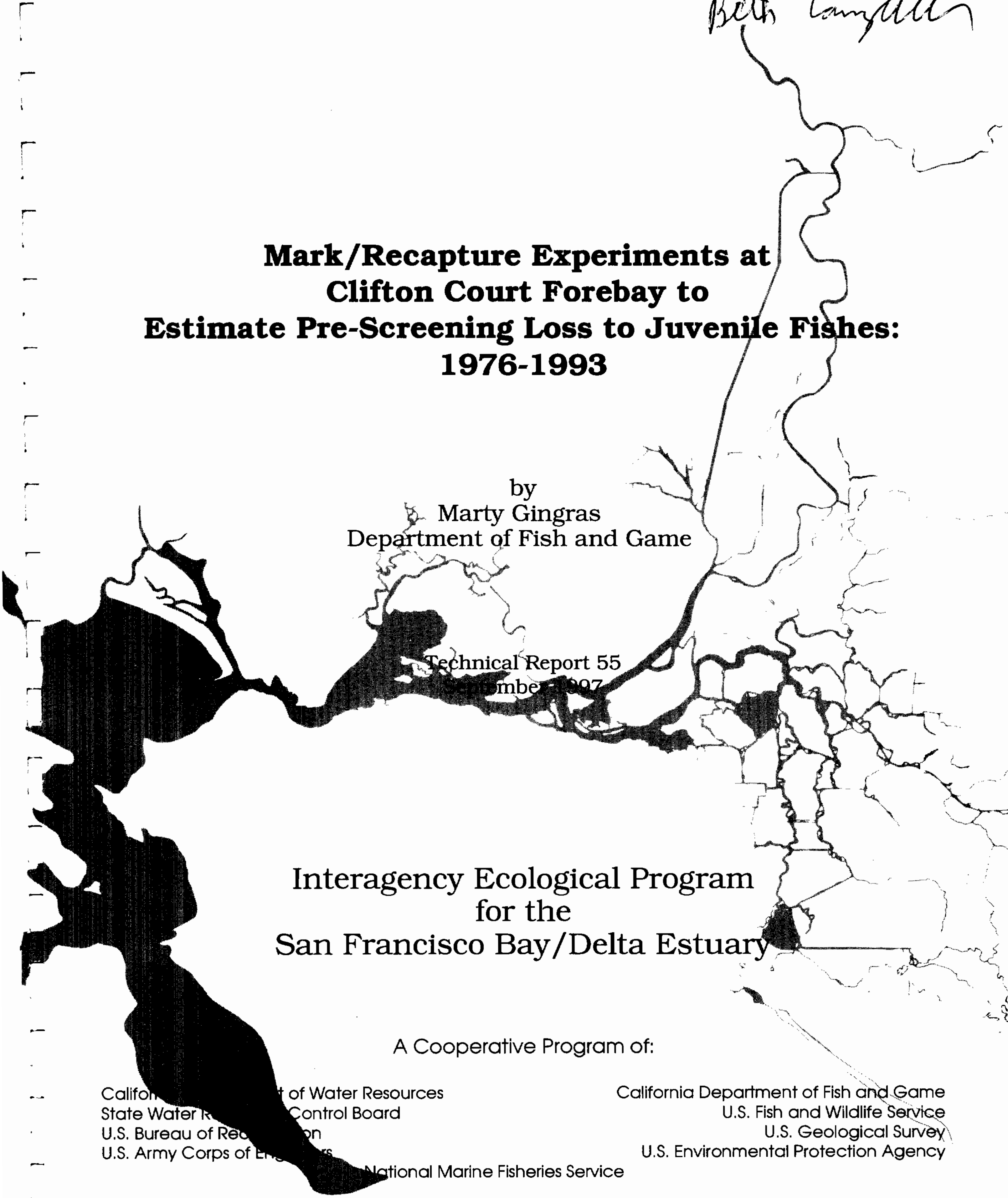
Mark/Recapture Experiments at Clifton Court Forebay to Estimate Pre-Screening Loss to Juvenile Fishes: 1976-1993

by
Marty Gingras
Department of Fish and Game

Technical Report 55
September 1997



Interagency Ecological Program
for the
San Francisco Bay/Delta Estuary

A Cooperative Program of:

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State Water R[...]Control Board
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California Department of Fish and Game
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Abstract

From October 1976 through November 1993, the California Department of Fish and Game conducted mark/recapture experiments at Clifton Court Forebay, designed to estimate pre-screen loss to entrained juvenile fishes. Ten studies were conducted; eight evaluated losses to hatchery-reared juvenile chinook salmon, and two evaluated losses to hatchery-reared juvenile striped bass. Pre-screen loss was calculated from the proportion of marked fish released at the radial gates that were subsequently recaptured during salvage operations at Skinner Fish Facility. The proportion was adjusted for handling mortality, fish facility louver efficiency, and any subsampling at the facility. Studies were conducted across a wide range of environmental conditions and State Water Project operations, with a wide range in the size of experimental fish. Pre-screen loss estimates for juvenile chinook salmon were 63-99%. Potential biases in estimates of pre-screen loss may be due to (1) the calculation for pre-screen loss, (2) under-representative and over-representative salvage of experimental fish at Skinner Fish Facility, and (3) the introduction of experimental fish directly into Clifton Court Forebay. A multiple-regression analysis of pre-screen loss to juvenile salmon showed that 91% of the variance in pre-screen loss can be explained by export rate, experimental fish size, and water temperature.

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Acknowledgments

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Introduction

Clifton Court Forebay (Figure 1) is a tidally filled impoundment (1,833 acres) from which water is pumped into the California Aqueduct. At the discretion of State Water Project operators, a series of radial gates (Figure 2) is opened when Old River stage is higher than Clifton Court Forebay stage, drafting water and entraining fish into the forebay. Water velocity through the gates approaches 13 feet/second at maximum Old River/Clifton Court Forebay stage differential. Skinner Fish Facility, an entrained-fish salvage facility, operates continuously when the State Water Project exports water from Clifton Court Forebay to the California Aqueduct.

Skinner Fish Facility uses behavioral barriers (louvers) designed and operated to guide fish to collection facilities. Louvers are not 100% efficient in diverting fish, and efficiency varies by fish species, fish size, and water velocity at the screens (DWR and DFG 1973). For the purpose of take and mitigation calculations, fish passing through the louvers are designated as loss. Additional losses to entrained fish during movement from the radial gates to the screens, termed pre-screening losses, include predation by fish and birds. Predation by adult and subadult striped bass may account for much of the pre-screen loss. Kano (1990) and Brown *et al* (1995) described pre-screen loss as synonymous with predation by striped bass.

