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Evaluation of the Bonneville Dam Second Powerhouse new Juvenile Bypass System, 1999.

Annual Report for 1999.

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Table of Contents

List of Tables....ii

List of Figures....iii

List of appendices....v

Executive summary....vi

Introduction....1

Study site....1

Physiological effects of bypass system

- Methods....3
- Results
  - Time of capture sampling....8
  - Time series....11

Tailrace egress behavior

- Methods....16
- Results
  - Upriver releases....19
  - Additional JBS releases....20
  - PIT-tagged fish releases....23
  - Drogue releases and water velocities....23

Discussion....31

Acknowledgments....34

References....35

Appendices....36

List of Tables

Table 1. Sample size and detection rate of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing of physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999…………………........6

Table 2. Median travel time from the forebay to the outfall area for radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released upriver and into Bonneville Dam's Powerhouse II juvenile bypass system, 1999…………………......21

Table 3. Median and mean travel time from the outfall to the downriver exit site for radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released into Bonneville Dam's Powerhouse II juvenile bypass system and from upriver projects, 1999…………………………..22

Table 4. Number and percent of mobile tracking contacts below Bonneville Dam of radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released upriver and into the Juvenile Bypass System, 1999………......................................26

Table 5. Median and mean travel time through the conveyance pipe of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon at Bonneville Dam's powerhouse II juvenile bypass system, 1999………………..........................27

Table 6. Summary of drogue drift paths and concurrent fish positions during mobile tracking below Bonneville Dam's Powerhouse II juvenile bypass system, 1999…….........29

List of Figures

Figure 1. Bonneville Dam and Powerhouse II juvenile bypass system, conveyance pip, outfall, and sampling locations, 1999...……………………………..................................2

Figure 2. Bonneville Dam Powerhouse II juvenile bypass system evaluation area between outfall and exit station 8 km downriver from dam, 1999…………………………........2

Figure 3 Physiology sampling of PIT-tagged and river-run yearling chinook salmon, steelhead, and subyearling chinook salmon at Bonneville Dam's Powerhouse II juvenile bypass system, 1999…..............................….......……………….............5

Figure 4. Mean (+SE) plasma cortisol concentrations of hatchery steelhead, yearling chinook, and subyearling chinook sampled before release and immediately after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999....……………………………………………………………...............9

Figure 5. Mean (+SE) plasma cortisol concentrations of river-run steelhead, yearling chinook, and subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999........……..10

Figure 6. Mean (+SE) plasma lactate concentrations at time of capture of hatchery steelhead, yearling chinook, and subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999........………………………………………………………………………....12

Figure 7. Mean (+SE) plasma lactate concentrations at time of capture of river-run steelhead, yearling chinook, and subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999....……………………………………………………………......……....13

Figure 8. Mean (+SE) plasma cortisol concentrations over time series in hatchery steelhead and hatchery subyearling chinook salmon before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999....……………………………………………………………......……....14

Figure 9. Mean (+SE) plasma cortisol and lactate concentrations over time series in river-run subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999 …………...….....15

Figure 10. Mean (+SE) plasma cortisol concentrations over time in hatchery steelhead and hatchery subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999....……………………………………………………………...……....17

Figure 11. Mobile tracking locations of radio-tagged yearling chinook released directly into Bonneville Dam's Powerhouse II juvenile bypass system, and released from upriver studies that passed Bonneville Dam through the JBS and through non-JBS routes, 1999..24

Figure 12. Mobile tracking locations of radio-tagged steelhead released directly into Bonneville Dam's Powerhouse II juvenile bypass system and released from upriver studies that passed Bonneville Dam through the JBS and through non-JBS routes, 1999.........24

Figure 13. Mobile tracking locations of radio-tagged yearling chinook released directly into Bonneville Dam's Powerhouse II juvenile bypass system, and released from upriver studies that passed Bonneville Dam through the JBS and through non-JBS routes, 1999..25

Figure 14. Example of drogue drift path and associated fish positions. Fish positions are for radio-tagged steelhead released into the JBS on 26 May, 1999................................25

Figure 15. Water velocity interpolation from ADCP data below Bonneville Dam on 17 May, 1999……………………………………………………………………………….30

Figure 16. Water velocity interpolation from ADCP data below Bonneville Dam on 28 May, 1999……………………………………………………………………………….30

List of Appendices

Appendix 1. Fork length and weight of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing of physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999........……………………..........36

Appendix 2. Sample size (N), fork length, and weight and number sampled of river-run yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999……………………………………………………………………………..37

Appendix 3. Sample size (N), fork length, and weight of radio-tagged yearling chinook salmon and steelhead released into Bonneville Dam's Powerhouse II juvenile bypass system, 1999……………………………………………………………………………..38

Appendix 4. Comparison of blood plasma cortisol levels assayed by USGS and an independent laboratory...40

Executive Summary

In 1999, the U.S. Army Corp of Engineers completed the first phase of construction on a modified juvenile bypass system (JBS) at Bonneville Dam's Second Powerhouse (PH II) that included a new conveyance pipe and outfall. Prior to modification, hydraulic conditions in the immediate tailrace created favorable feeding conditions for Northern Pikeminnow (*Ptychocheilus oregonesis*) and subjected outmigrating salmonids to high rates of predation. The new bypass was designed to convey fish around the immediate tailrace area and liberate them 2.7 km downriver where high velocity water discourages predatory fish from maintaining feeding positions.

The U.S. Geological Survey evaluated the effects of travel through the modified bypass system. The main objectives of the study were to determine 1) the physiological effects on smolts of traveling through the conveyance pipe, 2) the effects of passage through the conveyance pipe on tailrace egress behavior, and 3) the influence of tailrace water velocities on fish movements.

Physiological effects of bypass system

To evaluate the effects of travel through the conveyance pipe we compared blood plasma cortisol and lactate concentrations in juvenile salmonids before entering and after passage through the conveyance pipe. We obtained fish from a hatchery, implanted them with passive integrated transponder (PIT) tags, and allowed them to recover for 72 h. To establish basal cortisol and lactate levels, we sampled some fish directly from the holding tanks. The remaining fish were allowed to rest for 12 h then released directly into the upstream end of the conveyance pipe. They were then recaptured using the PIT tag separator and sampled at the downstream end of the pipe. We also sampled river-run fish that entered the JBS on their own volition. We netted these fish directly from the upstream and downstream end of the conveyance pipe.

From 23 April to 23 June 1999, we measured blood plasma cortisol and lactate concentrations in 168 yearling chinook salmon, 336 steelhead, and 162 subyearling chinook salmon that we obtained from a hatchery. We also measured 112 yearling chinook salmon, 120 steelhead, and 120 subyearling chinook salmon that were actively migrating downriver and entered the bypass on their own volition.

We found that plasma cortisol and lactate concentrations increased between entrance to the conveyance pipe and after passage. Increases were most pronounced in fish obtained from a hatchery. These fish were subjected to the additional stress of a PIT-tag recapture system at the downstream end of the conveyance pipe, whereas river-run fish were netted directly from the pipe. When fish were allowed to recover in tanks, lactate levels increased, then returned to before-passage levels within 6 h. Cortisol showed more protracted increases followed by a decrease, but did not return to pre-entrance levels. We found no differences in cortisol and lactate concentrations between night and day diel periods.

Initially some PIT-tagged steelhead delayed within the pipe. This may have been due to a variety of factors including hatchery steelhead not being disposed to migrate and initial operations of the facility. As water temperatures increased and operations of the facility were adjusted, delay decreased.

Tailrace egress behavior

To evaluate dam passage and tailrace egress behavior we monitored the movements of radio-tagged salmonids released upriver of Bonneville Dam and directly into the JBS. We used shore-based antennas and boat tracking. Fish movements were monitored from the forebay through the JBS to the outfall area, and to an exit site 8 km downriver of the dam at U.S. Coast Guard navigational marker "Red 88". The influence of tailrace hydraulic conditions were evaluated by comparing the movements of radio-tagged fish to a passive drift buoy, or drogue, equipped with a global positioning system (GPS), and by measuring water velocities using an acoustic Doppler current profiler.

From 7 May to 15 July 1999, we obtained travel time and movement data on 454 yearling chinook, 361 steelhead, and 100 subyearling chinook released from upriver studies. Additionally, we released 134 yearling chinook salmon, 135 steelhead, and 148 subyearling chinook salmon into the upstream end of the bypass.

Overall, fish moved quickly through the conveyance pipe. We found no evidence of direct mortality caused by the conveyance pipe. Travel time between the forebay and the outfall area through the PH II JBS was longer than travel time through non-JBS passage routes. This was a result of the longer distance of the pipe compared to the Spillway and PH I tailrace areas. Yearling chinook took 79 min and steelhead took 74 min to travel between the forebay and the outfall area through the JBS. The majority of this time was spent in the conveyance pipe. Yearling chinook and steelhead that passed the dam through the spillway and Powerhouse I took between 24 and 30 min to travel from the forebay to the outfall area. Median travel time between the outfall and the downriver exit site was 36 min for yearling chinook, 33 min for steelhead, and 34 min for subyearling chinook. Travel time through the tailrace was similar for fish that passed through the JBS and non-JBS routes. Less than 5% of the fish monitored took more than 90 min to travel between the outfall area and the exit site.

During mobile tracking we contacted 224 (54%) of the fish we released. Of these, less than 1% were believed to be consumed by predators, 2.2% delayed while moving downriver, and 4% used the side channel behind Ives Island. We also contacted 96 fish that were released upriver. Of these, 5.2 % were believed to be consumed by predators, 7.3 % delayed before moving downriver, and 3.1 % used the side channel behind Ives Island.

We obtained GPS positions of the drogue and concurrent fish positions for 12 yearling chinook, 13 steelhead, and 18 subyearling chinook. Fish usually followed the same path as the drogue and tended to move passively along the thalweg. Occasionally fish took a different path from the drogue. During two tracking events the fish used the side channel behind Ives Island while the drogue followed the main channel.

Cross-channel velocity transects were obtained when total river discharge averaged 271 kcfs and 384 kcfs. Interpolations of data indicate higher velocity water (> 2.5 m/s) were located on the south side of the channel. Velocities behind Ives Island were below 1 m/s during the lower flows and closer to 2 m/s during the higher flows.

Introduction

Seaward migrating juvenile salmonids (*Onchorhynchus* spp.) are vulnerable to predation by northern pikeminnow (*Ptychocheilus oregonesis*) in the tailrace area of dams. At Bonneville Dam's Second Powerhouse (PH II) tailrace area, consumption of juvenile salmonids was found to be high compared to predation in reservoirs (Ward et al. 1995), and fish using the old PH II bypass showed reduced survival compared to that of fish passing through the turbines or over the spillway (Ledgerwood et al. 1990).

Recent evidence indicates that physiological stress associated with passage (Mesa et al. 1994) and the location of bypass outfalls (Shively et al. 1996) may increase predation. Snelling and Matson (1997) found that when smolts were released in areas away from shore, where water velocities were relatively high, they tended to move downriver readily.

In 1999, the U.S. Army Corps of Engineers (COE) completed the first phase of work on a new juvenile bypass system (JBS) and outfall at PH II. The system was designed to convey fish around the immediate tailrace area and liberate them in high velocity water where predators were less likely to maintain position. The new system became operational prior to any rigorous evaluation, and concerns that fish were being subjected to stress by traveling through the JBS needed to be addressed.

In 1999, the USGS evaluated the condition and behavior of yearling and subyearling chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) that passed through the new JBS, conveyance pipe and outfall. The objectives of this research were to determine: 1) the physiological effects on smolts of traveling through the conveyance pipe, 2) the effects of passage through the conveyance pipe on tailrace egress behavior, and 3) the influence of tailrace water velocities on fish movements.

Study site

Bonneville Dam is located on the Columbia River 233 km upriver from the mouth. The dam consists of two powerhouses and a single spillway, each separated by an island (Figure 1). PH II consists of eight turbine units and is located on the north side of the river, spanning from

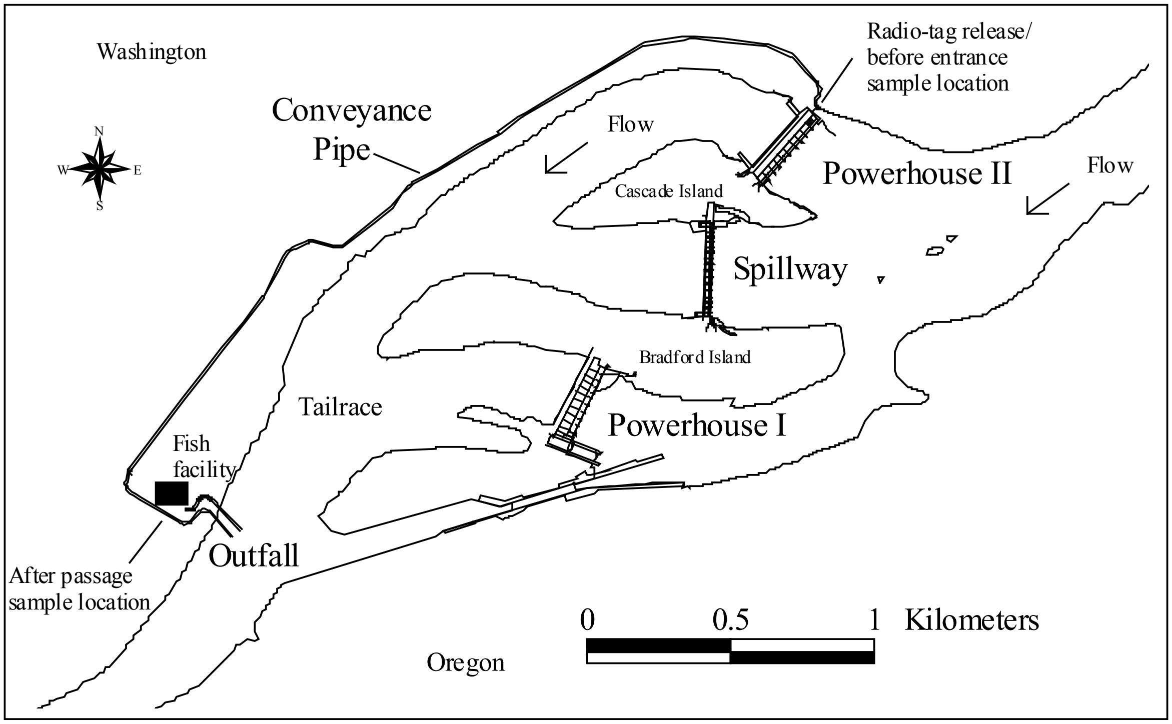

Figure 1. Bonneville Dam and Powerhouse II juvenile bypass system conveyance pipe, outfall, and sample locations, 1999.

