Integrated Management Plan for a Suburban Watershed: Protecting Fisheries Resources in the Salmon River, Langley, British Columbia

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INTEGRATED MANAGEMENT PLAN FOR A SUBURBAN WATERSHED: PROTECTING FISHERIES RESOURCES IN THE SALMON RIVER, LANGLEY, BRITISH COLUMBIA

by

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ABSTRACT

In the Pacific Northwest, a large number of stocks of anadromous salmonids have declined in size to a point where many of them are facing high to moderate risk of extinction. As a species, coho salmon (*Oncorhynchus kisutch*) is the most affected one. The decline of wild coho salmon is particularly marked in regions where human activities concentrate, suggesting that freshwater habitat loss is, in conjunction with excessive fishing, the possible cause of this problem. In this report we propose a multi-layered management plan aimed at protecting coho salmon habitat within the bounds of present land use patterns in a suburban watershed, Langley's Salmon River. This plan takes into account the different spatial scales of the watershed components affecting coho salmon distribution and abundance, and emphasizes the importance of maintaining the natural connectivity of an ecosystem altered by farming activities and urban development.

RÉSUMÉ

Dans le Pacifique Nord-Ouest, un grand nombre de stocks de salmonidés anadromes ont vu leurs effectifs chuter au point que bon nombre d'entre eux se trouvent exposés à des risques modérés à élevés d'extinction. Le saumon coho (*Oncorhynchus kisutch*) est l'espèce la plus touchée. Le déclin du coho sauvage est particulièrement marqué dans les régions où se concentrent les activités humaines, ce qui laisse penser que la perte d'habitat dulcicole est, avec la pêche excessive, la cause possible de ce problème. Dans le présent rapport, nous proposons un plan de gestion à volets multiples visant la protection de l'habitat du coho dans le cadre du profil actuel d'utilisation des terres dans un bassin suburbain, celui de la rivière Salmon dans la région de Langley. Ce plan prend en considération les différentes échelles spatiales des éléments du bassin qui affectent la répartition et l'abondance du coho, et met l'accent sur l'importance de maintenir la continuité naturelle d'un écosystème altéré par les activités agricoles et le développement urbain.

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INTRODUCTION

In the Pacific Northwest, many stocks of anadromous salmonids (genus *Oncorhynchus*) are currently under risk of becoming extinct, while others have declined up to 1/7 of their average historic abundance (DFO 1991; Nehlsen et al. 1991; Northcote and Burwash 1991; DFO 1992; Slaney et al. 1996). Although several hypotheses have been advanced to explain these declines (overfishing, habitat loss, interactions with hatchery fish, and changes in ocean conditions), freshwater habitat loss has been associated with every one of the 214 salmonid stocks from California to Washington State that Nehlsen et al. (1991) identified as either facing high to moderate risk of extinction or being of special concern. Slaney et al. (1996), in a report on the status of salmonid stocks in British Columbia and Yukon, concluded that coho salmon (*O. kisutch*) are in unquestionable decline (at the species aggregate level other anadromous salmonids, however, appear to have either stable or increasing escapements). The fact that the decline of wild coho salmon stocks is particularly marked in the Georgia Strait and southwestern Vancouver Island indicates that human activities concentrated in those regions are the possible cause of this problem (Slaney et al. 1996). The relatively long period of residence of coho salmon in small, low-gradient coastal streams (Sandercock 1991) makes this species particularly vulnerable to habitat alterations caused by the impoundment projects (Slaney et al. 1996), farming activities (Birtwell et al. 1988; Hicks et al. 1991), and urban development (Henderson 1991; Lucchetti and Fuerstenberg 1993; DFO 1994; Slaney et al. 1996) of southwestern British Columbia.

The Lower Fraser Valley (Fig. 1) is one of the areas in the province where agriculture and urbanization have most seriously degraded coho habitat (Moore 1990; Henderson 1991; SOE 1992; DFO 1994). As it flows westward through this valley, the Fraser River receives a number of tributaries that drain areas progressively more developed and urbanized. For example, in the eastern part of the Lower Fraser Valley, the Harrison and the Chilliwack rivers run through forested mountain land. In the central section, tributaries such as the Salmon River drain agricultural land with zones of low density residential development. Closer to the city of Vancouver most tributaries, such as the Brunette River, flow through urban and industrial zones (Fox 1976; Dorcey 1991). Within the city most streams have disappeared in culverts under the pavement and, as a result, stocks from twenty historic salmon-supporting streams have been lost (Harris 1978).

Based on the results of Giannico's (1996) empirical and experimental work in Langley's Salmon River and using information derived from the literature, we present a summary of habitat factors affecting coho salmon distribution at different spatial scales in low gradient watersheds. The Salmon River is used as a case study to illustrate different points in our presentation, because it is a good example of a suburban watershed which has suffered a slow but irreversible change from a forested to an agricultural to an increasingly urbanized landscape. This is a trend which may explain, at least in part, the dwindling numbers of coho salmon in a stream which has been ranked among the top coho producing systems in the Lower Fraser Valley. Finally, we make management recommendations, considering different spatial scale actions, to protect salmonid habitat in low gradient watersheds of the Pacific Northwest.

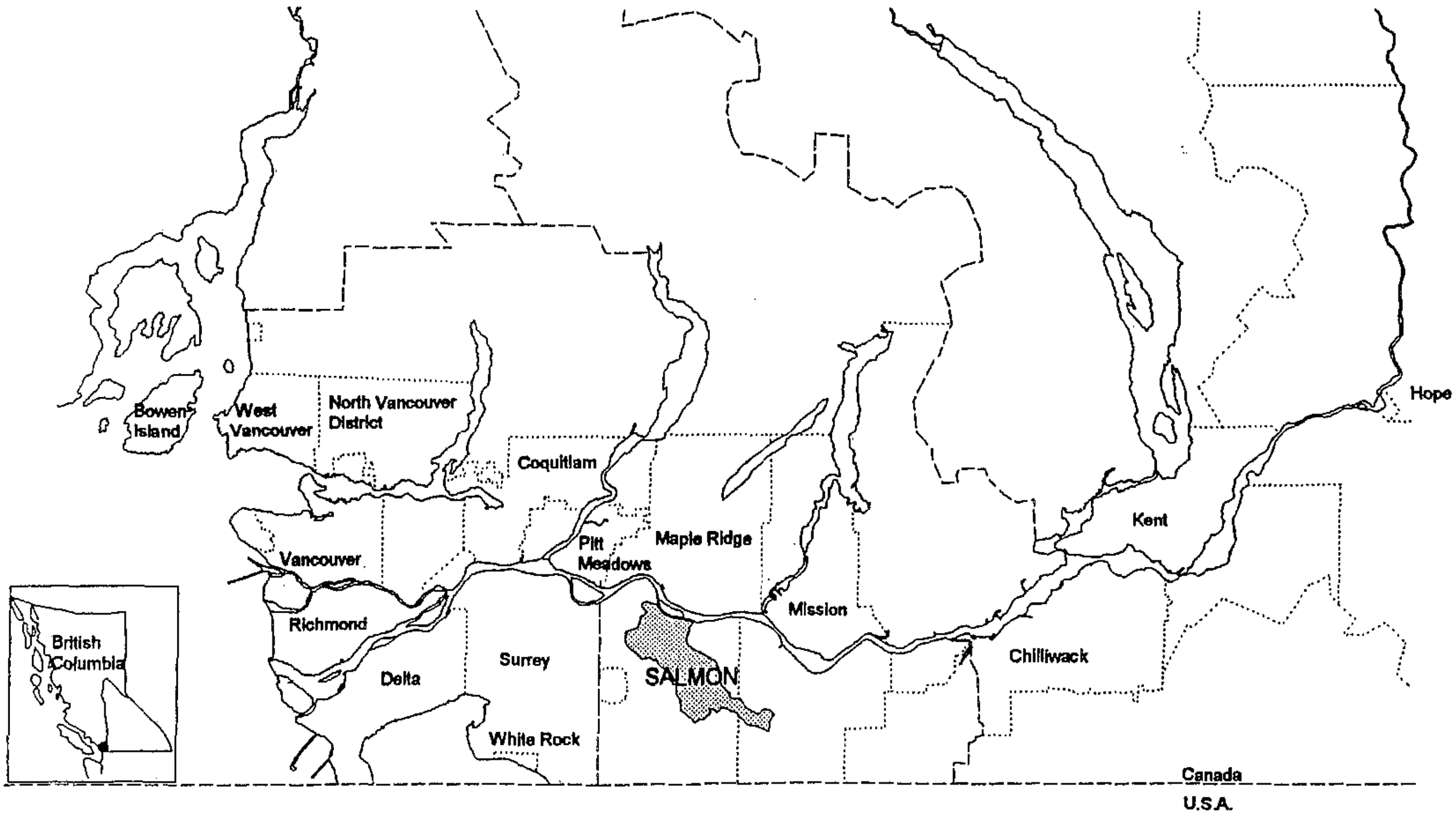

Figure 1. Location of the Salmon River Watershed within the Lower Fraser Valley

THE SALMON RIVER WATERSHED

The Salmon River flows for 33 km in a northwesterly direction before entering the Fraser River at Fort Langley (Figures 1 and 2), 60 km east of Vancouver. Its watershed, with an area of approximately 8,070 ha and an elevation that ranges from 2 to 137 m, is largely within the Township of Langley, and a small portion of the headwaters are located in the City of Abbotsford (Bradner area). Its main tributary, Coghlan Creek, joins it about 14 km upstream from the Fraser River (Watts 1992). The entire watercourse can be subdivided into 3 sections (upper, middle and lower reaches, Figure 3) taking into account its gradient, substrate type, channel configuration, and water velocity. The upper reaches (with an average gradient of 3%, slow water velocity, very low summer flows, flat stream slopes and a substrate dominated by fine sand and organic silt) begin upstream from 48th. Ave. for the Salmon River (extending for approximately 11 km), and upstream from 256th. St. for Coghlan Creek (with an estimated length of 2.5 km). The middle reaches (characterized by a steeper gradient - 5%, a rather constant summer flow derived from underground sources, distinct habitat units such as pools and riffles, and a substrate dominated by coarse sand, gravel and cobble) correspond to approximately 12 km of the Salmon River between 48th. Ave. and 72nd. Ave., and the lower 5 km of Coghlan Creek between 256th. St. and the confluence with the Salmon River. The river in this middle part runs through narrow and steep ravines, with slopes ranging from 15 to 60 percent (Luttmerding 1980) and has well developed riparian vegetation that shades the watercourse. The lower reaches (characterized by a low gradient - 0.5 to 3%, and uniform channel) begin downstream from 72nd. Ave. and continue to the confluence with the Fraser River, next to Fort Langley. The sequence of distinct pools and riffles present in the middle reaches disappear in this section. It acquires all the characteristics of a floodplain river, including a meandering deep channel with almost flat banks, slow flowing turbid waters, and a fine sediment substrate.

