Puntledge River High Temperature Study: Influence of High Water Temperature on Adult Chinook Salmon (*Oncorhynchus tshawytscha*)

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PUNTLEDGE RIVER HIGH TEMPERATURE STUDY: INFLUENCE OF HIGH WATER TEMPERATURE ON ADULT CHINOOK SALMON (*Oncorhynchus tshawytscha*)

by

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ABSTRACT

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Adult chinook salmon (Oncorhynchus tshawytscha) were exposed to three declining water temperature regimes prior to spawning. The means (and ranges) of the test temperatures (average daily values) for the chilled, ambient and heated regimes were 15.4 °C (12.0 – 17.7), 17.6 °C (14.0 – 20.1) and 19.9 °C (16.0 – 22.1), respectively, from August 20 to October 14, 2003. The experiment was compromised due to the sudden loss of all the females in the ambient group in early September. In spite of this unexplained loss, we continued to observe the chilled and heated groups. Comparisons of these groups showed that warmer water caused a 3 week delay in maturation and at least a 2 fold increase in pre-spawning mortality. Temperature effects on gamete viability could not be determined, with statistical validity, because of the small number of fish surviving to maturity. This study is being repeated and has commenced in the summer of 2005.

RÉSUMÉ

Jensen, J.O.T., McLean, W.E., Damon, W. and Sweeten, T. 2005. Puntledge River high temperature study: Influence of high water temperature on adult chinook salmon (*Oncorhynchus tshawytscha*). Can. Tech. Rep. Fish. Aquat. Sci. 2603: v + 27 p.

Des saumons quinnat adultes (Oncorhynchus tshawytscha) ont été exposés à trois régimes de températures décroissantes avant leur frai entre le 20 août et le 14 octobre 2003. La moyenne (et la gamme) de la température de l'eau en milieu refroidi, naturel et réchauffé étaient respectivement de 15,4 °C (12,0 °C – 17,7 °C), 17,6 °C (14,0 °C – 20,1 °C) et 19,9 °C (16,0 °C – 22,1 °C). L'étude a été perturbée par la perte soudaine de toutes les femelles du groupe évoluant en milieu ambiant début septembre. Nous avons poursuivi l'observation des groupes en milieu refroidi et en milieu réchauffé malgré ces pertes inexpliquées. L'analyse des résultats montre que le réchauffement de l'eau a retardé de 3 semaines la maturation des poissons et augmenté d'un facteur au moins égale à 2 le taux de mortalité avant le frai. Les effets de la température sur la viabilité des gamètes n'ont pas pu être déterminés de manière statistiquement fiable à cause du faible nombre de poissons ayant survécu jusqu'à maturité. Cette étude est actuellement reprise depuis l'été 2005.

1.0 INTRODUCTION

A study was carried out in 2002 that dealt with the influence of high temperatures on adult pink salmon (*Oncorhynchus gorbuscha*) (Jensen et al. 2004). Adult pinks were held in 10 ft circular ponds at 3 different temperature regimes (chilled, ambient and heated) in order to study effects on mortality, egg maturation and gamete viability. In August, 2003, a similar experiment was attempted with chinook salmon (*O. tshawytscha*) adults. However the chinook study was flawed due to the sudden loss of all the ambient females in early September. Although the mortality is unexplained, it is suspected that these fish died because of a sudden degradation in water quality. Because neither the chilled or heated fish appeared to be affected, the experiment was continued to completion. And, even though this study is missing information from the ambient treatment, the comparison between chilled and heated groups yields useful information.

2.0 MATERIALS AND METHODS

The experimental setup (ponds, chiller, heater, aeration towers etc.) was the same as for the pink study (Jensen et al. 2004). As in the previous year, two replicate ponds were assigned to each of the three temperature treatments (chilled, ambient and heated), with the number of chinook per pond reduced due to the larger size of the fish. At the initial pond loading, we attempted to load 6 females and 6 males to each pond (24 fish per treatment). The numbers of males and females was only approximate because of difficulties in distinguishing sex. The use of Jacks (precocious males) reduced pond biomass. Also to counter the effects of increased biomass, the water flow rate to each experimental pond was increased from 40 LPM (i.e. for pink salmon in 2002) to 95 LPM.

Males were loaded to the ponds on August 14 while most of the females were loaded on August 18. Fish were dip netted from the hatchery holding raceway and then transported by tank truck to the experimental ponds. A mild dose of anaesthetic (mirinal) was used during transport on August 14 so that fish were sedated. However no anaesthetic was used on August 18 because of concern over possible effects of the anaesthetic on females at high water temperatures.

Dissolved oxygen concentrations (DO in mg/L) were measured at the outflow of each pond routinely. Temperatures in each holding pond were recorded using Onset TidbiT temperature loggers, set to record at 5-minute intervals (i.e. 288 measurements per day). Water flow rates were not measured routinely during the experiment because the measurement procedure disturbs the fish. Instead DO was used to assess environmental conditions in the ponds.

Fish were routinely checked for maturity as with the pink salmon study in 2002 (Jensen 2004). Three replicate subsamples of approximately 100 eggs each, were taken from each female and fertilized with 0.3 mL of pooled sperm. These subsamples were placed in individual cells of divided Heath trays (20 cells per tray). Chilled water was used for all treatments up until Nov 7, 2003 when the chiller was turned off. Eggs were monitored until ponding time.

3.0 RESULTS AND DISCUSSION

3.1 Water Temperatures

Tables 1 to 6 show the average, minimum and maximum daily water temperatures for each experimental Pond. The number of measurements per day (count) and the standard deviation are also shown.

Table 1. Pond 1 (chilled) daily maximum, minimum and average temperature (°C).

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
19-Aug	18.70	17.59	18.24	0.35	148
20-Aug	18.38	16.94	17.60	0.48	288
21-Aug	18.38	17.11	17.69	0.45	287
22-Aug	18.05	17.11	17.58	0.34	288
23-Aug	17.59	16.63	17.10	0.35	288
24-Aug	17.11	16.15	16.50	0.24	288
25-Aug	16.79	16.15	16.42	0.19	288
26-Aug	16.94	16.00	16.42	0.31	288
27-Aug	17.59	15.85	16.56	0.62	288
28-Aug	17.89	16.47	17.12	0.49	288
29-Aug	17.89	16.47	17.17	0.51	288
30-Aug	17.89	16.63	17.29	0.43	288
31-Aug	18.05	16.94	17.45	0.39	288
1-Sep	17.73	16.47	17.11	0.47	288
2-Sep	18.54	16.47	17.49	0.67	257
3-Sep	18.86	16.31	17.48	0.87	288
4-Sep	19.02	16.47	17.66	0.87	288
5-Sep	18.86	17.11	17.85	0.52	288
6-Sep	17.59	16.47	16.83	0.26	288
7-Sep	17.11	15.69	16.39	0.45	288
8-Sep	17.27	15.37	16.39	0.54	288
9-Sep	17.27	15.21	16.04	0.6	288
10-Sep	16.47	15.53	15.85	0.32	288
11-Sep	16.15	15.21	15.67	0.31	288
12-Sep	16.63	15.21	16.05	0.37	288
13-Sep	16.31	15.53	15.90	0.2	288
14-Sep	16.31	15.53	15.96	0.23	288
15-Sep	16.15	15.21	15.64	0.35	288
16-Sep	15.53	14.74	15.19	0.23	288
17-Sep	15.21	14.44	14.74	0.19	288
18-Sep	14.74	14.29	14.39	0.14	288
19-Sep	14.90	14.14	14.49	0.29	288
20-Sep	15.05	14.14	14.62	0.28	288
21-Sep	15.21	13.98	14.55	0.36	288
22-Sep	15.05	14.14	14.57	0.3	287
23-Sep	15.21	14.44	14.81	0.28	288
24-Sep	15.05	14.14	14.42	0.24	288
25-Sep	15.05	13.98	14.49	0.35	288
26-Sep	15.05	14.14	14.61	0.31	288
27-Sep	15.37	14.29	14.78	0.34	288

Table 1 continued					
Date 2003	Max	Min	Avg	StDev	Count
28-Sep	15.37	14.44	14.94	0.3	288
29-Sep	15.37	14.59	14.96	0.27	288
30-Sep	15.21	14.59	14.89	0.18	289
1-Oct	15.37	14.44	14.83	0.33	288
2-Oct	15.21	14.29	14.77	0.29	288
3-Oct	14.90	14.59	14.67	0.09	288
4-Oct	14.90	13.98	14.39	0.32	288
5-Oct	14.59	14.29	14.36	0.09	288
6-Oct	14.29	13.83	13.94	0.14	287
7-Oct	14.44	13.67	13.95	0.25	288
8-Oct	14.14	13.36	13.69	0.19	288
9-Oct	13.67	13.05	13.40	0.2	288
10-Oct	13.36	13.05	13.19	0.12	288
11-Oct	13.67	12.91	13.09	0.24	288
12-Oct	14.59	12.44	13.28	0.79	288
13-Oct	12.75	12.13	12.41	0.15	288
14-Oct	12.60	11.82	12.19	0.24	286
15-Oct	12.13	11.97	12.02	0.07	288
16-Oct	11.97	11.21	11.55	0.2	288
17-Oct	11.67	11.36	11.49	0.1	288
18-Oct	11.67	11.51	11.62	0.07	288
19-Oct	11.51	10.90	11.17	0.18	288
20-Oct	11.51	11.06	11.39	0.14	287
21-Oct	11.21	11.06	11.14	0.07	288
22-Oct	11.21	11.06	11.14	0.07	288
23-Oct	11.06	10.59	10.84	0.13	288
24-Oct	10.90	10.59	10.72	0.08	288
25-Oct	11.06	10.59	10.70	0.13	288
26-Oct	10.74	10.43	10.57	0.1	300
27-Oct	10.74	10.59	10.65	0.07	197

Table 2. Pond 2 (ambient) daily maximum, minimum and average temperatures (°C)

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
19-Aug	21.07	19.95	20.65	0.35	148
20-Aug	20.74	19.30	19.98	0.5	288
21-Aug	20.74	19.47	20.08	0.47	288
22-Aug	20.59	19.30	19.97	0.37	288
23-Aug	19.95	18.97	19.45	0.37	288
24-Aug	19.30	18.51	18.84	0.25	288
25-Aug	19.14	18.51	18.76	0.2	288
26-Aug	19.30	18.34	18.76	0.33	288
27-Aug	19.95	18.02	18.91	0.67	288
28-Aug	20.27	18.81	19.45	0.54	288
29-Aug	20.44	18.81	19.54	0.55	288
30-Aug	20.44	18.97	19.67	0.48	288
31-Aug	20.44	19.14	19.82	0.43	288
1-Sep	20.27	18.67	19.47	0.52	288

