WORKING PAPER ON RESTORATION NEEDS

HABITAT RESTORATION ACTIONS
TO DOUBLE NATURAL PRODUCTION OF ANADROMOUS FISH
IN THE CENTRAL VALLEY OF CALIFORNIA

Volume 2

Prepared for the U.S. Fish and Wildlife Service
under the direction of the
Anadromous Fish Restoration Program Core Group

May 9, 1995

ORGANIZATION OF THIS WORKING PAPER

This is Volume 2 of three volumes that comprise the Anadromous Fish Restoration Program Working Paper (AFRP) on Restoration Needs. The contents of the three volumes are as follows:

> **Volume 1** describes how the WORKING PAPER was developed, explains the process envisioned for completing a final Restoration Plan, and summarizes the production goals, limiting factors, and restoration actions sections developed by the AFRP technical teams. Interested parties should read the letter from Dale Hall and Wayne White that appears at the beginning of Volume 1.
>
> **Volume 2** provides descriptions of Central Valley rivers and streams, summarizes information on historic and existing conditions for anadromous fish, identifies the problems that have led to the decline of anadromous fish populations, and identifies roles and responsibilities of state and federal agencies in managing anadromous fish. It also includes two key documents that were used by the AFRP Core Group and technical teams to develop the WORKING PAPER.
>
> **Volume 3** includes the complete production goals, limiting factors, and restoration actions sections as submitted by the AFRP technical teams and edited by USFWS staff. Volume 3 also includes citations for all three volumes of the WORKING PAPER. To request copies of this working paper, call the Anadromous Fish Restoration Program=s information line at (800) 742-9474 or (916) 979-2330 and dial extension 542 after the recorded message begins. You may also obtain copies by calling Roger Dunn, CVPIA Public Outreach, at (916) 979-2760 or by sending e-mail requests to roger_dunn@fws.gov. The Working Paper is available to be viewed and downloaded on the Internet at http://darkstar.dfg.ca.gov/usfws/fws_home.html.

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SACRAMENTO BASIN

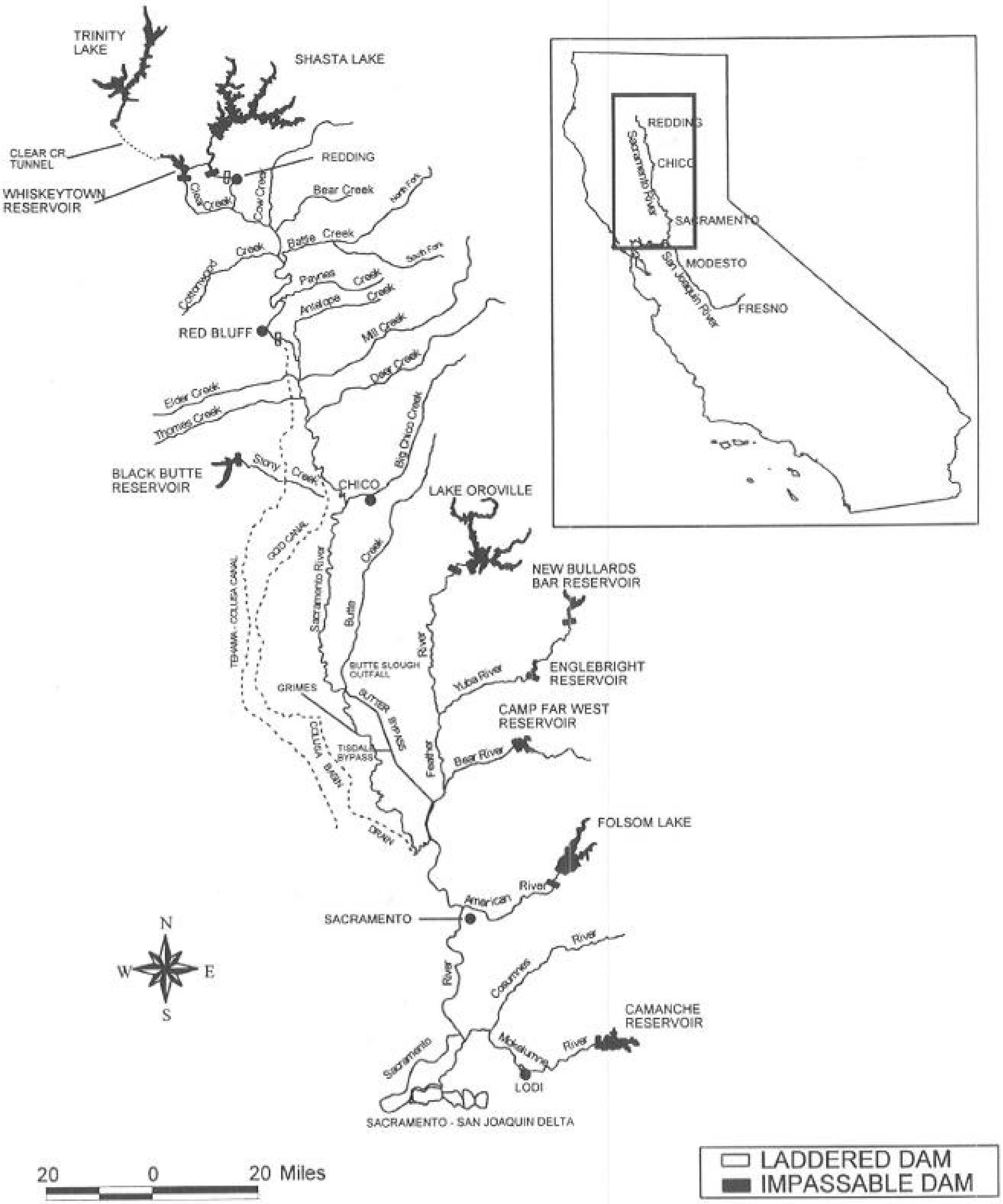
Upper Mainstem Sacramento River

The Sacramento River, the largest river system in California, yields 35% of the state's water supply. This river system supports one of the largest contiguous riverine and wetland ecosystems in the Central Valley (Figure 2-V-1). The median historical unimpaired run-off above Red Bluff is 7.2 million acre-feet (maf), with a range of 3.3-16.2 maf (Figure 2-V-2). At least eight state-listed and federally listed endangered and threatened species and several species of special concern exist in the river and adjacent riparian forest. The chinook salmon populations of the Sacramento River provide most of the state's sport and commercial catch.

Most of the Sacramento River flow is controlled by the U.S. Bureau of Reclamation's (USBR's) Shasta Dam, which stores up to 4.5 maf of water. River flow is augmented in an average year by transfer of up to 1 maf of Trinity River water through a tunnel to Keswick Reservoir. USBR operates the Shasta-Trinity Division of the Central Valley Project (CVP), which includes Shasta, Keswick, Trinity, Lewiston, Whiskeytown, and Spring Creek Debris dams; Red Bluff Diversion Dam (RBDD); and the Tehama-Colusa Canal (TCC) and Corning Canal. Other small- to medium-sized impoundments in the watershed, including Lake McCloud, Lake Britton, Iron Canyon Reservoir, and Big Sage Reservoir, can retain an additional 300+ thousand acre-feet (taf).

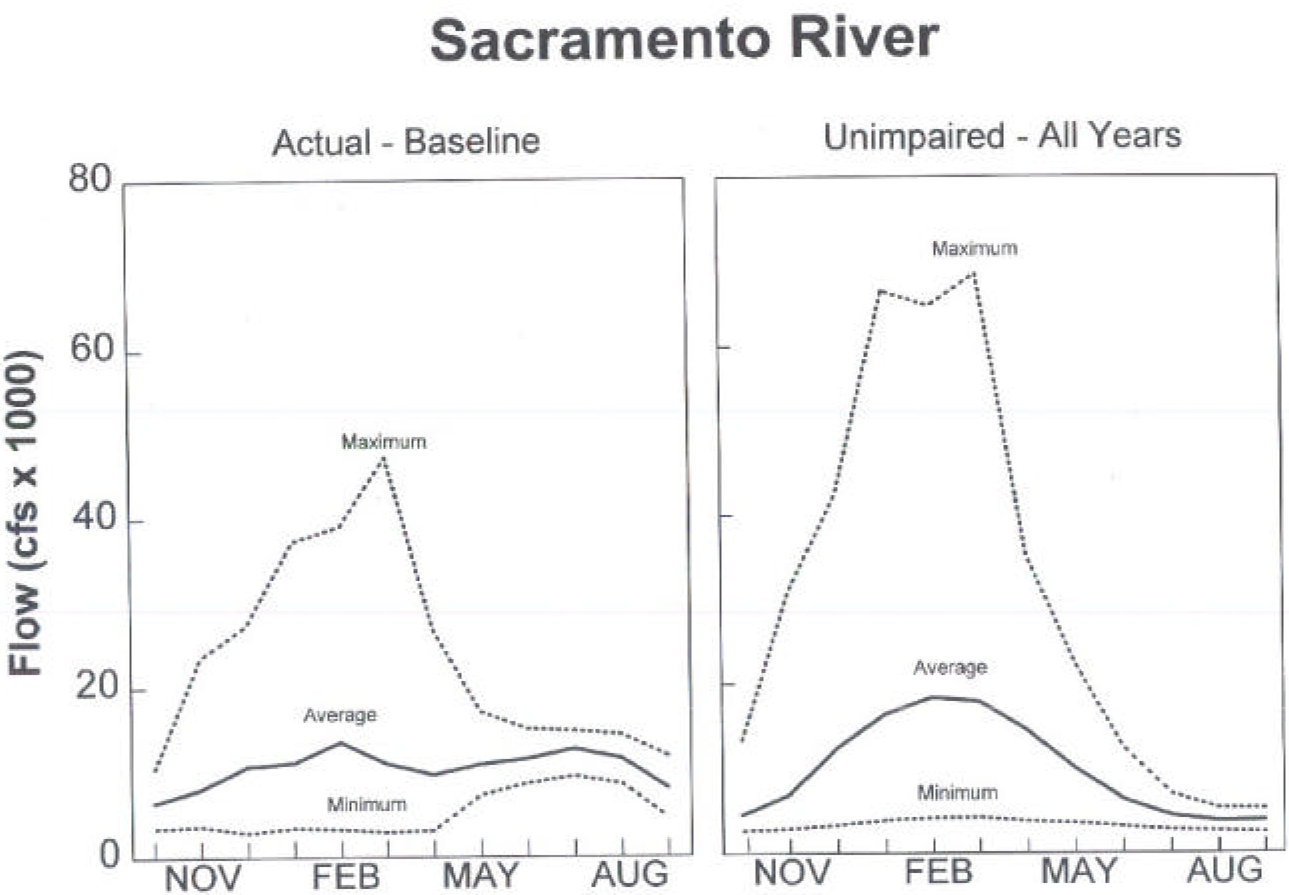
Upper Sacramento River Tributaries

Clear Creek - Clear Creek, the first major tributary to the Sacramento River below Shasta Dam (Figure 2-V-3), drains approximately 238 square miles. It originates in the mountains east of Clair Engle Reservoir and flows approximately 35 miles to its confluence with the Sacramento River just south of the Redding city limits. The median historical unimpaired run-off is 69 taf, with a range of 0-421 taf (Figure 2-V-4). Two dams are located on the creek. Whiskeytown Dam, constructed in 1963 near river mile (RM) 16.5, stores and regulates run-off from the Clear Creek drainage area and diversions from the Trinity River. The water is then diverted through the Spring Creek Tunnel to Keswick Reservoir where it provides water and power for use in the CVP. The second dam is the McCormick-Saeltzer Dam, constructed in 1903 and located approximately 10 miles downstream from Whiskeytown Dam at RM 6.5. This dam diverts 10 cubic feet per second (cfs) of water into the Townsend Flat water ditch for irrigation use.



