Environmental Services, Vancouver.
Several Compensation Monitoring reports such as this one are available through Bruce Clark. Monitoring from before and after compensation activities (sometimes yearly for up to 5 years) are available. Methodologies are not standardized and quality of the reports vary.

Davidson, L. W. (1979). On the physical Oceanography of Burrard Inlet and Indian Arm. M.Sc., University of British Columbia, Vancouver.

Department of Environment. (1971). The Burrard Inlet-Howe Sound Area, preliminary description of existing environmental conditions. Department of the Environment, Vancouver.
Included are a description of Oceanographic climate, spawning data for North Shore rivers and Streams, and results of a marine survey. Included: Species list from beach seines and beach gillnet, 1972, species captured in black cod traps and by long line, and descriptions of some underwater surveys. Data not useful.
Also includes an appendix on Oceanography: see Tabata 1971.

*ECL Envirowest Consultants. (1992). Biophysical surveys of twenty Burrard Inlet shore units utilizing Department of Fisheries and Oceans description and assessment procedures. Burrard Inlet Environmental Action Program, New Westminster.
Sampling was conducted in the intertidal and subtidal (using SCUBA) zones of 20 shore units along Burrard Inlet. Fish sightings are limited but a range of habitat parameters (substrate, vegetation, inverts, oceanography, foreshore) were collected as well as sightings.

*ECL Envirowest Consultants. (1993). Habitat mapping of thirty Burrard Inlet Shore units. Burrard Inlet Action Program, New Westminster.
Thirty more shore units (in addition to previous 20 (ECL 1992) were sampled. Methodology is similar, but more transects per site were performed. Again, habitat variables are recorded, but the numbers of fish seen are limited.

ENTECH Environmental Consultants. (1992). Inventory and evaluation of environmental monitoring programs in Burrard Inlet: 1985 to 1991. Burrard Inlet Environmental Action Program, Vancouver.
This contains a list of all environmental monitoring programs in the Burrard Inlet from 1985-1991. Bibliography and list of people contacted is useful.

Foreshore Technologies Inc. (1996). Report on the subtidal biophysical inventory of Burrard Inlet. *P-1659*, Prepared for: Burrard Inlet Environmental Action Program, New Westminster.
A diver was towed on a sled behind a boat and called out verbal descriptions of the biophysical features of the Burrard Inlet. Longitude and latitude were recorded along with the observations. Observations were then mapped.

*G.L. Williams and Associates Ltd. (1997). Pacific Coast Terminals saltmarsh compensation 1997 monitoring report. *BERC CPR #9202-011*, Prepared for Pacific Coast Terminals Co. Ltd., Coquitlam.
Several Compensation Monitoring reports such as this one are available through Bruce Clark. Monitoring from before and after compensation activities (sometimes yearly for up to 5 years) are available. Methodologies are not standardized and quality of the reports vary.

Gehlen, N. (1995). Adopt-a-shoreline 1995 quadrat study final report. Burrard Inlet Environmental Action Plan
Georgia Strait Alliance, Vancouver.
Volunteer intertidal data is available for 15 sites around the inlet. Not quantitative. Available from BIEAP library

*Goyette, D., Brand, D., and Thomas, M. (1988). Prevalence of idiopathic lesions in English sole and epidermal abnormalities in flatfish from Vancouver Harbour, British Columbia, 1986. *Regional Program Report*, Environment Canada Conservation and Protection, Vancouver.
The catch data dealt with in this report is presented in Goyette and Thomas, 1987.

*Goyette, D., and Thomas, M. (1987). Vancouver Harbour Benthic Environmental Quality Studies May 1985 to September 1986-Relative Species Abundance and Distribution, Trawl Catch. *87-03*, Environment Canada Environmental Protection, Vancouver.
The total catch data of several trawl surveys conducted in the Vancouver Harbour are presented. Dominant fish species caught were: English sole, rex sole, hybrid sole, and flathead sole. Otter trawl coordinates, depths, times, total catch, and size class distribution for some species are presented in an Appendix.

*Hancock, M. J., and Marshal., D. E. (1986). Catalogue of salmon streams and spawning escapements of statistical area 28 Howe Sound-Burrard Inlet. *557*, Department of Fisheries and Oceans, Vancouver.
Catalogue contains: each stream's location, spawning distribution, escapement records, barriers, general stream data, and topographic maps.

*Hanrahan, C. (1994). Wildlife inventory of the shoreline park system, Port Moody, B.C. , Burke Mountain Naturalists, Port Moody.
Contains a list of fish species found in the Port Moody Arm of the Burrard Inlet, but no quantitative data.

Harrison, P. J., Fulton, J. D., Taylor, F. J. R., and Parsons, T. R. (1983). Review of the Biological Oceanography of the Strait of Georgia: pelagic Environment. *Canadian Journal of Fisheries and Aquatic Sciences*, 40, 1064-1094.
Burrard Inlet is discussed along with the Georgia Strait.

Howard Paish and Associates Ltd. (1975). An ecological assessment of the Seymour-Maplewood foreshore area. Department of the Environment Canada, Vancouver.
Some data on the fish of the mudflats is presented in Appendix 3.

*Levings, C. D. (1973). Sediments and Abundance of Lycodopsis pacifica (Pisces, Zoarcidae) near Point Grey, B.C., with catch data for associated demersal fish. *393*, Department of Fisheries and Oceans, Vancouver.
Includes some catch data of trawls in outer inlet.

*Levings, C. D., and McDaniel, N. G. (1974). Invertebrates at the Maplewood Mudflats, a rare habitat in Vancouver Harbour. *1314*, Pacific Environment Institute, West Vancouver.
A study to investigate the invertebrate community at Maplewood mudflats is discussed.

*Levy, D. A. (1985). Biology and management of surf smelt in Burrard Inlet, Vancouver, B.C. *28*, Westwater Research Center, University of British Columbia, Vancouver.
The recreational surf smelt fishery in Burrard Inlet is investigated. Data on surf smelt populations are presented. No other fish species are discussed. The study area is outer Burrard Inlet.

*Levy, D. A. (1996). Juvenile salmon utilization of Burrard Inlet foreshore habitats. Prepared for the Department of Fisheries and Oceans, New Westminster.
The data from Bion (1995) is reworked in this report.

*Macdonald, J. S., and Chang, B. D. (1993). Seasonal use by fish of nearshore areas in an urbanized inlet in Southwestern British Columbia. *Northwest Science*, 67(2), 63-77.
Three sites on the north shore of Burrard Inlet were sampled for fish using a beach seine. 13 trips with a total of 76 sets were made between February and November of 1983. Lengths of all species of fish were recorded and the stomach contents of some fish were analyzed. Habitat parameters were not recorded along with the seines.

