The Use of a Pulp Mill Effluent Mixing Zone During Winter by Juvenile Chinook Salmon in the Fraser River at Prince George, British Columbia

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TABLE OF CONTENTS

ABSTRACT

B. Emmett, G.M. Kruzynski and I.K. Birtwell. 1996. The Use of a Pulp Mill Effluent Mixing Zone During Winter by Juvenile Chinook Salmon in the Fraser River at Prince George, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2341: 38 p.

A study was undertaken to assess the use of a pulp mill effluent mixing zone by chinook salmon during winter (1993/94) in the Fraser River near Prince George, B.C. The abundance and residency of juvenile chinook was examined in the effluent mixing zone and in an upstream reference zone. Snorkel surveys of the nearshore zone of the river, conducted at night, were used to assess fish abundance. Juvenile chinook were captured with a diver operated, submersible electrofisher and marked with freeze brands to assess residency. Additional snorkel surveys and conventional backpack electrofishing were conducted in the effluent and reference zones during the day to document the diel movements of juvenile chinook in winter.

Fish were present in the effluent mixing zone and the reference zone on all three survey dates (1) November, prior to ice formation (2) January, when extensive shore ice was present in both zones and (3) March, after most of the shore ice had receded. Over 90% of these fish were juvenile chinook. The abundance of juvenile chinook was similar in the effluent mixing zone and the upstream reference zone. Density estimates ranged between 20 and 75 chinook per 100m of shoreline (0.1 to 0.37 chinook per m^2) in the effluent zone and 14 to 61 chinook per 100m of shoreline (0.07 to 0.30 chinook per m^2) in the reference zone.

The determination of residency of juvenile chinook in the effluent mixing zone in winter remains problematic due to the small number of fish marked, and the possibility that the behavioural response of chinook to the marking procedure was to move downstream. A total of 154 juvenile chinook were marked in November and January, 48 in the effluent zone and 106 in the reference zone. Four of 65 chinook marked in November were recaptured at the survey sites two days after release. No marked fish were recaptured at the sites four to six weeks after release.

During the day, chinook salmon were sampled from within the interstitial spaces of nearshore pebble and cobble substrate, often under shorefast ice shelves. At dusk they moved into the water column and remained active throughout the night in very shallow, nearshore water.

Key words: chinook salmon behaviour, pulp mill effluent, overwinter habitat

RÉSUMÉ

B. Emmett, G.M. Kruzynski and I.K. Birtwell. 1996. The Use of a Pulp Mill Effluent Mixing Zone During Winter by Juvenile Chinook Salmon in the Fraser River at Prince George, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2341: 38 p.

On a entrepris une étude pour évaluer l'utilisation de la zone de brassage des effluents d'une usine de pâte par le saumon quinnat, durant l'hiver (1993-94), dans le fleuve Fraser, près de Prince George (Colombie-Britannique). L'abondance et le temps de séjour du saumon quinnat juvénile ont été étudiés dans la zone de brassage de l'effluent et dans une zone témoin en amont. Des relevés de la zone côtière du fleuve faits au tuba, la nuit, ont permis d'évaluer l'abondance du poisson. Des quinnats juvéniles ont été capturés à l'aide d'un appareil submersible de pêche électrique et cryomarqués pour évaluer la durée de séjour. D'autres études ont été faites à l'aide de tubas et d'appareils de pêche électrique classiques, portés sur le dos, dans la zone d'effluents et la zone témoin durant le jour pour documenter les déplacements nycthémérales du quinnat juvénile en hiver.

Des poissons étaient présents dans la zone de brassage de l'effluent et dans la zone témoin aux trois dates du relevé: (1) novembre, avant la formation des glaces; (2) janvier, lorsque les deux zones étaient presque entièrement recouvertes de glace de rivage; (3) mars, après le retrait de la majeure partie de la glace de rivage. Plus de 90% de ces poissons étaient des quinnats juvénile. L'abondance du quinnat juvénile était semblable dans la zone de brassage de l'effluent et la zone témoin en amont. Les évaluations de la densité variaient entre 20 et 75 quinnats par 100 m de rivage (0,1 à 0,37 quinnat par mètre carré) dans la zone de l'effluent et entre 14 et 61 quinnats par 100 mètres de rivage (0,07 à 0,30 quinnat par mètre carré) dans la zone témoin.

L'établissement de la durée de séjour du quinnat juvénile dans la zone de brassage de l'effluent en hiver demeure difficile en raison du faible nombre de poissons marqués, et de la possibilité que le poisson s'en aille en aval en réaction au marquage. Au total 154 quinnats juvéniles ont été marqués en novembre et en janvier, 48 dans la zone de l'effluent et 106 dans la zone témoin. Quatre des soixante-cinq quinnats marqués en novembre ont été recapturés dans les sites à l'étude deux jours après avoir été relâchés. Aucun poisson marqué n'a été recapturé dans les sites quatre à six semaines après avoir été relâchés.

Durant la journée, des saumons quinnats ont été échantillonnés dans les espaces intersticiels des substrats côtiers faits de galets et de cailloux, souvent sous les plates-formes des glace de rivage. À la tombée du jour, ils se déplaçaient dans la colonne d'eau et demeuraient actifs toute la nuit dans les eaux de la zone littorale très peu profondes.

Mots clés: comportement de saumon quinnat, effluent des usines de pâte, habitat hivernal

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) reside in the upper Fraser River throughout the winter and are particularly abundant near Prince George (Rosberg and Assoc. 1987). These chinook emerge from redds in spring and migrate to sea after one year of freshwater residency.

In the Nechako River (a major tributary of the upper Fraser) juvenile chinook salmon occupy different habitats during the day and night in winter, moving from nearshore cover or river substrate during the day to free swimming positions along the shoreline at night (Emmett and Convey 1990). Several other studies have also shown that, in winter, juvenile salmon and trout move into the bottom substrate or into positions along nearshore cover (Hartman 1965, Bustard and Narver 1975, Rimmer *et al.* 1983). Emmett *et al.* (1992a) demonstrated that snorkel surveys conducted at night provided the best estimate of juvenile chinook abundance during winter.

In the Fraser River at Prince George, chinook are exposed to effluent from several pulp mills. However information on the degree of exposure a fish experiences in a given time to a particular concentration of effluent is unknown. It is possible that in winter, fish may be attracted to effluent mixing zones by elevated temperatures caused by the addition of effluent at 20 - 30^{o} C. Thus effluent mixing zones could contain greater numbers of fish, residing for a longer time, than similar habitat unaffected by effluent. Information on the abundance and residency of juvenile chinook salmon in effluent mixing zones is required for the design of ecologically relevant experiments that will lead to an understanding of the sublethal effects of pulp mill effluent on resident fishes.

The present study was designed to assess the abundance and residency of juvenile chinook salmon during the winter of 1993/94 in a pulp effluent mixing zone and in an upstream reference zone. We chose a section of the Fraser River around the Northwood Pulp and Timber Ltd. pulp mill near Prince George because of the documented high abundance of juvenile salmon in this area (Rosberg and Assoc. 1987). In addition, the absence of pulp mills or other significant sources of industrial or domestic effluent upstream of the mill , ensures that the reference (control) zone would be unaffected by pollution.

The specific objectives of this study were:

a) to assess the occurrence and abundance of juvenile chinook and other fish species in early, mid and late winter at two sites on the Fraser River near Prince George; one site in a pulp effluent mixing zone and a second site in an upstream reference zone,

b) to assess residency of juvenile chinook salmon at these two sites over a four to ten week period in winter using mark/recapture methods,

c) to collect descriptive information on habitat used by overwintering chinook during the day and at night, and to document any specific use of the effluent mixing zone,

d) to collect preliminary data on water temperature, conductivity and dissolved oxygen in the study area to determine any changes in these parameters resulting from the addition of the pulp mill effluent.

STUDY LOCATION

The field work occurred at the point of effluent discharge of the Northwood Pulp and Timber Ltd. pulp mill, which is located on the Fraser River north of Prince George, approximately 10.5km upriver from the confluence with the Nechako River (Figure 1 inset).

The bleached kraft mill discharges treated effluent is through a three port diffuser located on the river bottom 20 - 30m from the shore at winter flow levels. Figure 2 is a colour photograph of aerial imagery of the effluent mixing zone taken in September, 1993 for Environment Canada by G.A. Borstad and Associates, Victoria, B.C. The imagery shows graphically that downstream of the diffuser, the effluent is concentrated along the outer (northwestern) bank of the river as far until it rounds the river bend. Further downstream, the plume disperses across the main river channel.

After consideration of safety, logistics, and access under winter conditions, we elected to locate our study within the effluent zone along the outer river bank just downstream of the effluent discharge, and in a reference zone 100 to 500m upstream of the diffuser. Within each effluent and reference zone, we selected a site to conduct detailed studies of juvenile chinook salmon abundance; the "effluent site" and the "reference site" (Figure 1). At low winter flow levels, the shoreline at the two sites comprises a shallow to moderately sloped pebble and sand beach. The pebble substrate occurs to a depth of about 0.5m (1.5 to 4m from shore). Fine sand and silt predominate in deeper water. In November, the nearshore surface current was measured to be 0.4 to $0.6 m \cdot s^{-1}$ at both sites. Downstream of the sites, between the two beaver lodges shown in Figure 1, the shoreline comprises a shallow, flat bank of fine sand and silt. Further downstream, the river bank has been modified by the placement of rip rap to support the road bed for the BC Rail line. Nearshore river flow by the rip rap is swifter than at the effluent and reference sites, as the river thalwag runs against the shore at this location.

At low winter flow levels, the rip rap is mostly exposed, and fine sand and silt substrate dominate at depths below 0.5m.

