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Progress Report
April – July 1990

Survival of Juvenile Chinook at the Glenn-Colusa Irrigation District's Intake

Submitted to
Glenn–Colusa Irrigation District
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Finally, this project would not have been possible without the vision and genuine concern for the fisheries resource of GCID directors and Manager, Robert Clark. The District was willing to overcome resistance from many sides to initiate this study, and Manager Clark always made sure that whatever resources were needed were made available.

Executive Summary

This summary outlines the progress report, "Survival of Juvenile Chinook at the Glenn-Colusa Irrigation District's Intake," dated September, 1990. It is intended to provide background for these studies and a brief summary of the interpretations and conclusions.

Mark-recapture sampling of juvenile chinook and Sacramento squawfish was conducted during May - July in the oxbow channel of the Sacramento River (RM 205 to 206) where Glenn Colusa Irrigation District (GCID) diverts up to 3,000 cfs during April through October. The mouth of the diversion is screened by 40 rotary-drum screens housed in a 450 ft cement abutment. Past evaluations of the screens have estimated that only 18% to 34% of the fish entering the oxbow successfully bypass the screens. However, operating conditions at the time of the tests were atypical of present-day operations. In order to determine the need for corrective measures, GCID commissioned this study to determine the magnitude and causes of losses of juvenile chinook passing the screens in 1990. This report presents findings through July, while field studies continue through October.

Nearly 45,000 juvenile chinook salmon were trucked from Coleman and Feather River hatcheries, marked, and released at four locations in the vicinity of the GCID headworks (See Figure 1) to estimate survival through the GCID oxbow channel. These fish were released on five dates with different river and pumping flows. Up to 23 uniquely marked groups were released on each test date and a portion were recovered in the CDFG trap at the fish screens, in a rotary screw trap maintained by GCID at the tail end of the oxbow, and in the USFWS push net fished about 0.5 miles below the outlet of the oxbow. Catches were largest and most consistent at the rotary screw trap. The screw trap was operated daily beginning April 23 and captured up to 462 unmarked chinook and up to 690 marked chinook in one night. Recoveries of branded chinook released 100 yds above the trap indicate the trap captured from 4.0% to 18.8% of the juvenile chinook exiting the oxbow, depending on flow and trap conditions.

The estimated proportion of branded chinook diverted into the GCID oxbow from releases at RM 208, 2 miles upstream of the oxbow entry, varied from 4.5% to 14.4% between tests. The proportion of flow diverted into the oxbow was never less than 16% and reached 31% during our tests. The proportion of fish diverted was always less than the proportion of flow diverted, and there was no correlation between the two (See Figure 6). Further sampling is necessary to determine if this unexpected result was caused by variation in current patterns at the oxbow inlet or by sampling biases. Recaptures by the CDFG trap of marked fish released at RM 208 were generally too low to be useful for evaluating the proportion of fish diverted. However, the CDFG trap did capture up to 50 spray-dyed or fin-marked chinook released from Coleman Hatchery each year during 1987 - 1990. Recapture rates of these fish varied up to six fold between years, which provides additional evidence that factors other than the proportion of flow diverted are influencing the proportion of fish diverted into the oxbow. Catches in the USFWS push net produced unusual results, believed to reflect uneven disbursement of marked fish across the channel when they passed the USFWS sampling location.

The estimated survival of branded fish migrating from the upper oxbow to the lower oxbow (past the fish screens) ranged from 27.7% to 90.6% and was negatively correlated ($r = -0.84$) to the volume of flow pumped by GCID (see Figure 8). The correlation of survival to bypass flow was not significant ($r = 0.75$, $P > .10$). The correlation to pumped flow leads us to conclude fish losses are related to impingement or entrainment at the fish screens.

A SCUBA diver inspection of the screens revealed only two minor gaps along the entire screening structure where fish could escape through the screens. Few fish probably escaped there. The diver, David Vogel, a fish biologist who has conducted research on the design of fish screens, found debris accumulation and high water velocity at the bottom of the fish screens and hypothesized that fish may be entrapped and killed there. Vogel noted that fish are probably guided to the river bottom by the current in conjunction with the overhanging slope of the fish screen. Once at the bottom of the screen, fish must swim at least 5 ft directly against the current in order to pass around the cement piers between each screen bay (see Appendix 2, Figure 2). This is an undesirable circumstance that acts to increase the time fish must spend in front of the fish screens, and probably leads to fatigue and eventual loss of many fish to impingement or predation.

Consistent with the theory that fish were being impinged and killed at the fish screens, mean lengths of branded fish recaptured in the lower oxbow were significantly ($P < 0.05$) larger than the fish released in the upper oxbow, and fish recaptured at the CDFG trap were significantly smaller ($P < 0.01$) than the mean of fish released in the upper oxbow (see Figure 9). These differences indicate fish loss at the screens was selective for smaller fish. These differences also indicate catches in the CDFG trap represent the smaller and weaker fish in the population.

The total number of juvenile chinook entering the GCID oxbow during May and June was estimated to be about 165,000. Many additional fish may have passed through the oxbow on the week of May 28 - June 3 when a freshet raised the river and temporarily halted trap operation. An estimated 62,000 juvenile chinook, or about 38%, of the chinook entering the oxbow during May - June died or escaped through the screens. However, captures in the CDFG trap during February - July indicate the majority of juvenile chinook had already migrated past the GCID oxbow prior to the April 24 beginning of the study reported here. Losses of juvenile chinook certainly occurred before April 24, but could not be estimated accurately.

Capture efficiency in the CDFG trap of branded fish varied from 0.07% to 1.06% and was highly correlated ($r = 0.97$, $P<0.01$) to the volume of water pumped by GCID. However, because the CDFG trap efficiency changed with the size of fish, its catches could not be used to estimate abundance of fish during mid February to mid April when fish averaged 20 mm - 30 mm smaller than during tests reported here.

Recovery rates at the CDFG trap of adipose-clipped chinook released from Coleman Hatchery on May 11 and 12 were less than one tenth that in the CDFG trap of branded fish released at RM 208. Ward (1989) used the capture rates of adipose-clipped chinook to estimate abundance of juvenile chinook passing the mouth of the GCID oxbow during 1987, 1988, and 1989. Our tests indicate the CDFG trap does not capture adipose-clipped fish in proportion to their abundance, so the methods used by Ward (1989) would have substantially over-estimated chinook abundance.

Sampling of Sacramento squawfish in front of the fish screens indicated fewer chinook were being lost to predation than anticipated. We captured, stomach sampled, tagged and released 71 squawfish by seining and 58 by angling. An estimated maximum of 390 squawfish were residing in the vicinity of the fish screens during June and they consumed only 564 chinook during June 12 to July 11. These estimates are rough at best, because only 12 tagged fish were recaptured and there were many sources of possible bias in our sampling.

Table of Contents

C-051290

C-051290

List of Tables

List of Figures

Introduction

This report presents progress during April through July 1990 on studies of juvenile chinook losses in the vicinity of the fish screens operated by California Department of Fish and Game (CDFG) at the intake of the Glenn-Colusa Irrigation District's (GCID) diversion from the Sacramento River at RM 206. Outmigration of juvenile fall chinook is nearing completion as this report is prepared; thus, findings regarding fall chinook are the focus of this report. Winter chinook will be sampled primarily from August through October. The overall purpose of the studies reported here is to determine the extent and causes of juvenile salmonid loss as they pass the GCID diversion, and to identify the most effective remedial actions.

Description of Study Area

The GCID diversion headworks are located on an oxbow of the Sacramento River at RM 206, about 3.5 miles north of Hamilton City (Figure 1). The oxbow is about 1.5 miles long and carries up to 25% of the river's flow during summer months. The GCID headworks are located midway down the oxbow and divert 1,000 to 3,000 cfs during April through October. Forty rotary-drum screens, each 8 ft wide by 17 ft in diameter, are housed in bays spaced across a 450 ft cement abutment in the pumping station forebay to prevent entry of fish. The drums are covered with stainless steel screen with wire diameter of 0.080 in. square openings of 0.17 in. and diagonal openings of 0.24 in. The effective open area of the mesh is 46%.

A fish bypass system was incorporated into the abutment structure to provide fish a means of escaping the current as they migrate downstream across the screens. Ten 6-inch-wide orifices were incorporated into the cement piers between every fourth screen bay. Each orifice empties into a graduated steel pipe buried behind and beneath the screening structure. The bypass empties through a 60 in. diameter pipe into the oxbow about 300 ft downstream of the last screen bay.

Operating conditions at the screens frequently exceed the design criteria of 0.8 ft/s approach velocity. Approach velocities to the screens exceed CDFG's revised criteria of 0.33 ft/s whenever pumping flow rises above about 1,500 cfs (Ward 1989). Higher than expected approach velocities have resulted from natural degradation of the river channel such that the water level in front of the screens is now 4 ft lower than in 1970 (GCID et al. 1989). The lower water level decreases the surface area of the screens through which the diverted flow passes. Operation of the bypass orifices has also been ineffective. Flow and velocities into the orifices is unbalanced (GCID et al

1989). The desired flow of 90 cfs through the bypass system cannot be maintained. As an alternative means of bypassing fish, CDFG has asked that 500 cfs be maintained past the screens into the channel exiting the oxbow.

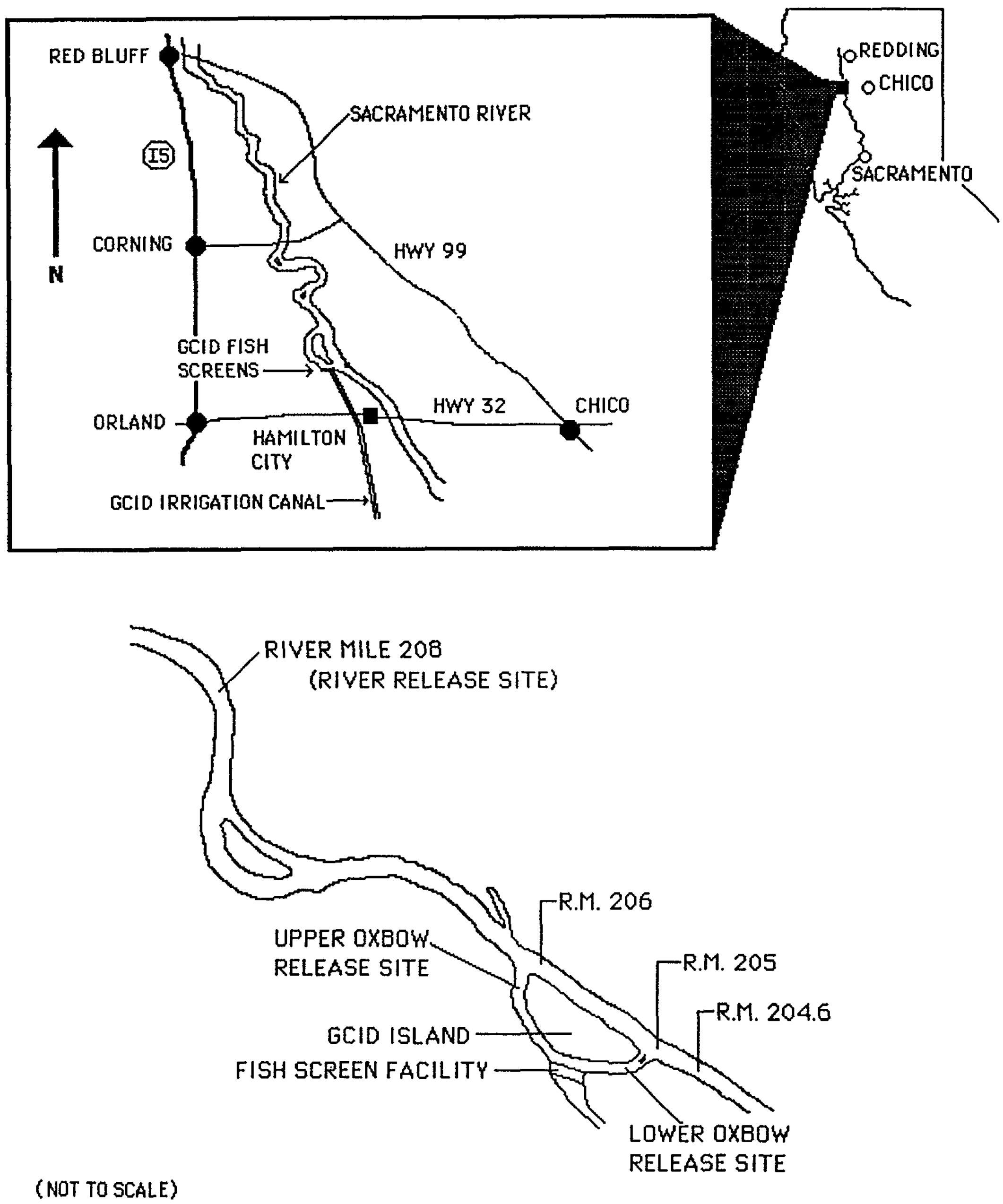

Figure 1 **Location map of Glenn-Colusa Irrigation District's water diversion facilities and sites where juvenile chinook were released and recaptured.**

Past Evaluations

In a review of existing data on mortality of juvenile salmon migrating past the Glenn-Colusa Irrigation District's (GCID) intake, Ward (1989) concluded, "After 1972 and the installation of the fish screen, losses probably ranged from 0.4 to >10 million fish annually." The number of adult fish these juveniles would have produced would be of substantial value, both economically and biologically. Thus, it is imperative that the causes of such mortality be identified and eliminated or substantially reduced. Toward this end, the fisheries agencies (CDFG, USFWS, and NMFS) have issued a "Joint Statement of Agreement" indicating their preference that a new set of fish screens be constructed near the head of the intake channel (CDFG et al. 1989).

As the process to obtain funding for this $32 million new fish screen continued, GCID desired to determine more accurately the magnitude and causes of juvenile chinook losses at the present fish screens. Corrective measures, such as aggressive dredging, have been implemented to modify operating conditions that were found previously to result in substantial losses of juvenile chinook; however, the effectiveness of these corrective measures was not evaluated. Decoto (1978) estimated from mark recoveries that 18% of fish released in the upper intake channel in 1974 used the bypass orifices (80 cfs total) when all other bypass flows were blocked, and that 34% used two culverts (170 cfs total) when the orifices and other bypass flows were blocked. In a follow-up study, Decoto (1979) estimated from fyke net catches behind the screens in 1975 that 300,000 juveniles escaped through the screen, but no estimate was made of the number of fish bypassing the screen. Ward (1989) estimated from recoveries of marked fish released in the upper intake channel that 21% were recovered in the fish trap in bay #24 when all other bypass flows were blocked. No other studies have been conducted to estimate fish bypass rates or mortality rates in the GCID intake channel.

Since the time of the tests cited here, standard operating procedures have been to simultaneously operate 1) the fish trap in screen bay #24, 2) the bypass culverts built into the diversion structure, and 3) to allow 300 - 500 cfs to flow past the screens and exit the oxbow. The efficiency of bypassing juvenile chinook with these conditions has not been tested. Even the entrainment estimated by Decoto (1979) should have decreased, because nylon brushes were later added along the bottom screen seals to block gaps created by uneven portions of the screen. Efficiency of the fish trap in screen bay #24 has also likely increased, because a fan pump was added in 1986 to increase inflow velocity. Clearly, additional studies were needed to determine the extent of fish losses and the factors affecting them at the GCID screens.

Additionally, the potential for increasing survival of salmonids by eradicating predators needs to be evaluated. The fisheries agencies' "Joint Statement of Agreement" indicates that, "Predation is believed to be high," throughout the GCID oxbow channel. Vogel et al. (1988) concluded from studies at Red Bluff Diversion Dam that losses of juvenile salmonids there were attributable almost entirely to predation. The conformation of the GCID oxbow channel appears to be suited to capture of squawfish by drift seining. Therefore, it was desirable to test the efficiency of this capture technique, and to estimate the extent of squawfish predation on salmonids.

Accordingly, the purpose of this study is to determine the abundance and mortality rate of juvenile salmonids migrating through the GCID intake channel on the Sacramento River and to assess the potential for using flow and predator control to reduce mortality. The study plan comprises two objectives, which are further divided into tasks. This report is organized according to these objectives and tasks. Accomplishments and findings under each task are reported here, although sampling is not yet complete for some tasks.

Methods

Objective 1.0 ***Determine the Total Number of Juvenile Chinook Lost in the GCID Intake Channel and Quantify the Influences of Fish Abundance, Fish Size, and Flow Diverted on These Losses.***

Experimental Design

The proportion of juvenile chinook that are diverted from the main stem into the GCID intake channel and the proportionate loss from among the fish diverted were estimated through the release and recapture of marked fish. Groups of juvenile fall chinook were obtained from Coleman and Feather River Hatcheries, were cold branded, and were held for several days at the GCID facility before release.

Marked fish were released at four locations in the vicinity of the GCID pumping facility and the proportions recaptured at three locations downstream (Figure 2) were compared. Fish released in the lower oxbow (location 1) served as controls that had to migrate past our trap in the lower oxbow (location A). Fish released in the upper oxbow (location 2) were assumed to migrate through the oxbow and served as the test groups to determine losses in the oxbow. Fish released at RM 208 (location 3) above the oxbow served as the test groups to determine the proportion diverted. Fish released at RM 205.5 outside the oxbow (location 4) served as controls that could be recaptured in the main river and compared to recaptures of fish released at RM 208 to determine survival in the Sacramento River between RM 208 and RM 205.5.

The experimental design called for releases under three different flow conditions and two different sizes. Not all desired test conditions were achieved, but test releases were accomplished on five different dates that provided data over a range of flow conditions. For each release condition, except the first release date (May1), 2 to 12 replicate groups of 400 to 800 fish were released at each location. The number of fish per replicate and the number of replicates at each location was designed to estimate mortality and the proportion diverted within 95% confidence intervals of ±5%, based on the anticipated rates of recapture. Sample sizes for fish released in the lower oxbow were designed to estimate trap efficiency within 95% confidence intervals of ±2%.

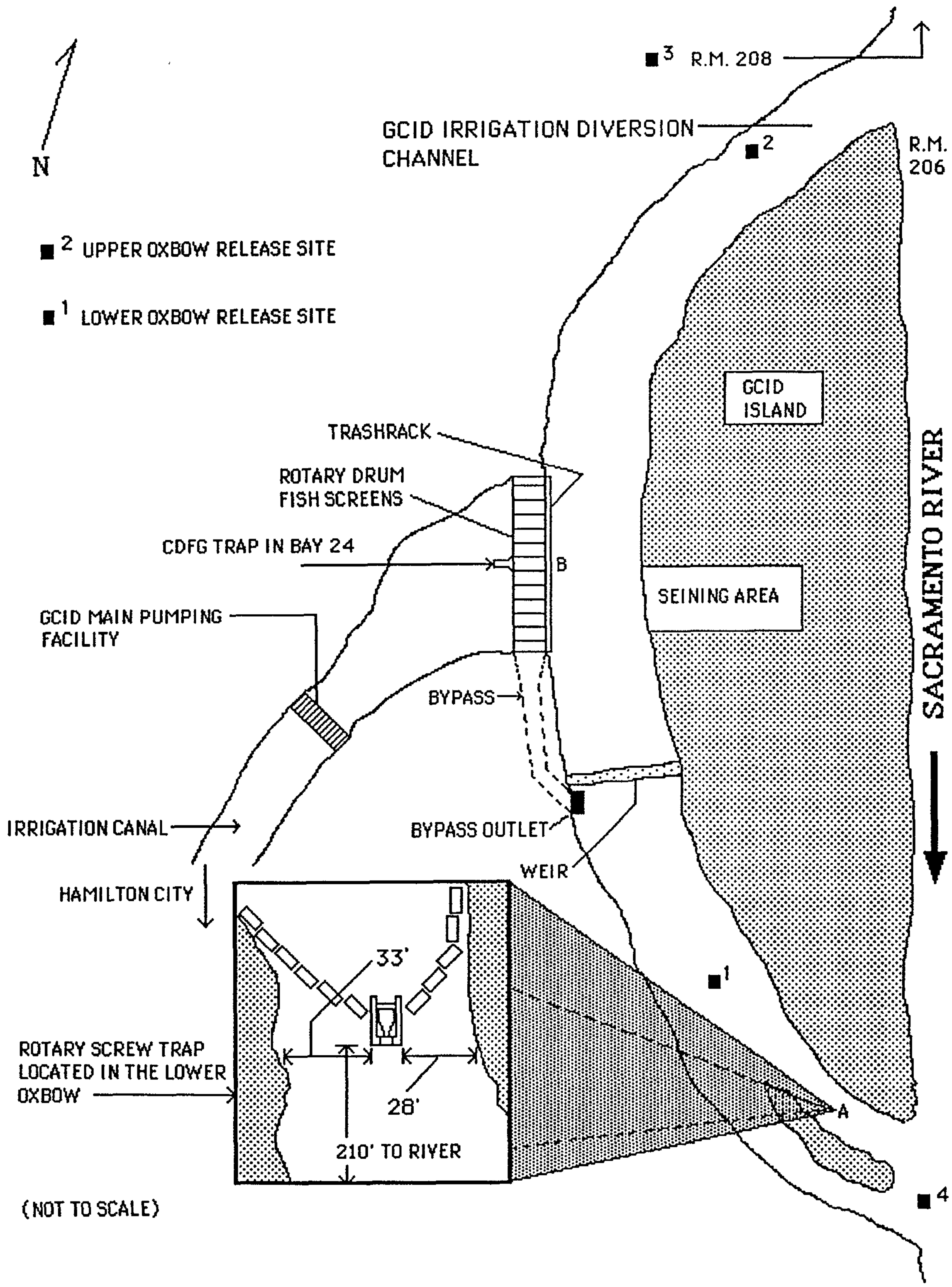

Figure 2 **Detailed location of rotary screw trap and fish release sites.**

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Experimental Release Groups

SOURCE AND TRANSPORT METHOD

The first three sets of experimental fish were transported from Coleman National Fish Hatchery and the last two sets were transported from Feather River Hatchery. Some wild salmon caught in our rotary screw trap were also used for the first two release sets. The total number of fish branded and released for each release date are listed in Table 1.

