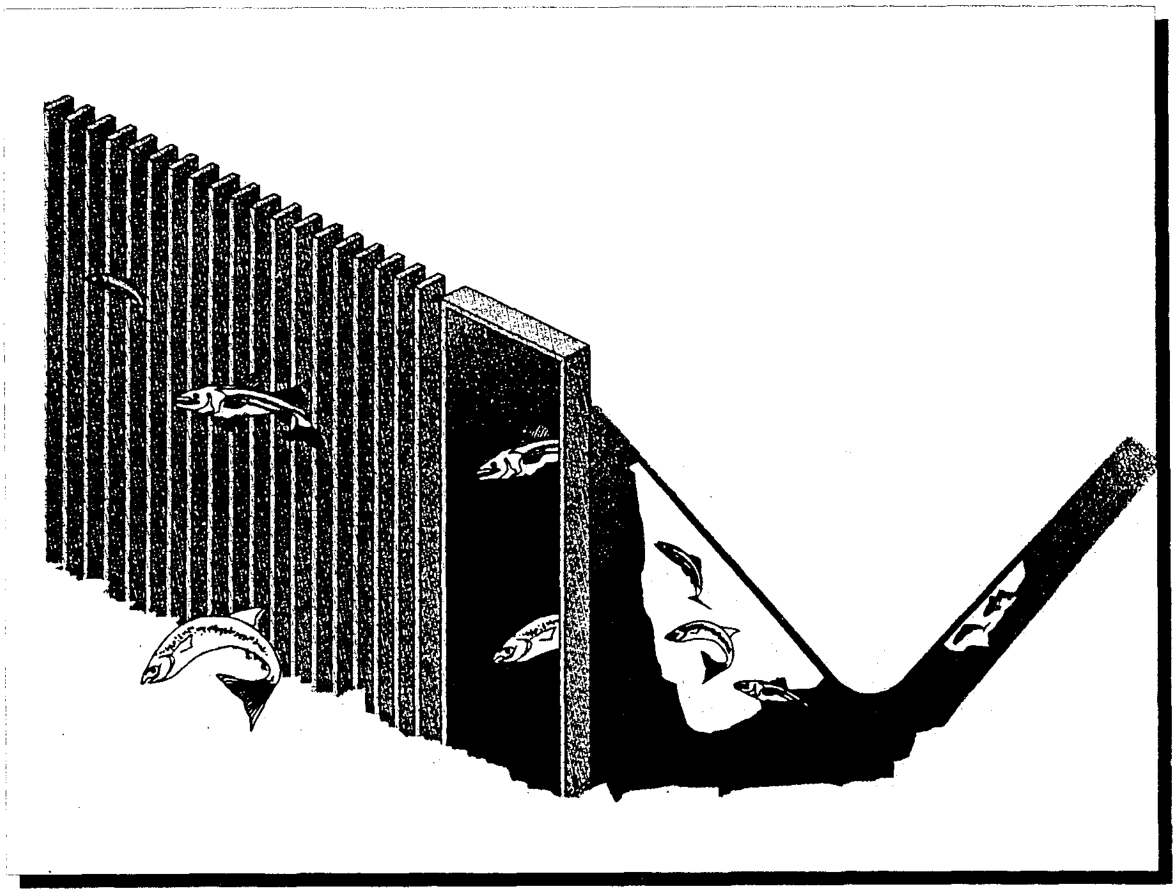

# TRACY FISH COLLECTION FACILITY STUDIES CALIFORNIA

## *Volume 16*

## Assessment of Survival and Condition of Fish Passed Through a Hidrostal Pump at the U.S. Bureau of Reclamation, Tracy Fish Collection Facility, California

*December 2000*

United States Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and the Technical Service Center

# Assessment of Survival and Condition of Fish Passed Through a Hidrostal Pump at the U.S. Bureau of Reclamation, Tracy Fish Collection Facility, California

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**Tracy Fish Collection Facility Studies California**

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## *Assessment of Survival and Condition of Fish Passed Through a Hidrostal Pump at the U.S. Bureau of Reclamation, Tracy Fish Collection Facility, California*