Figure 3 details the nearshore physical features we recorded at the effluent and reference sites (see also Figures 4 - 7; photographs of these sites over the winter period). The two sites were selected because they showed similar nearshore physical features (nearshore depth profile, substrate, flow, back-eddies and degree of nearshore cover) and their accessibility. The shoreline length at both sites was 125m.

The effluent site extended from 80 to 205m downstream of the effluent discharge. Nearshore substrate along most of this shoreline is pebble with a small amount of cobble at the downstream end. Several metres from shore, the substrate is a mixture of pebble, fine sand and silt. Prominent nearshore habitat features of this site are several small back-eddies at the north end and a beaver lodge just below the downstream portion. At times, this shoreline was covered with surface foam from the effluent discharge (Figure 4).

The reference site extended from 200 to 325m upstream of the effluent discharge. Nearshore substrate is primarily pebble, with a higher amount of fine sand and silt than at the effluent site, particularly in the upstream and middle portions. There is one nearshore area of large woody debris (LWD) in the upstream half of the site, and a second LWD area was created by a large cottonwood tree which blew into the river on November 20th, 1993 (Figure 7). There are also several back-eddies in the downstream portion of this reach.

METHODS

Three field trips were planned over the winter of 1993/94; the first in November prior to river freeze up, the second in January during freeze up, and the third in March. The abundance of chinook salmon was assessed at night using snorkel floats or, during ice covered periods, by SCUBA methods. In addition to examining the effluent and reference sites described above, ancillary surveys were conducted within the effluent and reference zones, extending to the rip rap shoreline downstream of the effluent site. A limited collection of water quality data was made to attempt to delineate the downstream extent of the effluent plume with the objective of correlating fish distribution to the presence of dilute effluent.

Dive Surveys, Sampling and Marking

During daylight hours, the effluent and reference sites were divided into 20m sections and marked by numbered pins. A diver obtained data on water clarity by measuring the horizontal (along the axis of river flow) extinction distance of a Secchi disk.

The dive surveys were initiated 1 to 2 hours after sunset, which was about 1830 h in November and January, and 1930 h in March. In general, two replicate floats were conducted at each site by divers equipped with dry suits. In ice free conditions a single diver (equipped with a snorkel) swam upstream or, in swifter current conditions, drifted downstream 1-3m from shore. At night, the diver used a high-powered light to search for fish. Counts of all species of fish were made and the data recorded by one of the shore crew, who were positioned adjacent to the diver.

In January, portions of both the effluent and reference sites were ice-covered and SCUBA methods were used to count fish. A rope-tethered diver, tended by a member of the shore crew, dove under the shore-fast ice ledge and counted fish using the underwater light. A second diver (fully suited and tethered to a second member of the shore crew) was present as a safety precaution.

Chinook salmon were captured using a diver operated, submersible electrofisher (Emmett *et al.* 1992b). The fish were retrieved with a dip net, quickly passed to the shore crew and placed in a bucket containing river water. A separate bucket was used for each 20m section of the site. The captured fish were then moved to a heated tent located on the shore adjacent the site where they were transferred to a bucket containing anaesthetic (tricaine methanosulfonate at a concentration of $50 mg \cdot L^{-1}$) and, while under anaesthetic, the fork length of each chinook was measured and recorded. In March, the weights (to 0.1g) of all juvenile chinook captured were also recorded. The fish were then freeze-branded with a silver tipped brand (dot or bar) which had been cooled to -70°C in a dry ice/acetone bath (Bryant *et al.* 1990). One of four specific areas above the lateral line of the fish (right or left anterior side, right or left posterior side) was marked. A unique mark was used for each survey date at each site. These marks are symbolized as follows:

RP •	Right Posterior Dot
RP –	Right Posterior Bar
LA •	Left Anterior Dot
LP •	Left Posterior Dot
LP –	Left Posterior Bar

Marked juvenile chinook were held in aerated 20 litre plastic buckets until they recovered from the anaesthetic, then replaced into the same 20m section of river where they had been captured.

Stomach Content Sampling

In order to assess whether the juvenile chinook at the effluent and reference sites were feeding in winter, four fish from the effluent site were collected in January, and sixteen fish (6 from the effluent site and 9 from the reference site) were collected in March. These were slit open and preserved in 10% formalin for subsequent gut contents analysis. The composition of the gut contents of fish collected in March was also determined.

Diel Movement

In March, diel habitat selection by juvenile chinook was examined experimentally by placing five fish, which were captured at night using the submersible electrofisher, into each of two 1 x 1m wire mesh (6mm mesh size) enclosures. The enclosures were installed 1m apart in the reference zone, approximately 1m from shore in water 10-30cm deep. The edges of the mesh were buried in the river substrate (pebble and medium sand with some cobble) to prevent the fish from escaping under the walls. Over a two day period, and at intervals of 2 to 8 hours, observations of these fish were made during the day and at night (using dive lights from above the water surface) to determine their presence in water or substrate.

In March, divers equipped with snorkels conducted surveys during daylight hours prior to the night floats to compare the presence of free swimming fish in nearshore areas during the day and night. In addition, backpack electrofishing (Smith Root Model 15A) was conducted during the day at two locations within the reference zone and one location in the effluent site to obtain data on the abundance of chinook within nearshore substrate cover and to record microhabitat features associated with the daytime position of the fish.

Water Quality Monitoring

During January and March, data on water temperature, pH, conductivity and dissolved oxygen were obtained at representative locations within the reference and effluent sites using a Hydrolab DataSonde 3 instrument. At the reference site, the Hydrolab was deployed overnight at a single location 230m upstream of the effluent discharge (Figure 9) and programmed to collect data on an hourly basis (1800 hours to 0900 hours). The same data collection program was used at two locations in the effluent site (85 and 180 m downstream of the effluent discharge (Figure 9). The DataSonde was also deployed at a depth of 1m directly in the effluent pond from the walkway providing access to the diffuser intake screen. The physicochemical characteristics of this effluent represent those of the final discharge into the Fraser River and provide a baseline for the corresponding plume data.

In an effort to delineate the effects of effluent discharge on surface water quality, the Hydrolab was also deployed from a small boat while it drifted downstream through the plume with the river current. These drifts extended from 230m upstream to 830m downstream of the diffuser. Two replicate drifts were made in January and three were conducted in March. Hydrolab readings were taken at stations spaced 50 - 100m apart along a trajectory parallel to, and approximately 4m from the shore (Figure 9). Positions were referenced to markers placed along the shoreline. With a shore mark abeam, the motor was used to hold position against the current, the Hydrolab was deployed over the bow with the monitoring probes at a depth of 0.2 to 0.3m and, when on station, the data were recorded.

RESULTS

The first field trip took place from November 17 - 21, 1993, the second from January 18 - 21, 1994 and the third from March 9 - 11, 1994. In November, mild temperatures prevailed until November 20, when the air temperature fell to -25°C (Table 1). This cold front was accompanied by strong to gale-force winds. The water temperature fell from 2 to 0°C and shore and drift ice formed rapidly. Figures 4 and 5 indicate ice conditions at the effluent and reference zones on November 18 and 21.

During the winter of 1993/94, the Fraser River did not freeze over completely at the study site, however the river did freeze over completely about 5km upstream (G. Hann, Northwood Pulp and Timber Ltd., pers. comm.). In January, there was a 4-8m wide ice shelf (10-20cm thick) at the effluent site and a 25-45m wide ice shelf (20-30cm thick) at the reference site (Figure 6). Slush pan ice floated continuously down the central part of the river. To facilitate diving efforts, we used a chainsaw to cut away the outer 2 to 4m of the ice shelf at the effluent site and the outer 15m of the ice shelf along a 40m section of the reference site (see Figure 6). In March, the extent of the shore ice was reduced and only several patches up to 3m wide remained (Figure 7).

For all surveys dates, water clarity, as measured by Secchi disk during daylight hours, ranged between 1.0 and 2.0m. Water clarity was greatest in January, presumably due to the lack of turbid runoff from land to the river. These visibility conditions were less than optimal for snorkel surveys and, at night, suspended particulate matter caused considerable scatter of the dive light beam. Nevertheless, using a light at night, a diver could identify chinook at a maximum distance of 0.5 to 1.5m, depending on water clarity.

Water Quality Measurements

Figure 9 indicates the location of the Hydrolab monitoring stations at the effluent and reference sites and details the sampling points for the surface water measurements made upstream and within the effluent mixing zone. Tables 2, 3a and 3b present data collected during replicate drifts in January and March. Table 4 compares data collected at a fixed station upstream of the diffuser with those at two stations downstream of the discharge where the plume overlaps nearshore chinook habitat. Data on final treated effluent during the time of the boat drifts are also provided in Tables 2 and 4.

Dissolved oxygen in surface water upstream of the diffuser was slightly undersaturated (96%) in January, and dropped to 85% by March. Effluent input reduced these values by a further 1-2% and clearly affected background temperature and conductivity (Table 3b) beyond the last downstream (830 m) station (Figure 9). On March 11th, the effluent plume raised the conductivity from a mean of 163 $\mu S \cdot cm^{-1}$ in the reference zone to 192 at station 20 (Table 3b). The corresponding temperature rise was 0.42°C. The maximum mean (replicate drifts) temperature (1.2°C) was recorded at station 4, 40m downstream of the diffuser. Single overnight recordings close to shore (Figure 9) indicated virtually no difference in temperature although a slight rise in conductivity and reduction in dissolved oxygen from 86.6% to 80.8 saturation were recorded (Table 4).

