Biological design criteria for fish passage facilities:

high-velocity flume development and improved wet-separator efficiency McNary Dam 1999

Fish Ecology Division

Northwest Fisheries Science Center

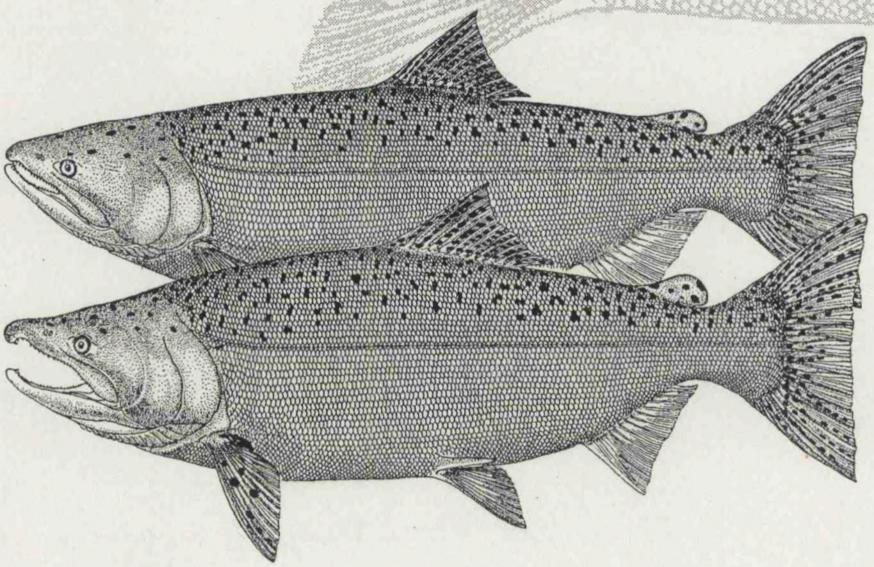
National Marine Fisheries Service

Seattle, Washington

by

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

October 2003



Biological Design Criteria for Fish Passage Facilities: High-Velocity Flume Development and Improved Wet-Separator Efficiency McNary Dam 1999

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

Report of research by

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

to

Walla Walla District
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, Washington 99362-1876
Delivery Order E86910060

October 2003

EXECUTIVE SUMMARY

During the 1999 spring and summer juvenile salmon migration periods, we continued research to provide design improvements for wet separators used in juvenile passage facilities at hydroelectric dams on the Snake and Columbia Rivers. In addition, we continued evaluation of design criteria for the high-velocity flume (HVF) wet separator.

River-run smolts from Gatewell 6B at McNary Dam were diverted to two mock-up separator units. Smolts were separated into small (<180 mm fork length (FL)) and large (≥180 mm FL) size groups, anesthetized, and sorted by species. In a mock-up unit simulating the existing conventional wet-separator at McNary Dam, four treatments were evaluated. Treatments compared the effects of separation-bar spacing (17 mm and 19 mm) and length of the collection period (diel and short duration) on salmonid separation efficiency, separator exit efficiency (a measure of residence time in the separator unit), and fish condition (descaling). Identical evaluations were conducted in the mock-up HVF separator.

Separation efficiency was significantly higher using the 17-mm separation-bar gap than the 19-mm gap for large fish groups in both mock-up units and for small fish groups in the conventional unit. In evaluations of the conventional unit, mean separation efficiency values were not significantly different between replicates collected over the short-term and diel periods except for small coho salmon. However, for the total salmonid catch during spring, and for all replicate groups evaluated during summer, there were no significant differences in separation efficiency values between the 17-mm and 19-mm separation-bar gap spacing.

There were also no interactions between replicate duration and separation-bar spacing for any comparison during spring or summer, and generally no difference in separation efficiency by replicate duration, using either separator unit.

Mean separator exit efficiency ranged from 93 to 100% for all comparisons in the conventional separator, and from 96 to 100% in the HVF separator. Because these exit efficiency values were high, and differences were negligible, analyses of these data could not have contributed meaningful results and were therefore not conducted for exit efficiency data from either the conventional or HVF mock-up separator.

Mean descaling was not significantly different between the 17- and 19-mm bar spacing in either separator, but was generally significantly higher for replicates collected over the diel than over the short-term periods. However, in all cases, descaling was low and at levels expected in fish exiting a gatewell; any differences were probably an artifact of sample procedure rather than indicating a real difference based on collection periods.

CONTENTS

INTRODUCTION

Separation of smolts by size is an objective of juvenile bypass systems at hydroelectric dams on the Columbia and Snake Rivers. Juvenile chinook salmon (*Oncorhynchus tshawytscha*) that are transported with juvenile steelhead (*O. mykiss*, which are generally larger than chinook salmon smolts) may experience higher levels of stress than those transported with other chinook salmon (McCabe et al. 1979, Congleton et al. 1997). In addition to stress reduction, separation provides management options based on different size classes.

Separation at U.S. Army Corps of Engineers (COE) operated facilities evolved from the initial 'dry' separation process, where fish were sorted using inclined pipes (McComas et al. 1998), to a wet separation approach. Currently operational wet separators used in bypass facilities at COE operated projects are similar to the separator developed and evaluated by Gessel et al. (1985). Since they keep fish submerged, wet separators are considered less stressful to migrants. These units rely primarily on behavioral responses to induce smolts to sound between separation bars just under the water surface.

The wet separation process was described and diagramed by McComas et al. (1998). Essentially, wet separators presently use a three stage separation process designed to remove first small fish; then larger smolts; and finally adult salmonids, non-salmonid incidental species, and debris. Spacing the separation bars appropriately in successive compartments determines the size of fish able to sound at each stage. Under ideal conditions, the first compartment, or 'A' section, is intended to segregate smaller smolts such as chinook, coho (*O. kisutch*), and sockeye (*O. nerka*) salmon from the larger, predominantly steelhead smolts, which are sorted in the B section.

In practice, there are several problems with existing wet separators. For example, in 1998 the A section in the McNary Dam separator produced separation efficiency values of 41.4, 22.9, and 26.7% for yearling chinook, coho, and sockeye salmon respectively (Hurson et al. 1999). Possible explanations included flow surges, which carry small fish through the first section with insufficient time to sound through the separation bars and inadequate stimuli to induce fish to sound between the bars.

Video monitoring associated with behavioral and physiological studies has indicated that fish also hold under the bars for extended periods, rather than exiting expeditiously from the separator unit (Schreck et al. 1995). This work suggests that fish may exit from fatigue generated by resistance to hydraulic conditions within the unit, resulting in increased overall stress which could ultimately affect survival.

During the early spring of 1996, interagency meetings were held to present solutions and alternatives to the conventional separator. One idea was the high-velocity flume model, in which fish would be induced to separate in a flume while passing over an array of separation bars. Preliminary studies to evaluate juvenile salmonid separation in a high-velocity environment were conducted in a small evaluation flume at McNary Dam during the latter part of the subyearling chinook salmon juvenile migration in 1996 (McComas et al.1998). Results demonstrated that if sufficient separation-bar length was available, a substantial proportion of subyearling chinook salmon would sound through separation bars when water velocities were higher than in existing wet separators.

Evaluations of an expanded HVF separator in 1997 and 1998 established initial criteria for separation-bar length, water velocity, separation-bar array orientation, submergence of the array, and separation-bar spacing. Promising results were obtained at a water velocity of 1 m/sec, with a 12-m long separation-bar array submerged 5 cm below the water surface and oriented parallel to the surface (McComas et al. 2000).

During the 1999 spring juvenile migration period, personnel of the National Marine Fisheries Service (NMFS) continued research to increase salmonid smolt separation efficiency using mock-ups of both a high-velocity flume (HVF) and a standard conventional wet separator. Specific research objectives in 1999 were:

1) Evaluate separation efficiency, exit efficiency and fish condition using two separation-bar spacings (17 mm and 19 mm) over two replicate time intervals (24-hour and short duration) using a standard wet separator.

2) Evaluate separation efficiency, exit efficiency and fish condition using two separation-bar spacings (17 mm and 19 mm) over two replicate time intervals (24-hour and short duration) using a high-velocity flume wet separator.

SEPARATION AND EXIT EFFICIENCIES AND FISH CONDITION IN A STANDARD WET SEPARATOR

Materials and Methods

In 1998, a mock-up separator unit was fabricated to simulate the function of the small fish section of an conventional wet separator, similar to those presently in use at McNary and Lower Monumental Dams (McComas et al. 1998). The unit built in 1998 was used during separation studies in 1999 (McComas et al. 2003). Several modifications were incorporated into this conventional separator during construction to reduce or eliminate recognized functional weaknesses in operational units. A full-sized separator section was used so that beneficial changes to the mock-up separator could be adapted to existing operational wet separators without requiring major revision to the existing unit.

The mock-up conventional separator measured 15.2 mm wide, 39.6 mm long, and 1.2 m high (5 × 13 × 4 ft). Maximum water depth was 0.8 m, with add-in water supplied through a 25.4-cm (10-in) siphon drawing water from the forebay. Major modifications to this basic unit involved removal of the downwell sump located in the downstream end of operational separators, and reduction and redirection of add-in water (McComas et al. in press).

In operational separators, a downwell sump serves as the transition to an exit orifice for fish which have sounded between the separation bars (separated fish). The orifice is located at the bottom of the downwell, approximately 1.5 m (5 ft) below the water surface. Video recordings of behavior near the sump entrance have shown that accelerating water velocities through the downwell cause smolts to resist entering the sump by swimming vigorously against the flow (James L. Congleton, University of Idaho, Personal communication). These hydraulic conditions may delay migration and increase stress to fish within the unit.

To simulate a modification to operational separators, the area containing the downwell sump was eliminated from the mock-up unit by installing a vertical partition 61 cm (2 ft) from the downstream end, and extending horizontally across the width, of the unit. The partition supported the downstream end of the separation-bar array at a height which allowed approximately 3 cm (1.25 in) water depth over the separation bars, forming an overflow orifice for fish not passing between the bars (non-separated fish).

The other major difference between the mock-up separator unit and an operational separator involved the make-up water delivery system, which was linked to placement of the submerged exit orifice. In addition to a drain supply furnishing water directly to the orifice, the volume of water needed to support a downwell orifice at the 1.5-m depth in an operational unit is augmented by inflow forced upward through a false bottom of perforated plate at three points along the longitudinal centerline of each separator section (Figure 1). Fish have been observed swimming into this flow, in a head-down orientation toward the perforated plate. At best, this hydraulic situation contributes to increased holding time in the separator, and it probably increases fatigue and stress to fish.

Previous studies using mock-up separators have demonstrated that a shallower orifice configuration can be more efficient at passing fish than an orifice deeper in the water column (McComas et al. 1998). The bottom of the submerged orifice in the mock-up unit for this study was placed 23 cm (9 in) below the water surface to reduce velocity and volume through the opening. The submerged orifice measured 7.6 by 61 cm (3 × 24 in), and was centered in the partition at the downstream end of the unit. A perforated plate false bottom sloped from the bottom edge of the submerged orifice to 15 cm (6 in) below the water surface at the upstream end of the separator.

