Mitigating the Impacts of Channel Maintenance in the Lower Fraser Valley

2003-2004 Field Trial
and
Literature Review

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Prepared by
Scott Barrett R.P.Bio.
Ecosystem Officer
Environmental Stewardship Division
Ministry of Environment

Executive Summary

Two different dredging techniques in similar channelized stream reaches of the same watershed were compared in a field trial in the lower Fraser Valley, near Chilliwack, British Columbia, during the late summer to early autumn of 2003 and 2004. The objective of this study was to assess the within-season and the one-year post impacts of drainage-channel maintenance on juvenile salmonid habitat. A reach of Marblehill Creek experienced a “hard” bank-to-bank dredging with little-to-no utilization of fish habitat mitigation measures. The second treatment reach, in Big Ditch, experienced a “softer” form of dredging where fish habitat structures, in the form of rip-rap rock weirs, were restored as the dredging was undertaken. The key variables used to determine effects through comparison between the treatments included: 1. an assessment of the relative abundance of juvenile fish using minnow trapping; 2. measurements of angular canopy density (ACD) along the stream channels (a proxy measurement for stream-channel shading); 3. an assessment of thalweg-velocity variability; and 4. the calculation of channel-roughness coefficients. The fish-use comparisons support four important conclusions regarding the juvenile salmonid habitat impacts relating to these dredging activities: 1. unmitigated channel dredging had a severe detrimental effect on the within-season relative abundance of over-summer rearing coho salmon (*Oncorhynchus kisutch*) (up to -94%) and coastal cutthroat trout (*O. clarki clarki*) (up to -98%); 2. unmitigated channel dredging had a significant longer-term (one-year post-maintenance) impact on the relative abundance of summer rearing coho salmon (-53%) and larger cutthroat (up to -90%); 3. mitigative efforts substantially accelerated the within-season recovery of both coho and cutthroat relative abundance, and 4. mitigative efforts allowed for full recovery of larger-size class cutthroat trout one-year subsequent to channel maintenance. The amount of shade at all dredging sites, as measured by the ACD, significantly declined immediately subsequent to dredging (up to -73%) and remained depressed one year later (up to -56%). The calculations of variability of thalweg velocity and the roughness coefficient showed numerical values that were less after dredging in the unmitigated reach. These suggest that channel dredging caused significant changes to the habitat complexity unless there was a directed effort to maintain these important features. In contrast, the mitigative techniques were highly successful in maintaining many of these habitat values; particularly the complexity of stream-flow.

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1.0 Introduction

Dredging of small lowland streams is a common maintenance activity within the agricultural lands of the lower Fraser Valley. In 2004 alone, over 230 kilometres of channel length were dredged in the Lower Mainland of British Columbia. Channel maintenance includes the removal of instream vegetation, riparian vegetation and sediment from small channelized streams, on a regular basis, to facilitate greater flow capacity and/or conveyance.

Recent declines in the populations of anadramous coastal cutthroat trout (*Oncorhynchus clarki clarki*) and other salmonids in coastal regions of the Pacific Northwest (PNW) (Slaney et al. 1996; Gregory and Bisson 1997; Johnson et al. 1999) are due, in part, to the degradation of freshwater habitats through human land-uses such as forestry, agriculture and urbanization (Bisson et al. 1992; Boule and Bierly 1986; Trotter et al. 1993). With the continued growth of urbanization and agro-business in the lower Fraser Basin (Hall and Schreier 1996; Langer et al. 2000), these impacts continue to escalate. Reduced stream complexity is one of the most pervasive cumulative effects of these activities (Bisson et al.1992).

Understanding the effects of these particular activities thought to reduce habitat complexity, and developing strategies to allay their impacts, are imperative if we are to protect and restore these stocks of salmonids. This requires a clear understanding of the processes that limit fish production and how they relate to these particular activities. As Hartman et al. (1996) state: “Programs to restore or protect natural functions to fish habitat must be evaluated and reported methodically if they are to succeed and provide useful information to habitat managers, stakeholders and user groups”.

1.1 Importance of Small Streams to Cutthroat and Coho Ecosystems

Cutthroat trout and coho salmon (*O. kisutch*) prefer very small, low- gradient streams (Hartman and Brown 1987; Rosenfeld et al. 2000; Bramblett et al. 2002). The highest densities of both species occur in channels 1.5-2.0 m wide, with gradients of 0-5% and discharges of less than 0.14 m^3/second (Rosenfeld et al. 2000; Johnston 1981).

Small streams are vital to the health and survival of coho salmon stocks. Coho that take advantage of smaller tributaries and side channels enjoy increased growth rates over those that remain in main-stem rivers (Scrivener and Anderson 1982). Bradford et al. (1997) found that watersheds with broader floodplains, where small streams are more representative, produce larger coho smolts. Coho salmon have an extended freshwater residence compared to other Pacific salmon. As such, they suffer a higher fry-to-smolt mortality rate but enjoy a higher marine survival rate (Drucker 1972). The higher marine survival rate is presumably due to a size advantage upon exiting the freshwater/estuarine environment. In years when marine survival is poor, larger individual coho smolts have been found to survive better than smaller individuals (Holtby et al. 1990; Bilton et al. 1982). Therefore smolt size upon exiting the freshwater environment is an important factor in the health of coho stocks. Use of small tributaries also tends to increase coho survival rates (Tschaplinski and Hartman 1983). This is likely associated with increased growth rates and decreased predation offered by superior cover (Boss and Richardson 2002; Rosenfeld 2000; McMahon and Hartman 1989). Coho preference for these smaller streams also serves to isolate them from competition with other salmonids such as rainbow trout (*O. mykiss*) (Johnston 1981).

Use of small tributaries also serves to isolate sympatric anadramous cutthroat from other salmonids, particularly rainbow trout. As hybridization occurs in the interface zone between cutthroat and rainbow trout habitats, failure of anadramous cutthroat to be site-specific in their habitat selection could be genetically lethal (Johnston 1981). Several size classes of cutthroat trout are represented in small streams (Hartman and Brown 1987; Rosenfeld 2000). The increased growth rates associated with small streams tend to yield larger trout that produce larger eggs which, in turn, enjoy higher survival rates (Trotter 1989).

The importance of small stream habitat has intensified as the productive capacity of fish habitat has been compromised across the landscape. Larger river systems in the lower Fraser Basin have suffered a decline in complexity along their margins (side channels and floodplain habitat) (Rosenfeld et al. 2000; Rosenau and Angelo 2004). Unfortunately, small low-gradient streams are often under-estimated in planning processes and have been most susceptible to channelization (Wang et al. 1998; Hartman and Gill 1967; Rosenfeld et al. 2002). This is likely due to the propensity of lowland flooding, the fact that small streams tend to be ubiquitous in larger low-gradient watersheds and the escalating market value of adjacent property.

1.1.1 Significance of Small Stream Summer-rearing Habitat

The amount of available summer rearing habitat is considered to be a critical factor in determining the population success of coho salmon (Sandercock 1991) and cutthroat trout. In the summer many portions of a coastal watershed represent suboptimal to unsuitable habitat due to shallow water and poor water quality (Brown 2002). During the summer, salmonids may move many kilometers upstream and downstream in order to monitor habitat conditions at a large spatial scale and gain access to habitat with favourable depths, good water quality, optimal foraging opportunities, reduced competition and superior cover (Gowan and Fausch 2002; Bramblett et al. 2001; Brown 2002). Spring through to late summer is the prime feeding and growth period for coho and cutthroat (Sandercock 1991; Mundie 1969). It is also the period of highest predation (Sandercock 1991) and competition (Glova 1986).

Small permanently-wetted streams with low-to-medium gradients are the key summer habitat for anadramous coastal cutthroat trout and coho salmon. These channels contribute disproportionately to summer rearing habitat in coastal areas for these species (Rosenfeld 2000). They tend to contain higher proportions of slack margin (edge habitats) than larger main-stem rivers (Rosenfeld 2000). Therefore these streams offer access to drifting food items while allowing coho (and cutthroat) to hold in their preferred areas of near-shore cover (Shirvell 1990). The midstream drift of larger/wider rivers is largely lost to coho (Sandercock 1991).

Healthy riparian vegetation that overhangs the channel is essential to summer growth rates. The availability of food items is likely a limiting factor in salmonid growth (Boss and Richardson 2002) and both summer-rearing cutthroat and coho feed heavily on drifting terrestrial (aerial drop) invertebrates and aquatic detrital insects (Rosenfeld and Boss 2001; Trotter 1989; Chapman 1966). The production and availability of these invertebrates is a function of available organic (plant) material (Bjornn and Reisser 1991).

Small streams offer superior levels of instream cover and structural complexity. Salmonids seek out this critical protective cover during periods of low-flow (Shirvell 1990, Bugert 1985). The first summer is the period of highest mortality for coho and is likely associated with higher predation during summer (Neave and Wickett 1953). As available protective cover increases in a channel the rates of predator captures decline (Wood 1984)**.**

1.1.2 Significance of Small Stream Over-wintering Habitat

The population success of both cutthroat and coho is dependant upon the survival of juveniles through their first winter. In the autumn, coho salmon move, usually downstream, into their winter positions in small tributaries, minor intermittent streams, debris-jams, side-channels, swamps and off-channel ponds (Bramblett et al. 2001; Brown 2002; Skeesick 1970). Several factors trigger the redistribution to wintering habitat including:

- time of year; usually mid-October (Brown and McMahon),
- water levels; off channel numbers peak within 2 weeks of first fall storms (Brown 2002), and
- water temperature; at approximately 7^0C (Bjornn and Reisser 1991).

Increased autumn flows allow coho to access very small habitats that may have represented suboptimal to unsuitable habitat due to low water and poor water quality in summer (Brown 1987). Even habitats completely devoid of water in summer (small ditches/channels, wetlands/swamps) are heavily used by coho in winter (accounting for up to 15% of smolt production) (Brown 2002; Brown 1987; Brown and Hartman 1988).

Movement to wintering habitat is primarily the selection of appropriate cover. Coho use of smaller drainages in winter is primarily a selection of habitat with lower velocity as refuge from high-flows and the choosing of warmer, more productive habitat (Shirvell 1990; McMahon and Hartman 1989). However, cover as protection from predation is also an important determinant (McMahon and Hartman 1989; Bustard and Narver 1975b; Brown and McMahon 1988). This may be especially important in very shallow habitats where predation tends to be higher (Lonzarich and Quinn 1995; Zarnowitz and Raedeke 1984).

Cutthroat trout migration to over-wintering habitat tends to be less consistent in autumn than coho (Brown 2002). Cutthroat will migrate upstream (Trotter 1989) and downstream into smaller tributaries and cluster together with coho in low-velocity areas in winter (Glova 1986). As such cutthroat will winter in small intermittent streams that are dry or only contain pools of isolated water in summer, but they are more often associated with permanent channels of sand and gravel substrates (Hartman and Brown 1987; Brown 1987).

While several factors such as channel morphometry, climatic conditions, predation affects and times of immigration may affect the winter survival of coho, off channel areas provide higher survival rates than main-stem streams and rivers (Brown 2002). As water temperatures warm in the late winter/ early spring coho begin a period of rapid growth before heading to the estuary. During this last 100 days of rearing juvenile coho do most of their growing; more than doubling their size (Brown 1985 in Brown 2002). It is the lower reaches of the watershed (small low-gradient channels) that produce most of the out-migrating smolts (Brown 2002).

1.2 Microhabitat Selection

Behavioural responses of juvenile salmonids such as site selection or avoidance are useful indicators of altered environmental factors (Bjornn and Reisser 1991). Microhabitat selection reflects a favourable balance between potential energetic profile (food versus metabolic costs), influence of competition and associated risks of predation (Spence 1989).

Possibly the most important factor in the selection of microhabitat is cover. The American Fisheries Society defines cover as “anything that provides protection from predators or ameliorates adverse conditions of streamflow and/or seasonal changes in metabolic costs” (Habitat Inventory Committee 1986). Cover is chosen by how it provides optimal levels of velocity, depth, light intensity and other variables within the constraints of social interactions (Shirvell 1990). Cover is provided both instream and by riparian vegetation. Forms of instream cover include:

- Large woody debris (LWD) (Bugert 1985),
- Undercut banks (Chapman and Knudsen 1980),
- Channel substrate (boulders, cobbles etc.) (Bugert 1985),
- Channel depth (Bugert et al. 1991), and
- Instream vegetation.

Increased cover complexity results in increased cover utilization and ultimately increased numbers of both coho and cutthroat remaining in stream channels (Rosenfeld 2000; McMahon and Hartman 1989; Scrivener and Anderson 1982). For the purposes of examining microhabitat selection I have divided cover into two classes: (1) protection and (2) refuge.

Social interaction is also a very important factor in habitat utilization that must be taken into account when habitat preferences are being inferred from fish distribution data (Shirvell 1990). Therefore, social interactions are discussed within the context of each cover type.

1.2.1 Protection during Feeding

The significant risks of predation from larger fish (salmonids, cottids, cyprinids etc.) and birds (herons, kingfishers, mergansers etc.) that juvenile salmonids face in the small streams of the PNW are an important factor in habitat selection (Lonzarich and Quinn 1995; Glova 1986). Overhead and instream cover, by mediating predator capture rates, may limit survival for salmon and trout (Boss and Richardson 2002; Wood 1984).

While coho and cutthroat densities correlate well with each other in small streams and both species are drift-feeding fish they tend to occupy slightly distinct niches based on different factors such as depth and velocity (Johnston 1981; Bugert 1985).

In summer coho are found in small stream habitat that is deep, dark and slow (0.09 to 0.21 metre/second) such as pools and low-gradient channels (Bugert 1985; Hoar et al. 1957; Pearson et al. 1970). Coho prefer to feed high in the water column, at the upper end of pools (Pearson et al. 1970; Bugert 1985). Staying close to the surface likely offers a competitive advantage in reaching food items first (Bugert 1985).

However, when structural cover, such as LWD, is lacking they tend to move into deeper pools and/or closer to the bottom (Bugert 1985). The increased depth of position offers an alternative form of cover (Bugert et al. 1991) and may also allow them to identify their position relative to stable substrate (Bugert 1985); as juvenile coho tend to maintain defined positions relative to certain objects in their environment (Chapman 1962b; Hoar 1951; Bugert 1985). However, moving closer to the bottom of the stream appears to decrease their rate of growth (Bugert et al. 1991).

Though all age classes of cutthroat trout also prefer to occupy pool habitats in a deeper portion of the water column, young-of-the-year trout are more associated with areas of sand and gravel-bottoms, shallower depth and higher velocities (riffle/run) (Rosenfeld and Boss 2001; Trotter 1989). These smaller cutthroat are more efficient exploiters of riffle habitat due to their smaller size, body shape, lower energetic needs and their ability to consume both bottom and drifting food items (Rosenfeld and Boss 2001; Glova 1986). Accessing higher drift rates in faster water can, in fact, lead to higher growth rates despite increased metabolic costs due to higher swim speeds (Spence 1989). However, larger cutthroat are restricted to pool habitat. Rosenfeld and Boss (2001) found that larger cutthroat actually lost weight when restricted to riffles and are required to shift from riffles to pools at 90mm fork-length to maintain a net energy balance in summer base-flows. Pool habitat may actually limit cutthroat abundance in lower-gradient pool-riffle channels (Rosenfeld 2000).