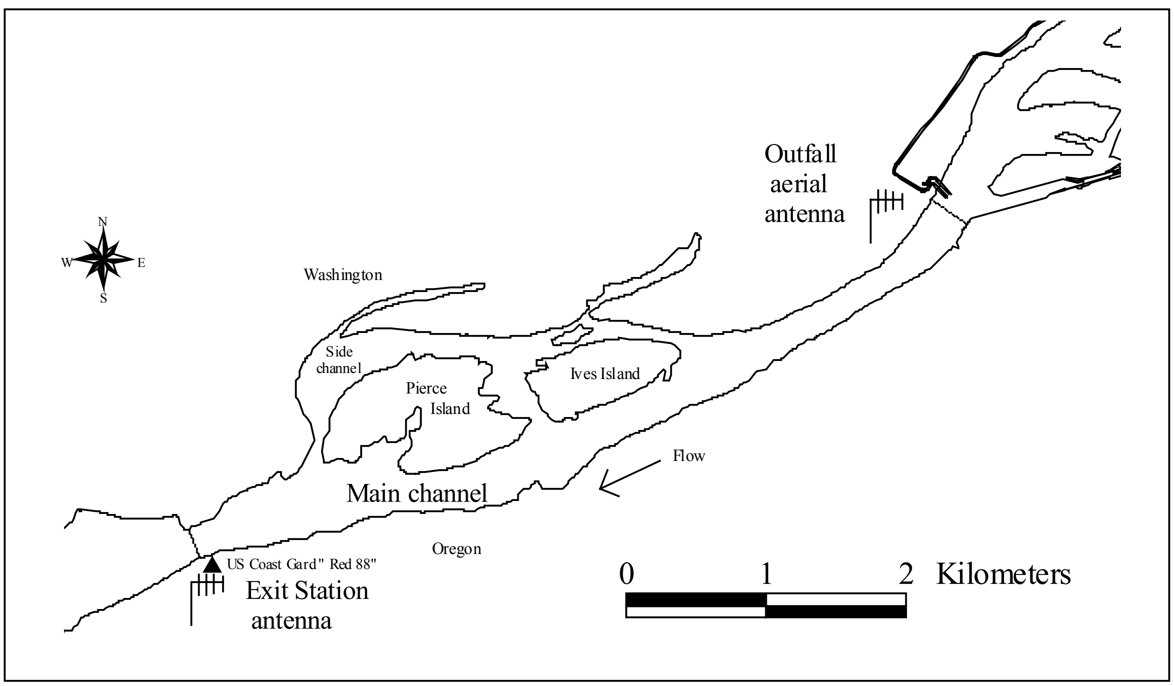

Figure 2. Bonneville Dam Powerhouse II juvenile bypass system evaluation area between outfall and exit station 8 km downriver from dam, 1999.

Cascade Island to the Washington shore. At PH II, juvenile fish are guided away from turbines by submersible traveling screens into a fish collection channel. The channel is partially dewatered at the north end of the facility where fish enter a 1.22 m diameter high density polyethylene plastic pipe. The conveyance pipe goes underground and runs west (downriver) for 3,530 m past a fish sampling facility, then terminates at an outfall. The outfall extends 50 m out over the main river channel. Fish are conveyed through the pipe by flowing water at 1.5 m/s to the outfall where fish and water plunge approximately 4 m into the main river channel. As the river level fluctuates, water is diverted to either a high outfall or a low outfall. At the fish sampling facility the pipe is partially dewatered. Juvenile salmonids drop through separator bars and are channeled through a passive integrated transponder (PIT) tag scanner and separator (Prentice et al. 1990). Fish with selected PIT codes are diverted to a holding tank where they can be collected and anesthetized. Non-diverted fish re-enter the pipe 180 m from the outfall and are liberated into the main channel.

From the outfall the river flows west (Figure 2). Two km downriver from the outfall, the river splits into a main channel and a series of side channels that form a group of islands on the north side of the river known as the Ives Island complex. The side channels are considered potential holding areas for juvenile salmonids. The side channels then rejoin the main river channel 6 km downriver from the outfall. Our study site reached from the PH II forebay downstream to Coast Guard navigational marker "Red 88", 8 km downriver of the dam.

Physiological effects of bypass system

Methods

Plasma cortisol and lactate are well known indicators of stress (Mesa 1994). To determine stress induced by passage through the conveyance pipe we measured blood plasma cortisol and lactate levels in yearling chinook, subyearling chinook, and steelhead that used the JBS. We used fish obtained from a hatchery and fish that were actively migrating down river and entered the bypass by their own volition. We compared levels in fish captured before entering the pipe to levels in fish sampled after passing through the pipe. To assess recovery time, we held some fish captured after passing through the pipe in tanks and sampled them sequentially over a 24 h period (Figure 3).

Yearling steelhead were transported from Skamania Hatchery, Washington Department of Fisheries and Wildlife in Skamania, WA, and yearling spring chinook and subyearling fall chinook salmon were transported from the Little White Salmon National Fish Hatchery to Bonneville Dam's PH II. To recapture hatchery fish at the downstream end of the pipe, we PIT tagged the fish then programmed the separator to divert only our fish to a holding tank. Two groups of 84 fish were implanted with PIT tags. PIT-tag number, length, and weight data were recorded. Tagged fish were placed in 30 gallon tanks with circulating river water, approximately 20 fish per tank, for 72 h to allow blood plasma cortisol levels to return to basal levels after transport. To obtain basal cortisol and lactate levels, 12 fish from each group were netted from the holding tanks and sampled prior to the bypass release. The remaining 72 fish were kept in the holding tanks, undisturbed, for 12 h then released into the upstream end of the conveyance pipe (Table 1). To document differences in stress response during light and dark diel periods, one group of fish was released at approximately 0930 hours (AM) and the other at 2130 hours (PM). Because of constraints on sampling crews, subyearling chinook were sampled on two different days and not at night. Once they reached the downstream end of the pipe fish were diverted, crowded, netted, and sampled immediately. Some fish were placed in holding tanks and sampled sequentially over time at 1,3,6,12, and 24 h after recapture.

Similar sampling was performed on river-run fish that entered the bypass on their own volition. Baseline data was established by netting 10 to 15 river-run migrants from the upstream end of the conveyance pipe and sampling them immediately. An additional 45 to 50 fish were netted from the downstream end of the pipe and sampled immediately or placed in holding tanks and sampled sequentially over time at 1,3,6 and 24 h after collection. It is important to note that all PIT-tagged fish were transported from a hatchery and river-run fish were not PIT tagged or recaptured using the PIT-tag diversion system.

Blood plasma samples were collected by netting fish and placing them in a lethal dose of tricain methanesulfonate (200 mg/L). Fish were then removed from the anesthetic and bled into an ammonium-heparinized capillary tube after severance of the caudal peduncle. Plasma was obtained by centrifugation, stored in liquid nitrogen for transport, then stored at -80^{0}C for future

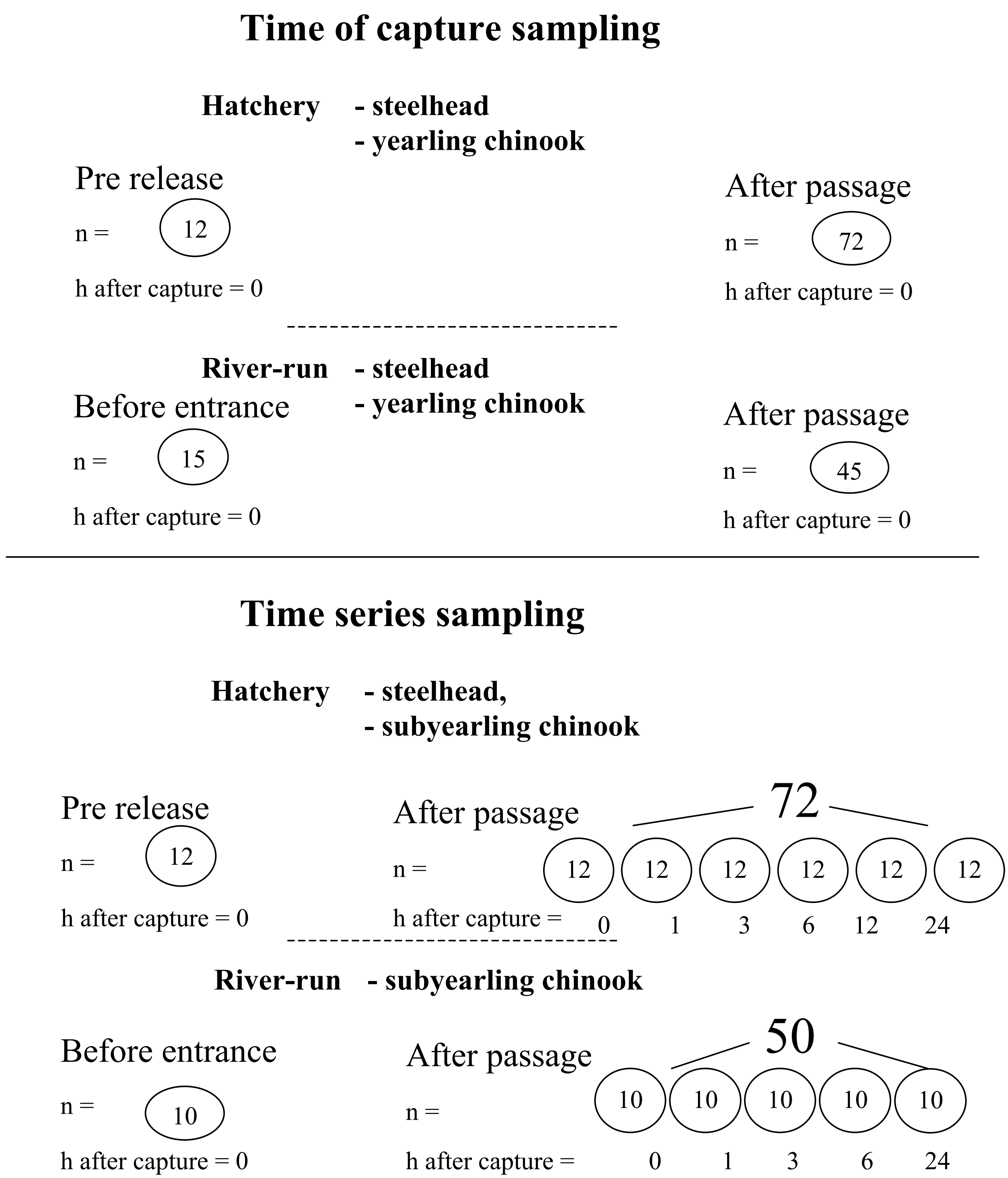

Figure 3. Physiology sampling of PIT-tagged and river-run yearling chinook salmon, steelhead, and subyearling chinook salmon at Bonneville Dam's Powerhouse II juvenile bypass system, 1999.

Table 1. Sample size and detection rate of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing of physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Releases occurred at 0930 hours (AM) and 2130 hours (PM).

Species/ Release date	Release period	Number			Number and % of released	
		Tagged	Sampled Pre-release	Released	Detected	Sampled After-Passage
Yearling spring chinook						
23 April	PM	84	12	72	72 (100)	70 (97)
25 April	AM	84	12	72	72 (100)	67 (93)
Overall:		168	24	144	144 (100)	137 (95)
Steelhead						
19 April	AM	84	12	72	58 (81)	54 (75)
21 April	PM	84	12	72	62 (86)	49 (68)
29 April	PM	84	12	72	58 (81)	48 (67)
1 May	AM	84	12	72	62 (86)	45 (63)
Overall:		336	48	288	240 (83)	196 (68)
Subyearling fall chinook						
21 June	AM	84	12	72	69 (96)	69 (96)
23 June	AM	84	12	72	70 (97)	70 (97)
Overall:		168	24	144	139 (96)	139 (97)

assay. Plasma cortisol was determined by an enzyme linked immunosorbent assay (ELISA) modified from procedures described by Munro and Stabenfeldt (1985). Plasma lactate was measured using a commercial kit assay (Sigma Diagnostics, St. Louis, Missouri) that we modified for use with micro plates.

