CENTRAL VALLEY FISH AND WILDLIFE MANAGEMENT STUDY

Predation of Anadromous Fish in the Sacramento River, California

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SPECIAL REPORT
March 1983

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MID-PACIFIC REGION • SACRAMENTO, CALIFORNIA

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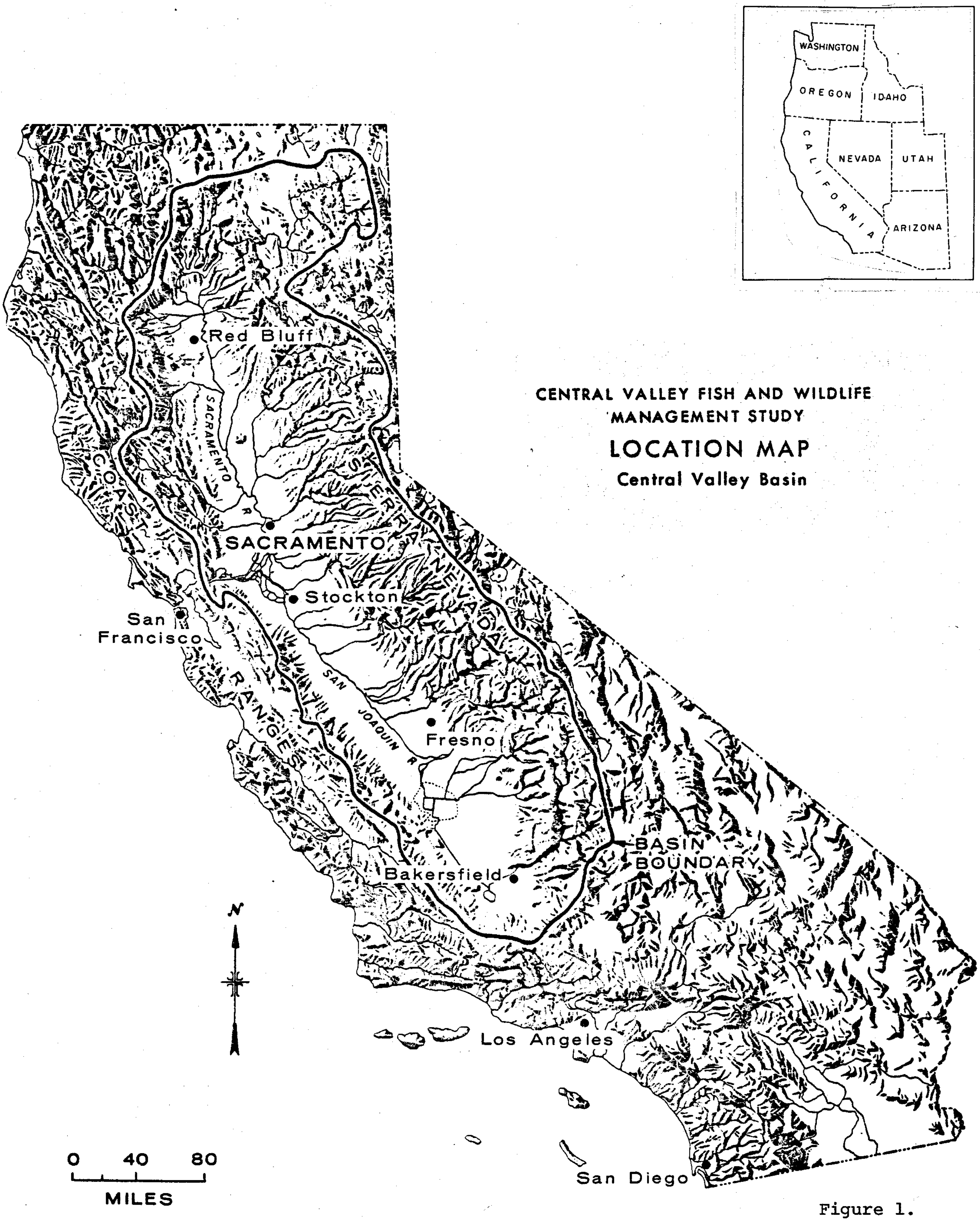


CENTRAL VALLEY FISH AND WILDLIFE MANAGEMENT STUDY

LOCATION MAP

Central Valley Basin

Figure 1.

ABBREVIATIONS USED

ACID	Anderson-Cottonwood Irrigation District
DWR	Department of Water Resources
cm	centimeter
ft^2	square feet
ft^3/s	cubic feet per second
lb, LB	pound
mm	millimeter
BY	brood year
in	inch
°C	Centigrade
°F	Fahrenheit
$\bar{X}$	mean value
FL	fork length
Co.	county
Cr.	creek
Res.	reservoir
No.	number
Aug.	August
Sep, Sept.	September
Oct.	October
Nov.	November
Dec.	December
Jan.	January
Feb.	February
Mar.	March
Apr.	April
avg.	average
wt.	weight
km	kilometer
g	grams
Irrig.	irrigation
UC	uncompleted

SUMMARY

The problem of predation of anadromous fish in the Sacramento River has been appraised as a part of the Central Valley Fish and Wildlife Management Study. Particular attention in this study was devoted to chinook salmon (Oncorhynchus tshawytscha) in the Upper Sacramento River from Keswick Dam to its confluence with the Feather River.

The study disclosed that Sacramento squawfish (Ptychocheilus grandis) and striped bass (Morone saxatilis) are the major predators in the Sacramento River system; yearling steelhead trout (Salmo gairdneri), juvenile salmon, and American shad (Alosa sapidissima) are lesser predators. Observations indicate that squawfish tend to be drawn to and remain in areas where prey congregate and are regularly abundant. Striped bass, in contrast, feed on prey encountered as the bass move about; once they have fed, they do not remain in an area.

The study also disclosed that presently available data on predation of anadromous fish in the Sacramento River appear insufficient to formulate any major predator control measures. A comprehensive study of predation dynamics in the Sacramento River system is warranted. Until such a program can be initiated, however, there may be some predator control measures that can be enacted whenever it can be demonstrated that these measures will reduce predation losses. In developing such measures the available information on causes for abnormal predation, that it was possible to bring together at this time, can be used as a guide. This

information indicates that predation is of minor significance in the unobstructed portion of the river system, but predation on outmigrating young salmonids increases at manmade structures and impoundments, for example, at Red Bluff Diversion Dam. Predator efficiency is increased near manmade structural complexities such as corners, hydraulic deadwater areas, riprap, and overhangs which cause shadows. When prey species are concentrated or stressed, increases in predation are significant. Most predators are sight feeders. At night or at times of high flows or turbidity, when predators are least efficient, mass migration would allow prey to escape more readily. A prerequisite to undertaking corrective measures is a confirmation that the predation actually depresses the survival rate of anadromous fish reaching the adult state.

In any project modifications or in any new project facilities, the potential effects of predation on anadromous fisheries should be adequately assessed. Facilities should be designed to eliminate or reduce to biologically acceptable levels the shadows, hydraulic deadwater areas, and any disorientation of anadromous fish.

PART I

INTRODUCTION

PURPOSE AND SCOPE

This report presents the results of an investigation on the predation of anadromous fish in the Sacramento River. The investigation utilized existing available information; no new data were developed. This analysis, originally limited to the Upper Sacramento River from Keswick Dam downstream to the confluence with the Feather River, eventually was expanded to include the downstream portion of the river.

The report focuses on the predation of two key game species--the chinook salmon and the steelhead trout. The downriver movement of wild (naturally reproduced) salmonids and of salmonids released from Coleman National Fish Hatchery and the Tehama-Colusa Fish Facilities, and the subsequent predation on these fish, are described in this report.

Facilities at which significant predation occurs, or would be expected to occur, are identified and the corresponding degree of predation is discussed.

Cooperating in preparation of the report by the Bureau of Reclamation were the staffs of the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the California State Departments of Fish and Game, and Water Resources.

Introduction

RELATIONSHIP TO OVERALL STUDY

This report is one of a series planned for the Central Valley Fish and Wildlife Management Study. The study area, shown on figure 1, is the Central Valley hydrologic basin. Objectives of the study are to:

1. Identify fish and wildlife problems and opportunities associated with water resource development, distribution, and utilization in the Central Valley.

2. Provide the basis for formulating and recommending a long-range management framework within which fish and wildlife resources can be protected and enhanced.

The overall study, initiated in fiscal year 1979, is being made to formulate a comprehensive fish and wildlife management plan for the Central Valley. This is essential to resolve some of the very complex and controversial water-related fish and wildlife issues.

Water resource development and utilization within the valley are so interrelated that localized modifications of water and land and of fish and wildlife management practices often result in corresponding impacts elsewhere in the valley. Any actions such as modernization of fish hatcheries, streamflow alterations, and modification of control structures cannot be pursued effectively without knowledge of the positive and negative impacts on beneficial uses throughout the system. The comprehensive study of existing basin-wide baseline conditions is being made so that the impacts of proposals to resolve existing fish and wildlife problems or the development of new water supplies can be evaluated adequately.

Introduction

Three categories of problems and opportunities are being addressed in the overall study. They are: anadromous fish, wildlife, and reservoirs and miscellaneous. This report, the first in the category titled anadromous fish, is identified as problem A-10 in table 1 which lists the problems for that category.

BASIN DESCRIPTION

The area covered by the Central Valley Fish and Wildlife Management Study includes two major river basins, the Sacramento on the north and the San Joaquin on the south. The combined basin is nearly 500 miles long and about 120 miles wide. It contains 38 million acres of land, or more than one-third of the area of California. Nearly one-third of the basin area is valley floor, where the bulk of the population, industry, and agriculture is located. The foothills and mountains in the two-thirds of the basin surrounding the valley floor receive most of the precipitation and provide the main source of the water supply for the valley. The summers are hot and usually rainless.

Most of the precipitation occurs in the winter. The water supply of the Central Valley is derived chiefly from snowmelt from the Sierra Nevada to the east, with minor amounts of runoff from the Coast Range mountains to the west, and from precipitation on the valley floor. Runoff varies widely from year to year and from season to season, being highest in the winter and spring, and low in the summer and fall months. Many streams in the area are intermittent, with flow only during wet periods of the year.

Table 1. Anadromous fish problems assigned to Plan Formulation Team A

Problem No.	Description
A-1	Determine the flows required in the Upper Sacramento River to provide for all freshwater life stages of salmon at various population levels.
A-2	Determine whether fish passage at Red Bluff Diversion Dam is a problem and, if so, formulate a solution.
A-3	Evaluate the disturbance that operation of ACID's dam at Redding may have on salmon spawning and egg incubation and its significance to all affected fish populations and formulate possible solutions to problems if needed.
A-4	Evaluate the status of Tehama-Colusa Canal Fish Facilities, including screens to canal intake and develop recommendations for resolving problems and making improvements.
A-5	Investigate the status of the salmon spawning habitat in the Upper Sacramento River and develop recommendations for resolving problems and making improvements.
A-6	Determine the need for additional support for ongoing evaluation of Coleman National Fish Hatchery and Keswick Fish Trap operations, and provide this support if necessary.
A-7	Evaluate the potential of a comprehensive restoration program for San Joaquin salmon and identify the actions required to accomplish this.
A-8	Evaluate the need for fish screens on diversion facilities along the Sacramento River.
A-9	Evaluate the disturbance that operation of Red Bluff Diversion Dam may have on salmon spawning and egg incubation and evaluate its significance to all affected fish populations, and formulate corrective measures if needed.
A-10	Determine whether predation of anadromous fish in the Upper Sacramento River is a problem and, if so, formulate a solution.
A-11	Evaluate the potential for improving the production of anadromous fish in tributaries to the Sacramento River.
A-12	Investigate the need and potential of enlarging Nimbus Fish Hatchery.

Introduction

Water development in the basin spans a period of more than 120 years. Basically, it progressed through four stages. In the first stage, local diversions were made directly from the rivers. The second stage was the widespread use of ground-water pumping adjacent to rivers. In the third, water was stored for use within a river basin. In all of these stages, the water facilities were constructed and operated by individuals, companies, districts, or other water service organizations.

Large-scale Federal water development in the Central Valley began in 1935 with the initial phases of construction of the Central Valley Project by the Bureau of Reclamation. This inaugurated the fourth stage and marked the beginning of coordinated interbasin water development in the Central Valley. In 1961, construction began on the California State Water Project, including joint Federal and State facilities. The primary source of water for the two projects is the Sacramento River Basin, although some water is derived from the San Joaquin Valley to the south, and some is imported from the Trinity River to the west.

The Central Valley Project is a series of storage facilities, conveyance systems, and powerplants constructed, under construction, or proposed, to make multipurpose use of the water supplies that can be controlled by the facilities. The project reservoirs are coordinated in their operation to make maximum use of the available water supply.

Introduction

STUDY AREA

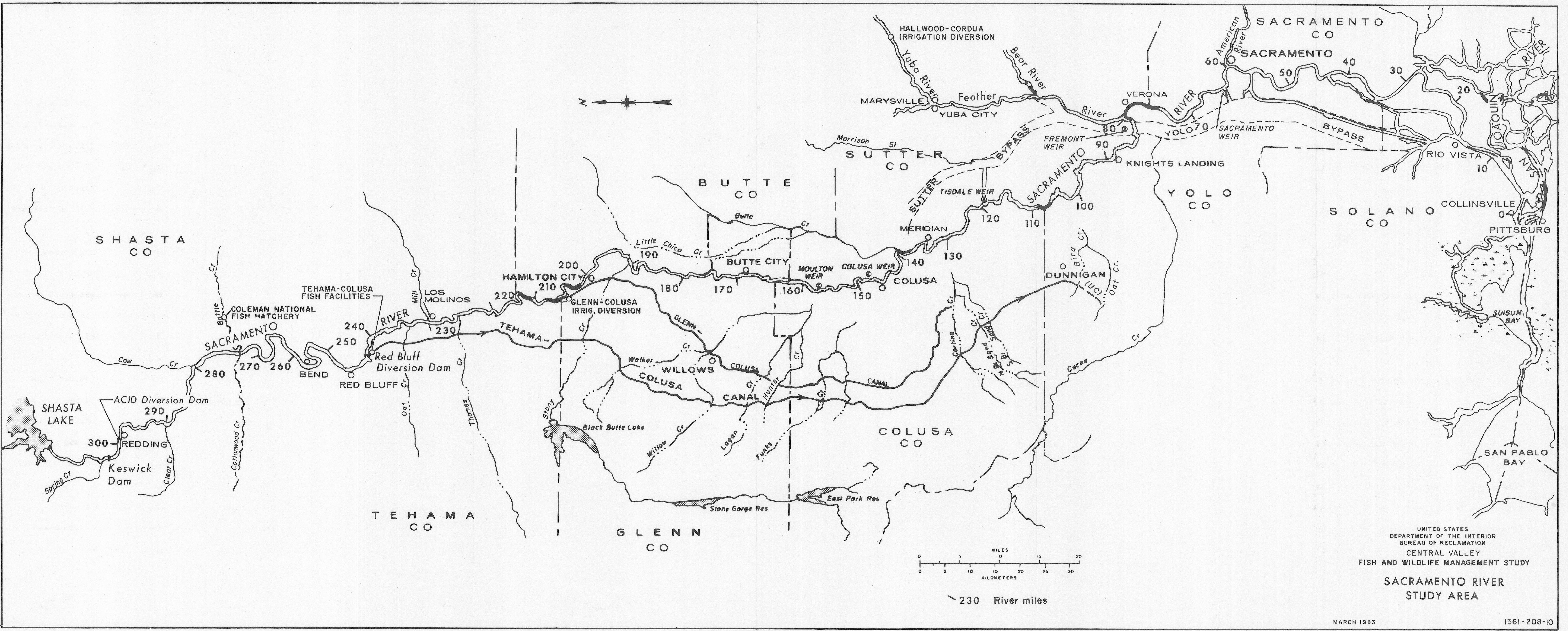
Sacramento River

The Sacramento River drains the northern portion of California's Central Valley, flowing southward, to converge with the San Joaquin River at the western edge of the Sacramento-San Joaquin Delta (figure 2). From there commingled flows continue toward the ocean through Suisun and San Pablo Bays to San Francisco Bay some 430 miles from the Sacramento River's point of origin. The main stem of the Sacramento River provides about 300 miles of salmon habitat.

From the standpoint of both water supply and fishery resource, the Sacramento River upriver from its confluence with the Feather River historically has been the most important reach of the river system. This reach, termed the "Upper Sacramento," is the portion of the river where spawning occurs and is the portion about which this report is primarily concerned.

At Keswick Dam, located approximately 5 miles north of Redding, upstream fish migration is completely blocked. A fish trap at the dam secures salmon spawners for Coleman National Fish Hatchery.

The Lower Sacramento River includes the main stem from the mouth of the Feather River (river mile 80) downstream to the confluence with the San Joaquin River at Collinsville (river mile 0, figure 2). There is no spawning in the lower portion, but main tributaries to the Lower Sacramento River--the American and Feather Rivers and the Yuba River tributary to the Feather River--are major spawning areas.



UNITED STATES
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CENTRAL VALLEY
FISH AND WILDLIFE MANAGEMENT STUDY

SACRAMENTO RIVER
STUDY AREA

MARCH 1983

1361-208-10

LAST PRINTED OR REVISED 4/80, 11/81, 5/82, 11/82

The Lower Sacramento River is relatively unobstructed. Unscreened diversions for various water districts and individuals exist along the entire Sacramento River. However, there is only one major diversion, the Yolo Bypass, a weir which is operated only during times of floodflows.

Delta and Ocean

The large low-lying area formed at the junction of the Sacramento and San Joaquin Rivers is known as the Sacramento-San Joaquin Delta. The Delta, triangular in shape, is bounded by Sacramento on the north, Pittsburg on the west, and Vernalis on the south (figure 3).

The Delta, which includes over 700,000 acres of land, 39,000 acres of water, 700 miles of navigable channels that vary in width from 4,500 feet to less than 100 feet, is comprised of about 30 large, below-sea-level islands surrounded by levees, and hundreds of small, unleveed islands (figure 3).

The Delta is a large, complex system of diverse habitats and a widely fluctuating aquatic environment. Tidal influence of the Pacific Ocean to the west creates strong reversing currents throughout the Delta, with water levels in the Delta channels rising and falling from 3 to 5 feet each day. Under some conditions salinity may increase or decrease as much as sixfold during a 24-hour period.

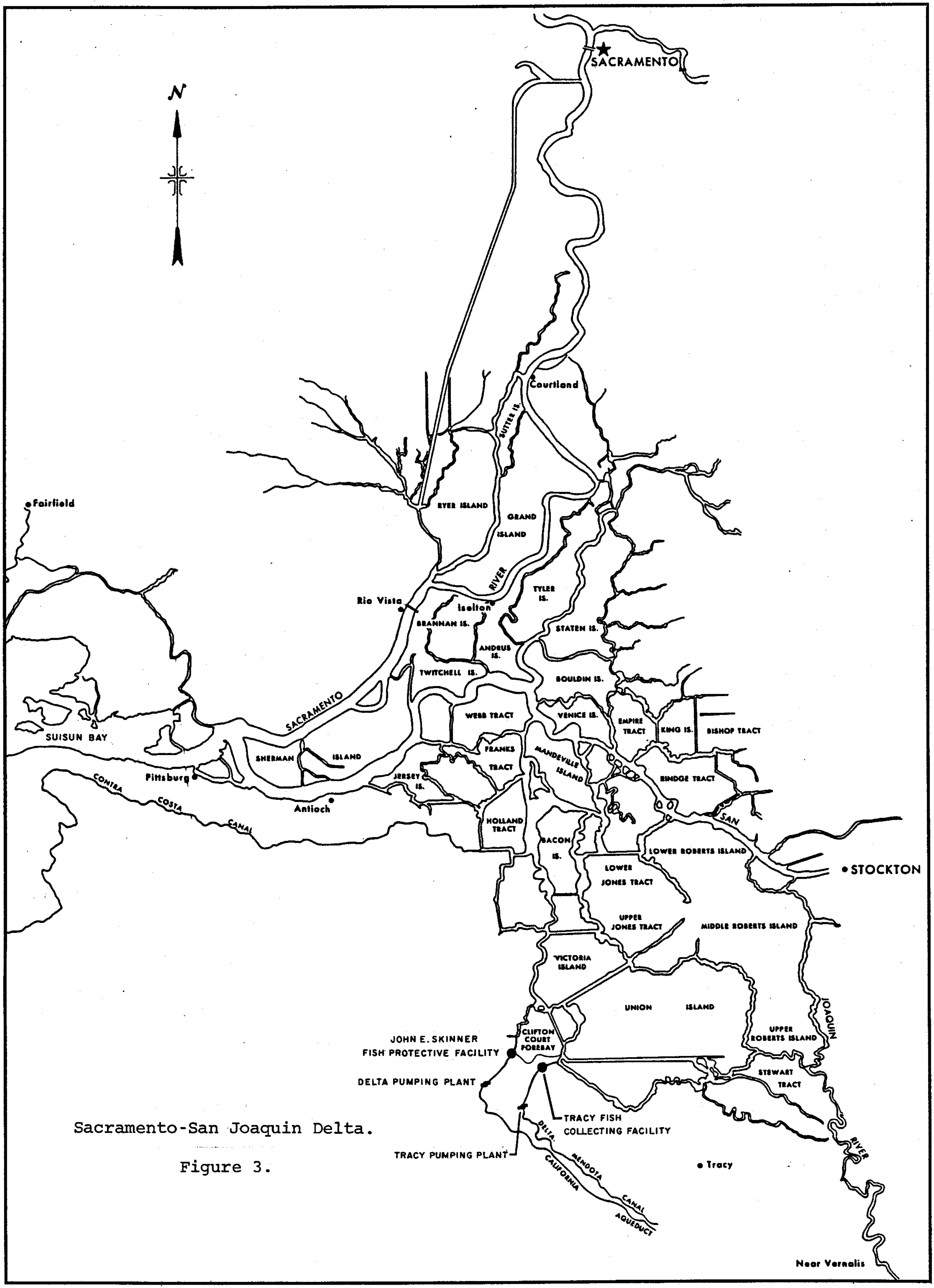
Water is diverted by the Central Valley Project (Map 214-208-4177) and the State Water Project to the San Joaquin Valley. The points of diversion for the two facilities are only 0.6 mile apart on Old River near Tracy. Typical export rates substantially exceed the flow of the San Joaquin River; hence, the remaining export needs are met by diversion of Sacramento River water via the Delta Cross Channel. Water is diverted from the Sacramento River through a short excavated channel and then flows through natural channels for about 50 miles to the vicinity of the pumps. These channels are too small to carry larger flows, so, at higher export rates, water is drawn up the San Joaquin River from its junction with the Sacramento River, causing net upstream flows or reverse flows in the San Joaquin River.