Table 2 continued

Date 2003	Max	Min	Avg	StDev	Count
2-Sep	20.90	18.51	19.79	0.7	261
3-Sep	21.40	18.51	19.80	0.96	286
4-Sep	21.57	18.67	19.99	0.95	288
5-Sep	21.24	19.47	20.16	0.55	288
6-Sep	19.79	18.67	19.04	0.27	288
7-Sep	19.47	17.70	18.59	0.49	288
8-Sep	19.30	16.76	18.01	0.81	288
9-Sep	19.63	17.22	18.23	0.76	288
10-Sep	18.81	17.70	18.09	0.37	288
11-Sep	18.51	17.38	17.91	0.36	288
12-Sep	18.97	16.60	17.86	0.81	288
13-Sep	18.34	17.38	17.90	0.34	288
14-Sep	18.67	17.54	18.10	0.36	288
15-Sep	18.02	16.76	17.32	0.36	288
16-Sep	17.86	17.06	17.49	0.27	287
17-Sep	17.54	16.76	17.02	0.2	288
18-Sep	17.06	16.60	16.66	0.11	288
19-Sep	17.22	16.45	16.79	0.31	288
20-Sep	17.38	16.45	16.93	0.33	288
21-Sep	17.54	16.29	16.86	0.42	288
22-Sep	17.38	16.29	16.88	0.36	288
23-Sep	17.54	16.60	17.11	0.33	288
24-Sep	17.38	16.29	16.71	0.25	288
25-Sep	17.38	16.13	16.79	0.41	288
26-Sep	17.54	16.45	16.93	0.36	288
27-Sep	17.70	16.60	17.11	0.39	288
28-Sep	17.86	16.76	17.30	0.36	288
29-Sep	17.86	16.76	17.31	0.33	288
30-Sep	17.54	16.92	17.26	0.22	289
1-Oct	17.86	16.60	17.15	0.37	288
2-Oct	17.70	16.60	17.11	0.35	288
3-Oct	17.22	16.76	17.00	0.11	288
4-Oct	17.22	16.29	16.71	0.34	288
5-Oct	16.92	16.60	16.64	0.09	288
6-Oct	16.60	16.13	16.22	0.13	286
7-Oct	16.45	15.81	16.14	0.2	288
8-Oct	16.13	15.34	15.68	0.19	288
9-Oct	15.65	14.72	15.17	0.28	288
10-Oct	15.34	14.88	15.16	0.14	288
11-Oct	15.04	14.72	14.90	0.12	288
12-Oct	14.72	14.25	14.39	0.12	288
13-Oct	14.56	14.10	14.28	0.17	288
14-Oct	14.56	13.63	14.06	0.28	287
15-Oct	13.94	13.78	13.89	0.07	288
16-Oct	13.78	12.88	13.30	0.28	288
17-Oct	13.34	12.88	13.15	0.1	288
18-Oct	13.34	13.19	13.29	0.07	288
19-Oct	13.19	12.41	12.76	0.23	288
20-Oct	13.03	12.72	12.94	0.13	288

Table 2 continued					
Date 2003	Max	Min	Avg	StDev	Count
21-Oct	12.88	12.57	12.73	0.12	288
22-Oct	12.88	12.57	12.74	0.08	288
23-Oct	12.72	12.25	12.39	0.13	288
24-Oct	12.41	12.10	12.25	0.08	288
25-Oct	12.57	12.10	12.22	0.13	288
26-Oct	12.25	11.79	12.03	0.12	300
27-Oct	12.41	11.94	12.15	0.13	276
28-Oct	12.25	11.50	12.07	0.19	288
29-Oct	11.50	10.57	10.89	0.25	288
30-Oct	10.88	10.26	10.53	0.17	288
31-Oct	10.57	9.94	10.25	0.22	288
1-Nov	10.41	9.94	10.15	0.16	288
2-Nov	10.41	9.80	10.07	0.18	288
3-Nov	10.10	9.49	9.75	0.21	288
4-Nov	9.80	9.18	9.49	0.17	288
5-Nov	9.49	9.03	9.20	0.11	167

Table 3. Pond 3(chilled) daily maximum, minimum and average temperatures (°C).

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
14-Aug	18.88	17.29	18.31	0.51	153
15-Aug	18.73	17.45	18.00	0.44	288
16-Aug	18.25	17.13	17.63	0.28	288
17-Aug	18.41	16.83	17.54	0.53	288
18-Aug	18.25	17.29	17.81	0.26	288
19-Aug	18.25	16.83	17.48	0.5	273
20-Aug	17.93	16.50	17.22	0.48	288
21-Aug	17.93	16.66	17.31	0.44	288
22-Aug	17.77	16.66	17.20	0.36	288
23-Aug	17.29	16.20	16.71	0.35	288
24-Aug	16.66	15.73	16.16	0.22	288
25-Aug	16.50	15.89	16.10	0.18	288
26-Aug	16.50	15.73	16.05	0.29	288
27-Aug	17.13	15.41	16.19	0.63	288
28-Aug	17.45	16.04	16.73	0.49	288
29-Aug	17.61	16.04	16.80	0.52	288
30-Aug	17.61	16.35	16.93	0.43	288
31-Aug	17.77	16.50	17.06	0.4	288
1-Sep	17.45	16.04	16.73	0.49	288
2-Sep	18.25	16.04	17.07	0.69	271
3-Sep	18.57	15.89	17.12	0.87	288
4-Sep	18.73	16.04	17.30	0.88	288
5-Sep	18.57	16.83	17.48	0.52	288
6-Sep	17.13	16.20	16.46	0.26	288
7-Sep	16.66	15.25	16.02	0.44	288
8-Sep	16.83	14.94	16.02	0.52	288
9-Sep	16.83	14.94	15.69	0.6	287
10-Sep	16.04	15.10	15.47	0.31	288

Table 3 continued

Date 2003	Max	Min	Avg	StDev	Count
11-Sep	15.89	14.79	15.31	0.33	288
12-Sep	16.20	14.79	15.67	0.37	288
13-Sep	16.04	15.25	15.52	0.21	288
14-Sep	15.89	15.25	15.60	0.23	288
15-Sep	15.73	14.79	15.25	0.34	288
16-Sep	15.10	14.47	14.81	0.22	287
17-Sep	14.79	14.02	14.36	0.19	288
18-Sep	14.33	14.02	14.07	0.09	288
19-Sep	14.63	13.71	14.13	0.28	288
20-Sep	14.63	13.86	14.26	0.29	288
21-Sep	14.79	13.71	14.18	0.36	288
22-Sep	14.63	13.71	14.20	0.31	288
23-Sep	14.79	14.02	14.44	0.29	288
24-Sep	14.63	13.71	14.05	0.23	288
25-Sep	14.63	13.56	14.13	0.35	288
26-Sep	14.63	13.71	14.24	0.31	288
27-Sep	14.94	13.86	14.42	0.34	288
28-Sep	15.10	14.17	14.60	0.31	288
29-Sep	15.10	14.17	14.61	0.29	288
30-Sep	14.79	14.17	14.55	0.2	288
1-Oct	14.94	14.02	14.45	0.34	288
2-Oct	14.94	14.02	14.41	0.29	288
3-Oct	14.47	14.17	14.31	0.12	288
4-Oct	14.47	13.56	14.03	0.31	288
5-Oct	14.17	13.86	13.99	0.1	288
6-Oct	13.86	13.41	13.61	0.12	286
7-Oct	14.02	13.25	13.57	0.27	288
8-Oct	13.86	12.95	13.31	0.2	288
9-Oct	13.25	12.64	13.04	0.22	288
10-Oct	12.95	12.64	12.81	0.12	288
11-Oct	13.25	12.49	12.68	0.23	288
12-Oct	14.17	12.03	12.88	0.77	288
13-Oct	12.34	11.88	12.04	0.17	288
14-Oct	12.34	11.41	11.80	0.27	286
15-Oct	11.72	11.56	11.67	0.08	288
16-Oct	11.56	10.96	11.20	0.19	288
17-Oct	11.25	10.96	11.14	0.12	288
18-Oct	11.25	11.10	11.25	0.02	288
19-Oct	11.10	10.50	10.80	0.19	288
20-Oct	11.25	10.80	11.00	0.13	287
21-Oct	10.96	10.65	10.72	0.09	186

Table 4. Pond 4 (ambient) daily maximum, minimum and average temperatures (°C).

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
19-Aug	21.05	19.93	20.54	0.35	149
20-Aug	20.72	19.13	19.88	0.51	288

Table 4 continued

Date 2003	Max	Min	Avg	StDev	Count
21-Aug	20.72	19.29	20.01	0.48	287
22-Aug	20.41	19.29	19.89	0.36	288
23-Aug	19.93	18.81	19.38	0.36	288
24-Aug	19.29	18.32	18.77	0.22	288
25-Aug	19.13	18.48	18.73	0.21	288
26-Aug	19.13	18.32	18.71	0.31	288
27-Aug	19.93	18.02	18.81	0.67	288
28-Aug	20.25	18.64	19.34	0.55	288
29-Aug	20.25	18.64	19.44	0.56	288
30-Aug	20.25	18.97	19.57	0.46	288
31-Aug	20.41	19.13	19.71	0.43	288
1-Sep	20.09	18.64	19.36	0.51	288
2-Sep	20.88	18.32	19.69	0.72	261
3-Sep	21.21	18.32	19.70	0.95	287
4-Sep	21.38	18.48	19.89	0.94	288
5-Sep	21.21	19.29	20.06	0.56	288
6-Sep	19.76	18.64	18.94	0.27	288
7-Sep	19.29	17.69	18.49	0.5	288
8-Sep	19.13	16.76	17.93	0.8	288
9-Sep	19.44	17.22	18.13	0.74	289
10-Sep	18.64	17.53	17.99	0.35	288
11-Sep	18.48	17.22	17.81	0.37	288
12-Sep	18.97	16.60	17.75	0.8	288
13-Sep	18.16	17.22	17.79	0.34	288
14-Sep	18.64	17.53	18.00	0.35	288
15-Sep	17.86	16.60	17.21	0.35	288
16-Sep	17.69	16.90	17.38	0.24	287
17-Sep	17.38	16.60	16.91	0.21	288
18-Sep	16.90	16.44	16.54	0.13	288
19-Sep	17.22	16.29	16.69	0.34	288
20-Sep	17.22	16.29	16.81	0.32	288
21-Sep	17.38	16.13	16.74	0.42	288
22-Sep	17.22	16.13	16.77	0.34	287
23-Sep	17.53	16.60	17.03	0.32	288
24-Sep	17.22	16.29	16.59	0.25	288
25-Sep	17.38	15.97	16.68	0.41	288
26-Sep	17.38	16.29	16.83	0.37	288
27-Sep	17.69	16.44	17.01	0.4	288
28-Sep	17.69	16.60	17.19	0.36	288
29-Sep	17.69	16.60	17.21	0.33	288
30-Sep	17.38	16.76	17.15	0.19	288
1-Oct	17.69	16.60	17.06	0.38	288
2-Oct	17.53	16.44	17.01	0.35	288
3-Oct	17.06	16.76	16.90	0.12	288
4-Oct	17.06	16.13	16.58	0.34	288
5-Oct	16.76	16.44	16.55	0.1	288
6-Oct	16.44	15.97	16.09	0.16	288
7-Oct	16.44	15.81	16.04	0.2	288