Make-up water was also redirected to eliminate the upward flow component, which appeared to attract fish. A 24.5-cm (10-in) PVC tube through the longitudinal centerline and along the floor of the separator under the false bottom received water from a siphon. Flow was regulated by 24.5-cm (10-in) valves on both ends of this tube. Four lateral 10-cm (4-in) pipes were attached to each side of the 24.5-cm tube, and each pipe was equipped with double rows of 1-cm (3/8-in) holes directed toward the floor at approximately 30° to the vertical. This arrangement dispersed make-up water inflow throughout the separator with no apparent upwelling.

Separation bars were contained in arrays oriented parallel to flow along the long axis of the mock-up unit, and sloped from 76 mm (3 in) below the water surface at the upstream end to 30 mm (1.25 in) below the surface at the downstream end. Both bar arrays used in this study consisted of two panels 0.76 m wide by 3.35 m long (2.5 × 11 ft), with individual bars of 254-mm (1-in) ID aluminum tubing. Two interchangeable arrays were used, with nominal spacings of 17 and 19 mm (0.69 and 0.75 in) between individual bars. Total separation-bar area of the mock-up separator unit (with reduced length due to the downwell modification) was 5.11 m^2 (55 ft^2), or approximately 85% of the total area available in the upstream section of a conventional separator (5.85 m^2, 65 ft^2).

To maximize the number of comparison treatments during the juvenile migration period, previous evaluations using the mock-up separator units have concentrated on obtaining a minimum number of 30 chinook salmon for each replicate. Replicates for these tests were often collected over a short period of time (0.5 to 6 h) relative to the continuous collection of fish in an operational separator unit. In 1999, we compared separation and exit efficiency values and descaling rates obtained from replicate

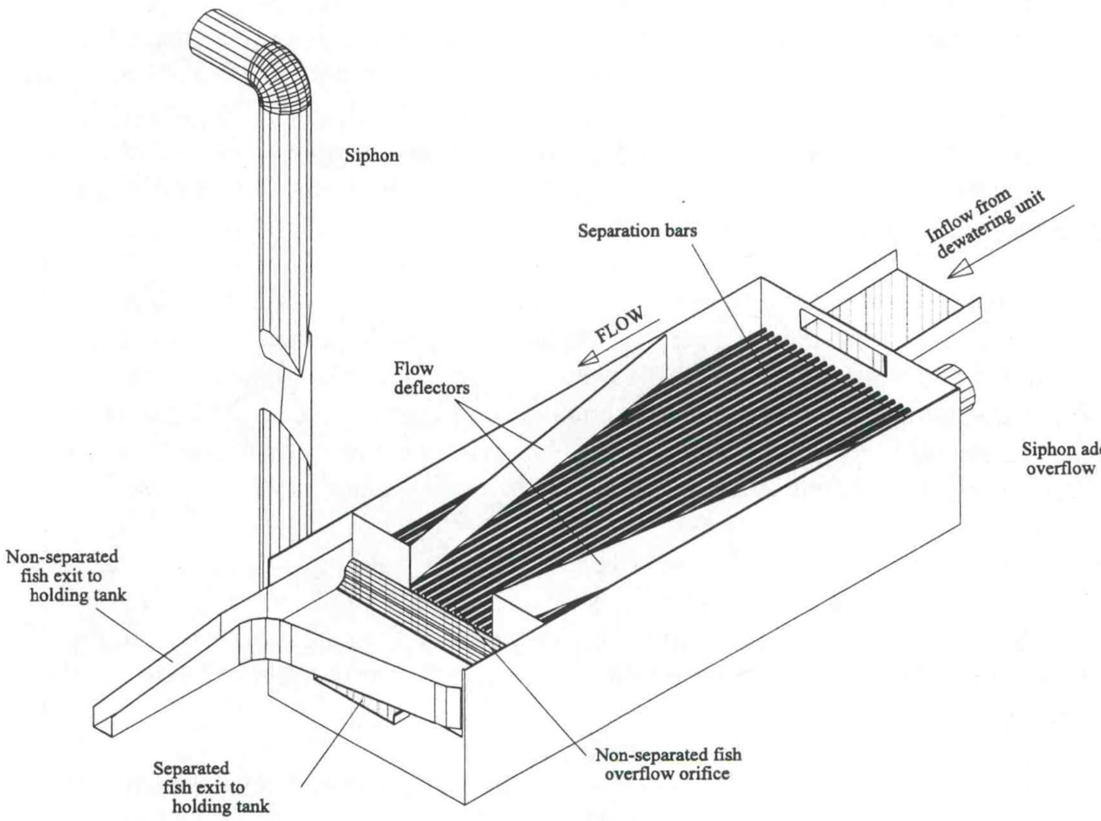


Figure 1. Components of the simulated conventional wet separator used for wet-separator efficiency development studies at McNary Dam in 1999.

collection periods of short duration to those of collection periods covering a 24-h (diel) interval to determine whether the results were comparable between short and long collection periods.

The mock-up separator was operated continuously 4 days per week to provide four replicates collected over a 24-h period. Replicates for the short collection period were collected on one day each week, wherein several (4 or more) replicates were collected over a 24-h period. A minimum sample size of 25 fish per replicate was collected under the short collection period for statistical accuracy in the analyses, as described in previous separator evaluation studies (McComas et al. 1998, 2000, in press). To evaluate the effects of separation-bar gap size and collection period duration on separation efficiency and exit efficiency, treatments were completed in 5-day blocks consisting of four diel-collection replicates and several short-collection period replicates performed on the remaining day.

Before initiating a replicate, water depth in the separator was stabilized at approximately 20 mm (0.8 in) over the overflow orifice. A replicate was initiated by opening the gatewell orifice, which allowed test fish to enter the upstream end of the unit along with enough additional inflow to raise the depth across the separator overflow orifice to approximately 30 mm (1.25 in). Fish exiting through the two separator orifices (overflow and submerged) were detained in separate holding tanks for examination.

For diel replicates, fish were collected from the holding tanks at least once each hour. During short duration sampling, fish were left in the tanks until the end of the replicate. After separation, test fish were collected first from above, then from below the separation bars within the separator unit. Animals from the two holding tanks were examined last.

Each group was anesthetized separately using tricane methanesulfonate (MS-222), enumerated by species, and categorized by length group as small fish (<180 mm fork length) or large fish (≥180 mm FL). Fish condition was also noted for each species using Fish Transportation Oversight Team descaling criteria (Ceballos et al. 1992). Following recovery from anesthetic, all fish were released directly into the juvenile fish bypass channel.

One test series was completed during the spring migration, and one during the summer juvenile migration, with each series involving multiple blocks of the four treatments. Blocks and treatments within blocks were performed sequentially. The order of separation-bar spacing treatments was randomized within each duration treatment. However, the order of treatments for short vs. long collection periods within each block was not random.

Because of maintenance work on the test turbine, the turbine unit was not operated for several hours on one day each week. During these periods, the test gatewell was not collecting fish, so 24-h collections could not be performed on days when maintenance was scheduled. Short-term collection replicates were therefore scheduled for days when the test unit turbine was partially out of service, and replicates were run consecutively for the remainder of the day when the unit was again in service.

Separation efficiency (SE_F) was calculated similarly for both length groups (by species and for the total catch), as the number of separated fish in a given length group compared to the total number of smolts from that group entering the separator during the test interval:

$$SE_F = \frac{F}{T} \times 100 \quad (1)$$

where SE_F = Separation efficiency
F = Total number of separated smolts
T = Total number of fish that entered the separator

Separation efficiency values have a somewhat different implication for each of the two length groups. For small fish, separation efficiency was calculated using the fraction (F) which sounded between the separation bars as the number of separated fish, whereas separation efficiency of large fish was calculated using the fraction (F) which did not sound between the bars. However, in both cases, separation efficiency was calculated using the number of fish from each group which separated properly.

Separator exit efficiency (EE_A) was calculated by species as the proportion of fish in each size group having exited the separator compared to the total number of fish in that group entering the separator during the test interval.

$$EE_A = \frac{A}{T} \times 100 \quad (2)$$

where EE_A = Separator exit efficiency
A = Total number of fish from size group A that exited the orifice
T = Total number of fish from group A entering the separator

The ANOVA procedure was used to determine the significance of observed mean differences among treatments by length group for each species (small fish, large fish, and total catch per species) and by length group the for the total salmonid catch. For each group, separation efficiency, separator exit efficiency, and descaling were analyzed.

Results and Discussion

During the spring juvenile migration, a total of 33,617 smolts were included in conventional wet separator treatment comparisons. Small yearling chinook salmon comprised approximately 56% (18,863) of the catch, while large steelhead smolts composed about 11% (3,736) of the catch. For the summer juvenile migration period, subyearling chinook salmon made up 89% (3,967) of a total catch of 4,439 smolts. Salmonid catch data are presented by replicate in Appendix Table 1. The non-target incidental catch is cataloged in Appendix Table 2.

One divergence from the planned study design was that for some short-duration tests, our minimum sample size criteria of 25 fish per replicate was not met. Therefore, we pooled adjacent replicates of the same treatment to attain the minimum sample size. The analyses for these data sets were thus reduced to completely randomized analyses of variance (ANOVA).

For small smolt groups from the spring migration period, adequate numbers of replicates were available for analysis by species for yearling chinook, coho, sockeye salmon, and steelhead. For large smolt groups, only yearling chinook salmon and steelhead had sufficient numbers for analysis by species. Subyearling chinook salmon <180 mm FL comprised the only group with sufficient numbers of replicates for analysis during the summer juvenile migration. Since virtually all coho, sockeye, and subyearling chinook salmon were <180 mm, separate analyses by length group were not done for these species.

Separation Efficiency

Mean separation efficiency values for each group analyzed are presented in Table 1. In general, separation efficiency increased for small fish and decreased for large fish as separation-bar gap size increased. However, there was generally no difference in separation efficiency between replicates from long and short collection periods, and there were no interactions between replicate collection periods and separation-bar spacing conditions for any of the separation efficiency comparisons using the conventional separator. Complete results of statistical analyses among separation efficiency comparisons using the conventional wet separator are presented in Appendix Table 3. Time intervals of the short-duration replicates were dependent on obtaining a minimum sample size. Intervals ranged from 0.5 to 6.0 h, depending on the numbers of chinook salmon entering the test separator unit.

During the spring migration, there was a significant difference in mean separation efficiency values between separation-bar spacing conditions for small yearling chinook ($F = 0.01$, $df = 1$, $P = 0.001$), large yearling chinook ($F = 18.26$, $df = 1$, $P = 0.000$), and the total catch of yearling chinook salmon ($F = 6.89$, $df = 1$ $P = 0.013$). This was also

Table 1. Mean percent separation efficiency values obtained by length group for salmonid smolt groups during separation efficiency evaluations using a mock-up conventional wet separator at McNary Dam, 1999.

