The Contribution of Constructed Side-Channels to Coho Salmon Smolt Production in the Oyster River

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THE CONTRIBUTION OF CONSTRUCTED SIDE-CHANNELS TO COHO SALMON SMOLT PRODUCTION IN THE OYSTER RIVER

by

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ABSTRACT

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During 1985-1999, three side-channels were constructed in the lower Oyster River to provide rearing habitat for juvenile coho salmon (*Oncorhynchus kisutch*). In 2000, the numbers of coho smolts outmigrating from the side-channels and from the mainstem/tributary area were monitored to assess the contribution of the side-channels to overall smolt production in the Oyster River system. Spring outmigrants from the side-channels contributed significantly to overall smolt production in the system. Based on stream length, the mean density of outmigrating coho smolts was 2.3 times greater for the side-channels compared to the Oyster River mainstem (4,857 versus 2,117 smolts·km^{-1}). While the side-channels accounted for 6% of the total habitat in the system by stream length, smolt outmigrants from these sites represented 13% (± 1.3%) of the estimated total smolt production for the Oyster River (24,284 of 191,116 smolts ± 17,460). The use of mark-recapture methodology and rotary screw traps provided a relatively precise (± 10%) estimate of smolt numbers for the mainstem/tributary area (166,832 ± 17,460). However, the accuracy of this estimate was less certain as it was unclear whether the mark-recapture assumption of equal catchability for marked and unmarked smolts was met.

RÉSUMÉ

Decker, A.S., and M. J. Lightly. 2004. The contribution of constructed side-channels to coho salmon smolt production in the Oyster River. Can. Tech. Rep. Fish. Aquat. Sci. 2515:32 p.

Entre 1985 et 1999, trois chenaux latéraux ont été aménagés dans la basse Oyster pour créer un habitat de grossissement à l'intention des cohos (*Oncorhynchus kisutch*) juvéniles. En 2000, on a surveillé le nombre de smolts de coho qui quittaient les chenaux latéraux et la portion du cours principal et des affluents pour évaluer la contribution des chenaux aménagés à la production globale de smolts du réseau de la rivière Oyster. Les smolts qui quittaient les chenaux au printemps contribuaient de façon significative à la production globale de smolts du réseau. Par rapport à la longueur de cours d'eau, la densité moyenne des smolts émigrants était 2,3 fois plus grande pour les chenaux aménagés que pour le cours principal de l'Oyster (4 857 contre 2 117 smolts·km^{-1}). Tandis que les chenaux représentaient 6 % du total de l'habitat dans le réseau par rapport à la longueur de cours d'eau, les smolts qui en étaient issus constituaient 13 % (± 1,3 %) de la production totale estimée de la rivière Oyster (24 284 sur 191 116 smolts ± 17 460). L'utilisation de la méthode de marquage-recapture et des pièges rotatifs a fourni une estimation relativement précise (± 10 %) du nombre de smolts pour la portion du cours principal et des affluents (166 832 ± 17 460). Toutefois, un doute existe quant à l'exactitude de cette estimation étant donné qu'on ne sait pas si l'hypothèse d'une capturabilité égale des smolts marqués et non marqués s'est vérifiée.

1.0. INTRODUCTION

In southwestern British Columbia, juvenile coho salmon (*Oncorhynchus kisutch*) generally spend one, but sometimes two years in fresh water before migrating to sea as smolts (Bradford et al. 1997). In many streams, freshwater production appears to be limited by survival during the winter (Hartman et al. 1996; Nickelson et al. 1992a), and there is considerable evidence to suggest that overwinter survival is influenced by habitat quality (Nickelson et al. 1992b; Quinn and Peterson 1996; Sharma and Hillborn 2001; Solazzi et al. 2000). Hartman et al. (1996) reported that biological and physical interactions affected coho survival rates at all life stages, but the availability and quality of winter habitat were the crucial factors affecting overall smolt carrying capacity.

Over the last two decades, the importance of off-channel habitat (e.g., riverine ponds, ephemeral tributaries, wetlands, groundwater-fed tributaries) in providing refuge from adverse winter conditions in streams has been recognized (see Cunjak 1996 for a review). Sharma and Hillborn (2001) recently showed that variation in coho smolt production among 14 streams in western Washington could be explained in part by the amount of off-channel habitat (ponds) available in each stream. Consequently, construction of off-channel habitat has been a major component of watershed restoration programs in B.C. and the U.S. Pacific Northwest (Peterson 1985; Sheng et al. 1990; Lister and Finnigan 1997). Also, in many streams, the use of both mainstem and off-channel habitat by overwintering coho may act to stabilize freshwater production because poor survival in one type of habitat is often balanced by relatively high survival in the other (Brown and Hartman 1988; Lestelle et al. 1993).

Construction of off-channel habitat, including side-channels and ponds, may be a more effective restoration technique compared to placement of structures in the mainstem area of a stream. This is because off-channel habitat is less prone to failure in destabilized, high energy coastal watersheds (Reeves et al. 1991; Frissell and Nawa 1992). Moreover, coho may prefer off-channel habitat to mainstem habitat, providing it is structurally complex (Brown 1985).

Examined in isolation, constructed side-channels and ponds have been shown to support relatively high densities of overwintering juvenile coho (Peterson 1985; King and Young 1986; Swales and Levings 1987). However, few studies have considered the overall effect of off-channel habitat restoration on smolt production in a watershed (Lestelle et al. 1993; Decker and Lewis 2000; Decker et al., in press). In most cases, it is uncertain whether enhancement has increased carrying capacity of the system, or merely shifted fish production away from the existing natural habitat (Riley and Fausch 1995; Keeley and Walters 1996).

Since the early 1980s, there has been a growing concern about declining returns of coho salmon and other anadromous species in many east coast Vancouver Island streams including the Oyster River. In the mid-1980s, Fisheries and Oceans Canada (DFO) together with the Oyster River Enhancement Society (ORES), a local conservation group, began working to rehabilitate wild Oyster River coho and other salmon populations through habitat restoration. A major initiative was the construction between 1985 and 1998 of three side-channels in the lower reaches of the Oyster River. These side-channels were designed to provide off-channel spawning and rearing habitat for coho salmon.

During the spring seaward migration of 2000, we monitored the numbers of coho smolt outmigrants from these three areas and from the mainstem/tributary area of the Oyster River. Our primary objective was to assess the contribution of the side-channels to overall coho smolt production in the system. Our secondary objective was to examine the utility and problems associated with the use of mark-recapture methodology to estimate numbers of migrating smolts in a stream too large to permit the use of full-span downstream weirs.

2.0. METHODS

2.1. Study area

The Oyster River is situated 24 km north of the city of Courtenay on the east coast of Vancouver Island (Figure 1). It flows in an easterly direction from Mount Washington and discharges into the Strait of Georgia. The stream is approximately 55 km in length and drains a watershed of about 409 km^2. Mean annual discharge during 1974-2000 was 13.3 cms with observed maximum and minimum discharges of 348 cms and 0.5 cms, respectively (Water Survey of Canada, Station 08HD011). Mean annual precipitation is about 1000 mm of which 15% occurs during summer months.

Thirteen percent of the Oyster River watershed lies within Strathcona Provincial Park. The remainder is mostly privately-owned and managed for timber production or agriculture. In 1988, over 400 people were living within the Oyster River watershed, mostly in the lower 3 km (Frank 1991).

During 1900-1960 an estimated 90% of the watershed below 500 m in elevation was clear-cut (Frank 1991). More recent timber harvesting was conducted primarily in the upper portions of the watershed. The riparian zone of the lower Oyster River is presently dominated by second-growth coniferous forest. In logged portions of the watershed reduced forest cover and extensive road-building have led to slope instability, altered run-off patterns and sediment loading in the stream channels (Frank 1991). Removal of trees from the stream bank has resulted in loss of large woody debris and increased bank erosion. Habitat quality in the Oyster River is expected to improve over the next several decades as the riparian forest grows back and watershed processes are restored.

The Oyster River watershed includes several fish-bearing tributaries (Little Oyster River, and Woodhus and Bear creeks) and provides a total of 48.7 km of habitat accessible to anadromous fish (Table 1). An impassable falls on the Oyster mainstem 24 km upstream of the mouth creates a natural migration barrier to all anadromous fish.

The Oyster River sustains chum (*Oncorhynchus keta*), pink (*O. gorbusha*), and coho salmon, as well as smaller numbers of chinook (*O. tshawytscha*), sea-run cutthroat trout (*O. clarki*) and steelhead (*O. mykiss*) (Brown et al. 1977). Resident rainbow (*O. mykiss*) and cutthroat trout (*O. clarki*) as well as Dolly Varden char (*Salvelinus malma*) are also present.

Salmon escapements have been visually estimated since 1953 (Serbic 1991). These estimates are qualitative because average spawner residence time and observer efficiency were not considered, and observers and methods varied over the years. During the 1950s, the Oyster River supported adult salmon returns of up to 100,000 pinks, 15,000 chum and 15,000 coho. Pink, chum, coho and chinook numbers all declined steadily during the next three decades. By the 1980s, these stocks were reduced to less than 10% of their historical abundance. As with other Georgia Basin coho stocks, this decline is likely attributable to loss of freshwater habitat, over-fishing and poor ocean survival (Walters 1992).

