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Passive and Passive-Active Separator Fish Sorting Studies for the Tracy Fish Collection Facility

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14. ABSTRACT
The Bureau of Reclamation's Hydraulic Investigations and Laboratory Services group in Denver, Colorado tested passive and passive-active fish separator configurations under several conditions using a physical model. Test fish included rainbow trout (*Oncorhynchus mykiss*), Sacramento splittail (*Pogonichthys macrolepidotus*), and fathead minnow (*Pimephales promelas*). Investigations using the passive separator found best overall separation efficiencies occurred during a downwelling flow condition combined with a 5° separator angle and 122-cm/s (4-ft/s) channel velocity. Separator efficiencies were all equal to or greater than 92% for this test condition. Both angle and velocity of the passive separator influenced efficiency of fish separation of rainbow trout but did not affect results for fathead minnow or splittail. The highest average separator efficiency for rainbow trout occurred when the angle was 0°. Higher channel and approach velocities significantly increased separation of this species. There was also a statistically significant interaction effect between the two variables. The second configuration tested consisted of a passive separator similar to what had already been tested, followed by an active separator positioned 1.30 m (4.25 ft) downstream from the passive separator. Tests using this configuration demonstrated total sorting efficiencies in the range of 99–100% could be achieved for a single flow condition for all species tested. Slower velocities were found to significantly increase passive separator efficiency for sorting white suckers and total (*i.e.*, passive and active) separator efficiency for sorting splittail. When spotlights illuminated the passive separator section of the passive-active separator configuration, separator efficiency improved for Chinook, splittail, and rainbow trout.

15. SUBJECT TERMS
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Passive and Passive-Active Separator Fish Sorting Studies for the Tracy Fish Collection Facility

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by

Leslie Hanna[1], Raymond Bark[2], Mark Bowen[2], Brent Mefford[1], Rafael Lopez[3], and Rebecca Siegle[4]

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Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

[1]Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory Group
PO Box 25007
Denver CO 80225-0007

[2]Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group
PO Box 25007
Denver CO 80225-0007

[3]Bureau of Reclamation
Environmental Group
302 East 1860 South
Provo UT 84606-7317

[4]Science Applications International Corporation, Inc.
Fisheries and Wildlife Resources Group
PO Box 25007
Denver CO 80225-0007

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Tracy Fish Facility Improvement Program

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Donald E. Portz, Ph.D.
U.S. Department of the Interior–Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225–0007

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TABLE OF CONTENTS

Tables

Table of Contents – continued

Figures

Appendix

EXECUTIVE SUMMARY

The Bureau of Reclamation (Reclamation) investigated methods for improving fish sorting and holding systems to better address fish protection at the Tracy Fish Collection Facility in Tracy, California. Reclamation's Hydraulic Investigations and Laboratory Services Group, in conjunction with the Fisheries and Wildlife Resources Group, in Denver, Colorado, tested passive and passive-active fish separator configurations under several conditions using a physical model.

Two horizontal bar rack fish separator systems were tested in a lab flume. A passive separator was tested to determine its effectiveness for separating large fish from small fish in the horizontal plane. Test fish included rainbow trout (*Oncorhynchus mykiss*), Sacramento splittail (*Pogonichthys macrolepidotus*), and fathead minnow (*Pimephales promelas*). Wiper bass (*Morone saxatilis* x *M. chrysops*) was added to act as a large predatory species. Best overall separation efficiencies for splittail, rainbow trout, and fathead minnow occurred during a downwelling flow condition combined with a 5° separator angle and 122-cm/s (4-ft/s) channel velocity. Separator efficiencies were all equal to or greater than 92% for this test condition. Both angle and velocity of the passive separator influenced efficiency of fish separation of rainbow trout but did not affect results for fathead minnow or splittail. The highest average separator efficiency for rainbow trout occurred when the angle was 0°. Higher channel and approach velocities significantly increased separation of this species. There was also a statistically significant interaction effect between the two variables.

The second configuration tested consisted of a passive separator similar to the one already investigated, followed by an active separator positioned 1.30 m (4.25 ft) downstream from the passive separator. For the passive-active configuration, test fish included rainbow trout, Sacramento splittail, fathead minnow, and white sucker (*Catostomus commersoni*). White suckers were added to act as a demersal species and wiper bass were again the predatory species. Delta smelt (*Hypomesus transpacificus*) and Chinook salmon (*O. tshawytscha*) were tested later when they became available. Tests using this configuration demonstrated that total sorting efficiencies of 99–100% could be achieved for a single flow condition for all species tested. Slower velocities were found to significantly increase passive separator efficiency for sorting white suckers and total (*i.e.,* passive and active) separator efficiency for sorting splittail. When spotlights illuminated the passive separator section of the passive-active separator configuration, separator efficiency improved for Chinook, splittail, and rainbow trout.

INTRODUCTION

The Bureau of Reclamation (Reclamation) has an ongoing fish salvage evaluation program investigating methods to improve operations and salvage efficiency at the Tracy Fish Collection Facility (TFCF), Tracy, California (Liston *et al*. 2000). The TFCF, Tracy Pumping Plant, and Delta-Mendota Canal facilities of the Central Valley Project, Sacramento-San Joaquin River Delta (Delta) divert water for irrigation, municipal, industrial, and environmental needs in South-Central Valley while reducing associated fish loss. The purpose of TFCF is to salvage fish entering the Delta-Mendota Canal by way of the Tracy Pumping Plant under Central Valley Project development. Title 34, Central Valley Project Improvement Act (signed into law October 30, 1992), mandates changes in management of the Central Valley Project, particularly for protection, restoration, and enhancement of fish and wildlife. Thus, an onsite Tracy Experimental Fish Facility (TEFF) was proposed for testing effectiveness of various fish screening and holding designs before constructing replacement fish salvage facilities for state and federal water diversions in the south Delta. The proposal of TEFF prompted initial smaller scale fish sorting studies by Reclamation's Hydraulic Investigations and Laboratory Services Group, in conjunction with the Fisheries and Wildlife Resources Group, in Denver, Colorado. However development of the TEFF is no longer considered feasible.

Fish sorting systems could play a critical role in returning live fish to the Delta. Currently, fish are collected, held in large holding tanks, and returned to the Delta downstream away from the influence of pumps. Fish are removed from tanks one to three times per day, transferred into tanker trucks, and transported to one of two release sites in the Delta for restocking. When predatory species such as striped bass (*Morone saxatilis*) and white catfish (*Ameiurus catus*) are mixed with native species in holding tanks and transport trucks at TFCF, the predators may eat large numbers of native fish (Fausch 2000). The in-ground circular collection system at TFCF may be inadequate because fish are confined in multiple species assemblages for 8–24 h. Confinement may cause fish to become vulnerable to stress and predation (Portz *et al*. 2005). Delta smelt (*Hypomesus transpacificus*) and Chinook salmon (*Oncorhynchus tshawytscha*) are federally listed and require protection at TFCF. At present, there is no system in place to separate listed species from larger predatory species. Potentially, predatory fish could remove substantial numbers of native fish drawn into the TFCF to be salvaged, including smolts of Chinook salmon and steelhead trout (O. *mykiss*), delta smelt, and Sacramento splittail (*Pogonichthys macrolepidotus*).

There is technology available for passively and actively separating predators from prey. Passive separators use fixed separators that depend on fish behavior and response to achieve fish passage and sorting. Water flowing past the separator is divided. A portion of the flow passes through and beneath separator bars while the remaining flow continues downstream above the separator, thereby providing fish with an option to either pass through or pass over the separator. Passive separator design considers hydraulics and fish response behavior to encourage fish to pass through the separator without forcing passage. Passive separators reduce potential for fish injury because fish are not forced to come in direct contact with separator bars. However, because passive separators depend on fish response to achieve separation they are less effective than active separators, which rely on flows to guide fish. Several factors can encourage target species to pass through the separator, including separator angle, channel geometry, and hydraulic conditions such as separator approach and sweeping velocity. These variables were investigated to determine the configuration and operation most effective for separating large and small fish into separate holding areas.

Active separators physically pass all waterflow through the separator, thus requiring fish to either pass through the separator or, if fish are too large to pass, to be retained directly by the separator. Active separators achieve high sorting efficiencies by plunging flows through the bar rack, forcing fish to pass through. Fish that are small enough will physically pass the separator, but larger fish are retained as in a typical fish size grader. Because of the nature of active separators, fish come in direct contact with separator arrays and the potential for fish injury is increased. Applied active separators include horizontal and vertical bar arrays through which a flow field is passed, separator panels that are swept through the flow (*i.e*., holding pools or raceways), and baskets that are vertically raised through holding tanks.

Reclamation referenced previous fish separation studies to obtain hydraulic design and operational data for the initial concept evaluations of fish sorting and dewatering. Literature regarding active separators was extremely sparse and no studies were found. However, discussions and published studies provided insight into performance considerations with passive separators.

