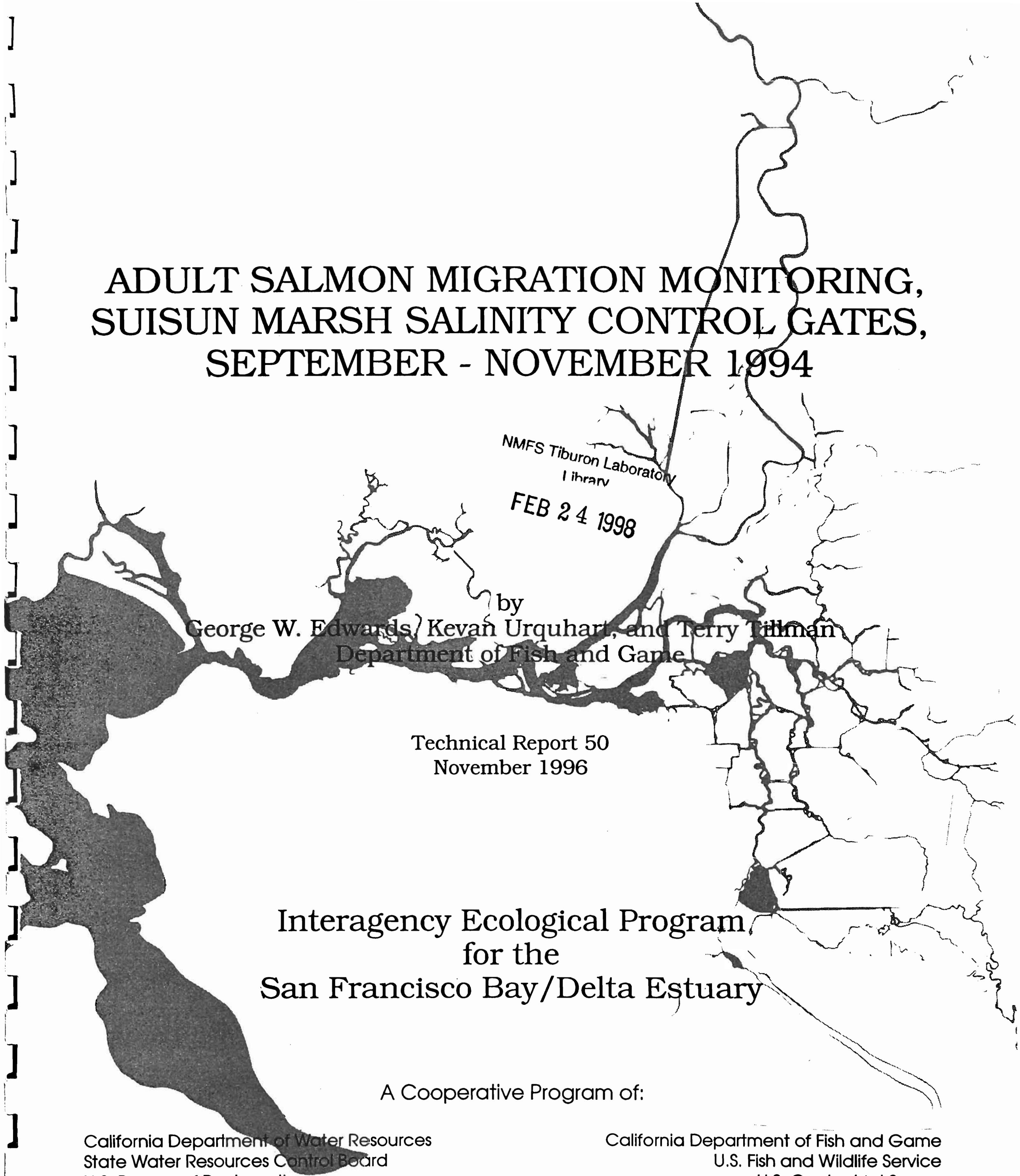

ADULT SALMON MIGRATION MONITORING, SUISUN MARSH SALINITY CONTROL GATES, SEPTEMBER - NOVEMBER 1994

by
George W. Edwards, Kevan Urquhart, and Terry Tillman
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Technical Report 50
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Summary

This study is a continuation of the 1993 adult salmon migration study in Montezuma Slough. It was designed to repeat the 1993 study of salmon migrational movements through the Suisun Marsh Salinity Control Gates during the facility's three operational phases.

The 1994 study began after water temperature was ≤20°C. Migrational movements of 59 adult fall-run chinook salmon (*Oncorhynchus tshawytscha*) were monitored during three operational configurations of the control gates. At intervals (beginning of each operational phase) from September 26 to November 14, 1994, fall-run chinook salmon were captured downstream of the gates, implanted with sonic tags, and telemetrically monitored for movement past the gates.

During Phase I (flashboards out and gates raised), 78% of the tagged salmon passed the structure, in an average of 58 hours after tagging. During Phase II (flashboards in and gates raised), 45% of the tagged salmon passed through the gates, in an average of 61 hours. During Phase III (gates fully operational), salmon passage did not vary significantly from Phase II, with 58% passing the gates, in an average of 88 hours.

Salmon movement past the control gates during Phases I and II was primarily associated with flood and high-tide conditions. Movement past the gates during Phase III occurred only during flood and ebb tides, indicating that salmon are moving through the gates before the radial gates close on the flood tide and after the gates have opened during the ebb tide.

The proportion of fish passing during each of the three phases during the 1994 study was similar to the 1993 results, in which 91% of the fish passed through the control gates during Phase I, 47% during Phase II, and 50% during Phase III. Passage times in the 1993 study were much lower: 12 hours for Phase I, 23 hours for Phase II, and 25 hours for Phase III. In the 1993 study, a significant difference was noted in fish passage times between operational phases. In 1994, no statistically significant differences were observed between average passage times for the three phases.

Flow conditions during the 1994 study also differed from the 1993 study in that water was diverted into the northern portion of Suisun Marsh from the Sacramento River via the North Bay Aqueduct (flows ranged from zero to 1.42 m^3/sec), and flows coming from the Sacramento River were greater than experienced in 1994. The operational configurations were also executed in a different chronological order than in the 1993 study.

Although the 1994 data alone do not show significant difference in fish passage proportions, an analysis of the data for 1993 and 1994 combined found a highly significant difference ($p<0.01$) for the number of fish passing between operational phases. This analysis indicated that the highest fish passage proportion occurred in Phase I, followed by Phase III and II. We

addressed the issue that these significant results do not necessarily mean there is a meaningful environmental impact.

It appears that the Suisun Marsh Salinity Control Gates may have some effect on salmon movement through Montezuma Slough under partial and full operational conditions (Phases II and III). Both the 1993 and 1994 studies indicate that a larger percentage of salmon are passing through the gates when the facility is in the nonoperational mode (Phase I) — when the flashboards are not in and the gates are up. The 1993 study showed that some salmon were blocked from migrating through the control gatesduring full operation and, as a result, migrated back downstream to Grizzly Bay. The 1993 and 1994 studies also indicate that mean fish passage times increased from the nonoperational to the fully operational configuration; however, no statistically significant difference was noted in the 1994 passage times. An analysis of the combined 1993 and 1994 data did show a significant difference in fish passage numbers between phases when Phase I was contrasted against Phases II and III. This analysis also indicated that the highest fish passage proportion occurred in Phase I, followed by Phase III and II.

