Biological design criteria for fish passage facilities:
high-velocity flume development and improved wet-separator efficiency, 2001

Fish Ecology Division

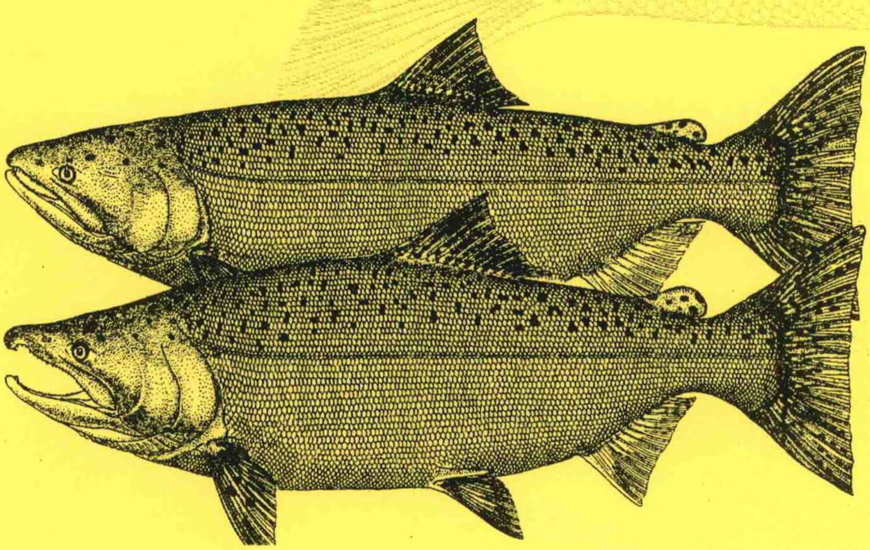
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
R. Lynn McComas, Benjamin P. Sandford,
and John W. Ferguson
and
Daniel M. Katz

March 2008



Biological Design Criteria for Fish Passage Facilities: High-Velocity Flume Development and Improved Wet-Separator Efficiency, 2001

R. Lynn McComas, Benjamin P. Sandford, and John W. Ferguson

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

and

Daniel M. Katz

Hydrology Department
Walla Walla District
U.S. Army Corps of Engineers
201 North Third Avenue
Walla Walla, Washington 99326-1876

Report of research for

Walla Walla District
U.S. Army Corps of Engineers
201 North Third Avenue
Walla Walla, Washington 99326-1876
Delivery Order E86910060

March 2008

EXECUTIVE SUMMARY

Size separation is important for the effective management of juvenile migrant salmonids of the Columbia and Snake Rivers and for the fish transportation program. Studies continued in 2001 at Ice Harbor Dam on the Snake River and at McNary Dam on the Columbia River to improve wet separation techniques for implementation in juvenile bypass facilities at hydroelectric facilities.

The effects of eight treatments on separation efficiency, separator exit efficiency (a measure of residence time in the separator unit), and fish condition (descaling) were evaluated using river-run juvenile salmonid outmigrants over the spring migration period at the Ice Harbor Dam high-velocity flume (HVF) test separator facility. Treatment factors included combinations of lighting (high and low intensity), substrate color (light and dark) and presence or absence of splitter plates. Fish were separated into small fish (<180 mm fork length; FL) and large fish (≥180 mm FL) groups by species, using bars spaced 17 mm apart to effect the separation.

Seventeen replicates were completed for each treatment using a randomized block experimental design. Total catch separation efficiency was highest with lights on and dark substrate (82%, SE = 1.3), separator exit efficiency was virtually 100% for all treatments under these conditions. Descaling for the total catch was significantly higher using dark substrate (5.3%, SE = 0.32) compared to light colored substrate (4.2%, SE = 0.32). Splitter plates had no effect on separation efficiency for any size group.

At McNary Dam separation research was conducted over the spring juvenile chinook salmon migration using the juvenile fish facility operational wet separator. Two separator conditions were compared: the upstream or 'A' section of the conventional separator was compared to a modified A section using an insert containing separation enhancements. Separator conditions were evaluated over 2-d test periods by installing and removing the insert. In addition, two light conditions (on and off) were compared to evaluate the effects of artificial light on size separation, separator exit efficiency, and descaling. Nine replicates of each of the resulting four treatments were completed in a randomized block design over the yearling chinook salmon spring migration.

Separation efficiency for the total salmonid catch was significantly higher using the insert separator (73%, SE = 1.2) than under the conventional (69%, SE = 1.2) condition, and significantly higher for lighted (73%, SE = 1.2) than for unlighted (69%, SE = 1.2) treatments. Mean total catch separation efficiency values using the high light level during the juvenile spring migration was 75% using the conventional separator and 82% using the HVF unit. Mean descaling for the total catch was not significantly different among treatments.

Blood samples were collected from yearling chinook salmon and steelhead at McNary Dam during the juvenile spring migration to evaluate relative stress associated with passage through the four treatments. There was no interaction between separator and light treatments for plasma cortisol or plasma lactate for either species. Observed differences between mean values obtained from blood plasma parameters were not significant for either species.

CONTENTS

INTRODUCTION

Bypass facilities at hydroelectric dams on the Snake and Columbia Rivers are used to collect juvenile salmonids for subsequent transport and/or release downriver. Because it is believed that juvenile chinook salmon transported with juvenile steelhead (which are generally larger than chinook salmon smolts) experience higher levels of stress than those transported with other chinook salmon (McCabe et al. 1979), separation of smolts by size has been an objective for juvenile bypass systems (JBS) since shortly after their inception. A study in 1981 (Gessel et al. 1985) led to the implementation of wet separators at collection/bypass sites. These wet separators have been used since 1983, but with mixed results.

Most wet separators utilize a three-stage separation process, described in detail by McComas et al. (1998). Following partial dewatering, all fish are deposited in the first section (A section) of the separator. Bars just under the water surface in this section are spaced to allow smaller fish to pass through to a collection area under the bars and egress to a "small fish" holding area. Larger fish continue on to the second section (B section), where the next size class is removed in a similar manner. Fish too large to negotiate separation-bar spaces in the B section pass into a flume at the end of the system for return to the river. For salmonids, under ideal conditions, the A section is intended to segregate smaller smolts such as chinook *Oncorhynchus tshawytscha*, coho *O. kisutch*, and sockeye *O. nerka* salmon from the larger, predominantly hatchery steelhead *O. mykiss* smolts, which are filtered through the B section. Large fish eliminated from the process are generally adult salmonid fallbacks and non-salmonid incidental species.

In practice, there are several problems with existing wet separators. For example, in 1998, the McNary separator exhibited poor performance in the A section, which resulted in separator efficiencies of 41.4, 22.9, and 26.7% for yearling chinook, coho, and sockeye salmon, respectively (Hurson et al 1999). Possible reasons include flow surges which carry smaller fish through the first section with insufficient time to sound through the separator bars, and an inadequate stimulus to generate a sounding response.

Behavior and physiology studies have indicated that fish also hold under the bars for extended periods rather than exit expeditiously from the separator unit (Schreck et al. n.d.). This suggests that many fish exit only after they are fatigued as a result of swimming to resist hydraulic conditions within the unit.

A series of studies was initiated to explore methods for improving wet separator performance using two approaches, and two evaluation separator units were constructed to evaluate juvenile salmonid behavior relative to various design changes (McComas et al. 2000). One approach was to improve the function and design of existing operational separators; the second was to explore alternatives to the existing separator design. A promising alternative concept was the high-velocity flume (HVF) approach.

Under this strategy, smolts enter a section of open flume directly after transport from the bypass channel. While traveling at higher velocities than found in conventional separators (1-2 m/s), smaller smolts could sound between appropriately spaced separation bars within the flume, effecting separation from larger smolts unable to fit between the bars. Both groups would continue to different holding areas without the interruption caused by velocity reduction, and without migration timing delays, stress, and fatigue induced by combating flows within the separator.

Results using an evaluation HVF separator during the 1998 juvenile migration at McNary Dam indicated that separation efficiencies of over 80% could be achieved for the total catch of all species combined. These results were obtained using a transport velocity of 1 m/s, separation bars submerged 50 mm below the water surface, and configured parallel to the water surface and spaced 19 mm apart (McComas et al. 2001).

Based on these conclusions, a full-scale prototype HVF separator was constructed for evaluation at Ice Harbor Dam during the 1999 juvenile migration. However, although these evaluations used the same velocity and bar configuration as in 1998, they resulted in a preliminary estimate of less than 70% separation efficiency. These results were mixed, indicating that fish may resist sounding at the lower velocity of 1 m/s, but that they did separate more efficiently with the separation-bar array submerged at 50 rather than at 100 mm. Separation efficiency was also higher at a transport velocity of 2 rather than 1 m/s.

During the 2001 juvenile migration of spring and summer chinook salmon, the National Marine Fisheries Service continued to evaluate conditions intended to improve salmonid smolt separation efficiency using the prototype HVF wet separator at Ice Harbor Dam. Concurrently, similar evaluations were conducted at McNary Dam to investigate the effects of artificial light and separator improvements comparing a conventional wet separator to a separator modified with an insert.
Specific objectives in 2001 were:

1) Evaluate the effects of artificially produced light, substrate color and intermediate splitter plates on volitional sounding response (resulting in salmonid size class separation), exit efficiency, and fish condition in a high-velocity flume environment

2) Evaluate differences in separation efficiency, exit efficiency, and fish condition between operational and test McNary-style wet separator conditions under two lighting conditions using an operational (existing) wet separator.

3) Evaluate relative differences in the physiological effects of artificial lighting and separator treatments on juvenile salmonids.

OBJECTIVE 1: Evaluate effects of artificial light, substrate color, and splitter plates on volitional sounding response, exit efficiency, and fish condition in a high-velocity flume

Approach

A prototype HVF wet-separator test facility was constructed parallel to and north of the existing Ice Harbor Dam juvenile fish bypass (JFB) facility (Katz 1996; Katz et al. 1999; McComas et al. 2003a). A new drop gate upstream from the existing facility allows the entire water flow and fish collection from the JFB to be diverted through the wet-separator test facility during test periods, or through the current juvenile fish bypass facility during normal operation.

Following diversion to the test facility, flows pass through a primary dewaterer to reduce volume, then through a combined adjustable-slope channel and test-separator section. Two distribution flumes, for separated fish (fish which have sounded between the separation bars) and non-separated fish, provide egress routes at the downstream end of the adjustable-slope channel/test-separator unit. Switch gates in each of the distribution flumes permit fish to be directed into the bypass facility outfall pipe for direct return to the river, or diverted to holding tanks for examination and enumeration.

The adjustable-slope channel and test separator form a single 30.5-m unit mounted to twin I-beams. Slope of the channel is set using a hydraulic lift mechanism under local control, and is variable from 0 to 4° to provide water velocities up to approximately 3 m/s. The high-velocity flume test separator occupies the downstream 12-m section of the variable-slope flume.

The separator is 1 m wide, 1.5 m high, and comprised of four 3-m sections, which can be used to vary total separation-bar length to a maximum of 12 m. Separation-bar array angle is independently variable relative to the floor of the separator from 0° to approximately 2.3° with 12-m separation bars, or about 9.1° over one 3-m section. Water depth over the separation-bar array can be varied using vertical adjusters to raise and lower the array , by adjusting the angle of the variable-slope flume/test separator unit, or by regulating the primary water supply and an independent makeup water supply under the separation bars at the upstream end of the separator unit.

A false floor under the separation bars is also constructed in four 3-m sections, and sections are independently adjustable from 0 to 360 mm depth under the bars. Each false floor panel or the entire false floor can be angled or flat in relation to the floor of the separator flume.

Volitional separation efficiency, separator exit efficiency, and fish condition were evaluated using 12-m separation-bar arrays oriented parallel to the water surface. Separation bars were made of 25.4-mm (1-in) aluminum tubing with a 32 mm (1.25-in) outside diameter. Spacing, or gap, between individual bars was 17 mm, intended to segregate small salmonid outmigrants (fish <180 mm fork length, FL) from larger smolts (≥180 mm FL).

Spacing between separation bars was maintained by three cross supports perpendicular to the separation bars at 1.5-m (5-ft) intervals along each of the four panels forming the 12-m array. Two separation-bar array styles were used in 2001 with the style determined primarily by cross section of the these supports. Comparison of the two styles during similar evaluations (McComas et al. 2003b) revealed no difference in total salmonid separation efficiency, separator exit efficiency or descaling.

Flow through the prototype separator was 2 m/s for all replicates. Adjustments (adjustable-slope flume angles, makeup-water requirements, and dewatering settings) were established and documented prior to the beginning of the juvenile tmigration season (Appendix A).

Substrate, for purposes of this study, was defined as the separation-bar array and false floor of the separator portion of the adjustable-slope flume. The interior of the separator, including the false floor, were painted beige. Coupled with untreated aluminum separation bars, this was used as the light color substrate condition. The contrasting dark substrate condition was made up of another separation-bar array painted flat black and a black rubber tarp covering over the false floor.

Light has been shown to improve separation performance under controlled conditions using an evaluation HVF separator at McNary Dam (McComas et al. 2003b) Normal ambient light striking the Ice Harbor prototype HVF varies with time of day and weather conditions. In addition, light can vary from full sun to shadow across the width inside the unit at a given time. To control this variability, the separator facility was covered with light-proof tarps from the drop gate downstream through the transition flume leading from the adjustable slope portion of the separator. A covered frame over the separator portion enabled access under the tarp covering for monitoring fish movement and changing treatments, and afforded an attachment for suspension of an artificial lighting fixture above the flume.

The artificial light fixture consisted of a 12-m Light Pipe [1] system manufactured by the 3M corporation. This system was composed of a 1,000-W metal halide lamp

---

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

directed through a 254-mm (10-in) horizontal polymer tube with a reflectorized upper surface. Light striking the upper surface was conducted through the translucent polymer, resulting in consistent (shadow free) illumination over the length and width of the separation-bar array surface. The light tube was suspended 1,422 mm (56 in) above the separation-bar array and along the longitudinal centerline of the separator for all replicates. The high light level was defined as the full intensity light emitted from the light tube. The low light condition was effectively dark, with the light source turned off. So far as possible, extraneous light was excluded for all replicates.