The Oyster River Enhancement Society, in co-operation with DFO, began operating a small hatchery facility on the Oyster River in 1986. The ORES hatchery produces pink, chinook, coho and chum salmon. Since inception of the hatchery program, annual returns of pink salmon have increased from about 100 in the mid-1980s to a recent estimated high of 80,000 (Serbic 1991). For coho, the 10-year average escapement for the 1990s was nearly triple that for the 1980s (see below). The contribution of hatchery production to annual returns was not assessed. Estimated coho escapement for the 1998 brood year associated with smolt production during the 2000 study year, was 9,000 adults.

Coho escapement to the Oyster River*

	Period				
	1950-59	1960-69	1970-79	1980-89	1990-99
Escapement	12,900	8,750	4,040	1,400	3,600

* Serbic 1991

Wild coho spawn throughout the 24 km length of the Oyster River mainstem below the falls, as well as in the lower reaches of the accessible tributaries. Natural coho production has been supplemented by the release of hatchery smolts and fry since 1986. During 1996-2000, hatchery releases of coho fry and smolts averaged 116,000 and 48,000, respectively (see below).

Hatchery coho releases in the Oyster River (1996 - 2000)

	Year					
	1996	1997	1998	1999	2000	Average (1996-2000)
Fry	75,600	178,000	88,000	140,000	100,000	116,300
Smolts	21,767	44,489	61,780	55,261	57,840	48,227

* ORES, data on file

Coho smolts were typically released during late-April, and fry during mid-July. During some years, hatchery fry are outplanted upstream of the barriers in the Oyster River mainstem and Woodhus Creek. When these upstream reaches are included, natural anadromous habitat in the watershed totals 78.8 km (Table 1).

2.1.1 Side-channel construction

In the mid-1980s, three side-channels were constructed in the floodplain of the lower Oyster River to increase the amount of available off-channel habitat. These side-channels are typical of the dozens of groundwater and surface water fed side-channels that have been built in southwestern B.C. to provide spawning and rearing habitat for chum and coho salmon (Bonnell 1991; Lister and Finnigan 1997). In total, the side-channels (Raven, Rippingale, Beaver) provide about 5 km or 35,000 m^2 of wetted habitat (Table 1). Each side-channel is fed by groundwater, which originates from subsurface flow along the gravel fan of the Oyster River, as well as water diverted directly from the Oyster River through one or more low-flow intake structures. Discharge in each channel is less than 1 cms and relatively stable year-round. The side-channels were excavated by machine and are relatively straight with little variance in width, depth, or substrate composition (for a comprehensive description of the design and construction of these type of side-channels, see Bonnell 1991 or Lister and Finnigan 1997). However, two of the side-channels (Beaver and Rippingale) also include some pond habitat (see below). Substrate in the side-channels consists mostly of native or introduced gravels (size range 2-10 cm).

Work at the first site, Beaver Channel, began in the fall of 1985. This 1.0 km long side-channel was constructed approximately 5 km upstream of the Oyster River mouth (Beaver Channel 1; Figure 2). The following year, the ORES hatchery was built adjacent to this site, and the upper 200 m of the side-channel was sequestered for hatchery rearing, and the lower 800 m left for natural spawning and rearing. During 1988-89, a 0.4 km long side-channel (Beaver Channel 2) was built roughly parallel to Beaver Channel 1, but with an independent surface water intake. Finally, in 1999 a natural wetland area (3,000 m^2) was added to Beaver Channel by excavating a short connecting channel between the wetland and Beaver Channel 1. Channels 1 and 2 average 9 m and 6 m in wetted width, respectively. Total wetted length and area for Beaver Channel (including the wetland) are ≈1.5 km and 12,800 m^2, respectively.

In 1995, Raven Channel was built adjacent to the Little Oyster River about 100 m upstream of its confluence with the Oyster River and approximately 9 km upstream of the

Oyster River mouth (Figure 2). Raven Channel is about 1.5 km long and about 7 m wide. Total habitat area is about 10,500 m^2.

In 1998 the Rippingale Channel was built in the lower Oyster River adjacent to Beaver Channel (Figure 2). Flow in Rippingale Channel is derived primarily from groundwater and from Beaver Channel via a small diversion pipe. Rippingale Channel consist of a 1.6 km long main channel that is about 7 m wide and a 300 m long by 1 m wide secondary channel that joins the main channel at its midpoint. The secondary channel includes an excavated pond (710 m^2). Total length of Rippingale Channel (including the pond) is 1,900 m, and total area is 11,810 m^2.

2.2. Side-channel population estimates

Coho outmigrants from the three side-channels were enumerated at full-span converging weir fish traps (Conlin and Tutty 1979). Installed just upstream of the side-channel outlets, the downstream weirs consisted of 1 m x 2.5 m wooden panels screened with 0.5 cm square galvanized wire mesh, 15 cm diameter plastic entrance pipes, and welded aluminum trap boxes with screened sides. Additional mesh panels were installed in the intake structures of the side-channels to force all outmigrating smolts to enter the downstream weirs. For each side-channel, total smolt production was estimated as the total catch at the downstream weir.

Weir operation commenced on March 21, 29 and 31 at Rippingale and Beaver side-channels, respectively, and ended on June 4 at all three side-channels. Each day the downstream traps were emptied of their catch, thoroughly cleaned, inspected for damage, and repaired if necessary. Water temperatures were also recorded daily.

All captured fish were identified to species and counted. Based on findings by Bradford et al. (1997) for streams of similar latitude, we assumed that all coho captured that were yearlings or older were smolts. Sub-samples of coho smolts from Rippingale Channel were also measured for fork length (nearest mm) on a weekly basis; length sampling was less frequent at the Beaver and Raven side-channels. A sub-sample consisted of the first 50 smolts that were retrieved from a weir on a given sampling day. All smolts from a given day's catch were measured if less than 50 were present.

2.3. Oyster River population estimates

In order to provide a marked population of coho smolts, a portion of coho captured at the side-channel weirs were marked prior to release (unmarked fish from the side-channels and mainstem/tributary area served as the unmarked population). Tattoo marks were applied with a Pan-Jet dental inoculator using Alcian Blue dye (Herbinger et al. 1990). We will refer here to fish marked at the side-channel weirs as the side-channel mark group. An additional 58,000 hatchery coho smolts were released in the lower Oyster River during April 2000 (see Section 1.1, p.3). These smolts were identifiable by their missing adipose fin and were not included in the daily catch totals for unmarked mainstem/tributary smolts.

The total abundance of coho smolts in the Oyster River system was estimated using the numbers of marked (side-channel) coho and unmarked coho captured in two rotary screw traps (RSTs) (Thedinga et al. 1994). These traps were 2.0 m in diameter and were operated in the lower mainstem downstream of the side-channels (RST 1 installed 3.2 km from tidewater, RST 2 installed 900 m from tidewater, Figure 2). Both RSTs were operated in relatively deep (> 1 m) areas of the mainstem where current velocity was relatively swift. Each RST intercepted approximately 25% of total discharge at the site.

Both RSTs commenced operation on April 21 and finished on June 4 (RST 1) and May 13 (RST 2). Operation of RST 2 was ended earlier because of concern for excessive trap mortality (F. Petruzelka, ORES, pers. comm.). Although downstream trapping at the side-channel weirs began prior to the operation of the RSTs, marking of the side-channel smolts was delayed until the RSTs were installed.

The use of two RSTs allowed for a second group of smolts to be marked, thereby providing a second, estimate of RST capture efficiency and total smolt abundance. During the early portion of the study (April 21- May 13), a unique mark (upper caudal fin-clip) was applied to a randomly selected portion of each day's catch of unmarked smolts at RST 1. These fish were recaptured downstream at RST 2 along with marked side-channel smolts and unmarked fish. During the latter half of the study (May 14-June 4) when RST 2 was not operated, newly fin-clipped smolts from RST 1 were released 500 m upstream at a mid-stream location and recaptured at RST 1. We will refer to smolts marked at RST 1 as the mainstem mark group.

The RSTs were sampled daily (twice daily during peak of smolt migration), and cleaned and repaired as necessary. All captured fish were identified to species and counted. Coho juveniles were also measured for fork-length (nearest mm), examined for marks and released downstream. Prior to counting, adipose-clipped hatchery coho smolts were removed from the catch. Size data for mainstem smolts were collected only during the latter half of the study period (May 10-June 4), when weekly sub-samples of 50 coho smolts from RST 1were measured for fork length (nearest mm). Water temperatures for the Oyster River mainstem were measured each morning at RST 1.

