

Jordan River Pink Salmon Incubation Study

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1.0 Executive Summary

The Jordan River drains a watershed of approximately 165 km². The watershed has been severely impacted by hydroelectric development, mining and logging. The impacts have resulted in the elimination of anadromous fish production in the lower Jordan River.

In 2000 – 2001 as part of the Jordan River Water Use Planning Process, a study found that the lower Jordan River was capable of supporting the incubation of coho salmon eggs. However, it was concluded that coho were not likely to re-establish due to the probable sub-lethal effects of rearing in water with elevated copper levels. Consideration was given to the introduction of pink salmon into the Jordan River since they leave fresh water immediately after emerging from the gravel. A proposal was submitted in September 2001 to the BC Hydro Fish and Wildlife Bridge Coastal Restoration Program to assess pink salmon egg to fry survival in the lower Jordan River and determine if the emergent fry would be able to adapt to salt water. In the fall of 2002, Phase 1 of the Lower Jordan River Pink Salmon Restoration Project was initiated.

The study found that incubation success was highest at Site 3 with a mean survival of 87%, while at Sites 1 and 2 mean survival was 15% and 8% respectively. Copper levels were similar for the 3 sites, ruling out copper as the cause of the low incubation success. The cause of the low survival is inconclusive. Although intragravel dissolved oxygen measurements taken at Sites 1 and 2 were within acceptable limits for salmon incubation (> 6.0 mg/l), we suspect that the measurements may have been overestimated by the apparatus used to extract the sample from intragravel flows. The low velocities observed at Sites 1 and 2 and the prolonged low flow periods experienced in 2002-2003 are likely the factors contributing to the low survivals at these sites. The Jordan River WUP Consultative Committee has recommended a minimum flow release of 0.25 cms. If approved, the additional flow should improve conditions for incubating eggs and provide a dilution of current copper sources. This minimum flow would be extremely important during years with prolonged periods of low flow.

A 96 hour LC50 copper bioassay was performed on pink salmon from the control group held at Puntledge River hatchery using water from the Jordan River. Pink fry exposed to 165 µg/l copper experienced 20.5% mortality. Although the results of the bioassay are inconclusive in that they do not establish an LC50 for pink fry, they do suggest that something in the water chemistry of the Jordan River may be binding the copper and making it unavailable to the fish.

Pink fry from Site 3 exhibited 100% survival after a 5 day salt water test at 27.5 ppt, thus further supporting the above hypothesis.

If we consider the following observations made during this and the previous incubation study:

- high egg to fry survival during the 2000-2001 study,
- high egg to fry survival at Site 3 in 2002- 2003,
- elevated copper levels do not seem to affect egg to fry survival, and
- 100% of the fry survived the sea water test,

then upon approval of the minimum fisheries flow release of 0.25 cms recommended by the Jordan River WUP Consultative Committee, a pilot project to begin a pink salmon transplant program would be warranted.

A more detailed habitat assessment and prescription development to restore spawning and rearing habitat in the lower Jordan River should be considered if a transplant is initiated.

2.0 Introduction

The lower Jordan River has historically supported a variety of fish including pink, chum and coho salmon, sea-run cutthroat trout, steelhead and resident trout (rainbow and cutthroat). Industrial activities (forestry, mining, hydroelectric development) in the watershed have decimated anadromous fish populations in the lower river over the past three decades and currently, only rainbow trout are known to be present (RRL Recreation Resources Ltd., 2001).

During the Jordan River Water Use Planning Process (2000-2001), a bioassay was conducted to test the suitability of habitat in the lower Jordan River for coho salmon egg incubation. Results from this study indicated that the habitat in the lower river (between the tailrace and the boulder obstruction) was capable of supporting the incubation of coho salmon (egg to fry survival averaging 85%) (DFO unpublished report). It was concluded however that coho were not likely to re-establish in the copper contaminated habitat due to the adverse effects of rearing through the summer and the expected high concentrations of copper during low flow. Pink salmon however leave fresh water immediately after emerging from the gravel and would likely suffer little from the copper contamination. The WUP consultative committee has recommended a proposed minimum flow release of 0.25 cms (8.7 cfs). If this is approved, the additional flow will improve conditions for incubating eggs and may provide a dilution of the current sources of copper. Local residents have expressed interest in re-establishing a pink salmon run in order to enjoy fish in the Jordan River and, to initiate a sport fishery at the mouth of the river.

2.1 Objectives

The objectives of the study were to:

- Evaluate incubation success, water chemistry, intragravel dissolved oxygen concentrations, water temperature and flows in the lower Jordan River to determine if a sustainable pink population can be re-established in the lower Jordan River;
- Determine the effects of elevated copper levels on incubating embryos; and
- Determine whether emergent fry would be affected by exposure to ambient levels of copper (i.e. will fry be able to adapt to salt water)

2.2 Background

Hydroelectric development in the Jordan River watershed was initiated in 1909 and operated continuously between 1912 and 1969. During this period, flows passing through the powerhouse discharged into a 500 m long man-made tailrace before emptying into the river estuary. This tailrace sustained the majority of the pink and chum spawning in the lower river until the hydro facility was redeveloped in 1971. Anecdotal evidence and the DFO Annual Stream Survey data estimate peak numbers of pink and chum salmon in the 1950's and 60's between 5000 and 10,000. Following redevelopment, flows down the mainstem were diverted at Elliott Dam through a penstock, leaving only minor tributary flow to wet the lower Jordan River through the summer and early fall. The tailrace of the old generating station was decommissioned and was no longer wetted after redevelopment. The new powerplant and tailrace now situated on the opposite (west) side of the river, empties directly into the lower Jordan River approximately 200 m upstream of the estuary. The location of the new tailrace

scours old spawning beds and creates extreme fluctuations of flow in the section of river downstream. In addition, three dams (Elliot, Diversion and Bear) have blocked the recruitment of gravel from the upper watershed, reducing the available spawning area to a few small pockets. Elders from T'Sou-ke Nation recall large areas of good quality gravel in this reach historically (RRL Recreation Resources Ltd., 2001).

Mining activities in the Jordan River occurred between the early 1900's and the 1980's. Abandoned mine shafts and seepages continue to deliver copper contaminated water at various points along the east bank and through a large mine tailings, which periodically slumps and erodes into the river (Appendix 7, Plate 1). Mine tailings were also deposited to the inshore shelf in the Jordan River estuary between 1960 and 1974. Failures in the pipeline during this period resulted in tailings being deposited closer to shore.

Logging activity in the watershed dates back to the 1880's. Western Forest Products (WFP) have managed logging operations and conducted booming and towing operations in the lower Jordan River since 1934. The present Site of the log sort activities at the river mouth was once a salt marsh that was infilled with materials from a mining slump.

Decommissioning the old powerhouse and tailrace, an altered flow regime below Elliot Dam, copper contamination, and logging related impacts have eliminated anadromous fish production in the lower Jordan River.

3.0 Study Area

The Jordan River is located along the southwest coast of Vancouver Island approximately 50 km west of Victoria. It flows southwesterly between the Sooke Hills and the Seymour Mountain Range and drains into the Juan de Fuca Strait. The total drainage area is approximately 165 km². A series of boulder obstructions located 1.2 km above the mouth restricts anadromous fish production to this lower reach.

4.0 Methods

4.1 Incubation Success

Eyed pink salmon eggs (*Oncorhynchus gorbuscha*) were obtained from Puntledge Hatchery (Quinsam River stock) and transported to the Jordan River on November 1, 2002. They were planted in the gravel in Jordan-Scotty incubation cassettes, at three different sites in the river. Six cassettes, each containing 200 eyed eggs were planted at each site. The locations of the incubation sites were as follows:

- Site 1 - Lower Impact Site, located in the tailout of the large pool downstream of the mine site. This site was used in the 2000 –2001 study.
- Site 2 - Tailings Impact Site, located near the center of the mine site, at the confluence of a small drainage at the lower end of the mine site.
- Site 3 - Upper Impact Site is about 50 m below the first boulder obstruction at the upper end of the mine tailings pile. These cassettes were placed in pockets of suitable gravel.

Egg survival was checked at hatch and again at 90% button-up. When possible, the cassette was replaced in the gravel; otherwise the alevins were buried in the gravel.

4.2 Water Quality

4.2.1 Copper

Water quality was monitored for total extractable and dissolved copper throughout the study period at the three incubation sites and at three additional sites (Site 4, 5 and 6). For more information on total extractable and dissolved copper go to www.gov.bc.ca/wat/wq/Bcguidlines/copper.html. Site 4 was the control site, which is located upstream of the mine site, above the first boulder obstruction. Sites 5 and 6 were drainages on the left bank originating within the mine site (Figure 1). Water samples were taken from surface and intragravel substrate on 5 of the 7 site visits. Intragravel water samples were taken from standpipes located at the 3 study sites. The standpipes were capped at both ends. The bottom of the pipe was perforated and embedded in approximately 40 cm of substrate. Water was extracted with a 50 ml syringe attached to surgical tubing that terminated at the perforations in the pipe. A clean syringe was used for each sample. Samples were placed in clean 125 ml plastic bottles and sent to the lab for analysis.

4.2.2 Water Hardness

Water hardness was measured using a LaMotte kit. One sample was also sent for lab analysis to verify the results using the kit.

4.2.3 Water Temperature

Intragravel water temperature was monitored at each site using Hobo Temperature Loggers buried in the gravel (approximately 15 cm). Surface water temperatures were collected on each of the site visits.

4.2.4 Surface and Intragravel Dissolved Oxygen

Intragravel oxygen samples were collected with a 30 cm long metal syringe. Intragravel water samples extracted were expelled into a 500 ml plastic container where dissolved oxygen (DO), percent saturation and water temperatures were taken with a YSI 55 Dissolved Oxygen meter.

Surface flow dissolved oxygen levels and water temperature were also collected with the YSI 55 dissolved oxygen meter.

4.3 Stage and Discharge

River stage and discharge were monitored by BC Hydro's gauging station datalogger located just upstream of Site 2 on the rightbank.

Water velocities were measured at 0.6 of the total water depth over each cassette using a Swoffer Current Meter.