At the end of the separation process, separated fish (those having successfully sounded between the separation bars) are below the bars, and the non-separated contingent is above the bars. At the downstream end of the separation bars immediately prior to entering the transition to distribution flumes, flows (and the two fish groups) are divided by a 1-m long plate (splitter plate) lying on a plane with the separation-bar array. During separation evaluations over preceding years, approximately 5% of fish exiting over the splitter plate were observed swimming vigorously back upstream into separator, where an attempt was then made to sound between the bars. In an effort to elicit similar behavior within the separator, intermediate splitter plates were attached at two points along the separation bars. The intermediate plates consisted of two 610-mm (24-in) long untreated aluminum panels, attached 3,352 mm and 7,925 mm from the upstream end of the separation bar array. Evaluation variables (separation efficiency, separator exit efficiency, and descaling) were compared with the splitter plates attached (on) and removed (off).

Together, the three conditions (substrate, lighting, and intermediate splitter plate presence) formed eight treatments (Table 1). To minimize the effect of timing bias, the

Table 1. Conditions for treatments evaluated during separation efficiency studies using a prototype high velocity flume wet separator at Ice Harbor Dam, 2001.

Treatment number	Light level	Substrate color	Intermediate splitter plates
1	high	light	off
2	high	light	on
3	high	dark	off
4	high	dark	on
5	low	light	off
6	low	light	on
7	low	dark	off
8	low	dark	on

eight treatments were performed as a block, and blocks were conducted successively throughout the spring juvenile migration. One entire block of all eight treatments was evaluated before beginning the next block, with all eight treatments randomized within the block.

Test procedure was similar for each replicate. Prior to the replicate, conditions were established in the flume relative to the treatment under evaluation. A replicate was initiated by opening the drop gate, allowing fish and flows exiting the Ice Harbor juvenile fish bypass channel (JFB) to be routed into the test-separator facility. River-run juvenile salmonid migrants were used as test fish. Initial target sample size was 50-150 juvenile chinook salmon per replicate and replicate duration was dependent primarily on numbers of fish entering the flume rather than on time. A minimum sample size of 25 chinook salmon per replicate was required for statistical validity, and the duration of replicates was contingent on obtaining at least this minimum sample.

Fish exiting the separator section were routed into one of two holding tanks, dependent on whether they had sounded between the separation bars. When sufficient numbers of yearling Chinook salmon had accumulated in the holding tanks, the drop gate was closed to shunt fish and flows back through the JFB. Operating on flush water, fish remaining in the separator were removed first from above and then from below the separation bars. These respectively formed the non-separated and separated groups used in separator exit efficiency calculations.

Fish from each group were anesthetized separately using tricane methane sulfonate (MS-222), enumerated by species, and each specimen was categorized by length group as small fish (<180 mm fork length; FL) or large fish (≥180 mm FL). Fish condition was also noted as percent descaling for each species using current Fish Transportation Oversight Team descaling criteria (Ceballos et al. 1992). Following a suitable period in fresh water for recovery from the effects of anesthetic, all fish were released into the existing JFB outfall pipe for return to the Snake River.

Separation efficiency values (ES) were estimated, by species, as the fraction of a given length group negotiating the separation bars divided by the total number of fish in that group having entered the separator during the replicate:

$$ES_A = \frac{A}{T} \times 100\%$$

Where: A = *separated fraction*
T = *total number entering the test separator*

The separated fraction used in the calculation was relative to the size group under consideration. The fraction for small fish groups represented the sum of fish from the separated fish holding tank and those found in the separator below the separation bars at the end of the replicate. For large fish, the separated fraction represented fish from groups which had not sounded between the bars (non-separated holding tanks and from the separator above the separation bars). Therefore, separation efficiency for small fish groups increased with the number sounding between the separation bars, while separation efficiency for large fish increased with the number not sounding between the bars.

Separator exit efficiency (EE) values were estimated as the fish fraction having exited the test separator by the end of the test replicate, divided by the total number of fish entering the separator unit during the replicate:

$$EE = \frac{A}{T} \times 100\%$$

Where: A = *fraction exiting the separator*
T = *total number entering the test separator*

Results and Discussion

A total of 31,043 salmonid smolts were encountered during evaluation of Objective 1 using the Ice Harbor Dam prototype HVF separator facility in 2001. Yearling Chinook salmon and steelhead comprised 76.7% (23,815) and 23.2% (7,201) of the total catch, respectively. Steelhead made up 63% of the large fish catch, while 97% of the small fish catch was yearling Chinook salmon. Salmonid catch data are presented by replicate in Appendix Table B1. Total catch numbers for non-target incidental species are tabulated in Appendix Table B2.

Seventeen replicates were completed for each treatment between 23 April and 8 June. Where sample size for a given species/length group was <25 fish, data were pooled with similar treatments from adjacent blocks to form a valid sample, and data were analyzed using a randomized block analysis of variance (ANOVA). Sample block was included as a covariate when pooling over successive blocks was not excessive.

In general, significant numbers of smolts were available for separation efficiency, separator exit efficiency, and descaling analyses for small, large, and total yearling Chinook salmon groups, large and total steelhead catch, and the combined small, large and total salmonid catch. Total catch data for a given comparison were calculated using the combined mean separation efficiency, descaling, or exit efficiency values for individual species large and small size groups.

Separation Efficiency

Results of statistical analyses among treatments for all separation efficiency comparisons are included in Appendix Table B3. Splitter plate presence or absence was not a significant factor for any separation efficiency comparison.

For small yearling Chinook salmon there was a significant interaction between light and substrate (F = 9.38, df = 1, P = 0.003). Separation efficiency was significantly higher with lights on and dark substrate (78%, SE = 1.7) than for other combinations of light and substrate. For large Chinook salmon, separation efficiency was significantly higher (F = 15.00, df = 1, P = 0.000) with lights off (93%, SE = 0.88) than for lighted treatments (88%, SE = 0.92).

Since 83% of the total Chinook salmon catch were small fish, total Chinook separation efficiency was similar to that for small Chinook salmon with a significant interaction between light and substrate factors (F = 5.11, df = 1, P = 0.026). Separation efficiency was significantly higher using lights on with a dark substrate (80%, SE = 1.6).

For the large steelhead group, mean separation efficiency ranged from 86% to 96% across all treatments. There was a significant interaction among all three conditions (F = 3.98, df = 1, P = 0.050), such that separation efficiency for this group was statistically higher with lights off, light colored substrate, and splitter plates on than for all other treatments. A similar significant interaction occurred for the total steelhead catch (F = 11.04, df = 1 P = 0.001). However, separation efficiency with lights off, light colored substrate and splitter plates on (92%, SE = 1.4) was not significantly different from several other treatments (Table 2).

Separation efficiency for the total small salmonid catch (all species combined) followed that for the small Chinook salmon catch, resulting in a significant interaction for the small fish catch between light and substrate (F = 7.90, df = 1, P = 0.006). Using lights on and dark substrate produced significantly higher separation efficiency (77%, SE = 1.7) than other light and substrate combinations. All three conditions interacted significantly (F = 4.76, df = 1, P = 0.031) for the total large fish catch, so that using lights off with light colored substrate and splitter plates on produced significantly higher separation efficiency (94%, SE = 1.25) than all treatments using lights on, but statistically similar to other treatments with lights off (Table 3).

Table 2. Mean steelhead separation efficiency values for treatments using combinations of artificially produced light, substrate color, and intermediate splitter plates in a prototype high velocity flume at Ice Harbor Dam, 2001. Values with the same superscript denote statistically similar relationship.

Treatment conditions: Artificial light	Treatment conditions: Substrate color	Treatment conditions: Splitter plates	Mean separation efficiency	Standard Error
off	light	off	87.8 [b c]	1.37
off	light	on	91.6 [a]	1.43
off	dark	off	90.4 [a]	1.37
off	dark	on	87.2 [c d]	1.50
on	light	off	89.1 [a b c]	1.37
on	light	on	87.1 [c d]	1.37
on	dark	off	84.6 [d]	1.43
on	dark	on	89.3 [a b c]	1.43

Table 3. Mean total large salmonid catch separation efficiency values for treatments using combinations of artificially produced light, substrate color, and intermediate splitter plates in a prototype high velocity flume at Ice Harbor Dam, 2001. Values with the same superscript denote statistically similar relationship.

Treatment conditions: Artificial light	Treatment conditions: Substrate color	Treatment conditions: Splitter plates	Mean separation efficiency	Standard Error
off	light	off	91.4 [a]	1.25
off	light	on	93.7 [a]	1.25
off	dark	off	93.3 [a]	1.25
off	dark	on	91.6 [a b]	1.25
on	light	off	90.3 [a b c]	1.25
on	light	on	88.5 [c d]	1.25
on	dark	off	86.8 [d]	1.25
on	dark	on	88.9 [c d]	1.25

Separation efficiency for the total salmonid catch probably offers the most practicable indication of overall performance for an operational separator. In general, separation was high for large fish groups and lower for small size cohorts, indicating that fish tend to pass over the separation bars with less than optimal stimulus to produce a strong sounding response. For the total catch, separation efficiency displayed a significant interaction ($F = 5.90$, $df = 1$, $P = 0.017$) between light and substrate conditions. Smolts separated significantly more efficiently when lights were on and a dark substrate was used (82%, SE = 1.3) than for all other treatments. Treatments where the light was on with a light colored substrate had similar separation efficiency (76%, SE = 1.3) to using lights off and a dark substrate (77%, SE = 1.3), and both were significantly higher than using no lights with a light colored substrate (66%, SE = 1.3).

Sufficient data were available to analyze sample block as a covariate to separation efficiency for all comparisons, and the correlation was significant for all length groups (Table 4).

Table 4. Analysis of variance outcomes of correlation between mean salmonid separation efficiency values and sample block, using sample block as a covariate. Asterisks denote significant relationships.

Group	F	df	*P*	
Yearling Chinook salmon <180 mm	4.32	15	0.000	*
Yearling Chinook salmon≥180 mm	2.91	14	0.003	*
Yearling Chinook salmon, total catch	2.14	16	0.011	*
Steelhead ≥180 mm	5.02	14	0.000	*
Steelhead, total catch	5.97	14	0.000	*
Total salmonid catch <180 mm	5.48	16	0.000	*
Total salmonid catch≥180 mm	4.43	16	0.000	*
Total salmonid catch	3.75	16	0.000	*

Separator Exit Efficiency

Mean separator exit efficiency was virtually 100% for all replicates, regardless of species or size group under consideration. Data for this variable did not warrant formal analysis.

Fish Condition

Results of statistical analyses among treatments for all descaling comparisons are presented in Appendix Table B4. Small Chinook salmon descaling ranged from 0 to nearly 24% over all treatments for replicates with more than 25 animals. Mean descaling using dark substrate (8.1%, SE = 0.44) was 1.4% higher than using light colored substrate (6.7%, SE = 0.44). The difference was significant ($F = 5.02$, $df = 1$, $P = 0.027$), and represents the only real descaling difference for Chinook salmon.

There was a significant interaction ($F = 3.96$, $df = 1$, $P = 0.050$) between substrate and splitter plates for total steelhead catch descaling, resulting in an 0.8% higher value for treatments using dark substrate with no splitter plate (1.1%, SE = 0.19) than for other substrate/splitter plate combinations.

Descaling involving total salmonid groups was influenced by the predominance of small yearling Chinook catch. For example, mean descaling for the total small salmonid catch was a significant ($F = 4.73$, $df = 1$, $P = 0.032$) 1.3% higher using dark colored substrate (7.5%, SE = 0.41) than with the light colored substrate (6.3%, SE = 0.41). A similar significant ($F = 5.33$, $df = 1$, $P = 0.023$) relationship resulted for the total salmonid catch. For this group, using the dark colored substrate resulted in mean descaling of 5.3% (SE = 0.32), compared to 4.2% (SE = 0.32) using light colored substrate.

It should be noted that significant differences in descaling discussed above are minimal, ranging from 0.8% to 1.4%, reflecting a detectable difference (statistical resolution) range of 0.3 to 0.6%, respectively. From a biological standpoint, descaling differences at this level are of questionable consequence.

Over the course of the spring migration, personnel from the Washington Department of Fisheries and Wildlife (WDF&W) monitored migrant smolts to assess condition, including descaling, for fish passing through the Ice Harbor bypass facility. Total daily descaling values for each species obtained using the test separator facility were compared to similar values from the WDF&W sample on days for which both facilities were operated to gauge whether operation of the test separator facility was causing excessive injury to smolts. Descaling using the test facility was generally lower than the smolt monitoring values for steelhead throughout the sample period. Yearling Chinook salmon descaling using the HVF separator facility displayed an increasing trend as the juvenile migration progressed (Figure 1).

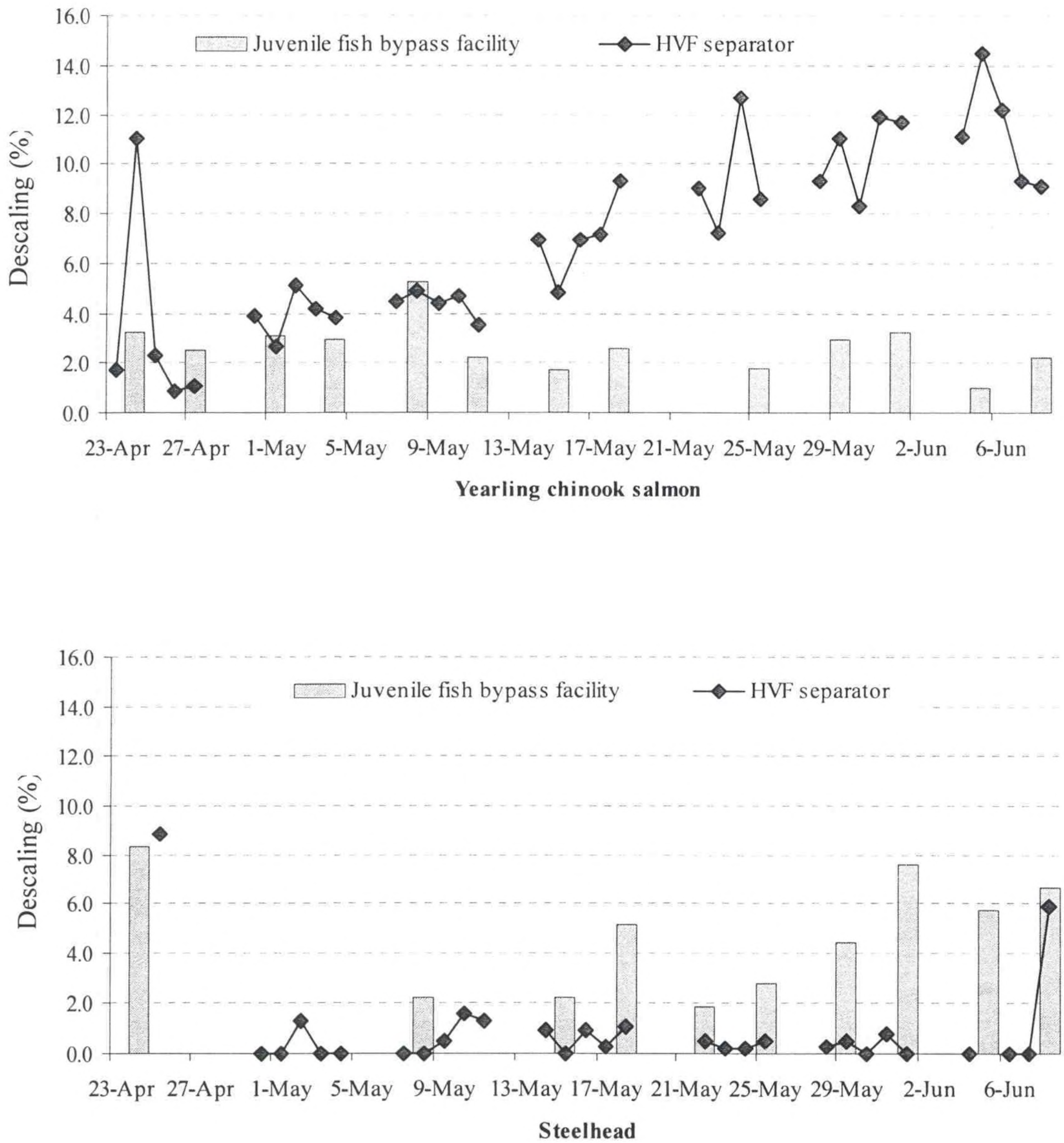


Figure 1. Yearling Chinook salmon and steelhead descaling values obtained from the Ice Harbor Dam juvenile fish bypass and high velocity flume (HVF) separator facilities by sample date, 2001. Bypass facility values are means for wild and hatchery fish from smolt monitoring samples obtained by Washington State Department of Fisheries and Wildlife. HVF separator values are means of all replicates completed by date during separation efficiency evaluations using the prototype HVF wet separator.