2.3.1. Mark-recapture estimates

As a first step, we used the side-channel mark group to compute the estimated total smolt abundance (and 95% confidence interval) for the portion of the Oyster River upstream of RST 2. This estimate includes the three side-channels and the mainstem and tributary stream sections upstream of barriers where fry stocking occurred (see Table 1). For this single mark release or pooled Petersen estimate (PPE), we assumed that the recovery sample was taken without replacement, which leads to a "hypergeometric" form (Seber 1982, eq. for N* and v* on p. 60):

$$N_T = (M_I+1)(C_I+1) / (R_I+1) \qquad (1.1)$$

$$\mathrm{Var}(N_T) = (M_1+1)(C_1+1)(M_1-R_1)(C_1-R_1) / (R_1+1)^2 (R_1+2) \qquad (1.2)$$

$$95\%\ \mathrm{C.I.}(N_T) = \pm\ 1.96 \sqrt{\mathrm{Var}(N_T)} \qquad (1.3)$$

where

M_1 = number of marked smolts released from constructed side-channels
C_1 = number of marked and unmarked smolts recovered at RSTs
R_1 = number of marked smolts recovered at RSTs
N_T = population estimate for the Oyster River including side-channels

To estimate the total number of smolts for Oyster River excluding the side-channels (N_1):

$$N_1 = N_T - N_{\text{side-channel}} \qquad (1.4)$$

$$95\%\ \mathrm{CI}\ (N_1) = \pm\ 1.96 \sqrt{\mathrm{SE}(N_T)} \qquad (1.5)$$

To estimate total smolt abundance for the system using the mainstem mark group, we substituted M_2, C_2 and R_2 for M_1, C_1 and R_1 in equations 1.1 and 1.2:

M_2 = total number of smolts captured at RST 1 that were marked and released downstream (upstream after May 14)
C_2 = total number of marked and unmarked smolts that were recovered at RST 2 (RST 1 after May 14); marked side-channel smolts were included as part of the unmarked population
R_2= total number of marked smolts from RST 1 that were recovered at RST 2 (RST 1 after May 14).

Seber (1982) noted that the PPE may not be appropriate for migrating populations, particularly if the following assumptions are not met: 1) the population is closed (i.e., sampling period covers most of the smolt outmigration period), 2) the proportions of marked to unmarked individuals in recovery catches are constant, 3) probability of capture (capture efficiency) at the RSTs is constant over time, 4) mark loss is negligible and 5) capture efficiency is equal for marked and unmarked individuals. These assumptions are addressed below.

1. Population closure: We considered the assumption of population closure by plotting for each year, the histograms of daily catch totals at the side-channel weirs and the RSTs over time, and comparing daily numbers of smolts captured at the beginning and end of the trapping period to the numbers captured during the migration peak.

2. Constant proportions of marked to unmarked recoveries over time: To test this assumption, the RST recovery catches were stratified into five consecutive nine-

day periods (see Table 4), and the proportion of marked to unmarked smolts among temporal strata were compared (Pearson chi-square test).

3. Constant capture efficiency over time: In this study, our ability to detect differences in capture efficiency over time was limited because smolts were not differentially marked by capture period (see Arnason et al. 1996). We conducted a simple test of the assumption of constant capture efficiency over time by comparing capture efficiency at RST 1 for side-channel smolts released during the early half of the study period (April 21- May 13) to that for side-channel smolts released during the latter half (May 14-June 4; Pearson chi-square test).

4. Mark loss and marking-induced mortality: Potential mark loss and marking-induced mortality were not assessed. However, in a similar study, Decker and Lewis (1999) observed that for hatchery coho smolts held in enclosures for 50 days, the estimated Pan-jet tattoo retention rate was 99%. They also found that mortality was negligible during a 24-hour period following marking. Therefore, for this study, we assumed a mark retention rate of 100% and a marking-induced mortality rate of 0%.

5. Equal capture efficiency for marked side-channel smolts and "unmarked" mainstem/tributary smolts: We tested this assumption indirectly by comparing, for each RST, the estimated capture efficiency for marked side-channel smolts and marked mainstem smolts (Pearson chi-square test).

To examine whether failure to meet assumptions 2,3 and 5 biased the estimate of smolt abundance for the Oyster River, we computed additional estimates of smolt abundance that were specific to recovery site (RST 1 or RST 2), recovery period (early or late) and mark group (side-channel or mainstem).

3.0. RESULTS

3.1. Side-channels

A total of 24,284 outmigrating coho smolts were captured at the three side-channel weirs (Table 2). Overall, smolt density in the side-channels averaged 4,857 smolts·km^{-1} (0.7 smolts·m^{-2}; Table 2), and ranged from 2,761 smolts·km^{-1} (0.39 smolts·m^{-2}) at Raven Channel to 7,804 smolts·km^{-1} at Rippingale Channel (1.3 smolts·m^{-2}).

Peak emigration occurred during the second week of May for Rippingale Channel and during the third week of May for the other two side-channels (Figure 3). No incidence of weir failure was reported at any of the side-channels. For Beaver Channel, the shape of the daily catch histogram, suggests that the vast majority of coho smolts migrated during the period of trap operation, thus, the assumption of population closure was likely met (Figure 3). At the other two side-channels, relatively high daily catches at the beginning of the trapping period suggests that the assumption of population closure was not met (Figure 3).

Although length data were not collected at the other trap sites during the first three weeks of the trapping period, average weekly fork lengths of smolts from Rippingale Channel were relatively small (< 70 mm) compared to average lengths observed at all sites later in the study (Figure 4). During May and early June, average lengths were generally similar for smolts captured at the side-channel weirs and at RST 1 in the Oyster River mainstem (Figure 4). Beaver Channel was a notable exception; smolts appeared to be larger at this site compared to smolts in the other side-channels and the mainstem.

For all three side-channels, the observed mortality for coho smolts was less than 2%. Other fish species captured at the side-channel weirs included juvenile chinook, chum salmon, steelhead and resident rainbow trout, cutthroat trout, sculpins (*Cottus spp.*), three-spine stickleback (*Gasterosteus aculeatus*), and lamprey (*Lampetra spp.).*

3.2. Oyster River

During the period of RST trapping in the Oyster River mainstem, water temperatures ranged from 4 to 8°C; water temperatures in the side-channels were often warmer, ranging from 4 to 11 °C (Appendix 1). Discharge in the lower Oyster River during the study ranged from 8 to 18 $m^3 \cdot s^{-1}$, but there was no consistent pattern of increasing or decreasing flow (Appendix 2). Daily coho smolt catch at the RSTs was not significantly correlated with either discharge or water temperature ($P < 0.05$ for all cases).

3.2.1. Population estimates based on different mark groups

Side-channel mark group: During April 21-June 4, a total of 12,367 coho smolts, or about 50% of the total number of side-channel outmigrants were marked and released at the three side-channel weirs (Table 3, data set 1). At RST 1, a total of 413 marked side-channel smolts and 5,748 unmarked smolts were captured (3.3% capture efficiency). RST 1 data provided a Petersen mark-recapture estimate of smolt abundance for the Oyster River system of 184,085 (95% CI: ± 16,817 smolts; Table 3, data set 1). When the catch data for RST 1 were grouped by the early (April 21-May 13) and late portions of the study (May 14-June 4), the estimated smolt abundance for these two periods was 62,998 (± 15,448 smolts) and 118,301 (± 11,507 smolts; Table 3, data sets 3,6), respectively. The total of these two estimates (181,299) was similar to the estimate of 184,085 smolts generated using the pooled data. Because RST 2 was removed on May 14 at the peak of the smolt run (Figure 3), catch data from this trap were used only to compute an estimate of smolt abundance for the early portion of the study period. During this period, a total of 1,668 marked smolts were released at the side-channel weirs (Table 3, data set 4). At RST 2, a total of 159 marked side-channel smolts and 5,141 unmarked smolts were captured (9.5% capture efficiency). These data provided a smolt abundance estimate for the Oyster River system during the early portion of study of 55,296 (± 7,998 smolts; Table 3, data set 4). This estimate did not differ significantly from the estimate computed using the RST 1 recovery data (62,998 smolts).

Mainstem mark group: During the early portion of the study period, 2,098 of the 2,226 unmarked smolts that were captured at RST 1 were marked and released downstream (Table 3, data set 5). During the same period, 195 of these fish were recaptured at RST 2 along with 5,111 unmarked smolts (9.3% capture efficiency). RST 2 data produced an estimate of smolt abundance for the Oyster River system during the early portion of study of 57,155 (± 7,459 smolts; data set 5). This estimate was similar to the smolt abundance estimates obtained using side-channel mark group recoveries at RST 1 and RST 2 (62,998 and 55,296 smolts, respectively). During the late portion of the study period (May 14-June 4) a total of 497 unmarked smolts that were captured at RST 1 were marked and released about 500 m upstream (Table 3, data set 7). Forty-one of these fish (8.2%) were recaptured at RST 1 along with 3,638 unmarked smolts. These data provided a smolt abundance estimate for the Oyster River system during the latter portion of study of only 43,634 (± 12,409 smolts; data set 7). This estimate was three times lower compared to the estimate based on recoveries of marked side-channel smolts at RST 1 (118,301 smolts). The sum of the early (RST 2) and late season (RST 1) estimates based on the mainstem mark group data provides a total smolt abundance estimate for the Oyster River system of (100,789 smolts ± 14,478; data set 2), which was also considerably lower than the total abundance estimate based on the side-channel mark group data (184,085 smolts).