Fish were transported from the hatcheries in a 6 ft x 4 ft x 3 ft covered tank (on loan from USFWS) mounted on a flatbed truck. The tank was divided into two compartments, each with a capacity of approximately 183 gal. In addition to the two aerators mounted on the tank, oxygen was delivered to each tank at 4 - 6 psi through 1/2 in. hosing terminating in airstones. Fish were held in the tank for up to 8 h, but were never in transport for more than 2 h. The water temperature never rose more than 2° F above hatchery conditions.

TABLE 1. Source and number of fall chinook obtained for each set of test releases during 1990.

Source	Pick-up Date	Number Wild	Number Branded	Number Released	Release Date
Wild/Coleman	4/27	1,604	8,343	3,188	5/1
Wild/Coleman	5/4	373	8,993	8,552	5/8
Coleman	5/10	0	8,604	8,248	5/16
Feather	5/18	0	10,385	10,088	5/24
Feather	6/5	0	11,221	9,262	6/11 & 12

BRANDING PROCEDURE

Each release was composed of up to 23 distinctly marked groups of fish. Fish were marked by cold branding with five different symbols (T,V,U,I,O) in two locations (front or rear). The symbol orientation was either vertical, upside down, tilted right, or tilted left (only two orientations for "I" and one orientation for "O"). All fish for a given release were branded on the same side and alternate releases were branded on opposite sides. This aided in identification of the appropriate release date for fish recaptured after release.

Branding tools were machined from 4/16 in. welding rod. Each brand was about 9 in. long with 1/2 in. fuel line hosing on the top half acting as a handle. Overall lengths and widths of the symbols varied from 3/16 in. - 4/16 in., and the thickness of the symbol lines was approximately 1/16 in. The brands were immersed in liquid nitrogen held in 4 in. diameter by 4 in. tall Thermos jars. Holes were drilled in the thermos tops to allow a branding rod to be dipped in.

Fish were anesthetized before branding in a mixture of MS-222 (tricaine methansulfonate) and quinaldine (Mullin, 1970). The cold brand was held against the fish for about one second. After branding, fish were held 4 to 7 days to allow the brands to darken (Figure 3). Mortalities were removed and recorded daily. Some losses of fish to predation by birds and to escapement by jumping out of the net pens went unrecorded. However, we took measures to limit these losses and they are believed to be negligible.

HOLDING METHODS

Fish were held following branding in two types of containers. The first consisted of an 18 ft x 36 in. x 22 in. stainless steel trough (on loan from CDFG) which was separated into 18 smaller compartments (Figure 4). An electric pump delivered up to 0.93 gal/s of river water to the tank through a pipe suspended above the tank. The pipe served as a manifold with holes drilled in it such that a stream of water sprayed into each of the 18 compartments. We used a control valve to reduce the flow at desired times. Water drained through a standpipe at one end of the trough.

The partitions used to divide the tank into compartments were made of 1/8 in. metal screening stretched across a frame of 1 in. x 2 in. wood. Silicon caulking was used to fasten the frames to the tank walls. The top of the tank was screened to prevent fish from jumping out.

As fish were branded, they were placed into a compartment labeled with their respective brands. As many as 500 fish with an average size of 75 mm - 85 mm fork length (FL) were held in one compartment. Using this method, as many as 7,700 fish were held in the trough at one time for a period of 7 days. Fish and water temperature were monitored continually. The tank temperature never rose more than 2°F above the water temperature in the oxbow.

Additional fish were also held in six net pens. These 4 ft x 4 ft x 4 ft nets were constructed of nylon 1/8 in. delta mesh and were divided into two compartments. They were suspended from pontoons in the oxbow channel. As many as 850 fish, also with an average size of 75 mm - 85 mm FL were contained in one compartment for as many as 7 days.Patio shading was wired to the top of the nets to decrease sunlight penetration, as well as reduce predation by birds and small mammals. Like the trough, water was pumped into the net pens to increase aeration.

PRERELEASE SAMPLING

Additional fish were sampled for mean length and brand clarity on the day prior to release. We randomly removed and anesthetized 30 fish from each uniquely

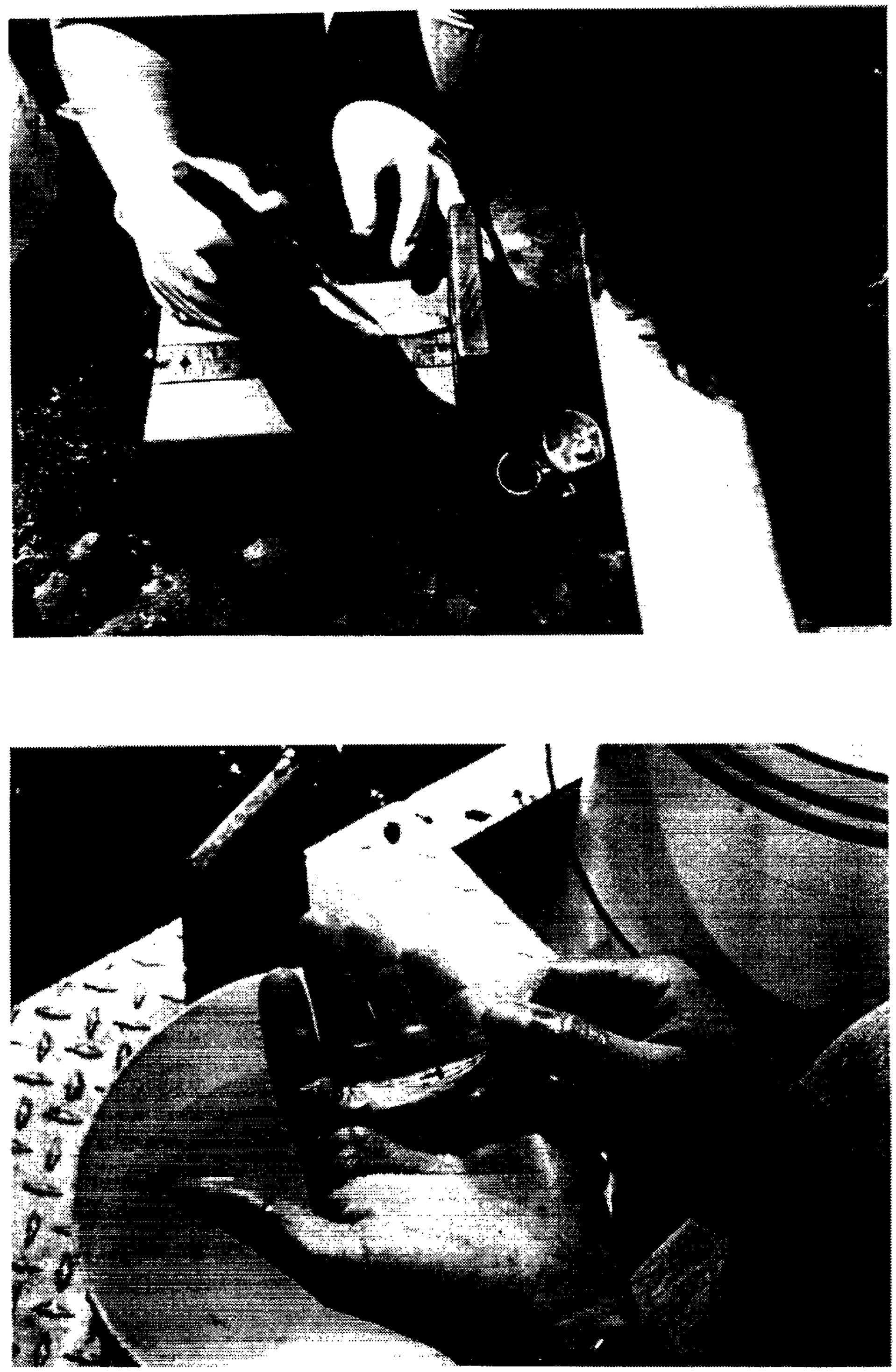

Figure 3 Cold branding. Top photo shows fish being branded. Bottom photo shows darkened brand several days later.

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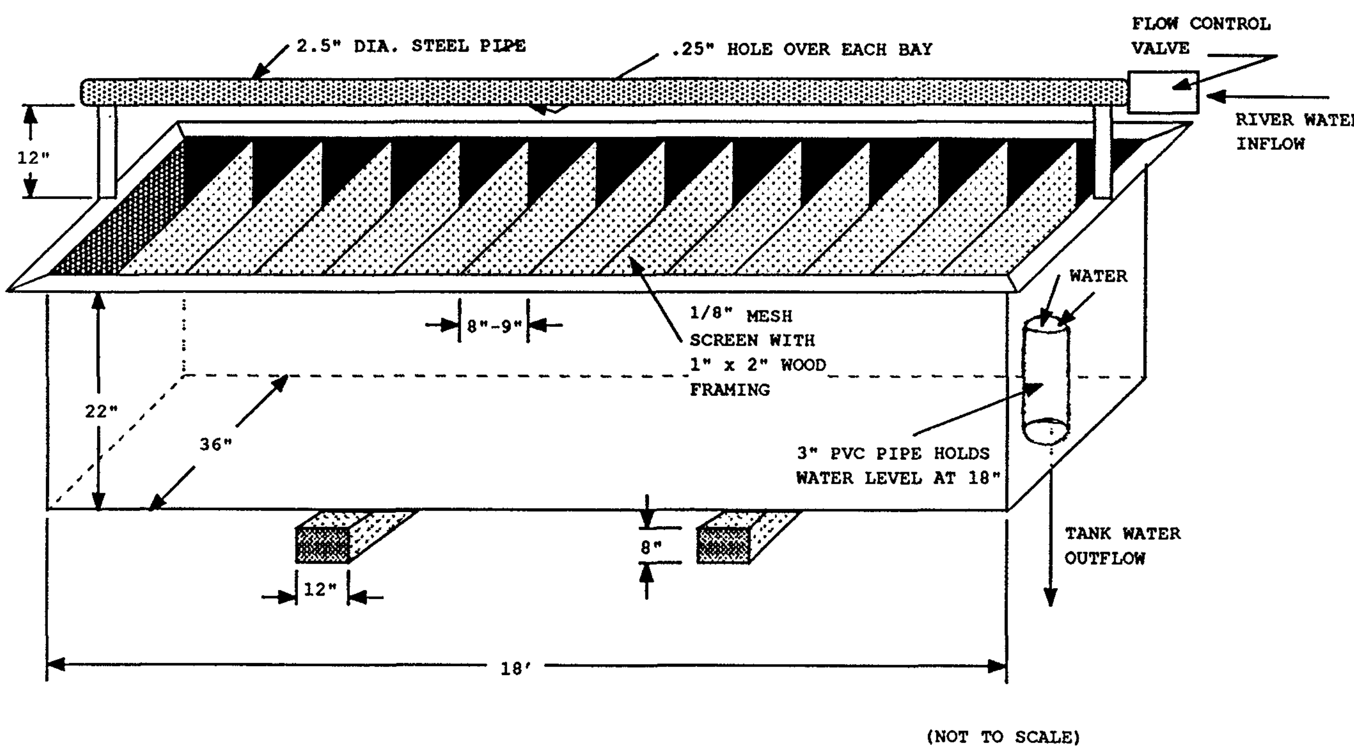

Figure 4 Schematic of the trough and water delivery apparatus used to hold up to 18 groups of branded fish. Trough actually had 18 compartments rather than the 14 shown here.

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marked group. Brand clarity was rated as good, unidentifiable, or absent. Good meant the brand was present and identifiable, unidentifiable meant that although a brand was present, its mark and orientation were not distinguishable. Absent meant no brand was evident.

The proportion (P) of fish found to have clear brands in each group was used to estimate the actual number of branded fish released with clear brands (except for groups released on May 1), as follows:

$$BRANDS(clear,i) = P \times BRANDS(total,i)$$

where i represents a uniquely branded group. Values of P normally ranged from 90% to 100% and were most frequently 100%. For most groups, the 95% confidence interval on P was less than ±3%.

Every fish released on May 1 was examined individually for the presence or absence of a brand, and the number of branded fish was tabulated. This was necessary because of poor brand retention. This problem was remedied for all later releases by using larger brands.

RELEASE PROCEDURES

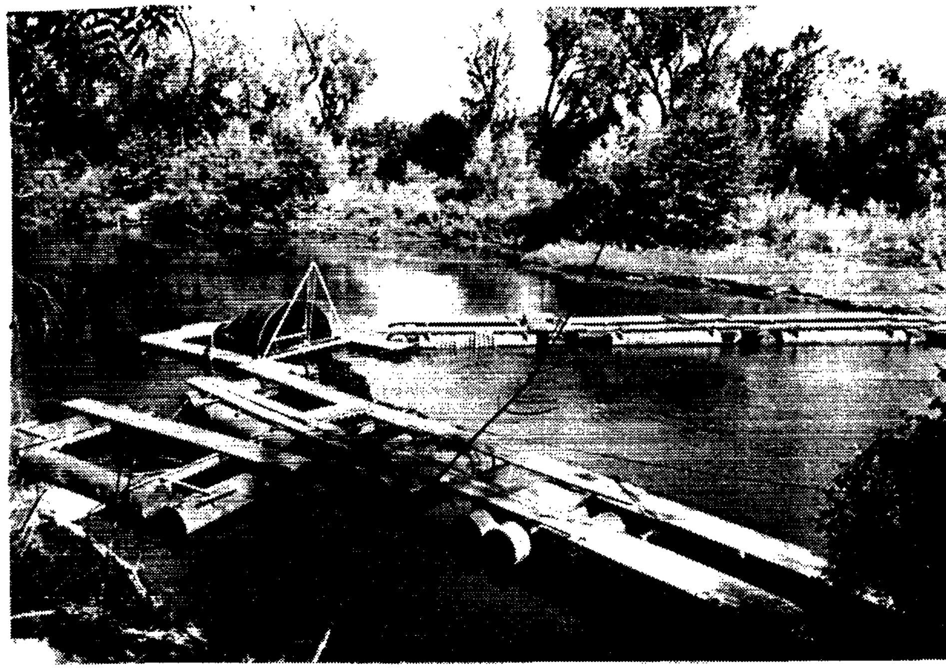
Releases of branded fish on each test date began at dusk and were completed between 11 pm and 1 am. On June 12, one set of groups was released during 10 am to noon, and another set was released in the usual manner after dusk. Fish were dip netted from their holding tank and placed in 30 gal plastic buckets for transport by boat to the release site. Each bucket was normally limited to transporting one branded group of up to 450 fish. Pressurized oxygen was bubbled into each bucket through tubing fitted with an airstone. Transport time varied from 5 to 30 minutes depending on where the fish were released. At the site of release, replicate groups were released at different distances across the channel.

Fish Capture Methods

Juvenile chinook were captured by three methods. GCID operated a rotary screw trap in the lower end of the oxbow. CDFG operated a trap in bay 24 of the fish screens, and USFWS fished a boat-mounted push net in the river during two of the releases.

GCID SCREW TRAP

The GCID trap is an 8 ft diameter rotary screw trap (Figure 5) manufactured by E.G. Solutions of Eugene, Oregon. The trap was placed in the oxbow just above river mile 205. It was held in a static position by cables anchored on both shores. Pontoons were placed along the cables for easy access to the trap. The trap was positioned so that water entering the upstream end of the trap strikes the angled



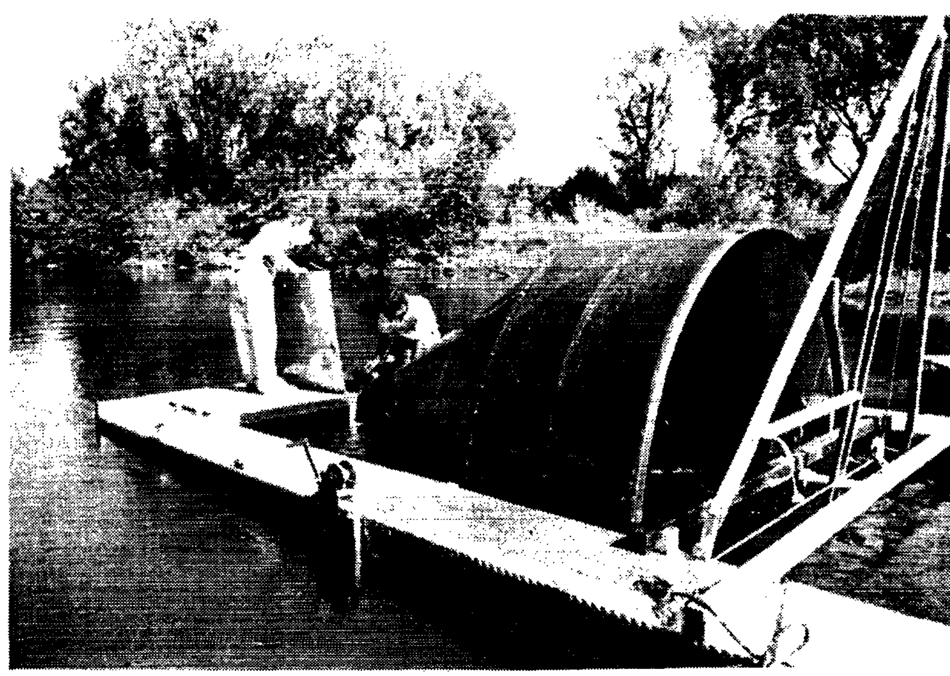


Figure 5 **Photographs of rotary screw trap fished at the lower end of the GCID oxbow.**

surface of the internal screw core. This rotates the entire screw assembly. As the assembly rotates, fish are trapped within the chambers formed by the screw and are forced rearward into the livebox, where they are retained unharmed. Contents of the livebox were removed daily, juvenile chinook were examined for marks, counted and a random sample of 30 were measured. All recaptures were measured. All fish were released into the river below the trap.

To increase the efficiency of the trap, a "V" shaped fence was constructed in the water to guide fish into the trap (see Figures 2 and 5). This structure started at the mouth of the trap and continued upstream along the pontoons to each shore (approximately 30 yds). The shore the fence reached on the west side was actually an island, so a small portion of the oxbow outflow passed to the west side of the island and was not fenced (see Figure 2). The fence consisted of two types of grating panels driven into the substrate and attached to the pontoons. Mesh size on the grating were 1-2 inches in diameter, so the fence was intended only as a fish guidance system.

The efficiency with which this fence guided fish into the trap varied. Screen panels were changed from time to time and the river current scoured gravel from the base of the panels, at times creating large openings under the screens. Also, as flows varied, the proportion of flow passing on the west side of the island adjacent to the trap varied. Thus, it was necessary to reestimate the capture efficiency of the trap during each experimental release of fish.

CDFG TRAP

The CDFG fyke trap is located at bay 24 of the 40 bay fish screen facility. The drum screen was removed from bay 24 so that water entered a V-trap (Ward 1989). The trap is a stationary, 24 ft x 13 ft x 8 ft apparatus with 3/16 in. perforated aluminum siding. The trap was monitored daily by the CDFG. All fish caught were examined for marks and a subsample was measured.

USFWS PUSH NET

USFWS fished a pushnet in the main channel of the river following two of the releases. The pushnet was mounted on the bow of a 21 ft boat with a 115 horsepower engine. The net was 6 ft high by 6 ft wide by 19 ft long, with an upstream-most panel 7 ft long with 3 in. mesh, a 7 ft panel with 1 in. mesh, and a 5 ft panel with 1/2 in. mesh (USFWS, 1988). This net was fished in the riffle below the outlet of the oxbow between RM 204.6 and RM 205.1. The operators tried to maintain a static position, fishing mainly on the west side of the riffle (personal communication with Jerry BigEagle, USFWS, Red Bluff, California).

Objective 2.0 ***Identify the relative importance of various sources of juvenile salmon loss in the GCID intake channel and evaluate possible corrective measures.***

All sampling under this objective was directed toward estimation of predation by squawfish and evaluation of seining as a method of squawfish removal. Squawfish were captured in front of the fish screens by angling and seining.

Capture Methods

ANGLING

We angled with normal spinning gear. Either live fish, pieces of fish, or lures were used as bait. We fished 3-4 days/week, alternating between morning and evening hours. We normally fished from a boat anchored in front of the trashracks. On one occasion trot lines were used as an attempt to sample the area directly between the trashracks and the fish screens, but were discontinued due to their inefficiency.

SEINING

We netted squawfish with a quick-sinking 300 ft beach seine. We seined in the morning and evening, 2 - 3 times per week, opposite days of angling. Mesh size and depth of the net varied. The center panel was 2 in. stretch mesh 100 ft x 14 ft. On each side of the center panel were panels with 4 in. stretch mesh tapering from 14 ft deep to 9 ft deep, with one panel 75 ft long and the other 150 ft long.