The lower reaches of the river have been dyked to prevent flooding of adjacent farm land. Historically this area was probably a large seasonally flooded wetland. Several small tributaries that discharged into the Salmon River across this floodplain have also been dyked, and in some cases (such as Davidson Creek) straightened into a network of channels to improve the drainage and make adjacent land use easier. Where these creeks bisected the dykes along the mainstem they have been gated. Another important modification to the natural drainage of this river was the installation of a flood gate and a pumphouse at the mouth of the river in 1949. The purpose of this complex was to prevent flooding of the watershed's floodplain during the spring freshets of the Fraser River. The gates are closed and the pump is in operation from late March to July interfering with the spring migration of coho and trout smolts. Smolts have to go through the pump to get to the Fraser, which according to the Department of Fisheries and Oceans estimates introduces a 25 to 31% mortality on the migrating fish (Paish 1981)

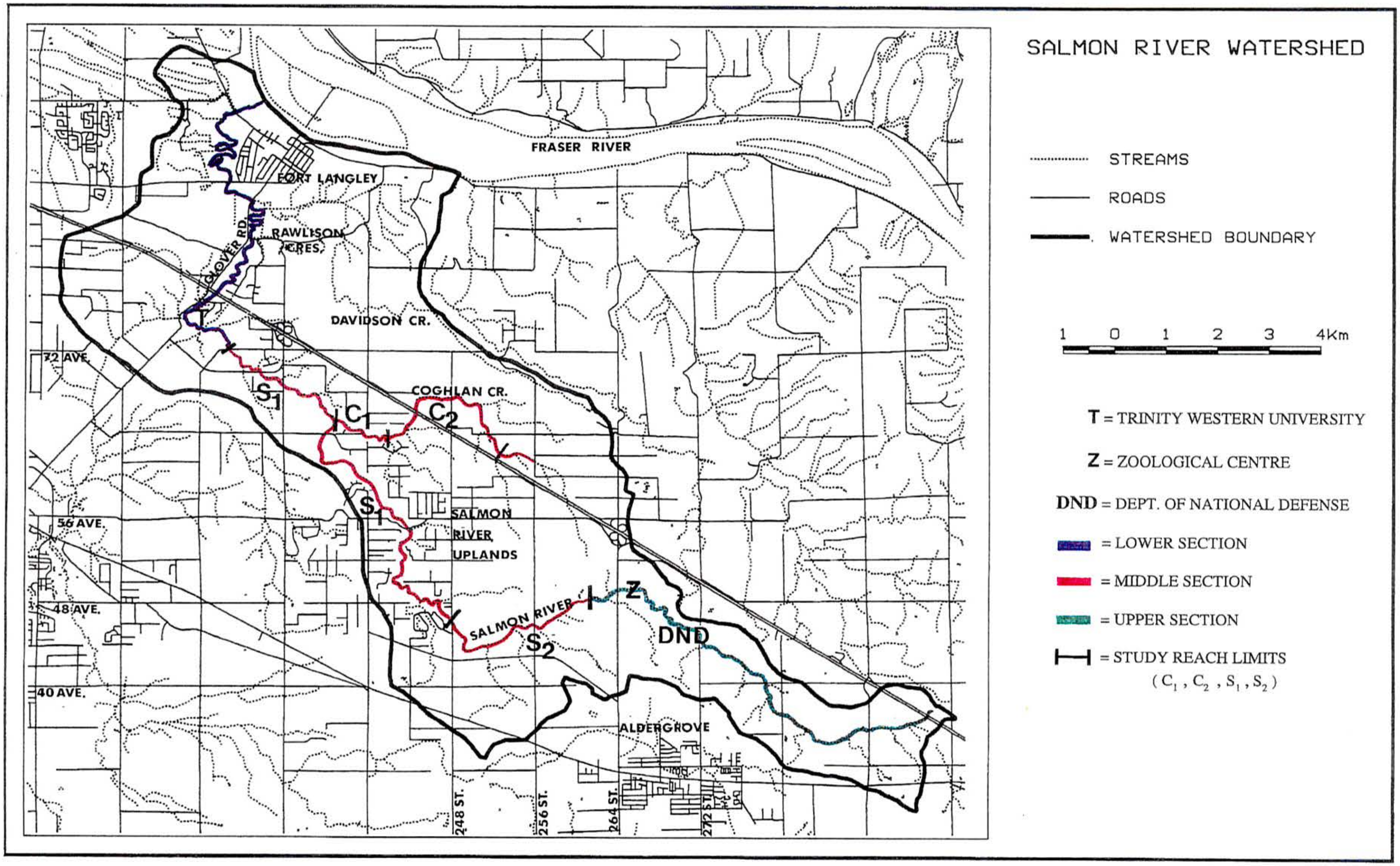

Figure 2. Location of the Salmon River, its main tributaries, and the residential areas within the watershed in the Township of Langley

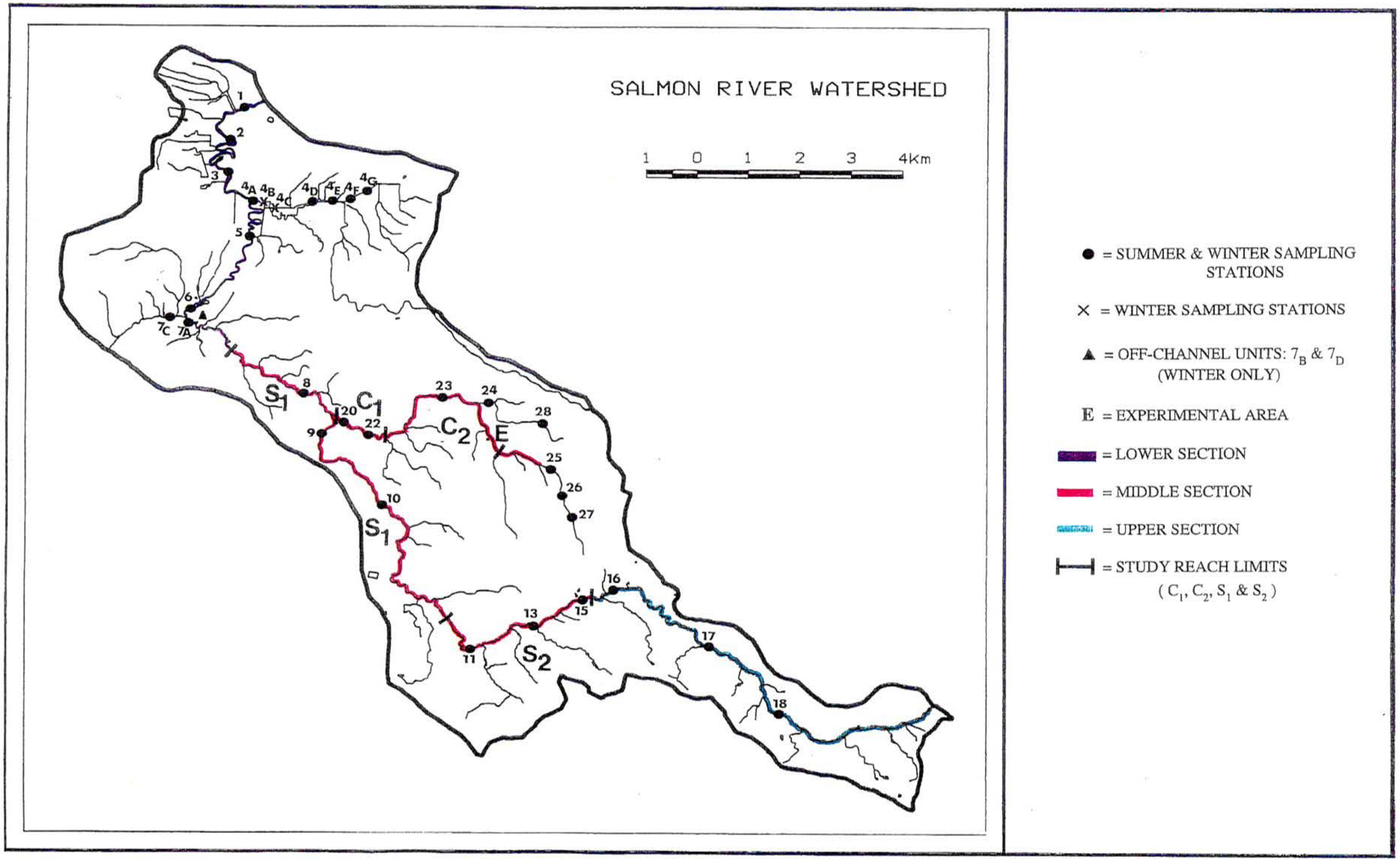

Figure 3. Location of sampling stations on the Salmon River (Map source: Watts 1992)

WATER DISCHARGE AND WATER QUALITY

Discharge records for 1970-1993 from the Salmon River gauging station (#08MH090, Water Resources Branch, Environment Canada) indicate that the lowest flows (about 0.10 to 0.35 m^3/s) occur during the summer months (July to October), whereas the late fall and early winter (November to February) experiences the highest flows of the year (between 13 and 25m^3/s). The flow regime of this stream is driven by autumn-winter rainfall. The average annual precipitation measured at a weather station situated south of the Salmon River in Langley Prairie was 1,554 mm/yr based on a 30 year record (Watts 1992).

The quality of the water in the Salmon River is relatively good for fish production when compared to other tributaries of the Lower Fraser River. However, considering the degradation of some of those systems, this does not mean that there are no reasons for concern in this watershed. Water pH levels recorded during Giannico's (1996) field work in the system ranged from 6.7 to 7.8, and are within those recommended for drinking water (6.5 to 8.5). Dissolved oxygen was recorded by S. Thornton for the Westwater Research Centre (UBC) during the low flow period to determine whether adequate oxygen levels exist during the summer for salmonids. Dissolved oxygen should be above 5.0 mg/; below this concentration salmonid egg mortality increases, and the metabolic rates as well as the swimming performance of salmon and trout are negatively affected (Björnn and Reiser 1991). The three river sections showed different dissolved oxygen levels and contrasting daily variation patterns. In the headwaters of the Salmon River (measured at 272 St.) the levels of dissolved oxygen were too low (1.9 mg/l) for salmonid survival. The situation in the middle reaches (measured at Williams Park) was very different, with dissolved oxygen levels always close to saturation levels (between 10 and 11 mg/l) and not showing any daily fluctuation. But in the lower reaches of the river (measured at Glover Rd. and Rawlison Crescent) oxygen concentrations were high during the day (approximately 8 - 9 mg/l) and dropped dramatically at night (3.8 mg/l), well below the lower tolerance level of salmonids. In the lower reaches the daily fluctuation was clearly due to the photosynthetic cycle. During day hours, rooted plants and algae produced and released more oxygen than that respired by the aquatic community, whereas once photosynthesis ceased the oxygen concentration in water was brought down by ongoing respiration.