### ABSTRACT

Passage survival, descaling, and injury rates of marked Sacramento splittail *(Pogonichthys macrolepidotus)* and juvenile chinook salmon *(Oncorhynchus tshawytscha)* which were inserted into the entrance (suction side) of the Hidrostal pump were compared to those of control fish which were inserted at the exit (pressure side) in 130 paired trials conducted from December 1998 to July 1999. The Hidrostal pump had no significant effect ($P < 0.001$) on immediate or latent mortality (96 hours(h)), descaling, or body injury rates for all flow rates, and sizes and densities of fish tested, except for 96 h mortality of Sacramento splittail in June. Immediate survival rates for splittail and chinook salmon pumped averaged 99 percent, and cumulative (96 h) survival for these species averaged 93 and 96 percent, respectively. Average scale loss on Sacramento splittail and chinook salmon usually was low (1.9 and 2.4 percent, respectively) and the frequency of injury to head, eyes, skin, and fins was typically low and not significantly different among quality control, control, and treatment fish. Observations on wild fish (26 species; 7,197 fish) entrained from the Sacramento-San Joaquin River Delta during the pumping trials indicated high immediate survival (99 percent). The Hidrostal pump transported a variety of sizes and numbers of native fishes with low mortality and injury rates over a range of pump velocities and environmental conditions. Hidrostal pumps that can safely transport fish screened from a water diversion canal through a bypass return to a river may have significant fisheries management application.


### INTRODUCTION

Fish passage and protection at water export facilities and at dams are fundamental to maintaining and restoring anadromous and nonanadromous fishes. The cumulative impact of thousands of dams, hydropower facilities, and irrigation water diversions on riverine fish populations has become increasingly apparent with the decline of Pacific salmon and other stocks (Nemeth and Kiefer 1999; Williams et al. 1999). Catastrophic ecological and economic consequences have accompanied the collapse of important commercial and recreational fisheries as a result of the dam's impassibility and canal and turbine entrainment of fish (National Research Council 1996).

To mitigate the significant declines in river fisheries worldwide, less damaging pumping technologies are now available. Among these, the Hidrostal pump, which uses a screw-type centrifugal impeller and has been used to move agricultural crops without damage, may prove useful for the safe passage of fish at dams and at water export facilities. Those pumps that can safely transport fish from a water diversion canal through a bypass return to a river or around a dam would have significant fisheries management application.

Few comprehensive investigations of Hidrostal pump systems have been published. Limited evaluations of small (15- and 25-cm-diameter inlet) Hidrostal pumps have demonstrated relatively low mortality (0 to 28 percent) and injury rates (< 3 percent) for a few species and sizes of fish (Baldwin l973, Rodgers and Patrick 1985, and Patrick and McKinley l988, Grizzle et al. 1992, Grizzle and Lovshin l994, Wagner and Driscoll 1994). However, the feasibility of using a large (41-cm-diameter) Hidrostal pump to move commercial volumes of water and to bypass a diverse assemblage of fishes, sizes, and densities over a range of pump speeds back into a river system is uncertain.

The U.S. Bureau of Reclamation's (Reclamation's) Tracy Pumping Plant (TPP) in the Central Valley of California exports over 2.5 billion cubic meters of water per year into the Delta Mendota Canal for irrigation, municipal, and industrial water needs. The Tracy Fish Collection Facility at the TPP was designed to intercept and exclude juvenile and adult sport and nongame fish inhabiting the Sacramento and San Joaquin rivers from export water (Helfrich et al. 1999). At the canal intake, fish are directed by louvers into underground tanks where they are held until lifted by bucket into transport trucks for stocking back into the rivers. In this study, we used a Hidrostal pump as an alternative to the lift bucket in order to evaluate its influence on fish survival and condition.

The objectives of this research were to: (1) assess survival, descaling, and injury rates of Sacramento splittail *(Pogonichthys macrolepidotus)* and chinook salmon *(Oncorhynchus tshawytscha)* transported by a large Hidrostal pump; (2) examine immediate survival of native and introduced fish species entrained during pumping experiments; and (3) characterize relationships among fish mortality (immediate and delayed), descaling, and body injury as a function of fish species, size, density, pump speed, debris loads, and other environmental conditions.

## METHODS

A 41-cm-diameter Hidrostal (internal helical, centrifugal) pump built by Wemco Pump (EnviroTech Pumpsystems) was installed at the Reclamation's Fish Salvage Facility, Tracy, California, in October 1998 for these experiments. This pump was designed to minimize shear, pressure changes, turbulence, and abrasion. The screw-type pump impeller is completely enclosed (shrouded) to protect the fish (Figure 1). The pump is driven by a 50-hp electric motor controlled with a variable speed drive to test selected water discharge and velocity. During these trials, pump speed ranged from

461 to 601 rpm and waterflows ranged from 0.17 to 0.40 $m^3/s$, respectively, depending on canal hydraulics and tidal conditions. Pumping time per trial ranged from 25 to 35 minutes.