3.2.2. Population estimate for the Oyster River

For the purpose of estimating total coho smolt abundance for the Oyster River system (including the side-channels), we relied on the population estimate computed using the side-channel mark group (184,085 smolts ± 16,817 smolts). By extrapolating this estimate to include the 3.2 km of mainstem habitat downstream of RST 1, the estimate of total smolt abundance for the system was 191,116 (± 17,460 smolts; Table 2). Excluding the estimated number of smolts from the three side-channels (24,284), the estimate for the total mainstem/tributary area was 166,832 smolts (± 17,460; Table 2).

We considered these estimates to be more reliable than the ones based on the mainstem mark group for two reasons. First, considering that capture efficiency for side-channel smolts at RST 1 was consistent during the early (April 21-May 13) and late (May 14-June 4) portions of the study (3.5% and 3.3%, respectively; Table 3), and that capture efficiency was similar for marked side-channel and mainstem/tributary smolts at RST 2 during the early portion (9.3% and 9.5%, respectively; Table 3), the relatively high capture efficiency for mainstem/tributary smolts at RST 1 during the late portion of the study (8.2%; Table 3) appeared suspect. Secondly, the overall numbers of marked side-channel smolts released (12,367) and recaptured (413) were much higher compared to the numbers of marked mainstem/tributary smolts released (2,595) and recaptured (236) (Table 3).

3.2.3. Mark-recapture assumptions

Population closure: The difference in the daily numbers of smolts captured at RST 1 at the beginning and ends of the period of operation compared to the numbers captured during the migration peak suggested that the major portion of the smolt migration in the Oyster River mainstem began after the start of RST trapping on April 21 and was largely complete by the end of the trapping period on June 4 (Figure 3). The daily catch histogram for RST 2 suggests that this trap was removed at the peak of the smolt run on May 13 (Figure 3).

Constant proportions of marked to unmarked recoveries over time: Unmarked coho, most of which were from the mainstem/tributary area, migrated through the downstream RST recovery site (RST 2) somewhat earlier than did the marked side-channel fish (Figure 5). As a result, when catch data for RST 1 were stratified into five recovery periods, the proportion of marked side-channel smolts among the recovery strata increased significantly from 1% at the beginning to 13% at the end of the study period (chi-square, df = 4, $X^2 = 101.27$, $P < 0.0001$; Table 4).

When data for RST 1 was compared to that for RST 2, (non-stratified catch data for April 21-May 13), the proportion of marked to unmarked smolts was similar for the two traps (2.7% and 3.1%, respectively; chi-square, df = 1, $X^2 = 0.87$, $P = 0.35$).

Constant capture efficiency over time: At RST 1, capture efficiency was similar for side-channel smolts released during the early and late parts of the study (3.5% and 3.3% respectively; Pearson chi-square, df = 1, $X^2 = 0.11$, $P = 0.74$; Table 3, data sets 5,7).

Equal capture efficiency for marked side-channel smolts and "unmarked" mainstem/tributary smolts: Given that we marked about 50% of the smolts released at the side-channels, and that these fish represent only 7% of the total catch at RST 1 (Table 4), it is reasonable to assume that most unmarked smolts captured at the RSTs were from the mainstem/tributary area. Therefore, we tested the assumption of equal catchability for marked (side-channel) and unmarked (mainstem/tributary) smolts indirectly by comparing RST capture efficiency for the side-channel and mainstem mark groups. For RST 2, during April 21-May 13 capture efficiency was similar for the side-channel and mainstem mark groups (9.5% and 9.3%, respectively; chi-square, df = 1, $X^2 = 0.05$, $P = 0.82$; Table 3, data sets 4,5). By contrast, at RST 1 during May 14-June 4, capture efficiency for the side-channel and mainstem mark groups was significantly different (3.3% and 8.2%, respectively; df = 1, $X^2 = 33.85$, $P < 0.001$; Table 3, data sets 6 and 7).

4.0 DISCUSSION

4.1. Contribution of side-channels to smolt production

In 2000, total coho smolt abundance for the Oyster River system upstream of RST 1 (including side-channel fish) was estimated at 191,116 (± 17,460; Table 2), or 166,832 smolts (± 17,460) when the estimated number of smolts from the three side-channels (24,284) was excluded.

Coho smolt density (based on stream length) in the side-channel habitat was 2.3 times higher than that for the mainstem/tributary area (4,857 versus 2,117 smolts$\cdot$km^{-1};

Table 2). Fry releases in 1999 totaled 60,000 in the 15.1 km section of the Oyster River upstream of its anadromous barrier, and 40,000 in the 15.0 km section of Woodhus Creek upstream of its barrier (see Section 1.1, p.3). To what degree the stocking of 100,000 hatchery fry in these areas contributed to smolt numbers in 2000 is unknown. If potential smolt production for the 30.1 km combined length for these two reaches (Table 1) is not considered, smolt density in the side-channels was 1.4 times higher than that for the mainstem/tributary area (4,857 versus 3,426 smolts$\cdot$km^{-1}).

The side-channels represented only 6% of the available habitat by stream length, but supported 12.7% (95% CI: ± 1.3%) of the estimated total smolt population for the system (24,284 of 191,116 smolts ± 17,460; Table 2). Including the side-channels, the estimated smolt density for the 83.8 km of habitat in the Oyster River system was 2,281 smolts$\cdot$km^{-1} (3,559 smolts$\cdot$km^{-1} if the 30.1 km of mainstem/tributary upstream of the barriers is excluded; Table 2). High smolt densities in the side-channels compared to the mainstem/tributary area did not appear to be the result of underseeding of fry in the latter habitat. A coho smolt production model developed by Bradford et al. (2000) for Pacific coastal streams of similar latitude to the Oyster River predicted that, on average, the minimum spawner density needed to fully seed a stream (i.e., achieve smolt carrying capacity) was 19 female spawners$\cdot$km^{-1}. The AUC estimate of coho escapement to the Oyster River for 1998 (2000 smolt year) was 9,000 fish (Serbic 1991). Assuming a spawner sex ratio of 45% females (Bradford et al. 2000), estimated spawner density for the 2000 smolt year was 75 females$\cdot$km^{-1} for the 53.8 km of habitat accessible to wild spawners (Table 1). This suggests that smolt production in the Oyster River in 2000 was not likely affected by underseeding of fry.

Estimated coho smolt densities for the mainstem/tributary area (2,281 smolts$\cdot$km^{-1}) and for the overall Oyster River system (3,559 smolts$\cdot$km^{-1}) in 2000 were considerably higher than the mean value of 1,476 coho smolts$\cdot$km^{-1} reported for Pacific coastal streams of similar latitude that were assumed to be unaffected by insufficient adult recruitment (Bradford et al. 1997). However, mean density for coho smolts in the constructed side-channels in the Oyster River in 2000 (0.69 smolts$\cdot$m^{-2}; Table 2) was remarkably similar to the average coho smolt density for a large number of constructed side-channels in B.C. and the Pacific Northwest (0.67 smolts$\cdot$m^{-2}; Koning and Keeley 1997).

While the side-channels constructed in the Oyster River supported 12.7% of the total coho smolt population in 2000, the contribution of constructed side-channels and ponds to total smolt production in other streams was somewhat higher. In a three-year study conducted in the Coquitlam River (B.C.) an average of 46% of the coho smolt population overwintered in six constructed side-channel and pond sites which represented about 14% of the available habitat. In another three-year study, Decker et al. (in press) found that an average of 20% of coho in the Englishman River (B.C.) overwintered in two constructed side-channels that represented 8% of total habitat. In the Cheakamus River (B.C.), 46% of the total smolt population for the system overwintered in six side-channels which represented about 40% of the available habitat (Decker and Foy, in press). Everest et al. (1986) reported that, three years after construction, a constructed off-channel pond in Fish Creek, (OR) which represented only 1% of the total rearing area, contributed 50% to the total coho smolt output. Comparisons of smolt production in natural side-channel and pond versus mainstem habitat yielded similar findings to those above. For example, Lestelle et al. (1993) found that as many as 30% of coho in the Queets River (WA) reared in natural or man-made off-channel ponds during part of the year, while Brown and Hartman (1988) found that an average of 19% of coho in Carnation Creek (BC) overwintered in natural off-channel habitat. Since smolt densities in the Oyster River side-channels were comparable to values reported for constructed side-channels and ponds in other systems, the lesser contribution to total smolt production by Oyster River side-channels is likely the result of relatively high smolt production in the mainstem tributary area in 2000 (Bradford et al. 1997), or the lower proportion (6%) of side-channel versus mainstem/tributary habitat in the Oyster River compared to other restored streams.