Eutrophication from farmland run-off was identified by Hall and Wiens (1976) as causing elevated BOD (Biochemical Oxygen Demand) that reduced oxygen concentration in some small tributaries in the upstream portion of the middle reaches. They also observed that nitrate levels, although below suggested drinking water limits (10 mg/l), were higher than in the mainstem of the Fraser River, particularly during the low flow period. Cook (1994), in a detailed study of the water quality and land use in the watershed, concluded that both nitrate and phosphate were contaminating the waters of a large portion of the Hopington Aquifer (the largest ground-water reservoir in the watershed, which is an important contributor to the stream baseflow during the summer months and a source of water for many households in the area). The most likely sources of pollution, according to Cook's study, were septic systems, fertilizers and manure. Hall and Wiens (1976) also recorded high levels of fecal coliforms, indicating human fecal contamination, in the lower reaches of the river. Additionally, the levels of certain trace metals, such as copper and zinc, have been observed to be high in the Salmon River compared to other streams in the region (Hall and Wiens 1976). Their increased concentration at higher flows suggest that they originate from non-point sources. Although most water problems in the watershed are associated with non-point sources of pollution, two clear sources of nitrate and fecal bacteria contamination exist: Trinity Western University and the Greater Vancouver Zoological Centre (previously the Vancouver Game Farm).

Water temperature in the Salmon River is suitable for salmonid fishes, except for some particular stream sections. During 1991, we recorded mean summer (May-September) temperatures of: 12.1°C in the upper reaches, 9.3°C in the middle reaches, and 14.2°C in the lower reaches. However, the same August temperatures were dangerously high for salmonids at both the uppermost reaches (19.2°C), above 48th. Ave. (see Figure 2), and the lower reaches (18.9°), near 88th. Ave. Mean water temperatures during the January-February periods of 1992 and 1993 were: 4.8°C (1992) and 3.8°C (1993) near 48th Ave., 7.3°C (1992) and 4.4°C (1993) in the middle reaches, and 4.4°C.

HUMAN-INDUCED CHANGES TO THE VEGETATION OF THE WATERSHED

Fort Langley, the first permanent European settlement on the Lower Mainland of the province, was established in 1827 near the confluence of the Salmon and Fraser Rivers (Crawford 1993). Originally, most of the Salmon River basin must have been covered by coniferous forest (Land Surveyors Notebooks 1873 -1874). But by the 1870s large stands of coniferous trees had already been logged and/or burned down, and were replaced by mixed deciduous regeneration forests (Land Surveyors Notebooks 1873-1874). A historic vegetation map of the watershed (Pauline Landry, for Westwater Research Centre), based on information from land surveyors' notebooks (Land Surveyors Notebooks 1873-1874), shows that most of the floodplain was covered by prairie grass and shrubs. Shrub describes a community including willow (Salix spp.), crabapple (Malnus fusca), and hardhack (Spiraea douglassi). The middle reaches of Davidson Creek ran through a red alder (Alnus rubra) and willow forest; whereas its upper reaches and a section of the lower Salmon River (between 72nd. Ave. and Rawlison Crescent) crossed a mixed deciduous regeneration forest of red alder, willow, cherry (Prunus spp.), black cottonwood (Populus trichocarpa), and crabapple, with some second growth western hemlock (Tsuga heterophylla) and Douglas fir (Pseudotsuga menziesii). Most of the middle reaches of both the Salmon River and Coghlan Creek ran through mixed coniferous stands of: western red cedar (Thuja plicata), hemlock, Douglas fir, grand fir (Abies grandis), and Sitka spruce (Picea sitchensis), accompanied - particularly in riparian zones - by alder, willow, vine maple (Acer circinatum), broadleaf maple (Acer macrophyllum), and dogwood (Cornus nuttallii).

Logging and farming began in the floodplain in the late 1800s, and subsequently spread to the upper regions of the basin (McMynn and Vernon 1954). Much of the riparian vegetation in agricultural lands was removed, and although in some areas stream side trees have been reestablished they have a much lower density than natural stands. Cattle access to the river and its small tributaries (i.e. Davidson Creek) has prevented riparian vegetation recovery and has caused bank erosion in many areas.

The central part of the watershed, which has less productive soils, was cleared and developed later (McMynn and Vernon 1954). In this middle section, both the Salmon River and Coghlan Creek have a relatively pristine appearance. But at a closer examination it is possible to observe that riparian forest alteration and clearing occurred in some areas due to different land use activities in the vicinity of the channel. However, extensive riparian removal is relatively uncommon. Most of the mixed deciduous and coniferous woods of this region have been gradually removed for farming and, more recently, residential development. Many of the small tributaries and ephemeral watercourses in the middle reaches of the watershed (near the residential development known as Salmon River Uplands) have been severely altered by urbanization. Even at Williams Park the natural vegetation has been removed, and sections of the stream bank have been stabilized with rock filled gabions. In many locations of the river, upstream passage of fish has been reduced or impeded where roads cross the stream channel and elevated culverts were placed in the channel.

Farming activities in the vicinity of the Salmon River upper section have also caused riparian alterations. The narrow and shallow channel in the upper reaches is more vulnerable to riparian alterations than the large floodplain channel near Fort Langley. In this part of the watershed the mixed forest cover has been slowly eliminated and cattle grazing prevents the regeneration of riparian vegetation. Other land uses in this section of the watershed are likely to have an equivalent if not greater negative impact on the stream system. The upper reaches of the Salmon River run through a zoological garden and a military base, and some residential areas (Aldergrove) are extending closer to the headwaters of the system. The Greater Vancouver Zoological Centre straddles the creek, and its animal waste and bank erosion contribute to the degradation of the aquatic habitat. Further upstream in the DND (Department of National Defense - CFS) lands, degradation continues as a result of military training exercises and vegetation removal. These headwaters of the Salmon River resemble a roadside ditch. Although no salmonids currently use this part of the watershed, land use impacts on these reaches affect the hydrology and the quality of fish habitat further downstream.

The upper section of Coghlan Creek appears to be slightly less damaged, and provides better salmonid habitat. However, during low summer flows water extraction for irrigation may potentially cause serious problems to fish (Paish 1981).

A complete description of land use dynamics from 1980 to 1990 and its potential effect on fish habitat is provided by Watts (1992). We will briefly mention the conclusions of that study that are the most relevant in the context of the current dissertation. In this predominantly agricultural watershed (4,038 ha of farmland or 50% of the whole watershed), residential and undeveloped lands have expanded (3% and 4% respectively) at the expense of farmland (-9%). Because Watts classified as undeveloped both wood lots and "idle" land ("wait-listed" for urbanization), the actual potential for residential development in these lands is higher than it may seem at first glance. Moreover, compared to the general situation in the whole watershed, increases in undeveloped land within a 500 m wide riparian buffer zone are higher (6%), suggesting a higher potential for urbanization in the vicinity of the watercourse. According to Watts (1992), changes in land use are even more dramatic within the riparian buffer zone in the middle reaches of the river near Williams Park. There, on Coghlan Creek and the Salmon River, agricultural land decreased by 32% and 22% respectively. Undeveloped land increased by 34% on Coghlan Creek and by 6% on the Salmon River, while residential areas were augmented by 15% and 17% respectively.

We conducted an examination of historic and recent aerial photographs of the Salmon River watershed to determine changes in forested area, including riparian buffer zones, that have occurred during the last 40 years. We summarized the distribution of forest cover in 1:25,000 scale vegetation maps of the watershed for the years 1954, 1963, 1978 and 1989. Area estimation from these maps was done by comparing the weight (to the nearest 1 mg) of a piece of map paper of known area, to the weight of each paper piece that represented every forest patch in the watershed. By calculating the percentage of watershed area that was covered by forests in 1954 (37.4%, see Table 1), it is evident that most of the deforestation occurred before then.

Table 1. Forest cover in the Salmon River Watershed for different years between 1954 and 1989, based on a total area of 8,070 ha (% of the total watershed). Total width of riparian buffer strip = 280 m.

Year	Forested Area	Not Forested Area	Forested Buffer	Not Forested Buffer
1954	3,018 (37.4%)	5,052 (62.6%)	826.2 (45.9%)	973.8 (54.1%)
1963	3,164 (39.2%)	4,906 (60.8%)	810.0 (45%)	990.0 (55%)
1978	2,486 (30.8%)	5,584 (69.2%)	795.6 (44.2%)	1,004.4 (55.8%)
1989	2,856 (35.4%)	5,213 (64.6%)	784.8 (43.6%)	1,015.2 (56.4%)

From 1954 to 1979 forest cover in the whole watershed declined slightly, and then increased somewhat by 1989 (Table 1). The latter increase probably reflects farmland removed from production followed by establishment of an alder scrub forest. This is supported by the increase in undeveloped land reported by Watts (1992). However, riparian forest cover has steadily declined from 1954 to 1989 (Table 1) as evidenced by the diminishing amount of forested buffer. Yet, the percentage change in the proportion of the riparian area that is forested is not large (5%). Although this seems in conflict with the increase in undeveloped land detected by Watts (1992) within the buffer zone he analyzed, it is possible that the majority of this land was "idle" waiting for subdivision and immediate residential development and no forest growth was allowed.

Changes to the vegetation cover, and particularly to the riparian forest, will affect the stream system by modifying the water collection, retention, and delivery mechanisms of the entire watershed ecosystem. Because the different components of a watershed (i.e.

geomorphology, channel morphology, hydrologic pattern, water quality, riparian communities, stream habitat, etc.) are inter-connected (Stanford and Ward 1992), human induced changes to the terrestrial components will reflect on the characteristics and the functions of the aquatic component. Therefore, land uses in the uplands of a basin may alter fish habitat in its middle or lower reaches as a result of the system's connectivity.

Despite increased land development and riparian alterations, the Salmon River still sustains a rich fish fauna. The number of coho salmon it produced annually during the early 1980s was estimated to represent almost 5% of the total coho production of the Fraser River Sub-basin (Farwell et al. 1987). Marshall and Britton (1990), comparing it to other systems of equivalent size, ranked it among the top coho streams in the province, with an estimated yield of 2,430 smolts/km ($\cong$ 70 smolts/100m^2).