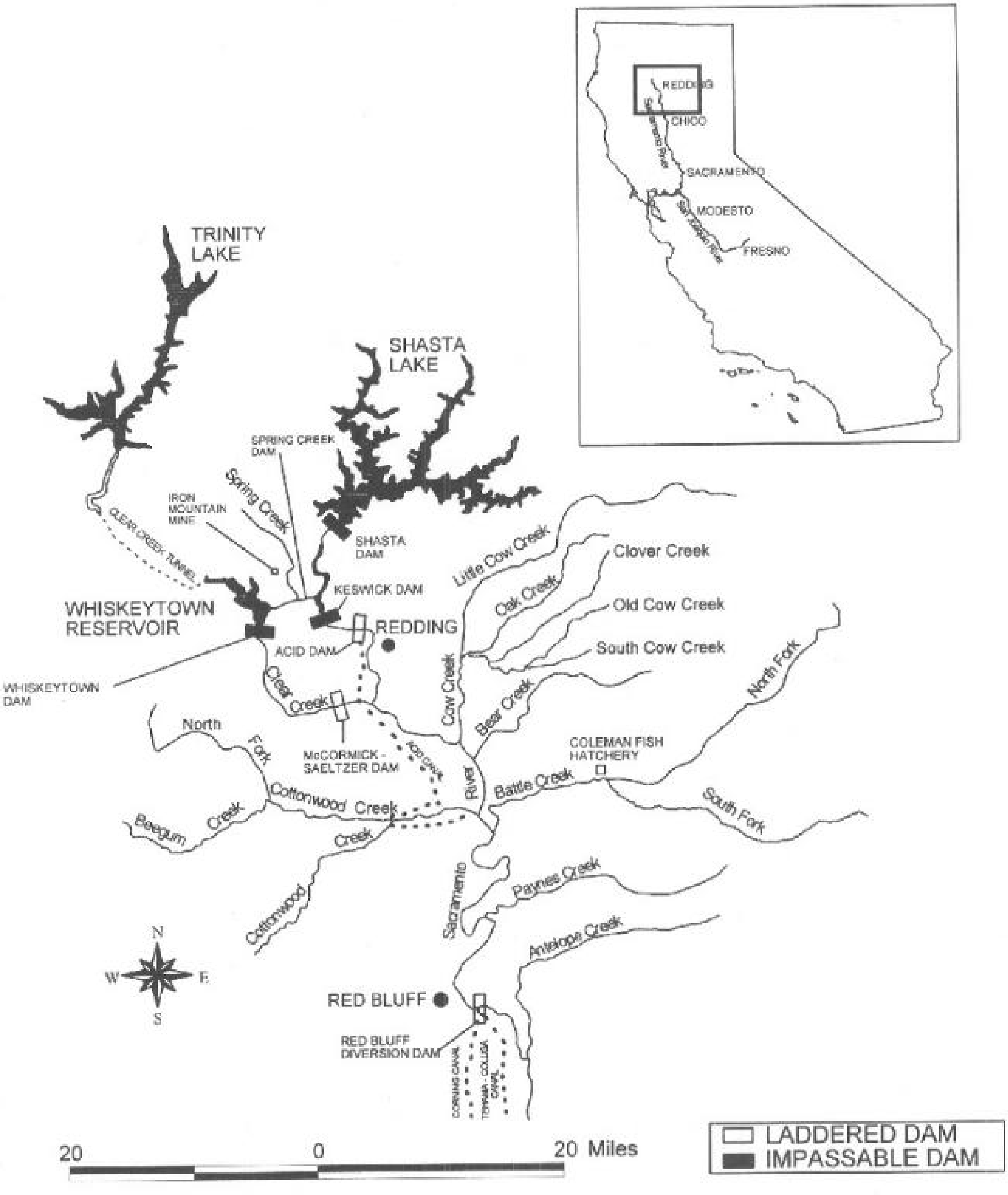
MAP OF THE SACRAMENTO RIVER BASIN

FIGURE 2-V-1



SACRAMENTO RIVER MEAN MONTHLY FLOW: ACTUAL (AT KESWICK, 1967-1991) AND UNIMPAIRED (NEAR RED BLUFF, 1922-1991)

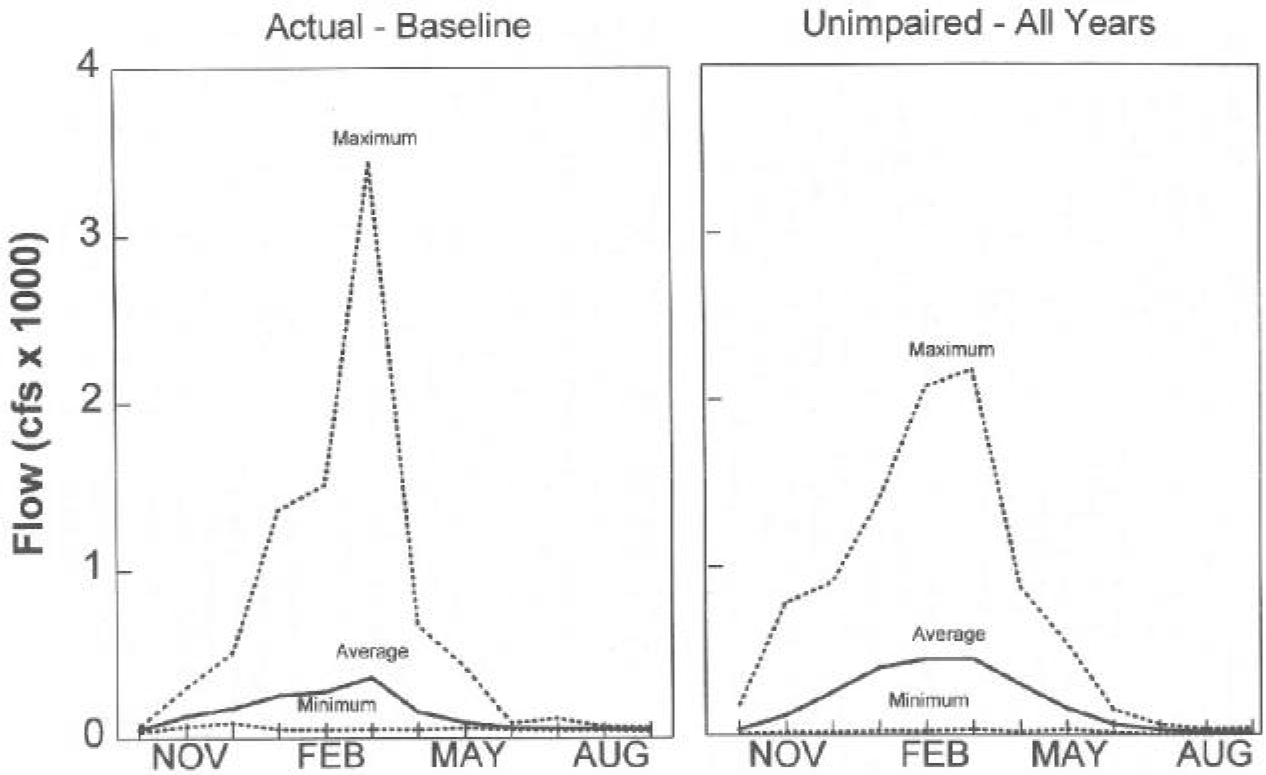
FIGURE 2-V-2



MAP OF THE UPPER SACRAMENTO VALLEY DEPICTING LOCATIONS OF THE SACRAMENTO RIVER AND ITS TRIBUTARIES

FIGURE 2-V-3

Clear Creek



CLEAR CREEK MEAN MONTHLY FLOW AT FRENCH GULCH: ACTUAL (1967-1991) AND UNIMPAIRED (1922-1991)

FIGURE 2-V-4

Cow Creek - Cow Creek flows through the southwestern foothills of the Cascade Range and enters the Sacramento River at RM 280, 4 miles east of the town of Anderson in Shasta County (Figure 2-V-3). Cow Creek has five major tributaries: Little (North) Cow, Oak Run, Clover, Old Cow, and South Cow creeks. Old Cow and South Cow creeks are the largest tributaries. The drainage area is approximately 425 square miles, and the average annual discharge is more than 500 taf (Reynolds et al. 1993). The total length of streambed in the drainage is about 66 miles. Headwaters for most of the tributaries originate between 5,000 and 7,000 feet in elevation, and the stream gradient in the upper reaches of the tributaries is relatively steep. Mixed conifer forest of ponderosa pine, Douglas-fir, incense cedar, and California black oak is the predominant vegetation in the higher elevations. In the lower foothills that abut the valley floor, the oak-digger pine association is predominant. The valley floor is dominated by oak grassland and pasture. Fall-run and late fall-run chinook salmon spawn in the creek on the valley floor and in all five tributaries.

Bear Creek - Bear Creek originates south of Latour Butte in Shasta County at an elevation of about 6,800 feet. It enters the Sacramento River 5 miles below Anderson as a small eastside tributary approximately 4 miles north of Battle Creek (Figure 2-V-3). Approximately 24 miles of habitat are available to salmon before the first natural barrier. The stream has low streamflow in spring through fall of most years and no flow during periods of below-normal rainfall. During spring and summer, the limited natural streamflow is further reduced by unscreened irrigation diversions in the lower reaches where the stream enters the valley floor. Although adequate streamflows in fall and spring are prerequisites for anadromous fish migration and reproduction, the drainage is known to support fall-run salmon and some steelhead.

Cottonwood Creek - Cottonwood Creek originates on the east side of a rugged section of the Coast Ranges in the Yolla Bolly-Middle Eel Wilderness in Tehama County at an elevation of approximately 4,000 feet. Cottonwood Creek drains the west side of the Central Valley and enters the Sacramento River a short distance downstream from the Redding-Anderson area (Figure 2-V-3). It has a drainage area of approximately 929 square miles. The three forks of Cottonwood Creek and tributaries encompass approximately 83 miles of habitat available to salmon. Cottonwood Creek responds quickly to rainfall and is prone to flash flooding. Poor land use practices resulting from overgrazing, timber harvest, road building, and development have significantly degraded existing fish habitat. The results have been high silt levels, armoring of gravel beds, and elevated water temperatures. Extensive gravel mining in the valley section of Cottonwood Creek has not only damaged in-creek spawning but significantly reduced gravel recruitment to the Sacramento River. Rainbow Lake is a small impoundment in the upper watershed with a capacity of 3,600 af.

Battle Creek - Battle Creek drains the western flank of Mount Lassen and enters the Sacramento River at RM 271, approximately 5 miles southeast of the Shasta County town of Cottonwood (Figure 2-V-3). Its two main branches, the North Fork and the South Fork, join 16.6 miles above the mouth and flow into the Sacramento Valley from the east, draining a watershed of approximately 360 square miles. Although boulder-laden areas can impede fish migration in the Eagle Canyon section of the North Fork, all diversion dams on Battle Creek have fish ladders (McCumber Reservoir Dam and North Battle Creek Reservoir

Dam are above barrier falls). Because of high summer (June-October) base flows of about 290 cfs (Payne & Associates 1991c) and the relative lack of consumptive water use, Battle Creek has the greatest restoration potential of the Sacramento River tributaries. Most of the Battle Creek drainage is privately owned. One other small impoundment in the watershed is Baldwin Reservoir.