The lower bays include that portion of the San Francisco Bay Estuary below the Sacramento-San Joaquin Delta. The bays include Suisun, San Pablo, and San Francisco. The ocean, as used in this report, consists of that portion of the Pacific Ocean inhabited by salmon which have migrated out of the Sacramento River system.

Facilities

Coleman National Fish Hatchery. The U.S. Fish and Wildlife Service funds and operates Coleman National Fish Hatchery on Battle Creek. The hatchery was constructed by the Bureau of Reclamation to mitigate fish losses due to the construction of Shasta Dam. It is also operated for the investigation, protection, improvement, and conservation of fish in the Sacramento River Basin. Chinook salmon and steelhead trout are the only fish presently propagated there.

Red Bluff Diversion Dam. Red Bluff Diversion Dam is located on the Sacramento River near Red Bluff at river mile 243 (figure 2). The dam provides hydraulic head for flow diversion into the Tehama-Colusa Canal and to the Corning Canal, an irrigation canal which branches off from the Tehama-Colusa Canal. The dam gates were first closed in 1966, backing up



Sacramento-San Joaquin Delta.

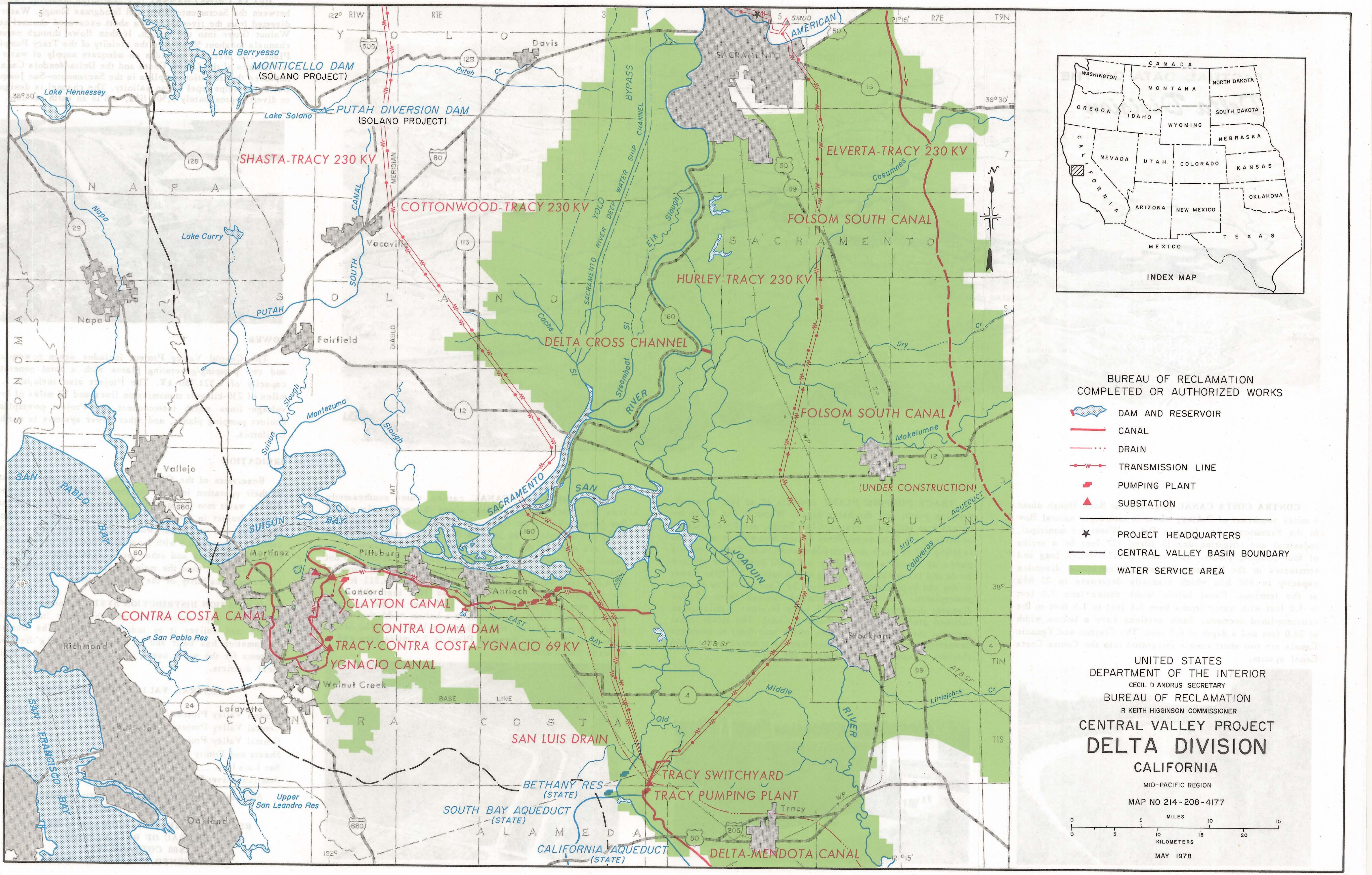
Figure 3.

water for approximately 3 miles to form Lake Red Bluff. The dam and forebay are features of the Federal Central Valley Project which supplies water for irrigation and for fish production at the Tehama-Colusa Canal Fish Facilities.

The dam consists of 11 underflow gate sections, each 60 feet wide. One gate (11) is an automatic regulating gate which helps maintain a constant forebay level. In addition, the dam includes headworks for the fishways at both ends of the concrete section of the dam and low earth dikes at each abutment.

Tehama-Colusa Fish Facilities. Fish facilities of the Tehama-Colusa Canal headworks are designed to bypass fish around Red Bluff Diversion Dam and prevent them from entering the Tehama-Colusa Canal. Louvers in the fish bypass facilities guide the young fish and exclude them from entering the canal.

The fish facilities, a combination mitigation/enhancement facility for the Sacramento Canals Unit, became operational in 1971. The facilities, originally designed to accommodate a total of 40,000 chinook salmon, include two types of spawning canals: a dual-purpose canal which is 3.2 miles long, and is used for irrigation water conveyance and spawning; and two single-purpose spawning canals, each 1 mile long, which branch from the dual-purpose canal. Spawners placed in the channels can be trucked from the fish trapping facility at the diversion dam or diverted directly into the access canal by the fish excluder structure on Coyote Creek, a tributary of the Sacramento.



BUREAU OF RECLAMATION
COMPLETED OR AUTHORIZED WORKS

- DAM AND RESERVOIR
- CANAL
- DRAIN
- TRANSMISSION LINE
- PUMPING PLANT
- SUBSTATION
- ★ PROJECT HEADQUARTERS
- CENTRAL VALLEY BASIN BOUNDARY
- 🟩 WATER SERVICE AREA

UNITED STATES
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R KEITH HIGGINSON COMMISSIONER

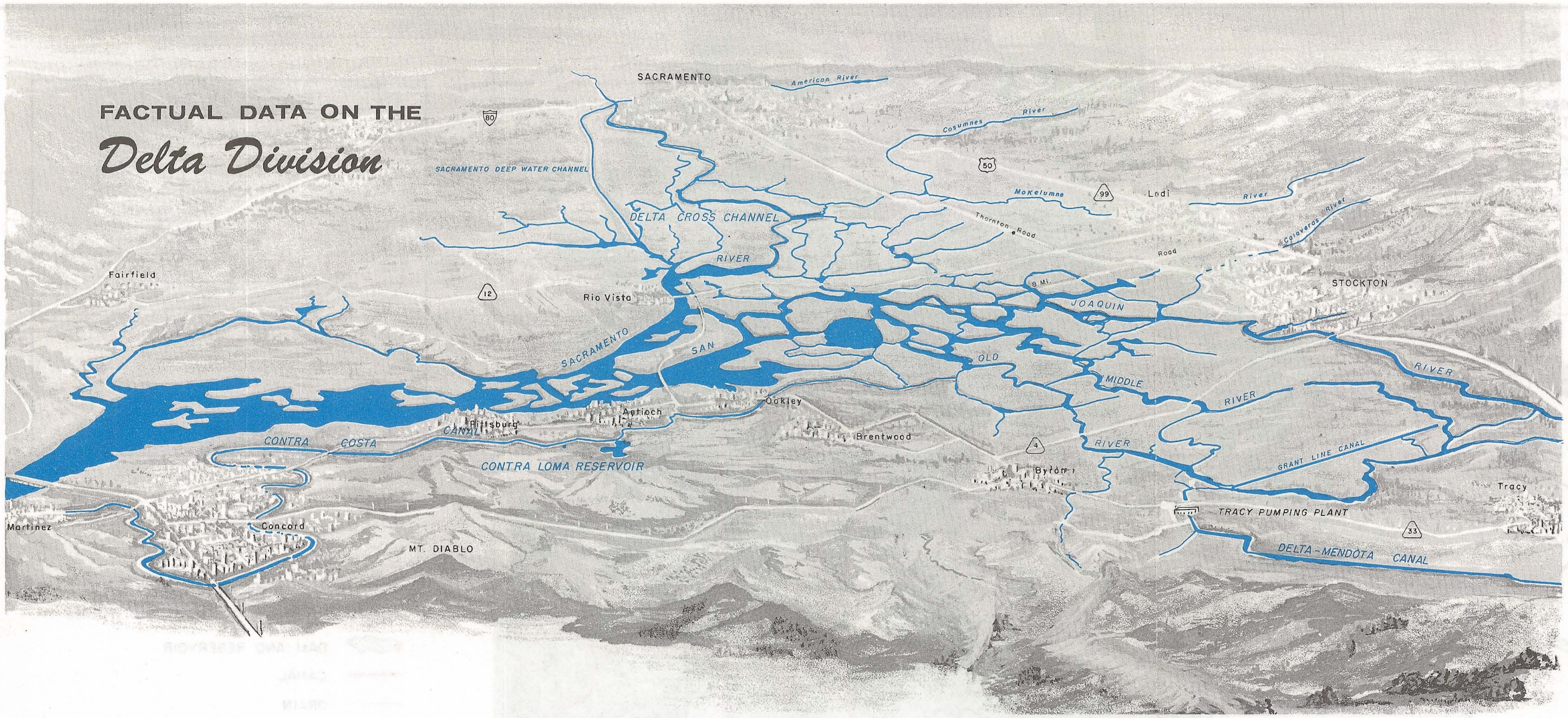
CENTRAL VALLEY PROJECT
DELTA DIVISION
CALIFORNIA

MID-PACIFIC REGION
MAP NO 214-208-4177

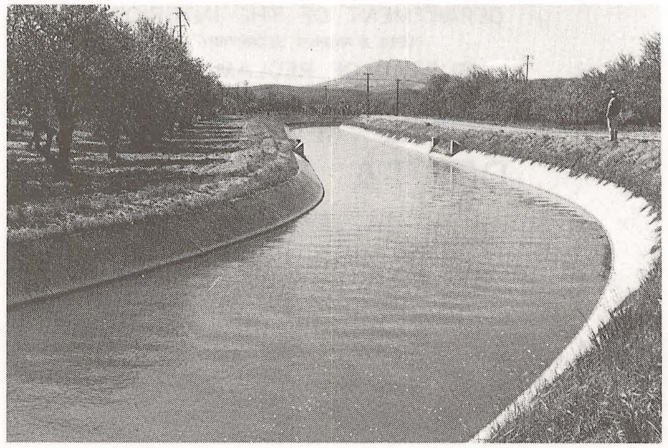
MILES 0 5 10 15
0 5 10 15 20 KILOMETERS

MAY 1978

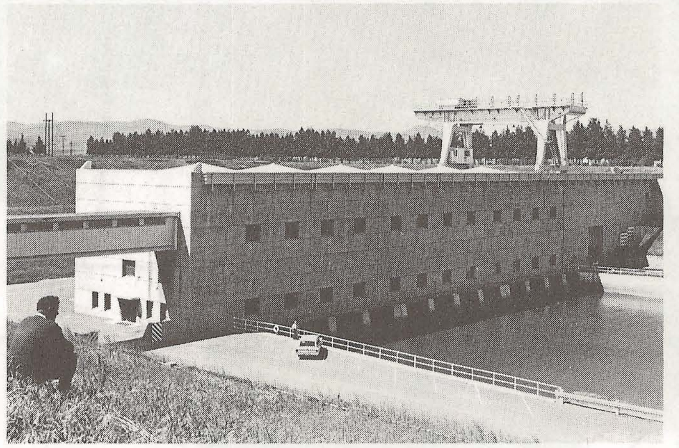
FACTUAL DATA ON THE *Delta Division*



CONTRA COSTA CANAL originates at Rock Slough about 4 miles southeast of Oakley, where it intercepts natural flow in the Sacramento–San Joaquin Delta. Water for municipal, industrial and irrigation use is lifted 127 feet by a series of four pumping plants. The canal is 47.6 miles long and terminates in the Martinez Reservoir. The initial diversion capacity is 350 ft³/s which gradually decreases to 22 ft³/s at the terminus. Canal bottom width varies from 7.0 feet to 3.0 feet with water depths from 7.4 feet to 1.8 feet in the concrete-lined sections. Earth sections have a bottom width of 24.0 feet and a depth of 6.5 feet. The Clayton and Ygnacio Canals are two short canals integrated into the Contra Costa Canal system.

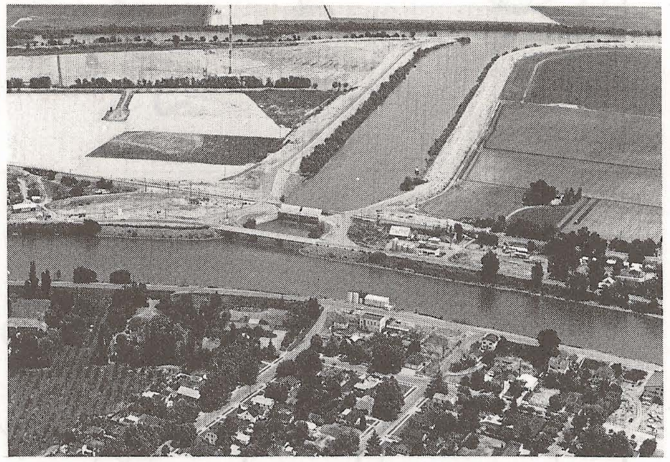


TRACY PUMPING PLANT consists of an inlet channel, pumping plant, and discharge pipes. Water in the Delta released from storage in Shasta, Clair Engle, and Folsom Lakes or entering the Sacramento River system below those reservoirs is lifted 197 feet into the Delta-Mendota Canal. Each of the six pumps at Tracy is powered by a 22,500 horsepower electric motor and is capable of pumping at the rate of 767 ft³/s. Power to run the huge pumps is supplied by Central Valley Project powerplants. The water is pumped through three 15-foot-diameter discharge pipes which carry it about 1 mile up an inclined grade to the Delta-Mendota Canal. The intake canal includes the Tracy Fish Screen which was built to intercept downstream migrant fish so they may be returned to the main channel to resume their journey to the ocean.



DELTA-MENDOTA CANAL carries water southeasterly from the Tracy Pumping Plant along the west side of the San Joaquin Valley for irrigation supply, use in the San Luis Unit, and to replace San Joaquin River water stored by Friant Dam and used in the Friant-Kern and Madera systems. The canal is 117 miles long and terminates at the Mendota Pool about 30 miles west of Fresno. The initial diversion capacity is 4,600 ft³/s which is gradually decreased to 3,211 ft³/s at the terminus. Canal bottom width is 48.0 feet with water depths varying from 16.6 feet to 14.0 feet in the concrete-lined sections. Earth sections have a bottom width that varies from 84 feet to 60 feet with a depth of 13.9 feet. The intake channel to the Tracy Pumping Plant is 2.5 miles long and is an earth lined section.

DELTA CROSS CHANNEL is a controlled diversion channel between the Sacramento River and Snodgrass Slough. Water is diverted from the river through a short excavated channel near Walnut Grove into the slough. It then flows through natural channels for about 50 miles to the vicinity of the Tracy Pumping Plant. The diversion provides an adequate supply of water to the intakes of the Contra Costa and the Delta-Mendota Canals, improves the irrigation supplies in the Sacramento–San Joaquin Delta and helps repel ocean salinity. The channel is designed to divert approximately 3,500 ft³/s, and is an earth section.



POWER

The Central Valley Project includes seven powerplants and two pumping-generating plants with a total generating capacity of 1,321,780 kW. The Project also includes 1,145 miles of 230-kilovolt transmission lines and 72 miles of lower voltage lines which interconnect the Project powerplants, Project pumping plants, and other power systems in northern California.

IRRIGATION

Reservoirs of the Central Valley Project are coordinated in their operation in order to obtain maximum yields and to deliver water into the main river channels and into the canals of the Project in the most efficient and economical manner. Irrigation and municipal water is delivered from the main canals in accordance with long-term contracts negotiated with irrigation districts and other local organizations. The distribution of water from the main canals to the individual users is the responsibility of the local districts.

IRRIGATION DISTRIBUTION SYSTEMS consists of lateral canals and pipe systems to take the water from the main canals and deliver it to individual farms. The Bureau of Reclamation has built and is presently building distribution systems for the water users, while others are being built by local districts.

CENTRAL VALLEY PROJECT MAPS

Central Valley Project	214–208–5133
Central Valley Project, North Half	214–208–4174
Central Valley Project, South Half	214–208–4175
Shasta and Trinity River Divisions	214–208–4469
San Luis Unit	214–208–5165
American River Division	353–208– 138

Address all inquiries regarding additional information concerning this project to:

REGIONAL DIRECTOR, MID-PACIFIC REGION
BUREAU OF RECLAMATION
2800 COTTAGE WAY
SACRAMENTO, CALIFORNIA 95825

Introduction

Glenn Colusa-Irrigation District Diversion. The Glenn-Colusa District's irrigation diversion is on a side channel which forms an island on the right bank of the Sacramento River approximately 3-1/2 miles northwest of Hamilton City at river mile 205 (figure 2). During the irrigation season from March through October, a dam is installed in the diversion channel to provide hydraulic head for the pumps which divert 2,700 cubic feet per second from the river. A fish screen complex, located at the head of the irrigation canal, consists of a concrete structure housing 40 horizontal rotating drum screens that are removed in winter. A trashrack keeps large debris from entering the screen wells. Ten bypasses, one located at the downstream end of every fourth screen, join and lead to a bypass outlet.

Hallwood-Cordua Irrigation Diversion. A fish screen bypass and fish collection facilities are located on the Hallwood-Cordua irrigation diversion (figure 2) near Daguerre Point Dam on the Yuba River about 12 miles east of Marysville. The screening facility, located in the canal about 1,300 feet downstream from the diversion site, consists of approximately 3,900 square feet of aluminum perforated plate distributed over three sections. The primary screen is a vertical wall "V"-section which is centered in the diversion channel with the wide end upstream, and has a screen floor throughout its length. At the upstream end of the "V", vertical panels perpendicular to the flow extend to shore. On the downstream end of the primary screen section is a trashrack of rectangular steel bars spaced about 1 inch apart.

The collection facility includes a flow control tower, a discharge line from the control tower to a concrete fish collection tank where fish are identified and counted, and an aboveground bypass, 1,000 feet long, entering the Yuba River about 500 feet downstream from the dam.

Yolo Bypass. The Yolo Bypass, normally dry and farmed in the summer, is a broad shallow channel designed to divert floodflows safely from the Sacramento River and its tributaries. Diversion of water is controlled by five weir gates. The Moulton, Colusa, and Tisdale Weirs divert floodflows into the Sutter Bypass which empties into the Yolo Bypass; the Fremont and Sacramento Weirs divert water directly into the Yolo Bypass (figure 2). Only the Sacramento Weir is operated manually in accordance with criteria established by the California Department of Water Resources. There are a total of 48 gates which can be opened mainly to relieve flows from the American River above 115,000 ft^3/s. The bypass parallels the Sacramento River Deep Water Ship Channel to reenter the Sacramento River near Rio Vista.