Pools offer a higher salmonid carrying capacity of up to three-fold over riffles as they provide reduced energy costs, increased mobility and higher feeding efficiency (Glova 1986; Bugert 1985). The productivity of a pool for salmonids is somewhat dependant upon the size and productivity of riffles immediately upstream (Pearson et al. 1970). Upstream riffles are a key source of drifting aquatic invertebrates. The increased carrying capacity of pools is also related to their success in offering protective cover from predators (Bugert 1985; Power 1984; Lonzarich and Quinn 1995). Pools with significant cover allow fish to range freely, increasing their foraging ability (Bugert et al. 1991). Pools lacking cover (decreased depth, less overhead riparian vegetation etc.) tend to experience higher mortalities and are often avoided by fish species in the PNW (Lonzarich and Quinn 1995). Selection of darker habitat, especially under sunny skies, as coho grow older (Bugert 1985; Bugert et al. 1991; Hoar 1957), may also serve to reduce exposure to ultra-violet radiation (Kelly and Bothwell 2002).

While the ability of smaller cutthroat to exploit a variety of habitat types allows for their segregation from coho, it is clear that social interactions (competition) and varying emergence timing (size differences) are important factors (Glova 1986; Rosenfeld and Boss 2001; Sabo and Pauley 1997). It seems that smaller cutthroat trout are forced into the shallower and faster riffles by more competitively-dominant coho or larger cutthroat (Trotter 1989). Earlier emergence and the corresponding larger body size of coho is the likely explanation for their dominance (Johnston 1981). Sabo and Pauley (1997) found that size-matched cutthroat surpassed coho in foraging success and aggression. Therefore coho dominance over young-of-the-year cutthroat is likely a size-dependant-behavioural-tactic.

Size-dependant-behavioural tactics also lead to segregation within-species. Pearson et al. (1970) found that coho occupying the front of a pool, the prime foraging area, are larger than those at the back. Furthermore larger 1+ cutthroat have wider ranging instream movement than the smaller 0+ fish (Johnston 1981). The degree of aggressiveness within a population may also be factor in segregation, as the level of aggression is considered an inherited trait that varies between distinct populations (Rosenau and McPhail 1987).

Riparian and instream protective cover is fundamental to the productive capacity of small streams. Similar to how the selection of small stream habitat produces benefits in decreased competition and lowered potential hybridization with other salmonids, microhabitat selection (segregation) results in decreased competition between cutthroat and coho. In short, it allows for more complete resource utilization (Bugert 1985; Johnston 1982). Protective cover, such as woody debris plays an important role in segregation by reducing aggressive inter-species interactions through visual screening (Bugert et al. 1991; Lonzarich and Quinn 1995). A lack of cover or varying stream depth increases overlaps in distribution of coho and trout and increases the effects of large trout on young-of-the-year densities in pool habitat (Rosenfeld and Boss 2001; Lonzarich and Quinn 1995). This may partially explain why highly complex reaches yield higher densities for both larger cutthroat and coho (Rosenfeld 2000). Species segregation also provides an opportunity for habitat managers in that efforts to increase abundance of one species should not be detrimental to another (Dahlberg et al. 1968).

1.2.2 Cover as Refuge

Salmonids also require cover that offers refuge from higher-flows. In small streams this cover is provided by complex areas that offer pockets or entire reaches of slower velocities (Lonzarich and Quinn 1995; Shirvell 1990). Refuge cover is considered of more significance for over-winter survival in British Columbia’s coastal watersheds due to increased flows and decreased water temperatures associated with severe and recurrent storms in the autumn and winter. Some fish that have reared in the estuary will actually move upstream to overwinter in stable and complex habitat of small streams (Miller and Sadro 2002). In the absence of available refuge areas, fish are forced to emigrate downstream into larger, slower habitats (McMahon and Hartman 1989).

While both species tend to cluster in low-velocity off-channel areas during high-flows and in winter (Glova 1986), there is some segregation between cutthroat and coho. Coho are found in both permanent and non-permanent off-channel habitats of varying sizes whereas cutthroat are associated with larger, more permanent off-channel areas (Johnston 1981; Brown 2002). Though not confirmed, Brown (2002) suggests that winter distribution may also be associated with size-dependant-behavioural tactics.

While salmonids continue to feed in cold water (2.5^{0}C) through the winter (McMahon and Hartman 1989) they tend to experience limited-to-no growth. However, Brown (1985) noted higher coho growth in placid ephemeral swamps over mainstems. This may be related to slightly warmer temperatures and more available food. Small seasonally-wetted ditches are often sources of higher water temperatures in winter due to the influence groundwater. Ephemeral habitats may also maintain populations of aquatic invertebrates that remain dormant in summer but are available as food for coho during higher water levels in winter (Brown 2002). Greater densities of invertebrates are observed when rooted vegetation is present in off-channel habitats (Brown 2002).

Cutthroat and coho remaining in the main-stem channels, that tend to experience high thalweg velocities, are dependant upon various forms of instream cover to provide refuge areas of lower velocity from high winter flows (Brown 2002; Brown and McMahon).

1.3 Effects of Channelization

Destruction of wetland habitat, reduction of stream habitat quality and diminution of stream biota numbers, size and diversity are well-established impacts of straightening, narrowing and incising streams. Channelization is the term used to describe the initial realignment (usually straightening), relocation, leveling and deepening of natural streams. While the literature that discusses the effects of channelization, reviewed for this report, is variable in terms of ecoregion, biota and stream size, the fundamental outcomes are consistent. Several assessments suggest that these impacts are long-term and/or permanent (Chapman and Knudsen 1980; Cederholm and Koski 1977; Hooton and Reid 1975).

1.3.1 Habitat

The changes in physical fish habitat quality associated with channelization and dredging are largely associated with changes to volume and type of cover (Shields 1994). The simplification of channel form, removal of LWD and loss of riparian vegetation amount to a reduction in available physical habitat (Chapman and Knudsen 1980). Explicitly, channelization results in:

- the shortening of stream length (up to 54%) (Hansen and Muncey 1971; Hooton and Reid 1975),
- the loss of wetted area (up to 20%) (Chapman and Knudsen 1980),
- the conversion of pool/riffle sequences into deep glides (Negishi et al. 2002; Cowx et al. 1986),
- the loss of undercut banks (Headrick 1976),
- the loss of floodplain-based habitats (Rosenau and Angelo 2005) , and
- the loss of lateral heterogeneity, such as meanders and side channels (Chapman and Knudsen 1980).

Changes to the morphological features reduce the capacity of the stream to provide refugia from high-velocities and reduce available wintering habitat for salmonids by 45% to 77% (Chapman and Knudsen 1980; Negishi et al. 2002). The newly-formed glides or over-sized pools tend to provide suboptimal conditions (Pearson et al. 1970). Channelization may also decrease the stability of the stream, triggering increased bank erosion and unstable bedload (Headrick 1976; Rees 1956). During the first winter after channelization, Cederholm and Koski (1977) found the channelized reach, that represented approximately 5% of the watershed, was contributing 822% more sediment than the remainder of the watershed. Over a four year period the total amount of sediment supplied by the channelized reach was 7.6 times greater than the rate of sediment contribution in unchannelized sections. This large volume of scoured material began to cause flooding concerns downstream and resulted in the destruction of 55% of the chum spawning redds in the stream. Streambed instability in a channelized reach may also cause instability in natural reaches upstream (Cederholm and Koski 1977).

Channel dredging often involves the physical removal of LWD that is perceived to interfere with the conveyance of flows or decrease the capacity of a channel (Chapman and Knudsen 1980; Cederholm and Koski 1977). As LWD provides protective and refuge cover for juvenile salmonids, its retention has been shown to assist in the maintenance of habitat quality and recovery from landscape-level land-use changes (Young 1999). LWD also tends to result in the formation of pools that are deeper (approximately 10%) than those formed by freeform bank scour (Rosenfeld 2000). The increased pool depth is significant during summer low-flows and may be the difference between survival and local population extinctions of cutthroat trout (Rosenfeld 2000).

Cover offered by vegetation both instream and along the banks (riparian) is often removed both deliberately and unintentionally in conjunction with channelization projects (Cederholm and Koski 1977, Nunnally 1979). Chapman and Knudsen (1980) found that channelization reduced overhead cover by over 89% in PNW streams. Cederholm and Koski (1977) determined that the total amount of bank cover was still only 55% of pre-channelization levels four years after the initial channelization works. Such a dramatic reduction in the amount of riparian cover:

- virtually eliminates an important food source (insect-drop) (Rees 1956; Chapman 1966),
- converts the channel nutrient sources from allochthanous (terrestrial-based) to autochthanous (instream-based) (Chapman 1962a),
- eliminates a temperature-regulating source of shade,
- reduces protective cover from avian predators (Boss and Richardson 2002) and
- exposes fish to increased levels of ultra-violet radiation (Kelly and Bothwell 2002).

The elimination of native vegetation also leaves the channel open to encroachment by invasive plant species such as bank grasses and aquatic plants that provide sub-optimal cover and nutrients (Chapman and Knudsen 1980; Maddock 1972 in Nunnally 1978).

Instream vegetation that may also serve as an important source of food, protective cover, dissolved oxygen and shade during various times of the year is often completely eliminated through channelization. Slaney and Northcote (2003) found that the partial removal of instream vegetation may be beneficial to the dissolved oxygen concentration in small channels in the summer by slightly increasing flow conveyance and decreasing biological oxygen demands of decaying plant material. This may provide some opportunities to improve habitat conditions through channel maintenance. However, in order to determine the benefits of instream vegetation removal for aquatic habitat, a variety of factors, including seasonal use and the value of riparian shade plants, must be carefully considered.

As very little attention is given to natural fluvial processes in their design most, channelization projects have caused the inadvertent simplification and destruction of physical aquatic habitat (Nunnally 1979). Channelized streams offer reduced amounts of available food while slightly increasing the metabolic costs; a poor energetic profile. Unfortunately these impacts are not restricted to a particular time of year (Headrick 1976).

1.3.2 Water Quality

Channelization affects a number of water quality parameters including temperature, dissolved oxygen concentrations (DO), transport of dissolved phosphorus, suspended sediments and the cumulative effects of each.

Several authors suggest an increase in water temperature (Nunnally 1979, Headrick 1976) and higher daily temperature fluctuations (Hansen 1971) occurs in conjunction with channelization. This is likely associated with increased exposure to solar radiation due to decreased shade and shallower pools (Brown and Hartman 1988). Salmonids in the Pacific Northwest are coldwater stenothermal animals that are sensitive to higher temperatures or sudden temperature clines (Brett 1952). Forage activity of coho tends to increase from 5^0C to 15^0C and is severely decreased at 20^0C (Spence 1989). The optimum sustained swimming temperature also peaks out at about 20^0C (Davis et al. 1963). Increased water temperatures lead to more aggressive behaviour in coho (Mason and Chapman 1965), setting off a chain of impacts including boosting downstream migration (Chapman 1962b), increased use of less suitable rearing habitat and higher mortality due to predation (McFadden 1969). It also tends to result in earlier seaward migration of smolts; decreasing the numbers of multiple age-classes in freshwater channels (Holtby 1988). The number and progress of potentially fatal infections in salmonids also increases with increased water temperatures whereas reduced temperatures tend to retard the growth of these infections (Groberg et al. 1978). Long term (more than a week) exposure to temperatures greater than 25^0C is considered lethal for all salmonids (Brett 1952).

Increased water temperatures also negatively impact dissolved oxygen (DO) concentrations. Salmonids in the PNW require high concentrations of DO in order to maintain swimming performance (Davis et al. 1963), foraging success and, ultimately, survival in small streams. As channelization usually converts riffle/pool sequences into glides (Negishi et al. 2002), it may reduce aeration of the water column.

Smith et al. (2006) found that dredging channels increased the transport-rate of phosphorus in the water column. This is presumably associated with two factors: (1) the loss of finer-textured sediments, living organisms and organic material that can remove labile phosphorus from the water column and (2) an increased release of phosphorus from sediment post-dredging.

Channelized and incised streams tend to experience both short-term (Nunnally 1979) and long-term increases in turbidity associated with suspended sediments (Shields 1994). The effects on juvenile salmonids of suspended sediments released through channel dredging include:

- initial stress,
- avoidance,
- gill clogging and abrasion,
- decreased egg survival (Scrivener and Brownlee 1988),
- increased biological oxygen demand and decreased light penetration that affects primary production and the dissolved oxygen balance in the water column (Mortensen 1976).

Avoidance of sediment-laden water by coho begins at turbidity levels of 70 nephelometric turbidity units (NTU) and greater, likely due to the decreased feeding efficiency (Bisson and Bilby 1982).

It is important to keep in mind that many channelization activities have occurred in agricultural landscapes where other pollutants such as fertilizers, farm waste and pesticides have been known to generate water quality concerns in the receiving environments.

1.3.3 Channel Hydraulics and Hydrology

Channel shape depends on the interaction between stream flow and erodible materials along the stream bed and banks. There are a number of independent controls on channel shape such as geology, climate and vegetation. Variables such as stream discharge and sediment load are the dominant controls on channel shape, but in turn are affected by channel shape through a series of complex feedback processes. Knighton (1998) concluded that a stream must satisfy at least three physical relations in adjusting its flow geometry:

1. the relation of continuity: stream discharge (Q)= wetted width(w) x mean depth (d) x mean velocity (v);

2. a flow resistance relation expressed empirically by the Manning equation, Chezy equation or Darcy Weisbach equation;
3. a sediment transport equation, typically expressed as rating curves relating sediment transport to some measure of stream power (e.g., Water-surface slope) or discharge.

Changes to one or more of the dependant hydraulic variables of channel slope, length, depth, width and roughness must feedback to the others, promoting a new equilibrium (Nunnally 1978). For instance shortened stream length increases the channel slope and width (Cederholm and Koski 1977; Nunnally 1978). Dredging to satisfy one set of discharges upsets the equilibrium and may cause bank erosion during frequent high discharges and deposition in the channel during low-flows. Some channelization may ultimately be less efficient at transporting water; especially at intermediate discharges (Nunnally 1978). Other factors such as groundwater levels may have even bigger effects on peak-flow formation (flooding) than channel conveyance or capacity (Iritz 1994).

Channelization also leads to a number of changes in stream hydrology. The elimination of off-channel areas and wetlands brought about by ditching causes a reduction in summer low-flows due to a decrease in available recharge (Brown 2002; Hooton and Reid 1975). It is also suggested that the increased flow efficiency may increase winter runoff volume (Brown 2002; Hooton and Reid 1975).