These relationships were more defined in the ANOVA analysis using sample block as a covariate. HVF descaling trends were associated with size cohorts, so that small cohorts demonstrated a strong correlation of increased descaling as block numbers (time) increased, while large fish descaling values demonstrated no identifiable association with sample block (Table 5).

Table 5. Analysis of variance outcomes of correlation between mean salmonid descaling values and sample block, using sample block as a covariate. Asterisks denote significant relationships.

Group	F	df	*P*	
Yearling Chinook salmon <180 mm	4.17	15	0.000	*
Yearling Chinook salmon≥180 mm	1.09	14	0.391	
Yearling Chinook salmon, total catch	4.99	16	0.000	*
Steelhead ≥180 mm	0.68	14	0.782	
Steelhead, total catch	0.44	14	0.953	
Total salmonid catch <180 mm	3.78	16	0.000	*
Total salmonid catch≥180 mm	1.40	16	0.994	
Total salmonid catch	2.91	16	0.001	*

OBJECTIVE 2: Evaluate the effect of lighting on separation efficiency, exit efficiency, and fish condition

Approach

Over the 1998 through 2000 juvenile salmonid migration seasons, evaluations of conditions to enhance existing (operational) separators at COE hydroelectric projects were conducted using an evaluation unit with the same area dimensions as the upstream (A) section of an operational separator at McNary Dam. This was done to aid in transitioning beneficial improvements from evaluation separators to operational separators without serious modification to the operational unit structure. Revisions applied in the evaluation separator indicated substantial and consistent improvements in separation and exit efficiency using the evaluation unit. During the 2001 spring migration, we conducted direct comparison evaluations to determine whether the evaluation unit modifications resulted in increased size separation of salmonid smolts compared to a standard operational unit condition.

Two separator conditions (operational and test) were compared. The operational (McNary) condition consisted of the McNary Dam juvenile fish bypass separator in normal operation (Figure 2). This condition had separation bars spaced 19 mm apart,

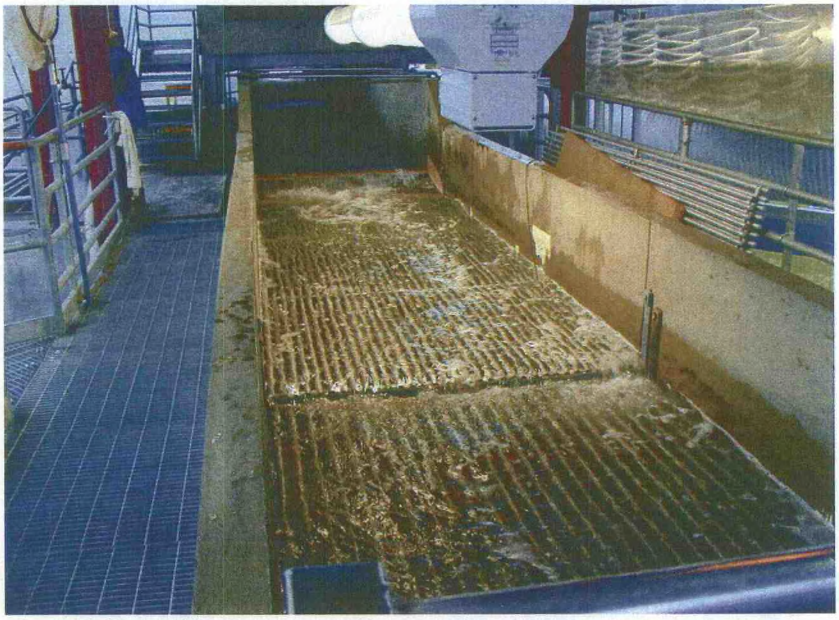


Figure 2. McNary separator operating under normal hydraulic conditions with the 'light on' treatment during separation efficiency evaluations at McNary Dam, 2001.

with a volume under the separation bars (bounded by the separation-bar array on the upper surface and by perforated plate false bottom beneath) of approximately 1.54 cu m. A 610-mm square submerged orifice under the separation bars provided an exit route for separated fish. The submerged exit was contained in a downwell sump at the downstream end of the A section, and the sump ultimately exited to transport flumes through the side of the separator approximately 1.5 m below the water surface (McComas et al. 1998).

The comparison (test) condition had 25-mm aluminum separation bars spaced 17 mm apart, with volume under the bars reduced to approximately 0.81 cu m by raising the perforated plate floor of the test unit. The test condition submerged orifice used the operational separator downwell structure as a transport corridor, but the orifice was built into the downstream end of the test separator, in line with and perpendicular to transport flow entering the separator. The submerged orifice in the test unit was 76 mm (3 in) high and 610 mm (24 in) wide.

Due to the necessity for using the existing separator exit-orifice structure to evacuate separated fish, the downstream 610 mm (2 ft) of the insert separator under the separation bars was occluded by a vertical plate containing the test condition submerged orifice. Separation-bar length was thus reduced from 3.96 m (13 ft) in the McNary operational condition to 3.35 m (11 ft) in the test separator, resulting in a 15% loss of separation-bar area in the test condition. A horizontal aluminum plate covering the downstream 610 mm (24 in) of the McNary separator A section (including the downwell area) carried non-separated fish and flows across the intervening space and into the downstream ('B') section of the separator.

To expedite random exchange of separator conditions, test separator modifications were contained in an insert. The insert was fundamentally a box constructed of 48-mm (3/16-in) aluminum plate and sized to fit tightly within the A section of the McNary separator when the operational condition separation bars were removed (Figure 3).

Functional modifications for the test condition involved reduced makeup-water volumes, transport inflow, and depth over the separation bars compared to the McNary condition. Under operational separator conditions, water depth over the separation bars at the downstream end of the separator (to provide transport of non-separated fish into the B section) is generally a minimum of 50 mm (2 in) deep. Under test separator conditions depth over the downstream end of the bars was maintained as closely as possible at 30 mm (1.2 in). Also, transport inflow during test condition replicates was the minimum required to safely deliver fish to the separator, so that surface flow through the A section was reduced compared to the McNary condition.

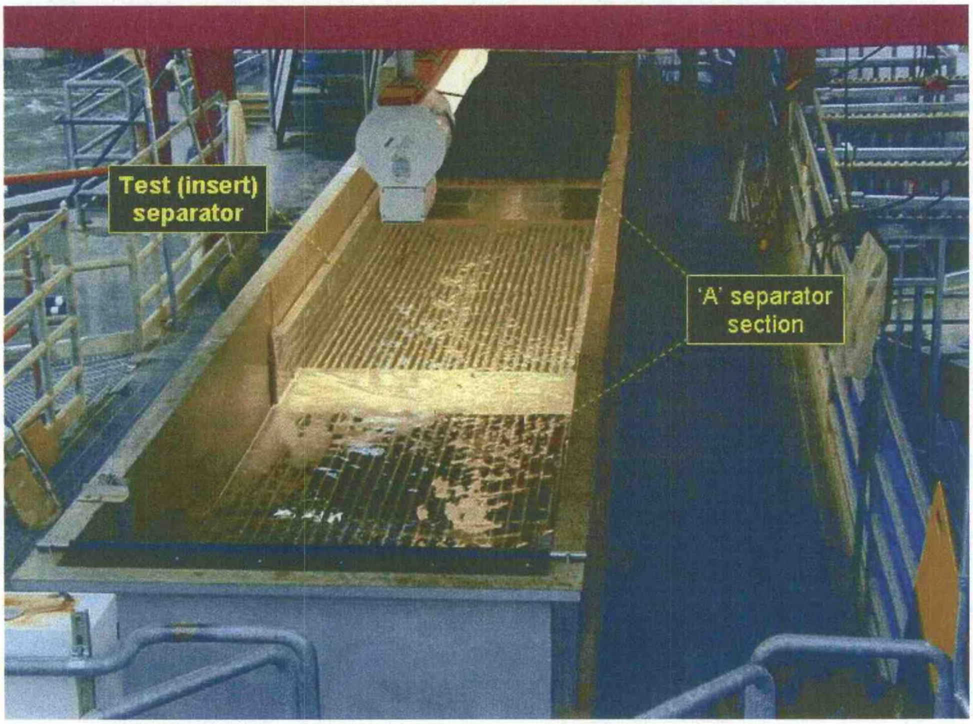


Figure 3. McNary operational separator with the test (insert) separator installed in the upstream (A) section during separation efficiency evaluations at McNary Dam, 2001. The aluminum plate at the downstream end of the test separator covers the A section downwell sump and houses the vertical exit orifice for separated fish for the test condition.

To evaluate the effect of artificial light on separation, two lighting conditions (low and high) were used in combination with each of the separator conditions. A 4-m long Light Pipe similar to the unit used for Objective 1 was suspended 1220 mm (48 in) above the longitudinal centerline of the separator for all replicates. The lamp was illuminated only during high light replicates. The low light condition used ambient natural light occurring over the duration of the replicate.

Previous estimates of separation efficiency, exit efficiency, and descaling using an evaluation separator were conducted with finely controlled transport flows bringing fish into the evaluation separator. By comparison, direct observation of the McNary separator has shown that transport flow to the unit can fluctuate markedly over the span of a few minutes in response to rapid changes in bypass gallery influx. Dewatering structures immediately upstream from the McNary separator are not designed to accommodate these rapid variations.

To minimize potential for bias caused by flow variability to the separator, and since previous testing has shown that there is no difference in separation efficiency or descaling as a result of replicate duration (McComas et al. 2003a), we used a 2-d replicate duration in 2001.

Combinations of separator and light conditions resulted in a block of four treatments as follows:

Treatment No.	Separator condition	Light condition
1	Operational (McNary)	high
2	Operational (McNary) McNary	low
3	Test (insert)	high
4	Test (insert)	low

Treatments were evaluated using a block sampling design, with the order of the treatments randomized within each block.

A replicate was initiated by diverting fish and flows from the JBS to the river using the primary bypass switch gate immediately upstream from the McNary separator. The separator was subsequently drained, and fish remaining in the unit were allowed to exit or removed. Separator and lighting conditions were established relative to the treatment under consideration, and the switch gate was closed to divert fish back into the separator.

To minimize handling, the daily smolt monitoring sample collected by WDF&W personnel was used to estimate separation efficiency and fish condition (descaling). Handling procedure was similar to handling for Objective 1, and separation efficiency was calculated by species and length group as described for Objective 1 using the total smolt monitoring catch. However, descaling was not differentiated by length group during smolt monitoring. In addition, a maximum of 100 smolts of each species were examined for descaling from each of the separated and non-separated groups, as an estimate of total descaling for that species and group. For this study, descaling was calculated using these smolt monitoring descaling data for separated, non-separated and total catch groups by species.

The procedure used for Objective 1 to assess separator exit efficiency for was not possible for this study, since the calculation would have required enumeration of the entire collection passing McNary Dam, by species and length, over the study period. In addition, the 2-d replicate duration would have yielded little useful information without knowledge of individual fish tracking to determine entrance and exit time for the separator. However, two methods were implemented to evaluate whether fish were exiting the two units similarly. First, video cameras were used to determine whether fish in the A section appeared to be stressed using the test insert submerged orifice compared to the operational condition. This method at least offered a qualitative comparison of fish reaction to conditions near the submerged exit orifice.

A second opportunity for gauging residence time in the separator presented itself during the migration season, and involved use of radio-tagged yearling Chinook salmon released at Ice Harbor Dam to assess survival through the McNary impoundment (Axel et al. 2003). These fish were injected with passive integrated transponder (PIT) tags and had individually coded radio tags gastricly implanted. As these radio-tagged fish traveled through the McNary separator, the first recorded radio-tag signal on either of two antennas placed in the A and B sections of the McNary separator was used to evince entrance time into the separator unit. Exit time was defined as the record of PIT-tag detection on the A or B separator exit smolt monitoring gate PIT-tag detection antenna located immediately downstream from the separator. The positive difference between entrance and exit times was used as an index of residence time in the separator.

Results and Discussion

A total of 96,747 salmonid smolts were included in evaluation of treatments for Objective 2 at McNary Dam in 2001. Subyearling Chinook salmon comprised 49% (47,686) of the total catch. Yearling Chinook salmon and steelhead comprised 65 (31,838) and 27% (13,234) of the yearling smolt catch, respectively. Steelhead made up 75% (12,080) of the large yearling fish, while 85% (27,812) of small yearling fish were Chinook salmon. Salmonid catch data are presented by replicate in Appendix Table B5.

Nine 2-d replicates were completed for each separator/light treatment between 14 April and 22 June. As was done with samples from Objective 1, sample sizes with fewer than 25 fish data were pooled with similar treatments from adjacent blocks. Data were analyzed using a randomized block analysis of variance (ANOVA) procedure. Where pooling over successive blocks was not limiting, block was included as a covariate.