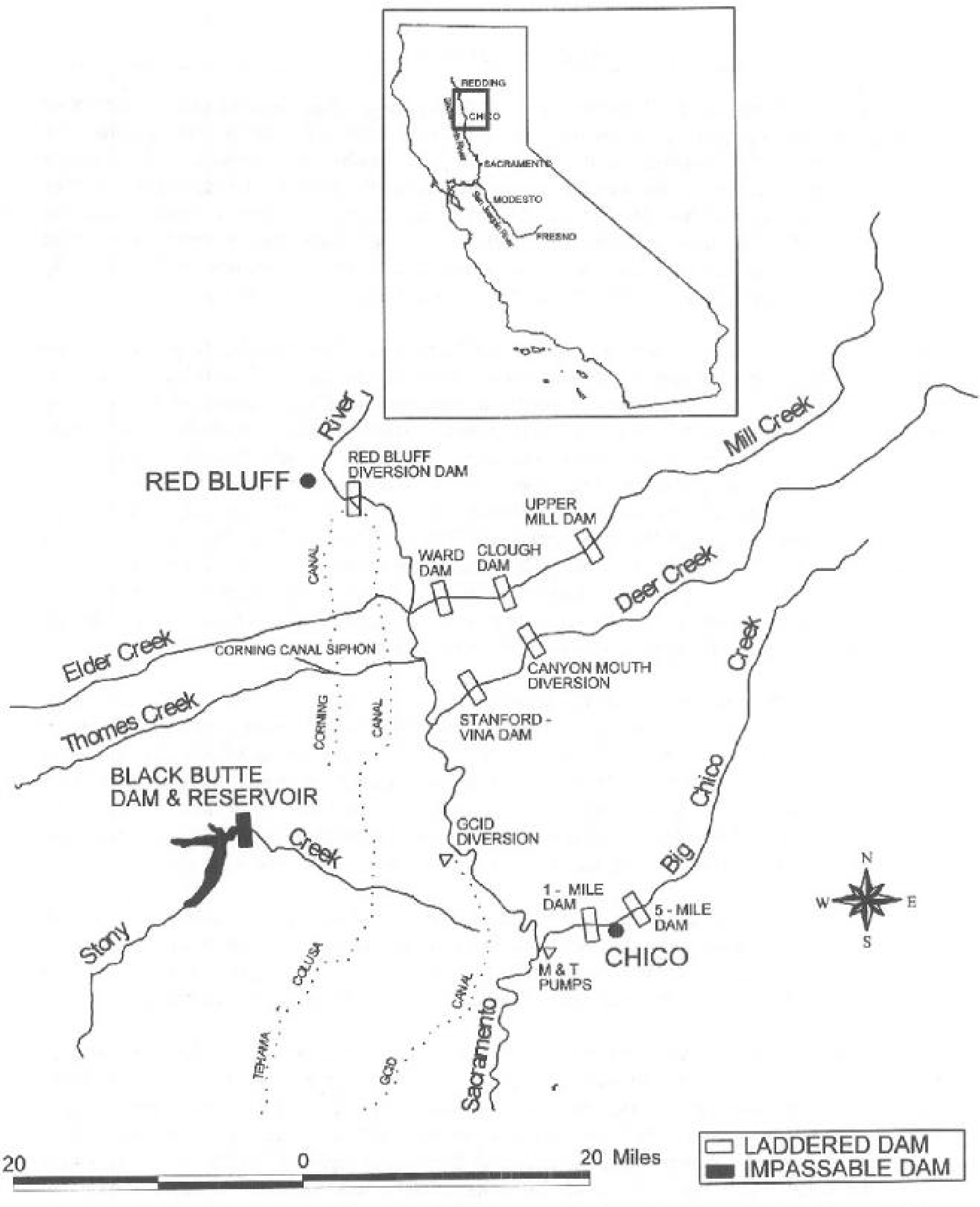
Paynes Creek - Paynes Creek enters the Sacramento River at RM 253, 5 miles north of the town of Red Bluff (Figure 2-V-3). It flows into the Sacramento Valley from the east, draining a watershed of approximately 93 square miles. Paynes Creek originates in a series of small lava springs about 6 miles west of the town of Mineral. Although the stream has no significant dams, flows in Paynes Creek have been significantly affected by the recent drought conditions, as well as by 16 seasonal diversions for irrigation, stock watering, and fish culture. The lowermost irrigation diversion, about 2 miles upstream from the mouth, is the largest, with a capacity of approximately 8 cfs. It provides water to irrigate the Bend District. The California Department of Fish and Game (DFG) owns and operates a screen on this diversion.

Paynes Creek is known to support fall-run salmon when water conditions are adequate. Low flow and inadequate spawning gravel have been identified as significant factors limiting salmon production in Paynes Creek, however. In 1988, DFG built five spawning riffles using 1,000 tons of spawning gravel. Because of low flows attributable principally to the recent drought, however, the reconstructed riffles have been sparsely used.

Antelope Creek - Antelope Creek originates in the Lassen National Forest in Tehama County at an elevation of about 6,800 feet. The creek flows southwest from the foothills of the Cascade Range and enters the Sacramento River at RM 235, 9 miles southeast of the town of Red Bluff (Figure 2-V-3). The drainage is approximately 123 square miles and the average stream discharge is 107 taf per year. The fish habitat of Antelope Creek is relatively unaltered above the valley floor, but the lack of adequate migratory flows from the Sacramento River to this habitat prevents optimum use by anadromous fish.

Water diversions and a braided channel near the canyon mouth often create problems for fish passage during the typical diversion period from April 1 through October 31. One diversion is operated by the Edwards Ranch with a water right of 50 cfs, and the other is run by the Los Molinos Mutual Water Company with a water right of 70 cfs. Because the average annual flow during April through October from 1940 to 1980 was 92 cfs, the lower reach of the stream is usually dry when both diversions are operating. Thus, adult fall-run and spring-run chinook salmon are generally unable to enter the stream during the diversion season.

Elder Creek - Elder Creek enters the Sacramento River at RM 230, 12 miles south of the town of Red Bluff (Figure 2-V-5). The stream flows into the Sacramento Valley from the west, draining a watershed of approximately 142 square miles. There are no significant dams on the stream, but several small water diversions are present. The stream is generally intermittent with a highly fluctuating flow regime. Flow



MAP OF THE CENTRAL SACRAMENTO VALLEY DEPICTING LOCATIONS OF THE SACRAMENTO RIVER, AND MILL, DEER, AND BIG CHICO CREEKS

FIGURE 2-V-5

records indicate peak flows of more than 11,000 cfs, but the stream is normally dry from July to November. In recent years, it has supported only an occasional, small run of fall-run chinook salmon.

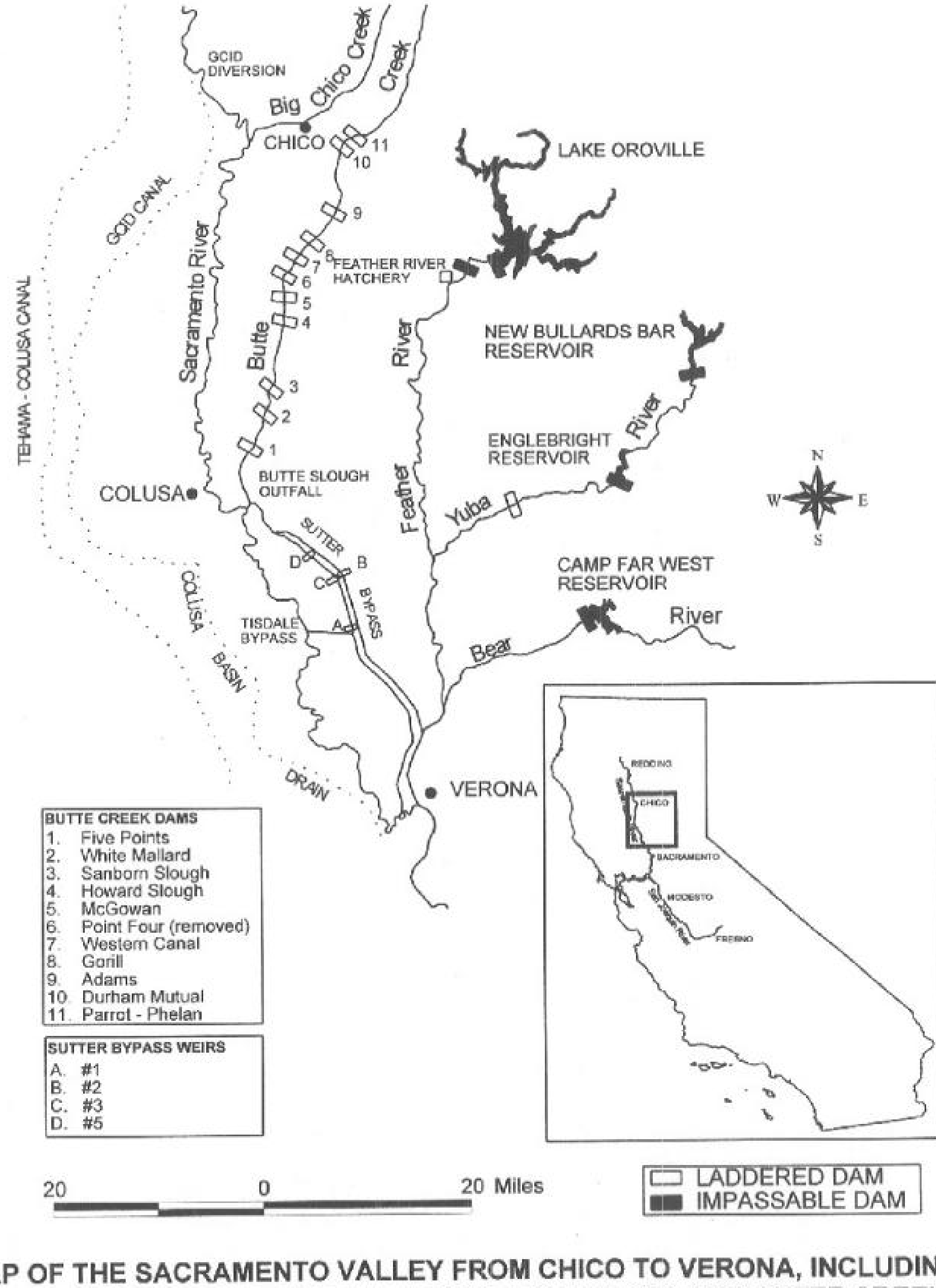
The stream reach from Rancho Tehama to the mouth is a low-gradient, braided channel with poor spawning and rearing conditions. A seasonal swimming area is created in summer by the placement of a gravel dam in the stream at Rancho Tehama, a rural housing development. Higher quality spawning gravel is located between Rancho Tehama and the point where the stream enters the valley floor. The U.S. Fish and Wildlife Service (USFWS) has recently purchased property near the confluence of Elder Creek and the Sacramento River as part of the Middle Sacramento River Wildlife Refuge. Approximately 20 miles upstream of the valley floor, the stream gradient increases rapidly in a rugged canyon area that supports resident trout and possibly a few steelhead.