From October 1976 through November 1993, the Department of Fish and Game (under the auspices of the Interagency Ecological Program) conducted mark/recapture experiments designed to estimate pre-screen loss to juvenile fish entrained into Clifton Court Forebay. The average pre-screen loss of three of the earliest studies has been integrated into the so-called 4-Pumps Agreement, providing mitigation for direct fish losses due to operation of the State Water Project. Subsequent studies were designed to determine if changes in

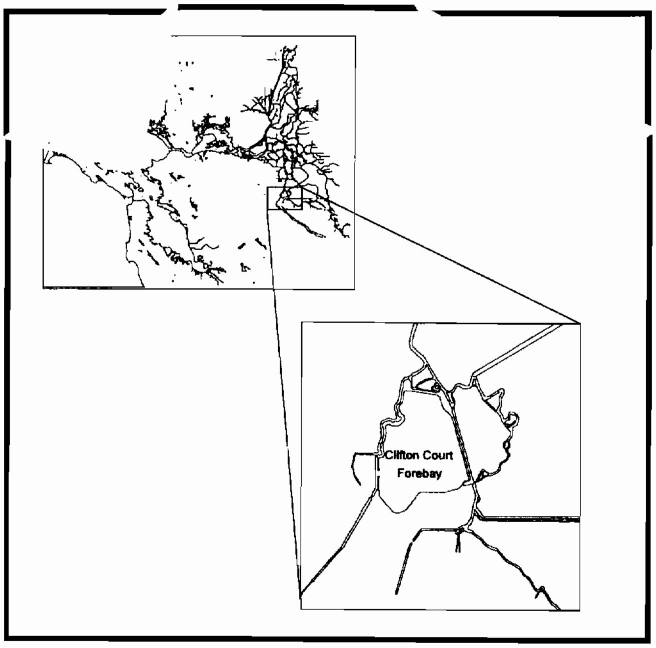

Figure 1
CLIFTON COURT FOREBAY

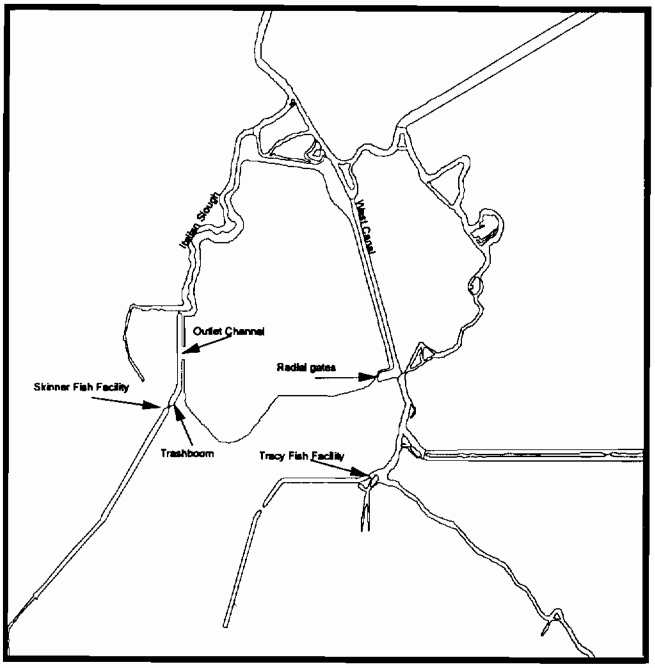

Figure 2
ORIENTATION OF STRUCTURES AROUND
CLIFTON COURT FOREBAY

operation or structural configuration could reduce pre-screen loss.

The two earliest studies were published as DFG Anadromous Fisheries Branch administrative reports. Subsequent study reports were circulated as memoranda among involved agencies. Because aspects of these studies have relevance beyond the confines of Clifton Court Forebay, this report summarizes the methodologies and findings of each study.

This section describes methods that were common among studies. Details of marking procedure and location, post-mark-application holding period and location, mark type, release method and precise location, Skinner Fish Facility operation (*eg*, subsampling routine, number and sequence of opened bays, debris status) are either described as quotations in this report, described in the referenced literature, or are not available.

Groups of hatchery-reared juvenile chinook salmon or striped bass used in the study were uniquely marked, allowing study fish to be distinguished from non-study fish during recapture efforts. Markings included some combination of coded-wire-tags, fin clips, and fluorescent dye. The most common mark was fluorescent dye (particulate) applied by low-pressure compressed-air spray gun (Phinney *et al* 1967; Hanson 1996). Up to four colors were used to distinguish release groups. Dye particles were easily observed under ultraviolet light.

Before being marked, subsamples were weighed and counted. The weight and number of subsamples varied with the size of fish — more and smaller samples were used with smaller fish. The number of fish released during each study (Table 1) was estimated from the calculated mean density of the weight of fish released and was adjusted for marking mortality, mark retention, and transport mortality. Hatchery personnel suggest that when this method is used, actual fish count is within 10% of the mean. Error is due to variance in fish length per lot and varies with fish size.

Groups of marked fish were released inside Clifton Court Forebay, adjacent to the radial gates, and some were subsequently recaptured at Skinner Fish Facility. Pre-screen loss was calculated using the general formula: pre-screen loss = $(1-(recap_g / rel_g)) * 100$, where $recap_g$ = number of recaptures of fish released at radial gates, and rel_g = number of fish released at radial gates. In some cases, $recap_g$ was adjusted for some

Table 1
DATES, OPERATIONAL AND EXPERIMENTAL VARIABLES, AND RESULTS, PRE-SCREEN LOSS STUDIES AT CLIFTON COURT FOREBAY

Year/Month	Species	Pre-Screen Loss (%)	Fork Length (mm)[1]	Mean Water Temperature (°F)	Flow[2] (cfs)	Mark Type	Release Site[3]	# Released[4] at Radial Gates	# Released[4] at Trashboom
1976/OCT	Salmon	97	114	69	252	dye	G	6,825	N/A
1978/OCT	Salmon	88	87	60	4,476	dye	G/O/T	10,510	1,907
1984/APR	Salmon	63	79	61	6,000	dye	G/T	13,493	5,853
1984/JUL	Striped Bass	94	52	N/A	4,000	dye	G/T	13,710	8,550
1985/APR	Salmon	75	44	62	6,825	dye	G/T	11,606	5,915
1986/AUG	Striped Bass	70	55	N/A	7,622	dye	G/T	18,486	8,943
1992/MAY	Salmon	99	77	75	306	dye	G/T	21,894	3,199
1992/DEC	Salmon	78	121	47	3,390[5]	dye	G/T	10,729	1,782
1993/APR	Salmon	95	66	63	3,390[5]	dye	G/T	10,332	2,518
1993/NOV	Salmon	99	117	53	6,780	dye/clip	G/T	4,246	469
								1,509	468
								4,260	233