4.4 Sea Water Challenge

When the fry reached the button-up stage (Feb. 14), approximately 120 fry from Site 3 were transported to Nanaimo, BC. A total of 50 fry were transferred to a 75 litre bucket containing 27.5 ppt saltwater and held for 109 hrs to determine whether exposure to ambient copper levels during the incubation period caused any deleterious developmental effects. A control group of 50 fry were retained in fresh water as a control.

4.5 Bioassay

Approximately 630 pink fry from the control group at Puntledge Hatchery were transferred to Rosewall Creek Hatchery and divided into 30 - 5 litre buckets containing water collected from the Jordan River (Site 4) spiked with known concentrations of copper acetate. In total there were 9 different concentrations (stocks) ranging from 26 ppb to 166 ppb (0.026 – 0.166 mg/l) and one control group (0 ppb) with three replicates for each stock. The fish were held for 96 hrs.

5.0 Results

5.1 Egg to Fry Survival

The results of the study show that incubation success was low for Sites 1 and 2, with Site 2 having the lowest survival (Table 1). At Sites 1 and 2, mean survival was 15.0% (range: 2.0 – 35.5) and 8.0% (range: 0.0 – 20.5) respectively. The majority of the mortality at Sites 1 and 2 was at hatch. Mean mortality at hatch for Sites 1 and 2 was 65% (range: 37 – 97) and 57% (range: 10 – 84). Egg to fry survival at Site 3 was high with a mean survival of 87.0% (range: 43.0 – 99.0). Plates 2 and 3 are examples of incubation cassettes checked on January 6, 2003. Plate 4 shows dead alevins.

The low survival at Site 2 was not surprising in that this site had the lowest intragravel dissolved oxygen levels (mean: 8.25 mg/l, range: 6.68 – 10.0) and heavy deposition of fines and sand over the cassettes. At Site 1 however, the results were surprising since this site had very little deposition of fines and coarser substrate. Dissolved oxygen levels were higher with a mean of 10.85 mg/l (range: 8.66 – 11.1) (Table 2, Appendix 1). Copper levels were similar for the three sites and therefore copper could be ruled out as the contributing factor. Velocities taken at the incubation sites were generally low for Sites 1 and 2, which would translate into lower intragravel flows. The prolonged periods of low flow during the incubation period suggests that low intragravel flow, especially at the time of hatch when oxygen demand is highest may well have been the primary factor for the low survival. At Site 3 the survival was high as were intragravel dissolved oxygen levels (mean: 10.99 mg/l, range: 10.4 – 11.72) and velocities (mean: 0.31 m/sec, range: 0.001 – 0.68) (Tables 2 and 3). The velocities over the cassettes at Site 3 were significantly higher than the ones observed at Sites 1 (mean 0.15 m/sec, range: 0.001 - 0.45) and 2 (mean 0.03 m/sec, range: 0.0 - 0.09) (Table 3, Appendix 2). Given that Site 3 had coarser substrate, higher stream gradient, higher velocities and higher intragravel dissolved oxygen, one can conclude that the high egg to fry survival can be attributed to higher quality habitat for incubation.

For Jordan River a lack of quality spawning habitat and flow would be considered the main limiting factors for Pink salmon. At present habitat quality would be considered

low. Both the quantity and quality of spawning and rearing habitat limit fish production in the Jordan River. In most areas spawning substrate is limited to isolated patches dispersed amongst large boulders (Plate 5).

5.2 Copper

Copper levels (Total Extractable) at incubation Sites 1, 2 and 3 were substantially lower than the ones observed at Sites 5 and 6 (Figure 2). All samples collected at the incubation sites were above (5 to 40 times) the provincial criteria of 0.002 mg/l. Appendix 3 summarizes the results of the water chemistry analysis.

Copper levels in the Jordan River above the copper mine impact area ranged from 0.0025 to 0.004, which is slightly above the provincial criteria. These levels were similar to those found in 2000 (0.00334 mg/l) and slightly lower than the levels observed on Feb. 21, 2001 (0.006 mg/l) (DFO unpublished report 2001).

Water chemistry data collected at Sites 5 and 6 show high levels of copper are present in these sources. Site 5 is located on the left bank between Sites 3 and 4 on the Jordan River. This source flows subsurface through the mine tailings. Site 6 is also on the left bank and originates from a sealed mine shaft. Water discharges from the mine shaft into the Jordan River through 300 mm PVC pipe. The copper levels for the two sites were 0.554 mg/l and 0.445 mg/l respectively, which is significantly higher than the provincial water quality criteria of 0.002 mg/l (Appendix 3).

5.3 Water Hardness

Water hardness (as CaCO_3) was 6.4 mg/l from samples sent for lab analysis and 8 mg/l when measured on-site with the LaMotte kit (Appendices 1 and 4).

5.4 Water Temperature

Intragravel water temperatures at the three incubation sites provided information on accumulated thermal units (ATU's) for predicting stages of development. Data collected with the Hobo Temperature loggers was summarized and data was input into a WinSIRP Excel spreadsheet to determine the time when 50% of the pink eggs would hatch and the approximate time of emergence. Water temperatures were similar for Sites 1 and 3 while Site 2 was slightly warmer by 0.5 to 1.0 degree Celsius (Figure 3). The model predicted that the time to 50 % hatch would be Dec. 9, 2002 and the time of emergence would be approximately Feb. 9, 2003. On December 5 100% of the eggs had hatched in the two cassettes checked. On February 14, 2003 >90% of the fry were buttoned up. Water temperatures at this time were low (approximately 4.0 °C). The remainder of the cassettes were removed on Feb. 28 and >95% of the fry were buttoned up. When fry were released in mid and late Feb., over 80% of the fry immediately swam to the stream bed and wiggled into the substrate, others swam along the surface. Although the fry were buttoned-up in early February, under natural conditions, emergence and migration into the estuary would likely occur later, since timing is strongly influenced by photoperiod (M. Sheng, *pers. comm.*).

5.5 Dissolved Oxygen

Surface and intragravel flow was sampled to determine dissolved oxygen levels at each of the 3 incubation sites. Results of dissolved oxygen sampling are presented in Appendix 1 and summarized in Table 2.

The data suggests that the intragravel concentrations of dissolved oxygen were within acceptable limits for buried embryo and alevin stages. At Site 2 the intragravel dissolved oxygen levels were lowest but were still within the water quality criteria instantaneous minimum of 6.0 mg/l. Although the data suggests that dissolved oxygen concentrations were within acceptable limits, the egg to fry survival data suggests otherwise. The low egg to fry survival at Sites 1 and 2 is most likely a result of the prolonged low flow periods observed during the 2002- 2003 incubation period (Figure 4 and 5). The low flows experienced at Sites 1 and 2 would have had an impact on intragravel dissolved oxygen concentrations. Wickett (cited in Heard 1991) found that high water levels were necessary for good survival of embryos. As stated earlier, most of the mortality at Sites 1 and 2 occurred at hatch. Alderdice et al. (cited in Heard 1991) observed that eggs subjected to low dissolved oxygen levels hatched pre-maturely at a rate dependent on the degree of hypoxia.

Given the low egg to fry survival at the two sites one could speculate that the method employed is overestimating intragravel dissolved oxygen levels. It is possible that when driving the syringe into the substrate, surface water, which is normally saturated with oxygen, may be drawn down along the syringe during extraction of the water sample. This would give a higher incorrect reading.

5.6 Water Velocity and Stage

Water velocities over individual incubation cassettes at each site are presented in Appendix 2 and summarized in Table 3.

Stage information obtained from BC Hydro's gauging station data logger is presented in Figure 4 and Figure 5. Discharge data collected for the lower Jordan River by BC Hydro was not available at the time of reporting. During the 2002 – 2003 incubation period water levels and flow remained low for prolonged periods of time compared to the same period in 2001 – 2002 (Figure 5). Water levels below a stage of 0.94 m provided water velocities that were barely detectable at Sites 1 and 2 (Appendix 2). At Site 3 velocities were significantly higher. The low water velocities at Sites 1 and 2 would lead to low intragravel flow, which would affect the delivery of oxygen to incubating eggs. The higher velocities observed at Site 3 would have provided higher intragravel flow resulting in the higher incubation success observed for that site.

Water levels in the fall and winter of 2001 – 2002 were significantly higher and remained above a stage of 1.2 m. Figure 4 shows a more typical hydrograph for the fall/winter of 2001 – 2002, while the hydrograph for the fall and winter of 2002 - 2003 is more of an anomaly. Regardless, the prolonged low stage observed in 2002 – 2003 contributed to the lower than expected survivals at Sites 1 and 2.

5.7 Sea Water Challenge

Our initial theory was that exposure to high levels of copper would adversely affect seawater survival. The saltwater test that was performed to determine the affect of copper exposure on emergent pink fry contradicted this theory. After 109 hours in seawater there were no mortalities observed. The results of the sea water test are summarized in Appendix 5.

5.8 Bioassay

Mortality of pink fry during the 96 hr bioassay ranged from 0 to 20.5 %, with the greatest mortality exhibited in fry exposed to 165 µg/l copper (Figure 6 and Appendix 4). Although the results from the 96 hr copper toxicity bioassay indicate an increasing mortality of pink salmon fry with exposure to increasing copper concentrations, the bioassay failed to meet the parameters of an LC50 test (the "lethal concentration" of a chemical that kills 50% of the test animals in a given time). Pink mortality did not follow the pattern typical of other LC50 copper bioassays (Figure 7).

6.0 Discussion

During the January 6, 2003 site visit, three cassettes were removed (one from each site) to assess survival to hatch. Survival ranged from 11.5% at Site 1 to 43% at Site 3 (Table 1). It was initially thought that the high mortality observed in these cassettes was the result of exposure to high copper concentrations during the more sensitive alevin stage. However, copper levels were similar in all three sites for each water-sampling event. Previous (Dec. 5) and subsequent (Feb. 14 and 28) observations of cassettes from the three sites showed high survivals at Site 3 and poor survival at Sites 1 and 2, thus contradicting our initial theory (Table 1). Although copper levels in the Jordan River mainstem were as much as 40 times the maximum criteria of 2 µg/l for freshwater aquatic life (BC Water Quality Guidelines), the pink fry did not appear to exhibit acute toxicity to the levels encountered.