Mill Creek - Mill Creek is a major tributary of the Sacramento River, flowing from the southern slopes of Mount Lassen and entering the Sacramento River at RM 230, 1 mile north of the town of Tehama (Figure 2-V-5). The stream originates at an elevation of approximately 8,000 feet and descends to 200 feet at its confluence with the Sacramento River. The watershed drains 134 square miles, and the stream is approximately 60 miles in length. The creek is confined within a steep-sided, relatively inaccessible canyon in the upper watershed. During the irrigation season, three dams on the lower 8 miles of the stream divert most of the natural flow, particularly during dry years. Most of the creek is bordered by U.S. Forest Service (USFS) land. Private land holdings exist only in the extreme headwaters and on the valley floor. The streamflows through the Ishi Wilderness Area and the Gray Davis Dry Creek Reserve, which is managed by The Nature Conservancy. Mill Creek spring-run chinook salmon are unique for spawning at an elevation of more than 5,000 feet, the highest elevation known for salmon spawning in North America.

Thomes Creek - Thomes Creek enters the Sacramento River at RM 225, 4 miles north of the town of Corning (Figure 2-V-5). It flows into the Sacramento Valley from the west, draining a watershed of approximately 188 square miles. No significant dams are located on the stream other than two seasonal diversion dams, one near Paskenta and the other near Henleyville. Several small pump diversions are operated seasonally in the stream. The stream is usually dry or flows intermittently below the U.S. Geological Survey (USGS) stream gauge near Paskenta until the first heavy fall rains. Fall-run chinook salmon enter and spawn in Thomes Creek in years of sufficient rainfall.

Deer Creek - Deer Creek, a major tributary to the Sacramento River, originates from several small springs near Childs Meadows to the north and from the northern slopes of Butt Mountain to the south. It enters the Sacramento River at RM 220, approximately 1.5 miles north of Woodson Bridge State Park (Figure 2-V-5). The watershed drains 200 square miles and is 60 miles long.

Below its source, Deer Creek flows through many miles of rugged canyon cut deeply through an ancient lava flow. At higher elevations, the terrain is forested with coniferous trees and, in lower regions, the cover is the typical valley oak-grassland association. State Highway 32 parallels about 25 miles of the upper stream. The lower 10 miles flow through the Sacramento Valley where most of the flow is diverted. In



MAP OF THE SACRAMENTO VALLEY FROM CHICO TO VERONA, INCLUDING THE FEATHER, YUBA, AND BEAR RIVER DRAINAGES AND BUTTE CREEK

FIGURE 2-V-6

many years, diversions at three dams deplete all of the natural flow from mid-spring to fall. All of the diversion structures have fish ladders and screens. Of all Sacramento Valley streams, Deer Creek has the greatest potential for spring-run chinook salmon restoration.

Stony Creek - Stony Creek is a westside stream originating in the Coast Ranges and draining into the Sacramento River south of Hamilton City in Glenn County (Figure 2-V-5). The watershed has three storage reservoirs with a combined storage capacity of more than 260 taf: Black Butte, Stony Gorge, and East Park. The lowermost dam, Black Butte, is a barrier to anadromous fish. The Glenn-Colusa Irrigation District (GCID) canal, which crosses Stony Creek downstream of Black Butte Dam, consists of a seasonal gravel dam constructed across the creek on the downstream side of the canal. This crossing allows the canal to continue flowing south and allows capture of Stony Creek water and thus acts as a complete barrier to salmon migration. Stony Creek supports fall-run chinook salmon in years when flow reaches the Sacramento River.

Big Chico Creek - Big Chico Creek originates on Colby Mountain and flows 45 miles west to its confluence with the Sacramento River at RM 193, 5 miles west of the City of Chico (Figure 2-V-5). The watershed ranges from about 121 feet in elevation at the mouth to 5,700 feet, draining a watershed of approximately 72 square miles. No significant impoundments are present on the stream, and the only major water diversion is within 1 mile of the mouth.

Most of Big Chico Creek is bordered by private land with smaller holdings by the USFS and U.S. Bureau of Land Management (BLM). The creek flows through Bidwell Park, the third largest municipal park in the United States; downtown Chico; and the California State University campus. The chief human impacts in the drainage basin upstream of Chico are logging, recreation, and associated road construction. A small, abandoned placer gold mine is located about midway between the origin of the creek and its confluence with the Sacramento River, but this mine is not known to significantly affect water quality. Habitat in areas upstream of the Five-Mile Diversion is relatively pristine because of the rugged nature of the canyon. Summer (June-October) base flow in Big Chico Creek above Five-Mile Diversion is typically 20-25 cfs. Most of this base flow is lost to infiltration in the region of the creek's outwash fan (roughly the city of Chico) so that, by late summer of most years, surface flow does not extend downstream of Rose Avenue.

Big Chico Creek has carved a deep canyon through the foothills. Upstream from Higgin's Hole (at RM 23), it has cut through metamorphic rock, creating a narrow canyon with big boulders, bedrock potholes, and spectacular waterfalls. In years when migration corresponds exactly to high flow, salmon might navigate this canyon to the waterfall at Bear Lake, but this would be unusual. For all practical purposes, Higgin's Hole is the upstream limit for anadromous fish. The size of the waterfalls and the scenic nature of the upstream canyon preclude construction of fishways.

Big Chico Creek tributaries -- Mud and Rock Creeks - Mud Creek and Rock Creek join Big Chico Creek about 0.75 mile before it enters the Sacramento River. These two tributaries are similar to each other but quite different from Big Chico Creek. Their channels are shorter and dendritic. They drain from the surface of the tilted Tuscan formation at relatively lower elevations than most of the Big Chico Creek drainage and receive their precipitation chiefly as rain, rather than snow. Accordingly, they are seasonal (flowing from about November to June in the Central Valley portion of their channels) and warm up more quickly in spring.

The drainage basins of Mud and Rock creeks are similar as well. The headwaters are in privately held forest land, foothill reaches are mostly pastured brush land or woodland, and Central Valley reaches traverse agricultural land. Both creeks pass through suburbs of Chico, with Mud Creek potentially being subject to pollution from the industrial park and airport. Both have minor agricultural diversions. In addition, Mud Creek is impounded for domestic water supply at Richardson Springs, a small resort. The Sycamore Diversion passes floodwater from Big Chico Creek to Mud Creek. Mud Creek is also subject to substantial illegal dumping from the West Sacramento Avenue Bridge.

Butte Creek - Butte Creek originates in the Jonesville Basin, Lassen National Forest, on the western slope of the Sierra Nevada, at an elevation of about 6,500 feet. The watershed area comprises approximately 150 square miles in the northeastern portion of Butte County. The creek enters the Sacramento Valley southeast of Chico and meanders in a southwesterly direction to the initial point of entry into the Sacramento River at Butte Slough (RM 139). A second point of entry into the Sacramento River is through the Sutter Bypass and Sacramento Slough (RM 80) (Figure 2-V-6).

Several small tributaries converge in the Butte Meadows basin, an area characterized by a series of wide meadows and repeating series of pools and riffles. Pine, cedar, and fir dominate the upper portion of the area, whereas the predominant riparian vegetation types in the meadow areas are alder and willow. Butte Creek flows from the Butte Meadows area approximately 25 miles through a steep canyon to the point where it enters the valley floor near Chico. Numerous small tributaries and springs enter the creek in the canyon area. Deep, shaded pools are interspersed throughout the upper section of the canyon above Centerville, whereas the area below has a shallower gradient and a riparian canopy of alder, oak, and willow.

Flows from the West Branch of the Feather River, diverted by Pacific Gas and Electric Company (PG&E) for power generation, enter Butte Creek via the Hendricks and Toadtown Canals at the Desabla Powerhouse. Two dams built by PG&E in 1917 divert water from Butte Creek for power generation. The lowermost, the Centerville Diversion Dam, located immediately below the Desabla Powerhouse, is generally considered to be the upper limit of anadromous fish migration. Anecdotal reports suggest that under extremely high flows, steelhead have been observed traversing this dam. Small impoundments in the watershed, including Magalia Reservoir, Paradise Lake, and Desabla Reservoir, store a combined 14.7 taf.

The upper watershed area above the valley floor comprises primarily private land holdings, with some national forest lands at the extreme upstream portion. Development in the upper watershed area of the mainstem of Butte Creek has been limited, although Little Butte Creek is regulated by two dams that provide domestic water for the town of Paradise. The Paradise area is being intensively developed and is currently undergoing a severe water shortage. Currently, except under extremely high, unregulated winter flows, Little Butte Creek makes only a minimal contribution to the flows of Butte Creek. Increased development, primarily residential, is occurring below the Centerville Powerhouse and along Butte Creek as far as Durham.

Colusa Basin Drain - The drainage area of the Colusa Basin extends from the Coast Ranges on the west to the Sacramento River on the east. Stony Creek and Cache Creek define the approximate northern and southern boundaries. The drainage area encompasses approximately 1,500 square miles in Glenn, Colusa, and Yolo counties. Of this area, approximately 570 square miles make up the watersheds of the various westside tributaries and the remainder are located in the relatively flat valley bottom. The watershed contains 67 individual streams, including forks and branches; approximately 11 of these currently empty directly into the Colusa Basin Drain (Table 2-V-1).

The main conveyance system within the Colusa Basin is known as the Colusa Trough, Reclamation District 2047 Drain, Colusa Basin Drainage Canal, or Colusa Basin Drain (Figure 2-V-6). Historically, the area within the basin was subject to periodic flooding from the Sacramento River. Flows in the basin generally discharged back into the river in a southeasterly direction through various sloughs. During the 1850s, reclamation efforts were begun that eventually eliminated much of the wetland area to provide land for agriculture. Levees were constructed along the west bank of the Sacramento River upstream from Knights Landing, beginning in approximately 1868. These levees blocked the natural drainage of the westside tributaries. Flows from the tributaries were instead routed through the Colusa Basin Drain to rejoin the Sacramento River near Knights Landing.

Before reclamation efforts began in the Colusa Basin, most of the westside tributaries were probably intermittent streams with little or no flow during summer. Most probably provided only opportunistic and sporadic access for salmon and steelhead. Until the drain was completed, the estuarine portions of the individual tributaries at the Sacramento River probably provided nursery and rearing habitat for juvenile salmon and steelhead. After completion of the Colusa Basin Drain, salmon are believed to have entered westside tributaries through the outfall at Knights Landing. In most instances, access to the upper portions of any of the westside tributaries would be blocked by the GCID canal and potentially the TCC and Corning Canal.

Following completion of the levee system and development of the Colusa Basin for agriculture, natural floodflows from westside tributaries could no longer dissipate rapidly to the Sacramento River. The result has been periodic flooding of various areas within the basin. Several investigations have been conducted to develop remedies for this situation. Studies conducted by the California Department of Water Resources (DWR) identified the potential for construction of small foothill reservoirs to dampen floodflows. The original investigation identified 17 sites (Table 2-V-1) that would encompass approximately 80% of the foothill portion of the watershed. Currently, the reservoir option is not being actively pursued; however, if reservoirs are subsequently constructed, potential might exist for controlled releases to facilitate salmon and steelhead spawning and rearing.