Other studies have shown that coho smolt carrying capacity can be limited by the availability of suitable winter habitat (Lestelle et al. 1993; Hartman et al. 1996; Solazzi et al. 2000), and that overwinter survival of coho rearing in side-channels and ponds is relatively high (Peterson 1982; Brown 1985; Swales and Levings 1987). In this study, we did not assess the relative survival of overwintering coho in the side-channels and the mainstem/tributary area. However, if we assume that side-channel habitat (Sharma and Hillborn 2001), or winter habitat in general (Solazzi et al. 2000) is a limiting factor for Oyster River coho, then, based on the relatively high smolt densities we observed in the constructed side-channels compared to the mainstem/tributary area, and the significant proportion of total smolt abundance accounted for by the side-channels, it is likely that habitat restoration has increased the productive capacity of Oyster River system.

Studies of natural side-channels and ponds showed that they are used primarily as winter habitat by juveniles emigrating from the mainstem during the fall (Cederholm and Scarlett 1982; Peterson 1982; Brown and Hartman 1988). However, studies of constructed side-channels and ponds found that most of juvenile coho using these sites were year-round residents, and recruitment depended mainly on adult spawning (Peterson 1985; Sheng et al. 1990; Decker 1999; Decker and Lewis 2000). Therefore, the relatively high smolt densities observed in the constructed side-channels in this study may indicate that artificial off-channel habitat is important not only for juvenile winter rearing, but also for spawning and summer fry rearing.

4.2. Reliability of mark-recapture estimates

The assumption of population closure appeared to be met as the majority of smolts appeared to leave Beaver Channel and the Oyster River mainstem during the period when a downstream weir and RST 1 were operated in these respective areas (Figure 3). This was not the case for the other two side-channels (Rippingale and Raven), where substantial numbers of smolts had already left at the start of weir operation (March 21 and 31, respectively; Figure 3). This 'pre-migration' ended by the second week of April at both sites, with the main period of smolt migration beginning in early May, similar to that at Beaver Channel and in the mainstem.

It is unlikely that movement of fish from these two side-channels during March represented a seaward migration as this would be unusually early for coho smolts (Sandercock 1991). It is more probable that these relatively small fish (Figure 4) were pre-smolts moving to rearing locations in the Oyster River mainstem prior to seaward migration. This apparent redistribution of some side-channel smolts to the mainstem does not affect the estimate of smolt abundance for the Oyster River system, but it may have biased low the estimate of the proportion of total smolt production attributed to the side-channels. This bias is potentially significant. Yearling coho that left the Rippingale and Raven side-channels during the portion of the 'pre-migration' period (March 21 - April 21) before the downstream traps were in place represented 23% of the total number of yearling outmigrants from the side-channels during the study (5,483 of 24,284). If, hypothetically, a similar number of yearlings also moved from the Rippingale and Raven side-channels to the mainstem during the early spring period prior to the installation of the side-channel weirs, the contribution of the side-channels to overall smolt production would be 15.6% instead of 12.7%.

The assumption of constant proportions of marked to unmarked recoveries over time was not met: unmarked coho from the mainstem/tributary area moved through the recovery site somewhat earlier than marked fish from the side-channels (Figure 6), resulting in a higher proportion of marked side-channel smolts in RST catches during the latter half of smolt run (Table 4). This demonstrates the importance of collected recovery data for marked fish during the entire migration period, rather than basing abundance estimates on "point estimates" for the proportion of marked to unmarked smolts.

Whether failure to meet this assumption biased our estimates of smolt abundance cannot be determined because we did not stratify fish marking by using different marks over the course of the smolt migration (see Arnason et al. 1996). However, in other studies where a stratified estimator (Darroch 1961) was used to address violations of this assumption, the stratified estimates were not significantly different from those derived from the non-stratified Petersen estimator used here (Dempson and Stansbury 1991; Schwarz and Dempson 1994; Decker et al. in press: Decker and Lewis 2000). This suggests the Petersen estimator may be robust to violation of the assumption of constant proportions.

Because smolts were not marked according to release period in this study, it was not clear whether the smolt abundance estimates were biased as a result of variation in capture efficiency over time. However, the similar estimates of capture efficiency for marked side-channel smolts at RST 1 for the early and late portions of the smolt migration (3.5% and 3.3%, respectively; Table 3) suggest that the assumption of constant capture efficiency was met reasonably well. Moreover, fluctuation in discharge, which is a common source of variation in RST capture efficiency (Roper and Scarnecchia 1996; Irvine et al. 1996; Decker and Foy, in press), was relatively low in the Oyster River during the 2000 study period (7-17 cms; Appendix 2). Nevertheless, in future assessments, the uncertainty of smolt abundance estimates could be reduced by differentially marking smolts according to release period. This would allow for the use of stratified mark-recapture estimators that do not depend on this assumption of constant capture efficiency (Arnason et al. 1996).

We could not test directly the assumption of equal RST capture efficiency for marked side-channel smolts and unmarked mainstem/tributary smolts. However, comparison of capture efficiency for marked side-channel and marked mainstem/tributary smolts suggests the assumption was met for RST 2, but not for RST 1. During the early part of the study, capture efficiency at RST 2 was similar for marked smolts released from the side-channels and marked smolts released from RST 1 (9.5% and 9.3%, respectively; Table 3). Correspondingly, smolt abundance estimates generated for the early period using these two mark groups were also similar (55,296 ± 7,998 and 57,155 ± 7,459 smolts, respectively). Also similar to these estimates, was the abundance estimate for the early period generated using the side-channel mark group and data from RST 1 (62,998 smolts ± 15,448; Table 3).

By contrast, during the latter part of the study period, marked side-channel smolts were almost three times less likely to be recaptured at RST 1 compared to marked mainstem/tributary smolts initially captured at RST 1 then marked and released upstream (capture efficiencies: 3.3% and 8.2%, respectively; Table 3). As a result, abundance estimates generated for the latter part of the study period using these two mark groups differed by almost a factor of 3 (118,301 ± 11,507 and 43,634 ± 12,409, respectively). Unequal capture efficiency for side-channel and mainstem coho smolts was also evident in similar studies conducted in two other B.C. streams (Decker and Lewis 2000; Decker et al. in press).

The estimates of total smolt abundance for the early and late study periods that were computed using the mainstem mark group and recovery data for RST 1 (late) and RST 2 (early) (Table 3, data sets 5 and 7, respectively), when summed together produced a substantially lower estimate of smolt abundance for the entire study period (100,789 smolts ± 14,478; data set 2) compared to estimate computed using the side-channel mark group and recovery data for RST 1 (184,085 smolts ± 16,817 smolts; Table 3, data set 1). While this difference is best explained by the difference in RST 2 capture efficiency for the two mark groups discussed above, there is no way of knowing with certainty which of the two estimates of total smolt abundance is the more accurate.

5.0. CONCLUSIONS

Constructed side-channels are used extensively by wild coho salmon in the Oyster River system. In 2000, spring outmigrants from three side-channels contributed significantly (13%) to overall smolt production in the system. However, in order to state unequivocally that side-channel development has increased overall smolt production, a long-term monitoring program would have to be conducted before and after enhancement. Nevertheless, our study indicates that the construction of 35,000 m^2 of side-channel habitat in the Oyster River has affected the distribution of coho production. If coho smolt production in the Oyster River is limited by overwintering habitat, then it is reasonable to suggest that overall coho carrying capacity of the system has been increased as a result of habitat enhancement.

6.0. SUMMARY

1. During 1985-1999, 5.0 km (35,000 m^2) of side-channel habitat was constructed at three sites in the Oyster River to increase off-channel rearing area for juvenile coho salmon.

2. In 2000, coho smolt outmigrating from the three side-channels totaled 24,284, while the number of smolts for the entire system was estimated at 191,116 (95% CI: ± 17,460).

3. The mean density of outmigrating coho smolts was 2.3 times greater for the side-channels compared to the mainstem/tributary area (4,857 versus 2,117 $\text{smolts}\cdot\text{km}^{-1}$).

4. While representing only 6% of the total stream area (by channel length), the side-channels accounted for 12.7% (95% CI: 1.3%) of the estimated total smolt production in the system.

5. The use RSTs and mark-recapture methodology appears to be a practical way to estimate the abundance of migrating smolts in larger streams such as the Oyster River where the installation of full-span downstream weir traps in the mainstem is not possible.

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Table 1. Estimated lengths (km) for anadromous reaches of the Oyster River System (including two reaches above barriers that were stocked with hatchery coho fry) and for three constructed side-channels.

Stream or side-channel	Anadromous length (km)	Length of stocked reaches above barriers (km)	Total stream length (km)
Natural river			
Oyster River	24.2	15.1	39.3
Little Oyster River	18.5	-	18.5
Woodhus Creek	0.5	15.0	15.5
Bear Creek	5.5	-	5.5
Total (natural)	48.7	30.1	78.8
Constructed side-channels			
Raven	1.5	-	1.5
Rippingale	2.0	-	2.0
Beaver	1.5	-	
Total (side-channel)	5.0	-	5.0
Overall total	53.7	30.1	83.8

Table 2. Summary of estimated numbers and densities of coho smolts in 2000 for three side-channels (SC) the mainstem/tributary area of the Oyster River system, and the overall system including the side-channels.