Chinook Abundance

Over the winter, counts of juvenile chinook made by divers at the effluent and reference zones ranged between 14 - 172 per 100m of shoreline (Table 5). The lowest count (14 chinook per 100m) was made at the reference site on the night of November 20th when high winds and rapidly falling air temperatures (to -25°C), triggered the rapid formation of shore ice and increased turbulence due to wave action. The highest count of 172 per 100m on March 10th was obtained over a 50m section of the reference site where a large number of chinook were aggregated under a small ice shelf. At the reference site, the greatest densities were recorded in January and March; 50 - 60 chinook per 100m as compared to 14 - 32 chinook per 100m in November.

At the effluent site, chinook densities were greatest in January; 65 - 75 chinook per 100m as compared to 20 - 30 chinook per 100m in November and March.

Juvenile chinook were observed in all six 20m sections of both sites, but were particularly abundant at specific locations. In November, in the absence of ice, many chinook were located close to shore in water less than 10 cm deep. In January and March, the fish aggregated under ice ledges, usually in water from 20cm to 1 m deep. At all times, very few chinook were observed in deeper water 2-3m from shore. At the effluent site, chinook salmon were most abundant in the upstream 30m section, which contained a number of back-eddies and in the downstream 20m section, where they were associated with beaver lodge cover (Figure 3). In November at the reference site, chinook were associated with the upstream large woody debris shown in Figure 3. In March, 40 - 50 chinook were observed under a section of shore ice 10m long by 1.5m wide just downstream of a fallen cottonwood tree (Figure 7).

As seasonal changes in shoreline habitat (including ice cover) appeared to influence the distribution and abundance of juvenile chinook, it is difficult to ascertain whether they were attracted specifically to the effluent zone, where the water temperatures were slightly higher (~ 0.5°C) than at the upstream reference site. There is some suggestion that this might have been the case in January. When the water temperature outside of the effluent zone was - 0.06°C, the density of chinooks within the plume (mean 0.67°C N=18) was 2 to 3 times greater than in November when the water temperature outside of the effluent zone was 1 to 2°C. The counts for the reference site in November and January cannot be similarly compared as only the lower section of the site was accessible in January.

Snorkel surveys of the upstream end of the rip rap area were conducted in November and March, however the efficiency of the divers' observations was limited by higher water velocity and turbidity than encountered in the upstream sites. In November, chinook abundance in the rip rap was similar to that in the effluent and reference zones, whereas in March, far fewer chinook were observed in the rip rap than upstream (Table 5).

Length, Weight and Gut Contents of Chinook

In November, the mean length of chinook captured at the reference (68.8 mm) and effluent (67.6mm) sites was very similar (Table 7 and Figure 8). In January, the mean length of chinook at the effluent site was identical to the November sample (68.8mm). However, in March the mean length of fish from the effluent site was 4mm less than the January and November sample. This difference is significant ($p < 0.05$ and 0.01) using a two sample t-test. At the reference site, the mean length of fish sampled in March was 2.5mm less than the November sample, a significant difference at $p < 0.05$ but not significant at < 0.01 (two sample t-test).

All the chinook sampled for stomach content analysis appear to have been recently feeding, with gut contents representing a range of 0.40 - 2.81% of wet body weight. A comparison of means of gut contents as percentage body weight was not made because of the split timing of collection of chinook from the effluent zone. However, median values and ranges were 1.01 (0.50 - 1.60%) for the effluent zone and 1.03% (0.40 - 2.61%) for the reference zone respectively. Table 8 presents the lengths, weights and stomach content weights of these preserved fish, whereas the composition of the gut contents is outlined in Table 9. Insect larvae and nymphs including chironomids, simuliids (blackflies), Ephemeroptera (mayflies) and Plecoptera (stoneflies) comprised the major prey items of juvenile chinooks at this time of year (Table 9).

Mark/Recapture Data

Table 6 summarizes the mark recapture data at the effluent and reference sites. A total of 154 chinook were marked with one of five unique freeze brands; 48 from the effluent site in November and 106 from the reference site in November and January. At the effluent site, 25 chinook were marked and released on November 18 (left posterior dot, LP•), and 25 marked and released on November 20 (left posterior bar, LP–). One of the fish marked on November 18 was recaptured at the effluent site two nights later (November 20). In November, 48 chinook were marked and released at the reference site, 40 on November 18 (RP•), and 8 on November 20 (RP–). Three of the fish released at the reference site on November 18 were recaptured 2 nights later, two at this site and the third about 300m downstream at the effluent site.

At the effluent site, 61 chinook were examined in January for marks applied in November. No marks were observed. Of these 61 fish, 56 were marked (LA•) and released. In March, 32 chinook were examined for marks applied in November and January. Again no marks were observed.

At the reference site, no fish were captured in January due to the extensive ice shelf which precluded operation of the submersible electrofisher. In March, 86 chinook were captured and examined for marks applied in November and January. One of these chinook may have been marked (LP•, applied November 18 at the effluent site), but the mark was sufficiently faded that it could not be identified with certainty. If this fish was marked, it would be the only fish of a total of 154 with demonstrated extended residency in a small reach of the river over the winter.

Diel Movement

In March, the diel movement of chinook in and out of positions within nearshore substrate or cover was investigated using three methods: enclosures, snorkel drifts during the day and night, and backpack electrofishing during the day.

At 1930 h on March 9, five chinook were placed in each of the two enclosures. At 2300 h of the same night, four fish were visible (emerged from the substrate) in the upstream enclosure and five chinook were visible in the downstream enclosure. At 1045 h (daylight) on March 10, no fish were visible in the upstream enclosure and two fish were visible in the downstream enclosure. This same pattern continued throughout daylight hours, with one to three fish visible in one of the two enclosures. The following night (2230 h) four chinook were visible in each of the two enclosures. When the enclosures were dismantled during the day on March 11 only four chinook were recovered from each enclosure. These observations show a general pattern of retreat into substrate during the day and emergence at night, however the observations were equivocal as the pattern of retreat and emergence appeared to continue throughout daylight hours. This could be an artifact related to the enclosure method, as the fish were observed, both during the day and at night, attempting to escape the enclosure. One fish from each enclosure did escape over the two day observation period.

On March 9 and 10 comparative day and night snorkel counts were carried out at the effluent and reference sites. At the effluent site, six fish were observed during the day float and 25 chinook during the night float. The fish observed during the day could not positively be identified as chinook as most were startled from under ice ledges or pebble substrate and moved rapidly from the diver. Four of the six fish observed during the day at the effluent site were seen under ice shelf cover. At the reference site one fish was observed during the day float and 60 chinook at night.

On March 10 and 11, a single backpack electrofishing pass was conducted at three locations in the study area. The first location was the downstream 40m section of the effluent site. A single chinook salmon was captured from pebble substrate (2-5cm in size) at a depth of approximately 30cm.

The second sampling area was 67m of shoreline approximately 50 m upstream of the effluent discharge. Four chinook were captured from positions within pebble and cobble substrate (2-10cm in size). All fish were positioned within 1.5m of shore, in water less than 30cm deep.

The third sampling area was a 30m section of shoreline containing ice shelf at the downstream end of the reference site. A total of 55 chinook had been taken from this section the previous night using the submersible electrofisher. During the day, 31 chinook were captured from under the ice ledge. The mean length ($\pm$ standard deviation) of these chinook (65.9 $\pm$ 5.6mm) was virtually identical to chinook sampled from this section the previous night (66.0 $\pm$ 5.4 mm).

Diver Observations in the Effluent Mixing Zone

In November, a dive was made during daylight hours at the point of effluent discharge into the Fraser River (Figure 1). At the time, it appeared that only one of the three diffuser ports was operating. At the point of discharge the river depth was 2 - 3m and the substrate was primarily pebble with associated sand and silt. The diver entered the water about 10m downstream of the effluent diffuser and drifted downstream in the centre of the plume for approximately 40m. Visibility within the effluent plume was less than 20cm and no observations of fish could be made.

At the effluent site, the turbidity within the effluent plume was greatest approximately 15m from shore. However, discoloured water indicative of effluent mixing, was observed up to the shoreline. On several occasions in November and March, surface foam from the effluent accumulated along 50 to 100% of the shoreline at the effluent site (Figure 4).

Other Fish Species

In January, no other species other than chinook salmon were observed in the dive surveys (Table 5). However, in November and March, mountain whitefish (*Prosopium williamsoni*) ranked second in abundance to chinook. Several Dolly Varden (*Salvelinus malma*), 20-30cm in length, were also observed as well as a number of cyprinids and catostomids. In March, a single adult rainbow trout (*Oncorynchus mykiss*) was observed in the rip rap.

Most of the mountain whitefish were juveniles, similar in size (55-90mm) to juvenile chinook. About 10% were larger sub-adults, 100-150mm in size. The juvenile mountain whitefish were generally observed in nearshore positions similar to those described above for juvenile chinook (eg. in water less that 1m deep and under ice ledges). The sub-adults were observed in deeper water further from shore.

DISCUSSION

This study set out to examine whether fish, particularly juvenile chinook salmon, utilized the effluent mixing zone during winter low flow conditions. In addition, we wanted to determine if there was a preferential use of the effluent mixing zone by fish in winter, possibly due to the elevated temperature regime. Finally we wished to investigate the residency time of fish utilizing the effluent mixing zone.

During this study, unforseen circumstances dictated that the concurrent water quality sampling effort originally planned be scaled back. However, the limited data clearly document the downstream influence of the effluent discharge on the nearshore habitat as far as 830m. The temperature and conductivity were elevated, pH remained unchanged and dissolved oxygen saturation was reduced by approximately 2% in the effluent reach during a winter when ice cover in the study area was limited to shelf ice. Since oxygen saturation in the reference reach was depressed (85 %), in years when more extensive ice cover is present, the oxygen demand of the effluent could most likely reduce dissolved oxygen to approximately 80% saturation at least as far as 830m downstream.