Miscellaneous small tributaries - Along the Sacramento River are many small, often ephemeral, tributaries that are not used to any significant extent by spawning anadromous salmonids. Maslin and McKinney (1994) have shown that these tributaries may be used as rearing habitat by juvenile salmonids. Only a few of the potential tributaries have been investigated, but those that have been examined contained juvenile chinook salmon. In some cases, the juveniles had gone as far as 14 miles upstream from the river. Most of these tributaries also have resident rainbow trout populations in upstream perennial reaches. For many, there are anecdotal accounts of steelhead runs in the past.

Table 2-V-1. Tributaries contributing flow to the Colusa Basin Drain.

Major tributary entering drain	Tributaries entering major tributary	Reservoir capacity (af)	Drainage area (square mile)
Willow Creek	Walker Creek	0	175
	Wilson Creek	2,200	
	French Creek	11,000	
	Unnamed Creek	2,200	
	Willow Creek	12,600	
Hunters Creek	Logan Creek	3,300	36
	Hunters Creek	2,500	
Stone Corral Creek	Funks Creek	7,600	84
	Stone Corral Creek	5,800	
Lurline Creek	Lurline Creek	0	Unknown
Freshwater Creek	Freshwater Creek	7,000	60
	Salt Creek		
	Spring Creek	2,700	
Cortina Creek	Cortina Creek	5,300	34
	North Branch Sand Creek	0	
South Branch Sand	South Branch Sand Creek	0	Unknown

Major tributary entering drain	Tributaries entering major tributary	Reservoir capacity (af)	Drainage area (square mile)
Creek			
Salt Creek	Salt Creek	3,000	19
Buckeye Creek	Buckeye Creek	5,000	31
Bird Creek	Bird Creek	1,300	8
Oat Creek	Oat Creek	4,300	27

For this report, a list was compiled of small tributaries in which juvenile salmon had been reported. Characteristics of these known rearing streams were then compared to those of streams for which no information was available. Table 2-V-2 lists small Sacramento tributaries thought to be unimportant for salmonid spawning and divides them into the following types:

- those known to support juvenile rearing,
- those similar in morphometry and location to known rearing streams and thus presumed to support juvenile rearing, and
- those that have steep gradients near the river or that enter the river upstream from any spawning habitat and therefore are presumed to have low potential to support juvenile rearing.

Table 2-V-2. Sacramento tributaries that typically provide only rearing habitat for salmonids.

Name	USGS Quad	Side of Tributary
Tributaries known to support juvenile salmonid rearing		
Pine	Ord Ferry	east
Toomes	Vina	east
Dye	Los Molinos	east
Oat	Los Molinos	west
Coyote	Gerber	west
Reeds	Red Bluff East	west

Name	USGS Quad	Side of Tributary
Brewery	Red Bluff East	west
Blue Tent	Red Bluff East	west
Dibble	Red Bluff East	west
Inks	Bend	east
Anderson	Ball's Ferry	west
Olney	Enterprise	west
Tributaries presumed to support juvenile salmonid rearing		
Burch	Foster Island	west
Jewett	Vina	west
McLure	Vina	west
Red Bank	Red Bluff East	west
Salt	Red Bluff East	east
Ash	Ball's Ferry	east
Stillwater	Ball's Ferry	east
Churn	Cottonwood	east
Sulfur	Redding*	east
Tributaries with low potential to support juvenile salmonid rearing		
Seven Mile	Red Bluff East	east
Frasier	Bend	west
Spring	Bend	west
Clover	Cottonwood	east
Middle	Redding[a]	west
Salt	Redding[a]	west
Jenny	Redding[a]	west
Rock	Redding[a]	west

[a] Indicates 15-minute topographical quadrangle map.

Many small streams that feed larger tributaries may be found to be important for salmonid rearing. Even though these small streams may have characteristics and problems similar to those listed in Table 2-V-2, for convenience they will be discussed along with the main tributary.

In addition to its many tributaries, the Sacramento River has many sloughs (partially abandoned river or creek channels). The dynamics of the river change sloughs too rapidly for topographic maps to be useful in locating or describing them. Therefore, this report can address them only generally. Sloughs that are open to the river, particularly if they have any flow from seepage, small tributaries, or agricultural drainage, have potential to provide rearing habitat. These sloughs have characteristics and habitat needs similar to tributaries.

North westside tributaries - Small streams draining the west side of the Sacramento Valley in the Redding-Anderson municipal area include Olney, Anderson, Salt, Middle, and Churn creeks. These creeks do not have natural flow during the dry season. During the wet season, however, they have large flows for the small size of the watersheds. The high flash-flood potential of the streamflow regime is attributable to the intensity of rainstorms at the north end of the valley and is further amplified by urbanization of the watershed. These tributaries enter the Sacramento River downstream of Shasta Reservoir.

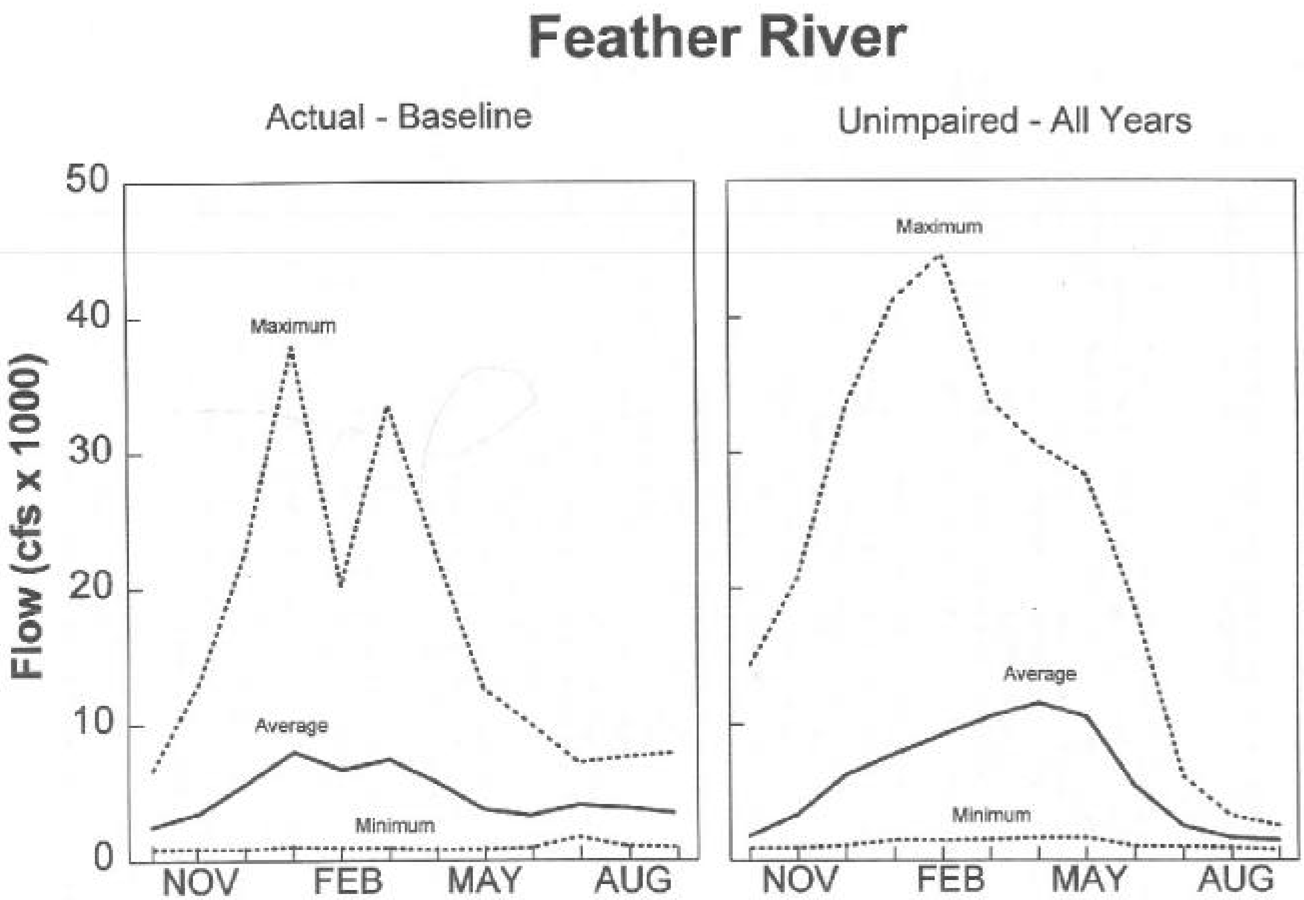
The watersheds of these streams drain parts of the Coast Ranges and Klamath Mountains. The soils in these mountains are moderately to severely erodible in contrast to the soils of the eastside Sierra Nevada watersheds. Also in contrast with the eastside tributaries, the geology of the west side of the valley is not as conducive to the large groundwater springs that provide cold, sustained flows in the dry season.

The rainfall on the west side of the Central Valley is less than that on the east side, with mean seasonal precipitation in the higher elevations of about 60 inches. The lower elevations near Redding receive 40 inches of precipitation, whereas low elevations near Red Bluff receive only 20 inches of precipitation. Thus, these smaller tributaries draining the region below the northern end of the Central Valley have inconsistent streamflow.

Large peak flows attract salmon from the Sacramento River into these streams. The influence of these attraction flows on salmon is probably increased because the river flow does not increase proportionally during the storms. Instead, Shasta Dam, upstream from the confluence of the tributaries, captures most of the storm run-off.

Lower Sacramento River and Delta Tributaries

Feather River - The Feather River, with a drainage area of 3,607 square miles, is the largest tributary of the Sacramento River below Shasta Dam (Figure 2-V-6). The median historical unimpaired run-off is 3.8 maf,



FEATHER RIVER MEAN MONTHLY FLOW: ACTUAL (BELOW THERMOLITO AFTERBAY, 1967-1991) AND UNIMPAIRED (NEAR OROVILLE, 1922-1991)