Experimental trials (N =130 paired comparisons) were conducted during December 8-11, 1998, and February 22-23, March 15-17, April 12-15, May 24-27, June 21-23, and July 26-28, 1999. These dates were selected in order to evaluate passage through the pump by a variety of native species over a range of environmental conditions. Physiochemical conditions, including pH, dissolved oxygen, oxygen saturation, specific conductance, salinity, redox, and water temperature were monitored hourly by a Hydrolab ® Suveyor 20. Wet weight (g) of all herbaceous and woody debris naturally entrained in the pump were estimated for each trial.

Sacramento splittail, a threatened native species, and juvenile fall-run chinook salmon were used for the pumping experiments. Adult Sacramento splittail were collected from the Sacramento-San Joaquin River Delta during the summer of 1998 and held in the Tracy Aquaculture Facility until the trials. Mean total lengths (TL) of Sacramento splittail during the study (December 1998 to July 1999) increased from 83 to 107 mm and those of juvenile fall-run chinook salmon obtained from the Mokelmumne River Hatchery increased from 44 to 97 mm from February to May. Numbers, species, and lengths of all wild fish entrained during the pumping trials were recorded.

All experimental fish were carefully handled and transferred in water treated with a solution of NaCl (5 g/L) and PolyAqua (0.13 ml/L) to promote osmotic balance and reduce stress. Experimental fish were marked with bismark brown dye to distinguish them from similar size wild fish entrained during the trials. All fish were randomly assigned to a numbered cage (4-L capacity) at a density of 20 to 30 fish per cage, depending on species and size. They were acclimated to ambient (canal water) conditions in a flow-through tank for 48 h before testing.

After the Hidrostal pump was operating at a selected, constant test speed, a group of treatment fish (N = 20 to 30) were inserted with waterflow into a 30.5-cm-diameter port (standpipes) located immediately upstream (suction side) of the pump (Figure 1). In separate trials, control fish were subjected to the same conditions as the treatment fish, but were inserted into a port downstream (pressure side) of the pump. After injection, water and any entrained fish were lifted 3.7 m vertically and conveyed 13.7 m horizontally through smooth pipe and discharged into a large rectangular holding pool (4.2 x 8.5 x 1.2 m deep).

The holding pool was designed to convey a 0.4 $m^3/s$ flow at an average speed of 3.67 cm/s. Fish were collected by hand net in the pool sump, (57x 9 x 5 cm deep) after excess water was gradually drained through a rotating drum screen (perforated plate, 0.24-cm mesh). The rotating drum screen was mounted at the downstream end of the holding pool to prevent escape of fish and to remove debris. It was designed to maintain an approach velocity of 3.67 cm/s and to reduce the potential for fish impingement in the holding pool.

Before each trial, two fish from each live cage were randomly selected as quality controls to determine potential handling and transport impact. Quality control fish were compared to all post-treatment and post-control fish in each trial by microscopic analysis for descaling and physical injury. For descaling analyses, 100 percent of the total scaled body surface was microscopically examined and scale loss (% of body) was estimated according to Kostecki et al. (1987). Body injury rates (% fish) were used to enumerate any abnormalities, abrasions, or distortions occurring to the head, eyes, skin, and fins.

Immediately after each trial, survival rates of fish in the holding pool were recorded. Two live fish from each trial were sacrificed by an overdose of tricaine methanesulfonate (MS-222), placed in a plastic bag with water, and examined for descaling and external injury within 10 minutes of collection. The remaining fish were transferred to live cages and examined for delayed mortality at 24-h intervals for 4 days.

Monthly replicate trials (N = 6 to 21) were conducted for each treatment (pump passage) and control (no pump passage) group for Sacramento splittail (7 months) and chinook salmon (4 months). Each numbered live cage was randomly assigned as a treatment or control. Our null hypotheses were that: (1) no differences in mean survival, descaling, or body injury rates for Sacramento splittail and Chinook salmon associated with Hidrostal pump passage under all environmental conditions (water temperature and debris loads) tested occurred; and (2) for each species tested, no differences in mean survival, descaling, or body injury rates as a function of fish size or density occurred. Despite widely varying environmental conditions (Table 1), recovery of Sacramento splittail and chinook salmon was high, averaging 97 percent for all trials (Tables 2 and 3). Fish not immediately recovered in the collection pool were typically captured in subsequent trials. Mean monthly total length of Sacramento splittail ranged from 83 to 102 mm in December to July, respectively, and that of chinook salmon ranged from 43 to 97 mm in February to May, respectively. Densities instantly injected into the pump averaged 25 fish/L, but ranged from 8 to 39 fish/L per trial depending on the species and sizes used.