The low mortalities of pink fry during the bioassay further supports the above conclusion. Previous bioassays conducted on pink salmon swim-up fry using water from the Tsolum River generated an LC50 of 120 µg/l (Sweeten and McLean 1999). The results from the 96 hr copper toxicity bioassay on the Jordan River do not provide an LC50 for pink fry. This indicates that something in the water chemistry of the river may be binding the copper and making it unavailable to the fish. Based on the results of the previous bioassays we did not see the high mortalities we expected in the group exposed to the highest copper concentration (165 µg/l).

Several factors have been found to affect (reduce) the acute lethality of copper to fish including hardness, alkalinity, temperature, pH, sodium, fish size and the complexing capacity of the water (Singleton, 1987). For example, Chapman and McCrady (cited in Singleton, 1987) showed that the 96 hr LC50s for chinook salmon (*Oncorhynchus tshawytscha*) fry in water hardnesses of 13, 46, 182, and 359 mg/l CaCO₃ were 10, 25, 90, and 125 µg/l respectively. The low water hardness (<10 mg/l) in the Jordan would not likely be a factor in reducing copper toxicity. Similarly, other water quality components (alkalinity, sodium, pH, and temperature) do not appear to be present in amounts that would have an affect, according to the literature. Therefore, of the factors

listed above, it is likely the complexing capacity of the water, which is influencing the tolerance of pink fry to copper in the Jordan River. Substances shown to complex copper include phosphates, humic acid, suspended particulate matter, and organic chelators (Singleton, 1987). The bioassay and the water quality testing did not isolate the specific substance involved. This would require further water chemistry analysis.

Sublethal effects of copper to fish have also been extensively studied and include effects on reproduction, behavior, growth, and osmoregulation to name a few (Singleton, 1987). Courtois (cited in Singleton, 1987) reported that copper affects osmoregulation in fish by interfering with the control of water intake or excretion through the gills. Spear and Pierce (cited in Singleton, 1987) found that in the absence of copper complexing agents in the water, the range of threshold concentration of copper required to affect osmoregulation in freshwater fish is around 27 – 60 µg/l.

Given that pink fry exposed to this range of copper levels in the Jordan River exhibited 100% survival during a 5 day salt water test at 27.5 ppt further supports the argument that Jordan River water contains significant copper complexing capacity.

As stated above copper toxicity did not seem to have a deleterious effect on developing pink embryos. The study indicates that the low survivals at Sites 1 and 2 were likely related to low intragravel flow and more specifically the delivery of dissolved oxygen to the developing embryos that would sustain all stages of development. Unfortunately the data on intragravel DO is inconclusive in that the DO levels observed were within the water quality criteria recommended (minimum of 6 mg/l) in the Guidelines for Interpreting Water Quality Data for developing embryos. This has led us to believe that the method of sampling and/or the low sample effort may be providing us with artificially high intragravel DO levels. Velocity and stage data give us the strongest argument that intragravel DO may be the cause of high mortality at the two sites. Wickett (cited in Heard, 1991) found that high flows during the early stages of incubation were necessary for good survival of embryos, especially in higher densities. He demonstrated at Nile Creek that intragravel flows were directly related to water levels. Water velocities taken over individual cassettes show that high water levels provided higher surface flow, which likely translated into higher intragravel flow. During the study water levels remained below normal for the most of the incubation period (Figure 4). At Site 2 the low survival could also be attributed to the large accumulation of silt and sand over the incubation cassettes. Heard 1991, states that it is well known that large amounts of silt on and in spawning beds adversely influence survival of salmonid eggs and alevins. The effects of silt on survival are generally indirect through reduced permeability of spawning gravels and inadequate intragravel flow to meet oxygen requirements.

To ensure adequate intragravel flow to support incubating pink embryos a minimum discharge of 0.25 cms as proposed by the Jordan River WUP Consultative Committee will be required. This proposed minimum discharge will be extremely important during years when prolonged periods of low flow (as was the case for 2002-2003) are experience during the incubation period.

If we consider the following observations made during this and the previous incubation study

- high egg to fry survival during the 2000-2001 study,
- high egg to fry survival at Site 3 in 2002- 2003,
- elevated copper levels do not seem to affect egg to fry survival, and

- 100% of the fry survived the sea water test,

then upon approval of the minimum fisheries flow release of 0.25 cms recommended by the Jordan River WUP Consultative Committee, a pilot project to begin a pink salmon transplant program would be warranted.

7.0 Recommendations

1. If a transplant of pink salmon is planned for this year (2003/04) then we will have to determine the time of release. This study shows that fry are buttoned up by mid to late February. Releasing them at this early date would possibly initiate migration into the estuary at a time when there would be little opportunity for growth and survival.
2. Determine the carrying capacity for spawning (previous study indicates approximately 100 m²).
3. To ensure that a future transplant program is successful, an assessment of the existing habitat should be conducted to develop prescriptions for rehabilitation of the existing spawning and rearing habitat.
4. Determine the incubation technique best suited for a transplant program (i.e. Jordan-Scotty Incubators or units with a higher capacity).

8.0 Acknowledgements

We are grateful for the financial support for this study from BC Hydro through the Bridge Coastal Fish and Wildlife Restoration Program, and Fisheries and Oceans Canada (Resource Restoration).

We also wish to thank the following individuals for their contributions to this study: Puntledge River Hatchery and staff for providing eyed pink salmon eggs and monitoring the control group; John Jensen and Ted Sweeten (DFO Science) for coordinating and conducting the copper bioassay; Rosewall Creek Hatchery for providing space for the bioassay; Bill McLean (consultant) for his expertise on copper toxicity; Mel Sheng for critical direction and support for this study; Al McLean (BC Hydro); Dave Slater and Dwayne Walsh (BC Hydro Jordan River) for their assistance during the field work.

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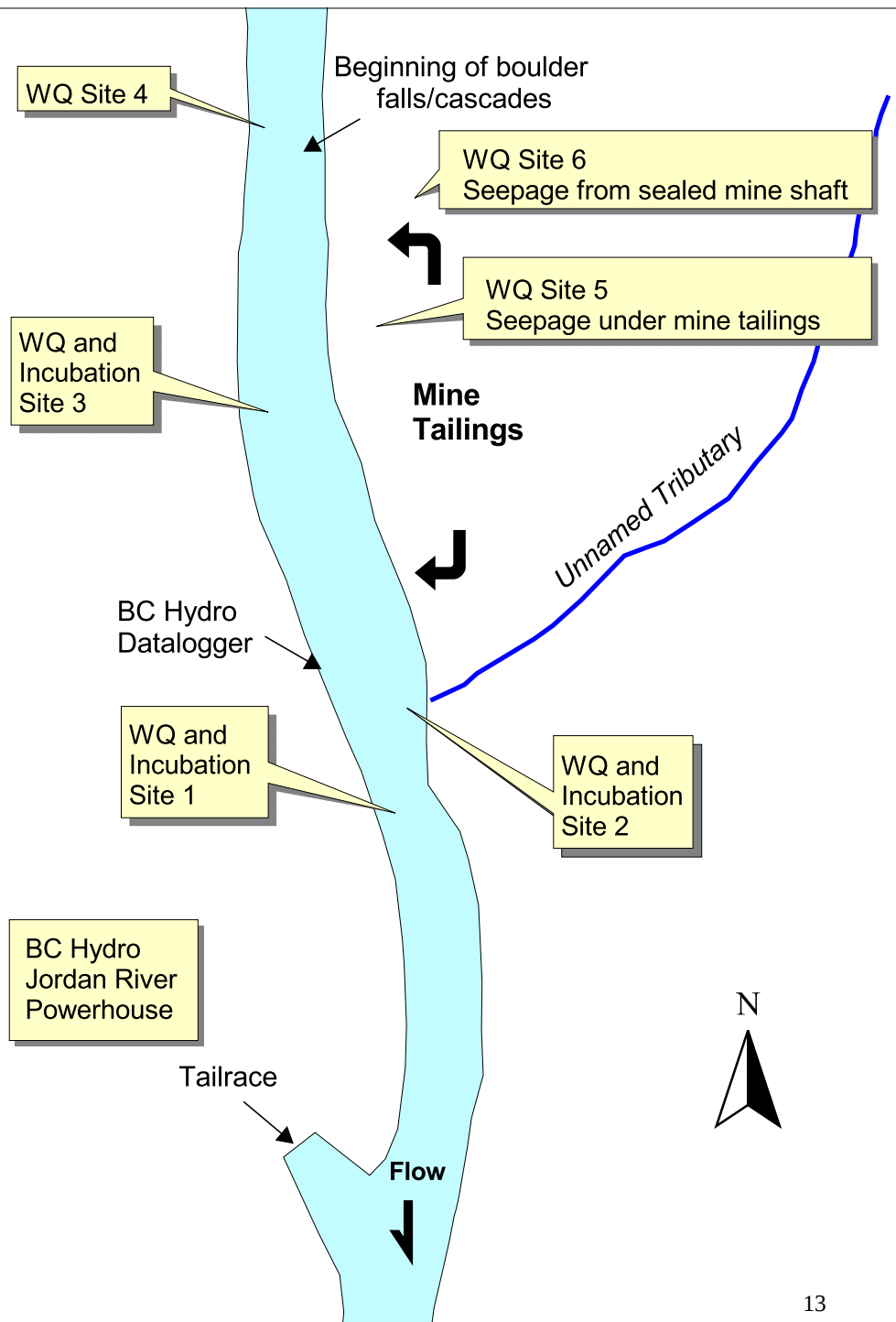
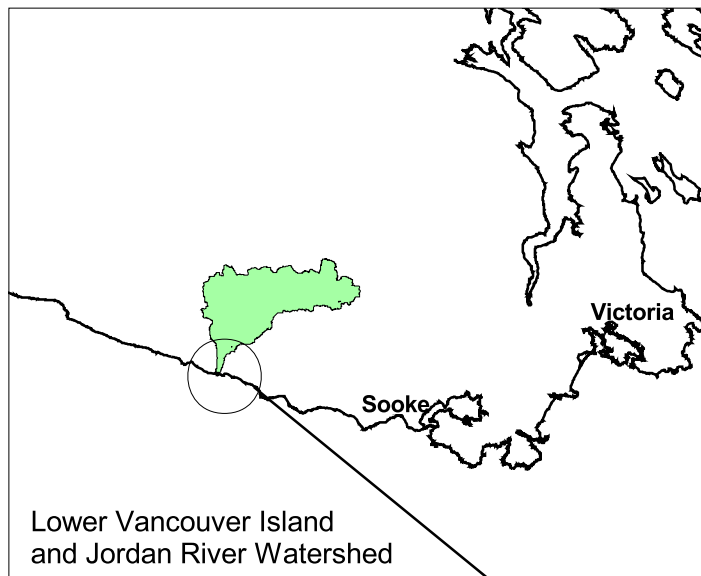


Figure 1. Map of the Jordan River watershed (inset) showing incubation and water quality sampling sites in the lower reach.