The seine was set from the bow of a 14 ft boat powered by a 70 horsepower engine. The bow was covered with 5/8 in. plywood so the net could be fed on and off the boat without snagging on the boat. The net was set in a semicircle, proceeding downstream, from the shore of the oxbow opposite the screens. Before beginning a set, the starting end (upstream) of the net was clipped to a cable anchored on the shore to prevent the net from getting away from us in the current. The net was set by backing the boat rapidly out and downstream as the net fed off the front of the boat. Once the end of the net was reached, the boat was pivoted, the endline was wrapped around a pullbar mounted near the back of the boat, and the end of the net was pulled to shore. Four crew members then retrieved the seine manually along the shore.

We attempted to set the net as close to the screens as possible (usually within 25 ft) without having the net dragged into the trashracks by the current. We were unable to seine along the entire length of the screens, because we discovered submerged "I" beam pilings that protruded from the bottom at several points along the screens. These pilings were removed at the beginning of August so the seining area is now unrestricted.

Fish Processing

All squawfish caught were measured, given a 1/4 in. hole punch in the left opercle, tagged with a Floy anchor tag just below the dorsal fin, and released. The opercle punch served as a secondary mark to asses tag loss. Each Floy tag had a unique number enabling us to track the times and locations of tagging and recapture of individual fish.

We examined the stomach contents of all squawfish captured. We used three methods to extract fore-gut contents from squawfish: (1) stroking, (2) flushing, and (3) dissecting. Stroking was performed by holding the fish in a vertical, head down position, and vigorously stroking the abdomen in a downward motion to induce regurgitation. Next, with the fish still in a vertical position, a 3/16 in. plastic tube with a flush bulb attached to its distal end was inserted into the fish's mouth, and carefully positioned into the posterior area of the fore-gut. Water was then pumped into the fore-gut promoting regurgitation. Stroking was again initiated as a last attempt to force regurgitation. We tested the efficiency of our methods by sacrificing seven fish to surgically sample its entire alimentary tract. No residual contents were observed in the alimentary tract of the dissected fish. Uremovitch et al (1980) used similar methods on northern squawfish in the Columbia River and found that pumping was 90% effective at extracting stomach contents.

Statistical Considerations

Special data transformations were performed on all binomial data before standard analysis of variance and confidence intervals were calculated. Binomial data are values expressed as a proportion, p, of 1.0, such as the proportion of fish recaptured. Binomial data are characterized by having a variance that changes with the value of the proportion, but a standard analysis of variance requires that variances be equal for all values included. Therefore, we used the angular (or arcsine) transformation (Snedecor and Cochran 1967) on binomial data to stabilize variance for all levels of p. This transformation has the greatest effect on proportions below 30% and above 70%. Most of the data we worked with were below 30% or above 70%, so the transformation was necessary.

Flow Monitoring

Flow of the Sacramento River above the mouth of the GCID oxbow was estimated by adding the GCID pumping plant flow to the 7:00 am Sacramento River flow at Hamilton City. Preliminary readings of the daily flows at Hamilton City were obtained from Paul Ward (CDFG, stationed at the Glenn-Colusa fish screens). After about one month, final readings of the Hamilton City gauge were obtained from California Department of Water Resources. The GCID pumping rate was obtained from daily records at the pumping plant. Flow data are contained in Appendix 1.

Bypass flow was measured periodically under varying river and pumping plant flows. These measurements were used in a multiple regression to estimate daily bypass flows through the lower oxbow. Bypass flows vary directly with both river and pumping plant flows. Depth was measured at 4 ft intervals across a single transect in the lower oxbow and velocity was measured with a Gurley Model 622 flow meter at 20% and 80% depth at each interval. The multiple regression equation to predict bypass flow, based on flow measurements in May and June, 1990 was:

$$\text{Bypass flow} = 0.09\cdot(\text{River flow}) - 0.17\cdot(\text{Pumped flow}) - 19.4$$

The intake flow to the oxbow was determined by adding the bypass flow to the GCID pumping plant flow.

Findings

Objective 1.0 ***Determine the Total Number of Juvenile Chinook Lost in the GCID Intake Channel and Quantify the Influences of Fish Abundance, Fish Size, and Flow Diverted on These Losses.***

Sampling with the rotary screw trap began April 23 and continued daily through July. Juvenile fall chinook were the predominant species captured and daily catches of unmarked chinook ranged from 2 to 462 fish. Additionally, we recaptured up to 690 branded juvenile chinook in one night following the five test releases. Numbers of test fish recaptured and their mean lengths from each release are presented in Tables 2-7.

Sampling at the CDFG trap in screen bay #24 began February 14 and continued daily through July. Daily catches of juvenile fall chinook, the predominant species captured ranged from 0 to 306 fish. Additionally, the trap recaptured up to 57 branded juvenile chinook in one night from the test releases by GCID. Numbers of branded fish recaptured by CDFG and their mean lengths from each test release are presented in Tables 2-7.

Marked fish moved immediately downstream at night following release. Over 95% of all recaptures were captured the night they were released. Data in Tables 2-7 include recaptures from all sampling through July. Several sources of evidence lead us to conclude that residualization or differences in migration rate between release groups did not affect our results. This evidence includes:

1. Greater than 95% of all branded fish were recaptured the first night. Rarely were any fish captured during the day. The only exception was a test group of fish released 100 yd. above the GCID trap just before noon.
2. Fish released at RM 208 were recaptured at RM 205 within 1-2 hours (see Task 1.1, Results from the USFWS push net).
3. Most fish released during the day in the oxbow waited until night to migrate (see Percentage Survival Effects of Time-of-Day). Thus migration at night was the normal condition and migration during daylight was abnormal.
4. Fish released in the upper oxbow at night were caught within a few hours in the rotary screw trap at the lower-end of the oxbow.
5. Vogel et al (1988) showed during three consecutive years (1984-1986) that juvenile chinook released in May from Coleman Hatchery migrated 40 miles downstream to Red Bluff Diversion Dam within 24 hours and essentially all passed the dam the first night following release (Vogel et al 1988, Figure23 on p 32).

Task 1.1 **Determine the proportion of downstream migrant chinook salmon diverted from the main-stem Sacramento River into the GCID oxbow.**

TABLE 2. Summary of release and recovery data for branded fall chinook released on May 1, 1990.

			Recaptures					
			GCID			CDFG		
Location Released	Brand Location	Number Released	Number	Percent	Mean Length(mm)	Number	Percent	Mean Length(mm)
Upper Oxbow	Left-side Back	1533	55	3.59%	69.6	15	0.98%	63.1
Lower Oxbow	Left-side Front	1655	191	11.54%	70.7	0	0.00%	---

TABLE 3. Summary of release and recovery data for branded fall chinook released on May 8, 1990.

Release Location	Brand	Number Released	Mean Length(mm)	Recaptures: GCID Number	GCID Percent	GCID Mean Length(mm)	CDFG Number	CDFG Percent	CDFG Mean Length(mm)	USFWS Number	USFWS Percent	USFWS Mean Length(mm)
Mile 208	* RF	796	74.8	8	1.01%	72.5	3	0.38%	70.7	3	0.38%	69.0
Mile 208	- RF	460	72.8	1	0.22%	71.1	1	0.22%	70.0	1	0.22%	75.0
Mile 208	- RB	426	71.6	6	1.41%	74.6	1	0.23%	65.0	1	0.23%	75.0
Mile 205.5	U RF	468	75.8	0	0.00%	---	0	0.00%	---	4	0.85%	69.8
Mile 205.5	U RB	441	74.3	0	0.00%	---	0	0.00%	---	1	0.23%	76.0
Mile 205.5	U! RF	446	73.0	0	0.00%	---	0	0.00%	---	5	1.12%	69.6
Upper Oxbow	T RB	408	72.7	26	6.37%	74.96	0	0.00%	---	0	0.00%	---
Upper Oxbow	T! RF	436	72.1	39	8.94%	75.7	5	1.15%	66.0	1	0.23%	75.0
Upper Oxbow	T! RB	453	69.4	44	9.71%	72.86	8	1.77%	71.3	1	0.22%	63.0
Upper Oxbow	TL RF	443	73.5	52	11.74%	73.2	10	2.26%	64.7	0	0.00%	---
Upper Oxbow	TL RB	435	74.6	49	11.26%	72.93	6	1.38%	65.8	0	0.00%	---
Upper Oxbow	TR RF	444	73.6	41	9.23%	73.63	0	0.00%	---	1	0.23%	85.0
Upper Oxbow	TR RB	409	73.4	32	7.83%	74.7	4	0.98%	68.3	1	0.23%	61.0
Upper Oxbow	1 RF	450	72.1	45	10.00%	74.23	7	1.56%	71.7	0	0.00%	---
Upper Oxbow	1 RB	439	71.5	47	10.71%	74.56	2	0.46%	69.5	1	0.23%	75.0
Lower Oxbow	V RF	411	74.6	50	12.18%	73.66	0	0.00%	---	0	0.00%	---
Lower Oxbow	V RB	434	74.4	81	18.66%	69.93	0	0.00%	---	0	0.00%	---
Lower Oxbow	V! RF	350	74.3	85	24.26%	70.13	0	0.00%	---	0	0.00%	---
Lower Oxbow	V! RB	403	72.7	87	21.58%	71.33	0	0.00%	---	0	0.00%	---

Note: First symbol of brand code is the symbol used. A second symbol adjacent to the first indicates a special orientation: ! = upsidedown, L = tilted left, R = tilted right. The first one or two symbols are followed by a space, then by two more symbols indicating position on the fish: RF = right-side front, RB = right-side back.

TABLE 4. Summary of release and recovery data for branded fall chinook released on May 16, 1990.

				Recaptures					
				GCID			CDFG		
Rlease Location	Brand	Number Released	Mean Length(mm)	Number	Percent	Mean Length(mm	Number	Percent	Mean Lenght(mm)
Mile 208	U LB	427	73.6	0	0.00%	---	0	0.00%	---
Mile 208	1 LF	428	71.2	0	0.00%	---	0	0.00%	---
Mile 208	1 LB	443	74.6	4	0.90%	78.0	0	0.00%	---
Mile 208	- LF	447	77.2	2	0.45%	---	1	0.22%	82.0
Upper Oxbow	U LF	461	76.0	23	4.99%	76.0	1	0.22%	72.0
Upper Oxbow	U! LF	377	72.8	20	5.31%	75.5	1	0.27%	59.0
Upper Oxbow	- LB	432	75.5	6	1.39%	76.4	1	0.23%	56.0
Upper Oxbow	TL LF	421	74.2	24	5.70%	77.3	6	1.43%	77.0
Upper Oxbow	TL LB	437	75.0	12	2.75%	77.8	1	0.23%	70.0
Upper Oxbow	TR LF	437	74.7	13	2.97%	78.7	3	0.69%	74.0
Upper Oxbow	TR LB	438	76.3	28	6.39%	78.5	0	0.00%	---
Upper Oxbow	T! RF	422	74.3	16	3.79%	77.6	2	0.47%	74.0
Upper Oxbow	T! LB	426	75.6	15	3.52%	78.5	4	0.94%	74.3
Upper Oxbow	T LF	463	73.9	13	2.81%	79.6	1	0.22%	65.0
Upper Oxbow	T LB	437	76.0	12	2.75%	78.2	4	0.92%	73.0
Lower Oxbow	V! LF	435	74.6	25	5.75%	76.2	0	0.00%	---
Lower Oxbow	V! LB	433	75.4	12	2.77%	77.5	0	0.00%	---
Lower Oxbow	V LF	450	75.3	19	4.22%	76.9	0	0.00%	---
Lower Oxbow	V LB	434	75.8	16	3.69%	75.4	0	0.00%	---

Note: First symbol of brand code is the symbol used. A second symbol adjacent to the first indicates a special orientation: ! = upsidedown, L = tilted left, R = tilted right. The first one or two symbols are followed by a space, then by two more symbols indicating position on the fish: RF = right-side front, LF = left-side front, LB = left-side back.

TABLE 5. **Summary of release and recovery data for branded fall chinook released on May 24, 1990.**

Release Location	Brand	Number Released	Mean Length(mm) Released	Recaptures: GCID Number	GCID Percent	GCID Mean Length(mm)	CDFG Number	CDFG Percent	CDFG Mean Length(mm)	USFWS Number	USFWS Percent	USFWS Mean Length(mm)
Mile 208	U RB	449	80.9	3	0.67%	77.3	0	0.00%	----	0	0.00%	----
Mile 208	1 RF	429	79.8	4	0.93%	77.5	1	0.23%	76.0	1	0.23%	83.00
Mile 208	1 RB	453	79.7	2	0.44%	80.0	0	0.00%	----	3	0.66%	76.70
Mile 208	- RF	449	79.4	1	0.22%	78.0	0	0.00%	----	1	0.22%	65.00
Mile 205.5	* RF	769	80.9	0	0.00%	---	0	0.00%	----	8	1.04%	73.10
Mile 205.5	* RB	753	84.3	0	0.00%	---	0	0.00%	----	10	1.33%	81.10
Upper Oxbow	- RB	450	79.9	18	4.00%	81.9	0	0.00%	----	1	0.22%	75.00
Upper Oxbow	U RF	376	81.1	6	1.59%	84.8	0	0.00%	----	0	0.00%	----
Upper Oxbow	U! RF	122	80.7	7	5.75%	84.0	0	0.00%	----	0	0.00%	----
Upper Oxbow	U! RB	435	83.8	19	4.37%	81.3	1	0.23%	80.0	0	0.00%	----
Upper Oxbow	TR RF	450	80.6	10	2.22%	78.7	2	0.44%	68.5	0	0.00%	----
Upper Oxbow	TR RB	450	78.9	16	3.56%	81.3	0	0.00%	---	0	0.00%	----
Upper Oxbow	TL RF	448	80.1	11	2.44%	80.0	1	0.22%	---	1	0.22%	73.00
Upper Oxbow	TL RB	450	78.2	20	4.46%	75.9	1	0.22%	67.0	0	0.00%	----
Upper Oxbow	T RF	448	79.1	8	1.79%	77.8	0	0.00%	----	0	0.00%	----
Upper Oxbow	T RB	450	81.1	27	6.00%	80.4	0	0.00%	----	1	0.22%	74.00
Upper Oxbow	T! RF	456	79.6	22	4.82%	83.4	0	0.00%	----	0	0.00%	----
Upper Oxbow	T! RB	449	79.3	21	4.68%	79.9	0	0.00%	----	0	0.00%	----
Lower Oxbow	V RF	444	79.7	20	4.50%	82.9	0	0.00%	----	2	0.45%	70.50
Lower Oxbow	V RB	465	81.4	19	4.09%	80.2	0	0.00%	----	0	0.00%	---
Lower Oxbow	V! RF	447	80.1	18	4.03%	80.7	0	0.00%	----	0	0.00%	---
Lower Oxbow	V! RB	446	77.7	27	6.05%	81.8	0	0.00%	----	1	0.22%	84.00

Note: First symbol of brand code is the symbol used. A second symbol adjacent to the first indicates a special orientation: ! = upsidedown, L = tilted left, R = tilted right. The first one or two symbols are followed by a space, then by two more symbols indicating position on the fish: RF = right-side front, RB = right-side back.

TABLE 6. Summary of release and recovery data for branded fall chinook released on the night of June 12, 1990.

				Recaptures					
				GCID			CDFG(a)		
Location Released	Brand	Number Released	Mean Length (mm)	Number	Percent	Mean Length(mm)	Number	Percent	Mean Length(mm)
Mile 208	1 LB	349	77.1	3	0.86%	88.3	0	0.00%	---
Mile 208	1 LF	353	75.0	2	0.57%	85.0	0	0.00%	---
Mile 208	* LF	780	81.0	4	0.51%	81.0	0	0.00%	---
Mile 208	* LB	725	74.5	2	0.28%	72.0	1	0.14%	70.0
Upper Oxbow	T LF	349	75.8	25	7.16%	80.0	1	0.29%	75.0
Upper Oxbow	T LB	395	77.1	22	5.57%	76.0	0	0.00%	---
Upper Oxbow	U! LF	313	76.9	19	6.07%	75.0	2	0.64%	66.6
Upper Oxbow	U! LB	297	79.6	21	7.07%	81.0	1	0.34%	68.0
Upper Oxbow	- LF	346	77.0	23	6.65%	77.0	0	0.00%	---
Upper Oxbow	- LB	359	80.6	27	7.52%	78.0	0	0.00%	---
Lower Oxbow	V LF	299	76.5	66	22.07%	80.0	0	0.00%	---
Lower Oxbow	T! LF	327	77.1	53	16.21%	77.0	0	0.00%	---
Lower Oxbow	T! LB	324	78.5	55	16.98%	77.0	0	0.00%	---

(a) The CDFG trap pump was mistakenly left off during the night of the releases, so catches were unusually low.

Note: First symbol of brand code is the symbol used. A second symbol adjacent to the first indicates a special orientation: ! = upsidedown, L = tilted left, R = tilted right. The first one or two symbols are followed by a space, then by two more symbols indicating position on the fish: LF = left-side front, LB = left-side back.

C-051317

TABLE 7. Summary of release and recovery data from branded fall chinook released on June 12, 1990 during midday.

				Recaptures					
				GCID			CDFG(a)		
Location Released	Brand	Number Released	Mean Length(mm)	Number	Percent	Mean Length(mm)	Number	Percent	Mean Length(mm)
Upper Oxbow	V LB	335	77.4	17	5.07%	76.0	0	0.00%	---
Upper Oxbow	V! LF	349	79.0	13	3.72%	78.8	0	0.00%	---
Upper Oxbow	V! LB	329	80.2	12	3.65%	77.9	0	0.00%	---
Upper Oxbow	VL LF	250	79.9	13	5.20%	82.9	2	0.80%	66.0
Upper Oxbow	VL LB	326	74.7	13	3.99%	73.8	0	0.00%	---
Upper Oxbow	VR LB	272	71.7	15	5.52%	81.3	0	0.00%	---
Lower Oxbow	VR LF	286	76.2	8	2.80%	68.8	0	0.00%	---
Lower Oxbow	TL LF	313	---	9	2.88%	80.1	0	0.00%	---
Lower Oxbow	U LF	317	77.0	9	2.84%	71.3	0	0.00%	---
Lower Oxbow	U LB	277	75.1	17	6.14%	70.4	0	0.00%	---

(a) The CDFG trap pump was mistakenly left off during the night following these releases, so catches were unusually low.

Note: First symbol of brand code is the symbol used. A second symbol adjacent to the first indicates a special orientation: ! = upsidedown, L = tilted left, R = tilted right. The first one or two symbols are followed by a space, then by two more symbols indicating position on the fish: LF = left-side front, LB = left-side back.

Results from the GCID trap

The estimated proportion of branded chinook diverted into the GCID oxbow after the four sets of releases at RM 208 (no fish were released at RM208 on May1, the first of the five release dates) varied from 4.45% to 14.37% (Table 8). The percentage diverted was estimated as:

$$\% \text{ DIVERT}(i) = [(\% \text{ RECOVER}(208,i)/(\% \text{ RECOVER}(U.O.,i)]*100$$

and

$$\% \text{ RECOVER} = (\Sigma[\text{RECAPS}(j)/\text{RELEASED}(j)]/n)*100$$

where RECAPS(j) = number recaptured from brand group j

RELEASED(j) = number released from brand group j

208 = groups released at RM 208

U.O. = groups released in the upper oxbow

i = week of release

n = number of groups, j, released at specified location

The percentage of fish recovered from releases at RM 208 averaged less than 1% for each set of releases, while the percentage recovered from releases in the upper oxbow ranged from 3.2% to 9.8%. Together, the recovery rates from these two release locations resulted in 95% confidence intervals on the percentage diverted that were generally under ±5% (Table 8).

Calculation of confidence intervals for the percentage diverted was complex because the mean value is estimated from the ratio of two variables, each with their own variance. The variance of such a ratio is given by:

$$\text{Var}(Y/Z) = (Y/Z)^2 \cdot [\text{Var}(Y)/Y^2 + \text{Var}(Z)/Z^2 - 2 \cdot \text{Cov}(Y,Z)/(Y \cdot Z)]$$

where Y =% RECOVER(208)

Z =% RECOVER(U.O.)