Passive separators are not widely applied in aquaculture; therefore, the concept is less proven and more developmental. Passive designs include separators (typically bar arrays) placed horizontally or on a slight incline (McComas *et al*. 1996 and 1997, Katz *et al*. 1999) and separators placed vertically, similar to a wall (J. Congelton 2003, personal communication).

Separator configuration and length, and its combined influence of flow depths and flow velocity, as well as fish species, sizes, and behavior, must be considered in the development of the passive separator design. Fish reaction and response can substantially influence separator performance. Fish reaction or response to the separator surface and flow field will vary with species, as well as between developmental stages. McComas *et al*. (1997) found that, for a specific separator design and operation, separation efficiencies ranged from 50–85% for various salmonid species including Chinook, coho (*O. kisutch*), sockeye (*O. nerka*), and steelhead.

To achieve effective separator performance, it is critical that a velocity and attraction field be generated to properly orient fish to the separator (M. Timmons 2003, personal communication). If fish orientation and separator design are not correct, fish will come

into contact with the separator and avoid it. The pectoral fin is a critical contact point and once the fish's head enters the separator, the fish will pass through.
Water velocity passing the separator and water depth over the separator or channel width passing the separator (for vertical separators) also will influence performance. Katz *et al*. (1999) evaluated horizontal separators with flow velocities of 1.0 and 2.0 m/s (3.3 and 6.6 ft/s) at submergences of 50 mm (2 in) and 100 mm (3.9 in) over the separator. Higher separation efficiencies were achieved with shallower water depths and higher velocities. This may be due, in part, to the development of standing waves that yield very shallow submergences at the wave troughs. Conversely, McComas *et al*. (1997) found that inclined separators (4° and 8° adverse slopes) with a water depth of 30 mm (1.2 in) over the downstream end of the separator achieved higher separation efficiencies with a 1.0-m/s (3.3-ft/s) sweeping velocity than with a 2.0-m/s (6.6-ft/s) sweeping velocity. To minimize injury of more fragile species, sweeping velocities less than 2.0 m/s (6.6 ft/s) are more appropriate.

Flow conditions behind or below the separator must be considered and refined, both to initially encourage fish passage through the separator and then to move fish away from the separator (McComas *et al*. 1996 and 1997). Supplemental flow may have to be introduced behind the separator to generate a well-directed flow field with a large enough flow cross section to attract fish.

The majority of passive separator research that has been conducted (McComas *et al*. 1996 and 1997, Katz *et al*. 1999) has focused on horizontal and slightly inclined (4° and 8° adverse slopes) separators. Timmons (2003, personal communication) observed that typical fish responses to separators indicated a sounding movement. Based on this, Timmons speculated that an adversely inclined separator bar rack might be most effective. McComas *et al*. (1997) evaluated passive horizontal separators ranging in length up to 12.0 m (39.4 ft) and slightly inclined separators ranging in length up to 4.5 m (14.8 ft). The longer separators produced better separation efficiencies for both horizontal and slightly inclined separators. Based on these limited studies, it appeared that horizontal or adversely inclined separators with a long separator length offer the best separation efficiencies.

Separator bar shape, free spacing between bars, and the material from which the separator is fabricated, will affect fish separator performance and the potential for fish injury. Bars with round cross sections are widely applied to eliminate sharp edges that can cause descaling and other fish injuries. The spacing applied between bars depends on the separation objectives and the body size and shape of the target species.

Separators have been fabricated from materials that include aluminum, clear acrylic, stainless steel, and gray polyvinyl chloride (PVC) bars. Aluminum oxidizes, which leads to roughened surfaces that can cause fish injury (D. Lance 2003, personal communication). Stainless steel is heavy and expensive and therefore Lance recommended acrylic materials. Fish have been found to avoid gray PVC and use of clear acrylic or aluminum bars substantially improves separator performance (M. Timmons 2003, R. McComas 2003, personal communications). Separation efficiencies were comparable and there were no distinguishable differences in descaling and injury to fish between the two materials. Results may be associated with differences in operation; the Timmons separator studies were conducted in aquaculture facilities, while the McComas studies were at a continuously operating field site.

To address changes to the current system that would better protect fish species, testing was carried out at Reclamation's Hydraulic Investigations Laboratory using a physical model of a fish separator for sorting and holding fish. Two fish separator configurations were tested to determine their effectiveness for sorting fish: a passive separator and a combination of passive and active separators.

METHODS

Passive Separator

An overhead view of the passive fish separator model is shown in Figure 1. Although the separator's outer dimensions (3.28 × 0.84 m; 10.75 × 2.75 ft) were on a 1:3 scale, the diameter of the bars and the spacing between the bars were sized based on fish species and flow conditions occurring at TFCF (Fausch 2000). Thus, the separator section of the model simulated a 1/3 width with actual target depth. The passive separator was constructed of 1.9-cm-diameter (0.75-in) steel tubing spaced 1.9 cm (0.75 in) apart to allow the smaller listed species to pass through the bar rack and into a separate holding area (Figure 2).

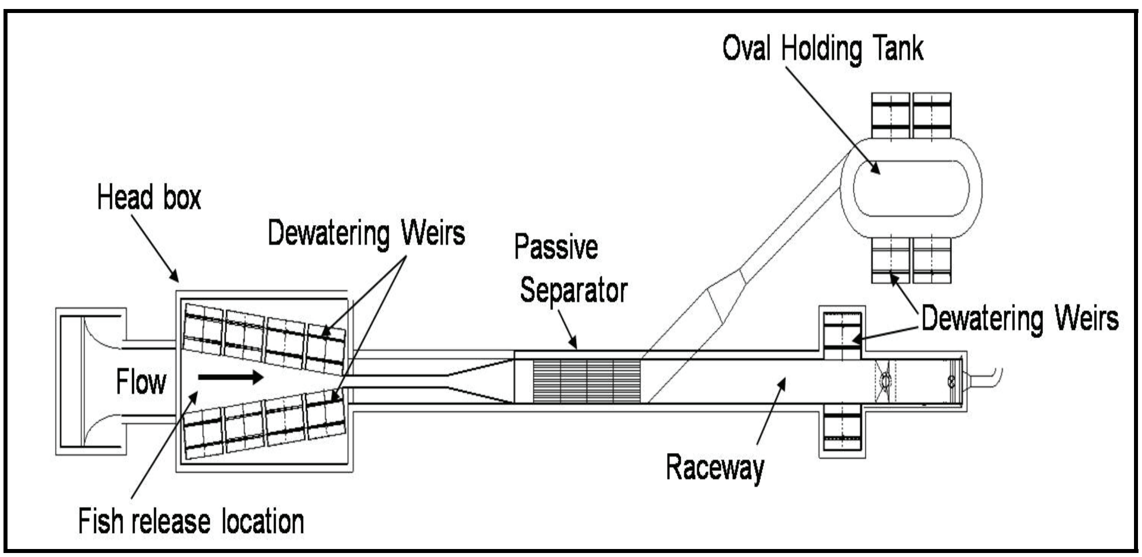

FIGURE 1.—Overhead view of the passive separator model.

FIGURE 2.—Passive separator model bar rack at a 0° angle leading into raceway.

Flow to the main channel was supplied using the laboratory venturi system. Auxiliary flow was pumped from the laboratory sump through a 20-cm (8-in) pipe beneath the upstream edge of the separator. The hydraulic model also included 14 screens and weir dewatering modules. Each module included a fixed vertical perforated metal screen followed by an adjustable overflow weir that controlled and monitored flow rates into the separator area. Weir and piezometer taps located throughout the model were measured and calibrated to determine flow depth and discharge. Average channel velocities (V_c) were measured 31.5 cm (1.0 ft) upstream from the leading edge of the separator with a Swoffer propeller flow meter (Swoffer Instruments, Inc., Seattle, Washington). Separator approach velocities (V_a; velocities perpendicular to the plane of the bar rack) were measured 5.1 cm (2.0 in) from the bar rack with a Sontek Acoustic Doppler Velocimeter (ADV) probe (Sontek/YSI Inc., San Diego, California).

The passive separator was tested to determine effectiveness for separating small fish from large fish (Figure 3). The bar rack configuration served as a passive separator because a 15.2 cm (6.0 in) flow depth was maintained above the separator bars, which is different from an active separator that is completely dewatered at the downstream end. Fish could then choose to go through bar rack openings or continue downstream above and past the separator. In addition, channel geometry was designed to decrease channel flow depth as it approached the separator. This design was based on the concept that fish, sensing lessening depth, would move to the channel bottom and could continue downward through bar rack openings, if small enough. Fish that were too large to pass through bar rack spacing would remain in the flow passing above bar racks and go into the raceway fish holding area (Figure 3).

