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ADULT SALMON MIGRATION MONITORING DURING THE VARIOUS OPERATIONAL PHASES OF THE SUISUN MARSH SALINITY CONTROL GATES IN MONTEZUMA SLOUGH, AUGUST - OCTOBER 1993.

by:
Terry Tillman, George Edwards, and Kevan Urquhart
Fish Facilities Unit
Bay-Delta and Special Water Projects Division

Bay-Delta and Special Water Projects Division
4001 North Wilson Way
Stockton, Ca. 95205-2486

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Abstract. Fifty adult fall-run chinook salmon (*Oncorhynchus tshawytscha*) were monitored for their migration movements during three operational phases of the Suisun Marsh Salinity Control Gates (SMSCG) in Montezuma Slough. At intervals, from August 23 through October 5, 1993, fall-run chinook salmon were captured downstream of the gates, implanted with sonic tags, and telemetrically monitored for movement past the SMSCG. Tagged fish ranged in size from 561 to 981 mm fork length. Fish mortalities that occurred during the first phase of the study were attributed to high water temperatures around 24°C (75 °F); seven of the 15 fish tagged, died. Salmon movement past the SMSCG during the first two operational phases were primarily associated with flood and high tide conditions. Movement past the SMSCG during the third operational phase was primarily associated with flood tides with salmon moving past the gates just prior to the radial gates closing. During Phase I, 91% of the viable tagged salmon passed the gates in an average of 12 hours from the time of tagging. During Phase II, with the flash boards in and gates raised, 47% of the tagged salmon passed in an average of 23 hours. During Phase III, with the gates fully operational, we observed 50% of the tagged salmon passing the SMSCG in an average of 25 hours. The proportion of viable tagged salmon that passed the SMSCG during Phase I was significantly greater than in either Phase II or Phase III, while the proportions of salmon passing in the latter two Phases were not significantly different from each other. The average passage time of viable tagged salmon which successfully passed the SMSCG was significantly less in Phase I than in either Phase II or Phase III, while the latter two Phases did not have significantly different passage times.

INTRODUCTION

Recognizing the potential adverse and cumulative effects of water projects on Suisun Marsh, the State Water Resources Control Board (SWRCB) established water quality criteria to protect the marsh (Decision 1485). In order to meet those water quality standards the Department of Water Resources (DWR) prepared the Suisun Marsh Plan of Protection (Plan) in 1984. A key feature of the Plan was the installation of the Suisun Marsh Salinity Control Gates (SMSCG) in Montezuma Slough. When operating, the SMSCG reduces the influx of higher salinity water into Montezuma Slough and Suisun Marsh from Grizzly Bay. By trapping lower salinity water flowing in from Collinsville, the SMSCG would reduce the average and high tide water salinity, especially during periods of low outflow from the Sacramento-San Joaquin Delta.

During the preparation of the Plan and the environmental documentation to begin its implementation, concerns were raised by the U.S. Environmental Protection Agency, National Marine Fisheries Service, and U.S. Fish and Wildlife Service biologists about potential impacts of the SMSCG to anadromous fish in Montezuma Slough. The primary concerns were: a) that the gates would increase predation losses of juvenile striped bass and migrating juvenile salmon, and b) that the gates would delay the migration of spawning adult salmon.

The Suisun Marsh Monitoring Agreement dated March 2, 1987 and DWR's U.S. Army Corps of Engineers (ACOE) permit (PN#16223E58) issued in 1986 required a fish monitoring program to assess the effects of SMSCG operation on anadromous fish in Montezuma Slough. In addition, the permit required criteria be applied to the monitoring data to determine if significant degradation occurred, and that a mitigation plan be implemented if adverse impacts were observed. The criteria have not yet been developed, and possible mitigation plans are pending the results of ongoing fisheries studies at the SMSCG.

DWR completed construction and commenced operation of the SMSCG in November of 1988 (Figures 1 and 2). In accordance with the monitoring agreement and the ACOE permit the Department of Fish and Game (DFG) has monitored the fish community around the SMSCG for DWR (DFG 1988a, 1988b, 1990, 1992a and 1992b). Early monitoring focussed on evaluating risks associated with increased fish predation as a result of the SMSCG construction. Observations of adult salmon migration behavior around the SMSCG, in 1991 and 1992, suggested that the presence and operation of the gates may delay the upstream movement of salmon through Montezuma Slough (DFG 1992a, 1992b). The 1993 study expands on those earlier observations to better understand the relationship between adult salmon migration behavior and SMSCG operations.

The objectives of the 1993 study are to measure adult salmon passage success and duration under each operational configuration of the SMSCG. The results are compared to determine any significant differences in the percent of salmon passing or passage rates, between SMSCG operating scenarios.