Table 4 continued					
Date 2003	Max	Min	Avg	StDev	Count
8-Oct	16.13	15.20	15.59	0.18	288
9-Oct	15.51	14.72	15.09	0.27	288
10-Oct	15.36	14.87	15.07	0.16	288
11-Oct	15.03	14.56	14.77	0.12	288
12-Oct	14.56	14.11	14.29	0.12	288
13-Oct	14.56	13.95	14.19	0.2	288
14-Oct	14.56	13.49	13.96	0.29	287
15-Oct	13.80	13.65	13.78	0.06	288
16-Oct	13.65	12.90	13.23	0.24	288
17-Oct	13.20	12.90	13.08	0.12	288
18-Oct	13.34	13.05	13.19	0.08	288
19-Oct	13.05	12.27	12.68	0.22	288
20-Oct	13.05	12.59	12.91	0.16	287
21-Oct	12.74	12.43	12.66	0.1	288
22-Oct	12.74	12.59	12.67	0.07	288
23-Oct	12.59	12.12	12.31	0.14	288
24-Oct	12.27	12.12	12.17	0.07	288
25-Oct	12.43	11.99	12.14	0.15	288
26-Oct	12.12	11.83	11.96	0.12	300
27-Oct	12.27	11.99	12.07	0.12	196

Table 5. Pond 5 (heated) daily maximum, minimum and average temperatures (°C)

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
14-Aug	23.13	21.62	22.59	0.53	153
15-Aug	23.13	21.96	22.43	0.4	288
16-Aug	22.79	21.62	22.13	0.33	288
17-Aug	22.96	21.46	22.00	0.54	288
18-Aug	22.79	21.96	22.30	0.24	288
19-Aug	22.46	21.29	21.84	0.38	288
20-Aug	22.46	20.96	21.59	0.51	288
21-Aug	22.62	21.12	21.78	0.54	285
22-Aug	22.46	21.29	21.82	0.39	288
23-Aug	21.96	20.79	21.33	0.41	288
24-Aug	21.46	20.46	20.77	0.24	288
25-Aug	20.96	20.46	20.70	0.19	288
26-Aug	21.29	20.30	20.66	0.32	288
27-Aug	21.96	19.97	20.76	0.63	288
28-Aug	22.29	20.62	21.29	0.57	288
29-Aug	22.29	20.62	21.41	0.59	288
30-Aug	22.29	20.96	21.58	0.48	288
31-Aug	22.46	21.12	21.69	0.44	288
1-Sep	22.12	20.62	21.33	0.54	288
2-Sep	22.46	19.65	21.38	0.75	289
3-Sep	22.79	20.46	21.57	0.73	288
4-Sep	22.79	20.79	21.74	0.68	288

Table 5 continued

Date 2003	Max	Min	Avg	StDev	Count
5-Sep	22.79	21.46	22.06	0.38	288
6-Sep	21.96	20.79	21.11	0.31	288
7-Sep	21.29	19.81	20.56	0.42	288
8-Sep	21.12	18.85	19.93	0.72	288
9-Sep	21.29	19.33	20.16	0.63	288
10-Sep	20.79	19.81	20.12	0.3	288
11-Sep	20.46	19.65	19.94	0.28	288
12-Sep	20.96	18.69	19.70	0.73	288
13-Sep	20.79	19.97	20.23	0.22	288
14-Sep	20.62	19.81	20.21	0.26	288
15-Sep	20.46	19.33	19.61	0.32	288
16-Sep	19.81	19.01	19.46	0.23	287
17-Sep	19.49	18.69	19.02	0.21	288
18-Sep	19.01	18.52	18.74	0.1	288
19-Sep	19.33	18.36	18.76	0.28	288
20-Sep	19.33	18.52	18.87	0.3	288
21-Sep	19.49	18.36	18.78	0.39	288
22-Sep	19.49	18.36	18.88	0.37	287
23-Sep	19.49	18.69	19.12	0.29	288
24-Sep	19.49	18.52	18.78	0.25	288
25-Sep	19.33	18.36	18.76	0.35	288
26-Sep	19.49	18.36	18.87	0.35	288
27-Sep	19.65	18.69	19.08	0.36	288
28-Sep	19.81	18.85	19.26	0.32	288
29-Sep	19.81	18.85	19.26	0.31	288
30-Sep	19.49	19.01	19.20	0.15	289
1-Oct	19.65	18.52	19.05	0.35	288
2-Oct	19.49	18.52	18.99	0.33	288
3-Oct	19.17	18.85	18.95	0.09	288
4-Oct	19.17	18.20	18.56	0.34	288
5-Oct	19.01	18.52	18.59	0.12	288
6-Oct	18.52	18.04	18.22	0.14	287
7-Oct	18.52	17.87	18.17	0.22	288
8-Oct	18.36	17.41	17.80	0.23	288
9-Oct	17.57	16.93	17.25	0.2	288
10-Oct	17.41	17.09	17.25	0.13	288
11-Oct	17.25	16.77	16.99	0.15	288
12-Oct	16.77	16.46	16.52	0.09	288
13-Oct	16.61	16.14	16.40	0.14	288
14-Oct	16.46	15.67	16.05	0.23	287
15-Oct	15.82	15.82	15.82	0	288
16-Oct	15.82	15.03	15.36	0.22	288
17-Oct	15.35	15.03	15.27	0.09	288
18-Oct	15.51	15.35	15.40	0.07	288
19-Oct	15.35	14.56	14.90	0.25	288
20-Oct	15.19	14.87	15.09	0.14	287
21-Oct	15.19	14.72	14.94	0.11	288
22-Oct	15.03	14.72	14.93	0.08	288
23-Oct	14.72	14.24	14.47	0.14	288

Table 5 continued					
Date 2003	Max	Min	Avg	StDev	Count
24-Oct	14.56	14.24	14.38	0.1	288
25-Oct	14.56	14.09	14.32	0.14	288
26-Oct	14.40	13.93	14.12	0.13	300
27-Oct	14.56	14.09	14.35	0.2	275
28-Oct	14.56	13.78	14.33	0.19	288
29-Oct	13.78	12.70	13.04	0.29	288
30-Oct	12.86	12.39	12.65	0.12	288
31-Oct	12.70	12.08	12.35	0.22	288
1-Nov	12.70	12.08	12.31	0.17	288
2-Nov	12.54	12.08	12.21	0.16	288
3-Nov	12.23	11.63	11.87	0.19	288
4-Nov	11.93	11.32	11.59	0.18	288
5-Nov	11.63	11.17	11.33	0.16	301
6-Nov	11.63	10.86	11.16	0.2	288
7-Nov	11.48	10.71	11.07	0.23	288
8-Nov	11.79	11.17	11.39	0.19	288
9-Nov	11.63	10.86	11.23	0.21	288
10-Nov	11.63	11.17	11.34	0.15	288
11-Nov	11.63	11.01	11.32	0.18	288
12-Nov	11.48	11.17	11.24	0.08	147

Table 6. Pond 6 (heated) daily maximum, minimum and average temperatures (°C).

Date 2003	*Max*	*Min*	*Avg*	*StDev*	*Count*
14-Aug	23.48	21.99	22.88	0.5	154
15-Aug	23.31	22.15	22.74	0.38	288
16-Aug	23.14	21.99	22.45	0.32	288
17-Aug	23.31	21.65	22.32	0.54	288
18-Aug	22.98	22.15	22.63	0.24	288
19-Aug	22.98	21.65	22.24	0.43	287
20-Aug	22.98	21.49	22.14	0.49	288
21-Aug	22.64	21.65	22.09	0.27	286
22-Aug	22.31	21.15	21.78	0.4	288
23-Aug	21.99	20.83	21.30	0.39	288
24-Aug	21.32	20.35	20.74	0.23	288
25-Aug	20.99	20.51	20.68	0.15	288
26-Aug	21.15	20.19	20.65	0.29	288
27-Aug	21.82	20.03	20.72	0.63	288
28-Aug	22.15	20.51	21.24	0.55	288
29-Aug	22.31	20.51	21.35	0.57	288
30-Aug	22.31	20.83	21.52	0.49	288
31-Aug	22.31	20.99	21.63	0.44	288
1-Sep	22.15	20.51	21.29	0.52	288
2-Sep	22.48	19.70	21.43	0.73	288
3-Sep	22.81	20.51	21.61	0.74	288
4-Sep	22.81	20.83	21.80	0.69	288
5-Sep	22.81	21.49	22.12	0.37	288
6-Sep	21.99	20.83	21.18	0.3	288