1.3.4 Stream Biota

Stream biota respond both behaviourally and physiologically (growth and health factors) to an array of environmental factors (Bjornn and Reisser 1991). Therefore shifts in composition and organization (numbers, size and diversity) of stream communities provide good evidence of altered habitat.

Channelization has been observed to result in significant reductions of fish use by several authors in the PNW and beyond including:

- Cowx et al. 1986
- Chapman and Knudsen 1980 (PNW)
- Griswald et al. 1978
- Cederholm and Koski 1977 (PNW)
- Headrick 1976
- Hooton and Reid 1975 (PNW)
- Stroud 1971
- Belusz 1970 in Heneger and Harmon 1971,
- Elser 1968
- Bayless and Smith 1967
- Peters and Alvord 1962
- Rees 1956 (PNW)

Reported reductions vary from 63% to 100% depending upon the species, age and size of fish and the severity of habitat alterations. Cederholm and Koski (1977) found that 2 years after being channelized the altered reach had 75%, 77% and 96% lower densities of coho, age 0+ trout and age 1+ trout respectively than control reaches. The reductions in fish abundance are thought to be caused by (1) mortality from the dredging machinery and stranding, (2) avoidance due to a lack of suitable or favourable habitat (Rees 1956) or (3) decreases in overwintering survival (Cederholm and Koski 1977). The duration of habitat avoidance, while not completely understood, also varies between channelized streams from a few weeks (Rees 1956) to several years (Chapman and Knudsen 1980; Cederholm and Koski 1977; Cowx et al. 1986). Chapman and Knudsen (1980) suggest that aspects of habitat alterations associated with channelization may effectively reduce the carrying capacity of the stream for salmonids permanently.

Habitat simplification also results in reduced fish species diversity, fish size and the number of age classes represented (Shields 1994). In the PNW, channelization particularly affects use by larger age 1+ trout (over 70 mm in fork-length) and coho (Chapman and Knudsen 1980; Cederholm and Koski 1977; Rees 1956). Cederholm and Koski (1977) determined that coho densities fully recovered 3 years after channelization works were completed whereas larger trout did not recover even after 5 years at the conclusion of their study. Severity of habitat alteration is also an important factor in the changes to fish abundance. For instance, young-of-the-year cutthroat trout that do not appear to be as severely affected were significantly reduced in numbers and biomass when channelization impacts were harsh (Chapman and Knudsen 1980). Coho biomass also appeared to be further reduced in severely altered reaches (Chapman and Knudsen 1980).

The destabilization of the streambed observed by Cederholm and Koski (1977) led to the displacement of redds thus leaving the salmon eggs high and dry, exposing them to predation by birds and causing them to be crushed during bedload shifts. The estimated mean chum survival to emergence for the first winter post dredging was 7.3% for an early run and 9.4% for the late run compared to a potential chum rate of survival to emergence of up to 90% in a healthy stable stream (Salo 1991).

Efforts to relocate fish prior to channel modification work are a required component of modern channelization projects. While salvaging efforts, including electrofishing, trapping and seining, are partially successful in removing fish from the potentially deadly path of machinery or from stranding, they are not benign or 100% effective. Capture by any technique induces stress on fish and may result in injury or death. The common practice of electrofishing is especially stressful and hazardous. Since most instream works occur during the summer, fish are often transplanted upstream or into parallel streams that are already occupied. As all streams have a rearing capacity, transplanted fish may not be able to take up residence in their new surroundings (Pearson et al. 1970). This forces them into marginal habitats increasing the likelihood of disease (Pearson et al. 1970), predation or early seaward migration.

Channelization also results in a decline in macroinvertebrate abundance, diversity and biomass (Negishi et al. 2002; Griswald et al. 1978; Rees 1956). These reductions are largely associated with a loss of habitat heterogeneity (Negishi et al. 2002). As with fish, altered reaches offer less refugia thus amplifying the impacts of higher flows (Negishi et al. 2002). Griswald et al. (1978) noted a change in the dominant taxa from clingers, and other riffle specialists, to burrowers revealing the shift from pool/riffle sequences to glide/pool habitat. Some studies noted an increase in drift-rates in channelized reaches possibly reflecting a lack of suitable substrate for macroinvertebrates.

1.4 Effects of Channel Maintenance

A stream that has been channelized usually experiences ongoing management required to maintain its size, shape and location in order to alleviate risks of flooding. Channel dredging, the most invasive form of maintenance, is conducted to remove alluvium and/or instream vegetation that is perceived to be reducing channel capacity or interfering with the conveyance of flows. Most of the research reviewed focuses on impacts associated with the initial channelization of streams. Very little research specific to the ongoing maintenance of channelized reaches appears to be available. However, several impacts may be inferred.

Numerous authors found that the biological integrity of channelized streams improved over time (Wang et al. 1998; Chapman and Knudsen 1980; Cederholm and Koski 1977; Headrick 1976). When no recent work had been completed, the streambed was stable, there was less silt in the water column and there were more pool-riffle sequences; all leading to higher standing crops of fish. This suggests that habitat conditions may partially recover from the initial channelization works and that regular channel maintenance likely interrupts the recovery process. The anticipated effects of channel maintenance on partially recovered habitat would mirror the impacts of channelization discussed in the previous section. Some aspects of the aquatic habitat and biological integrity of a channelized stream that do not fully recover from the initial channelization include stream biota diversity (Negishi et al. 2002) and biomass (Griswald et al. 1978).

Chapman and Knudsen (1980) conducted a before-after-control-impact (BACI) designed study to evaluate the effects of channel maintenance in Childs Creek, a channelized tributary of the Skagit River. Before the maintenance works were conducted, the maintained reach had 25% more salmonid biomass than the control but 10 days after the cleaning it had 95% less than its control. During the following winter, they observed reduced total biomass of coho (-81%) and all salmonids (-23%) in the impacted reach compared to the control reaches. Clearly, short-term effects of machinery operation may include depletions of all species and size class of salmonids.

Channel maintenance affects the macroinvertebrate assemblage usually includes the displacement of most of the benthic fauna from the affected reach of stream (Rees 1956). Partial recovery of invertebrate densities, through recolonization by drifting invertebrates from upstream reaches (Negishi et al. 2002), may occur as early as a few days to several weeks after a channel is dredged (Rees 1956). However, invertebrate recovery may take considerably longer depending upon the length of channel dredged, stream discharge and upstream abundance. Obviously, the previously noted impacts to macroinvertebrate abundance, diversity and biomass that may recuperate as the channelized habitat recovers would be further impacted by maintenance activities.

1.4.1 Mitigating the Effects of Channel Maintenance

Section 7.2 of the Ministry of Environment "Standards and Best Practices for Instream Works, March 2004" provides the mitigative measures recommended by our Ministry to alleviate impacts from channel maintenance activities. It strongly recommends that those planning works should consider the form and function of the local watershed in order to develop long-term solutions to flooding or debris-flow risks that eliminate or reduce stream and channel maintenance. These may include:

- Appropriately constructed and licensed sediment traps in the stream,
- Control or reduction of upstream sources of sediment,
- Increased drainage density in the watershed (i.e. the number of channels),
- Construction of off-line detention or retention facilities and
- Shade trees and shrubs planted to shade out instream vegetation.

The operational mitigative measures include:

- Minimizing the amount of material to be removed,
- Maintenance of healthy riparian cover/ no disturbance of stream banks,
- Upland and on-field sediment control measures,
- Monitoring by a qualified environmental professional,
- Fish salvage,
- Limiting the timing of works and
- Re-introduction of channel complexity by instream structures.

Though these measures are anticipated to partially mitigate the effects of channel maintenance (Griswald et al. 1978, Chapman and Knudsen 1980) there has been little effort made to analyze their effectiveness in the PNW (Shields et al. 2006). There are several key reasons why we should increase our understanding of the effectiveness of these measures:

- The large volume (over 230 km) of fish habitat annually subjected to channel maintenance activities in the Lower Mainland region,
- The importance of small stream habitat as it relates to:
    - Fry-to-smolt survival for coho averages at 1-2% in BC (Neave and Wickett 1953),
    - The significance of coho smolt size for ocean survival rates (Holtby 1990),
    - The sensitivity of cutthroat trout populations to freshwater habitat perturbations (Bisson et al. 1992) and
- The significant amount of effort and resources required to implement best practices.

The field trial reported here is an initial attempt to assess the effectiveness of a technique to mitigate the biological impacts of lineal channel dredging. The focus of data collection was to measure both "explanatory" and "response" variables relevant to the policies and maintenance techniques of those approving and conducting channel maintenance activities in the lower Fraser Valley; primarily Fisheries & Oceans Canada (DFO) and local governments.

2.0 Study Sites

2.1 Marblehill Creek – Treatment A Reach

Marblehill Creek (Figs. 1, 2 & 3) originates in the eastern hillsides of the City of Chilliwack, is a 1st order channelized stream, and is tributary to the Big Ditch. This water ultimately flows into Hope Slough, an anthropogenically semi-isolated side channel of the Fraser River. Marblehill Creek has a watershed area of approximately 4 km^2. The upland reaches of this stream are primarily second-growth upland forest with some suburban residential development while the lower reaches are dominated by agricultural activity. The study reach flows between two farm fields approximately 300 m perpendicularly east from Upper Prairie Road and approximately 400 m south of Patterson Road. The streambed of the reach is a mixture of small gravels, sands and silt. Much of the instream and riparian habitat complexity is a result of submergent aquatic and terrestrial vegetation, bed and bank scour, bedload deposition, overhanging vegetation and infrequently-occurring LWD. Summer salmonid densities were anticipated to be high based on previous observations. The City of Chilliwack excavates this reach as frequently as every 3 years to maintain the conveyance of flows. Removal of alluvium transported from the nearby hillsides is the primary objective of the maintenance activity.

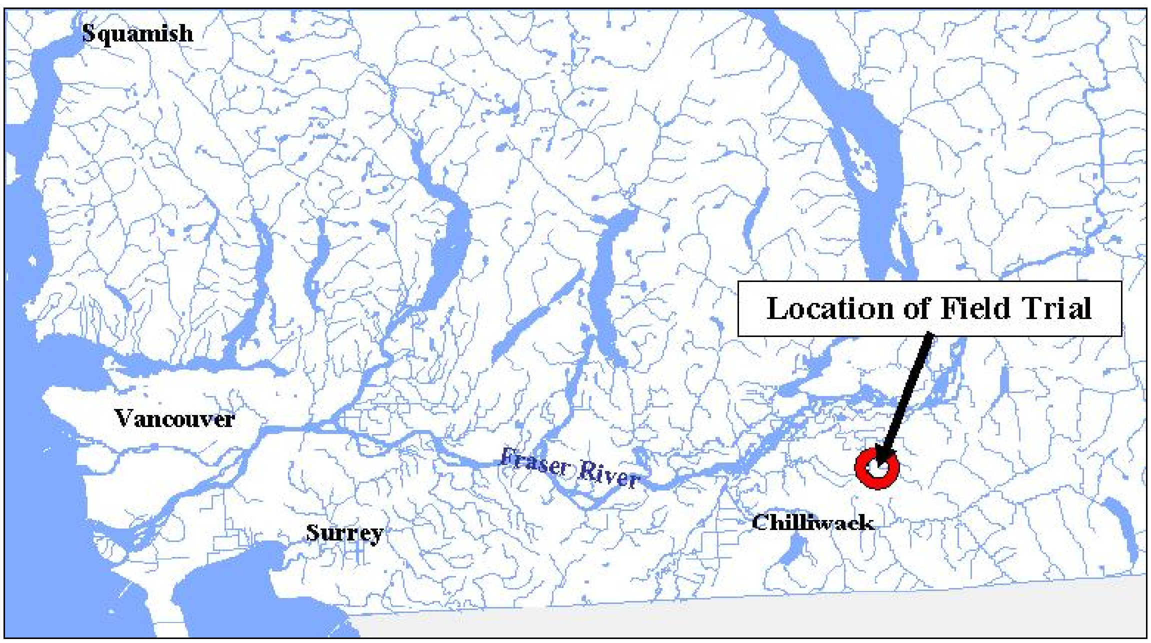

Figure 1. Location of field trial within the region.

Figure 2. Marblehill Creek, looking upstream from downstream end of Treatment A.


Figure 3. Marblehill Creek, close-up of channel conditions.

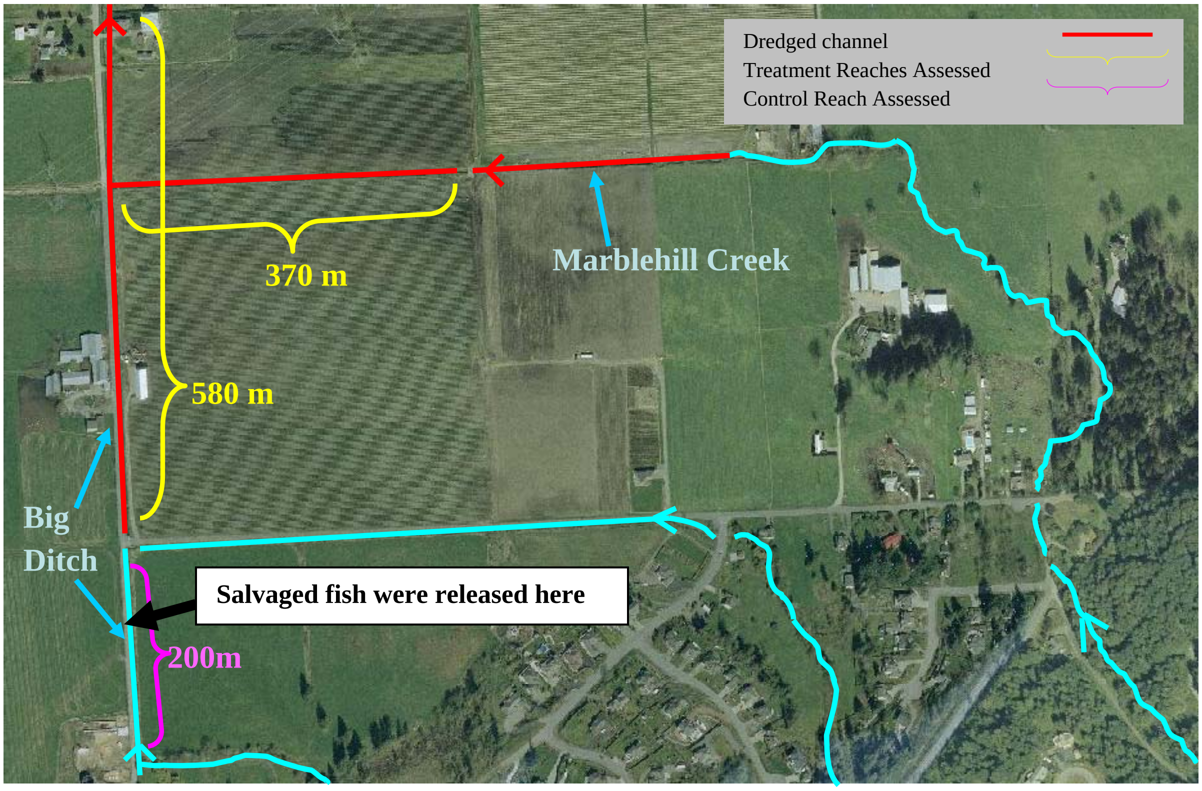

Figure 4. Aerial orthophoto of Marblehill Creek and Big Ditch reaches.