Millen, S., and Donaldson, S. (1994). Kitsilano shoreline marine biological survey of the intertidal zone 1993-1994. Point Grey Natural Foreshore and Waterfowl Sanctuary Protective Society, Burrard Inlet Environmental Action Program, Vancouver.
Transects in intertidal areas of English bay are studied 4 times: July 1993, October 1993, January 1994, April 1994. Full report is available from BIEAP library.

Ministry of Transportation and Highways. (1995). comparative environmental assessment of Lion's Gate crossing options related to Stanley Park and First Nations. , Province of British Columbia, Victoria.
This is of limited use as the data collected are not included.

*Munday, D. R., Ennis, G. L., Wright, D. G., Jeffries, D. C., McGreer, E. R., and Mathers, J. S. (1986). Development and evaluation of a model to predict effects of buried underwater blasting charges on fish populations in shallow water areas. *1418*, Department of Fisheries and Oceans, Vancouver.
Minimal data on fish populations: just some counts of dead fish after the blasts.

*Naito, B. G., Clark, B. A., and Hwang, J. (1998). Timing and distribution of juvenile salmonids in Burrard Inlet: February to August 1992. , Department of Fisheries and Oceans, New Westminster.
Contains some beach seine data for juvenile salmon at a few sites in Burrard Inlet.

*Nelles, S. (1978). Comments on juvenile salmonid utilization of Burrard Inlet and Vancouver Harbour. , Department of Fisheries and the Environment, Vancouver.
The data from a few sampling programs from the 1970's are analyzed to investigate salmonid usage of the Burrard Inlet. An estimate of the numbers of juvenile salmonids occupying the inlet as well as a breakdown of what each stream is contributing is also provided. Discussion is limited to when they are occupying the inlet and there is no discussion of what habitats are being used.

*Popham, J. D. (1985). The occurrence of abnormalities in the tissues of bottom-dwelling fish. *85-01*, Environment Canada Environmental Protection Service, Sidney.
A limited number of flatfish were caught from the Vancouver Harbour and English Bay and examined for lesions. Data on the numbers of fish and which species are presented.

*Quamme, D. L., Slaney, T. L., and Hinch, S. G. (1997). Burrard Thermal Generating Station cooling water effects study: distribution of fish in Burrard Inlet, Port Moody Arm, and

potential effects of migration of adult salmon. DRAFT. Aquatic Resources Limited, Prepared for: BC Hydro Burrard Thermal Generating Station, Vancouver.
A literature search to pull together existing data on the Burrard Inlet was an important part of this project. It therefore has a useful bibliography and list of contacts.

*Renyard, S. (1985). Initial development and strategies for the Burrard Inlet shore-based sport fisheries. Prepared for: Department of Fisheries and Oceans, Vancouver.-Alternate reference: M.Sc. Thesis, UBC (in Special Collections)
Limited data on fish species; mainly presence/absence but some CPUE data for some species caught by sport fishermen.

*Renyard, T. S. (1988). The fishes of Burrard Inlet. *Discovery*, 17(4), 126-129.
A list of fish species found in the Burrard Inlet is provided. No quantitative data.

Sandwell Inc. (1991). A risk analysis of tanker traffic movements within the Port of Vancouver, Vol. 2, characterization of the port and its environs. Vancouver Port Corporation, Vancouver.
Appendix, Volume iv, contains species lists and relative abundance scales of species found in the Vancouver Harbour, however, it seems to be based on a literature search rather than on field sampling. A description of B.I. is in Vol.ii. References are in Vol. ii, p. 7-40-46

*Sandwell Inc., and Castor Consultants. (1992). Dredged material management study Burrard Inlet. , Burrard Inlet Environmental Action Program, Vancouver.
Contaminants in dredged sediments are discussed with some recommendations.

Stanley Associates Engineering Ltd. (1992). Urban runoff quantification and contaminants loading in the Fraser River Basin and Burrard Inlet. *DOE FRAP 1993-19*, Fraser River Action Plan and Environment Canada, Surrey.

Stockner, J. G., and Cliff, D. D. (1979). Phytoplankton ecology of Vancouver Harbor. *Journal of the fisheries research board of Canada*, 36(1), 1-10.
A study of the ecology of phytoplankton in Burrard Inlet and Indian Arm. Some mention is also made of the zooplankton.

Tabata, S. (1971). A brief oceanographic description of the waters of Burrard Inlet and Indian Arm. Appendix D of the Burrard Inlet-Howe Sound Area, Preliminary Description of Environmental Conditions, Draft Report., Vancouver.
Clear description of oceanography of inlet.

Thomson, R. E. (1981). *Oceanography of the British Columbia Coast.* Department of Fisheries and Oceans, Sidney, B.C.
Chp. 10: Strait of Georgia, has a clear and concise description of the oceanography of Burrard Inlet. (p.169).

UMA Engineering Ltd. (1992). Combined sewer overflow inventory for the Fraser River Basin and Burrard Inlet. *DOE FRAP 1993-21*, Fraser River Action Plan
Environment Canada, Burnaby.

Waters, R. D. (1985). Initial environmental assessment profile of Vancouver Harbour, Volume II. *85-07*, Environment Canada Environmental Protection Service, Coquitlam.
This is an annotated bibliography of all studies that had been conducted in the Burrard Inlet up to 1984.

Waters, R. D. (1986). Initial environment assessment profile of Vancouver Harbour, Volume I. *85-06*, Environment Canada Environmental Protection Service, Coquitlam.
An overview of the Burrard Inlet is presented based on a literature search (see Volume II) is provided. It's focus is on toxicological aspects in water, sediment and biota.

Zogaris, S. (1980). Maplewood flats upland and basin: wildlife habitat significance. , Western Canada Wilderness Committee and Vancouver Natural History Society, Vancouver.
Foreshore and marsh areas of the Maplewood mudflats are described in this paper. No subtidal data.

Appendix 7. Burrard Inlet and Indian Arm Shoreline Segments.