We estimated the variance of Y and Z from the analysis of variance (ANOVA) in recovery rates at the GCID trap for each release date (recovery rates of individual brand groups are reported in Tables 2-7). However, these recovery rates were transformed to the arcsine$\sqrt{\%}$ before calculating the ANOVA (see Statistical

TABLE 8. **Mean recovery rates in the GCID screw trap from releases of marked fall chinook during May and June, 1990. Data were transformed using the angular transformation (Snedecor and Cochran 1967) to stabilize binominal variance before means were calculated. The values listed in this Table were then calculated by back transforming the angular means to percentages.**

Release Date	Release Time	% Recovered: Lower Oxbow	% Recovered: Upper Oxbow	% Recovered: Mile 208	Estimated Fish Diverted: Mean %	Estimated Fish Diverted: ± 95% C.I.	Estimated Oxbow Survival: Mean %	Estimated Oxbow Survival: ± 95% C.I.	Flow (cfs): River	Flow (cfs): Pumped	Flow (cfs): Bypassed
5/1	night	11.54%	3.20%	---	---	---	27.73%	4.20%	8665	2347	350
5/8	night	18.79%	9.53%	0.78%	8.18%	4.40%	50.73%	6.50%	9509	2259	431
5/16	night	3.97%	3.60%	0.13%	4.45%	4.50%	90.61%	23.50%	9640	1624	559
5/24	night	4.68%	3.68%	0.53%	14.37%	7.50%	78.68%	16.00%	11912	1134	835
6/12	night	17.93%	6.61%	0.37%	5.69%	2.70%	36.87%	4.40%	8780	2389	355
6/12	day	3.55%	4.37%	---	---	---	123.10%(a)	---	8780	2389	355

(a) The meaning of this value is discussed in the section on "Effects of time-of-day"

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Considerations). Therefore, the variances were also calculated in these transformed units. In order to backtransform the variances to normal % units, we converted the standard errors to a proportion of the mean (referred to as a coefficient of variation or CV) and then used this same proportion of the backtransformed mean to estimate variance. The process to calculate a confidence interval took the following steps:

1. Set $\underline{Y}(i,j) = \text{arcsine}\sqrt{Y(i,j)}$ and $\underline{Z}(i,j) = \text{arcsine}\sqrt{Z(i,j)}$ where i denotes the brand code and j the release location
2. Calculate an ANOVA between and within release locations. Calculate a separate analysis for each release date.
3. Backtransform the location means to percentages. That is $Y(j) = (\text{sine}(\underline{Y}(j)))^2$ and the same for Z
4. Calculate $CV(Y) = S.E.(\underline{Y})/\underline{Y}$ and the same for Z. S.E. is the pooled value for Y or Z from the ANOVA
5. Calculate backtransformed variance as $Var(Y) = (CV(Y) \cdot Y)^2$ and the same for Z
6. Complete the calculation of Var(Y/Z) as presented above. Assume Cov(Y,Z) = 0. Covariance would be positive if variation in Y and Z were positively correlated and negative if their variation was negatively correlated. We believe it reasonable to assume they vary independently.
7. Calculate the binomial variance for the recovered proportions from the May 1 release, because releases were not replicated and a ANOVA could not be preformed. Therefore, data were not transformed.
8. Tabulate t values based on n1 + n2 - 2 degrees of freedom,

where n1 = number of brand groups released at RM 208

and n2 = number of brand groups released in the upper oxbow.

Use z instead of t for May 1 release, based on number released.

9. Calculate confidence interval.

The estimated proportion of fish diverted into the oxbow was always less than the proportion of flow diverted (Table 8), and was not correlated to the proportion of flow diverted (Figure 6). In fact, the highest estimate of the proportion of fish diverted occurred during the May 24 test when the proportion of flow diverted was the lowest of any of the four test releases at RM 208. This finding casts doubt but does not disprove the hypothesis that fish are diverted into the oxbow in equal proportion to the flow diverted. The lack of any relationship between the estimated proportion of fish diverted into the oxbow and the flow diverted is illogical and causes us to suspect biases in our sampling. It appears probable from variability in the recovery rates of the marked groups released on May 8 (Table 3) that they did not disperse similarly across the channel. The one consistent finding between the four tests was that the estimated

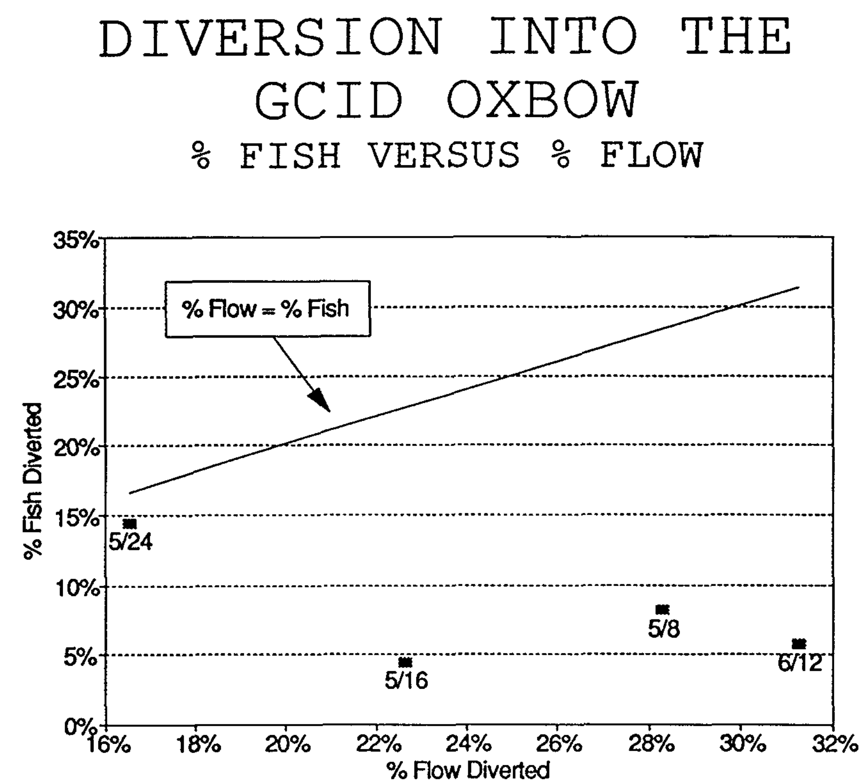

Figure 6 **Scatter diagram of the estimated proportions of chinook diverted from the Sacramento River into the GCID oxbow on the five test dates versus the proportion of flow diverted into the oxbow. Data from Table 8.**

proportion of fish diverted was always less than the proportion of flow diverted. However, possible biases in the data make it inappropriate to estimate how much less.

Other studies have shown that outmigrant chinook tend to concentrate in the current thalweg. In the Rogue River, Cramer et al. (1985, Appendix 35) found the proportion of fingerling chinook diverted into the Table Rock Irrigation Ditch varied dramatically between years, although the proportion of flow diverted varied little. The proportion of juvenile chinook diverted into the Table Rock Irrigation Ditch was directly related to how far the diversion berm extended into the main current of the river (personal communication with Tom Satterthwaite, Oregon Department of Fish and Wildlife, Grants Pass). Similarly, Willis and Uremovich (1981) found from gatewell sampling at Bonneville Dam on the Columbia River that juvenile chinook did not approach the powerhouse evenly, but concentrated in the center channel. The current patterns approaching Bonneville Powerhouse are not characteristic of a reservoir, but rather are similar to a swiftly flowing river with velocities in excess of 5 ft/s near the center channel. In contrast, Vogel et al. (1988) found that fingerling chinook in the Sacramento River were evenly distributed across the river as they approached Red Bluff Diversion Dam. This likely reflects uniformity in the current patterns through Lake Red Bluff.

The thalweg of the Sacramento River at the mouth of the GCID oxbow is on the east bank, but the oxbow is on the west bank. Thus, the low estimates for proportions of fish diverted are consistent with the findings of other studies on the behavior of outmigrating chinook. The pattern of currents at the mouth of the oxbow is likely to have a greater affect on the proportion of fish diverted than will the volume of flow diverted. If this is true, the proportion of fish diverted into the oxbow is likely to change between years and between different flows as current patterns change. Additionally, chinook fry (< 50 mm FL) are likely to distribute themselves near the shore, rather than in the thalweg. Therefore, it is probable that the proportion of fry diverted at a given flow will be higher than the proportion of smolts diverted. This discussion should make it clear that additional tests under a variety of flows, fish sizes, and current patterns at the oxbow inlet will be necessary to understand the dynamics governing the proportion of juvenile chinook diverted into the GCID oxbow.

Results from the CDFG trap

The number of branded fish released at RM 208 and recaptured in the CDFG trap was too low to be useful. On three of the four test dates, only one fish was recovered from RM 208 (see Tables 3-6). The percentage of fish diverted was estimated by the same calculation as for the GCID trap. The recapture rate at the CDFG trap of fish released in the upper oxbow was also low (Table 9), so even when only one fish was recaptured from the releases at RM 208, the estimated proportion diverted into the oxbow ranged from 11% (May 16) to 67% (May 24). The highest number of fish recovered from releases at RM 208 was from the May 8 release when

TABLE 9. Mean recovery rates in the CDFG trap and USFWS push net from releases of marked fall chinook during May and June, 1990. Data were not transformed.

		CDFG		USFWS			
Release Date	Release Time	Mile 208	Upper Oxbow	Mile 208	Mile 205	Upper Oxbow	Lower Oxbow
01-May	night	---	0.0098	---	---	---	---
08-May	night	0.0020	0.0106	0.0028	0.0073	0.0013	0.0000
16-May	night	0.0006	0.0054	---	---	---	---
24-May	night	0.0006	0.0009	0.0028	0.0118	0.0006	0.0017
12-June	night	a	a	---	---	---	---
12-June	day	---	0.0005	---	---	---	---

a. CDFG trap pump mistakenly left off. Catches abnormally low.

five fish were recaptured, yielding an estimated diversion rate of 20% compared to the estimate of 8% from recaptures at the GCID trap. The CDFG estimate is significantly ($P<0.05$) greater than the GCID estimate. This difference may be related to the selectivity of the CDFG trap for smaller than average fish (this is discussed in detail under the section, "Percentage Survival").

Recovery rates in the CDFG trap of marked fish released from Coleman Hatchery each year provide additional evidence that the proportion of migrant juvenile chinook diverted into the GCID oxbow varies independently of the proportion of flow diverted into the oxbow. Recovery rates in the CDFG trap of marked fall chinook released in May from Coleman Hatchery ranged six fold (0.004% to 0.024) during 1987-1990 (Table 10). During the same years, the proportion of flow diverted ranged only from 10% to 20%. The volume of pumped flow and the size of marked fish, both of which affect trapping efficiency (see Fish Abundance), varied between years, but not in such a way that enables explanation of the variation in recovery rates at the CDFG trap. Data in Table 10 show no indication of a correlation of recovery rates to fish size, pumped flow, or the proportion of the river diverted.

Results from the USFWS push net

Recapture rates in the USFWS push net (Table 9) are difficult to interpret and show some obvious sampling biases. The differences in recovery rate between fish released at RM 208 and RM 205.5 (Figure 7) indicate a 76% loss and a 72% loss of fish between those two points on May 8 and May 24, respectively. This seems unreasonable even considering that as high as 22% of the fish were diverted into the oxbow (22% was the upper confidence limit of the highest diversion rate we estimated). Loss rate was estimated as follows:

% LOSS = 1.0 - % SURVIVAL

% SURVIVAL(208,i) = [(% RECOVER(208,i)/(% RECOVER(205,i)]*100

% SURVIVAL(U.O.,i)=[(% RECOVER(U.O,i)/(% RECOVER(205,i)]*100

Even more odd, the recoveries show a 100% and a 86% loss for fish released in the lower oxbow on May 8 and May 24 compared to those released at RM 205.5. Apparently, fish exiting the oxbow did not distribute evenly across the river and tended to use a portion of the river not sampled by the USFWS push net.

TABLE 10. Release data and recovery rates at the CDFG trap of marked fall chinook released from Coleman Hatchery during 1987-1990.

Release Date	Release Location	Marked Fish Released	Fish/lb	Peak Recapture Date (1)	River Flow (2)	Pumped Flow (2)	% Flow (2) Diverted	CDFG Recovery Rate (1)
12-May-90	CNFH	52921	70.2	May 13 & 14	9968	1775	0.178	0.004%
	RBDD	52212	73.4					
09-May-89	CNFH	52170	123.4	May 10	14470	1460	0.101	0.009%
	RBDD	53058	118.8					
10-May-88	CNFH	52783	69.0	May 11	15110	1520	0.101	0.023%
	RBDD	53275	69.0					
03-May-87	RBDD	217035	67.3	May 5	11743	2600	0.221	0.024%

(1) All groups combined within each year.

(2) Flows measured on the date of peak recapture. Flows were averaged for May 13 &14 in 1990. River flow is the sum of the 7 a.m. flow at Hamilton City and the 7 a.m. flow in the GCID pumping plant.

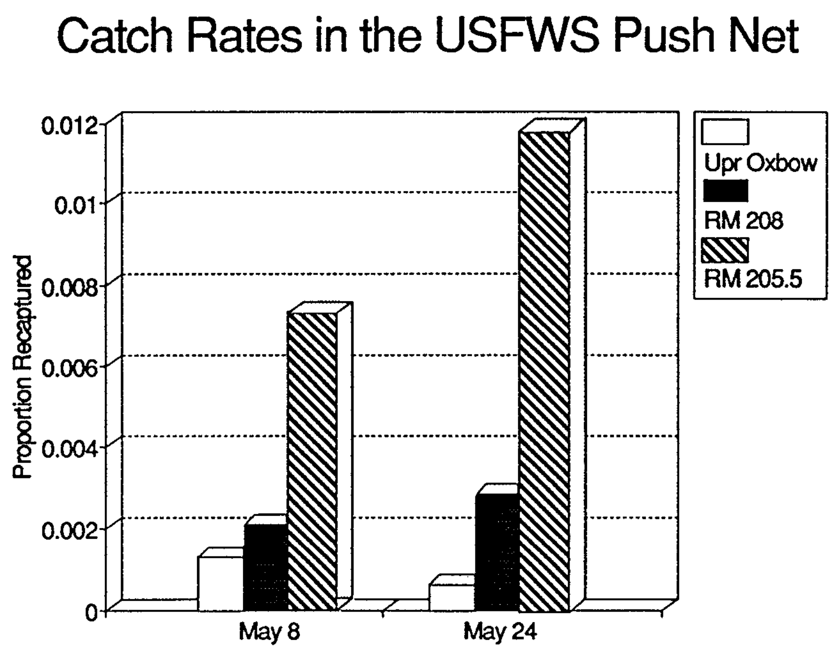

Figure 7 **Catch rates in the USFWS push net of branded chinook released at three locations on May 8 and May 24. Data from Table 9.**

Comparison of marked to unmarked ratios among fish captured in the USFWS push net to those among fish captured in the GCID trap indicated fish released at RM 208 were evenly distributed in the channel by the time they reached the oxbow. Among fish captured by these two methods, the ratio of marked fish from RM 208 to total unmarked fish (RECAPS(RM 208)/UNMARKED) was nearly identical. Following the May 8 release, this ratio was 0.0730 for fish captured in the GCID trap and 0.0735 for fish captured in the USFWS push net. Following the May 24 release, this ratio was 0.0286 for fish captured in the GCID trap and 0.0289 for fish captured in the USFWS push net. Therefore, if uneven dispersal of fish affected results of the USFWS push net, it must have been the groups released at RM 205.5 and in the lower oxbow that were unevenly dispersed. This is surprising because these fish were dispersed across the channel as they were released. Perhaps their vertical distribution in the water column or their avoidance response (or lack of one) to the push net were still atypical at the time they passed the point of sampling.

It appears from recapture data that marked fish passed the push net site in clumped groups. For example, on May 24, seven fish with a dot brand on the right-side front-half were recaptured between 9 and 10 pm, and only one more was recaptured for the rest of the night (Table 5). These fish had been released at RM 205.5 at 9:35

pm. Similarly, seven fish with a dot brand on the right-side back-half were recaptured between 10 and 11 pm, and only two were recaptured the hour before and one the hour after. These fish were also released at RM 205.5 at 9:35 pm. The next greatest number recovered from a single brand group was three from the brand "1" on the right-side back-half, which were released at RM 208 (Table 5). All three of these fish were recaptured between 10 and 11 pm after being released at 8:55 pm. These examples indicate branded fish tended to move quickly downstream together. This migration pattern is likely to result in large sampling errors when sampled by a 6 ft wide push net in a channel that is several hundred feet wide, if the net is fished too close to the release site. Therefore, we did not use the recapture rates by the USFWS push net to derive any conclusions. Future sampling could prove valuable if the net were fished further downstream and greater numbers of fish were released.

Task 1.2 **Determine the total loss of juvenile chinook salmon entering the GCID intake channel.**

Percentage Survival

The percentage survival of branded fish migrating from the upper oxbow to the lower oxbow, as estimated from recoveries at the GCID screw trap, ranged from 27.7% to 100% (Table 8). We also use the term "bypassed" to represent survival through the oxbow. Survival through the oxbow, or bypass efficiency, was estimated as follows:

$$\% \text{ SURVIVAL(U.O.,i)} = [\% \text{ RECOVER(U.O.,i)}/\% \text{ RECOVER(L.O.,i)}]*100$$

Confidence intervals for survival were calculated as described for % DIVERT. Because the CDFG trap did not catch fish released in the lower oxbow, recoveries of branded fish at the CDFG trap could not be used to estimate survival through the oxbow.

EFFECTS OF FLOW

The percentage of fish bypassed was negatively correlated ($r = -0.84$, $P = 0.08$) to pumping plant flow (Figure 8). The correlation to bypass flow was less ($r = 0.75$, $P > 0.1$), which indicates that pumped flows had a greater effect on fish bypass efficiency than did bypass flow. River temperature and fish length differed little between test releases, and so were ruled out as influencing factors. Pumped flow and bypass flow were highly correlated to each other, so the separate effects of bypass flow and pumped flow could not be evaluated. It may be possible to remedy this situation in 1991 by releasing marked groups at a variety of bypass flows while pumping flow is held constant. The tests showed that bypass efficiency decreased as the flow diverted to the pumps increased. Therefore, we used the regression of estimated survival on pumped flow to predict survival during weeks when survival was not estimated directly from brand recoveries. Regression data are given in Table 11.

TABLE 11. Statistics from the regression of survival through the oxbow on flow through the pumping plant. Survival values were transformed to the arcsine√(survival) before calculating the regression

Parameter	Estimate	Standard Error	T Value	Probability Level
Intercept	100.28	19.531	5.135	0.0143
Slope	-0.02579	0.0097	-2.657	0.0766

Analysis of Variance

Source	Sum of Squares	d.f.	Mean Square	F-Ratio	Prob. Level
Model	810.026	1	810.027	7.06	0.0766
Error	344.269	3	114.756		
Total	1154.29	4			

Correlation Coefficient = -0.838 R^2 = 0.702

Standard Error of Estimate = 10.712

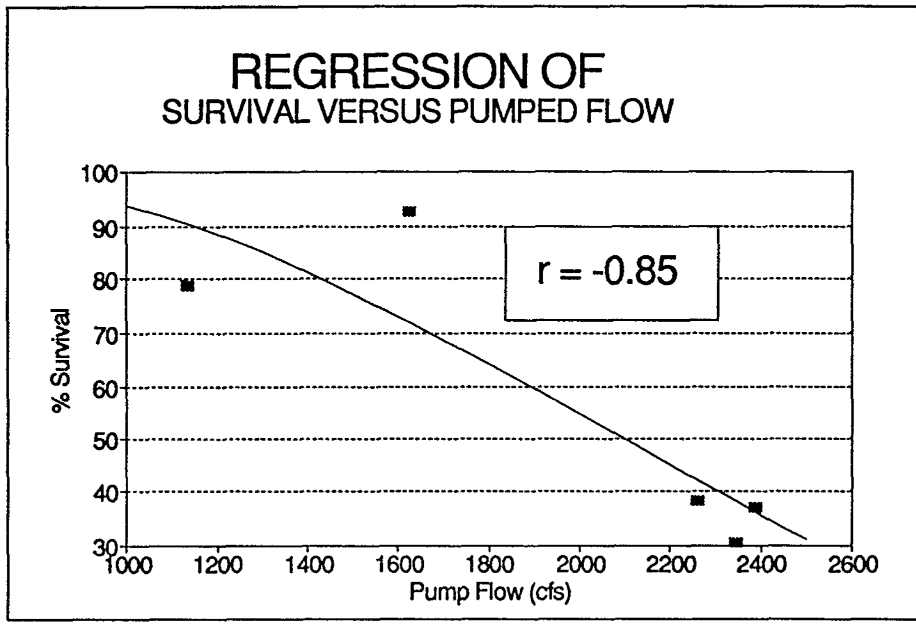

Figure 8 **Relationship of estimated survival rate of fall chinook migrating through the oxbow to the volume of flow pumped by GCID. Data from Table 8. Regression statistics are in Table 10.**

FISH SCREEN INSPECTION

The relationship to pumped flow suggests that most losses were related to flow through the screens; fish were either being impinged on the screens or were escaping through the screens to pass down the irrigation canal. Because we did not observe juveniles impinged on the rotary screen, we hypothesized there might be a gap somewhere in the screening structure where fish were escaping. Accordingly, a SCUBA diver (David Vogel, Red Bluff California) was retained to inspect the screens underwater and identify possible sources of loss. Vogel is a respected fish biologist who has conducted research on the design of fish screens. Vogel examined the entire battery of screens on June 17 when pumped flow was 2,365 cfs, near the maximum for the season. Vogel found only two small gaps through which fish could escape, but it is unlikely that large numbers of fish escaped through either gap. One gap was several inches high by 10-12 ft long at the bottom of the slide gate upstream from the first rotary screen. This gate is used to allow boats to pass from the afterbay to the forebay of the screens for maintenance purposes. Because this gap was located about 8-9 ft under water and was in a back eddy upstream of attraction flow through the screens, we believe it was not a substantial source of escape. The second gap was approximately 1-2 in. high by 8 ft long directly under the CDFG fish trap. The gap was created by a poor seal between the bottom of the trap and the floor beneath it. Because of the small size of the gap, it is probably not an important escape route for fish. More can be said about escapement through the screens after we operate a fish trap behind the screens during August through October.

Vogel did observe substantial debris accumulation and high velocity at the bottom of the rotary screens where they form a loose seal with the bottom of the abutment. Vogel believed the high through-screen velocity combined with the overhanging angle of the fish screen at its bottom would have washed any impinged fish off the screens so they would never be seen at the surface. This same scrubbing action by the current was causing accumulation of large quantities of debris at the bottom. Thus, many fish could have been impinged on the screens and washed back off without the fish rotating on the screen to the surface where they could be observed. Vogel further identified areas at the base of each screen that he hypothesized were "fish entrapment zones". These were areas where fish would have to swim directly against the current to reach a bypass port or to move further downstream. These are also the very areas where fish would naturally be guided by following the path of least resistance in the current in front of the screens. Vogel provides an excellent explanation and diagrams of this problem in his report attached as Appendix 2. Based on Vogel's report and the relationship of fish survival to volume of pumping, we believe the major source of fish loss is the entrapment zones identified by Vogel. Additional sampling with underwater video or by direct observation of a SCUBA diver should be undertaken when juvenile chinook are present to substantiate or reject this hypothesis.