Considering the difficulty of drifting along a fixed trajectory during winter conditions and the complex mixing processes of diffusers, the water quality data show remarkable consistency between replicate drifts. This suggests that the technique is feasible and could be repeated in the future to delineate the plume more precisely.

The snorkel surveys showed unequivocally that fish were present in the effluent mixing zone from November to March. Over 90% of the fish observed were juvenile chinook salmon. During the day, chinook salmon were found within nearshore pebble and cobble, often under ice shelves. At dusk, they were observed in the water column and remained active throughout the night in this shallow nearshore habitat. On several occasions this behaviour exposed the fish to surface foam from the effluent plume which accumulated along the shoreline on windy nights. Since BKME foam is known to fractionate xenobiotics, foam accumulation in this nearshore overwintering habitat could serve as additional exposure route of fish to persistent toxicants surviving the treatment process.

Gut contents analyses indicate that chinooks were actively feeding to an equivalent degree in both zones, most likely at night. This finding brings up the question of the potential contribution of the food chain in uptake of persistent contaminants by chinooks overwintering in nearshore habitat impacted by effluents.

Based on our limited mark and recapture effort, there was no clear evidence that the abundance of juvenile chinook was greater within the effluent mixing zone than in the upstream reference zone. On most sample dates, the counts of juvenile chinook salmon at the effluent and reference sites were similar. However in January, the density of chinook at the effluent site was 2-3 times greater than in November, indicating that fish could have aggregated in this area during the period of coldest water temperatures. At this time, the temperature differential between reference and the effluent zone reached 1.83°C at the diffuser and remained elevated by 0.57°C at the most downstream station (530m) downstream of the discharge. No differences in the behaviour or habitat selection preferences of chinook were noted between the two zones. However as juvenile chinook will aggregate around nearshore habitat features in winter (Emmett and Convey 1990), the quantity and quality of these features will play a large role in determining the number of fish which occupy a given section of shoreline under varying flow and ice conditions. In March, there was a smaller section of ice shelf at the effluent site than at the upstream reference site which also contained large woody debris at the upper limit of the shelf. Such physical features could be expected to greatly influence chinook abundance in the nearshore zone.

The length data (both mean length and the histograms) suggest two alternate possibilities. First that chinook captured at the effluent and reference sites in March were different fish than those taken in November or January. These smaller fish may have reared further upstream in colder water temperatures and by March, were gradually moving downstream. Second, by March, a higher proportion of larger sized fish (eg. >68mm) had moved downstream of the survey area.

The densities of juvenile chinook at the reference and effluent zones were at least an order of magnitude greater than those recorded on the Nechako River during the winter (Emmett and Convey 1990), where the mean density of juvenile chinook at 23 sites surveyed by single pass snorkel counts conducted at night was 1.8 chinook per 100m of shoreline. The range of these density estimates was 0 to 6.6 chinook per 100m; all less than density estimates for the Fraser River reference and effluent sites.

Rosberg and Associates (1987) sampled three Fraser River sites near Prince George but downstream of our study area from December 1986 to March 1987 using a backpack electrofisher during daylight hours. For these sites, the authors report chinook densities ranging from 0.04 to 0.19 fish $\cdot$ m^{-2}. In the current study in which we conducted only a limited amount of day electrofishing, the chinook density was 0.02 fish $\cdot$ m^{-2} at one site and 0.41 fish $\cdot$ m^{-2} at the second site. If we assume that at night, divers searched a 2 m wide area of nearshore river bottom, our observed chinook densities (14 to 79 fish per 100m of shoreline) would convert to 0.07 to 0.37 fish $\cdot$ m^2.

A recent study (Griffith and Smith, 1993) of the use of winter cover by juvenile cutthroat (*Oncorhynchus clarki*) and brown trout (*Salmo trutta*) indicated that not all (60-70%) of the juvenile trout population concealed in the substrate during the day emerged to swim in the water column at night. Thus care must be taken when comparing abundance estimates made by daytime electrofishing with estimates made utilizing night snorkel counts. If juvenile chinooks exhibited this behaviour, snorkel counts would underestimate the actual numbers.

The determination of residency time of juvenile chinook within the effluent mixing zone in winter remains problematic. Extremely difficult working conditions in November and January limited marking to a small number (154) of chinook. Four of the 65 fish marked in November were recaptured two days later and no marked chinooks were recaptured four to six weeks after marking. Based on these limited numbers, the results indicate that site fidelity is not high.

It is plausible that marked fish may move downstream in response to the stress resulting from capture, anaesthesia and marking procedures. However similar marking experiments with juvenile chinook and other salmonid species using a variety of marking methods, indicate that site fidelity in winter may be limited. Emmet et al. (1992 b) fin-clipped juvenile chinook at five sites on the Nechako River in mid-November just prior to freeze-up. Up to 50% (but more generally 10-25 %) of marked chinook were recaptured at the site of marking 1-2 days after release. Four of the five sites were re-surveyed two weeks after release and at these sites from 5-30 % of the marked fish were recaptured. Cunjak and Randall (1993) marked Atlantic salmon (Salmo salar) in early winter in three streams in Atlantic Canada. Recapture of marked individuals in late winter (March/April) ranged between 2 and 30%, with the highest recapture recorded for parr (ages 1 and 2) as compared to fry. In our study, four of 65 fish marked in November were recaptured two days later. Furtherore, there was no conclusive evidence that any of the marked chinook resided at the study sites for a period of four to six weeks after marking.

One method of estimating residency time is to mark a large number of fish over a short period of time, release these fish and sample for recaptures at regular intervals (ie. every day or every week following release). The residency time is estimated from area under the curve (AUC) calculations, which provides an estimate of the time that one half of the marked fish remain at the site (English *et al.* 1992). This method assumes that all marked fish present at the survey site are available for capture on any given sampling date; an assumption which may not be valid if a proportion of the chinook population at a particular site chose to remain in substrate rather than move into the water column at night. However, based on our experience, it would be difficult to implement this method of residency assessment in winter, when ice conditions and air temperatures can fluctuate greatly and are virtually guaranteed to interrupt the mark and recapture schedule.

In subsequent field studies of winter residency of juvenile chinook, the following points should be considered:

Mark retention could be improved by applying the freeze brands using liquid nitrogen (Mighell 1969, Knight 1990) rather than dry ice/acetone as a coolant.

PIT (passive integrated transponder) tags (Prentice *et al.* 1990) are a potential alternative marking method. The advantages include excellent tag retention, unequivocal identification of marked fish after capture and the ability to recognize individual fish. A disadvantage is cost ($4-5 per tag) and the requirement for a detector-decoder to identify tagged fish.

Visible implant tags, particularly fluorescent elastomers, could also be used to mark fish (J. Webster, Northwest Marine Technology, Olympia, Washington, pers. comm.). Fluorescent elastomers are injected as a liquid into non-pigmented tissue. The material solidifies and the colour is detected under UV light. It is quite feasible to mark chinook 50 to 90mm in size using this material. A major advantage of this marking system is that the marks could be seen underwater by divers, eliminating the need to recapture fish in order to detect marks.

Either the submersible electrofisher or a conventional backpack electrofisher could be used at night to capture fish for the initial application of marks. In order to increase the number of marked fish released, fish may have to be captured and marked over a two or three night period and held prior to release.

Downstream migration of marked chinook could conceivably be assessed by installing a fyke net at the downstream end of the survey site. However, ice conditions (both drift and unstable shore ice) could be expected to severely limit the use of this capture technique in the Fraser River.

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Table 1. Weather and river conditions during the sampling periods.

DATE	WEATHER		RIVER CONDITIONS		
	General	Air Temp. (^oC)	Water Temp. (^oC)	Visibility (m)	Ice
Nov. 17 - 21 1993	Overcast and sunny. Windy at times (50km.h^{-1})	+5 to -25	0.5 to 2	~ 1	No ice to Nov. 20, then frazil ice, thin shore ice, and drifting pans
Jan. 18 - 21 1994	Overcast, calm, snow flurries	+3 to -10	0	1 - 2	4 - 8m wide ledge at effluent zone. 15 - 30m wide ledge at reference zone. Drift slush ice in river.
Mar. 9 - 11 1994	Overcast, some snow flurries and drizzle	+5 to -10	0	~ 1.5	Patchy ice ledge to 2m wide at effluent zone. Patchy ice ledge to 4m wide at reference zone. Drift slush ice in river.