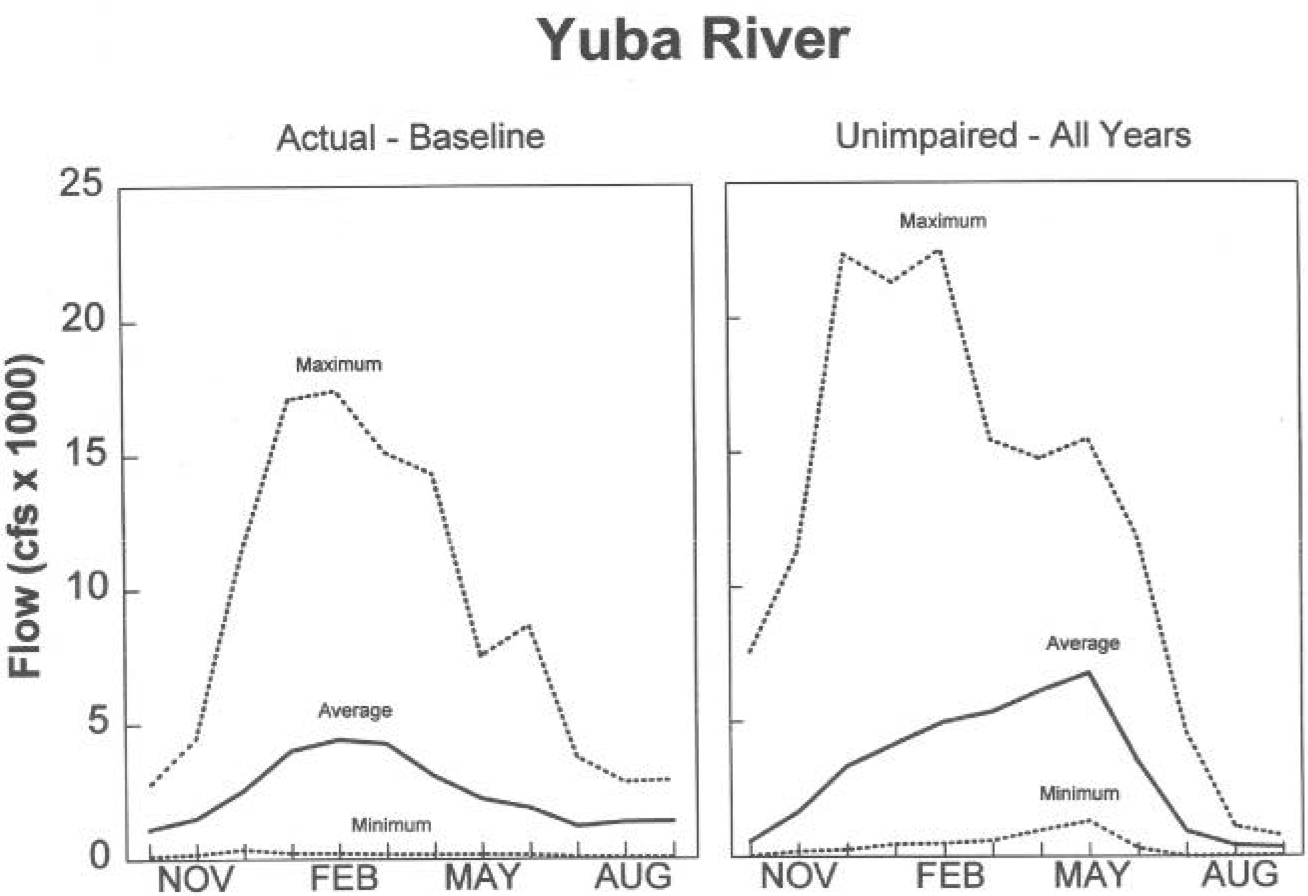
FIGURE 2-V-7

with a range of 1.0-9.4 maf (Figure 2-V-7). Oroville Reservoir, the lowermost reservoir on the river and the upstream limit for anadromous fish, is the keystone of the State Water Project (SWP) and is operated by DWR. Lake Oroville has a storage capacity of more than 3.5 maf. Water is released from Oroville Dam through a multilevel outlet to provide appropriate water temperatures for the operation of the Feather River Hatchery and to protect downstream fisheries. Approximately 5 miles downstream from Oroville Dam, water is diverted at the Thermalito Diversion Dam into the Thermalito Power Canal, thence to the Thermalito Forebay and another powerhouse, and finally into the Thermalito Afterbay. Water can be pumped from the Thermalito Diversion Pool back into Oroville Reservoir to generate peaking power. The Oroville-Thermalito complex, completed in 1968, provides water conservation, hydroelectric power, recreation, flood control, and fisheries benefits. The other major impoundment in the watershed is Lake Almanor, with a storage capacity of more than 1.1 maf. A number of other small- to medium-sized impoundments, including Mountain Meadows Reservoir, Bucks Lake, Little Grass Valley Reservoir, Lake Davis, Frenchman Lake, Butt Valley Reservoir, Sly Creek Reservoir, and Antelope Lake, store an additional 450 taf or more.

Feather River flows between the Thermalito Diversion Dam and the Thermalito Afterbay outlet are a constant 600 cfs. This section is often referred to as the "low-flow" river section. Water is released through a powerhouse, then through the fish barrier dam to the Feather River Hatchery, and finally into the low-flow section of the Feather River. Thermalito Afterbay has a dual purpose as an afterbay for upstream peaking-power releases to ensure constant river and irrigation canal flows and as a warming basin for irrigation water being diverted to rice fields. Thus, water temperatures in the approximately 14 miles of salmon spawning area from the Thermalito Afterbay outlet to the mouth of Honcut Creek (referred to as the "high-flow" section) are always higher than those in the 8 miles of the low-flow section.

Yuba River - The Yuba River watershed drains 1,339 square miles of the western slope of the Sierra Nevada and includes portions of Sierra, Placer, Yuba, and Nevada counties. The Yuba River is tributary to the Feather River (Figure 2-V-6), which in turn feeds into the Sacramento River. The median historical unimpaired run-off is 2.1 maf, with a range of 0.4-4.9 maf (Figure 2-V-8). The major impoundment in the watershed, Bullards Bar Reservoir, is operated by the Yuba County Water Agency, and has a storage capacity of just under 1 maf. Other small- to medium-sized impoundments in the watershed, including Lake Spaulding, Bowman Lake, Jackson Meadows Reservoir, Englebright Reservoir, Lake Fordyce, and Scotts Flat Reservoir, are able to store an additional 475 taf or more.

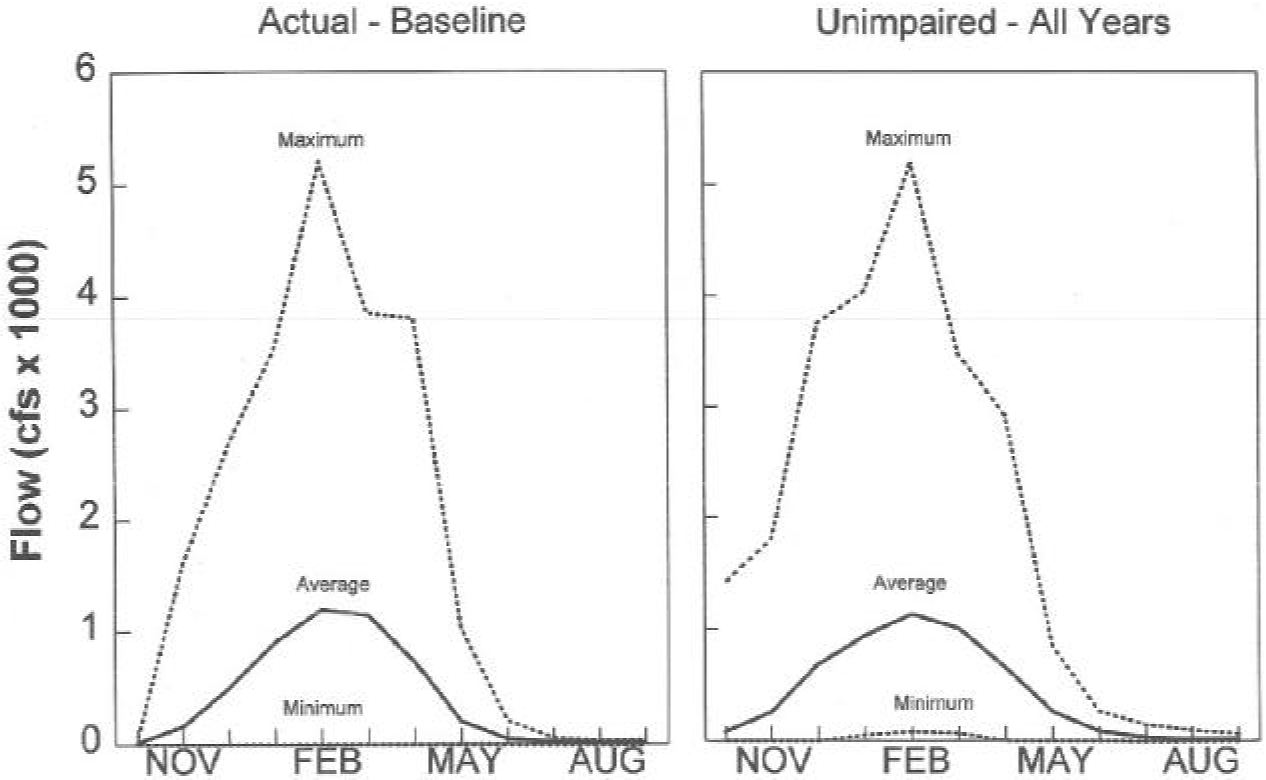
Most of the water from Englebright Dam, the lowermost dam on the river and the upstream limit of anadromous fish, is released through the Narrows 1 and 2 powerhouses for hydroelectric power generation. The 0.2-mile stretch of river between the dam and the two powerhouses has no flowing water except when the reservoir is spilling. The 0.7-mile stretch of river downstream of the Narrows 1 and 2 powerhouses to the mouth of Deer Creek is characterized by steep rock walls; long, deep pools; and short rapids. Below this area, the river cuts through 1.3 miles of sheer rock gorge called the Narrows, where the river forms a large, deep, boulder-strewn pool.



YUBA RIVER MEAN MONTHLY FLOW: ACTUAL (AT MARYSVILLE, 1967-1991) AND UNIMPAIRED (AT SMARTVILLE, 1922-1991)

FIGURE 2-V-8

Bear River



BEAR RIVER MEAN MONTHLY FLOW BELOW CAMP FAR WEST RESERVOIR: ACTUAL (1967-1991) AND UNIMPAIRED (1922-1991)

FIGURE 2-V-9

The river canyon opens into a wide floodplain at the downstream end of the Narrows where large quantities of hydraulic mining debris have been deposited during past gold mining operations. This 18.5-mile section is typified as open valley plain. Daguerre Point Dam, located 12.5 miles downstream from Englebright Dam, is the major diversion point on the lower river. The open valley plain continues 7.8 miles below Daguerre Point Dam to beyond the downstream terminus of the Yuba Goldfields. This section is composed primarily of alternating pools, runs, and riffles with a gravel and cobble substrate. By virtue of the quality and size of the substrate, this section contains most of the suitable chinook salmon spawning habitat found in the lower Yuba River. The remaining section of the lower Yuba River extends approximately 3.5 miles to the confluence with the Feather River. This section of river is bordered by levees and is subject to backwater influence of the Feather River.

Bear River - The Bear River is the second largest tributary to the Feather River, entering the Feather River at RM 12, immediately upstream from the town of Nicolaus (Figure 2-V-6). The median historical unimpaired run-off is 272 taf, with a range of 20-740 taf (Figure 2-V-9). The upstream limit of anadromous fish is the South Sutter Irrigation District's diversion dam, approximately 15 miles above the confluence with the Feather River. The largest impoundment in the watershed, Camp Far West Reservoir, is operated by the South Sutter Water District and has a storage capacity of 104 taf. Other small impoundments in the watershed include Rollins Reservoir and Lake Combie, which store an additional 70 taf or more.

American River - The American River is a major tributary entering the Sacramento River at RM 60 in the City of Sacramento, Sacramento County (Figure 2-V-10). It accounts for approximately 15% of the total Sacramento River flow. The American River drains about 1,900 square miles and ranges in elevation from 23 feet to more than 10,000 feet. Average annual precipitation over the watershed ranges from 23 inches on the valley floor to 58 inches at the river's headwaters. Snowmelt is the source of approximately 40% of the American River flow. Average historical unimpaired run-off at Folsom Dam, near the border between Sacramento and Placer counties, is 2.8 maf. The median historical unimpaired run-off is 2.5 maf, with a range of 0.3-6.4 maf (Figure 2-V-11). The American River has three major branches: the South Fork, the Middle Fork, and the North Fork.