	Replicate collection period (SE)		Separation-bar spacing (SE)	
Length group	Diel	Short	17 mm	19 mm
19 April-4 June				
Yearling chinook salmon				
<180 mm	69 (1.3)	68 (1.6)	65 (1.4)	72 (1.3)
≥ 180 mm	75 (2.0)	81 (4.2)	88 (3.3)	68 (3.2)
total yearling chinook salmon	70 (1.0)	70 (1.3)	68 (1.1)	72 (1.1)
Coho salmon <180 mm	44 (3.2)	61 (5.7)	51 (4.6)	54 (3.8)
Sockeye salmon <180 mm	76 (3.1)	73 (3.6)	75 (3.7)	74 (2.9)
Steelhead				
<180 mm	45 (3.8)	56 (7.0)	42 (6.3)	58 (4.9)
≥ 180 mm	87 (1.7)	81 (2.8)	91 (2.2)	77 (2.2)
total steelhead	80 (1.8)	76 (2.9)	82 (2.3)	73 (2.4)
Total small salmonids <180 mm	68 (1.7)	70 (2.1)	65 (1.9)	73 (1.8)
Total large salmonids ≥180 mm	83 (1.6)	82 (2.2)	91 (1.8)	74 (1.9)
Total salmonid catch	71 (1.3)	73 (1.6)	71 (1.5)	73 (1.4)
22 June-31 July				
Subyearling chinook salmon <180 mm	69 (2.9)	68 (3.7)	70 (3.2)	67 (3.4)

true for the large steelhead (F = 22.50, df = 1, P = 0.000), total catch of steelhead (F = 6.81, df = 1, P = 0.016), total catch of small salmonids (F = 8.42, df = 1, P = 0.007), and total catch of large salmonids (39.97, df = 1, P = 0.000). Small coho salmon formed the only group displaying a real separation efficiency difference between replicates collected during short and diel periods (Table 1). Based on 11 valid replicates, the difference was significant (F = 6.09, df = 1, P = 0.049).

Only 19 replicates were completed during the summer juvenile migration due to a siphon valve failure. Subyearling chinook salmon mean separation efficiency also exhibited no differences by separation-bar gap size (F = 0.45, df = 1, P = 0.628) or the duration of the collection period (F = 0.07, df = 1, P = 0.796). No interaction was observed between bar spacing and collection period (F = 1.31, df = 1 P = 0.273). Separation efficiency for subyearling chinook salmon ranged from 64 to 72% over the four treatments.

Separator Exit Efficiency

Separator exit efficiency ranged from 93 to 100% for groups analyzed during the spring juvenile migration (Table 2). Exit efficiency for the total salmonid catch ranged from 96 to 98% during the spring migration, and was virtually 100% for subyearling chinook salmon smolts during the summer migration. Because exit efficiency was high for all groups across all conditions, data from different treatments for this variable were not formally compared.

Fish Condition

Results of statistical comparisons for descaling are presented in Appendix Table 4. During the spring juvenile migration, mean descaling ranged from 0.9 to 5.4% for analyzed groups (Table 3). There was no interaction among treatment conditions for any comparison, and the only significant difference was between replicate duration factors for the total salmonid catch (F = 15.16, df = 1, P = 0.000). For this group, mean descaling was higher for diel collection period replicates (2.3%, SE = 0.2) than for replicates collected over a shorter period (1.0%, SE = 0.2). This was possibly an artifact of the sampling procedure, which differed somewhat for replicates in short vs. long collection periods.

As noted above, fish were removed from holding tanks periodically during the 24-h collection periods, whereas samples from the short-term collections were allowed to accumulate in the holding tank until the minimum number of smolts had been collected. In the latter case, fish were removed after the test had ended, and it was possible to pre-anesthetize the catch prior to removal from the tanks. However, since both sample procedures were completed over 24-h periods, it is unlikely that the descaling difference represents variation due to diel timing. In either case, both of these values represent minimal descaling, probably at or near levels typically observed in fish exiting a gatewell.

Table 2. Mean percent separator exit efficiency values obtained by length group for salmonid smolt groups during separation efficiency evaluations using a mock-up conventional wet separator at McNary Dam, 1999.

Length group	Replicate collection period (SE)		Separation-bar spacing (SE)	
	Diel	Short	17 mm	19 mm
19 April-4 June				
Yearling chinook salmon				
<180 mm	93 (0.5)	96 (2.1)	95 (1.1)	94 (1.4
≥180 mm	98 (0.9)	99 (1.0)	98 (1.5)	99 (0.3)
total yearling chinook salmon	95 (0.6)	96 (2.0)	96 (1.1)	95 (1.4
Coho salmon <180 mm	98 (1.1)	99 (1.2)	99 (0.8)	98 (1.3)
Sockeye salmon <180 mm	98 (0.8)	99 (0.5)	99 (0.3)	98 (0.8)
Steelhead				
<180 mm	100 (0.1)	100 (0.1)	100 (0.0)	100 (0.1)
≥180 mm	100 (0.1)	100 (0.1)	100 (0.0)	100 (0.1)
total steelhead	99 (0.2)	98 (2.0)	100 (0.2)	98 (1.6)
Total small salmonids <180 mm	96 (0.3)	98 (1.0)	97 (0.7)	96 (0.6)
Total large salmonids ≥180 mm	99 (0.6)	100 (0.1)	99 (0.8)	100 (0.2)
Total salmonid catch	96 (0.4)	98 (0.9)	97 (0.7)	97 (0.6)
22 June-31 July				
Subyearling chinook salmon <180 mm	99 (0.6)	100 (0.3)	99 (0.7)	100 (0.3)

Table 3. Mean percent descaling values, by length group, obtained for salmonid smolt groups during separation efficiency evaluations using a mock-up conventional wet separator at McNary Dam, 1999.

	Replicate collection period (SE)		Separation-bar spacing (SE)	
Length group	Diel	Short	17 mm	19 mm
	19 April-4 June			
Yearling chinook salmon				
<180 mm	2.1 (0.3)	1.3 (0.4)	1.9 (0.3)	1.5 (0.3)
≥180 mm	3.3 (0.7)	4.0 (1.6)	4.8 (1.2)	2.5 (1.2)
total yearling chinook salmon	2.3 (0.4)	1.5 (0.5)	2.3 (0.4)	1.6 (0.5)
Coho salmon <180 mm	1.2 (0.5)	2.8 (0.9)	3.1 (0.7)	0.9 (0.9)
Sockeye salmon <180 mm	1.9 (0.4)	1.1 (0.5)	1.0 (0.5)	2.1 (0.4)
Steelhead				
<180 mm	1.9 (0.6)	3.1 (1.0)	2.8 (0.9)	2.2 (0.7)
≥180 mm	4.2 (0.8)	4.0 (1.4)	5.4 (1.1)	2.8 (1.1)
total steelhead	3.8 (0.7)	3.5 (1.1)	4.6 (0.9)	2.7 (0.9)
Total small salmonids <180 mm	2.0 (0.3)	1.2 (0.3)	1.6 (0.3)	1.6 (0.3)
Total large salmonids ≥180 mm	3.9 (0.5)	2.1 (0.8)	3.3 (0.6)	2.7 (0.6)
Total salmonid catch	2.3 (0.2)	1.0 (0.2)	1.6 (0.2)	1.7 (0.2)
	22 June-31 July			
Subyearling chinook salmon <180 mm	1.1 (0.2)	0.8 (0.3)	1.0 (0.2)	1.0 (0.2)

SEPARATION AND EXIT EFFICIENCY AND FISH CONDITION IN A HIGH-VELOCITY FLUME WET SEPARATOR

Materials and Methods

The HVF wet separator constructed for concept evaluation in 1997 (McComas et al. 2000) was used during this series. The separator consists of an aluminum flume 0.76 m (30 in) square in cross section with a working separation-bar length of 12 m (40 ft). Individual separation bars were 25.4-mm (1-in) ID (31.8-mm, 1.25-in OD) aluminum tubing. The 12-m array was fabricated with 8 interconnecting panels, each 1.5 m long by 0.76 m wide (5 ft × 30 in). Panels were removable to facilitate exchange among bar spacing and slope treatments. To evaluate the effect of separation-bar spacing on separation efficiency and separator exit efficiency, two arrays of separation bars were fabricated with gaps of 17 and 19 mm (0.69 and 0.75 in) between bars.

Separation-bar panels were supported in the flume by 25.4-mm (1-in) square aluminum stanchions. Stanchions were placed in pockets set into, and flush with, the inside of the HVF. For all evaluations during 1999, separation-bar arrays were at 0° (flat) in relation to the water surface, and approximately 360 mm (14 in) above the bottom of the flume along the entire array length.

Flow in the 12-m working section of the flume was controlled by varying the height of a lift gate near the downstream end of the flume, and by regulating makeup water volume to a distribution box at the upstream end of the flume. Makeup water was supplied by forebay siphons. Velocity was measured and adjusted for each replicate using a Swoffer Model 2100 current velocity meter[1] (Swoffer Marine Instruments, Inc., Seattle, Washington) and water depth was adjusted to approximately 50 mm (2 in) over the downstream end of the separation bars for all treatments.

For each separation-bar spacing, replicate tests were conducted using groups from the short-term and diel collection periods using methods similar to those described previously for the conventional separator. Separation-bar spacing factors were randomized within replicate-duration conditions.

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

River-run smolts were obtained for the evaluation by trapping migrants from the south orifice of Gatewell 6B. After establishing treatment conditions in the separator, a replicate was initiated by opening the gatewell orifice to introduce test fish into the upstream end of the HVF along with partially dewatered gatewell-orifice flow. During short-term replicates, smolts were allowed to accumulate in the separator and holding tanks until at least 25 chinook salmon had entered the unit, at which time the replicate was terminated.

For long-term replicates, fish were removed from holding tanks during the replicate as they accumulated, but at least once every hour. After separation, recruitment from the gatewell was terminated by closing the gatewell orifice, and fish were removed from the unit and holding tanks in four groups (above bars, below bars, large-fish holding tank, small-fish holding tank). Fish were examined and enumerated as described previously for the conventional separator evaluations.

Results and Discussion

A total of 52,666 smolts were included in high-velocity flume wet separator treatment comparisons during the spring juvenile migration. Small yearling chinook and sockeye salmon, and large steelhead comprised approximately 55, 20, and 9% of the total catch, respectively.

For the spring migration period, adequate numbers of replicates were completed for separation efficiency and descaling analyses of small and large yearling chinook salmon, the total yearling chinook salmon catch, small and large steelhead, the total steelhead catch, small coho salmon, small sockeye salmon, the total small salmonid catch, the total large salmonid catch, and the total salmonid catch.

For the summer juvenile migration period, nearly 94% (55,984) of the total catch of 59,547 smolts were small subyearling chinook salmon. Small subyearling and yearling chinook salmon, small coho salmon, and the total small salmonid catch were analyzed from the summer juvenile migration. Salmonid catch data for the HVF are presented by replicate in Appendix Table 5.

Separation Efficiency

Complete results of statistical analyses among separation efficiency comparisons using the mock-up HVF separator are presented in Appendix Table 6. Among small fish groups, mean separation efficiency using the HVF during the spring juvenile migration ranged from 78 to 87% (Table 4). Small fish group separation was lower using the 17-mm separation-bar array than using the 19-mm array. There were no apparent trends by replicate duration conditions, and no significant differences between small fish group separation efficiency values for any comparison. For the total small fish catch, mean separation efficiency ranged from 83 to 85%.

Separation efficiency for large fish groups, represented only by steelhead and yearling chinook salmon, was considerably lower than for small fish (Table 4). There were no differences in separation by replicate duration for any comparison. However, large steelhead separation efficiency was significantly higher ($F = 24.01$, $df = 1$, $P = 0.000$) using 17-mm separation-bar spacing (58%, SE = 2.8) than using the 19-mm spacing (38%, SE = 2.9).