2.2 Big Ditch – Treatment B Reach

Big Ditch (Figs. 4 & 5) is a 2^{nd} order tributary to Elk Creek and Hope Slough and also originates in the eastern hillsides of Chilliwack. The watershed is approximately 7 km^2 in area. The upland portion of the watershed is primarily second growth forest with some rural residential development. The lower portion is dominated by agricultural activities. The treatment reach runs adjacent to the east side of Upper Prairie Road from Patterson Road to approximately 200 m south of Prairie Central Road. The streambed of the reach is a mixture of gravels, sands and fines**.** The habitat complexity of the reach is defined by submergent aquatic vegetation, instream grasses, bed and bank scour, bedload deposition, riparian vegetation and man-made rip-rap weirs. The City of Chilliwack excavates this reach every 4 -7 years to maintain the conveyance of flows. Removal of alluvium transported from the nearby hillsides is the primary objective of the maintenance activity.

Figure 5. Big Ditch facing upstream from middle of Treatment B.

2.3 Big Ditch –Control Reach

The control site is located upstream of the Big Ditch treatment reach. This reach has slightly more gradient; approximately 1% in the control reach versus 0% in the treatment reach. This causes slightly higher stream-flow velocities and larger streambed substrate. The control reach is otherwise similar to the two treatment reaches.

3.0 Methods and Materials

This field trial was designed as a before-after-control-impact (BACI) channel treatment comparison in two reaches of the Big Ditch watershed:

1. Treatment A – Marblehill Creek reach (370m) underwent:
    - standard bank-to-bank "hard" cleaning of the channel bed,
    - removal of riparian vegetation, and
    - partial manipulation of channel banks.

2. Treatment B – Big Ditch reach (580m) underwent:
    - standard bank-to-bank "hard" cleaning of the channel bed,
    - removal of riparian vegetation,
    - slightly less manipulation of channel banks (than Treatment A), and
    - partial reconstruction of habitat features in the form of man-made rip-rap weirs.

The objective was to explore the relative impact and rate-of-recovery of biological integrity by measuring relative abundance of salmonids, of the two treatment locations. The work plan for this site was to proceed as per normal operating and approval procedures of the City of Chilliwack and DFO. In addition to the mitigative measures in Big Ditch described above, DFO and the City of Chilliwack negotiated the construction of a sediment trap, interspersed with large woody debris, at the confluence of Marblehill Creek and Big Ditch; as partial compensation for impacts to both streams. This trial was not designed to test the efficacy of the sediment trap therefore care was taken in all measurements taken to avoid the confluence of the two streams plus a minimum of 30 metres upstream and downstream beyond the confluence.

A reference reach was also included to control for annual recruitment variability. It should be noted that fish salvaged out of both Marblehill Creek and Big Ditch, as a part these maintenance works, were released into the control reach between August 13 and August 21, 2003. Obviously this contaminated the 2003 post maintenance results in the control; this is dealt with further in the Results and Discussion.

3.1 Summer Fish Use

Catch-per-unit-effort (CPUE) using baited minnow (Gee's) traps was used to measure summer relative abundance of fish species. Trapping efforts are outlined in Table 1 below. Individual traps were placed approximately 10 metres apart along each reach. Care was taken to not place traps near the area of the new sediment trap at the confluence of the two streams.

Table 1. Outline of summer minnow trapping effort

Stream Reach	# of Traps Per Set	# of Trap-sets Pre-dredging 2003	# of Trap-sets Post-dredging 2003	# of Trap-Sets Post-dredging 2004	Total # of Traps Set
Marblehill Creek - Treatment A	30	2	5	5	360
Big Ditch - Treatment B	50	2	5	5	600
Big Ditch – Control	10	2	5	5	120
Total	90	6	15	15	1080

*Approximate trap counts: several trap results were discarded due to trap tampering or failed equipment

In 2003 two trap-sets (August 6 & 7 and August 11 & 12) were conducted prior to the maintenance activities proceeding. The initial study design called for four trap sets to be completed prior to the maintenance activities commencing, however the works commenced earlier than anticipated. Maintenance activities including the brushing of riparian vegetation, a fish salvage operation and the channel dredging commenced on August 13 and concluded August 21, 2003. Subsequent to the dredging, trap-sets were conducted 5 times in 2003 (August 26 & 27, September 3 & 4, 10 & 11, 17 & 18 and October 2 & 3) and 5 times in 2004 (August 11 & 12, September 1 & 2, 13 & 14, 20 & 21 and October 7 & 8). Traps were baited with one-half of a 106g can of spring water sardines and were soaked for approximately 24 hours. The species and fork-length of captured salmonids were recorded and the fish were released at each point of capture.

3.2 Angular Canopy Density (ACD)

ACD is defined as the mean proportion of the sun's path between 10 am and 2 pm that is obscured by vegetation. ACD data was collected using a Teti's Canopy Densiometer; an instrument consisting of a wooden clamshell case, a marked convex mirror, a bubble level and a magnetic compass. When oriented correctly this device offers a clear view of the sun's path, as marked on the mirror, at any given location to allow for the estimation of a density of vegetation, expressed as a percentage that would provide shade. Three ACD measurements were taken every ten metres along each reach before, after and one year after the maintenance activities had occurred. Care was taken to measure canopy density near the right bank, the left bank and the centre of the stream at each 10 metre point. These measurements were intended to objectively assess both changes to shade and cover provided by the remaining riparian vegetation subsequent to maintenance works.

3.3 Thalweg Velocity

For the purposes of this trial, thalweg velocity is defined as the maximum velocity detected within a cross-sectional velocity profile of a channel. Therefore, every ten metres along each reach, flow velocities were measured at varying depths and distances from the bank in order to detect the maximum velocity at that point in the stream. The highest velocity detected at each cross-section was recorded as the thalweg velocity. Flow velocities were measured using a Global Water Flow Probe flow-meter. These measurements were conducted before, after and one-year after maintenance activities had occurred.

Measurement of thalweg velocities is intended to gain insight into the relative changes to linear flow variability within in each reach, an important factor in habitat preference among salmonids.

3.4 Roughness Coefficient

The roughness coefficient (*n*) is a measure of the unevenness of the streambed surface as represented in the formula:

$$n=(1/V)R^{2/3}S^{1/2}$$

where V is the mean stream velocity expressed in metres per second, R is the hydraulic radius (cross-sectional area/wetted perimeter) expressed in metres and S is the channel slope. Cross-sections were measured using standard water survey techniques and channel slope was detected using a survey level. The roughness coefficient was calculated for each reach before and after maintenance activities. It was not measured in 2004, one-year later. It was measured to assess changes to the relative structural complexity of each reaches' streambed, another important factor in habitat preference among salmonids.

3.5 Other Observations

Observations of fish behaviour, both before and after maintenance activities, were made for each of the treatment reaches and reported. Other observations of the drainage maintenance activities are also provided.

4.0 Results and Discussion

4.1 Fish-use

Over the two season sampling period 2566 juvenile coho salmon, 1154 cutthroat trout, 2 rainbow trout (*O. mykiss*), 2344 threespine stickleback (*Gasterosteus aculeatus*), 33 sculpins (*Cottus spp*.), 2 minnows (Cyprinidae) and 10 lamprey (*Lampetra spp*.) were captured (Fig. 6). A partial summary of the fish-per-trap of coho and cutthroat in all three reaches are provided in Table 2.

Figure 6. Various fish species captured (clockwise from top-left: coho salmon, cutthroat trout, rainbow trout, threespine stickleback, sculpin and lamprey).

Review of the frequency distribution of the size of cutthroat captured in both 2003 and 2004 suggested that two size classes should be evaluated separately. These size classes vary between years as the fish captured in 2004 tended to be larger than those captured in 2003 (Figure 7). A warmer late-spring/ early summer may account for this. The size classes for 2003 are (1) 70mm or less and (2) greater than 70mm. The 2004 size classes are (1) 90 mm or less and (2) greater than 90mm.

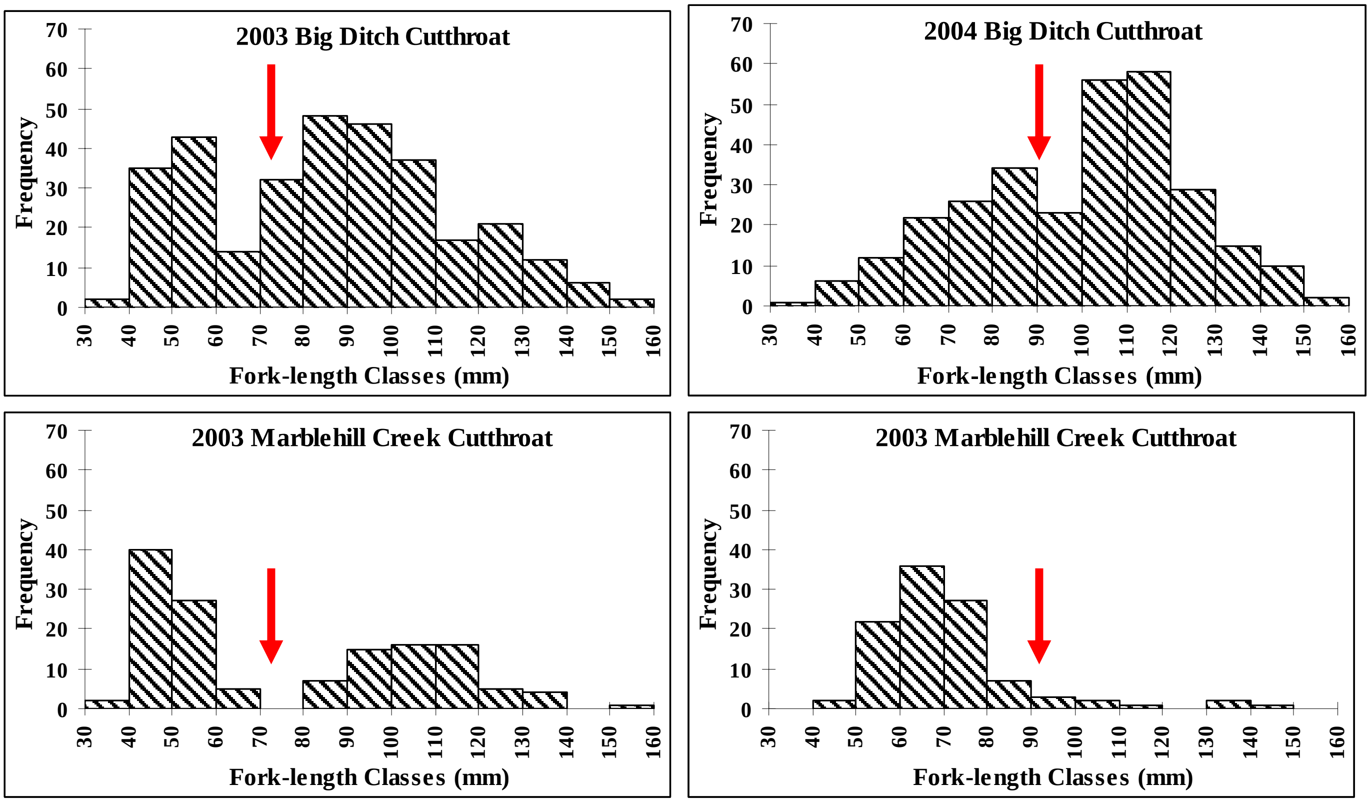

Figure 7. Cutthroat fork-length histograms for aggregated 2003 and 2004 datasets. Axes are the same for all histograms to allow simple comparison. The arrows mark the approximated separation in size-classes for each dataset. Notice that the 2003 cutthroat size classes split out at approximately 70mm fork-length whereas the 2004 cutthroat split out at approximately 90mm.

4.1.1 Big Ditch Control - Coho

Comparisons of the pre-dredging to 1-year post-dredging control data are useful to provide some indications of interannual variability in the relative abundance of coho (Figure 8 and Table 2).

Fish salvaged out of the treatment reaches as a part of the City's maintenance activities were released into the control reach by the City's biological monitor. This is the likely explanation for the dramatic increase in coho from pre-dredging to post (+292%), thus rendering the within-season post-dredging control data meaningless for our comparison.

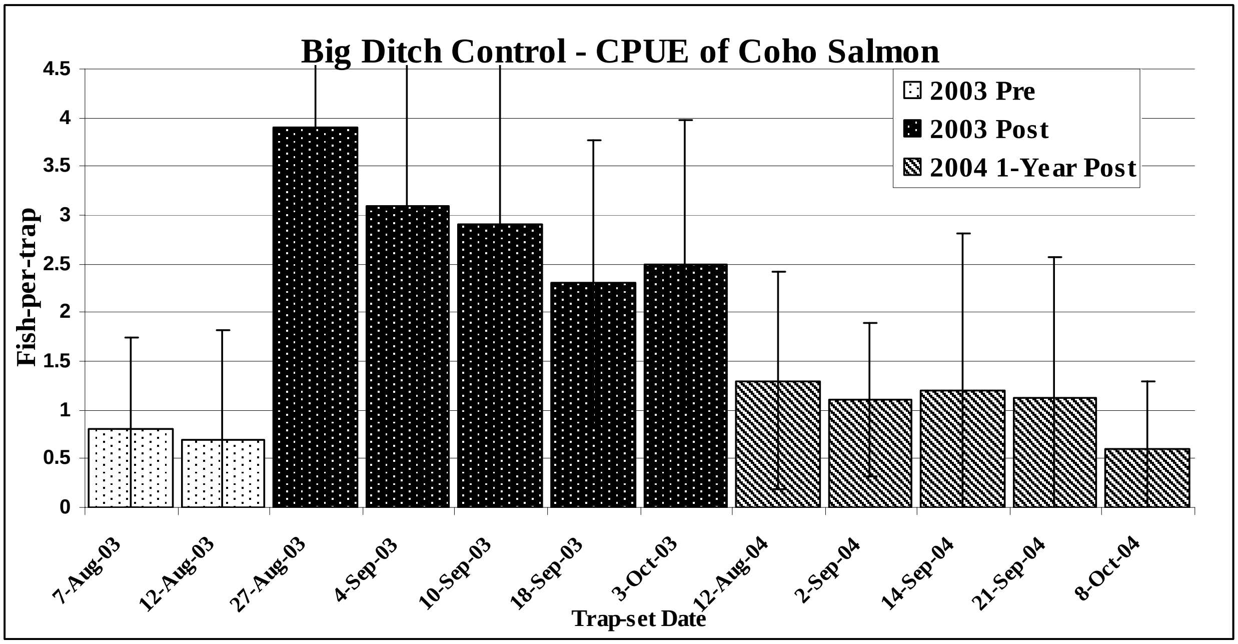

Figure 8. CPUE of coho salmon in the Big Ditch Control reach by trap-set (bars = 95% confidence intervals).

