

Are Juvenile Chinook Salmon Entrained at Unscreened Diversions in Direct Proportion to the Volume of Water Diverted?

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Abstract

Mark-recapture experiments were used to test the null hypothesis that juvenile chinook salmon smolts emigrating from the Sacramento River are entrained at unscreened water diversions in direct proportion to the water volume diverted. The experiments were conducted at the RD1004 Princeton Pumping Plant during June 1995, with a similar set of mark-recapture experiments conducted at the RD108 Wilkins Slough diversion. Results of four tests conducted at the RD1004 Princeton Pumping Plant showed an average of 0.05% of the marked salmon being entrained, compared to 1.03% of the Sacramento River flow diverted. Overall results at the RD108 Wilkins Slough diversion showed a similar pattern, with 0.08% of the marked salmon being recaptured compared to 1.1% of the Sacramento River flow being diverted. Based upon results of these tests the null hypothesis was rejected. The percentage of juvenile chinook salmon entrained was more than ten times lower than the corresponding percentage of Sacramento River flow diverted. Results of these tests have implications in the assessment of entrainment mortality of juvenile chinook salmon at unscreened diversions and the calculation of costs and biological benefits for intake screening projects. These study results are limited, however, due to the relatively low percentage of Sacramento River flow diverted during these 1995 tests, the assumption that hatchery-reared, spray-dyed salmon released a relatively short distance upstream of an unscreened diversion are representative of the behavioral patterns and distribution of wild salmon within the Sacramento River, and the size and configuration of water diversions tested.

Introduction

A large number of water diversions exist on the Sacramento and San Joaquin rivers and throughout the Delta (Herren and Kawasaki, this volume). The majority of these water diversions is unscreened. Concern has been expressed by resource agencies and other interested parties regarding the incremental increase in mortality to juvenile chinook salmon (*Oncorhynchus tshawytscha*), and other aquatic species, resulting from entrainment losses at these diversions. Data are not available, however, to quantify entrainment losses of juvenile chinook salmon at a majority of these sites. As part of the assessment evaluating diversion effects on juvenile chinook salmon, and benefits associated with positive barrier fish screens, an assumption has been made that fish entrainment is proportional to the volume of unscreened water diverted. To date few experimental tests have been performed within the Sacramento-San Joaquin system to verify or refute this fundamental assumption. Furthermore, no studies have been identified from the scientific literature that document the relationship between entrainment losses for juvenile salmon and steelhead in relationship to the volume of water diverted at unscreened intake structures located on west coast tributaries.

To test the null hypothesis that juvenile chinook salmon are entrained at unscreened diversions in direct proportion to flow diverted mark-recapture studies were performed in 1995 at an unscreened water diversion. The experiment was performed at the Reclamation District 1004 (RD1004) Princeton Pumping Plant. These tests were conducted as part of a more comprehensive investigation of the potential application of alternative fish protection devices (for example, acoustic barriers) in reducing juvenile chinook salmon entrainment losses at water diversions (Hanson 1996a).

Princeton Pumping Plant

The Princeton Pumping Plant is located on the east bank of the Sacramento River just north of the town of Princeton at river mile 164.4 (Figure 1). The pumping plant diverts water from the Sacramento River into Drumheller Slough, which serves as part of the RD1004 conveyance and distribution system. RD1004 provides water to approximately 15,000 acres of agricultural land and 10,000 acres of migratory waterfowl wetland habitat within the Butte Basin in Glenn and Colusa counties.

The Princeton Pumping Plant has been in operation since 1912, but was extensively rebuilt in 1981. The facility consists of four 150 hp, 36-inch diameter, vertical mix-flow pumps. The fifth pump is a 30-inch diameter, 100 hp, vertical mix-flow pump located on a separate platform. Each of the pumps has a

separate 36-inch diameter flap-gate and steel discharge line entering Drumheller Slough. At the time of the 1995 investigations the pumping plant diversion was unscreened.

Peak seasonal diversions at the Princeton Pumping Plant occur during the spring irrigation of rice fields and other agricultural lands and during the fall flooding of seasonal managed wetlands. During the remainder of the irrigation season, the pumping plant provides water for agricultural operations. The spring peak typically occurs from April 15 to May 30, which coincides with the primary seasonal period of fall-run chinook salmon smolt emigration from the Sacramento River. The fall and early winter peak pumping typically occurs between October and mid-January, a time when juvenile winter-run chinook may be emigrating.