To determine if mean plasma lactate and cortisol levels increased during passage through the pipe we compared baseline concentrations obtained from fish before entering the pipe to samples collected after fish passed through the pipe. To test for differences between mean cortisol and lactate levels in time of capture samples we used a t-test that assumed unequal variances. To test for differences between means in the time series sampling we used a one-way ANOVA followed by Dunnett's Multiple Comparison Test to determine which groups sampled after passage differed from the group sampled before release or entering the pipe. If variances were not equal we attempted to transform the data to stabilize variances. If successful, we ran the ANOVA and multiple comparison test again. If not successful we used a Kruskal-Wallis non-parametric test to compare medians, then used Dunn's multiple comparison. All statistical tests were conducted at a 95% confidence level.

Results

From 23 April to 23 June 1999, we measured plasma cortisol and lactate concentrations in 168 yearling chinook salmon, 336 steelhead, and 162 subyearling chinook salmon that we obtained from a hatchery, and from 112 yearling chinook salmon, 120 steelhead, and 120 subyearling chinook salmon that were actively migrating downriver and entered the bypass on their own volition. Steelhead obtained from Skamania Hatchery were between 137 and 235 mm fork length (Appendix 1). Yearling chinook salmon from the Little White Hatchery were between 118 and 194 mm FL, and subyearling chinook salmon from the Little White Hatchery were between 85 and 110 mm FL. River-run yearling chinook had lengths between 125 and 224 mm FL, steelhead were between 119 and 298 mm FL, and subyearling chinook were between 84 and 122 mm FL (Appendix 2).

During our initial releases, we found that some hatchery steelhead were holding in a fish separator system at the downstream end of the conveyance pipe. An in-season change to operations appeared to alleviate this problem. Low PIT tag recapture efficiencies during the first two releases of hatchery steelhead (Table 1) were caused by long delays in the bypass system and time constraints on sampling crews. Because of a change in PH II operations that altered hydraulic conditions in the JBS we performed two additional releases of steelhead.

Time of capture sampling

In fish obtained from a hatchery and sampled immediately, mean plasma cortisol concentrations were higher in fish sampled after passing through the pipe compared to fish sampled before release (Figure 4). Hatchery steelhead showed the largest increases. Cortisol concentrations increased from 66 to 152 $ng \cdot mL^{-1}$ and from 40 to 227 $ng \cdot mL^{-1}$ during the two daytime releases, and from 76 to 218 $ng \cdot mL^{-1}$ and from 129 to 181 $ng \cdot mL^{-1}$ during the two nighttime releases (Figure 4A). During two of these sampling periods, increases were significant. Plasma cortisol concentrations in yearling and subyearling chinook also increased from pre-release to after passage through the pipe (Figure 4B and 4C). During both day and night samples, yearling chinook showed significant increases. Increases in plasma cortisol of subyearling chinook were not significant. When differences were not significant, cortisol concentrations still increased. Cortisol concentrations in fish sampled during daylight were similar to concentrations found in fish sampled at night for steelhead, and yearling and subyearling chinook.

Among river-run fish, mean plasma cortisol concentrations increased during passage of the pipe by steelhead, yearling, and subyearling chinook (Figure 5). However, increases were less pronounced than in fish obtained from a hatchery. Initial cortisol concentrations (before entering the pipe) were higher in river-run fish compared to hatchery fish (Figures 4 and 5). In river-run steelhead, cortisol concentrations increased from 250 to 269 $ng \cdot mL^{-1}$ during daytime sampling and from 238 to 315 $ng \cdot mL^{-1}$ during nighttime sampling (Figure 5A). In yearling chinook, increases were significantly higher only during night sampling. In subyearling chinook, cortisol concentrations increased during day 1 and day 2 sampling but neither increase was significant. In yearling chinook, initial cortisol concentrations were lower in fish sampled at night compared to fish sampled during the day.

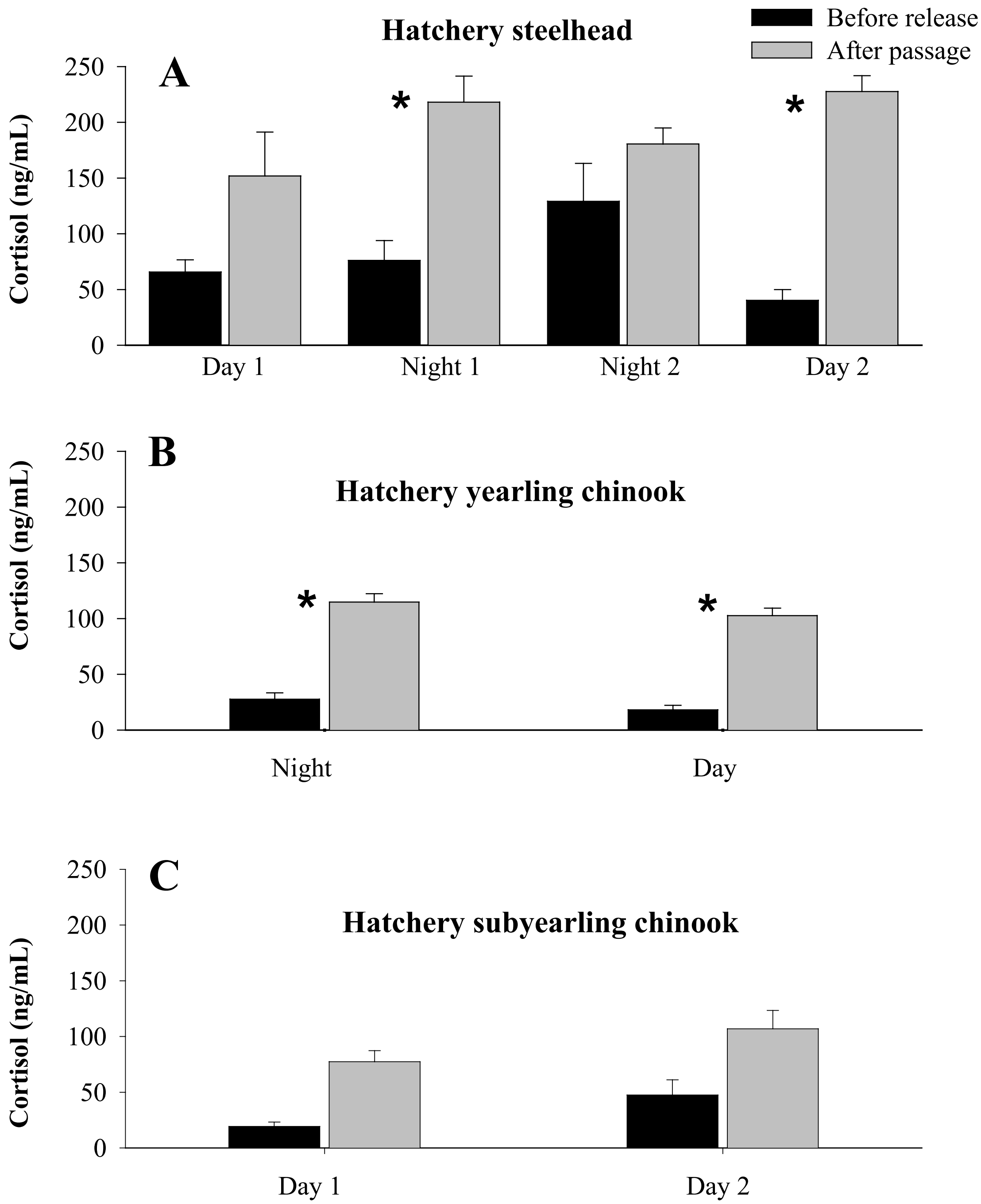

Figure 4. Mean (+ SE) plasma cortisol concentrations of hatchery steelhead, yearling chinook, and subyearling chinook sampled before release and immediately after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where mean cortisol concentrations differ significantly.

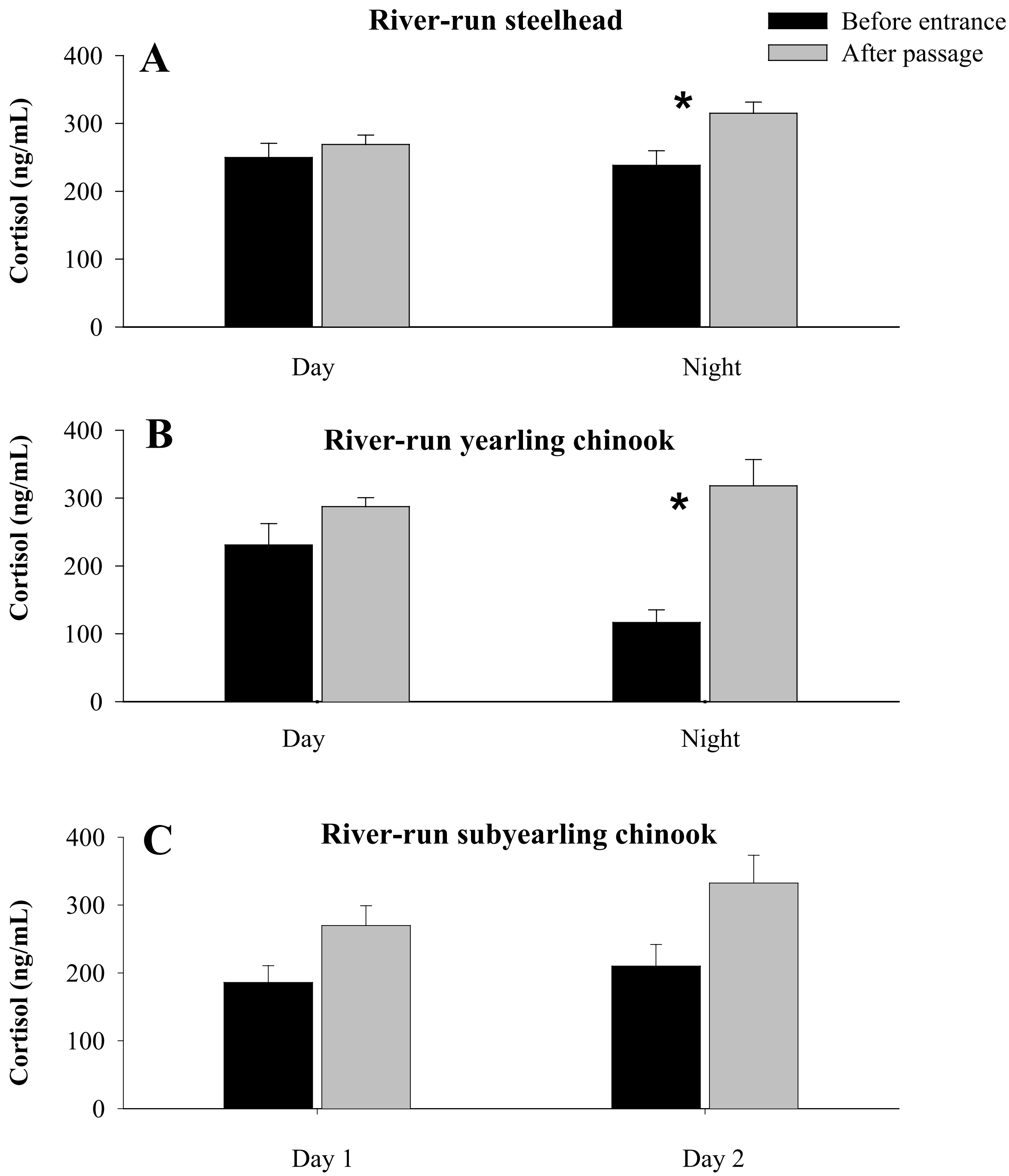

Figure 5. Mean (+ SE) plasma cortisol concentrations at time of capture of river-run steelhead, yearling chinook, and subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where mean cortisol concentrations differ significantly.

Blood plasma lactate concentrations in fish obtained from a hatchery increased from before entering the pipe to after passage in all experiments. Increases were most pronounced in steelhead; lactate concentrations rose from 13 to 80 and 33 to 131 mg·dL^{-1} during the two daytime samples, and from 44 to 146 and 23 to 112 mg·dL^{-1} during the two night samples (Figure 6A). Lactate concentrations increased significantly in yearling and subyearling chinook, as well, but did not reach the levels of steelhead sampled after passage (Figure 6B and 6C). In river-run fish, lactate concentrations increased among steelhead, yearling, and subyearling chinook, but only one of the increases were significant (Figure 7A, 7B, and 7C). After passage concentrations were less than 100 mg·dL^{-1} for all groups tested. Lactate levels in river-run fish sampled during daylight were similar to lactate levels in fish sampled during darkness.

Time series

To measure the delayed response and recovery time from the stress of passage through the pipe, fish were collected at the downstream end of the conveyance pipe, held in tanks, then sampled over time. In hatchery steelhead, mean cortisol levels increased from 66 ng·mL^{-1} before release to a maximum of 253 ng·mL^{-1} 1 h after capture at the downstream end of the pipe during the daytime (Figure 8A). Mean cortisol levels in hatchery subyearlings increased from 47 ng·mL^{-1} before release to a maximum of 118 ng·mL^{-1} 1 h after recapture (Figure 8B). Increases were significantly different from basal levels only 1 h after recapture. It took 6 h for levels to decrease to pre-release levels during daytime and nighttime experiments, except in hatchery steelhead, which took from 6 to 12 h.