Clifton Court Forebay. Clifton Court Forebay, with 2,200 surface acres, serves as a large holding reservoir for the Delta Pumping Plant. The forebay is a fluctuating pool that temporarily stores water diverted from Old River via five radial gates. Fish that pass through the gates must cross the forebay before being recovered at the John E. Skinner Delta Fish Protection Facilities. At the fish protection facilities, fish are collected, concentrated, identified, and counted. Salvaged fish are trucked to a release point on the Sacramento River approximately 4 miles downriver from Rio Vista.

Tracy Fish Collecting Facility. The Tracy Fish Collecting Facility, which diverts water from the Sacramento-San Joaquin Delta into the Delta-Mendota Canal for delivery to the San Joaquin Valley, is located approximately 2-1/2 miles northeast of the Tracy Pumping Plant. Young salmon, steelhead, striped bass, and other fish which have been diverted from their migration by the pumping plant are collected and returned to the Delta. Nonmigratory and larger fish also are collected for release. The fish are louvered, concentrated, collected, and hauled to release points far enough downstream to escape the influence of the pumps.

FOCUS OF REPORT

Commercial and recreational fisheries of the Upper Sacramento River have developed primarily around two main anadromous fish species: steelhead trout and chinook salmon. Millions of dollars have been spent on the management and propagation of these economically important fish. As a part of the mitigation measures for developing the rivers and streams of the Central Valley, salmon hatcheries and spawning channels were constructed. Considerable sums of money have been spent on habitat improvement, fish passage facilities, fish counting, tagging, and other management and research activities. However, the annual number of fall-run chinook salmon spawning in the Upper Sacramento River (above the Feather River) has declined, while spawning populations utilizing the Lower Sacramento River system have not shown a similar decline. The fall-spawning chinook salmon populations for 1953-76 in the Sacramento River system above the Feather River and the three primary spawning areas in the Lower Sacramento River system (Feather, Yuba, and American Rivers) are depicted in figure 4. The causes for this decline are not fully documented, but predation of downstream migrating smolts and juveniles has been suggested as being a major contributing factor.

Populations of living organisms fluctuate naturally depending on the factors acting to limit their numbers. In the absence of limiting factors, a population will expand. Eventually, however, some controlling factors will emerge to limit the population growth. Predators are one example. Another is the physical limitation of the habitat within which the population occurs. Unchecked population growth will eventually be controlled by density-dependent factors such as food availability, disease, reproductive failure, etc.

Balanced predator-prey relationships respond to fluctuations in the population levels of both the predator and prey species. These relationships can be disrupted by significant habitat changes favoring either species. For example, an increase in prey vulnerability can lead to greater food availability for predators, with increased survivability among predators, and, hence, their greater numbers. The greater number of predators will have a cumulative effect of cropping a greater number of prey organisms. Balanced relationships will recur, but at a level which supports an increased number of predators.

Naturally balanced predator-prey relationships apparently are due to a long, shared evolutionary history. The prey species evolve sufficient defense mechanisms for some individuals in each generation to survive. The predator species, likewise, have characteristics that assure an adequate harvest of prey. To eat and be eaten is fundamental to any aquatic habitat, and the annual removal of fish by piscivorous fish is one aspect of natural mortality. Breakdowns of these balanced relationships which result in major long-term changes are rare in nature and usually involve catastrophic events such as earthquakes, volcanic eruptions, etc. It is significant that many of the major changes which can be documented have resulted from man's actions.

This report focuses on increased predation of key game species resulting from manmade obstructions where fish are stressed, concentrated, or delayed in their downstream migration. The movement of salmonids as they are released from Coleman National Fish Hatchery and the Tehama-Colusa Fish Facilities through the predation gauntlet they face is described in this report. Wild (naturally reproduced) salmonids face similar problems. In addition, this report briefly discusses predation problems in streams tributary to the Sacramento River where specific studies have been made to document them.

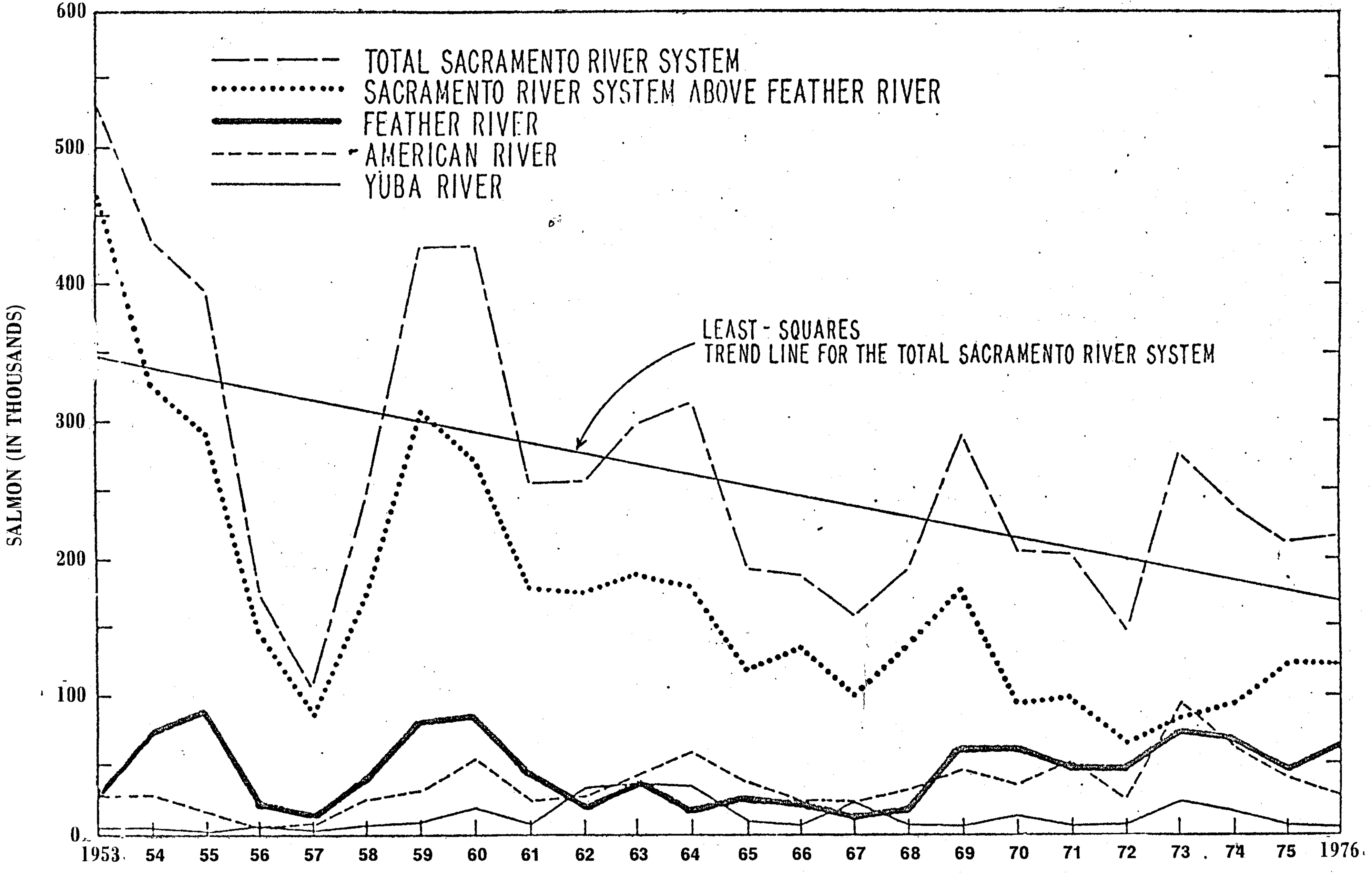


Figure 4. Fall spawning chinook salmon populations in the Sacramento River system, 1953-1976. Figure from R. J. Hallock, Anadromous Fisheries Branch, California Department of Fish and Game, undated manuscript entitled Status of the Sacramento River System Salmon Resource and Escapement Goals.

PART II

PREDATION AT COLEMAN NATIONAL FISH HATCHERY

At Coleman National Fish Hatchery (figure 5) eggs are collected from fall-run chinook salmon returning to Battle Creek and from fall and late-fall run chinook salmon collected at Keswick Dam Fish Trap. Progeny from these adults are reared to various sizes and released to migrate down the Sacramento River to sustain the population.

Hallock, et al., (1980) indicated that a relationship exists between the recovery of adult salmon and the size at which they were released into streams as juveniles. The percent of salmon recovered by the commercial ocean fishery varied directly with the weight at which these fish were released at three Sacramento River system hatcheries--Coleman National Fish Hatchery, the Feather River Hatchery and Nimbus Salmon and Steelhead Hatchery (figure 6), and at streams in Washington State where salmon were reared and released at various locations (figure 7). The data indicate that the highest rate of increase in recovery occurs at juvenile release sizes of less than 10 grams; thereafter, the rate of increase declines but the percentage of returns still remains higher at larger sizes.

Coleman National Fish Hatchery releases the majority of the salmon fingerlings in April and May at about 90 fish to the pound, or approximately 5 grams each (table 2). These releases coincide with the normal smolting period for fall-run chinook salmon. Earlier releases would

Table 2. Chinook salmon releases from Coleman National Fish Hatchery
Data from Richardson (1981)

	Juveniles released	
	Spring	Fall
Year	90/LB	40/LB
	(1,000)	
1951	8,738	1,694
1952	19,924	1,483
1953	28,220	1,483
1954	33,900	3,157
1955	17,307	2,713
1956	22,907	3,781
1957	14,689	3,808
1958	11,167	3,225
1959	5,220	2,270
1960	30,517	4,506
1961	29,136	4,089
1962	17,080	3,988
1963	34,192	5,484
1964	1,428	5,962
1965	13,239	5,375
1966	2,650	7,483
1967	129	6,157
1968	3,010	7,363
1969	1,278	2,281
1970	2,947	3,057
1971	5,129	2,619
1972	7,203	0
1973	4,697	0
1974	6,614	0
1975	1,943	1,896
1976	2,801	1,714
1977	6,519	1,221
1978	3,278	1,971
1979	427	2,195
1980	11,562	1,643
1981	14,495	2,135

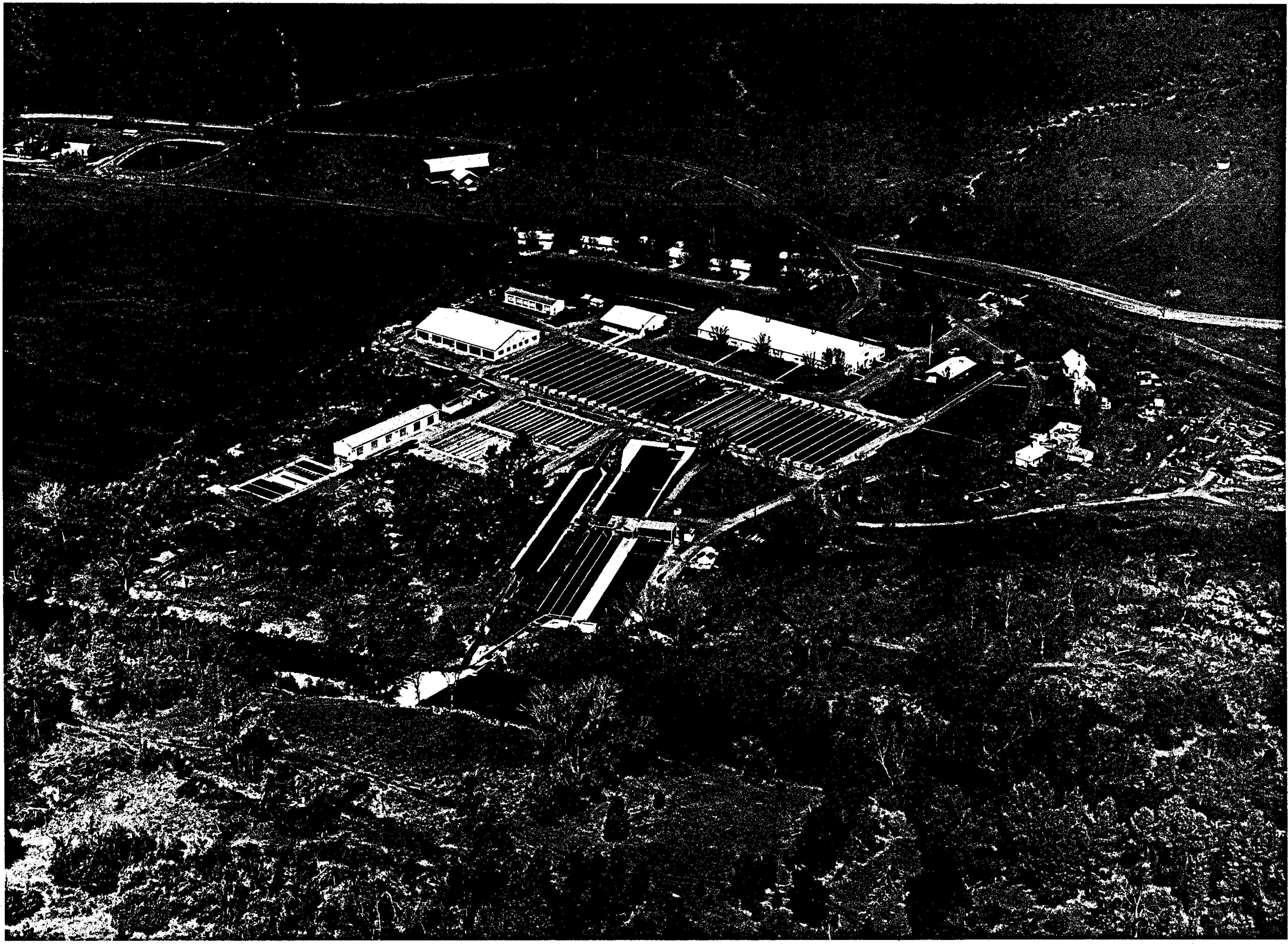


Figure 5. Coleman National Fish Hatchery.

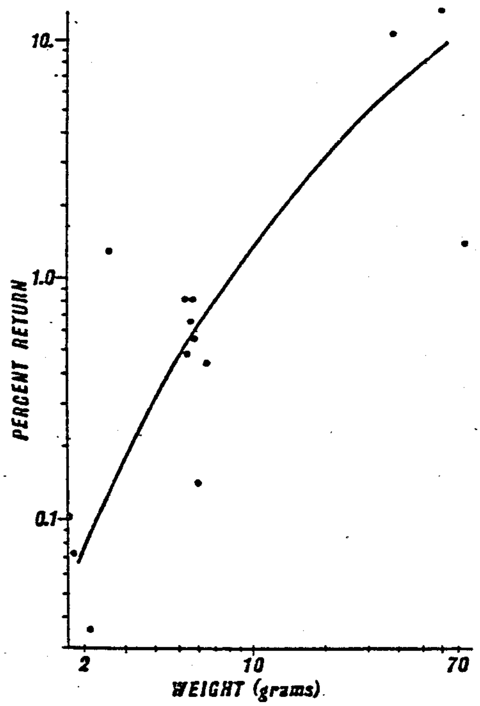
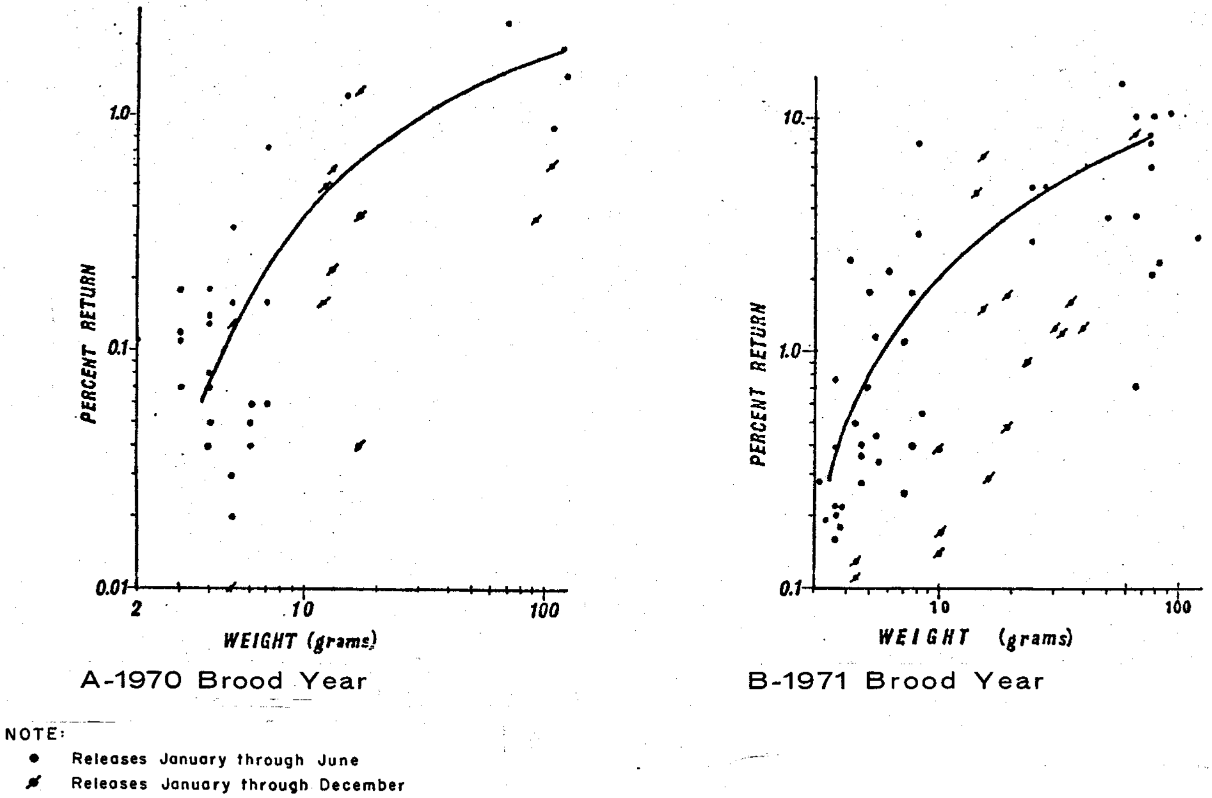


Figure 6. Percent recovery by the ocean fisheries and at the hatchery of marked groups of fall-run chinook salmon released in the Sacramento River system at different sizes. Figure from Hallock et al., 1980.



A-1970 Brood Year

B-1971 Brood Year

Figure 7. Percent recovery by the ocean fisheries of marked groups of fall-run chinook salmon released in Washington state streams. Figures from Hallock, et al., 1980.

result in decreased survival. Because high water temperature in the Delta from June through September precludes smolts from passing to the ocean with reasonably good survival rates, a relatively small number of late fall-run juveniles are held over the summer for an October release at about 40 fish per pound, or approximately 11 grams each. Chinook smolts cannot tolerate high water temperatures. Kjelson, et al., (1981a) state that smolts prefer water temperatures of 12-14 °C, but summer water temperatures in the Delta reach 22 °C. They stated that virtually all smolts in the Delta in June of 1978 and 1981 perished when the water temperature reached 23 °C.

Yearling steelhead trout are released in February and March at about 7 fish per pound, or 65 grams each. To minimize damage due to handling, the holding pond screens are removed in the morning, allowing the fish to exit into Battle Creek on their own.

Winter and spring run chinook salmon will be propagated at the hatchery. Water chillers needed to maintain suitable water temperatures for the propagation of these two races have been acquired but are very expensive to operate. The Fish and Wildlife Service has obtained power at lower rates so that the chillers may be operated.

Hatchery personnel consider predation at the release site to be minor in relation to the problem at Red Bluff Diversion Dam. However studies have shown that yearling steelhead trout released from the hatchery become predators of wild chinook salmon fry.

In 1975, the California Department of Fish and Game sampled stomachs of Coleman-released yearling steelhead to determine the extent of predation on naturally produced salmon fry and eggs in Battle Creek (Menchen 1981). Yearling steelhead releases (totaling 653,317) were made on three different dates: February 20, March 31, and April 2. Anglers using various artificial lures caught 910 of these hatchery-released yearling steelhead in Battle Creek from February 20 to April 18. Stomach analysis of the steelhead indicated that a variety of prey were consumed, including an average of 1.4 salmon fry and eggs per day per fish. If all the steelhead released had spent only 1 day in Battle Creek, they would have consumed approximately 900,000 fry and eggs; in 2 days, almost two million (digestion rate unknown). Menchen (1981) concluded that the portion of the salmon production in Battle Creek consumed by the steelhead migrating down Battle Creek to the Sacramento River was significant.

Painter and Wixom (1975) observed hatchery yearling salmon preying on chinook salmon fry in the Feather River below the Feather River Fish Hatchery. They evaluated predation by hatchery-released chinook salmon on chinook salmon fry. Stomach analysis of 157 predators (all were hatchery-released yearling chinook salmon) yielded an average of 1.3 salmon fry per yearling. The authors extrapolated these data to predict a loss of 7.5 million fry outmigrants to approximately 0.5 million yearling salmon released from the hatchery. The yearling salmon released from Coleman National Fish Hatchery may prey on fingerling salmon in Battle Creek and in the Sacramento River.

Sacramento squawfish have been observed congregating at the confluence of Battle Creek and the Sacramento River and preying upon young salmon. Squawfish are also known to move into Battle Creek to spawn during the peak downriver migration of wild and hatchery released chinook salmon. Squawfish have been characterized as opportunistic predators, feeding on whatever prey is most abundant at the time. No studies have been undertaken either to quantify or to qualify the magnitude of the losses. The role of squawfish as salmon predators is discussed in the following section on Red Bluff Diversion Dam, where a major problem is known to exist.