FISH SPECIES

There are 18 species of fish in the Salmon River Watershed (Hartman 1968) (Table 2). Some occur in the watershed only occasionally, whereas others are very common throughout the year. Few species distribute over the entire watershed (the exceptions being stickleback, Pacific lamprey, and western brook lamprey); the remainder are either restricted to the lower reaches of the system (largescale sucker, longnose sucker, brown bullhead, squawfish, carp, peamouth chub, brassy minnow, and redside shiner), or to the middle and upper reaches (salmonids). The Salish sucker, a species listed as endangered, is found in only three other streams in the province; within the Salmon River it is found exclusively in the upper reaches. We found this species to be relatively abundant in the deep pools of the upper Salmon River.

The species in Table 2 can be grouped into three classes: a) species with economic and recreational value (salmon and trout); b) endangered species (Salish sucker); and c) species that are neither endangered nor have market value, but contribute to the biodiversity of the stream system. Because salmonids have a relatively narrow range of environmental tolerance compared to most other species of fish present in the Salmon River, they will be the first ones to be affected by changes to the stream. Ensuring that salmonid habitat is not degraded or lost in the stream will normally be enough to guarantee that conditions in the entire watershed remain relatively unchanged and the other species will benefit as a result. However, special attention (deserving a separate detailed study of its own) has to be paid to Salish sucker habitat. The requirements of this endangered species are not well known, and it should not be assumed that a general stream conservation plan would be enough to protect it.

Effective habitat protection strategies have to be based on properly identified habitat factors (factors with an important controlling role in the ecology of the animal using the habitat), and a good understanding of the mechanisms that control (with spatial and temporal variations) the response of animals to these factors. In the following sections we briefly describe what is considered to constitute good coho salmon habitat and describe its general spatial distribution within the Salmon River Watershed.

Table 2. Species of fish present in the Salmon River Watershed (adapted from Hartman 1968, and Watts 1992). (-) = species that occur infrequently. (end.) = endangered.

Common Name	Scientific Name
Coho Salmon	*Oncorhynchus kisutch*
Steelhead Trout	*Oncorhynchus mykiss*
Cutthroat Trout	*Oncorhynchus clarki clarki*
Dolly Varden (-)	*Salvelinus malma*
Prickly Sculpin	*Cottus asper*
Largescale Sucker	*Catostomus macrocheilus*
Salish Sucker (end.)	*Catostomus sp.*
Longnose Sucker (-)	*Catostomus catostomus*
Northern Squawfish	*Ptycocheilus oregonensis*
Peamouth Chub	*Mylocheilus caurinus*
Redside Shiner	*Richardsonius balteatus*
Brassy Minnow	*Hybognathus hankinsoni*
Brown Bullhead (-)	*Ameiurus nebulosus*
Carp (-)	*Cyprinus carpio*
Threespine Stickleback	*Gasterosteus aculeatus*
Starry Flounder (-)	*Platichthys stellatus*
Pacific Lamprey	*Lampetra tridentata*
Western Brook Lamprey	*Lampetra richardsoni*

COHO SALMON HABITAT REQUIREMENTS

Juvenile coho salmon use freshwater nursery habitat during their first year, or more, of life before migrating to sea as smolts (Sandercock 1991). In some populations a proportion of the fry inhabit lakes, where they are found in the littoral zone (Mason 1974). The majority, however, prefer small coastal streams and small tributaries of larger rivers (such as it is the case of the Salmon River) where they set up territories shortly after emergence (Sandercock 1991). Juvenile coho salmon tend to be more territorial in stream reaches with faster flowing waters, whereas in some slow flowing areas it is not uncommon to find them forming loose aggregates and cruising for food (Mundie 1969). Those that "take residence" normally occupy a small space with slow moving waters, from where they make short excursions to feed or to chase intruders away. Subordinate individuals, which are chased and displaced by resident coho, tend to be less aggressive and grow more slowly due their lack of access to good feeding areas (Chapman 1962).

Highly productive coho salmon streams are small enough to provide a large proportion of marginal slow areas to midstream faster flowing waters, and have a relatively similar proportion (1:1 ratio) of alternating pools and riffles (Ruggles 1966; Sandercock 1991). Coho prefer zones with reduced water velocity. They favour pools over other types of habitat and use instream structures as protection from high water flows. In this manner, they may minimize their energy expenditures to maintain position while feeding on drifting prey (Mundie 1969; Everest and Chapman 1972; Shirvell 1990; Fausch 1993). Coho are visual predators and seldom feed from the bottom. They prefer to capture invertebrates that drift either suspended in the water column or on the surface (Hoar 1958; Hartman 1965; Nielsen 1992).

In addition to providing allochthonous prey items and shelter from water velocity, instream and riparian cover provide other benefits. Low-hanging overhead cover such as undercut banks and rootwads may decrease the amount of light reaching the water surface, thereby making fish less visible to potential predators (Murphy and Hall 1981; Helfman 1981). Instream cover can also provide refuge from predators and simultaneously increase visual isolation among competitors. Visual isolation may reduce aggressive interactions among competitors and could, therefore, lead to an increase in the number of fish occupying a given area (Dolloff 1986; Mesick 1988; Bugert et al. 1991; Fausch 1993).

In autumn, as water temperatures decline and coastal streams experience their first freshets due to increased rainfall, juvenile coho salmon redistribute either into deeper pools or to off-channel habitat (Bustard and Narver 1975; Cederholm and Scarlett 1982; McMahon and Hartman 1989; Nickelson et al. 1992a). Over-wintering coho salmon prefer reduced water flow and abundant cover, such as fallen logs, rootwads and undercut banks. These are conditions they normally find in small first order tributaries (Cederholm and Scarlett 1982; Scarlett and Cederholm 1984; Brown and Hartman 1988). They also use sidepools (or alcoves), sloughs and wetlands (Bustard and Narver 1975; Brown 1985; Tschaplinski and Hartman 1983), off-channel riverine ponds (Peterson 1982a and 1982b; Swales and Levings 1989), beaver ponds (Bryant 1984; Nickelson et al. 1992a), and even small lakes (Swales et al. 1988).

DISTRIBUTION OF COHO SALMON HABITAT WITHIN THE WATERSHED

Although studies on salmonid habitat in the Salmon River started as early as 1954, with McMynn and Vernon, and continued with Hartman (1965, 1968), there was no quantitative survey of the system and its habitat features until DeLeeuw (1982) looked at the effect of a major flood event that occurred during the winter of 1979. Nonetheless, it was Watts' (1992) research that has provided an overall evaluation of habitat in the entire watershed, as well as a systematic description of the morphology, cover abundance and substrate composition for selected reaches in the middle section of the stream.

The central part of the watershed, including both the middle reaches of the Salmon River and most of Coghlan Creek, offers the best nursery habitat for salmonids in the watershed (Watts 1992). It was in this part of the system that Hartman (1965) recorded the highest coho salmon densities (these density estimates, however, should be considered with care because of serious sampling methodology limitations). Unfortunately Hartman did not include in his survey the uppermost reaches of the mainstem, which are currently quite degraded and for the most part seem to be unoccupied by salmonids. Few fish have been found in the lower section of the system, this is particularly true in winter (Hartman 1965). In general, the floodplain portion of this watershed has been considered to play a minor role in coho salmon production. It has been mainly regarded as a mere migration corridor used by smolts leaving the system and by adults traveling toward the spawning grounds. Because of this view, no attention has been paid to the potential role that its small tributaries and abundant drainage channels and ditches may play as coho salmon overwintering habitat. Evidence from other systems indicates that coho salmon overwinter in side channels, riverine ponds, small tributaries and other kinds of off-channel habitat if these are available (Peterson 1982b; Cederholm and Scarlett 1982; Scarlett and Cederholm 1984).

HUMAN ACTIVITIES AND COHO SALMON HABITAT: THE CONFLICT

Since the mid 1800s the Salmon River Watershed has been progressively modified by human actions. By 1954 its forest covered area was only slightly larger than it is today, indicating that a largely forested basin lost, in less than 100 years, most of its natural vegetation and gradually became a landscape of anthropogenic patches. Corn and hay fields, vegetable patches, horse racing rings, roads, buildings, grazing pastures, commercial greenhouses, a zoo, a military training camp, gravel pits, chicken farms, golf courses, dairy farms, highways, gas stations, a university campus, and many more components of today's watershed landscape are the result of human land use activities. Thus, the catchment area within an agricultural/urban watershed can be described as a mosaic of terrestrial patches that are drained by a network of streams. Water flowing through this network inter-connects otherwise separate biological communities, and integrates the influence of a variety of natural and man made processes that occur within the watershed (Stanford and Ward 1992). The acknowledgment of the spatial and temporal variability of the components of lotic systems and their strong connectivity is central both to the understanding of impacts of human activities on fish habitat and to the planning of adequate management actions.

Human land use activities introduce elements that did not evolve with the rest of the watershed's components. The result is that most of these "introductions" somehow interfere with many of the natural connectivity processes. In this manner, development activities interfere with important connections and create new causal links that did not exist before. Thus, they may alter entire series of processes that connect regional (basin scale) to local (fish habitat scale) watershed components.

Approaching the lotic system at different hierarchical levels, as Frissell et al. (1986) proposed, propitiates a clear view of its different components and their connectivity. A hierarchical approach allows the effects of factors that are not observed at one spatial scale to become potentially more visible at a different scale. One simple way to illustrate this is as a multi-layered universe, where watershed scale components, such as basin geomorphology and hydrologic pattern (ranking high in the hierarchical classification), interact to control reach scale components, such as channel morphology or riparian community composition (with an intermediate ranking), which in combination affect smaller spatial scale components, such as fish habitat (with a lower functional hierarchy (Naiman et al. 1992). This ranking system is a tool that helps to identify the main spatial scale at which each ecosystem component influences the characteristics of the stream, but it does not imply that components at lower hierarchical levels are less important than those ranked higher. In fact, the connectivity of the lotic environment involves feedback mechanisms by which a variety of factors of the smaller scale components may influence larger scale ones (DeAngelis et al. 1986; Naiman 1988). Therefore, an effective fish habitat management plan has to consider factors controlling fish abundance and distribution at different spatial scales, from watershed to microhabitat. The alternative strategy - focusing exclusively on maintaining local fish habitat by protecting or enhancing selected reaches - is very ineffective in the long term because its effects are constantly neutralized by changes in the stream system that occur at larger scales (see Frissell and Nawa 1992).