The Wilcoxon's signed-ranks test was used to test for differences in survival between paired treatment and control groups. Variables were group (treatment or control) and time after pump passage (0, 24, 48, 72, and 96 h). The Kolmogorov-Smirnov test for goodness of fit (Sokal and Rohlf l981, Zar l984) was used to examine for differences in frequency distributions between descaling and body injury among treatment, control, and quality control (handling) groups. Expected frequencies were computed for data on the control group trials. Regression analysis was used to detect any significant relationships for 96-h fish survival as a function of pump speed, debris loading, and fish density (Sokal and Rohlf l981). An alpha level of 0.05 percent was used as the criteria for detecting statistical significance.

## RESULTS

Cumulative (4 day) recovery of inserted fish averaged 99 percemt. Unrecovered fish were considered missing, but not dead. In five preliminary trials consisting of 20 dead fish each, all fish injected into the system were recovered, suggesting that missing fish were probably alive but holding in the system until flushed into the holding tank in a subsequent trial.

Immediate survival after pump passage for Sacramento splittail (Table 2) and chinook salmon (Table 3) was high, averaging over 99 percent for both species, and did not differ significantly (Wilcoxon's signed-ranks test, $z = 0.48$, $p = 0.63$) between treatments and controls. Cumulative survival (4 d) after pump passage remained high, averaging 93 percent for Sacramento splittail and 96 percent for chinook salmon. No differences between treatment and control trials for Sacramento splittail ($z = 1.10$, $p = 0.27$) or for chinook salmon ($z = 0.73$, $p = 0.046$) were detected at the daily intervals, except in June when mean survival was significantly ($p = 0.001$) lower for the treatment than control group of Sacramento splittail at 4 days post-treatment. Adult Sacramento splittail typically are present at Tracy in early spring and would normally not be entrained at high water temperatures in June.

Fish survival (%) of both Sacramento splittail and chinook salmon was unrelated to pump speed over the range of 461 to 601 rpm tested ($R^2 = 0.01$, $p = 0.867$), debris loading of the 10 to 7,000 g/L experienced ($R^2 = 0.01$ $= 0.079$), or fish density of the 8 to 39 fish/L injected per trial ($R^2 = 0.06$; $p = 0.39$).

Descaling rates for Sacramento splittail (Table 4) and chinook salmon (Table 5) were low, averaging 1.9 and 2.4 percent of the body, respectively. Comparisons among quality control (handling effect), control (no pump passage), and treatment (pump passage) groups indicated that the Hidrostal pump had no significant (KS = 0.092, P = 0.318) effect on descaling for either Sacramento splittail or chinook salmon. Scale loss generally increased at warmer water temperatures for both species.

Body injury rates (% of fish) to the head, eyes, skin, and fins after pump passage averaged 1.5, 10.3, 1.3, and 8.5 percent , respectively, for Sacramento splittail (Table 4), and 0.1, 0.1, 0.2, and 0.6 percent, respectively, for Chinook salmon (Table 5) in all trials, and did not differ between control and treatment groups except for Sacramento splittail in March. In March, the proportion of Sacramento splittail with skin and fin injuries was greater ($p< 0.045$) in treatment than control groups. The relatively high injury rate exhibited by Sacramento splittail in our first pump trial in December was related to nitrogen supersaturation from a leaking air pipe in the holding tank and affected all experimental groups, suggesting that the injuries were not pump-related (Table 4).

Survival of a variety of native and introduced fishes (26 species, 7,197 individuals) entrained incidentally during the pumping trials averaged 99 percent (Table 6). Mortality was limited to one white catfish, two threadfin shad *(Dorosoma petenense)*, one Sacramento splittail, two chinook salmon, one delta smelt *(Hypomesus transpacificus)*, and two striped bass (*Morone saxitilis).* Although these could have been pump-induced mortalities, it is also conceivable that these fish may have been dead before pump entrainment. Fifteen fertile delta smelt, a fragile species (Swanson et al. 1996), passed through the pump alive and in good condition in February and all but 1 of the 543 post-larvae delta smelt entrained by the pump survived. Most fish entrained were small (<100 mm), but even large fish (750 mm) were collected unharmed after pump passage (Table 6).