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Introduction

Adult fall-run chinook salmon monitoring conducted in 1994 was a continuation of fishery work at Montezuma Slough since 1987 (Raquel 1988a, 1988b, 1990, 1992a, 1992b; Edwards and Tillman 1994; Tillman *et al* 1996). Both this study and the 1993 study were designed to address questions about the potential effects of the Suisun Marsh Salinity Control Gates operation on adult chinook salmon migration in Montezuma Slough, in particular, winter-run chinook salmon. Because of the endangered status of winter-run salmon and the abundance of fall-run salmon, only adult fall-run chinook salmon were studied.

Some concerns were raised that the handling of salmon during the warm water temperatures experienced at the beginning of the 1993 study may have affected salmon behavior and mortality. Other concerns were expressed on whether the run of salmon tagged, fall versus late-fall, may have had some effect on the outcome of the 1993 study. The 1994 study was undertaken to allay some of these concerns. Salmon were not tagged when water temperatures were above 20°C, and the chronological order of gate operations was changed to minimize the chance of different runs of salmon affecting passage results for each operational phase. Objectives of the 1994 study were to measure adult salmon passage success and duration under each operational configuration of the Suisun Marsh Salinity Control Gates. The results were compared to determine if there was a significant difference in the rate or magnitude of adult salmon migration through the gates under each operating scenario.

Recognizing the potential adverse and cumulative effects of water projects and other upstream diversions on Suisun Marsh, the State Water Resources Control Board established water quality standards (Decision 1485) to protect the marsh. To meet those water quality standards, the Department of Water Resources prepared the *Plan of Protection for the Suisun Marsh* in 1984. A key feature of the Plan of Protection was installation of the Suisun Marsh Salinity Control Gates in Montezuma Slough (Figure 1). When operating, the Suisun Marsh Salinity Control Gates reduce the influx of higher salinity water into Montezuma Slough and Suisun Marsh from Grizzly Bay. By trapping lower salinity water flowing from Collinsville, the gates reduce the average and high-tide water salinity, especially during periods of low outflow from the Sacramento-San Joaquin Delta.

During preparation of the Plan of Protection and the necessary environmental documentation, 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 Suisun Marsh Salinity Control Gates on anadromous fish in Montezuma Slough. The primary concerns were that the gates would increase predation losses of juvenile striped bass and migrating juvenile salmon and that the gates would delay the migration of spawning salmon.

The Suisun Marsh Monitoring Agreement[1] and U.S. Army Corps of Engineers Permit 16223E58, issued in 1986, required a fish monitoring program to assess the effects of Suisun Marsh Salinity Control Gates operation on anadromous fish in Montezuma Slough. The permit also required that criteria be applied to the monitoring data to determine if significant degradation had occurred and required that a mitigation

1 An agreement between the U.S. Bureau of Reclamation, Department of Water Resources, and Department of Fish and Game, dated March 2, 1987.

plan be implemented if adverse impacts were observed. The criteria have not yet been developed and are pending results of this study.

The Department of Water Resources completed construction and began operation of the Suisun Marsh Salinity Control Gates in November 1988. In accordance with the Monitoring Agreement and the Corps of Engineers permit, the Department of Fish and Game (under contract with DWR) has monitored the fish community around the control gates (Raquel 1988a, 1988b, 1990, 1992a, 1992b). Early monitoring focused on evaluating risks associated with increased fish predation as a result of gate construction. Observations of adult salmon migration behavior around the gates began in 1991 and suggested that the presence and operation of the gates may delay upstream movement of salmon through Montezuma Slough (Raquel 1992a, 1992b). The 1993 study results indicate that the control gates may delay upstream migration of salmon moving through Montezuma Slough (Tillman *et al* 1996).

The 1994 study expands on the earlier observations to better understand the relationship between adult salmon migrational behavior and operation of the Suisun Marsh Salinity Control Gates. The specific objective of this study was to determine if the control gates have an effect on upstream migration of adult salmon in Montezuma Slough.

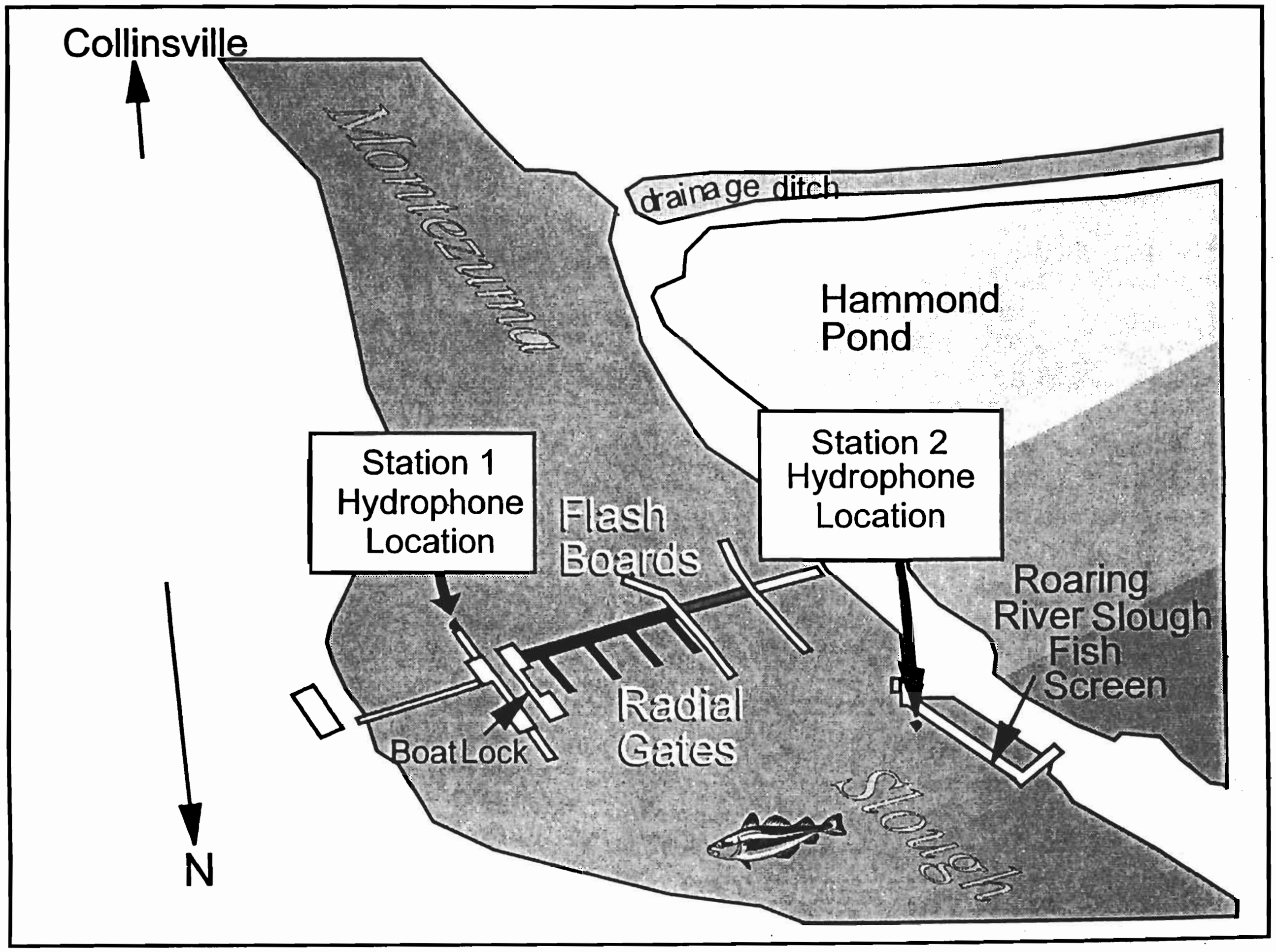

Figure 1
SUISUN MARSH SALINITY CONTROL GATES AND ONSHORE STATIONARY SONIC MONITORING SITES
September-November 1994

Materials and Methods

During each phase of the study, we measured surface dissolved oxygen and temperature, and recorded visual tidal conditions. Temperature was measured during fish capture and when a fish was detected by boat monitoring. High tide was defined as slack or no visible movement of water at peak height. Low tide was slack or no visible movement of water at minimum height. Flood tide was defined as the visible movement of water upstream (south toward the Sacramento River) and ebb tide as the visible movement of water downstream (north toward Grizzly Bay).