Striped bass have been observed in Battle Creek feeding on juvenile salmon. Bass are considered to be more effective predators than squawfish; however, squawfish far outnumber the bass. Therefore, the squawfish have a greater impact on salmon fry survival near Coleman National Fish Hatchery.

PART III

PREDATION AT RED BLUFF DIVERSION DAM

At Red Bluff Diversion Dam (figure 8), downstream migrants either pass through the gate sections beneath the open gates, through the fish ladders, or through the Tehama-Colusa Fish Facilities fish bypass. Gate 11 is usually held in a partially raised position. High water velocities create turbulence and a rollback phenomenon immediately downriver from the dam which tends to stress and disorient the fish. The fish bypass diverts the migrants back into the Sacramento River approximately 200 feet downriver from the dam. The fish are disoriented by being diverted through the canal intakes, being swept past the louver array, and being conveyed through several hundred feet of buried pipe at high velocities. Finally, they are forced through the diffuser grates at high velocities creating a "boil" effect (figure 9). Fish which are injured or disoriented are extremely vulnerable to predation.

GENERAL PREDATION

One of the major contributing factors to the declining salmon runs has been identified as predation below the dam on downstream migrating juveniles.

Hallock (1980) conducted a study between 1973 and 1977 to determine if losses were occurring among yearling steelhead trout. Approximately equal numbers of steelhead were marked and released at Coleman National Fish Hatchery and immediately downstream from Red Bluff Diversion Dam.

Predation at Red Bluff Diversion Dam

Of the group released below the dam, 36 percent more adults returned to the hatchery. No attempt was made to determine the cause of the losses. Losses occurring between the hatchery and the dam were assumed to be minimal; the decreased survival for steelhead released at Coleman National Fish Hatchery was assumed to be a result of passing the dam.

A series of tests was initiated in 1975 to determine if losses were occurring among fingerling salmon migrating downstream past the Red Bluff Diversion Dam. Studies were designed to determine whether passing under a dam gate was harmful to fingerlings (Menchen, 1977; and Hallock, 1981). The results of the studies proved to be inconclusive. No statistically significant differences were noted for two of the tests. Where there were significant differences, they were contradictory, i.e., in one test, fish released above the dam had higher recoveries than those released below, while in the subsequent year, the recoveries of fish released below the dam were greater. However, predation in the area below the dam observed during the periods when fingerlings were released was extreme (Hall, 1977). The observed predation has led to major concerns regarding salmonid losses due to piscivorous fish (mainly squawfish) immediately below the dam. No formal studies have been made to quantify predation losses in Lake Red Bluff or at the louver bypass exit. Projections of predator losses have been based on minimally reliable data. Predation has been demonstrated to be a significant problem in large impoundments such as Clifton Court Forebay (Schaffter, 1978; and Hall, 1980b) and Drano Lake on the Columbia River (Zimmer, 1953).

Figure 8. Red Bluff Diversion Dam, viewed from the left bank. Sacramento River flow is from right to left. The Tehama-Colusal Canal headworks are located on the right bank, center of figure.

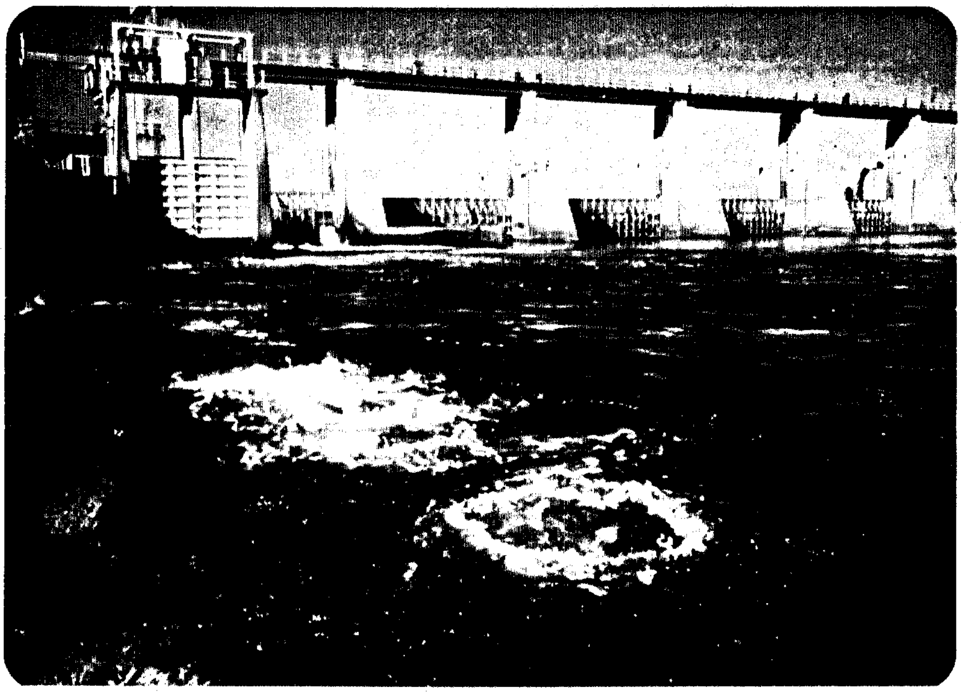


Figure 9. Turbulence at exit of fish bypass line from louvers downstream from Red Bluff Diversion Dam.

Predation at Red Bluff Diversion Dam

Losses of salmonids to squawfish at Red Bluff Diversion Dam prompted a request in 1977 for a permit to remove squawfish by angling from the closed area immediately below the dam. Since then a squawfish derby has been held each year. Prior to the start of the 1977 derby, 241 squawfish were caught in the 2 days of permit angling, marked, and released. Anglers fishing immediately below the dam removed 800 squawfish (of which 16 had been marked) (Hall, 1977). Chinook salmon smolts were released from Coleman National Fish Hatchery to coincide with the first day of fishing. No releases were made for the second day of permit angling a week later. Gross examination of a sample of the squawfish caught yielded salmon as the only identifiable remains in the stomachs. Of those caught the first day, the sample indicated 55 squawfish had consumed 80 salmon. The second day, the sample of 94 squawfish had consumed 55 salmon. The number of squawfish population concentrated below the dam was estimated at approximately 12,000.

Squawfish are not the only piscivorous fish found below Red Bluff Diversion Dam. In 1979, electrofishing below the spillway areas yielded numerous adult chinook salmon, striped bass, and American shad. One striped bass stomach dissected immediately after capture contained 21 skeletons closely resembling juvenile salmonids (Villa, 1979). Hall (1977) cited information which showed that five American shad taken below the dam in 1976 had each ingested from two to seven chinook salmon smolts. Upstream migration of shad past the dam begins to peak in May; a large number of salmonids are released in the same period. The relative density of each population may cause a unique predator-prey relationship due to the relative density of each population.

SQUAWFISH PREDATION

Although squawfish are not the only predators at Red Bluff Diversion Dam, they are the most numerous and have drawn the most debate regarding possible control measures especially since they are a nongame fish. There are three philosophies concerning ways of controlling squawfish. Some fisheries biologists--especially those charged with the task of trying to enhance the salmon runs--believe the only way to control predation is to remove all the squawfish migrating up the fish ladders to spawn upstream of the dam. Table 3 summarizes the estimated annual squawfish migration past the dam.

Many biologists advocate selective predator control of those predators doing the most harm (conditioned to feed on disoriented migrants passing the dam) during the peak smolt migration period (late April through early June). Other biologists believe that too little is known about the life cycle of the squawfish to design a successful predator control program, and that the results of such a program cannot be accurately predicted. With the data presently available, a review of the literature concerning predation with an emphasis on squawfish and how that information applies to problems at Red Bluff Diversion Dam follows.

While it has been well documented that squawfish are major predators in artificial situations such as below dams, at screen structures, or below hatcheries following releases of salmonids, various studies

Table 3. Counts of Sacramento squawfish and American shad migrating upriver past Red Bluff Diversion Dam. Data from daily unadjusted actual count records (unpublished) by U.S. Fish and Wildlife Service staff at the Tehama-Colusa Fish Facility

	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
Squawfish													
1977-78	1,575	102	287	179	37	8	673	2,243	9,182	7,092	4,057	699	26,134
1978-79	656	175	249	129	126	16	46	1,342	8,843	4,143	3,939	268	19,932
1979-80	352	91	115	135	333	103	520	737	2,648	5,001	3,446	814	14,295
1980-81	572	340	177	92	9	1	15	46	1,003	8,242	2,491	1,586	14,574
Shad													
1977-78	1,043	3	0	0	0	0	0	0	0	0	246	4,178	5,470
1978-79	189	2	0	0	0	0	0	0	0	1	7	7	206
1979-80	0	0	0	0	0	0	0	0	0	0	94	203	297
1980-81	87	5	0	0	0	0	0	0	0	0	31	2,433	2,556

No similar counts for shad. Squawfish annual counts for the period 1968-69 through 1976-77 are: 1968-69, 12,177; 1969-70, 10,144; 1970-71, 12,772; 1971-72, 18,676; 1972-73, 21,219; 1973-77, no counts.

indicate that salmonids are not major prey items under natural conditions (Moyle and Brown, 1982).

Buchanan, et al., (1980, 1981) suggested that previous reports of squawfish predation in flowing rivers were misleading because they were often based on artificial situations which could have inflated salmonid predation values. They devised a study to evaluate predation in the lower reaches of the Willamette River of Oregon during peak outmigrations of salmonids. Squawfish were captured in the spring of 1976 and 1977, and their stomach contents were examined immediately after capture. Of the total of 1,127 squawfish stomachs examined, only 3 percent in 1976 and 1 percent in 1977 contained salmonids. Table 4 summarizes the results of the examinations.

The unscheduled release of hatchery steelhead smolts during part of the study may have increased the percentage of salmonids found in squawfish stomachs in 1976. Of the total of 18 salmonids identified in squawfish stomachs, 7 were steelhead smolts from the release group. The major fish species present was sculpins (genus Cottus), found in 14.4 percent of the stomachs analyzed. Sculpins are themselves considered predators and competitors with salmon (Moyle, 1977). In 449 stomachs of squawfish captured on the St. Joe River of Idaho, sculpins were also the major fish species found, even though salmonids were present (Falter, 1969).

Moyle, et al., (1979) examined squawfish obtained from various locations in the Sacramento River drainage basin and the Sacramento-

Table 4. Stomach contents of northern squawfish captured in the Willamette River system in spring 1976 and 1977 (From Buchanan, et al., 1980)

Food items[a]	1976		1977		Total	
	Number	Percent[b]	Number	Percent[b]	Number	Percent[b]
Squawfish examined	552		575		1,127	
Stomachs with food	328	59.4	334	58.1	662	58.7
A. Fish	95	17.2	143	24.9	238	21.1
1. Salmonids	18	3.3	5	0.9	23	2.0
a) Steelhead trout	8	1.5	0	0.0	8	0.7
b) Trout	0	0.0	2	0.4	2	0.2
c) Salmon	9	1.6	2	0.4	11	0.9
d) Unknown	1	0.2	0	0.0	1	0.1
2. Sculpins	64	11.6	98	17.0	162	14.4
3. Other fish[c]	15	2.7	40	7.0	55	4.9
B. Insects	128	23.2	77	13.4	205	18.2
C. Crayfish	69	12.5	104	18.1	173	15.4
D. Other food[d]	54	9.8	30	5.2	84	7.5

[a] Four major food types are listed; some squawfish stomachs contained more than one food type so that subtotal percentages can be greater than the total percentages.

[b] Percentage based on the total number of squawfish examined (percentages containing food items).

[c] Cyprinidae, Catostomidae, and Petromyzontidae.

[d] Algae, fish eggs, earthworms, berries, and leaves.

San Joaquin Delta. At only two locations (table 5) were salmon remains found. One location had a small sample size (8 fish) and the other was collected below the Red Bluff Diversion Dam.

Currently there is no evidence that losses of juvenile salmonids to any predators in a free-flowing, "natural" stream environment have a major impact on the fisheries resource. Young salmon exhibit behavorial adaptations which reduce predation. Night migration in large concentrations or during times of high flow and increased turbidity results in prey saturation at times when the prey are most difficult to catch. Spring seine surveys in the Sacramento-San Joaquin Delta and the resulting weekly abundance index (prepared by the California Department of Fish and Game) based on the mean number of fish per haul, indicate that peak catches of salmon fry often follow flow increases associated with storm runoff (Kjelson, et al., 1981b). Schooling during daylight hours reduces the probability of individual capture. Within several days of exposure to predators, naive salmon (hatchery-reared) begin to exhibit predator avoidance responses (Ginety and Larkin, 1976).

Seaward-migrating salmonids entering the headworks of the Tehama-Colusa Canal are stressed by their passage through the louver and bypass system. Migrants that avoid entrapment by Tehama-Colusa Canal must pass under the gates, negotiating the high water velocities, turbulence, and roll-back effect, with disorientation resulting. Herting and Witt (1967) suggest that fish stressed by concentration or handling behave sluggishly, exhibiting little of their normal avoidance behavior. Schooling and

Table 5. Stomach contents of 309 squawfish collected from various stream sites in California (from Moyle, et al., 1979).

		Stomachs Examined			Stomach Contents (Percent by weight)				
Location	Date	Standard Length (mm)	No.	No. Empty	Insects	Crayfish	Salmonids	Non-Game Fish	Other
North Fork Yuba River	Aug.-Sept., 1979	<200	4	2	-	-	-	100	-
		<200	8	3	33.3	-	33.3	-	33.3
Middle Fork Yuba River	Aug.-Sept., 1979	<200	31	23	74.6	-	-	4.6	18.7
		200+	4	2	5	-	-	45.0	50.0
South Fork Yuba River	Aug. 17, 1979	<200	8	2	57.5	-	-	-	42.6
		200+	0	-	-	-	-	-	-
Oregon Creek	Aug.-Sept., 1979	<200	132	73	83.2	-	-	3.9	12.9
		200+	0	-	-	-	-	-	-
Sacramento River	May 26, 1979	<200	0	-	-	-	-	-	-
		200+	48	17	0.9	-	23.5	46.2	29.4
Deer Creek	Aug. 1977, 1979	<200	19	11	57.7	9.5	-	-	32.8
		200+	7	3	-	66.6	-	-	33.3
Sacramento Delta	Aug.-Sept., 1979	<200	0	-	-	-	-	-	-
		200+	3	0	-	-	-	100	-
Russian River	May 19, 1978	<200	1	1	-	-	-	-	-
		200+	0	-	-	-	-	-	-
North Fork Feather River	Sept. 17, 1977	<200	14	3	-	33.3	-	-	66.6
		220+	30	16	-	68.8	-	12.5	18.6

darting of juvenile salmon as escape mechanisms are disrupted. Schooling is important since it reduces predator success by putting predators in a conflicting situation in which attention to a potential victim is constantly changing (Stein, 1979).

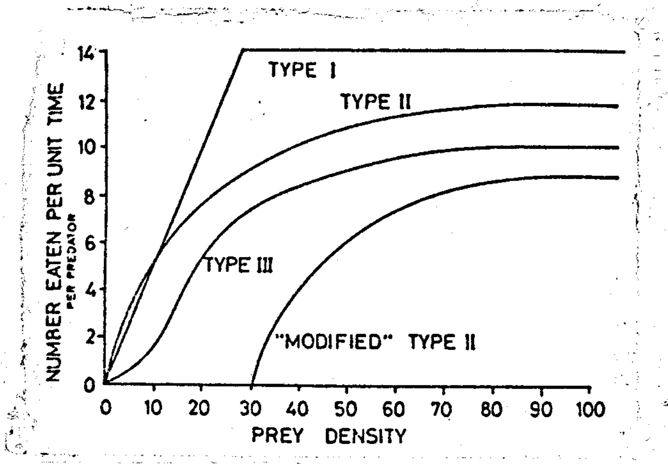
Large releases of salmonids from Coleman Fish Hatchery are made in April and May. Counts of squawfish for the last 4 years (table 5) show that their peak migration occurs from March through May. Counts of shad during this period show peak migration from May through July. Predation losses may be reduced by releasing juvenile salmonids prior to or after these peak periods although doing so would be releasing fish outside of the period during which wild fish migrate. The Fish and Wildlife Service (1957) noted that hatchery releases made on the Columbia River prior to the middle of May required no squawfish control measures. However, other problems occur. Early release can decrease chances of survival. Smoltification seems to trigger the need to migrate seaward. Release too long before or after smoltification might increase the residence time of the juvenile salmon prior to their seaward migration, possibly reducing survival and increasing competition with wild fish. In addition, early release during periods of flooding could strand juvenile salmon in the Yolo Bypass which diverts floodflows from the Sacramento River. At other times the Yolo Bypass remains dry.

Peterman and Gatto (1978) stress the importance of determining how present predation mortality varies with prey density (numbers in a given area at a particlar point in time) in understanding salmon population dynamics and the effect of enhancement projects. An overall understanding of predation mortality requires an investigation of the functional and numerical responses of predators. The functional response is described as the number of prey eaten per predator per unit time in relation to prey density. The numerical response is the variation in the number of predators as a function of some measure such as prey density. This numerical response can arise slowly through altered reproductive success, or quickly during times of aggregation of predators such as has occurred at the Red Bluff Diversion Dam. Figure 10 depicts four types of functional responses discussed by the authors. Each type of functional response becomes asymptotic at some level because of predator gut capacities, handling time constraints, etc.; each creates a different-shaped curve for percent mortality (figure 10).

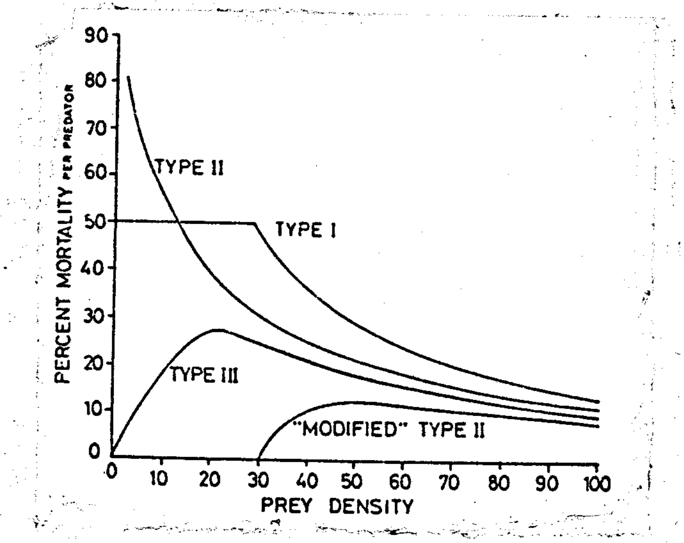
The shape of a curve showing the percent of mortality determines the level at which a population of juvenile salmon would demonstrate a significant drop in mortality due to swamping of predators. Swamping indicates more prey are available than can be consumed by predators because of some physiological constraints. If predators show a Type III response as in figure 10B and if prey densities are so low that predators are operating on the low end of the functional response curve, then salmon enhancement programs that boost production to 20 prey density units (number of prey available per predator in a given area at a particular point in time) will cause a higher percentage of predation mortality. Peterman and Gatto (1978) reached two significant conclusions from their review of salmon data. First, many salmon enhancement projects may increase the proportion of salmon eaten by predators instead of increasing the proportion caught by fishermen. Second, predator control programs may increase the efficiency of individual predators by decreasing competition among the remaining predators. The authors recommend prior to implementation of salmon enhancement or predator control actions that studies be undertaken to identify the functional response of predators.

Although squawfish are behavior generalists, preferring the quiet, slow-moving pool-type habitat, they have a streamlined body shape adapted to coping with swift currents. Their physiological tolerance is an adaptation to a wide range of water temperatures. Squawfish are opportunistic feeders, feeding on whatever prey is most prevalent at the time for the least outlay of energy (Thompson, 1959; Falter, 1969; Eggers, et al., 1978; Moyle, et al., 1979). The size and type of prey vary with the size and age of the predator. Smaller squawfish feed almost exclusively on small insects and plant material. A transition to fish as a major portion of the northern squawfish diet seems to occur when the squawfish are between 20 and 40 cm (8-16 in.) fork length (the length of a fish measured from the most anterior part of the head to the deepest point of the notch in the tail fin). (Figures 11 and 12.)

Thompson (1959) conducted a stomach analysis of northern squawfish from the Columbia River system. He reported that 87 percent of 1,272 countable fish found in the squawfish stomachs were salmon during periods which coincided with nearby hatchery releases. Populations of squawfish are large below dams on the Columbia River where from 20 to 88 percent of



A-Functional Response



B-Mortality Curves

Figure 10. Shapes of different types of hypothetical functional responses (A) and their corresponding percent mortality curves (B). Figures from Peterman and Gatto (1978).