60 0 60 Meters

A scale bar showing distances of 60, 0, and 60 meters.

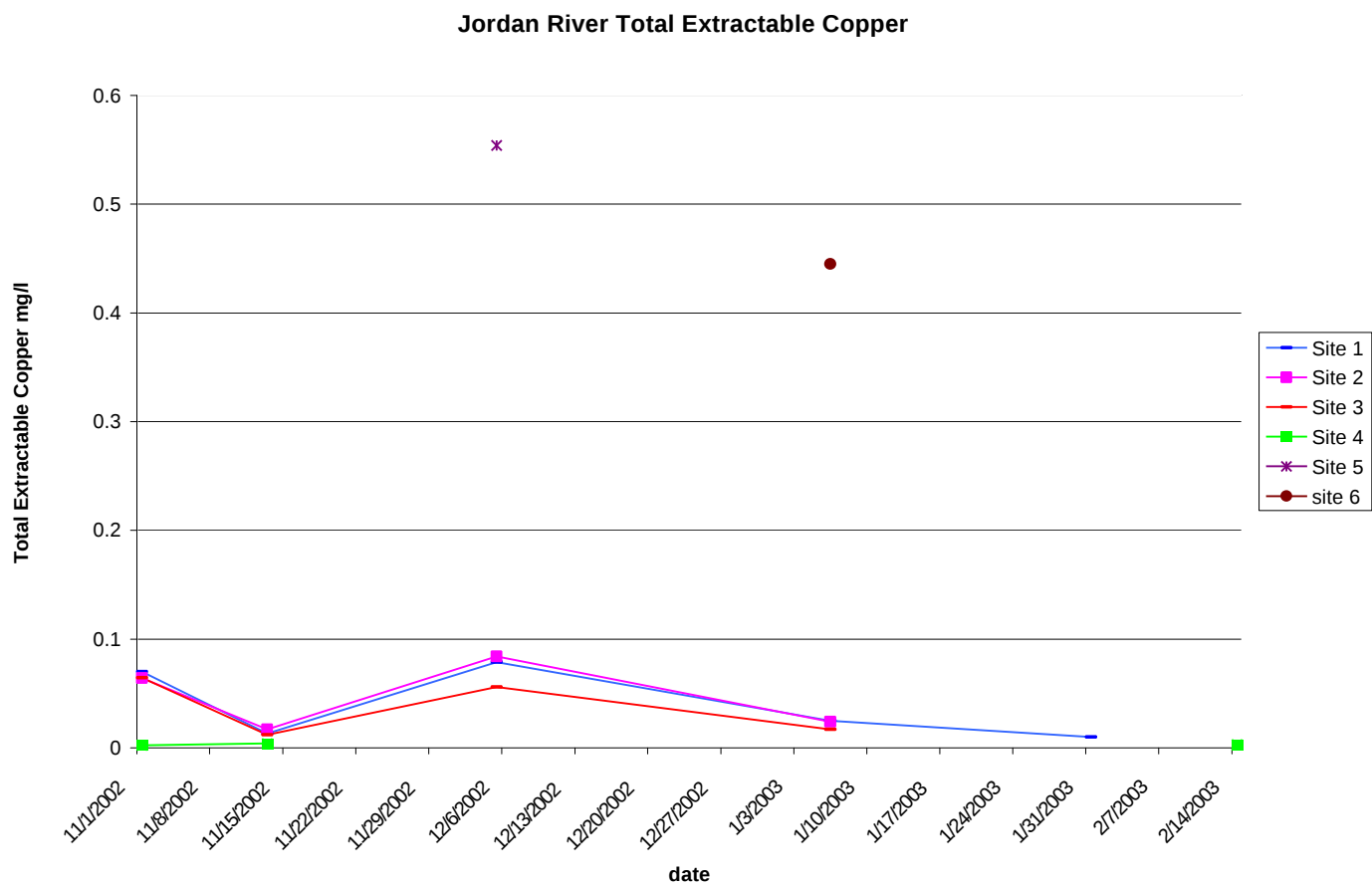


Figure 2. Total extractable copper concentrations in the Jordan River measured during sampling events from November 2002 – February 2003.

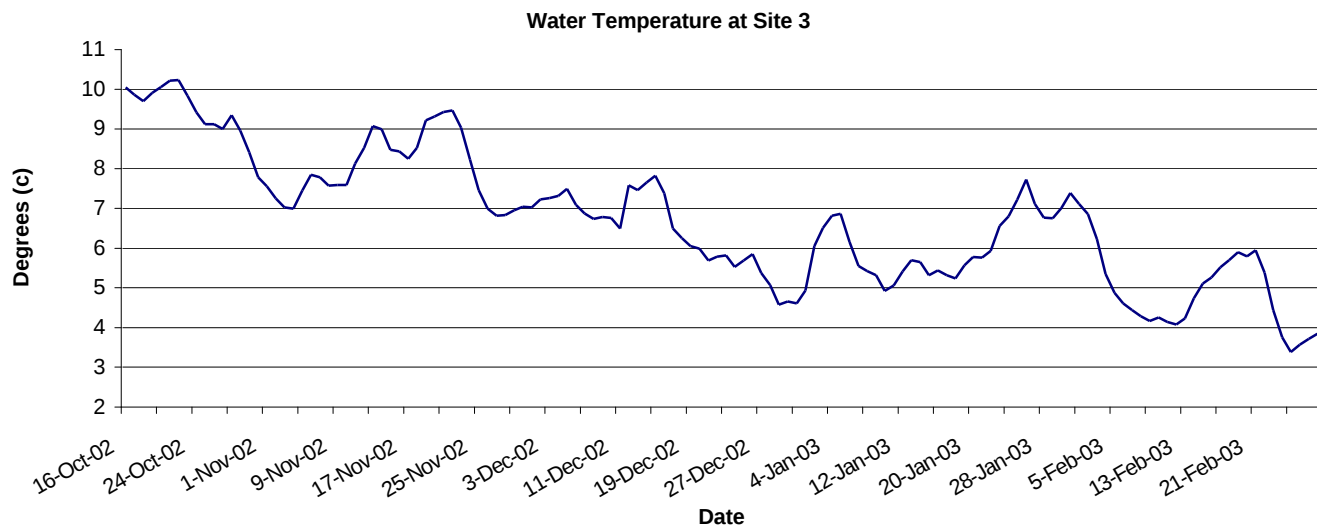
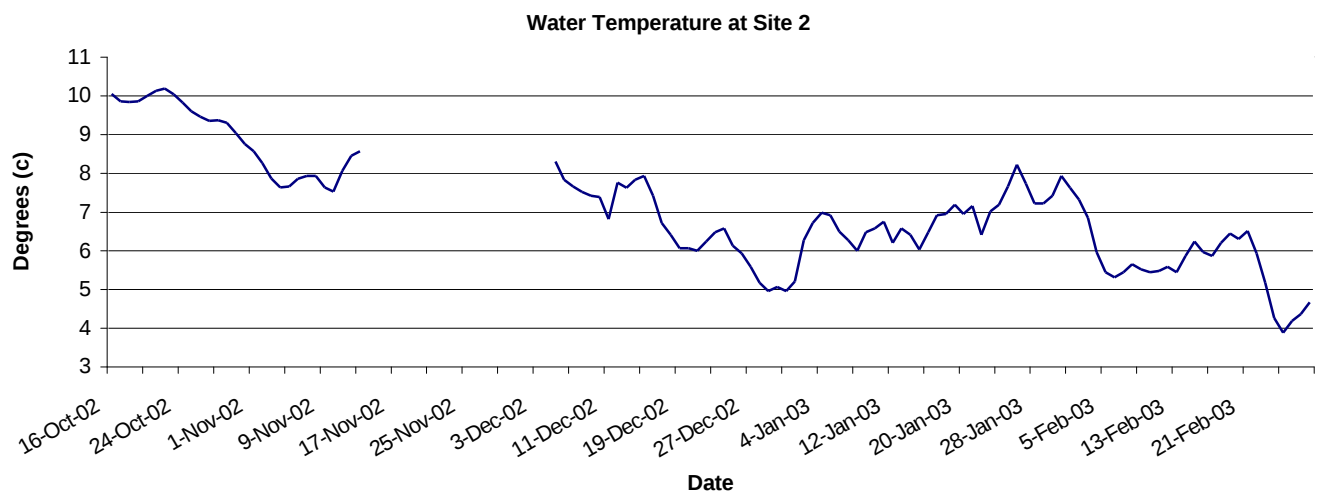
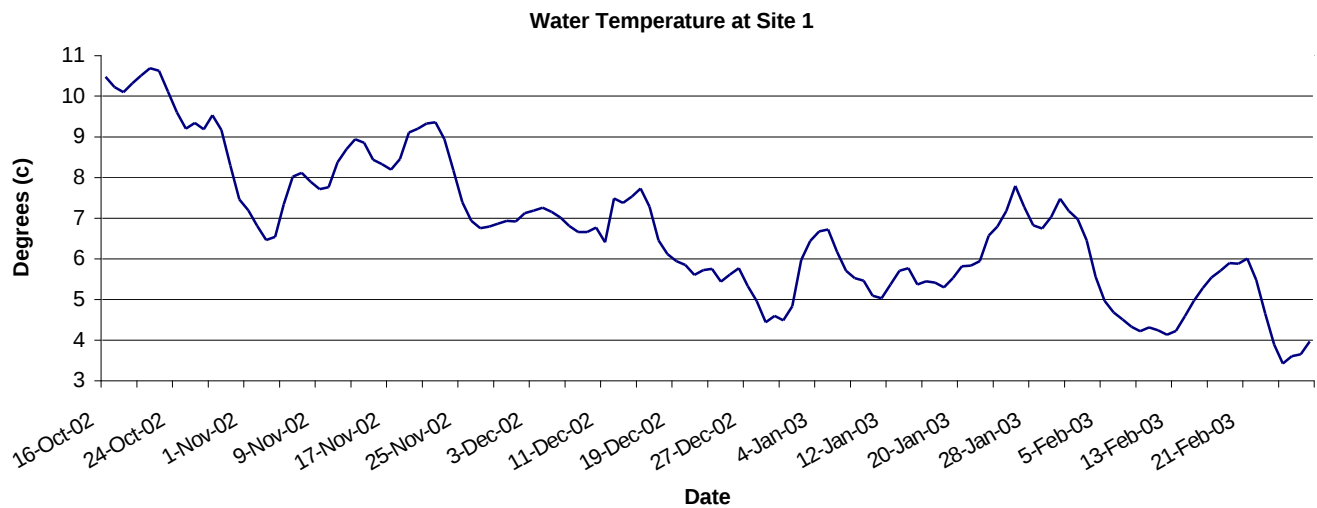