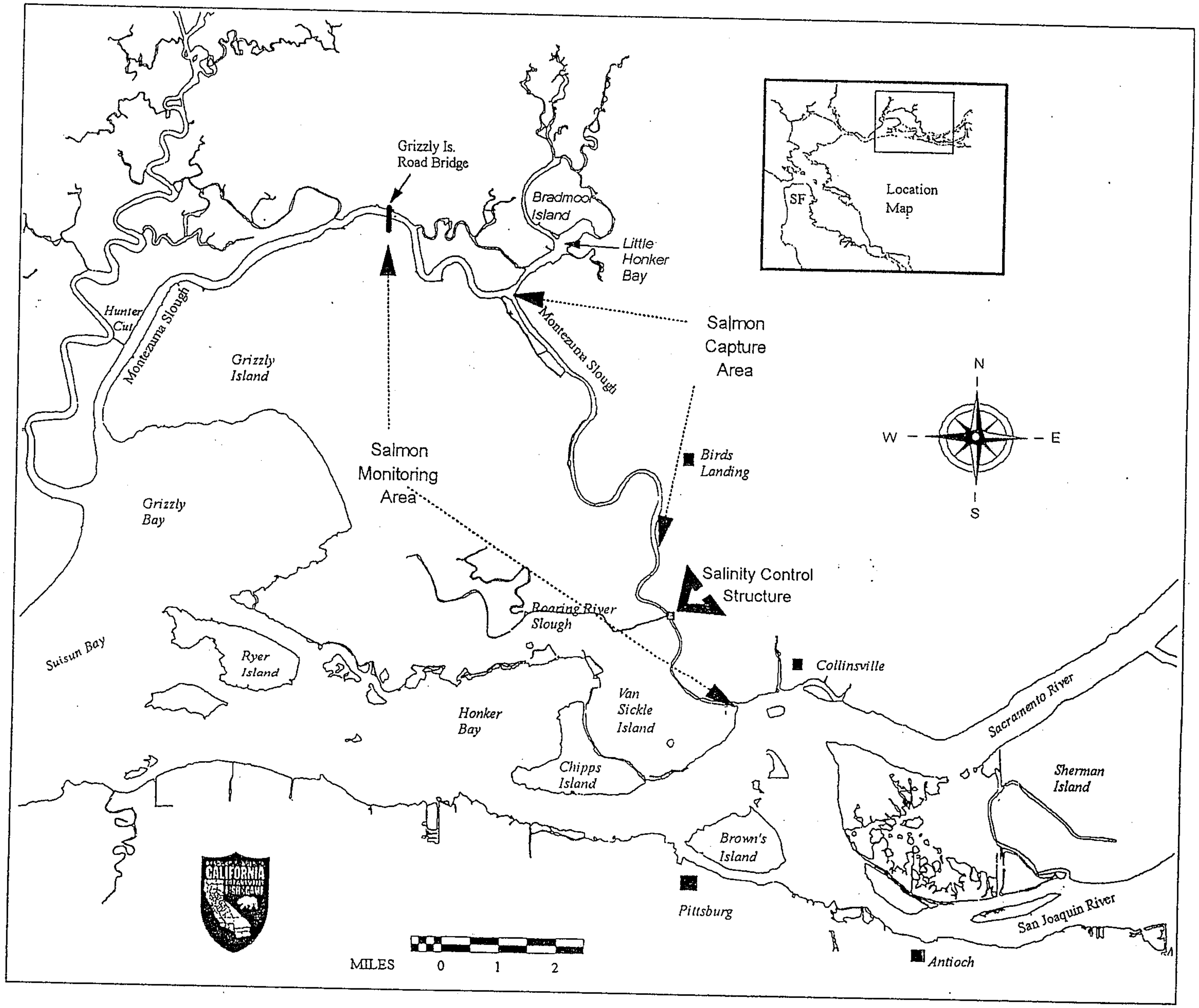

Figure 1. Study map showing adult salmon capture and monitoring areas in Montezuma Slough for August - October 1993.

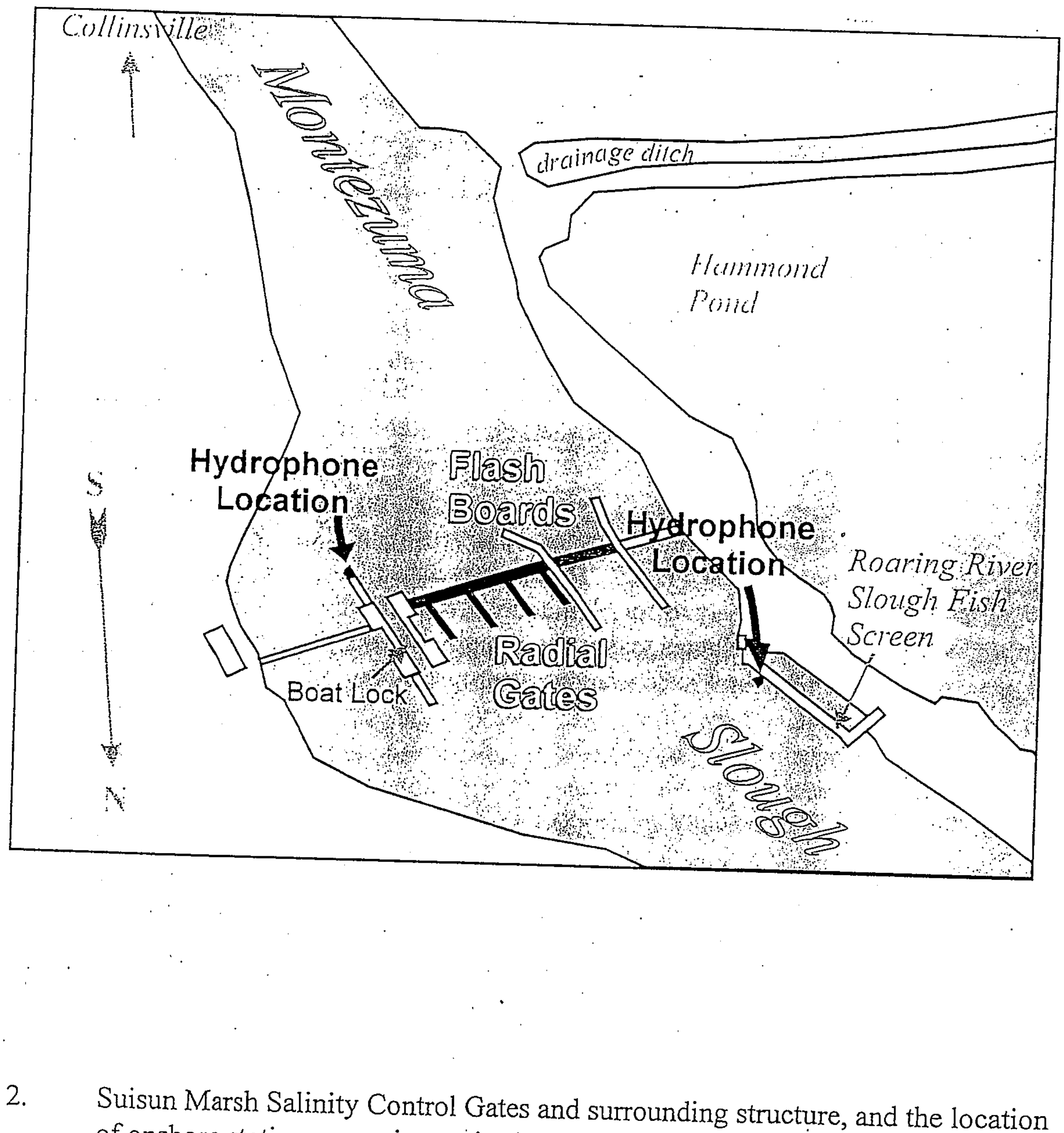

Figure 2. Suisun Marsh Salinity Control Gates and surrounding structure, and the location of onshore stationary sonic monitoring sites, August - October 1993.