The relative abundance of coho in the summer of 2004 is not anticipated to have been impacted by the release of salvaged fish in the summer of 2003. This is because almost all of the coho captured in both years are anticipated to be at age 0+; each year represents a completely different set of cohorts. Any remaining age 1+ or older fish would have redistributed over the winter.

It should also be noted that the control reach had a very small mean catch of coho pre-dredging (0.75 fish-per-trap (fpt)) compared to that of the treatment reaches in Marblehill Creek (4.12 fpt) and Big Ditch (4.14 fpt). Slightly higher gradient and the predominance of slightly larger substrate of the control likely contributed to the prevalence of cutthroat over coho in the control.

Table 2. Summary of CPUE coho and cutthroat in all three reaches. All units represent fish caught per trap per overnight set (fpt). Large cutthroat represent fish greater than 70mm fork-length in 2003 and fish greater than 90mm fork-length in 2004. The sample size (n) represents the number of traps set for each overnight sampling period.

		Pre (2003)			**Post** (2003)			**1-year Post** (2004)		
		Mean	*Std Dev*	n	Mean (%difference)	*Std Dev*	n	Mean (%difference)	*Std Dev*	n
Marblehill Creek Treatment	All Coho	**4.12**	*3.66*	*60*	**0.23** (-94%)	*0.82*	150	**1.94** (-53%)	*2.47*	150
	All Cutthroat	**2.2**	*2.75*		**0.04** (-98%)	*0.2*		**0.81** (-63%)	*1.26*	
	Large Cutthroat	**1.13**	*1.92*		**0.02** (-98%)	*0.18*		**0.12** (-90%)	*0.54*	
Big Ditch Treatment	All Coho	**4.14**	*4.45*	*100*	**2.98** (-28%)	*3.53*	250	**3.31** (-20%)	*4.8*	250
	All Cutthroat	**2.03**	*2.46*		**0.46** (-77%)	*0.86*		**0.96** (-53%)	*1.47*	
	Large Cutthroat	**1.32**	*1.81*		**0.19** (-85%)	*0.47*		**0.62** (-53%)	*1.04*	
Big Ditch Control	All Coho	**0.75**	*1.41*	*20*	**2.94** (+292%)	*3.79*	50	**1.05** (+40%)	*1.31*	50
	All Cutthroat	**4.4**	*2.7*		**4.14** (-6%)	*2.81*		**2.51** (-43%)	*1.55*	
	Large Cutthroat	**3.7**	*2.74*		**3.38** (-9%)	*2.74*		**1.74** (-53%)	*1.33*	

4.1.2 Marblehill Creek Treatment Coho

Marblehill Creek experienced a dramatic 94% reduction in the mean catch of coho from pre-to-post-dredging in 2003. As seen in Figure 9 this collapse persisted through the entire 2003 post-dredging sampling period (late August – early October). The fish salvage conducted immediately prior to the channel maintenance activities may have contributed to this substantial change in relative abundance, especially for the first couple of post-maintenance trap-sets. However, it is important to note that the fish were transplanted into occupied habitat only 300 metres upstream in Big Ditch and coho did not appear to return to this reach even six weeks after the works were completed. Even 0+ age-class salmonids will redistribute into unoccupied habitat as they continue to seek out suitable habitat in response to slight changes in flow, available food, competition and pressure from predators through the summer feeding season. The persistent decline in relative abundance of coho likely reflects the selection of other more-favourable habitat.

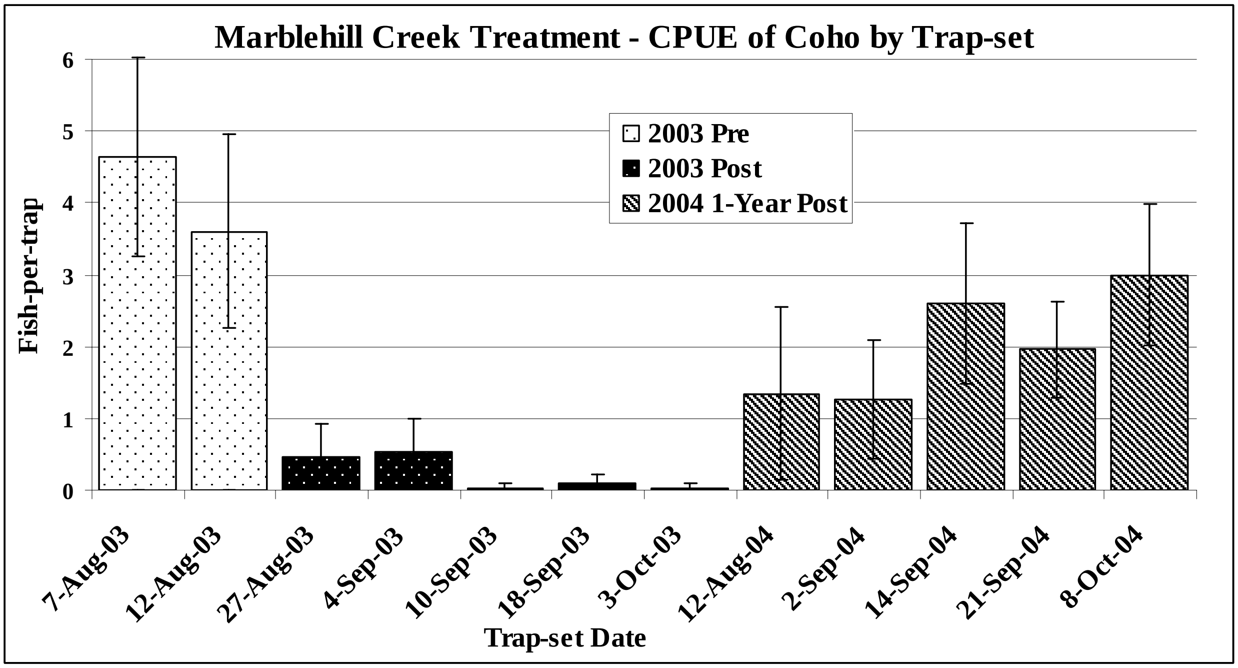

Figure 9. CPUE of coho in Marblehill Creek by trap set (bars = 95% confidence interval).

The following summer (2004), the overall mean catch was 53% less than the pre-dredge mean. Compared with the control over the same period, which suffered no decline (see Figure 8), this reduction suggests habitat impacts may be enduring with respect to coho use in Marblehill Creek one-year after works are completed.

4.1.3 Big Ditch Treatment Coho

While the mean coho catch in Big Ditch suggests a reduction (28%) from pre-to-post maintenance in 2003, it is not significant. The post-maintenance catch-per-unit-effort appears to be well within the variability around the mean detected prior to dredging. Figure 10 shows that this catch was relatively stable over all of the 2003 post-dredging trap sets. This is a notable improvement over the 2003 results in Marblehill Creek.

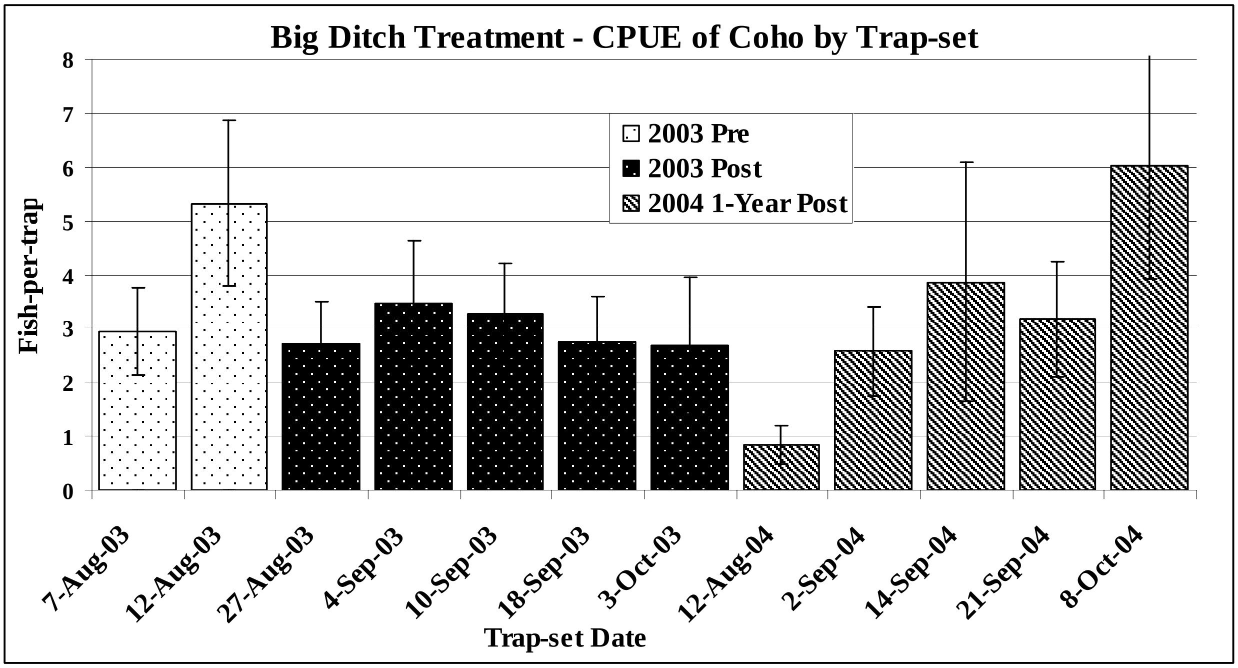

Figure 10. CPUE of all coho in Big Ditch by trap set (bars= 95% confidence interval).

One year later the trap-set results were more variable, however the overall mean (3.31 fpt) in 2004 was very similar to the post-dredging mean catch in 2003 (2.98 fpt). This consistency or slight improvement in relative abundance is likely a reflection of annual recruitment variability as the control reach also experienced a slight increase in relative abundance from the 2003 (pre-salvage/release)(0.75fpt) to 2004 (1.05 fpt).

4.1.4 Discussion of Coho Catch Data

Simple comparison of these results suggest that the mitigative techniques employed in the Big Ditch treatment reach were successful in reducing impacts to habitat conditions preferred by juvenile coho salmon; both within-season and one-year later. Four factors not fully controlled for in this field trial that may also have contributed to this difference in coho recovery include (i) proximity of the reaches to the release location of salvaged fish, (ii) differences in direction of flow in relation to the fish release location, (iii) slight differences in flow between the reaches and (iv) residual impacts of previous maintenance activities (a shifting baseline). These four concerns are examined below.

(i) As previously mentioned, the fish salvaged as a part of the dredging operation were released into the control reach in Big Ditch. This is immediately upstream of the Big Ditch treatment reach and approximately 350m upstream of the confluence with Marblehill Creek. Therefore, based upon channel distance, redistribution pressure was not equal between the two reaches. However, review of individual trap results in the Big Ditch treatment reach demonstrate that coho were equally as abundant 530m from the release location as they were 30m from the trap location, as early as 1 week after the works were complete. In fact the mean CPUE for the five traps closest to the confluence with Marblehill Creek on

August 27, 2003, one week subsequent to maintenance work, was 3.2 fpt and the five traps farthest away from the fish release had a mean of 4.40 fpt on the same day.

(ii) Fish redistributing from the release location need only swim downstream to gain access to the Big Ditch treatment reach. In order to gain access to Marblehill Creek from the salvage release location, fish would have to move downstream through a portion of the Big Ditch treatment reach and then head upstream into Marblehill Creek at the confluence. Under higher-flow conditions this may be a discriminatory factor between the reaches; however this field trial was conducted during low summer flows when fish movement was clearly not restricted, in any way, by stream velocity. Secondly, thalweg velocities (Figure 14) demonstrate that the lower portion of Marblehill Creek treatment reach experienced virtually no velocity at all.

(iii) Big Ditch is a larger watershed than Marblehill Creek and, as such, experiences higher flows throughout the year. This difference, especially as flows decrease later in the summer, may affect the relative abundance of coho. However, the pre-dredging CPUE of coho in the Marblehill Creek treatment reach (4.12 fpt) was virtually identical to that of the Big Ditch treatment reach (4.14 fpt). Secondly, the 2004 Marblehill Creek data suggests no measured declines in relative abundance over the August to October sampling period.

(iv) All of the reaches examined in this trial had been previously channelized and maintained. As mentioned earlier, the biological integrity of channelized streams improves over time. However, it is unclear how far along in this recovery process each of the reaches were at the time of this field trial. Both the spatial and temporal controls may represent residual impacts of previous works. As such, any impacts identified compared to these controls are conservative.

A discussion of how impacts to interannual variability of cutthroat density may have impacted on interannual variability of coho is offered in *Section 4.1.8*.

4.1.5 Big Ditch Control Cutthroat

Comparisons of the pre-dredging to 1-year post-dredging control data are useful to provide some indications of interannual variability in the relative abundance of cutthroat (Figures 11 & 12 and Table 2). The relative abundance of cutthroat in the summer of 2004 is not anticipated to have been impacted by the release of salvaged fish in the summer of 2003, as cutthroat also redistribute over the winter.

As with the coho data the “immediate” post-dredging control data should be meaningless due to the fish salvage and release into the control reach. However, it is interesting to note that the cutthroat numbers do not appear to have been considerably impacted by the fish release into this reach. In fact, there were slight declines in both all cutthroat (6%) and larger cutthroat (9%).

The mean CPUE of cutthroat declined (43%) between the two pre-maintenance trap-sets in 2003 and the five 1-year post-maintenance trap-sets in 2004 in the control (Figure 11). The larger size-class of cutthroat showed, proportionally, a similar decline (53%) over the same period (Figure 12).