Development on the American River began in the earliest days of the California Gold Rush of the late 1840s, when numerous small dams and canals were constructed. Today, 13 major reservoirs exist in the drainage with total storage capacity of 1.9 maf. Folsom Lake, the largest reservoir in the drainage, was constructed in 1956 and has a capacity of 974 taf. Additional water projects proposed for development in the basin include the 2.3-maf Auburn Dam and the 225-taf South Fork American River project. Folsom Dam, approximately 30 miles upstream from the mouth, is a major element of the CVP. The dam is operated by USBR as an integrated system to meet contractual water demands and instream flow and water quality requirements.

The American River historically provided for steelhead and chinook salmon that spawned principally in the watershed above the valley floor. Completion of Folsom and Nimbus dams in 1955 blocked access to the historical spawning and rearing habitat for each race and altered the flow regime in the lower American River.

Mokelumne River - The Mokelumne River drains approximately 661 square miles, with its headwaters at 10,000 feet on the crest of the Sierra Nevada mountains. It is a major tributary to the Sacramento-San Joaquin Delta, entering the lower San Joaquin River northwest of Stockton (Figure 2-V-13). The median historical unimpaired runoff is 696 taf, with a range of 129 taf-1.8 maf (Figure 2-V-12). The Mokelumne River has had a long history of water development. Existing developments on the Mokelumne River upstream of Comanche Reservoir include facilities for hydroelectric, irrigation, and municipal use. Downstream of Comanche Reservoir, developments include both hydroelectric and irrigation facilities. Three major impoundments in the watershed (Comanche, Pardee, and Salt Springs Reservoirs) are operated by East Bay Municipal Utilities District and PG&E. These impoundments have a combined storage capacity of more than 750 taf. One other small impoundment in the watershed, Lower Bear River Reservoir, stores 52 taf.

Four species of anadromous fishes are present in the Mokelumne River below Comanche Dam: fall-run chinook salmon, steelhead, American shad, and striped bass. The condition of the aquatic habitat and the variation of conditions in the lower Mokelumne River have resulted in widely varying population levels of these species.

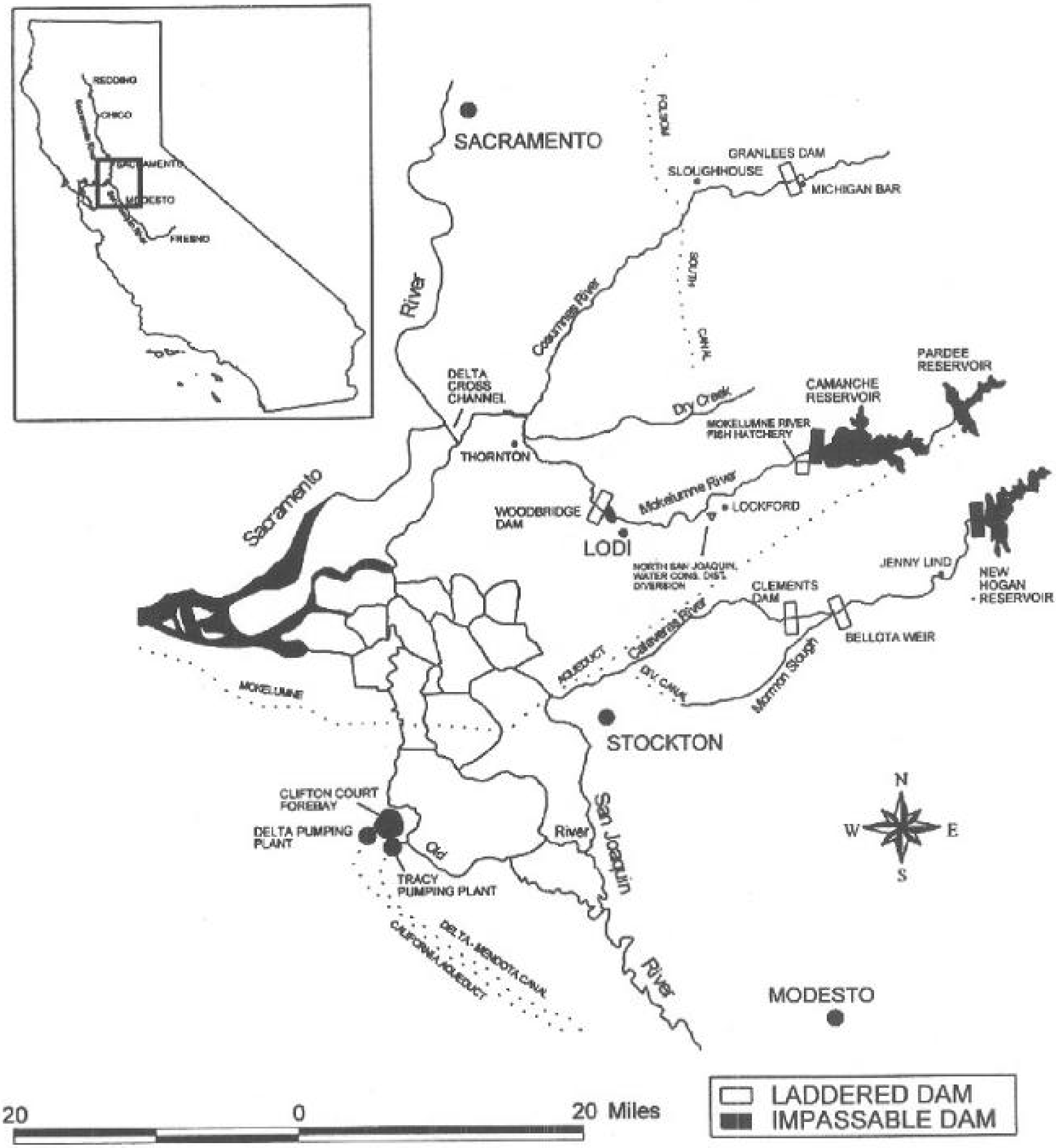
Cosumnes River - The Cosumnes River is tributary to the Mokelumne River, joining from the north near the town of Thornton (Figure 2-V-13). There are no water storage reservoirs on this system, and, because of the low elevation of its headwaters, the river receives most of its water from rainfall.

The Cosumnes River historically supported an average annual run of approximately 1,000 chinook salmon, although in recent years escapement estimates have generally been 100 fish or less. The river has extensive gravel areas suitable for salmon spawning and provides good rearing conditions for juvenile salmon.

There is one diversion dam (Granlees Diversion Dam) on the river, located approximately 1 mile upstream from the Highway 16 crossing (Figure 2-V-13). This dam has two functional fishways.

Calaveras River - The Calaveras River, tributary to the Delta, enters the San Joaquin River at Stockton (Figure 2-V-13). The river drains approximately 362 square miles and has an average annual runoff of 166 taf. The median historical unimpaired runoff is 130 taf, with a range of 8-600 taf (Figure 2-V-14). River flows are controlled by New Hogan Dam, constructed by the U.S. Army Corps of Engineers (Corps) and operated by USBR since 1964. Conservation yield from New Hogan Reservoir, with a gross pool capacity of approximately 325 taf, is contracted to Calaveras County Water District and Stockton East Water District. The dam and reservoir are located in western Calaveras County near Valley Springs.

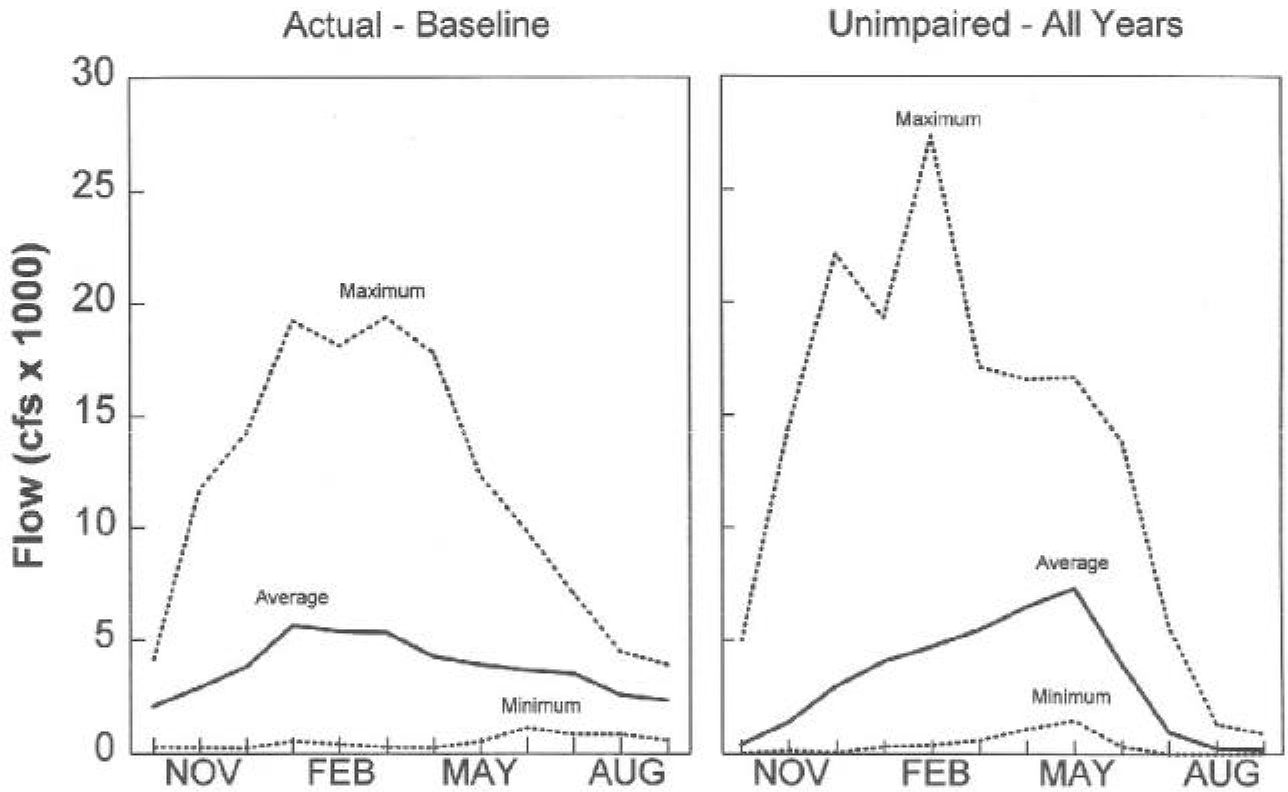
The Calaveras River drainage is almost entirely below the effective average snow level (5,000 feet in elevation) and thus receives runoff primarily as rainfall. About 93% of the runoff occurs from November