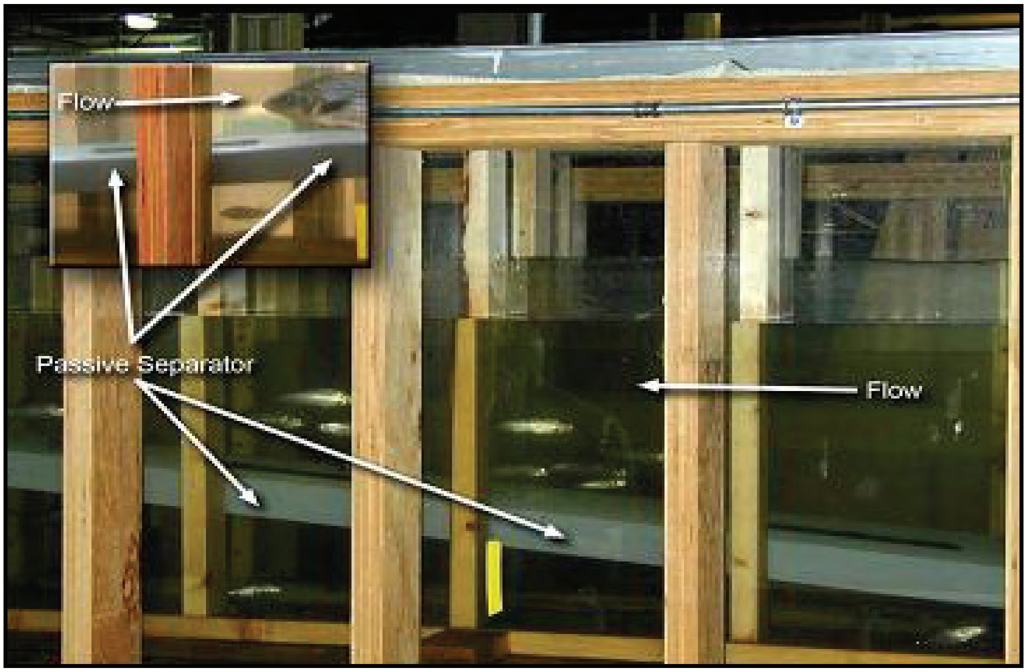

FIGURE 3.—Passive separator prevents large fish (inset) from passing into area beneath bar rack.

To determine which factors would be most effective for separating fish, a variety of test conditions were created involving two variables: separator angle and V_c. Test case conditions are summarized in Table 1. The separator angles tested were 0°, 2.25°, and 5°. For each separator angle tested, V_c and supplemental flows beneath the separator were varied to target several vertical flow regimes, defined by the manner in which flow passed through the separator.

TABLE 1.—Passive separator test case conditions.

Test Case	Average Channel Velocity (V_c) cm/s (ft/s)	Flow Regime	Average Approach Velocity (V_a) cm/s (ft/s)	Separator Angle (degrees)
1A, 2A	61.1 (2.0)	Even	0.61 (0.02)	0.0
1B, 2B	121.9 (4.0)	Downwelling	3.2 (0.12)	0.0
3	30.5(1)	Upwelling	-3.0 (-0.10)	0.0
5A	61.1 (2.0)	Even	1.8 (0.06)	2.25
5B	121.9 (4.0)	Downwelling	3.3 (0.11)	2.25
8A	61.1 (2.0)	Even	2.1 (0.07)	5.0
8B	121.9 (4.0)	Downwelling	4.0 (0.13)	5.0
9B	121.9 (4.0)	Strong downwelling	7.0 (0.23)	5.0

Average V_c were set by adjusting the amount of water flowing into the model and adjusting downstream raceway weirs to maintain a 15.25-cm (6-in) flow depth at the downstream end of the separator. Supplemental flow, entering beneath the leading edge of the separator, helped maintain target flow conditions above the separator and helped prevent vortices. Separator V_a was measured with a Sontek ADV probe at the centerline of the bar rack at four positions equally spaced along the length of the separator. Separator V_a is always given in terms of the component perpendicular to the plane of the separator. Flow regimes tested to determine hydraulic and biological performance were defined as follows (Figure 4):

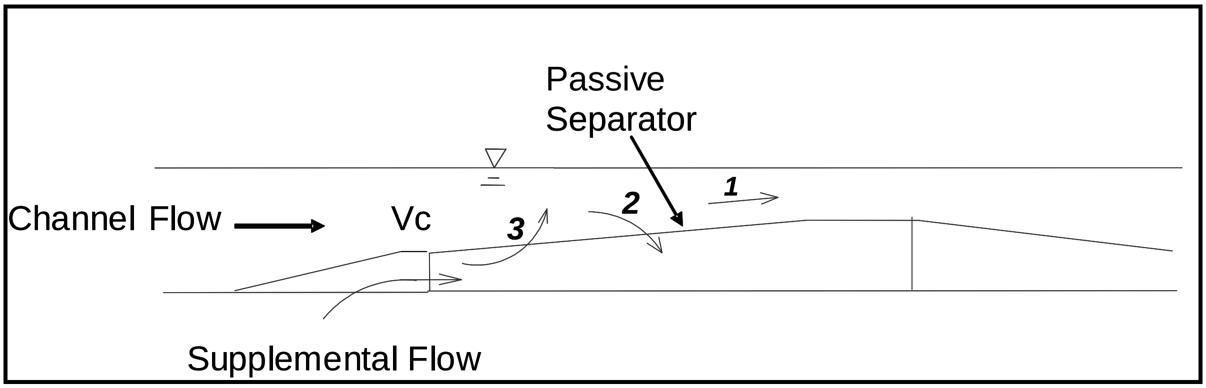

FIGURE 4.—Passive separator showing flow regimes tested: (1) even, (2) downwelling, and (3) upwelling. Channel velocity (V_c) was measured 30.5 cm (1.0 ft) upstream from separator.

- **Even –** This condition was produced when flows above and below the bar rack were similar, producing minimal net flow through the bar rack. Trials were defined as even if V_a was greater than -3.0 cm/s (-0.10 ft/s) and less than +3.0 cm/s (+0.10 ft/s). Average V_c measured upstream from the separator was 61.1 cm/s (2.0 ft/s) for this test condition.

- **Downwelling –** This test was conducted to determine if fish would follow a net downward flow through the bar rack. Separator V_a values greater than or equal to 3.0 cm/s (0.1 ft/s) were defined as downwelling. Average separator V_a measured for the 121.9-cm/s (4.0-ft/s) V_c test condition ranged from 3.0 cm/s (0.10 ft/s) to 4.0 cm/s (0.13 ft/s); therefore, this test condition was defined as downwelling. Separator V_a values for downwelling trials were limited to a maximum velocity of 4.0 cm/s (0.13 ft/s) to prevent undesirable vortices.

- **Strong downwelling –** To test the effect of greater downwelling flow conditions on separator efficiencies, turbulence at the downstream end of the separator was ignored to run one additional test case using higher V_a. Average V_a for this trial was 7.0 cm/s (0.23 ft/s) referenced as test case 9B in Table 1. Average V_c measured upstream from the separator was 121.9 cm/s (4.0 ft/s) for the strong downwelling flow condition.

- **Upwelling –** This test was conducted to determine if upward flow through the bar rack would serve as an attraction flow that fish would follow downward through the rack. Negative V_a values indicated upward (upwelling) vertical flow through the bar rack. Average V_a was -3.0 cm/s (-0.1 ft/s) with a maximum upward normal component of -4.0 cm/s (-0.13 ft/s) measured at the upstream section of the separator. In order to produce an upwelling flow condition, average V_c had to be reduced to 30.5 cm/s (1.0 ft/s), and the separator was limited to a level horizontal orientation (0°).

A minimum of three replicates was performed for each experimental test condition. For initial test conditions, three prey species were used: splittail, rainbow trout (*O. mykiss*), and fathead minnow (*Pimephales promelas*). Fathead minnow represented a weak swimmer, and rainbow trout represented a strong swimmer as well as being a surrogate for juvenile and other salmonids. Twenty-five individuals from each species were introduced into the flow at the upstream entrance to the model, referenced as headbox area. All prey test species were physically small enough to pass through the bar rack separator (see Appendix 1 for statistics on fish size). Ten wiper bass (*M. saxatilis* x *M. chrysops*) were also introduced into the flow to act as predatory species. The purpose for including a predatory species was to influence flight instinct of prey fish, which could encourage passage through the separator. However, 10% of wipers were physically small enough to pass through the separator. Wipers were fed about 1 h before each trial to minimize predation losses during experiments. Prey fish were held in 300-L (80-gal) insulated rectangular tanks, and predator fish were held in 475-L (125-gal) insulated cylindrical tanks adjacent to the separator flume. Fish holding tanks used the same water as the separator flume to maintain consistent water quality. Also, fish were held for a minimum of 1 d in holding tanks before testing to acclimate to laboratory water quality.