Peak diversion capacity at the Princeton Pumping Plant is approximately 290 cfs. During maintenance flow two to three pumps are typically in operation (120 to 180 total cfs), depending on water demand within the service area. Diversions occur both by active pumping and, when Sacramento River elevation is high, by gravity flow.

Methods

The experimental design of the field investigations was based on the release of spray-dyed marked juvenile chinook salmon into the Sacramento River upstream of the unscreened Princeton Pumping Plant diversion and subsequently monitoring the number of marked salmon recaptured at the water diversion over a 48-hour period. Results of more comprehensive fish investigations at two unscreened diversion sites (Hanson 1996a, 1996b) documented that a 48-hour sampling duration was appropriate for these mark-recapture tests.

Using release and recapture data, an estimate was calculated of the percentage of the marked salmon entrained at the unscreened diversion. Monitoring the volume of water diverted and the corresponding flow within the Sacramento River allowed calculation of the percentage of the Sacramento River flow diverted. The null hypothesis that juvenile chinook salmon are diverted in direct proportion to flow diversion could then be tested by comparing the estimated percentage of juvenile chinook salmon entrained with the corresponding estimate of the percentage of Sacramento River flow diverted during each test period.

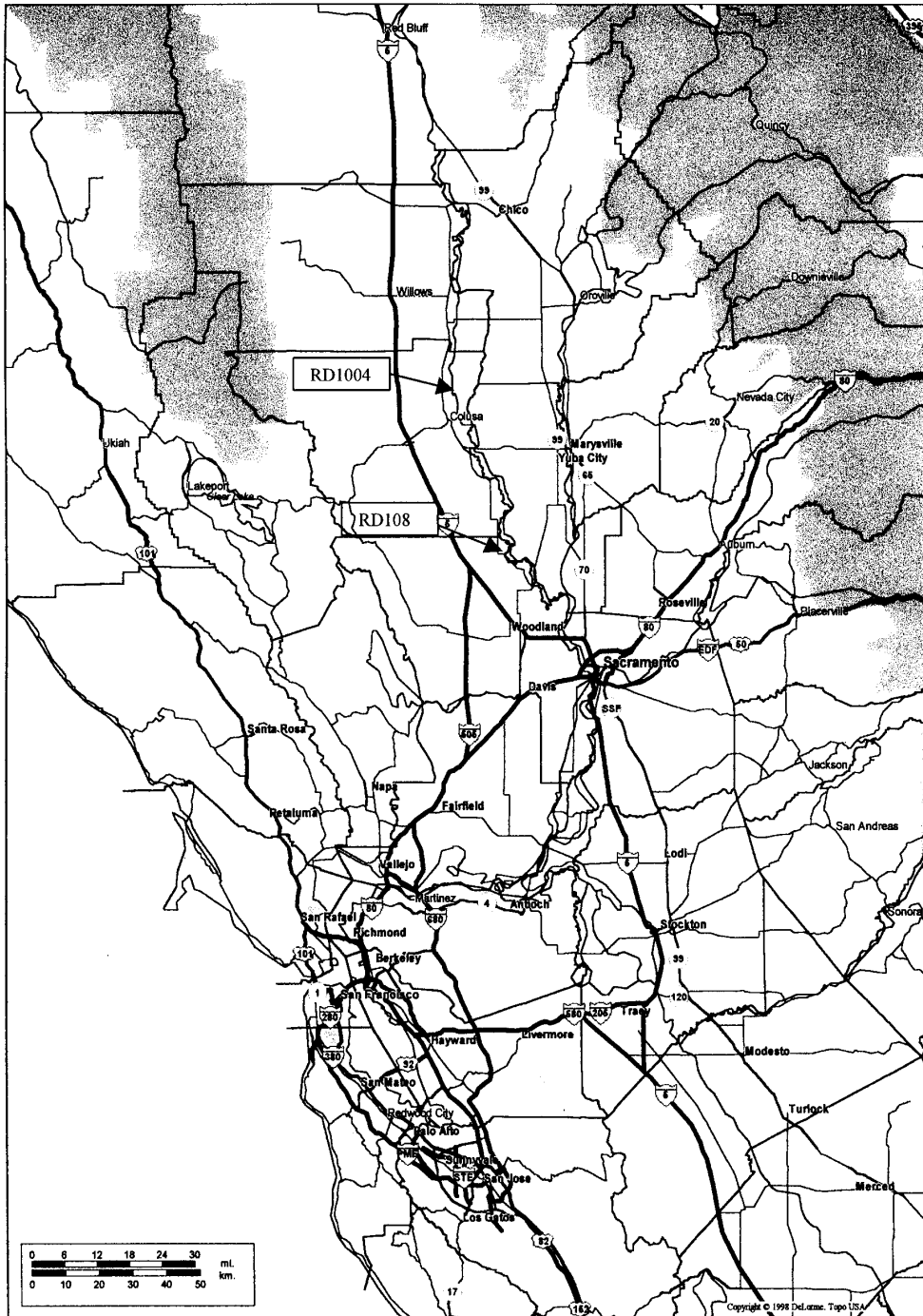


Figure 1 Location of the RD 1004 Princeton Pumping Plant and RD 108 Wilkins Slough diversion on the Sacramento River

Juvenile Salmon Spray-Dye Marking and Release

Juvenile chinook salmon used in these tests were obtained from the California Department of Fish and Game's (DFG) Feather River Hatchery. Juvenile salmon were marked using spray-dye (Scientific Marking Materials) at the hatchery. The number of fish marked was determined by weighing a sub-sample (number of fish per pound) and subsequently by weighing all marked fish within a test group. Juvenile salmon were marked without anesthesia and were retained in the Feather River Hatchery for a minimum of 72 hours after marking to recover from handling stress.

A sub-sample of approximately 100 marked fish from each release group was obtained from the transport truck and held on-site for a period of 48 hours, corresponding to the duration of the recapture collections for each test, to determine post-release survival. Fish held for post-release survival observations were inspected for dye retention as part of the quality assurance program.

Approximately 25,000 juvenile chinook salmon were marked for use in each release group. Mortalities occurring during and after marking were documented for each release group. After the hatchery recovery period, the marked group was loaded into a commercial hatchery truck for transport to the release location. Before release, fish within the transport truck were examined to determine the number of mortalities and the overall condition of the release group. Transport mortality ranged from 0.1% to 0.3%, while survival of a sub-sample from each release group 48-hours after release ranged from 98% to 100%. Inspection of the sub-sample of juvenile salmon held on-site from each release group confirmed 100% spray-dye retention and detection.