FACTORS CONTROLLING JUVENILE COHO SALMON DISTRIBUTION IN THE SALMON RIVER WATERSHED

Using Frissell et al.'s (1986) conception of watersheds as series of hierarchically nested habitats helps to visualize how its components can be inter-connected even when they have vastly different spatial scales. We applied this hierarchical model of organization and the concept of functional connectivity (Stanford and Ward 1992) to relate human induced alterations to components at the watershed scale with changes at the stream reach and fish habitat scales. In this report, we evaluate how human interference on the natural connectivity of the watershed affects different habitat factors (i.e., water temperature, flow, food, cover, etc.) controlling coho salmon distribution and, therefore, alters coho's total abundance in the watershed. We begin by examining large scale elements that rank high in the hierarchical organization (i.e., entire watershed, stream sections), and finish focusing on the lower levels and smaller scale components (i.e., fish microhabitat scale processes).

WATERSHED SCALE

At this scale, the distribution of young coho salmon reflects the strong physical (and biological) differences that exist among upper, middle and lower sections of the river (Fig. 3). Although its middle section is the only one that appears to be of any importance for coho salmon production, a closer examination reveals that that is not necessarily the case. Coho salmon utilize habitats throughout the entire drainage network at different stages of their life cycle, emphasizing the connectivity between different habitats.

Reaches of the upper Salmon River, with their low gradient, slow water velocity, very low summer flows and fine substrate, do not offer suitable spawning or rearing conditions to coho salmon, but they are very important in the initial collection, filtration, and channeling of water, nutrients and sediments as well as in their downstream delivery (Naiman et al. 1992). In this way, they contribute to create the favourable habitat that coho salmon occupy further downstream. In contrast, reaches in the middle section, with their pool-riffle sequence, abundant cover, higher benthic productivity, coarse substrate and permanent flow, offer the best juvenile coho salmon summer habitat in the entire watershed. The large numbers of coho salmon that occupy this section of the basin are evidence of this. The lower section of the watershed is almost unused by juvenile coho salmon during summer. Its high water temperatures, fluctuating dissolved oxygen levels, poor benthic insect production, and scarce cover do not provide what young coho salmon require. The importance of this section, however, changes with seasons. Coho salmon that move downstream with the first fall high flows find overwintering refuge in the abundant off-channel habitat of the lower reaches (Giannico 1996).

Among the many differences between watershed sections, water quality seems to be a dominant component affecting the distribution of coho salmon in summer. The watershed scale pattern of coho parr distribution in the Salmon River suggests that marginal habitat can be used by at least a small proportion of individuals provided water temperatures and oxygen concentrations are not beyond limiting values (Giannico 1996). This is likely due to the fact that other factors - such as food, cover and water velocity - either do not reach limiting levels in the entire watershed or where they do, they coincide with extreme water quality conditions and are masked by them.

As water temperatures begin to decline, coho salmon leave their main channel feeding grounds and move into protective habitat with abundant cover (Peterson 1982a; Tschaplinski and Hartman 1983; McMahon and Hartman 1989; Nickelson et al. 1992a). Initial habitat relocations likely take place within the same pool or, at least, the same reach that the individuals were occupying during summer (Giannico 1996). However, with the first fall freshets large numbers of coho salmon redistribute into available off-channel habitat (Scarlett and Cederholm 1984). This strategy protects them from being swept out of the system by fast flowing waters, especially when cold temperatures reduce their metabolism to the point of affecting their swimming ability (Hartman 1965). Under these conditions, even small increases in water velocity are sufficient to trigger coho's downstream movement (Giannico and Healey 1998). Water velocity controls their selection of habitat, and their distribution both within and between reaches reflects the pattern of distribution and abundance of areas sheltered from velocity. Therefore, the large number of coho salmon that utilize the off-channel habitat in the lower section of the system in winter suggests a shortage of suitable habitat elsewhere. Many of the reaches in the middle section run through narrow ravines that do not allow any side channel development.

Because only a fraction of the fish that move downstream during freshets are able to relocate (Peterson and Reid 1984) and the larger than average individuals are more successful at relocating in overwintering habitat (Scarlett and Cederholm 1984), large coho parr are abundant in the off-channel habitat of the Salmon River floodplain. It is likely that many of the fish that initially choose suboptimal winter habitat, which does not shelter them effectively from the current, move and relocate for a second time when water velocities increase. Many fish may go through this displacement process more than once during the fall-winter period, which may result in the loss of the individuals that either do not have enough energy reserves to relocate several times (Cederholm and Scarlett 1982) or reach the stream's mouth before finding a new holding location.

REACH SCALE

Water velocity is one of the main factors influencing the distribution of juvenile coho salmon among different types of habitat within a stream reach (Giannico 1996). Although in summer they are found in a variety of habitats, most young coho salmon prefer areas that are characterized by reduced water velocity, such as pools or glides, and a only small proportion of individuals occupy riffles. Juvenile coho salmon use instream structures as protection from water current. In this manner, they may minimize their energy expenditures to maintain position while feeding on drifting prey (Mundie 1969; Everest and Chapman 1972; Fausch 1993). Giannico's (1996) results indicate that the selection of foraging habitat by juvenile coho salmon changes with age, and suggest that individuals respond differently depending on a number of environmental (i.e. resources, temperature, number of competitors, predation risk, etc.) and physiological conditions (such as energy reserves, see Croy and Hughes 1991).

The summer distribution of juvenile coho salmon, among habitats of comparable water velocity, responds most strongly to food. When cover is absent, juvenile coho distribute among separate pools in relation to their foraging quality. The presence of woody debris, however, affects coho's response to differences in prey abundance among stream pools (Giannico 1996). Its effect on fish distribution is complex, because it represents a resource in itself and not a mere barrier to coho's acquisition of information. Shortly after emergence, coho salmon fry do not show preference for units with woody debris over clear ones, but this changes with time and in late summer coho parr always prefer pools that offer some type of cover. As young coho salmon mature and move away from the stream margins into the mid-channel waters (Bisson et al. 1987) cover becomes an important habitat component, one that represents refugia from both predation and water velocity (Dolloff 1986; Mesick 1988; Bugert and Björnn 1991; Bugert et al. 1991; Fausch 1993). The importance of woody debris reaches a peak in winter, when coho use it as both water velocity and predation refuge.

The influence that woody debris has on the distribution of coho salmon among the pools in a stream reach is evidence of the important role that riparian forests have at the reach scale in the upper and middle sections of a watershed. Large woody debris plays an important role as a structural element in the creation of salmonid habitat in low gradient and intermediate order reaches (Bisson et al. 1987; Bilby and Ward 1989; Naiman et al. 1992; Ralph et al. 1994). Large fallen logs deflect the flow of water and, depending on their position, create different types of pools that coho use in summer (Bisson et al. 1982). Although the impact of large woody debris on channel structure decreases towards the mouth of the river, it still remains an important element of the bank structure that can influence the pattern of meanders (Naiman et al. 1992). This changes in winter, because any riparian forest left on the banks of lower mainstem, as well as along the lateral channels in the river floodplain, directly or indirectly creates coho salmon winter habitat (Naiman et al. 1992).

In addition to supplying cover and altering the structure of the stream channel, riparian forests also influence the distribution of coho salmon among reaches through other indirect processes. The density of the forest canopy controls the amount and quality of light that reaches the water, thus affecting its temperature, the level of primary productivity in the reach, and even the behaviour of organisms (Naiman et al. 1992). Riparian forests also regulate the productivity of streams through the contribution of allochthonous (terrestrial) organic matter. Leaves, wood, and nutrients dissolved in subsurface waters all represent an important source of energy for benthic invertebrates (Anderson and Sedell 1979; Richardson 1991) which are eventually consumed by fish. Terrestrial insects that fall from the riparian vegetation are another important contribution of fish food. This resource is particularly important for juvenile coho, because it has been reported to constitute between 21 and 40% (dry weight) of their daily prey consumption (Chapman 1965).

POOL/RIFFLE SCALE

At the level of pools or glides, as for entire reaches, coho salmon respond to prey abundance and distribution. Pool patches with higher prey densities attract more fish but their numbers are not proportional to prey abundance if the pool has either instream woody debris or overhead cover (Giannico 1996). The effect that cover has on coho parr distribution at this scale differs markedly from that reported for entire reaches. The young fish prefer pools that have woody debris at a low to intermediate density, but their distribution within each pool tends to be biased in favour of clear areas. The results of Giannico's (1996) experimental work suggest that fish overestimation of the foraging quality of unobstructed patches is the cause of such bias. Yet nearby patches with woody debris are beneficial, because they offer accessible refugia from predation, dominant individuals and water velocity changes. The spatial distribution of the invertebrate drift is another important factor controlling coho's patch choice within pools (Giannico 1996). Therefore, the pattern of flow that sweeps benthic invertebrates into pools influences the distribution of coho salmon within pools, and may account for the tendency of dominant individuals to position themselves at the pool's head (Hartman 1965; Jenkins 1969; Fausch 1984; Fausch and White 1986). The pattern of flow is controlled by the morphology of the stream channel and the presence of logs and large boulders that deflect the water.

Backwater pools and off-channel units offer coho salmon excellent overwintering habitat. But within the main channel, lateral scour pools are the most utilized type of unit, because of their abundant debris and undercut banks with well developed riparian rootwads (Giannico 1996).

The above mentioned factors represent a subset of some of the most important forces regulating coho salmon smolt production, and reflect the state of different components of a healthy watershed (i.e. water quality, riparian forests characteristics, and aquatic habitat features). In the following section we reflect on the connectivity of the watershed ecosystem to evaluate the potential impacts that the prevalent land uses in a basin like the Salmon River can have on factors controlling juvenile coho salmon distribution and abundance.

THE EFFECTS OF LAND USE ON COHO SALMON HABITAT

Human activities, through the modification of watershed components, such as hydrologic regime, stream channel morphology, and riparian communities, can have a strong impact on the availability and quality of fish habitat and therefore, in an indirect way, limit fish production. The impacts of forestry on salmonid bearing systems have been the subject of many investigations since the early 1970's (see Hartman 1982, for a review on ten years of research in Carnation Creek; Hicks et al. 1991 and Bisson et al. 1992, summarize more recent developments in this field). The study of the effects of agriculture on streams has attracted less attention and most of it has been focused on one specific activity - livestock grazing (Johnson 1992). In contrast, the role of urbanization as an agent of stream alteration has been overlooked (MacKenzie 1987; Booth 1991) and very few investigators have studied its impact on salmonid habitat (Perkins et al. 1980; Steward 1983; Lucchetti and Fuerstenberg 1993).

As we mentioned before, agriculture is the predominant human activity in the Salmon River watershed (approximately 50% of its catchment area is classified as farmland). However, residential land use has increased steadily. Watts (1992) estimated that between 1979 and 1989 the percentage area of the basin under urbanization increased 3% in the entire watershed, to a total of 7% (the actual urban area is closer to 14% after some areas were revised and reclassified based on aerial photographs and two previously unmapped zones of the watershed were completed, Sandra Brown and Alice Kenney, pers. comm.). Development is not uniform throughout the watershed and in some areas the rate of urbanization was higher than in others. For example, within a 500 m wide riparian corridor located in the middle reaches of the watershed, urban development increased approximately 16% during that decade (Watts 1992). Although both agricultural and urban land uses can have a detrimental impact on fish habitat, it is urbanization with its profound and irreversible changes in the stream's flow regime that poses a more serious threat to the production of coho salmon in a watershed like the Salmon River.