Each passive separator trial was conducted for 30 min, and fish were crowded from the headbox to the throat of the flume at 10, 20, and 28 min of elapsed time. This was completed by placing a 0.6-cm (0.25-in) mesh seine net at the upstream end of the headbox and then moving the seine downstream until the narrow throat of the flume was reached, about 1.52 m (5 ft) upstream of the passive separator. At the end of each experiment, a barrier net also made from 0.6-cm (0.25-in) mesh was placed over the separator; the separator model was dewatered and fish were recovered from their respective locations, counted, and measured. All test cases were evaluated for separation efficiency of sorting fish using the following formula:

$$\text{Percent efficiency} = \frac{\text{(Total recovered from oval holding tank)}}{\text{(Total recovered from oval holding tank + raceway)}} \times 100$$

Efficiencies were calculated based only on those fish that passed the separator by the end of each trial. Fish that remained in the headbox, in the narrow throat of the flume, or above the separator at the time the experiment ended were not included in the efficiency calculation.

Mean efficiencies for fish passage through the passive separator were calculated by combining three trials, then calculating the mean efficiency for each test condition by species. Test cases that were performed and resulted in identical water velocities and separator angle (1A, 2A and 1B, 2B) were combined. For each test case, the corresponding V_c, V_a, separator angle, and flow regime are listed in Table 1.

A Student's t-test or Analysis of Variance (ANOVA) was used for statistical analyses. Independence of observations, homogeneity of variance, and normality were tested for separation efficiency. Data that did not meet these assumptions were tested using the non-parametric Mann-Whitney-Wilcoxen or Kruskal-Wallis tests.

Passive-Active Separator

The second phase of testing used a combination of passive and active separator configurations. The original passive separator model was modified so that an active separator could be installed downstream from the passive separator. The passive separator remained 3.2 m (10.75 ft) in length but was reduced from 84 cm (2.75 ft) to 40.54 cm (1.33 ft) in width and was angled at 5.0° for passive-active trials. The active separator (61.1 × 39.6 cm; 2.0 × 1.3 ft) was positioned 1.30 m (4.25 ft) downstream from the end of the passive separator (Figures 5 and 6).

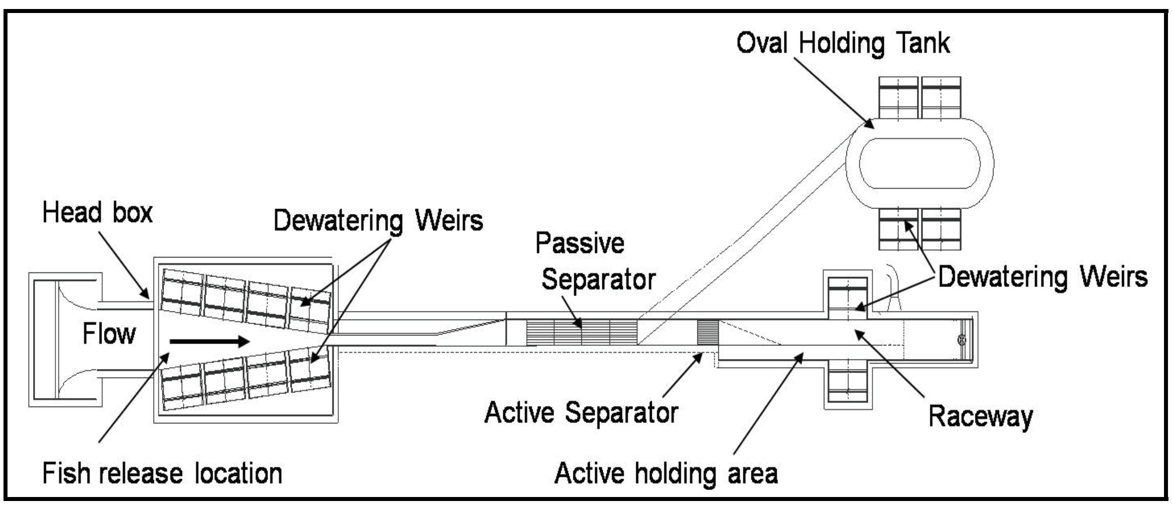

FIGURE 5.—Overhead view of the passive-active separator model.

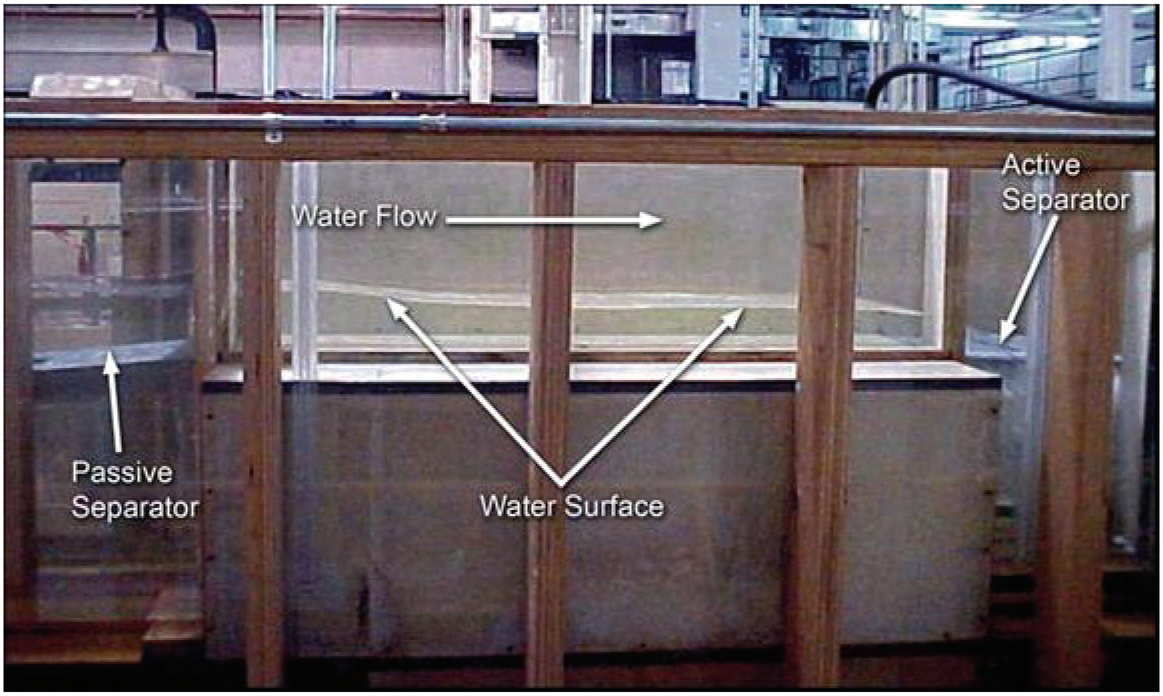

FIGURE 6.—Passive-active separator model, looking through Plexiglass side-viewing window.

The active separator was sloped downward at a 2° angle to facilitate larger fish to slide over the bar rack and into the raceway holding area (Figures 7 and 8). Each separator was constructed of 1.9-cm-diameter (0.75-in) metal tubing spaced 1.9 cm (0.75 in) apart to allow smaller species to pass through the bar rack. A third holding area, called the active-holding area, was created for active-separated fish. This was accomplished by splitting the original raceway holding area into two sections and extending the active holding channel partially below the raceway section and beneath the active separator (Figure 9). As a result, fish that passed through the active separator passed into the lower channel and into the active holding area.

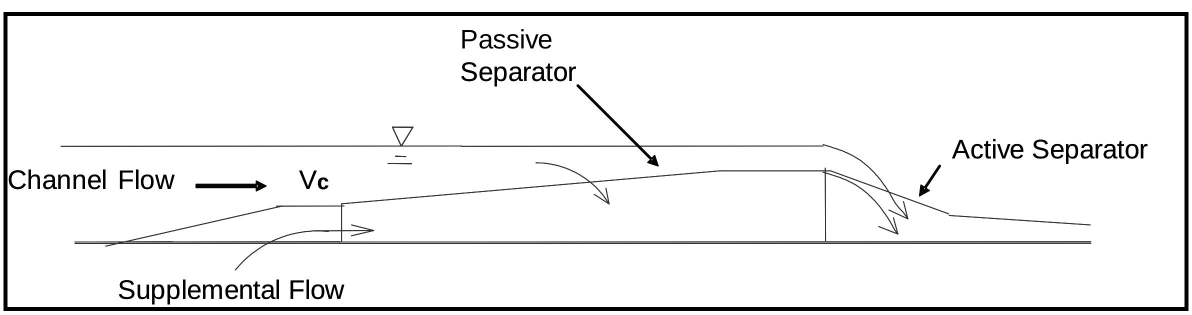

FIGURE 7.—Cross section of the passive-active separator model.