Site	Estimation method	Length (km)	Area (m^2)	N smolts	± 95% CI	% CI	Smolt density		% of smolt run
							/km	/m^2	
Raven SC	Count	1.5	10,500	4,141	-	-	2,761	0.39	2.2%
Rippingale SC	Count	2.0	11,810	15,608	-	-	7,804	1.32	8.2%
Beaver SC	Count	1.5	12,800	4,535	-	-	3,023	0.35	2.4%
Total SC	Count	5.0	35,110	24,284	-	-	4,857	0.69	12.7%
Main/trib (above and below barriers)[1]	MR	78.8		166,832	17,460	10%	2,117		87.3%
Total system (above and below barriers)	MR	83.8		191,116	17,460	9%	2,281		100%
Total system (below barriers only)[2]	MR	53.7		191,116	17,460	9%	3,559		100%

[1] Length of natural mainstem/tributary habitat includes all natural stream reaches downstream of anadromous barriers, and two stocked reaches (total length 30.1 km) upstream of barriers (see Table 1).

[2] Length of total system below barriers includes the three side-channels and all natural stream reaches excluding the two stocked reaches upstream of barriers (i.e., 83.8 km – 30.1 km).

Table 3. Comparison of total smolt production estimates (N) that were computed using two groups of marked fish (side-channel smolts and mainstem smolts marked at RST 1) and two recapture locations (RST 1 and RST 2). M, C and R refer to the number of smolts marked at the channels (M), the total number of marked and unmarked smolts captured at the RSTs (C) and the number of marked smolts captured at the RSTs (R). Early and late portions of the study refer to April 21-May 13, and May 14-June 4, respectively.

Data set	Portion of study	Mark group	Recap. site	M	C	R	Cap. effic. (R/M)	N smolts	± 95% CI	% CI
1	Entire	Side-channel	RST 1	12,367	6,161	413	3.3%	184,086	16,817	9%
2	Entire	Mainstem	RST 1&2					274,386 [2]	14,478 [3]	5%
3	Early	Side-channel	RST 1	1,668	2,226	58	3.5%	62,998	15,448	25%
4	Early[1]	Side-channel	RST 2	1,668	5,300	159	9.5%	55,296	7,998	14%
5	Early	Mainstem	RST 2	2,098	5,336	195	9.3%	57,155	7,459	13%
6	Late	Side-channel	RST 1	10,699	3,935	355	3.3%	118,301	11,507	10%
7	Late	Mainstem	RST 1	497	3,679	41	8.2%	43,634	12,409	28%

[1] RST 2 was removed on May 14.

[2] Based on the sum of the estimates for data sets 5 and 7.

[3] Based on summed variances of the estimates for data sets 5 and 7.

Table 4. Total number of side-channel (SC) coho smolts marked and released at side-channel weirs, numbers of marked SC smolts, and unmarked smolts recovered at RST 1 in the lower Oyster River during five nine-day recovery periods, and the proportion of marked smolts in recovery catches during each period.

Recovery data for RST 1	Total SC marks released (21 Apr - 4 Jun)	Recovery stratum 1 21-Apr 29-Apr	2 30-Apr 8-May	3 9-May 17-May	4 18-May 26-May	5 27-May 4-Jun	Total
	12,367						
Marked SC smolts		1	10	218	114	70	413
Unmarked smolts		165	971	2,962	1,162	488	5,748
Total recovered		166	981	3,180	1,276	558	6,161
Marked proportion		1%	1%	7%	9%	13%	7%

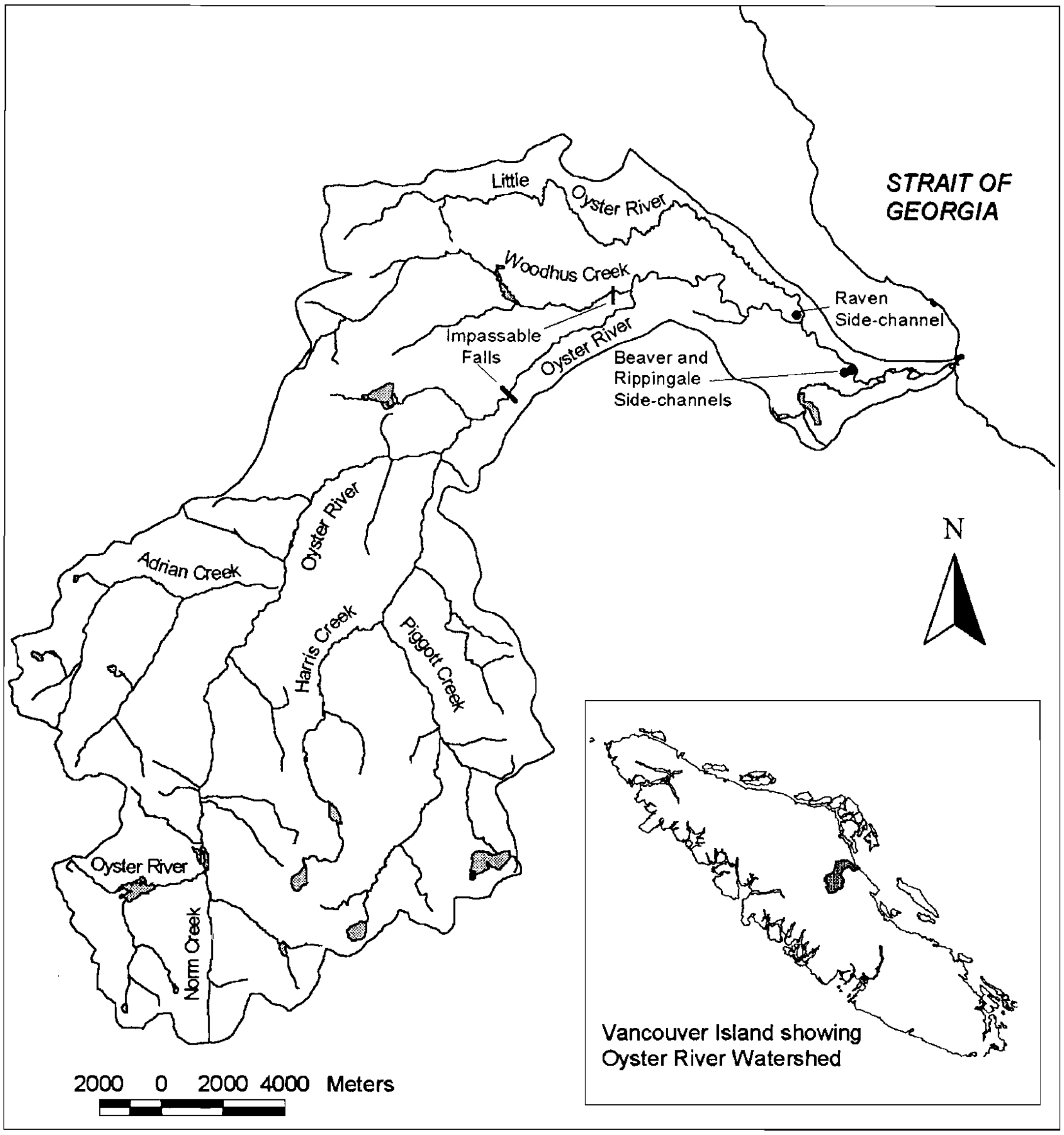


Figure 1. Map of the Oyster River watershed. Inset map shows the location of the Oyster River on the east coast of Vancouver Island.