In general, significant numbers of smolts were available for separation efficiency, and descaling analyses for small fish from all species. Large fish groups included in the analysis were yearling Chinook salmon, steelhead, and the total salmonid catch. Total catch separation efficiency and descaling values for a given comparison were calculated using the combined mean values for an individual species large and small size groups.

Separation efficiency

There were no significant interactions between separator and light factors for any separation efficiency comparison at McNary Dam in 2001. Complete results of statistical analyses among treatments for all separation efficiency comparisons are included in Appendix Table B6.

Separation efficiency was not significantly different between separator conditions or between light conditions for the small or total yearling Chinook salmon groups (Table 6). For large Chinook salmon, the insert separator had nearly 25% higher mean separation efficiency than using the McNary operational separator. The difference was significant (F = 64.32, df = 1, P = 0.000).

As with small Chinook salmon, small steelhead separation efficiency values were not significantly different between separator and light factors. However, since large fish predominated in the steelhead catch, mean separation efficiency was significantly higher for both the large steelhead group (F = 53.31, df = 1, P = 0.000) and the total steelhead catch (F = 53.90, df = 1, P = 0.000), using the insert separator (Table 6).

Only small coho and sockeye salmon were encountered in sufficient numbers for analysis and both groups had significantly higher separation efficiency using the test separator than using the conventional McNary separator (F = 10.22, df = 1, P = 0.010 and F = 20.46, df = 1, P = 0.001, respectively). Neither group displayed a significant influence of light on separation efficiency.

Table 6. Mean separation efficiency values by comparison group (separator condition, light condition, and treatment) for juvenile salmonid length groups encountered during separation efficiency studies using conventional (MCN) and test (insert) separators at McNary Dam, 2001. Values in shaded cells were significantly different ($\alpha = 0.05$).

	Separator condition		Light condition		Treatment (separator condition, light condition)			
Length group	Insert	McNary	off	on	Insert off	Insert on	McN off	McN on
Yearling Chinook salmon								
<180 mm	60 (2.2)	58 (2.2)	56 (2.2)	61 (2.2)	56 (3.1)	64 (3.1)	56 (3.1)	59 (3.1)
≥180 mm	94 (2.1)	69 (2.2)	82 (2.0)	81 (2.2)	93 (2.8)	94 (2.8)	71 (2.8)	67 (2.8)
Total catch	64 (2.0)	59 (2.0)	60 (2.0)	64 (2.0)	61 (2.9)	68 (2.9)	59 (2.9)	60 (2.9)
Steelhead								
<180 mm	65 (4..0)	63 (3.5)	62 (3.5)	67 (4.0)	63 (4.9)	66 (6.4)	59 (4.9)	67 (4.9)
≥180 mm	93 (1.4)	78 (1.4)	87 (1.4)	84 (1.4)	93 (2.0)	93 (2.0)	81 (2.0)	76 (2.0)
Total catch	91 (1.3)	77 (1.3)	85 (1.3	83 (1.3)	90 (1.8)	91 (1.8)	80 (1.8)	75 (1.8)
Coho salmon								
<180 mm	32 (1.7)	24 (1.7)	28 (1.7)	28 (1.7)	32 (2.6)	32 (2.6)	24 (2.6)	24 (2.6)
Sockeye salmon								
<180 mm	60 (3.5)	35 (3.7)	44 (3.7)	53 (3.5)	50 (5.3)	71 (5.3)	37 (5.3)	36 (5.3)
Total yearling catch								
<180 mm	66 (1.9)	62 (1.9)	61 (1.9)	67 (1.9)	62 (2.7)	69 (2.7)	60 (2.9)	64 (2.9)
≥180 mm	93 (1.4)	75 (1.4)	85 (1.4)	83 (1.4)	93 (2.0)	93 (2.0)	77 (2.0)	72 (2.0)
Total catch	73 (1.2)	69 (1.2)	69 (1.2)	73 (1.2)	70 (1.7)	77 (1.7)	69 (1.7)	70 (1.7)
Subyearling Chinook salmon								
<180mm	77 (3.6)	74 (3.6)	73 (3.6)	79 (3.6)	75 (3.5)	80 (3.5)	71 (3.5)	77 (3.5)

Since none of the small fish groups showed a significant response to light conditions by individual species, it was remarkable that separation efficiency for the total small salmonid catch was significantly higher ($F = 4.25$, $df = 1$, $P = 0.050$) using the lighted as opposed to the unlighted condition (Table 6). A similar trend was noted for the total large fish catch, which had significantly higher separation efficiency ($F = 85.61$, $df = 1$, $P = 0.000$) using the test insert than for the conventional separator. Both groups appeared to influence the total catch, so that separation efficiency for all salmonid smolts combined was higher using the lighted condition than for the unlighted condition ($F = 4.93$, $df = 1$, $P = 0.036$), and higher using the test insert than using the McNary conventional separator ($F = 5.79$, $df = 1$, $P = 0.024$).

Sufficient numbers of subyearling Chinook salmon were captured over 13 replicates to effect separation efficiency evaluations. Mean separation efficiency was somewhat higher using the insert separator (77%, SE = 3.6) than for the McNary condition (74%, SE = 3.6) and higher with lights on (78%, SE = 3.6) than with lights off (73%, SE = 3.6), but these differences were not significant.

Descaling

A total of 6670 yearling smolts from separated fish holding tanks, and 10335 smolts from non-separated tanks, were assessed for condition during separator evaluation studies at McNary Dam in 2001. An additional 2753 subyearling Chinook from the separated tank and 1193 from the non-separated holding tank were assessed over the study period. Mean descaling values for all yearling smolt groups ranged 0.4-23.7%. However, descaling was less than 5% for all species except sockeye salmon (Table 7). Subyearling Chinook salmon descaling was typically low, ranging 0.2-2.8%. Results of statistical analyses among treatments for descaling comparisons are included in Appendix Table B7.

Statistically significant differences were found only between separator types for separated yearling Chinook salmon ($F = 5.83$, $df = 1$, $P = 0.024$) and separated total salmonid catch groups ($F = 8.76$, $df = 1$, $P = 0.007$). Yearling Chinook salmon mean descaling values using the insert and McNary separators were 3.0 and 2.1%, respectively. For the total separated salmonid catch, mean descaling for these conditions were 3.3 and 2.2%, respectively. While the differences were statistically valid, the real biological impact of a 1% difference in descaling is questionable.

Table 7. Mean descaling values by comparison group (separator condition, light condition, and treatment) for juvenile salmonid length groups encountered during separation efficiency studies using conventional (McNary, McN) and test (insert) separators at McNary Dam, 2001. Values with the same letter superscript were significantly different ($\alpha = 0.05$).

	Separator condition		Light condition		Treatment (separator condition, light condition)			
Species length	Separator		Light		Insert		McN	
group	Insert	McNary	off	on	off	on	off	on
				Yearling Chinook salmon				
Separated	3.0 (0.28)	2.1 (0.28)	2.3 (0.28)	2.8 (0.28)	3.1 (0.39)	2.9 (0.39)	1.5 (0.39)	2.6 (0.39)
Non-separated	2.1 (0.36)	1.9 (0.36)	2.0 (0.36)	2.0 (0.36)	1.6 (0.52)	2.5 (0.52)	2.4 (0.52)	1.4 (0.52)
Total catch	2.5 (0.23)	2.0 (0.23)	2.2 (0.23)	2.4 (0.23)	2.4 (0.33)	2.8 (0.33)	1.9 (0.33)	2.0 (0.33)
				Steelhead				
Separated	0.9 (0.52)	1.9 (0.43)	1.6 (0.48)	1.3 (0.47)	1.5 (0.74)	0.4 (74)	1.6 (0.62)	2.2 (0.58)
Non-separated	0.8 (0.32)	1.4 (0.26)	1.3 (0.29)	0.9 (0.29)	1.1 (0.45)	0.4 (0.45)	1.4 (0.38)	1.4 (0.36)
Total catch	0.8 (0.28)	1.5 (0.23)	1.3 (0.26)	1.0 (0.25)	1.2 (0.39)	0.4 (0.39)	1.4 (0.33)	1.6 (0.31)
				Coho salmon				
Separated	3.5 (1.33)	1.6 (1.33)	2.3 (1.33)	2.8 (1.33)	2.8 (2.00)	4.3 (2.00)	1.8 (2.00)	1.3 (2.00)
Non-separated	1.3 (0.53)	2.0 (0.53)	1.8 (0.53)	1.5 (0.53)	1.0 (0.80)	1.6 (0.80)	2.6 (0.80)	1.4 (0.80)
Total catch	2.1 (0.53)	1.9 (0.53)	2.0 (0.53)	2.1 (0.53)	1.6 (0.80)	2.7 (0.80)	2.4 (0.80)	1.5 (0.80)
				Sockeye salmon				
Separated	19.6 (3.04)	19.5 (3.22)	18.0 (3.22)	21.0 (3.04)	19.7 (4.56)	19.4 (4.56)	16.3 (4.56)	22.6 (4.56)
Non-separated	18.3 (2.79)	21.0 (2.96)	17.6 (2.96)	21.6 (2.79)	17.0 (4.19)	19.5 (4.19)	18.3 (4.19)	23.7 (4.19)
Total catch	18.6 (2.12)	19.7 (2.24)	17.0 (2.24)	21.3 (2.12)	18.2 (3.17)	19.1 (3.17)	15.9 (3.17)	23.5
				Total yearling salmonids				
Separated	3.3 (0.27)	2.2 (0.27)	2.7 (0.27)	2.8 (0.27)	3.5 (0.39)	3.2 (0.39)	1.8 (0.39)	2.5 (0.39)
Non-separated	2.5 (0.37)	2.9 (0.37)	2.5 (0.37)	2.9 (0.37)	2.5 (0.53)	2.5 (0.53)	2.6 (0.53)	3.2 (0.53)
Total catch	3.0 (0.04)	2.6 (0.04)	2.6 (0.04)	2.9 (0.04)	3.0 (0.27)	2.9 (0.27)	2.2 (0.27)	2.9 (0.27)
				Subyearling Chinook salmon				
Separated	0.7 (0.46)	1.4 (0.46)	1.3 (0.46)	0.8 (0.46)	0.8 (0.67)	0.7 (0.67)	1.9 (0.67)	0.9 (0.67)
Non-separated	2.1 (0.59)	0.7 (0.59)	1.3 (0.59)	1.5 (0.59)	1.5 (0.81)	2.8 (0.81)	1.2 (0.81)	0.2 (0.81)
Total catch	1.2 (0.27)	1.3 (0.27)	1.4 (0.27)	1.0 (0.27)	1.0 (0.37)	1.3 (0.37)	1.8 (0.37)	0.7 (0.37)

Separator exit efficiency

Video images of fish movements near the two submerged separator orifices indicated differential reaction to conditions near the openings. Fish approaching the McNary orifice (downwell) condition always appeared to resist passing through the opening by continuous, rapid swimming. The active swimming resistance continued as the fish entered the opening, resulting in a vertical head-up orientation. This behavior continued until the individual appeared to fatigue, effecting passage down through the opening with flow from the separator.

By contrast, smolts exiting from the insert submerged orifice appeared to offer little resistance to passage, often actively swimming head first through the opening. While these observations did not quantify exit efficiency, they do indicate that passage may be less behaviorally traumatic using the insert orifice compared to using the operational downwell condition. Objective 3 (below) was included to index physiological stress for the two treatments.

Radio tagged fish suggested a more rigorous comparison of passage timing through the separator treatments. A total of 953 radio-tagged yearling Chinook salmon entered the separator from 11 May through 2 June. Of these, 920 fish yielded positive timing information. Median residence timing data from individual radio-tagged fish were grouped over 24-h periods and analyzed using an ANOVA procedure. Residence time information is summarized in Table 8.

Residence time for the 920 fish sampled ranged from 11 seconds to 22.47 h, about a median of 5.83 minutes. There was no significant interaction between separator and light conditions on residence time for fish exiting either the A section ($n = 538$) or the B section ($n = 382$), and light condition did not significantly effect residence in either section. Separator condition being evaluated in the A section also had no effect on residence in the B section. However residence time in the A section using the insert separator (3.7 min, $SE = 0.6$) was significantly less ($F = 18.94$, $df = 1$, $P = 0.000$) than using the McNary operational unit (7.3 min., $SE = 0.6$), indicating a propensity for radio-tagged yearling Chinook salmon to pass more expeditiously through the insert separator condition than through the conventional separator.

Table 8. Mean median residence time by treatment for radio-tagged yearling Chinook salmon entering the upstream (A) and downstream (B) sections of the McNary Dam juvenile fish separator during separation efficiency studies using conventional (McNary, McN) and test (insert) separators at McNary Dam, 2001. Values with the same letter superscript are significantly different ($\alpha = 0.05$).

Separator section	Separator condition		Light condition		Treatment (separator condition, light condition)			
					Insert		McN	
	Insert	McNary	off	on	off	on	off	on
A section	**3.7 (0.6)**	**7.3 (0.6)**	5.4 (0.6)	5.6 (0.5)	4.4 (0.8)	3.0 (0.8)	6.4 (0.9)	8.2 (0.8)
B section	6.7 (1.2)	7.2 (1.3)	6.1 (1.4)	7.8 (1.2)	6.9 (1.8)	6.5 (1.7)	5.3 (2.1)	9.1 (1.7)

OBJECTIVE 3: Evaluate relative differences in the physiological effects of artificial lighting and separator treatments on juvenile salmonids

Approach

Blood samples were collected from yearling Chinook salmon and steelhead to establish an index of physiological effects of passage through each of the four treatments evaluated at McNary Dam in 2001. Collections were done on the second day of 2-d separator replicates to avoid possible stresses associated with changing between conditions, and only non-PIT-tagged fish with adipose fin clips (assumed hatchery stock) were used for collections.

All fish were collected at the juvenile fish facility raceways downstream from the separator to preclude inducing handling stress. To effect collection, a holding pen 1.22 m (4 ft) square was floated in the raceway. Fish were diverted into the holding pen in small groups of up to 20 individuals using raceway diversion gates. The diversion gates were then closed, and the group of fish was held in the pen for 15 minutes to allow the kinetics of stress indicator chemistry to accumulate in the blood plasma. At the end of the 15-minute period, target species fish were removed from the pen using a dip net, anesthetized in 100 mg/l tricaine methane sulphonate (MS-222), and checked for presence of PIT tags and adipose clips. During the inspection process, up to 8 adipose clipped fish meeting the selection criteria were sacrificed by placing them in a 200 mg/L solution of MS-222. Fish not selected were placed in a container of river water to recover from the effects of anesthetic, and released upon recovery.