1 Mean fork length of fish released at the radial gates
2 Flow through the radial gates at release of experimental fish
3 Location of releases: G = radial gates, O = outlet channel, and T = trashboom
4 Estimated number of fish released at the trashboom (Multiple releases were combined, except for November1993.)
5 Export from Clifton Court Forebay

combination of: (1) subsampling at Skinner Fish Facility, (2) long-term mark retention, and (3) estimated mortality due to handling. In the 1976 and 1978 studies, $recap_g$ was adjusted for louver efficiency at Skinner Fish Facility. In subsequent studies, $recap_g$ was adjusted by survival of fish released at the trashboom ($survival_{tb}$), and louver efficiency was assumed constant for releases at the radial gates and at the trashboom.

A multiple linear regression model was used to analyze the relationship between pre-screen loss of juvenile salmon and water export, water temperature, and fish size. Pre-screen loss is based on proportional data and is a restricted range variable (0-100%). The pre-screen loss values were arcsine transformed to unrestrict and normalize the distribution of this data (Wilkinson *et al* 1996). Multiple linear regression analysis was performed using SYSTAT© Version 7.0 software.

Report Summaries

This chapter summarizes methodologies and findings of pre-screen loss studies.

Fall 1976

The first pre-screen loss estimate used fall-run chinook salmon smolts from Coleman National Fish Hatchery (Schaffter 1978). Staff released about 6,825 fluorescent-dyed fish (10% less than estimated from density of fish released, to account for estimated mortality due to infection and other handling-associated causes) in a single group at the radial gates. Schaffter described recovery efforts:

> Half hour counts were taken every two hours the first night (October 12); during the next 14 days fish counts were continuous. Counts from October 26 through November 12 were conducted during approximately 50 percent of pumping and extrapolated. All [chinook] salmon were examined under ultraviolet light for dye and [measured to the nearest mm fork length]. Recoveries were divided by 0.6 to compensate for the [67 percent louver efficiencies] established for 100-125 mm (3.9-4.9 inches) [chinook] salmon (Heubach et al. 1973)....

Ninety percent (171 fish) of all recoveries (191 fish) were made by 0700 hours the day following release. Mean fork length of recovered salmon increased over time. Calculated pre-screen loss to the release group was 97%.

Fall 1978

This iteration used late-fall-run chinook salmon from the Feather River Hatchery (Hall 1980). Staff released fluorescent-dyed fish in three groups at three locations: the radial gates, the trashboom, and the upstream end of the outlet channel. On October 30, about 10,510 fish were released at the radial gates, another 1,907 were released at the trashboom, and 5,252 were released at the outlet channel. Hall described recovery efforts:

> All salmon collected at the [Skinner Fish Facility] were inspected under fluorescent light for dye marks and measured to the nearest millimeter fork length (FL). A single adhering particle of fluorescent pigment was used as the criterion for a fish being considered marked.
>
> Actual recoveries were expanded to calculated total recoveries by the following formula: total recoveries = [acre feet exported * $recap_g$/acre feet sampled * louver efficiency], to account for louver efficiencies and subsampling at the [Skinner Fish Facility]. A louver efficiency of 0.81, previously determined by Heubach et al (1973) for chinook salmon 50 mm to 100 mm (2.0 in. to 3.9 in) FL at primary channel approach velocities of 0.9 to 1.1 m^3/s (3.0 to 3.5 ft/s), was used.
>
> Schaffter (1978) performed continuous sampling of downstream migrant chinook salmon as they entered the facility. In this study, the first hour's recoveries were made from a complete count of all chinook salmon recovered in the [Skinner Fish Facility]. All subsequent recoveries of marked fish were made from subsamples

due to large numbers of other species, which precluded continuous sampling in the facility.

Of calculated total recoveries of fish released at the radial gates, 57% were recovered within 24 hours. Mean fork length of recovered salmon increased over time. Pre-screen loss was 64% for the group released at the outlet channel, 15% for the group released at the trashboom, and 88% for the group released at the radial gates.

Spring and Summer 1984

Pre-screen loss estimates were calculated for fall-run chinook salmon smolts from the Mokelumne River Hatchery and for juvenile striped bass from the Central Valley Hatchery. Results were described in an office memorandum (Collins 1985).

Chinook Salmon

Staff released fluorescent-dyed fish in three groups at the radial gates and the trashboom. On April 25, about 13,493 fish were released at the radial gates at 1830 hours. Two groups were released at the trashboom: about 2,900 fish at 1930 hours and 2,953 fish at 2200 hours. Collins described recovery efforts and recoveries:

> Recoveries of marked fish were made by monitoring the catches of the [Skinner Fish Facility] starting immediately after the radial gate release and ending on 5 May at 0800 hours. Any chinook salmon found were examined under ultraviolet light to determine if fluorescent marks were present. From 1830 hours on the day of release until 2400 hours on the following day recoveries were made by examining the entire catch of the facility. Subsequent recoveries of marked salmon were made by taking 20 minute long subsamples at least once every two hours. Numbers of salmon found by subsampling were expanded to actual numbers of fish caught.
>
> A total of 3,910 salmon from the trashboom releases and 3,310 fish from the radial gate releases were recovered. Marked salmon from the trashboom groups were present in the facility catch immediately after release, with the majority of total recoveries occurring by midnight of that day. The first recovery of a radial gate group salmon was made approximately two hours after that release. Peak returns from the radial gate [release group] occurred two days after release, and by 1 May, 95% of total recoveries were found. Marked fish were undoubtedly present in the facility catches after we ended our sampling but this number was probably small.

Expanding counts to incorporate 0.74 average louver efficiency, $survival_{tb}$ was 0.90 and pre-screen loss to the group released at the radial gates was 63.3%. Collins observed that pre-screen loss to chinook salmon was lower in this study than in previous studies, perhaps because this study was conducted in spring. He noted:

> The evaluations conducted in 1984 again determined that large losses of young fish occurred in Clifton Court Forebay. Juvenile chinook salmon suffered 63% losses between the radial gates and the facility trashboom. These losses were much lower than those experienced in the previous evaluations, despite the fact that mean size of salmon used in 1984 was smaller. The earlier studies, however, were conducted in the fall instead of the spring, and this difference may be the major contributor to [the] difference in losses....