Dissolved oxygen and temperature were measured within the transport truck and Sacramento River at the time of release. Water temperature within the hatchery transport truck and Sacramento River at the release site were within 0 to 1.7 °C (0 to 3 °F), thereby avoiding significant temperature changes and thermal shock for fish at the time of release.

Marked fish were released at a location on the east side of the Sacramento River approximately 0.55 miles upstream of the RD1004 Princeton diversion. The release location selected for use in these tests was based upon access to a location sufficiently far upstream to provide the juvenile salmon an opportunity to disperse within the Sacramento River before encountering the unscreened diversion, yet sufficiently far downstream of identified sources of mortality, including other unscreened diversion locations.

Juvenile Salmon Entrainment Monitoring Using Fyke Nets

Monitoring the number of juvenile chinook salmon and other fish species entrained was performed using fyke nets approximately 35 feet long, mounted over the discharge of each pump. The fyke nets sampled 100% of the flow diverted from the Sacramento River. Fyke nets were constructed using 1/8-inch mesh equipped with a live box at the cod end. Collections were made from each live box to remove both fish and debris without the necessity of removing the entire net. Each live box was accessed from a floating dock located within the discharge canal of the Princeton Pumping Plant.

Fyke nets were processed to remove entrained fish and debris a minimum of twice per day (morning and afternoon), although more frequent processing was also performed as part of diel distribution studies. Although rips and tears in the fyke nets were uncommon, the nets were removed and inspected approximately every four to six days.

Direct release studies were performed to determine collection efficiency of the fyke nets. Collection efficiency studies were performed by releasing a known number of marked juvenile chinook salmon into the intake of diversion pump number one, and subsequently documenting the number of marked fish retained in the fyke net at the completion of the sampling cycle. Sampling cycles varied from 2 to 24 hours after release of marked fish into the diversion pump to determine the effects of sampling duration on net retention. Typically 40 juvenile chinook salmon were used in each collection efficiency test. Juvenile chinook salmon used in these tests ranged from 76 to 142 mm FL (mean length 102 mm). Salmon were alive at the time of release into the diversion pump. Fyke net collection efficiency studies had an overall recapture efficiency of 80%, with a range of 65% to 100%.