Blood samples were collected from sacrificed fish immediately after gilling activity had ceased by severing the caudal vasculature, after the method described in Barton et al. (1986). Samples were collected in 0.25 mL ammonium-heparinized capillary tubes, and placed on ice in centrifuge tubes numbered by sample. Recovered fish and any fish still remaining in the net pen were released, and the sample procedure was repeated until up to 15 samples had been collected for each species. Steelhead were sampled from the B section submerged exit flume, and yearling Chinook salmon were sampled from the A section flume for each replicate, for a total of 30 samples per replicate. At the end of the replicate, samples were spun in a centrifuge, plasma was effused and the plasma samples were immediately frozen. Plasma cortisol and lactate were assayed at Oregon State University using radioimmunioassay and fluorimetric enzyme reaction procedures, respectively (Barton et al. 1986; Barton and Schreck 1987).

Results and Discussion

A total of 240 blood samples were collected for each species between 27 April and 8 June. Samples were collected over four replicates for each of the four light and separator treatments. Median plasma cortisol and lactate values for each replicate are presented by species and treatment in Table 9.

There was no interaction between separator and light treatments for plasma cortisol or plasma lactate for either species. Yearling Chinook salmon plasma cortisol levels ranged 136.5 to 204.4 ng/mL, and lactate levels ranged 69.5-90.7 mg/dL. For steelhead, values ranged 129.4-212.45 for cortisol and 59.4-96.9 for lactate. None of the observed differences between mean values obtained for plasma lactate and cortisol (Table 10) were significant for either species. The lack of significance in these comparisons indicates that physiological stress is similar between treatments, and implementation of treatment conditions is not limited by stress considerations.

Table 9. Median fork length, plasma lactate, and plasma cortisol levels for yearling Chinook salmon and steelhead sampled using a test separator (Insert) and the conventional McNary separator (MCN) during evaluation of separation efficiency treatments at McNary Dam, 2001.

	Treatment		Yearling Chinook salmon			Steelhead		
Sample date	Separator condition	Light condition	Fork length (mm)	Plasma lactate (mg/dL)	Plasma cortisol (ng/mL)	Fork length (mm)	Plasma lactate (mg/dL)	Plasma cortisol (ng/mL)
27 Apr	Insert	on	153	75.029	141.55	229	70.300	138.69
5 May	Insert	on	155	82.738	145.03	230	89.914	147.14
13 May	Insert	on	165	80.615	173.90	238	68.959	194.12
31 May	Insert	on	163	65.688	183.13	234	76.723	214.37
29 Apr	Insert	off	155	80.465	151.15	247	55.445	143.19
1 May	Insert	off	160	80.482	144.99	248	77.580	171.51
19 May	Insert	off	161	76.542	167.97	248	67.561	217.16
29 May	Insert	off	157	64.448	207.53	236	69.100	164.31
3 May	McN	on	155	72.230	139.19	250	71.340	172.09
15 May	McN	on	169	86.467	174.01	248	64.148	175.69
25 May	McN	on	166	84.141	168.28	221	86.603	199.43
6 Jun	McN	on	154	82.191	200.08	228	58.159	179.82
7 May	McN	off	154	89.914	160.86	248	79.961	169.69
9 May	McN	off	162	85.705	182.17	233	71.449	184.81
27 May	McN	off	160	68.500	188.60	231	70.585	169.64
8 Jun	McN	off	157	76.672	166.81	229	65.094	168.04

Table 10. Mean ($\bar{x}$) plasma lactate and plasma cortisol values by condition for yearling Chinook salmon and steelhead sampled using a test separator (Insert) and the conventional McNary separator (MCN) during evaluation of separation efficiency treatments at McNary Dam, 2001. Observed differences were not significant for any comparison ($\alpha = 0.05$).

		Plasma lactate (mg/dL)		Plasma cortisol (ng/mL)	
Source		$\bar{x}$	SE	$\bar{x}$	SE
		Yearling Chinook salmon			
Separator type	Insert	75.75	2.77	164.4	7.93
	McNary	80.73	2.77	172.5	7.93
Light condition	off	77.84	2.77	171.3	7.93
	on	78.64	2.77	165.6	7.93
		Steelhead			
Separator type	Insert	71.95	3.37	173.8	8.87
	McNary	70.92	3.37	177.4	8.87
Light condition	off	69.60	3.37	173.5	8.87
	on	73.27	3.37	177.7	8.87

SUMMARY

1) Using the prototype HVF separator at Ice Harbor Dam, total salmonid catch separation efficiency was significantly higher when lights were on and a dark substrate was used (82%, SE = 1.3) than for all other treatments. Treatments where the light was on with a light colored substrate had similar separation efficiency (76%, SE = 1.3) to using lights off and a dark substrate (77%, SE = 1.3), and both were significantly higher than using no lights with a light colored substrate (66%, SE = 1.3).

2) Separator exit efficiency using the Ice Harbor prototype HVF separator was virtually 100% regardless of light, substrate, and splitter plate treatment conditions evaluated during 2001.

3) Descaling using the prototype HVF separator was significantly higher for the total catch using dark colored substrate (5.3%, SE = 0.32), compared to treatments using light colored substrate(4.2%, SE = 0.32). However, the real biological implication of a 1.1% difference in mean descaling is debatable.

4) During evaluations comparing the operational McNary separator to a modified test (insert) separator at McNary Dam, mean separation efficiency for the total yearling salmonid smolt catch combined was significantly higher using lighted conditions (64%, SE = 2.0) than for the unlighted conditions (60%, SE = 2.0), and higher using the test insert (64%, SE = 2.0) than using the McNary conventional separator (59%, SE = 2.0). There was no difference in mean separation efficiency values for subyearling Chinook salmon among treatment conditions.

5) Yearling Chinook salmon mean descaling values using the insert and McNary separators were 3.0 and 2.1%, respectively. For the total separated salmonid catch, mean descaling for these conditions were 3.3 and 2.2%, respectively.

6) Comparison of video images of fish reaction to conditions near submerged exit orifices of the two separator treatments at McNary Dam indicated that passage may be less behaviorally traumatic using the test (insert) orifice (horizontal exit) compared to using the McNary operational downwell (vertical exit) condition.

7) Residence time for radio tagged yearling Chinook salmon in the A section using the insert separator (3.7 min, SE = 0.6) was significantly less than using the McNary operational unit (7.3 min., SE = 0.6).

8) There was no interaction between separator and light treatments for plasma cortisol or plasma lactate for either species. Observed differences between mean plasma lactate and cortisol values were not significant for either yearling Chinook salmon or steelhead, indicating that physiological stress is similar between separator and light treatments evaluated at McNary Dam in 2001.

ACKNOWLEDGMENTS

We express our appreciation to our seasonal employees for their interest and efforts in this project. We extend special thanks to Ms. Rebecca Kalamasz and Marvin Shutters of the Walla Walla District COE, and at Ice Harbor Dam to Mr. Bill Rose and Mark Plummer for their invaluable cooperation and support. We also extend special thanks to our support staff, especially Mr. Ira Brickey and Mr. Wayne Henry for their efforts and insight during this study.

REFERENCES

Axel, G. A, M. Brad Eppard, E. E. Hockersmith, and B. P. Sandford. 2003. Passage distribution and survival of hatchery yearling Chinook salmon passing Ice Harbor Dam, 2001. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Barton, B. A., C. B. Schreck, and L. A. Sigismondi. 1986. Multiple acute disturbances evoke cumulative physiological stress responses in juvenile Chinook salmon. Transactions of the American Fisheries Society 115:245-251

Barton, B. A., and C. B. Schreck. 1987. Metabolic cost of acute physical stress in juvenile steelhead. Transactions of the American Fisheries Society 116:257-263

Ceballos, J. R., S. W. Pettit, and J. L. McKern. 1992. Fish Transportation Oversight Team. Annual Report-1991. Transportation operations on the Columbia and Snake Rivers. NOAA Technical Memorandum NMFS F/NWF-29. 77 p. plus Appendix.

Gessel, M. H., W. E. Farr, and C. W. Long. 1985. Underwater separation of juvenile salmonids by size. Marine Fisheries Review 47(3):38-42.

Hurson, D., and 19 coauthors. 1999. Juvenile fish transportation program 1998 annual report. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Katz, Daniel M. 1996. Juvenile fish separator design. Pages 47-52 *in* Chenchayya Bathala, editor. Conference Proceedings, North American Water and Environment Congress & Destructive Water. New York, NY.

Katz, Daniel M., R. L. McComas, and L. Swenson. 1999. Juvenile fish separator design. Pages 173-183 *in*: Chenchayya Bathala, editor. Conference Proceedings, North American Water and Environment Congress & Destructive Water. New York, NY.

McCabe, G. T., Jr., C. W. Long, and D. L. Park. 1979. Barge transportation of juvenile salmonids on the Columbia and Snake Rivers, 1977. Marine Fisheries Review 41(7):28-34.

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 1998. Studies to establish biological design criteria for wet separators, 1996. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2000. Studies to establish biological design criteria for fish passage facilities: Improved wet-separator efficiency and high velocity flume development, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2001. Studies to establish biological design criteria for fish passage facilities: Improved wet-separator efficiency and high velocity flume development, 1998. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

McComas, R. L., B. P. Sandford, C. D. Magie and J. W. Ferguson. 2003b. Evaluation of a prototype separator at Ice Harbor Dam, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

McComas, R. L., B. P. Sandford, C. D. Magie and J. W. Ferguson. 2003b. Studies to establish biological design criteria for fish passage facilities: Improved wet-separator efficiency and high velocity flume development, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C. B., L. E. Davis, L. Burtis, P. A. Wood, J. Congleton, T. Mosey, S. Rocklage, and B. Sun. No date. Evaluation of facilities for collection and transport of outmigrating Chinook salmon, Annual Report 1994. Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