Striped Bass

Staff released fluorescent-dyed fish in four groups at the radial gates and the trashboom. On July 16, about 13,710 fish were released at the radial gates at 1020 hours. On July 23, three groups of fish were released at the trashboom: about 4,126 fish at 1015 hours, another 1,967 fish at 2130 hours, and 2,457 fish at 2300 hours. The more complicated release pattern was designed to allow a comparison of loss patterns relative to day and night releases and "off-peak" water export. Collins described recovery efforts and recoveries:

> The recovery of marked striped bass was conducted from 16-26 July by again sampling the catch at [Skinner Fish Facility]. A total of 219 striped bass from the radial gate release, and 2,374 bass from the three trashboom releases were recovered. The returns for bass released at the trashboom during the day were much lower than those of the night release groups. A total of 177 day-released fish were recovered, while 2,197 marked bass were recovered from night releases. The majority of recoveries for both groups, however, occurred within 24 hours of release. The first recoveries of the radial gate group did not occur until 10 hours after release, and throughout the recovery period there was no large influx of returns.

Expanding counts to incorporate 0.76 average louver efficiency, $survival_{tb}$ (combined) was 0.37 and pre-screen loss to the group released at the radial gates was 94.1%. He attributed the high losses of juvenile striped bass to predation:

> The population studies of predators in Clifton Court Forebay ... found that sub-adult and adult striped bass are present in large numbers in the forebay. Population size tends to fluctuate throughout the year with the low occurring in early summer and peaking in late fall. The striped bass [pre-screen loss] study described in this report, in which losses of 94% were found, was conducted when the predator population was increasing and losses are more consistent with earlier findings.

Spring 1985

Pre-screen loss estimates were calculated for fall-run chinook salmon fingerlings collected from the Merced River Hatchery spawning channel (Kano 1985; IESP 1987). Staff released fluorescent-dyed fish in three groups at the radial gates and the trashboom. On April 2, about 11,606 fish were released at the radial gates at 1830 hours. On April 3, about 4,066 fish were released at the trashboom at 2345 hours. On April 4, about 1,849 fish were released at the trashboom at 1700 hours. Kano described recovery efforts and recoveries:

> Recoveries of marked fish were made by monitoring the catches of the [Skinner Fish Facility] starting immediately after the first trashboom release and ending on 12 April at 0800 hours. Any chinook salmon found were examined under ultraviolet light to determine if fluorescent marks were present. During the first 20 hours of recoveries the entire catch of the facility was examined for salmon. Subsequent recoveries of marked fish were made by taking subsamples at least once every two hours, and expanding numbers of salmon found to obtain actual numbers caught.
>
> A total of 1,058 marked salmon from the [group released at the radial gates] and 2,117 salmon from the two [groups released at the trashboom] were recovered. Returns from the [group released at the radial gates] were found in the first facility sampling and peaked two days after release. The majority of [the recoveries of fish released at the trashboom] were recovered the same evening after release. The group [released at night while water was being exported], had a slightly higher return (37.4%) than [salmon released during daylight with no water export (32.9%)].

Expanding counts to incorporate 0.69 average louver efficiency, $survival_{tb}$ (combined) was 0.52 and pre-screen loss to the group released at the radial gates was 74.6%. Kano observed that fish used in this study would have been subjected to more predation than in the previous study because:

- The fish were smaller — average size 44.1 mm versus 78.7 mm fork-length,

- Smaller fish would be less likely to move with the flow toward the salvage facility, and
- Subadult and adult striped bass catch-per-unit-effort was 265% greater, indicating that more predators were in Clifton Court Forebay.

Kano also noted:

> Reduced on-peak water exports immediately after the 1985 radial gate release undoubtedly increased delay in movement of fish through the forebay. Comparison of the recovery rate of radial gate releases showed that during 1984 tests, 95% of total recoveries were made by the fifth day (120 hours) after release, while in 1985 tests, that level was not reached until the ninth day (216 hours).

Summer 1986

Pre-screen loss estimates were calculated for juvenile striped bass from the Central Valley Hatchery (Kano 1986). Staff released fluorescent-dyed fish in three groups at the radial gates and the trashboom. On August 6, about 18,486 fish were released at the radial gates at 1040 hours and two groups were released at the trashboom — about 3,369 fish at 1100 hours and 5,574 fish at 2145 hours. Kano described recovery efforts and recoveries:

> Recoveries of marked fish were made by monitoring the catches of the [Skinner Fish Facility] starting immediately after the first trashboom release and ending at 0700 hours on 16 August. Striped bass which were found were examined under ultraviolet light to determine if fluorescent marks were present. During the first 48 hours of collections, recoveries were made from samples taken hourly. Subsequent recoveries were made by subsampling the facility catch at least every two hours whenever possible. Actual numbers of bass found in a subsample of the facility collection were expanded over time to obtain an estimate of numbers caught since the previous sample.
>
> A total of 1,189 marked bass from the radial gate release, and 1,936 bass from the combined trashboom releases were recovered. The first returns from the radial gate group were recovered at the facility four hours after their release. The majority of recoveries for this group of fish were made during the first 24 hours of sampling. The [recovery of fish released at the radial gates] declined rapidly after that, although returns were seen throughout the sampling period. Fish from the radial gate release undoubtedly continued to be collected in the facility after we ended our sampling, but this number was probably small.
>
> The returns of bass released at the trashboom during the day were much lower than those of the night group. A total of 255 day-released fish were recovered, compared to 1,681 marked bass recovered from the night release. Most of the recoveries from both releases occurred during the first evening of sampling, and after three days [fish released at the trashboom were no longer being recovered].

Expanding counts to incorporate 0.76 average louver efficiency, $survival_{tb}$ (combined) was 0.29 and pre-screen loss to the group released at the radial gates was 70.3%. Kano observed that pre-screen loss was lower in this study than in previous studies and that water export during this study was held at a constant rate, higher than in the 1984 striped bass pre-screen loss study. He noted:

> The 1986 Clifton Court Forebay loss evaluation resulted in approximately 70% losses suffered by young-of-the-year striped bass moving through the forebay. This estimate of loss, while still large, was lower than that of the previous evaluation. Reduced losses may have been due to water flows through the forebay allowing faster movement of fish from the radial gates to the facility. Flow through the radial gates when marked fish were released was greater and continued longer in the 1986 experiment; 7,600 cfs for 2.5 hours after release compared to

4,000 cfs for 0.5 hours in 1984. The export rate from the forebay was held at a constant 5,270 cfs throughout the 1986 evaluation. During 1984, exports at the time of peak release were 3,310 cfs, and varied between that level for on-peak hours (0800-2200) and 6,400 cfs for off-peak hours (2200-0800). The 1986 forebay operation probably provided a better orientation flow for bass, decreasing the length of time they were exposed to predators in the forebay.