No.	Sub-Area	Shore	Category	Substrate Type	Map cm	Distance m	Notes	Chart
1	Port Moody	S	mixed fines	mud	23.3	2330.0	Rocky Point	3495
2	Port Moody	S	seawall	built	1.1	110.0	scale 1:10000	3495
3	Port Moody	S	mixed fines	mud	12.8	1280.0		3495
4	Port Moody	S	riprap	riprap	1.5	150.0		3495
5	Port Moody	S	dock	dock/riprap	7.1	710.0		3495
6	Port Moody	S	Unconsolidated	boulder/cobble	2.6	260.0		3495
7	Port Moody	S	riprap	riprap	2.0	200.0		3495
8	Port Moody	S	dock	dock/riprap	10.4	1040.0		3495
9	Port Moody	S	seawall	built	1.3	130.0		3495
10	Port Moody	S	dock	dock/riprap	5.9	590.0		3495
11	Port Moody	S	Unconsolidated	cob/gr/sand	0.6	60.0		3495
12	Port Moody	S	riprap	riprap	0.7	70.0		3495
13	Port Moody	S	Unconsolidated	cob/gr/sand	1.5	150.0		3495
14	Port Moody	S	Unconsolidated	boulder/cobble	1.2	120.0		3495
15	Port Moody	S	Unconsolidated	cob/gr/sand	2.5	250.0		3495
16	Port Moody	S	Unconsolidated	boulder/cobble	1.8	180.0		3495
17	Port Moody	S	Unconsolidated	cob/gr/sand	2.5	250.0		3495
18	Port Moody	S	Unconsolidated	boulder/cobble	2.6	260.0		3495
19	Port Moody	S	Unconsolidated	cob/gr/sand	4.1	410.0		3495
20	Central	S	Unconsolidated	cobble/rubble	1.7	170.0	Barnett	3495
21	Central	S	riprap	rubble/boulder	0.7	70.0	Barnett	3495
22	Central	S	mixed fines	gr/sand	2.6	260.0	Barnett	3495
23	Central	S	riprap	rubble	1.8	180.0	Barnett	3495
24	Central	S	riprap	riprap	2.4	240.0		3495
25	Central	S	mixed fines	gr/sand	0.8	80.0		3495
26	Central	S	riprap	riprap	3.1	310.0		3495
27	Central	S	mixed fines	gr/sand	0.9	90.0		3495
28	Central	S	riprap	riprap	4.5	450.0		3495
29	Central	S	Unconsolidated	cob/gr/sand	4.6	460.0		3495
30	Central	S	dock	dock/gr/sand	1.2	120.0		3495
31	Central	S	dock	dock/riprap	1.7	170.0		3495
32	Central	S	riprap	riprap	3.9	390.0		3495
33	Central	S	mixed fines	gr/sand	0.9	90.0		3495
34	Central	S	riprap	riprap	0.6	60.0		3495
35	Central	S	mixed fines	sand/mud	3.5	350.0		3494
36	Central	S	dock	dock/mud	1.2	120.0		3494
37	Central	S	mixed fines	gr/sand/mud	4.0	400.0		3494
38	Central	S	riprap	riprap	4.2	420.0		3494
39	Central	S	dock	dock/riprap	1.0	100.0		3494
40	Central	S	riprap	rubble/riprap	4.2	420.0		3494
41	Central	S	Unconsolidated	bo/cob/gr/sa	15.7	1570.0		3494
42	Central	S	Unconsolidated	cob/gr/sand	2.5	250.0		3494
43	Central	S	dock	dock/gr/sand	2.1	210.0		3494
44	Central	S	Unconsolidated	bo/cob/gr/sa	2.7	270.0		3494
45	Central	S	Consolidated	bedrock	1.9	190.0		3494
46	Central	S	Consolidated	boulder	0.7	70.0		3494
47	Central	S	Consolidated	bedrock	2.7	270.0		3494

48	Central	S	Unconsolidated	cob/gr/sand	0.6	60.0		3494
49	Central	S	Consolidated	bedrock	1.3	130.0		3494
50	Central	S	riprap	riprap	1.9	190.0		3494
51	Central	S	Consolidated	bedrock	1.3	130.0		3494
52	Central	S	riprap	rubble/riprap	3.2	320.0		3494
53	Inner	S	mixed fines	gr/sand	0.6	60.0		3493
54	Inner	S	seawall	built	2.1	210.0		3493
55	Inner	S	dock	dock/riprap	5.5	550.0		3493
56	Inner	S	Unconsolidated	cob/gr/sand	0.4	40.0		3493
57	Inner	S	riprap	riprap	0.4	40.0		3493
58	Inner	S	Unconsolidated	cob/gr	0.5	50.0	NB	3493
59	Inner	S	riprap	riprap	1.1	110.0	NB	3493
60	Inner	S	Unconsolidated	cob/gr	0.8	80.0	NB	3493
61	Inner	S	riprap	riprap	4.6	460.0		3493
62	Inner	S	seawall	built	1.0	100.0		3493
63	Inner	S	Unconsolidated	cobble	0.3	30.0		3493
64	Inner	S	riprap	riprap	2.9	290.0		3493
65	Inner	S	seawall	built	0.7	70.0		3493
66	Inner	S	riprap	riprap	6.4	640.0		3493
67	Inner	S	dock	dock/riprap	0.8	80.0		3493
68	Inner	S	riprap	riprap	0.7	70.0		3493
69	Inner	S	seawall	built	4.2	420.0		3493
70	Inner	S	riprap	riprap	0.8	80.0		3493
71	Inner	S	seawall	built	1.9	190.0		3493
72	Inner	S	riprap	riprap	0.2	20.0		3493
73	Inner	S	seawall	built	1.0	100.0		3493
74	Inner	S	riprap	rubble/riprap	0.2	20.0		3493
75	Inner	S	seawall	built	1.1	110.0		3493
76	Inner	S	riprap	rubble/riprap	0.6	60.0		3493
77	Inner	S	seawall	built	0.5	50.0		3493
78	Inner	S	riprap	riprap	1.8	180.0		3493
79	Inner	S	seawall	built	18.8	1880.0		3493
80	Inner	S	riprap	riprap	1.4	140.0		3493
81	Inner	S	seawall	built	0.3	30.0		3493
82	Inner	S	riprap	riprap	4.8	480.0		3493
83	Inner	S	dock	dock/riprap	0.7	70.0		3493
84	Inner	S	riprap	riprap	1.0	100.0		3493
85	Inner	S	seawall	built	3.1	310.0		3493
86	Inner	S	dock	dock/riprap	1.8	180.0		3493
87	Inner	S	seawall	built	1.4	140.0		3493
88	Inner	S	riprap	riprap	2.3	230.0		3493
89	Inner	S	seawall	built	3.4	340.0		3493
90	Inner	S	riprap	riprap	0.3	30.0		3493
91	Inner	S	seawall	built	16.8	1680.0		3493
92	Inner	S	riprap	riprap	4.0	400.0		3493
93	Inner	S	dock	dock/riprap	1.2	120.0		3493
94	Inner	S	seawall	built	1.6	160.0		3493
95	Inner	S	riprap	riprap	2.4	240.0		3493
96	Inner	S	seawall	built	1.3	130.0		3493
97	Inner	S	dock	dock/riprap	1.2	120.0		3493
98	Inner	S	riprap	riprap	0.6	60.0	Portside	3493