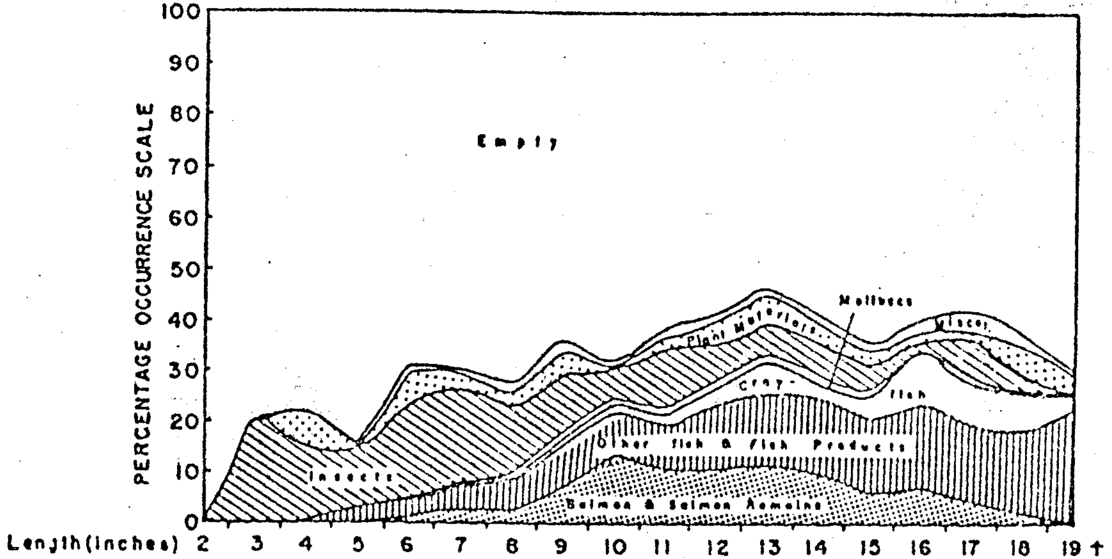


Figure 11. Percent occurrence of food items and empty stomachs by 1-inch length groups of northern squawfish in the Colombia River system. Table from Thompson (1959).

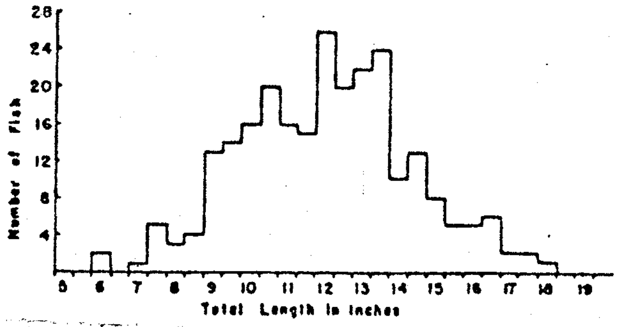


Figure 12. Length-frequency distribution of salmon-eating northern squawfish in the Columbia River system. Table from Thompson (1959).

squawfish consumed salmonids during the salmon migration period (Sims, et al., 1977, 1978). It has even been observed that squawfish follow adult salmon as they migrate upstream at spawning time (U.S. Fish and Wildlife Service, 1957). Since this occurred in the fall after the squawfish had spawned, it was presumed that they were looking for food.

In studies of squawfish feeding habits, investigators have found a large percentage of the fish have empty stomachs. The relatively high portion of squawfish sampled with empty stomachs may be due in part to the tendency of the fish to regurgitate when captured (Brown and Moyle, 1981). Food digestion rates could be a contributing cause of the high percentage of empty stomachs found during feeding habit studies. Thompson (1959) indicated salmon remains can be ejected from the anus when squawfish are first handled. The growth rate of squawfish is slow when compared to other minnow-type fish indicating a likelihood of infrequent feeding. Falter (1969) observed large quantities of visceral fat in northern squawfish year-round, suggesting periods of heavy feeding followed by periods of little or no feeding.

Northern squawfish digestion rates were studied by Falter (1969) and by Steigenberger and Larkin (1974). Steigenberger and Larkin (1974) found that the digestion rate of squawfish, when held at 10-12 °C and which were fed sockeye salmon, was 14 percent per hour. Increases in temperature caused logarithmic increases in rates of digestion. Falter (1969) studied the voluntary feeding rate of small northern squawfish (<19 cm). He provided a superabundant food supply and determined the weight of food consumed daily (mean daily ration) to be 9.9 percent of the total body weight. Mean daily rations for squawfish from the St. Joe and St. Marie Rivers were 1.07 percent for small fish versus 1.49 percent for large fish (>36 cm).

Assuming the same variation for large squawfish in an area of superabundent food supply, such as the large number of hatchery-released juvenile salmon below Red Bluff Diversion Dam, the mean daily ration could be as high as 14 percent $(\frac{0.099}{(0.107)} = \frac{x}{0.149}$ thus $x = 0.14$ or 14%).

No studies similar to Falter's (1969) have been made of squawfish in the Sacramento River; therefore, the losses due to predation are not known. Losses have been estimated using data obtained from studies of the northern squawfish.

Hall (1977) discussed squawfish predation at Red Bluff Diversion Dam and quantified potential predation mortality to chinook salmon. His estimates were not based on a rigorous data collection and analysis effort, thereby restricting the utility of these mortality figures. However, they are useful in suggesting the relative magnitude of the predation problem.

Information from Hall's memorandum (1977) on predation at Red Bluff Diversion Dam indicates that in the Sacramento River below the dam there were about 12,000 squawfish at an average fork length of 491 mm. Hall assumed that (1) a squawfish with a fork length of 491 mm weighs 1,500 grams, (2) the weight of one juvenile chinook salmon released at Coleman National Fish Hatchery is 5 grams (90/lb.), and (3) the mean daily ration for large squawfish in an area of superabundant food supply is 14 percent (derived from Falter, 1969). He then concluded the possible number of salmon consumed in 1 day by 12,000 squawfish would be:

$$\frac{1{,}500 \text{ g/squawfish } \times 12{,}000 \text{ squawfish} \times 0.14}{5 \text{ g/salmon fry}} = 500{,}000 \text{ salmon/day}$$

A cursory review of such potentially large losses at a single location in a river system might indicate an immediate need for a squawfish eradication program. However, other facts must be considered. Heavy predation can be expected because juvenile salmon are released at the time of peak squawfish spawning migration. Fish passage counts at Red Bluff Diversion Dam indicate fewer squawfish are likely to be present at other times of the year. Eggers (1978) and Hobson (1979) state that most predators cannot function as effectively in darkness as in daylight. Salmon released at night migrated faster and with less evidence of predation than when released during daylight hours (Foerster and Ricker, 1941; Zimmer, 1953; U.S. Fish and Wildlife Service, 1957; and Sims et al., 1977). If prey density at which the predator population is satiated can be determined, then fisheries managers could take this degree of mortality into account. A loss of 500,000 to 1 million hatchery-released salmon from a total of 14 million migrating downstream in a 1- to 2-day period may be tolerable; a similar loss for a total release of 2 million juveniles may not be tolerable.

Trucking juvenile salmon past Red Bluff Diversion Dam for release into the Sacramento River downstream has been tested as a means of reducing predation. Two studies were conducted with Sacramento River system chinook salmon (Hallock and Reisenbichler, 1979). The first study covered 1959 through 1966, and the second 1969 through 1975. In 1959, the 1958 brood year (BY), marked fingerlings were released under four conditions: (1) trucked to the Sacramento River near Chico (several miles east of Hamilton City), (2) trucked to Rio Vista, (3) trucked to Rio Vista, then boated to San Francisco Bay, or (4) trucked to San Francisco Bay. An attempt was made in 1959 to estimate the "effective" number of marked fingerlings released by noting mortalities of the marked fish held in tank cars at each release site. From 1960 to 1962 (1959-61 BY), marked fish were released directly from Coleman National Fish Hatchery, trucked to Rio Vista, then boated to San Pablo Bay. Marked fish from the 3 brood years 1968-70 were released at the Coleman National Fish Hatchery and trucked to Rio Vista. Tables 6, 7, and 8 summarize the findings of these studies. Analysis of the fish returning indicates that those released at Rio Vista contributed an average of 1.5 times more to the fisheries than those released at the hatchery. However, returns to Coleman National Fish Hatchery from hatchery releases averaged 4.8 times more than those from the Rio Vista releases. When returning to spawn, fish released at Rio Vista strayed considerably from the parent stream. Predation by striped bass was observed to be heavy at the Rio Vista and San Francisco release sites (Tom Luken, Coleman National Fish Hatchery Director--retired--U.S. Fish and Wildlife Service; personal communication).

If fewer adults return each year to Coleman National Fish Hatchery because juvenile salmon are released downriver, the objective of

Table 6. Estimated returns of marked 1958 brood year fall-run chinook salmon, reared at Coleman National Fish Hatchery, based on (A) total numbers of marked fish that left the hatchery, and (B) on estimated numbers of effective marks released. Table from Hallock and Reisenbichler (1979)

Release				Recovery							
				Ocean		Inland[2]					
			Avg. Wt.	Fisheries[1]		Coleman Hatchery		Upper Sacramento River System [3]		Other [4]	
Brood Year	Locality	Number	(g)	Number	Percent	Number	Percent	Number	Percent	Number	Percent
						(A) Total numbers of marked fish					
1958	Sacramento River (Chico)	287,000	2.5	3,314	1.15	418	0.146	414	0.144	218	0.076
1958	Rio Vista	297,000	2.3	2,820	0.95	168	0.057	72	0.024	4	0.001
1958	San Francisco Bay (Boat)	322,000	3.4	3,705	1.15	185	0.057	262	0.081	32	0.010
1958	San Francisco Bay (Truck)	291,000	2.5	1,474	0.51	69	0.024	97	0.033	2	>0.001
						(B) Estimated numbers of effective marks released					
1958	Sacramento River (Chico)	242,000	2.5	3,314	1.37	418	0.173	414	0.171	218	0.090
1958	Rio Vista	216,000	2.3	2,820	1.31	168	0.078	72	0.033	4	0.002
1958	San Francisco Bay (Boat)	108,000	3.4	3,705	3.43	185	0.171	262	0.242	32	0.030
1958	San Francisco Bay (Truck)	67,000	2.5	1,474	2.20	69	0.103	97	0.145	2	0.003

[1] California, Oregon, and Washington sport and commercial fisheries catch estimates based on sampling the landings.

[2] Hatchery recoveries are actual numbers handled. Other inland recoveries are incomplete estimates based on sampling the catch and spawning stocks.

[3] Above the mouth of the Feather River.

[4] Feather River and other Central Valley streams below the Feather River.

Table 7. Estimated returns of marked 1959, 1960, and 1961 brood year fall-run chinook salmon, reared at Coleman National Fish Hatchery. Table from Hallock and Reisenbichler (1979)

	Release			Recovery							
				Ocean		Inland[2]					
Brood			Avg. Wt.	Fisheries[1]		Coleman Hatchery		Upper Sacramento River System[3]		Other[4]	
Year	Locality	Number	(g)	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1959	Coleman Hatchery	384,000	2.1	108	0.03	22	0.006	40	0.010	14	0.004
1960	Coleman Hatchery	578,685	1.8	426	0.07	18	0.003	17	0.003	2	<0.001
1961	Coleman Hatchery	535,000	1.7	401	0.08	125	0.023	0	-	7	0.001
	Total Fish	1,497,685		935		165		57		23	
	Unweighted Mean				0.06		0.011		0.004		0.002
1959	Rio Vista	387,000	2.1	239	0.06	7	0.002	0	-	56	0.014
1960	Rio Vista	568,690	1.8	958	0.17	19	0.003	2	<0.001	1	<0.001
1961	Rio Vista	573,000	1.7	1,243	0.22	39	0.007	0	-	7	0.001
	Total Fish	1,528,690		2,440		65		2		64	
	Unweighted Mean				0.15		0.004		<0.001		0.005
	(boat)										
1959	San Pablo Bay	378,000	2.1	253	0.07	13	0.003	15	0.004	15	0.004
1960	San Pablo Bay	547,550	1.8	707	0.13	4	0.007	1	<0.001	46	0.008
1961	San Pablo Bay	565,000	1.7	204	0.04	6	0.001	0	-	0	-
	Total Fish	1,490,550		1,164		23		16		61	
	Unweighted Mean				0.08		0.004		0.002		0.004

[1] California, Oregon, and Washington sport and commercial fisheries mark recoveries based on sampling the landings.

[2] Hatchery recoveries are actual numbers handled. Other inland recoveries are incomplete estimates based on sampling the catch and spawning stocks.

[3] Above the mouth of the American River.

[4] Feather River and other Central Valley streams below the Feather River.

Table 8. Estimated returns of marked 1968, 1969, and 1970 brood year fall-run chinook salmon, reared at Coleman National Fish Hatchery. Table from Hallock and Reisenbichler (1979)

Release				Recovery							
				Ocean		Inland[2]					
Brood Year	Locality	Number	Avg. Wt. (g)	Fisheries[1]		Coleman Hatchery		Nimbus Hatchery		Feather River Hatchery	
				Number	Percent	Number	Percent	Number	Percent	Number	Percent
1968	Coleman Hatchery	294,834	6.4	1,127	0.382	176	0.060	5	0.001	0	-
1969	Coleman Hatchery	327,962	5.2	2,514	0.766	191	0.058	7	0.002	4	0.001
1970	Coleman Hatchery	371,672	5.5	2,283	0.614	203	0.055	9	0.002	1	0.001
	Total Fish	994,468		5,924		570		21		5	
	Unweighted Mean				0.587		0.058		0.002		0.001
1968	Rio Vista	320,586	6.6	2,307	0.720	51	0.016	133	0.041	30	0.009
1969	Rio Vista	327,265	4.6	2,746	0.839	32	0.010	113	0.034	31	0.009
1970	Rio Vista	367,869	5.8	3,256	0.885	17	0.005	193	0.052	39	0.010
	Total Fish	1,015,720		8,309		100		439		100	
	Unweighted Mean				0.815		0.010		0.042		0.009

[1] California, Oregon, and Washington sport and commercial fisheries mark recoveries based on sampling the landings. Brood year assignment is based on scale analysis and fish lengths.

[2] Hatchery recoveries are actual numbers handled. Other inland recoveries, not listed, include 136 from Coleman Hatchery releases and 296 from Rio Vista releases, and are incomplete estimates based on sampling the sport catch and spawning stocks. Inland mark recoveries were assigned to brood year by applying a combination of fish lengths and percentage returns of Nimbus Hatchery marked salmon.

maintaining spawning runs is not being met. Alternative release sites at Knights Landing and downriver from Red Bluff Diversion Dam are being evaluated, but information is not yet available on this analysis.

SQUAWFISH CONTROL

General techniques for predator control have been employed or tested. One nonlethal control measure is capture and confinement (Meachum and Clark, 1979). Other measures, still in the experimental stage, are electric barriers (Maxfield, Lander, and Voly, 1970), repellent acoustics (Meachum and Clark, 1979), and nontoxic alarm substances or repellants (Pfeiffer 1962, 1963a, and 1963b; Reed, 1969; and Reuter and Verheijen, 1969). Capture and confinement of squawfish downstream from the Red Bluff Diversion Dam is impractical due to high water velocities and turbulence.

Lethal control measures include: (1) gill netting (Foerester and Ricker, 1941; and Jeppson and Platts, 1959), (2) permit angling (Hall, 1977), (3) dynamite (Jeppson, 1957), and (4) use of chemicals (MacPhee, 1966; MacPhee and Ruells, 1969; and Welsh, 1975). Gill netting, shown to be up to 90 percent effective in removal of squawfish from lakes and slower moving streams, cannot be done efficiently downriver from the dam due to high water velocities and turbulence unless the dam gates were adjusted to divert flows to one side of the river. The same limitation would seem to apply to electrofishing. However, electrofishing for squawfish was successfully conducted by Ecological Analysts (consultants for city of Redding) during May 1982 downstream from Red Bluff Diversion

Dam (Steve Hanson, Ecological Analysts, personal communication). Explosives are nonspecific and have potential for damage to structures and personnel. The usefulness of explosives has been primarily with spawning congregations. Permit angling, as tested at the Red Bluff Diversion Dam, does not result in significant predator removal.

Three chemicals are used in predator control, two of which, Rotenone and Antimycin A, are nonspecific toxins. The third, Squoxin, has been shown to be an effective toxin to northern squawfish at a lesser concentration than that which kills salmonids. Limited testing with Sacramento squawfish has shown that the concentration necessary is much higher than for northern squawfish and, thus, less selective (MacPhee, 1966). Personal communication with Rosalee Schnick of the Fish Control Laboratory, Fish and Wildlife Service, confirmed that Squoxin is not currently registered for use by the Environmental Protection Agency (EPA). Mammalian and environmental safety studies as required by the EPA have not been completed. The necessary studies not yet begun were estimated to cost $1.5 million and take approximately 5 years.

Another method of control which has been suggested but not tried is removal of adult squawfish spawners from the fish ladders as they migrate upriver past the dam. If this proved to be an effective control measure, it would be relatively easy and inexpensive to implement. It might also reduce predation problems in Battle Creek and Coyote Creek. Although these squawfish are not the immediate problem downriver from the dam, they do contribute to future squawfish problems. Therefore, their removal may assist in reducing the overall predation problem at the dam.

An additional method of squawfish control, which may be attempted in the near future, is a spearfishing derby similar to the derby for permit angling. Spearfishing has been effectively used to remove predators from tailwaters or other parts of various facilities (Dave Vogel, personal communication, Fisheries Assistance Office, Fish and Wildlife Service, Red Bluff).

Most of the literature cited on squawfish migration patterns, population dynamics, recruitment, and age composition deals with the northern squawfish found in Oregon and Washington. The commonly referenced study of Sacramento squawfish by Taft and Murphy (1950) does not examine those in the main stem Sacramento River. Peter Moyle of the University of California at Davis, who has studied the Sacramento squawfish, identified aspects of squawfish life history needing further investigation including digestion rates, migration, and size distribution (Moyle, et al., 1979). Lack of such information reduces the predictable effectiveness of any particular reduction method.

Predator control programs may actually increase the efficiency of individual predators by decreasing competition among the remaining members of the population. Removing large adult squawfish may allow a greater number of smaller juveniles to occupy the vacated niche, resulting in higher predation. For example, if the removal of large squawfish temporarily reduces competition with smaller squawfish, the smaller individuals should demonstrate accelerated growth rates. If the metabolic demands of these rapid-growing smaller individuals cumulatively exceed those of the slower growing, larger squawfish, the removal of large squawfish could actually accelerate rates of predation in a long-term predator control program.

Four possible consequences of indiscriminant predator control are listed by Campbell (1979):

1. The predator probably utilizes more than one prey. Reduced predation pressure may allow alternate prey species to increase and become predator competitors with the desired species.
2. The predator may be controlling the predators of another desirable species.
3. The young of the predator may be serving as food for the prey.
4. Large increases in prey population may be beyond the carrying capacity of the system, resulting in overcrowded, stunted, and underutilized resources.

The applicability of these possible consequences to anadromous fisheries should be investigated not only in regard to the Upper Sacramento River, but also to the whole Sacramento-San Joaquin and Delta system.

TEHAMA-COLUSA FISH FACILITIES

At the Tehama-Colusa Fish Facilities (figure 13), juvenile salmon are allowed to leave the canals at will and, therefore, vary in size from sac fry in January to as large as 60 per pound by June. Because of louver leakage at the Red Bluff Diversion Dam headworks, juvenile fish, instead of being diverted back to the Sacramento River, pass through the louvers and enter the sedimentation basin of the Tehama-Colusa Fish

Facilities in significant numbers. There is then little impediment to keep them from moving into the dual-purpose canal. The louvers are ineffective in excluding fish smaller than 41-mm fork length, and do not exclude larger salmon, even yearlings. Predators, such as squawfish, can enter the system in the same manner. Although predation losses are assumed to occur in the sedimentation basin and in the dual-purpose canal, fisheries biologist have made no studies to determine whether there is a problem.

Dense aquatic vegetation around the perimeter of a slow-moving body of water would seem to make the sedimentation basin an ideal habitat for fish. Sampling, however, has not been adequate to document the presence of a resident fish population. Yearly applications of herbicide in the dual-purpose canal prior to salmon spawning effectively kill all fish including young salmon and steelhead. Several species of rough or nongamefish were killed by such treatment. This gives evidence of the potential for establishment of a resident fish population in the sedimentation basin.