Table 6 continued

Date 2003	Max	Min	Avg	StDev	Count
7-Sep	21.32	19.86	20.65	0.4	288
8-Sep	21.15	18.90	20.02	0.72	287
9-Sep	21.32	19.38	20.23	0.62	288
10-Sep	20.83	19.86	20.20	0.31	288
11-Sep	20.51	19.70	20.02	0.29	288
12-Sep	20.99	18.74	19.80	0.73	288
13-Sep	20.83	20.03	20.31	0.23	288
14-Sep	20.66	19.86	20.30	0.26	288
15-Sep	20.51	19.38	19.68	0.33	288
16-Sep	19.86	19.22	19.52	0.24	288
17-Sep	19.70	18.74	19.14	0.2	288
18-Sep	19.22	18.74	18.83	0.14	288
19-Sep	19.38	18.58	18.86	0.3	288
20-Sep	19.38	18.58	18.97	0.3	288
21-Sep	19.54	18.42	18.91	0.39	288
22-Sep	19.54	18.58	19.01	0.35	288
23-Sep	19.70	18.74	19.21	0.31	288
24-Sep	19.54	18.42	18.80	0.3	288
25-Sep	19.38	18.26	18.76	0.37	288
26-Sep	19.38	18.42	18.88	0.35	288
27-Sep	19.70	18.58	19.10	0.37	288
28-Sep	19.86	18.74	19.29	0.33	288
29-Sep	19.86	18.90	19.29	0.31	288
30-Sep	19.54	18.90	19.29	0.18	289
1-Oct	19.70	18.74	19.15	0.34	288
2-Oct	19.54	18.58	19.07	0.33	288
3-Oct	19.22	18.90	19.02	0.1	288
4-Oct	19.22	18.26	18.66	0.34	288
5-Oct	19.06	18.58	18.66	0.13	288
6-Oct	18.58	18.26	18.32	0.11	285
7-Oct	18.58	18.10	18.29	0.18	288
8-Oct	18.42	17.45	17.91	0.22	288
9-Oct	17.77	17.15	17.34	0.19	288
10-Oct	17.61	17.15	17.32	0.11	288
11-Oct	17.30	16.82	17.09	0.15	288
12-Oct	16.82	16.50	16.59	0.1	288
13-Oct	16.66	16.34	16.46	0.13	288
14-Oct	16.50	15.87	16.14	0.21	288
15-Oct	16.03	15.87	15.96	0.08	288
16-Oct	15.87	14.93	15.37	0.3	288
17-Oct	15.25	14.93	15.16	0.1	288
18-Oct	15.41	15.25	15.34	0.08	288
19-Oct	15.25	14.46	14.79	0.25	288
20-Oct	15.25	14.93	15.09	0.08	288
21-Oct	15.09	14.93	15.02	0.08	288
22-Oct	15.09	14.93	15.01	0.08	288
23-Oct	14.93	14.46	14.59	0.12	288
24-Oct	14.62	14.31	14.48	0.08	288
25-Oct	14.62	14.31	14.43	0.12	288

Table 6 continued					
Date 2003	Max	Min	Avg	StDev	Count
26-Oct	14.46	14.16	14.27	0.11	300
27-Oct	14.62	14.16	14.41	0.12	275
28-Oct	14.46	13.86	14.35	0.17	288
29-Oct	13.86	12.77	13.08	0.28	288
30-Oct	12.93	12.47	12.71	0.12	288
31-Oct	12.77	12.16	12.43	0.21	288
1-Nov	12.63	12.16	12.39	0.17	288
2-Nov	12.63	12.01	12.28	0.16	288
3-Nov	12.32	11.70	11.94	0.19	288
4-Nov	12.16	11.39	11.70	0.19	288
5-Nov	11.85	11.24	11.46	0.17	299
6-Nov	11.70	11.08	11.29	0.2	288
7-Nov	11.54	10.94	11.18	0.2	288
8-Nov	11.85	11.24	11.47	0.18	288
9-Nov	11.70	11.08	11.30	0.21	288
10-Nov	11.70	11.24	11.41	0.15	288
11-Nov	11.70	11.08	11.39	0.18	288
12-Nov	11.54	11.24	11.28	0.07	147

Figure 1 shows average daily temperatures plotted against time for chilled, ambient and heated ponds.

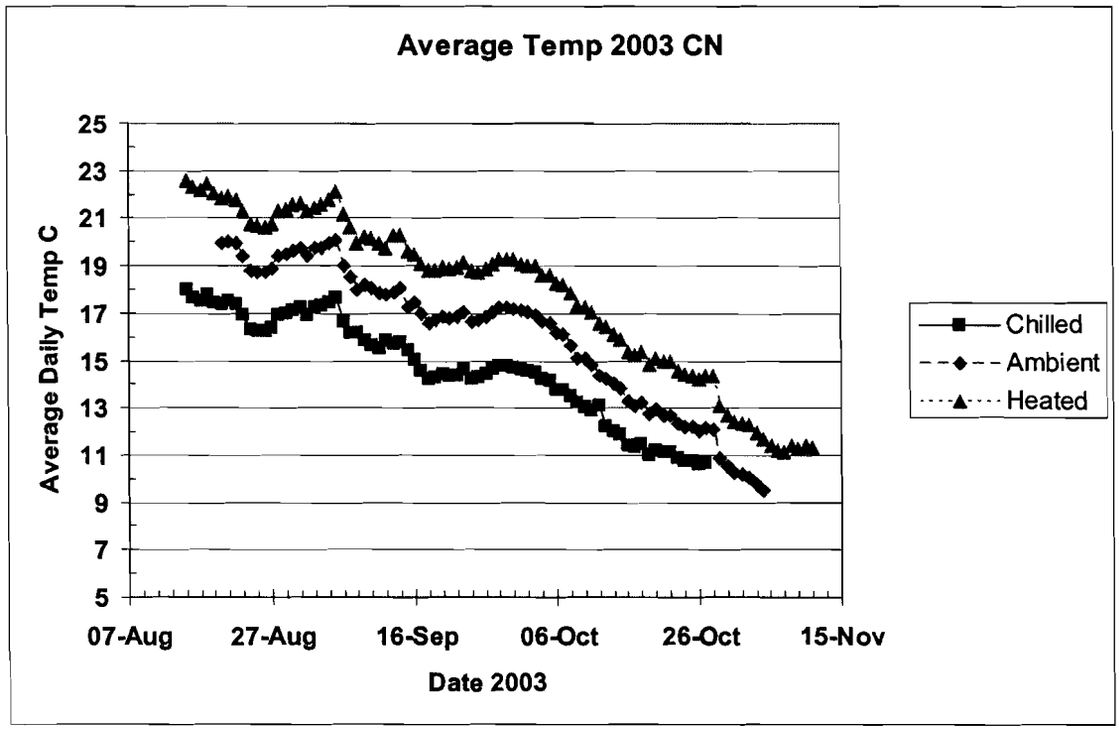

Figure 1. Average daily temperatures (°C) for 3 experimental treatments, chilled, ambient and heated.

Table 6 continued					
Date 2003	Max	Min	Avg	StDev	Count
26-Oct	14.46	14.16	14.27	0.11	300
27-Oct	14.62	14.16	14.41	0.12	275
28-Oct	14.46	13.86	14.35	0.17	288
29-Oct	13.86	12.77	13.08	0.28	288
30-Oct	12.93	12.47	12.71	0.12	288
31-Oct	12.77	12.16	12.43	0.21	288
1-Nov	12.63	12.16	12.39	0.17	288
2-Nov	12.63	12.01	12.28	0.16	288
3-Nov	12.32	11.70	11.94	0.19	288
4-Nov	12.16	11.39	11.70	0.19	288
5-Nov	11.85	11.24	11.46	0.17	299
6-Nov	11.70	11.08	11.29	0.2	288
7-Nov	11.54	10.94	11.18	0.2	288
8-Nov	11.85	11.24	11.47	0.18	288
9-Nov	11.70	11.08	11.30	0.21	288
10-Nov	11.70	11.24	11.41	0.15	288
11-Nov	11.70	11.08	11.39	0.18	288
12-Nov	11.54	11.24	11.28	0.07	147

Figure 1 shows average daily temperatures plotted against time for chilled, ambient and heated ponds.

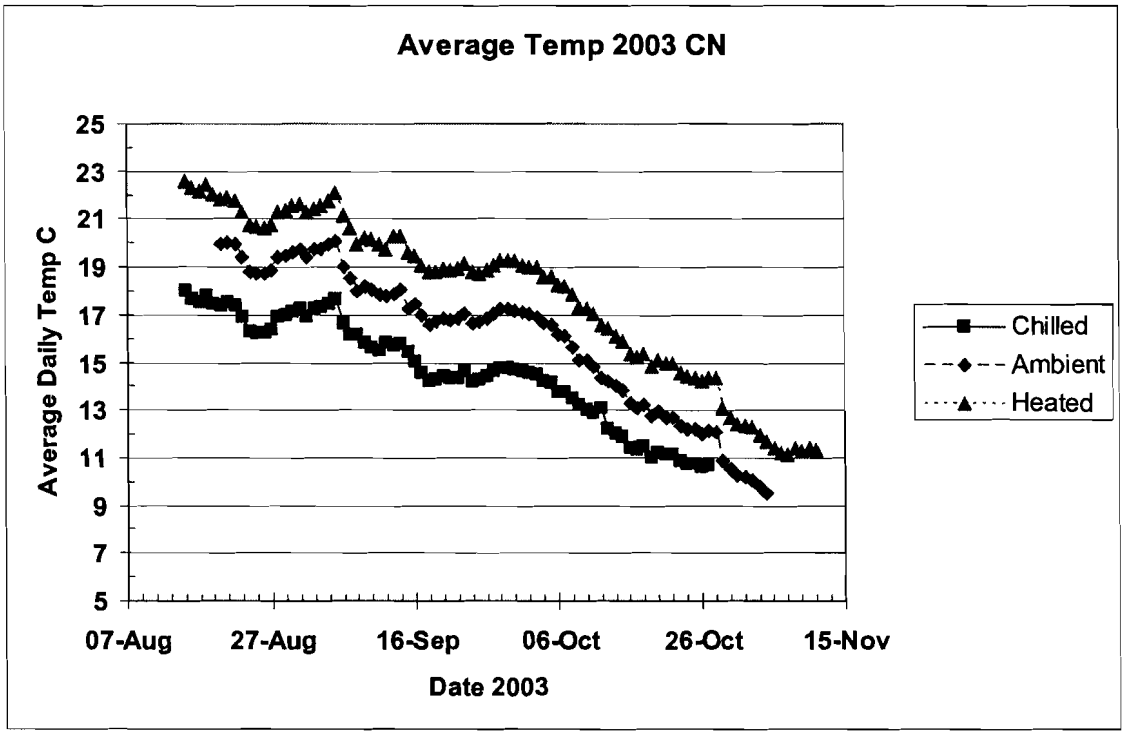

Figure 1. Average daily temperatures (°C) for 3 experimental treatments, chilled, ambient and heated.

Delta T (ΔT) denotes the temperature increase or decrease in heated and chilled water relative to ambient and is plotted against time in Figure 2. Daily variation depends on performance of the equipment and changes in water flow. Between August 20 and October 14 (56 days), the mean (range) of the average daily temperatures of the chilled, ambient and heated ponds were: 15.28 °C (11.99 – 17.66), 17.62 °C (14.01 – 20.11) and 19.65 °C (16.10 – 22.10) respectively. On average, the chilled ponds were 2.34 °C cooler (ΔT) while the heated ponds were 2.04 °C warmer than ambient.