Salmon Capture Methods

Adult salmon were captured, tagged, and monitored during each of the Suisun Marsh Salinity Control Gates operational configurations that normally occur during salmon migration (DWR 1989, 1991). The three operational configurations (phases) sampled during this study are described in Table 1.

Salmon were captured only when water temperatures were 20°C. Salmon were captured both day and night by drifting a 200-foot-long by 12-foot-deep nylon, drift gill-net with 5.5- to 7-inch stretch mesh. The net was fished on the downstream side of the Suisun Marsh Salinity Control Gates from about 0.4 km north of the Grizzly Island Wildlife Area boat ramp to 0.8 km north of the control gates (Figure 2). Drift times for each net set varied from 5 to 60 minutes, depending on how quickly fish were being entrapped by the net.

The net was constantly monitored by boat, and captured fish were immediately removed from the net to a 946-liter black plastic tub that contained 190 to 380 liters of aerated water. Each fish was measured to the nearest millimeter (fork length), the base of its dorsal fin was clipped, and a sonic tag was placed in its stomach. Then each fish was transported to the Grizzly Island Wildlife Area boat ramp and released midstream. This entire procedure was accomplished in less than 5 minutes.

Dorsal fin clipping was used to differentiate tagged from untagged fish in subsequent gill-net catches. Fish that were

Table 1
OPERATIONAL PHASES OF THE
SUISUN MARSH SALINITY CONTROL GATES
September - November 1994

Phase	Gate Configuration*	Dates of Operation
I	Flashboards not in place, gates up, boat lock closed.	October 24 - November 14
II	Flashboards in place, gates up, the boat lock operational.	October 8 - October 23
III	Flashboards not in place, gates tidally operated, boat lock operational.	September 3 - October 7

*The phases correspond to operational configurations during the 1993 study but occur in a different chronological order from that of 1993.

assessed to be in good health after tag insertion were released immediately. Tags were removed from fish that were not in good health after tagging. Captured fish that were injured or did not appear in good health were not tagged. Fish were not anesthetized during this study.

Sonic Telemetry Monitoring Equipment and Methods

Sonic telemetry monitoring was accomplished by boat and six stationary, onshore automatic-monitoring stations. The stationary monitoring stations detected and recorded tagged fish at the Suisun Marsh Salinity Control Gates, Beldons Landing, confluence of Montezuma Slough and Hunter Cut, Hunter Cut, and Cordelia Slough (Figure 2) on a 24-hour basis. Boat monitoring was used to track tagged fish movement in Montezuma Slough and to locate any dead tagged fish. Boat monitoring covered the area from the mouth of Montezuma Slough, near Collinsville, downstream to Hunter Cut (Figure 2). Passage times were calculated, to the nearest hour, as the time from fish release to the time the fish was first observed upstream of the control gates.

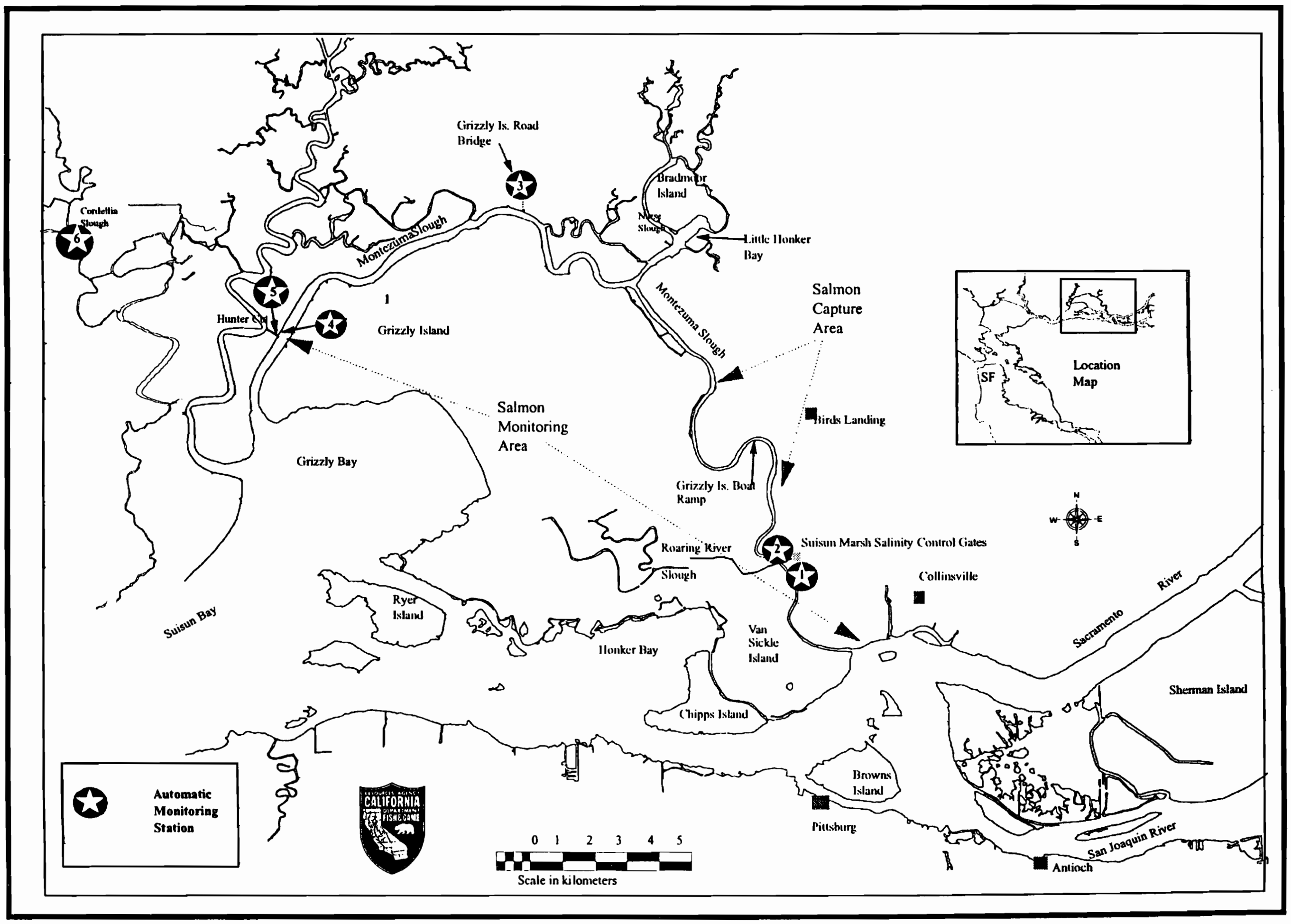

Figure 2
ADULT SALMON MONITORING AND CAPTURE AREAS AROUND THE SUISUN MARSH SALINITY CONTROL GATES, 1994

Sonic Tag Monitoring Equipment

The sonic tag monitoring equipment (Sonotronics[2], Tucson, Arizona) consisted of seven automatic scanning receivers (USR-90), one portable digital receiver (USR-5W) with headphones for boat monitoring, and seven hydrophones (model DH2). Each automatic scanning receiver was connected to a hydrophone and portable computer and was powered by a 12-volt car battery. A Basic language computer program (Q-Basic, provided by Sonotronics and modified by DFG) allowed the computers to record receiver data: date, time, and the specific pulse interval identification number and frequency for each tag on detection. These data were later downloaded onto floppy discs and taken back to the DFG Bay-Delta Division office in Stockton for analysis.