Spring 1992

Pre-screen loss estimates were calculated for fall-run chinook salmon fingerlings from Mokelumne River Hatchery (Bull 1992). Staff released fluorescent-dyed fish in two groups at the radial gates and the trashboom. On May 4, about 21,894 fish were released at the radial gates at 2030 hours and 3,199 fish were released at the trashboom at 2130 hours. Bull described recovery efforts and recoveries:

> Recoveries of marked fish were made by monitoring the catches of the [Skinner Fish Facility] starting immediately after the first trashboom release. Any chinook salmon found were examined under ultraviolet light to determine if fluorescent marks were present. During the first 30 hours of recoveries the entire catch of the facility was examined for salmon.
>
> A total of 58 marked salmon from the radial gate release, and 639 salmon from the trashboom release were recovered. While first returns from the radial gate group were found in the 0300 sampling on May 5, all fish recovered from this group were recovered by the 2200 hour on May 5. Most of the trashboom group was recovered the same evening after release.

Expanding counts to incorporate 0.29 $survival_{tb}$, pre-screen loss to the group released at the radial gates was 98.7%. Bull observed that pre-screen loss to the group released at the radial gates was higher than in any previous study:

> Although forebay exports were at a maximum 6,400 cfs on 5 May until 0900 hours, at 1000 hours exports were reduced to 375 cfs and further reduced to zero cfs at 2200 hours where it remained for 48 hours. The drastic reduction in water export affected water flow across the forebay toward the salvage facility, which undoubtedly delayed the movement of fish through the forebay, exposing them to increased predation. In addition, the three days prior to the salmon smolt release were unseasonably hot, which may have created additional stress on the young fish.

Winter 1992

Pre-screen loss estimates were calculated for late-fall-run chinook salmon fingerlings from Coleman National Fish Hatchery (Tillman 1993a). Staff released fluorescent-dyed fish in two groups at the radial gates and the trashboom. On December 13, about 10,729 fish were released at the radial gates at 2030 hours and 1,782 fish were released at the trashboom at 2330 hours. Tillman described recovery efforts and recoveries:

> Recoveries of marked fish were made by monitoring total fish collections at the [Skinner Fish Facility]. To accomplish this, collecting tanks at the facility were drained and the entire contents of the fish buckets examined for salmon. Salmon were then removed to a holding container and anesthetized with MS-222 before being examined. Periodic recoveries began soon after the fish release and lasted through January 13 (after approximately 725 hours) until no marked salmon occurred in the collections.

All chinook salmon fingerlings collected were carefully examined under ultraviolet light to detect fluorescent dye markings. Marked fish were then counted and subsamples of fork-lengths recorded at the time of collection.

A total of 1,202 [salmon released at the trash-boom], and 1,677 [salmon released at the radial gates] were recovered. Most of the [recoveries of fish released at the trashboom were] within the first 26 hours following the release....

Subsamples of each release group were held to monitor mark retention and delayed mortalities, to more accurately attribute experimental fish loss to the forebay and to the outlet channel. Tillman noted:

Examination at the end of the study confirmed 100% mark retention for each release sub-sample control group.

Accounting for control group survival in trashboom and radial gate release groups, and expanding counts to incorporate 0.75 $survival_{tb}$, pre-screen loss to the group released at the radial gates was 77.8%.

On relating the results of this study to previous studies, Tillman wrote:

They [Schaffter and Hall] observed an increase in mean fork length of fish recovered, ranging from 16% to 19% increases, over the duration of their studies (10 to 11 days). They attribute this change to selective predation on the smaller juvenile salmon. Nonetheless, results from the present study did not indicate a statistically significant relationship between size at recovery and residence time. However, analysis of the current data clearly indicates a positive relationship between size and survivability ....

Instead, Tillman notes,

Analysis of the current data clearly indicates a positive relationship between size and survivability.

Spring 1993

Pre-screen loss estimates were calculated for fall-run chinook salmon fry from Mokelumne River Fish Hatchery (Tillman 1993b). Staff released fluorescent-dyed fish in three groups at the radial gates and the trashboom. On April 7, about 10,332 fish were released at the radial gates at 2115 hours and two groups of fish were released at the trashboom: about 1,309 fish at 1045 hours and 1,209 fish at 2335 hours. Exports during the study were 3,390 cfs. Tillman described recovery efforts and recoveries:

Recoveries began immediately after the initial release, and continued through April 11, until no marked salmon occurred in the collections. For the first seventy-two hours, total fish collections at [the Skinner Fish Facility] were examined for marked salmon. Thereafter, salvage tank collections were periodically sub-sampled and the contents examined for marked fish. Salmon recovered from the salvage tanks were moved to a holding container and anesthetized with MS-222. All juvenile chinook salmon were examined under ultraviolet light to detect fluorescent dye pigment....

Salvage operations recovered 121 salmon released at the radial gates, 248 released at the trashboom during the day, and 388 released at the trashboom during the night.

Recoveries of [fish released at the trashboom] occurred immediately, with [these fish appearing in the Skinner Fish Facility] salvage collections immediately following each respective release. [Fish released at the radial gates], did not begin to appear in salvage collections until approximately eight hours after release, the bulk appearing about 24 hours [after release].

Roughly 900 marked salmon fry were held from 24 to 72 hours in four pens floated in the forebay and outlet channel. The effort was to address comments that loss across the forebay may be attributed to factors other than predation (eg, water quality, handling stress). Of the 900 penned fish, 34% escaped, and no conclusions were drawn.

Accounting for control group survival for trashboom and radial gate release groups, and expanding counts to incorporate 0.25 $survival_{tb}$ (the average of day and night releases), pre-screen loss to the group released at the radial gates was 95%.