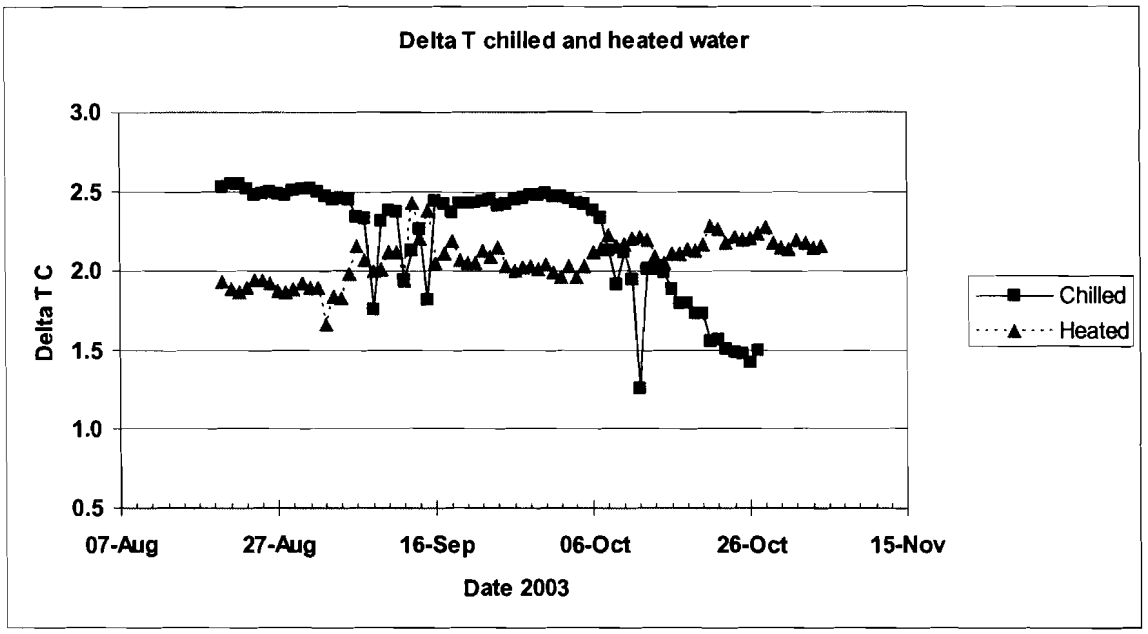

Figure 2. Degree of heating and chilling (ΔT) for each treatment.

3.2 Initial Fish Numbers, Flow and Dissolved Oxygen Measurements

Numbers of fish, biomass, pond flow (LPM) and load rate (kg of fish per LPM) at the start of the experiment (August 18, 2003) are shown in Table 7. As fish died or were removed for eggs, the biomass in the pond decreased and the DO increased. DO was measured in mg/L and as % saturation over the study period at the pond outflow. Because DO fluctuates during the day, these measurements were made in the early morning (08:00 – 09:00 AM) and in the afternoon (15:00 – 16:00 PM).

Table 7. Initial numbers of fish, pond flow, biomass and load rate.

Location	*Treatment*	*Flow (LPM)*	*Female*	*Male*	*Jacks*	*Total*	*Biomass (Kg)*	*Load (kg/LPM)*
Pond 1	Chilled	98.3	5	2	5	12	54.25	0.55
Pond 3	Chilled	92.2	6	2	4	12	75.21	0.82
Total	Chilled	190.5	11	4	9	24	129.5	0.68
Pond 2	Ambient	97.6	5	1	6	12	52.41	0.54
Pond 4	Ambient	92.3	7	0	5	12	72.35	0.78
Total	Ambient	189.9	12	1	11	24	124.8	0.66
Pond 5	Heated	93.5	5	2	5	12	57.55	0.62
Pond 6	Heated	95.2	7	2	3	12	75.35	0.79
Total	Heated	188.7	12	4	8	24	132.9	0.70

DO in mg/L and % saturation are summarized for each Pond in Table 8 while DO for each temperature treatment is shown over the holding period in Figures 3, 4 and 5. The low DO on August 25 (5.5 mg/L or 50% saturation) was due to a momentary flow disruption – all ponds were affected. On average, DO was over 85% saturation (Table 8).

Table 8. Summary of DO (mg/L) and O2 (%) at the outflow of each pond. Number of measurements (n), standard deviation (SD) and the minimum DO are also calculated.

Measurements	*Pond 1*	*Pond 3*	*Pond 2*	*Pond 4*	*Pond 5*	*Pond 6*
	Chilled	Chilled	Ambient	Ambient	Heated	Heated
Avg DO mg/L	8.7	8.3	9.3	8.7	8.9	8.7
SD	0.79	0.80	1.29	1.25	1.17	1.01
n	65	65	79	66	83	83
min mg/L	5.5	5.5	5.5	5.4	5.4	5.2
Avg O_2 %	88.3	84.8	94.9	91.2	93.8	92.6
SD	4.96	5.59	8.24	9.42	6.88	5.02
n	65	65	79	66	83	83
min % Sat	58.0	58.0	60.0	59.0	61.0	59.0

The total flow to the heated ponds was 189 LPM (Table 7). To achieve this 65 LPM was passed through the water heater and then (after aeration) mixed with 124 LPM of ambient water. This provided enough flow for the ponds and resulted in a suitable ΔT. To achieve the desired ΔT for chilled water, a total flow of 296 LPM was passed through the chiller. Lower flow would have resulted in a larger ΔT. Ponds 1 and 3 required only 191 LPM (Table 7) so 105 LPM of chilled water was allowed to flow to waste.

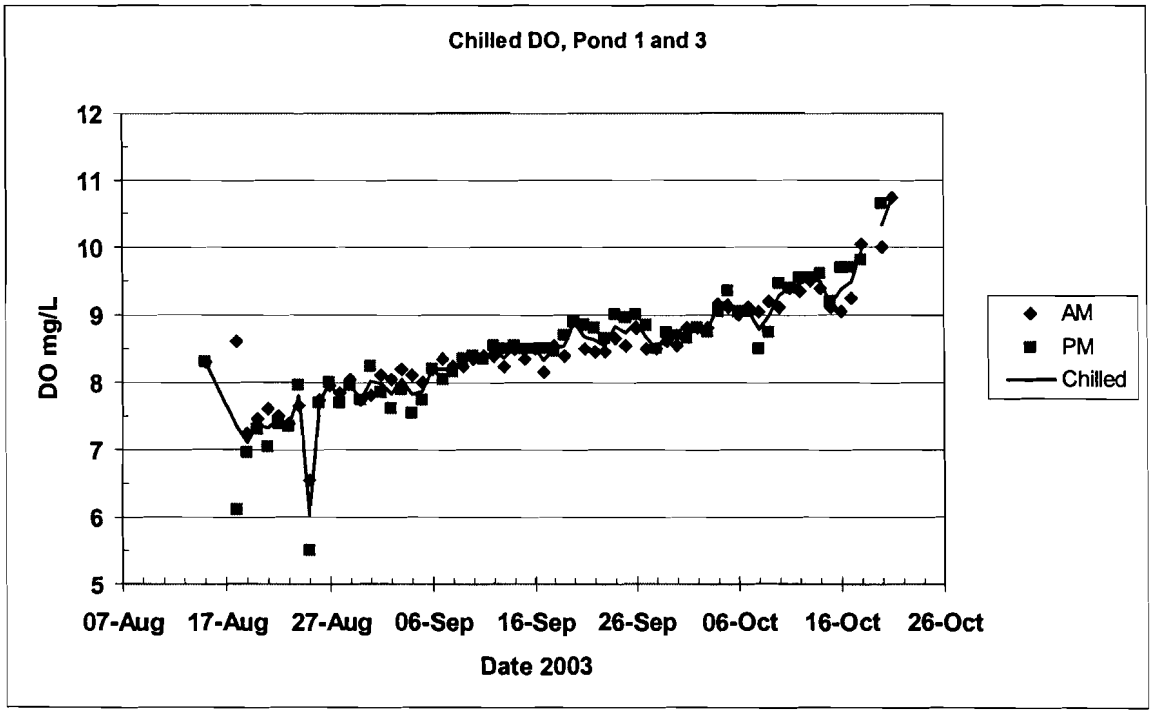

Figure 3. DO at the outlet of Ponds 1 and 3 (chilled).

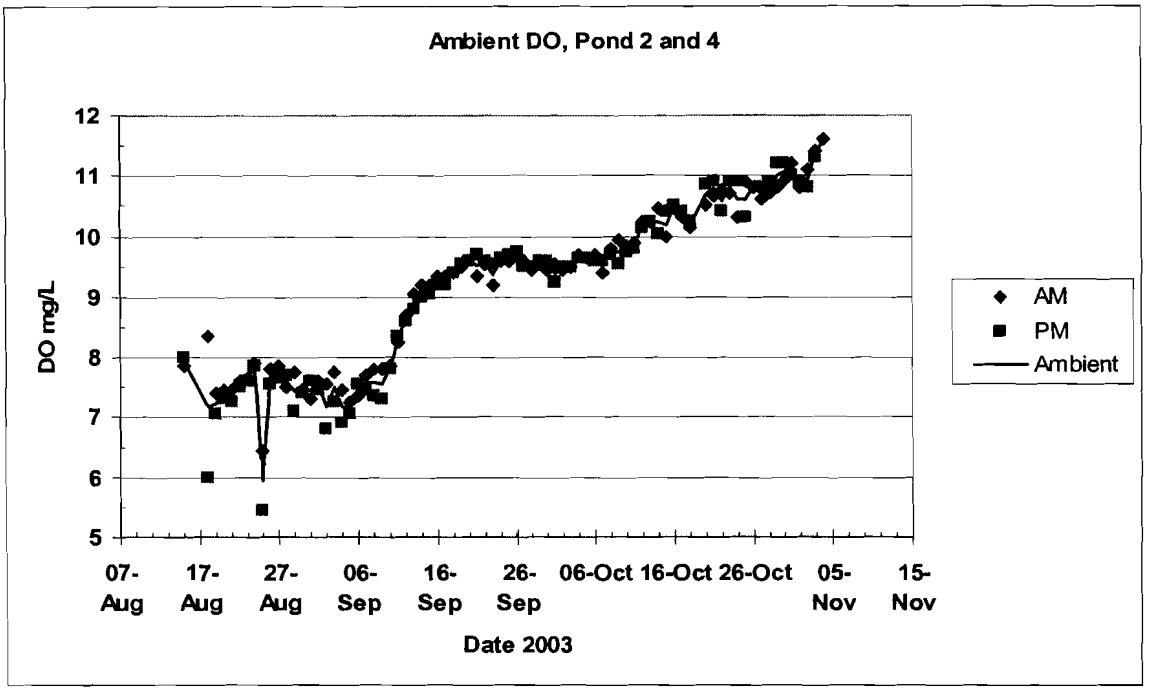

Figure 4. DO at the outlet of Ponds 2 and 4 (ambient).