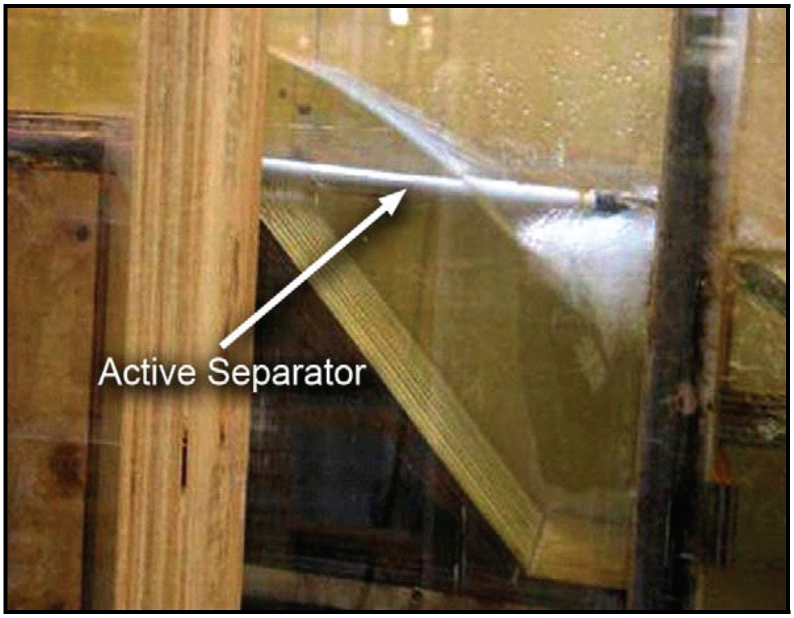

FIGURE 8.—Active separator looking through Plexiglass side-viewing window.

FIGURE 9.—Active separator divider wall showing separate holding areas for actively separated small fish and raceway area for large fish that are not separated.

The active separator was positioned so remaining channel water (water not diverted into the passive separator section) flowed through it, and the last 15.24 cm (6.0 in) of the bar rack was dewatered at the downstream end. This configuration allowed fish to first have the opportunity to pass through the passive separator of their own volition to escape predation. Fish that were small enough to pass through the passive separator but instead continued downstream were forced to pass through the active separator into a separate holding area. Larger fish that continued downstream, but were too wide to pass through either separator, were forced to slide along the active separator bar rack into a raceway holding area**.** Potential injury resulting from passing through an active separator would be better than predation mortality that could occur if these smaller species passed into a raceway holding area with large piscivores.

Test conditions for passive-active separator experiments are listed in Table 2. For this series of investigations, downwelling conditions through the passive separator were controlled by adjusting dewatering weirs located within the oval tank structure. For each

TABLE 2.—Test case conditions for passive separator in passive-active separator experiments.

Test Case	Channel Velocity (V_c) cm/s (ft/s)	Flow Regime	Approach Velocity (V_a) cm/s (ft/s)	Separator Angle (degrees)	Illumination
PAV2	61.1 (2.0)	Downwelling	6.1 (0.2)	5°	No
PAV2SL	61.1 (2.0)	Downwelling	6.1 (0.2)	5°	Yes
PAV3	91.4 (3.0)	Downwelling	9.1 (0.3)	5°	No
PAV3SL	91.4 (3.0)	Downwelling	9.1 (0.3)	5°	Yes
PAV4	121.9 (4.0)	Downwelling	12.2 (0.4)	5°	No

test condition, a minimum flow depth of 15–20 cm (6–8 in) was maintained at the downstream end of the passive separator. Flow to the main channel was supplied using the laboratory venturi system to control average V_c measured at the leading edge of the passive separator. Flow could no longer be controlled into the raceway area downstream of both separators, thus producing a slight downwelling condition for all passive-active tests. Also, auxiliary flow feeding beneath the passive separator was eliminated.

An additional factor was included in the passive-active investigations that was not a variable when testing only the passive separator. In two test cases (PAV2SL and PAV3SL), spotlights were directed at the passive separator to determine what effect illumination would have on separation efficiencies. For these test conditions, hydraulic flow settings were identical to test cases PAV2 and PAV3 (see Table 2), but spotlights were positioned at each end and above the passive separator. Two General Electric dual 500-watt Halogen Quartz bulbs were placed 2.6 m (8.5 ft) above the water surface and directed downward to illuminate the full length of the passive separator bar rack. The species tested and holding methods in passive-active investigations were identical to the passive separator except, in the final set of trials, Chinook salmon and delta smelt replaced rainbow trout and splittail (Appendix 1). White sucker (*Catostomus commersoni*) was added to act as a demersal (*i.e.,* bottom-oriented) species, and wiper bass was a predatory species. Again, each test condition consisted of three 30-min trials. However, the method for crowding fish from the headbox area was improved by installing a 0.48-cm (0.19-in) mesh seine net that blanketed the bottom and sides of the headbox area. The upstream end of the seine was lifted and rolled downstream in the headbox; therefore only one pass of the seine was necessary and was done after 20 min of elapsed time for each trial. After 30 min, the barrier net was placed over the passive-separator and an additional net was placed at the downstream end to prevent fish from passing into the active-separator area. Once these nets were in place, the separator model was dewatered and fish were recovered from their respective locations, counted, and measured. Each test condition was evaluated for efficiency for separating small fish from large fish.

For the passive-active configuration, passive efficiencies (PE) and total separator efficiencies (TSE) for separating fish were calculated for each species and test condition. PE was calculated based on the number of fish that passed through the passive separator into the oval holding tank, divided by the total number of fish that passed into the oval holding tank, plus the total number that passed into the raceway area, plus those that passed into the active-holding area (AHA), so that:

$$PE = \frac{\text{(Fish in oval holding tank)}}{\text{(Fish in oval holding tank + raceway + AHA)}} \times 100$$

TSE was calculated by adding the number of passive and active separated fish together and then again dividing by the total number of fish that had passed into all holding areas combined:

$$TSE = \frac{\text{(Fish in oval holding tank + AHA)}}{\text{(Fish in oval holding tank + raceway +AHA)}} \times 100$$

Fish remaining in the headbox or above the separator at the time the experiment ended were not included in either of the efficiency calculations.

For the passive-active configuration, statistical analyses used ANOVA or the non-parametric equivalent Kruskall-Wallis test to compare mean PE and mean TSE for all test conditions listed in Table 2.

RESULTS

Passive Separator

Best overall efficiencies, when considering all three species, occurred under test case 8B (Table 3) with a downwelling flow condition, a separator angle of 5.0°, and a V_c of 121.9 cm/s (4.0 ft/s). Mean separator efficiencies were ≥92% for all species. Efficiencies were highest under these conditions for splittail and rainbow trout, although higher efficiencies occurred for fathead minnow under test cases 5A and 9B.

Poorest overall efficiencies occurred during upwelling flow conditions with low V_c (test case 3). Many fish held position above the separator where upwelling flow was strongest and inhibited their downward movement. Poorest efficiencies for rainbow trout and fathead minnow occurred with this condition. Test cases 5A and 8A produced comparable low separation efficiencies for rainbow trout at a 61.1 cm/s (2.0 ft/s) V_c with an even flow condition and separator angle of 2.25° and 5°, respectively.

TABLE 3.—Passive separator efficiencies for test species for each test case.

Separator Efficiency						
	Splittail		Rainbow Trout		Fathead Minnow	
Test Case	% Mean Efficiency	Standard Error	% Mean Efficiency	Standard Error	% Mean Efficiency	Standard Error
1A, 2A	87	4.7	78	7.3	84	6.3
1B, 2B	76	5.0	69	2.7	90	1.7
3	80	4.4	29	21.7	55	7.1
5A	79	2.8	39	3.4	96	2.0
5B	70	7.6	77	7.3	88	7.2
8A	86	4.6	33	2.4	81	7.6
8B	92	4.1	94	3.2	92	5.6
9B	87	4.3	78	5.1	100	0

Mean separator efficiencies were statistically compared to test effects of angle and velocity on passive separator design by species. All test cases were analyzed with exception of test case 3, which was not included due to low separator efficiencies. For splittail, a separator angle of 5° resulted in somewhat higher mean efficiency rates, however this difference, although close ($P = 0.080$), was not significant at 95% confidence level ($\alpha = 0.05$; Table 4). The velocities tested did not have a statistically significant influence on separator efficiencies for this species. There was also not a significant interaction effect between angle and velocity.

TABLE 4.—Statistical comparison of the effect of angle and velocity on passive separator mean efficiency for splittail.