Sonic Tags

The internal sonic tags used in this study had a minimum battery life of 120 days. Each tag was coded with a specific pulse interval and frequency to distinguish it from other tags used in the study. Tag frequencies ranged from 65 to 81 kHz. Tag weight varied from 21 to 24 grams in air (about 8 grams in water). Each tag was modified by placing three #14 fish hooks spaced evenly around the girth of the tag, and securing them with nylon fishing line and varnish. The hooks minimized tag regurgitation that was noted in other studies that used internal tags. The sonic tags were inserted down the throat and into the stomach of each fish with the aid of a livestock pill-balling (cattle/horse pill dispenser) device (Figure 3).

Stationary Monitoring Sites

Stationary automatic monitoring sites were set up on the north (station 2, downstream) and south (station 1, upstream) sides of the Suisun Marsh Salinity Control Gates to detect passage of salmon. Additional stationary monitoring stations were located at Beldons Landing (station 3, about 19.8 km downstream), the junction of Montezuma Slough and Hunter Cut (station 4, about 30.6 km downstream), Hunter Cut (station 5, about 30.6 km downstream), and Cordelia Slough (station 6, about 40.2 km downstream). Hydrophones were placed at least 0.5 to 1 meter below the water level for the lowest tide at each station. Each hydrophone was connected to a corresponding receiver by 100 feet of coaxial cable. The receivers and

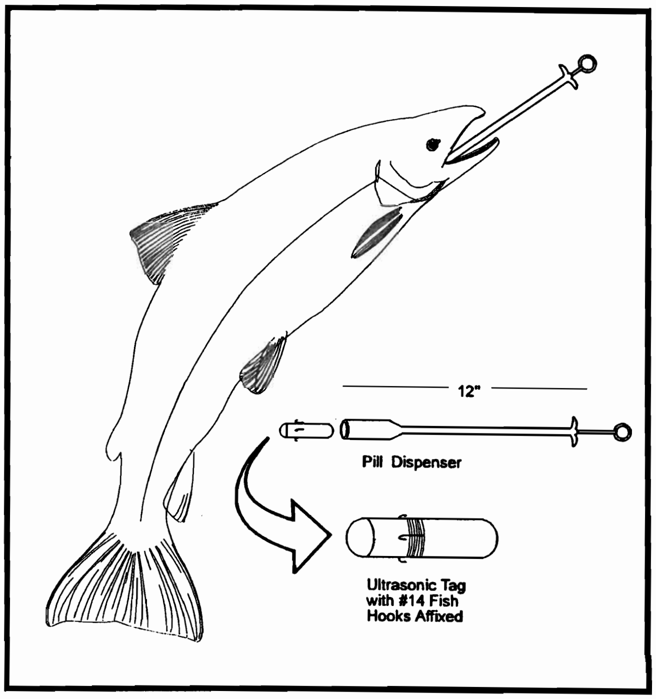

Figure 3
PILL DISPENSING TOOL USED TO INSERT
ULTRASONIC TAGS INTO ADULT SALMON

2 Use of trademarks or brand names is not a product endorsement by the Interagency Ecological Program or its member agencies.

associated equipment were housed in secured DWR buildings that contain tidal monitoring and other scientific equipment. The hydrophones at stations 1-4 were oriented across the width of Montezuma Slough (horizontal transect) to detect the presence of tagged fish at each site. The hydrophones at Hunter Cut and Cordelia Slough were also oriented across the width of the channels. Salmon detected by stationary monitors at stations 1 and 2 were assumed to have passed through the Suisun Marsh Salinity Control Gates. Salmon last detected at station 5 (inside Hunter Cut) were assumed to have migrated into Suisun Slough or downstream toward Grizzly Bay; fish detected at station 6 were assumed to have migrated into Cordelia Slough.

Electrical outlets (120 volts) were available for providing power for the computers at stations 1, 2, 3, and 6. Battery power was used at stations 4 and 5. Battery power was eventually used for the computer at station 6, because of consistent power failures that resulted in the loss of data. Except for power failures or battery failure, the stationary receivers constantly monitored fish passing by the stations. Power failures at stations 2 and 6 resulted in the loss of data for several days during the study. Detection of fish by boat monitoring or other stations mitigated for this loss of data.

Boat Monitoring

The area monitored in Montezuma Slough (~34 km) extended from the confluence of Montezuma Slough and the Sacramento River to Hunter Cut (Figure 2). One complete sweep of the tracking area took about 7 hours. Fish that were last detected by the stationary monitor at station 4 and no longer found by boat were assumed to have migrated downstream to Grizzly Bay.

Boat monitoring was conducted for a minimum of 5 days for each phase of the study. Salmon were monitored around the clock for the first 48 hours after the last fish was tagged for that phase, and 6-8 hours every Monday, Wednesday, and Friday thereafter. Fish were assumed dead if a tag was detected for more than 3 days at a location.

Monitoring was accomplished by stopping the boat every 100 meters, lowering a hydrophone into the water, then listening for any tag signatures with the digital receiver and headphones. The hydrophone was rotated 360 degrees for a minimum of three rotations. On contact with a tag, the boat was guided to the point where the signal was strongest and coordinates were recorded using a Global Positioning System. The tag number, date, and time were also recorded. The tag signature was also recorded to a computer by an automatic scanning receiver that was plugged into the hydrophone once a strong, clear detection was made by the digital unit. Upon detection, four recordings were made on the computer for each fish, if possible.

Salmon detected by boat monitoring on the downstream side of the control gates and shortly thereafter on the upstream side were assumed to have passed through the gates. This was verified, when possible, by records at the corresponding stationary sites. Tagged fish that were not detected by any of 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 gates.

Data Analysis

Data from the computers were analyzed using a manipulation-reduction program, in which an algorithm was used to filter tagged fish data from noise. The program also converted data files from an ASCII format into a dBASE format and assigned tag numbers to data that conformed to identification signatures of sonic tags used during this study. Fish that did not pass through the Suisun Marsh Salinity Control Gates during the operational phase of their release were not used in calculating fish passage times.

$Log_e(x)$-transformed passage times for tagged fish, by phase, were tested using ANOVA ($P<0.05$) to detect significant differences across gate operations. In addition, Chi-square contingency tests ($P<0.05$) were performed on the observed percentages of fish successfully passing the control gates, by phase. The contingency tests indicate whether any differences in percent passage between phases could be attributed to more than random variation.

During all operational phases of the Suisun Marsh Salinity Control Gates, 59 adult chinook salmon were tagged (Table 2). All salmon were captured within 1.5 km of the Grizzly Island Wildlife Area boat ramp and were released adjacent to the ramp (midstream and downstream of the gates). Tagged fish ranged in size from 560 to 1030 mm fork length (Appendixes A-C). For data analysis, two fish were removed from the sample population: tag number 45 (Phase I), which was not detected after release, and tag number 50 (Phase III), which was considered to have either been regurgitated or to represent a dead fish. The latter tag was constantly detected at the same location and did not exhibit any noticeable movement during the entire study.