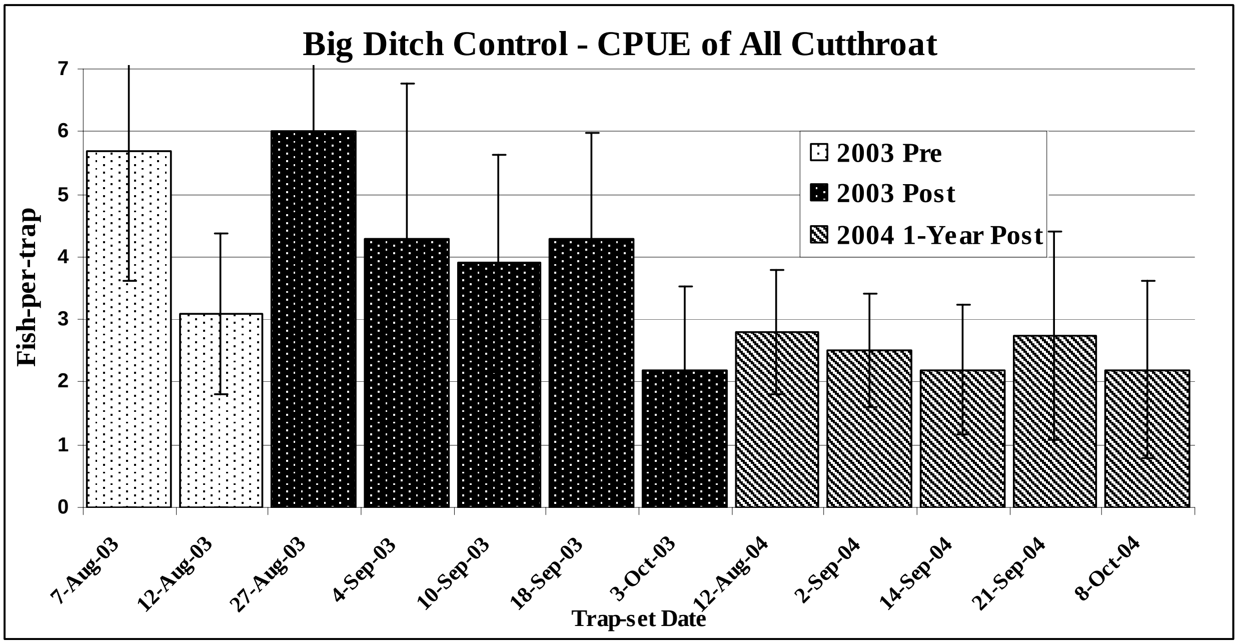

Figure 11. CPUE of all size-classes of cutthroat trout in the Big Ditch control reach (bars = 95% confidence interval).

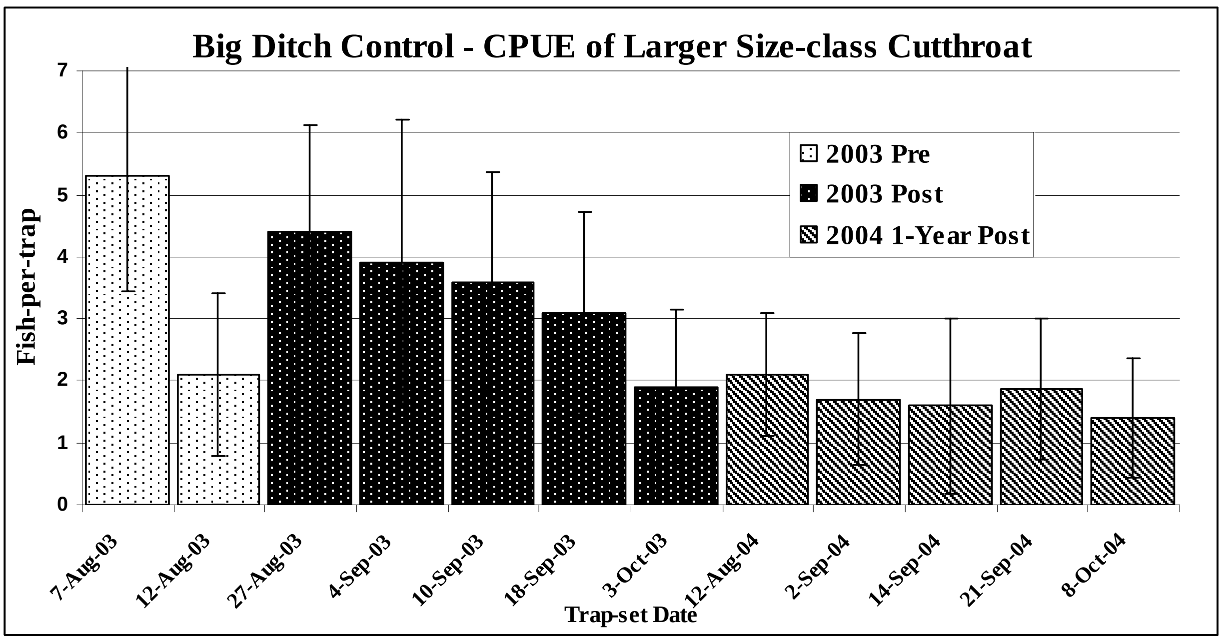

Figure 12. CPUE of larger size-class cutthroat trout in the Big Ditch control reach (bars = 95% confidence interval)

4.1.6 Marblehill Creek Treatment Cutthroat

The catch in Marblehill Creek post-dredging revealed a remarkable 98% decline in both the larger cutthroat and all cutthroat in 2003, through the 7-week period assessed (Figures 13 & 14). As with the 2003 coho catch, this decline was consistent through all five of the 2003 post-maintenance trap sets.

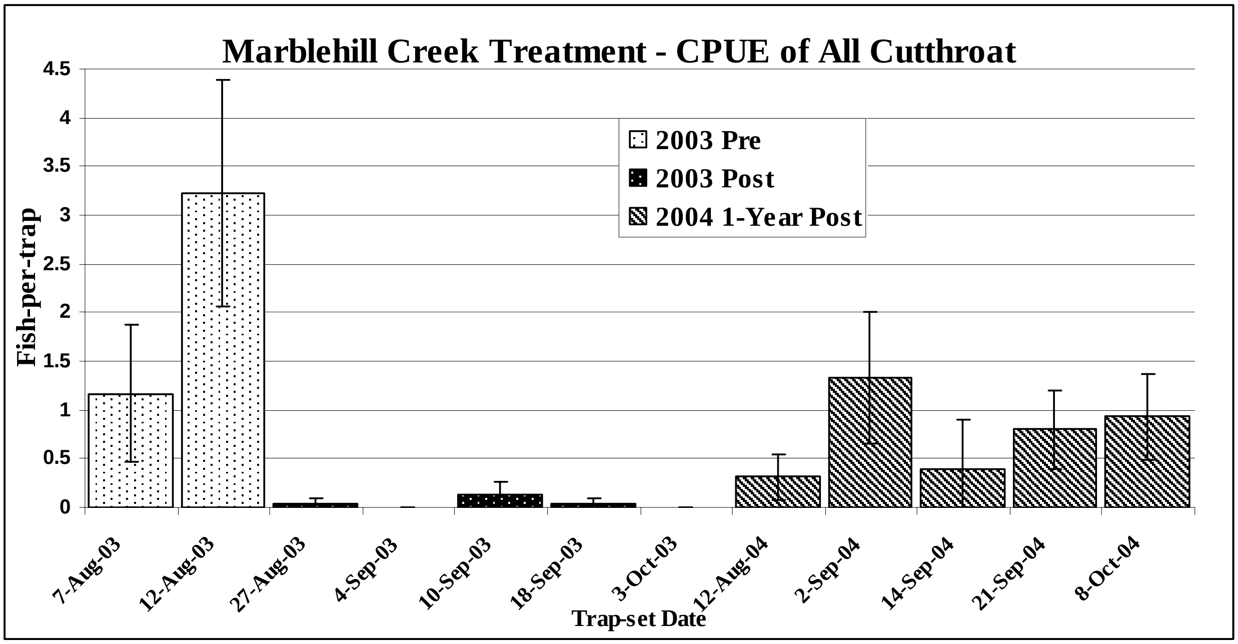

Figure 13. CPUE of all size-classes of cutthroat in the Marblehill Creek treatment reach by trap set (bars = 95% confidence interval).

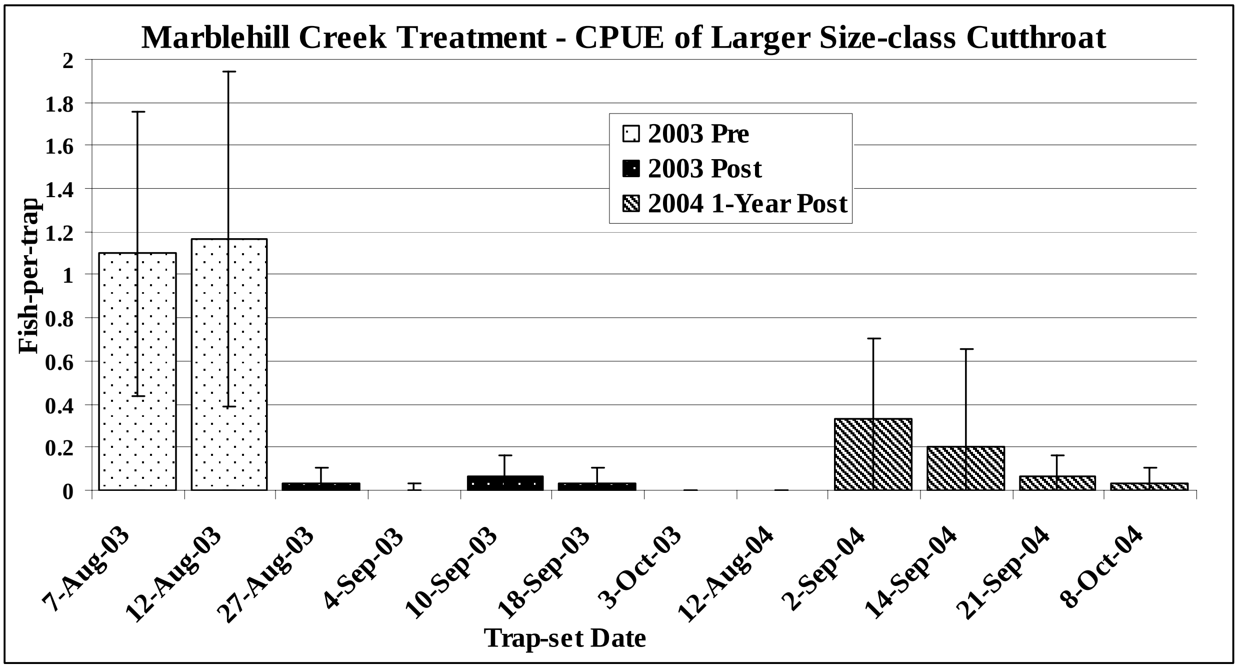

Figure 14. CPUE of large cutthroat in Marblehill Creek by trap set (bars = 95% confidence interval).

One-year later, all cutthroat combined appeared to have, at least partially, recovered. Though a 63% decline was detected over the pre-dredging catch, this is roughly consistent with the 43% decline detected in the control reach over the same time period. However, the mean catch of larger cutthroat had not sizeably improved remaining at 90% less than the pre-dredging mean.

4.1.7 Big Ditch Treatment Cutthroat

The mean catch in the Big Ditch treatment reach (Figures 15 & 16) showed a dramatic decline over the 6-to-7 week period immediately following the maintenance activities of both all cutthroat (77%) and larger cutthroat (85%). These declines are slightly less than those suffered in Marblehill Creek (98% for both). Particularly, the numbers for all size-classes of cutthroat appear to have been allayed when compared with the Marblehill Creek data (Table 2).

One-year later, declines to the relative abundance of all size classes of cutthroat (53%) and larger cutthroat (53%) are in step with declines detected in the control (43% & 53% respectively). It would appear that the relative abundance of cutthroat recovered within one year in this reach.

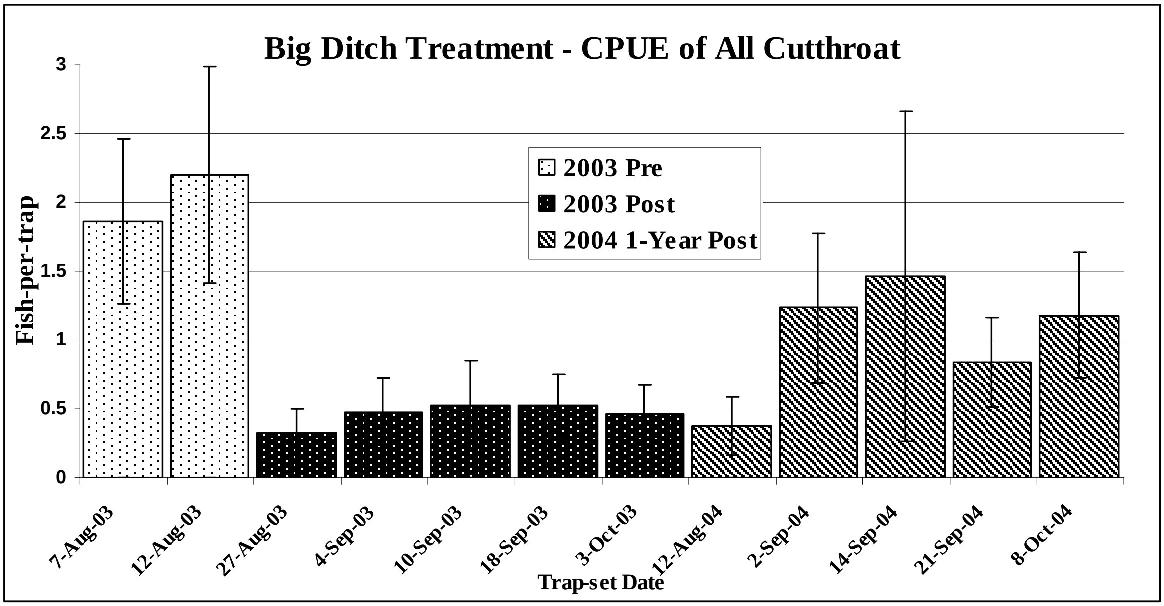

Figure 15. CPUE of all cutthroat in the Big Ditch treatment reach (bars = 95% confidence interval).