Since large steelhead predominated in both the total steelhead catch (85%) and in the total salmonid large fish catch (69%), it is not surprising that separation efficiency was significantly higher for the total steelhead catch ($F = 24.39$, $df = 1$, $P = 0.000$) and for the total large fish catch ($F = 23.84$, $df = 1$, $P = 0.000$). Respective mean separation efficiency values were 61% (SE = 2.4) and 54% (SE = 2.7) using the17-mm bar gap, and 45% (SE = 2.4) and 35% with the 19-mm spacing.

Only small fish groups were represented in analyses for work conducted over the summer juvenile migration, dominated by subyearling chinook salmon. Separation for these groups mirrored that for small fish during spring in that separation efficiency values were consistently higher using the 19-mm separation-bar gap vs. the 17-mm gap (Table 4). There were also no significant differences between mean separation values for any comparison during the summer juvenile migration. Separation efficiency was at least 90% for all comparison groups except for yearling chinook salmon using a 17-mm separation-bar spacing (86%, SE = 2.9) and using a diel replicate duration (85%, SE = 2.2). For the total salmonid catch, mean separation efficiency ranged from 90 to 92%.

These data indicate an overall propensity for salmonids to sound using the mock-up HVF, resulting in higher mean separation efficiency values for small fish and lower separation for large fish as the separation bar gap increases. Regardless of replicate length, fish from individual species groups appear to have passed between the bars more readily using the larger 19-mm spacing in all cases (Table 4), and significantly more for

Table 4. Mean percent separation efficiency values, by length group, obtained for salmonid smolt groups during separation efficiency evaluations using a mock-up high-velocity flume wet separator at McNary Dam, 1999.

	Replicate collection period (SE)		Separation-bar spacing (SE)	
Length group	Diel	Short	17 mm	19 mm
	19 April-4 June			
Yearling chinook salmon				
<180 mm	84 (1.5)	87 (1.4)	84 (1.5)	87 (1.4)
≥ 180 mm	41 (3.3)	41 (5.6)	47 (4.9)	36 (4.4)
total yearling chinook salmon	81 (1.8)	82 (1.6)	81 (1.5)	82 (1.7)
Coho salmon <180 mm	81 (2.5)	84 (3.1)	80 (2.7)	86 (2.8)
Sockeye salmon <180 mm	80 (2.3)	79 (2.1)	78 (2.2)	81 (2.2)
Steelhead				
<180 mm	82 (2.8)	80 (6.0)	78 (5.3)	85 (4.0)
≥180 mm	51 (2.4)	44 (3.3)	58 (2.8)	38 (2.9)
total steelhead	56 (2.2)	50 (2.8)	61 (2.4)	45 (2.4)
Total small salmonids <180 mm	85 (1.7)	84 (1.4)	83 (1.7)	85 (1.5)
Total large salmonids ≥180 mm	48 (2.4)	41 (3.0)	54 (2.7)	35 (2.7)
Total salmonid catch	79 (1.6)	78 (1.3)	80 (1.4)	78 (1.4)
	22 June-31 July			
Subyearling chinook salmon <180 mm	92 (1.1)	91 (0.7)	90 (0.9)	93 (0.9)
Chinook salmon <180 mm	85 (2.0)	90 (3.1)	86 (2.9)	90 (2.2)
Coho salmon <180 mm	90 (1.4)	93 (1.8)	90 (1.6)	93 (1.6)
Total salmonid catch <180 mm	91 (1.1)	91 (0.7)	90 (0.9)	92 (1.0)

the large fish groups analyzed. Therefore, the higher total salmonid catch separation efficiency during the spring juvenile migration using 17-mm separation bars (80%, SE = 1.4), relative to the 19-mm treatment (78%, SE = 1.4), appears to have been the result of increased separation for large fish using the smaller gap.

Interestingly, the data from this study are diametric to findings from a similar evaluation over the same spring time period using a prototype HVF at Ice Harbor Dam (McComas et al. in prep). In the Ice Harbor study, using 1 m/s water velocity and separation bars spaced 19 mm apart, fish tended to avoid sounding, resulting in lower separation efficiency for small fish and higher efficiency for large fish. Assuming that geographical location, treatment, and salmonid stock dissimilarities did not contribute to substantive disparity in behavior between the two size groups, the two most obvious differences between these two studies involved incident light on the separator and entrance conditions to the units. Since light conditions change continuously on a functioning separator, future work should include objectives designed to evaluate the effects of incident light on separation behavior.

Separator Exit Efficiency

Mean separator exit efficiency using the HVF ranged from 96 to 100% for all groups analyzed from the spring juvenile migration, and was virtually 100% for all groups from the summer juvenile migration (Table 5). Exit efficiency values were high enough, and differences were sufficiently negligible, that formal comparison would not have contributed meaningful results. Formal analyses were therefore not done for exit efficiency data.

Table 5. Mean percent separator exit efficiency values, by length group, obtained for salmonid smolt groups during separation efficiency evaluations using a mock-up high-velocity flume wet separator at McNary Dam, 1999.

	Replicate collection period (SE)		Separation-bar spacing (SE)	
Length group	Diel	Short	17 mm	19 mm
19 April-4 June				
Yearling chinook salmon				
<180 mm	99 (0.2)	99 (0.4)	99 (0.4)	100 (0.2)
≥180 mm	99 (0.8)	98 (1.5)	98 (1.8)	99 (0.7)
total yearling chinook salmon	99 (0.2)	99 (0.4)	99 (0.5)	100 (0.2)
Coho salmon <180 mm	100 (0.2)	99 (0.5)	100 (.02)	99 (0.5)
Sockeye salmon <180 mm	100 (0.10	100 (0.1)	100 (0.1)	100 (0.1)
Steelhead				
<180 mm	98 (0.7)	96 (2.3)	96 (1.5)	97 (1.8)
≥180 mm	99 (0.4)	96(1.9)	97 (1.8)	98 (1.2)
total steelhead	99 (0.3)	96(1.7)	97 (1.6)	97 (1.2)
Total small salmonids <180 mm	100 (0.1)	100 (0.1)	100 (0.2)	100 (0.1)
Total large salmonids ≥180 mm	99 (0.3)	97 (1.5)	97 (1.6)	98 (0.8)
Total salmonid catch	100 (0.3)	99 (0.3)	99 (0.3)	100 (0.1)
22 June-31 July				
Subyearling chinook salmon <180 mm	100 (0.3)	100 (0.2)	100 (0.2)	100 (0.2)
Yearling chinook salmon <180 mm	100 (0.2)	100 (0.0)	100 (0.0)	100 (0.2)
Coho salmon <180 mm	100 (0.0)	100 (0.0)	100 (0.0)	100 (0.0)
Total salmonid catch <180 mm	100 (0.3)	100 (0.2)	100 (0.2)	100 (0.2)

Fish Condition

Complete results of statistical comparisons between mean descaling values are documented in Appendix Table 7. Mean descaling during the spring juvenile migration ranged from 1.5 to 4.9% for analyzed groups (Table 6). There were no interactions between bar spacing and replicate duration for any comparison, and no difference in mean descaling values between separation-bar spacing conditions for any of the comparison groups. Significant descaling differences were found only between replicate duration factors, as follows:

	Mean percent descaling (SE)				
Group	Diel duration	Short duration	F	df	P
Yearling chinook salmon					
<180 mm	2.9 (0.3)	1.8 (0.3)	5.69	1	0.021
total yearling chinook	3.1 (0.3)	1.8 (0.3)	7.91	1	0.007
Sockeye salmon					
<180 mm	4.1 (0.5)	1.7 (0.5)	12.51	1	0.001
Steelhead					
≥180 mm	4.6 (0.5)	2.8 (0.7)	4.43	1	0.043
total steelhead	4.3 (0.5)	2.3 (0.6)	6.97	1	0.012
Total salmonids					
<180 mm	2.6 (0.3)	1.5 (0.2)	8.88	1	0.004
total catch	2.9 (0.3)	1.6 (0.1)	10.00	1	0.003.

Note that the difference between mean descaling values is relatively constant, ranging from 1.1 to 2.4% (mean = 1.6, SE = 0.2), and probably represents sampling bias caused by the method required for processing the catch over a diel replicate (as discussed previously in the conventional separator evaluation), rather than a true difference in descaling between the two factors. Also, as with the conventional mock-up unit, these mean values probably represent descaling near expected levels for fish exiting a gatewell.

For the summer juvenile migration period, the small yearling chinook salmon group had significantly higher descaling (F = 7.72, df = 1, P = 0.014) using a short duration replicate (5.2%, SE = 1.3) than with the diel replicate (0.9%, SE = 0.8). This difference was probably due to the pooling of replicates during the short duration tests to satisfy minimum sample size requirements for statistical analysis. There were no other significant descaling differences between treatment factors for the summer juvenile migration.

Table 6. Mean percent descaling values by length group for salmonid smolts during separation efficiency evaluations using a mock-up high-velocity flume wet separator at McNary Dam, 1999.

	Replicate collection period (SE)		Separation-bar spacing (SE)	
Length group	Diel	Short	17 mm	19 mm
19 April-4 June				
Yearling chinook salmon				
<180 mm	2.9 (0.3)	1.8 (0.3)	2.2 (0.3)	2.5 (0.3)
≥180 mm	4.7 (0.7)	3.5 (1.2)	4.9 (1.1)	3.3 (0.9)
total yearling chinook salmon	3.1 (0.3)	1.8 (0.3)	2.4 (0.3)	2.5 (0.3)
Coho salmon <180 mm	1.5 (0.4)	1.9 (0.5)	1.6 (0.5)	1.8 (0.5)
Sockeye salmon <180 mm	4.1 (0.5)	1.7 (0.5)	2.5 (0.5)	3.3 (0.5)
Steelhead				
<180 mm	2.7 (0.6)	3.3 (1.4)	4.1 (1.2)	1.9 (0.9)
≥180 mm	4.6 (0.5)	2.8 (0.7)	4.8 (0.6)	3.0 (0.6)
total steelhead	4.3 (0.5)	2.3 (0.6)	3.7 (0.5)	2.8 (0.5)
Total small salmonids <180 mm	2.6 (0.3)	1.5 (0.2)	1.9 (0.2)	2.1 (0.2)
Total large salmonids ≥180 mm	4.6 (0.6)	2.9 (0.7)	4.6 (0.6)	2.9 (0.6)
Total salmonid catch	2.9 (0.3)	1.6 (0.2)	2.3 (0.3)	2.2 (1.3)
22 June-31 July				
Subyearling chinook salmon <180 mm	0.6 (0.1)	0.5 (0.1)	0.6 (0.1)	0.6 (0.1)
Yearling chinook salmon <180 mm	0.8 (0.8)	5.2 (1.3)	4.6 (1.2)	1.5 (0.9)
Coho salmon <180 mm	1.4 (0.6)	2.4 (0.8)	2.4 (0.7)	1.4 (0.7)
Total salmonid catch <180 mm	0.7 (0.2)	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)

ACKNOWLEDGMENTS

We express appreciation to our seasonal employees for their interest and efforts in this project. We extend special thanks to Ms. Rebecca Kalamasz of the Walla Walla District COE, and at McNary Dam, to Mr. David Coleman, Mr. William Pruit, and the rigging crew for their invaluable support and cooperation. 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

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. U.S. Department of Commerce, NOAA Technical Memorandum NMFS F/NWR-29.

Congleton, J. L., W. J. LaVoie, and D. Elliott. 1997. Evaluation of procedures for collection, bypass, and downstream passage of outmigrating salmonids, 1995. Report to the U.S. Army Corps of Engineers.