MATERIALS AND METHODS

The 1993 monitoring of adult fall-run chinook salmon in Montezuma Slough is a continuation of fisheries work which began in 1987 (DFG 1988a, 1988b, 1990, 1992a and 1992b). The 1993 study was designed to address questions about the potential effects of SMSCG operations on anadromous fish migrations in Montezuma Slough, in particular, adult chinook salmon. Because of the endangered status of winter-run chinook salmon and the abundance of fall-run chinook salmon, only adult fall-run fish were used in the study. Adult chinook salmon were captured, tagged, and monitored during each SMSCG operation phase, all of which normally occur during salmon migration (DWR 1989, 1991). The three operational configurations (Phases) sampled during this study are described in Table 1 below:

Table 1. Operational Phases of the Suisun Marsh Salinity Control Gates, August - October, 1993.

Phase & Description		Dates of Operation
I	Flash boards not in place, gates up, and boat lock closed.	August 24 - September 6, 1993.
II	Flash boards in place, gates up, and the boat lock operational.	September 7 - 16, 1993.
III	Flash boards in place, gates tidally operated, and boat lock operational.	September 17 - October 4, 1993.

Salmon were captured both day and night by drifting a 200 foot by 12 foot deep nylon gill-net with 5.5 - 7 inch stretched mesh. The net was fished on the downstream side of the SMSCG from Little Honker Bay to approximately ½ mile north of the SMSCG (Figure 1). Net drift times varied from five minutes to one hour, depending on how quickly fish were being entrapped by the net. The net was constantly monitored by boat and fish were removed as quickly as possible once captured in the net. Fish were then transferred to a 250 gallon black plastic tub, which contained between 50 to 100 gallons of aerated water. Each fish's fork-length was measured to the nearest mm, the adipose fin was clipped, and a sonic tag placed in the stomach. This process was usually completed within three minutes of landing the fish in the boat. Tags were inserted with the aid of a livestock pill-balling (dispensing) device (Figure 3). Adipose fin clips differentiated tagged from untagged fish in subsequent gill-net catches. After tag insertion, fish were released near the Grizzly Island boat ramp, approximately 1.6 statute miles downstream from the SMSCG. Latitude and longitude coordinates, using a Global Positioning System (GPS), were taken at the fish release site. Fish which were injured or did not appear in good health, were not tagged and were immediately released.

Sonic telemetry monitoring was accomplished by boat and two onshore automatic stations set up at the SMSCG. The onshore monitoring stations provided fixed locations from

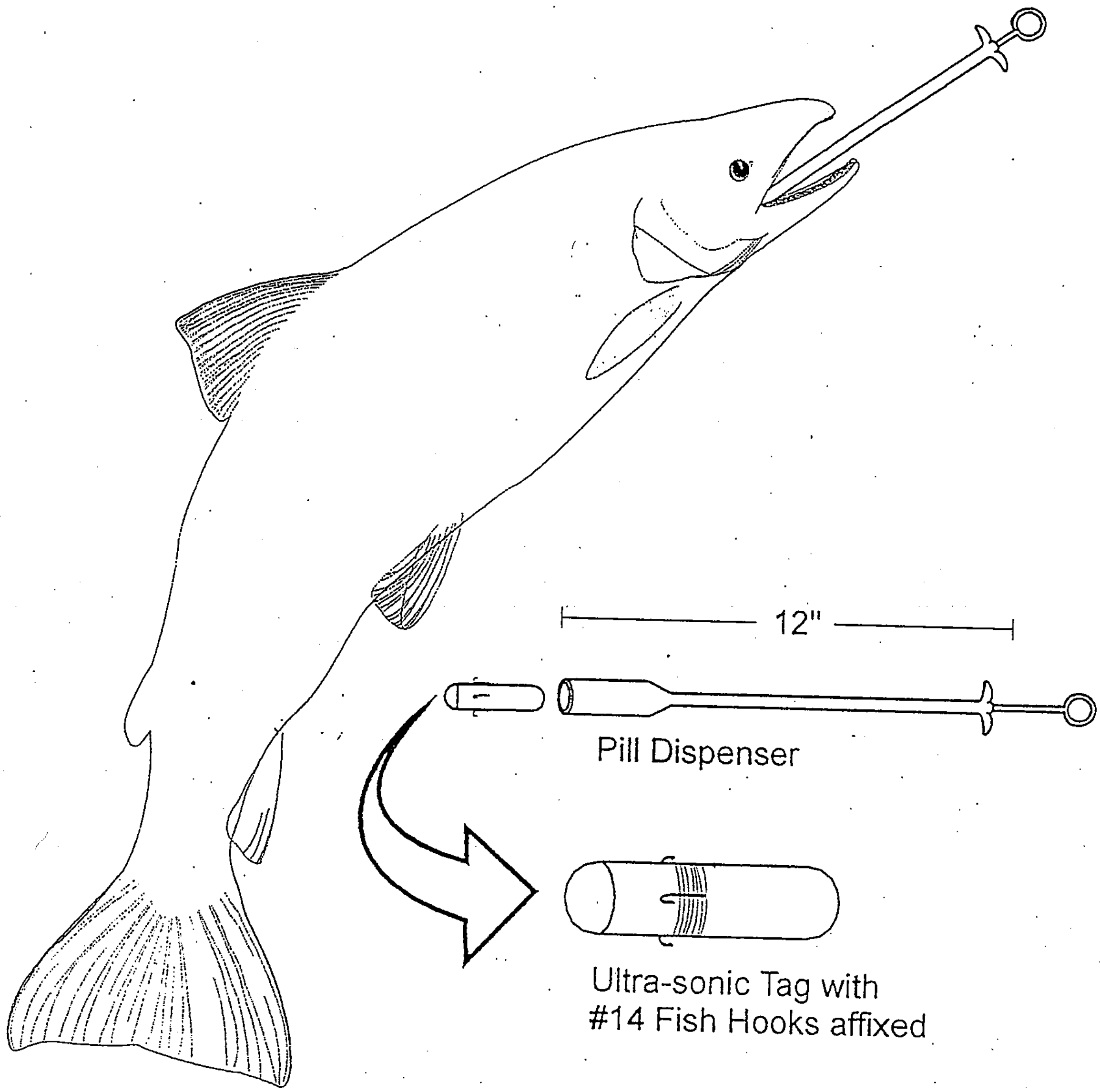

Figure 3 Diagram of the pill dispensing tool used to insert internal ultra-sonic tags in adult salmon.

which tagged fish could be detected and recorded passing through the SMSCG (Figure 2) twenty-four hours a day. Boat monitoring was used to track tagged fish movement in the slough and to locate tagged fish that had died. The boat monitoring covered the area from the mouth of Montezuma Slough, near Collinsville, downstream to the Grizzly Island bridge (Figure 1). Passage times were calculated, to the nearest hour, as the time from tagging and release to when the fish was first observed upstream of the SMSCG.