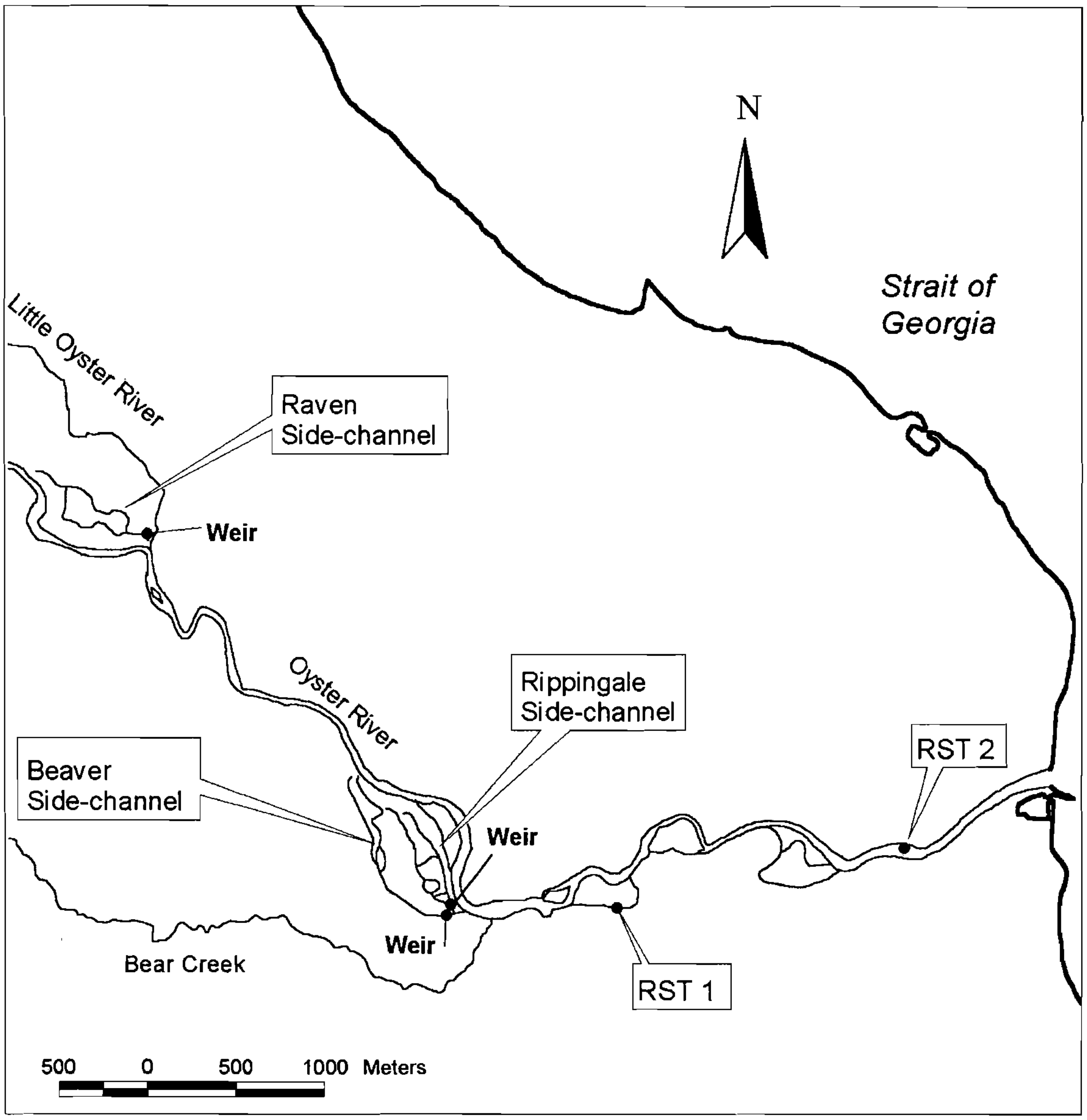


Figure 2. Map of the lower Oyster River and side-channels showing release sites for marked side-channel smolts (weirs) and marked mainstem/tributary smolts (RST 1), and mainstem recovery sites at RST 1 and RST 2.

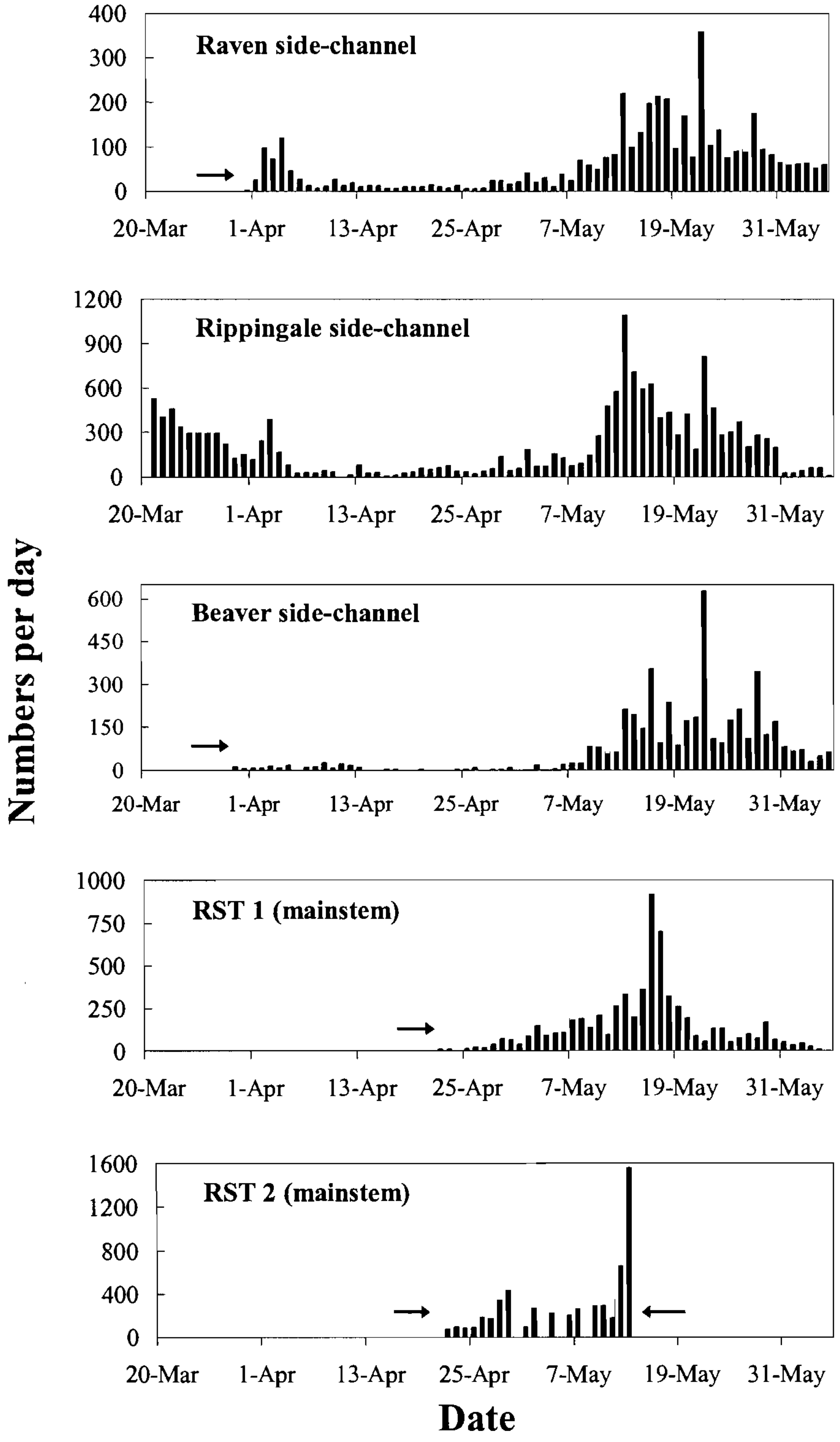


Figure 3. Daily catches of coho smolts at downstream weirs in three side-channels and at two rotary screw traps (RSTs) in the Oyster River during March 21-June 4, 2000 (where present, arrows indicate the beginning or end date for trapping at a particular site).

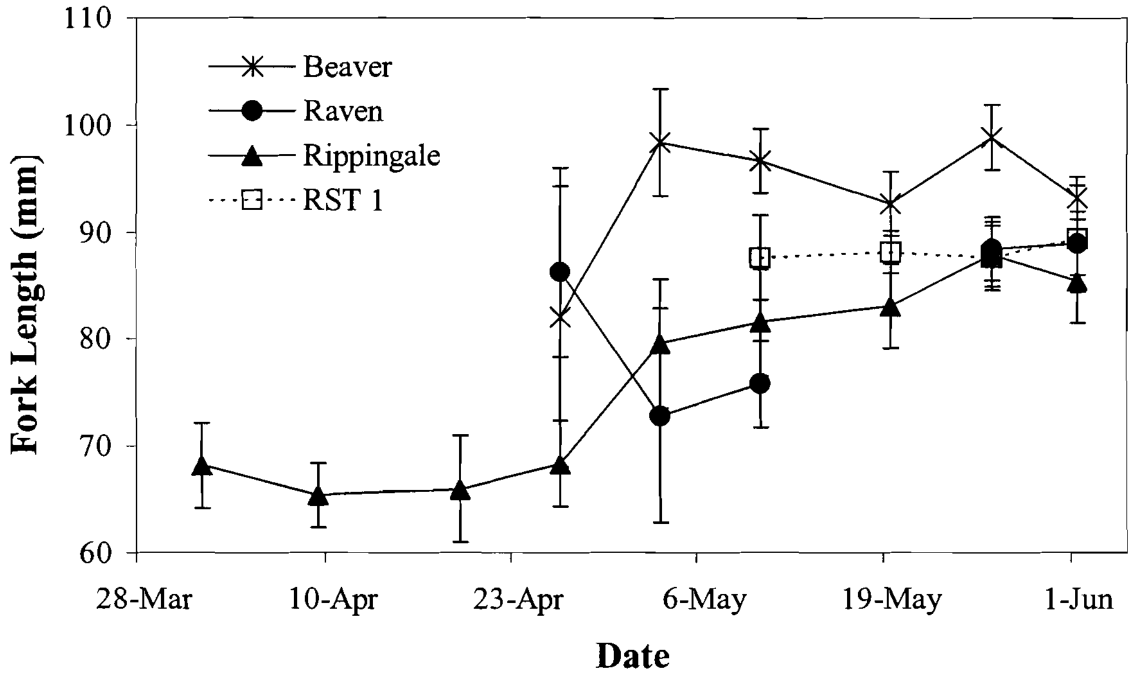


Figure 4. Mean fork lengths (± 1 standard error) for coho smolts at three side-channels (Beaver, Raven and Rippingale) and at a rotary screw trap (RST 1) in the Oyster River mainstem during 2000.