Natural debris loading varied greatly in weight and character, ranging from less than 50 g to nearly 7,000 g/trial depending on the season. Despite large differences in debris loading within and among seasons, fish survival was not significantly related to debris loading over the ranges encountered (regression, $R^2 = 001$, $P = 0.861$). Debris loads were dominated (98 percent) by herbaceous matter, largely fragments of *Egeria densa* in December, but greater amounts of debris, including woody debris (twigs, bark, and sticks), were evident in subsequent trials.

## DISCUSSION

The Hidrostal pump tested was designed to minimize shear, pressure changes, turbulence, and abrasion. It is larger, but similar in design to those that have been widely used in the aquaculture industry to harvest, grade, and move fish with high survival and low injury (Baldwin 1973, Grizzle et al.1992, Grizzle and

Lovshin l994, and Wagner and Driscoll 1994). The pump used in this study was effective in passing a variety of species, sizes, and densities over a wide range of environmental conditions with little mortality or injury. Environmental conditions during most months were suitable for fish survival. However, the use of chinook salmon was discontinued in June when the number of wild chinook salmon in the salvage declined, and ambient water temperatures in the Sacramento-San Joaquin Delta exceeded 21°C and were unsuitable for coldwater species. Test fish were more susceptible to stress and mortality during mid-summer, but significantly reduced survival occurred only in June for 4-day post-treatment fish.

We deliberately injected Sacramento splittail and chinook salmon and indirectly entrained 26 fish species, most with relatively low immediate mortality (average <1 percent) and injury rates. Other authors have reported similar results. Patrick and McKinley (l987) found no mortality and minimal (<3 percent) injury for American eels *(Anguilla rostrata)* when passed through a small Hidrostal pump. Rodgers and Patrick (1985) reported no mortality among gizzard shad (*Dorosoma cepedianum*), white sucker (*Catostomus commersoni*), and brown bullhead (*Ictalurus nebulosus*) tested in a 25-cm Hidrostal pump at 600 and 950 rpm. They also found <2 percent mortality for rainbow trout (*Oncorhynchus mykiss)* but higher mortality (0 to 29 percent) for yellow perch *(Perca flavescens)*, and 5 to 22 percent for alewife (*Alosa pseudoharengus*), depending on pump speed and transport times. Wagner and Driscoll (1994) compared the stress response in cutthroat trout among three fish loading systems (helical pump, conveyer, and dip netting), and reported only minor differences.

Several authors have reported survival and injury varied with impeller speed, particularly for small Hidrostal pumps, operated at high pump speed (Baldwin 1973, Grizzle et al. 1992, Grizzle and Lovshin 1994). Rodgers and Patrick (1985) reported higher mortalities of yellow perch and alewife, at pump speeds above 600 rpm. Grizzle and Lovshin (l994) found increased skin hemorrhage in channel catfish at pump speeds above 385 rpm. They and others have emphasized the importance of determining optimum pump speed for each circumstance, size, and species of fish. In contrast, we found no significant relationship between pump speed or discharge and fish survival at speeds up to 600 rpm and discharges up to 0.40 $m^3/s$. When our Hidrostal pump was operating within its engineered optimum velocity (400 to 600 rpm) and discharge (0.1 to 0.40 $m^3/s$), the resultant hydraulic conditions were acceptable and fish mortality, descaling, and injury rates were low.

Pump size may play an important role in passing fish safely. Our Hidrostal pump was the largest commercial model available and nearly twice as large as those used in aquaculture. Theoretically, this size pump should be less damaging than smaller ones because of the reduced contact surface relative to the volume of water pumped and the resulting lower probability of abrasion and impact. The largest experimental Hidrostal pump (91 cm) built passed chinook salmon and other native species in the Sacramento River with comparable low mortality, descaling, and injury (McNabb et al. 1998) and stress (Weber and Borthwick 2000). Pump size may also mitigate fish survival during high debris loads.

Fish density and body size of pumped fish did not influence fish survival or injury rates. Our injected densities (8 to 39 fish/L) were much higher than natural fish concentrations (typically 2 fish/1000L) at the Tracy Pumping Plant, and we observed little mortality and injury even at the highest densities. Patrick and Mckinley (1987) reported no mortality and little (< 3 percent) injury to American eels pumped at densities of 0.34 to 5.5 fish/L, despite a fish:water ratio of 80:20 which far exceeded the optimum (40:60 solid to liquid) for 15-cm pump efficiency. Large fish, such as an American eel (76 cm TL) were passed undamaged.