99	Inner	S	Unconsolidated	cob/gr/sand	1.2	120.0	Portside	3493
100	Inner	S	riprap	riprap	2.6	260.0	Portside	3493
101	Inner	S	dock	dock/riprap	1.1	110.0		3493
102	Inner	S	riprap	riprap	2.1	210.0		3493
103	Inner	S	seawall	built	1.8	180.0		3493
104	Inner	S	riprap	riprap	1.7	170.0		3493
105	Inner	S	seawall	built	9.9	990.0		3493
106	Inner	S	dock	dock/riprap	4.3	430.0		3493
107	Inner	S	riprap	riprap	5.5	550.0		3493
108	Inner	S	dock	dock/riprap	12.4	1240.0	Coal Harbour	3493
109	Inner	S	Unconsolidated	cob/gr	0.7	70.0		3493
110	Inner	S	seawall	built	1.6	160.0	Stanley Park	3493
111	Inner	S	dock	dock/co/gr/mu	13.2	1320.0	Rowing Club	3493
112	Inner	S	Unconsolidated	bo/cob/gr/mu	10.7	1070.0	Stanley Park	3493
113	Inner	S	Consolidated	bed/bo/co/gr	6.4	640.0	Stanley Park	3493
114	Inner	S	Unconsolidated	cobble	0.6	60.0	Stanley Park	3493
115	Inner	S	Consolidated	bed/bo	2.2	220.0	Stanley Park	3493
116	Inner	S	Unconsolidated	boulder/cobble	6.4	640.0	Stanley Park	3493
117	Inner	S	mixed fines	gr/sand	2.2	220.0	Stanley Park	3493
118	Inner	S	Unconsolidated	boulder/cobble	5.0	500.0	Stanley Park	3493
119	Inner	S	Consolidated	bed/bo	19.8	1980.0	Stanley Park	3493
120	Outer	S	Consolidated	bo/sa	1.1	110.0	Stanley Park	3493
121	Outer	S	Consolidated	bedrock	2.9	290.0	Stanley Park	3493
122	Outer	S	Consolidated	bo/sa	1.8	180.0	Stanley Park	3493
123	Outer	S	Consolidated	bedrock	1.0	100.0	Stanley Park	3493
124	Outer	S	Consolidated	bo/sa	1.6	160.0	Stanley Park	3493
125	Outer	S	Consolidated	bed/bo	1.9	190.0	Stanley Park	3493
126	Outer	S	mixed fines	sand	0.3	30.0	Third Beach	3493
127	Outer	S	Consolidated	bed/bo	3.5	350.0	Third Beach	3493
128	Outer	S	Unconsolidated	cob/sand	0.8	80.0	Stanley Park	3493
129	Outer	S	Consolidated	bedrock	0.7	70.0	Stanley Park	3493
130	Outer	S	Consolidated	bo/sa	2.6	260.0	Stanley Park	3493
131	Outer	S	mixed fines	gr/sand	5.3	530.0	Stanley Park	3493
132	Outer	S	Consolidated	bedrock	0.4	40.0	Stanley Park	3493
133	Outer	S	Unconsolidated	cob/gr/sand	6.7	670.0	Second beach	3493
134	Outer	S	mixed fines	sand	7.1	710.0	English Bay	3493
135	Outer	S	riprap	riprap	3.1	310.0		3493
136	Outer	N	riprap	riprap	0.6	60.0		3493
137	Outer	N	mixed fines	gr/sand	3.9	390.0		3493
138	Outer	N	riprap	riprap	1.1	110.0		3493
139	Outer	N	Unconsolidated	cob/gr/sand	3.9	390.0		3493
140	Outer	N	riprap	riprap	0.3	30.0		3493
141	Outer	N	Unconsolidated	cob/gr/sand	1.5	150.0		3493
142	Outer	N	riprap	riprap	0.4	40.0		3493
143	Outer	N	Unconsolidated	cob/gr/sand	6.7	670.0		3493
144	Outer	N	Unconsolidated	boulder/cobble	1.3	130.0		3493
145	Outer	N	riprap	riprap	0.8	80.0		3493
146	Inner	N	Unconsolidated	bo/cob/gr	12.1	1210.0		3493
147	Inner	N	riprap	riprap	0.6	60.0		3493
148	Inner	N	seawall	built	5.8	580.0		3493
149	Inner	N	dock	dock/riprap	5.5	550.0		3493

150	Inner	N	riprap	riprap	11.0	1100.0		3493
151	Inner	N	dock	dock/riprap	4.3	430.0		3493
152	Inner	N	riprap	riprap	1.1	110.0		3493
153	Inner	N	dock	dock/riprap	2.7	270.0		3493
154	Inner	N	seawall	built	6.3	630.0		3493
155	Inner	N	dock	dock/riprap	5.8	580.0		3493
156	Inner	N	riprap	riprap	3.2	320.0		3493
157	Inner	N	Unconsolidated	bo/cob/rub	5.9	590.0		3493
158	Inner	N	dock	dock/riprap	9.9	990.0	Burrard Yacht	3493
159	Inner	N	riprap	riprap	2.3	230.0		3493
160	Inner	N	seawall	built	5.6	560.0		3493
161	Inner	N	riprap	riprap	1.0	100.0		3493
162	Inner	N	seawall	built	11.2	1120.0		3493
163	Inner	N	riprap	riprap	1.3	130.0		3493
164	Inner	N	seawall	built	0.4	40.0		3493
165	Inner	N	riprap	riprap	1.5	150.0		3493
166	Inner	N	seawall	built	2.0	200.0		3493
167	Inner	N	riprap	riprap	3.1	310.0		3493
168	Inner	N	dock	dock/riprap	2.9	290.0		3493
169	Inner	N	riprap	riprap	1.4	140.0		3493
170	Inner	N	seawall	built	17.6	1760.0		3493
171	Inner	N	riprap	riprap	1.7	170.0		3493
172	Inner	N	seawall	built	2.7	270.0		3493
173	Inner	N	riprap	riprap	4.6	460.0		3493
174	Inner	N	seawall	built	8.1	810.0	2nd Narrows	3493
175	Inner	N	dock	dock/riprap	10.2	1020.0		3494
176	Central	N	Unconsolidated	bo/cob/gr	10.9	1090.0		3494
177	Central	N	riprap	riprap	1.6	160.0		3494
178	Central	N	mixed fines	gr/sand	3.7	370.0		3494
179	Central	N	seawall	built	4.3	430.0		3494
180	Central	N	mixed fines	gr/mud	9.8	980.0		3494
181	Central	N	riprap	riprap	1.1	110.0		3494
182	Central	N	mixed fines	gr/sand	2.8	280.0		3494
183	Central	N	dock	dock/riprap	1.2	120.0		3494
184	Central	N	seawall	built	2.6	260.0		3494
185	Central	N	mixed fines	sand	2.3	230.0		3494
186	Central	N	Unconsolidated	cob/gr	5.2	520.0		3494
187	Central	N	dock	dock/cob	1.8	180.0		3494
188	Central	N	mixed fines	gr/mud	2.3	230.0		3494
189	Central	N	mixed fines	mud	24.5	2450.0	Maplewood	3494
190	Central	N	Unconsolidated	gravel	2.3	230.0	Maplewood	3494
191	Central	N	Unconsolidated	boulder/cobble	10.6	1060.0	Maplewood	3494
192	Central	N	Unconsolidated	gravel	2.3	230.0	Maplewood	3494
193	Central	N	mixed fines	mud	5.8	580.0	Maplewood	3494
194	Central	N	riprap	riprap	1.3	130.0		3494
195	Central	N	mixed fines	gr/sand	2.7	270.0		3494
196	Central	N	Unconsolidated	boulder/cobble	2.1	210.0		3494
197	Central	N	mixed fines	gr/sand	33.2	3320.0		3494
198	Central	N	Unconsolidated	boulder/cobble	2.4	240.0		3494
199	Central	N	riprap	riprap	2.4	240.0		3494
200	Central	N	Unconsolidated	bo/cob/gr/sa	3.8	380.0		3494