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

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, 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, Washington.

McComas, R. L., M. H. Gessel, B. P. Sandford, and D. B. Dey. 2003. 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, Washington.

McComas, R. L., B. P. Sandford, C. D. Magie, J. W Ferguson, D. M. Katz, and M. Plummer. In prep. 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, Washington.

Schreck, C. B., L. E Davis, L. Burtis, P. A. Wood, J. Congleton, T. Mosey, S. Rocklage, and B. Sun. 1995. Evaluation of facilities for collection and transport of outmigrating chinook salmon 1994. Draft report to U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

APPENDIX TABLES

Appendix Table 1. Total catch, by species, for individual separation efficiency test replicates using a conventional mock-up wet separator at McNary Dam, 1999.

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 1, 20 April										
Bar spacing 17 mm, diel										
Tanks: separated			58	8	1	2			3	2
non-separated			67	89	1	11			1	
Separator: separated										
non-separated										
Replicate 2, Treatment 1, 22 April										
Bar spacing 17 mm, diel										
Tanks: separated			172	14		3			1	
non-separated			227	85	9	42			6	
Separator: separated			35		1	1				
non-separated										
Replicate 3, Treatment 1, 26 April										
Bar spacing 17 mm, diel										
Tanks: separated			94	5	4	4			2	
non-separated			71	22	1	82			3	
Separator: separated			6		1					
non-separated										
Replicate 4, Treatment 1, 28 April										
Bar spacing 17 mm, diel										
Tanks: separated			112	7	8	4			5	
non-separated			68	24	9	58			2	1
Separator: separated			14						1	
non-separated										
Replicate 5, Treatment 1, 3 May										
Bar spacing 17 mm, diel										
Tanks: separated			244	8	5	5	1		200	
non-separated			121	62	21	35	4		53	
Separator: separated			27		1	1				
non-separated						1				
Replicate 6, Treatment 1, 11 May										
Bar spacing 17 mm, diel										
Tanks: separated			308	5	3	14	4		570	
non-separated			166	42	4	160	3		186	
Separator: separated			53		6				6	
non-separated										

Appendix Table 1. 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 7, Treatment 1, 13 May										
Bar spacing 17 mm, diel										
Tanks: separated			804	31	14	5	25		429	
non-separated			410	100	16	172	14		111	
Separator: separated			76						6	
non-separated										
Replicate 8, Treatment 1, 18 May										
Bar spacing 17 mm, diel										
Tanks: separated			549	5	2	4	20		317	
non-separated			295	34	9	67	19		79	
Separator: separated			62						6	
non-separated										
Replicate 9, Treatment 1, 21 May										
Bar spacing 17 mm, diel										
Tanks: separated			1443	58	12	32	38		406	
non-separated			672	107	11	262	68		159	
Separator: separated			83						12	
non-separated				1						
Replicate 10, Treatment 1, 25 May										
Bar spacing 17 mm, diel										
Tanks: separated			229	2	8	3	30		305	
non-separated			143	22	14	107	64	1	113	
Separator: separated			39				5		18	
non-separated										
Replicate 11, Treatment 1, 27 May										
Bar spacing 17 mm, diel										
Tanks: separated			53		4	3	31		109	
non-separated	2		25	2	11	70	49		100	7
Separator: separated			9						9	
non-separated										
Replicate 12, Treatment 1, 24 June										
Bar spacing 17 mm, diel										
Tanks: separated	207		14							
non-separated	99		1		1	2	1			
Separator: separated	2									
non-separated										

Appendix Table 1. 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 13, Treatment 1, 28 June										
Bar spacing 17 mm, diel										
Tanks: separated	296		17				21			
non-separated	91		3				2			
Separator: separated							2			
non-separated										
Replicate 14, Treatment 1, 2 July										
Bar spacing 17 mm, diel										
Tanks: separated	55		1				4			
non-separated	28					2	7		1	
Separator: separated	3						1			
non-separated										
Replicate 15, Treatment 1, 8 July										
Bar spacing 17 mm, diel										
Tanks: separated	73		3				1			
non-separated	44		3			2	3			
Separator: separated	7									
non-separated										
Replicate 16, Treatment 1, 12 July										
Bar spacing 17 mm, diel										
Tanks: separated	107		7				8			
non-separated	68		12			2	5			
Separator: separated										
non-separated										
Replicate 1, Treatment 2, 5 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			36	1	6	5			12	
non-separated			12	4	4	48			7	
Separator: separated										
non-separated				1						
Replicate 2, Treatment 2, 5 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			42	2	2	1			55	
non-separated			30	12	2	17			30	
Separator: separated										
non-separated										

Appendix Table 1. 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 3, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			97			2			207	
non-separated			50	22	1	14			30	
Separator: separated										
non-separated										
Replicate 4, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			75	2	3	2	2		34	
non-separated			31	12	6	29			12	
Separator: separated										
non-separated										
Replicate 5, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			114		4	6	2		12	
non-separated			61	11	2	31	5		2	
Separator: separated										
non-separated										
Replicate 6, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			152	3			10		176	
non-separated			89	26		8	6	1	39	
Separator: separated			53						12	
non-separated										
Replicate 7, Treatment 2, 26 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			79		8	3	33		18	
non-separated			50	8	13	30	28	1	8	
Separator: separated										
non-separated										

Appendix Table 1. 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 8, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	201		2				4			
non-separated	19		2	1		1	2	1		
Separator: separated										
non-separated										
Replicate 9, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	85		5				3			
non-separated	73		1							
Separator: separated	2									
non-separated										
Replicate 10, Treatment 2, 6 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	161		14				28			
non-separated	108		7				17			
Separator: separated										
non-separated										
Replicate 11, Treatment 2, 7 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	108		9			1	14			
non-separated	26						2			
Separator: separated										
non-separated										
Replicate 1, Treatment 3, 21 April										
Bar spacing 19 mm, diel										
Tanks: separated			82	22	3	4			2	
non-separated			41	44		10			1	1
Separator: separated			8	3						
non-separated										
Replicate 2, Treatment 3, 23 April										
Bar spacing 19 mm, diel										
Tanks: separated			160	24	6	18	1		2	
non-separated			99	52	3	44			3	
Separator: separated			5							
non-separated										

Appendix Table 1. 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 3, Treatment 3, 27 April										
Bar spacing 19 mm, diel										
Tanks: separated			118	2		7			4	1
non-separated			55	24	4	64	1		1	
Separator: separated			10							
non-separated										
Replicate 4, Treatment 3, 29 April										
Bar spacing 19 mm, diel										
Tanks: separated			311	22	3	7			25	
non-separated			147	36	7	46			11	
Separator: separated			32							
non-separated										
Replicate 5, Treatment 3, 4 May										
Bar spacing 19 mm, diel										
Tanks: separated			224	19	11	18	1	1	259	
non-separated			91	45	4	106			72	
Separator: separated			32	2		2			3	
non-separated										
Replicate 6, Treatment 3, 6 May										
Bar spacing 19 mm, diel										
Tanks: separated			285	30	4	32			268	
non-separated			141	77	6	92			93	
Separator: separated			22	2					3	
non-separated										
Replicate 7, Treatment 3, 7 May										
Bar spacing 19 mm, diel										
Tanks: separated			1162	121	18	58	4		1746	
non-separated			451	188	11	152	1		289	
Separator: separated			108	6		1			22	
non-separated										
Replicate 8, Treatment 3, 10 May										
Bar spacing 19 mm, diel										
Tanks: separated			384	38	20	54	2		725	
non-separated			168	47	11	112	5		141	
Separator: separated			53	1	2	2			13	
non-separated										

Appendix Table 1. 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 9, Treatment 3, 17 May										
Bar spacing 19 mm, diel										
Tanks: separated			993	33	11	41	16		215	
non-separated			226	51	12	125	19		43	
Separator: separated			75		2				4	
non-separated										
Replicate 10, Treatment 3, 18 May										
Bar spacing 19 mm, diel										
Tanks: separated			540	11	7	14	15	1	248	
non-separated			343	51	25	144	26	2	78	
Separator: separated			69		1		2		13	
non-separated										
Replicate 11, Treatment 3, 24 May										
Bar spacing 19 mm, diel										
Tanks: separated			534	11	3	22	21	1	272	
non-separated			174	29	18	103	27		84	12
Separator: separated			56		2		8			
non-separated										
Replicate 12, Treatment 3, 25 June										
Bar spacing 19 mm, diel										
Tanks: separated	294		12				3		1	
non-separated	116		6			2	1			
Separator: separated										
non-separated										
Replicate 13, Treatment 3, 29 June										
Bar spacing 19 mm, diel										
Tanks: separated	371		5				11			
non-separated	99		2			1				
Separator: separated	3		1							
non-separated										
Replicate 14, Treatment 3, 1 July										
Bar spacing 19 mm, diel										
Tanks: separated	108		3				10			
non-separated	68		3			3	3		1	
Separator: separated										
non-separated										

Appendix Table 1. 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 15, Treatment 3, 5 July										
Bar spacing 19 mm, diel										
Tanks: separated	144		11				18			
non-separated	66		1	2		3	16			
Separator: separated	4									
non-separated										
Replicate 16, Treatment 3, 9 July										
Bar spacing 19 mm, diel										
Tanks: separated	232		9				28			
non-separated	121		2				14	1	1	
Separator: separated										
non-separated										
Replicate 17, Treatment 3, 13 July										
Bar spacing 19 mm, diel										
Tanks: separated	148		5				5			
non-separated	49		3			1	3			
Separator: separated										
non-separated										
Replicate 1, Treatment 4, 5 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			9	1		1			12	
non-separated			9	4	2	14			5	
Separator: separated										
non-separated										
Replicate 2, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			87	3		4	1		12	
non-separated			31	18	2	5	1		5	
Separator: separated										
non-separated										
Replicate 3, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			60						281	
non-separated			32	1		1			24	
Separator: separated			11						8	
non-separated										

Appendix Table 1. 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 4, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			79	3	5	12	1		39	
non-separated			29	6	1	21			24	
Separator: separated										
non-separated										
Replicate 5, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			532	31	23	64	7		17	
non-separated			120	39	7	90	14	1	30	
Separator: separated										
non-separated										
Replicate 6, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			114	5	6	3			31	
non-separated			43	12	1	12	1		10	
Separator: separated										
non-separated										
Replicate 7, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			116	1		1			83	
non-separated			48	3		1			18	
Separator: separated			17		1				1	
non-separated										
Replicate 8, Treatment 4, 26 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			76	1	5	6	48		350	
non-separated			64	2	13	70	40		271	34
Separator: separated			56		2	1	12			
non-separated										
Replicate 9, Treatment 4, 26 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			261	3	18	17	60		45	
non-separated			53	12	5	56	32	5	17	
Separator: separated										
non-separated										

Appendix Table 1. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 10, Treatment 4, 23 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	47									
non-separated	24				2	3				
Separator: separated	2									
non-separated										
Replicate 11, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	62					1	9			
non-separated	38						2			
Separator: separated										
non-separated										
Replicate 12, Treatment 4, 6 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	15		1				2			
non-separated	3						1			
Separator: separated										
non-separated										
Replicate 13, Treatment 4, 7 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	55		11				3			
non-separated	35		3				3			
Separator: separated										
non-separated										

Appendix Table 2. Incidental species captured during separator efficiency studies at McNary Dam, 19 April-31 July, 1999. Species are listed in order of total capture frequency.