Mean cortisol levels in river-run subyearling chinook increased from 209 ng·mL^{-1} before entering the pipe to a maximum of 792 ng·mL^{-1} 3 h after capture at the downstream end of the pipe (Figure 9A). These were the highest mean cortisol concentrations we found during our experiments. This peak occurred on day 2 of the sampling. During day 1, mean cortisol levels increased from 186 ng·mL^{-1} before entering the pipe to 545 ng·mL^{-1} 3 h after capture at the downstream end of the pipe. There were no apparent differences between day 1 and day 2 sampling except a higher peak 3 h after recapture. Because cortisol concentrations in

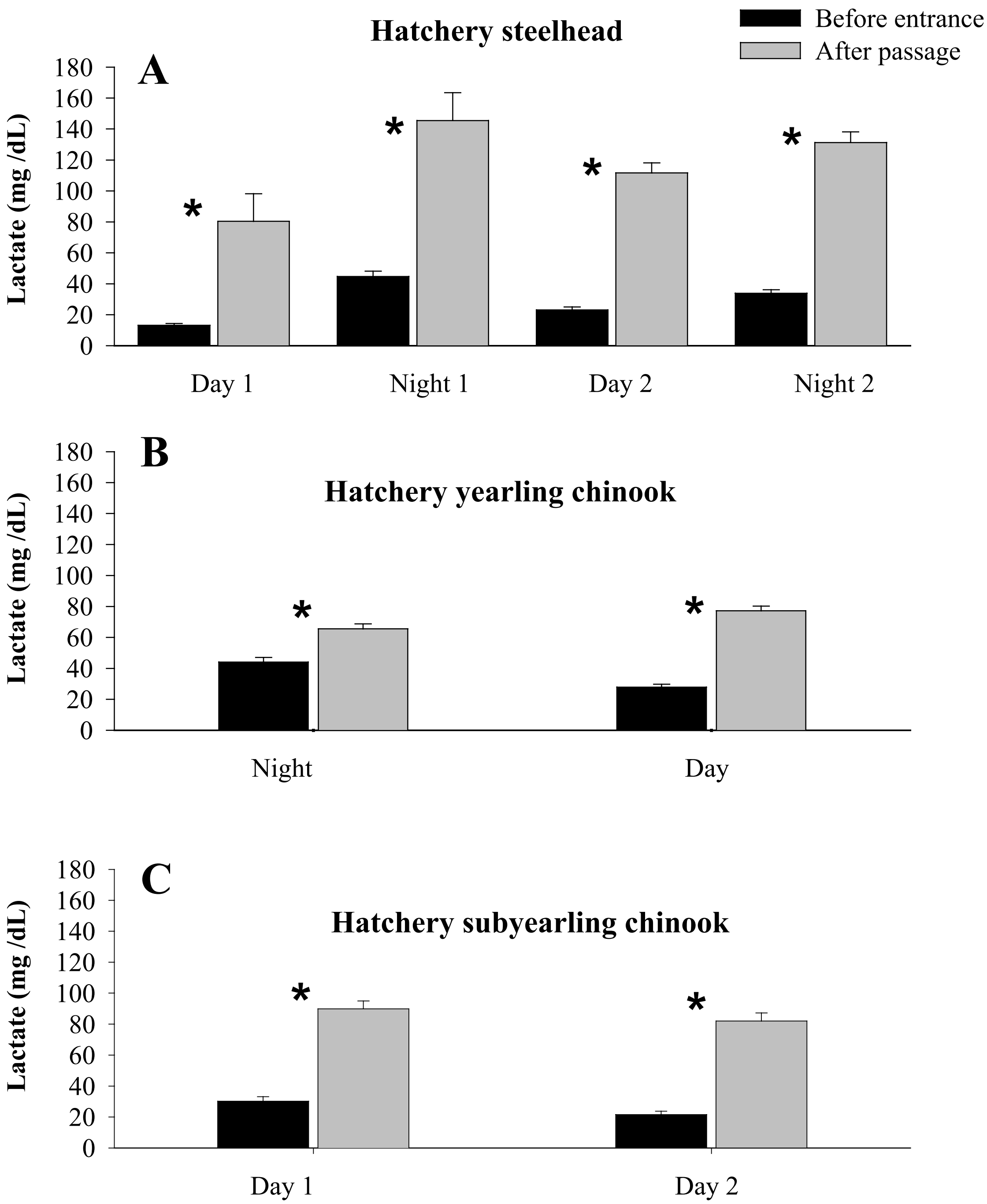

Figure 6. Mean (+ SE) plasma lactate concentrations at time of capture of hatchery steelhead, yearling chinook, and subyearling chinook before entering and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where mean lactate concentrations differ significantly.

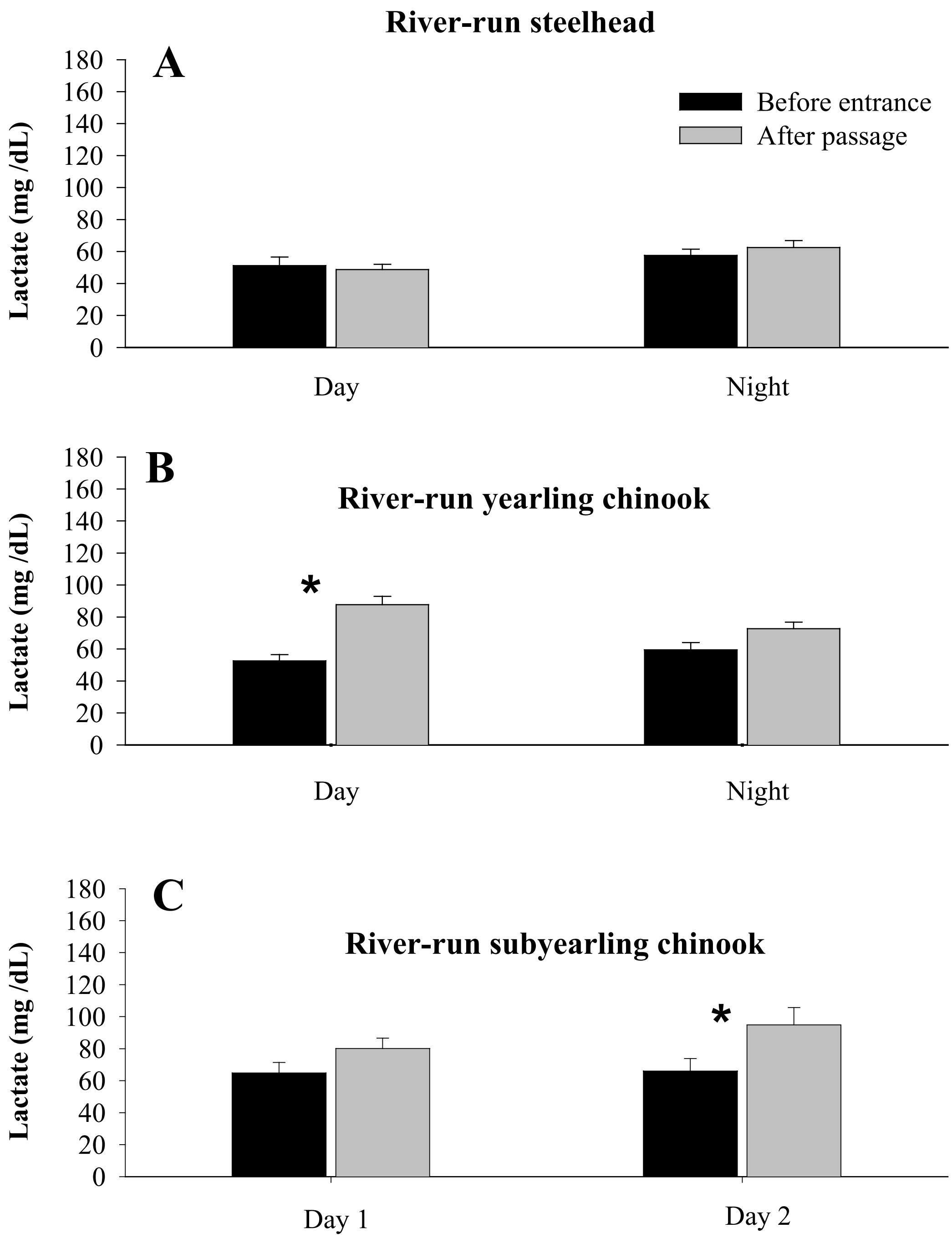

Figure 7. Mean (+ SE) plasma lactate concentrations at time of capture of river-run steelhead, yearling chinook, and subyearling chinook before entrance and after passage through the conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where mean cortisol concentrations differ significantly.

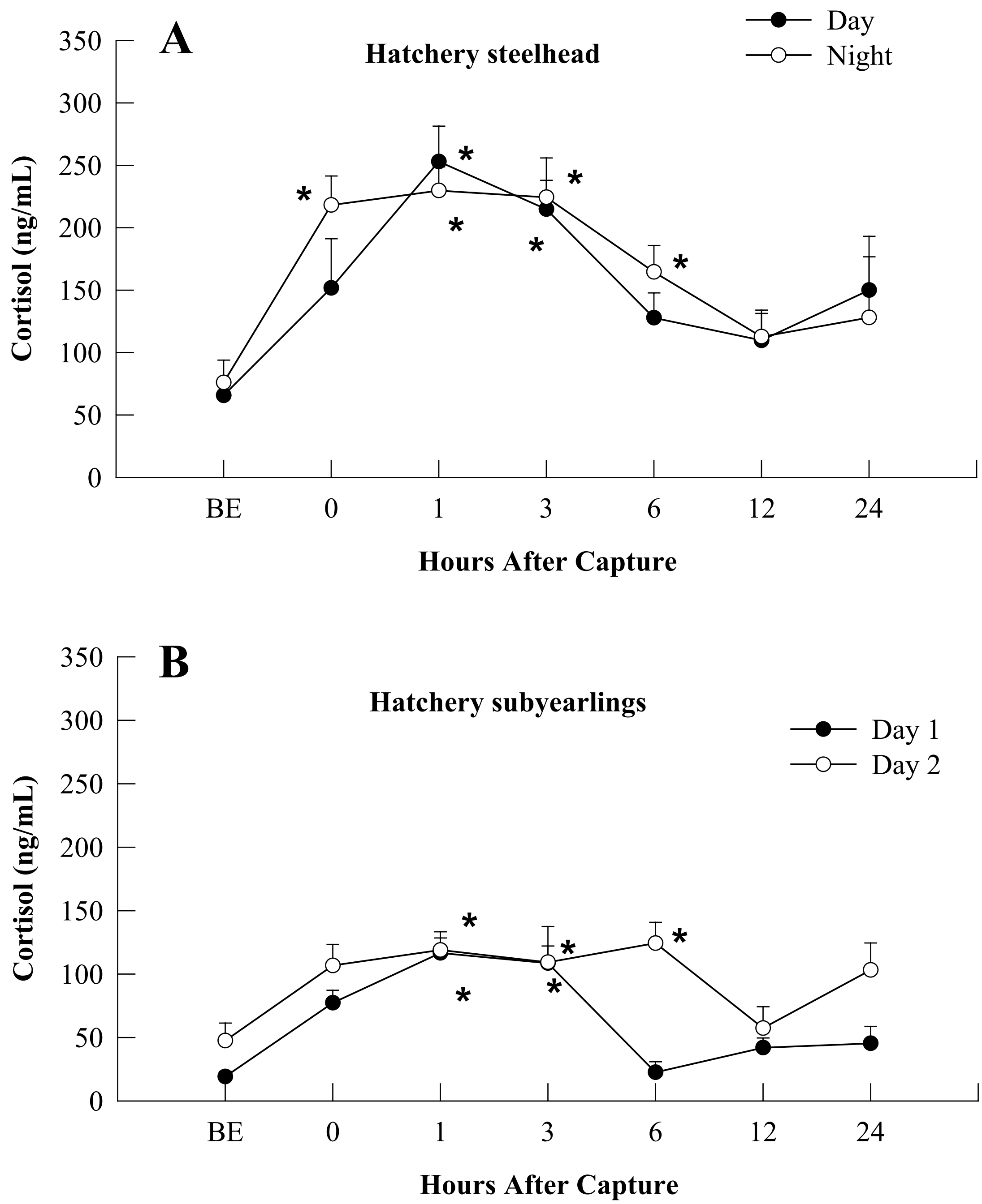

Figure 8. Mean (+ SE) plasma cortisol concentrations over time series in hatchery steelhead and hatchery subyearling chinook salmon before entrance (BE) and after passage through conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where before entrance values differ significantly from after passage values.