Table 2. **Data on surface water temperature, pH, conductivity [1] and dissolved oxygen collected using the Hydrolab DataSonde 3 during replicate boat drifts through the Northwood plume conducted on January 21, 1994 (1245-1532h). Concurrent effluent parameters were measured in the effluent diffuser pond.**

SURFACE DRIFTS

STATION[2]	TEMP (°C)	pH (units)	CONDUCT. ($\mu S \cdot cm^{-1}$)	DISSOLVED ($mg \cdot L^{-1}$)	OXYGEN (% Sat)
1	-.05 -.07	7.47 7.51	160 160	13.14 13.12	97.0 96.9
2	-.05 -.07	7.47 7.51	160 160	12.95 12.98	95.6 95.8
3	1.78 0.40	7.47 7.46	309 175	12.22 13.55	95.1 101.3
4	1.44 0.57	7.47 7.49	322 224	12.45 12.38	96.0 93.0
5	0.76 0.95	7.46 7.52	253 233	12.82 12.34	96.9 93.8
6	0.60 0.40	7.45 7.52	222 191	12.92 12.30	97.3 92.0
7	0.69 0.40	7.48 7.51	226 203	12.73 11.91	96.0 89.1
8	0.47 0.50	7.49 7.49	207 211	12.51 12.35	93.8 92.7
9	0.47 0.60	7.49 7.50	207 217	12.47 12.49	93.4 94.0
10	0.48 0.60	7.49 7.51	206 218	12.45 12.49	93.4 94.0
14	0.52 0.50	7.50 7.50	210 209	12.89 12.72	96.8 95.4
EFFLUENT	24.91	7.32	2210	2.01	26.5

[1] Conductivity corrected to 25°C

[2] Station locations as indicated in figure 9

Table 3a. **Data on surface water temperature, pH, conductivity and dissolved oxygen collected using the Hydrolab DataSonde 3 during replicate boat drifts[1] through the Northwood effluent plume conducted on 10 March, 1994.**

STATION	TEMPERATURE (°C)	pH (units)	COND.[2] ($\mu S \cdot cm^{-1}$)	DISSOLVED ($mg \cdot L^{-1}$)	OXYGEN (% sat)
1	0.05 0.05	6.90 7.21	159 159	11.68 11.56	86.7 85.7
2	0.03 0.08	7.01 7.25	159 159	11.61 11.49	86.0 85.3
3	0.03 0.07	7.02 7.24	159 159	11.61 11.50	86.0 85.3
4	0.45 0.22	7.05 7.27	185 173	11.34 11.26	85.1 83.9
5	0.41 0.67	7.08 7.27	190 213	11.36 11.19	85.1 84.5
6	0.64 0.36	7.09 7.27	208 185	11.32 11.29	85.3 84.5
7	0.36 0.41	7.11 7.28	186 186	11.37 11.30	85.1 84.7
8	0.43 0.53	7.13 7.28	190 199	11.35 11.27	85.1 84.8
9	0.38 0.41	7.14 7.28	184 186	11.36 11.32	85.1 84.8
10	0.33 0.21	7.14 7.28	178 166	11.41 11.38	85.3 84.8
11	0.55 0.36	7.17 7.28	200 182	11.32 11.35	85.2 84.9
12	0.43 0.29	7.18 7.29	186 175	11.33 11.37	85.0 84.9
13	0.38 0.31	7.20 7.30	184 174	11.34 11.40	84.9 85.2
14	0.45 0.46	7.18 7.30	190 189	11.51 11.31	86.3 84.9
15	0.52 0.45	7.13 7.24	191 190	11.66 11.43	87.3 85.7

[1] Station locations as indicated in Figure 9. First drift started at 12:58 h; second at 13:51 h. Starting distance of trajectories from shore estimated at 4m.
[2] Conductivity corrected to 25°C

Table 3b. Data on surface water temperature, pH, conductivity and dissolved oxygen collected using the Hydrolab DataSonde 3 during replicate boat drifts[1] through the Northwood effluent plume conducted on 11 March, 1994.

STATION	TEMPERATURE (°C)		pH (units)		COND.[2] (µS • cm⁻¹)		DISSOLVED (mg • L⁻¹)		OXYGEN (% sat)	
1	0.07	0.09	7.17	7.22	163	163	11.38	11.38	86.0	84.5
2	0.07	0.14	7.21	7.26	162	163	11.50	11.24	85.3	83.6
3	0.07	0.09	7.22	7.27	162	163	11.42	11.26	84.7	83.6
4	1.48	0.91	7.21	7.28	279	227	11.06	10.91	85.4	82.9
5	0.22	0.48	7.25	7.28	173	193	11.26	11.11	83.9	83.4
6	0.22	0.38	7.26	7.30	174	185	11.32	11.09	84.4	83.0
7	0.38	0.22	7.25	7.31	189	165	11.32	11.15	84.7	83.1
8	0.59	O.29	7.27	7.31	204	173	11.22	11.18	84.5	83.5
9	0.33	0.26	7.27	7.29	180	168	11.26	11.18	84.2	83.4
10	0.26	0.31	7.28	7.31	170	169	11.32	11.17	84.5	83.4
11	0.40	0.29	7.29	7.31	187	177	11.26	11.22	84.4	83.8
12	0.41	0.36	7.28	7.32	187	181	11.23	11.12	84.2	83.2
13	0.43	0.45	7.30	7.32	188	183	11.24	11.09	84.3	83.2
14	0.40	0.62	7.28	7.32	185	204	11.43	11.01	85.6	83.0
15	0.48	0.62	7.25	7.32	193	204	11.47	11.01	86.1	83.0
16	0.50	0.50	7.26	7.32	197	197	11.18	11.02	84.0	82.8
17	0.26	0.43	7.19	7.33	184	193	11.75	11.06	87.6	82.9
18	0.19	0.43	7.19	7.32	170	194	11.81	11.03	87.9	82.7
19	0.31	0.28	7.19	7.33	187	197	11.46	11.17	85.7	83.4
20	0.36	0.48	7.20	7.32	186	197	11.20	11.03	83.8	82.8

[1] Four additional stations (16-20) were added at 50 m intervals as indicated in Figure 9. First drift began at 12:37 h; second at 13:00 h. Initial distance of trajectories from shore estimated at 4m.

[2] Conductivity corrected to 25°C

Table 4. **Means and ranges of water temperature, pH, conductivity and dissolved oxygen measurements collected overnight[1] March 9/10 and 10/11, 1994 using the Hydrolab Data Sonde at fixed monitoring stations[2] located within the reference effluent sites and the Northwood effluent diffuser pond[3].**

STATION	TEMP (°C)	pH (units)	CONDUCTIVITY ($\mu S \cdot cm^{-1}$)[4]	DISSOLVED OXYGEN ($mg \cdot L^{-1}$)	(% Sat)
CONTROL	**-0.05**	**7.42**	**157**	**11.71**	**86.6**
	-0.07-0.00	7.34-7.45	156-158	11.60-11.87	86.0-87.8
EFFL 1	**-0.05**	**7.42**	**162**	**10.91**	**80.8**
	-0.09-0.00	7.39-7.44	160-164	10.40-11.37	76.9-84.2
EFFL 2	**-0.01**	**7.43**	**165**	**11.37**	**84.1**
	-0.03-0.02	7.41-7.44	164-166	11.31-11.42	83.7-84.6
EFFL. POND	**24.96**	**7.29**	**2067**	**2.15**	**28.4**
	24.95-24.97	7.26-7.31	2067-2068	2.12-2.18	28.0-28.7

1 N=16; Data collected hourly from 1800 h to 0900h the following day.
2 Station locations as indicated in Figure 9.
3 N=3; Data collected at 30 min intervals beginning at 1344 h March 11, 1994.
4 Conductivity corrected to 25°C.

Table 5. Summary of fish counts from night snorkel or SCUBA surveys.

LOCATION	DATE	SHORE LENGTH (m)	# FLOATS	CHINOOK		OTHER FISH SPECIES				
				#	# per 100m	WF	RBT	DV	CYP	CAT
Effluent Site	[1]Nov.18	125	2	25	20	4	-	-	1	-
	[1]Nov.20	125	2	34	27	3	-	-	1	-
	Jan.18	125	1	86	69	-	-	-	-	-
	Jan.19	125	1	94	75	-	-	-	-	-
	[1]Mar.9	125	2	32	26	1	-	-	-	-
	Mar.10	125	1	27	22	5	-	1	-	1
Reference Site	[1]Nov.18	125	2	40	32	2	-	-	-	-
	[1]Nov.20	125	2	18	14	3	-	1		1
	[1]Jan.20	45	1	22	50	-	-	-	-	-
	[1]Mar.10	50	2	86	172	2	-	-	1	-
	Mar.11	125	1	76	61	3		1	1	-
Other Areas										
Effluent Zone	Nov.17	210	1	62	30	18	-	1	5	-
(rip rap)	[2]Nov.17	150	1	40	-	1	-	-	2	27
	[2]Mar.11	100	2	7	7	-	1	-	-	7
Reference Zone	Nov.17	300	1	72	24	5	-	-	-	1
Reference Zone	[2]Nov.19	125	1	46	37	1	-	-	-	1

CH = Chinook (O. tshawytscha); WF = Whitefish (Prosopium williamsoni); RBT = Rainbow trout (O. mykiss); DV = Dolly Varden (Salvelinus malma); CYP = cyprinids; CAT = catostomids

1 Chinook count is the sum of chinook captured in two replicate floats.

2 Chinook count is mean count of two replicate floats where chinook were counted but not captured for marking.

Table 6. **Mark/Recapture Data.**

SITE	DATE	# CHINOOK CAPTURED			MARKS APPLIED		RECAPTURE	
		Float 1	Float 2	Total	# Chinook	Type	# Chinook	Type
Effluent	Nov.18	10	15	25	25	LP•	n/a	n/a
	Nov.20	19	8	27	25	LP–	1 1	LP• RP•
	Jan.19	61	n/a	61	56	LA•	0	
	March 9	25	7	32	n/a	n/a	0	
Reference	Nov.18	32	8	40	40	RP•	n/a	n/a
	Nov.20	8	3	11	8	RP–	3	RP•
	March 10	60	26	86	n/a	n/a	1 (?)	LP•

n/a = not applicable; ? = mark could not be identified with certainty

Table 7. **Mean length and weight of chinook sampled at the effluent and reference sites.**

SITE	DATE	LENGTH (mm)			WEIGHT (g)		
		Mean	SD	N	Mean	SD	N
Effluent	Nov.18/20	68.8	7.6	49	-	-	-
	Jan.19	68.8	5.9	61	-	-	-
	March 9	64.8	5.5	32	2.9	0.8	32
Reference	Nov.18/20	67.6	7.0	48	-	-	-
	March 11	65.0	5.3	86	3.0	0.8	86