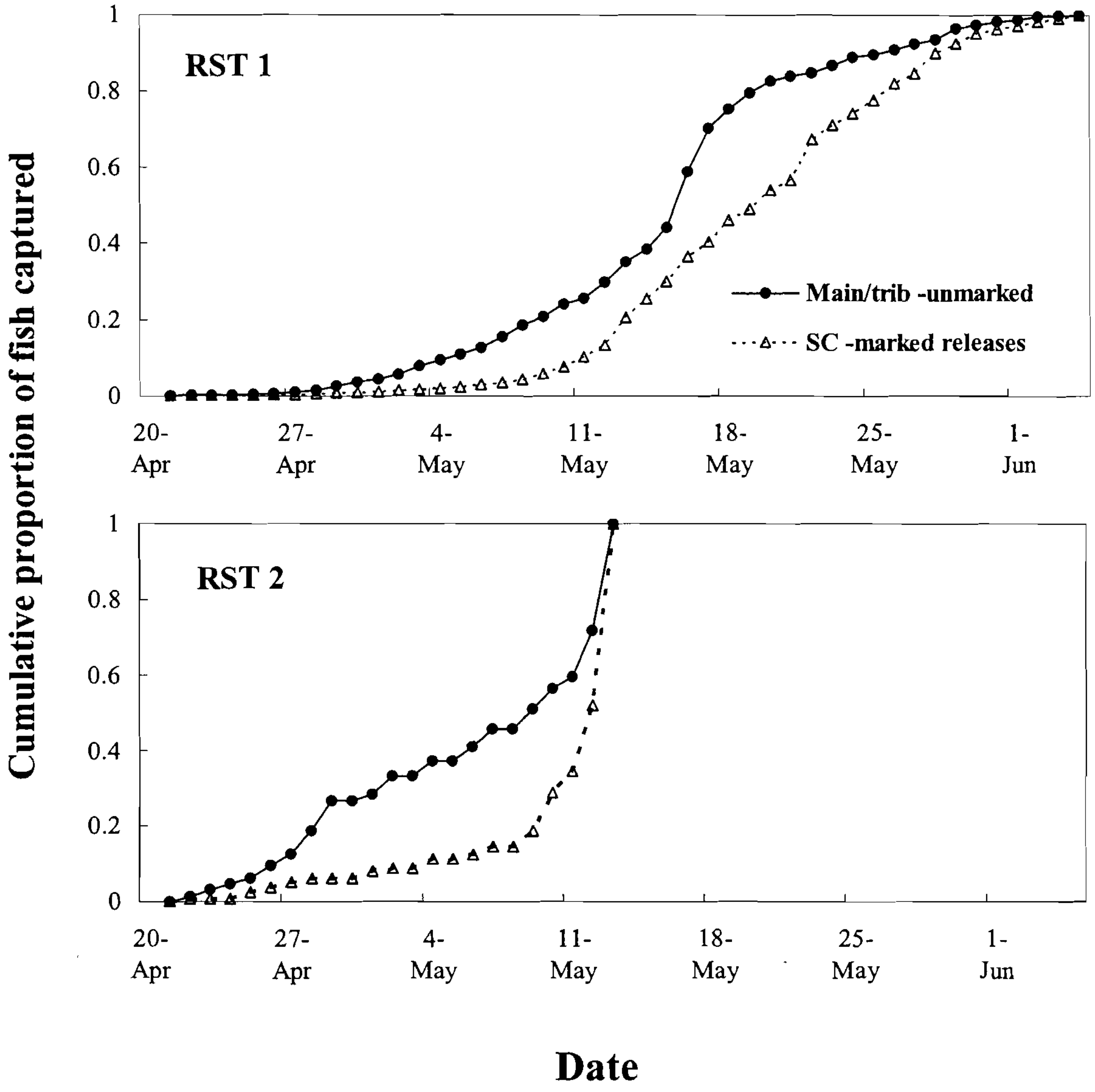
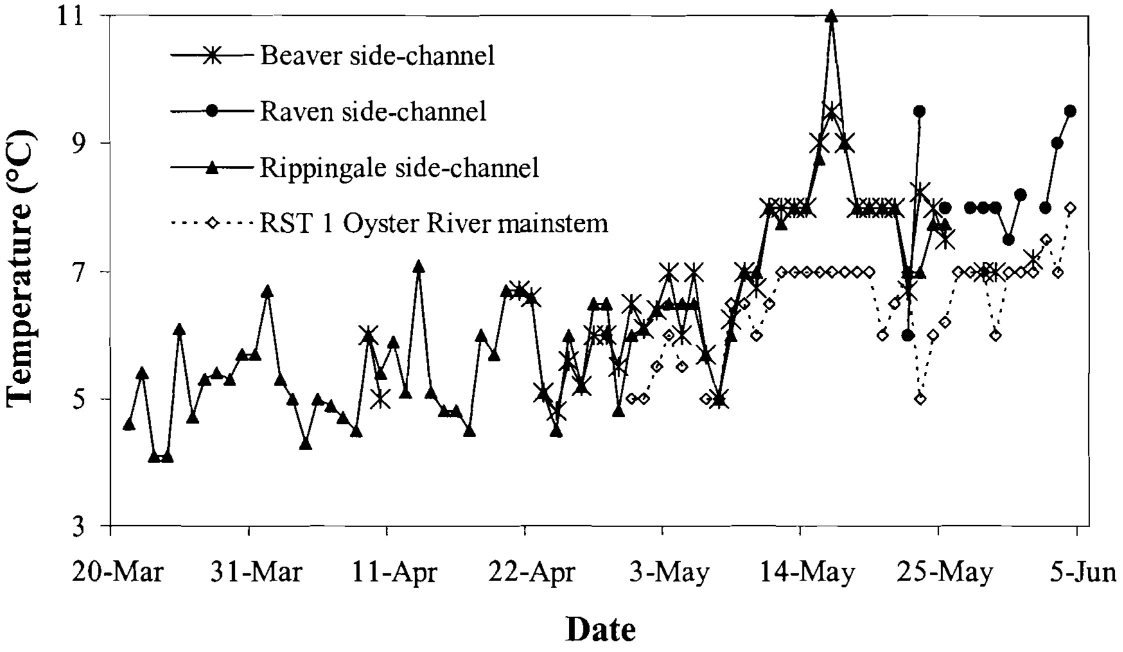
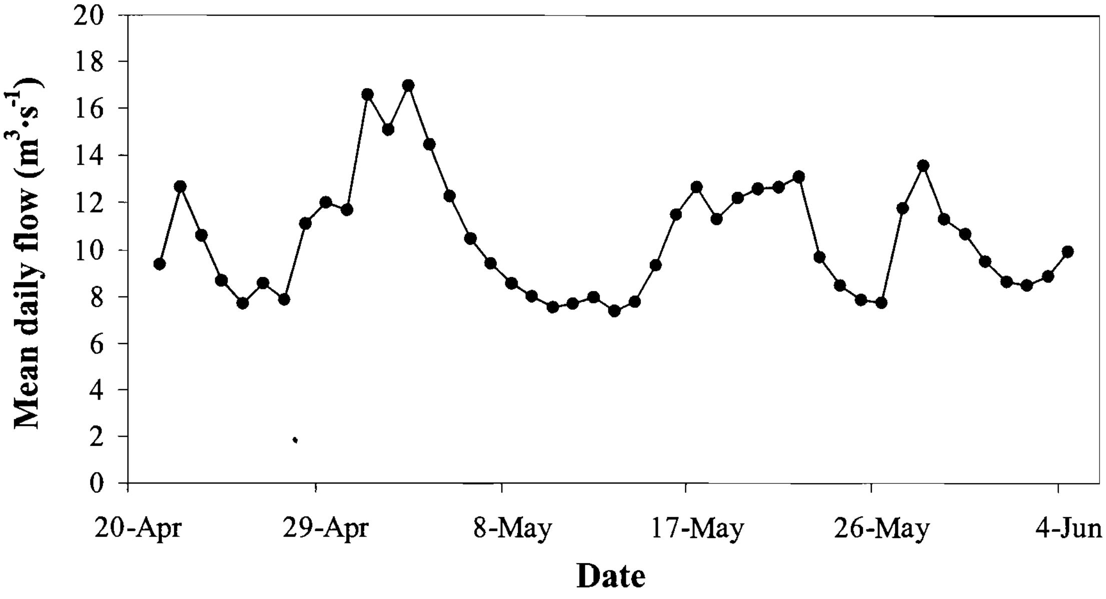


Figure 5. Cumulative daily proportions of marked side-channel smolts (SC) and unmarked mainstem/tributary smolts recovered at two rotary screw traps in the lower Oyster River mainstem during April 21- June 4 (RST 1) and April 21- May 13 (RST 2), 2000.

APPENDICES



Appendix 1. Water temperatures (°C) for three side-channels and the Oyster River mainstem during March-June, 2000.



Appendix 2. Stream discharge ($m^3 \cdot s^{-1}$) for the lower Oyster River mainstem during April-June, 2000 (Water Survey of Canada, Station 08HD011).