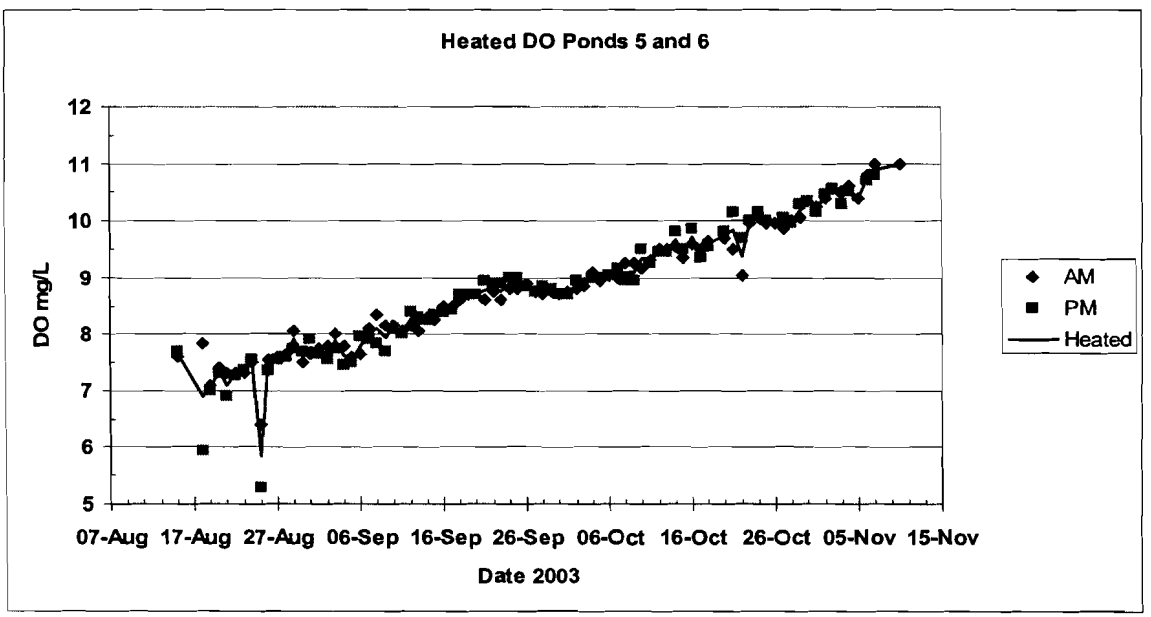

Figure 5. DO at the outlet of Ponds 5 and 6 (heated)

3.3 Length Weight Relationship

All fish that died during holding or that were killed during egg takes were weighed (W kg) and measured for post-orbital hypural length (POHL, cm) (Figure 6). The relationship was derived using Table Curve 2D (SPSS Inc., Chicago, IL, USA) and is: $W = a * (POHL)^b$ where: a = 2.3864 * 10-5 , b = 2.9878, $r^2 = 0.9716$ and n = 88.

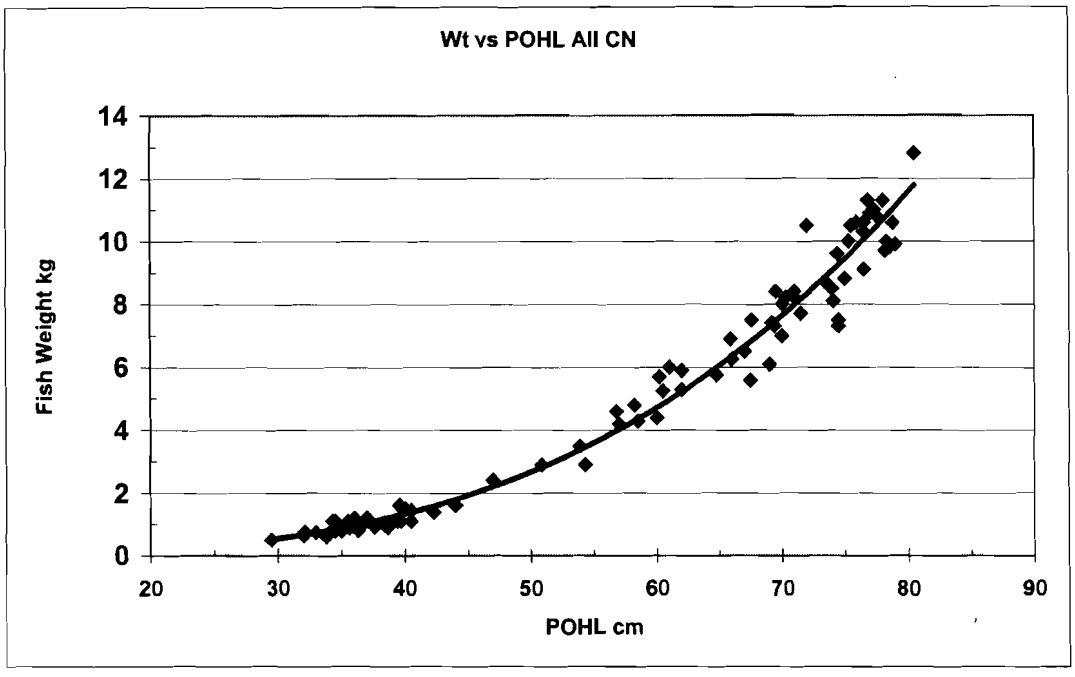

Figure 6. Individual weight (kg) vs POHL cm, female and male chinook (solid line: W = a *(POHL)^{b}).

3.4 Adult Mortality

Daily mortalities for chilled, ambient and heated ponds are shown in Tables 9, 10 and 11.

Table 9. Adult chinook salmon holding pond mortality in the chilled treatment (Ponds 1 and 3). Females that produced eggs and males that died during egg takes are not included.

Date	*Pond 1*				*Pond 3*				*Cumulative Mortality (%)*		
Initial Numbers	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total Female	total Male	
14-Aug-03	5	2	5	12	6	2	4	12			
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
15-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
16-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
17-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
18-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
19-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
20-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
21-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
22-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
23-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
24-Aug-03	0	0	0	0	0	0	0	0	0.0	0	0.0
25-Aug-03	0	0	0	0	1	0	0	1	9.1	0	4.2
26-Aug-03	0	0	0	0	0	0	0	0	9.1	0	4.2
27-Aug-03	0	0	0	0	0	0	0	0	9.1	0	4.2
28-Aug-03	0	0	0	0	0	0	0	0	9.1	0	4.2
29-Aug-03	1	0	0	1	0	0	0	0	18.2	0	8.3
30-Aug-03	0	0	0	0	0	0	0	0	18.2	0	8.3
31-Aug-03	0	0	0	0	1	0	0	1	27.3	0	12.5

Table 9 continued

Date	Pond 1				Pond 3				Cumulative Mortality (%)		
	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
1-Sep-03	0	0	0	0	0	0	0	0	27.3	0	12.5
2-Sep-03	0	0	0	0	0	0	0	0	27.3	0	12.5
3-Sep-03	0	0	0	0	0	0	0	0	27.3	0	12.5
4-Sep-03	0	0	0	0	0	0	0	0	27.3	0	12.5
5-Sep-03	0	0	0	0	1	0	0	1	36.4	0	16.7
6-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
7-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
8-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
9-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
10-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
11-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
12-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
13-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
14-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
15-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
16-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
17-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
18-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
19-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
20-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
21-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
22-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
23-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
24-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
25-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
26-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
27-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
28-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
29-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
30-Sep-03	0	0	0	0	0	0	0	0	36.4	0	16.7
1-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
2-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
3-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
4-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
5-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
6-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
7-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
8-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
9-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
10-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
11-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
12-Oct-03	0	0	0	0	0	0	0	0	36.4	0	16.7
13-Oct-03	0	1	0	1	0	0	0	0	36.4	7.692	20.8
14-Oct-03	0	0	0	0	0	0	0	0	36.4	7.692	20.8
15-Oct-03	0	0	1	1	0	0	1	1	36.4	23.08	29.2
16-Oct-03	0	0	0	0	0	0	0	0	36.4	23.08	29.2
17-Oct-03	0	0	0	0	0	0	0	0	36.4	23.08	29.2

Table 9 continued											
Date	Pond 1				Pond 3				Cumulative Mortality (%)		
	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
18-Oct-03	0	0	0	0	0	0	0	0	36.4	23.08	29.2
19-Oct-03	0	0	0	0	0	0	0	0	36.4	23.08	29.2
20-Oct-03	0	0	4	4	1	0	2	3	45.5	69.23	58.3

Table 10. Adult chinook salmon holding pond mortality in the ambient treatment (Ponds 2 and 4). Females that produced eggs and males that died during egg takes are not included.

Date	*Pond 2*				*Pond 4*				*Cumulative Mortality (%)*		
Initial numbers	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total Female	total Male	
14-Aug-03	5	1	6	12	7	0	5	12			
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
15-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0
16-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
17-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
18-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
19-Aug-03	1	0	0	1	0	0	0	0	8.3	0.0	4.2
20-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
21-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
22-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
23-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
24-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
25-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
26-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
27-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
28-Aug-03	0	0	0	0	0	0	0	0	8.3	0.0	4.2
29-Aug-03	1	0	0	1	0	0	0	0	16.7	0.0	8.3
30-Aug-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
31-Aug-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
1-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
2-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
3-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
4-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
5-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
6-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
7-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
8-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
9-Sep-03	0	0	0	0	0	0	0	0	16.7	0.0	8.3
10-Sep-03	1	1	0	2	0	0	0	0	25.0	8.3	16.7
11-Sep-03	0	0	0	0	3	0	0	3	50.0	8.3	29.2
12-Sep-03	0	0	0	0	0	0	0	0	50.0	8.3	29.2
13-Sep-03	0	0	0	0	2	0	1	3	66.7	16.7	41.7
14-Sep-03	0	0	0	0	1	0	0	1	75.0	16.7	45.8
15-Sep-03	1	0	1	2	1	0	0	1	91.7	25.0	58.3
16-Sep-03	0	0	0	0	0	0	0	0	91.7	25.0	58.3

Table 10 continued

Date	Pond 2				Pond 4				Cumulative Mortality (%)		
	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
17-Sep-03	1	0	1	2	0	0	0	0	100.0	33.3	66.7
18-Sep-03	0	0	1	1	0	0	1	1	100.0	50.0	75.0
19-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
20-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
21-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
22-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
23-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
24-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
25-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
26-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
27-Sep-03	0	0	0	0	0	0	0	0	100.0	50.0	75.0
28-Sep-03	0	0	1	1	0	0	0	0	100.0	58.3	79.2
29-Sep-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
30-Sep-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
1-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
2-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
3-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
4-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
5-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
6-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
7-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
8-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
9-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
10-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
11-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
12-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
13-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
14-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
15-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
16-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
17-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
18-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
19-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
20-Oct-03	0	0	0	0	0	0	0	0	100.0	58.3	79.2
21-Oct-03	0	0	0	0	0	0	3	3	100.0	83.3	91.7
22-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
23-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
24-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
25-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
26-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
27-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
28-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
29-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
30-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
31-Oct-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
1-Nov-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
2-Nov-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7

Table 10 continued											
Date	Pond 2				Pond 4				Cumulative Mortality (%)		
	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
3-Nov-03	0	0	0	0	0	0	0	0	100.0	83.3	91.7
4-Nov-03	0	0	2	2	0	0	0	0	100.0	100.0	100.0

Table 11. Adult chinook salmon holding pond mortality in the heated treatment (Ponds 5 and 6). Females that produced eggs and males that died during egg takes are not included.