Table 8. **Preserved lengths, weights and gut contents of chinook salmon captured in the effluent and reference zones 19 January and 9/10 March, 1994.**

			INTACT	FISH	GUT	CONTENTS
SITE	DATE	ID #[1]	LENGTH (mm)	WEIGHT (g)	WEIGHT (g)	% BODY WEIGHT
Effluent	Jan 19	/	69	4.39	0.056	1.28
		/	79	6.26	0.115	0.80
		/	70	3.98	0.028	0.70
		/	67	3.90	0.027	0.70
	Mar 9	1	89	4.79	0.040	0.84
		2	69	4.04	0.020	0.50
		3	48	1.34	0.015	1.11
		4	62	3.38	0.040	1.18
		5	56	1.88	0.030	1.60
		6	55	2.29	0.035	1.53
Reference	Mar 10	7	66	3.24	0.020	0.62
		8	58	3.47	0.030	0.86
		9	76	4.93	0.040	0.81
		10	64	3.32	0.040	1.20
		11	58	2.71	0.030	1.11
		12	58	2.16	0.050	2.31
		13	59	2.67	0.075	2.81
		14	58	2.29	0.045	1.97
		15	60	2.51	0.010	0.40
		16	57	2.72	0.015	0.55

[1] Numbers correspond to fish id # (gut content) in Table 9. Contents of sample 16 were subsequently lost and #16 does not appear in Table 9.

Table 9. **Stomach contents and number of prey items found in juvenile chinook sampled 9/10 March, 1994 in the effluent and reference zones.**

TAXA	FISH I.D. NO.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Collembola			5						1						
Chironomidae larva	1	1	1				1								
Simuliidae larva		4			1				2						1
Ephemeroptera adult													1		1
Ephemeroptera nymph						1									
Baetidae nymph	1					1			2			1		1	
Corixidae adult	2														
Plecoptera adult				1											
Plecoptera nymph		2						1			2				
Nemouridae nymph														3	
Chloroperlidae nymph	1								3	1		1			
Perlodidae nymph									1						
Capniidae nymph				1								1			1
Insecta parts	+				+			+		+		+			
Digested material	+	+		+	+						+	+	+	+	+

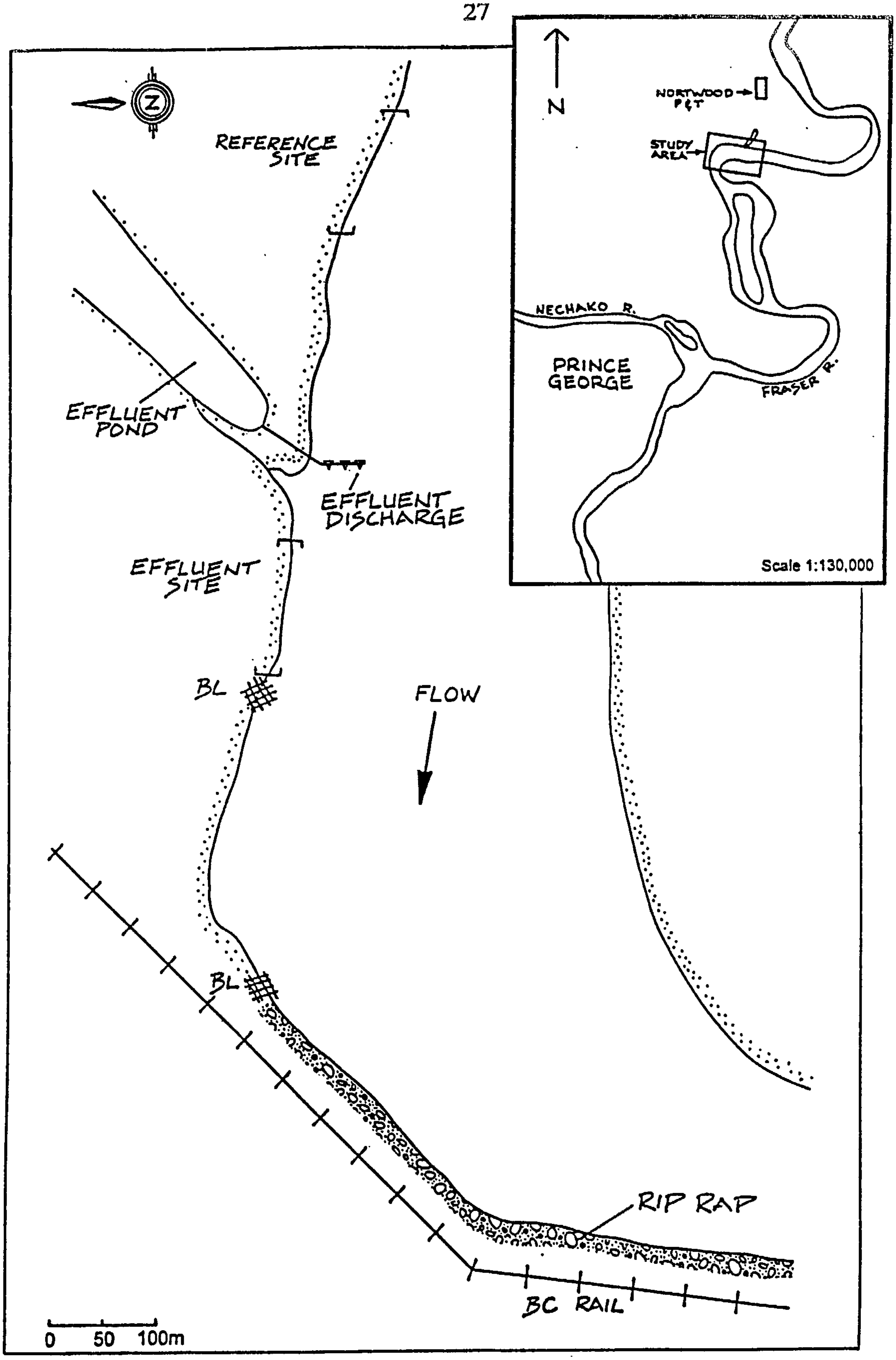

Figure 1. Study area map, showing location of the effluent and reference sites relative to the effluent discharge of the Northwood Pulp and Timber Ltd. pulp mill. Inset shows the location of the study area relative to Prince George. BL = Beaver lodge.

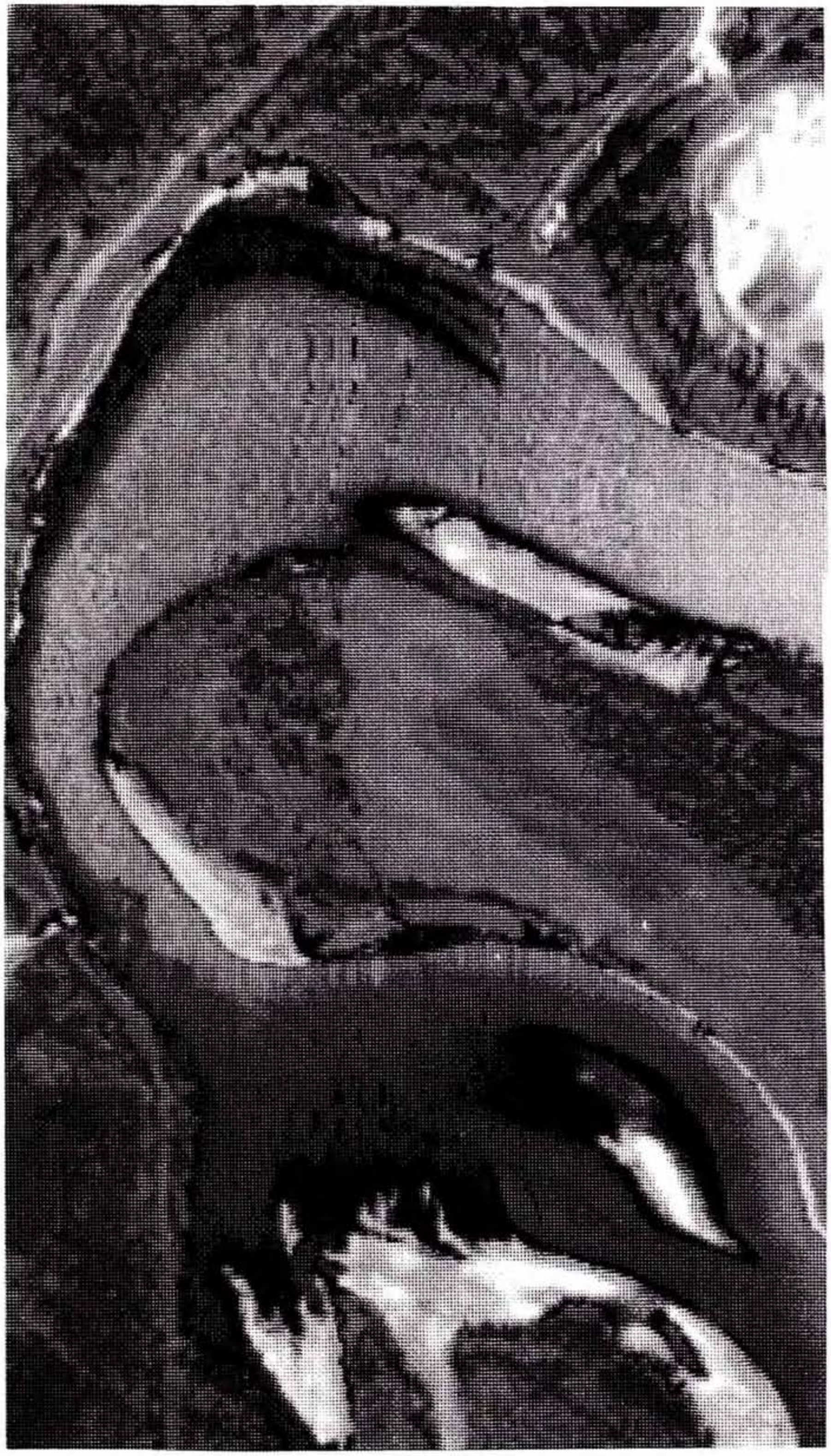

Figure 2. Aerial imagery of effluent mixing zone produced by G.A. Borstad and Associates, Victoria, BC. in September 1993. Three diffuser ports were operational at this time.