A total of 34 tagged salmon passed through the control gates (Table 3). During the three phases, 45-78% of the fish passed through the gates (Table 4). The largest percentage of tagged fish passed through the gates during Phase I, and 53% passed through during the flood tide (Table 5).

Table 2
ADULT CHINOOK SALMON TAGGED DURING ALL OPERATIONAL PHASES OF THE SUISUN MARSH SALINITY CONTROL GATES, 1994

Date Tagged	Operational Phase	Number Tagged in Group	Number Tagged per Tide Stage	
October 31	I	19	High	10
			Food	3
			Ebb	2
			Low	4
October 11	II	20	High	2
			Flood	11
			Ebb	6
			Low	1
September 26	III	20	High	3
			Flood	14
			Ebb	3
			Low	0

Table 3
FATE OF SONIC-TAGGED ADULT FALL-RUN CHINOOK SALMON DURING EACH OPERATIONAL PHASE OF THE SUISUN MARSH SALINITY CONTROL GATES, 1994

Phase	Dates	Number Tagged	Number Passing Gates	Number Not Passing Gates
I	Oct 31 - Nov 14	19	14 Live	4 Live 1 Not Detected
II	Oct 11 - Oct 23	20	9 Live	11 Live
III	Sep 26 - Oct 8	20	11 Live	8 Live 1 Dead

Table 4
RESULTS OF 1994 ADULT SALMON MONITORING AT THE SUISUN MARSH SALINITY CONTROL GATES

	Phase I	Phase II	Phase III
Percentage of Salmon Passing	78	45	58
Average Time to Pass (Hours)	58	61	88

Number Tagged	59
Size (Fork Length)	560-1030 millimeters
Water Temperature (Surface)	13-21°C
Tagging or Handling Mortality	1
Fish Not Detected after Release	1

Table 5
PERCENTAGE OF ADULT SALMON THAT PASSED THROUGH THE SUISUN MARSH SALINITY CONTROL GATES, BY TIDE STAGE, NOVEMBER 1994

Phase	Tide Stage: Flood	High	Ebb	Low
I	65% (N=9)	14% (N=2)	14% (N=2)	7% (N=1)
II	33% (N=3)	33% (N=3)	22% (N=2)	11% (N=1)
III	55% (N=6)	0%	45% (N=5)	0%
All	53% (N=18)	15% (N=5)	26% (N=9)	6% (N=2)

Suisun Marsh Salinity Control Gates Operation Phase I

The nineteen salmon tagged during Phase I (flashboards out, boat lock closed, and gates up, October 31 to November 14) ranged from 600 to 1010 mm fork length (Appendix A). One fish was removed from all data analysis because it was not detected after tagging and release. Surface water temperature was 14-17°C, and dissolved oxygen (surface) ranged from 6.9 to 8.4 ppm.

During Phase I, fourteen tagged salmon (78%) passed through the control gates. Of those, seven continued their migration upstream and seven moved back downstream through the structure toward Grizzly Bay. Two of those that continued their upstream migration did move downstream temporarily (Appendix A) before passing back through the gates and into the Sacramento River. The seven fish that moved back downstream to Grizzly Bay after passing through the structure were not detected in the system after November 7. The average time for the fourteen fish to pass through the structure after tagging was 58 hours (time for swimming from the release site to the upstream side of the structure; SD=66).

Four salmon (22%) did not pass through the control gates. Those four moved downstream to Grizzly Bay and were not detected in the monitoring area after November 6.

Suisun Marsh Salinity Control Gates Operation Phase II

Twenty fish, ranging from 571 to 1030 mm fork length (Appendix B), were captured and tagged during Phase II (flashboards in place, gates up, boat lock operating, October 11 to 24, 1994). Surface water temperature was 17-20°C during fish capture and tagging operations. Surface dissolved oxygen ranged from 4.0 to 8.7 ppm. The 4.0 ppm reading, detected at only one site during boat monitoring, may have been the result of a water discharge from one of the duck club ponds.

During Phase II, nine (45%) tagged salmon passed through the control gates. Of the nine, seven migrated upstream and two (tags 57 and 60) migrated back downstream to Grizzly Bay and were last detected in Hunter Cut. Average time for the nine fish to pass through the structure after tagging was 61 hours (SD=76).

Eleven fish (55%) did not pass through the control gates during this phase. One of these (tag 55) was detected at Cordelia Slough. Two others (tags 10 and 41) were later detected passing through the gates during Phase I, but were not counted as having passed, since they did not move through during the operational phase in which they were released. The other eight fish moved downstream to Grizzly Bay and were not detected in the system after October 20.

Suisun Marsh Salinity Control Gates Operation Phase III

Twenty fish were captured and tagged during Phase III (flashboards in place, gates and boat lock operating, September 26 to October 8, 1994). Fork lengths ranged from 560 to 970 mm (Appendix C). One fish, tag 50, was assumed to have died or regurgitated its tag, since the tag signal was in the same position throughout the study. This fish was discarded from the sample population. Surface water temperature was 16-

21°C, and surface dissolved oxygen ranged from 7.4 to 11.2 ppm.

Eleven (58%) of the tagged fish migrated through the structure. Six of these continued upstream (one of these, tag 26, was later detected during Phase I). The other five returned and moved downstream to Grizzly Bay, and three of the five (tags 15, 17, 38) were detected at the control gates during subsequent phases. The average time for the eleven fish to pass through after tagging was 88 hours (SD=75).

Eight fish (42%) did not pass through the control structure during this phase. Seven moved downstream to Grizzly Bay, and one (tag 48) swam between the structure and Grizzly Bay before finally moving out to Grizzly Bay during a subsequent phase.

Power problems caused the computer to shut down at station 2, and a crimped hydrophone cable resulted in some lost data from September 26 to 30. Because of this problem, we could not determine when tagged salmon encountered the downstream side of the control gates during 5 days of Phase III. As a result, we were unable to ascertain if any of these fish arrived when the gates were closed or closing or whether these fish waited for the gates to open or migrated back downstream. The upstream monitor was functioning during this period and would have picked up any tagged salmon that passed through the gates.

Passage Proportions of Sample Groups

The percentages of viable tagged fish that successfully passed the gates were: Phase I, 78%; Phase II, 45%; and Phase III, 58%. A Chi-square contingency test on these ratios did not indicate a significant difference ($P<0.05$) in the number of fish passing the control structure under each operational phase. However, the Chi-square test did reveal differences that are not likely to be attributable to random variation ($P=0.119$) alone.

Passage Times

A one-way ANOVA was used to detect statistically significant differences in salmon passage times over the three operational phases. Because the data on passage times were not normally distributed, and to avoid problems with heterogeneity of variance, a logarithmic transformation was performed on the passage data (Zar 1984). No significant difference ($P=0.402$) was noted for salmon passage times. However, average passage time did appear to increase from operational Phases I through III: 58, 61, and 88 hours, respectively.

The 1994 adult salmon monitoring study confirmed some of the results and trends of the 1993 study. The percentage of salmon passing through the Suisun Marsh Salinity Control Gates during 1993 and 1994 was:

	1993	1994
Phase I	91%	78%
Phase II	47%	45%
Phase III	50%	58%

The percentage that passed the gates was greater during Phase I (gates up, flashboards out, boat lock nonoperational) than during Phases II and III in both studies (Figure 4). Passage rates for the other two phases were similar between years.