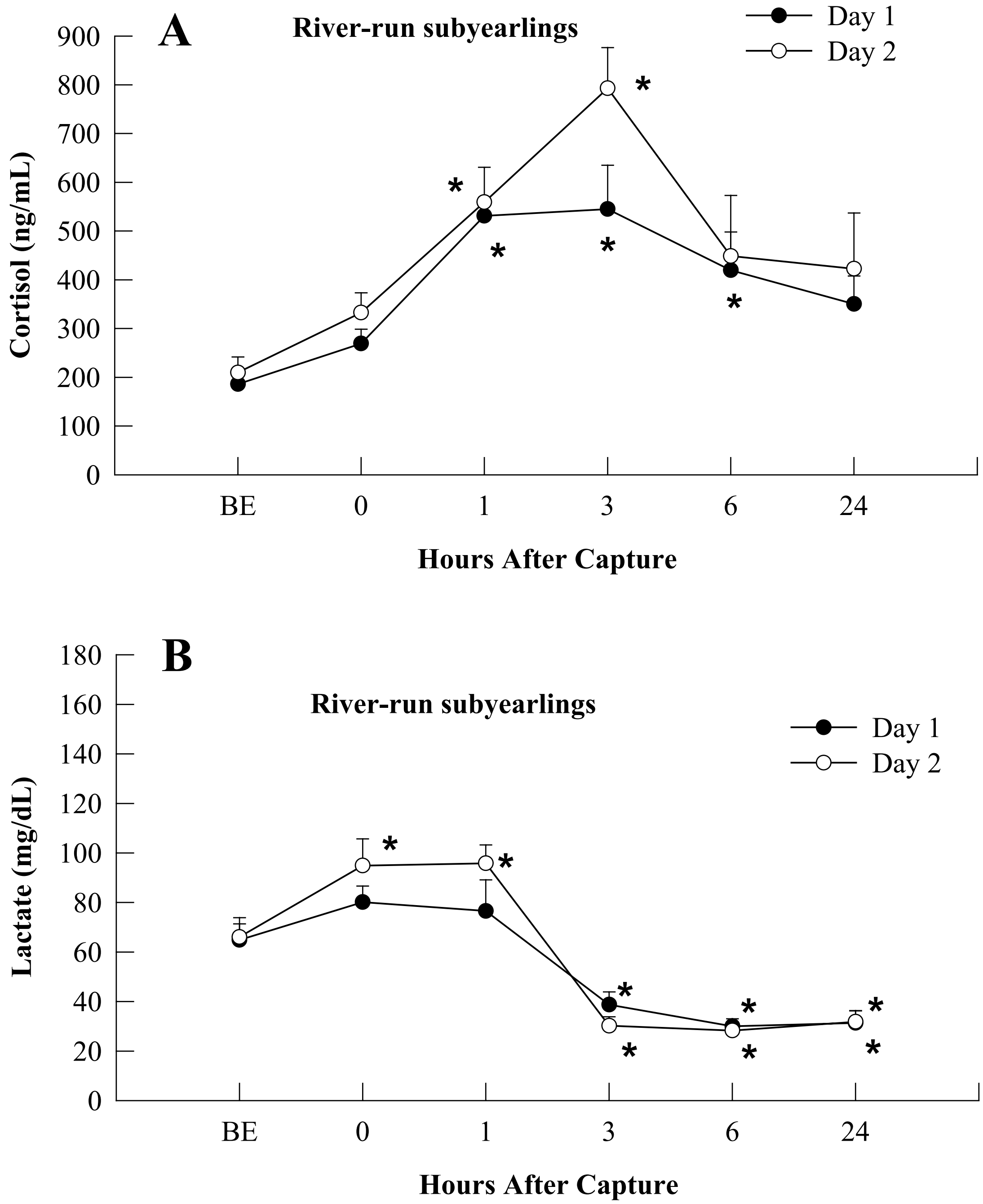

Figure 9. Mean (+ SE) plasma cortisol and lactate concentrations over time series in river-run subyearling chinook before entrance (BE) and after passage through conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate where before entrance values differ significantly from after passage values.

subyearling chinook were extremely high (Figure 9A) blood samples were re-assayed by researchers at an independent laboratory using a different type of assay. Data from the independent analysis had lower concentrations but was positively correlated to our data (r = 0.93, Appendix 4).

Lactate levels in hatchery steelhead increased from 13 to 94 $mg \cdot dL^{-1}$ and 45 to 145 $mg \cdot dL^{-1}$ 1 h after capture at the downstream end of the pipe, then returned to basal levels by 6 h after capture (Figure 10A). Hatchery subyearling chinook showed similar trends but peak levels 1 h after capture were below 100 $mg \cdot dL^{-1}$ (Figure 10B). Lactate levels remained low from 6 h after capture for the duration of the sampling period at 24 h after capture. Lactate levels in hatchery steelhead had higher peaks during the day sample 0 and 3 h after capture compared to the night sample. Levels in subyearlings were similar during day 1 and day 2 sampling. Mean lactate concentrations in river-run subyearlings increased from 66 $mg \cdot dL^{-1}$ before entering the pipe to 95 $mg \cdot dL^{-1}$ 3 h after collection at the downstream end of the pipe (Figure 9B). These were the same fish that had extremely high cortisol levels.

Tailrace Egress Behavior

Methods

Radio telemetry has been used extensively throughout the Columbia River basin to determine behavior of juvenile salmonids. We used radio telemetry to determine the effects of passage through the JBS and new conveyance pipe on tailrace egress behavior. Fixed-site antennas and boat tracking were used to monitor radio-tagged fish released from upriver telemetry studies and into the JBS. Travel times and migrational paths through the JBS and tailrace area were compared to times and paths of fish passing through the spillway and Power House One (PH I). Due to violations in assumptions of normality, a non-parametric Kruskal-Wallis test was used to test for differences in median travel time among passage routes. All statistical tests were conducted at a 95% confidence level. To maximize contacts of fish released from upriver studies, boat tracking was performed during crepuscular periods when concentrations of migrating salmonids were highest. This also allowed us to document

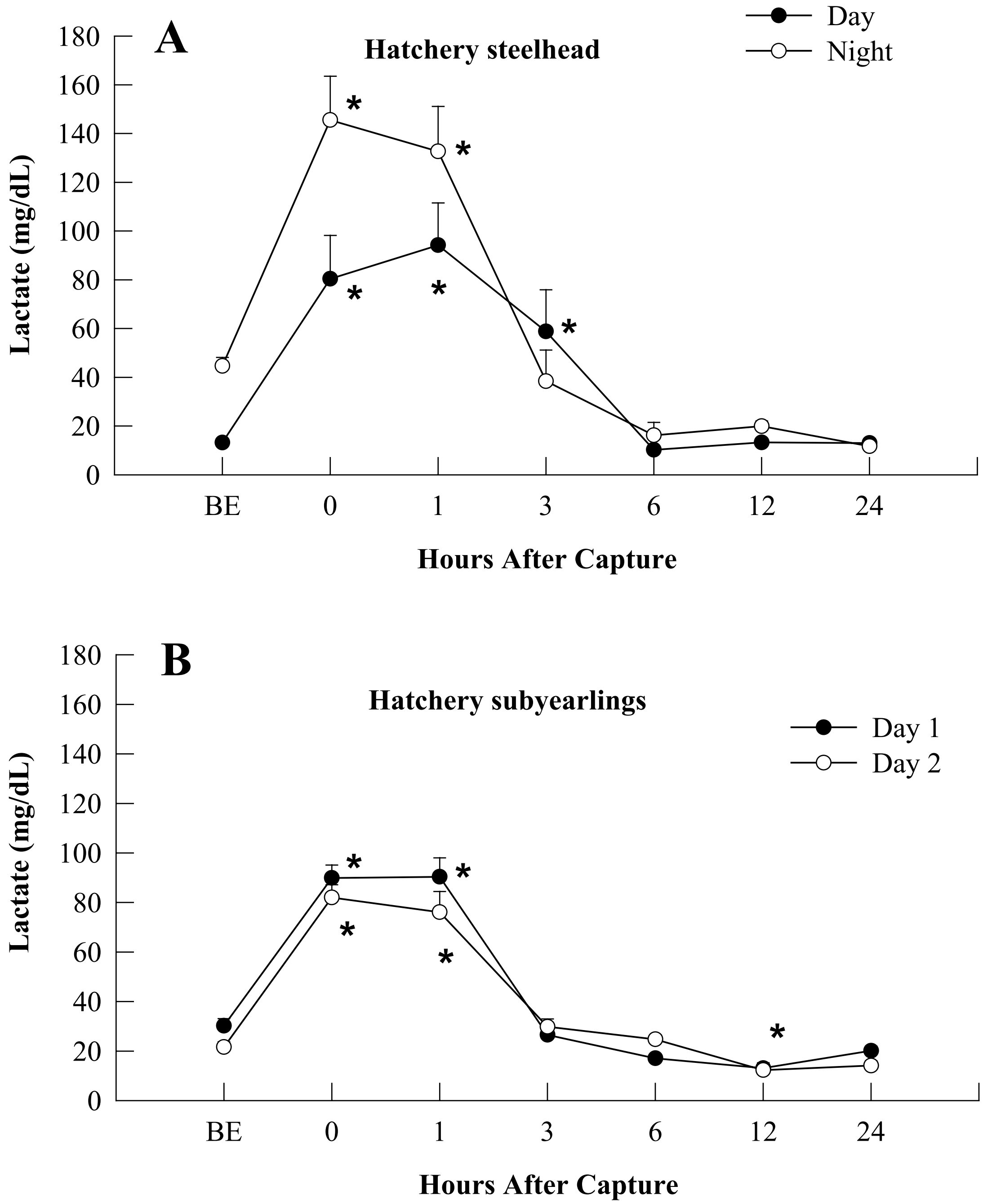

Figure 10. Mean (+ SE) plasma lactate concentrations over time in hatchery steelhead and hatchery subyearling chinook before entrance (BE) and after passage through conveyance pipe at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Asterisks indicate before entrance levels differ significantly from after passage values.

behavioral differences during AM (0300 - 1059 hours) and PM (1500 - 2359 hours) diel periods.

Yearling and subyearling chinook salmon and juvenile steelhead to be implanted with radio transmitters were obtained from the Downstream Monitoring Facility operated by the Pacific States Marine Fisheries Commission at PH I. Fish were held 12-24 h at the facility to allow for stomach content evacuation, and then transported to PH II for tagging and release. Transmitters were gastrically implanted following procedures described by Adams et al. (1998). Groups of 21 to 25 steelhead or 16 to 22 yearling chinook were implanted with digitally-coded transmitters. Because of their smaller size, groups of 15 subyearling chinook were implanted with smaller pulse-coded transmitters (Appendix 3). After tagging, fish were placed in 30 gallon holding tanks, two fish per tank, and supplied with circulating river water. Fish were held for 12 to 24 h, checked for mortalities and regurgitated tags, then released directly into the JBS collection channel immediately upstream from the dewatering facility and entrance to the conveyance pipe (Figure 1).

Fish movements were tracked using fixed-site telemetry gear and boats equipped with telemetry antennas and receivers. Underwater antennas were positioned near the entrance, midpoint, and exit to the conveyance pipe. Four and six-element Yagi (aerial) antennas were positioned near the outfall area 2.7 km downriver of the dam and at the study area exit site 8 km downriver of the dam at US Coast Guard navigational marker "Red 88" (Figure 2). Aerial antenna coverage extended across the river and allowed for monitoring of radio-tagged fish that passed the dam through both JBS and non-JBS routes such as the spillway, PH I, and other PH II routes. Antennas were connected to a Lotek SRX 400 data logging receiver. During monitoring of chinook and steelhead, a Lotek Digital Spectrum Processor (DSP) was also used. The DSP allowed receivers to monitor all frequencies concurrently.

We also utilized antennas and receivers positioned in Bonneville Dam’s forebay, set up by other projects, to monitor movements of radio-tagged fish released upriver from Rock Creek Washington, and The Dalles and John Day dams. This data allowed us to determine travel time from the PH II forebay to the start of conveyance pipe, and the start of conveyance pipe to outfall. It also allowed us to make comparisons to travel times from the Spillway and PH I forebay to the outfall area. A passive float was released into the JBS to measure travel time of water through the pipe. Fish released directly into the JBS or from upriver telemetry studies were mobile tracked from the outfall to the downriver exit site using boats equipped with six-element Yagi antennas and Lotek telemetry receivers. Fish released into the JBS were released in pairs and we attempted to track at least one fish from each pair. When the boat was in close proximity to the fish a global positioning system (GPS) was used to record its position. Approximately four positions per fish were recorded between the outfall and the exit site.

To describe how water movement and hydraulic conditions in the tailrace influenced fish movement, we released a free-drifting drogue buoy equipped with a GPS. Relative positions of the fish and drogue were monitored and their spatial relationship over time was determined. We used a metal drogue (1.2 x 0.5 m) attached to a PVC cylinder equipped with GPS which recorded its path and chronological history. Drogues were released at the first contact position of the fish concurrently being tracked and allowed to drift downriver to the exit site where it was retrieved. Complete drogue drift paths and associated fish positions were plotted using Arcview geographic information system (GIS) software to determine if fish were being passively transported downriver.

To determine where high velocity water was located, describe river hydraulics, and determine a relationship between fish and drogue movement, cross-sectional transects of water velocity measurements were sampled using an acoustic Doppler current profiler (ADCP). Transects were geospatially referenced using a GPS. Stable operating conditions at the dam were requested for an 8-12 h period to enhance water velocity measurements during two different flow regimes. The data was plotted using Arcview GIS software, and water velocities were interpolated between transects and presented as a Triangulated Irregular Network (TIN). The TIN representation was used to determine where high velocity water was located, describe river hydraulics, and determine a relationship between fish and drogue movement.