Splittail			
Test Case	**Angle (°)**	**Channel Velocity (V_c) cm/s (ft/s)**	**Mean Efficiency (%)**
1A/2A	0	61.1 (2.0)	87
1B/2B	0	121.9 (4.0)	76
5A	2.25	61.1 (2.0)	80
5B	2.25	121.9 (4.0)	70
8A	5	61.1 (2.0)	86
8B	5	121.9 (4.0)	92
9B	5	121.9 (4.0)	87
Statistical significance (alpha = 0.05)	P = 0.080	P = 0.210	Interaction (Angle, V_c) P = 0.335

For rainbow trout, angles tested did have a significant influence on separator efficiency (P = 0.015; Table 5). Velocity also appeared to significantly affect efficiency of the passive separator (P <0.001). Mean separator efficiencies for channel velocities of 121.9 cm/s (4 ft/s) were significantly greater than for velocities of 61.1 cm/s (2.0 ft/s). The interaction between angle and velocity was also statistically significant (P <0.001).

TABLE 5.—Statistical comparison of effect of angle and velocity on passive separator mean efficiency of rainbow trout.

Rainbow Trout			
Test Case	**Angle (°)**	**Channel Velocity (V_c) cm/s (ft/s)**	**Mean Efficiency (%)**
1A/2A	0	61(2)	81
1B/2B	0	122 (4)	69
5A	2.25	61 (2)	39
5B	2.25	122 (4)	77
8A	5	61 (2)	33
8B	5	122 (4)	94
9B	5	122 (4)	78
Statistical Significance (alpha = 0.05)	P = 0.015	P <0.001	Interaction (Angle, V_c) P <0.001

For fathead minnow, statistical analysis indicated neither angle nor velocities tested had significant influence on mean separator efficiency (Table 6). No interaction was found between angle and velocity for this species.

TABLE 6.—Statistical comparison of the effect of angle and velocity on passive separator mean efficiency of fathead minnow.

Fathead Minnow			
Test Case	**Angle (°)**	**Channel Velocity (V_c) cm/s (ft/s)**	**Mean Efficiency (%)**
1A/2A	0	61 (2)	84
1B/2B	0	122 (4)	90
5A	2.25	61 (2)	96
5B	2.25	122 (4)	88
8A	5	61 (2)	81
8B	5	122 (4)	92
9B	5	122 (4)	100
Statistical Significance (alpha = 0.05)	P = 0.631	P = 0.328	Interaction (Angle, V_c) P = 0.128

As discussed earlier, test conditions that appeared to be optimal for separator efficiency were included in test case 8B with downwelling flow condition, a separator angle of 5°, and a V_c of 121.9 cm/s (4.0 ft/s). Test cases were statistically compared to determine significant differences in passive separator efficiency based on various test conditions. No statistical differences between test cases were found for splittail or fathead minnow (Table 7). For rainbow trout, ANOVA identified significant differences in separator efficiencies between test cases ($P <0.001$). This result may have been due to the influence of velocity on mean separator efficiency of this species. Optimal test case 8B had a V_c of 121.9 m/s (4.0 ft/s), a velocity that provided significantly greater efficiencies than a Vc of 61.1 cm/s (2.0 ft/s) for rainbow trout ($P = 0.012$; see Table 5). A multiple comparison using Fisher's least significant difference (LSD) procedure to determine which means are significantly different showed test cases 5A and 8A (both with velocities of 61.1 cm/s; 2.0 ft/s) have significantly lower efficiencies than test case 8B. Results of this multiple comparison procedure support the hypothesis that velocity had a strong influence on separator efficiency of rainbow trout.

TABLE 7.—Comparison of passive separator efficiencies between test cases by species.

Species	**Statistical Significance (alpha = 0.05)**
Splittail	P = 0.144
Rainbow Trout	P < 0.001
Fathead Minnow	P = 0.205*

*Kruskall-Wallis test.

Differences between weak downwelling and strong downwelling conditions were statistically compared using the same test conditions for both, where angle was 5° and V_c

was 121.9 cm/s (4.0 ft/s). There were no statistical differences identified between weak and strong downwelling conditions for any of the species tested (Table 8). Fathead minnow showed a slightly higher mean separator efficiency when strong downwelling occurred, unlike the other two test species which had lower efficiencies with strong downwelling.

TABLE 8.—Comparisons between mean efficiencies of weak and strong downwelling conditions when angle = 5° and V_c = 121.9 cm/s (4.0 ft/s) for passive separator.

Species	Downwelling	Mean Efficiency (%)	Statistical Significance (alpha = 0.05)
Splittail	Weak	92	P = 0.484
	Strong	87	
Rainbow Trout	Weak	94	P = 0.061
	Strong	78	
Fathead Minnow	Weak	92	P = 0.197*
	Strong	100	

*Mann-Whitney-Wilcoxen test of medians.

Passive-Active Separator

For the passive-active configuration, mean PE (efficiency of just the passive separator section of the passive-active configuration) and TSE (efficiency of both separators in the passive-active configuration) for separating fish from two species assemblages are given in Table 9. Test conditions for each test case are listed in Table 2. Mean TSE of three replicates for all test cases and species was ≥85% in all instances with exception of one (splittail in PAV4).

Differences in passive separator efficiencies between those calculated for passive-only trials and those calculated for passive-active separator trials may be attributed, in part, to differences in flow conditions immediately downstream from the passive separator. In the passive-only separator experiments, velocities measured at a position about 45.7 cm (1.5 ft) downstream from the passive separator showed a deceleration of 10–30%. In passive-active test trials, velocities measured at the same position showed an acceleration of about 30% caused by flow dropping through the active separator.

For the passive-active configuration, Table 9 shows the highest passive and overall efficiencies for splittail and Chinook salmon occurred during the spotlighted test condition. Spotlighting the passive separator increased PE by 30% for identical flow conditions (PAV2 vs PAV2SL) for splittail and 25% for identical flow conditions (PAV3 vs PAV3SL) for Chinook salmon. Separator efficiencies were also relatively high for the other three species tested while spotlights were on. However, due to the small sample size, more trials may be necessary to confirm improved efficiencies can be repeated.

Without spotlighted conditions, there did not appear to be one test condition that appreciably increased PE or TSE.

TABLE 9.—Passive-active separator efficiencies.

Passive Separator Efficiencies (PE) and Total Passive-Active Separator Efficiencies (TSE)								
Species Assemblage 1								
Test Case (n = 3)	**Splittail**		**Rainbow Trout**		**Fathead Minnow**		**White Sucker**	
	PE%	TSE%	PE%	TSE%	PE%	TSE%	PE%	TSE%
PAV2	50	96	77	97	66	98	97	99
PAV3	59	96	82	92	70	91	93	99
PAV4	26	71	69	93	76	95	93	97
PAV2SL	79	100	79	100	76	100	94	98
Species Assemblage 2								
Test Case (n = 3)	**Chinook Salmon**		**Delta Smelt**		**Fathead Minnow**		**White Sucker**	
	PE%	TSE%	PE%	TSE%	PE%	TSE%	PE%	TSE%
PAV2	65	92	23	94	93	100	98	100
PAV3	68	88	47	94	96	100	98	98
PAV4	50	85	32	90	82	99	78	97
PAV3SL	93	98	NA	NA	NA	NA	NA	NA

For passive-active experiments, all parameters were constant except velocity and illumination. The three channel velocities in passive-active separator experiments (*i.e.*, 61.1 cm/s, 2.0 ft/s; 91.4 cm/s, 3.0 ft/s; and 121.9 cm/s, 4.0 ft/s) were statistically compared to determine if they affected PE and TSE by species. Fathead minnow and white sucker were the only species included in trials for both fish assemblages. Data from each assemblage were combined for these two species (n = 6).

Comparisons between the non-illuminated test cases (*i.e.*, PAV2, PAV3, and PAV4) found that V_c did not significantly affect PE for any species tested except white sucker (P = 0.032; Table 10). Fisher's LSD procedure indicated mean PE for V_c = 121.9 cm/s (4.0 ft/s) was significantly less than PE for lower velocities for white sucker. For splittail, the P-value was 0.0560 and V_c values were examined more closely. Multiple comparison for this species showed PE at V_c = 91.4 cm/s (3.0 ft/s) (59%) was significantly greater than V_c = 121.9 cm/s (4.0 ft/s) (26%).

There were no statistically significant differences identified in TSE between V_c for species tested except splittail (P = 0.002; Table 10). Fisher's LSD procedure indicated mean TSE for V_c = 121.9-cm/s (4.0 ft/s) was significantly less than TSE for lower velocities for this species.

TABLE 10.—Results of statistical analysis comparing mean passive efficiencies and mean total separator efficiencies of test species for V_c = 61.1 cm/s (2.0 ft/s) versus V_c = 91.4 cm/s (3.0 ft/s) versus V_c = 121.9 cm/s (4.0 ft/s).