201	Central	N	mixed fines	mud	0.6	60.0		3494
202	Central	N	seawall	built	1.4	140.0		3494
203	Central	N	Consolidated	bo/gr/sa	6.3	630.0		3494
204	Port Moody	N	Consolidated	bedrock	4.0	400.0		3495
205	Port Moody	N	Consolidated	bo/gr/sa	3.2	320.0		3495
206	Port Moody	N	Unconsolidated	boulder/cobble	4.4	440.0		3495
207	Port Moody	N	Consolidated	bedrock	2.0	200.0		3495
208	Port Moody	N	Unconsolidated	boulder/cobble	4.8	480.0		3495
209	Port Moody	N	Consolidated	bedrock	0.8	80.0		3495
210	Port Moody	N	Unconsolidated	boulder/cobble	8.4	840.0		3495
211	Port Moody	N	Consolidated	bedrock	0.6	60.0		3495
212	Port Moody	N	Unconsolidated	boulder/cobble	2.1	210.0		3495
213	Port Moody	N	riprap	riprap	6.2	620.0		3495
214	Port Moody	N	Unconsolidated	boulder/cobble	2.4	240.0		3495
215	Port Moody	N	Unconsolidated	cob/gr/sand	1.3	130.0		3495
216	Port Moody	N	dock	dock/riprap	3.4	340.0		3495
217	Port Moody	N	Unconsolidated	cobble	2.2	220.0		3495
218	Port Moody	N	dock	dock/cob/rub	2.0	200.0		3495
219	Port Moody	N	Unconsolidated	boulder/cobble	1.0	100.0		3495
220	Port Moody	N	mixed fines	mud	0.7	70.0		3495
221	Port Moody	N	Unconsolidated	boulder/cobble	1.2	120.0		3495
222	Port Moody	N	Unconsolidated	cob/gr/mud	9.6	960.0		3495
223	Port Moody	N	dock	dock/cob/mud	8.4	840.0		3495
224	Outer	S	Unconsolidated	bo/cob/gr/sa	0.7	280.0	scale 1:40000	3311
225	Outer	S	mixed fines	sand	0.9	360.0		3311
226	Outer	S	Consolidated	bedrock/sand	0.2	80.0		3311
227	Outer	S	Unconsolidated	bo/cob/gr/sa	1.3	520.0		3311
228	Outer	S	Consolidated	bedrock/sand	0.6	240.0		3311
229	Outer	S	mixed fines	gr/sand	1.9	760.0		3311
230	Outer	S	Consolidated	bed/cob/sand	1.7	680.0		3311
231	Outer	S	dock	dock/bed/cob/sand	0.7	280.0		3311
232	Outer	S	Consolidated	bed/cob/sand	0.7	280.0		3311
233	Outer	S	mixed fines	gr/sand	1.2	480.0		3311
234	Outer	S	Consolidated	bo/sa	1.3	520.0		3311
235	Outer	S	mixed fines	sand/mud	17.6	7040.0	Spanish Banks	3311
236	Outer	N	Unconsolidated	cob/sand	0.2	80.0		3311
237	Outer	N	Unconsolidated	cob/gr/sand	2.0	800.0		3311
238	Outer	N	Consolidated	boulder	0.3	120.0		3311
239	Outer	N	riprap	riprap	1.2	480.0		3311
240	Outer	N	mixed fines	sand	0.8	320.0		3311
241	Outer	N	Unconsolidated	gravel	0.8	320.0		3311
242	Outer	N	Unconsolidated	cobble	2.6	1040.0		3311
243	Outer	N	Consolidated	boulder	0.9	360.0		3311
244	Outer	N	Consolidated	bedrock/sand	6.4	2560.0		3311
245	Outer	N	seawall	built	0.4	160.0		3311
246	Outer	N	riprap	riprap	0.5	200.0		3311
247	Outer	N	Unconsolidated	cob/sand	2.8	1120.0		3311
248	Outer	N	Consolidated	bedrock	1.9	760.0		3311
249	Outer	N	mixed fines	mud	0.6	240.0		3311
250	Outer	N	Consolidated	bedrock	3.3	1320.0		3311