Results

Upriver releases

Radio-tagged fish released from upriver telemetry studies had time to acclimate to river conditions and were considered most representative of seaward migrating juvenile salmonids.

Radio-tagged fish from upriver studies that passed through the JBS took longer to reach the outfall area compared to fish that passed through the turbines or spillway (Table 2). The majority of their time in the JBS was spent in the conveyance pipe. Fish travel times through the pipe were longer than water flow travel time (33 min to the separator), indicating that fish resist the flow. We found no significant difference in travel times through the conveyance pipe for radio-tagged fish released during AM and PM diel periods (P = 0.36, yearling chinook; P = 0.87, steelhead).

Median travel time from the outfall to the downriver exit site was 36 min for yearling chinook, 33 min for steelhead, and 34 min for subyearling chinook (Table 3). Less than 5% of the fish that we obtained travel times for took more than 90 min to travel between the outfall area and the exit site. Median tailrace travel times for fish that used the JBS were not significantly different from travel times of fish that passed the dam through non-JBS routes (P = 0.36).

Additional JBS releases

To increase the number of radio-tagged fish that passed through the JBS, we released radio-tagged steelhead, and yearling and subyearling chinook directly into the JBS. From 7 May to 15 July 1999, we released 134 yearling chinook salmon, 135 steelhead, and 148 subyearling chinook salmon into the upstream end of the bypass. Yearling chinook and steelhead had median travel times through the conveyance pipe that were approximately equal to travel times of fish released upriver (Table 2). Median travel times from the outfall to the exit site were also equivalent to those of fish released upriver (Table 3). Subyearlings released upriver took slightly longer to reach the exit site compared to subyearlings released into the JBS. Steelhead had the widest range of travel times to the exit site taking as long as 17 h. Figures 11, 12, and 13 show locations of fish contacted during mobile tracking. Of the 320 fish we contacted, 12 (3.8%) delayed before moving downriver (Table 4). We observed seven (1.9%) fish that we believed were consumed by predators. Most fish stayed within the main channel except for 12 (3.7%) fish that used the side channel behind Ives Island. When fish entered the side channel, they moved downriver quickly and re-entered the main channel. Subyearling chinook delayed and used the side channel more often than yearling chinook and steelhead, but were not observed to

Table 2. Median travel time (min) from the forebay to the outfall area for radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released upriver and into Bonneville Dam's Powerhouse II juvenile bypass system (JBS), 1999. Pipe refers to the upstream end of the conveyance pipe.

Release site/ Passage route	Yearling chinook .		Steelhead .		Subyealing chinook .	
	N	Median travel time (min)	N	Median travel time (min)	N	Median travel time (min)
Upriver releases						
PH II bypass	79	79.4	69	74.0	NA	NA
Forebay to pipe	75	20.8	73	16.6	NA	NA
Pipe to outfall	78	50.3	103	56.6	NA	NA
PH II turbines	70	36.3	25	52.6	NA	NA
PH II unknown	NA	NA	NA	NA	34	58.7
Spillway	192	25.5	135	24.6	40	23.7
PH I	113	24.7	123	29.5	26	24.4
JBS releases						
Pipe to outfall	86	44.7	116	59.5	51	41.3

Table 3. Median and mean travel time (min) from the outfall to the downriver exit site for radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released into Bonneville Dam's Powerhouse II juvenile bypass system (JBS) and from upriver projects, 1999.

Species/ Release type	Passage route	N	Travel time (min) to exit site			
			Median	Mean	SD	Range
Yearling chinook						
Upriver	JBS	76	35.4	40.0	18.1	24.4 - 132.6
Upriver	Non-JBS	353	36.0	42.7	24.9	24.9 - 278.1
additional JBS	JBS	80	36.6	40.5	18.6	26.4 - 138.6
Overall:		509	36.0	42.0	23.1	24.4 - 278.1
Steelhead						
Upriver	JBS	86	31.0	49.1	115.6	25.9 - 1055.0
Upriver	Non-JBS	374	33.2	39.5	53.2	22.1 - 897.9
additional JBS	JBS	101	32.9	45.1	51.4	25.6 - 473.6
Overall:		561	32.8	41.9	66.3	22.1 - 1055.0
Subyearling chinook						
Upriver	Unknown	22	36.4	43.0	18.2	31.1 - 96.7
additional JBS	JBS	64	32.9	38.6	16.9	28.1 - 119.4
Overall:		86	34.0	39.7	17.3	28.1 - 119.4

be consumed by predators in higher numbers. Steelhead that used the JBS as a passage route delayed less and were consumed by predators less often than steelhead that passed the dam through non-JBS routes (Table 4).

PIT-tagged fish releases

In addition to travel times determined using radio-tagged fish, the PIT-tag diversion system allowed us to determine travel time through the pipe and recapture efficiency of fish obtained from a hatchery and used in physiology sampling. Median travel time through the conveyance pipe was 264 min for PIT-tagged steelhead, 42 min for yearling chinook, and 35 min for subyearling chinook (Table 5). A passive float released into the conveyance pipe took an average of 33 min to reach the separator bars just upstream of the PIT-tag detector, indicating that yearling and subyearling chinook moved passively with the water and that steelhead resisted to a greater degree. Some steelhead delayed in the pipe for as long as 80 h. See results of physiology sampling for more on steelhead holding. We found median travel times to be significantly higher for yearling chinook (P = 0.0025) and steelhead (P = 0.015) when released during the AM diel period compared to travel times recorded during the PM diel period.

Drogue releases and water velocities

During the spring outmigration of yearling chinook and steelhead, both the fish and the drogue followed mid-channel paths during 11 of the 25 drogue drifts (44%, Table 6). During eight of the drogue drifts (32%), the fish and drogues traveled on the south side of the river, and during one drift (4%) the fish took the side channel behind Ives Island and the drogue traveled on the south side of the river. During four drifts (16%) both fish and drogue traveled mid-channel then moved toward the south side of the river, and during one drift (4%), the drogue moved along the south side of the river and the fish moved mid channel. Some drogue paths were incomplete due to GPS signal interference caused by high mountains on both sides of the river. Daily average river discharge ranged from 268 to 384 kcfs. Figure 14 provides an example of a drogue path along with concurrent drogue and fish positions.

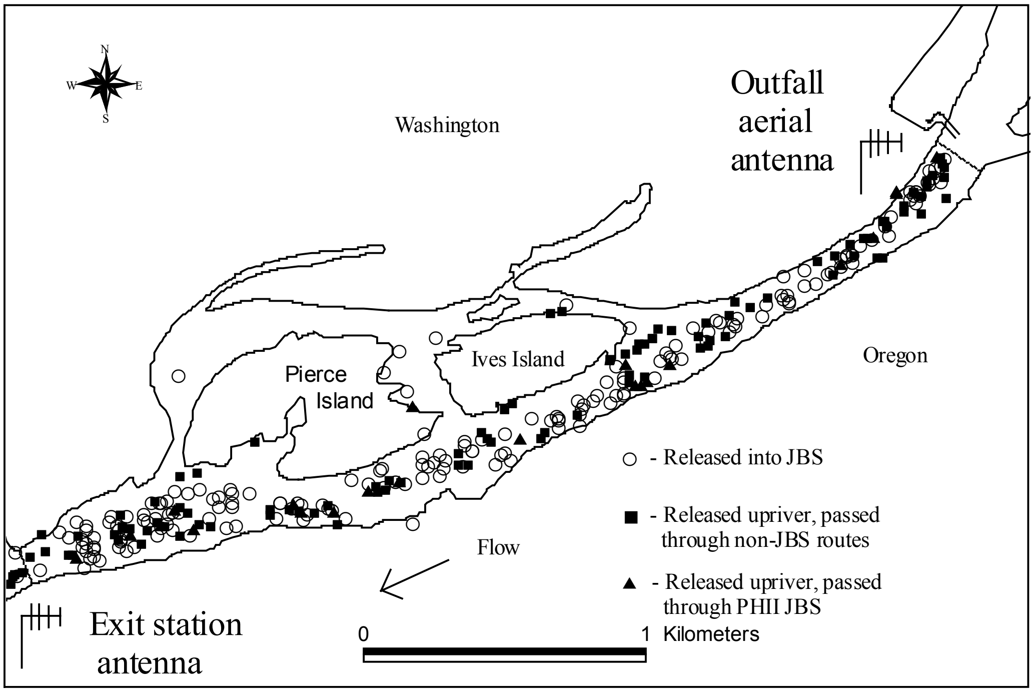

Figure 11. Mobile tracking locations of radio-tagged yearling chinook salmon released directly into Bonneville Dam Powerhouse II juvenile bypass system (JBS), and released from upriver studies that passed Bonneville Dam through the JBS and through non-JBS routes, 1999.

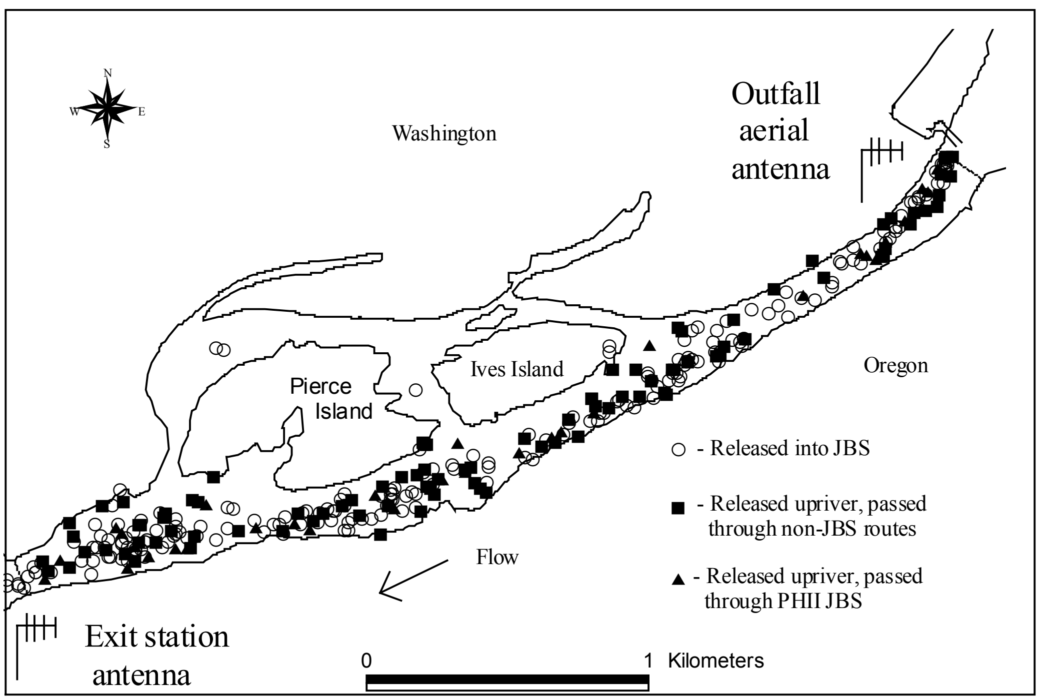

Figure 12. Mobile tracking locations of radio-tagged steelhead released directly into Bonneville Dam Powerhouse II juvenile bypass system (JBS) and released from upriver studies that passed Bonneville Dam through the JBS and through non-JBS routes, 1999.

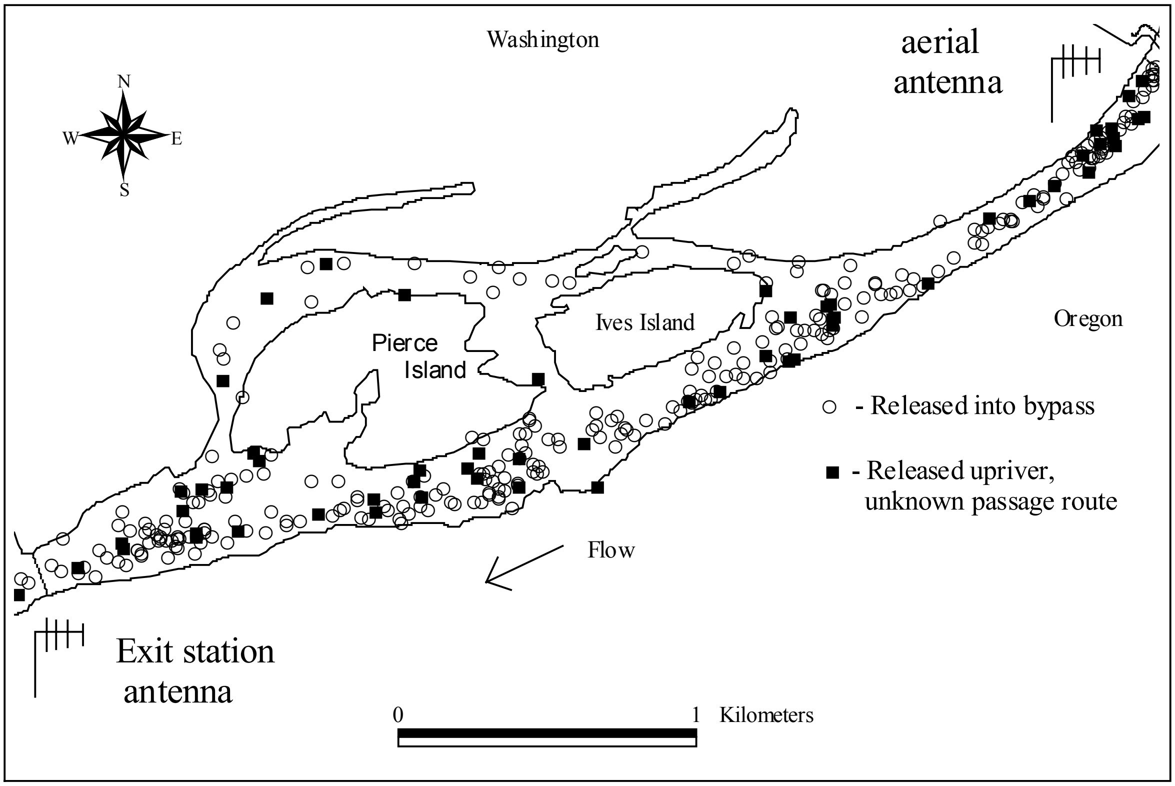

Figure 13. Mobile tracking locations of radio-tagged subyearling chinook released directly into the Bonneville Dam Powerhouse II juvenile bypass system (JBS), and released from upriver studies that passed Bonneville Dam, 1999.