EFFECTS OF FISH SIZE

If fish were being impinged on the screens, one would expect loss to be related to swimming performance and therefore to fish size. Smaller fish should be more vulnerable to loss than larger fish. Differences in mean length between marked fish released in the upper oxbow and those recovered in the traps were consistent with this hypothesis. Following the first three test releases, analysis of variance in mean lengths showed that branded fish recaptured in the CDFG trap were significantly smaller than the mean length of the fish at release, while fish recaptured in the GCID trap in the lower oxbow averaged significantly larger than the mean size at release (Table 12; Figure 9). Fish released in the lower oxbow and recaptured in the GCID trap showed no difference in mean length. These findings indicate smaller fish were more susceptible to capture by the CDFG trap near the middle of the screens and that larger fish were able to avoid the trap. In contrast, the increase in mean size of fish captured at the tail end of the oxbow (GCID trap) indicates smaller fish were selectively removed from the population during passage through the oxbow. Following the last two test releases, few fish were recaptured in the CDFG trap and the difference in mean length between fish at release and at recovery in the GCID trap were insignificant. Size selection apparently became less distinct as the fish became larger (see Tables 2-6).

Similar to the difference in size of branded fish captured at the two traps, unbranded fish captured at the GCID trap were also significantly larger than those captured in the CDFG trap. Throughout May, mean lengths of fish captured in the CDFG trap averaged about 1 cm smaller than fish captured in the GCID trap (Figure 10). This

TABLE 12. Analysis of variance of difference in lengths of branded fish at release in the upper oxbow, at recapture at the CDFG trap, and at GCID trap following each test release.

MAY 1 RELEASE AT UPPER OXBOW

Source of variation	d.f.	Mean square	F-Ratio	Sig. level
Between locations	2	239.8	6.35	0.0025
Within locations	102	37.8		

MAY 8 RELEASE AT UPPER OXBOW

Source of variation	d.f.	Mean square	F-Ratio	Sig. level
Between locations	2	71.6	21.64	0.0000
Within locations	22	3.3		

MAY 16 RELEASE AT UPPER OXBOW

Source of variation	d.f.	Mean square	F-Ratio	Sig. level
Between locations	2	182.0	11.03	0.0003
Within locations	29	16.5		

MAY 24 RELEASE AT UPPER OXBOW

Source of variation	d.f.	Mean square	F-Ratio	Sig. level
Between locations	1	1.98	0.45	0.5163
Within locations	22	4.41		

JUNE 12 RELEASE AT UPPER OXBOW

Source of variation	d.f.	Mean square	F-Ratio	Sig. level
Between locations	1	0.00	0.00	1.00
Within locations	10	4.38		

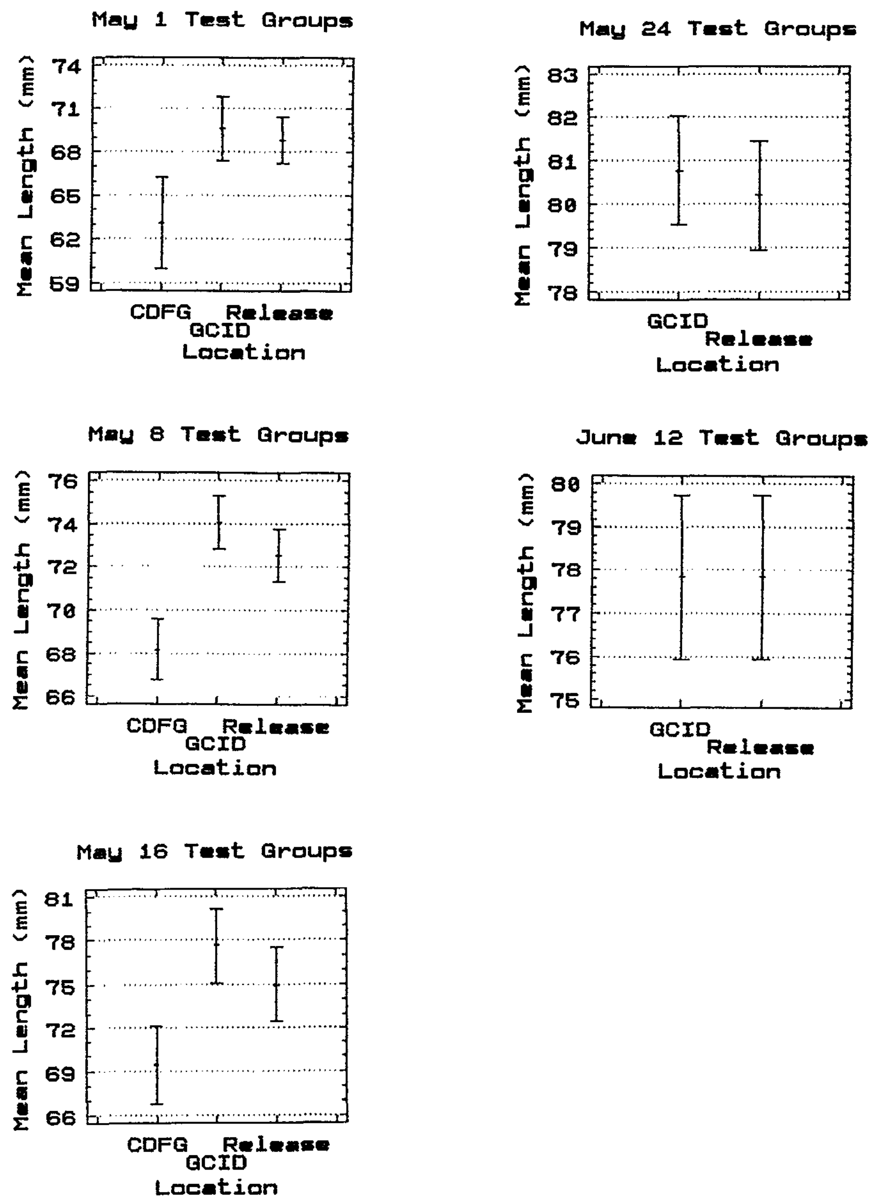

Figure 9 **Mean lengths and their 95% confidence intervals for branded chinook released in the upper oxbow and recaptured in the CDFG and GCID traps on each test date. Confidence intervals are based on analysis of variance results in Table 11.**

difference became less in June as the size range of fish available for capture decreased, and as the catch rates in the CDFG trap also dropped off to less than one tenth those in the GCID trap (see Figure 14 and Appendix 3). These findings, coupled with those from lengths of branded fish, indicate the efficiency of the CDFG trap decreases as fish size increases, and that survival of fish migrating through the oxbow increases as fish size increases.

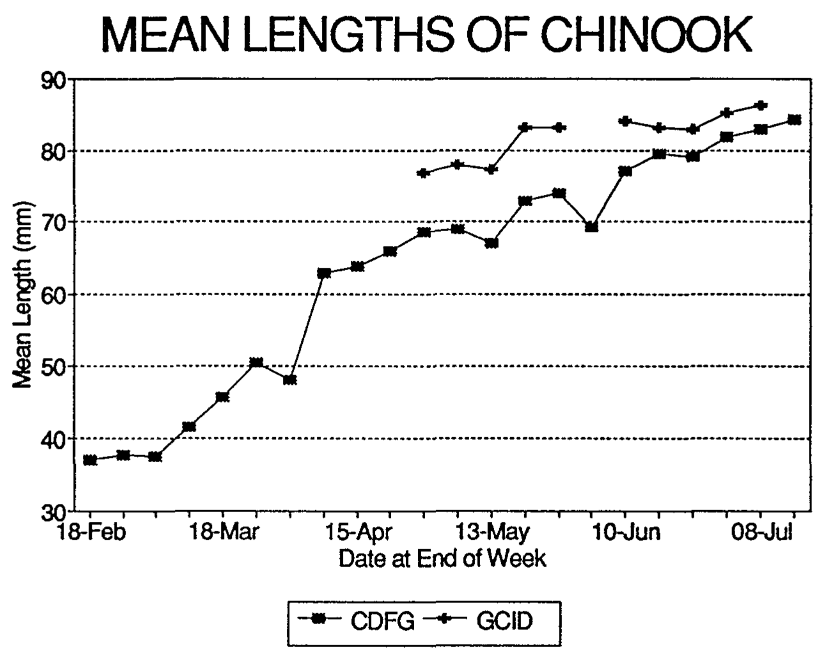

Figure 10 **Weekly mean lengths of unbranded chinook captured in the CDFG and GCID traps during February - July, 1990. Data from Appendix 3.**

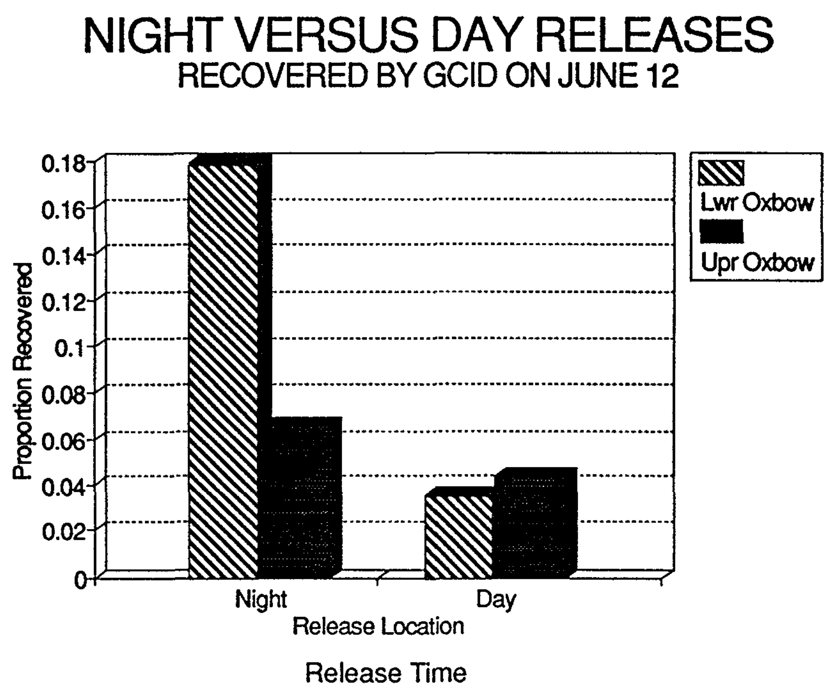

Figure 11 Comparison of recovery rates in the GCID trap of branded chinook released during the day to those released at night on June 12. Data from Table 8.

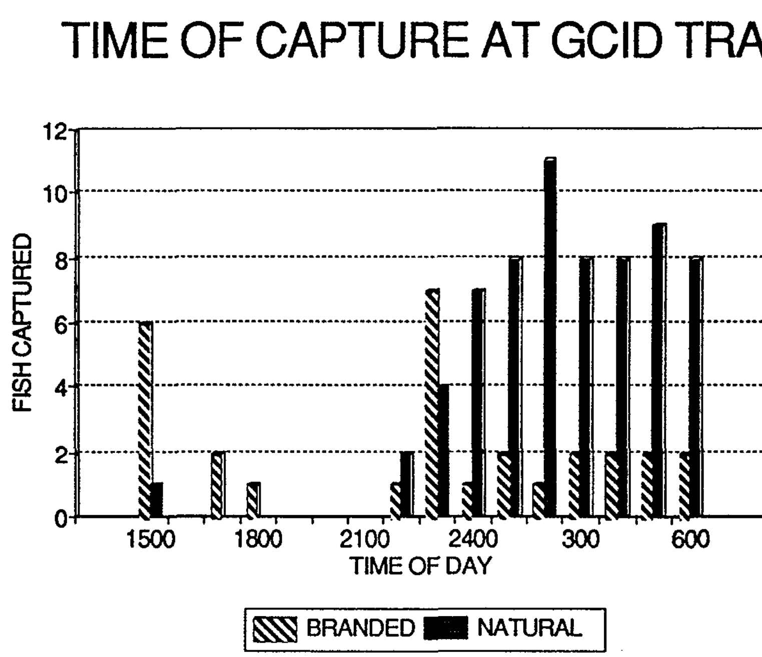

Figure 12 Hourly catch of unmarked fish in the GCID trap on June 11 and 12 compared to hourly catch of branded chinook released in the lower oxbow on June 11.

EFFECTS OF TIME-OF-DAY

Catches at the CDFG trap and at the GCID trap indicated fish were migrating at night. In order to mimic this natural behavior, we also released our test fish shortly after dark. However, on June 12 we released a set of branded groups in the late morning and another set shortly after dark, to determine if release time influenced our results. Recapture rates of fish released during the day were substantially less than during the night and the ratio of recovery rates between fish released in the upper and lower oxbow changed dramatically between day and night (Figure 11). The lower recovery rate of fish released during the day probably resulted from migration of some test fish during the day when they were able to see and avoid the trap. We captured 9 branded fish during the day and 20 at night from the test release, in contrast to unmarked fish of which all except one were captured at night (Figure 12). This movement of fish during the day probably resulted from test fish attempting to acclimate themselves to the new environment, recovering from the stress of handling at the time of release, and locating a suitable holding area.

The ratio of recovery rates for fish released during the day in the upper oxbow compared to the lower oxbow indicates there was no loss between the upper and lower oxbow. This may indicate that visual orientation during the day enabled the fish to stay away from the fish screens at night, or a high proportion of fish released during the day in the lower oxbow passed the trap during daylight when they were able to avoid the trap. Other scenarios are also possible. Data are insufficient to determine which hypothesis is true. We recommend that any test releases in the future be made at night, in keeping with normal migration behavior of the fish.

Fish abundance

ESTIMATES BASED ON GCID TRAP CATCHES

After estimating the rate of fish loss in the channel, we next estimated the number of fish using the oxbow channel so the total number of fish lost could be estimated. We estimated the abundance of fish exiting the oxbow based on the number of fish captured in the rotary screw trap. Marked fish released in the lower oxbow were released only 50-100 yards upstream of the trap, so the proportion recaptured provides a direct estimate of trap efficiency. That is:

$$\% \text{ EFFICIENCY}(i) = \% \text{ RECOVER}(L.O.,i)$$

where i represents the week test fish were released. Trap efficiency varied from 4% to 18.8% (Figure 13).

We estimated trap efficiency from recoveries of marked fish each week during May, so we applied these weekly estimates to the total number of unbranded fish captured during that week to estimate the number of fish exiting the oxbow (Table 3). That is;

FISH(bypass,i) = CATCH(i)/EFFICIENCY(i)

where bypass = fish exiting the oxbow

CATCH(i) = total unbranded fish captured in week i

During weeks when trap efficiency was not estimated, we used the estimate from the nearest week in which conditions were similar. A large freshet sharply increased flows from May 28 to June 1 and temporarily displaced many of the fish-guidance panels extending upstream from our trap, so we made no estimates for that week. It is likely, however, that large numbers of fish migrated during that week because freshets generally stimulate outmigration (Cramer et al 1985).

We also estimated the number of fish entering the oxbow by accounting for mortality during passage through the oxbow. To do this, we divided the estimated number exiting the oxbow each week by the estimated survival rate through the oxbow that week. That is:

FISH(enter,i) = FISH(bypass,i)/SURVIVAL(i)

Estimated numbers of fish entering the oxbow are listed in Table 13.

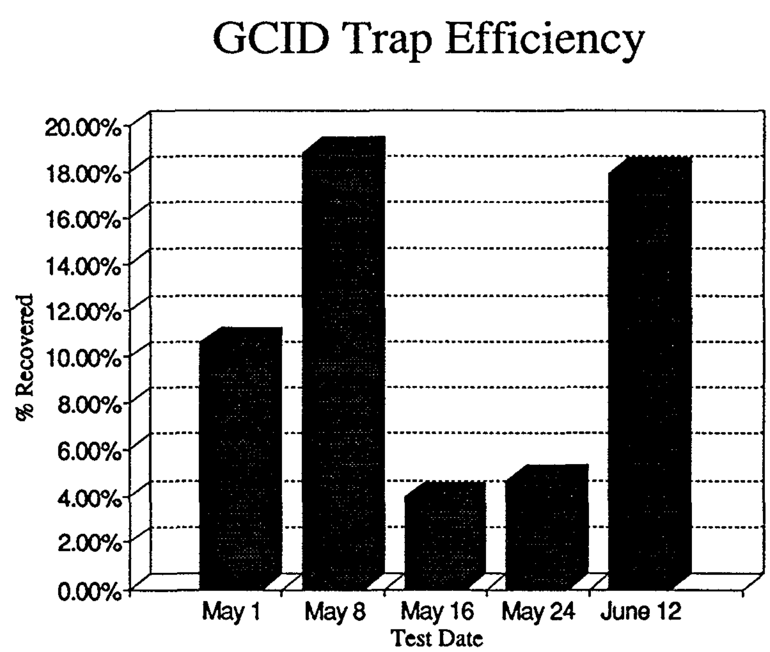

Figure 13 **Mean estimates of GCID trap efficiency (% of lower oxbow releases recaptured) for branded chinook from each of the five test dates. Data from Table 8.**

The number of juvenile chinook entering the oxbow in May of 1990 was probably much lower than recent years, because most chinook released from Coleman Hatchery in 1990 were trucked and released in the Sacramento River and estuary downstream from the GCID oxbow. In previous years, the vast majority of chinook from Coleman Hatchery were released upstream of the GCID oxbow. For example, the number of juvenile chinook released above the oxbow during May was 9.1 million in 1987, 11.1 million in 1988, 11.5 million in 1989, and only 105,000 in 1990.

ESTIMATES BASED ON CDFG TRAP CATCHES

It was also possible to estimate abundance of juvenile chinook migrating through the GCID oxbow based on capture data from the CDFG trap. Sampling by the CDFG trap began on February 14 when pumping by GCID began. Catches at the CDFG trap indicate the majority of the chinook probably migrated out before we began operating the GCID screw trap (Figure 14). We found the capture efficiency of the CDFG trap for branded fish released in the upper oxbow varied from 0.07% to 1.06% (Figure 15). This is substantial variation, so we would have to predict the

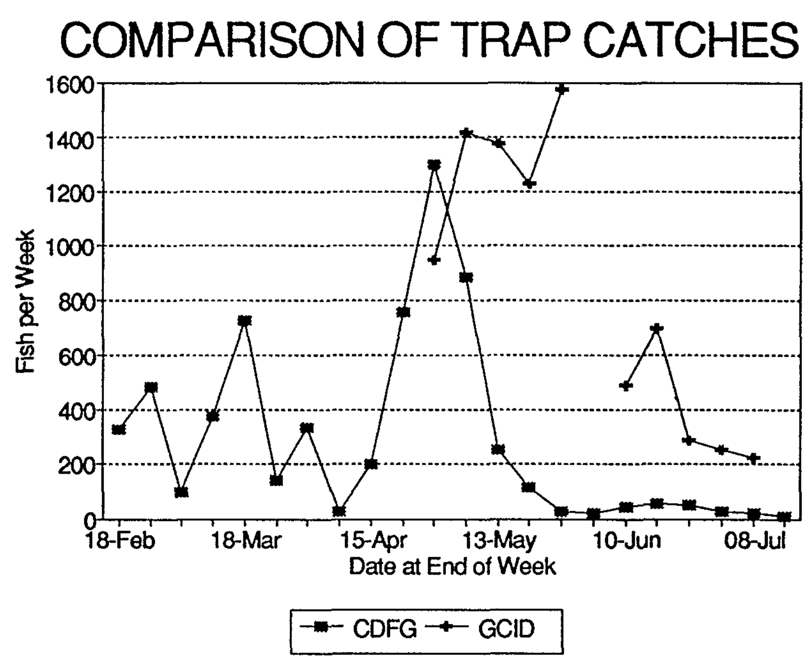

Figure 14 Weekly catches of unbranded chinook in the CDFG and GCID traps during February - July, 1990. Data from Appendix 3.

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TABLE 13. Trap catches, pumped flow, and estimates of total chinook entering and exiting the GCID oxbow during May and June, 1990. Survival estimated by regression on pumped flow (see Table 10).

Week Ending	GCID Weekly Catches	Pumped Flow	Mean	Lower 95% limit	Upper 95% limit	Total Fish to L. Oxbow	Estimated Survival	Total Fish in U. Oxbow	Total Fish Lost
29-Apr	945	2177	---	---	---	---	---	---	---
06-May	1420	2448	0.115	0.100	0.131	12305	0.364	33784	21479
13-May	1376	2092	0.188	0.159	0.221	7323	0.523	14008	6684
20-May	1227	1605	0.040	0.025	0.059	30907	0.733	42179	11273
27-May	1574	1231	0.047	0.033	0.063	33632	0.866	38840	5208
03-Jun	---	1322	---	---	---	---	---	---	---
10-Jun	490	1911	0.047	0.033	0.063	10470	0.604	17348	6877
17-Jun	702	2368	0.179	0.155	0.204	3915	0.399	9807	5892
24-Jun	285	2307	0.179	0.155	0.204	1590	0.426	3729	2139
01-Jul	250	2340	0.179	0.155	0.204	1394	0.412	3388	1993
08-Jul	218	---	0.179	0.155	0.204	1216	---	---	---

Note: Some weekly values of catch are expanded to include 1-3 missing days of data based on the average catch during days sampled.