APPENDIX

Data Tables

Appendix Table 1. Total catch, by species, for individual replicates using a prototype high-velocity flume wet separator at Ice Harbor Dam, 2001.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, April 23, Light on, substrate color light, splitter plate off										
Tanks: separated			14	6	1					
non-separated			33	18		2				
Separator: separated										
non-separated										
Replicate 2, Treatment 1, April 26, Light on, substrate color light, splitter plate off										
Tanks: separated			83	7						
non-separated			40	190		4				
Separator: separated										
non-separated										
Replicate 3, Treatment 1, May 2, Light on, substrate color light, splitter plate off										
Tanks: separated			163	7	1					
non-separated			65	35	1	25				
Separator: separated										
non-separated										
Replicate 4, Treatment 1, May 3, Light on, substrate color light, splitter plate off										
Tanks: separated			89	6	2	2				
non-separated			72	40	1	34				
Separator: separated										
non-separated										
Replicate 5, Treatment 1, May 4, Light on, substrate color light, splitter plate off										
Tanks: separated			86	2						
non-separated			65	51		10				
Separator: separated										
non-separated										
Replicate 6, Treatment 1, May 8, Light on, substrate color light, splitter plate off										
Tanks: separated			192	3	2	1				
non-separated			104	36	2	14			1	
Separator: separated										
non-separated										
Replicate 7, Treatment 1, May 9, Light on, substrate color light, splitter plate off										
Tanks: separated			115	2	4	14				
non-separated			25	11		21				
Separator: separated										
non-separated										
Replicate 8, Treatment 1, May 11, Light on, substrate color light, splitter plate off										
Tanks: separated			270	4	4	13				
non-separated			21	35	1	35				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 9, Treatment 1, May 15, Light on, substrate color light, splitter plate off										
Tanks: separated			75	2	2	2				
non-separated			38	5	1	40				
Separator: separated										
non-separated										
Replicate 10, Treatment 1, May 16, Light on, substrate color light, splitter plate off										
Tanks: separated			84	2	2	4				
non-separated			55	13		22				
Separator: separated										
non-separated										
Replicate 11, Treatment 1, May 17, Light on, substrate color light, splitter plate off										
Tanks: separated			89		8	6				
non-separated			23	12	1	34				
Separator: separated										
non-separated										
Replicate 12, Treatment 1, May 22, Light on, substrate color light, splitter plate off										
Tanks: separated			93		10	16				
non-separated			20	4		150				
Separator: separated										
non-separated										
Replicate 13, Treatment 1, May 23, Light on, substrate color light, splitter plate off										
Tanks: separated			74			4				
non-separated			32	7		52				
Separator: separated										
non-separated										
Replicate 14, Treatment 1, May 25, Light on, substrate color light, splitter plate off										
Tanks: separated			61		2	10				
non-separated			60	3	2	138				
Separator: separated										
non-separated										
Replicate 15, Treatment 1, May 28, Light on, substrate color light, splitter plate off										
Tanks: separated			30		4	3				
non-separated			14	3		52				
Separator: separated										
non-separated										
Replicate 16, Treatment 1, May 30, Light on, substrate color light, splitter plate off										
Tanks: separated			150		6	3				
non-separated			70	11	1	40			2	
Separator: separated										
non-separated										
Replicate 17, Treatment 1, June 7, Light on, substrate color light, splitter plate off										
Tanks: separated			44		6	2				
non-separated			21			40				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook <180	Subyearling Chinook ≥180	Yearling Chinook <180	Yearling Chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 1, Treatment 2, May 24, Light on, substrate color light, splitter plate on										
Tanks: separated			11	3						
non-separated			10	50		6				
Separator: separated										
non-separated										
Replicate 2, Treatment 2, April 26, Light on, substrate color light, splitter plate on										
Tanks: separated			31	8						
non-separated			22	60		8				
Separator: separated										
non-separated										
Replicate 3, Treatment 2, May 1, Light on, substrate color light, splitter plate on										
Tanks: separated			128	10	2					
non-separated			55	78		43				
Separator: separated										
non-separated										
Replicate 4, Treatment 2, May 2, Light on, substrate color light, splitter plate on										
Tanks: separated			37	3		3				
non-separated			29	19	1	14				
Separator: separated										
non-separated										
Replicate 5, Treatment 2, May 2, Light on, substrate color light, splitter plate on										
Tanks: separated			88	8	4	2				
non-separated			30	22	2	36				
Separator: separated										
non-separated										
Replicate 6, Treatment 2, May 8, Light on, substrate color light, splitter plate on										
Tanks: separated			273	2	2	3				
non-separated			75	62		12				
Separator: separated										
non-separated										
Replicate 7, Treatment 2, May 9, Light on, substrate color light, splitter plate on										
Tanks: separated			84	3	5	7				
non-separated			8	26		14				
Separator: separated										
non-separated										
Replicate 8, Treatment 2, May 11, Light on, substrate color light, splitter plate on										
Tanks: separated			193	9	1	6				
non-separated			21	22	1	7				
Separator: separated										
non-separated										
Replicate 9, Treatment 2, May 14, Light on, substrate color light, splitter plate on										
Tanks: separated			54	1	4	6			1	
non-separated			26	8	1	49				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 10, Treatment 2, May 16, Light on, substrate color light, splitter plate on										
Tanks: separated			150	2	3	6				
non-separated			101	15	6	47				
Separator: separated										
non-separated						2				
Replicate 11, Treatment 2, May 17, Light on, substrate color light, splitter plate on										
Tanks: separated			59			5				
non-separated			45	8	5	73				
Separator: separated										
non-separated										
Replicate 12, Treatment 2, May 22, Light on, substrate color light, splitter plate on										
Tanks: separated			39		12	8				
non-separated			21		3	178				
Separator: separated										
non-separated										
Replicate 13, Treatment 2, May 24, Light on, substrate color light, splitter plate on										
Tanks: separated			48		2	5				
non-separated			20		2	145				
Separator: separated										
non-separated										
Replicate 14, Treatment 2, May 28, Light on, substrate color light, splitter plate on										
Tanks: separated			50		6	6			1	
non-separated			25	3	1	133				
Separator: separated										
non-separated						2				
Replicate 15, Treatment 2, May 29, Light on, substrate color light, splitter plate on										
Tanks: separated			81		1	3				
non-separated			31	3	2	64				
Separator: separated										
non-separated										
Replicate 16, Treatment 2, May 31, Light on, substrate color light, splitter plate on										
Tanks: separated			153		7	12				
non-separated			96	9	7	49				
Separator: separated										
non-separated										
Replicate 17, Treatment 2, June 1, Light on, substrate color light, splitter plate on										
Tanks: separated			261	5	5	11			1	
non-separated			141	18	1	67			1	1
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 3, April 25, Light on, substrate color dark, splitter plate off										
Tanks: separated			23	2						
non-separated			8	59		6				
Separator: separated										
non-separated										
Replicate 2, Treatment 3, April 25, Light on, substrate color dark, splitter plate off										
Tanks: separated			21	6						
non-separated			9	33		22				
Separator: separated										
non-separated										
Replicate 3, Treatment 3, May 1, Light on, substrate color dark, splitter plate off										
Tanks: separated			360	33						
non-separated			120	210	1	31				
Separator: separated										
non-separated										
Replicate 4, Treatment 3, May 2, Light on, substrate color dark, splitter plate off										
Tanks: separated			86	5		1				
non-separated			62	50	2	17				
Separator: separated										
non-separated										
Replicate 5, Treatment 3, May 3, Light on, substrate color dark, splitter plate off										
Tanks: separated			46	1		1				
non-separated			11	18		7				
Separator: separated										
non-separated										
Replicate 6, Treatment 3, May 8, Light on, substrate color dark, splitter plate off										
Tanks: separated			174	9	1	1				
non-separated			57	38	3	5				
Separator: separated										
non-separated										
Replicate 7, Treatment 3, May 8, Light on, substrate color dark, splitter plate off										
Tanks: separated			167	6	2				1	
non-separated			31	38	2	5				
Separator: separated										
non-separated										
Replicate 8, Treatment 3, May 10, Light on, substrate color dark, splitter plate off										
Tanks: separated			103	3	7	19				
non-separated			22	20	2	62				
Separator: separated										
non-separated										
Replicate 9, Treatment 3, May 14, Light on, substrate color dark, splitter plate off										
Tanks: separated			58	1	3	12				
non-separated			19	9	1	40				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 10, Treatment 3, May 16, Light on, substrate color dark, splitter plate off										
Tanks: separated			80	1	2	9				
non-separated			24	10	2	40				
Separator: separated										
non-separated										
Replicate 11, Treatment 3, May 17, Light on, substrate color dark, splitter plate off										
Tanks: separated			166	3	2	6				
non-separated			9	14		47				
Separator: separated										
non-separated										
Replicate 12, Treatment 3, May 22, Light on, substrate color dark, splitter plate off										
Tanks: separated			63		5	10				
non-separated			13	1		91				
Separator: separated										
non-separated										
Replicate 13, Treatment 3, May 23, Light on, substrate color dark, splitter plate off										
Tanks: separated			35	1	8	20				
non-separated			6		1	103				
Separator: separated										
non-separated										
Replicate 14, Treatment 3, May 24, Light on, substrate color dark, splitter plate off										
Tanks: separated			294	3	4	19				
non-separated			42	13	1	171				
Separator: separated						1				
non-separated										
Replicate 15, Treatment 3, May 29, Light on, substrate color dark, splitter plate off										
Tanks: separated			51	1	7	5				
non-separated			33	5	1	33				
Separator: separated										
non-separated										
Replicate 16, Treatment 3, May 31, Light on, substrate color dark, splitter plate off										
Tanks: separated			400	4	4	14				
non-separated			41	12	3	60				
Separator: separated										
non-separated										
Replicate 17, Treatment 3, June 5, Light on, substrate color dark, splitter plate off										
Tanks: separated			66	1		2				
non-separated	1		10	1	1	16				
Separator: separated										
non-separated										
Replicate 1, Treatment 4, April 25, Light on, substrate color dark, splitter plate on										
Tanks: separated			19	1					1	
non-separated			21	37	1	19				
Separator: separated						1				
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 2, Treatment 4, April 27, Light on, substrate color dark, splitter plate on										
Tanks: separated			19	1						
non-separated			13	60		6				
Separator: separated										
non-separated										
Replicate 3, Treatment 4, May 2, Light on, substrate color dark, splitter plate on										
Tanks: separated			54	4		2				
non-separated			30	35		26				
Separator: separated										
non-separated										
Replicate 4, Treatment 4, May 2, Light on, substrate color dark, splitter plate on										
Tanks: separated			61	1						
non-separated			35	45	1	8				
Separator: separated										
non-separated										
Replicate 5, Treatment 4, May 4, Light on, substrate color dark, splitter plate on										
Tanks: separated			81	8		2				
non-separated			41	34		9				
Separator: separated										
non-separated										
Replicate 6, Treatment 4,May 7, Light on, substrate color dark, splitter plate on										
Tanks: separated			142	5	1	2				
non-separated			52	34	2	9				
Separator: separated										
non-separated										
Replicate 7, Treatment 4, May 9, Light on, substrate color dark, splitter plate on										
Tanks: separated			42	3	4	9				
non-separated			21	10	2	24				
Separator: separated										
non-separated										
Replicate 8, Treatment 4, May 11, Light on, substrate color dark, splitter plate on										
Tanks: separated			118	6	3	2				
non-separated			36	21		15				
Separator: separated										
non-separated										
Replicate 9, Treatment 4, May 15, Light on, substrate color dark, splitter plate on										
Tanks: separated			64		5	2				
non-separated			20	2	4	74				
Separator: separated										
non-separated										
Replicate 10, Treatment 4, May 16, Light on, substrate color dark, splitter plate on										
Tanks: separated			119	2	2	7				
non-separated			45	5		41				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 11, Treatment 4, May 17, Light on, substrate color dark, splitter plate on										
Tanks: separated			173	6	4	6				
non-separated			34	11		34				
Separator: separated										
non-separated										
Replicate 12, Treatment 4, May 22, Light on, substrate color dark, splitter plate on										
Tanks: separated			93	1	7	10				
non-separated			16	5		108				
Separator: separated										
non-separated										
Replicate 13, Treatment 4, May 24, Light on, substrate color dark, splitter plate on										
Tanks: separated			69		10	11	1			
non-separated			19	7		109				
Separator: separated										
non-separated										
Replicate 14, Treatment 4, May 25, Light on, substrate color dark, splitter plate on										
Tanks: separated			170	4	5	9				
non-separated			29	8	2	89			1	
Separator: separated										
non-separated										
Replicate 15, Treatment 4, May 29, Light on, substrate color dark, splitter plate on										
Tanks: separated			106			1				
non-separated			9	1		22				
Separator: separated										
non-separated										
Replicate 16, Treatment 4, May 31, Light on, substrate color dark, splitter plate on										
Tanks: separated			88	1	4	2				
non-separated			9			17				
Separator: separated										
non-separated										
Replicate 17, Treatment 4, June 6, Light on, substrate color dark, splitter plate on										
Tanks: separated	2		318	1	2	7				
non-separated			42	9	1	73				
Separator: separated										
non-separated										
Replicate 1, Treatment 5, April 23, Light off, substrate color light, splitter plate off										
Tanks: separated			7	1						
non-separated			9	30	1	2				
Separator: separated										
non-separated										
Replicate 2, Treatment 5, April 27, Light off, substrate color light, splitter plate off										
Tanks: separated			20	4						
non-separated			15	49		4				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 3, Treatment 5, April 30, Light off, substrate color light, splitter plate off										
Tanks: separated			58	15						
non-separated			97	76		5				
Separator: separated										
non-separated										
Replicate 4, Treatment 5, May 2, Light off, substrate color light, splitter plate off										
Tanks: separated			57	3	1					
non-separated			66	54		23				
Separator: separated										
non-separated										
Replicate 5, Treatment 5, May 4, Light off, substrate color light, splitter plate off										
Tanks: separated			54	2					1	
non-separated			155	65	1	8				
Separator: separated										
non-separated						1				
Replicate 6, Treatment 5, May 7, Light off, substrate color light, splitter plate off										
Tanks: separated			101	5	2	2				
non-separated			67	36	2	11				
Separator: separated										
non-separated										
Replicate 7, Treatment 5, May 10, Light off, substrate color light, splitter plate off										
Tanks: separated			77	3	3	5				
non-separated			21	17	1	19				
Separator: separated										
non-separated										
Replicate 8, Treatment 5, May 11, Light off, substrate color light, splitter plate off										
Tanks: separated			204	5	7	10				
non-separated			50	54		35				
Separator: separated										
non-separated										
Replicate 9, Treatment 5, May 14, Light off, substrate color light, splitter plate off										
Tanks: separated			59	2	6	8				
non-separated			80	11	3	40				
Separator: separated										
non-separated										
Replicate 10, Treatment 5, May 15, Light off, substrate color light, splitter plate off										
Tanks: separated			75	2	2	4				
non-separated			108	12	5	40				
Separator: separated										
non-separated										
Replicate 11, Treatment 5, May 17, Light off, substrate color light, splitter plate off										
Tanks: separated			59		2	6				
non-separated			41	7	3	45			1	
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 12, Treatment 5, May 22, Light off, substrate color light, splitter plate off										
Tanks: separated			199		5	8				
non-separated			122	13		74				
Separator: separated										
non-separated										
Replicate 13, Treatment 5, May 23, Light off, substrate color light, splitter plate off										
Tanks: separated			64			8				
non-separated			80	10	2	62	1			
Separator: separated										
non-separated										
Replicate 14, Treatment 5, May 25, Light off, substrate color light, splitter plate off										
Tanks: separated			93	1						
non-separated			95	10	3	42				
Separator: separated										
non-separated										
Replicate 15, Treatment 5, May 29, Light off, substrate color light, splitter plate off										
Tanks: separated			246	1	5	3				
non-separated			158	11	3	48			1	
Separator: separated										
non-separated										
Replicate 16, Treatment 5, May 31, Light off, substrate color light, splitter plate off										
Tanks: separated			40		2	3				
non-separated			70	4	8	69			1	
Separator: separated										
non-separated										
Replicate 17, Treatment 5, June 8, Light off, substrate color light, splitter plate off										
Tanks: separated			30	1	1	2				
non-separated			47	1	1	66				
Separator: separated										
non-separated										
Replicate 1, Treatment 6, April 25, Light off, substrate color light, splitter plate on										
Tanks: separated			9							
non-separated			24	70		2				
Separator: separated										
non-separated										
Replicate 2, Treatment 6, April 30, Light off, substrate color light, splitter plate on										
Tanks: separated			82	1		1				
non-separated			47	41		15				
Separator: separated										
non-separated										
Replicate 3, Treatment 6, April 30, Light off, substrate color light, splitter plate on										
Tanks: separated			43	6						
non-separated			35	66		12				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 4, Treatment 6, May 3, Light off, substrate color light, splitter plate on										
Tanks: separated			57	2						
non-separated			120	61		20				
Separator: separated										
non-separated										
Replicate 5, Treatment 6, May 4, Light off, substrate color light, splitter plate on										
Tanks: separated			43	5		1				
non-separated			89	37		5				
Separator: separated										
non-separated										
Replicate 6, Treatment 6, May 8, Light off, substrate color light, splitter plate on										
Tanks: separated			84	1						
non-separated			75	55		1				
Separator: separated										
non-separated										
Replicate 7, Treatment 6, May 9, Light off, substrate color light, splitter plate on										
Tanks: separated			39	1	2					
non-separated			42	9	2	18				
Separator: separated										
non-separated										
Replicate 8, Treatment 6, May 10, Light off, substrate color light, splitter plate on										
Tanks: separated			24	3	4	2				
non-separated			19	11	2	31				
Separator: separated										
non-separated										
Replicate 9, Treatment 6, May 14, Light off, substrate color light, splitter plate on										
Tanks: separated			35		2	3				
non-separated			52	11	7	43				
Separator: separated										
non-separated										
Replicate 10, Treatment 6, May 15, Light off, substrate color light, splitter plate on										
Tanks: separated			26		3	2				
non-separated			88	21	2	30				
Separator: separated										
non-separated										
Replicate 11, Treatment 6, May 17, Light off, substrate color light, splitter plate on										
Tanks: separated			26	2		4				
non-separated			19	6	1	42				
Separator: separated										
non-separated										
Replicate 12, Treatment 6, May 22, Light off, substrate color light, splitter plate on										
Tanks: separated			19		5	8				
non-separated			16	4	1	106				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 13, Treatment 6, May 23, Light off, substrate color light, splitter plate on										
Tanks: separated			121	1	3	13				
non-separated			176	14	3	126				
Separator: separated										
non-separated										
Replicate 14, Treatment 6, May 28, Light off, substrate color light, splitter plate on										
Tanks: separated			46		1	2				
non-separated			51	3	8	122				
Separator: separated										
non-separated										
Replicate 15, Treatment 6, May 29, Light off, substrate color light, splitter plate on										
Tanks: separated			328	5	2	2				
non-separated			236	11	2	27				
Separator: separated										
non-separated										
Replicate 16, Treatment 6, May 30, Light off, substrate color light, splitter plate on										
Tanks: separated			55	1	3	2				
non-separated			97	11	2	57				
Separator: separated										
non-separated										
Replicate 17, Treatment 6, June 4, Light off, substrate color light, splitter plate on										
Tanks: separated			11		1					
non-separated			25	4	5	67				
Separator: separated										
non-separated										
Replicate 1, Treatment 7, April 25, Light off, substrate color dark, splitter plate off										
Tanks: separated			19							
non-separated			25	60	1	5				
Separator: separated										
non-separated										
Replicate 2, Treatment 7, April 26, Light off, substrate color dark, splitter plate off										
Tanks: separated			13	2						
non-separated			17	47		5				
Separator: separated										
non-separated										
Replicate 3, Treatment 7, May 1, Light off, substrate color dark, splitter plate off										
Tanks: separated			181	8	2					
non-separated			164	150	1	26				
Separator: separated										
non-separated										
Replicate 4, Treatment 7, May 2, Light off, substrate color dark, splitter plate off										
Tanks: separated			171	5	3					
non-separated			87	65	2	25				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 5, Treatment 7, May 3, Light off, substrate color dark, splitter plate off										
Tanks: separated			31							
non-separated			32	40		10				
Separator: separated										
non-separated										
Replicate 6, Treatment 7, May 7, Light off, substrate color dark, splitter plate off										
Tanks: separated			101	5		4				
non-separated			93	55		10				
Separator: separated										
non-separated										
Replicate 7, Treatment 7, May 9, Light off, substrate color dark, splitter plate off										
Tanks: separated			92		5	2				
non-separated			44	23	3	22				
Separator: separated										
non-separated										
Replicate 8, Treatment 7, May 10, Light off, substrate color dark, splitter plate off										
Tanks: separated			141	4	2	4			1	
non-separated			44	25		23				
Separator: separated										
non-separated										
Replicate 9, Treatment 7, May 14, Light off, substrate color dark, splitter plate off										
Tanks: separated			74	2	4	3			1	
non-separated			33	14	3	38				
Separator: separated										
non-separated										
Replicate 10, Treatment 7, May 16, Light off, substrate color dark, splitter plate off										
Tanks: separated			125		3	5				
non-separated			38	16		64				
Separator: separated										
non-separated										
Replicate 11, Treatment 7, May 18, Light off, substrate color dark, splitter plate off										
Tanks: separated			99	2	5	9				
non-separated			31	6	1	107				
Separator: separated										
non-separated										
Replicate 12, Treatment 7, May 18, Light off, substrate color dark, splitter plate off										
Tanks: separated			288	5	4	6				
non-separated			50	19	3	70				
Separator: separated										
non-separated										
Replicate 13, Treatment 7, May 23, Light off, substrate color dark, splitter plate off										
Tanks: separated			22		4	1			1	
non-separated			8	6		104				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 14, Treatment 7, May 28, Light off, substrate color dark, splitter plate off										
Tanks: separated			45		3	4				
non-separated			19	4	1	171				
Separator: separated										
non-separated										
Replicate 15, Treatment 7, May 29, Light off, substrate color dark, splitter plate off										
Tanks: separated			89		2	9				
non-separated			20	4		27				
Separator: separated										
non-separated										
Replicate 16, Treatment 7, May 30, Light off, substrate color dark, splitter plate off										
Tanks: separated			114	2	4	3			1	
non-separated			37	3	2	58				
Separator: separated										
non-separated										
Replicate 17, Treatment 7, June 7, Light off, substrate color dark, splitter plate off										
Tanks: separated			141		2	1				
non-separated			45	9	1	33				
Separator: separated										
non-separated										
Replicate 1, Treatment 8, April 24, Light off, substrate color dark, splitter plate on										
Tanks: separated			7							
non-separated			8	11		1				
Separator: separated										
non-separated										
Replicate 2, Treatment 8, April 30, Light off, substrate color dark, splitter plate on										
Tanks: separated			25							
non-separated			15	25		6				
Separator: separated										
non-separated										
Replicate 3, Treatment 8, April 30, Light off, substrate color dark, splitter plate on										
Tanks: separated			129	11						
non-separated			40	120		1				
Separator: separated										
non-separated										
Replicate 4, Treatment 8, May 3, Light off, substrate color dark, splitter plate on										
Tanks: separated			35	2						
non-separated			43	49	1	31				
Separator: separated										
non-separated										
Replicate 5, Treatment 8, May 3, Light off, substrate color dark, splitter plate on										
Tanks: separated			60	3						
non-separated			45	40		6				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 6, Treatment 8, May 7, Light off, substrate color dark, splitter plate on										
Tanks: separated			170	3	2					
non-separated			95	73	4	12				
Separator: separated										
non-separated										
Replicate 7, Treatment 8, May 9, Light off, substrate color dark, splitter plate on										
Tanks: separated			111	5	8	4			1	
non-separated			60	19	6	23				
Separator: separated										
non-separated										
Replicate 8, Treatment 8, May 11, Light off, substrate color dark, splitter plate on										
Tanks: separated			106	1	3	2				
non-separated			41	10		13				
Separator: separated										
non-separated										
Replicate 9, Treatment 8, May 14, Light off, substrate color dark, splitter plate on										
Tanks: separated			141	5	2	7				
non-separated			86	19	9	44				
Separator: separated										
non-separated										
Replicate 10, Treatment 8, May 15, Light off, substrate color dark, splitter plate on										
Tanks: separated			39	2	3	6				
non-separated			26	10	2	29				
Separator: separated										
non-separated										
Replicate 11, Treatment 8, May 16, Light off, substrate color dark, splitter plate on										
Tanks: separated			144	2	4	6				
non-separated			62	16	3	51				
Separator: separated										
non-separated										
Replicate 12, Treatment 8, May 18, Light off, substrate color dark, splitter plate on										
Tanks: separated			95	1	6	5				
non-separated			38	7	3	63				
Separator: separated										
non-separated						1				
Replicate 13, Treatment 8, May 24, Light off, substrate color dark, splitter plate on										
Tanks: separated			48		7	15				
non-separated			15	3	3	156				
Separator: separated										
non-separated										
Replicate 14, Treatment 8, May 25, Light off, substrate color dark, splitter plate on										
Tanks: separated			266	4	4	10				
non-separated			32	4	2	84				
Separator: separated										
non-separated										