Winter 1993

Pre-screen loss estimates were calculated for late-fall-run chinook salmon juveniles from Coleman National Fish Hatchery (Bull 1994). All fish had clipped adipose fins, and all were coded-wire-tagged and fluorescent dyed. On November 21, three groups of fish were released at the radial gates; about 4,246 were released at 1515 hours, another 1,509 pen-held fish (acclimated in pens floated in the forebay) were released at 1530 hours, and 4,260 were released at 2350 hours. On November 22, three groups of fish were released at the trashboom: about 469 at 1000 hours, another 468 at 1434 hours, and 233 at 2045 hours. Bull described recovery efforts and recoveries:

> Examination of the entire Skinner Fish Facility catch began at 1530 hours on November 21, and continued 72 h. Partial collections of 10-30 min duration were made for the remainder of the experiment. The count of marked fish captured during partial collections was increased using procedures for fish count expansions used in routine Skinner Fish Facility fish salvage operations.
>
> A total of 45 salmon released at the radial gates and 874 salmon released at the trashboom were recovered during the study. The first recovery of a fish released at night at the radial gates was at 1300 hours on November 22 (13 h after release), and the first recovery of a fish released during the day at the radial gates was at 1900 hours on November 22 (28 h after release). Most of the recoveries of fish released at the radial gates were within 48 h, with the last recovery at 2300 hours on November 28. Recoveries of fish released at the trashboom began within an hour of release.

Accounting for control group survival for trashboom and radial gate release groups, and expanding counts to incorporate 0.32 and 0.31 $survival_{tb}$ in the morning and at midday, and 0.47 for the nighttime release, pre-screen loss to groups released at the radial gates (combined) was 99.2%, with 99.8% loss to the group released during daylight and 98.6% loss to the group released at night. Loss to the pen-held group released at the radial gates was 100%.

From the first pre-screen loss study at Clifton Court Forebay to the most recent date, methods used and utility of the studies have received close scrutiny. Comment and observation have revolved around potential biases in the methods used, suggested alternative methods, and the predictive value of modeling pre-screen loss based on the results of extant studies. This chapter addresses each of those categories of comment and observation.

Potential Biases

Several aspects common to the pre-screen loss studies may contribute to bias in pre-screen loss estimates and/or require clarification before comparing pre-screen loss estimates among studies. Quantifying the biases — or designing methods to eliminate them — would be especially challenging. In many cases, as these potential biases were identified, study design was changed to address them.

Biases Due to Calculation for Pre-Screen Loss

The formula for calculating pre-screen loss was:

pre-screen loss = (1-(recapg / relg)) * 100

Biases due to the calculation involve expansion of recapg for losses due to factors at Skinner Fish Facility and estimation of relg. The 1976 and 1978 studies expanded their recapg estimates using published louver efficiencies appropriate for the average size of fish used in the studies. These published louver efficiencies did not incorporate predation and other losses from the louvers through to the holding tanks at Skinner Fish Facility (Skinner 1974). Since the reported louver efficiencies did not account for all sources of loss at Skinner Fish Facility, it is likely that expansion of recapg by these louver efficiencies will underestimate recapg. This potential bias cannot be quantified precisely; yet in this respect alone, the 1976 and 1978 pre-screen loss estimates may be somewhat high. Subsequent studies expanded recapg by survival$_{tb}$, which is an empirical measure of the combined effects of all sources of loss at Skinner Fish Facility. This expansion allows sole attribution of loss to fish released at the radial gates to factors acting upstream of the facility (ie, Clifton Court Forebay).

The number of fish released during each study (relg) was estimated using a mean value for fish/pound. The practical necessity of estimating the large number of fish released during each study will cause error in estimates of pre-screen loss. Within the range of observed recaptures, and assuming ±10% error in the number of fish released, error in estimated pre-screen loss due to this factor is only 1-5%.

Under-Representative Salvage of Experimental Fish

One procedure and several fish behaviors could lead to artificially low recapg values. Loss of marks on experimental fish would result in underestimation of survival to Skinner Fish Facility. Long-term mark retention was evaluated in the winter 1992 and subsequent studies; in all cases mark retention was >95%.

Emigration of marked fish from Clifton Court Forebay would underestimate survival to Skinner Fish Facility. Based on published data on the swimming ability of juvenile salmon (Blaxter 1969 in Hall 1980; Fisher 1981; Taylor 1991) and juvenile striped bass (Young and Cech 1993, 1994; Sazaki et al 1972), marked fish cannot emigrate through the radial gates during most gate operations. However, as hydraulic head across the radial gates diminishes, flow can (but typically does not) approach zero. There is no evidence that marked fish have emigrated through the radial gates (Odenweller 1988). The assumption that marked fish do not emigrate through the radial gates can be evaluated experimentally, in part through recapture efforts outside Clifton Court Forebay (Odenweller 1988).

Marked fish could take up residence in Clifton Court Forebay and be salvaged after recapture efforts have ended; this effect would underestimate survival to Skinner Fish Facility. The forebay, where significant accumulations of large and fine woody debris are actively removed and the bottom and banks are relatively smooth gunite, is not preferred habitat for outmigrating and/or rearing salmonids (Everest and Chapman 1972; Lister and Genoe 1970; Culp, Scrimgeour, and Townsend 1996). Although the lack of preferred habitat does not preclude marked fish from residing in the forebay, it does reduce the likelihood that they will survive long enough to be salvaged (Bisson et al 1987 in Culp et al 1996; Shirvell 1990; Fausch 1993). The assumption that marked fish do not take up extended residence can be evaluated by increasing the duration of recovery efforts, through active sampling for marked fish in Clifton Court Forebay (Hall 1980), and through the use of telemetry tagging methods.

Poor swimming performance among experimental fish, relative to habituated fish, would lead to lower relative louver efficiency during pre-screen loss studies and would underestimate survival to Skinner Fish Facility. Published louver efficiencies (DFG 1973) were derived from the ratio of habituated fish (ie, wild or hatchery fish entrained into Clifton Court Forebay during outmigration) recovered at Skinner Fish Facility to the number of habituated fish recovered downstream of the louvers at Skinner Fish Facility. Because Skinner Fish Facility louvers are behavioral barriers, louver efficiency varies with the swimming ability of fish exposed to them. There is a growing literature on the relative swimming ability of exercised and non-exercised fish, both wild (habituated) and hatchery-reared. Critical swimming speeds were somewhat lower for hatchery-reared than for habituated young-of-the-year striped bass (Young and Cech 1993, 1994).