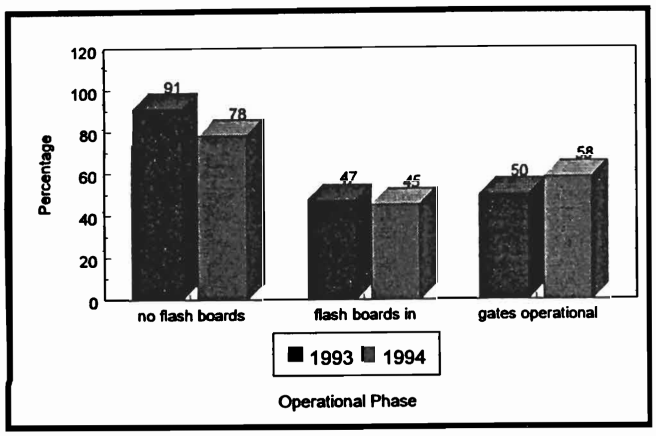

Figure 4
PERCENTAGE OF SALMON THAT PASSED THROUGH THE GATES DURING EACH OPERATIONAL PHASE IN 1993 AND 1994

Chi-square was used to test for a significant difference in the numbers of fish that did or did not pass through the Suisun Marsh Salinity Control Gates during Phases I, II, and III in 1994. The test did not show a statistically significant difference in passage numbers at P=0.05. However, the P value of 0.119 suggests that the number of fish that passed during each operational phase was not likely to be due to random variation alone. A Chi-square test did indicate a significant difference (P=0.058) at the 90% probability for fish passage ratios when Phase I passage numbers were compared to the combined Phase II and III passage rates. In contrast, the 1993 study showed a significant difference (P<0.05) for fish passage numbers, when Phase I passage rates were compared to Phase II and III rates. This trend is also exhibited in the 1994 data and suggests that the placement of the flashboards (Phase II) has an effect on the number of salmon passing through the gates equivalent to that of full-scale operation (Phase III).

Average fish passage times were very different between the 1993 and 1994 studies:

	1993	1994
Phase I	12 hours	58 hours
Phase II	23 hours	61 hours
Phase III	25 hours	88 hours

Fish passage times varied far more (4-212 hours) in the 1994 dataset than in 1993 (1-71 hours). The 1993 study showed significant difference in passage times between the structure fully operational (gates tidally operated, flashboards in, and boat lock operational), semioperational (flashboards only), and nonoperational phase (P<0.05, ANOVA). The 1994 study did not show a significant difference in fish passage times for these operations (P=0.41, ANOVA). However, both datasets show the same trends — an increase in mean fish passage time from the nonoperational phase to the fully operational phase.

Although passage rates and times differed between 1993 and 1994, the trends are consistent between years and are nonrandom and significant. An analysis of the data for both years combined (Tables 6 and 7) by Philip Law (DFG Biometrics Division) found a highly significant difference (p<0.01, analysis of contrasts) for fish passage proportions between phases. The greatest significance was noted when Phase I passage numbers were compared to Phases II and III. No significant difference (p=0.4907) was noted in the contrast of Phase II versus III. Weighted least square estimates showed by the sign and magnitude of estimates that the highest passage rate occurred in Phase I, followed by Phase III, and Phase II showed the lowest passage rate. An ANOVA (saturated model) showed no significant interaction between year and phase and no effect of year on fish passage (p=0.7963).

Table 6
NUMBER OF ADULT CHINOOK SALMON THAT DID OR DID NOT PASS THROUGH THE SUISUN MARSH SALINITY CONTROL GATES IN 1993 AND 1994 STUDIES, BY OPERATIONAL PHASE

1993

Phase	Did Pass	Did Not Pass	Total
I	8	1	9
II	7	8	15
III	10	10	20

1994

Phase	Did Pass	Did Not Pass	Total
I	14	4	18
II	9	11	20
III	11	8	19

Table 7
ANALYSIS OF PROPORTIONS OF ADULT CHINOOK SALMON PASSING THE SUISUN MARSH SALINITY CONTROL GATES IN 1993 AND 1994 STUDIES, BY OPERATIONAL PHASE

Contrast	Chi-Square	P Value	Degree of Freedom
Phase I vs Phase II	11.30	0.0008	1
Phase I vs Phase III	7.42	0.0065	1
Phase II vs Phase III	0.47	0.4907	1

This study, as well as the 1993 study, indicates that most of the salmon are moving through the control gates on a flood tide: 59% of the salmon in 1993 and 53% in 1994 (Figure 5). In addition, when the gates are fully operational (Phase III), fish are primarily moving through the gates on the flood tide before the gates close and on the ebb tide after the gates have opened (Table 5).

In the Columbia River estuary, adult chinook salmon usually move in the direction of the prevailing current, and tidal currents are a major component in their horizontal movement (Olson and Quinn 1993). Chinook salmon also tend to hold in an area during periods of low current velocity, and temporary reversals of direction were associated with changing tides (Olson and Quinn 1993). A similar study on sockeye salmon movement in the Skeena River (Groot *et al* 1975) indicated that they tend to move upstream on flood tide and that some exited the estuary briefly on strong ebb tides. An acoustical survey of sockeye salmon in the Frasier River, British Columbia (Levy and Cadenhead 1995), also associated the upstream migration of adult sockeye salmon with the upstream flow of flood tides. This survey suggested that adult sockeye salmon primarily avoided

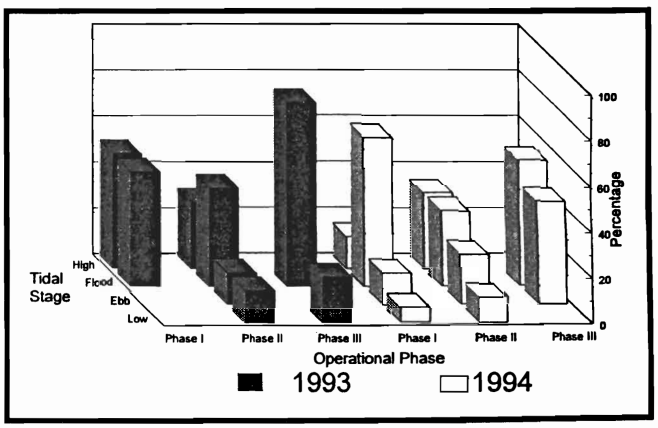

Figure 5
PERCENTAGE OF ADULT CHINOOK SALMON THAT PASSED THROUGH THE SUISUN MARSH SALINITY CONTROL GATES IN 1993 AND 1994, BY TIDAL STAGE AND OPERATIONAL PHASE

downstream current flows and ebb tides, by holding close to the river bottom and waiting for the next flood tide. An ultrasonic striped bass tagging study (Finlayson 1976) indicated that striped bass in the Sacramento-San Joaquin estuary also tend to move with tidal currents, reversing their direction when the tide reversed. These studies suggest that full operation (Phase III) of the Suisun Marsh Salinity Control Gates, when the gates are closed on a flood tide, could delay or prevent salmon from passing, as noted in our 1993 study.