Figure 3. Mean daily water temperature (°C) recorded at three sites on the Jordan River, October 2002 – February 2003.

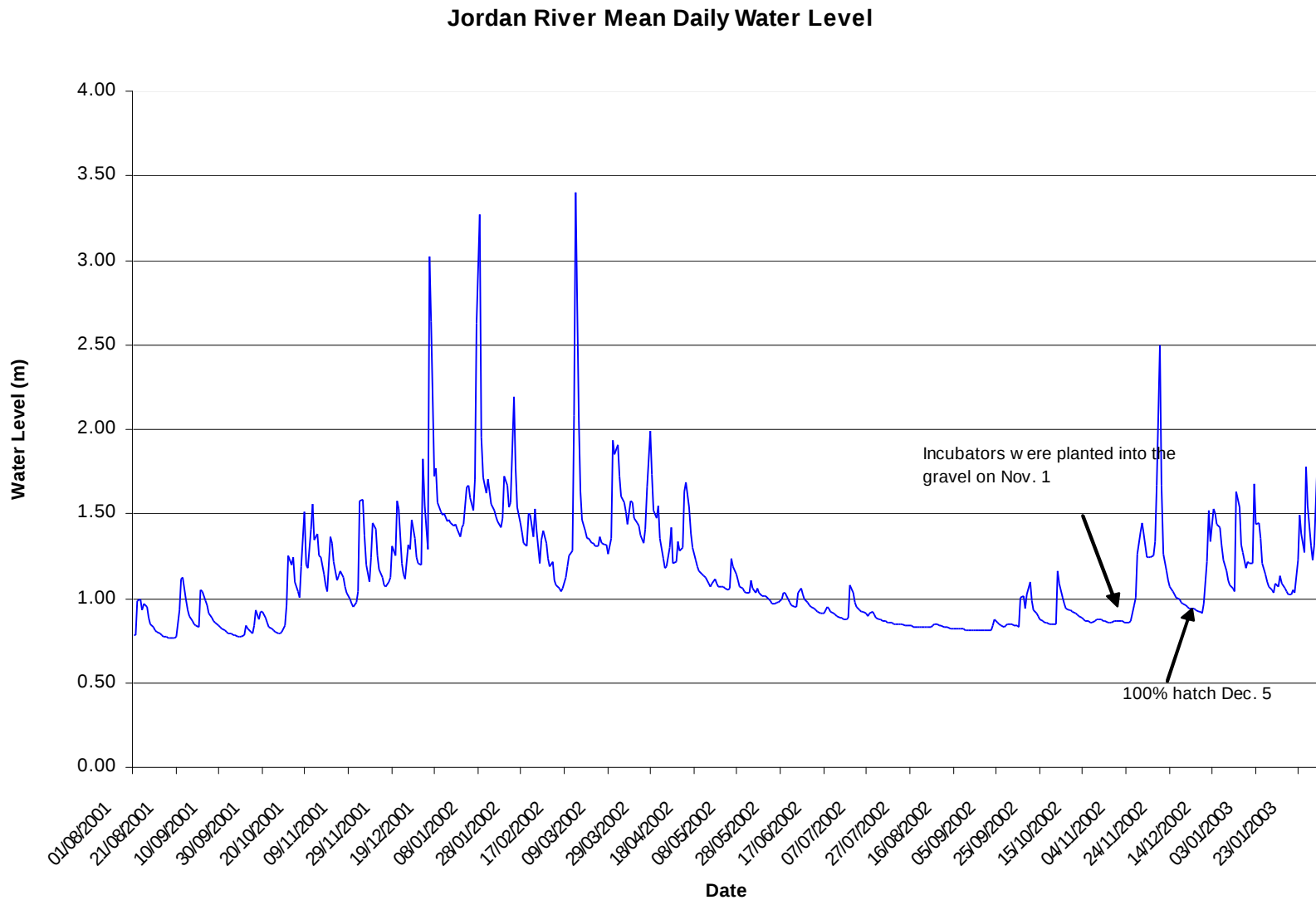


Figure 4. Mean daily water levels recorded at the BC Hydro data logger station, Jordan River, August 2001 – January 2003.

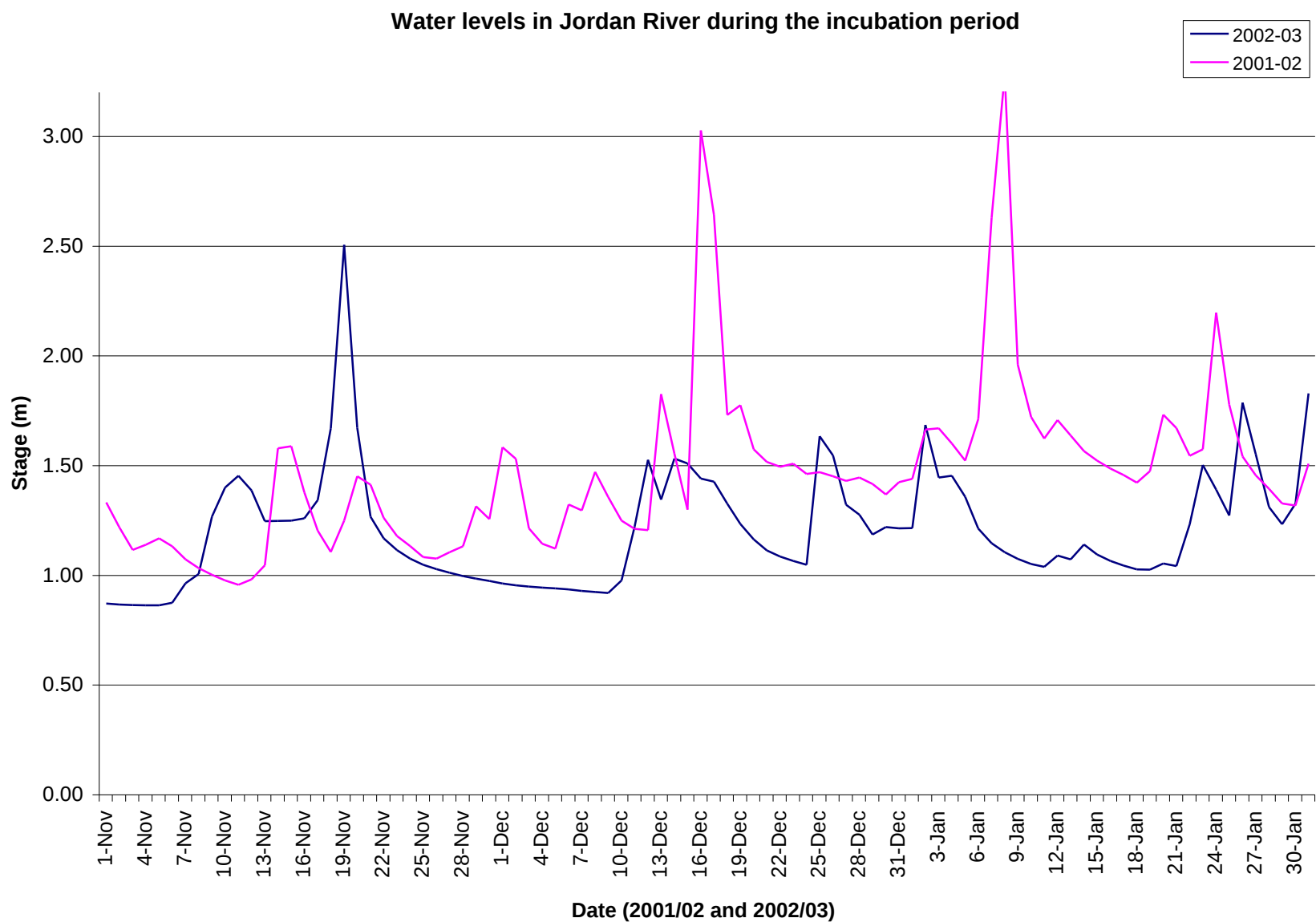


Figure 5. Comparison of water levels in the Jordan River during the pink salmon incubation study (2002/03) to the same period in 2001/02.