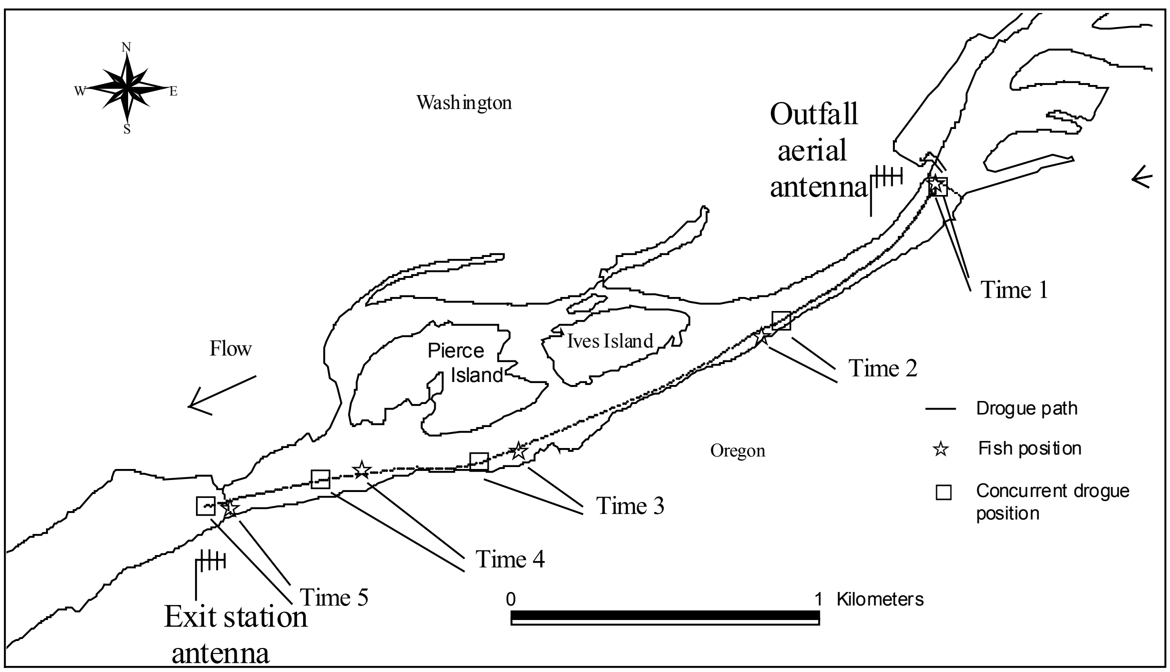

Figure 14. Example of drogue drift path and associated fish positions. Fish positions are for a radio-tagged steelhead released into the JBS on 26 May, 1999.

Table 4. Number and percent of mobile tracking contacts below Bonneville Dam of radio-tagged yearling chinook salmon, steelhead, and subyearling chinook salmon released upriver and into the Juvenile Bypass System (JBS), 1999. Included are number predated, use of side channel by Beacon Rock, and delay in the tailrace area.

Release Site/ Species/ Passage Route	Number		Number and % of Contacted		
	released	contacted (% of released)	predated	side channel used	delayed
Upriver Releases					
Yearling chinook					
JBS passage		8	0 (0.0)	0 (0.0)	1 (12.5)
non-JBS passage		17	0 (0.0)	1 (5.9)	0 (0.0)
unknown passage		1	0 (0.0)	0 (0.0)	0 (0.0)
Overall:		26	0 (0.0)	1 (3.8)	1 (3.8)
Steelhead					
JBS passage		5	0 (0.0)	0 (0.0)	0 (0.0)
non-JBS passage		43	4 (9.3)	0 (0.0)	3 (7.0)
unknown passage		7	1 (14.3)	0 (0.0)	0 (0.0)
Overall:		55	5 (9.1)	0 (0.0)	3 (5.5)
Subyearling chinook		15	0 (0.0)	2 (13.3)	3 (20.0)
Overall upriver:		96	5 (5.2)	3 (3.1)	7 (7.3)
JBS Releases					
Yearling chinook	133	69 (52)	2 (2.9)	2 (2.9)	0 (0.0)
Steelhead	134	72 (54)	0 (0.0)	2 (2.8)	1 (1.4)
Subyearling chinook	148	83 (56)	0 (0.0)	5 (6.0)	4 (4.8)
Overall JBS:	415	224 (54)	2 (0.9)	9 (4.0)	5 (2.2)
Upriver and JBS overall:		320	7 (2.2)	12 (3.8)	12 (3.8)

Table 5. Median and mean travel time through the conveyance pipe of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon at Bonneville Dam's Powerhouse II juvenile bypass system, 1999.

Species/ Release date	Diel period	N	Travel time (min) Median	Mean	SD	Range
Yearling chinook						
23 April	PM	72	42.4	47.4	20.3	36.4 - 190.4
25 April	AM	72	46.4	85.1	118.2	35.8 - 644.2
Overall:		144	44.9	66.2	86.6	35.8 - 644.2
Steelhead						
19 April	PM	58	396.5	432.6	349.7	54.3 - 2157.2
21 April	PM	62	181.7	444.9	565.0	50.5 - 3020.0
29 April	PM	58	162.2	364.6	540.0	49.3 - 2742.5
1 May	AM	62	180.1	591.7	838.1	46.4 - 4845.3
Overall:		240	264.2	460.5	605.3	46.4 - 4845.3
Subyearling chinook						
21 June	AM	69	35.0	36.3	5.4	26.0 - 68.0
23 June	AM	70	35.0	35.8	3.2	31.0- 47.0
Overall:		139	35.0	36.0	4.3	26.0 - 68.0

During the summer outmigration of subyearling chinook salmon, both the fish and the drogue traveled on the south side of the river during 11 of 18 (61%) drogue drifts. During four (22%) of the drifts the drogue moved through the south part of the channel while the fish traveled mid-channel. During two (11%) of the drifts the drogue traveled in the mid-channel and the fish moved in the southern part of the channel. During one drogue drift the fish took a side channel behind Ives Island on the north side of the river, and the drogue traveled on the south side. Daily average river discharge ranged from 259 to 337 kcfs.

Interpretations of water velocity data collected during flows of 271 kcfs and 384 kcfs indicated that higher velocity water was found between mid-channel and the south shore (Figures 15 and 16). Drogues tended to drift closer to the south shore during high flows and were dispersed across the river during lower flows. An increase in flow from 271 kcfs to 384 kcfs caused water velocities behind Ives Island to rise above 50 cm/s.

Table 6. Summary of drogue drift paths and concurrent fish positions during mobile tracking below Bonneville Dam's Powerhouse II juvenile bypass system, 1999.

Path of fish	Path of drogue	Yearling chinook	Steelhead	Subyearling chinook
South channel	South channel	3	5	11
South channel	Mid channel			4
South channel then midchannel	South channel then midchannel	3	1	
Mid channel	South channel		1	2
Mid channel	Mid channel	5	6	
side channel	South channel	1		1
overall:		12	13	18

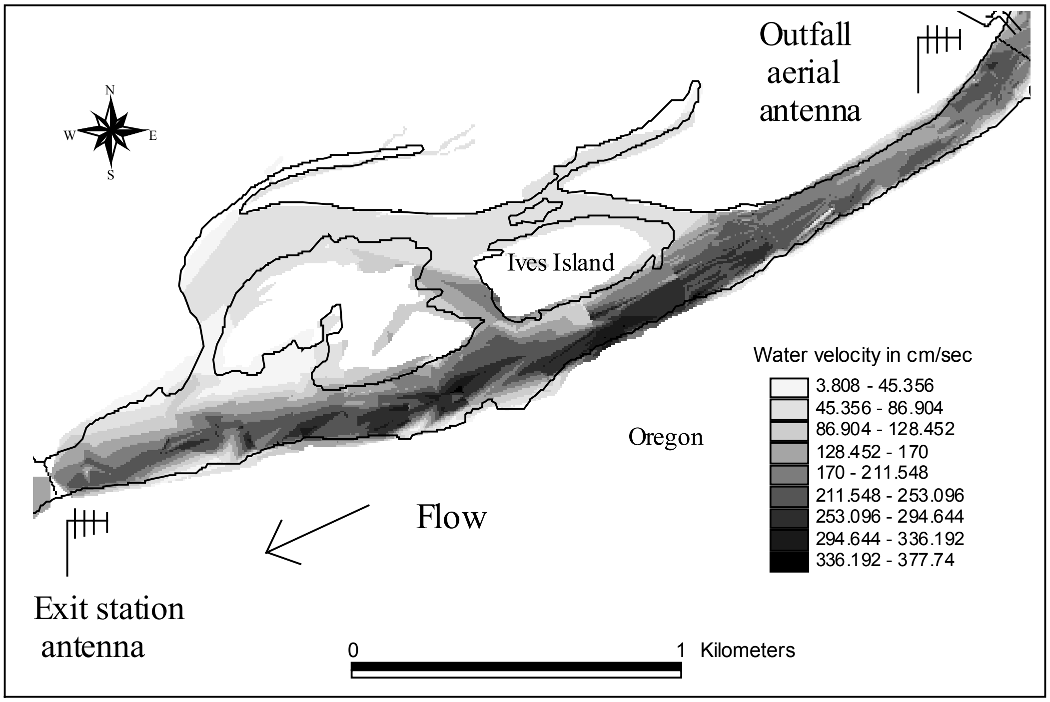

Figure 15. Water velocity interpolation from ADCP data below Bonneville Dam on 17 May, 1999. Average daily total river discharge = 271 kcfs.

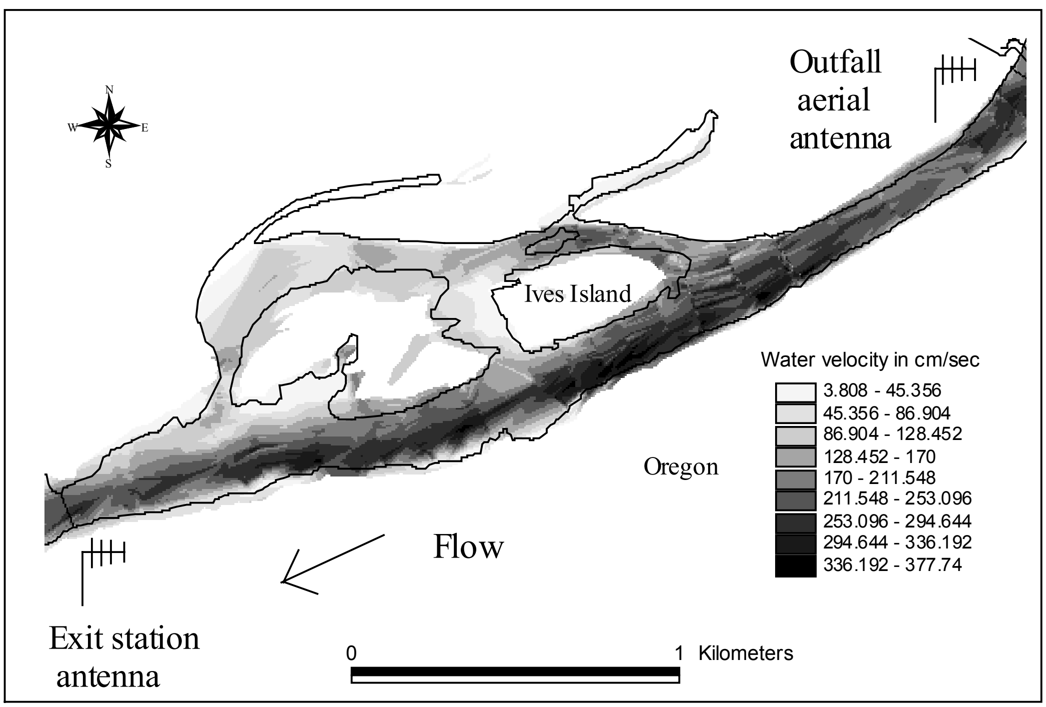

Figure 16. Water velocity interpolation from ADCP data below Bonneville Dam on 28 May, 1999. Average daily total river discharge = 384 kcfs.