251	False Creek	S	riprap	riprap	0.8	80.0		3493
252	False Creek	S	unconsolidated	bo/cob/gr/sa	7.9	790.0		3493
253	False Creek	S	unconsolidated	bo/co	1.2	120.0		3493
254	False Creek	S	dock	dock/riprap	8.0	800.0		3493
255	False Creek	S	unconsolidated	co	0.4	40.0		3493
256	False Creek	S	riprap	riprap	1.0	100.0		3493
257	False Creek	S	dock	dock/riprap	1.6	160.0		3493
258	False Creek	S	seawall	built	1.2	120.0		3493
259	False Creek	S	riprap	riprap	0.4	40.0		3493
260	False Creek	S	seawall	built	6.5	650.0		3493
261	False Creek	S	riprap	riprap	6.3	630.0		3493
262	False Creek	S	dock	dock/riprap	1.4	140.0		3493
263	False Creek	S	riprap	riprap	1.8	180.0		3493
264	False Creek	S	riprap	bo/riprap	1.0	100.0		3493
265	False Creek	S	riprap	riprap	4.0	400.0		3493
266	False Creek	S	dock	dock/riprap	2.5	250.0		3493
267	False Creek	S	riprap	riprap	5.1	510.0		3493
268	False Creek	S	seawall	built	2.1	210.0		3493
269	False Creek	S	riprap	riprap	2.6	260.0		3493
270	False Creek	S	unconsolidated	bo/co	1.1	110.0		3493
271	False Creek	S	riprap	riprap	2.1	210.0		3493
272	False Creek	S	seawall	built	5.6	560.0		3493
273	False Creek	N	riprap	riprap	3.6	360.0		3493
274	False Creek	N	consolidated	bo	0.5	50.0		3493
275	False Creek	N	seawall	built	3.5	350.0		3493
276	False Creek	N	riprap	riprap	3.0	300.0		3493
277	False Creek	N	unconsolidated	co/gr	1.6	160.0		3493
278	False Creek	N	riprap	riprap	6.7	670.0		3493
279	False Creek	N	unconsolidated	co/gr	0.8	80.0		3493
280	False Creek	N	mixed fines	sa	0.8	80.0		3493
281	False Creek	N	unconsolidated	co/gr	4.9	490.0		3493
282	False Creek	N	riprap	riprap	1.0	100.0		3493
283	False Creek	N	seawall	built	0.5	50.0		3493
284	False Creek	N	dock	dock/riprap	2.6	260.0		3493
285	False Creek	N	seawall	built	0.8	80.0		3493
286	False Creek	N	dock	dock/riprap	1.9	190.0		3493
287	False Creek	N	riprap	riprap	1.1	110.0		3493
288	False Creek	N	seawall	built	2.3	230.0		3493
289	False Creek	N	riprap	riprap	1.7	170.0		3493
290	False Creek	N	unconsolidated	gr/sa	1.1	110.0		3493
291	False Creek	N	riprap	sa/riprap	0.7	70.0		3493
292	False Creek	N	mixed fines	sa	0.4	40.0		3493
293	False Creek	N	riprap	sa/riprap	1.6	160.0		3493
294	False Creek	N	unconsolidated	gr/sa	0.4	40.0		3493
295	False Creek	N	riprap	sa/riprap	0.9	90.0		3493
296	False Creek	N	unconsolidated	bo/sa	1.2	120.0		3493
297	False Creek	N	riprap	sa/riprap	0.5	50.0		3493
298	False Creek	N	unconsolidated	bo/sa	0.6	60.0		3493
300	Indian Arm		unconsolidated	gr/sa	1.2	120.0		3495
301	Indian Arm		consolidated	bed/bo	2.0	200.0		3495
302	Indian Arm		consolidated	bed/co	2.6	260.0		3495

303	Indian Arm		mixed fines	sa	0.5	50.0		3495
304	Indian Arm		consolidated	bed/co	1.4	140.0		3495
305	Indian Arm		consolidated	bed/bo	3.2	320.0		3495
306	Indian Arm		mixed fines	sa	0.9	90.0		3495
307	Indian Arm		consolidated	bed	2.0	200.0		3495
308	Indian Arm		mixed fines	sa	0.6	60.0		3495
309	Indian Arm		consolidated	bed	0.7	70.0		3495
310	Indian Arm		unconsolidated	co/sa	2.3	230.0		3495
311	Indian Arm		consolidated	bed	0.5	50.0		3495
312	Indian Arm		mixed fines	sa	0.4	40.0		3495
313	Indian Arm		dock	bed/bo/co/dock	4.2	420.0		3495
314	Indian Arm		unconsolidated	gr/sa	0.8	80.0		3495
315	Indian Arm		unconsolidated	bo/co/gr	3.5	350.0		3495
316	Indian Arm		dock	dock/riprap	0.5	50.0		3495
317	Indian Arm		consolidated	bed/gr/sa	5.0	500.0		3495
318	Indian Arm		dock	bed/sa/dock	2.3	230.0		3495
319	Indian Arm		consolidated	bed	2.9	290.0		3495
320	Indian Arm		unconsolidated	co/gr/sa	1.0	100.0		3495
321	Indian Arm		consolidated	bed	2.3	230.0		3495
322	Indian Arm		unconsolidated	bo/co	1.0	100.0		3495
323	Indian Arm		consolidated	bed	0.2	20.0		3495
324	Indian Arm		consolidated	bo	0.3	30.0		3495
325	Indian Arm		consolidated	bed	1.6	160.0		3495
326	Indian Arm		consolidated	bo	0.4	40.0		3495
327	Indian Arm		consolidated	bed	1.3	130.0		3495
328	Indian Arm		consolidated	bo	0.8	80.0		3495
329	Indian Arm		consolidated	bed/bo/co	3.6	360.0		3495
330	Indian Arm		dock	dock/riprap	0.5	50.0		3495
331	Indian Arm		consolidated	bed	2.7	270.0		3495
332	Indian Arm		mixed fines	sa	1.4	140.0		3495
333	Indian Arm		unconsolidated	co/gr	0.9	90.0		3495
334	Indian Arm		consolidated	bed	2.0	200.0		3495
335	Indian Arm		unconsolidated	co	0.3	30.0		3495
336	Indian Arm		consolidated	bed	1.0	100.0		3495
337	Indian Arm		mixed fines	sa	1.2	120.0		3495
338	Indian Arm		consolidated	bed	1.7	170.0		3495
339	Indian Arm		unconsolidated	bo/co	0.4	40.0	Bedwell Bay	3495
340	Indian Arm		consolidated	bed	2.1	210.0	Bedwell Bay	3495
341	Indian Arm		unconsolidated	bo/co	0.6	60.0	Bedwell Bay	3495
342	Indian Arm		consolidated	bed	1.3	130.0	Bedwell Bay	3495
343	Indian Arm		mixed fines	sa	1.3	130.0	Bedwell Bay	3495
344	Indian Arm		consolidated	bed	0.9	90.0	Bedwell Bay	3495
345	Indian Arm		unconsolidated	bo/co	0.7	70.0	Bedwell Bay	3495
346	Indian Arm		consolidated	bed	1.4	140.0	Bedwell Bay	3495
347	Indian Arm		unconsolidated	bo/co	0.7	70.0	Bedwell Bay	3495
348	Indian Arm		seawall	built	0.3	30.0	Bedwell Bay	3495
349	Indian Arm		unconsolidated	bo/co/sa	1.1	110.0	Bedwell Bay	3495
350	Indian Arm		consolidated	bed	2.8	280.0	Bedwell Bay	3495
351	Indian Arm		mixed fines	sa	1.0	100.0	Bedwell Bay	3495
352	Indian Arm		consolidated	bed	1.0	100.0	Bedwell Bay	3495
353	Indian Arm		mixed fines	sa	2.7	270.0	Bedwell Bay	3495