The onshore fixed monitoring sites were located on the north (downstream) and south (upstream) sides of the SMSCG (Figure 2). Hydrophones were submerged in the water at each monitoring site at least 2-3 feet below the average low-low tide level. One-hundred feet of coaxial cable connected each hydrophone to a corresponding receiver at each fixed monitoring site. The hydrophone on the north side of the gates was attached to the Roaring River Slough fish screen, toward the west bank approximately 50-60 feet downstream of the SMSCG. The receiver and associated equipment were housed in a secured DWR building which contained tidal monitoring and other water quality equipment. The hydrophone on the south side of the gates was attached to a floating boat dock near the east bank and upstream of the boat lock. The receiver and other equipment were housed inside the boat lock control building. Any tagged salmon detected at both onshore stations were assumed to have passed through the gates.

Sonic monitoring equipment consisted of two Sonotronics (Tucson, Arizona)[1/] automatic scanning receivers (Sonotronics USR-90), one portable digital ultrasonic receiver (Sonotronics USR-5W) with headphones for boat monitoring, and three hydrophones. Each automatic scanning receiver was powered from a 12-volt car battery, and was connected to a hydrophone and portable computer. Power outlets in each onshore building provided 120 volt power for the computers. A data acquisition program, in Q-Basic, enabled the computers to record the scanning receiver data: date, time, and the specific pulse interval identification number for each tag detected. Data was later downloaded to floppy disk and taken to DFG's Stockton Division office for analysis. Except for brief periods of equipment maintenance or down-time, the stationary receivers were constantly monitoring for fish passing by the SMSCG. During the brief maintenance periods any tagged salmon that moved upstream of the SMSCG could only be detected by means of boat monitoring.

Boat monitoring was accomplished by stopping the boat about every 100 yards along the Slough, lowering a hydrophone in the water and listening for a tag signal using a digital ultrasonic receiver and headphones. This procedure was repeated over the entire distance of the boat monitoring area, which extended from the confluence of Montezuma Slough and the Sacramento River to the Grizzly Island Road bridge (approximately 8 statute miles, Figure 1). At each locale the hydrophone was rotated a full 360 degrees, for three or more rotations, to thoroughly scan the area. Boat monitoring (tracking) was conducted for a minimum of five days,

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1/ Use of a trademark or commercial brand name is not a product endorsement by the Department of Fish and Game or State of California.

for each Phase of the study. Salmon were monitored by boat around the clock for the first 24 hours following each group tagging process, thereafter boat monitoring was reduced to 6-8 hours per day, during daylight hours. One complete sweep of the boat monitoring area shown in Figure 1 takes approximately five hours. On contact with a tag, the boat was guided to the point where the signal was strongest and GPS coordinates recorded. Along with the GPS data, the tag number, date and time were recorded. Fish were assumed dead if a tag was detected for more than three days at the same location. Tagged fish which were not detected by the onshore monitoring stations or in the boat monitoring area during the respective study Phase, were assumed to have left the study area without passing through the SMSCG.

The internal sonic tags used in this study all had a minimum battery life of 120 days. Each tag was coded with a specific ultrasonic pulse frequency code or signature to distinguish individual tags used. Tag frequencies ranged from 65 to 80 HZ. Tags varied in weight between 21 and 24 grams in air (approximately 8 grams in water). Each sonic tag was modified by placing three #14 fish hooks spaced evenly around the girth of the tag, and secured with nylon fishing line and varnish. The hooks minimized tag regurgitation by the salmon, noted to occur in other studies that used internal tags. Tags were placed in the stomachs of salmon with a veterinary balling gun (cattle/horse pill dispenser) which was inserted down the throat of each fish (Figure 3). The tag was then gently pushed down the esophagus until it was lodged in the stomach. Fifty adult salmon were tagged in this manner during the various operating Phases of the SMSCG.

Dissolved oxygen (DO), tidal conditions, temperature, conductivity, and turbidity readings or samples were taken during the tagging operations (for each Phase) and during the mobile boat monitoring. Water quality data were taken at the time of release of the tagged salmon, or on a three-hour interval, whichever occurred first. Water temperature was measured periodically throughout the study, in conjunction with the mobile boat monitoring, whenever a tagged fish was detected. Tidal stage, described as high (high slack), low (low slack), ebb or flood, was recorded at the release of each tagged fish and also when mobile monitoring detected a tagged fish. Flood tide was defined as visible movement of water to the south (toward the Sacramento River) and ebb tide as the visible flow of water to the north (toward Grizzly Bay).

$Ln_e(x + 1)$-transformed passage times for tagged fish, by Phase, were tested using ANOVA ($P<0.05$) to detect significant differences across SMSCG operations. The ANOVA was followed with an a-posteriori Tukey's HSD test ($P<0.05$, Zar 1984) to detect specific differences between individual means. In addition, Chi-square contingency tests ($P<0.05$) were performed on the observed proportions (percentages) of fish successfully passing the SMSCG, by Phase, followed by an a-posteriori Tukey style test ($P<0.05$, Zar 1984) of ratios to compare specific individual pairs of passage proportions. The contingency tests indicate whether any differences in percent passage, between Phases, are significantly greater than could be attributed to random variation.

RESULTS

Fifty adult chinook salmon were tagged during all operational Phases of the SMSCG (Table 2): 15 were tagged during the first Phase, 15 during the second Phase, and 20 during the third Phase. All fish were released near the site of capture (downstream of the SMSCG) and ranged in size form 561 to 981 mm fork length (appendixes A-C). A summary of the tagging activities by SMSCG operation Phase, is presented in Table 2 below. Water quality value ranges for the study are given in Table 3. The ultimate fates of the tagged fish, during each operational Phase, are summarized in Table 4.

Table 2. Tagging dates and number of salmon tagged and corresponding operational Phase of the Suisun Marsh Salinity Control Gates, August - September 1993.