The single-purpose spawning channels are shallow with a water depth of 1-1/2 feet, allowing birds to become important predators of the salmon fry. From January to mid-April as many as 37 common mergansers (*Mergus merganser*) have been observed feeding on fry in the channels at one time. A merganser can consume 50 fry per day. Assuming a mean resident population of 20 mergansers each consuming 50 fry/day for the 100-day period January-April, salmonid losses due to mergansers alone would total 100,000 fish per year (U. S. Fish and Wildlife Service, 1977). This loss

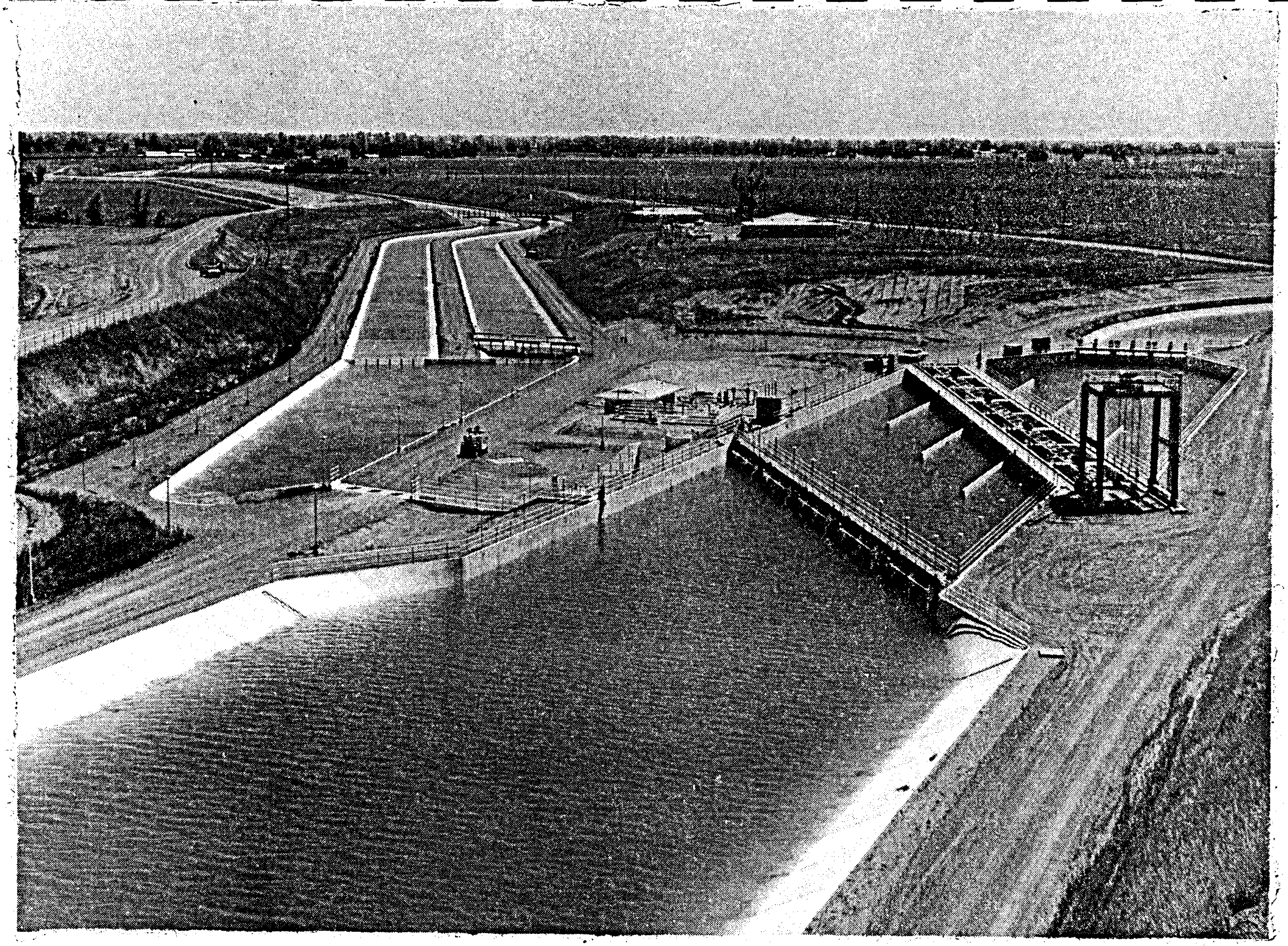


Figure 13. Tehama-Colusa Canal Fish Facilities, downcanal view. Single-purpose spawning channels at upper left, Tehama-Colusa Canal at upper right and dual-purpose spawning channel and drum screen complex in right foreground.

is 7 percent of the mean annual salmon outmigration from the single-purpose spawning channels.

Great blue herons (*Ardea herodias*) and common egrets (*Casmerodius albus*) also are predators. Because they are protected birds, traditional stomach analysis to estimate predation losses has not been performed. Scare tactics, using poppers and shot shells which make a lot of noise, are employed in an attempt to control these predators.

Young salmon, upon exiting from the single-purpose spawning channel, must migrate 2 miles down Coyote Creek before reaching the Sacramento River. Squawfish are the major predators in Coyote Creek and appear in the latter part of April after the majority of the salmon have migrated out of the creek. Personnel at the Tehama-Colusa Fish Facility remove aproximately 100 squawfish from the creek annually by permit angling, but this has had no apparent effect on reducing squawfish numbers. Stomach analyses of fish caught indicated a mean content of 22 fry per squawfish. The digestion rate of squawfish is not known. Assuming that the 100 squawfish consumed 22 salmon fry daily, and that the fry would be migrating from the Tehama-Colusa Fish Facilities for an additional month, total production at the facilities would be reduced by as many as 66,000 fry (personal communication, Ron Pelfry, U.S. Fish and Wildlife Service, Tehama-Colusa Fish Facilities).

PART IV

PREDATION IN SYSTEM BELOW RED BLUFF DIVERSION DAM

GLENN-COLUSA IRRIGATION DISTRICT DIVERSION

No quantitative evaluation of salmon losses at the Glenn-Colusa Irrigation District diversion (figures 14 and 15) has been made.

A series of tests conducted in 1974 attempted to evaluate the efficiency of the screens and bypasses as well as the effect of the trashrack on salmon migrants. Fingerling chinook salmon obtained from the Feather River Salmon and Steelhead Hatchery were fin clipped, and released at predetermined points in the area of the screens. The fate of 66 to 82 percent (depending on the test) of the marked salmon released but not recaptured could not be determined (Decoto, 1978). Four possible explanations were given: (1) the salmon returned upstream and out to the river, (2) they escaped through the drum screens, (3) they were eaten by predators, or (4) combinations of the first three. These tests were generally inconclusive, but one important conclusion was reached--marked salmon, as well as wild salmon, migrated mainly during periods of reduced light. During the study, it was observed that the bypasses are too small for fish to pass freely through them. Any situation that delays the downstream migration of juvenile salmonids increases the potential for squawfish to prey on these fish.

Predation in System Below Red Bluff Diversion Dam

One striped bass and two Sacramento squawfish were tracked by ultrasonic tags in 1978 (Hall, 1980a). Position fixes were obtained from the bass at least once every few hours for a period of 45 hours. The striped bass proceeded upstream in a "rest and go" pattern with the last position fix placing it approximately 3 miles from the screens. The squawfish were monitored for 7 days but remained within 350 feet of the screens. Position fixes indicated they utilized a range of water velocity from 0.1 to 3.0 ft/s which often occurred within 20 feet. This further demonstrates the capability of the squawfish to adapt to varying riverine conditions. It is not known what behavioral changes in squawfish result from handling and tagging.

This limited experiment indicates that bass are present only intermittently to act as predators, while squawfish seem to set up residency near the screens. Salmon are in a stressful and disorienting situation which allows predators to feed with the least amount of expended energy, the very conditions to which squawfish seem to be drawn.

HALLWOOD-CORDUA IRRIGATION DIVERSION

Although the Hallwood-Cordua Irrigation Diversion Facility (figure 16) is not on the main stem Sacramento River, it is relevant to the discussion of predation because a study conducted in 1977 and 1978 (Hall, 1979) demonstrated similarities to problems at the Red Bluff Diversion Dam.

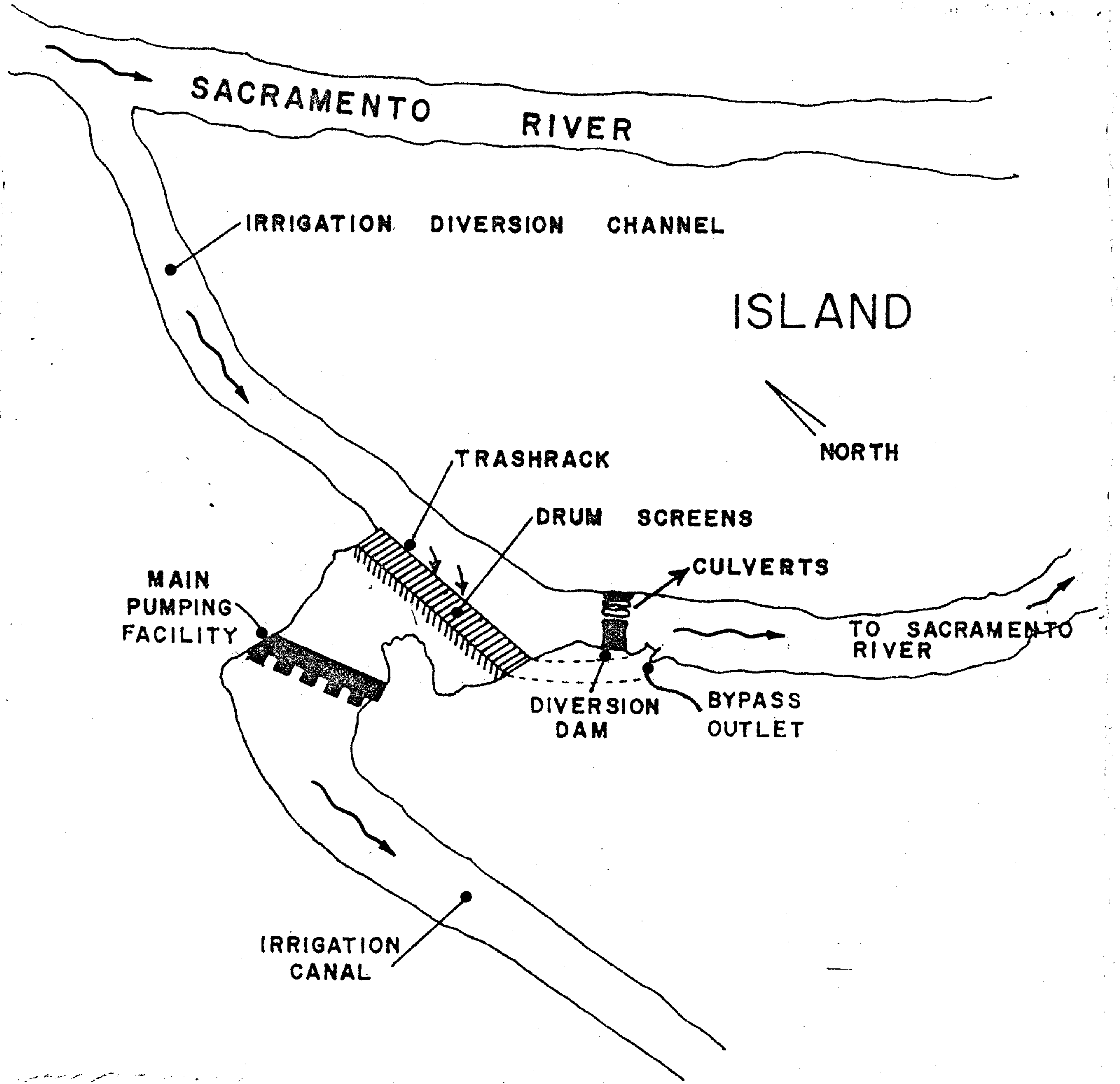


Figure 14. Diagram (not to scale) of the Glenn-Colusa Irrigation District diversion facilities.

Figure 15. Glenn-Colusa Irrigation District diversion drum screen complex.

Figure 16. Hallwood-Cordua Irrigation diversion fish screen facility. The vertical wall V-screen is in the foreground, the flow control tower is visible in the upper left. View from the right bank of the diversion canal.

Predation in System Below Red Bluff Diversion Dam

Two types of releases of fingerling salmon were made in 1977 to determine predation losses at the fish screen and in the channel upstream from the screen. "Mass" releases were made by allowing marked fish to swim out together. "Dribble" releases were made by allowing marked individual fish to leave the holding container through a 1-inch opening. One test was performed to compare recoveries from a mass release and a dribble release. A second test was made to determine the differences in returns of day and night mass releases. Recoveries from both the night (78 percent) and day (81 percent) mass releases were significantly higher than the recoveries from 1-day dribble release (62 percent). These higher recoveries may have been due to a satiating effect on the predators by the mass release. Recovery differences between day and night releases were not significant. Surface observation of predation upstream from the screen face showed that Sacramento squawfish, juvenile steelhead trout, and smallmouth bass (Micropterus dolomieui) were present. A diver counted 50 Sacramento squawfish and 14 steelhead trout on one transect between the release site and the screen face. A second diving transect yielded 75 predators; and a concurrent surface count 4 hours later yielded 84 predators.

The 1978 study was undertaken to identify the location of predation losses indicated by the information collected in 1977. Fish were released downstream from the fish screens, at the screen face, and at the upstream release site used in 1977. Recoveries were greatest for the downstream control group (74 percent), while there was no significant difference between the upstream (54 percent) and screen face (50 percent) groups. Observed predation accompanying the releases was minimal. However, within 1 hour of the releases, several squawfish were visible beneath schools of fingerling chinook salmon holding at the screen face. Sacramento squawfish were also observed on the downstream side of the primary screen section, holding parallel to the flow with their snouts nearly touching the screen.

The trashrack of this facility creates a rollback effect which, although on a smaller scale, is very similar to that observed at Red Bluff Diversion Dam. Schooling behavior was disrupted, fingerlings were forced to swim vigorously due to the added flow component, and exposure time to predation was increased due to disorientation. Observed predation during the study period was greatest at the location of this rollback effect. It is significant to note that squawfish were observed entering the area only after the releases in 1978 of fingerling salmon which also happens at Red Bluff Diversion Dam.

YOLO BYPASS

The Yolo Bypass is a broad shallow channel which diverts floodflows from the Sacramento River Deep Water Ship Channel to reenter the Sacramento River near Rio Vista. Figure 17 shows the Sacramento Weir during floodflows. Tables 9 and 10 show the periods of overflow at the two major weirs, Fremont and Sacramento, and table 11 the periods of inundation of Yolo Bypass.

Predation mortalities related to the operation of the Yolo Bypass have not been evaluated. The bypass has no resident fish population

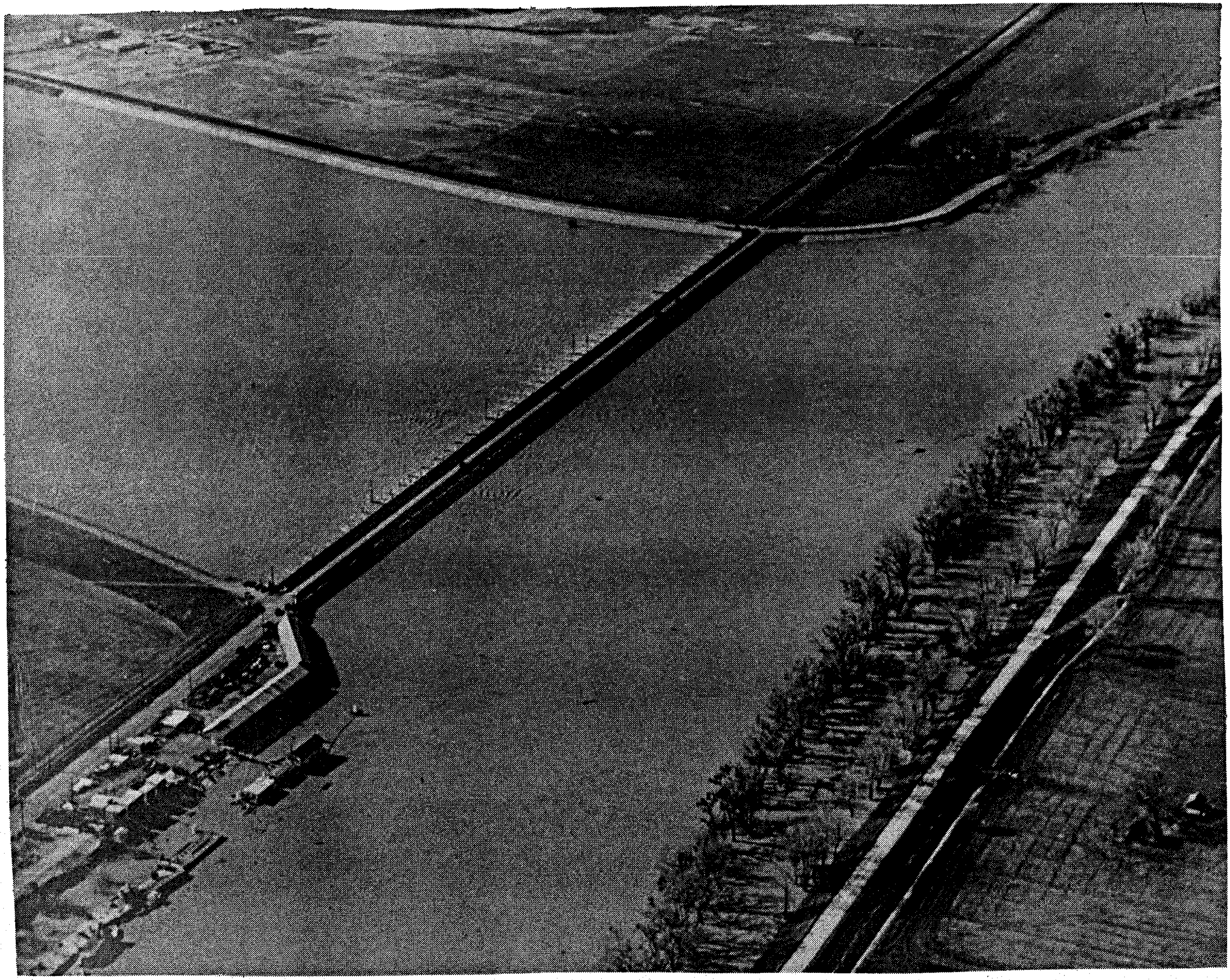
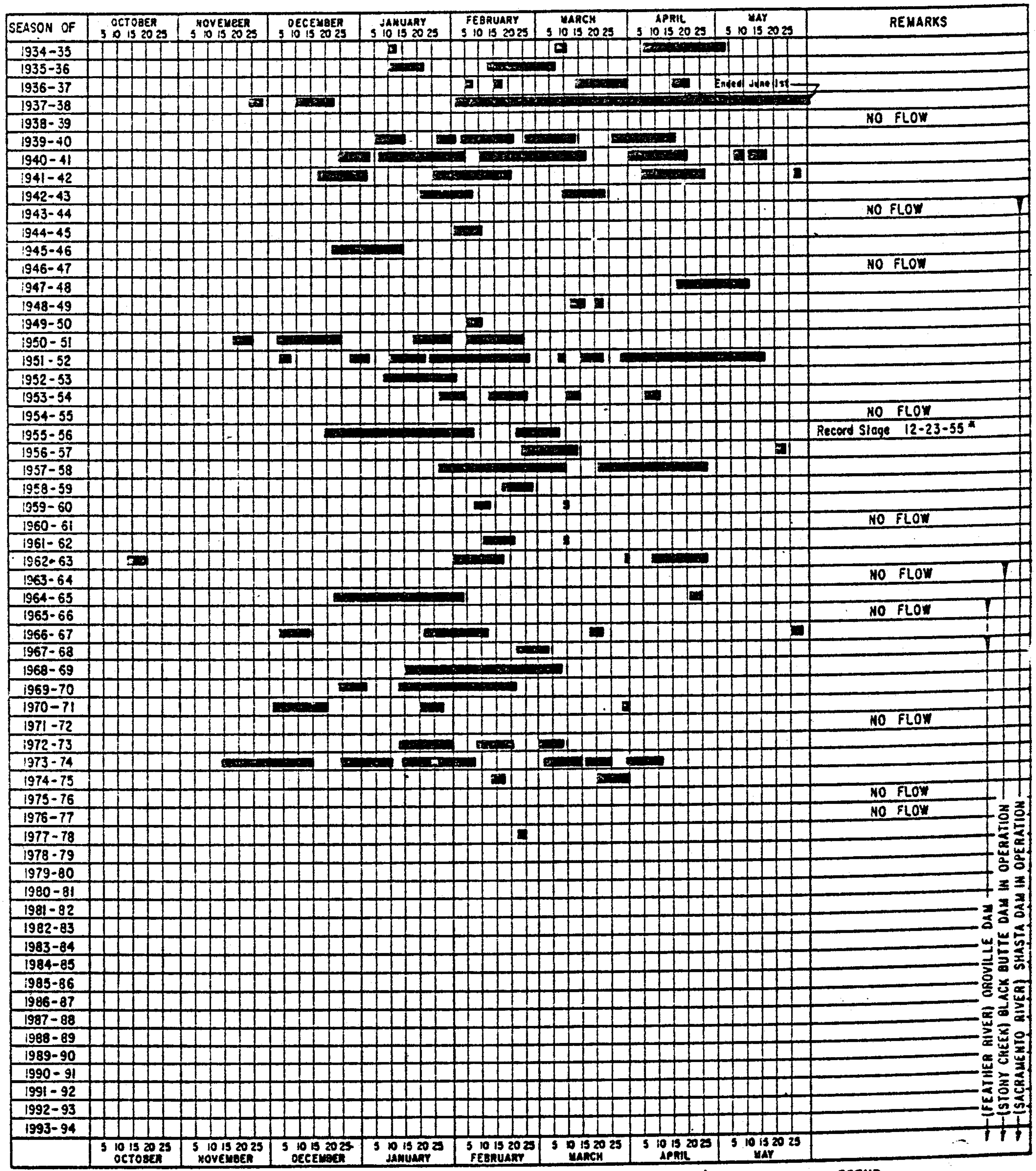


Figure 17. Sacramento Weir during floodflow.

Table 9. Fremont Weir overflow record (through the 1977-78 season).
Table from Bulletin No. 202-78, California Department of Water Resources, 1979.)



NOTE:

Data compiled from records of D.W.R. stream gaging station "Sacramento River at Fremont Weir, West End"

Datum: 0 = 0' U.S.E.D.