Although coastal watersheds of the Pacific Northwest are adapted to natural disturbances, they do not recover in a similar manner from anthropogenic alterations. The reason behind this is that the types of disturbances differ in fundamental aspects (Franklin 1992). Natural catastrophic events (i.e. landslides, floods, fires, etc.) tend to be restricted in area and in time, thus increasing the complexity and patchiness of the system and contributing to the perpetuation of high species diversity. They also leave behind a very large number of surviving organisms (biological legacy) that contribute to the relatively fast redevelopment of the system's complexity (Franklin 1990 & 1992). In contrast, human disturbances, even temporary ones (i.e. clearcutting), reduce the biological legacy so drastically that the total recovery of the system is much slower (Franklin 1992). If the disturbance is permanent (i.e. agricultural use of land, and urbanization) the ecosystem never recovers its original complexity and biodiversity.

AGRICULTURE AND URBANIZATION

At the watershed scale, the main effect of agriculture (including livestock production) and urban development on stream systems is the overall change in hydrologic regime they cause. Hydrological changes associated with both types of land uses are similar in nature. But those created by urbanization are much more extreme in magnitude than those brought about by forestry or agriculture. The combined effects of vegetation removal, soil compaction and, in the case of urban development, construction of buildings and roads, modify the type and the amount of storm runoff (water which enters a stream channel within approximately a day after landing as rainfall) (Booth 1991).

Water can reach a channel directly as surface runoff (also known as overland flow) or indirectly as subsurface flow. The latter predominates in the coastal region of the Pacific Northwest, due to the combined effects of soil characteristics, vegetation abundance, and rainfall frequency (Booth 1991). However, most of the subsurface flow in forested areas is lost to evaporation and plant transpiration; only a small fraction of it is stored in the soil and reaches the water table. Despite this, the frequent winter storms in the coastal region contribute enough water to the subsurface flow to rise the water table, expanding the area of saturated ground around the channel and increasing the stream flow (Hewlett and Hibbert 1967; Booth 1991). These processes are all altered by the increase in impervious surfaces (i.e. compacted soils pavement, roofs) associated with agricultural and urban development, and result in a larger proportion of rainfall reaching the channels as surface runoff instead of subsurface flow (Lucchetti and Fuerstenberg 1993).

Under agricultural land use, flow alterations derive from two common practices: vegetation cover removal and large scale water withdrawal for irrigation. The elimination of vegetation cover decreases the rate of water percolation in the soil, magnifying peak water discharges during heavy rainfalls and reducing baseflows during the dry season (McMynn and Vernon 1954; Hamilton and Buell 1976). The use of large amounts of either surface or underground water for irrigation can affect stream flow during the dry season. In the Salmon River, the already low summer flows are, in theory, further affected by large scale water withdrawal for agriculture from the stream. According to Paish (1980), the large number of water license holders in this system may reduce the stream summer flow by 25% in the mainstem, and by 50% in Coghlan Creek. Lower summer flows not only reduce the amount but also the quality of fish habitat, by augmenting water temperatures, and reducing dissolved oxygen levels and benthic prey abundance (Hamilton and Buell 1976).

Perhaps the most obvious impact of urbanization is the dramatic increase of the maximum water discharge associated with flood events. Booth (1991) argues that urban development not only magnifies peak discharges, but also creates entirely new ones. Depending on their magnitude, high flows can have important disrupting effects on stream habitat (causing channel erosion and expansion, woody debris displacement, pool filling, gravel bar scouring, etc.). This type of disturbance, however, increases habitat heterogeneity and can, theoretically, benefit the lotic system as long as its frequency of occurrence is relatively low (approximately one major channel alteration every ten years, Naiman et al. 1992). Urbanization not only increases the magnitude but also the frequency of peak water discharges, thus altering in a permanent way the physical characteristics of the stream. Its substrate becomes uniform, its channel looses it complexity with the elimination of distinctive hydraulic units, and its banks are eroded and cut almost vertically. Woody debris is eliminated over time and the severely altered riparian vegetation cannot replace it (Booth 1991). All this results in the loss of habitat and a decline in species diversity (both invertebrates and vertebrates), because while some species are favoured by this process, most are not. In the particular case of salmonids, coho salmon numbers decline markedly whereas cutthroat abundance increases, to the point that cutthroat is often the only salmonid species left in many urban creeks (Muto and Shefler 1983; Lucchetti and Fuerstenberg 1993). Coho salmon are particularly sensitive to the reduction in abundance of relatively large pools, off-channel habitat, and woody debris caused by urban development. The species, given its reliance on small coastal streams, has been exposed to urbanization in many areas along the coast of the Pacific Northwest. The largest declines in Washington State coho salmon populations, for example, have been observed in the most urbanized areas of King County, where more than half of the "urban" streams are used exclusively by small resident cutthroat trout (Lucchetti and Fuerstenberg 1993).

Although in the Salmon River watershed only a small percentage (14%) of the total catchment area has been developed as residential land, a slow but steady rate of urban development in the watershed represents a serious threat to the integrity of the stream system and to the size of its coho salmon population. This is particularly so if the pattern observed in the 1980's is allowed to continue. During that decade, the fastest rates of residential development in the entire watershed occurred in the middle reaches within 250 m of the stream (Watts 1992). This developed area integrates a larger urban zone of approximately 680 ha, known as the Salmon River Uplands, that in combination with Fort Langley (by the river mouth) is occupied by about 55% of the population in the watershed (Corporation of the Township of Langley 1994).

Additional urbanization in the Aldergrove area and the neighbouring City of Abbotsford area threatens to alter the headwaters of the river. This area plays, as mentioned before, a very important role in water collection and routing into the surface and underground subsystems of the middle section of the basin. The connectivity of the system will make the urban development in this area to affect the hydrologic pattern of the entire watershed, and impact negatively on coho salmon rearing downstream.

Besides the alterations to the hydrograph previously discussed, agricultural practices such as land tillage and livestock grazing promote soil erosion and compaction. Their impacts on the aquatic environment vary largely in scale - from entire watershed sections to short reaches - depending on the intensity, the extension and the location of these activities in the basin. Soil exposed before seeding or after harvesting can be easily washed into the stream. This erosion not only reduces the fertility of the soil, but contributes to soil compaction. Compacted soils have reduced water holding capacity (SOE Report 1992). From the stream perspective, erosion increases the load of fine sediments in water. Sediments threaten salmonid egg and alevin survival by clogging spawning gravel, thus causing anoxia and physical entrapment (Björnn and Reiser 1991). Depending on the amounts, sediments may also fill in pools and smother or displace benthic invertebrates, causing a reduction of fish habitat and food production (Armour et al. 1991; Harr and Nichols 1993). Concurrently, the systems productivity may be affected because suspended sediments increase the turbidity of the water, which reduces the amount of light reaching the primary producers in the benthos (Moore 1989).

Livestock grazing may affect aquatic habitat. Cattle are attracted to the riparian zone because of the quality and variety of forage, availability of water, and shade (Ames 1988). The animals can reduce the riparian vegetation, and cause bank degradation, channel widening and off-site soil erosion (Platts 1989; Armour et al. 1991; Johnson 1992). In the upper-middle (S2) and upper reaches of the Salmon River and Coghlan Creek, cattle stream wading and trampling is a common occurrence, and entire reaches have had their riparian vegetation reduced or entirely eliminated as a result. In contrast, the negative impact of livestock grazing in the riparian areas of the river's floodplain is largely restricted to the small tributaries. This is so because farmers, for the most part, restrict the access of livestock to the mainstem of the river.

Intensive farming, which normally increases with growing urbanization, results in a greater risk of severe soil erosion. Its excessive dependence on agrochemicals (i.e. pesticides, insecticides and fertilizers), and the accumulation of large amounts of manure (which is also used as fertilizer) derived from high density livestock production, presents another serious threat to water quality in many Fraser Valley streams (Moore 1990; Schreier et al. 1991). In the Salmon River Watershed, intensive agricultural operations occupy 11% of the total catchment area. But these operations, as in the case of urban development, concentrate in the central part of the basin, surrounding the Salmon River Uplands. They are located above the Hopington Aquifer, where - along with the numerous septic systems from the residential areas - they contribute to groundwater contamination with NO_3-N (Cook 1994). Nitrogen and phosphorus concentrations in stream water, however, are not high enough at any time of the year to be of concern as causes of eutrophication (with the exception of a few "trouble" sites in small tributaries and immediately downstream from the Greater Vancouver Zoological Centre) (Cook 1994).

Septic systems are the predominant wastewater disposal and treatment method that residents of the Salmon River Watershed use. Only a small area in the northwest side of the basin is serviced with sewers (Cook 1994). No wastewater disposal system is totally problem free. Nitrate pollution by sewage overflow and leaching into groundwater and then to streams is a common problem associated with deteriorated septic systems (Hall and Wiens 1976). Municipal rezoning that allows increasing residential densities, particularly in environmental sensitive areas (ESAs) (i.e. above aquifers, next to watercourses, etc.), only make matters worse.

With regards to agricultural and urban stream systems, stormwater runoff is probably a more significant, and more direct, source of contaminants than septic systems. Because it represents a nonpoint source of pollution, its control poses the most difficult problem in water quality management (Hall and Wiens 1976; MacKenzie 1987). Agricultural runoff carries pesticides, fertilizers, and animal manure. The list of pollutants in urban runoff according to several studies reviewed by MacKenzie (1987) include: high levels of suspended solids (i.e. rubber particles, asbestos fibres, general litter), nitrogen, phosphates, hydrocarbons, phenols, chlorides, lead (and other trace metals), and coliform bacteria. In the Salmon River levels of copper and zinc which exceeded the "threshold of harm" (10 μg/l) recommended for salmonid fishes were recorded by Hall and Wiens (1976) in eight of fourteen sampling stations. The fact that higher trace metals concentrations were measured during high flow periods suggests that this pollution was associated with diffuse sources. Hall and Wiens (1976) indicate that high trace metal levels in some of the samples they collected - in the Salmon lower reaches and Coghlan upper reaches, for example - could derive from soils of marine sediment origin, whereas this type of pollution in middle reaches' samples may be caused by runoff from the Salmon River Uplands residential zone.