During Phase II, 33% of the fish passed through the gates on the high tide cycle. Hypothetically, if all other environmental conditions are similar, this means that up to 33% of the adult salmon could have been delayed in migrating through the control gates during Phase III when the gates are closed on the high tide. Because of problems with the monitoring station on the downstream side of the structure during Phase III, we could not ascertain when fish first encountered the downstream section of the structure. Consequently, we could not determine directly if the structure blocked the passage of any fish arriving on the downstream side when the gates were closed. In the 1993 study (Phase III), four fish were detected at the downstream side when the gates were closed, and all four reversed direction and migrated downstream.

Twenty-three (40% of the sample population) tagged and healthy salmon did not pass through the gates during the operational phases in which they were tagged and released. Twenty of these fish migrated downstream to Grizzly Bay and could have successfully completed their migration to the Sacramento or San Joaquin basin by swimming through Grizzly Bay, Suisun Bay, and past Chipps Island to the Delta. Of the three remaining fish, one was last detected in Cordelia Slough and the other two passed through the Suisun Marsh Salinity Control Gates during a later operational phase.

Thirty-four tagged salmon passed through the control gates during the same operational phase in which they were released. Nineteen of these continued their migration upstream; the other fifteen returned to pass through the gates and remained downstream of the structure for the rest of that operational phase. Of the fifteen fish that moved downstream, thirteen moved to Grizzly Bay and two returned to migrate upstream through the gates during an operational phase other than the one in which they were tagged and released.

Fish behavior in 1994 was similar to that in the 1993 study, in which three primary behavioral modes were exhibited (Table 8):

Mode 1 Salmon never passed the gates but did go downstream.

Mode 2 Salmon passed the gates but returned and went downstream.

Mode 3 Salmon passed the gates and did not go back downstream.

Table 8
BEHAVIOR MODES OF ADULT SALMON TAGGED DURING 1994 STUDIES AT THE SUISUN MARSH SALINITY CONTROL GATES
Based only on those fish that survived for the duration of each operational phase.

Phase	Mode 1	Mode 2	Mode 3
I	22% (N=4)	39% (N=7)	39% (N=7)
II	55% (N=11)	10% (N=2)	35% (N=7)
III	42% (N=8)	26% (N=5)	32% (N=6)

Pearson Chi-Square = 5.940; P=0.204
Likelihood Ratio Chi-Square = 6.392; P=0.172

Mode 1 Did not pass Suisun Marsh Salinity Control Gates and moved downstream.
Mode 2 Passed the Suisun Marsh Salinity Control Gates but subsequently returned to move back downstream.
Mode 3 Passed the Suisun Marsh Salinity Control Gates and continued to move upstream.

As in the 1993 study, a large number of salmon that initially passed through the structure (41% of the fish that passed) returned to migrate back downstream. This group comprised 25% of the viable salmon tagged in the 1994 study. Their behavior is difficult to explain and could be due to: (1)tagging and handling stress, (2)how prepared an individual fish is to migrate upstream, (3) the back-and-forth movement of fish with tidal currents during resting periods. If Mode-2 fish are removed from the sampling population, a greater percentage of fish will have still passed through the control gates during Phase I, while a nearly equal percentage would have passed during the other two operational conditions: 64%, 39%, and 43% for operational Phases I, II, and III respectively.

Many researchers have noted that salmon do not always move directly upstream after moving into an estuary. Salmon have been known to delay migration in estuaries up to one month (Olson and Quinn 1993). Communications with other biologists in DFG and elsewhere suggest that, depending on the race of salmon tagged (fall-run versus late fall-run) and the time of year tagged, fish may or may not move quickly upstream to spawn. Hallock *et al* (1970), in a study of king salmon migration in the San Joaquin Delta, noted that some fish reach the delta well in advance of their spawning time and wait to ripen, even when nothing blocks their migration.

We do not know whether the Suisun Marsh Salinity Control Gates are having a significant impact on the salmon population, since we do not know what percentage of the salmon population migrates through Montezuma Slough or if the delays experienced by fish passing through the gates affect the viability of an individual salmon or its ability to reproduce successfully. Personal communication with Frank Fisher (DFG, Inland Fisheries Division, Red Bluff) did indicate that the greatest risk to delaying adult salmon migration may occur when late-fall run salmon enter the system. These fish are usually very ripe with eggs upon arrival into the delta, and any delays in spawning may result in the fish releasing their eggs before reaching the spawning areas. Other studies (Hallock *et al* 1982; USFWS 1988) hypothesize that a delay of mature salmonids could result in fecundity declines (decreased egg viability), increased prespawning mortality, and spawning in less desirable habitat.

The natal origins and juvenile release sites of adult salmon tagged during this study may have contributed to the behavior of fish that did not pass the Suisun Marsh Salinity Control Gates or, after passing it, returned downstream. The relative ability to home or desire to migrate directly to the spawning grounds may differ between wild fish, hatchery fish released at the hatchery, and hatchery fish released farther downstream. State and Federal hatcheries continue to release large numbers of juvenile fish throughout the delta for research purposes and to enhance survival. However, the natal origins (stream or hatchery) and initial juvenile planting or release sites of the adult salmon we tagged could not be determined. Given the timing of our studies and the time of appearance of most of the fish, we believe they were fall-run chinook salmon. Salmon that have reached this point in the estuary are already undergoing the physiological changes necessary to adapt to fresh water and would not undergo these changes if not actively migrating upstream.

It has been suggested that passage rates should be computed based only on fish exhibiting behavior Modes 1 and 3. This is an invalid approach to analyzing these datasets for the following reasons. First, there is a reduced potential for fish to exhibit behavior Mode 2 in Phase III, due to the closure of the control gates. 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 Phases 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 to pass in a downstream direction has no bearing on measurements of their ability to pass in an upstream direction during each operational phase. Although the issue of whether "net upstream-only passage rates" differ between phases may be scientifically valid question and of significant regulatory or management concern, it is not feasible to use the few fish that were collected and monitored in a limited geographic area for a limited time to conduct a population-level analysis for each race of salmon or the whole population of migratory chinook salmon.

During this study, some augmentation with Sacramento River water (up to 1.42 m3sec) occurred at Cordelia Slough, downstream of the Suisun Marsh Salinity Control Gates. We do not know if this augmentation could have had an effect on any tagged salmon that temporarily migrated downstream. One fish was detected by a monitor at the Cordelia Slough site. This site, however, was non-functional for several days due to power failures, and additional fish could have migrated into Cordelia Slough without being detected. DFG and DWR biologists did find numerous salmon in the upper portion of Cordelia Slough (unlined ditch that flows into the slough) on October 26, 1994. None of the fish displayed any markings to indicate they had been sonic tagged. A water model designed by DWR predicted that the influence of the flow augmentation would extend beyond Hunter Cut downstream to Grizzly Bay. Eleven fish were detected at the Hunter Cut site.

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 Suisun Marsh Salinity Control Gates. The only way to address the issue of whether hydrology (*eg*, 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. We would also have to tag hundreds of salmon to obtain sufficient data to establish the significance of trends based on correlation analyses.

While model-generated data may be available, using a model poses significant problems for analysis, since it is not the equivalent of actual 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 1994 for analysis versus modeled data is so small (N=57) that one could only hope to detect a few extremely strong trends. The end result would be to generate hypotheses about how modeled hydraulics may have affected actual biological results. Hypotheses generated from analysis of modeled data would have to be tested by conducting field studies over a number of years to draw firm conclusions about the effect of channel hydraulics on fish behavior near the control gates.

Recommendations

Future studies should be designed to detect the upstream migration of tagged adult salmon into the Sacramento and San Joaquin river systems. These studies should focus primarily on:

- Estimating what percentage of the salmon population migrating into the Sacramento and San Joaquin river systems use Montezuma Slough as a spawning route.
- The fates of salmon (tagged near the gates) that do not pass through the structure during its three operational phases to determine if these salmon take an alternate route to migrate into the Sacramento and San Joaquin river systems, or fail to migrate upstream.