Scale: 1:10,000

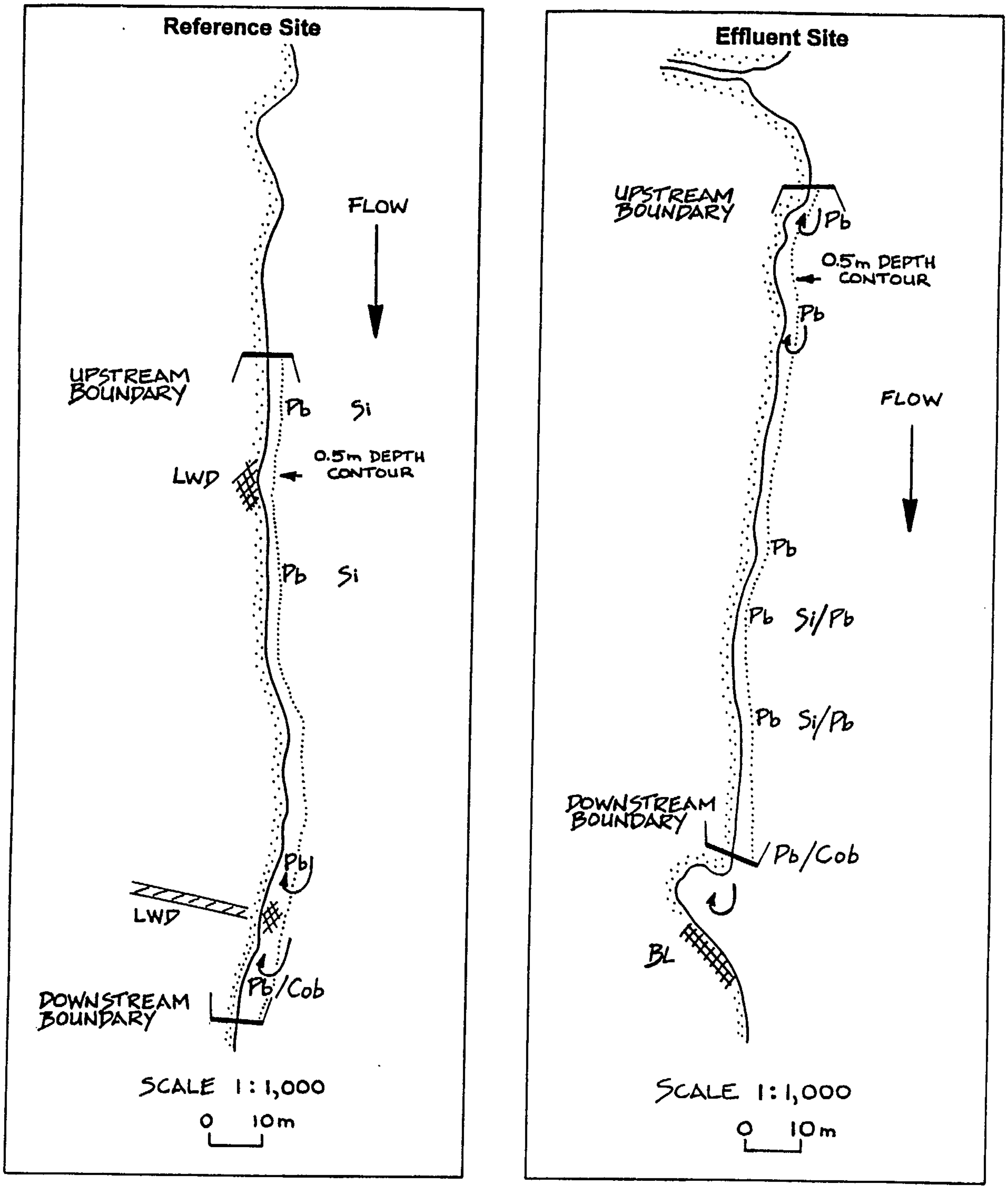

Figure 3. Detail of nearshore habitat features at the reference and effluent sites. LWD = Large woody debris, BL = Beaver lodge, Cob = Cobble, Pb = Pebble, Si = Silt. Curved arrows indicate backeddies

Figure 4. Effluent (top photograph) and reference (bottom photograph) zones, November 18, 1993. Note surface foam accumulation along the shoreline in the effluent zone.

Figure 5. Effluent (top photograph) and reference (bottom photograph) zones at the initiation of ice conditions, November 20, 1993.

Figure 6. Effluent (top photograph) and reference (bottom photograph) zones, January 19/20, 1994. A chainsaw was used to cut away the outer portion of the ice ledge at both sites.

Figure 7. Effluent (top photograph) and reference (bottom photograph) zones on March 9/10, 1994.

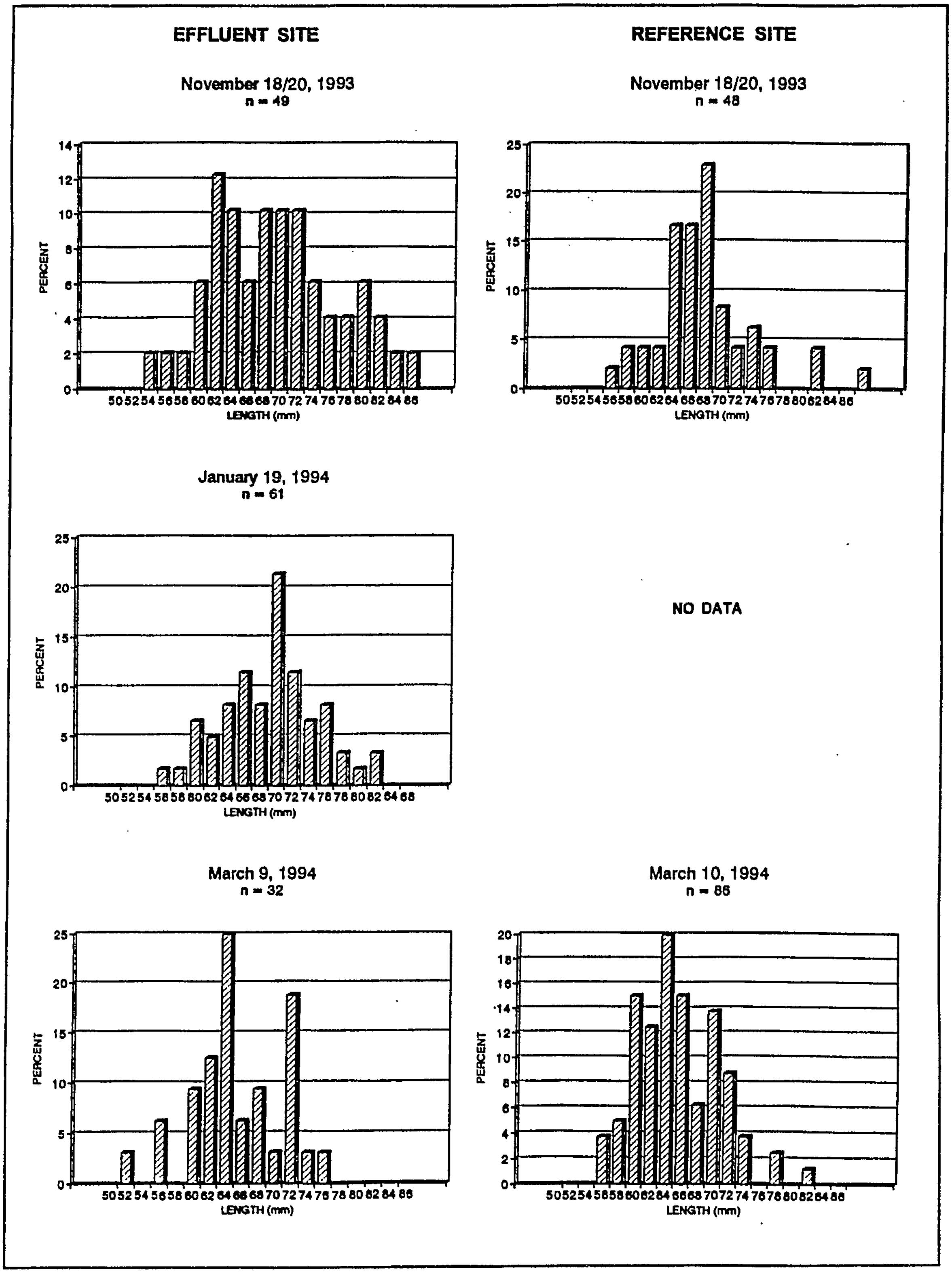

Figure 8. Length frequency of chinook sampled at the effluent and reference sites

Position of Hydrolab monitoring stations at the effluent and reference sites

Monitoring Station	Date	Distance from Shore (m)	Depth (m)	Comments
Reference	Jan.18	4.7	1.2	Hole in ice
	March 09	3.0	0.7	No ice
Effluent 1	Jan. 19	4.5	1.0	Hole in ice
	March 10	4.0	0.8	No ice
Effluent 2	Jan.20	3.5	0.5	Over ice shelf
	March 21	4.5	0.8	No ice

Distance of water quality sample points from effluent discharge source.