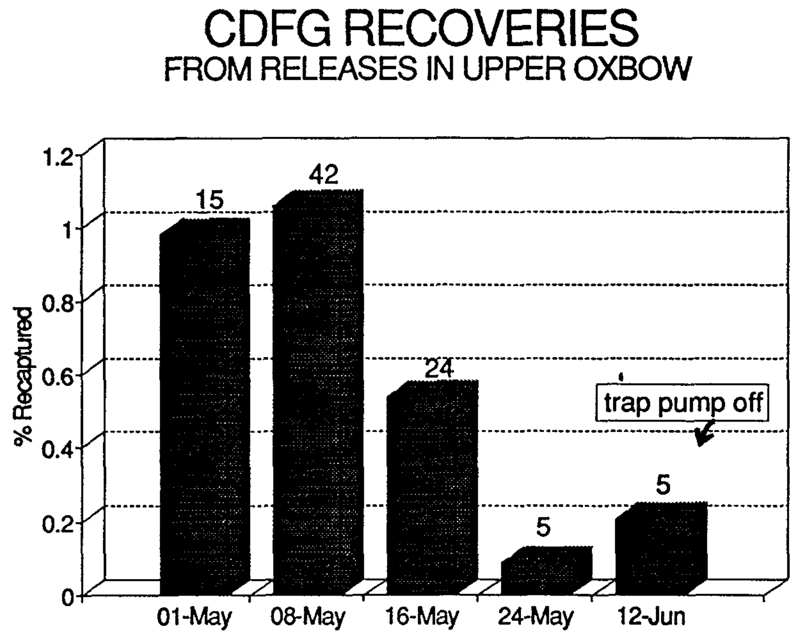

Figure 15 **Mean recapture rates in the CDFG trap of marked juvenile chinook released in the upper oxbow. Data from Table 9.**

efficiency of the CDFG trap in any given week in order to estimate total fish passage from its catches.

The pattern of catches in the CDFG trap appeared to somewhat reflect the volume of flow pumped by GCID (Figure 16).We found the proportion of branded fish recaptured by the CDFG trap on four release dates was highly correlated to pumping flow. Recapture rate on the fifth release date (June 12) was disregarded because the CDFG trap pump was inadvertently left off the night of the release, which artificially reduced trap efficiency. A multiplicative regression provided an excellent fit to the data (R^2=0.937, P=0.032)(Figure 17). The regression equation was:

$$\% \text{ RECOVER} = (1.087 \times 10^{-11}) \cdot \text{PUMPING}^{3.28}$$

where PUMPING = cfs pumped the day fish were recaptured

A multiplicative relationship between recovery rate and pumping flow is logical because it predicts no fish will be captured when pumping flow is zero and that recovery rate will increase ever more rapidly as pumping flows increase at least up to 2300 cfs. Although the regression fits the data well, it should be accepted with caution, because it is based on only four data points. It also does not account for the affects of fish size, although the trap was demonstrated to be size selective.

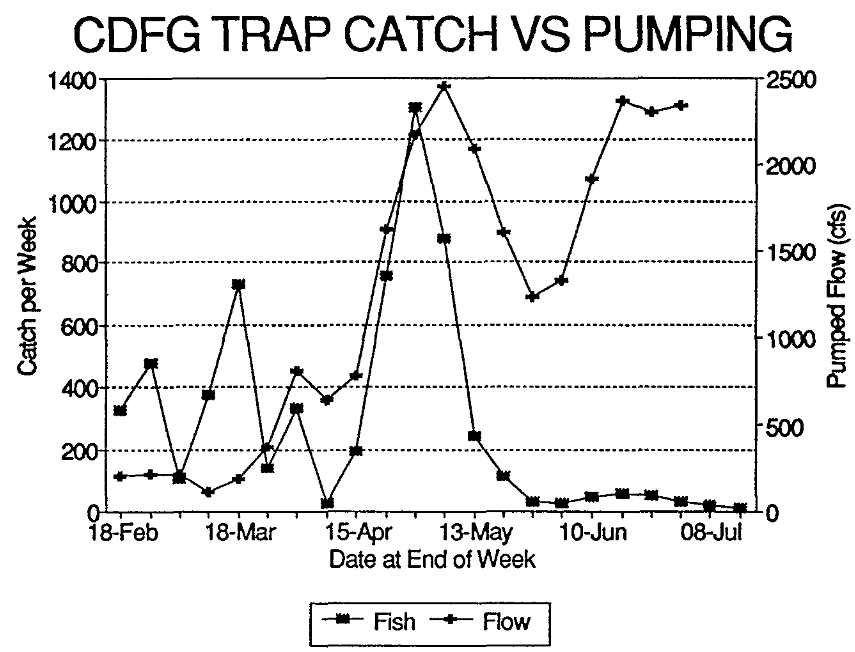

Figure 16 Comparison of the weekly catches of unbranded chinook in the CDFG trap to the volume of flow pumped by GCID during February - July, 1990. Data from Appendix 3.

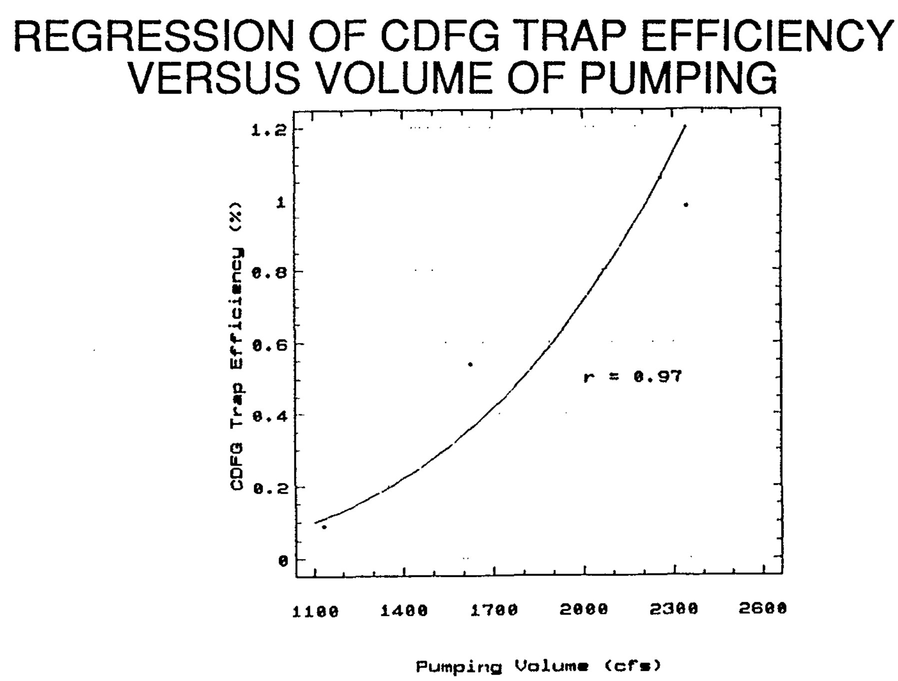

Figure 17 Regression of the mean percentage of branded chinook recaptured in the CDFG trap after release in the upper oxbow versus the volume of flow pumped by GCID. Data from Tables 8 & 9.

Use of the above regression to predict efficiency of the CDFG trap resulted in population estimates, based on captures of unmarked fish, that were similar during May and June to those based on catches in the GCID trap (Table 14). Estimated weekly abundance varied substantially between the two methods, but the sum of weekly estimates during May and June was nearly identical between the two methods (Table 14). We did not use the CDFG catches to predict chinook abundance prior to May because mean lengths of chinook captured in March and April were 1-2 cm smaller than the marked fish for which we estimated recovery rate (see Figure 10). CDFG trap efficiency was likely much higher for those smaller fish than predicted by our regression.

TABLE 14. Estimated total juvenile chinook entering the GCID oxbow during May-June, 1990 based on catches in the CDFG trap compared to those based on catches in the GCID trap.

Week Ending	CDFG Weekly Catch	Pumped Flow	Estimated CDFG Effic(%)	Estimated Chinook Entering Oxbow	
				CDFG	GCID
06-May	881	---	1.378	63934	33784
13-May	247	2092	0.823	29999	14008
20-May	111	1605	0.346	32127	42179
27-May	29	1231	0.145	20022	38840
03-Jun	21	1322	0.183	---	---
10-Jun	43	1911	0.612	7025	17348
17-Jun	55	2368	1.236	4450	9807
24-Jun	47	2307	1.0135	4143	3729
01-Jul	29	2340	1.189	2440	3388
08-Jul	17	---	---	---	---
		May & June Total		164141	163083

Data gathered in this study make it possible to evaluate the assumptions used by Ward (1989) to estimate the total chinook exposed to the GCID fish screens. Ward used the recovery rate at the CDFG trap of marked chinook smolts released from Coleman Hatchery as an estimator of the CDFG trap efficiency. These marked smolts were released on May 3-4 in 1987, May 9-13 in 1988, and May 8-10 in 1989. Marked smolts were usually recaptured at the CDFG trap within 1 wk of release from Coleman Hatchery. Thus, even if this method accurately estimates the capture efficiency of the

CDFG trap, that estimate is good for 1 wk and cannot be accurately projected to the rest of the season, as shown in Figure 15.

In each year, the marked fish from Coleman Hatchery were released in equal numbers at two locations: Battle Creek and below Red Bluff Diversion Dam. On May 11, 1990 Coleman Hatchery released 51,069 adipose-clipped chinook in Battle Creek (RM 270), and on May 12 another 51,533 adipose-clipped chinook below Red Bluff Diversion Dam (RBDD). Between May 13 and May 20, we recovered 225 of these fish (219 on May 13 & 14). The adipose clip indicates the fish also have a coded-wire tag (CWT) implanted in their snout that identifies the location of release. We sacrificed 69 of the adipose-clipped fish and delivered them to CDFG for decoding of the CWT's. Of the 66 that had readable codes, 45 fish or 68.2% were from the group released below Red Bluff. The difference in recapture rates of the two groups indicates survival between Battle Creek and Red Bluff was 21/45 = 47%. Thus, it would be incorrect to assume the full number of fish released at Coleman Hatchery reach RM 206, the mouth of the GCID oxbow.

We can also compare recovery rates of marked smolts released from Coleman Hatchery in 1990 with recovery rates of branded fish released at the head of the oxbow and at RM 208 on May 16. Recovery rates in the GCID screw trap were higher for adipose clipped fish on May 13 & 14 (0.22%) than for branded fish released at RM 208 on May 16 (0.16%; Table 15). However, recovery rates of branded fish released at RM 208 on May 16 were unusually low and probably subject to sampling error. Recovery rates of fish released at RM 208 on the three other test dates ranged from 0.37% to 0.78%, all higher than the average rate of 0.22% for adipose-clipped fish on May 13-20 (Table 15). If we assume 68% of the 225 adipose-clipped fish recaptured at the GCID trap were released at RBDD then the recovery rate of fish released at RBDD was 0.30%, still lower than three of our estimated recovery rates of fish released at RM 208.

TABLE 15. Recovery efficiencies of adipose clipped chinook from Coleman Hatchery and from branded chinook released at RM 208. Adipose-clipped chinook were recaptured on May 13 and 14.

	GCID Trap			CDFG Trap	
Test Date	RM 208 Efficiency	Adipose Efficiency	RBDD Adipose Efficiency (a)	RM 208 Efficiency	Adipose Efficiency
08-May-90	0.78%			0.21%	
16-May-90	0.16%	0.22%	0.30%	0.06%	0.004%
24-May-90	0.53%			0.06%	
12-Jun-90	0.37%			0.03%	

(a) Includes only marked fish released at RBDD.

The recovery rate of adipose-clipped fish at the CDFG trap was less than one tenth that at the CDFG trap of branded fish released at RM 208. The recovery rates of adipose-clipped fish at the CDFG trap in 1987, 1988, and 1989 (see Table 10) were also less than the lowest recovery rate of fish released at RM 208 in 1990 (Table 15). This indicates that estimates by Ward (1989) of fish passing the mouth of the GCID oxbow are highly inflated. For data collected in 1990, the method used by Ward would have inflated abundance estimates by about 10 fold. The degree of error in other years cannot be estimated from available data. The low recovery rate of adipose clipped fish by the CDFG trap probably resulted from the size selectivity of the trap, as discussed previously. Most adipose-clipped fish were large enough to avoid the trap.

Objective 2.0 ***Identify the Relative Importance of Various Sources of Juvenile Salmon Loss in the GCID Intake Channel and Evaluate Possible Corrective Measures.***

Task 2.1 **Determine the total number of juvenile salmonids eaten by squawfish in the GCID intake channel and estimate the effectiveness of seining for removing squawfish.**

SQUAWFISH ABUNDANCE

We tagged and recaptured fewer squawfish than we anticipated. We captured 71 squawfish seining directly in front of the fish screens between April 28 and July 26. We tagged and released all 71. We caught 70 squawfish angling during the same period. Of these, we tagged and released 58. We recaptured 12 fish (9.3% of the total tagged), all by angling (Table 16). Of the recaptured fish, 9 (12.7% of seined fish) had originally been caught by seine, and 3 (5.2% of angled fish) were originally caught by angling. Two fish were recaptured twice. The only location sampled was in front of the fish screens. All fish recaptured retained their tags and the opercle punch was clearly distinguishable. Identification of recaptures was assumed to be 100%. Mortality of handled fish could not be assessed, but we assume it was negligible because we identified only one dead tagged fish on the fish screens during the season.

Our catch of squawfish per seine haul was not indicative of fish abundance through time. Seining was frequently hampered by the net becoming snagged on submerged pilings left from construction of the fish screen. Because of this snagging, the area we were able to sample was highly restricted. By August, we were able to obtain divers and equipment to remove the pilings so seining could proceed without obstruction; however, data reported here only extend through July. The number of squawfish seined declined to near zero by the end of June. We captured 71% of our seined fish in two seine hauls, one on June 7 and one on June 8 (Table 17). We suspect catches decreased because fish became "seine smart", or because fish migrated out of the area. The data indicate squawfish may have learned to avoid the seine, because seining was the least successful June 27 to July 11, while angling was the most successful then (1.71 fish/hour)(Table 16). We also know from counts in the fish ladder at Red Bluff Dam that squawfish are migratory, because large numbers of squawfish are counted passing upstream each year during April and May (Garcia 1989).

TABLE 16. Sampling effort and numbers of squawfish tagged and recaptured infront of the screens.

	Sampling Effort		Number Tagged		Number Recaptured	
Date	Seine Sets	Hours Angling	Seine	Angling	Seine	Angling
4/28-5/12	0	5.00	---	3	---	0
5/13-5/27	0	9.00	---	10	---	0
5/28-6/11	4	9.00	52	3	0	0
6/12-6/26	10	18.00	13	13	0	2
6/27-7/11	4	19.25	6	25	0	8
7/12-7/26	0	10.00	0	4	0	2
Total	18	70.25	71	58	0	12

The area sampled by angling and seining differed slightly. Seining captured fish in the middle of the channel or along the shore opposite the screens. We were never able to seine closer than about 25 ft to the trashracks. However, it was near these trashracks where angling was the most successful. Although we angled in the middle of the channel, as well as near the opposite shore, we caught few fish there. Higher angling success near the trashracks supports our theory that this is a preferred area by squawfish to prey on juvenile chinook.

Because of the various sampling biases in our data, we had to restrict the mark-recapture data that we used to estimate abundance of squawfish. An important assumption of mark- recapture estimates is that marked and unmarked fish are equally vulnerable to capture. In order to meet this assumption, we first divided our sampling into six 15 day periods so, analytically, we could treat one 15 day period as the time for tagging and the following 15 day period as the time for recovery. This allowed tagged fish a recovery period to resume normal behavior and mix with the population. Secondly, we restricted the number of fish tagged to those captured by seining, and the number of fish examined for tags to those captured by angling. Because we were concerned that fish were becoming "seine smart" and avoiding the net, we could not use seining as an unbiased method of recovering fish that had been tagged after capture by seining. In fact, we never recaptured a fish by seining that had also been

TABLE 17. Daily seining effort and catch of squawfish through July 6, 1990.

Date	Start Time	Fish Tagged	Mean Length (mm)	Length Range	Number W/fish Parts	Number W/Salmon Parts
6/7	1610	1	51.0	0	0	0
6/7	1930	36	46.3	34-56.5	2	0
6/8	2000	1	50.0	0	0	0
6/8	2100	14	42.8	30.5-54	2	0
6/14	1100	2	58.3	51-65.5	2	0
6/14	1310	3	56.0	55-57	0	0
6/18	1730	0	-	-	-	-
6/18	1800	0	-	-	-	-
6/18	1830	1	39.0	0	1	0
6/18	1900	1	49.5	0	0	0
6/20	0800	4	49.3	45-54	1	0
6/20	0915	0	-	-	-	-
6/22	0700	1	20.0	0	0	0
6/28	1830	1	42.0	0	0	0
6/28	1930	0	-	-	-	-
6/28	2000	3	42.3	39.5-46	1	0
7/2	2030	3	42.3	39.5-45	1	0
7/6	2000	0	-	-	-	-

tagged by seining. We were also concerned that fish captured by angling would be less vulnerable to recapture by angling, as has been demonstrated among northern squawfish on the Columbia River (Uremovitch et al. 1980). Our limited recapture data show the recapture rate by angling was twice as high for fish that had been tagged by seining (12.7%) as it was for fish that had been tagged by angling (5.2%).

We used the simple Petersen method to estimate squawfish abundance as follows:

$$N(i) = M(i-1) \cdot C(i)/R(i)$$

where N = Number of fish in the population

M = Marked fish available

C = Catch of fish examined for marks

R = Recaptures in the catch from the M marked fish

i = designation for sampling period

For example, during June 12 to June 26 (Period 4) we captured 15 fish by angling, two of which were tagged from previous sampling periods when 52 had been tagged after capture by seining (Table 18). Thus, we have

$$N(4) = 52 \cdot 15/2 = 390$$

Since the number of recaptures is small, the variance of R can be estimated from the Poisson Distribution. Therefore, we calculated 95% confidence intervals by determining the 95% confidence interval for R and then substituting these values into the equation for N. The 95% limits for R = 2 are 0.2 and 7.2 and for R = 7 (June 27 to July 11) are 2.8 and 14.4 (Ricker 1975). Substituting these values into the equation for N, we find

Recaptures	Lower 95% limit	Estimate	Upper 95% limit
2	108	390	39,000
7	148	306	766

Obviously, our confidence in the population estimate is low when the number of recaptures is only two, but our confidence interval was much narrower during June 27-July 11 when we recaptured 7 fish. We were unable to estimate population size for any other time period because either we had no marked fish out or we did not recapture any marked fish. The two estimates we made should be regarded as maximal, because we made no adjustment for mortality or migration of marked fish, both of which

TABLE 18. Population estimates of squawfish in the vicinity of the GCID fish screens based on fish tagged during seining and recaptured during angling.

Period	Date	Number Tagged Seining	Total Tagged Available	Number Recaptured Angling	Total Angling Catch	Population Estimate
1	4/28-5/12	-	-	-	3	-
2	5/13-5/27	-	-	-	10	-
3	5/28-6/11	52	0	0	3	-
4	6/12-6/26	13	52	2	15	390
5	6/27-7/11	6	65	7	33	306
6	7/12-7/26	0	71	0	6	-
TOTAL		71	71	9	70	

probably occurred and would inflate our estimates. The abundance we estimated corresponds to the population in which tagged fish are freely intermixing. We assume this population remains in the immediate vicinity of the screens, but have not tested this assumption.

Our angling success was highest during June 27 to July 11 when the population was estimated to be 306 fish. We have yet to establish whether angling success is related to the number of squawfish present. Interestingly, angling peaked at a time when there were few juvenile salmon in the system (see Figure 14). Angling success and squawfish abundance might have been higher in the spring, but our sampling was not fully underway until the first week of June.

Recoveries of squawfish tagged by the USFWS during electrofishing in the GCID oxbow on four dates in 1988 demonstrate that at least some squawfish in the GCID oxbow are migrating elsewhere. USFWS used their electrofishing boat from Red Bluff to capture and tag 8 squawfish on March 9, 29 squawfish on April 28, 33 squawfish on June 16, and 9 squawfish on August 18 of 1988 (personal communication with Dave Vogel, formerly with USFWS, Red Bluff California). USFWS never recaptured tagged fish on sequential electrofishing trips, but anglers returned three of the tags: one tagged on March 9 was captured upstream at RM 235, one tagged on April 28 was captured upstream at RM 220, and one tagged on June 16 was captured about 3 miles downstream of the GCID oxbow. Migration of tagged fish out of the oxbow, if others are migrating in, would inflate our population estimates by decreasing the ratio of marked-to-unmarked fish in the population. The extent of such a bias cannot be estimated with existing data.

We examined length composition of the squawfish captured, because consumption rate by squawfish logically is related to size. The length composition of squawfish captured seining shows a wide range in length representing several age groups (Figure 18). Because of the wide range in lengths, it would be desirable to estimate population size and consumption rate by length intervals; however, the number of fish we were able to mark and recapture was insufficient for such detail.