Date	*Pond 5*				*Pond 6*				*Cumulative Mortality (%)*		
Initial Numbers	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total Female	total Male	
14-Aug-03	5	2	5	12	7	2	3	12			
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
15-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0
16-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
17-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
18-Aug-03	0	0	0	0	0	0	0	0	0.0	0.0	0.0
19-Aug-03	1	0	0	1	3	1	0	4	33.3	8.3	20.8
20-Aug-03	0	0	0	0	0	0	0	0	33.3	8.3	20.8
21-Aug-03	0	0	0	0	0	0	0	0	33.3	8.3	20.8
22-Aug-03	0	0	0	0	0	0	0	0	33.3	8.3	20.8
23-Aug-03	0	0	0	0	0	0	0	0	33.3	8.3	20.8
24-Aug-03	0	0	0	0	0	0	0	0	33.3	8.3	20.8
25-Aug-03	1	0	0	1	0	0	0	0	41.7	8.3	25.0
26-Aug-03	0	0	0	0	0	0	0	0	41.7	8.3	25.0
27-Aug-03	0	0	0	0	0	0	0	0	41.7	8.3	25.0
28-Aug-03	0	0	0	0	1	0	0	1	50.0	8.3	29.2
29-Aug-03	1	0	0	1	0	0	0	0	58.3	8.3	33.3
30-Aug-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
31-Aug-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
1-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
2-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
3-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
4-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
5-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
6-Sep-03	0	0	0	0	0	0	0	0	58.3	8.3	33.3
7-Sep-03	0	0	0	0	1	0	0	1	66.7	8.3	37.5
8-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
9-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
10-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
11-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
12-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
13-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
14-Sep-03	0	0	0	0	0	0	0	0	66.7	8.3	37.5
15-Sep-03	1	1	0	2	0	0	0	0	75.0	16.7	45.8
16-Sep-03	0	0	0	0	0	0	0	0	75.0	16.7	45.8
17-Sep-03	0	0	0	0	0	0	0	0	75.0	16.7	45.8

Table 11 continued

Date	Pond 5				Pond 6				Cumulative Mortality (%)		
Initial	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
18-Sep-03	0	0	0	0	0	0	0	0	75.0	16.7	45.8
19-Sep-03	1	0	0	1	0	0	0	0	83.3	16.7	50.0
20-Sep-03	0	0	0	0	0	0	0	0	83.3	16.7	50.0
21-Sep-03	0	0	0	0	0	0	0	0	83.3	16.7	50.0
22-Sep-03	0	1	0	1	0	0	0	0	83.3	25.0	54.2
23-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
24-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
25-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
26-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
27-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
28-Sep-03	0	0	0	0	0	0	0	0	83.3	25.0	54.2
29-Sep-03	0	0	1	1	0	0	0	0	83.3	33.3	58.3
30-Sep-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
1-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
2-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
3-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
4-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
5-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
6-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
7-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
8-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
9-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
10-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
11-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
12-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
13-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
14-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
15-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
16-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
17-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
18-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
19-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
20-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
21-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
22-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
23-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
24-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
25-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
26-Oct-03	0	0	0	0	0	0	0	0	83.3	33.3	58.3
27-Oct-03	0	0	0	0	0	0	1	1	83.3	41.7	62.5
28-Oct-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
29-Oct-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
30-Oct-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
31-Oct-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
1-Nov-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
2-Nov-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5

Table 11 continued											
Date	Pond 5				Pond 6				Cumulative Mortality (%)		
Initial	Female	Male	Jacks	Total	Female	Male	Jacks	Total	total	total	
	Daily Mortality				Daily Mortality				Female %Mort	Male %Mort	Total %Mort
3-Nov-03	0	0	0	0	0	0	0	0	83.3	41.7	62.5
4-Nov-03	0	0	0	0	0	0	1	1	83.3	50.0	66.7
5-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
6-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
7-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
8-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
9-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
10-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
11-Nov-03	0	0	0	0	0	0	0	0	83.3	50.0	66.7
12-Nov-03	0	0	0	0	0	0	1	1	83.3	58.3	70.8

Cumulative mortality rates for females and males during the adult holding phase of the experiment are plotted in Figures 7 and 8. Female holding mortality only includes fish that did not survive to maturity and which therefore did not produce viable eggs. The female that died on October 20 in Pond 3 (Table 9) was not included in the mortality rate in Figure 7 (or Table 12) because she died at maturity -- eggs were not taken simply because the fish were not examined frequently enough. If the ponds had been examined a few days earlier this fish undoubtedly would have produced viable eggs. Cumulative male mortality in Figure 5 (and Table 12) was only plotted until October 14, 2003. After this, males started to die simply because they were over mature. Holding mortality rates for females and males are summarized in Table 12

Table 12. Holding mortality rates (%) for females and males.

	Chilled	*Ambient*	*Heated*
Female	36.4	100	83.3
Males	7.7	58.3	33.3

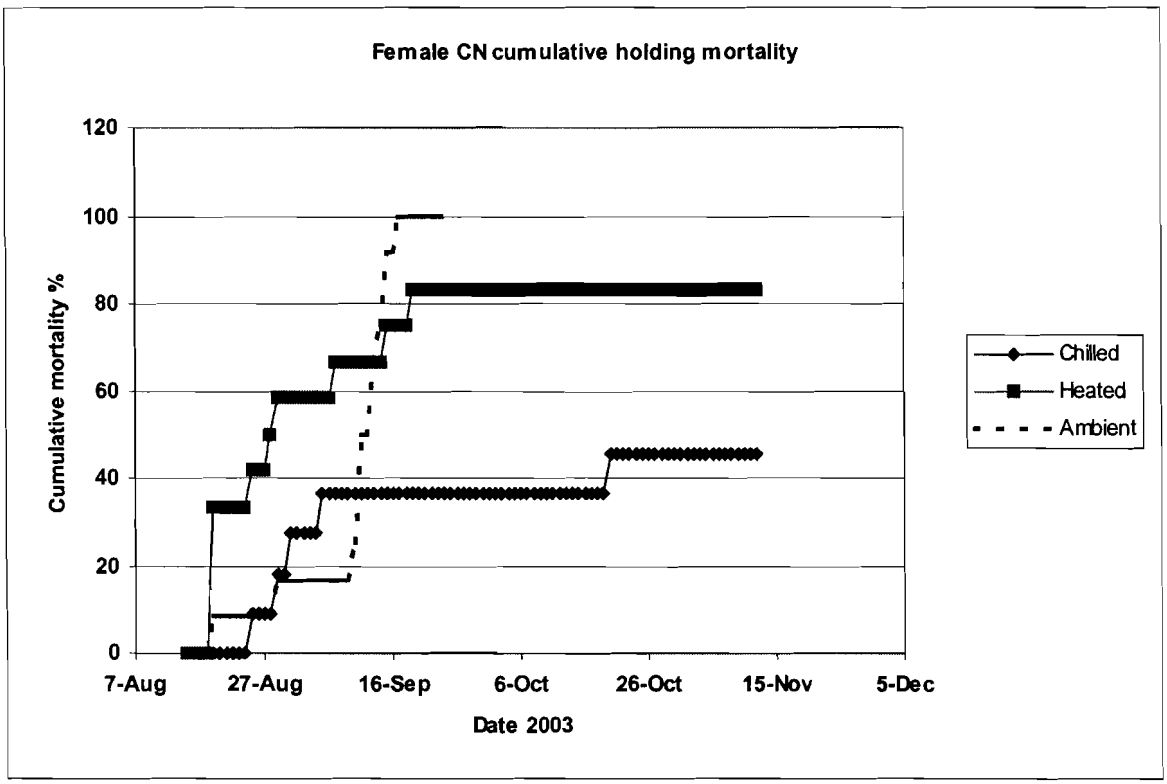

Figure 7. Female mortality (cumulative %) for experimental treatments.

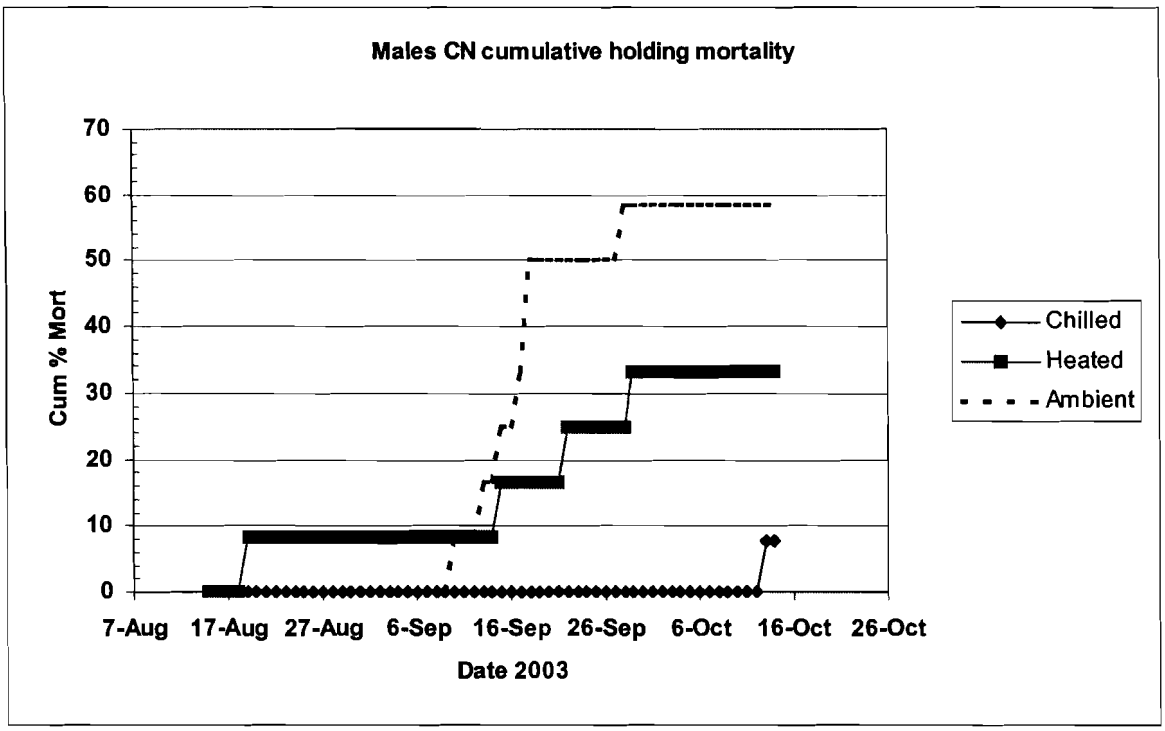

Figure 8. Male mortality (cumulative % to Oct 14) for experimental treatments.