Tagging dates	Gate operational Phase corresponding to the tagging group	Number of salmon tagged in the group	Number tagged per tidal stage
August 24-25	Phase I: flash boards not in place, gates up, and boat lock closed.	15	high 6 flood 5 ebb 2 low 2
September 7	Phase II: flash boards in, gates up, and boat lock operational.	15	high 4 flood 6 ebb 0 low 5
September 20	Phase III: flash boards in, gates tidally operated, and boat lock operational.	20	high 5 flood 7 ebb 3 low 5

Six fish in the Phase I group of 15 died after tagging, representing a 40% mortality rate during that respective study Phase. Most of the fish mortalities were attributed to the stress of capturing and handling during water temperatures that reached 24°C (75°F). However, one dead tagged fish was found to have a ruptured stomach wall and the tag lodged in the abdominal cavity. This indicates that the tag was placed too deep in the stomach during the tagging procedure, and ruptured the stomach wall.

Tags detected repeatedly in the same area of the Slough, staying relatively motionless for three or more days, were assumed to be dead fish or a regurgitated tag. Regurgitation is highly

Table 3. Summary of results from the 1993 adult salmon monitoring under the three operational Phases of the Suisun Marsh Salinity Control Gates

August - October 1993	
Fall-run chinook salmon:	50 tagged
Size (mm fork-length):	561 - 981
Water temperature range:	17-24°C (63-75°F)
Dissolved oxygen range:	8.0 - 10.6 mg/L
Electro-conductivity range:	1509 - 5663 μohms
Turbidity range:	16 - 48 NTUs
Tagging (or handling) mortalities:	6

SMSCG operation	% salmon passing	Avg. time to pass (hrs)
Phase I	91%	12
Phase II	47%	23
Phase III	50%	25

Table 4: Fates of sonic tagged adult fall-run chinook salmon studied in each operational Phase of the Suisun Marsh Salinity Control Gates, August 1993 - October 1993.

Operation Phase dates & number of fish tagged	Last known condition of fish successfully passing the gates, at Phase end	Last known condition of fish that did not pass the gates, at Phase end
Phase I: Aug 24 - Sep 6 15 fish tagged	live 8[a] died 2	live 1 died 4[b]
Phase II: Sep 7 - Sep 16 15 Fish Tagged	live 7 died 0	live 8 died 0
Phase III: Sep 17 - Oct 4 20 Fish Tagged	live 10 died 0	live 10 died 0

a/ One of the "live" tagged fish was found dead on September 21, 1993 (during Phase III), about 28 days after tagging and 27 days after passing through the SMSCG. Nonetheless, it was counted as a live or viable fish for the purposes of passage data.

b/ These tagged fish were removed from the sample group for the respective Phase, thus reducing the number of viable tagged fish used in the analyses, to 11.

unlikely in light of the preventive measures taken (#14 fish hooks, Figure 3). Unless the fish passed through the gates in one hour or less, data from the moribund fish were not used in the subsequent analysis since the exact time of death or tag loss could not be confirmed. However, given the distance from the fish release site to the upstream side of the SMSCG, adult salmon would have to be actively swimming to pass the gates within an hour of being tagged. Still, removing the passage times for three fish that died after passing through the gates, does not change the outcome of the data analyses. No fish mortalities were noted during the last two Phases of the study, when water temperatures were cooler. The percentages of fish from each group which passed through the SMSCG are shown in Table 3.

SMSCG Operation Phase I

During a portion of this first Phase of the monitoring study, some data loss occurred at the onshore stationary monitoring sites. This loss amounted to about 36 hours worth of upstream monitoring time for one of the onshore monitoring stations. However, boat monitoring during these dates provided continuous coverage on salmon passage at the SMSCG.

The 15 salmon tagged during Phase I ranged in size from 630 to 946 mm fork-length (Appendix A). With the exception of two fish captured and tagged near Little Honker Bay, all fish were tagged and released about 1.6 statute miles downstream (North) of the SMSCG. As noted above, a 40% mortality rate occurred for the 15 salmon tagged during Phase I of the study. Of the six salmon that died during the respective study Phase, one died from a ruptured stomach and the rest are assumed to have died from a combination of handling and temperature stress.

Ten sonic tagged salmon (91%) successfully passed through the SMSCG during Phase I, as shown in Table 4 and Appendix A. Two of these fish later died during Phase I monitoring, but did pass through the gates within one hour of tagging and release. Of the five fish that did not pass through the gates, four were confirmed dead soon after tagging and one migrated downstream toward Grizzly Bay. The four fish that died were removed from the sample group for data analysis (see Table 4).

Data for 11 fish were used in the analysis of passage times and proportions of tagged fish passing. Two fish that eventually died after tagging, we believe were actively swimming in order to pass the gates in under one hour, and so were still included in our analyses. Of the ten fish passing through the gates, all ten passed through the on a flood or high tide (Appendix A).

A total of eight viable fish passed the SMSCG and remained alive (Table 4). Three of these fish ended up turning back and swimming downstream of the gates by the end of the study Phase. The other five remained upstream of the SMSCG. Most of the 10 fish that passed moved through the SMSCG, did so within one to three hours of tagging, two fish had times of 37 and 71 hours, respectively, for an average of 12 hours.

SMSCG Operation Phase II

Fifteen fish, ranging in fork-length from 574 to 904 mm (Appendix B), were captured and tagged during the second Phase of the study (flash boards in place, gates up, and boat lock operating, September 7 - 16). All fish were captured and tagged within one mile of the SMSCG. No mortalities were noted during this Phase of the study. Water temperatures ranged from 21-22°C (70-72°F) during fish capture and tagging operations.

Seven (47%) of these salmon passed through the gates, as shown in Table 4. Five of the seven fish passed through during flood or high tide (Appendix B). Two of the seven fish that passed through the gates later migrated back downstream. The average passage time for fish that passed through the SMSCG was 23 hours.

The eight fish which did not migrate through the gates were assumed to have left the monitoring area (Table 4). All of the fish appeared active and moved around covering considerable portions of the boat monitoring area. No tagged fish were detected in the study area after September 11, during this Phase of the study. However, one fish (tag# 2525, Appendix B) migrated upstream through the SMSCG toward the Sacramento River on the 8th, and was seen again passing upstream through the gates during the third Phase of the study (September 22). The data suggests that this fish may have migrated to the Sacramento River and then down toward Suisun Bay before again moving upstream through Montezuma Slough.