Common name	Scientific name	Total catch
lamprey	*Lampetra tridentata*	1,030
whitefish	*Prosopium williamsoni*	87
sucker	*Catostomus* spp.	48
yellow perch	*Perca flavescens*	32
peamouth	*Mylocheilus caurinus*	20
carp	*Cyprinus carpio*	15
bass	*Micropterus* spp.	11
redside shiner	*Richardsonius balteatus*	6
channel catfish	*Ictalurus punctatus*	5
northern pikeminnow	*Ptychocheilus oregonensis*	5
chiselmouth	*Acrocheilus alutaceus*	2
crappie	*Proxomus* spp.	2
sand roller	*Columbia transmontanus*	1
shad	*Alosa sapidissima*	1
three-spined stickleback	*Gasterosteus aculeatus*	1

Appendix Table 3. Statistical analysis results of comparisons between least squares mean separation efficiency values by group for treatments evaluated using a mock-up conventional wet separator at McNary Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Yearling chinook salmon				
<180 mm	replicate duration	0.01	1	0.936
	separation-bar spacing (gap)	14.14	1	0.001 *
	duration vs. spacing	0.58	1	0.451
≥180 mm	replicate duration	1.41	1	0.251
	separation-bar spacing (gap)	18.26	1	0.000 *
	duration vs. spacing	0.59	1	0.451
total yearling chinook	replicate duration	0.22	1	0.640
	separation-bar spacing (gap)	6.89	1	0.013 *
	duration vs. spacing	0.03	1	0.857
Coho salmon <180 mm	replicate duration	6.09	1	0.049 *
	separation-bar spacing (gap)	0.25	1	0.634
	duration vs. spacing	0.19	1	0.676
Sockeye salmon ≥180 mm	replicate duration	0.32	1	0.579
	separation-bar spacing (gap)	0.09	1	0.773
	duration vs. spacing	1.37	1	0.254
Steelhead				
<180 mm	replicate duration	1.96	1	0.199
	separation-bar spacing (gap)	3.56	1	0.096
	duration vs. spacing	0.60	1	0.460
≥ 180 mm	replicate duration	2.18	1	0.154
	separation-bar spacing (gap)	22.5	1	0.000 *
	duration vs. spacing	0.21	1	0.649

Appendix Table 3. Continued.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Total steelhead	replicate duration	1.04	1	0.319
	separation-bar spacing (gap)	6.81	1	0.016 *
	duration vs. spacing	0.00	1	0.992
Total small salmonids <180 mm	replicate duration	0.33	1	0.568
	separation-bar spacing (gap)	8.42	1	0.007 *
	duration vs. spacing	1.23	1	0.276
Total large salmonids ≥180 mm	replicate duration	0.03	1	0.869
	separation-bar spacing (gap)	39.97	1	0.000 *
	duration vs. spacing	0.14	1	0.715
Total salmonid catch	replicate duration	0.63	1	0.435
	separation-bar spacing (gap)	1.61	1	0.213
	duration vs. spacing	0.65	1	0.428
	2 June-31 July			
Subyearling chinook salmon <180 mm	replicate duration	0.07	1	0.796
	separation-bar spacing (gap)	0.25	1	0.628
	duration vs. spacing	1.31	1	0.273
Total salmonid catch <180 mm	replicate duration	0.00	1	0.982
	separation-bar spacing (gap)	0.20	1	0.661
	duration vs. spacing	1.72	1	0.213

Appendix Table 4. Statistical analysis results of comparisons between least squares mean descaling values by group for treatments evaluated using a mock-up conventional wet separator at McNary Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Yearling chinook salmon				
<180 mm	replicate duration	3.08	1	0.89
	separation-bar spacing (gap)	0.73	1	0.401
	duration vs. spacing	0.21	1	0.652
≥180 mm	replicate duration	0.16	1	0.691
	separation-bar spacing (gap)	1.87	1	0.188
	duration vs. spacing	1.07	1	0.316
total yearling chinook	replicate duration	1.46	1	0.237
	separation-bar spacing (gap)	1.18	1	0.285
	duration vs. spacing	0.55	1	0.464
Coho salmon <180 mm	replicate duration	2.17	1	0.191
	separation-bar spacing (gap)	5.86	1	0.055
	duration vs. spacing	2.11	1	0.196
Sockeye salmon ≥180 mm	replicate duration	1.93	1	0.179
	separation-bar spacing (gap)	3.17	1	0.089
	duration vs. spacing	0.85	1	0.367
Steelhead <180 mm	replicate duration	0.95	1	0.358
	separation-bar spacing (gap)	0.30	1	0.601
	duration vs. spacing	0.72	1	0.421

Appendix Table 4. Continued.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Steelhead ≥180 mm	replicate duration	0.01	1	0.910
	separation-bar spacing (gap)	2.86	1	0.104
	duration vs. spacing	1.76	1	0.197
Steelhead total catch	replicate duration	0.05	1	0.163
	separation-bar spacing (gap)	2.18	1	0.154
	duration vs. spacing	1.66	1	0.210
Total small salmonids <180 mm	replicate duration	3.12	1	0.087
	separation-bar spacing (gap)	0.01	1	0.925
	duration vs. spacing	0.02	1	0.888
Total large salmonids ≥180 mm	replicate duration	3.66	1	0.066
	separation-bar spacing (gap)	0.42	1	0.523
	duration vs. spacing	0.21	1	0.650
Total salmonid catch	replicate duration	15.16	1	0.000 *
	separation-bar spacing (gap)	0.28	1	0.602
	duration vs. spacing	2.55	1	0.120
	2 June-31 July			
Subyearling chinook salmon <180 mm	replicate duration	0.78	1	0.392
	separation-bar spacing (gap)	0.04	1	0.843
	duration vs. spacing	0.15	1	0.708
Total salmonid catch <180 mm	replicate duration	1.80	1	0.202
	separation-bar spacing (gap)	0.15	1	0.701
	duration vs. spacing	0.00	1	0.981

Appendix Table 5. Total catch, by species, for individual separation efficiency test replicates using a high-velocity flume wet separator at McNary Dam, 1999.

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 1, 20 April										
Bar spacing 17 mm, diel										
Tanks: separated			203	83	2	9			2	
non-separated			31	56	2	38			1	
Separator: separated										
non-separated										
Replicate 2, Treatment 1, 22 April										
Bar spacing 17 mm, diel										
Tanks: separated			327	34	3	13			6	
non-separated			104	47		50				
Separator: separated										
non-separated										
Replicate 3, Treatment 1, 26 April										
Bar spacing 17 mm, diel										
Tanks: separated			156	15	6	21			6	
non-separated			31	16	1	99			2	
Separator: separated										
non-separated										
Replicate 4, Treatment 1, 28 April										
Bar spacing 17 mm, diel										
Tanks: separated			165	11	5	7	2		17	
non-separated			44	14	3	40			4	
Separator: separated			2							
non-separated										
Replicate 5, Treatment 1, 3 May										
Bar spacing 17 mm, diel										
Tanks: separated			669	16	18	24	2		181	
non-separated			47	45		45			31	
Separator: separated						2				
non-separated										
Replicate 6, Treatment 1, 6 May										
Bar spacing 17 mm, diel										
Tanks: separated			768	63	22	58			392	
non-separated			162	107	5	71			105	
Separator: separated									1	
non-separated				1						

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 7, Treatment 1, 11 May										
Bar spacing 17 mm, diel										
Tanks: separated			1664	46	30	140	2		1244	10
non-separated			260	76	12	173	1		246	
Separator: separated			9	3	2	2				
non-separated										
Replicate 8, Treatment 1, 13 May										
Bar spacing 17 mm, diel										
Tanks: separated			2657	61	48	111	21		532	
non-separated			443	39	2	111	5		182	
Separator: separated			4			3				
non-separated						2				
Replicate 9, Treatment 1, 14 May										
Bar spacing 17 mm, diel										
Tanks: separated			3514	110	84	157	51		562	
non-separated			615	93	30	249	7		194	
Separator: separated			7			2			1	
non-separated			3			1			2	
Replicate 10, Treatment 1, 18 May										
Bar spacing 17 mm, diel										
Tanks: separated			1613	60	11	60	26		320	
non-separated			263	19	4	38	11		95	
Separator: separated			2							
non-separated										
Replicate 11 , Treatment 1, 24 May										
Bar spacing 17 mm, diel										
Tanks: separated			1196	31	25	68	86	2	338	
non-separated			81	36	2	63	9		40	1
Separator: separated			10		1		2		1	
non-separated			1							
Replicate 12, Treatment 1, 31 May										
Bar spacing 17 mm										
Tanks: separated	257		74		21	54	65		47	
non-separated	31		14	6	16	205	13		7	
Separator: separated	2		2		1	2	1		1	
non-separated										

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 13, Treatment 1, 3 June										
Bar spacing 17 mm, diel										
Tanks: separated	991		61	4	20	15	105	7	55	
non-separated	152		40	8	6	35	32	2	28	
Separator: separated	1		2		1		1			
non-separated										
Replicate 14, Treatment 1, 22 June										
Bar spacing 17 mm, diel										
Tanks: separated	2699		157		3	7	55		1	
non-separated	309		38	4		17	13			
Separator: separated	1					3				
non-separated										
Replicate 15, Treatment 1, 25 June										
Bar spacing 17 mm, diel										
Tanks: separated	3912		107	2		2	20		1	
non-separated	728		21	2		12	5	1		
Separator: separated	1				1					
non-separated										
Replicate 16, Treatment 1, 28 June										
Bar spacing 17 mm, diel										
Tanks: separated	3878		9				38			
non-separated	398		2			1	3		1	
Separator: separated	7									
non-separated										
Replicate 17, Treatment 1, 2 July										
Bar spacing 17 mm, diel										
Tanks: separated	1092		4			2	93			
non-separated	78		3				8			1
Separator: separated										
non-separated										
Replicate 18, Treatment 1, 9 July										
Bar spacing 17 mm, diel										
Tanks: separated	2053		44			3	108			
non-separated	172		10	1		7	13			
Separator: separated										
non-separated										

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 19, Treatment 1, 12 July										
Bar spacing 17 mm, diel										
Tanks: separated	939		18				23		1	
non-separated	59		2	1		1				
Separator: separated										
non-separated										
Replicate 20, Treatment 1, 15 July										
Bar spacing 17 mm, diel										
Tanks: separated	583		31				23			
non-separated	57		3			2				1
Separator: separated	2									
non-separated										
Replicate 21, Treatment 1, 19 July										
Bar spacing 17 mm, diel										
Tanks: separated	2294		81				69		1	
non-separated	99		8			3	11			
Separator: separated	1									
non-separated										
Replicate 22, Treatment 1, 23 July										
Bar spacing 17 mm, diel										
Tanks: separated	816		17				28			
non-separated	127		4				9			
Separator: separated	1									
non-separated										
Replicate 23, Treatment 1, 27 July										
Bar spacing 17 mm, diel										
Tanks: separated	806		7				22			
non-separated	61		5							
Separator: separated										
non-separated										
Replicate 24, Treatment 1, 30 July										
Bar spacing 17 mm, diel										
Tanks: separated	480		2							
non-separated	79		2			2				
Separator: separated	2									
non-separated										