Jordan River Pink Salmon Bioassay

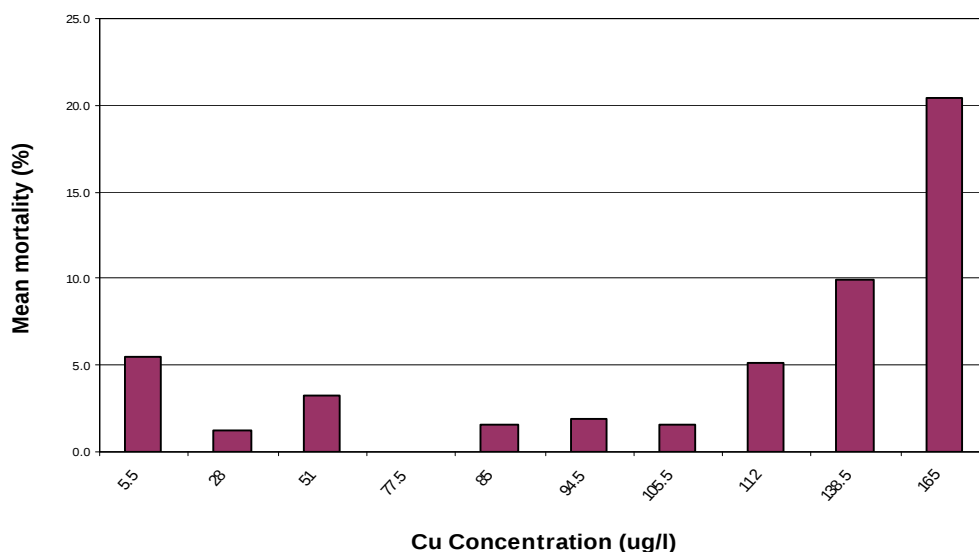


Figure 6. Mean mortality (%) observed for varying copper concentrations used in the Jordan River pink salmon bioassay.

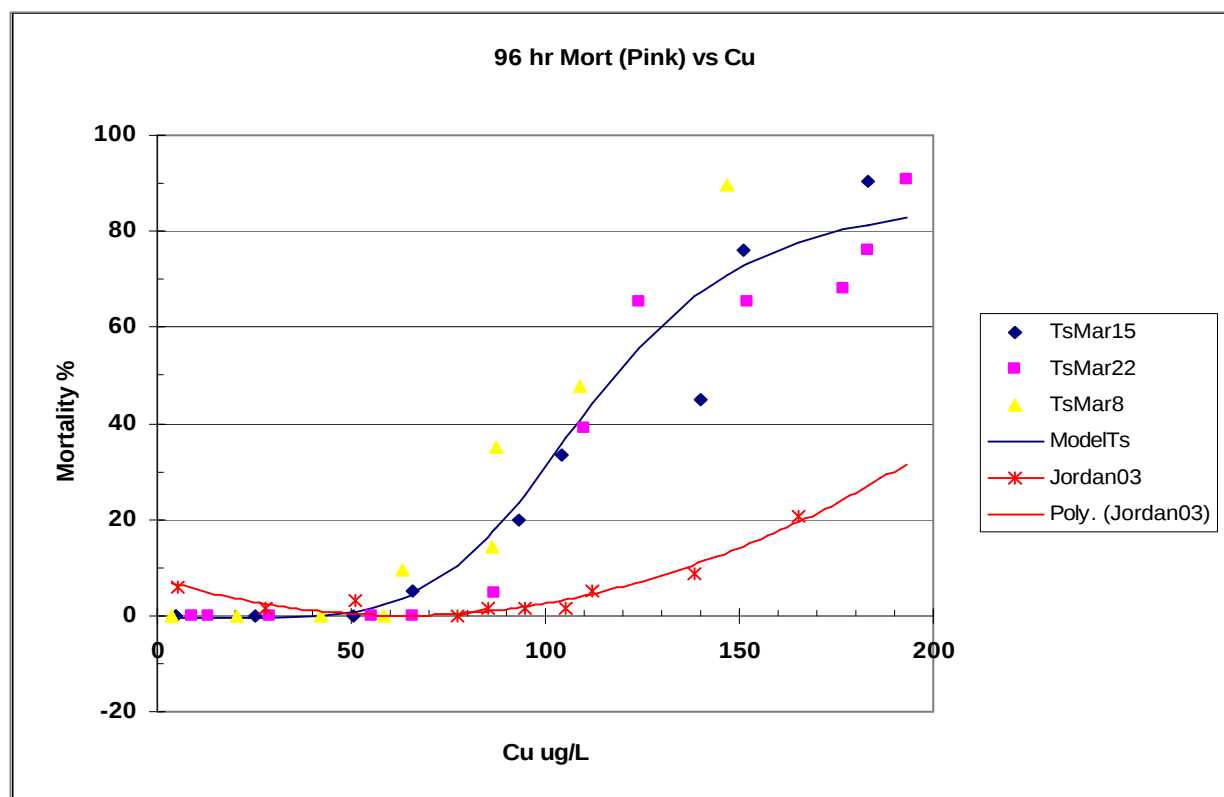


Figure 7. Mortality of pink fry as a function of copper concentration for Tsolum (1999) and Jordan Rivers (2003). The Tsolum least square model is for combined data (Mar. 8, 15, and 22) (Sweeten and McLean, 1999).

Table 1. A summary of egg to fry survival for the Jordan River incubation sites 1, 2 and, 3, 2002 - 2003.

Date Incubators were Planted	Location	Cassette Number	Number of eggs per cassette	Date of removal	Number of dead eggs	Mortality at hatch	Number of dead alevins	Number of dead fry	Total Dead	% Survival	Comments
01-Nov-02	Jordan River Site 1	1	200	11-Feb-03	0	193	0	0	193	3.5	All of the mortality occurred at hatch or a short time after hatch. There was low silt content in the incubation cells. Fungus was noted in 4 of the cells.
		2	200	28-Feb-03	0	73	102	1	176	12	
		3	200	28-Feb-03	0	160	36	0	196	2	Very little silt in the incubation cells.
		4	200	06-Jan-03	0	177	0		177	11.5	This cassette had some silt in the upper left hand cells.
		5	200	11-Feb-03	4	85	64	0	153	23.5	20 fry completely buttoned up. 7 were approximately 1 week from button up and 20 had a slit remaining.
		6	200	31-Jan-03	3	86	40	0	129	35.5	Low silt content in cells in lower half of the cassette. Moderate to low silt content in the upper half of the cassette
01-Nov-02	Jordan River Site 2	1	200	28-Feb-03	180	20	0	0	200	0	No silt
		2	200	28-Feb-03	80	80	40	0	200	0	
		3	198	06-Jan-03	0	157	0		157	20.5	The stage of development was more advanced than Site 1. The mortality would have occurred at or post hatch. This cassette was the one closest to the right bank tributary. There has been high deposition of fines and sand at this location since the incubators were planted.
		4	200	28-Feb-03	80	90	30	0	200	0	Low silt content in the cells. Heavy deposition of silt and sand at this site.
		5	200	14-Feb-03	0	167	3	0	170	15	minor amounts of silt in the incubation cells.
		6	200	14-Feb-03	8	165	4	2	179	10.5	Very little silt in the incubation cells.

Table 1 (cont'd). A summary of egg to fry survival for the Jordan River incubation sites 1, 2 and, 3, 2002 - 2003.

Date Incubators were Planted	Location	Cassette Number	Number of eggs per cassette	Date of removal	Number of dead eggs	Mortality at hatch	Number of dead alevins	Number of dead fry	Total Dead	% Survival	Comments
01-Nov-02	Jordan River Site 3	1	200	14-Feb-03	0	0	11	0	11	94.5	Approximately 50% of the fry were retained and transported to the Pacific Biological Station for a sea water challenge test. The remainder were released into the Jordan River at Site 3. Very little silt in the cassette.
		2	200	06-Jan-03	0	114	0	0	114	43	Very little silt in the incubation cells.
		3	200	14-Feb-03	0	0	2	0	2	99	Approximately 50% of the fry were retained and transported to the Pacific Biological Station for a sea water challenge test. The remainder were released into the Jordan River at Site 3. Very little silt in the cassette.
		4	200	28-Feb-03	0	0	2	0	2	99	On Dec. 5, 2002 this cassette was completely exposed and was found attached to the rebar. The cassette was opened to check the condition of the eggs. All of the eggs had hatched with 99% survival. The cassette was returned to the gravel in a more secure area along the right bank margin. On Feb. 28 the cassette was removed. The fry were >95% buttoned up. Half of the fry were released into the river at Site 3, the remainder were released into the estuary downstream of the highway bridge.
		5	200	28-Feb-03	4	0	0		4	98	On Dec. 5, 2002 this cassette was completely exposed as above. Again, all of the eggs had hatched with 98% survival. The cassette was returned to the gravel in a more secure area along the right bank margin. On Feb. 28 the cassette was removed as above.
		6	200								Cassette was lost during storm pre-Dec. 5, 2002

Table 2. Mean surface and intragravel dissolved oxygen measurements at Sites 1, 2, and 3.

Site number	Mean surface DO (mg/l)	Range	Mean Intragravel DO (mg/l)	Range
1	11.91	11.5 – 12.4	10.85	8.66 – 11.1
2	11.57	11.0 – 12.3	8.25	6.68 – 10.0
3	11.82	11.0 – 12.93	10.99	10.4 – 11.72

Table 3. Mean velocities observed over incubation cassettes at Sites 1, 2 and 3.