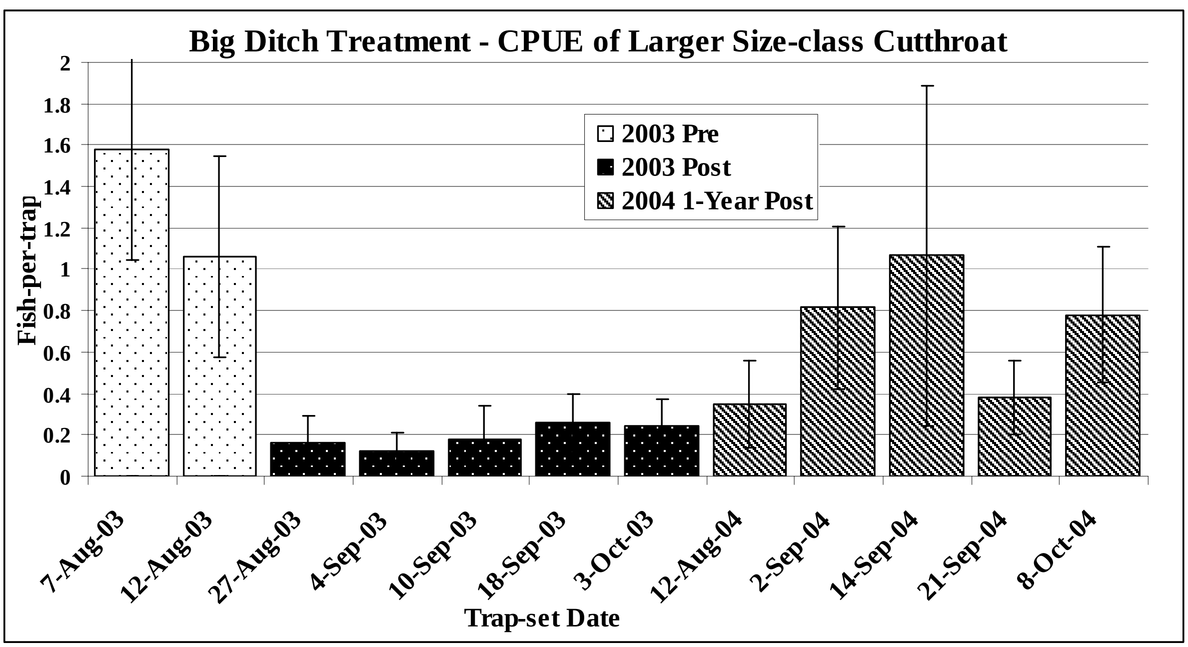

Figure 16. CPUE of large cutthroat in Big Ditch treatment by trap set (bars = 95% confidence interval).

4.1.8 Discussion of Cutthroat Catch Data

Initial comparison of these results suggests that mitigative efforts in the Big Ditch treatment reach were partially successful in the recovery of relative abundance of both all cutthroat and larger cutthroat within the season of the works. Possibly, more important is the apparent full recovery of larger cutthroat trout one-year later where these measures were employed (Figure 17).

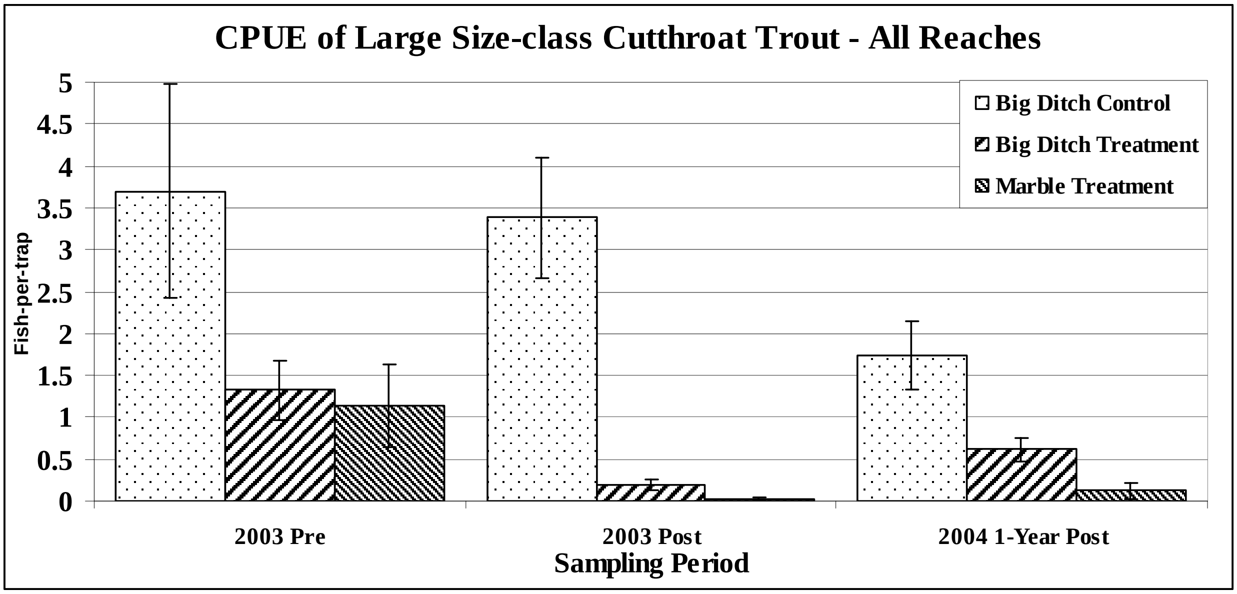

Figure 17. CPUE of larger size-class salmonids in Big Ditch and Marblehill Creek

In addition to the concerns discussed for the coho data, another key factor that was not completely controlled for in this field trial and particularly affects the interpretation of the cutthroat trout data, is the interannual variability. In an attempt to use a control site that would experience all of the same non-maintenance variables as the treatment reaches, a reach directly upstream of one of the treatment sites was chosen. However, the maintenance activities potentially impacted the overall abundance of this stream's cutthroat trout, particularly the fish at age 0+ in 2003 that may represent the age 1+ fish in 2004. Therefore, the interannual variability detected in the control may have been impacted by the maintenance works. If so, the overall impacts to the relative abundance of cutthroat trout, particularly one-year later, were not fully detected.

This factor may have also impacted on coho density in the control reach. As previously noted, both larger and size-matched cutthroat outcompete coho in aggression and foraging success. As such, any channel maintenance related impacts to the age 1+ cutthroat density in 2004 may have in fact had an inverse impact on coho density in the control. The increased coho density in 2004 (40%) in the control may, in part, be an effect of the channel maintenance.

4.2 Angular Canopy Density

The riparian Angular Canopy Density (ACD) was significantly reduced in both of the treatment reaches immediately following channel maintenance (Fig. 10). The ACD partially improved in 2004, one-year later. While most of the initial reduction in ACD is likely associated with the channel maintenance, it should be noted that ongoing farm activities such as partial brushing of the riparian vegetation were obviously limiting the recovery of riparian vegetation. As a result, significant instream growth was observed, particularly in Marblehill Creek. The ACD of instream growth was measured to be 65% (sd= 39%) in 2004. While the ACD of instream plants was not explicitly measured in 2003, field observations and review of photographs of the Marblehill Creek treatment reach prior to channel maintenance suggest that instream growth was in the range of 5% to 15%.

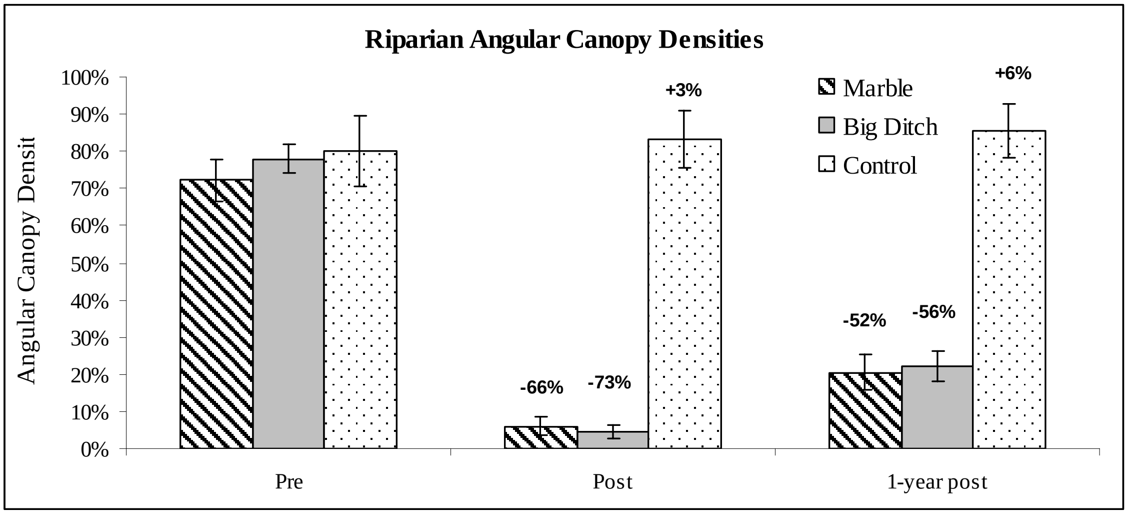

Figure 18. Riparian angular canopy densities in all three reaches (bars = 95% confidence intervals).

4.3 Thalweg Velocity

The Marblehill Creek thalweg velocities are displayed in Figures 19 and 20. It is clear that channel dredging dramatically simplified the flow velocities over the length of Marblehill Creek immediately following the dredging activity. One year later, the complexity of flows partially recovered. This recovery is likely a function of the settlement of upstream sources of sediment and freeform bed and bank scour. These results also suggest that the placement of rock-weir structures (Figure 21) was successful in providing the intended flow variability in Big Ditch.

As can be seen there are two distinct reaches in Marblehill Creek as defined by thalweg velocities. The distinction between reaches is more apparent for the post-maintenance data sets. It appeared that the channel dredging reduced the invert of the streambed for this downstream reach to below the level of a newly-installed weir structure in Big Ditch downstream. Therefore this downstream reach was in fact back-watered from Big Ditch during low-flow conditions.

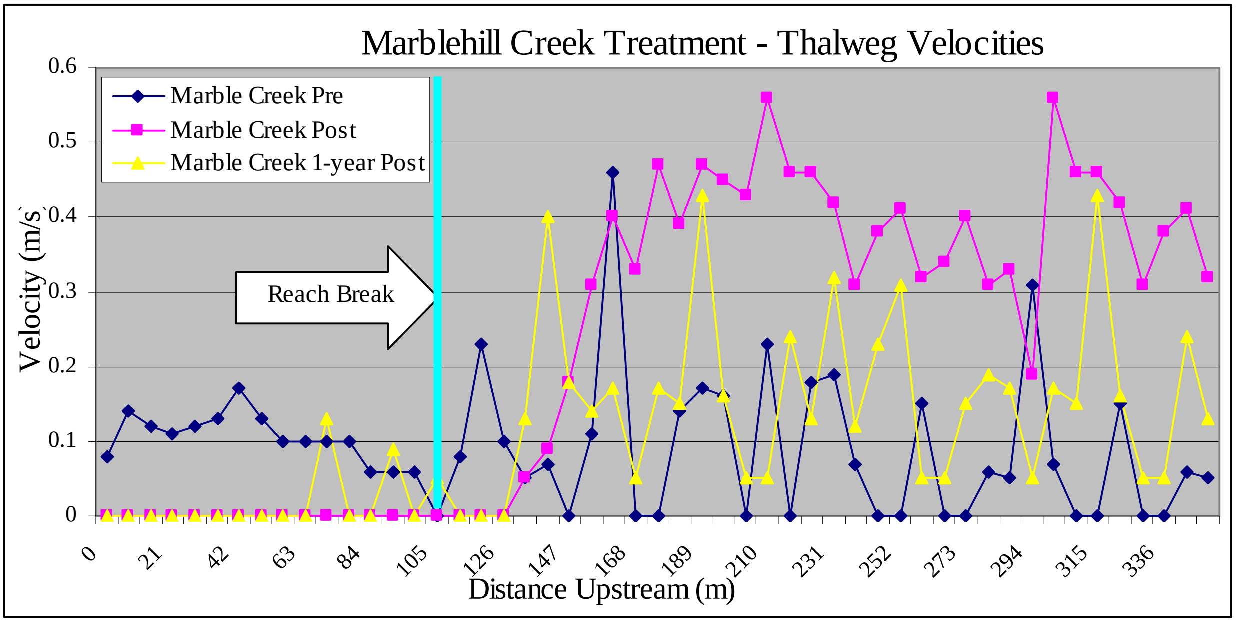

Figure 19. Marblehill Creek thalweg velocities.

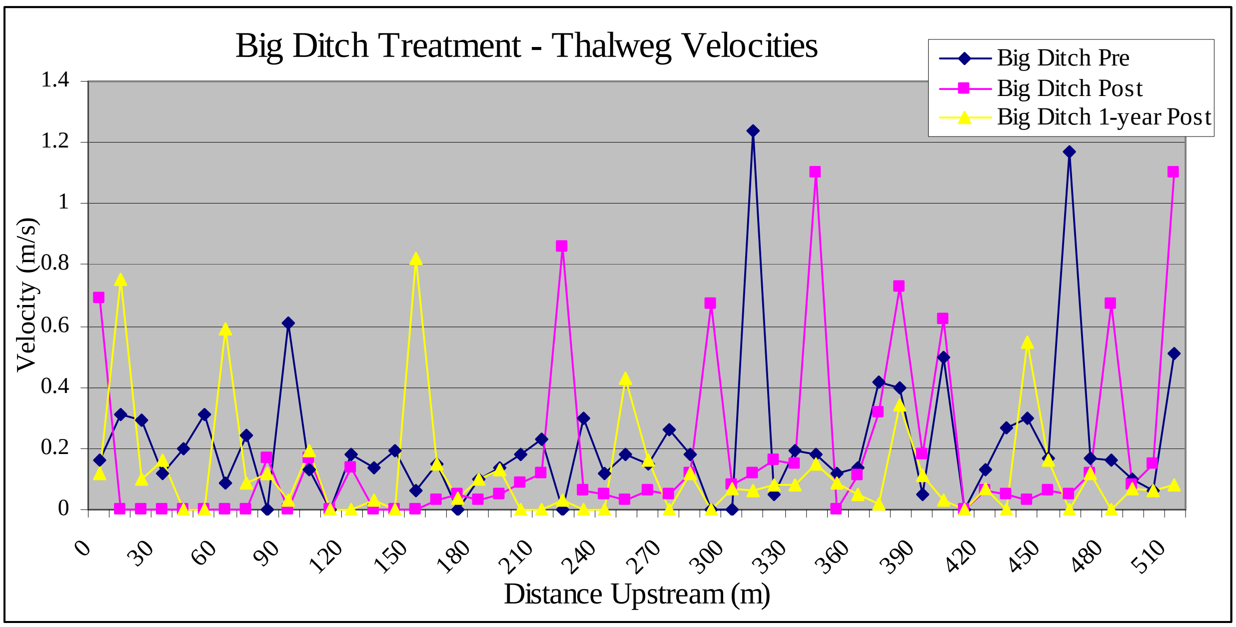

Figure 20. Big Ditch thalweg velocities.

The thalweg velocities in the upstream reach increased from a mean of 0.09m/s pre-dredging to 0.36m/s post-dredging. The variability, expressed as the standard deviation as a percentage of the mean, decreased from 118% to 36% over the same period for this reach. One year later, the mean thalweg velocity in the upstream reach had declined to 0.17m/s and the standard deviation increased to 65% of the mean.

In the downstream reach the mean thalweg velocity decreased from 0.10 m/s to 0.0 m/s. The standard deviation pre-dredging was 39% of the mean whereas there was no variation of the thalweg velocity

immediately post-dredging. One-year later the mean thalweg velocity slightly increased to 0.02 m/s and the standard deviation increased to 238% of the mean.
The mean thalweg velocity in Big Ditch decreased slightly from pre-dredging (0.22 m/s) to post-dredging (0.18 m/s) whereas the standard deviation increased from 111% of the mean to 159% of the mean over the same period. One-year later, the mean thalweg velocity (0.12 m/s) and the standard deviation (152% of the mean thalweg velocity) decreased only slightly.