SMSCG Operation Phase III

Twenty fish were captured and tagged in the third Phase of the study (September 17 - October 4, 1993). They ranged in fork-length from 561 to 981 mm (Appendix C). All fish were captured and tagged within one mile of the SMSCG. In addition, these fish appeared to be fresh from the ocean, bright and silvery in color. During this operational Phase, the surface water temperature during capture and release of salmon did not exceed 20°C. No mortalities were noted in the Phase III group of tagged fish (Table 4).

Ten of the 20 fish (50%) migrated through the gates (Table 4 and Appendix C) during the study Phase. The average time for fish to pass through the gates after tagging was 25 hours. None of these fish that passed the SMSCG were later observed to move downstream through the gates. Some of these fish waited as long as 15 hours at the SMSCG (detected by downstream stationary monitor) before passing through the gates. One of the fish that passed the gates, tag #258, was later recovered from the Feather River by an angler.

Nine of the 10 fish which did not pass through the SMSCG during Phase III, were detected in the monitoring area, either by boat monitoring or the stationary receiver, only on the downstream side of the gates (Table 4). The tenth fish was not detected again after its initial release. Of these nine fish, three were repeatedly detected on the immediate downstream side of the gates when the gates were closed, and were never detected upstream of the gates. One of the nine fish that did not pass the gates, tag #356, was later recovered from the Feather River by an angler. None of the ten fish were detected in the monitoring area after four days from tagging and release.

One fish, (Tag #2525 from Phase II), was detected during this part of the study. This fish was seen at the downstream side of the gates by both boat and stationary monitor when the gates were closed. This fish never migrated through the gates during the study Phase.

Passage Proportions of Sample Groups

As mentioned above, the percentages of the viable tagged fish that successfully passed the gates were 91%, 47%, and 50%, for Phase I, II, and III, respectively. Testing these ratios (percentages) for statistically significant differences using a Chi-square contingency test, revealed significant differences that could not be attributed to random variation ($P=0.044$). In addition, an a-posteriori contrast of the proportions of successful passage, by Phase, indicated that more fish passed in Phase I than in either Phase II or Phase III ($P<0.05$), but the proportion of fish that passed in Phase II was not significantly different from the proportion in Phase III ($P>0.05$). Test results are shown in Appendix D.

Passage Times

A one-way ANOVA was used to detect statistically significant differences in salmon passage times over the three operational Phases of the SMSCG. Tests on passage times were performed on $\ln_e$[hours + 1] transformed data, where "hours" represent the passage times rounded to the nearest whole hour, because the data on passage times were not normally distributed and tended to display a negative binomial distribution (Zar 1984). A significant difference ($P=0.002$) in salmon passage times was detected among the three Phases.

In addition, a-posteriori contrasts between Phases were performed using the Tukey Honestly Significant Differences (HSD) test on $\ln_e(x+1)$ transformed data. Test results shown in Appendix E indicate that there is a stronger difference in passage times due to the flash boards, than the radial gates operation. Statistically significant differences were observed between Phase I and Phase II ($P=0.017$), and between Phase I and Phase III ($P=0.002$). However there wasn't a statistically significant difference in the transformed salmon passage times between Phase II and Phase III ($P=0.881$).

DISCUSSION

Prior fisheries monitoring in Montezuma Slough in 1991 indicated that the SMSCG may delay the upstream migration of adult salmon (DFG 1992a). Our results support this hypothesis and suggest that 50% or more of the adult fall-run chinook salmon may be blocked in their migrational movement through Montezuma Slough by the operation of the SMSCG from August to October.

Fish passage rates were 91%, 47% and 50% for Phase I, II, and III, respectively. Average fish passage times for each operational Phase were 12, 23, and 25 hours, respectively. Passage rates and times in Phase I were significantly different ($P<0.05$) than those in Phase II or Phase III, but passage rates and times in the latter two Phases were not significantly different ($P>0.05$) from each other.

Four salmon out of 20 tagged during Phase III and one returning fish from Phase II, were detected just to the north side of the SMSCG (downstream) when the gates were in a closed position. These five fish were never detected upstream of the SMSCG during Phase III, but were confirmed to have left the study or monitoring area by traveling downstream along Montezuma Slough. This suggests that the SMSCG presents an obstruction to some migrating fish, rather than just prolonging their passage time through the slough. The results also suggest that the last two operational Phases, with the flash boards in place, significantly delay and tend to decrease passage rates for migrating adult salmon. Delaying the migration of sexually-maturing adult salmonids may result in fecundity declines (decreased egg viability), increased prespawning mortality, and spawning in less desirable habitat (Hallock et al. 1982, Vogel et al. 1988).

Studies on adult salmon movement in British Columbia (Groot et al. 1975) found that sockeye salmon in the Skeena River Estuary tended to move with the tidal currents. Striped bass studies by Finlayson (DFG 1976) indicated that striped bass in the Sacramento-San Joaquin estuary also tended to move with tidal current. While it may not be applicable to make comparisons to other species, or other geographic areas, little information is available on adult salmon movement in the lower reaches of migratory routes. It is interesting though, that 23 of the 27 salmon that passed through the SMSCG in this study did so on a flood or high tide, while only four passed on low or ebb tides. This is also consistent with anecdotal observations that the adult fall-run salmon showed more upstream movement during flood or high tides. This was evidenced by higher catch rates during the tagging portions of this study, under high or flood tide conditions.

During the initial portion of Phase I, 40% of the tagged fish died. High water temperatures during netting activities, and the stress of handling and tagging at these temperatures were probably the main cause of fish mortality. The dead fish were removed from our sample group for Phase I, with the exception of two fish that passed through the structure within one hour and died much later. A total of four dead fish were removed from the Phase I sample group.

Seven fish (29% of the viable fish) in the first two Phases of the study migrated past the structure and then back downstream. The reason for this behavior is not known but conversations with DFG biologists (personal communication - Frank Fisher, DFG Redding) suggested that the high water temperatures and the sexual condition of the salmon (ripeness of eggs and sperm) may have been the reasons for the migrating back downstream. Hallock (1970) noted that water temperatures above 19°C prevented salmon from migrating up the San Joaquin River. It is possible that some of the salmon moving back and forth in Montezuma Slough were holding until the water temperatures were appropriate for migrating upstream.. Water temperatures were 22-24°C during Phase I of the study, and 21-22°C during Phase II. However, the majority of salmon were out of Montezuma Slough in less than three days. None of the fish captured in the last Phase of the study (Phase III) migrated back downstream after passing through the structure. Two of the fish captured during the Phase III of the study were returned by anglers fishing in the Feather River, one of which never passed the SMSCG. Water temperatures were much cooler during Phase III, 17-20°C.