Date	Mean Water Level (m)	Site 1 – Mean Velocity m/sec	Site 2 – Mean Velocity m/sec	Site 3 – Mean Velocity m/sec
November 13, 2002	1.24	0.13 range: 0.08 – 0.16	0.063 range: 0.01 – 0.09	0.398 range: 0.26 – 0.52
December 5, 2002	0.94	0.001 range: 0.001 – 0.001	0.001 range: 0.0 – 0.001	0.166 range: 0.001 – 0.26
January 6, 2003	1.21	0.107 range: 0.06 – 0.13	0.037 range: 0.01 – 0.08	0.38 range: 0.04 – 0.68
January 31, 2003	1.82	0.348 range: 0.25 – 0.45	No reading	No reading

Appendix 1. Water quality data collected at Sites 1, 2 and 3, Jordan River, October 2002 - January 2003

Jordan River Site 1											Comments
Date	unit	Dissolved Oxygen				Hardness (mg/l)	Conductivity 1	Conductivity 2	Temp 1	Temp 2	
		Surface 1	Surface 2	Subsurface 1	Subsurface 2		µS/cm	µS/cm	°C	°C	
16-Oct-02	mg/l						55.8			10.4	Conductivity 1 = Jordan River Site1 Temperature 1 = surface water temp. Temperature 2 = sub-surface water temp. Hardness reading should be ignored. Probably a sampling error
	% Sat.										
1-Nov-02	mg/l	11.59		9.5	8.05				7.6	7.8	
	% Sat.	96.5		79.5	67.6						
13-Nov-02	mg/l	11.5		11.1		12	28.3		8.8	9	
	% Sat.	102		97							
5-Dec-02	mg/l	12.01	11.92	8.35	8.97	60			6.75	7.1	
	% Sat.	98.5	98	69	74.3						
6-Jan-03	mg/l	12.39	11.83	11.73	9.97	8	25.1		6.2	6.6	
	% Sat.	100	97.6	95.6	81.5						
31-Jan-03	mg/l	12.4		10.9		8	18.9		7.5	8.7	
	% Sat.	103		92							
Jordan Rive Site 2											
Date	unit	Dissolved Oxygen				Hardness (mg/l)	Conductivity 1	Conductivity 2	Temp 1	Temp 2	
		Surface 1	Surface 2	Subsurface 1	Subsurface 2		µS/cm	µS/cm	°C	°C	
16-Oct-02	mg/l						77.3	77.3		10.6	Conductivity 1 = Jordan River Site 2 Conductivity 2 = Left Bank Trib Site 2 Temperature 1 = surface water temp. Temperature 2 = sub-surface water temp. Water Temp. LB trib = 7.9 C
	% Sat.										
1-Nov-02	mg/l	11.6		9.86	9.36				7.6	8.05	
	% Sat.	97.4		83.4	79.1						
13-Nov-02	mg/l	11		10			28.8	84.8	8.8	9.1	
	% Sat.	96		88							
5-Dec-02	mg/l	11.65		7.87	5.48		46.6	70.4	7.3	8.1	
	% Sat.	96.9		67.2	46.3						
6-Jan-03	mg/l	12.3	11.77	6.73		8	25.7	54.3	6.2	6.8	
	% Sat.	99.2	96	55.7							
Jordan Rive Site 3											
Date	unit	Dissolved Oxygen				Hardness (mg/l)	Conductivity 1	Conductivity 2	Temp 1	Temp 2	
		Surface 1	Surface 2	Subsurface 1	Subsurface 2		µS/cm	µS/cm	°C	°C	
16-Oct-02	mg/l						54.3			10.3	Conductivity 1 = Jordan River Site 3 Temperature 1 = surface water temp. Temperature 2 = sub-surface water temp.
	% Sat.										
1-Nov-02	mg/l										
	% Sat.										
13-Nov-02	mg/l	11		10.4			29.1		8.7	9	
	% Sat.	95		90							
5-Dec-02	mg/l	11.86	11.87	10.86	10.28		40.5		7.1	7.7	
	% Sat.	97.7	98.2	90.5	86.6						
6-Jan-03	mg/l	12.93	12.26	11.72			25.5		6.2	6.4	
	% Sat.	104.4	100.2	95.2							

Appendix 2. Water velocities recorded at individual incubation cassettes by date and site, 2002 -2003.

Date	Water	Site	Flows at individual incubation cassettes (m/s)												Comments
	Level (m)		C-1 Depth	C-1 Velocity	C-2 Depth	C-2 Velocity	C-3 Depth	C-3 Velocity	C-4 Depth	C-4 Velocity	C-5 Depth	C-5 Velocity	C-6 Depth	C-6 Velocity	
16-Oct-02	0.31														
13-Nov-02	0.66	1	0.75	0.12	0.83	0.08	0.82	0.16	0.63	0.15	0.64	0.1	0.64	0.17	
		2	0.87	0.08	0.7	0.09	0.65	0.03	0.85	0.01	0.79	0.08	0.67	0.09	
		3	0.58	0.45	0.55	0.43	0.54	0.52	0.63	0.26	0.81	0.37	0.78	0.36	
05-Dec-02	0.375	1	0.52	0.001	0.62	0.001	0.55	0.001	0.34	0.001	0.38	0.001	0.44	0.001	
		2	0.57	0	0.52	0	0.4	0	0.47	0	0.31	0	0.31	0	
		3	0.23	0.2	0.18	0	0.25	0.26	0.52	0.2	0.4	0.17	cassette missing		
06-Jan-03	0.65	1	0.72	0.1	0.7	0.09	0.75	0.13	0.63	0.13	0.63	0.06	0.67	0.13	C1-4 removed
		2	0.75	0.04	0.73	0.04	0.68	0.02	0.72	0.01	0.73	0.03	0.57	0.08	C2-3 removed, C2-4 located behind a boulder
		3	0.59	0.46	0.5	0.16	0.53	0.68	0.67	0.04	0.53	0.56	cassette missing		
31-Jan-03	1.04	1	1.16	0.35	1.27	0.29	1.2	0.36	0.95	0.45	1.03	0.25	1.04	0.39	C1-6 removed
		2													Water levels too deep to sample site 2
		3													Water levels too deep to sample site 3

Appendix 3. A summary of water samples taken for copper analysis (total extractable and from Sites 1, 2, 3, 4 and 5 in the Jordan River, November 2002 - February 2003.

Date	Site	Total Extractable Cu		Dissolved Cu	
		Surface	Intragravel	Surface	Intragravel
01-Nov-02	1	0.07	0.0615	0.069	0.054
13-Nov-02	1	0.013	0.017	0.012	0.015
05-Dec-02	1	0.079	0.067	-	-
06-Jan-03	1	0.025	0.014	-	-
31-Jan-03	1	0.01	0.013	-	-
01-Nov-02	2	0.064	-	0.0635	-
13-Nov-02	2	0.017	0.035	0.015	0.027
05-Dec-02	2	0.084	0.03	-	-
06-Jan-03	2	0.024	0.015	-	-
31-Jan-03	2	-	-	-	-
01-Nov-02	3	0.0645	-	0.0625	-
13-Nov-02	3	0.012	-	0.011	-
05-Dec-02	3	0.056	-	-	-
06-Jan-03	3	0.017	0.018	-	-
31-Jan-03	3	-	-	-	-
01-Nov-02	4	0.0025	-	0.0025	-
13-Nov-02	4	0.004	-	0.004	-
14-Feb-03	4	0.003	-	-	-
05-Dec-02	5	0.554	-	-	-
06-Jan-03	6	0.445	-	-	-

Appendix 4. Water quality analysis of Jordan River stock water from Site 4 and analysis of water samples spiked with varying concentrations of copper.

Copper Bioassay Analytical Report - Feb. 28, 2003

			Results			Detection Limit
Inorganic Nonmetallic Parameters		Units	Jordan Stock Water	Distilled Water	# 9	
Phosphate	as P	mg/l	<0.05	<0.05	<0.05	0.05
Metals Extractable						
Silicon		mg/l	2.74	0.09	2.72	0.05
Sulphur		mg/l	0.51	<0.05	0.43	0.05
Mercury		mg/l	<0.0001	<0.0001	<0.0001	0.0001
Aluminum		mg/l	0.073	<0.005	0.078	0.005
Antimony		mg/l	<0.0002	<0.0002	<0.0002	0.0002
Arsenic		mg/l	<0.0002	<0.0002	<0.0002	0.0002
Barium		mg/l	0.003	<0.001	0.005	0.001
Beryllium		mg/l	<0.0001	<0.0001	<0.0001	0.0001
Bismuth		mg/l	<0.0005	<0.0005	<0.0005	0.0005
Boron		mg/l	0.002	<0.002	0.002	0.002
Cadmium		mg/l	0.00012	<0.00001	0.00019	0.00001
Chromium		mg/l	<0.0005	<0.0005	<0.0005	0.0005
Cobalt		mg/l	<0.0001	<0.0001	<0.0001	0.0001
Copper		mg/l	0.004	<0.001	0.178	0.001
Lead		mg/l	0.0109	0.0002	0.029	0.0001
Lithium		mg/l	<0.001	<0.001	<0.001	0.001
Molybdenum		mg/l	<0.001	<0.001	<0.001	0.001
Nickel		mg/l	<0.0005	<0.0005	0.0005	0.0005
Selenium		mg/l	<0.0002	<0.0002	<0.0002	0.0002
Silver		mg/l	0.0001	0.0001	0.0001	0.0001
Strontium		mg/l	0.005	<0.001	0.005	0.001
Thallium		mg/l	<0.00005	<0.00005	<0.00005	0.00005
Tin		mg/l	<0.001	<0.001	<0.001	0.001
Titanium		mg/l	0.0008	<0.0005	0.0011	0.0005
Uranium		mg/l	<0.0005	<0.0005	<0.0005	0.0005
Vanadium		mg/l	0.0002	<0.0001	0.0002	0.0001
Zinc		mg/l	0.007	0.001	0.011	0.001
Zirconium		mg/l	<0.001	<0.001	<0.001	0.001
Physical and Aggregate Properties						
Temperature of observed pH		°C	18	17.5	17.5	
Solids	Total Suspended	mg/l	<1	6	<1	1
Routine Water						
pH			1.81	1.71	1.65	
Chloride	Dissolved	mg/l	4.3	0.8	5.2	0.5
Fluoride		mg/l	<0.04	<0.04	<0.04	0.04
Nitrate - N		mg/l	240	309	346	0.004
Nitrite - N		mg/l	<0.02	<0.02	<0.04	0.002
T - Alkalinity	as CaCO ₃	mg/l	<5	<5	<5	5
Hardness	as CaCO ₃	mg/l	6.9	<1	6.3	
Calcium	Extractable	mg/l	1.7	<0.2	1.7	0.2
Magnesium	Extractable	mg/l	0.6	<0.2	0.5	0.2
Potassium	Extractable	mg/l	<0.4	<0.4	<0.4	0.4
Sodium	Extractable	mg/l	2.9	<0.4	2.6	0.4
Iron	Extractable	mg/l	0.02	<0.01	0.01	0.01

Water Sample ID #	Extractable Copper Start (mg/l)	Water Sample ID #	Extractable Copper End (mg/l)
Stock	0.004	10	0.007
1	0.029	11	0.027
2	0.053	12	0.049
3	0.087	13	0.068
4	0.097	14	0.073
5	0.103	15	0.086
6	0.117	16	0.094
7	0.120	17	0.104
8	0.150	18	0.127
9	0.178	19	0.152

Appendix 5. Results of the 109 hour sea water challenge at 27.5 ppt

Date	Time	Number of Fry per Bucket	Fresh Water Control Temp (°C)	Number of Mortalities in Control Group	Salt Water Temp (°C)	Number of Mortalities in Salt Water	Comments
Feb. 14	1830	50	8.5	0	8.0	0	Fry in the saltwater group concentrated at the surface. Fry in the freshwater group were concentrated at the bottom of the bucket
	2114			0		0	
	2215			0		0	
	2315			0		0	
Feb. 15	0815	50	8.5	0	8.5	0	
	1015			0		0	Both groups of fish were concentrated at the bottom of the buckets
	1430			0		0	
	1530			0		0	
	2015			0		0	
	2230			0		0	
Feb. 16	0745		8.5	0	8.5	0	
	1045			0		0	
	1630			0		0	
Feb. 17	0830		8.5	0	8.5	0	
	1830			0		0	
Feb. 18	0830		8.5	0	8.5	0	
Feb. 19	0730		8.5	0	8.5	0	

Appendix 6. Results of the copper bioassay study for Jordan River pink salmon fry, February 2003.