Period of record: 1934 to present

Crest elevation = 33.50 feet (10.22 metres)

Metric Equivalent:
1 FOOT = 0.305 METRES

LEGEND

▬ Designates periods of flow over weir

*	39.7	feet
	(12.1	metres)

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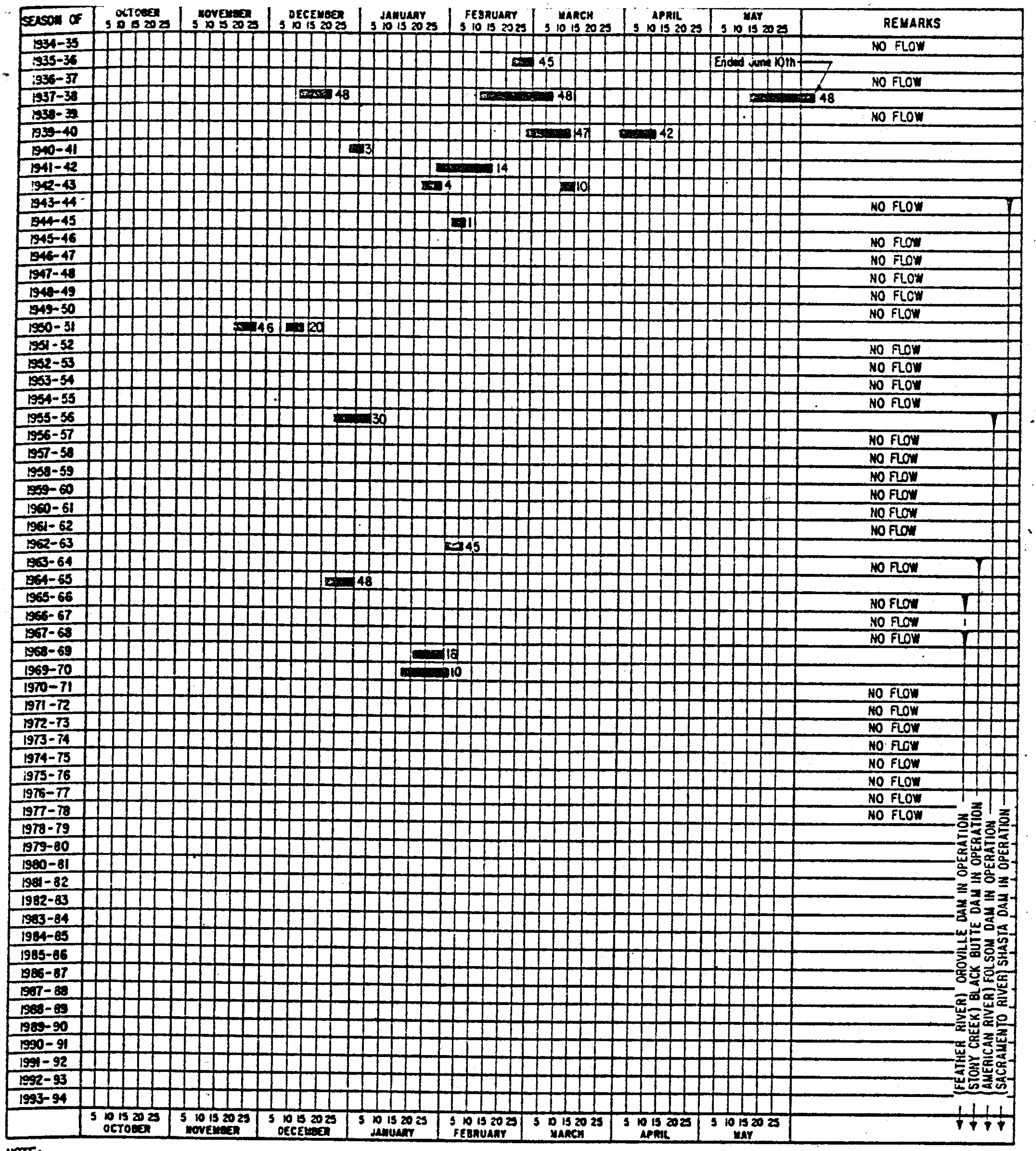
Table 10. Sacramento Weir overflow record (through the 1977-78 season). (Table from Bulletin No. 202-78, California Department of Water Resources, 1979.)



NOTE:

Data compiled from records of D.W.R. stream gaging station "Sacramento Weir Spill to Yolo Bypass, near Sacramento.

Datum: 0=0' U.S.E.D.

Period of record: 1926 to present

Crest elevation = 24.75 feet (7.55 metres)

Elevation of top of gates = 31.0 feet (9.45 metres)

Metric Equivalent:
1 FOOT = 0.305 METRES

LEGEND

▬ 5	Designates periods of flow over weir and total number of gates opened.

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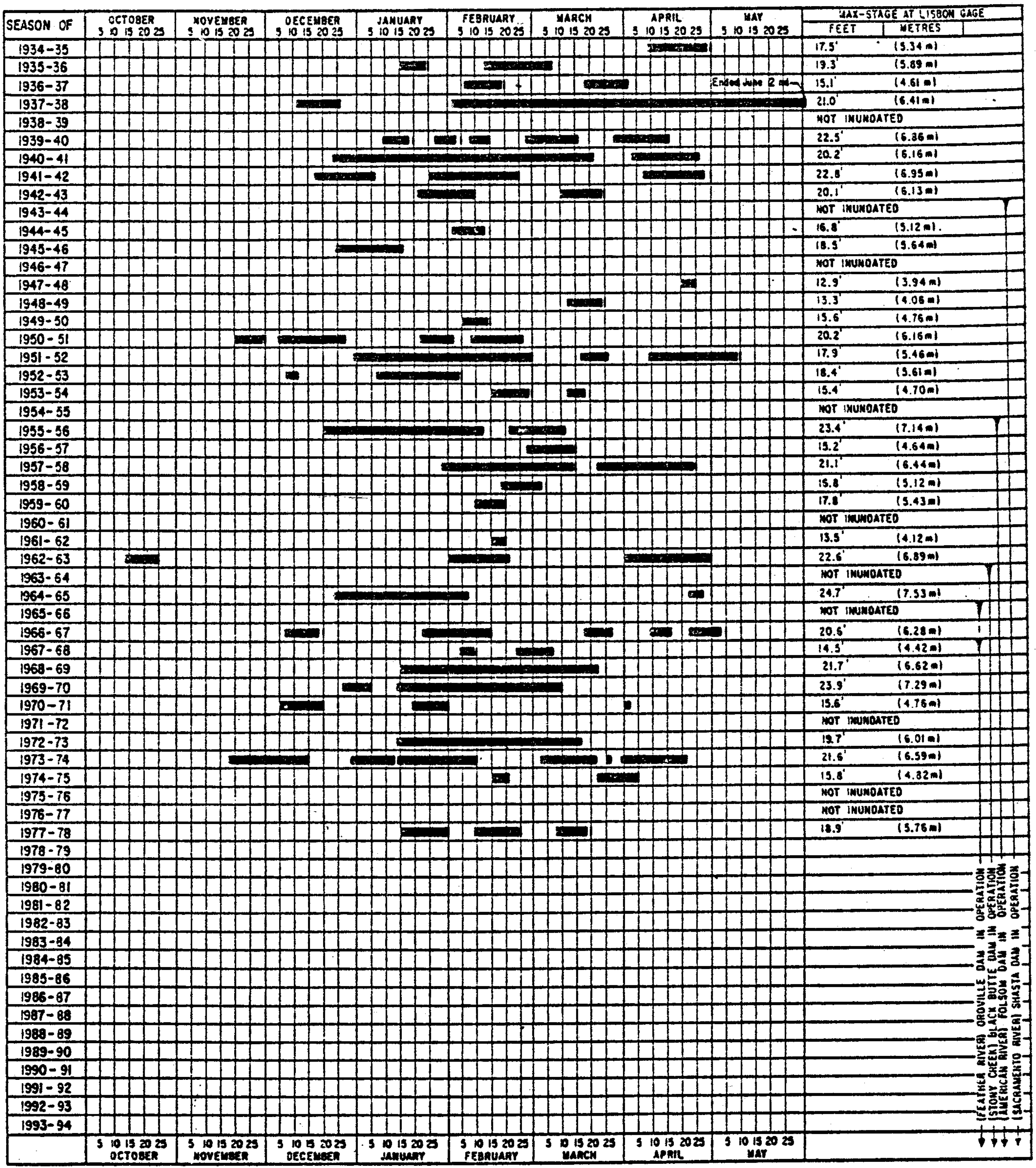
Table 11. Yolo Bypass Weir overflow record (through the 1977-78 season). (Table from Bulletin No. 202-78, California Department of Water Resources, 1979.)



SEASON OF	MAX-STAGE AT LISBON GAGE FEET	METRES
1934-35	17.5'	(5.34 m)
1935-36	19.3'	(5.89 m)
1936-37	15.1'	(4.61 m)
1937-38	21.0'	(6.41 m)
1938-39	NOT INUNDATED	
1939-40	22.5'	(6.86 m)
1940-41	20.2'	(6.16 m)
1941-42	22.8'	(6.95 m)
1942-43	20.1'	(6.13 m)
1943-44	NOT INUNDATED	
1944-45	16.8'	(5.12 m).
1945-46	18.5'	(5.64 m)
1946-47	NOT INUNDATED	
1947-48	12.9'	(3.94 m)
1948-49	13.3'	(4.06 m)
1949-50	15.6'	(4.76 m)
1950-51	20.2'	(6.16 m)
1951-52	17.9'	(5.46 m)
1952-53	18.4'	(5.61 m)
1953-54	15.4'	(4.70 m)
1954-55	NOT INUNDATED	
1955-56	23.4'	(7.14 m)
1956-57	15.2'	(4.64 m)
1957-58	21.1'	(6.44 m)
1958-59	15.8'	(5.12 m)
1959-60	17.8'	(5.43 m)
1960-61	NOT INUNDATED	
1961-62	13.5'	(4.12 m)
1962-63	22.6'	(6.89 m)
1963-64	NOT INUNDATED	
1964-65	24.7'	(7.53 m)
1965-66	NOT INUNDATED	
1966-67	20.6'	(6.28 m)
1967-68	14.5'	(4.42 m)
1968-69	21.7'	(6.62 m)
1969-70	23.9'	(7.29 m)
1970-71	15.6'	(4.76 m)
1971-72	NOT INUNDATED	
1972-73	19.7'	(6.01 m)
1973-74	21.6'	(6.59 m)
1974-75	15.8'	(4.82 m)
1975-76	NOT INUNDATED	
1976-77	NOT INUNDATED	
1977-78	18.9'	(5.76 m)
1978-79		
1979-80		
1980-81		
1981-82		
1982-83		
1983-84		
1984-85		
1985-86		
1986-87		
1987-88		
1988-89		
1989-90		
1990-91		
1991-92		
1992-93		
1993-94		

NOTE:

Data compiled from records of D.W.R. stream gaging station "Yolo Bypass near Lisbon."

Datum: 0=U.S.E.D. Datum

Period of Record: 1914 to Present

Assumed overflow of Bypass at stage above 11.5' (3.51 metres) on the Lisbon gage.

Metric Equivalent:
1 FOOT = 0.305 METRES

LEGEND

▬ Designates period of inundation of Bypass.

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because it is dry most of the year. The borrow ditches on either side of the bypass, however, are seldom dry, flooding when the bypass floods. Catfish (Ictalurus sp.), crappie (Pomoxis sp.), and bass occur in the borrow ditches. Both prey and predators would be disoriented by the turbulence occurring when the weir gates are initially opened; neither prey nor predator would gain an advantage under these conditions. High turbidity associated with bypass flooding would tend to limit predator efficiency. Generally the bypass is flooded for brief periods but in some years the period of inundation exceeds 1 month. It is not known whether this length of time would be sufficient for predators to become established and begin feeding. For 9 out of 44 years of operation, the bypass has been inundated during April and May, the time Coleman National Fish Hatchery was releasing juvenile chinook salmon. The number of juvenile salmon falling prey to predators in the bypass is unknown. Stranding is probably a bigger problem for both adult and juvenile salmon.

The weirs introduce structural complexities such as piers, other supportive structures, and corners or other irregularities in offriver channels to the river habitat, thus creating protuberances or overhangs. By providing locations for waiting predators, the corners, interstices, and other structural components which create boundary edges contribute to maximum foraging efficiency. Where structural boundary edges are maximized, the highest populations of predators will occur (Cooper and Crowder, 1979).

Predation in System Below Red Bluff Diversion Dam

SACRAMENTO-SAN JOAQUIN DELTA

With problems such as reverse flows, tidal exchange, and relatively rapid salinity changes faced by fish populations, predation in the Sacramento-San Joaquin Delta would seem to be a minor survival problem. The salmon runs on the Yuba, Feather, and American Rivers must pass through the Delta, yet only the Upper Sacramento River salmon run is showing a decline. Predation-related losses in the Delta have been evaluated only as related to the Central Valley Project and State Water Project export pumping facilities.

CLIFTON COURT FOREBAY

Schaffter (1978) suggested that predators in the Clifton Court Forebay to the State's Delta Pumping Plant (figure 18) may be eating salmon as the salmon are drafted from the inlet gates to the louver recovery system (figure 19). Two studies were conducted to define the problem. To evaluate predation losses, marked chinook salmon fingerlings were released in 1976 at the radial gate intake to Clifton Court Forebay. Based on a 22,000 acre-foot capacity of Clifton Court, a 67 percent louver efficiency, pumping rates as supplied by Department of Water Resources, and a viable release of 6,825 fish (releases less 10 percent handling mortality), the recovery expected was 6,336 fish. Actual recovery was 191 or 3 percent of the expected recovery. Schaffter (1978) considered six possible fates for the fish released into Clifton Court Forebay. They could have been: (1) louvered and recovered by the facility (accounting for only 3 percent), (2) passed through the louvers to the pumping plant (louver efficiency of 67 percent was used to estimate expected returns, (3) swam out the intake against the tidal inflow, although it is doubtful that the fish could overcome the estimated velocity of 10 ft^3/s at the gates, (4) remained in the forebay which is unlikely because of the near zero recoveries at the louvers beyond the first 3 days of month-long intensive sampling, (5) eaten by predators in the forebay as the seine and netting operation in the forebay yielded striped bass, threadfin shad (Dorosoma pretenense), and white catfish (Ictalurus catus), and (6) a combination of the above. Schaffter concluded that predation was the most likely cause of the low returns.

A subsequent study was conducted to verify the magnitude of the losses documented in Schaffter's earlier test and to establish the location of the losses (Hall, 1980b). Dye-marked salmon fingerlings were released in 1978 at three locations; trashboom (100 feet from the fish facilities), the entrance to the outlet channel (3,000 feet from the fish facilities), and at the radial gates (10,000 feet from the fish facilities).

Returns for those released 100 feet from the salvage site were 85 percent, but returns dropped to 12 percent for those released near the radial gates (10,000 feet from the salvage site). An increase in the mean size of the recovered marked fish suggested selective mortality was occurring (table 12). Hook-and-line sampling yielded 20 striped bass in less than 30 minutes, indicating a substantial bass population. Stomach samples of three out of four randomly selected striped bass contained

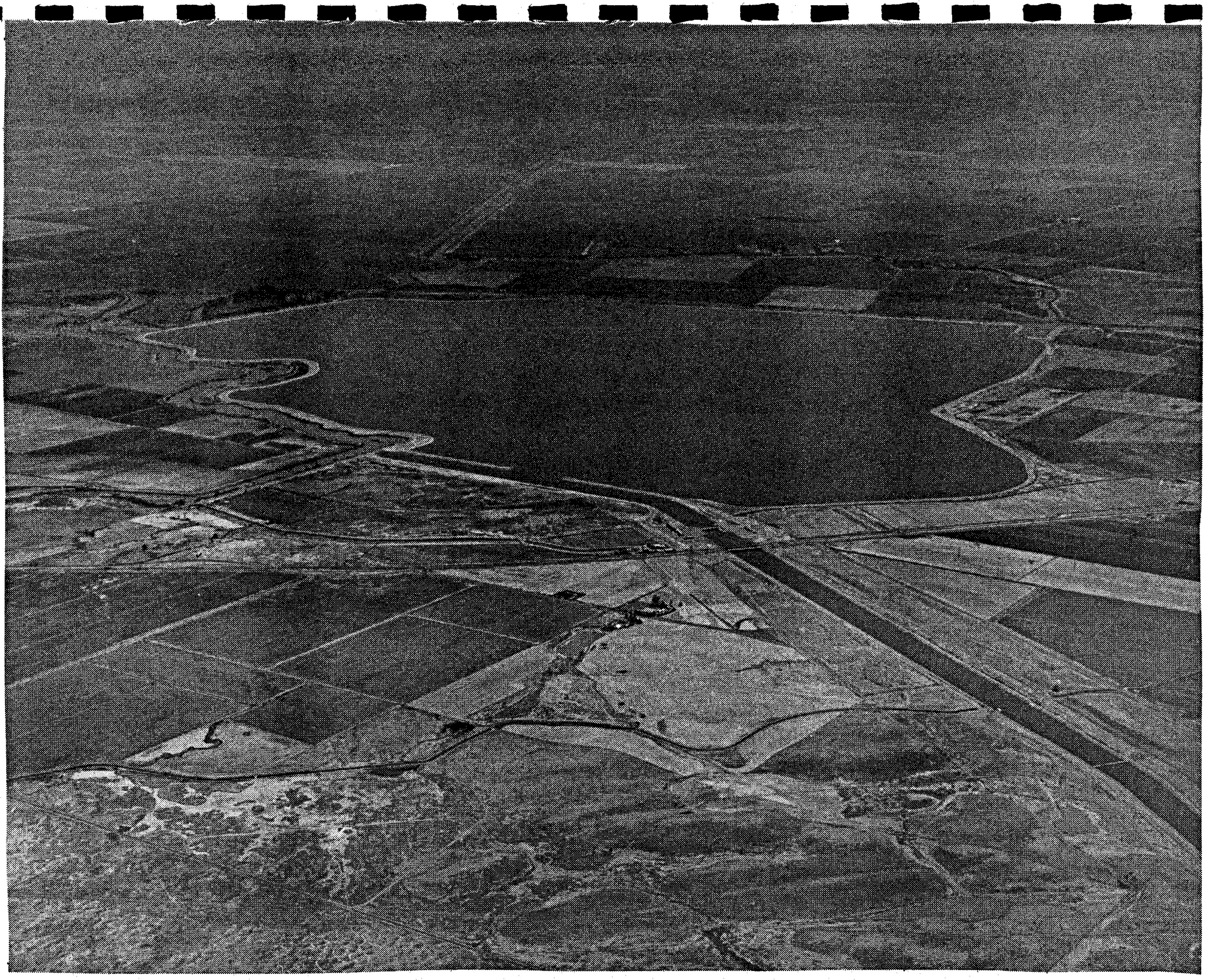

Figure 18. Clifton Court Forebay. John E. Skinner Fish Protective Facility in diversion channel, center right in photo.

fish, with one of the three containing recognizable remains of two salmon fingerlings.

Both of the studies by Schaffter and by Hall recommended that future Delta diversion facilities should not include a forebay because it would provide extensive habitat for predators. It was also recommended that debris should not be allowed to accumulate in existing impoundments because debris also provides cover for predators.

A study conducted from 1976 to 1978 measured differences in predation between a fish release site and a site where no fish releases occur (Grover and Hall, unpublished). Sampling sites selected were a deepwater release site, a control site, and a site near the intake for the proposed Peripheral Canal. At the three sites, gill nets were fished periodically. All fish captured were recorded by species and measured for fork length. The stomach contents of all predatory fish were preserved for later analysis. The most numerous predators were striped bass and Sacramento squawfish. The number of other predators captured was too low to be included in the analysis. It was concluded that striped bass do not congregate around the release site; instead they stay in an area utilizing the abundant food supply until either their foraging efficiency is sufficiently reduced, or they are satiated, whereupon they resume their migration. Squawfish, which tend to be drawn to the release site, set up stations to lie in wait for the regularly released food supply.

Predation in System Below Red Bluff Diversion Dam

TRACY FISH COLLECTING FACILITY

The Tracy Fish Collecting Facility (figure 20) is located approximately 2-1/2 miles northeast of the Tracy Pumping Plant which diverts water from the Sacramento-San Joaquin Delta into the Delta-Mendota Canal for delivery to the San Joaquin Valley. Young salmon, steelhead, striped bass and other fish which have been diverted from their migration by the Tracy Pumping Plant, are collected at the Tracy Fish Collecting Facility for return to the Delta. They are hauled to release points far enough downstream to escape the influence of the pumps.

The Jersey Island release site on the San Joaquin River was chosen for a predation study in 1966 and 1967 to determine how predators react to different concentrations of prey (Orsi, 1978, draft report). The study consisted of releasing small fish at the release (test) site and at a control site, then gill netting for predators at both sites. Single- and multiple-release patterns were used. Single releases consisted of a single truckload of 10,000 to 100,000 fish released daily at the test site. Multiple releases consisted of 4 to 11 truckloads totaling 112,000 to 1,780,000 fish daily. Stomach contents were preserved and analyzed for all predators captured. Both the number of predators caught and the number of prey fish consumed were greater at the test site than at the control site (table 13). The control site was sampled only three times in 1967 because of the great difference in predation between the two sites the previous year. Sampling at the control site in 1967 yielded one squawfish, one striped bass and one perch, none of which had fish

Table 13. Results of gill netting for predators at the test site and the Curtis Landing control site, Sacramento-San Joaquin Delta. Single and multiple releases combined. (Data from Orsi, 1968.)