These data were measured to roughly demonstrate relative changes to flow variability in relation to the installation of the rock-weirs. As such, they are intended to communicate the broader objective of mimicking or improving existing flow variability. They are not intended to be transformed into a numerical management objective. Unfortunately, they do not fully account for discharge-dependant changes in variability.

Figure 21. Example of Rock-weir structure installed in Big Ditch.

4.4 Roughness Coefficient

Stream discharge diminished considerably at both treatment sites between the pre-cleaning and post-cleaning measurements. Big Ditch declined from 19.84 l/s to 10.69 l/s and Marblehill Creek decreased from 8.88 l/s to 2.59 l/s. This, in combination with the fact that roughness in such, small shallow streams during low-flows will be largely dependant upon the discharge stage, is cause to disregard the within-stream comparisons of roughness.

That said, the very similar gradients of the two streams (0.20% and 0.22%) should allow for some between-stream comparisons. The roughness coefficient in Big Ditch increased from a Manning's n-value of 0.21 to 1.54, pre to post-dredging; the n-value in Marblehill Creek increased from 0.051 to 0.114. The estimates of roughness coefficient for the post-cleaning period should be disregarded, as the current speed estimates to derive Mannings n were imprecise. Most of the measurements were not detectable using the current meter, so assumed values of 0.01 m/s were adopted. It is possible that each "true" value could be in error by +/- 100% (i.e. +/- 0.01m/s).

This data does allow for the calculation of the Froude number, a measure of the relative 'smoothness' of the flow. Prior to cleaning, Marblehill Creek had a Froude number (0.165) that was about four times greater than that of Big Ditch (0.048). Subsequent to dredging, Marblehill Creek had a Froude number (0.068) about ten times greater than Big Ditch (0.005) due to a considerable (order of magnitude) reduction in Froude number at Big Ditch. This suggests that flow is considerably more turbulent in Big Ditch post-dredging compared to Marblehill Creek.

4.5 Other Observations

Several field observations of fish activity and habitat characteristics were carefully noted over the sampling period. These observations are partially sketched out in Figures 22 and 23. As anticipated, prior to dredging, coho were observed feeding near the surface of the water at the head or tail-out of pools when riparian or instream cover was abundant. Smaller cutthroat, though less visible, were associated with the slightly faster runs (or riffles) and close to the bottom of the stream. The larger cutthroat were restricted to the bottom of deeper pools. Subsequent to dredging, as habitat characteristics changed dramatically, coho moved deeper in the water column with little or no segregation from, the now more visible, smaller cutthroat. Loss of pool habitat meant that larger cutthroat were not observed at all. There was also a notable increase in the presence of threespine stickleback.

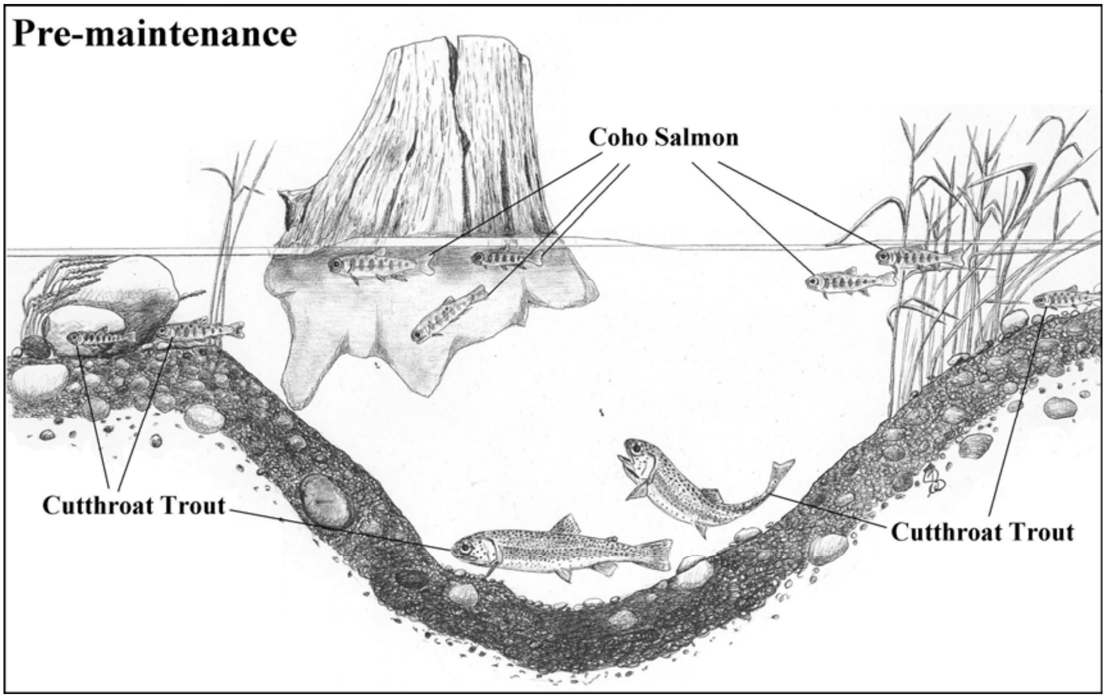

Figure 22. Simplified depiction of habitat characteristics and micro-habitat selection in a pre-dredged channel. (Based upon field observations.)

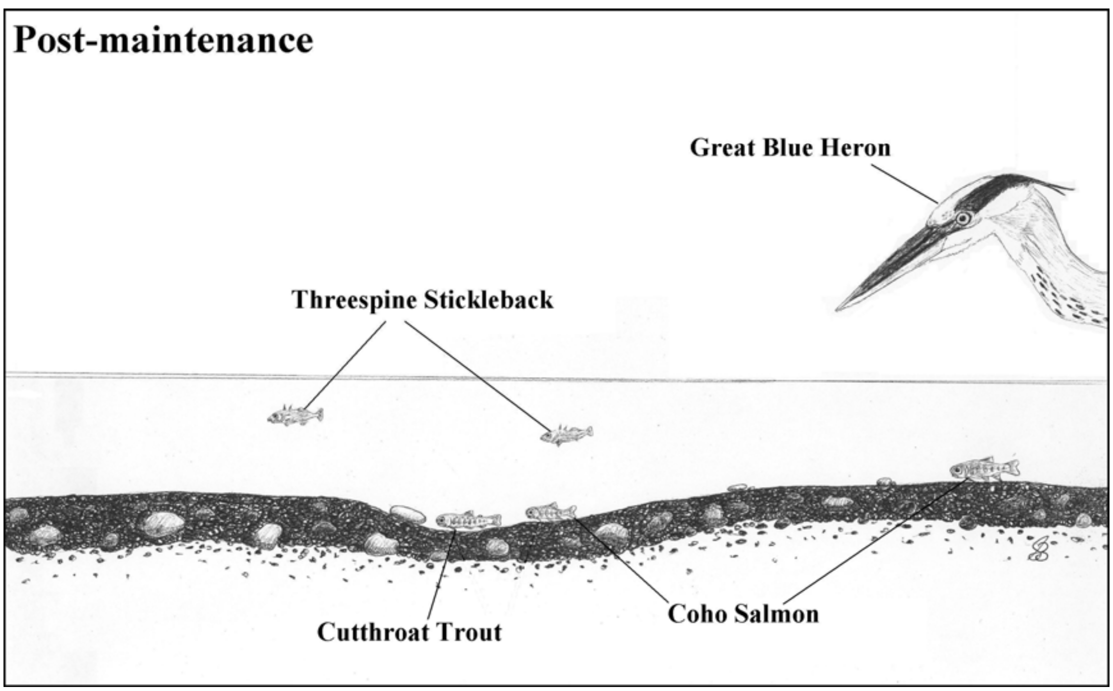

Figure 23. Simplified depiction of habitat characteristics and micro-habitat selection in a channel recently dredged. (Based upon field observations)

An increase in the presence of great blue herons (*Ardea herodius*) feeding was observed in both of the treatment reaches post-dredging. It was suspected that their increased presence was a function of increased visibility in the channel thus creating better opportunities to successfully forage on stream biota. A heron was observed feeding on fish directly upstream of a dredging machine in Big Ditch (Figure 16).

This was of particular note as the heron was feeding in an area that had been brushed to allow for increased visibility to conduct the fish salvage and where the salvage was already complete.

Figure 24. Great blue heron hunting for fish directly upstream of dredging operation. Note the fish salvage stop-net in the foreground.

Though they were not observed at all prior to channel dredging, several giant water bugs (Hemiptera: Belostomatidae) were captured in traps or observed swimming post-dredging. One captured in a trap in Big Ditch successfully killed and partially consumed a coho in the same trap (Figure 17).

Figure 25. Giant water bug consuming a coho in a Big Ditch treatment trap post-dredging.

A sizeable fish kill in Marblehill Creek during channel maintenance activities was also observed. The event occurred mid-day of August 15, 2003. At least 50 individual fish (coho and cutthroat) were observed floating or at the bottom of the channel at the lower end of the Marblehill Creek treatment reach (Figure 18). No fish salvage or dredging had yet occurred in the reach, however the machine mounted brush saw was clearing vegetation along the banks. No lethal temperature cline was detected, however dissolved oxygen concentrations appeared to decline along the reach. It was suspected that organic plant matter dropped into the water column from the brush saw in combination with increased exposure to solar energy on the water surface rapidly increased the biological oxygen demand. The City's biological consultants attempted to alleviate this issue by raking all plant material out of the water column immediately following brushing.

Figure 26. Fish-kill observed on August 15, 2003 in Marblehill Creek.

5.0 Conclusions

5.1 Fish-use

Channel dredging reduced the within-season relative abundance of both coho salmon (up to 94%) and cutthroat trout (up to 98%).

Observed reductions of the relative abundance of coho one-year later (up to 53%) suggest a lingering effect, especially compared to the increase observed in the control reach (40%) over the same time period. No enduring impact was observed for smaller cutthroat trout one-year later, as the observed declines in the treatment reaches (53% & 63%) were relatively consistent with those observed in the control (43%). However, the relative abundance of the larger size-class cutthroat trout were impacted (up to 90%) even one-year later.

Therefore, channel dredging in Marblehill Creek without the use of any mitigation was confirmed to:

- cause dramatic short-term reductions in relative abundance of cutthroat and coho, and
- cause significant long-term impacts to use by coho and larger size-class cutthroat.

The placement of rock-weirs and other mitigative measures in Big Ditch was confirmed to:

- substantially accelerate within-season recovery of coho relative abundance,
- partially increase the within-season recovery of cutthroat relative abundance, and
- allow full recovery of larger-size class cutthroat relative abundance one-year post-dredging.

Channel dredging appeared to have impacted use by all salmonids, particularly larger size-classes. Smaller size-classes of salmonids appeared to benefit from habitat mitigation immediately following dredging whereas larger size-classes benefit from these efforts one-year later.

5.2 Habitat

Both of the treatments suffered significant declines in overhead cover as measured as ACD. The reduction in shade may be counter-productive to the hydrologic objectives of those undertaking dredging activities; particularly when instream plant growth is a major drainage concern. There were no clear correlations between the rate-of-recovery of ACD and that of fish-use in each of the reaches.

Stream-flow was dramatically altered where no instream mitigative techniques were employed. The variability of the thalweg velocity dramatically declined where rock-weirs were not installed (Marblehill Creek) from a standard deviation that was 118% of the mean velocity to 36%. One year later the flow variability in Marblehill Creek was considerably improved.

Stream-flow complexity was successfully maintained and even slightly enhanced where mitigative techniques were employed. Rock-weir placements were effective at retaining and improving the standard deviation of thalweg velocity (111% of the mean to 159% immediately following maintenance; and 153% one-year later). In this field trial the variability of thalweg velocity correlates well with the response by fish to channel maintenance and the mitigative techniques.

Though somewhat clumsy, data collected to calculate the roughness coefficient data also confirmed a higher degree of flow variability within the reach where rock-weirs and other mitigative techniques were used.

5.3 Other

Visual field observations of juvenile salmonid microhabitat selection and species segregation confirmed niche preferences described in the literature. These observations along with other biological variables, such as predation rates and increased abundance of habitat generalists such as threespine stickleback may prove to be useful in assessing impacts from dredging activities in the future.

The observed fish kill in Marblehill Creek further substantiates the requirement for biological monitors to be on-site during channel maintenance in productive habitat.

The results presented represent only one field trial and the lack of replication of treatment sites does present a scientific challenge. However it does not preclude the acquisition of valuable information (Gray et al. 2002).

6.0 Recommendations

1. The dredging of channelized streams, particularly the extensive "hard-clean", should be avoided whenever possible.

2. When channel maintenance cannot be avoided careful consideration should be given to incorporating the following mitigative techniques:
   - Rock-weirs to replicate natural pool:riffle ratios of 1:1;
   - Maintenance by hand that targets flow conveyance limitations while limiting impacts to habitat features,
   - Emulate natural channel forms,
   - Retention of undisturbed areas within maintained reaches to provide important refugia habitat (Luey and Adelman 1980), and
   - Replanting of riparian areas.

   In cases where habitat productivity is very high, consideration should be given to partially enlarging the channel length and floodway cross-section while maintaining the pre-dredge low-flow cross-sectional profile. This is in order to incorporate important habitat features without limiting high-flow capacity of the stream.

3. The Ministry and DFO should support the use of Habitat Conservation Trust Fund (HCTF) or other source funds to encourage property owners to incorporate the above-noted techniques. Restricted use conservation covenants should be also negotiated to protect these areas for the future.

4. The Ministry should develop a better understanding of the amount of habitat affected by channel maintenance and other instream work activities within Lower Mainland region. This should include a geo-reference database that summarizes biological and proponent information from notifications and approvals under Section 9 of the BC *Water Act*.

5. Consideration should be given to further examine the relationship between riparian shade and instream plant growth in channelized streams. These results may be useful in further revealing the benefits of riparian vegetation.

6. Consideration should be given to repeating similar field trials in other streams in the lower Fraser Valley. Several authors recommend continued data collection on physical and biological effect of habitat alterations to further evaluate best practices/opportunities (Cederholm and Koski 1977). Any longer-term monitoring efforts must be more careful to establish locally-independent control sites. These sites must be established to control for interannual variability as well as lingering affects of past channelization and maintenance activities.

7. A poster and presentation package summarizing the results of this field trial and the literature review should be developed in conjunction with the Ministry of Agriculture and Lands and key local governments for distribution within the agricultural community and municipal drainage

departments in the lower Fraser Valley. The package should summarize both potential impacts of channel maintenance and the benefits of mitigative best practices.

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