These studies, like the 1993 and 1994 studies, should be designed to note any significant differences between migration times and numbers of fish that pass and do not pass through the Suisun Marsh Salinity Control Gates. Monitoring sites in the delta would record the upstream passage of these fish. Studies to meet these objectives would be both staff and equipment intensive. Numerous fish might have to be tracked simultaneously, and multiple stationary monitoring sites would have to be established in the lower Sacramento and San Joaquin rivers, as well as in Montezuma Slough. Fish might have to be tagged with a combination of radio or sonic tags to facilitate detection and tracking in euryhaline conditions.

In conjunction with the recommended studies, a repetition of the 1993 and 1994 Montezuma Slough adult salmon monitoring studies could be done at the Suisun Marsh Salinity Control Gates. Tagged salmon would be monitored during a different order of gate operations than in the past two studies. The order of gate operations would be: flashboards in and gates nonoperational, flashboards out and gates nonoperational, and flashboards in and gates fully operational. Under this scenario, another possible combination of gate operations will have been covered in 3 years of studies at Montezuma Slough, and additional data will have been gathered on the gates' effects on migrating adult salmon. Adult salmon would have to be tagged well within the zone of influence of the Suisun Marsh Salinity Control Gates, which would have to be estimated by a DWR model. Fish that migrated downstream and were not detected within the zone of influence would be deleted from the population sample.

To discount the effect of other-than-normal inflow during future studies, it is recommended that freshwater flows not be augmented from sources outside the Suisun Marsh area, since chemical constituents in these waters could potentially affect the downstream and upstream movement (homing movement) of adult salmon in Montezuma Slough.

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Appendix A

Summary of Salmon Tagged During Phase I Operations of the Suisun Marsh Salinity Control Gates, October 31, 1994

Fork Length (mm)	Tag Number	Hours to Passage	Tide Stage at Passage	Comments
780	1	8	flood	Passed through gates and continued to move upstream.
680	4			Did not pass through gates, last detected at station #4.
835	5	41	ebb	Initially, fish passed through the gates, then returned to temporally move downstream (5 days), pass through the gates again before finally reversing course and moving downstream to Grizzly Bay.
825	9	39	ebb	After initial passage through the gates, returned and then moved downstream of gates.
970	11			Did not pass gates, moved downstream to Grizzly Bay.
765	19	22	flood	After initial passage through the gates, returned and then moved downstream of gates.
780	21	42	flood	After initial passage through the gates, returned and then moved downstream of gates
750	22	22	flood	After initial passage (11-1)through the gates moved downstream (11-2) and then back through the gates (11-13).
1005	23	18	high	Initially passed through the gates on 11-1, then moved downstream and back through the structure two other times, the last passage through the gates was noted on 11-13 on the upstream side.
600	24	17	flood	After initial passage through the gates returned to pass downstream of structure on 11-1.
965	30	13	flood	After initial passage through the gates returned to pass downstream of gates.
870	31			Did not pass gates, moved downstream to Grizzly Bay.
820	33	207	flood	Passed through gates and moved upstream.
770	40			Did not pass gates, migrated downstream to Grizzly Bay.
1010	42	94	high	Passed through the gates and back three times before moving upstream to the Sacramento River.
830	45			Not detected after tagging.
822	52	70	low	Passed through gates and moved upstream.
925	56	16	flood	Passed through the gates and then moved downstream of gates.
602	58	200	flood	Passed through gates and moved upstream.

Appendix B

Summary of Salmon Tagged During Phase II Operations of the Suisun Marsh Salinity Control Gates, October 11, 1994

Fork Length (mm)	Tag Number	Hours to Passage	Tide Stage at Passage	Comments
845	2			Did not pass gates, moved downstream to Grizzly Bay.
620	3	31	high	Passed through the gates and upstream into the Sacramento River.
815	6			Did not pass gates, moved downstream to Grizzly Bay.
855	10			Did not pass gates, moved downstream to Grizzly Bay but was detected on the upstream side gates during Phase I, (10/28).
903	14	8	high	Passed through the gates and into the Sacramento River.
894	16	40	high	Passed through the gates to the Sacramento River.
755	20	4	ebb	Passed through the gates to the Sacramento River.
827	25			Did not pass gates, moved downstream to Grizzly Bay.
969	28			Did not pass gates, moved downstream to Grizzly Bay.
596	32			Did not pass gates, moved downstream to Grizzly Bay.
1030	34	20	flood	Passed through the gates and into the Sacramento River.
626	37			Did not pass gates, moved downstream to Grizzly Bay.
632	41			Did not pass through gates moved downstream to Grizzly Bay but was detected on upstream side gates during Phase I (11/01).
640	43	199	flood	Passed through the gates and migrated to the Sacramento River.
800	49			Did not pass the gates, moved downstream to Grizzly Bay.
665	51			Did not pass the gates, moved downstream to Grizzly Bay.
728	53	47	low	Passed gates, moved upstream to Sacramento River.
571	55			Did not pass gates, moved downstream to Cordelia Slough.
820	57	186	ebb	Passed through the gates, returned and moved downstream.
815	60	16	flood	Passed through the gates, returned and moved downstream.

Appendix C

Summary of Salmon Tagged During Phase III Operations of the Suisun Marsh Salinity Control Gates, September 26, 1994

Fork Length (mm)	Tag Number	Hours to Passage	Tide Stage at Passage	Comments
970	7	10	flood	Passed through gates, then moved upstream.
645	8	213	flood	After tagging, migrated downstream to Hunter Cut for seven days and then returned to the gates before passing through it.
560	12	168	flood	Passed through the gates, then moved upstream to Sacramento River.
703	13			Did not pass gates, moved downstream to Grizzly Bay.
885	15	17	ebb	After initial passage through gates, moved downstream, back and forth between Hunter Cut and the upstream side of the gates for 11 days and then not detected in the monitoring area until Phase . The fish was during Phase II (10/15).
687	17	88	flood	After initial passage through the gates, migrated back downstream and was detected several days later at Hunter Cut. Detected at the gates during Phase I (11/03) when the fish once again passed through the gates.
825	18	200	ebb	After initial passage through the gates, migrated back downstream to Grizzly Bay.
772	26	42	ebb	Passed through gates. Also detected latter during Phase I (11/2) .
845	29			Did not pass gates, moved downstream to Grizzly Bay.
845	35			Did not pass gates, moved downstream to Grizzly Bay.
632	36			Did not pass gates, moved downstream to Grizzly Bay.
686	38	87	flood	After initial passage through the gates, moved downstream to Hunter Cut and 21 days later passed through the gates during Phase II.
835	39	86	flood	Passed through the gates and continued to move upstream.
614	44			Did not pass gates, moved downstream to Grizzly Bay
734	46			Did not pass gates, moved downstream to Grizzly Bay.
650	47	32	ebb	Passed through gates, then moved upstream of Sacramento River.
634	48			Did not pass through gates, moved downstream to Grizzly Bay but detected during Phase II (10/17).
602	50	dead		Located at same spot for two months.
793	54	19	ebb	After initial passage, moved back and forth between the upstream side of the gates and Hunter Cut. Finally outmigrated to either Suisun Slough or Grizzly Bay during Phase II.
927	59			Did not pass through gates, moved downstream to Grizzly Bay.

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