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, 5 May										
Bar spacing 17 mm, Short Duration										
Tanks: separated			99	7	9	37			21	
non-separated			16	9	1	33			2	
Separator: separated										
non-separated										
Replicate 2, Treatment 2, 5 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			36		3	10			18	
non-separated			6	6		20			7	
Separator: separated										
non-separated										
Replicate 3, Treatment 2, 5 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			111	5		5			35	
non-separated			7	5		13	1		15	
Separator: separated										
non-separated										
Replicate 4, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			137	4	2	15	1		29	
non-separated			15	7		12			3	
Separator: separated										
non-separated										
Replicate 5, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			160	15	1	11			85	
non-separated			34	5		7			42	
Separator: separated			4							
non-separated						1				
Replicate 6, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			64		1				61	
non-separated			19	1					36	
Separator: separated			1							
non-separated										

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 7, Treatment 2, 12 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			86			1			124	
non-separated			37	2		1			63	
Separator: separated										
non-separated										
Replicate 8, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			225	6	2	12	8		10	
non-separated			35	1	2	9	2			
Separator: separated										
non-separated										
Replicate 9, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			424	21	1	10	5		147	
non-separated			40	1	1	4			38	
Separator: separated			2							
non-separated										
Replicate 10, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			131	2		1			52	
non-separated			12	2					8	
Separator: separated										
non-separated										
Replicate 11, Treatment 2, 19 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			89	1					342	
non-separated			14						6	
Separator: separated									1	
non-separated										
Replicate 12, Treatment 2, 26 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			419	16	15	147	144	4	153	
non-separated	2		64	5	7	77	17		16	
Separator: separated										
non-separated										

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 13, Treatment 2, 26 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			63		1	13	32		14	
non-separated			10			17	4	1	3	
Separator: separated										
non-separated										
Replicate 14, Treatment 2, 26 May										
Bar spacing 17 mm, Short duration										
Tanks: separated			22		2	1	31		125	
non-separated			13	1	5	6	16		67	
Separator: separated			5	1	2	3	1			
non-separated										
Replicate 15, Treatment 2, 1 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	24		11	1	7	3	10		22	
non-separated	3		3	2	1	11	7		16	
Separator: separated					3	5			1	
non-separated						5				
Replicate 16, Treatment 2, 2 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	51		7			6	10	1	2	
non-separated	17		4			17	5		1	
Separator: separated										
non-separated										
Replicate 17, Treatment 2, 2 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	72		15	2	4	6	11	2	4	
non-separated	2					1	1			
Separator: separated					1	1				
non-separated										
Replicate 18, Treatment 2, 23 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	961		2			2	5		2	
non-separated	56					6				1
Separator: separated										
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 19, Treatment 2, 23 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	661					2	2			
non-separated	75					1	2			
Separator: separated										
non-separated										
Replicate 20, Treatment 2, 23 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	116				1		1			
non-separated	31									
Separator: separated										
non-separated										
Replicate 21, Treatment 2, 30 June										
Bar spacing17 mm, Short duration										
Tanks: separated	956		1				16			
non-separated	55					1				
Separator: separated										
non-separated										
Replicate 22, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	516						30	1		
non-separated	31						2			
Separator: separated										
non-separated										
Replicate 23, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	336		6		1		3			
non-separated	23									
Separator: separated										
non-separated										
Replicate 24, Treatment 2, 30 June										
Bar spacing 17 mm, Short duration										
Tanks: separated	86									
non-separated	27									
Separator: separated	2									
non-separated										

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 25, Treatment 2, 1 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	77						5			
non-separated	15									
Separator: separated										
non-separated										
Replicate 26, Treatment 2, 1 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	68						2			
non-separated	11									
Separator: separated										
non-separated										
Replicate 27, Treatment 2, 6 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	1862		78		1		140			
non-separated	144		9			1	23			
Separator: separated										
non-separated										
Replicate 28, Treatment 2, 7 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	430						31		1	
non-separated	24						2			
Separator: separated										
non-separated										
Replicate 29, Treatment 2, 7 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	170		7				7			
non-separated	5									
Separator: separated										
non-separated										
Replicate 30, Treatment 2, 7 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	156		5				3			
non-separated	14		1			2	1			
Separator: separated	1									
non-separated										

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 31, Treatment 2, 13 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	171		2							
non-separated	14									
Separator: separated										
non-separated										
Replicate 32, Treatment 2, 13 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	98									
non-separated	11					2				
Separator: separated										
non-separated										
Replicate 33, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	232		11				24			
non-separated	15		2				1			
Separator: separated										
non-separated										
Replicate 34, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	170		6				13			
non-separated	8						1			
Separator: separated										
non-separated										
Replicate 35, Treatment 2, 14 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	1126		10				2			
non-separated	82		1			1	1			
Separator: separated										
non-separated										
Replicate 36, Treatment 2, 21 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	53		4				4			
non-separated	7		3							
Separator: separated										
non-separated										

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 37, Treatment 2, 21 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	31						2			
non-separated	5									
Separator: separated										
non-separated										
Replicate 38, Treatment 2, 21 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	50									
non-separated	8									
Separator: separated										
non-separated										
Replicate 39, Treatment 2, 21 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	28									
non-separated	3									
Separator: separated										
non-separated										
Replicate 40, Treatment 2, 28 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	63									
non-separated	5									
Separator: separated										
non-separated										
Replicate 41, Treatment 2, 28 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	51									
non-separated	4									
Separator: separated										
non-separated										
Replicate 42, Treatment 2, 28 July										
Bar spacing 17 mm, Short duration										
Tanks: separated	307		3				16			
non-separated	4					1	3			
Separator: separated										
non-separated										

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 43, Treatment 2, 28 July Bar spacing 17 mm, Short duration										
Tanks: separated	47									
non-separated	12					1				
Separator: separated	5									
non-separated										
Replicate 1, Treatment 3, 21 April Bar spacing 19 mm, diel										
Tanks: separated			176	54	5	11			2	
non-separated			21	17	1	7			1	
Separator: separated						1				
non-separated										
Replicate 2, Treatment 3, 23 April Bar spacing 19 mm, diel										
Tanks: separated			277	20	6	30			9	
non-separated			73	15		30			4	
Separator: separated			1			1				
non-separated										
Replicate 3, Treatment 3, 27 April Bar spacing 19 mm, diel										
Tanks: separated			325	66	10	46			4	
non-separated			44	16		49			1	
Separator: separated										
non-separated										
Replicate 4, Treatment 3, 29 April Bar spacing 19 mm, diel										
Tanks: separated			215	26	6	26			18	
non-separated			71	6	2	24			3	
Separator: separated										
non-separated										
Replicate 5, Treatment 3, 30 April Bar spacing 19 mm, diel										
Tanks: separated			987	108	14	61	5		75	
non-separated			104	43	5	40	1	1	21	
Separator: separated			11	3		6			1	
non-separated				1		3			1	

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 6, Treatment 3, 4 May										
Bar spacing 19 mm, diel										
Tanks: separated			854	70	25	126	3	2	329	
non-separated			74	20	1	55			51	
Separator: separated			2		2					
non-separated										
Replicate 7, Treatment 3, 10 May										
Bar spacing 19 mm, diel										
Tanks: separated			1062	48	33	196	7	2	918	
non-separated			129	20	1	97	1		143	
Separator: separated										
non-separated										
Replicate 8, Treatment 3, 17 May										
Bar spacing 19 mm, diel										
Tanks: separated			1352	36	27	114	14	2	244	
non-separated			130	24	9	46	2		58	
Separator: separated			4	1	4	3			1	
non-separated										
Replicate 9, Treatment 3, 20 May										
Bar spacing 19 mm, diel										
Tanks: separated			844	30	22	80	58	2	243	
non-separated			153	37	3	76	12	1	71	
Separator: separated					2					
non-separated										
Replicate 10, Treatment 3, 25 May										
Bar spacing 19 mm, diel										
Tanks: separated			1165	18	16	132	115	3	560	
non-separated			117	10	2	52	10	2	32	
Separator: separated			3	2	1	2			1	
non-separated										
Replicate 11, Treatment 3, 27 May										
Bar spacing 19 mm, diel										
Tanks: separated	22		192	3	25	122	184	5	185	
non-separated	5		71	3	9	97	62		50	
Separator: separated			1		4	3	4			
non-separated										

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 12, Treatment 3, 28 May										
Bar spacing 19 mm, diel										
Tanks: separated	68		578	12	48	189	428	3	119	
non-separated	10		93	5	3	138	96	1	21	
Separator: separated			30	4	1	6	7		1	
non-separated						2	1			
Replicate 13, Treatment 3, 4 June										
Bar spacing 19 mm, diel										
Tanks: separated	682		96	15	27	47	182	2	49	
non-separated	129		25	7	1	27	48		27	
Separator: separated			4		1	4	3			
non-separated										
Replicate 14, Treatment 3, 21 June										
Bar spacing 19 mm, diel										
Tanks: separated	1469		88		4	2	10		2	
non-separated	106		7	1		6			1	
Separator: separated	3		4							
non-separated										
Replicate 15, Treatment 3, 24 June										
Bar spacing 19 mm, diel										
Tanks: separated	2587		46			2	2			1
non-separated	325		9			2				
Separator: separated										
non-separated										
Replicate 16, Treatment 3, 29 June										
Bar spacing 19 mm, diel										
Tanks: separated	5387		29			1	124	1		
non-separated	406		2	1		1	6			
Separator: separated	5									
non-separated										
Replicate 17, Treatment 3, 5 July										
Bar spacing 19 mm, diel										
Tanks: separated	1797		37		1		137		2	
non-separated	134		9				15			
Separator: separated										
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 18, Treatment 3, 8 July										
Bar spacing 19 mm, diel										
Tanks: separated	664		51			1	44		1	
non-separated	26		2			2	2			
Separator: separated										
non-separated										
Replicate 19, Treatment 3, 16 July										
Bar spacing 19 mm, diel										
Tanks: separated	1129		9				42			
non-separated	41		4	1			2			
Separator: separated	3									
non-separated										
Replicate 20, Treatment 3, 20 July										
Bar spacing 19 mm, diel										
Tanks: separated	1336		45	2			63			
non-separated	42		1				14			
Separator: separated										
non-separated										
Replicate 21, Treatment 3, 22 July										
Bar spacing 19 mm, diel										
Tanks: separated	820		22	1			55			
non-separated	58		4				5			
Separator: separated										
non-separated										
Replicate 22, Treatment 3, 26 July										
Bar spacing 19 mm, diel										
Tanks: separated	716		9				21			
non-separated	37		3				1			
Separator: separated	1									
non-separated										
Replicate 23, Treatment 3, 29 July										
Bar spacing 19 mm, diel										
Tanks: separated	666		5			1	5			
non-separated	67		2							
Separator: separated	2									
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 1, Treatment 4,										
Bar spacing 19 mm, Short duration										
Tanks: separated			48	12	4	27			17	
non-separated			2	3	1	13			4	
Separator: separated						1				
non-separated										
Replicate 2, Treatment 4,										
Bar spacing 19 mm, Short duration										
Tanks: separated			46	4	1	3			10	
non-separated			10	11		9			1	
Separator: separated										
non-separated										
Replicate 3, Treatment 4, 5 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			81	6	6	9			45	
non-separated			40	13	4	18			24	
Separator: separated				1		4				
non-separated										
Replicate 4, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			148	4	5	15	2		47	
non-separated			10	2		4			6	
Separator: separated										
non-separated										
Replicate 5, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			104	1					87	
non-separated			7						36	
Separator: separated			2							
non-separated										
Replicate 6, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			66	2					104	
non-separated			16			1			39	
Separator: separated										
non-separated										