Data collected in association with each fyke net sample included identification and enumeration of all fish species collected. All salmon collected were examined using ultraviolet lights to determine the number and color of marked fish recaptured. Fork-length was measured for juvenile chinook salmon. Length measurements were made for a sub-sample of other fish species. Data were recorded for each collection identifying the individual fyke net where the collection was made, the start and end times of the sampling interval, and the water volume sampled. Mortality and damage to fish collected was also documented. After processing, live fish were released approximately 0.25 miles downstream of the diversion.

Sacramento River Flow and Diversion Operations

Data on daily Sacramento River flows in the vicinity of the Princeton diversion (Colusa Bridge) were obtained from the California Department of Water Resources (DWR) California Data Exchange Center Database (CDEC). Daily average Sacramento River flow during the study ranged from approximately 13,300 to 14,100 cfs.

The volume of water diverted from the Sacramento River by individual pumps at the Princeton facility was documented coincident with each fish collection. To the extent possible, diversion pump operations were held constant throughout each test to reduce effects attributable to variation in diversion operations. The diversion rate (cfs) and total volume diverted (acre-foot) were monitored for each individual diversion pump using a Sparling Inline flowmeter. Diversion rates for individual pumps typically ranged from 50 to 70 cfs. Diversion pump number five was not operational during the June 1995 study period. Diversion pump number three experienced operational problems and was removed from service in mid-June. Diversion pumps one, two, and four operated on a relatively consistent basis throughout the study period.

Results

Four mark-recapture tests were performed, which provided information on the percentage of juvenile chinook salmon entrained at the unscreened Princeton Pumping Plant. During the four mark-recapture tests included in this analysis (Table 1), a total of 124,394 salmon was released into the Sacramento River.

Spray-dyed chinook salmon were recaptured in low numbers in the RD1004 Princeton Pumping Plant fyke nets (see Table 1). The percentage of marked fish recaptured ranged from 0% to 0.1%, with an overall average for the four tests of 0.05%. The corresponding estimate of the percentage of Sacramento River flow diverted during each of these test periods ranged from 0.9% to 1.2% (see Table 1), with an overall average of 1.03%.

Table 1 Summary of juvenile chinook salmon mark-recapture test results used to determine the percentage of entrainment at the RD1004 unscreened Princeton Pumping Plant diversion in June 1995

<i>Date</i>	<i>Number released</i>	<i>Number recaptured</i>	<i>Expanded number recaptured^a</i>	<i>Sacramento River flow (cfs)</i>	<i>Percentage of salmon entrainment</i>	<i>Percent Sacramento River flow diverted</i>
7–9 June	24,865	21	26	14,068	0.10	1.0
17–19 June	24,850	0	0	14,139	0	0.9
21–23 June	24,869	0	0	13,286	0	1.0
28–30 June	49,810	28	35	13,772	0.07	1.2
Total or Average	124,394	49	61		0.05	1.03

^a Recaptures were expanded based on 80% fyke net collection efficiency (see text).

Discussion

The numbers of marked salmon entrained and recaptured at the RD1004 unscreened diversion was substantially and consistently lower than the percentage of Sacramento River flow diverted (Figure 2). The overall percentage of juvenile salmon recaptured was 0.05% (adjusted for net collection efficiency), compared with an average of 1.03% of the Sacramento River flow diverted during the period of these studies. The substantially lower percentage of fish diverted in these tests demonstrates that marked hatchery-reared juvenile chinook salmon are not entrained in direct proportion with the water volume diverted at the RD1004 intake and, the results suggest juvenile salmon are substantially less vulnerable to entrainment losses than would be expected based purely on a volumetric relationship. Factors such as the location of the diversion with respect to major flow patterns, topographic characteristics of the Sacramento River channel, the location of the diversion pump inlet within the water column, and the behavioral response of chinook salmon smolts to turbulence and velocity differences associated with operation of the intake may contribute to a reduction in the susceptibility of juvenile salmon to entrainment. In addition, the juvenile salmon used in these mark-recapture tests were hatchery reared and released a relatively short distance upstream of the diversion (0.55 miles) and may, therefore, not be representative of the behavioral patterns or distribution of wild salmon within the Sacramento River.