Sample Point	Distance (m)		
	Jan. 21	March 10	March 11
1	+230	+230	+230
2	+40	+40	+40
3	0	0	0
4	-40	-40	-40
5	-80	-80	-80
6	-130	-130	-130
7	-180	-180	-180
8	-230	-230	-230
9	-280	-280	-280
10	-330	-330	-330
11		-380	-380
12		-430	-430
13		-480	-480
14	-530	-530	-530
15		-580	-580
16		-630	-630
17			-680
18			-730
19			-780
20			-830

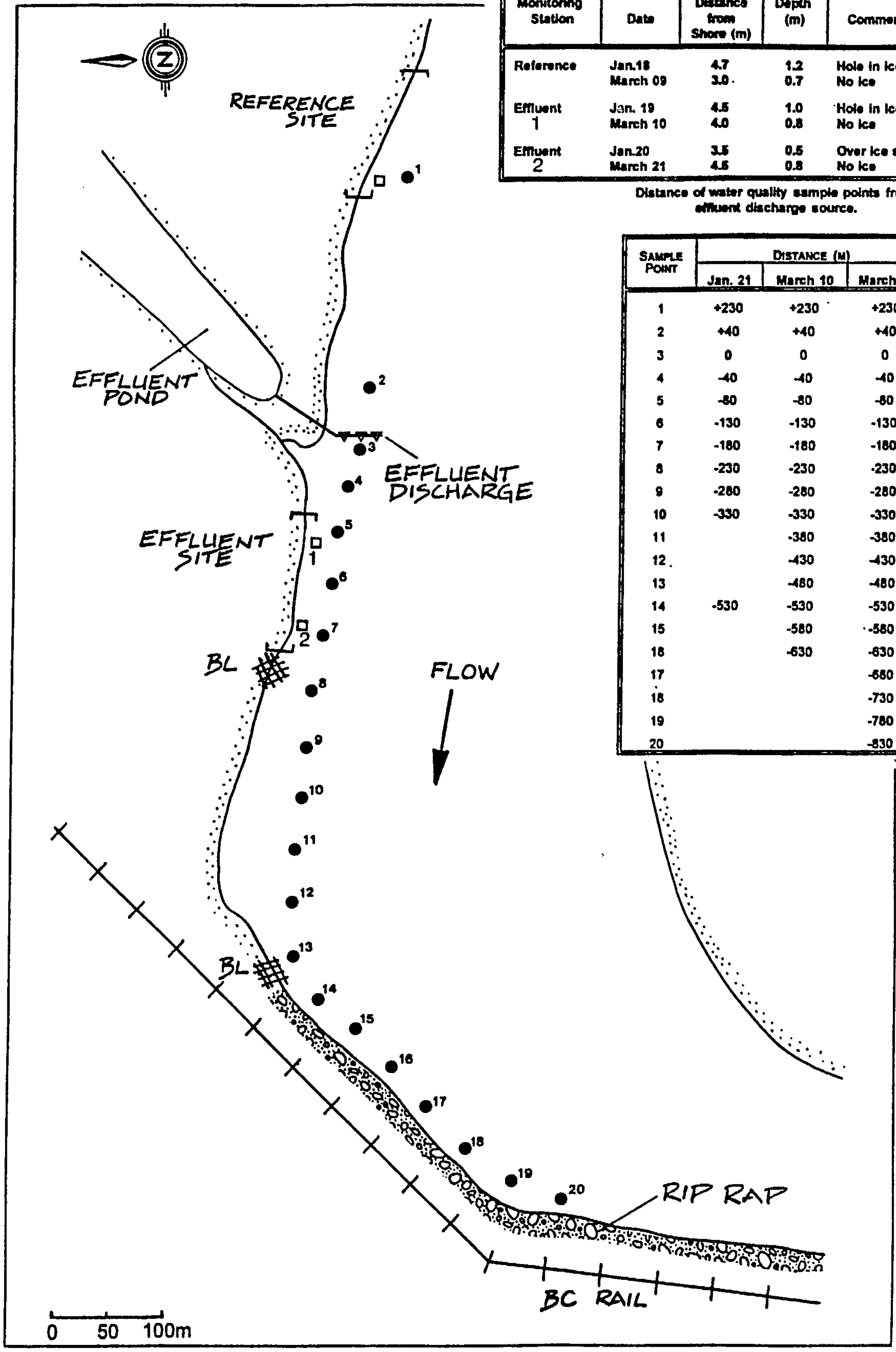

Figure 9. Location of Hydrolab monitoring stations at the effluent and reference sites (□ symbol). Sample points for surface water quality measurements upstream and within the effluent mixing zone (● symbol).

APPENDIX

Length and weight of juvenile chinook sampled in the effluent and reference zones. All fish captured at night using the submersible electrofisher unless otherwise noted. ST= stomach sample; MT = mortality; BK = backpack electrofisher; D = day sample.

Table 5. **Length and weight of juvenile chinook sampled in the effluent and reference zones. All fish captured at night using the submersible electrofisher unless otherwise noted. ST= stomach sample; MT = mortality; BK = backpack electrofisher; D = day sample.**

EFFLUENT ZONE				REFERENCE SITE #1				
Nov 18/20	Jan 19	March 9		Nov 18/20	March 10		March 11	
Len (mm)	Len (mm)	Len (mm)	Wt (g)	Len (mm)	Len (mm)	Wt (g)	Len (mm)	Wt (g)
54	55	51	2.1	55	55	2.0	54 BK	1.9
55	58	56 ST		58	55	2.0	54 BK,D	
58	60	56 ST	1.3	58	56	1.8	55 BK,D	
59	60	59	2.5	59	57	2.1	55 BK	1.9
60	60	59 ST	2.0	60	57	1.7	57 BK	2.4
60	60	60	2.1	61	57	1.9	57 BK,D	
61	61	61	2.3	62	57	1.9	58 BK,D	
61	62	61	2.9	63	59 ST	2.3	58 BK,D	
62	64	62	2.1	63	59	2.6	59 BK,D	
62	64	62	2.3	64	59	2.5	59 BK,D	
62	64	63 ST	3.4	64	59	2.2	59 BK,D	
62	64	63	2.4	64	59	2.6	59 BK	2.0
63	64	64	2.5	64	60 ST	2.6	60 BK,D	
63	64	64	2.7	64	60	2.8	60 BK	2.2
63	65	64	1.9	64	60	2.4	60 BK,D	
64	65	64	3.3	65	60	3.1	60 BK,D	
64	65	64	3.1	66	60	2.9	61 BK,D	
65	65	64	2.2	66	60	2.7	61 BK	2.2
65	65	65	2.8	66	61	2.8	61 BK	2.8
65	66	65	3.3	66	61	2.9	62 BK,D	
68	66	67	3.3	66	61	2.1	62 BK,D	
68	67	67	2.8	66	61 ST	2.7	63 BK,D	
68	67	68	3.1	67	61 ST	2.6	65 BK,D	
68	68	69	3.1	67	62	2.3	65 BK,D	
68	68 ST	71	4.4	67	62	3.3	66 BK	2.5
69	68	71	3.5	67	62	2.5	67 BK	3.1
69	69	71	3.5	67	62 ST	3.2	67 BK,D	
70	69	71	3.5	68	62	2.5	68 BK,D	
70	69	72	3.9	68	63	2.7	68 BK,D	
70	69	72 ST	4.1	68	63	2.2	68 BK,D	
71	70	73	4.0	68	63 ST	2.1	68 BK,D	
71	70	76 ST	4.8	68	63	3.1	68 BK,D	
72	70			68	63	2.5	68 BK	3.0
72	70			69	64	3.2	68 BK,D	
72	70			70	64	3.2	68 BK,D	
73	70 MT			70	64	2.5	69 BK,D	
73	70			70	64 ST	3.2	70 BK,D	
73	70			71	64	2.4	70 BK,D	

EFFLUENT ZONE				REFERENCE SITE #1				
Nov 18/20	Jan 19	March 9		Nov 18/20	March 10		March 11	
Len (mm)	Len (mm)	Len (mm)	Wt (g)	Len (mm)	Len (mm)	Wt (g)	Len (mm)	Wt (g)
75	70			71	64	3.1	70 BK,D	
76	71 ST			73	64	2.6	70 BK	3.5
77	71			73	64	2.4	71 BK,D	
77	71			73	64	3.1	71 BK	4.2
77	71			75	65	2.6	72 BK,D	
80	71			75	65 ST	2.5	73 BK,D	
80	72			82	65	3.2	73 BK,D	
80	72 ST			82	65	2.6	74 BK,D	
81	74			98	65	2.4	75 BK	4.1
81	74				66	3.0	75 BK	4.2
84	74				66	2.8	75 BK	4.1
85	74				66	2.8	76 BK,D	
	75				66	2.8	91 BK	9.5
	75				66	2.9		
	75				67	2.9		
	75				67	2.5		
	76				67	3.9		
	78				68	2.6		
	78				68	3.7		
	80				69	4.2		
	82 ST				69 ST	3.1		
	82				69	4.1		
					69	3.1		
					69	3.4		
					69	3.1		
					70	3.4		
					70	4.2		
					70	4.0		
					70	4.3		
					70	4.2		
					71	4.0		
					71	3.6		
					71	3.3		
					71	4.6		
					72	4.0		
					72	3.5		
					73	3.5		
					73	3.6		
					74	4.9		
					78	5.7		
					78	5.9		
					82 ST	4.8		