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 7, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			82	1	3	2			143	
non-separated			78	1	1	4			98	
Separator: separated			5							
non-separated										
Replicate 8, Treatment 4, 12 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			192	4	8	13	2	1	74	
non-separated			25	4		8			8	
Separator: separated										
non-separated										
Replicate 9, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			473	10	13	48	14		205	
non-separated			59	14	1	14	1		15	
Separator: separated										
non-separated										
Replicate 10, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			112	5		4	4	1	8	
non-separated			15	5		4			1	
Separator: separated										
non-separated										
Replicate 11, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			62	1					48	
non-separated			3	1		1	1		4	
Separator: separated			1							
non-separated										
Replicate 12, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			116		1	2				
non-separated			4			1				
Separator: separated										
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 13, Treatment 4, 19 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			80	1	2	1			46	
non-separated			8			1			7	
Separator: separated						1				
non-separated										
Replicate 14, Treatment 4, 26 May										
Bar spacing 19 mm, Short duration										
Tanks: separated			166	2	7	46	55	3	10	
non-separated			10			19	3		3	
Separator: separated										
non-separated										
Replicate 15, Treatment 4, 26 May										
Bar spacing 19 mm, Short duration										
Tanks: separated	17		296	12	6	22	34		280	
non-separated	1		16			7	2		29	
Separator: separated							1			
non-separated										
Replicate 16, Treatment 4, 1 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	225		93	7	22	115	76	3	23	
non-separated	29		5	1	2	38	8		3	
Separator: separated										
non-separated										
Replicate 17, Treatment 4, 2 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	58		8	4	1	40	25	1	24	
non-separated	5		2	1	2	21	2		2	
Separator: separated										
non-separated										
Replicate 18, Treatment 4, 2 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	114		7	1	1	2	6			1
non-separated	11		3	1	4	2	12		1	
Separator: separated										
non-separated										

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 19, Treatment 4, 2 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	98		11	1	1	1	8		9	
non-separated	12		2		1	1	1		4	
Separator: separated					2		1			
non-separated										
Replicate 20, Treatment 4, 23 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	691		2			1	4		1	
non-separated	129			1		1				
Separator: separated										
non-separated										
Replicate 21, Treatment 4, 23 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	481					1	2		1	
non-separated	31					1				
Separator: separated										
non-separated										
Replicate 22, Treatment 4, 23 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	557		475	2		6	14		1	
non-separated	115		43			2				
Separator: separated										
non-separated										
Replicate 23, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	876		6				14			
non-separated	17		1							
Separator: separated										
non-separated										
Replicate 24, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	408						22			
non-separated	24						1			
Separator: separated										
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 25, Treatment 4, 30 June										
Bar spacing 19 mm, Short duration										
Tanks: separated	51									
non-separated										
Separator: separated	2									
non-separated										
Replicate 26, Treatment 4, 1 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	78						5			
non-separated	9									
Separator: separated	1									
non-separated										
Replicate 27, Treatment 4, 1 July										
Bar spacing mm										
Tanks: separated	81						2			
non-separated	9									
Separator: separated										
non-separated										
Replicate 28, Treatment 4, 1 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	89						2			
non-separated	27									
Separator: separated										
non-separated										
Replicate 29, Treatment 4, 6 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	67									
non-separated	8						2			
Separator: separated	3									
non-separated										
Replicate 30, Treatment 4, 7 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	231		29		1	1	24			
non-separated	15		1	1						
Separator: separated										
non-separated										

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 31, Treatment 4, 7 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	54		4				4			
non-separated	3		1							
Separator: separated										
non-separated										
Replicate 32, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	959		27			2	38			
non-separated	30						1			
Separator: separated										
non-separated										
Replicate 33, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	182			1						
non-separated	4									
Separator: separated										
non-separated										
Replicate 34, Treatment 4, 13 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	258		1							
non-separated	25									
Separator: separated	5					1				
non-separated										
Replicate 35, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	183		5				15			
non-separated	6									
Separator: separated										
non-separated										
Replicate 36, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	170		6	1			6			
non-separated	17		1				2			
Separator: separated										
non-separated										

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 37, Treatment 4, 14 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	78									
non-separated	17									
Separator: separated										
non-separated										
Replicate 38, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	60		6							
non-separated	6		5							
Separator: separated										
non-separated										
Replicate 39, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	451		21				41			
non-separated	38						4	2		
Separator: separated	1									
non-separated										
Replicate 40, Treatment 4, 21 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	33									
non-separated	1									
Separator: separated										
non-separated										
Replicate 41, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	64									
non-separated	7									
Separator: separated										
non-separated										
Replicate 42, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	66									
non-separated	13		1							
Separator: separated										
non-separated										

Appendix Table 5. Continued.

Source	Subyearling chinook		Yearling chinook		Steelhead		Coho		Sockeye	
	<180	≥180	<180	≥180	<180	≥180	<180	≥180	<180	≥180
Replicate 43, Treatment 4, 28 July										
Bar spacing 19 mm, Short duration										
Tanks: separated	143									
non-separated	9		1							
Separator: separated										
non-separated										

Appendix Table 6. Statistical analysis results of comparisons between least squares mean separation efficiency values by group for treatments evaluated using a mock-up high-velocity flume wet separator at McNary Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Yearling chinook salmon				
<180 mm	replicate duration	1.46	1	0.232
	separation-bar spacing (gap)	2.76	1	0.103
	duration vs. spacing	0.41	1	0.526
≥180 mm	replicate duration	0.00	1	0.973
	separation-bar spacing (gap)	2.80	1	0.107
	duration vs. spacing	2.10	1	0.160
total yearling chinook	replicate duration	0.87	1	0.354
	separation-bar spacing (gap)	0.02	1	0.877
	duration vs. spacing	0.13	1	0.719
Coho salmon <180 mm	replicate duration	0.42	1	0.526
	separation-bar spacing (gap)	2.47	1	0.137
	duration vs. spacing	0.86	1	0.367
Sockeye salmon ≥180 mm	replicate duration	0.15	1	0.699
	separation-bar spacing (gap)	0.85	1	0.364
	duration vs. spacing	0.29	1	0.592
Steelhead				
<180 mm	replicate duration	0.15	1	0.705
	separation-bar spacing (gap)	1.01	1	0.337
	duration vs. spacing	0.03	1	0.876
≥180 mm	replicate duration	3.15	1	0.085
	separation-bar spacing (gap)	24.01	1	0.000 *
	duration vs. spacing	1.66	1	0.207
total steelhead	replicate duration	3.46	1	0.071
	separation-bar spacing (gap)	24.39	1	0.000 *
	duration vs. spacing	1.13	1	0.294

Appendix Table 6. Continued.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Total small salmonids	replicate duration	0.32	1	0.576
<180 mm	separation-bar spacing (gap)	0.99	1	0.324
	duration vs. spacing	0.34	1	0.564
Total large salmonids	replicate duration	2.54	1	0.120
≥180 mm	separation-bar spacing (gap)	23.84	1	0.000 *
	duration vs. spacing	1.95	1	1.171
Total salmonid catch	replicate duration	0.12	1	0.734
	separation-bar spacing (gap)	0.53	1	0.468
	duration vs. spacing	2.11	1	0.152
	2 June-31 July			
Subyearling chinook salmon	replicate duration	0.90	1	0.347
<180 mm	separation-bar spacing (gap)	2.40	1	0.126
	duration vs. spacing	0.62	1	0.435
Yearling chinook salmon	replicate duration	1.36	1	0.262
≥180 mm	separation-bar spacing (gap)	1.05	1	0.322
	duration vs. spacing	0.32	1	0.577
Coho salmon <180 mm	replicate duration	1.29	1	0.272
	separation-bar spacing (gap)	2.46	1	0.135
	duration vs. spacing	0.02	1	0.901
Total salmonid catch	replicate duration	0.78	1	0.379
<180 mm	separation-bar spacing (gap)	2.31	1	0.133
	duration vs. spacing	0.69	1	0.411

Appendix Table 7. Statistical analysis results of comparisons between least squares mean descaling values by group for treatments evaluated using a mock-up high-velocity flume wet separator at McNary Dam, 1999. Asterisks indicate significant differences ($\alpha = 0.05$) between treatment factors.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Yearling chinook salmon				
<180 mm	replicate duration	5.69	1	0.021 *
	separation-bar spacing (gap)	0.33	1	0.567
	duration vs. spacing	0.32	1	0.574
≥180 mm	replicate duration	0.71	1	0.408
	separation-bar spacing (gap)	1.17	1	0.290
	duration vs. spacing	3.15	1	0.089
total yearling chinook	replicate duration	7.91	1	0.007 *
	separation-bar spacing (gap)	0.10	1	0.748
	duration vs. spacing	0.75	1	0.389
Coho salmon <180 mm	replicate duration	0.44	1	0.519
	separation-bar spacing (gap)	0.10	1	0.757
	duration vs. spacing	0.30	1	0.593
Sockeye salmon ≥180 mm	replicate duration	12.51	1	0.001 *
	separation-bar spacing (gap)	1.24	1	0.272
	duration vs. spacing	0.09	1	0.761
Steelhead				
<180 mm	replicate duration	0.18	1	0.677
	separation-bar spacing (gap)	2.29	1	0.158
	duration vs. spacing	2.29	1	0.158
≥180 mm	replicate duration	4.43	1	0.043 *
	separation-bar spacing (gap)	3.22	1	0.082
	duration vs. spacing	3.22	1	0.595
total steelhead	replicate duration	6.97	1	0.012 *
	separation-bar spacing (gap)	1.29	1	0.264
	duration vs. spacing	0.03	1	0.858

Appendix Table 7. Continued.

Group	Treatment conditions	Calculated statistic F	df	P
	19 April-4 June			
Total small salmonids <180 mm	replicate duration	8.88	1	0.004 *
	separation-bar spacing (gap)	0.26	1	0.611
	duration vs. spacing	0.16	1	0.693
Total large salmonids ≥180 mm	replicate duration	3.49	1	0.055
	separation-bar spacing (gap)	3.86	1	0.057
	duration vs. spacing	1.22	1	0.275
Total salmonid catch	replicate duration	10.00	1	0.003 *
	separation-bar spacing (gap)	0.07	1	0.788
	duration vs. spacing	0.07	1	0.793
	2 June-31 July			
Subyearling chinook salmon <180 mm	replicate duration	0.36	1	0.553
	separation-bar spacing (gap)	0.02	1	0.891
	duration vs. spacing	0.26	1	0.610
Yearling chinook salmon <180 mm	replicate duration	7.72	1	0.014 *
	separation-bar spacing (gap)	4.06	1	0.062
	duration vs. spacing	3.45	1	0.083
Coho salmon <180 mm	replicate duration	1.03	1	0.324
	separation-bar spacing (gap)	0.89	1	0.358
	duration vs. spacing	0.19	1	0.670
Total salmonid catch <180 mm	replicate duration	0.09	1	0.770
	separation-bar spacing (gap)	0.00	1	0.998
	duration vs. spacing	0.19	1	0.662