Appendix Table 1. Continued.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 15, Treatment 8, May 30, Light off, substrate color dark, splitter plate on										
Tanks: separated			92	1	3	2				
non-separated			46	5	3	151				
Separator: separated										
non-separated										
Replicate 16, Treatment 8, June 1, Light off, substrate color dark, splitter plate on										
Tanks: separated			120	1	5	4				
non-separated			44	9		58				
Separator: separated										
non-separated										
Replicate 17, Treatment 8, June 7, Light off, substrate color dark, splitter plate on										
Tanks: separated			135		4	3				
non-separated			55	4	4	25				
Separator: separated										
non-separated										

Appendix Table 2. Incidental species captured during separation efficiency studies using a prototype high velocity flume wet separator at Ice Harbor Dam, 23 April-8 June, 2001. Species are listed in order of total capture frequency.

Common name	Scientific name	Total catch
sucker	*Catostomus* spp.	71
mountain whitefish	*Prosopium williamsoni*	52
channel catfish	*Ictalurus punctatus*	24
lamprey	*Entosphenus tridentata*	17
crappie	*Proxomus* spp.	13
yellow perch	*Perca flavescens*	8
bass	*Micropterus* spp.	3
bluegill	*Lepomis macrochirus*	2
northern pikeminnow	*Ptychocheilus oregonensis*	1
walleye	*Stizostedion vitreum*	1
white sturgeon	*Acipenser transmontanus*	1

Appendix Table 3. Statistical analysis results of comparisons among mean separation efficiency values by group for treatments evaluated using a prototype high velocity flume wet separator at Ice Harbor Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
	Yearling Chinook salmon				
<180 mm	replicate series (block)	4.32	15	0.000	*
	light condition	76.18	1	0.000	*
	substrate	69.19	1	0.000	*
	splitter plate	1.53	1	0.219	
	light condition vs. substrate	9.38	1	0.003	*
	light condition vs. splitter plate	0.19	1	0.660	
	substrate vs. splitter plate	0.02	1	0.898	
	light condition vs. substrate vs. splitter	1.56	1	0.215	
≥180 mm	replicate series (block)	2.91	14	0.003	*
	light condition	15.00	1	0.000	*
	substrate	0.72	1	0.402	
	splitter plate	0.30	1	0.586	
	light condition vs. substrate	1.52	1	0.224	
	light condition vs. splitter plate	0.00	1	0.969	
	substrate vs. splitter plate	0.02	1	0.882	
	light condition vs. substrate vs. splitter	1.38	1	0.246	
total catch	replicate series (block)	2.14	16	0.011	*
	light condition	44.08	1	0.000	*
	substrate	63.79	1	0.000	*
	splitter plate	1.22	1	0.272	
	light condition vs. substrate	5.11	1	0.026	*
	light condition vs. splitter plate	0.52	1	0.472	
	substrate vs. splitter plate	0.09	1	0.762	
	light condition vs. substrate vs. splitter	0.57	1	0.452	
	Steelhead				
≥180 mm	replicate series (block)	5.02	14	0.000	*
	light condition	12.42	1	0.001	*
	substrate	2.47	1	0.121	
	splitter plate	1.45	1	0.233	
	light condition vs. substrate	0.14	1	0.707	
	light condition vs. splitter plate	0.00	1	0.970	
	substrate vs. splitter plate	0.02	1	0.899	
	light condition vs. substrate vs. splitter	3.98	1	0.050	*

Appendix Table 3. Continued.

Group	Treatment conditions	Calculated statistic F	df	*P*	
	Steelhead (continued)				
Total catch	replicate series (block)	5.97	14	0.000	*
	light condition	2.79	1	0.100	
	substrate	1.10	1	0.298	
	splitter plate	0.67	1	0.415	
	light condition vs. substrate	0.02	1	0.890	
	light condition vs. splitter plate	0.28	1	0.597	
	substrate vs. splitter plate	0.00	1	0.948	
	light condition vs. substrate vs. splitter	11.04	1	0.001	*
	Total salmonids				
<180 mm	replicate series (block)	5.48	16	0.000	*
	light condition	77.65	1	0.000	*
	substrate	68.30	1	0.000	*
	splitter plate	1.63	1	0.204	
	light condition vs. substrate	7.90	1	0.006	*
	light condition vs. splitter plate	0.04	1	0.844	
	substrate vs. splitter plate	0.02	1	0.897	
	light condition vs. substrate vs. splitter	1.16	1	0.285	
≥180 mm	replicate series (block)	4.43	16	0.000	*
	light condition	17.95	1	0.000	*
	substrate	0.80	1	0.372	
	splitter plate	0.06	1	0.810	
	light condition vs. substrate	0.65	1	0.424	
	light condition vs. splitter plate	0.00	1	0.944	
	substrate vs. splitter plate	0.00	1	0.988	
	light condition vs. substrate vs. splitter	4.76	1	0.031	*
Total salmonid catch	replicate series (block)	3.75	16	0.000	*
	light condition	36.75	1	0.000	*
	substrate	42.86	1	0.000	*
	splitter plate	0.48	1	0.927	
	light condition vs. substrate	5.90	1	0.017	*
	light condition vs. splitter plate	0.54	1	0.464	
	substrate vs. splitter plate	1.43	1	0.235	
	light condition vs. substrate vs. splitter	0.00	1	0.979	

Appendix Table 4. Statistical analysis results of comparisons among mean descaling values by group for treatments evaluated using a prototype high velocity flume wet separator at Ice Harbor Dam, 2001. Asterisks indicate significant differences ($\alpha = 0.05$) among treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Yearling Chinook salmon					
<180 mm	replicate series (block)	4.17	15	0.000	*
	light condition	0.94	1	0.335	
	substrate	5.02	1	0.027	*
	splitter plate	0.70	1	0.403	
	light condition vs. substrate	0.01	1	0.917	
	light condition vs. splitter plate	0.50	1	0.479	
	substrate vs. splitter plate	0.44	1	0.510	
	light condition vs. substrate vs. splitter	0.00	1	0.957	
≥180 mm	replicate series (block)	1.09	14	0.391	
	light condition	0.77	1	0.385	
	substrate	0.08	1	0.777	
	splitter plate	0.78	1	0.383	
	light condition vs. substrate	0.37	1	0.548	
	light condition vs. splitter plate	1.33	1	0.254	
	substrate vs. splitter plate	0.08	1	0.775	
	light condition vs. substrate vs. splitter	1.46	1	0.233	
total catch	replicate series (block)	4.99	16	0.000	*
	light condition	2.31	1	0.131	
	substrate	3.43	1	0.067	
	splitter plate	1.01	1	0.317	
	light condition vs. substrate	0.24	1	0.628	
	light condition vs. splitter plate	0.59	1	0.444	
	substrate vs. splitter plate	0.03	1	0.859	
	light condition vs. substrate vs. splitter	0.06	1	0.805	

Appendix Table 4. Continued.

Group	Treatment conditions	Calculated statistic F	df	P	
Steelhead					
≥180 mm	replicate series (block)	0.68	14	0.782	
	light condition	0.73	1	0.395	
	substrate	1.54	1	0.219	
	splitter plate	3.18	1	0.079	
	light condition vs. substrate	2.10	1	0.152	
	light condition vs. splitter plate	0.55	1	0.460	
	substrate vs. splitter plate	2.62	1	0.110	
	light condition vs. substrate vs. splitter	0.18	1	0.671	
Total catch	replicate series (block)	0.44	14	0.953	
	light condition	0.41	1	0.525	
	substrate	3.29	1	0.074	
	splitter plate	4.22	1	0.044	
	light condition vs. substrate	2.91	1	0.093	
	light condition vs. splitter plate	0.71	1	0.403	
	substrate vs. splitter plate	3.96	1	0.050	*
	light condition vs. substrate vs. splitter	0.35	1	0.553	
Total salmonids					
<180 mm	replicate series (block)	3.78	16	0.000	*
	light condition	0.91	1	0.343	
	substrate	4.73	1	0.032	*
	splitter plate	1.13	1	0.290	
	light condition vs. substrate	0.10	1	0.751	
	light condition vs. splitter plate	0.33	1	0.565	
	substrate vs. splitter plate	0.51	1	0.476	
	light condition vs. substrate vs. splitter	0.01	1	0.929	
≥180 mm	replicate series (block)	1.40	16	0.157	
	light condition	0.00	1	0.994	
	substrate	0.15	1	0.700	
	splitter plate	0.28	1	0.600	
	light condition vs. substrate	0.03	1	0.873	
	light condition vs. splitter plate	0.68	1	0.411	
	substrate vs. splitter plate	2.49	1	0.118	
	light condition vs. substrate vs. splitter	0.02	1	0.884	
total salmonid catch	replicate series (block)	2.91	16	0.001	*
	light condition	1.47	1	0.228	
	substrate	5.33	1	0.023	*
	splitter plate	0.29	1	0.591	
	light condition vs. substrate	0.09	1	0.759	
	light condition vs. splitter plate	0.63	1	0.428	
	substrate vs. splitter plate	0.34	1	0.561	
	light condition vs. substrate vs. splitter	0.49	1	0.486	

Appendix Table 5. Total catch, by species, for individual test dates using the McNary operational separator and a separator insert at McNary Dam, 2001.