Mean Passive Efficiency (PE)				
Species	**V_c = 61.1 cm/s (2.0 ft/s) (%)**	**V_c = 91.4 cm/s (3.0 ft/s) (%)**	**V_c = 121.9 cm/s (4.0 ft/s) (%)**	**Statistical Significance (alpha = 0.05)**
Splittail	50	59	26	P = 0.056
Rainbow Trout	77	82	69	P = 0.277
Fathead Minnow	80	83	79	P = 0.899
White Sucker	97	96	86	P = 0.032*
Chinook Salmon	65	68	50	P = 0.149
Delta Smelt	24	47	32	P = 0.425
Mean Total Separator Efficiency (TSE)				
Species	**V_c = 61.1 cm/s (2.0 ft/s) (%)**	**V_c = 91.4 cm/s (3.0 ft/s) (%)**	**V_c = 121.9 cm/s (4.0 ft/s) (%)**	**Statistical Significance (alpha = 0.05)**
Splittail	96	96	71	P = 0.002
Rainbow Trout	97	92	93	P = 0.545
Fathead Minnow	98	91	95	P = 0.621*
White Sucker	99	99	97	P = 0.299*
Rainbow Trout	97	92	93	P = 0.545
Chinook Salmon	92	88	85	P = 0.322

*Kruskall-Wallis test of medians.

Three replicates of test case PAV2 (V_c = 61.1 cm/s; 2.0 ft/s) were performed using spotlights, referred to as test case PAV2SL. PE of splittail increased significantly with spotlights by 25% (Table 11). However, TSE did not increase statistically when spotlights were used. Results indicated when spotlights were on, splittail used the passive separator more efficiently, but this did not lead to a statistical increase in TSE most likely due to high TSE without spotlights. Rainbow trout TSE also significantly improved when spotlights were used (P = 0.014), although PE for this species did not change significantly.

In addition, test case PAV3 (V_c = 91.4 cm/s; 3.0 ft/s) was investigated under a spotlighted condition using only Chinook salmon, referred to as test case PAV3SL. When spotlights were on, mean PE increased 25% and mean TSE increased 10% (Table 11). Both of these improvements in separator efficiency were statistically significant (Table 11).

TABLE 11.—Results of statistical analysis comparing mean passive efficiencies and total separator efficiencies of test species with spotlights versus without spotlights.

Mean Passive Efficiency (PE)			
Species	**Without Lights (%)**	**With Lights (%)**	**Statistical Significance (alpha = 0.05)**
Splittail	50	79	P = 0.045
Rainbow Trout	77	79	P = 0.755
Fathead Minnow	66	76	P = 0.438
White Sucker	97	94	P = 0.193
Chinook Salmon	68	93	P = 0.023
Mean Total Separator Efficiency (TSE)			
Species	**Without Lights (%)**	**With Lights (%)**	**Statistical Significance (alpha = 0.05)**
Splittail	96	100	P = 0.158
Rainbow Trout	97	100	P = 0.014
Fathead Minnow	98	100	P = 0.117
White sucker	99	98	P = 0.976
Chinook Salmon	88	98	P = 0.028

DISCUSSION

Passive Separator

Based on results from statistical analysis, both angle and velocity of the passive separator influenced efficiency of fish separation of rainbow trout but did not affect results for fathead minnow or splittail. The highest average separator efficiency for rainbow trout occurred when the angle was 0°. Higher channel and approach velocities significantly increased separation of this species. There was also a statistically significant interaction effect between the two variables. Separator efficiency dropped considerably when the V_c decreased from 121.9 cm/s (4.0 ft/s) to 61.1 cm/s (2.0 ft/s) even though angle remained at 5°. Efficiencies may have been higher for rainbow trout at higher V_c because this species was more likely to seek refuge at locations of lower velocity near the bottom of the channel. As a result, more rainbow trout passed through the separator during higher V_c test case experiments. A few splittail sought refuge from the high V_c flow condition of 121.9 cm/s (4.0 ft/s) by bracing themselves between the separator frame and the sidewall. Therefore, efficiencies may be slightly increased if the separator can be structurally designed to maintain a 1.9-cm (0.75-in) clearance from the sidewall along most of its length. Low V_c test conditions (<61.1 cm/s; <2.0 ft/s) allowed splittail and rainbow trout to move upstream and downstream at will. As a result, these fish swam into the raceway (sometimes in schools), stayed there for a period of time, and then swam back upstream towards the separator. Some fish also tended to stay in the upstream ramp area approaching the separator.

A strong downwelling condition appeared to promote separator efficiency for a poor swimmer (*i.e*., fathead minnow). Although the difference between strong and weak downwelling conditions were not statistically significant, fathead minnow efficiencies did increase with strong downwelling conditions. This outcome seems logical; downward flow would essentially push weak swimmers through the separator. Results were opposite for stronger swimmers (*i.e*., splittail and rainbow trout); strong downwelling actually decreased separator efficiencies for these species.

Some general observations were made during experiments regarding design and operation of the passive separator model. High auxiliary pump flows, with exit velocities >76 cm/s (>2.5 ft/s), reduced the number of fish holding directly beneath the separator and therefore should reduce the number of fish stranded in this area during fish recovery. Also, it appeared that fish stranding was reduced when flume floor slopes were greater than approximately 3°.

Passive-Active Separator

Based on results from statistical analysis, slower velocities were found to slightly improve PE and significantly increase TSE for separating splittail. Slower velocities significantly increased PE for white suckers, but did not affect TSE for this species. These findings were somewhat contrary to results from the passive-only tests, in which slower velocities significantly decreased separator efficiency of rainbow trout but did not statistically affect the efficiency of splittail.

When spotlights illuminated the passive separator section of the passive-active separator configuration, PE improved for splittail; however, no difference was detected for TSE. Furthermore, a spotlighted condition increased Chinook salmon PE, which also led to a higher mean TSE. During the spotlighted test condition, observations indicated splittail and Chinook salmon had a tendency to dive head forward through passive separator openings immediately upon entering the spotlighted area. The spotlighted condition also increased TSE of rainbow trout, but not PE. For all other species, the use of spotlights did not affect PE or TSE.

For some species, statistically significant improvements in separator efficiency arose from an increased use of the passive separator when illuminated. Higher numbers of fish (splittail and Chinook salmon) separated by the passive separator in the passive-active configuration would lead to a decrease in the number of fish separated by the active separator. This could result in less physical injury by decreasing the potential for fish to come in direct contact with active separator arrays. Thus, having spotlights on the passive separator may be beneficial to splittail and Chinook salmon by increasing passive separation, which in turn might reduce injury and increase survival.

Some general observations were made during experiments regarding the design and operation of the passive-active separator model. Although data presented here do not include conditions tested with auxiliary flow supplied beneath the leading edge of the passive separator, observations indicated this auxiliary flow deterred fish from holding beneath the passive separator, thus resulting in fewer stranded fish during the dewatering and recovery process. Adjusting the weir control for the active-holding area caused a small overflow on the downstream end of the active separator and provided a water cushion for large fish sliding on the bar rack, facilitating their recovery and downstream movement. This also provided a steady flow-through water supply for the raceway holding area and therefore, auxiliary water was not needed there. As a result, this adjustment is recommended during all operations.

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Appendix 1

Average Total Length, Average Total Width, and Size Range of Fish Used in Separator Tests

TABLE A1-1.— Average total length and width and size range (measured in millimeters) of test fish used in passive separator test.