Average descaling rates for Sacramento splittail and chinook salmon were minimal and similar among experimental groups. Kostecki et al. (l987) reported that 43 percent of the Atlantic salmon smolts that passed through a turbine had scale loss of 20 to 28 percent, which was approximately 10 percent greater than the control. In our study, differences in descaling between species were negligible. However, in contrast to scales of Sacramento splittail and other species entrained, salmonid scales are deciduous and were more easily lost and replaced, particularly during smolting. Small chinook salmon (< 50 mm) have transparent scales which were not readily visible and could not be used to estimate scale loss reliably. The use of quality control fish was critical in these trials because descaling and fin abrasions were common for fish held for prolonged periods at high densities at the aquaculture facility.

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Table 1. Mean hourly physiochemical conditions during the pumping trials.

| Month | Dissolved oxygen (mg/L) | Oxygen saturation (%) | pH | Water temperature ( °C) | Specific conductance (mS/cm) | Salinity (%) | Redox (mV) |
|---|---|---|---|---|---|---|---|
| Dec | 9.9 | 86.9 | 7.6 | 8.8 | 0.65 | 0.33 | 588 |
| Feb | 8.2 | 74.5 | 6.9 | 10.7 | 0.33 | 0.10 | 554 |
| Mar | 9.9 | 91.3 | 7.3 | 12.1 | 0.30 | 0.13 | 512 |
| Apr | 11.4 | 110.2 | 8.2 | 13.5 | 0.38 | 0.21 | 222 |
| May | 8.5 | 94.9 | 7.5 | 20.7 | 0.47 | 0.25 | 410 |
| June | 8.4 | 99.1 | 7.5 | 21.6 | 0.40 | 0.23 | 400 |
| July | 8.4 | 101 | 7.4 | 24.1 | 0.09 | 0.01 | 400 |

Table 2. Mean recovery (%) and immediate (0 hour) and 4 day survival (%) of Sacramento splittail passed through the Hidrostal pump (treatment) and those of the control fish.

| Group | Month | Trials (N) | Fish in (N) | Fish out (%) | Survival (%) O H | Survival (%) Day 4 |
|---|---|---|---|---|---|---|
| Treatment | Dec | 10 | 295 | 98.3 | 99.6 | 97.8 |
| Control | | 10 | 284 | 96.9 | 99.0 | 90.8 |
| Treatment | Feb | 9 | 177 | 99.4 | 100 | 100 |
| Control | | 9 | 179 | 95.5 | 99.4 | 98.3 |
| Treatment | Mar | 6 | 142 | 97.9 | 99.1 | 99.1 |
| Control | | 6 | 162 | 98.6 | 92.9 | 92.9 |
| Treatment | Apr | 12 | 240 | 97.1 | 98.3 | 94.7 |
| Control | | 12 | 237 | 97.1 | 99.5 | 95.7 |
| Treatment | May | 11 | 240 | 98.7 | 98.6 | 83.1 |
| Control | | 11 | 218 | 97.2 | 100 | 85.9 |
| Treatment | Jun | 21 | 409 | 99.3 | 99.8 | 83.0 |
| Control | | 21 | 416 | 97.8 | 100 | 90.0 |
| Treatment | Jul | 20 | 447 | 98.5 | 98.9 | 92.6 |
| Control | | 20 | 430 | 99.2 | 99.5 | 95.6 |

Table 3. Mean recovery (%) and immediate (0 hour) and 4 day survival (%) of chinook salmon passed through the Hidrostal pump (treatment fish) and those of the control fish.

| Group | Month | Trials (N) | Fish in (N) | Fish out (%) | Survival (%) 0 H | Survival (%) Day 4 |
|---|---|---|---|---|---|---|
| Treatment | Feb | 7 | 160 | 95.6 | 98.1 | 96.9 |
| Control | | 7 | 138 | 99.3 | 99.3 | 99.3 |
| Treatment | Mar | 13 | 332 | 95.7 | 98.6 | 98.6 |
| Control | | 13 | 311 | 94.7 | 99.6 | 98.8 |
| Treatment | Apr | 11 | 263 | 99.6 | 98.9 | 92.4 |
| Control | | 11 | 263 | 98.5 | 99.6 | 78.3 |
| Treatment | May | 10 | 220 | 98.3 | 99.5 | 95.8 |
| Control | | 10 | 201 | 99.0 | 100 | 96.4 |