354	Indian Arm		consolidated	bed/bo	0.9	90.0	Bedwell Bay	3495
355	Indian Arm		consolidated	bed	1.0	100.0	Bedwell Bay	3495
356	Indian Arm		unconsolidated	bo/co	1.1	110.0	Bedwell Bay	3495
357	Indian Arm		mixed fines	mud	2.1	210.0	Bedwell Bay	3495
358	Indian Arm		unconsolidated	co/gr/sa	1.9	190.0	Bedwell Bay	3495
359	Indian Arm		consolidated	bo	0.8	80.0	Bedwell Bay	3495
360	Indian Arm		mixed fines	sa	0.8	80.0	Bedwell Bay	3495
361	Indian Arm		consolidated	bo	1.1	110.0	Bedwell Bay	3495
362	Indian Arm		dock	bo/co/gr/sa/ dock	10.2	1020.0	Bedwell Bay	3495
363	Indian Arm		unconsolidated	bo/co/gr	1.6	160.0	Bedwell Bay	3495
364	Indian Arm		consolidated	bed	7.8	780.0		3495
365	Indian Arm		consolidated	bed/bo	1.6	160.0		3495
366	Indian Arm		consolidated	bed	0.9	90.0		3495
367	Indian Arm		unconsolidated	co	0.6	60.0		3495
368	Indian Arm		consolidated	bed	0.4	40.0		3495
369	Indian Arm		unconsolidated	bo/co	0.8	80.0		3495
370	Indian Arm		consolidated	bed	1.9	190.0		3495
371	Indian Arm					0.0	joined to 370	3495
372	Indian Arm		unconsolidated	gr/sa	1.8	180.0		3495
373	Indian Arm		unconsolidated	gr	1.7	170.0		3495
374	Indian Arm		consolidated	bed/bo	3.7	1121.2		3495 A
375	Indian Arm		unconsolidated	co	0.7	212.1		3495 A
376	Indian Arm		unconsolidated	gr/sa	1.1	333.3		3495 A
377	Indian Arm		consolidated	bed/bo	4.4	1333.3		3495 A
378	Indian Arm		mixed fines	sa	0.2	60.6		3495 A
379	Indian Arm		consolidated	bed/bo	5.6	1697.0		3495 A
380	Indian Arm		dock	dock/co/ru	0.8	242.4		3495 A
381	Indian Arm		consolidated	bed/bo	2.4	727.3		3495 A
382	Indian Arm		consolidated	bo	0.2	60.6		3495 A
383	Indian Arm		unconsolidated	co/gr/sa	1.6	484.8		3495 A
384	Indian Arm		consolidated	bo	0.3	90.9		3495 A
385	Indian Arm		consolidated	bed/bo	5.7	1727.3		3495 A
386	Indian Arm		riprap	riprap	0.2	60.6		3495 A
387	Indian Arm		consolidated	bed/bo	1.3	393.9		3495 A
388	Indian Arm		mixed fines	sa	0.5	151.5		3495 A
389	Indian Arm		consolidated	bed/bo	2.6	787.9		3495 A
390	Indian Arm		dock	sa/dock	0.5	151.5		3495 A
391	Indian Arm		dock	bo/co/dock	0.6	181.8		3495 A
392	Indian Arm		dock	sa/dock	0.3	90.9		3495 A
393	Indian Arm		dock	dock/riprap	0.2	60.6		3495 A
394	Indian Arm		dock	bo/co/dock	0.7	212.1		3495 A
395	Indian Arm		dock	dock/riprap	0.2	60.6		3495 A
396	Indian Arm		unconsolidated	bo/co	1.8	545.5		3495 A
397	Indian Arm		mixed fines	sa	0.4	121.2		3495 A
398	Indian Arm		consolidated	bed/bo	0.7	212.1		3495 A
399	Indian Arm		unconsolidated	bo/co	0.5	151.5		3495 A
400	Indian Arm		consolidated	bed/bo	1.7	515.2		3495 A
401	Indian Arm		dock	bo/co/dock	0.7	212.1		3495 A
402	Indian Arm		consolidated	bed/bo	0.5	151.5		3495 A
403	Indian Arm		riprap	riprap	0.1	30.3		3495 A