Poor predator avoidance behavior (lack of habituation to predators) among experimental fish, relative to habituated fish, would underestimate survival to Skinner Fish Facility. Juvenile fish experience significantly lower predation and exhibit different behaviors following exposure to piscivorous predators (Thompson 1966, Kanayame 1968, and Volkova 1976 Patten 1977 in Healey and Reinhardt 1995; Ginetz and Larkin 1976; Olla and Davis 1989). Habituated salmon school in response to the presence of predators; naive salmon do not (Ginetz and Larkin 1976). In all but one case, salmon and striped bass used in pre-screen loss studies were not habituated to predators before introduction into Clifton Court Forebay. From the literature, these fish should experience higher mortality than fish entrained during routine operations.

Information on survival of habituated and naïve fish in Clifton Court Forebay is scarce. None of the 1,500 pen-held fish were recovered during complete counts at Skinner Fish Facility. A single fish was recaptured from a pilot release of <500 habituated fish captured in the Sacramento River (DFG unpublished data). These losses are not substantially different than losses from the conventional pre-screen loss studies. In that the effects of both habituation and release group size were "tested" during these two efforts, it is not possible to attribute the results to habituation alone.

Density-dependent louver efficiency, where fish density and louver efficiency are inversely proportional, would underestimate survival to Skinner Fish Facility. Experimental releases of fish during pre-screen loss studies are probably much larger than influxes during routine operations, leading to higher density at the Skinner Fish Facility louvers. Published louver efficiencies used to expand recapg during the pre-screen loss studies are significantly higher than measured $survival_{tb}$ and may be an indication of inversely proportional density-dependent louver efficiency.

Over-Representative Salvage of Experimental Fish

Two fish behaviors could lead to artificially high recapg values. Predation may be lower on large experimental release groups. This effect would overestimate survival to Skinner Fish Facility. Schooling and large school size are thought to be evolutionary responses to reduce predation (Ginetz and Larkin 1976; Hall, Wardle, and MacLennean 1986; Hamilton 1971; Major 1978 in Healey and Reinhardt 1995). Because the number of fish released during pre-screen loss studies is probably much larger than influxes during routine operations and assuming that experimental fish school after release into Clifton Court Forebay, predation may be lower due to large school size.

The effect of release group size on predation at the Hallwood-Cordua fish screen was evaluated by Hall (1979): loss to fish released en masse was significantly lower than loss to fish released in smaller groups. If this effect occurs at Clifton Court Forebay, pre-screen loss during routine operations is underestimated. Additional information speaks to releasing large groups of fish at the radial gates and is somewhat contrary to Hall's work. Predation on groups of small fishes after release into delta waters was proportional to the number of fish released (Orsi 1967). If this effect occurs at Clifton Court Forebay, the proportion of fish lost during pre-screen loss tests and during routine operations should be similar.

Density-dependent louver efficiency, where fish density and louver efficiency are directly proportional, would overestimate survival to Skinner Fish Facility. Experimental releases of fish during pre-screen loss studies are probably much larger than influxes during routine operations. Marked fish released at the radial gates must travel a relatively long distance and time before reaching the louvers; even without significant predation within the forebay, marked fish density upon reaching the louvers is likely to be lower than at release and lower than for groups released at the trashboom. Because $survival_{tb}$ in large part drives the calculation for pre-screen loss, this effect would underestimate the number of marked fish released at the radial gates surviving to Skinner Fish Facility.

Introducing Experimental Fish Directly into Clifton Court Forebay

Introduction of experimental fish directly into Clifton Court Forebay may contribute a large portion of observed pre-screen loss, regardless of other experimental and/or operational variables (eg, release group size, experimental fish size, degree of habituation, and export rate). Experimental fish are typically subject to varying degrees of (1) temperature shock (Orsi 1971; Coutant 1973; Kjelson and Brandes 1989), (2) altered salinity, and (3) altered light regime, in addition to turbulent flow and predation at the radial gates. Habituated fish entrained into Clifton Court Forebay would only be subject to turbulent flow and predation near the radial gates. The combined and differential effect of these "acute stressors" on experimental fish should increase vulnerability to predation (Coutant 1969; Orsi 1971; Olla et al 1992; Young and Cech 1993; Mesa 1994; Cech *et al* 1996).

Alternative Methods

The potential biases discussed above may result in pre-screen loss values that are substantially different than experienced during routine operations. Two experimental approaches and an alternative to experimental methods have been proposed to evaluate the magnitude of pre-screen loss.

An alternative to introducing experimental fish directly into Clifton Court Forebay was suggested by Brown (1988) and entailed:

- Release of coded-wire-tagged fish outside Clifton Court Forebay,
- Estimates of coded-wire-tagged fish abundance at sites adjacent to Clifton Court Forebay (ie, fish not entrained into the forebay),
- Estimates of coded-wire-tagged fish abundance at Skinner Fish Facility, and
- Returns of coded-wire-tagged fish from the ocean fishery.

This method would eliminate possible biases due to introducing experimental fish into Clifton Court Forebay and is similar to the methods used by the U.S. Fish and Wildlife Service (Kjelson and Brandes 1989) to estimate survival of smolts through various delta channels. Potential difficulties with this sort of approach were described by Collins (1988) and are primarily related to gear efficiency issues at multiple recapture locations.

Another alternative method, suggested by Odenweller (DFG, Inland Fisheries Division, personal communication), entailed:

- Multiple, small releases of coded-wire-tagged fish inside Clifton Court Forebay,
- A large release of coded-wire-tagged fish at Chipps Island, and
- Returns of coded-wire-tagged fish from the ocean fishery.

This method would eliminate possible biases due to emigration of marked fish from Clifton Court Forebay, marked fish taking up extended residence in Clifton Court Forebay, and differential predation on large experimental release groups.

Bioenergetics modeling of pre-screen loss is an alternative to experimental evaluations of pre-screen loss. Used where mark/recapture techniques are not feasible (Beamesderfer et al 1990; Rieman and Beamesderfer 1990), and suggested by Hanson (1989) for use in Clifton Court Forebay, modeling includes parameters representing predator and prey behavior, abundance, and density, as well as environmental and operational parameters (Kitchell et al 1977). Generating and verifying such a model would represent a significant challenge, though a substantial literature exists on many of these parameters and could form the basis of preliminary estimates. These estimates could be compared with empirical measures from pre-screen loss studies, and the feasibility of pursuing a bioenergetics approach could be evaluated.

A heuristic argument related to using a bioenergetic approach to quantify pre-screen loss at Clifton Court Forebay — and in a sense, to further efforts to refine pre-screen loss values — was offered by Odenweller (1988). The assertion was that using then-current estimates of predator abundance in Clifton Court Forebay, pre-screen loss of the magnitude observed would be explained by a predation rate of 1.1 juvenile salmon/predator/month. The implication was that even if estimates of striped bass abundance in Clifton Court Forebay are too high — say 100% too high — pre-screen loss approaching 95% is reasonable based on the food habits of predator-sized striped bass.