The origin and release site, as juveniles, of adult salmon tagged during this study may have contributed to the behavior of fish that did not pass the SMSCG, or after passing it, returned to go downstream. The origins (natal stream or hatchery) and initial planting or release sites (as juveniles) of the adult salmon we tagged could not be determined. The relative ability to home or desire to migrate directly to the spawning grounds may differ between wild fish or hatchery fish released at the hatchery, versus hatchery fish released farther downstream. State and Federal hatcheries continue to release large numbers of juvenile fish throughout the Sacramento-San Joaquin Delta, for research purposes, and at Benecia, to enhance survival and contribution to the ocean fishery. Even if we captured an adult, adipose-fin-clipped fish, obviously, we could not sacrifice it to read its coded-wire tag. Genetic stock typing and identification techniques have not yet been developed, either, so there was no reason to collect tissue samples for that purpose. Given the timing of our studies and the appearance of most of the fish, we have good reason to assume they were fall-run chinook salmon. It is possible that some of the fish we tagged were late-fall-run fish, who's tendency to migrate directly upstream might have been less than would be expected for fish in the prime of their upstream migration. However, salmon who have reached this point in the estuary probably are already undergoing the physiological changes necessary to adapt to fresh water, and would be unlikely to do so if not actively migrating upstream.

Nineteen salmon did not pass through the gates (43% of the total viable fish) and left the study area by exiting downstream of the SMSCG. These nineteen fish may have migrated downstream toward Grizzly Bay, since they were not detected in the monitoring area by the end of the study. Nor were they considered dead, since they did not remain at one location for three or more days. These fish could have successfully completed their migration to the Sacramento or San Joaquin basin by returning through Grizzly Bay, Suisun Bay, and on to the Delta past Chipps Island.

Of the tagged fish that did pass the gates, one fish in Phase I, eight in Phase II, and four in Phase III, remained in the boat monitoring area by the end of their corresponding operation Phase. It is possible that one of these fish, which migrated downstream in Phase I, did so because of tagging and handling stress during high water temperatures. The migrational patterns of the other fish, were probably affected in some way by the operation of the SMSCG, primarily the installation of the flash boards (though Phase II did have some elevated water temperatures).

An analysis of the migration behavior of tagged fish revealed other differences across the SMSCG operational Phases (Appendix F). Three distinct behavior modes were observed in the tagged fish, and were used to group and enumerate salmon behavior patterns as: Mode-1 behavior, where salmon never passed the SMSCG but did go downstream, Mode-2 where they did pass the SMSCG but returned and went downstream, and Mode-3 where they did pass the SMSCG and continued upstream. Using the Chi-square contingency test for forty-four cases (the subset of viable fish), the probability that the combinations of behavior modes exhibited under each operational Phase could have occurred randomly was low ($P=0.047$). Thus, we can probably reject the null hypotheses, that the behavior mode patterns are the same across all Phases of SMSCG operations. However, many of the individual cell counts in the Chi-square were so low ($n<5$) that the results of the test cannot be considered completely robust. It is interesting to note that fish exhibiting behavior Mode 2 contributed greatly to the high passage rates in Phase I. If the study is repeated, we will have to see if a similar pattern of behavior modes occurs again.

It has been suggested that passage rates should be computed based only on fish exhibiting behavior Modes 1 and 3, excluding those fish exhibiting behavior Mode 2. This is an invalid approach to analyzing this data set for the following reasons. First, there is a greatly reduced potential for fish to exhibit behavior Mode 2 in Phase III, due to the closure of the SMSCG. Therefore, the absence of observations of behavior Mode 2 during Phase III is not necessarily significant. Second, dropping behavior Mode 2 fish from analyses of Phase I and II artificially depresses the number of fish available to test for significant differences in behavior (reduces statistical power), and enhances the probability of accepting a false null hypothesis (Type II Error). Third, given that this study was a site-specific evaluation of upstream fish passage, the fact that fish return later on to pass in a downstream direction has no bearing on measurements of their ability to pass in an upstream direction during each different operational Phase of the SMSCG. While the issue of whether "net upstream-only passage rates" differ between Phases may be a valid scientific question and significant regulatory or management concern, it is not feasible to conduct a population-level analysis for each race of salmon or the whole population of migratory chinook salmon from so few fish, collected and monitored in a limited geographic area for a limited time period.

This study was not designed to evaluate the influence of local hydrology and channel hydraulics on the movement of chinook salmon in the vicinity of the SMSCG. The only way to address the issue of whether hydrology (e.g. water year and degree of freshwater inflow) affects behavior, is to repeat the study under a range of hydrologic conditions, holding all other major factors constant. This is probably infeasible due to funding and time constraints, as well as our inability to control other major confounding influences. It would also require us to tag large numbers of salmon (100s) to have sufficient data to establish the significance of trends based on correlation analyses.

No hydraulic field data was available for the vicinity and time period of our study. While model-generated data may be available, its use poses significant problems for analysis, since it cannot be considered the equivalent of actual real-world data collected in the vicinity of and concurrently with the actual study. The complications of analyzing model generated data and the exposition and justifications necessary for its use are beyond the scope of this report. In addition, the amount of field data available from 1993 for analysis versus modeled data is so small (N = 46) that one could only hope to detect a few extremely strong trends. While it might be enlightening to undertake such an analyses as part of another study, the end result would simply be to generate hypotheses about how modeled hydraulics may have affected the actual biological results. Hypotheses generated from the analysis of modeled data would have to be tested by conducting actual field studies over a number of years, in order to draw firm conclusions about the effect of channel hydraulics on fish behavior near the SMSCG.

Recommendations

Based on these findings we recommend further salmon monitoring be done at Montezuma Slough, under the same three SMSCG operational conditions, but when water temperatures are below 20°C. Under cooler water conditions, temperature should not stress the fish or potentially influence migrational patterns. Further study would also validate data collected in this 1993 pilot effort; especially percent passage and passage times through the SMSCG. If further studies are contemplated, additional onshore monitoring sites should be included, for example near the Grizzly Island Road bridge to confirm the passage of fish downstream toward Grizzly Bay.

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Appendix A.