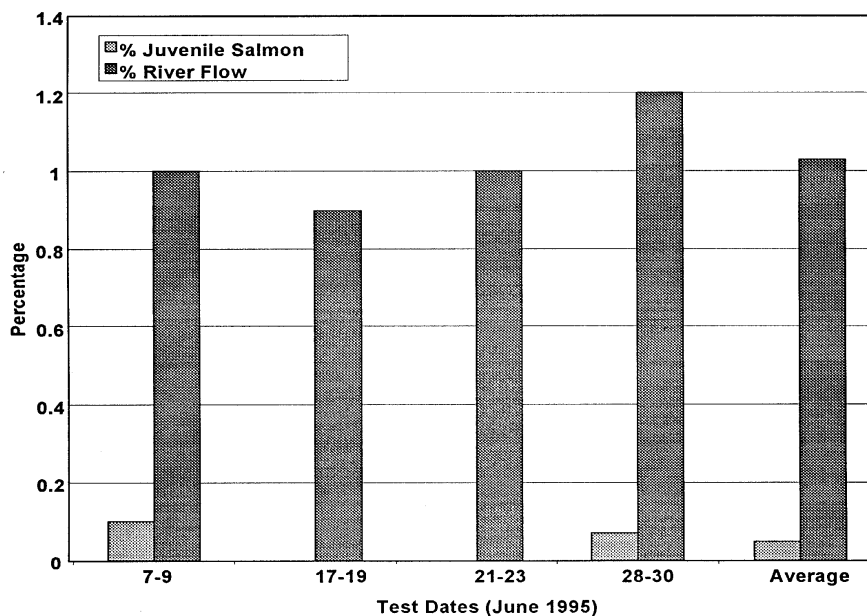


Figure 2 Comparison of the percentage of marked juvenile chinook salmon entrained and Sacramento River flow diverted at the unscreened RD 1004 Princeton Pumping Plant in June 1995

Results of the mark-recapture studies conducted at the RD1004 Princeton Pumping Plant are consistent with results of a similar mark-recapture investigation conducted in 1995 on the Sacramento River at the RD108 Wilkins Slough diversion (Hanson 1996b). Reclamation District No. 108 operates the Wilkins Slough Pumping Plant, located on the west bank of the Sacramento River at river mile 117.8, which was unscreened during 1995. A mark-recapture experiment was used at RD108 to evaluate entrainment of juvenile chinook salmon during four experiments conducted during June 1995. Spray-dyed salmon were released along the west bank of the Sacramento River at locations 0.45 to 0.65 miles upstream of the Wilkins Slough diversion. Marked salmon were subsequently recaptured within the Wilkins Slough diversion using fyke nets and processed in a manner similar to that described for the RD1004 investigation. During this study average daily Sacramento River flow ranged from approximately 13,000 to 14,500 cfs, while average daily diversion rates ranged from 118 to 221 cfs. Additional information regarding the four mark-recapture experiments conducted in 1995 at the RD108 Wilkins Slough diversion is documented in Hanson (1996b). Results of the RD108 mark-recapture tests are summarized below and compared to results from the RD1004 experiments.

<i>Diversion location</i>	<i>Number of marked salmon released</i>	<i>Expanded number recaptured^a</i>	<i>Percentage of salmon entrainment</i>	<i>Percentage of Sacramento River flow diverted</i>
Princeton Pumping Plant ^b	124,394	61	0.05	1.03
Wilkins Slough Diversion ^c	99,419	75	0.08	1.1

^a Fyke net collections were expanded assuming a collection and retention efficiency of 80%.

^b Source: this study.

^c Source: Hanson 1996b.

Results of the 1995 studies were consistent in demonstrating the low susceptibility of hatchery-reared juvenile chinook salmon to entrainment losses, and the fact that marked juvenile salmon were not entrained in direct proportion to the volume of Sacramento River water flow diverted by either the RD1004 Princeton Pumping Plant or the RD108 Wilkins Slough diversion. Results of these experiments provide useful insight into the vulnerability of juvenile chinook salmon to entrainment losses and can be used as part of the basis for assessing the risk of adverse impacts resulting from unscreened water diversion operations. Additional studies will be required, however, to provide data on the relationship between the vulnerability of hatchery-reared, marked salmon released a relatively short distance upstream from the diversion to entrainment losses and the vulnerability of wild salmon to entrainment losses at these unscreened diversion locations. The percentage of juvenile salmon entrained during mark-recapture studies should also be viewed in context with the flow occurring in the Sacramento River, diversion operations, and the percentage of Sacramento River flow diverted during these tests. Results of the 1995 tests may or may not be representative of the relationship between unscreened diversion operations and the susceptibility of juvenile chinook salmon to entrainment losses under other environmental conditions in which the Sacramento River flow may be reduced, and the percentage of river flow diverted may be higher than that observed during the 1995 tests.

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