404	Indian Arm		dock	co/gr/dock	1.3	393.9		3495 A
405	Indian Arm		riprap	riprap	0.1	30.3		3495 A
406	Indian Arm		unconsolidated	bo/co	3.9	1181.8		3495 A
407	Indian Arm		consolidated	bo	0.4	121.2		3495 A
408	Indian Arm		unconsolidated	bo/co	0.3	90.9		3495 A
409	Indian Arm		consolidated	bed	1.2	363.6		3495 A
410	Indian Arm		riprap	riprap	0.2	60.6		3495 A
411	Indian Arm		mixed fines	sa	0.7	212.1		3495 A
412	Indian Arm		riprap	riprap	0.2	60.6		3495 A
413	Indian Arm		consolidated	bed/bo	1.0	303.0		3495 A
414	Indian Arm		unconsolidated	bo/co	1.8	545.5		3495 A
415	Indian Arm		unconsolidated	co/gr	0.3	90.9		3495 A
416	Indian Arm		dock	sa/dock	0.5	151.5		3495 A
417	Indian Arm		unconsolidated	bo/co	2.2	666.7		3495 A
418	Indian Arm		dock	dock/riprap/bo	0.4	121.2		3495 A
419	Indian Arm		riprap	bo/riprap	1.2	363.6	log dump	3495 A
420	Indian Arm		mixed fines	mud	2.1	636.4		3495 A
421	Indian Arm		dock	gr/dock	0.8	242.4		3495 A
422	Indian Arm		unconsolidated	co	0.3	90.9		3495 A
423	Indian Arm		consolidated	bed/bo	4.0	1212.1		3495 A
424	Indian Arm		unconsolidated	co	0.7	212.1		3495 A
425	Indian Arm		dock	sa/dock	0.4	121.2		3495 A
426	Indian Arm		unconsolidated	bo/co/gr/sa	0.8	242.4		3495 A
427	Indian Arm		unconsolidated	co/gr	1.5	454.5		3495 A
428	Indian Arm		consolidated	bed	3.1	939.4		3495 A
429	Indian Arm		unconsolidated	gr/sa	2.3	697.0		3495 A
430	Indian Arm		consolidated	bed	8.2	2484.8		3495 A
431	Indian Arm		consolidated	bo	0.8	242.4		3495 A
432	Indian Arm		consolidated	bed	4.4	1333.3		3495 A
433	Indian Arm		consolidated	bo	0.2	60.6		3495 A
434	Indian Arm		dock	co/gr/sa/dock	1.7	515.2		3495 A
435	Indian Arm		unconsolidated	co	0.3	90.9		3495 A
436	Indian Arm		consolidated	bed/bo	7.9	2393.9		3495 A
437	Indian Arm		dock	co/gr/sa/dock	2.4	727.3		3495 A
438	Indian Arm		unconsolidated	co	0.4	121.2		3495 A
439	Indian Arm		unconsolidated	gr	0.2	60.6		3495 A
440	Indian Arm		consolidated	bed	4.2	1272.7		3495 A
441	Indian Arm		unconsolidated	co/gr	0.9	272.7		3495 A
442	Indian Arm		consolidated	bed	2.3	697.0		3495 A
443	Indian Arm		dock	bo/co/gr/dock	1.6	484.8		3495 A
444	Indian Arm		consolidated	bed	3.5	1060.6		3495 A
445	Indian Arm		unconsolidated	co/gr/sa	0.3	90.9		3495 A
446	Indian Arm		consolidated	bed/bo	1.0	303.0		3495 A
447	Indian Arm		mixed fines	sa	1.0	100.0		3495
448	Indian Arm		consolidated	bed	2.2	220.0		3495
449	Indian Arm		mixed fines	sa	0.6	60.0		3495
450	Indian Arm		consolidated	bed	0.6	60.0		3495
451	Indian Arm		unconsolidated	gr	1.4	140.0		3495
452	Indian Arm		unconsolidated	co/gr/sa	3.9	390.0		3495
453	Indian Arm		consolidated	bed	2.4	240.0		3495
454	Indian Arm		unconsolidated	co	0.7	70.0		3495

455	Indian Arm		consolidated	bed	6.2	620.0		3495
456	Indian Arm		unconsolidated	co	0.3	30.0	Deep Cove	3495
457	Indian Arm		consolidated	bed	0.6	60.0	Deep Cove	3495
458	Indian Arm		unconsolidated	co	0.3	30.0	Deep Cove	3495
459	Indian Arm		dock	dock/bed	3.1	310.0	Deep Cove	3495
460	Indian Arm		dock	co/gr/sa/dock	6.0	600.0	Deep Cove	3495
461	Indian Arm		unconsolidated	co/gr/sa	2.3	230.0	Deep Cove	3495
462	Indian Arm		dock	co/gr/sa/dock	1.0	100.0	Deep Cove	3495
463	Indian Arm		unconsolidated	co/gr/sa	1.7	170.0	Deep Cove	3495
464	Indian Arm		consolidated	bed/sa	0.4	40.0	Deep Cove	3495
465	Indian Arm		mixed fines	sa	0.4	40.0	Deep Cove	3495
466	Indian Arm		consolidated	bed/co	0.6	60.0	Deep Cove	3495
467	Indian Arm		unconsolidated	bo/co	0.8	80.0	Deep Cove	3495
468	Indian Arm		dock	dock/bed	1.3	130.0	Deep Cove	3495
469	Indian Arm		consolidated	bo	0.7	70.0	Deep Cove	3495
470	Indian Arm		consolidated	bed	0.2	20.0	Deep Cove	3495
471	Indian Arm		consolidated	bo	0.7	70.0	Deep Cove	3495
472	Indian Arm		consolidated	bed	0.9	90.0	Deep Cove	3495
473	Indian Arm		consolidated	bo	0.7	70.0	Deep Cove	3495
474	Indian Arm		dock	dock/bed	7.0	700.0		3495
475	Indian Arm		dock	bo/co/gr/dock	4.7	470.0		3495
476	Indian Arm		unconsolidated	gr/sa	1.4	140.0		3495
477	Indian Arm		consolidated	bed	2.7	270.0		3495
478	Indian Arm		dock	bo/co/gr/sa/ dock	8.6	860.0		3495
479	Indian Arm		unconsolidated	bo/co/sa	3.1	310.0		3495
480	Indian Arm		unconsolidated	bo/co	1.9	190.0		3495
481	Indian Arm		mixed fines	sa	1.6	160.0		3495
482	Indian Arm		unconsolidated	bo/co/sa	0.3	30.0		3495
483	Indian Arm		mixed fines	sa	1.1	110.0		3495
484	Indian Arm		unconsolidated	bo/co/gr/sa	0.4	40.0		3495
485	Indian Arm		unconsolidated	co/gr/sa	1.4	140.0		3495
486	Indian Arm		unconsolidated	bo/co	0.8	80.0		3495
487	Indian Arm		unconsolidated	gr/sa	1.5	150.0	Roche Pt	3495

Appendix 8. Common and species names of fishes identified in Chapter 5.

Common Name	Species Name
Chum	*Oncorhynchus keta*
Chinook	*Oncorhynchus tshawytscha*
Coho	*Oncorhynchus kisutch*
Salmon smolt	*Oncorhynchus sp.*
Sockeye	*Oncorhynchus nerka*
Cutthroat	*Oncorhynchus clarki*
Starry flounder	*Platichthys stellatus*
English sole	*Pleuronectes vetulus* (formerly genus *Parophrys*)
Speckled sanddab	*Citharichthys stigmaeus*
Flatfish (juvenile)	*Pleuronectidae*
Tidepool sculpin	*Oligocottus maculosus*
Fluffy sculpin	*Oligocottus snyderi*
Staghorn sculpin	*Leptocottus armatus*
Buffalo sculpin	*Enophrys bison*
Padded sculpin	*Artedius fenestralis*
Smoothead sculpin	*Artedius lateralis*
Juvenile sculpins	*Cottidae*
Shiner surfperch	*Cymatogaster aggregata*
Kelp surfperch	*Brachyistius frenatus*
Crescent gunnel	*Pholis laeta*
Saddleback gunnel	*Pholis ornata*
Cockscomb	*Anoplarchus sp.*
Penpoint	*Apodichthys flavidus*
Pipefish	*Leptorynchus griseolineatus* (formerly genus *Syngnathus*)
Arrow goby	*Clevlandia ios*
Threespine stickleback	*Gasterosteus aculeatus*
Lingcod	*Ophiodon elongatus*
Sandlance	*Ammodytes hexapterus*
Surf smelt	*Hypomesus pretiosus*