Predictive Value

Because most of the experimental pre-screen loss studies used similar methods, biases in the studies should be similar. Thus, although the magnitude of pre-screen loss is open to debate, the results may identify underlying mechanisms influencing pre-screen loss and suggest operational criteria to reduce such loss. Tillman (1993) suggested using regression analysis to evaluate how pre-screen loss varied with experimental fish size, water export, water temperature, and predator-sized striped bass abundance in Clifton Court Forebay. Although the studies were not explicitly designed for use in a regression analysis and data are insufficient to evaluate pre-screen loss to juvenile striped bass, the approach warrants exploration.

Striped bass abundance (relative or absolute) is not used in the following exploratory analysis. Predation by striped bass in Clifton Court Forebay clearly influences pre-screen loss, but there are no rigorous estimates of striped bass absolute or relative abundance in Clifton Court Forebay. Striped bass have been shown to move freely through the radial gates (Gingras and McGee 1997), invalidating absolute abundance estimates from previous mark/recapture studies. Although a rigorous striped bass catch/effort index could substitute for absolute abundance, none has been generated (assuming the proportion of the total.

A multiple-linear regression model relating pre-screen loss to juvenile salmon, water export, fish size, and water temperature was not significant ($p = 0.491$). Figure 3 shows how the parameters relate to each other; it is not surprising that the model lacks explanatory power. After omitting data from the winter 1993 study (number 8 in Figure 3), the model was significant ($p = 0.043$) and explains 91% of the variance in pre-screen loss. This result is likely due to differences in the methods used in the winter 1993 study relative to methods used in other studies (ie, several small groups of

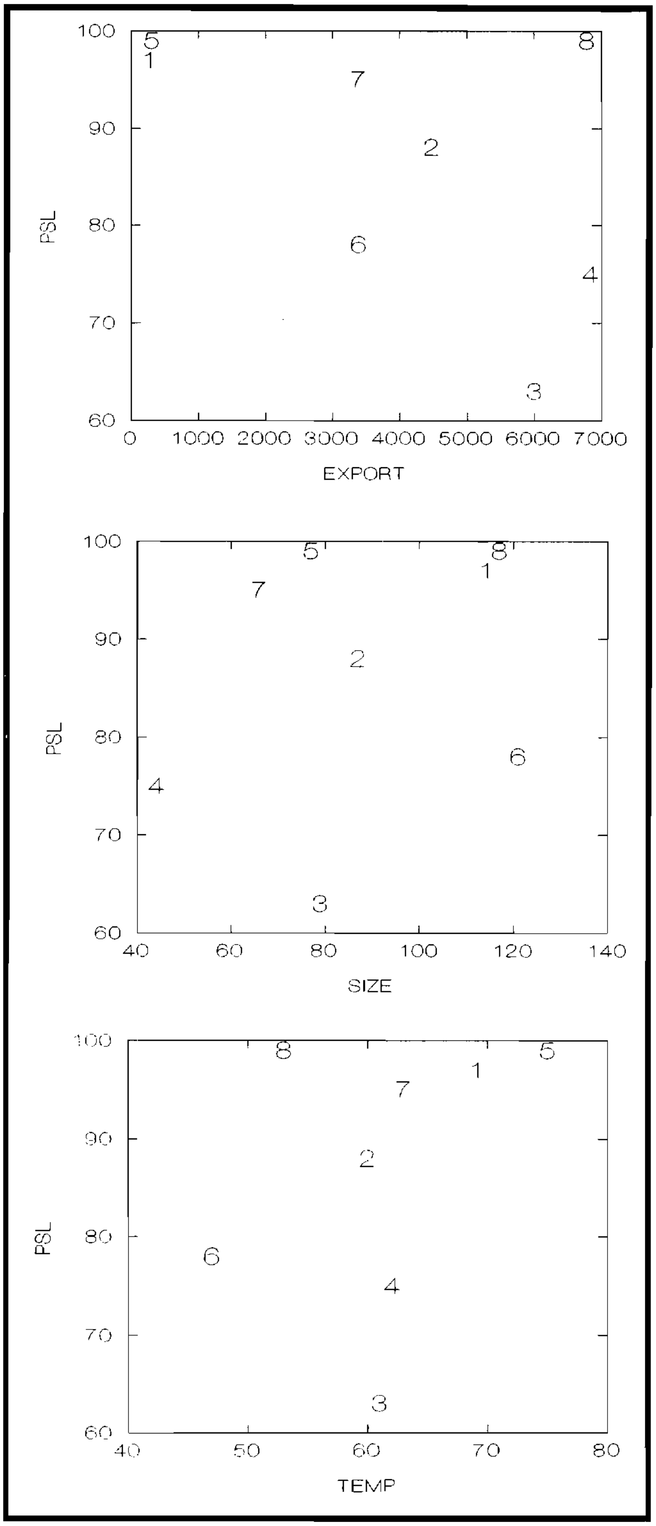

Figure 3
PARAMETERS FROM PRE-SCREEN LOSS STUDIES FOR JUVENILE CHINOOK SALMON, 1976-1993
Symbols indicate study number from 1-8, excluding striped bass studies. In this figure, pre-screen loss values are not arc-sine transformed.

fish were released at the radial gates, rather than one large group; see "Potential Biases").

The strongest single relationship among documented variables that may affect pre-screen loss to juvenile salmon in Clifton Court Forebay is with export rate (multiple $R2 = 0.75$); as export rate increases, loss decreases. This result is not surprising because the relationship between outmigrant residence time within an impoundment and survival is generally quite strong, and inverse (Mullan 1980, Fields 1966, Trefethen 1968 in Hamilton 1991). Residence time in Clifton Court Forebay for a water mass C and presumably for outmigrant salmon and other outmigrant fishes C is inversely proportional to export rate.

Because a large fraction of the variability in calculated pre-screen loss of juvenile salmon at Clifton Court Forebay is explained by a single operational variable (export), the source of pre-screen loss within Clifton Court Forebay is somewhat obscured. As export increases, exposure to predators and/or environmental stressors is reduced. Controlling predator abundance and likely environmental stressors for experimental purposes — or in routine operations to reduce pre-screen loss — is not feasible. Instead, this result simply suggests that operational criteria are warranted to minimize the amount of time entrained juvenile salmon are exposed to Clifton Court Forebay.

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