Test Condition*		Wiper				Splittail				Rainbow Trout				Fathead Minnow			
		Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range
1A	All Fish	30	260.6	32.9	173-313	75	123.7	11.9	95-163	73	39.8	4.9	31-47	70	36.5	4.5	25-43
	No Decision	24	256.8	33.2	173-313	20	119.3	11.6	106-142	36	40.7	4.9	36-47	24	37	4.8	31-43
	Separated	0				46	125.5	11.7	95-163	27	39.3	4.8	31-43	33	36.4	4.4	25-43
	Not-Separated	6	275.7	32	175-313	9	125.3	12.8	110-144	10	39	5.3	35-45	13	36.1	4	33-41
1B	All Fish	30	250.8	33	165-310	75	124.5	12.8	95-155	67	38.3	4.9	29-47	68	52.7	6.4	38-64
	No Decision	16	256.4	33.7	166-310	25	121.3	12.7	97-150	7	40.3	5.3	38-43	10	58.7	7.2	51-64
	Separated	0				40	126	12.8	95-149	42	38.7	5	33-47	53	51.3	6.3	38-60
	Not-Separated	14	244.9	32.3	165-303	10	127.7	13.1	101-155	18	37.1	4.5	29-45	5	48.8	5.4	40-54
2A	All Fish	30	228.6	28.8	153-311	74	126.3	12.1	104-166	71	39.6	4.3	25-52	68	40.1	4.7	33-64
	No Decision	12	240.6	31.5	153-311	25	120.7	12.6	104-152	24	40	4.1	33-50	20	44.4	4.8	35-64
	Separated	0				43	125.3	11.8	109-155	41	38.2	4.4	25-52	45	37.7	4.6	33-54
	Not-Separated	18	220.6	27	160-304	6	136.5	12.7	120-166	6	44.5	4.5	35-52	3	38.3	4.8	36-40
2B	All Fish	30	248.8	33.8	131-324	74	124.8	11.9	95-177	70	39.9	4.8	29-65	74	53.9	6.1	43-69
	No Decision	18	253.8	32.7	163-305	39	123.6	12.3	95-143	10	42.2	5	35-65	30	57.1	6.2	43-69
	Separated	0				25	127	11.9	96-177	40	39.7	4.7	29-45	39	52.3	6	43-67
	Not-Separated	12	240.9	35.7	131-324	10	123.2	10.6	96-149	20	39.2	4.7	32-47	5	48.8	6	45-62
3	All Fish	30	196.2	22.2	152-275	75	126.8	11.5	100-182	74	43.2	4.8	36-54	68	40	4.6	31-66
	No Decision	10	215.3	25.3	152-275	10	121.7	12.2	105-168	53	42.7	5	36-53	39	41.7	4.5	32-66
	Separated	0				52	127.7	11.4	100-178	6	43.5	4.3	40-48	16	39.8	5	34-53
	Not-Separated	20	186.6	20.7	159-249	13	128	11.5	111-182	15	44.1	4.8	40-54	13	36.4	4.2	31-44
5A	All Fish	30	206.2	24.4	146-283	75	166.3	17.5	131-225	67	59.4	6.6	42-80	72	61	7.1	51-81
	No Decision	14	190.7	21.9	146-266	7	162.6	17.3	144-175	22	59	6.6	46-76	16	59.8	7.1	53-81
	Separated	0				54	158.1	16.2	131-191	18	57.3	6.5	45-75	54	61.6	7.1	51-80
	Not-Separated	16	219.8	26.5	193-283	14	185.6	20.6	163-225	27	61.2	6.6	42-80	2	61	6.5	61
5B	All Fish	30	207.8	23.3	143-331	73	167.1	14.6	126-233	70	57.5	4.6	44-87	70	58.6	4.7	39-72
	No Decision	0				2	219.5	17.5	210-229	26	59.8	4.7	44-87	26	59.8	4.7	52-72
	Separated	2	144	13.8	143-145	50	157.9	14.3	126-189	35	55.9	4.5	44-72	38	59.3	4.9	51-68
	Not-Separated	28	212.3	24	153-331	21	175.4	14.9	142-233	9	55.7	4.4	46-72	6	50.2	4	39-56
8A	All Fish	30	192.8	22	142-278	72	157.7	15.7	127-207	69	49.9	5.1	36-65	67	43.3	4.5	34-66
	No Decision	21	190.8	21.8	143-278	5	152	15.8	130-185	33	49.5	4.8	36-65	5	41.2	4	38-45
	Separated	1	142	14	142	58	155.5	15.1	127-180	12	48.5	4.5	37-65	50	43.7	4.6	34-66
	Not-Separated	8	204.4	23.5	152-258	9	169	17.9	143-207	24	51	5.7	40-65	12	42.8	4.1	39-54
8B	All Fish	30	204.4	23.7	145-275	70	164.6	15.3	130-200	65	52.6	4.4	39-68	56	46.4	4.6	38-65
	No Decision	1	150	14	150	5	183	18.3	157-199	33	54.3	4.5	41-68	6	49	4.4	43-63
	Separated	2	160.5	17.3	149-172	60	160.2	14.8	130-200	30	51.6	4.4	43-64	46	46.1	4.7	38-65
	Not-Separated	27	209.7	24.5	145-275	5	175	15.1	150-196	2	42	3.5	39-45	4	44.8	3.8	39-50
9B	All Fish	30	216.9	25.9	146-291	74	169.6	17.4	133-202	69	72.3	7.2	49-95	43	45.6	4.8	35-60
	No Decision	2	213	25	212-214	7	178.3	16.4	148-200	20	79.9	7.1	64-95	4	52.0	5.3	47-55
	Separated	1	150	18	150	56	167	17.3	133-202	38	70.1	7.1	49-89	39	44.7	4.8	35-60
	Not-Separated	27	219.7	26.3	146-291	8	173.8	19.6	145-190	11	71.9	7.5	58-88	0			

* No decision = fish that did not enter separator area from headbox.

TABLE A1-2.—Average total length and width and size range (measured in millimeters) of test fish used in passive-active separator test.

Test Condition		Wiper				Splittail				Rainbow Trout				Fathead Minnow				White Sucker			
		Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range
PAV2	All Fish	90	280.9	34.5	167-416	74	55.2	5.1	44-68	222	92.7	9.3	61-132	190	57.8	6.1	42-80	72	103.7	10.3	85-136
	No Decision	49	284.5	35.1	167-416	0				31	91.4	9.4	66-123	22	52.3	5.8	42-65	5	106.8	10.2	94-120
	Separated	1	207	22	207	71	55.3	5.2	44-68	186	92.9	9.2	61-132	164	58.2	6.1	43-80	66	103.4	10.3	85-136
	Not-Separated	40	278.4	34.1	173-385	3	53	4.3	51-55	5	95	9	73-117	4	53.5	6.3	47-63	1	105	13	105
PAV3	All Fish	60	303.8	38	234-395	69	56.4	4.9	43-70	154	117.7	12.8	56-160	137	52.5	5.2	35-70	144	108.7	10.7	86-130
	No Decision	34	309.4	38.5	235-395	1	58	7	58	16	127.9	14.5	105-157	28	49	5.4	35-58	14	114	11.7	90-124
	Separated	0				65	56.3	4.8	43-70	127	116	12.6	56-160	99	53.9	5.2	35-70	127	108.3	10.6	86-130
	Not-Separated	26	296.6	37.3	234-345	3	58.7	5.5	51-65	11	122.9	12.9	80-146	10	48.3	4.9	40-60	3	98.7	10	90-106
PAV4	All Fish	60	292.5	34.8	140-423	75	56	5	45-64	146	74.8	6.6	45-105	123	52.4	4.9	31-76	144	104.5	9.2	85-156
	No Decision	5	343.6	42.8	259-393	0				8	74.1	5.7	60-90	14	46.3	3.7	38-62	17	107.3	10.2	95-130
	Separated	7	155.6	14.6	140-174	71	56	5	45-64	135	74.7	6.6	45-105	109	53.2	5.1	31-76	125	104.2	9	85-156
	Not-Separated	48	307.1	37	153-423	4	57.3	5.3	54-64	3	81.3	8.3	72-87	0				2	96.5	11	90-103

Test Condition		Striped Bass				Chinook Salmon				Delta Smelt				Fathead Minnow				White Sucker			
		Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range	Number	Average Total Length	Average Width	Range
PAV2	All Fish	15	225.3	25.8	180-320	75	106.9	10.8	71-121	69	74.7	6.3	59-87	78	58.6	6.0	50-67	68	80.6	9.6	70-94
	No Decision	12	222.6	25.8	180-320	7	106	11.0	103-114	0				2	58.5	6.0	56-61	4	83	10	80-86
	Separated	0				63	106.3	10.8	71-121	65	74.4	6.3	59-87	76	58.6	6.0	50-67	64	80	9.5	70-94
	Not-Separated	3	236.0	26.0	193-320	5	132	17.1	105-116	4	132	6.3	70-83	0				0			
PAV3	All Fish	15	235.3	27	180-320	76	105.8	10.6	77-120	73	76.1	7.0	59-92	82	59.9	8.5	47-76	68	81.4	9.6	72-90
	No Decision	11	224.7	26.1	180-320	2	100.5	10.5	90-111	1	76.0	6	76	1	60	8.0	60	6	81	9.2	72-89
	Separated	1	180	21.0	180	65	105.6	10.5	77-120	68	76	7.1	59-92	81	59.9	8.5	47-76	61	81.7	9.5	72-90
	Not-Separated	3	271.7	31.0	200-320	9	108.1	11.2	95-115	4	78.3	6.7	69-84	0				1	76.0	10	76
PAV4	All Fish	15	226.1	25.9	180-320	74	112.3	11	74-132	70	75.6	5.3	55-89	74	53.0	8.3	53-75	77	80.9	9.0	70-95
	No Decision	2	259.0	29.5	198-320	0				0				3	54.0	5.5	53-55	8	85.9	9.0	79-91
	Separated	0				63	112.1	10.5	74-132	63	75.2	5.3	55-89	70	62.1	8.5	54-75	67	79.6	8.9	70-95
	Not-Separated	13	221.0	25.4	180-230	11	113.4	11.4	97-121	7	79.1	5.5	70-87	1	62.0	8	62	2	83.0	9.1	80-86

No decision = fish that did not enter separator area from headbox.