Summary information on salmon tagged during Phase I gate operations					
Date tagged	Size FL (mm)	Tag number	Hours to passage	Tide stage at passage	Comments
08/23/93	823	248	2	high	Passed through structure, then moved downstream of gates
08/23/93	878	284	1	high	Passed through structure and stayed upstream for Phase duration
08/24/93	630	249			Did not pass, found dead
08/24/93	946	267			Did not pass structure
08/24/93	830	285	1	high	Passed through structure and stayed upstream for Phase duration
08/24/93	942	375	1	flood	Passed through structure, then moved downstream of gates
08/24/93	700	465			Did not pass structure, assumed dead.
08/24/93	783	2228	71	flood	Passed through structure and stayed upstream for Phase duration
08/24/93	695	2246	37	flood	Passed through structure and stayed upstream for Phase duration
08/24/93	700	2327	1	flood	Passed through structure, but later found dead upstream of gates
08/24/93	655	2336	1	flood	Passed through structure and stayed upstream for Phase duration, (found dead on downstream side 27 days afterwards).
08/24/93	770	2363	3	high	Passed through structure, then moved downstream of gates
08/24/93	no length	2534	1	high	Passed through structure, then moved downstream of gates, found dead downstream of gates.
08/24/93	780	2543			Did not pass structure, assumed dead
08/24/93	653	3344			Did not pass structure, found dead

Fish located in the same position for more than three days were considered dead.

Appendix B.

Summary information on salmon tagged during Phase II gate operations					
Date tagged	Size FL (mm)	Tag number	Hours to passage	Tide stage at passage	Comments
09/07/93	574	88			Did not pass gates
09/07/93	880	97	4	ebb	Passed through gates, and stayed upstream for Phase duration
09/07/93	677	257			Did not pass gates
09/07/93	780	266			Did not pass gates
09/07/93	709	276			Did not pass gates
09/07/93	828	456	21	flood	Passed through gates, then moved downstream of gates
09/07/93	614	2264			Did not pass gates
09/07/93	789	2354	65	flood	Passed through gates, and stayed upstream for Phase duration
09/07/93	623	2435	31	high	Passed through gates, and stayed upstream for Phase duration
09/07/93	856	2444	17	low	Passed through gates, and stayed upstream for Phase duration
09/07/93	904	2453			Did not pass gates
09/07/93	640	2525	16	flood	Passed through gates, and stayed upstream for Phase duration
09/07/93	700	2633			Did not pass gates
09/07/93	775	3335			Did not pass gates
09/07/93	695	3344	8	high	Passed through gates, then moved downstream of gates (tag reused from fish found dead in August)

Appendix C.

Summary information on salmon tagged during Phase III gate operations					
Date tagged	Size FL (mm)	Tag number	Hours to passage	Tide stage at passage	Comments
09/20/93	561	258	7	flood	Passed through gates, tag later recovered by fisherman from Feather River.
09/20/93	590	275	17	low	Passed through gates, and stayed upstream for Phase duration
09/20/93	883	293			Did not pass gates
09/20/93	580	294			Did not pass gates
09/20/93	580	338			Did not pass gates
09/20/93	660	347			Did not pass gates
09/20/93	720	348	69	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	960	356			Did not pass gates, tag later recovered by fisherman from Feather River.
09/20/93	690	365			Did not pass gates
09/20/93	981	366	20	low	Passed through gates, and stayed upstream for Phase duration
09/20/93	780	374			Did not pass gates
09/20/94	750	384	24	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	755	555			Did not pass gates
09/20/93	630	2237	27	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	660	2255			Did not pass gates
09/20/93	800	2273	21	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	565	2336	24	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	610	2345	24	flood	Passed through gates, and stayed upstream for Phase duration
09/20/93	600	2426			Did not pass gates
09/20/93	885	3434	18	flood	Passed through gates, and stayed upstream for Phase duration

Appendix D.

Chi-square, q, and P values for Chi-square tests on the proportion of salmon passing the Suisun Marsh Salinity Control Gates. August - October 1993.

Pearson Chi-Square	= 6.227	P = 0.044
Likelihood Ratio Chi-square	= 7.216	P = 0.027

Tukey style ratio test for differences in the proportion of fish passage contrasted between operational Phases. August - October 1993.

Phase I vs. Phase II: No flash boards in place and gates non-operational vs. flash boards in place and gates non-operational. $P < 0.05$.

Phase I vs. Phase III: No flash boards in place and gates non-operational vs. flash boards in place and gates operational. $P < 0.05$.

Phase II vs. Phase III: Flash boards in place and gates non-operational vs. flash boards in place and gates operational. $P > 0.05$.

Matrix of pair-wise comparison q values for $q_{critical}$ ($P = 0.05$; infinity and 3 D.F.) of 3.314:

	Phase I	Phase II	Phase III
Phase I	0.00		
Phase II	6.70	0.00	
Phase III	6.52	0.61	0.00

Appendix E.

F and P values for ANOVA tests on salmon passage times, using a ln_e[hours +1] transformation of passage time data. August - October 1993.		
	F = 8.273	P = 0.002

Tukey Honestly Significant Differences (HSD) test for differences in passage times contrasted between operational Phases, using ln_e[hours +1] transformed data. August - October 1993.

Phase I vs. Phase II: No flash boards in place and gates non-operational vs. flash boards in place and gates non-operational. P=0.017

Phase I vs. Phase III: No flash boards in place and gates non-operational vs. flash boards in place and gates operational. P=0.002

Phase II vs. Phase III: Flash boards in place and gates non-operational vs. flash boards in place and gates operational. P=0.881

Matrix of pair-wise comparison probabilities:

	Phase I	Phase II	Phase III
Phase I	1.000		
Phase II	0.017	1.000	
Phase III	0.002	0.881	1.000

APPENDIX F.

Behavior modes of adult salmon tagged during the three operational Phases of the Suisun Marsh Salinity Control Gates in August-October 1993, based only on those fish that survived for the duration of each operational Phase.			
Pearson Chi-Square Likelihood Ratio Chi-square		= 9.641 = 11.503	P = 0.047 P = 0.021
	Behavior Mode		
Operational Phase	Mode 1 Did not pass SMSCG, and moved downstream	Mode 2 Passed the SMSCG, but subsequently returned to move back downstream	Mode 3 Passed the SMSCG and continued to move upstream
Phase I	11% (N=1)	33% (N=3)	56% (N=5)
Phase II	53% (N=8)	13% (N=2)	33% (N=5)
Phase III	50% (N=10)	0%	50% (N=10)