	Test Site	Control Site
	(number of fish)	
Predators caught		
Striped bass	11	11
Black crappie	115	2
Squawfish	6	5
Total	132	8
Actual fish in stomach	110	7
(Percent of total)	(89%)	(30%)
Fish consumed		
Total	1,924	25
Average per predator	14.6	1.3

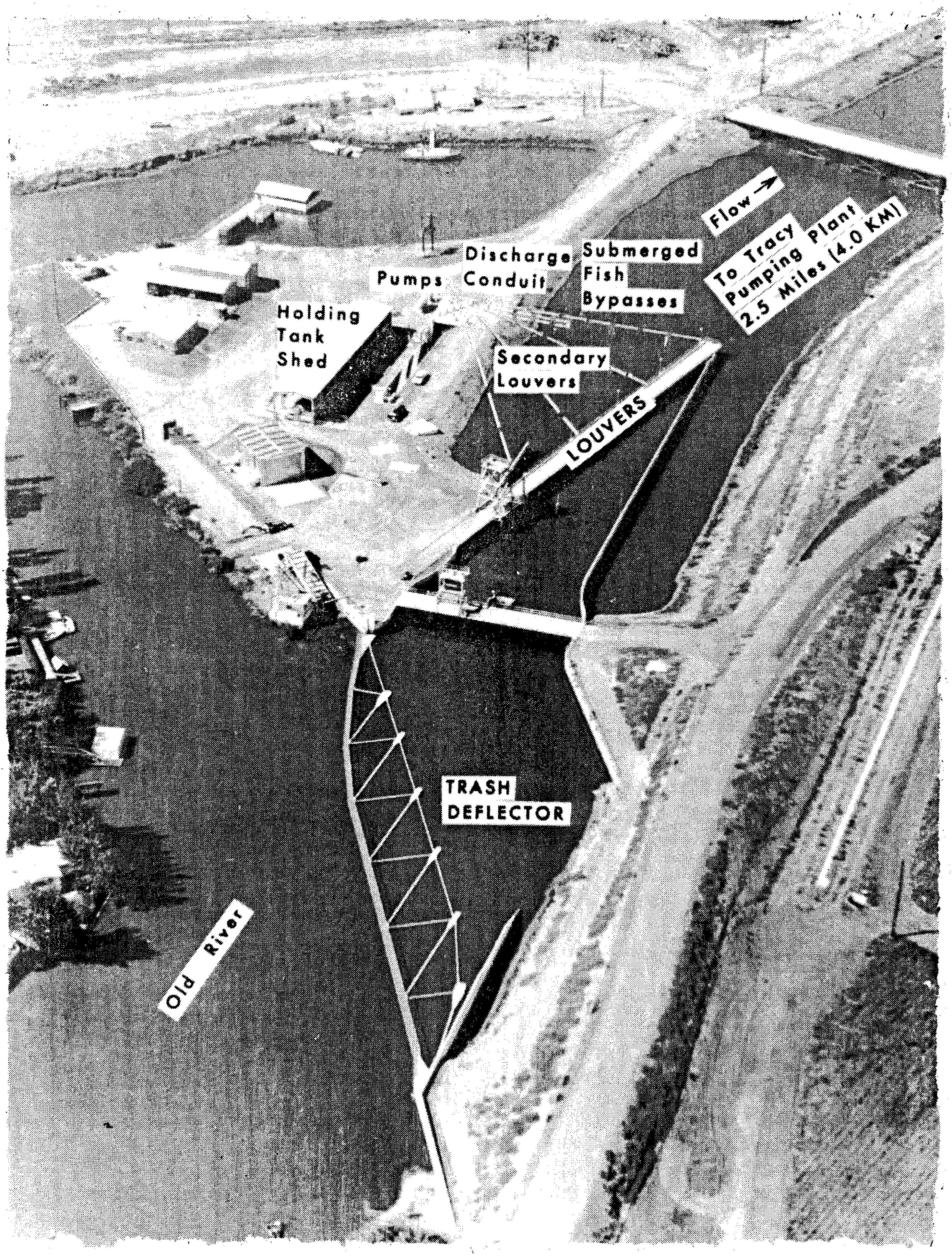

Figure 20. Tracy Fish Collecting Facility.

Table 14. Results of gill netting for predators at the Curtis Landing control site, 1966 and 1967. (Data from Orsi, 1968)

	Release			
	1966		1967	
	Number of fish			
	Multiple	Single	Multiple	Single
Predators caught				
Total	82	50	224	44
Actual (fish in stomach)	75	35	191	29
(Percent of total)	(91.4)	(70.0)	(86.0)	(65.9)
Fish consumed				
Total	1,774	150	852	208
Average per predator	21.6	3.0	3.8	4.7

Colusa on the Sacramento River to the central and western Delta and downstream through San Francisco Bay is significant. Striped bass are also caught by anglers each year in the Pacific Ocean from Tomales Bay to the north to Monterey Bay to the south. Even though striped bass have been shown to be a major predator in the Delta, most predator control measures aimed at striped bass are unlikely to gain acceptance. In recent years, the striped bass population has declined.

LOWER BAYS AND OCEAN

Salmon smolts migrating downriver to the ocean appear to move rapidly through the lower bays, spending little time in the brackish water portion of the estuary. Residence times of salmonids in the Sacramento River system vary, depending on the size of the fish. Residence times of up to 78 days have been recorded for juvenile chinook salmon (Kjelson, et al., 1981). No studies have been conducted to document losses of outmigrating salmon to predation in San Francisco Bay.

The State of Alaska has supported considerable research to identify predation of salmon. It has also taken a variety of fishery management actions. Gull and tern predation on salmon smolts was investigated by Dr. Archie Massman along the Kvichak River in 1959. He found that during 8 days of smolt outmigration, up to 252,240 smolts could have been consumed (Meachum and Clark, 1979).

Probably the most frequently encountered predators on salmonids are other fish. Large adult chinook salmon will feed on juvenile salmon when these young fish are available. In Alaska, the predation impact of the Dolly Varden (Salvelinus malma) and Arctic char (Salvelinus alpinus) have probably received the greatest attention. One of the most destructive predator removal programs was the establishment of a bounty on char in Alaska which lasted from 1928 to 1940 (Meachum and Clark, 1979). Millions of char were destroyed during the 12-year program, which was based on severe levels of predation occurring at relatively few locations. The program was dropped when it was learned that heavy predation by char on juvenile salmon did not occur throughout Alaska. Also, numbers of species other than char were being turned in for the bounty (Meachum and Clark, 1979).

Although California does not have the same wildlife population as Alaska, many of the same types of predators could be feeding on California's ocean salmon. For example, the California sea lion is a predator on salmon in the San Francisco Bay. The most likely fish predator in California is striped bass. However, valuable lessons can be learned from Alaska's experience, such as their experience with the Arctic char.

During the 1 to 4 years salmon spend in the marine environment before migrating back upriver to their home stream to spawn, man becomes a major harvester of the ocean-living salmon. Table 15 summarizes the commercial and commercial party boat catches from 1960 to 1976.

Table 15. Annual commercial catch and commercial chinook and silver salmon party boat catch from 1960-1976. (Data from California Department of Fish and Game, Fish Bulletins.)

Year	Commercial catch	Commercial party boat catch
	(lbs)	
1960	6,221,445	37,941
1961	8,637,907	42,965
1962	6,672,861	87,612
1963	7,859,186	72,457
1964	9,481,215	92,021
1965	9,737,775	51,677
1966	9,446,995	70,151
1967	7,401,729	84,946
1968	6,951,931	127,584
1969	6,150,906	111,389
1970	6,610,661	98,301
1971	8,116,878	130,812
1972	6,422,171	151,595
1973	9,668,966	124,676
1974	8,749,013	107,942
1975	6,925,082	73,857
1976	7,776,520	66,099

PART V

FINDINGS AND CONCLUSIONS

FINDINGS

Based on the results of the research and studies for this special report, these are the findings concerning predators, predation in general, operations at Coleman National Fish Hatchery, and predation at Red Bluff Diversion Dam.

Predators

The major predators in the Sacramento River system are Sacramento squawfish and striped bass. Yearling steelhead, juvenile salmon, and American shad are lesser predators.

Striped bass feed on prey encountered as the bass move about. Bass do not appear to remain in an area once they have fed. Striped bass are unlikely candidates for control measures because they are a major sport fishery resource.

Little is known about the Sacramento squawfish. Conclusions concerning their life history, migration, feeding habits, etc., are based on rather extensive studies conducted on the northern squawfish of Idaho and Oregon.

Sacramento squawfish tend to be drawn to and remain in areas where prey congregate and are regularly abundant. They cause significant predation problems where prey species are concentrated or stressed.

A study is now being conducted by Dr. Peter Moyle, University of California, Davis, who is under contract with the Department of Water Resources to: (1) assemble and analyze the information and data available on squawfish from agency and institutional files; (2) conduct studies of growth rates using scales already collected by agency biologists, supplemented with collections made during his study; (3) conduct studies on digestive rates of squawfish; and (4) make recommendations for the conduct of additional work needed to expand the knowledge of squawfish biology. This study should produce valuable information on squawfish for future squawfish management decisions.

Predation

Predation on outmigrating young salmonids increases at manmade structures and impoundments. Predation is probably of minor significance in the unobstructed portion of the river system.

Predation increases significantly when prey species are concentrated or stressed. Predator efficiency is higher near manmade structural complexities such as corners, hydraulic deadwater areas, riprap, and overhangs which cause shadows.

Most predators are sight feeders. Mass migration at night or at times of high flows or turbidity allows prey to escape at a time when predators are least efficient.

Operations at Coleman National Fish Hatchery

Predation of salmon in Battle Creek is generally considered to be minor in relation to that at Red Bluff Diversion Dam. Steelhead trout and squawfish are the principal predators in Battle Creek.

Salmon return at greater rates to Coleman National Fish Hatchery as adults when they are released as fingerlings at the hatchery rather than downstream at Rio Vista. The fish released at Rio Vista, however, have greater survival rates to the adult stage and, upon return to freshwater, stray to other spawning streams to a greater extent than the hatchery-released fish.

Predation at Red Bluff Diversion Dam

Juvenile chinook salmon may be preyed upon at unnaturally high rates in Lake Red Bluff. The lake, formed upstream from Red Bluff Diversion Dam, creates water velocity conditions that are favorable for squawfish predation. There are no valid estimates of juvenile chinook salmon losses as the juveniles pass through the lake.

Predation at Red Bluff Diversion Dam has been attributed to disorientation of the young salmon as they emerge from the boil immediately downstream of the dam gates and in the vicinity of the bypass release pipe. The estimates on the magnitude of these losses have not been based on rigorously controlled scientific investigations.

Efforts to control squawfish in the vicinity of Red Bluff Diversion Dam have been attempted. The justification for these efforts has been the assumption that squawfish cause significant losses to juvenile chinook salmon migrating downstream. The relative success of these efforts has not been determined.

CONCLUSIONS

The conclusions in this report are based on a review of existing data. No new data were developed specifically for this report. The conclusions follow.

1. Any new project facilities or project modifications should be designed to minimize potential predation on anadromous fish to biologically acceptable levels and consistent with the primary purpose of the project or any modification.
2. Those deficiencies in structural design or operation of existing facilities, which contribute to significant predation on anadromous fisheries that would not have occurred in the absence of the project, need to be corrected expeditiously.
3. Appropriate field studies should define the magnitude of predation at existing project facilities.
4. In solving predation problems, the operating water project entity needs to direct its efforts toward securing research funding, committing manpower to the tasks, and producing definitive solutions expeditiously.
5. A limited program to control squawfish in the vicinity of Red Bluff Diversion Dam, including an analysis of the effectiveness of the program would be desirable.
6. Operational changes to the extent practicable at salmonid hatcheries in the Central Valley would reduce predation of salmonids within the facilities or in the river following release of the salmonids.

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APPENDIX

LIFE HISTORY

OF

CHINOOK SALMON,
STEELHEAD TROUT,
STRIPED BASS,
SACRAMENTO SQUAWFISH,
AND
AMERICAN SHAD

Appendix

Chinook Salmon

Chinook salmon spawn in cool streams where there is a gravel bottom and suitable current. The preferred spawning area is the lower end of a pool where the water is beginning to pick up speed, just above a riffle, or the riffles themselves. Immediately prior to spawning, the female salmon selects a spot and digs a nest by rolling on her side near the bottom and moving the gravel downstream with a pumping or swimming motion. She deposits some of her eggs in the pit she has dug. These eggs are immediately fertilized by a waiting male. The female then moves upstream a short distance and resumes her digging, thus covering her previously deposited eggs. More eggs are deposited, and the process is repeated until she is spawned out. After spawning, adult chinook salmon die.

For maximum egg survival, water temperatures have to be less than 14 °C. Eggs hatch in 50 to 60 days. Usually within 3 to 4 weeks after hatching, the young wriggle up through the gravel to the water above. When newly hatched, the young have a large pinkish yolk sac which gives them a tadpole-like appearance. They live off this yolk sac until it is absorbed and then start feeding on minute forms of life in the stream. Most young chinook salmon migrate to the ocean in the spring within several months after hatching. Late fall and winter chinook salmon usually do not immediately migrate to the ocean because of low flow and high water temperature conditions in the Lower Sacramento River. Most juveniles reside in the stream until the fall. A small percentage reside in the stream an entire year before migrating downriver.

Appendix

Four different runs or races of chinook salmon spawn in the Sacramento River each year: spring, fall, late fall, and winter runs. While in fresh water, juvenile chinook salmon are opportunistic drift feeders and take a wide variety of terrestrial and aquatic insects. In the Sacramento-San Joaquin Delta, terrestrial insects are the most important food, but crustaceans are also taken in large numbers. Adult salmon feed mostly on fish. Spring-run salmon enter the river system between March and June, spawning from late August through early October with the peak being in September. Downstream migration of the smolts begins in December, peaks in January and February, and is complete by the end of April.

Fall-run salmon, the largest run in numbers of fish, migrate into the Sacramento River from September through November and spawn from early October though December. The young migrate downstream from February through early June.

The late fall run migrate upstream from early November through February and spawn from January through March. Young begin migrating downstream in April. Many late fall chinook salmon reside in the Upper Sacramento River and migrate to sea the following fall.

Winter-run salmon enter the Sacramento River from early January through mid-June. Spawning usually occurs between mid-April and mid-July. Downstream migration of the young occurs between November and February.

Appendix

Salmon, either as adult spawners migrating upstream or as smolts migrating downstream, can be found in the main stem of the Sacramento year-round.

References. Fry, 1973; Hallock, 1977; Kjelson, Raquel, and Fischer, 1981; and Moyle, 1976.

Steelhead Trout

The steelhead is a subspecies of the rainbow trout. Rainbow trout will survive temperatures of 0 to 28 °C. They can withstand temperatures at the upper end of this range only if gradually acclimated and the water is saturated with oxygen. Optimum temperatures for growth seem to be 13 to 21 °C. At low temperatures, they can withstand oxygen concentrations as low as 1.5 to 2.0 ppm but concentrations close to saturation are required for growth. Tolerance to varying chemical conditions of water is also broad. They can live in water ranging in pH from 5.8 to 9.6, but best growth seems to be achieved in waters with a pH of 7 to 8. A spring-run type of steelhead enters streams in the spring or summer and waits through the dry season until the following spring to spawn. The great majority of steelhead, however, are known as fall-run or winter-run steelhead. Fish of this type enter the stream and spawn during the same season. The time of migration varies. If the river is large enough and cool enough, the steelhead may enter in the late summer or early fall. Whether steelhead start upstream in August or in January, the spawning run usually continues until March or April.

Spawning resembles that of the salmon. The urge to migrate seems to be eye-related. Young steelhead usually migrate to the ocean after spending two seasons in freshwater. Faster growing fish migrate after one season, but slow growers may spend up to four seasons in freshwater.

After reaching saltwater, steelhead grow quickly and usually return to spawn in their home streams after one or two seasons. Unlike salmon, steelhead do not necessarily die after spawning. The rigors of migration and spawning do cause many deaths, but fish that have spawned two or three times are not uncommon.

Trout are highly aggressive and defend feeding territories. Young and adult feeding habits are similar, varying only by what is available to a particular size range. They feed on a variety of terrestrial insects, adult and emergent aquatic insects, aquatic insect larvae, amphipods, snails, and smaller fish.

References. Fry, 1973; and Moyle, 1976.

Striped Bass

Striped bass move regularly between saltwater and freshwater, usually spending much of their life cycle in estuaries. Spawning begins in the spring when water temperatures reach 58 °F. Most spawning occurs between 61 and 69 °F with the spawning period extending April to mid-June. Striped bass must spawn in freshwater where there is moderate to swift current. The section of the San Joaquin River between Antioch Bridge and the mouth of Middle River, together with the other channels in the area, is an important spawning ground. The Sacramento River from Courtland to Colusa is the most important spawning area.

Females usually spawn for the first time in their fifth year while most males mature when they are 2 years old. Striped bass are mass-spawners with thousands of large bass aggregating close to the bank, just off the main current. Groups of 5 to 30 fish, predominantly males, break off from the main group and swim out into the main river close to the surface. Depending on her size, the female will release anywhere from 11,000 to 2 million eggs in a season.

The eggs are transparent and are only slightly heavier than water. This causes them to slowly sink to the river bottom. If they remain on the bottom for any length of time, they will not survive, but even a slight current will keep them suspended. The eggs hatch in about 48 hours and are totally dependent on their yolk sacs for nourishment for the next 7 to 8 days. The young then begin to feed on small zooplankton. Essentially, the larval bass from both the Sacramento River and the San Joaquin River are carried by the bottom currents into an area where freshwater and saltwater meet called the "entrapment zone," where they remain suspended. Thus, when they begin to feed, they are located in the most productive area of the estuary.

In the Delta, adult striped bass feed mostly on threadfin shad and smaller striped bass, while in San Pablo Bay they take a wide variety of fish as well as bay shrimp. Juvenile striped bass, in contrast, are primarily invertebrate feeders, the importance of fish in the diet increasing as the bass increase in size. Young of the year (5 to 23 cm SL--the distance from the tip of the snout to the end of the vertebral column) rely mostly on opposum shrimp, although amphipods, copepods, and small threadfin shad are important. The diet of juvenile bass (13 to 35 cm FL--the distance from the tip of the snout to the deepest part of the tail fork) is similar to that of the young of the year, but fish are more important, especially late in the summer when young of the year striped bass and other small fish become available. Subadult bass (age 2+, 26 to 47 cm FL) are primarily piscivorous, like the adults, although invertebrates are still important in the winter and spring when small fish are hard to find.

References. Fry, 1973; and Moyle, 1976.

Appendix

Sacramento Squawfish

Sacramento squawfish are sexually mature by the beginning of their third or fourth year. These mature fish move upstream during April and May to spawn in riffles when water temperatures exceed 14 °C. Spawning behavior of the Sacramento squawfish has not been recorded in any detail, but it is thought to be similar to that of the northern squawfish which has been the subject of more extensive study.

Adult northern squawfish congregate over a rocky-bottomed area. Any female swimming past a swarm of males would be immediately pursued by one to six males. Spawning occurs when a female dips close to the bottom and releases a number of eggs which are simultaneously fertilized by one or more males swimming close behind her. The fertilized eggs sink to the bottom and adhere to the rocks and gravel. The eggs hatch in 4 to 8 days. Schooling behavior begins in 11 to 15 days. Young squawfish migrate downstream when river flows are lower in the summer months.

Squawfish are opportunistic feeders, relying on whatever prey is most prevalent at the time for the least outlay of energy. The size and type of prey varies with the size and age of the squawfish. Smaller squawfish feed almost exclusively on small insects and plant material. A transition to fish as a major portion of their diet seems to occur between 20 to 40 cm (8 to 16 in.) fork length.

References. Moyle, 1976.

Appendix

American Shad

Adult American shad, with the exception of a population introduced into Millerton Lake, are found in freshwater only when they move up into rivers to spawn. Spawning runs are from late April to early June. In many of the spawning streams, some shad go as far upstream as they are able, but, unlike salmon, they do very poorly at ascending fishways and are likely to be stopped by a relatively low dam. Formerly, shad ascended the Sacramento River to Redding in some years. Since the construction of the Red Bluff Diversion Dam, most of the run stops at that point. Although a few do migrate through the fishways at the dam, it is not known how much farther upstream they reach.

Most male shad mature in 3 to 4 years while most females mature in 3 to 5 years. They do not move into freshwater until temperatures exceed 10 to 11 °C. Peak spawning occurs at 15 to 20 °C. Spawning is a mass affair that takes place mostly in the main channels of the river. Each spawning act is initiated when a male presses alongside a female. The two then swim rapidly side by side, releasing eggs and sperm. Most shad die after spawning, but a few do return to the ocean and spawn again the next year.

Shad eggs are only slightly heavier than water so that they stay suspended in the current, gradually drifting downstream. Hatching takes 3 to 6 days depending on the water temperature. Newly hatched shad gradually move out to sea, lingering in the Delta for several weeks to several months. By December, most of these shad have left freshwater.

Adult American shad do feed while in freshwater, unlike their counterparts on the Atlantic coast. The most abundant organisms found in their stomachs are oppossum shrimp, followed by copepods, cladocerans, and amphipods. Occasional clams and fish larvae are also taken.

Young shad utilize those food items which are most readily available. Studies of young shad on the Atlantic coast have shown small crustaceans and insects are common foods. Limited data on young American shad show cladocerans and copepods are consumed.

References. Fry, 1973; Moyle, 1976; and Stevens, 1966.

Appendix

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