Discussion

We found no evidence of direct mortality caused by travel through the new conveyance pipe. These findings concur with a physical injury and descaling study conducted by the National Marine Fishery Service (Gilbreath and Prentice 1999). During the early part of the evaluation when availability of river-run fish was low, fish obtained from a hatchery were valuable surrogates to river-run fish. During early releases when water temperatures were cold, PIT-tagged steelhead transported from a hatchery delayed in the conveyance pipe. These steelhead may have had a lower level of smoltification and may not have been disposed to migrate. Conditions within the bypass may also have been a factor in the delay. During later releases of PIT-tagged steelhead and all releases of radio-tagged steelhead, conditions changed enough to reduce delay. After the initial releases, radio-tagged and most PIT-tagged fish moved quickly through the conveyance pipe. However, comparisons of median travel time of radio-tagged fish to a passive object indicate that fish, especially steelhead, show some resistance to flow.

Plasma cortisol is a well known indicator of physiological stress (Mesa 1994). Passage through the pipe and capture or recapture elicited an increase in plasma cortisol concentrations in the juvenile salmonids we tested. Increases were most pronounced in fish obtained from a hatchery and to a lesser degree in river-run fish. However, a comparison of cortisol concentrations measured before fish entered the conveyance pipe showed river-run fish to have higher levels. Higher pre-entrance levels in river-run fish were likely a result of stressors encountered upstream of the conveyance pipe, within the PH II bypass system upstream of the entrance to the conveyance pipe, or during capture. Elevated levels of cortisol are associated with smoltification (Barton et al. 1986). Also, fish from a hatchery were sequestered in holding tanks and allowed to recover from the stress of transport for 72 hours before being sampled, and were subjected to the stress of the PIT-tag separator and crowding system that river-run fish were not. Throughout all of our sampling, netting or capture stress undoubtedly contributed to increases in cortisol in both river-run and hatchery fish, before and after passage through the pipe. As a quality control measure, we sent our samples to an independent laboratory to be assayed. Results from the independent lab showed cortisol concentrations from the same samples to be lower than ours. We conclude that our measurements were elevated but highly correlated with the independent laboratory. Although transport through the pipe did appear to elicit a cortisol stress response, considering the contributions of additional stressors, detrimental effects caused by the pipe were probably not severe.

Increased lactate levels in the blood indicate muscular fatigue. Comparisons of lactate levels before and after passage through the pipe showed an increase in lactate concentrations after fish passed through the pipe. These increases were only statistically significant in hatchery fish. River-run fish showed much smaller increases. This was likely the result of hatchery fish being sequestered in holding tanks where lactate basal levels were lower. Hatchery steelhead had the highest peaks in lactate levels. This indicated that hatchery steelhead were most likely to swim against the current in the conveyance pipe and became fatigued. Again, this could be attributed to hatchery fish not being disposed to migrate.

Sampling over time showed that although mean cortisol and lactate concentrations increased immediately after passage, cortisol peaked three hours after capture and then decreased to near basal levels within six hours. Lactate in hatchery and river-run fish peaked immediately after capture then returned to basal levels within 3 h. Lactate levels were higher in hatchery steelhead when compared to hatchery subyearlings and river-run subyearlings. Higher lactate levels, in conjunction with hatchery steelhead's longer travel times through the conveyance pipe, indicated hatchery steelhead were resisting transport through the pipe, possibly to the point of fatigue. However, quick recovery time from the stress of passage through the pipe and handling indicated the fatigue is more acute than chronic and that fish were recovering. It is unknown if recovery time in the river differs from recovery time in holding tanks.

Radio-tagged fish traveling from the forebay to the outfall area took significantly longer when traveling through the JBS compared to fish that passed the dam through non-JBS routes such as PH I, the Spillway, and PH II turbines. This was likely due to the longer traverse through the JBS conveyance pipe compared to the shorter distance across the PH I and Spillway tailrace areas. This longer traverse through the JBS in itself is not detrimental to fish if predation in the PH II immediate tailrace area is reduced. After radio-tagged fish released upriver or into the JBS entered the conveyance pipe they generally did not delay, and moved to the outfall. Steelhead took the longest to pass through the pipe. Although, a small number of steelhead delayed for a considerable time. We believe this to be a result of steelhead being larger and having relatively higher swimming speed in body lengths than yearling and subyearling chinook.

After radio-tagged fish exited the bypass system they exhibited similar behavior to fish that passed the dam through non-bypass routes. Travel time through the tailrace was the same for both JBS and non-JBS fish. Because most fish stayed near the thalweg where water velocities were highest and moved downriver and exited the study area quickly, it appeared that both JBS and non-JBS fish were healthy and actively migrating downriver. This indicated that fish that passed the JBS were not negatively impacted compared to fish that passed through other routes. Also, the percentage of fish that delayed or were lost to predation was low for both groups. From mobile tracking, we found the percentage of fish using the side channel behind Ives island (< 4%) to be lower than the 10% figure reported by Snelling and Matson (1995). We attribute this to either a difference in flows or a difference in behavior due to the methods of Snelling and Matson (1995).

Because the free-drifting drogue moved in close proximity to our radio-tagged fish, the potential exists for fish in a compromised condition to be passively transported downriver. Future evaluation of the behavior of fish passing through JBS and non-JBS routes should include releases of dead radio-tagged fish.

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Appendix 1. Fork length and weight of PIT-tagged hatchery yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing of physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999.

Species/		Fork Length (mm)			Weight (g)		
Release Date	N	Mean	SD	Range	Mean	SD	Range
Yearling chinook							
23 April	84	139.0	11.9	120-194	31.3	10.2	19-90
25 April	84	135.6	8.6	118-158	28.4	6.3	18-47
Overall:	168	137.3	10.5	118-194	29.8	8.6	18-90
Steelhead							
19 April	84	200.2	16.4	137-232	82.4	21.5	27-145
21 April	84	199.2	13.9	165-235	80.6	19.1	42-155
29 April	84	202.1	13.2	164-232	77.3	16.0	43-125
1 May	84	201.1	14.6	161-242	77.6	17.6	41-136
Overall:	336	200.6	14.6	137-242	79.5	18.7	27-155
Subyearling chinook							
21 June	84	92.0	4.6	85-104	8.3	1.8	5.4-12.6
23 June	84	92.5	4.9	85-110	8.7	1.7	6.1-15.3
Overall:	168	92.2	4.8	85-110	8.5	1.7	5.4-15.3

Appendix 2. Sample size (N), fork length, and weight and number sampled of river-run yearling chinook salmon, steelhead, and subyearling chinook salmon used in testing physiology response at Bonneville Dam's Powerhouse II juvenile bypass system, 1999. Included are number sampled before entrance to the conveyance pipe (pre), and number sampled after passage through the conveyance pipe (post).

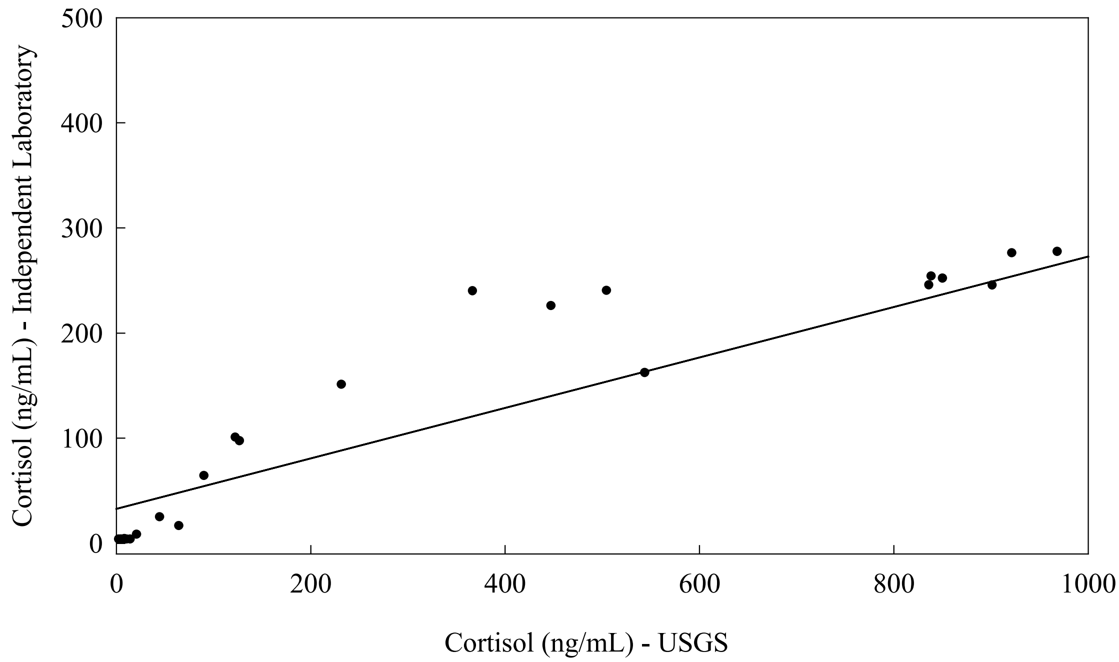
Species/ Collection Date	Diel Period	N	Sampled		Fork Length (mm)			Weight (g)		
			Pre	Post	Mean	SD	Range	Mean	SD	Range
Yearling chinook										
3 May	AM	56	15	41	149.2	18.4	126-224	35.6	17.1	20-129
3 May	PM	56	15	41	146.5	16.1	125-208	34.5	11.9	20-85
Overall:		112	30	82	147.9	17.3	125-224	35.0	14.7	20-129
Steelhead										
3 May	AM	60	15	45	226.1	28.5	119-298	107.0	37.6	49-220
3 May	PM	60	15	45	219.4	24.4	124-260	95.3	25.2	41-157
Overall:		120	30	90	222.8	26.7	119-298	101.1	32.4	41-220
Subyearling chinook										
24 June	AM	60	10	50	102.2	7.4	85-122	11.0	2.3	6.2-18.2
25 June	AM	60	10	50	102.1	7.3	84-114	11.2	2.3	5.3-15.9
Overall:		120	20	100	102.2	7.4	84-122	11.1	2.3	5.3-18.2

Appendix 3. Sample size (N), fork length, and weight of radio-tagged yearling chinook salmon and steelhead released into Bonneville Dam's Powerhouse II juvenile bypass system, 1999. PM diel period refers to fish released at approximately 1500 hours and AM refers to fish released at 0200 hours.

Species/	Diel		Fork Length (mm)			Weight (g)		
Release Date	Period	N	Mean	SD	Range	Mean	SD	Range
Yearling chinook								
7 May	PM	16	151.3	13.6	131-174	35.0	11.6	22-60
10 May	PM	22	155.8	19.2	132-198	38.6	17.0	20-83
13 May	AM	19	151.1	17.0	127-188	33.1	13.7	18-75
17 May	PM	21	147.1	14.9	127-174	30.0	10.1	17-49
20 May	AM	17	155.8	17.0	130-180	36.7	12.8	18-58
24 May	PM	18	148.4	10.6	129-171	29.3	6.8	19-48
27 May	AM	21	160.5	18.0	141-197	40.2	17.6	24-90
Overall:		134	153.0	16.4	127-198	34.8	13.8	17-90
Steelhead								
11 May	PM	24	219.5	22.4	164-262	89.6	29.5	34-166
14 May	AM	21	217.3	22.8	187-268	85.2	28.8	53-164
18 May	PM	22	217.2	19.8	184-256	89.1	24.8	50-135
21 May	AM	21	224.1	28.9	176-300	95.8	40.8	42-213
25 May	PM	22	220.5	20.7	188-260	90.5	25.9	58-155
28 May	AM	25	208.8	22.6	172-263	80.3	33.9	44-191
Overall:		135	217.7	23.1	164-300	88.2	30.9	34-213

Appendix 3 (continued). Sample size (N), fork length, and weight of radio-tagged subyearling chinook salmon released into Bonneville Dam's Powerhouse II juvenile bypass system, 1999. PM diel period refers to fish released at approximately 15:00 h and AM refers to fish released at 200 h.

Species/	Diel		Fork Length (mm)			Weight (g)		
Release Date	Period	N	Mean	SD	Range	Mean	SD	Range
Subyearling chinook								
26 June	PM	13	113.7	3.6	110-119	14.6	2.0	12.6-18.3
27 June	PM	14	114.4	5.5	110-130	16.0	3.0	13.8-24.5
30 June	AM	14	116.6	4.6	113-131	17.1	2.8	14.9-24.2
30 June	PM	9	116.6	3.2	112-121	16.8	1.5	14.5-19.3
2 July	AM	14	113.7	3.4	110-123	15.2	1.7	12.3-19.6
7 July	AM	15	114.8	6.5	110-136	15.9	3.2	12.8-26.0
7 July	PM	12	117.3	4.9	111-127	17.8	2.9	14.5-23.5
8 July	PM	15	119.7	8.1	113-142	18.5	3.6	14.9-28.6
9 July	AM	13	121.3	7.6	112-134	18.4	3.2	13.2-22.4
15 July	AM	15	117.5	5.0	112-132	17.1	2.4	14.7-22.9
15 July	PM	14	117.7	6.1	112-135	17.1	2.8	13.7-23.4
Overall:		148	116.7	5.9	110-142	16.8	2.9	12.3-28.6



Appendix 4. Comparison of blood plasma cortisol samples assayed by USGS and an independent laboratory.