Additional impacts on stream systems are caused by channelization, dredging and dyking, which are designed to eliminate the natural instability of rivers (i.e. channel migration, seasonal floods, etc.) in agricultural and residential areas. The problem, however, is that they disconnect fluvial systems from their floodplains. Consequently, seasonal wetlands, secondary channels, beaver ponds, sloughs, small tributaries and riverine ponds are eliminated with the ensuing reduction in productivity, filtering capacity, biodiversity, and critical habitat for wildlife - including fish - in the basin (Pinay et al. 1990; Henderson 1991). In the particular case of the Salmon River, channel dyking and dredging affects the lower section of the system. Dyking of the river mouth to prevent the Fraser's spring freshet from flooding the lowlands has an important impact on salmonid resources. Spring migrating salmon and trout smolts are held up by the system's flood gates, and the dyke's water pump represents their only way into the Fraser River. This "migration route" has a relatively high mortality risk associated with it. Dredging of the lower mainstem and its floodplain tributaries to increase their land draining capacity may seriously alter critical coho parr off-channel winter habitat in that section of the basin (Henderson 1991).

Channelization and stream bank stabilization, designed to constrain the flow to a single channel, eliminate complex edge habitat along stream margins. The most developed edge habitat (i.e., backwater areas, eddy pools, etc.) is used extensively by juvenile coho (and other species) throughout the year. Newly emerged coho fry remain closely associated with the stream edge until their swimming skills allow them to venture into the middle of the channel (Bisson et al. 1987), and migrating coho smolts may use the edge habitat along the lower river section as resting and feeding areas (Bisson et al. 1992).

Considering that the restoration of the watershed to its pre-colonial times is not a viable alternative, we propose a management plan that could maximize the capacity of the system to sustain coho salmon within the bounds of present land use patterns. Our plan takes into account the different spatial scales of the watershed components affecting coho salmon distribution and abundance, and emphasizes the importance of maintaining the connectivity of the system.

COHO SALMON HABITAT PROTECTION: APPLYING AN INTEGRATED WATERSHED MANAGEMENT PLAN

The close links and mutual interactions between a stream and its valley require that we consider rivers in a landscape context (Hynes 1975; Vannote et al. 1980; Pinay et al. 1990; Stanford and Ward 1992). Managers have to be particularly aware of this, because any stream protection or rehabilitation plan will be effective only if the entire watershed is adequately managed and protected (Reeves et al. 1991).

Simplistic habitat rehabilitation methodologies that are described in the literature have varying degrees of success in achieving their goal, and they cannot be used to compensate for poor watershed management practices. The problem is that if the structural and functional nature of the entire watershed is ignored, all localized management practices will likely produce results very different from the expected ones. This is because habitat enhancement projects that are not planned in the context of the entire ecosystem tend to interfere at some point with the processes that maintain the connectivity among watershed components. For example, high rates of damage to, and failure of, artificial stream structures were reported in southwest Oregon and Washington streams following high peak flows (Frissell and Nawa 1992). Artificial stream structures which caused flow alterations and changes in channel morphology and stability were the ones subject to the highest rates of damage and displacement. In contrast, anchored naturally occurring woody debris accumulations, which minimally altered pre-existing channel characteristics, showed lower rates of failure or impairment. In all cases, the highest failure rates of these habitat enhancement projects were observed within watersheds with eroding roads, logged slopes, and deteriorated riparian areas (Frissell and Nawa 1992). This indicates that watershed-driven processes controlling channel dynamics need to be considered when stream habitat restoration projects are planned. The use of a stream hierarchical classification system (see Frissell et al.

1986) in the early planning stages of these types of projects would greatly increase their success rate.

Unfortunately, agencies responsible for fish habitat management have a tendency to apply "handbook" methodologies, which rely either on little empirical and experimental information or were developed for different ecosystems than those in which they are implemented (i.e. coastal instead of interior streams, valley instead of upland wetlands, etc.). Programmes of stream rehabilitation that consist of a variety of isolated and target oriented management techniques (the target being a particular habitat type associated with a specific stage of the fish life-cycle) are not uncommon. It is likely that these practices are further encouraged both by studies reporting increased salmonid abundance as a result of local manipulations of stream habitat (Shetter et al. 1946; Saunders and Smith 1962; Hunt 1969 & 1971; Ward and Slaney 1981; House et al. 1991; Nickelson et al. 1992b), and by the fact that studies showing no effect or even negative effects on fish abundance have been published less frequently than those with favourable results (Hamilton 1989).

An additional problem associated with small scale habitat rehabilitation projects is that the vast majority of them, after completion, are never monitored over extended periods of time to assess whether the initial long term goals are actually met (Stanford and Ward 1992). The risk of this practice is that potentially valuable management techniques and initiatives may lose public support over time, as people realize that of the many habitat rehabilitation projects that were publicly funded over the last decade very few were ever evaluated or produced documented evidence of an actual increase in salmonid numbers (Reeves et al. 1991).

Despite their limitations, properly planned local habitat enhancement projects may benefit salmonids, and may be better than no action at all. Giannico's (1996) experiments and field observations showed that juvenile coho salmon move among pools in stream reaches (both downstream and upstream) and they respond to local conditions by settling into the most suitable habitat patch they find. Evidence of high rates of fish movement in streams is also provided by Riley and Fausch (1995) and Fausch et al. (1995), who reported that localized increase in trout densities in response to the installation of individual log structures was largely caused by fish immigration from untreated stream sections. As a result of this, small scale habitat enhancement projects may potentially boost streamwide fish production by making available to "subordinate" individuals habitat left vacant elsewhere.

However, a watershed management perspective is fundamental to ensure that the increase in fish production achieved through local habitat enhancement projects is maintained in the long term. An integrated (or cooperative) management plan represents a more rational approach to watershed management. A single agency, much less an individual manager, cannot possibly deal with the actual complexity of an entire catchment area. Cooperation among a large number of "managers" from different government agencies and interest groups is necessary for the evaluation of the best management practices (BMPs) (state-of-the-art environmental protection measures, as defined in Bisson et al. 1992) that are based on long term data and research and that do not interfere with the natural connectivity of the watershed.

Approximately twelve years passed between completion of the first reports recommending cooperative watershed management in the Salmon River (see Paish 1980 & 1981) and the first clear step towards implementing such a management plan. This step was the creation of the Salmon River Watershed Management Partnership (SRWMP) in 1992. The SRWMP represents a concerted effort by a variety of government agencies, public organizations and educational institutions to overcome the difficulties associated with fragmented jurisdictions among agencies and to eliminate traditional insular approaches to resource management. Its list of current members, in addition to the Township of Langley, includes federal agencies: DFO, Environment Canada, Fraser Basin Management Program, and the Fraser River Action Plan; provincial agencies: Ministry of Environment, Lands and Parks (MOELP), and the Ministry of Agriculture, Fisheries and Food (MOAFF); educational institutions: the University of British Columbia, and Kwantlen College; and non-government organizations: Langley Environmental Partners Society, Langley Environmental Organization, Langley Field Naturalists, Fort Langley Farmers, and the Matsqui/Langley Soil Conservation Group.

Of the several phases in the development of a watershed management plan, the SRWMP has completed the first and fundamental one - a preliminary scientific survey of habitat sensitivity or vulnerability (see Cook et al. 1993). This type of analysis indicates the sensitivity that habitats, communities, and species have to environmental change. It also identifies very fragile components that are difficult to restore. The next phase would involve the development of the management component of the plan in relation to social needs and desires. At this point, options for protecting, rehabilitating, or modifying the system's hydrologic pattern and the stream channel characteristics have to be chosen. For example, if the integrity of the stream and the conservation of salmonid resources are important, it will be necessary to consider a minimum guaranteed summer flow, and plan an acceptable winter flood regime that enhances the connectivity of the stream with its valley and increases the availability of fish habitat. The next option involves making management decisions regarding biological components of the watershed, which can be manipulated to attain predetermined objectives (i.e. riparian community, beaver populations, fish species, etc.). Land use management decisions follow, and they must be consistent with the selected flow and biological options chosen earlier. They involve controls on man-induced damage to the physical and biological components of the system (i.e. rezoning of sensitive areas, cattle fencing, manure management, etc.). The last option to be included in the plan is the compensation scheme and the non-development alternative. Compensation may be necessary if development is allowed in areas of high or intermediate sensitivity (ESA 1 and ESA 2 in Cook et al. 1993). For example, developers using land either in or adjacent to ESAs should be required either to dedicate or set a conservation covenant of an environmentally sensitive area (for a detailed explanation on different local governments tools to encourage non-development in ESAs see DFO 1993). The high level of "sensitivity" of an area (i.e. presence of endangered species) may justify its designation as a conservation zone.

MANAGEMENT RECOMMENDATIONS

Valuable information for the development of the Salmon River cooperative management plan is already available from the evaluation of ESAs in the Township of Langley by Cook et al. (1993), and from several general manuals on fish habitat protection and enhancement by DFO and MOELP (Adams and Whyte 1990; Chilibeck et al. 1992; DFO 1993), and agriculture waste management guidelines (MOAFF 1992a, 1992b). The implementation, through different incentives, of many of the management practices presented in the above mentioned publications will help in attenuating human impacts on stream habitat. However, the redefinition of terms of cooperation among agencies, the design of effective regulatory instruments (see Bowen 1987; Feitelson 1987; Hocker 1987; and Pearce et al. 1989 for information on taxation, trusts and other regulatory instruments), and the arrangement of an active public consultation system, represent important "political" obstacles that still have to be overcome for the management plan to actually achieve the desired effects.

Technical problems, although very important in many circumstances, tend to be less of an obstacle. It is important to remember that a management plan will be most effective if it is flexible enough to respond to new scientific knowledge and the development of new techniques. In addition, the plan efficacy will be enhanced by the consideration of the following three principles:

a) watershed integrity should be protected through the conservation and enhancement of connectivity among its components;

b) long-term monitoring and study programs should be conducted to evaluate the effectiveness of best management practices, and determine whether environmental changes are naturally caused or man-induced; and

c) management decisions should be made within the context of the entire watershed, and contingency plans should be developed in case monitoring reveals that the implemented management actions interfere with processes that maintain the connectivity of the system (Stanford and Ward 1992).

Because of this connectivity, the long term protection of salmon habitat can only be accomplished within the context of integrated watershed management. Given the hierarchical organization that a stream system has, and for practical purposes, a management project should consider the different spatial scales of the watershed components and linking processes.

Therefore, a possible strategy would be to devise two "spatially nested" plans.