Table 4. Descaling (% body) and injury (% fish) for quality control (handling), control (no pump passage), and treatment (pump passage) groups of Sacramento splittail at Tracy Pumping Plant, California.

| | Month | Fish (N) | Descaling (% body) | Body Injury (% fish) | | | |
|---|---|---|---|---|---|---|---|
| Group | | | | Head | Eyes | Skin | Fins |
| Quality Control | Dec. | 40 | 1.4 | 20 | 55.0 | 2.5 | 52.5 |
| Control | | 20 | 1.6 | 10 | 95.0 | 5.0 | 55.0 |
| Treatment | | 20 | 1.0 | 15 | 80.0 | 5.0 | 15.0 |
| Quality Control | Feb. | 36 | 3.1 | 0 | 2.8 | 0 | 30.6 |
| Control | | 18 | 2.8 | 0 | 5.5 | 0 | 11.1 |
| Treatment | | 18 | 2.6 | 0 | 0 | 0 | 0 |
| Quality Control | March | 32 | 1.4 | 0 | 6.3 | 0 | 9.4 |
| Control | | 18 | 1.9 | 0 | 5.6 | 5.6 | 5.6 |
| Treatment | | 18 | 1.3 | 0 | 0 | 11.1 | 22.2 |
| Quality Control | April | 44 | 1.1 | 0 | 0 | 0 | 0 |
| Control | | 22 | 1.5 | 0 | 0 | 0 | 0 |
| Treatment | | 22 | 1.3 | 0 | 0 | 0 | 0 |
| Quality Control | May | 40 | 1.6 | 0 | 0 | 0 | 0.2 |
| Control | | 20 | 1.8 | 0 | 0 | 0 | 0.4 |
| Treatment | | 20 | 2.2 | 0 | 0 | 0 | 0.4 |
| Quality Control | June | 50 | 3.9 | 0 | 5 | 0 | 6.5 |
| Control | | 25 | 3.9 | 2 | 2 | 0 | 8.0 |
| Treatment | | 25 | 2.6 | 2 | 2 | 0 | 6.0 |
| Quality Control | July | 40 | 2.4 | 0 | 0.3 | 0 | 0.1 |
| Control | | 20 | 2.7 | 0 | 0.3 | 0 | 0.1 |
| Treatment | | 20 | 2.6 | 0 | 0.4 | 0 | 0.1 |

Table 5. Descaling (% body) and injury analysis (% fish) for quality control (handling), control (no pump passage), and treatment (pump passage) groups of chinook salmon at Tracy Pumping Plant, California.

| Group | Month | Fish (N) | Descale (% body) | Body Injury (% fish) Head | Eyes | Skin | Fins |
|---|---|---|---|---|---|---|---|
| Quality Control | Feb. | 28 | 0.1 | 14.3 | 0 | 3.6 | 3.6 |
| Control | | 14 | 0.1 | 7.1 | 14.3 | 7.1 | 0 |
| Treatment | | 14 | 0.6 | 0 | 0 | 0 | 14.3 |
| Quality Control | March | 38 | 0.3 | 0 | 0 | 0 | 18.4 |
| Control | | 20 | 1.5 | 0 | 0 | 5 | 20.0 |
| Treatment | | 18 | 4.3 | 0 | 0 | 0 | 0 |
| Quality Control | April | 44 | 0.7 | 0 | 0 | 0 | 0 |
| Control | | 22 | 0.3 | 0 | 0 | 0 | 0 |
| Treatment | | 22 | 0.8 | 0 | 0 | 0 | 0 |
| Quality Control | May | 40 | 3.8 | 0 | 0 | 0 | 0 |
| Control | | 20 | 3.8 | 0 | 0 | 0 | 0 |
| Treatment | | 20 | 4.0 | 0 | 0 | 0 | 0 |

Table 6. Number, total length (range), and survival of native and non-native fish entrained and passed through the helical pump.