The adult mortality rates of the ambient temperature group (Figures 7 and 8 and Table 12) are completely anomalous. The sudden loss of females and males during the 2nd week of September is probably related to changes in the hatchery water supply that occurred on September 2 and has nothing to do with water temperature. At that time the water supply was switched from "penstock" to "pumped" water. Penstock water flows from the upper river by gravity through a large pipeline, while pumped water comes from the lower river. It is thought that flow surges in the river following this change, dislodged large quantities of the benthic algae gomphonema that blanketed the river bottom at that time. This suspended material pumped into the water supply increased stress on fish in the ponds. Just prior to the onset of mortality, mats of gomphonema had been observed on the travelling screens that protect the pump intake. Over a period of 7 days (Sept 10 to Sept 17) all the females in the ambient group died. Male mortality was also unusually high. It is not clear why the ambient group was more severely affected than the chilled and heated groups. However water supplied to chilled and heated fish came from a different head tank than the ambient fish and it is conceivable that they were exposed to lower concentrations of suspended gomphonema.

Because of this event, the only valid comparison is between the chilled and heated treatments. Female mortality in the heated group was over 2 times higher than the chilled group (83.3% vs 36.4%) while the male mortality was over 4 times higher (33.3% vs 7.7%). Seven females survived to maturity in the chilled group while only 2 females survived in the heated treatment.

3.5 Maturity Rates

The mean maturity date of females in the chilled group was Oct 18/03, while the mean date for heated fish was November 8/03. Thus the heated group was delayed 21 days compared to the chilled treatment. The same trend was found with pink salmon females held at different water temperatures (Jensen et al. 2004).

3.6 Egg Mortality

Table 13 shows % mortality for eggs incubated in the divided Heath trays. Only eggs from the chilled and heated treatments are compared – no females survived the ambient treatment. Since only 2 females survived the heated treatment, there was no statistical analysis of egg mortality rates. However we noted that the egg quality was very good. This is surprising given the pink salmon results in 2002. In this case egg quality from females surviving the high temperature regime was very poor (Jensen 2004). Because of the small number of surviving chinook, this difference might just be a statistical outlier. It could also be due to the slightly higher temperatures in the 2002 heated treatment.

Table 13. Mortality (%) for eggs incubated in 20 cell divided Heath trays. There were 3 replicates for each female. (ET = egg takes).

Chilled	*Chilled*	*Chilled*	*Chilled*	*Heated*	*Heated*	*Heated*	*Heated*
ET Date	Female No.	Reps	Mean	ET Date	Female No.	Reps	Mean
08-Oct	1	1.39		05-Nov	1	0.91	
08-Oct	1	2.94		05-Nov	1	2.78	
08-Oct	1	1.52	1.95	05-Nov	1	0.98	1.56
08-Oct	2	2.99		12-Nov	2	3.23	
08-Oct	2	5.56		12-Nov	2	0	
08-Oct	2	5.41	4.65	12-Nov	2	0.94	1.39
20-Oct	3	4.11					
20-Oct	3	1.2					
20-Oct	3	1.32	2.21				
20-Oct	4	5					
20-Oct	4	6.85					
20-Oct	4	5.95	5.93				
20-Oct	5	1.56					
20-Oct	5	9.23					
20-Oct	5	34.78	15.19				
20-Oct	6	1.32					
20-Oct	6	0					
20-Oct	6	0	0.44				
		Chilled Mean %	5.06			Heated Mean %	1.47

Figure 9 shows that in late August the pinks (2002) were exposed to higher temperatures for several days. Differences in egg survival might also be due to stock adaptation, since Puntledge summer chinook have had to mature in warm water for many generations.

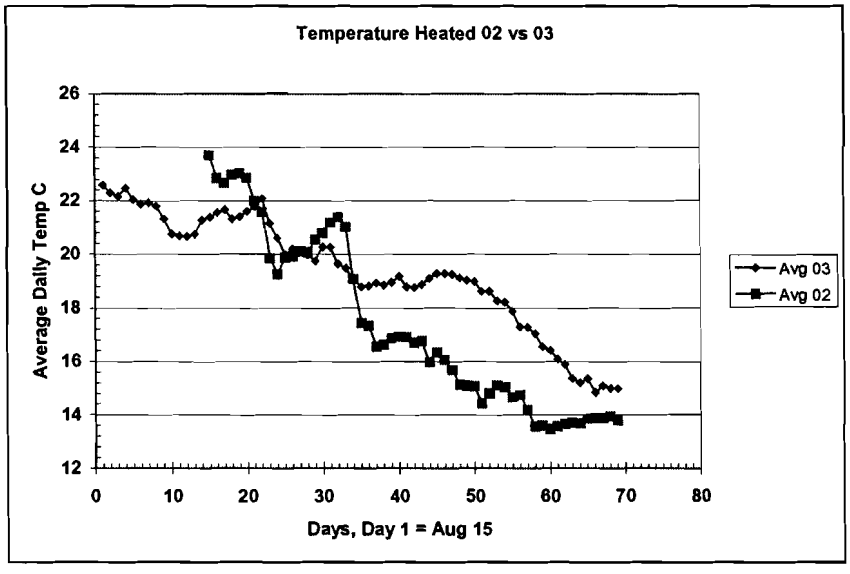

Figure 9. Temperature regimes of Heated treatments in 2002 and 2003.

3.7 Egg Size.

Egg size was assessed at the eyed stage for each female from the Chilled and Heated groups. Ten replicate samples of 50 eggs each were weighed to get the mean and standard deviation (Table 14). Comparisons between groups were not made because of small number of females surviving the Heated treatment.

Table 14. Egg size (mg) of Chilled and Heated females. Ten replicate samples of 50 eggs each were weighed at the eyed stage. Individual egg weights (means of replicates), standard deviation of replicates (sd), length (POHL cm) and weight (kg) are shown for each female. The standard deviation of egg weight (S) was estimated from: $S = sd*\sqrt{50}$. (ET = egg takes).

Chilled Group						
ET Date/03	8-Oct	8-Oct	20-Oct	20-Oct	20-Oct	20-Oct
Female no.	1	2	3	4	5	6
Length (cm)	69.0	74.0	69.4	67.6	70.3	70.0
Weight (kg)	6.1	8.5	7.3	7.5	8.2	7.0
Replicate	Egg Wt(mg)	Egg Wt(mg)	Egg Wt(mg)	Egg Wt(mg)	Egg Wt(mg)	Egg Wt(mg)
1	308.60	314.40	346.60	321.00	378.40	330.00
2	308.20	312.60	331.20	319.20	385.00	327.00
3	313.40	312.20	329.60	320.80	386.60	325.80
4	307.80	314.60	338.60	325.00	383.40	325.80
5	300.20	315.80	340.00	316.00	381.80	325.20
6	310.20	314.80	341.20	327.60	381.40	323.80
7	310.40	316.00	330.00	320.00	383.20	323.60
8	308.40	313.80	333.60	317.20	380.60	328.60
9	307.00	316.80	330.00	325.80	383.00	325.60
10	306.40	315.20	326.40	324.40	381.40	330.40
Mean	**308.06**	**314.62**	**334.72**	**321.70**	**382.48**	**326.58**
s.d	**3.41**	**1.46**	**6.50**	**3.84**	**2.31**	**2.39**
S	**24.12**	**10.29**	**45.93**	**27.18**	**16.32**	**16.87**
Heated Group						
ET Date/03	5-Nov	12-Nov				
Female no.	1	2				
Length (cm)	73.5	70.0				
Weight (kg)	8.7	7.0				
Replicate	Egg Wt(mg)	Egg Wt(mg)				
1	291.80	328.80				
2	288.80	333.40				
3	292.00	333.40				
4	291.60	347.40				
5	290.40	331.40				
6	291.20	330.40				
7	293.00	332.00				
8	292.20	331.40				
9	291.40	333.20				
10	289.60	332.00				
Mean	**291.20**	**333.34**				
s.d	**1.26**	**5.14**				
S	**8.94**	**36.37**				

3.8 CWT Returns

Five of the returning adults used in the experiment had a coded wire tag (CWT). The life-history of these fish is shown in Table 15.

Table 15. Tag codes (E no.), sex, length (POHL, cm), capture date (2003), brood year and stock (falls or summers) of tagged experimental fish.

Tag E no.	Sex	POHL cm	Date 2003	Pond no.	Tag Code	Chinook Stock	Brood Year
399635	Female	720	19-Aug-	6	18 38 39	Fall	1999
399636	Female	783	29-Aug	5	18 38 38	Fall	1999
339640	Female	753	20-Oct	3	18 38 41	Fall	1999
339641	Male	543	20-Oct	3	18 48 43	Summer	2000
339647	Jack	338	12-Nov	5	18 48 53	Summer	2001

The first two females died before reaching maturity. These results show that both stocks are represented in the experiment.

This study is currently being repeated in 2005 in attempt to resolve the above questions that arose from the unexplained loss of fish in the ambient treatments.

4.0 ACKNOWLEDGEMENTS

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5.0 REFERENCES

Jensen, J.O.T., McLean, W.E., Damon, W., and Sweeten, T. 2004. Puntledge River high temperature study: Influence of high water temperature on adult pink salmon mortality, maturation, and gamete viability. Can. Tech. Rep. Fish. Aquat. Sci. 2523: vi + 50p.