1 - A large scale plan should encompass the entire watershed and focus on ecosystem components that are higher in the functional hierarchy. These are components that can only be effectively managed for the entire basin (i.e. hydrologic regime, water quality, etc.). For example, the preservation of a hydrologic regime that ensures a regular flow of low temperature waters in the river during summer and maintains the natural frequency and magnitude of floods in winter, is crucial for the conservation of salmon habitat. This can only be achieved if actions are taken at the watershed scale to control, among other things, underground water extraction and urban sprawling. Excessive extraction of water from aquifers and the expansion of urbanized areas close to the headwaters (Aldergrove) and in the middle reaches (Salmon River Uplands) of the stream will negatively affect water quality and flow regime. Unusually frequent and large winter peak flows, induced by vegetation removal and urbanization, will displace and damage small scale habitat enhancement projects.

A first step to deal with these problems is to implement appropriate zoning, which in the case of the Salmon River watershed, is represented by the Agricultural Land Reserve (ALR). Because changes to the system's hydrology caused by agricultural lands are smaller than those created by urbanized areas, the protection of the agricultural character of a large proportion of the watershed facilitates the conservation of a regular flow regime. But, although land zoning is a useful management tool, it cannot successfully protect the stream from human disturbances if additional control mechanisms are not implemented. This is illustrated in part by the fact that despite the ALR, a progressive withdrawal of land from agriculture is occurring in the watershed (Watts 1992). A small fraction of it has been urbanized, while the largest proportion remains undeveloped, possibly awaiting the opportunity for subdivision. Further interference with the watershed's hydrology and the quality of its water will likely be increased by the implementation of intensive farming practices, suggesting that the impact of the individual farms on the lotic system will perhaps increase. More emphasis on conservation of natural areas (i.e. dense woods, wetlands, etc.) is recommended, but as an isolated strategy will not be enough to counter balance the effects of increasingly intensive agricultural practices and slow, but ongoing, residential development. Therefore, the large scale management plan must include mechanisms that complement land zoning legislation. Farm water use optimization should be promoted (evidence suggests that less than half the water used in irrigation actually benefits the crops, see Postel 1990), water needs of water license holders should be reviewed, and underground water extraction should be regulated. An education campaign should be carried out to increase the awareness of the watershed's residents about the negative impacts, the routes (point vs. non-point sources), and sources (i.e. household chemicals, fertilizers, manure, etc.) of pollution that affect both stream and underground water quality. Finally, mitigation strategies to reduce the impact of urbanized lands on the hydrology of the system should be considered a "must" if the preservation of the stream normal hydrograph is actually expected (for a review of techniques see DFO 1993; and for engineering flaws associated with some of those techniques see Booth 1991).

2 - The smaller scale management plan should seek to protect watershed components of a lower hierarchical level, managing them at the scale of reaches and stream sections (i.e. riparian communities, input of woody debris, channel morphology, bank erosion, etc.). Because the stream characteristics change from the headwaters to the mouth, the plan should consider the application of different management strategies to the three main sections of the Salmon River. As Giannico's (1996) winter surveys revealed, the lower reaches of the watershed are important in the winter phase of coho's life cycle because they provide refugia. In summer, however, they only offer - along with some of the upper reaches - suboptimal summer nursery habitat for coho salmon.

Protecting and increasing the amount of available winter habitat in the lower reaches should have a positive effect on a system like the Salmon River, which seems to have an overall shortage of winter refugia in its middle reaches. A first step would involve a thorough field survey of potential winter habitat in the watershed to estimate whether it actually represents a bottle-neck to coho salmon production in the Salmon River. If its scarcity is confirmed, the next action should be directed to improve the existing off-channel habitat (tributaries like Davidson Creek, riverine ponds at MacMillan Park, side ditches, sloughs, etc.). Winter habitat enhancement plans should include several kinds of actions: a) to increase the availability of woody debris in many of the already existing habitats (i.e. surveyed riverine ponds had very little woody debris); b) to improve connection between these off-channel units and the mainstem of the river (fish should be able to have access to off-channel habitat, and move out of them when their water level declines); c) to deepen some of the ditches, and place natural flow deflectors in case storm's run-off increases the velocity of the water in them (juvenile coho salmon are extremely sensitive to changes in water velocity during winter); d) to redesign those ditches that have been dredged to drain faster into the mainstem so they retain water for longer periods of time (fish use them if water velocity in them is slow; and d) livestock should be fenced off all channels and ponds, to protect the physical integrity of all these habitats. Some habitats may respond very quickly to the slightest improvement and attract increasing numbers of fish, while others may remain unused for a variety of reasons. It is important to ensure that any enhancement work conducted in the stream is adequately supervised and its effects are monitored over an extended period of time. Lack of post-treatment data is a common problem in many habitat enhancement programs, and this information is necessary to assess the actual effectiveness of the selected rehabilitation technique. In many instances choosing enhancement methodologies out of a "manual" is relatively simple. But we recommended that small scale experimental manipulations be conducted in the field, to identify the most effective enhancement technique for a particular habitat type.

Only if after enhancing the currently available winter habitat (both in the lower and the middle reaches) its abundance was confirmed to set a limit to the production of juvenile coho in the Salmon River, should construction of artificial winter habitat areas be considered (see Adams and Whyte 1990, for information).

Management in the lower reaches offers a unique opportunity for testing the *in situ* effectiveness of a number of habitat enhancement methodologies. A flexible strategy combining best management practices, with research and long-term monitoring, will increase the chances of successfully increasing not only winter but perhaps also summer habitat in this part of the river. The management plan to be implemented in the lower reaches should emphasize off-channel habitat physical protection. It is likely that impact mitigation techniques (i.e., riparian tree planting, fencing, bank stabilization, etc.) will have to be utilized frequently, particularly where agricultural activities reach the watercourse. However, the cooperative nature of the plan should allow fisheries managers to work more effectively with farmers.

In the central zone of the watershed, considering it offers coho very good spawning and summer rearing habitat, the management plan should emphasize protection from man-made disturbances. The maintenance of a well developed riparian forest is very important because it works as a buffering agent that diminishes the impact of land use in the vicinity of the stream channel. It is important to underline that riparian buffer strips can reduce but not eliminate all problems created by different land uses. In Alaska, their minimum effective width has been estimated to be approximately 30 m on either side of the stream. Apparently, any significant supply of either woody debris, aquatic food or shading for the stream decreases markedly beyond this distance (Murphy et al. 1986; Budd et al 1987). Many municipalities in Washington State have also adopted a 30 m wide buffer corridor. However, the optimal buffer strip width has to be re-considered on a regional basis, taking into account the local topography, hydrology, soil composition and the adjacent development. Indeed, there is evidence suggesting that a 30 m wide buffer strip may not be enough to protect stream habitat from the impacts of high density urban development or extraction activities (Booth 1991).

Riparian forests not only protect stream banks from erosion, but increase hydrological diversity by incorporating elements of "roughness" (i.e. logs, etc.) that deflect or slow down the water current. Large fallen logs (especially red cedar, *Thuja plicata*) create different types of pools that offer a variety of habitat conditions for juvenile salmonids. Pools with intermediate to low densities of woody debris which offer open foraging grounds close to covered areas constitute the type of habitat that coho salmon prefer. Giannico (1996) reported that pools with high density of fine woody debris had a lower density of coho in them than pools with intermediate-low debris abundance. His results indicated that high densities of woody debris cause shortage of the type of open areas that coho prefer to forage in. Therefore, caution is important against indiscriminate artificial placement of woody debris, because there is a risk of having too much of a supposedly "good" thing. Giannico (1996) also concluded that short riparian clearings (the length of a few pools) may not have a negative impact on the capacity of the system to produce coho salmon. Small open areas may even increase the local production of benthic invertebrates that coho salmon feed upon; therefore, their entire obliteration by excessive tree planting may not be the best management strategy. Besides, tree planting projects should put the emphasis on recreating the diversity of the original riparian community, not just on planting the largest possible number of trees. Trees like the ones that dominate the second growth riparian forest in the middle reaches of this watershed (red alder and vine maple) contribute mainly fine woody debris to the stream. Compared to old conifer logs, red alder logs are too small to have any important effect on the morphology of the channel and do not last long (a red cedar log may last over 100 years in the stream). For these reasons, projects involving large woody debris stabilization, addition of large coniferous stumps and rootwads in reaches that lack hydraulic complexity, and riparian coniferous planting should be given priority in this section of the watershed.

Management in the upper section of the watershed should have a similar approach to that already described for the lower section. It should also emphasize the implementation of mitigation and protection actions. The effectiveness of any of the mitigation methodologies should be monitored and, as in the lower reaches, there is the possibility of conducting small scale experimental manipulations to developed habitat enhancement and mitigation techniques that better adapt to the specific characteristics of this system. The fact that these reaches are occupied by Salish suckers (a species listed as endangered in British Columbia) should help to further promote the protection of the systems headwaters in any management strategy. Because of the very important role the upper sections of the river play in the collection and downstream transference of water and sediments, their management should stress soil erosion control (i.e., riparian planting, cattle fencing, adequate land tillage, etc.) and improvement of water retention capacity in the land they drain (i.e., development of holding ponds and wetlands to offset the impact of urban zones, restriction of further urbanization near the system's headwaters).

The protection of structural complexity and habitat heterogeneity is a fundamental tenet in any watershed management plan designed to maintain, or increase, the production of salmon smolts. An effective management plan protects habitat heterogeneity by controlling the causes of its reduction (i.e. frequent peak flows, lack of instream structures) and preventing further degradation, instead of fighting their consequences with small scale enhancement projects alone. Management of natural resources has often been reactive in its approach; a more proactive view is long overdue. This implies that the prevention of habitat degradation and loss must start now, instead of considering that current mismanagement can continue, because effective rehabilitation techniques will always be available in the future. Habitat protection is by far the most effective strategy to prevent permanent damage to stream systems, and to avoid the cost of rehabilitation as well as the uncertainties associated with rehabilitation and enhancement techniques. The intention of the SRWMP of creating a long term cooperative management plan for the watershed is an important step in the right direction.

Effective salmon habitat protection plans will require that land use within watersheds change to reflect the needs of aquatic organisms. The endorsement of such a stream habitat protection plan by farmers, among other watershed residents, will be necessary to ensure its viability. In order to obtain the support of farmers, the cost (i.e., impacts on farm income) to farmers associated with increased stream protection and sustainable management plans may need to be met by the broader public. It is possible that the benefits to both the local and the regional economy derived from the protection of stream resources are enough to offset those costs. Healthy coho salmon stocks will maintain a lucrative sport fishing industry and will also contribute to the economy of the commercial industry. Taxes generated from these sectors could contribute to pay for the rehabilitation of stream habitat. At a municipal scale, it is likely that the long term preservation of the rural nature of the watershed gave origin to economic activities (i.e., organic farming, recreation, short-term tourism, etc.) that could also contribute to counterbalance some of the costs derived from environmentally sound farming practices and limited residential development.

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PERSONAL COMMUNICATIONS

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