CONSUMPTION RATE

Food items were found in 12% of the squawfish examined. All food items examined were fish parts either identifiable, or unidentifiable. Angling yielded 1 fish (1.4%) with unidentifiable fish parts and 6 fish (8.6%) with recognizable salmon in foreguts. Seining yielded 10 fish (14%) with unidentifiable fish parts and 0 recognizable salmon. These percentages of squawfish containing fish in their foreguts are far below the 58% to 61% of squawfish with chinook in their foreguts found at Red Bluff Diversion Dam in late May following releases of chinook from Coleman Hatchery (personal communication with Bruce Vondracek, University of California, Davis). Vondracek found an average of 5.9 juvenile chinook in each of 63 squawfish that contained chinook in their foreguts. Vondracek estimated the average consumption

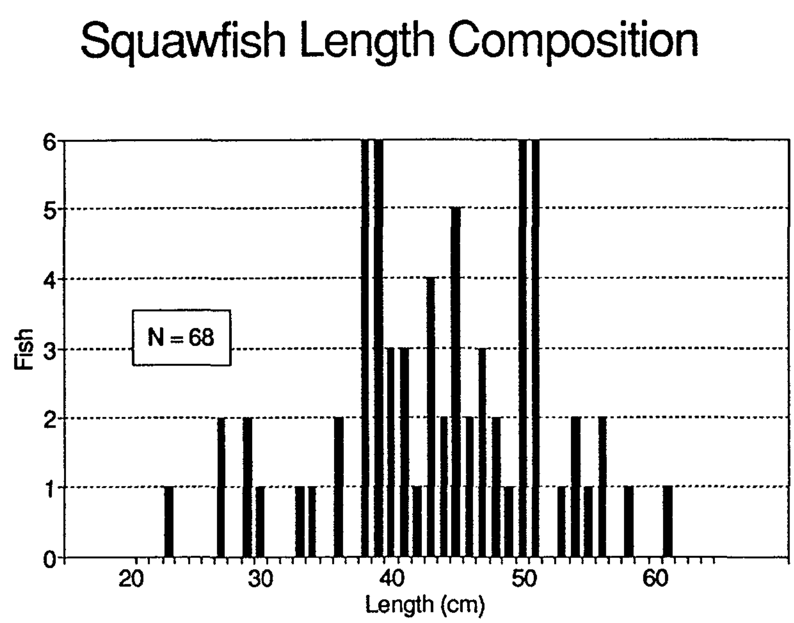

Figure 18 **Length composition of squawfish captured by seining infront of the fish screens during June 7 to July 6, 1990.**

rate of salmonids by squawfish to be 3.0 to 5.75 fish per day in May and 0.3 fish per day in September. The equation used by Vondracek was:

$$C = A(24/t)$$

where C = daily consumption rate (fish per day)

A = mean number of fish in digestive tract at capture

t = time (h) to 90% gastric evacuation

To complete this estimate from our study, we have

$A = 0.086$ chinook/squawfish caught angling

$t = 15$ h at 60°F based on Vondracek (1987)

so $C = 0.086(15/24) = 0.054$ chinook/day

Clearly, consumption rate of juvenile chinook by squawfish at the GCID fish screens is dramatically lower than by squawfish under the conditions studied at Red Bluff Diversion Dam.

We reviewed two factors that might have caused us to underestimate consumption rates of salmon by squawfish, but found no cause to disregard our estimates. The two factors were time of sampling and regurgitation. Vondracek (personal communication) found that squawfish below Red Bluff Dam consumed juvenile salmon primarily from dusk to dawn. If we had sampled squawfish primarily during mid day we would certainly have found most fish with empty stomachs. Our actual sampling effort and our catch was concentrated at dawn and dusk (Figure 19). These should have been peak times of consumption according to the findings of Vondracek (personal communication). In the future, we will focus more sampling effort between 10pm and midnight to ensure that fish have had ample time for evening feeding.

Regurgitation by squawfish may have reduced the number of fish we observed in their foreguts. On two occasions, we witnessed regurgitation of recognizable salmon after landing squawfish by angling. Although some squawfish captured by angling may have regurgitated before we saw them, studies by Uremovich et al. (1980) on the Columbia River found high rates of salmon in the foreguts of squawfish captured by angling. Thus, regurgitation alone would not account for the low rate we observed of salmon in squawfish stomachs. We suspect that seined fish also regurgitate fish. It took from 15 to 90 minutes to complete a seine haul and process the fish captured, so squawfish had much time to regurgitate without us observing it. This may partially account for the lack of recognizable fish remains in their fore-guts.

Also, seining may have selected for non-feeding fish. Of the fish seined, 14% had unrecognizable fish parts in their fore-gut compared to only 1.4% among angled fish. Assuming we could identify a salmon near 50% digested, this would mean these fish had ingested the non identifiable fish at least 7 hours previously (Vondracek, 1987).

Perhaps the most important reason for the low rate of predation we observed is the lack of highly turbulent hydraulics infront of the screens. Vigg et al. (1988) found the consumption rate of salmonids by squawfish was 70% grater in the turbulent tailrace of John Day Dam than in the forebay. Vigg et al. estimated the average daily consumption rate of salmonids by squawfish in the John Day reservoir to be 0.053 fish per day, similar to our estimate of 0.054 at the GCID fish screens. Vogel et al. 1988 used SCUBA gear to observe squawfish preying on juvenile chinook in the Red Bluff Dam tailrace and found that predation was concentrated in the highly turbulent zones where juvenile chinook were temporarily disoriented. These findings in other studies lead us to conclude that our estimates are reasonable.

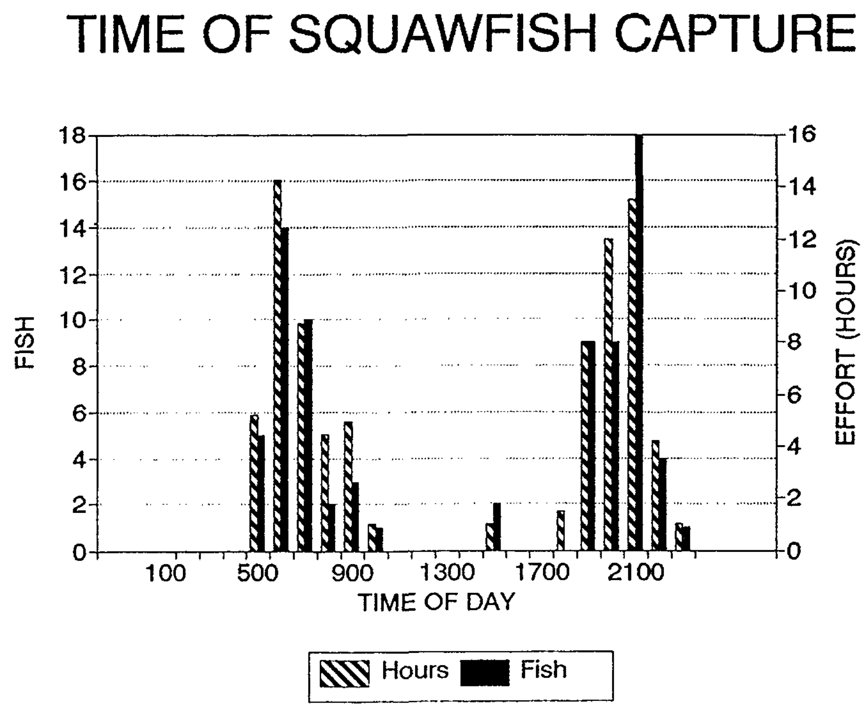

Figure 19 **Total squawfish captured each hour of the day by angling during April 28 through July 26, 1990.**

TOTAL PREDATION

Only during the two 15 day periods for which we estimated population size was it possible to roughly estimate total predation. Total predation in the vicinity of the GCID screens was estimated as:

$$\text{PREDATION(i)} = \text{N(i)} \cdot \text{C} \cdot 15$$

where PREDATION = total chinook eaten by squawfish

N = Number of squawfish in the population

C = Consumption rate (fish/day) by squawfish

i = specific 2 week period

15 = number of days in period i

Thus,

$$\text{PREDATION(6/12-6/26)} = 390 \cdot 0.054 \cdot 15 = 316 \text{ chinook}$$

$$\text{PREDATION(6/27-7/11)} = 306 \cdot 0.054 \cdot 15 = 248 \text{ chinook}$$

These losses are small when compared to the estimated total loss through the oxbow of about 9,000 juvenile chinook during June 10 to June 24 (see Table 13). This is consistent with findings from our test releases of branded chinook, because the high correlation of survival rate through the oxbow to pumped flow indicates that loss is directly associated with the fish screens. Predation estimates should be regarded as highly speculative because of the many potential sources of sampling bias, combined with the sampling error of our small sample sizes.

The preliminary conclusion derived from our predation studies so far (they will continue through October) is that loss rate of juvenile chinook to predation in the vicinity of the GCID screens during June and July was low. Predation rate was probably greater during April and May when juvenile chinook were more abundant and may become higher when winter chinook fry are present during August - October. Squawfish are opportunistic predators and will consume more chinook when they are available (Vigg et al 1988). Further sampling should be conducted in the spring of 1991 to estimate total predation at the time we expect it to be greatest.

Task 2.2 Determine the total number of salmonids impinged on the fish screens.

This Task was intended for winter chinook fry which begin appearing in August. No sampling designed for this Task was conducted during April- July. Qualitative information regarding fall chinook impingement was obtained during an underwater inspection of the screens by fish biologist and SCUBA diver David Vogel. Vogel's report is contained in Appendix 2. Our finding that losses of juvenile fall chinook migrating through the oxbow are as high as 70% and that these losses are related to pumping flow underscore the importance of completing Task 2.2 for fall chinook during their outmigration in 1991.

Task 2.3 Determine the total number of salmonids entrained through the fish screens.

This Task was intended for winter chinook fry which begin appearing in August. As with Task 2.2, only qualitative information on fall chinook entrainment was obtained from the underwater inspection by SCUBA diver. Again, this Task should be completed for fall chinook during their outmigration in 1991.

Summary and Conclusions

1. The estimated proportion of juvenile chinook diverted from the Sacramento River into the GCID oxbow channel during May and June varied from 4.5% to 14.3% and was less than and unrelated to the proportion of flow diverted. Additional tests under a variety of flows, fish sizes, and current patterns at the oxbow inlet will be necessary to understand the dynamics governing the proportion of juvenile chinook diverted into the GCID oxbow.

2. Estimated losses of juvenile chinook migrating through the GCID oxbow ranged from 0% to 72.3% and were related to the volume of flow pumped by GCID. The effects of bypass flow on survival of chinook could not be determined. The most likely cause of the losses was impingement on the lower portion of each fish screen. Our results indicate losses should decrease to less than 10% when mean fish size is greater than 70 mm and pumping is reduced below 1,200 cfs. The high survivals estimated when pumping plant flows were lowest indicates fish can survive well in their migration through the oxbow if the problems associated with high pumping flows can be resolved.

   The gradient restoration project being carried out by the USACE should reduce approach velocities to the fish screens for a given volume of pumped flow by raising the water level on the screens about 3 ft. This would also change the current patterns fish experience as they approach the screens, because most juvenile chinook migrate within a few feet of the surface. With the water level 3 ft higher, fish would generally encounter the screens above the midline of the drums and the path of least resistance to the current would guide fish toward the surface rather than toward the bottom. Thus, the relationship of survival to pumped flow should improve once the river gradient has been restored.

3. Over 62,000 juvenile chinook, representing 38% of the chinook migrating through the oxbow during June and July were estimated to have died or escaped through the screens. This loss rate was undoubtedly higher in mid April when pumping rate exceeded 1,000 cfs and most chinook were less than 70 mm

long. Although the loss rates estimated in this study are far below those implied by Ward (1989), the losses through the year are substantial and warrant immediate corrective action.

4. Losses of juvenile chinook to predation by squawfish near the fish screens was minimal during June and July. Losses may have been greater during March through May when chinook were smaller and more vulnerable to predation; however, this is unlikely because there are no areas of high turbulence in front of the fish screens. Studies below Red Bluff Dam and in the Columbia River have demonstrated that predation by squawfish is most successful in the turbulent tailraces below dams where juvenile chinook become temporarily disoriented.

5. Seine netting in front of the fish screens may provide an effective means of removing squawfish and reducing losses to predation, but was not adequately evaluated. Even with a highly restricted seining area, we captured 15% of the estimated population in our first two snag-free seine hauls of the year. The snags remained in place and impaired our seining through July, but they have since been removed so seining access is unrestricted along the entire frontage of the screens. However, unless predation rates are dramatically higher in March-April than during May-June, efforts to remove squawfish are unwarranted.

Recommendations

1. GCID and CDFG should develop interim structural measures to prevent fish from being entrapped and impinged under the deepest portion of the rotary drum screens. In conjunction with these interim measures the River Gradient Restoration Project should be expedited to restore water levels at the screens to the elevation for which the screens were designed. This increase in water level should substantially decrease fish losses at the screens while the final fish protection facilities are being prepared.

2. Mark-recapture studies of juvenile chinook survival through the GCID oxbow should continue in 1991 with emphasis on chinook under 70 mm migrating in March and April. Marked fish should be released at a variety of sizes, pumping flows and bypass flows to increase our understanding of how these factors interact to affect chinook survival. It would be desirable to estimate survival through the oxbow channel when no water is being pumped. Estimated survival with no pumping could then be used as a baseline for determining the pumping levels at which measurable loss begins to occur.

   The proportion of fry that are diverted into the oxbow channel at various flows and fish sizes should be estimated. Behavior of fry differs from that of the 60 mm to 80 mm juveniles we worked with in May-July 1990, so the relationships of the proportions diverted and of survival to flow are likely to differ. These differences should be documented and understood to provide a baseline against which to measure the success of remedial actions.

3. The abundance of squawfish and their consumption rate of salmonids during March through May should be determined in 1991. Abundance of squawfish is likely to differ from June and July, because squawfish migrate upstream to spawn during April and May. Their consumption rate of juvenile chinook is also likely to increase while chinook are smaller and more abundant. If total consumption of chinook by squawfish is no higher during March-May than we found during June-July, then efforts to eliminate squawfish would be needless.

4. Underwater video should be explored to evaluate the behavior of juvenile chinook as they approach the fish screens to determine if impingement truly is occurring. Because chinook migrate at night, this would require underwater lighting. Perhaps turning on a light momentarily at spaced intervals can give "snapshots" of fish behavior at the screens.

5. Different types of lighting at the screens should be evaluated as a possible aid to fish survival. Lights have been purposely left off in the past, because it was believed lights might be aiding predation on juvenile chinook. However, in this study, branded juveniles released during the day had a much higher survival rate than juveniles released at night. It may be that the ability of the fish to see the fish screens increases their ability to avoid them. The Oregon Department of Fish and Wildlife (ODFW) found that addition of flood lights to the bypass orifices at Savage Rapids Dam on the Rogue River greatly increased chinook usage of the bypass system (personal communication with Bill Haight, ODFW, Portland).

6. Survival of juvenile chinook through the oxbow should be reevaluated following restoration of the river gradient. If our deductions of fish behavior at the fish screens are correct, then gradient restoration will dramatically increase survival of juvenile chinook as they migrate through the oxbow.

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Appendix 1

Flow and temperature data for the Sacramento River in the vicinity of the Glenn-Colusa Irrigation District's pumping station.

Appendix 1-1. Flow and temperature data for the Sacramento River in the vicinity of the GCID diversion during April 1990. Hamilton City flows were obtained from California Department of Water Resources.

APRIL DAY	HAM. CTY. FLOW (cfs)	PMP. PLNT. FLOW (cfs)	SAC.RIV. FLOW (cfs)	INTAKE FLOW (cfs)	BYPASS FLOW (cfs)	CHANNEL ELEVATIONS IN ft. NO. ISLE	SCRN. 40	BYPASS	SO. ISLE	TEMP. DEG. F
1	5290	700	5990	1095	395	--	--	--	--	57
2	5634	721	6355	1145	424	136.33	136.32	135.45	135.14	56
3	5556	615	6171	1040	425	136.47	136.47	135.59	135.27	56
4	5832	615	6447	1065	450	136.53	136.51	135.62	135.32	57
5	5832	615	6447	1065	450	--	--	--	--	58
6	5403	603	6006	1016	413	136.37	136.35	135.78	135.18	58
7	--	642	--	--	--	--	--	--	--	58
8	--	668	--	--	--	--	--	--	--	56
9	6950	668	7618	1213	545	136.90	136.88	136.02	135.64	54
10	7181	615	7796	1185	570	136.95	136.94	136.09	135.68	54
11	7135	615	7750	1181	566	136.89	136.87	136.18	135.65	55
12	7371	695	8066	1276	581	--	--	--	--	56
13	7712	802	8514	1404	602	--	--	--	--	56
14	8065	912	8977	1537	625	--	--	--	--	56
15	--	1151	--	--	--	--	--	--	--	--
16	8014	1100	9114	1705	605	137.12	137.06	136.40	135.85	56
17	7912	1315	9227	1893	578	137.16	137.07	136.39	135.88	57
18	7812	1500	9312	2054	554	137.09	136.97	136.30	135.81	56
19	7323	1660	8983	2157	497	--	--	--	--	57
20	6904	1844	8748	2289	445	136.84	136.65	135.99	135.62	57
21	6634	1966	8600	2377	411	136.77	136.55	135.94	135.57	57
22	7467	1966	9433	2451	485	137.00	136.76	136.13	135.74	57
23	7762	1966	9728	2477	511	137.08	136.84	--	135.81	56
24	7912	2050	9962	2568	518	137.14	136.88	136.25	135.87	55
25	8116	2044	10160	2580	536	137.17	136.93	136.30	135.91	56
26	8168	2129	10297	2663	534	137.14	136.86	136.30	135.86	56
27	7467	2200	9667	2666	466	136.98	136.70	136.09	135.75	56
28	--	2350	--	--	--	--	--	--	--	--
29	6634	2500	9134	2867	367	136.75	136.38	135.82	135.56	56

Appendix 1-2. Flow and temperature data for the Sacramento River in the vicintiy of the GCID diversion during May 1990. Hamilton City flows were obtained from California Department of Water Resources.

MAY DAY	HAM. CTY. FLOW (cfs)	PMP. PLNT. FLOW (cfs)	SAC.RIV. FLOW (cfs)	INTAKE FLOW (cfs)	BYPASS FLOW (cfs)	CHANNEL ELEVATIONS IN ft. NO. ISLE	SCRN. 40	BYPASS	SO. ISLE	TEMP. DEG. F
1	6373	2355	8728	2711	356	--	136.34	135.79	135.49	56
2	6427	2338	8765	2700	362	136.84	136.50	135.93	135.62	56
3	6502	2422	8924	2784	362	136.82	136.43	--	135.60	57
4	6679	2469	9148	2842	373	136.78	136.35	135.82	135.56	57
5	6679	2519	9198	2888	369	--	--	--	--	--
6	--	2569	--	--	--	--	--	--	--	--
7	7323	2320	9643	2763	443	137.00	136.62	--	135.71	54
8	7371	2319	9690	2766	447	136.97	136.65	136.03	135.70	54
9	7712	2199	9911	2687	488	137.14	136.85	136.21	135.84	54
10	7762	2108	9870	2608	500	137.13	136.82	136.18	135.83	56
11	8220	1985	10205	2536	551	137.22	136.98	136.30	135.92	57
12	8272	1896	10168	2458	562	--	--	--	--	--
13	8220	1816	10036	2380	564	--	--	--	--	--
14	8168	1733	9901	2300	567	137.30	137.08	136.41	135.97	56
15	8220	1676	9896	2252	576	137.23	137.04	136.36	135.93	56
16	8279	1640	9919	2224	584	137.27	137.09	136.40	135.95	56
17	7712	1607	9319	2143	536	137.15	136.96	136.27	135.85	56
18	7371	1527	8898	2039	512	--	--	--	--	56
19	7323	1527	8850	2035	508	--	--	--	--	--
20	--	1527	--	--	--	--	--	--	--	--
21	7712	1421	9133	1973	552	137.11	136.96	136.25	135.82	57
22	7912	1368	9280	1942	574	137.18	137.04	136.34	135.88	58
23	9027	1318	10345	1995	677	137.51	137.36	136.67	136.14	56
24	12150	1212	13362	2176	964	137.89	137.74	137.16	136.45	55
25	8439	1143	9582	1782	639	137.21	137.12	136.37	135.90	57
26	8014	1124	9138	1727	603	--	--	136.31	--	--
27	8324	1029	9353	1667	638	--	--	--	--	--
28	16050	912	16962	2249	1337	139.41	--	--	--	--
29	14860	912	15772	2142	1230	138.84	138.67	138.16	137.24	55
30	12580	965	13545	1988	1023	138.12	138.02	137.40	136.64	59
31	16010	952	16962	2282	1330	--	140	139	--	56

Appendix 1-3. Flow and temperature data for the Sacramento River in the vicinity of the GCID diversion during June 1990. Hamilton City flows are preliminary readings obtained from Paul Ward, CDFG.