| Species | Dec (n) | Jan (n) | Mar (n) | Apr (n) | May (n) | Jun (n) | Jul (n) | Length (mm) | Survival (%) |
|---|---|---|---|---|---|---|---|---|---|
| White catfish, *Ictalurus catus* | 25 | 5 | 37 | 22 | 3 | 26 | 100 | 70-208 | 99 |
| Threadfin shad, *Dorosoma petenense* | 3 | 21 | 22 | 3 | | 9 | 40 | 49-98 | 98 |
| American shad, *Alosa sapidissima* | 3 | 8 | | 1 | | 1 | 75 | 74-119 | 100 |
| Splittail, *Pogonichthys macrolepidotus* | 2 | 7 | | | 1 | 7 | 21 | 21-206 | 97 |
| Yellowfin goby, *Acanthogobius flavimanus* | 2 | | | | | | 1 | 85-179 | 100 |
| Tule perch, *Hysterocarpus traski* | 3 | 3 | 2 | 3 | 2 | | 2 | 99-138 | 100 |
| Channel catfish, *Ictalurus punctatus* | 3 | 2 | 2 | 2 | | 25 | 22 | 71-129 | 100 |
| Brown bullhead, *Ictalurus nebulosus* | 1 | 1 | | 1 | 4 | | | 121-316 | 100 |
| Redear sunfish, *Lepomis microlophus* | 1 | 2 | | | 1 | 1 | 3 | 154-280 | 100 |
| Bluegill, *Lepomis macrochirus* | 1 | | 2 | 5 | 3 | 6 | 7 | 78-143 | 100 |
| Chinook salmon,*Oncorhynchus tschawtscha* | | 44 | 13 | 137 | 195 | 38 | | 50-106 | 100 |
| Delta smelt, *Hypomesus transpacificus* | | 15 | | | 379 | 164 | | 33-72 | 99 |
| Striped bass, *Morone saxitilis* | | 9 | 6 | 2 | 353 | 4,913 | 298 | 17-118 | 99 |
| Golden shiner, *Notemigonus crysoleucas* | | 3 | 6 | | | 2 | | 107-170 | 100 |
| Red shiner, *Cyprinella lutrensis* | | 2 | | | | | | 59-60 | 100 |
| Steelhead, *Oncorhynchus mykiss* | | 1 | 7 | 7 | 1 | | | 222-288 | 100 |
| Blackfish, *Orthodon microlepidotus* | | 1 | | | | | | 139 | 100 |
| Bigscale logperch, *Percina macrolepida* | | 1 | 1 | 1 | | | | 117-133 | 100 |
| Carp, *Cyprinus carpio* | | | 1 | 1 | | 1 | 2 | 163-228 | 100 |
| Black crappie, *Pomoxis nigromaculatus* | | | 1 | | | | | 238 | 100 |
| Inland silverside, *Menidia beryllina* | | | 7 | | | | 1 | 60-74 | 100 |
| Largemouth bass, *Micropterus salmoides* | | | | 2 | | 2 | 1 | 58-371 | 100 |
| Longfin smelt, *Spirinchus thaleichthys* | | | | 2 | | | | 38 | 100 |
| Prickly sculpin, *Cottus asper* | | | | | 5 | 9 | 6 | 38-51 | 100 |
| Hitch, *Lavinia exilicauda* | | | | | | | 1 | 260 | 100 |
| American eel, *Anguilla rostrata* | | | | | | | 1 | 780 | 100 |

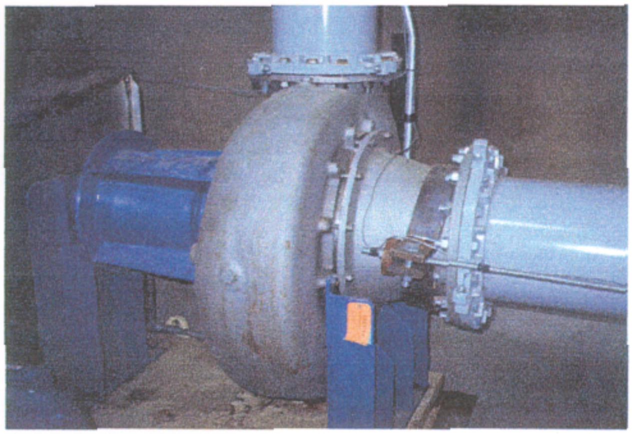

Figure 1. WEMCO-Hidrostal centrifugal pump used for the fish passage experiments.

Figure 2. Fish collection pool. Fish were collected by handnet after pumping.

Firgue 3. Microscopic analysis of potential scale loss and condition of pumped fish.

Figure 4. Cross section view of the Hidrostal pump and fish injection ports (fish protective impeller shroud is not shown in this drawing).