Bucket #	Cu Added (ml)	Cu Conc (ppb)	Total fry at start	% Mortality	Water Sample ID		Copper Levels (ppb)		
					Start	End	Start	End	Mean
1	0	0	20	0.00	Stock	10	4	7	5.5
2	0	0	25	8.00	Stock	10	4	7	5.5
3	0	0	24	8.33	Stock	10	4	7	5.5
4	3	0	21	0.00	1	11	29	27	28.0
5	3	26	26	3.85	1	11	29	27	28.0
6	3	26	20	0.00	1	11	29	27	28.0
7	6	50	20	0.00	2	12	53	49	51.0
8	6	50	19	5.26	2	12	53	49	51.0
9	6	50	22	4.55	2	12	53	49	51.0
10	9	73	21	0.00	3	13	87	68	77.5
11	9	73	19	0.00	3	13	87	68	77.5
12	9	73	19	0.00	3	13	87	68	77.5
13	10.5	85	21	0.00	4	14	97	73	85.0
14	10.5	85	20	0.00	4	14	97	73	85.0
15	10.5	85	21	4.76	4	14	97	73	85.0
16	12	96	18	5.56	5	15	103	86	94.5
17	12	96	21	0.00	5	15	103	86	94.5
18	12	96	20	0.00	5	15	103	86	94.5
19	13.5	108	21	0.00	6	16	117	94	105.5
20	13.5	108	21	4.76	6	16	117	94	105.5
21	13.5	108	17	0.00	6	16	117	94	105.5
22	15	120	21	0.00	7	17	120	104	112.0
23	15	120	19	10.53	7	17	120	104	112.0
24	15	120	20	5.00	7	17	120	104	112.0
25	18	143	20	0.00	8	18	150	127	138.5
26	18	143	16	25.00	8	18	150	127	138.5
27	18	143	21	4.76	8	18	150	127	138.5
28	21	166	22	13.64	9	19	178	152	165.0
29	21	166	26	26.92	9	19	178	152	165.0
30	21	166	24	20.83	9	19	178	152	165.0

Results Summary	
Cu Conc (ppb)	Mean Mortality (%)
5.5	5.44
28	1.28
51	3.27
77.5	0.00
85	1.59
94.5	1.85
105.5	1.59
112	5.18
138.5	9.92
165	20.46

Appendix 7. Photos from the Jordan River Pink Salmon Incubation Study, 2002 - 2003.



Plate 1. Photograph looking downstream from the left bank at Site 3 on the Jordan River. Note mine tailings on the left bank.

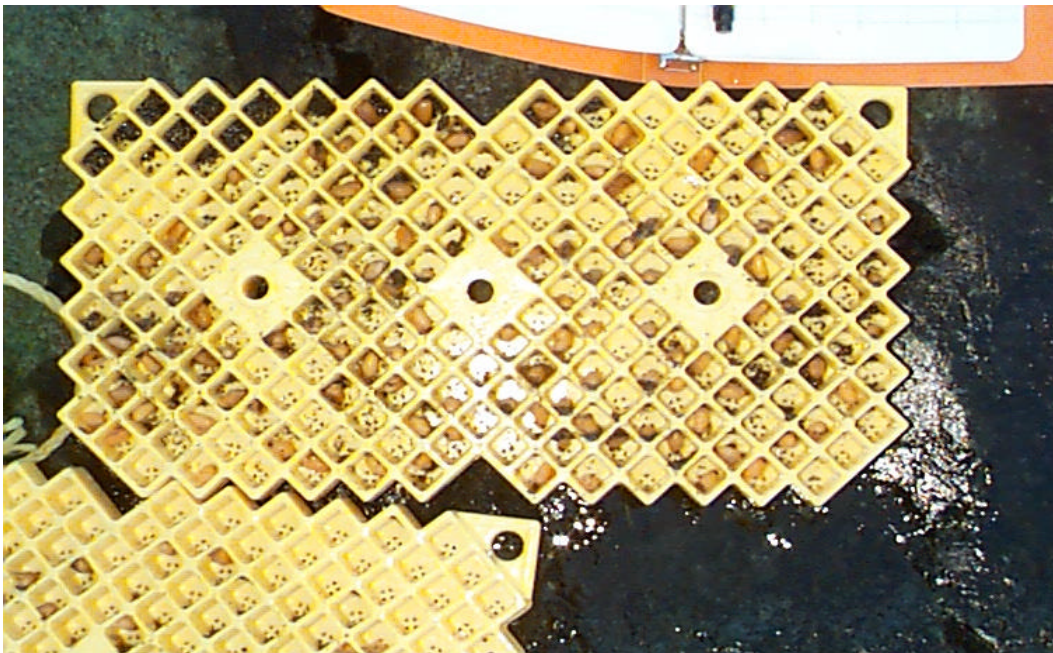


Plate 2. An example of a Jordan - Scotty Incubation cassette removed from the substrate at Site 2, January 6, 2003.

Appendix 7. Photos from the Jordan River Pink Salmon Incubation Study, 2002 - 2003.

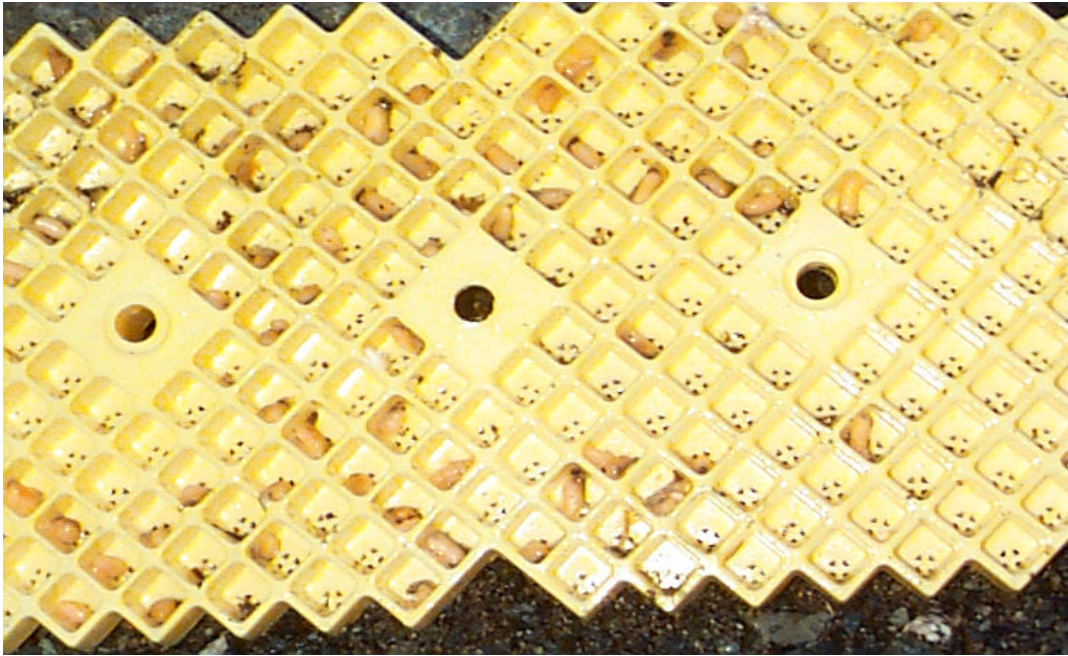


Plate 3. An example of a Jordan - Scotty Incubation cassette removed from the substrate at Site 2, January 6, 2003. Note the dead alevins in the individual cells.



Plate 4. Dead alevins removed from an incubation cassette at Site 2 on January 6, 2003.

Appendix 7. Photos from the Jordan River Pink Salmon Incubation Study, 2002 - 2003.



Plate 5. Looking upstream from Site 3 at the Jordan River. Spawning substrate was limited to isolated patches interspersed throughout the boulder substrate.

Appendix 8.



Financial Statement

Income & Expenses

	Income	Expensed	
Income			
BCRP	\$ 5000		
(DFO In-kind)	\$ 10,994.53		
Total Income	\$ 15,994.53		
Expenses		BCRP	(DFO In-kind)
Project Personnel			
Wage	3700		3700
Consultant fees	8585.94	3555.64	5030.30
(Technician)			
Equipment & Expenses			
Equipment rental	200		200
Equipment purchase			
Materials purchased	563.94	294.36	269.58
Travel expenses	1478	350	1128
Permits			
Water sample analysis	1291.65	800	491.65
Overhead			
Office supplies			
Photo copies & printing	25		25
Postage, courier	100		100
Lab space	250		250
Subtotal	16,194.53	5000	11,194.53
Total Expensed	16,194.53	5000	11,194.53
Balance	0	*0	0

*Unspent BCRP financial contribution to be returned to: BC Hydro, BCRP
6911 Southpoint Drive (E16)
Burnaby, BC. V3N 4X8
ATTENTION: JANICE DOANE