JUNE DAY	HAM. CTY. FLOW (cfs)	PMP. PLNT. FLOW (cfs)	SAC.RIV. FLOW (cfs)	INTAKE FLOW (cfs)	BYPASS FLOW (cfs)	CHANNEL ELEVATIONS IN ft. NO. ISLE	SCRN. 40	BYPASS	SO. ISLE	TEMP. DEG. F
1	14860	1004	15864	2227	1223	138.48	138.36	137.72	136.96	59
2	--	1128	--	--	--	--	--	--	--	--
3	8014	1281	9295	1871	590	--	--	--	--	--
4	6904	1463	8367	1939	476	136.85	136.72	135.96	135.60	64
5	5792	1723	7515	2079	356	--	--	--	--	66
6	5142	1935	7077	2215	280	136.22	135.94	135.46	135.12	66
7	4926	2025	6951	2279	254	136.25	135.93	135.45	135.12	66
8	4615	2195	6810	2407	212	136.11	135.85	135.34	135.01	66
9	--	2329	--	--	--	--	--	--	--	--
10	4997	2337	7334	2571	234	--	--	--	--	63
11	5403	2338	7741	2608	270	136.41	135.99	135.49	135.26	63
12	5832	2348	8180	2656	308	136.61	136.20	135.67	135.41	63
13	6950	2429	9379	2830	401	135.87	136.49	135.90	135.64	62
14	6590	2394	8984	2766	372	135.80	136.40	135.82	135.56	60
15	7088	2365	9453	2783	418	136.93	136.58	135.97	135.67	60
16	--	2365	--	--	--	--	--	--	--	--
17	7112	2365	9477	2786	421	--	--	--	--	--
18	7912	2296	10208	2794	498	137.14	136.82	136.18	135.83	60
19	7762	2259	10021	2746	487	137.12	136.81	136.15	135.82	60
20	7614	2316	9930	2785	469	137.11	136.77	136.10	135.81	60
21	--	2316	--	--	--	--	--	--	--	--
22	7516	2302	9818	2764	462	137.03	136.71	--	135.79	--
23	--	2302	--	--	--	--	--	--	--	--
24	--	2302	--	--	--	--	--	--	--	--
25	7229	2302	9531	2738	436	136.98	135.97	135.97	135.71	60
26	7516	2350	9866	2808	458	137.04	136.70	136.03	135.79	60
27	7467	2350	9817	2803	453	137.03	136.69	136.01	135.77	60
28	7181	2350	9531	2778	428	136.97	136.62	135.95	135.71	60
29	7467	2350	9817	2803	453	137.10	136.75	136.08	135.80	60
30										

Appendix 2

Reports of David Vogel from his SCUBA dive inspection on June 17, 1990 of the fish screens at the Glenn-Colusa Irrigation District's pumping station. The volume of flow being pumped was 2,365 cfs.

Engineers
Planners
CH2M HILL Economists
Scientists

August 14, 1990

RDD3013.A0

Mr. Steve Cramer
1140 NW Walnut Boulevard
Corvallis, Oregon 97330

Dear Steve:

Enclosed are some additional diagrams relative to the California Department of Fish and Game fish screens at the Glenn-Colusa Irrigation District's Sacramento River pumping station. I had Figures 1 and 2 (originally provided to you on July 19, 1990) redrawn to more appropriately display the extent of the fish entrapment zones under the fish screens.

Figure 3 shows another major design flaw at the downstream-most portion of the fish screen structure. The fish entrapment zone is much more extensive at this location than at any other location under the fish screens. Downstream migrant fish under the downstream-most screen (designated with an "X" on Figure 3) would have to swim approximately 18 feet in an "upstream" direction (i.e. directly against the flow) to escape into the main bypass channel. For reasons discussed in my July 19, 1990 letter to you, these fish are not likely to enter the fish bypass entrance shown because it stops 2 feet short of the bottom and approximately 5 feet in front of the lower-most portion of the fish screens.

There findings are significant because downstream migrant fish screens are supposed to be designed so that fish would never have to actively swim in an upstream direction directly against the flow of water. Furthermore, fish bypasses should be designed such that downstream migrants should not have to actively swim to find the entrances. As these drawings show, the California Department of Fish and Game fish screens near the GCID pumping station on the Sacramento River possess these major anomalies.

Mr. Steve Cramer
Page 2
August 14, 1990
RDD3013.A0

Please call me if you have any questions.

Sincerely,

CH2M HILL

David A. Vogel

David A. Vogel
Senior Fisheries Biologist

cc: Bob Clark/GCID

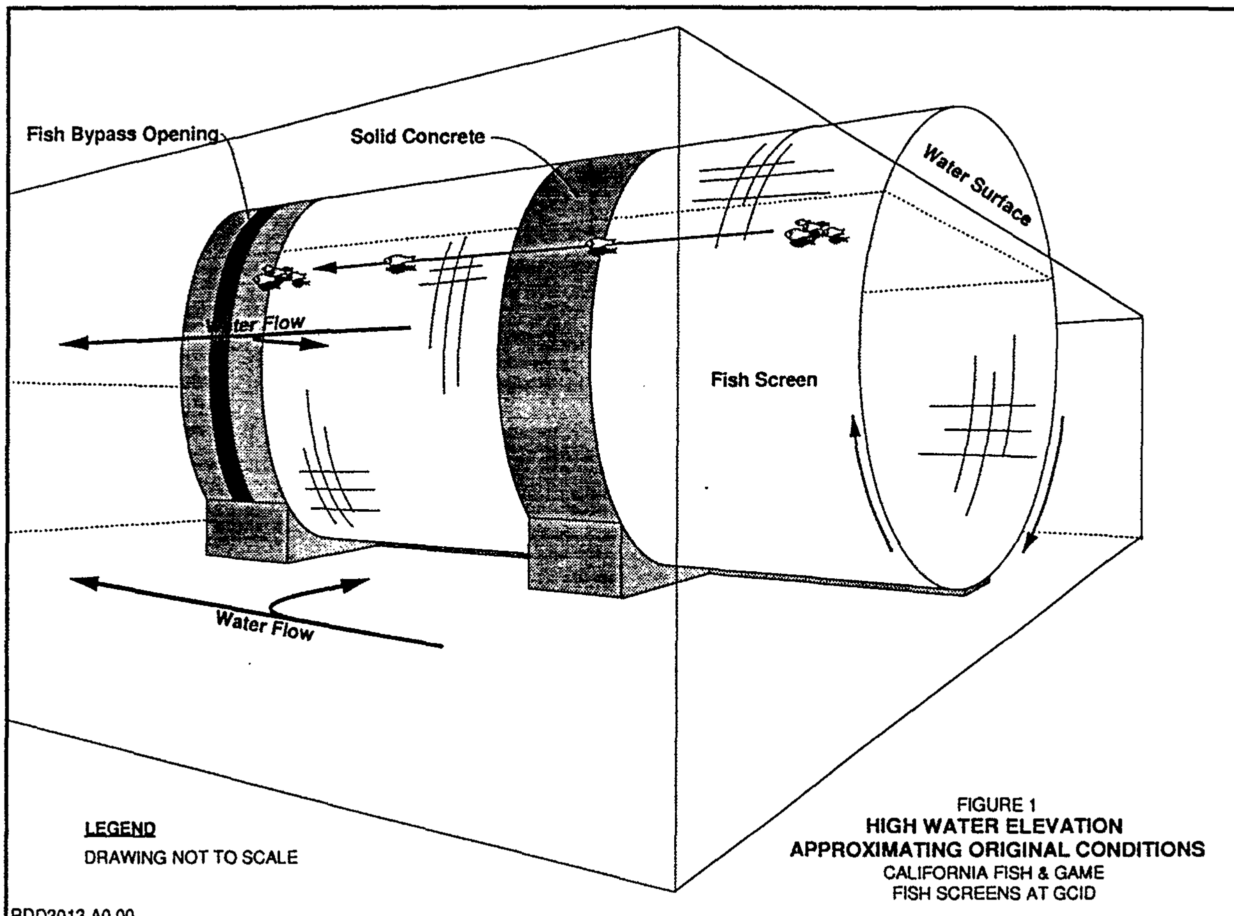

FIGURE 1
HIGH WATER ELEVATION APPROXIMATING ORIGINAL CONDITIONS
CALIFORNIA FISH & GAME
FISH SCREENS AT GCID

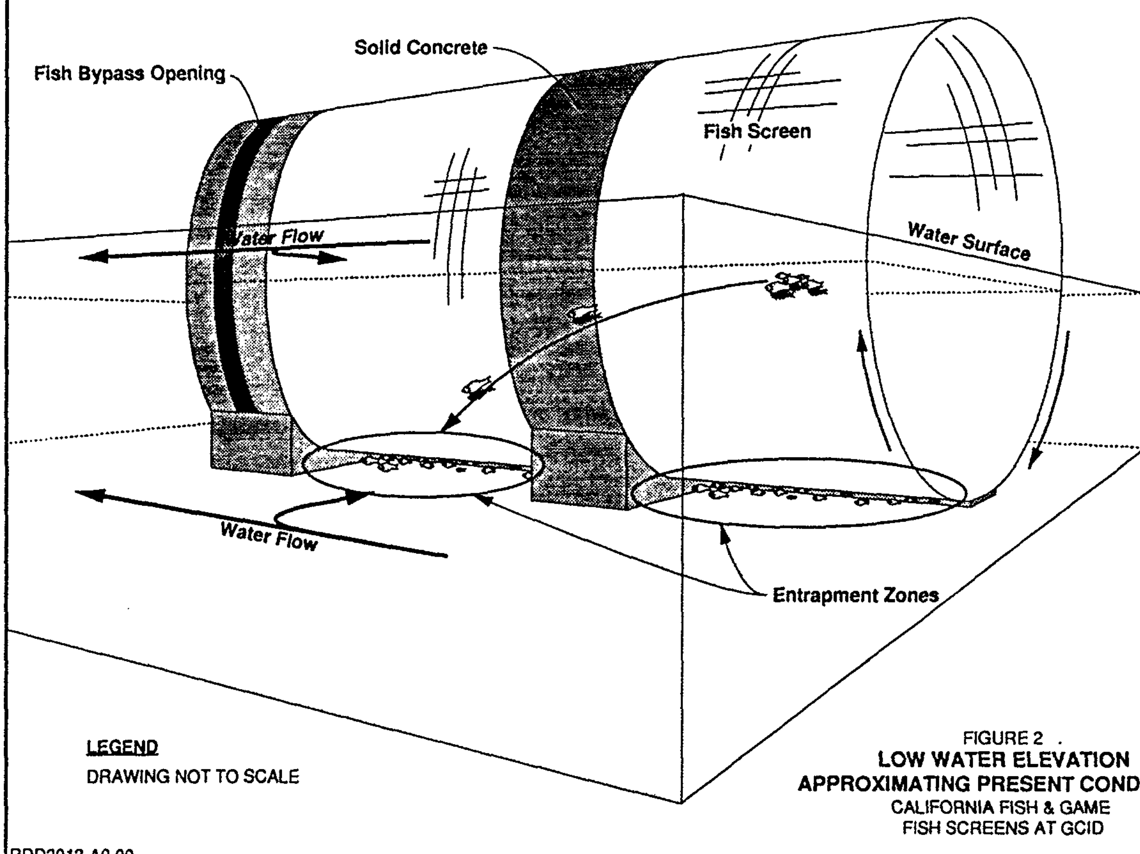

FIGURE 2 .
LOW WATER ELEVATION
APPROXIMATING PRESENT CONDITIONS
CALIFORNIA FISH & GAME
FISH SCREENS AT GCID

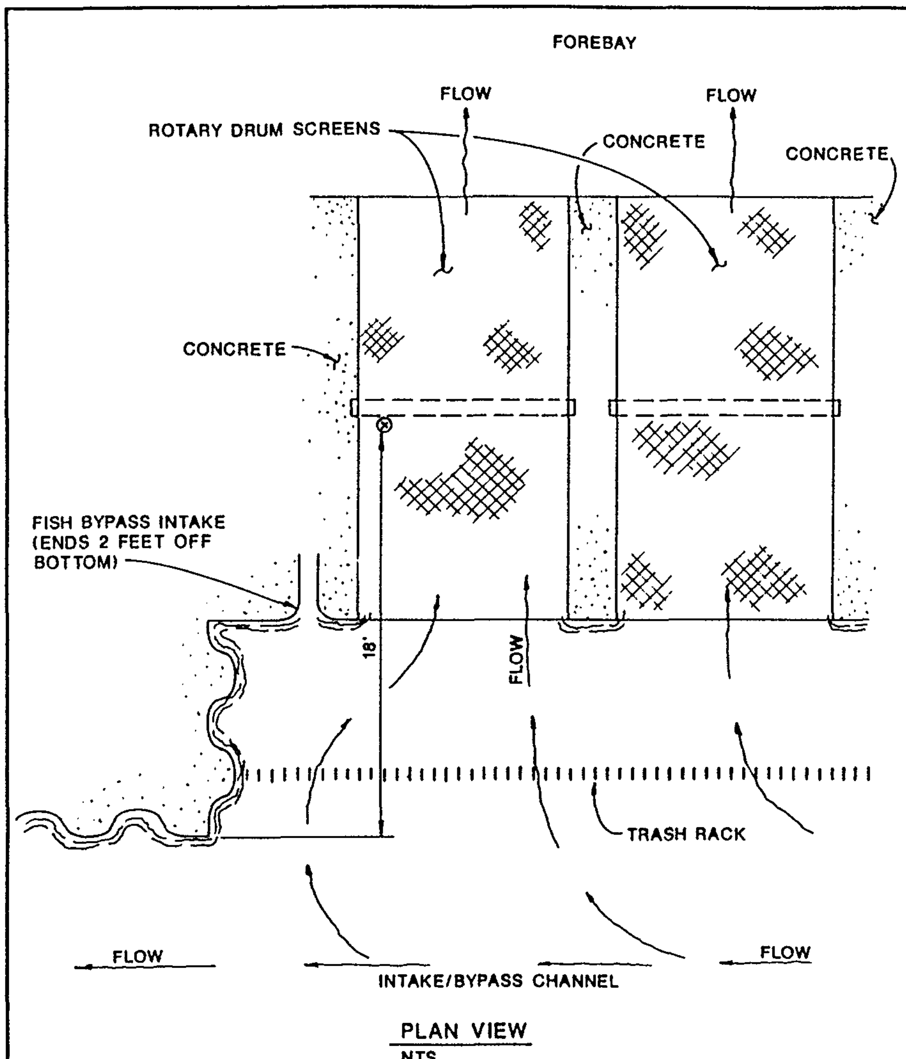

FIGURE 3

Downstream-most portion of the California Department of Fish and Game fish screens at GCID's Sacramento River pumping station

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C-051367

C-051367

Engineers
Planners
Economists
Scientists

July 19, 1990

RDD3013.A0

Mr. Steve Cramer
1140 NW Walnut Boulevard
Corvallis, Oregon 97330

Dear Steve:

Bob Clark asked me to convey my thoughts to you concerning a possible cause for some of the "unexplainable" fish losses at the California Department of Fish and Game fish screens near the Glenn-Colusa Irrigation District's Sacramento River pumping station.

Basically, I'm convinced that significant entrapment zones for small downstream migrant fish exist on the river channel (intake) side of the fish screens. The best way to describe the situation is by referring to the enclosed diagrams.

Figure 1 shows a hypothetical situation as though the water surface was higher than present conditions. This would approximate conditions when the screens were originally designed and installed. As you know, most downstream migrants are present in the upper portion of the water column and should follow the route shown. Fish approaching and moving along the face of the screens are exposed to water velocities through the screens and water velocities down the river channel. Since these fish avoid impingement, they would maintain their relative position off the face of the screens and concurrently follow the flow along the path of least resistance down the river channel. These fish would ultimately enter one of the fish bypass openings or continue down the river channel past all the screens. Most fish approaching the screens in the upper portion of the water column probably stay near the surface. The screen's angle relative to the fish is such to keep them oriented near the surface because a portion of the screen is essentially directly under them.

Mr. Steve Cramer
Page 2
July 19, 1990
RDD3013.A0

Figure 2 shows a different situation with the water surface much lower near the mid-point of the screen diameter; this approximates present conditions. As in Figure 1, because most downstream migrants move in the upper portion of the water column, the initial approach of fish at the screen face is probably as shown. However, unlike the fish shown in Figure 1, the fish shown in Figure 2 would have greater difficulty maintaining their position near the surface as they move down the river channel because now the screens' angle (relative to the fish) is oriented in the opposite direction as compared to Figure 1. If they simply follow the path of least resistance while avoiding impingement, these fish would be "guided" down underneath the fish screens. This occurrence by itself would probably not be harmful if the fish could continue to move downstream in the river channel or into one of the fish bypasses. However, I don't think many of the fish are likely to follow the latter two escape routes because of some serious design flaws on the screening structure.

Fish "guided" under the fish screens as shown in Figure 2, quickly reach a position under the deepest portion of the fish screens between the two supporting solid concrete structures. At this point, the fish can only escape by aggressively swimming directly against the water velocity going through the screens because there is no longer a downstream flow component for them to follow as a path of least resistance. To avoid impingement and concurrently minimize energy expenditure, fish in these "entrapment zones" (shown in Figure 2) probably maintain themselves in the current at those locations until they succumb to exhaustion and die from eventual impingement. On the other hand, assuming these fish aggressively swam directly against the velocity, i.e. move in an "upstream" direction (uncharacteristic of downstream migrants), they would have to do so over a distance of approximately 5 feet to get around the concrete support structure shown in the diagram. In that circumstance, the fish are not likely to enter the fish bypass system because the deepest portion of the opening stops 2 feet short of the bottom. If the fish successfully escape one entrapment zone, they would immediately encounter another one under the next fish screen. It's unlikely young downstream migrants have the stamina to do this repeatedly before succumbing to the direct, through-screen velocity and become impinged. It's also important to recognize that if fish are first exposed to the uppermost screen in the river channel, those fish would have to contend with this situation at all 40 screens.

Mr. Steve Cramer
Page 3
July 19, 1990
RDD3013.A0

Very little, if any, physical evidence of this adverse condition would be visible from the surface. Most dead, impinged fish in these entrapment zones wouldn't "ride" the screen face up to the water surface because the combination of the relatively high through-screen velocity, the slow rotation of the screens, and the extremely low angle at the bottom of the screens would continually sweep the carcasses back under the screens until they decompose.

These entrapment zones for small fish are also entrapment zones for riverine debris for the same basic reasons just described for fish. Over time, the accumulation of large quantities of debris under the screens creates additional hazards to young fish entering these areas because of physical injury upon direct contact with debris in the turbulence. I believe debris entrapment at these locations also explains the origin of numerous dents on the fish screens. Debris constantly churns under the screens and under the right conditions would become impinged on the screen face and ride the upward screen rotation until contacting a submerged horizontal support bar positioned several inches in front of the screens (not shown on the figures). If the debris is of a size and strength to wedge between the screen face and the support bar, the upward screen rotation compresses the debris into the screen face thereby creating a dent.

Please call me if you have any questions.

Sincerely,

CH2M HILL

David A. Vogel

David A. Vogel
Senior Fisheries Biologist

cc: Bob Clark

Aqua-View

Underwater Video Services

Post Office Box 362
Red Bluff, CA 96080

Telephone
(916) 529-0831

June 24, 1990

Mr. Ben Pennock
Glenn-Colusa Irrigation District
P. O. Box 150
Willows, CA 95988

Dear Ben:

Enclosed is a seven-minute video tape showing portions of the underwater inspection I conducted on June 17, 1990, at the upstream side of Fish and Game's fish screens near GCID's Sacramento River pumping station.

The two areas showing the largest gaps where young fish could enter the forebay between the screens and the pumping station were under the large slide gate for the dredge and under the fish trap. The opening under the slide gate was the largest of the two.

The first sequence on the video tape shows the large gap under the slide gate. The most important items to notice in this sequence are the size of the opening (the lens of the underwater light is five inches high) and the flow of water under the gate evident by silt movement. At one point in this sequence, I turned the camera on its side to show daylight on the other side of the gate. This large gap extended over a distance of about one-fourth to one-third the width of the gate at the upstream-most portion of the base of the gate.

The second sequence shows the gap under the Fish and Game fish trap and begins with my finger pointing on the left side of the picture and the underwater light on the right side. Notice the movement of silt and algae showing the water flow under the trap.

During the inspection, I observed large quantities of riverine debris under each fish screen. The debris apparently accumulates in these locations due to the water velocities and the configuration of the base of the screen bays (i.e., there's nowhere for the debris to go). I suspect it's this debris that's causing the dents on the face of the screens; impinged debris rides up with the screen rotation and wedges against the submerged horizontal support bars bending the screen inward.

As you requested, I also located several I-beams protuding one to four feet off the bottom in the main bypass channel outside of the trash rack.

Sincerely,

Dave

David A. Vogel

Appedix 3

Appendix 3. Weekly total catches and mean lengths of unbranded chinook at the CDFG and GCID traps in 1990.

Week Ending	Julian Week	CDFG Weekly Catch	GCID Weekly Catches	CDFG length	GCID length	Pumped Flow	Bypassed Flow
18-Feb	7	329		37.0		203	
25-Feb	8	481		37.6		204	
04-Mar	9	99		37.5		204	
11-Mar	10	374		41.3		99	
18-Mar	11	729		45.6		181	
25-Mar	12	139		50.5		370	
01-Apr	13	334		48.1		803	
08-Apr	14	26		62.8		640	432
15-Apr	15	194		63.8		780	573
22-Apr	16	754		65.7		1622	511
29-Apr	17	1302	945	68.3	76.8	2177	440
06-May	18	881	1420	68.8	77.8	2448	362
13-May	19	247	1376	66.9	77.2	2092	508
20-May	20	111	1227	72.8	83.1	1605	547
27-May	21	29	1574	73.8	83.1	1231	664
03-Jun	22	21		69.0		1322	1094
10-Jun	23	43	490	77.0	83.8	1911	302
17-Jun	24	55	702	79.4	82.9	2368	365
24-Jun	25	47	285	79.0	82.7	2307	479
01-Jul	26	29	250	81.7	85.0	2340	446
08-Jul	27	17	218	82.8	86.1		
15-Jul	28	8		84.2			

Note: Some weekly values of catch are expanded to include 1-3 missing days of data based on the average catch during days sampled.

C—051373

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