	Subyearling Chinook		Yearling Chinook		Steelhead		Coho		Sockeye	
Source	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 1, April 14-15, McNary separator, Light off										
Tanks: separated	3		60	7	23	63			2	1
non-separated	4		71	62	21	251	4		1	
Replicate 2, Treatment 1, April 22-23, McNary separator, Light off										
Tanks: separated	3		179	5	1	240	1			
non-separated			506	34	146	1657	5		4	
Replicate 3, Treatment 1, May 6- 7, McNary separator, Light off										
Tanks: separated	11		426	25		54	2		5	
non-separated	11		328	62	71	240	22	3	16	
Replicate 4, Treatment 1, May 8-9, McNary separator, Light off										
Tanks: separated	9		751	54		40	4		6	
non-separated	7		510	97	54	232	11		7	
Replicate 5, Treatment 1, May 20-21, McNary separator, Light off										
Tanks: separated	47		769	59	5	25	5		10	
non-separated	18		289	85	210	454	19		13	
Replicate 6, Treatment 1, May 24-25, McNary separator, Light off										
Tanks: separated	154		2241	252	3	85	12		37	1
non-separated	29		620	234	97	214	25	2	32	1
Replicate 7, Treatment 1, June 7-8, McNary separator, Light off										
Tanks: separated	305		265	14	2	83	89		27	
non-separated	140		118	37	92	191	260	1	107	
Replicate 8, Treatment 1, June 15-16, McNary separator, Light off										
Tanks: separated	634		65	3	2	5	5			
non-separated	320		60	10	5	56	14		26	
Replicate 9, Treatment 1, June 23-24, McNary separator, Light off										
Tanks: separated	10378		33	3		1			2	
non-separated	2541		36	10	1	25	2		3	

Appendix Table 5. Continued.

Source	Subyearling Chinook <180	Subyearling Chinook ≥180	Yearling Chinook <180	Yearling Chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 1, Treatment 2, April 16-17, Insert separator, Light off										
Tanks: separated	45		170	4	22	21	2		3	
non-separated	27		338	67	20	251	4	1		
Replicate 2, Treatment 2, April 28-29, Insert separator, Light off										
Tanks: separated	12		367	5	27	23	3			
non-separated			213	64	13	551	6	3	2	
Replicate 3, Treatment 2, April 30-May 1, Insert separator, Light off										
Tanks: separated	14		374	2	53	27	5		5	
non-separated	1		239	128	20	535	12	8		
Replicate 4, Treatment 2, May 10-11, Insert separator, Light off										
Tanks: separated	13		554	7	4		3		9	
non-separated	9		479	111	4	139	4		8	1
Replicate 5, Treatment 2, May 18-19, Insert separator, Light off										
Tanks: separated	32		590	14	10	10	7		5	
non-separated	9		432	131	5	87	20		10	
Replicate 6, Treatment 2, May 28-29, Insert separator, Light off										
Tanks: separated	334		594	14	18	3	24		103	
non-separated	139		453	167	6	77	56	1	119	
Replicate 7, Treatment 2, June 3-4, Insert separator, Light off										
Tanks: separated	672		216	8	2	15	16		43	
non-separated	264		151	55	1	82	34	1	39	
Replicate 8, Treatment 2, June 11-12, Insert separator, Light off										
Tanks: separated	1831		116	3	10	15	8		17	
non-separated	547		89	44	4	127	15		36	
Replicate 9, Treatment 2, June 17-18, Insert separator, Light off										
Tanks: separated	15173		773	9	11	9	98		42	
non-separated	3170		449	98	11	290	158		21	

Appendix Table 5. Continued.

Source	Subyearling Chinook <180	Subyearling Chinook ≥180	Yearling Chinook <180	Yearling Chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 1, Treatment 3, April 20-21, McNary separator, Light on										
Tanks: separated	83		111	3	29	115	1			
non-separated	10		295	72	20	558	2	1	2	
Replicate 2, Treatment 3, April 24-25, McNary separator, Light on										
Tanks: separated	1		113	1	27	231	3	1		
non-separated			295	16	13	722	5	1		
Replicate 3, Treatment 3, May 1-2, McNary separator, Light on										
Tanks: separated	3		740	68	63	181	5	1	8	
non-separated			390	124	18	554	32	8	10	
Replicate 4, Treatment 3, May 14-15, McNary separator, Light on										
Tanks: separated	21		1002	62	12	50	3		5	
non-separated	10		380	118	5	134	5		10	
Replicate 5, Treatment 3, May 22-23, McNary separator, Light on										
Tanks: separated	84		974	104	57	152	5		8	
non-separated	37		393	136	31	459	30		10	
Replicate 6, Treatment 3, May 26-27, McNary separator, Light on										
Tanks: separated	169		1480	124	9	27	15		91	
non-separated	81		512	150	5	138	50		218	
Replicate 7, Treatment 3, June 5-6, McNary separator, Light on										
Tanks: separated	262		193	28	7	40	20		41	
non-separated	72		118	32	4	77	68		77	
Replicate 8, Treatment 3, June 9-10, McNary separator, Light on										
Tanks: separated	495		126	9	3	12	11		19	
non-separated	110		92	22	27	24	17		40	
Replicate 9, Treatment 3, June 19-20, McNary separator, Light on										
Tanks: separated	4188		133	7	2	14	30		15	
non-separated	909		103	17	1	69	62		20	

Appendix Table 5. Continued.

Source	Subyearling Chinook <180	Subyearling Chinook ≥180	Yearling Chinook <180	Yearling Chinook ≥180	Steelhead <180	Steelhead ≥180	Coho <180	Coho ≥180	Sockeye <180	Sockeye ≥180
Replicate 1, Treatment 4, April 18-19, Insert separator, Light on										
Tanks: separated	19		348	6	46	31	2	1	4	
non-separated	7		379	126	29	517	6	3	2	2
Replicate 2, Treatment 4, April 26-27, Insert separator, Light on										
Tanks: separated	5		142		9	30			1	
non-separated			78	24	7	606	4	1		
Replicate 3, Treatment 4, May 4-5, Insert separator, Light on										
Tanks: separated	8		507	5	25	18	4		7	
non-separated			209	75	4	224	9	3	1	
Replicate 4, Treatment 4, May 12-13, Insert separator, Light on										
Tanks: separated	15		578	12	8	11	1		9	1
non-separated	4		273	113	4	131	4			1
Replicate 5, Treatment 4, May 16-17, Insert separator, Light on										
Tanks: separated	25		708	4	8	13	2		6	
non-separated	12		233	152	4	123	6		6	
Replicate 6, Treatment 4, May 30-31, Insert separator, Light on										
Tanks: separated	366		1096	25	15	23	87		295	
non-separated	118		621	229	10	205	164		212	
Replicate 7, Treatment 4, June 1-2, Insert separator, Light on										
Tanks: separated	343		625	13	1	7	43		183	
non-separated	81		486	129	3	95	61		86	
Replicate 8, Treatment 4, June 13-14, Insert separator, Light on										
Tanks: separated	2323		143	1	33		5		18	
non-separated	412		71	27	1	42	22		6	2
Replicate 9, Treatment 4, June 19-20, Insert separator, Light on										
Tanks: separated	4188		50	1		3	2		8	
non-separated	909		30	7		37	8		5	

Appendix Table 6. Statistical analysis results of comparisons between least squares mean separation efficiency values by group for treatments evaluated using the juvenile fish facility wet separator and a separator inert at McNary Dam, 14 April-24 June 2001. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

		Calculated statistic			
Group	Treatment conditions	F	df	*P*	
Yearling Chinook salmon					
<180 mm	replicate series (block)	4.23	8	0.003	*
	separator type	0.56	1	0.462	
	light condition	2.74	1	0.111	
	separator type vs. light cond.	0.72	1	0.403	
≥180 mm	replicate series (block)	2.56	8	0.044	*
	separator type	64.32	1	0.000	*
	light condition	0.15	1	0.706	
	separator type vs. light cond.	0.86	1	0.364	
total catch	replicate series (block)	2.71	8	0.028	*
	separator type	0.82	1	0.106	
	light condition	1.81	1	0.191	
	separator type vs. light cond.	0.87	1	0.360	
Coho salmon					
<180 mm	replicate series (block)	3.37	4	0.054	
	separator type	10.22	1	0.010	*
	light condition	0.01	1	0.911	
	separator type vs. light cond.	0.03	1	0.873	
Sockeye salmon					
≥180 mm	replicate series (block)	1.23	4	0.364	
	separator type	20.46	1	0.001	*
	light condition	3.36	1	0.100	
	separator type vs. light cond.	4.05	1	0.075	
Steelhead					
<180 mm	separator type	0.11	1	0.743	
	light condition	0.89	1	0.362	
	separator type vs. light cond.	0.24	1	0.632	

Appendix Table 6. Continued.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Steelhead (continued)					
≥180 mm	replicate series (block)	2.00	8	0.091	
	separator type	53.31	1	0.000	
	light condition	2.15	1	0.155	
	separator type vs. light cond.	1.21	1	0.283	
Total catch	replicate series (block)	2.39	8	0.047	*
	separator type	53.90	1	0.000	*
	light condition	1.42	1	0.245	
	separator type vs. light cond.	1.88	1	0.183	
Total salmonid catch					
≥180 mm	replicate series (block)	7.59	8	0.000	*
	separator type	1.41	1	0.247	
	light condition	4.25	1	0.050	*
	separator type vs. light cond.	0.32	1	0.575	
≥180 mm	replicate series (block)	2.77	8	0.025	*
(yearling	separator type	85.61	1	0.000	*
outmigrants)	light condition	1.80	1	0.192	
	separator type vs. light cond.	1.74	1	0.200	
total salmonid	replicate series (block)	4.20	8	0.003	*
catch	separator type	5.79	1	0.024	*
(yearling	light condition	4.93	1	0.036	*
outmigrants)	separator type vs. light cond.	2.19	1	0.152	
Subyearling Chinook salmon					
<180 mm	replicate series (block)				
	separator type	0.91	1	0.355	
	light condition	2.93	1	0.106	
	separator type vs. light cond.	0.01	1	0.906	

Appendix Table 7. Statistical analysis results of comparisons between least squares mean descaling values by group for treatments evaluated using the juvenile fish facility wet separator and a separator inert at McNary Dam, 14 April-24 June 2001. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Yearling Chinook salmon					
Separated	replicate series (block)	1.35	8	0.267	
	separator type	5.83	1	0.024	*
	light condition	1.56	1	0.223	
	separator type vs. light cond.	2.53	1	0.125	
Non-separated	replicate series (block)	0.87	8	0.555	
	separator type	0.12	1	0.733	
	light condition	0.01	1	0.915	
	separator type vs. light cond.	3.28	1	0.083	
Total catch	replicate series (block)	0.62	8	0.751	
	separator type	3.50	1	0.074	
	light condition	0.51	1	0.482	
	separator type vs. light cond.	0.23	1	0.638	
Coho salmon					
Separated	replicate series (block)	0.98	4	0.460	
	separator type	1.05	1	0.331	
	light condition	0.06	1	0.805	
	separator type vs. light cond.	0.23	1	0.644	
Non-separated	replicate series (block)	0.80	4	0.553	
	separator type	0.69	1	0.425	
	light condition	0.12	1	0.737	
	separator type vs. light cond.	1.43	1	0.259	
Total catch	replicate series (block)	0.46	4	0.763	
	separator type	0.07	1	0.797	
	light condition	0.01	1	0.915	
	separator type vs. light cond.	1.69	1	0.223	

Appendix Table 7. Continued.

Group	Treatment conditions	Calculated statistic F	df	*P*	
Sockeye salmon					
Separated	replicate series (block)	5.23	4	0.019	*
	separator type	0.00	1	0.989	
	light condition	0.43	1	0.529	
	separator type vs. light cond.	0.47	1	0.510	
Non-separated	replicate series (block)	2.09	4	0.165	
	separator type	0.41	1	0.536	
	light condition	0.91	1	0.366	
	separator type vs. light cond.	0.10	1	0.755	
Total catch	replicate series (block)	6.44	4	0.010	*
	separator type	0.11	1	0.743	
	light condition	1.80	1	0.212	
	separator type vs. light cond.	1.02	1	0.339	
Steelhead					
Separated	separator type	2.02	1	0.170	
	light condition	0.16	1	0.697	
	separator type vs. light cond.	1.75	1	0.200	
Non-separated	separator type	2.29	1	0.145	
	light condition	0.80	1	0.382	
	separator type vs. light cond.	0.58	1	0.455	
Total catch	separator type	3.52	1	0.075	
	light condition	0.89	1	0.356	
	separator type vs. light cond.	1.94	1	0.179	
All salmonids					
Separated	replicate series (block)	5.79	8	0.000	*
	separator type	8.79	1	0.007	*
	light condition	0.21	1	0.650	
	separator type vs. light cond.	1.75	1	0.199	
Non-separated	replicate series (block)	4.54	8	0.002	*
	separator type	0.76	1	0.392	
	light condition	0.47	1	0.501	
	separator type vs. light cond.	0.59	1	0.450	

Appendix Table 7. Continued.

Group	Treatment conditions	Calculated statistic F	df	*P*	
All salmonids (continued)					
Total salmonid catch	replicate series (block)	15.22	8	0.000	*
	separator type	1.80	1	0.192	
	light condition	1.30	1	0.266	
	separator type vs. light cond.	2.02	1	0.168	
Subyearling Chinook salmon					
Separated	replicate series (block)	0.68	6	0.665	
	separator type	0.89	1	0.359	
	light condition	0.81	1	0.381	
	separator type vs. light cond.	0.38	1	0.546	
Non-separated	replicate series (block)	0.22	6	0.965	
	separator type	2.96	1	0.105	
	light condition	0.03	1	0.868	
	separator type vs. light cond.	1.80	1	0.199	
Total catch	replicate series (block)	1.68	6	0.191	
	separator type	0.06	1	0.814	
	light condition	10.10	1	0.310	
	separator type vs. light cond.	3.16	1	0.095	