MAP OF THE LOWER SACRAMENTO AND SAN JOAQUIN RIVERS DEPICTING THE EASTSIDE TRIBUTARY STREAMS

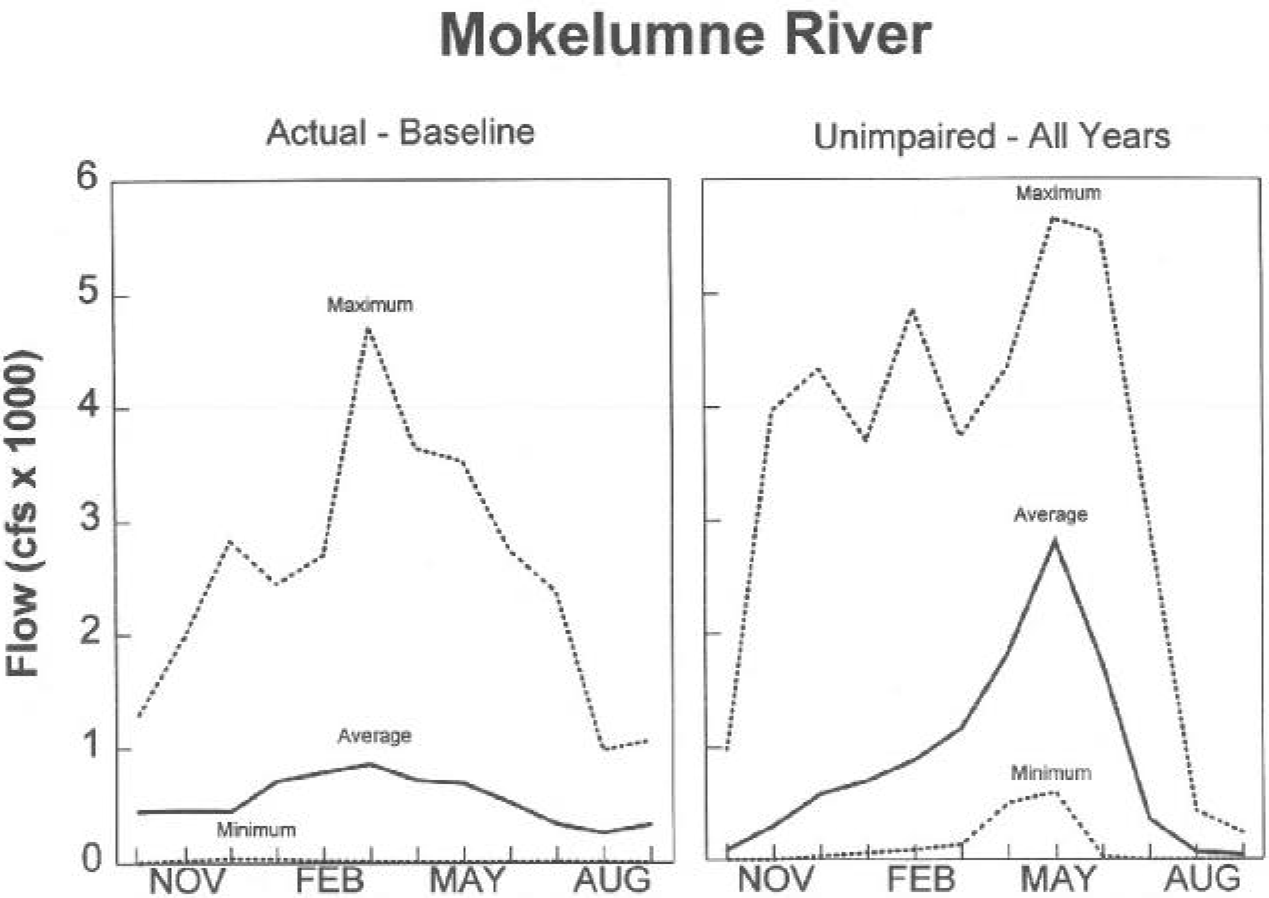
FIGURE 2-V-10

American River



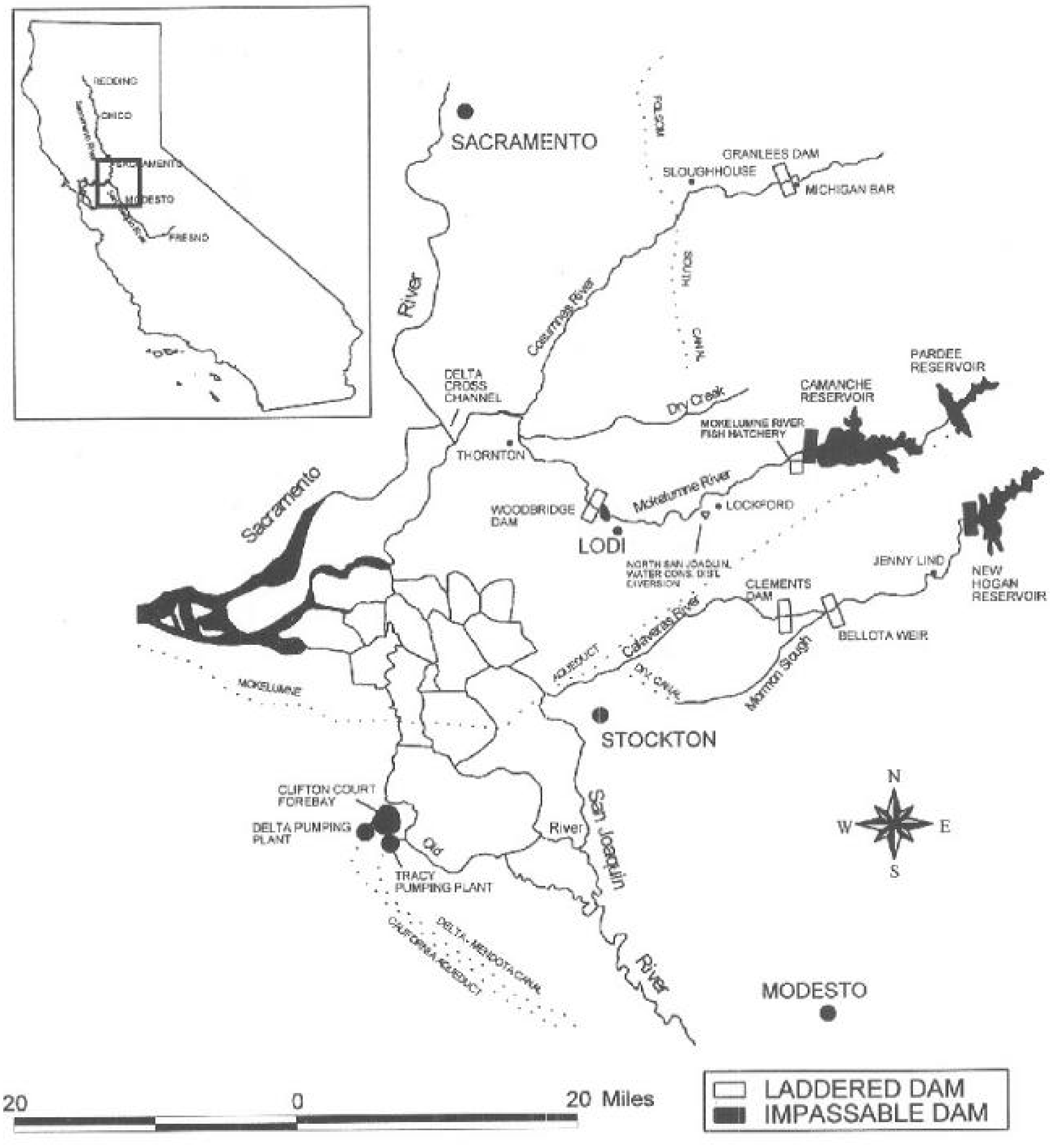
AMERICAN RIVER MEAN MONTHLY FLOW AT FAIR OAKS: ACTUAL (1967-1991) AND UNIMPAIRED (1922-1991)

FIGURE 2-V-11



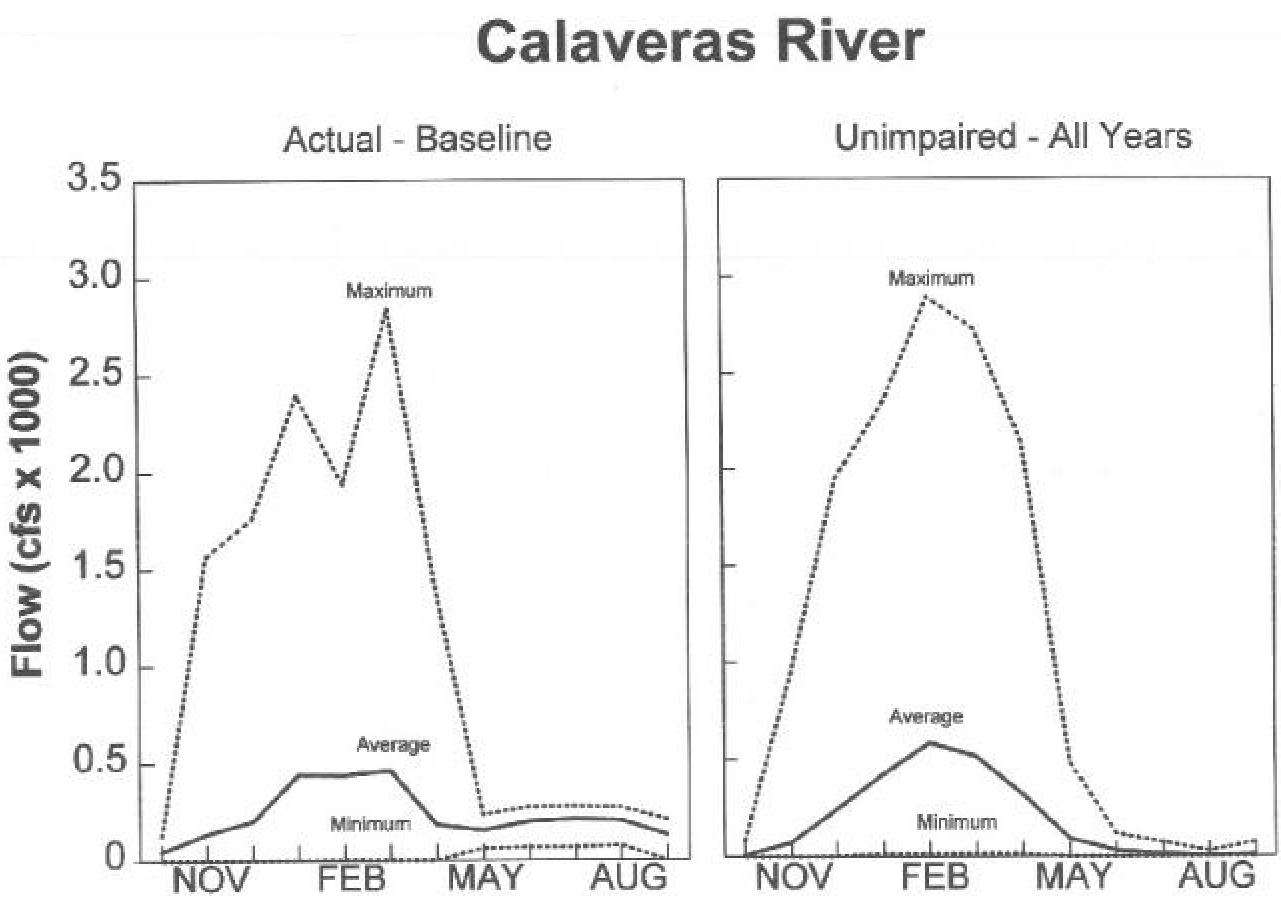
MOKELUMNE RIVER MEAN MONTHLY FLOW: ACTUAL (AT WOODBRIDGE, 1967-1991) AND UNIMPAIRED (AT PARDEE RESERVOIR, 1922-1991)

FIGURE 2-V-12



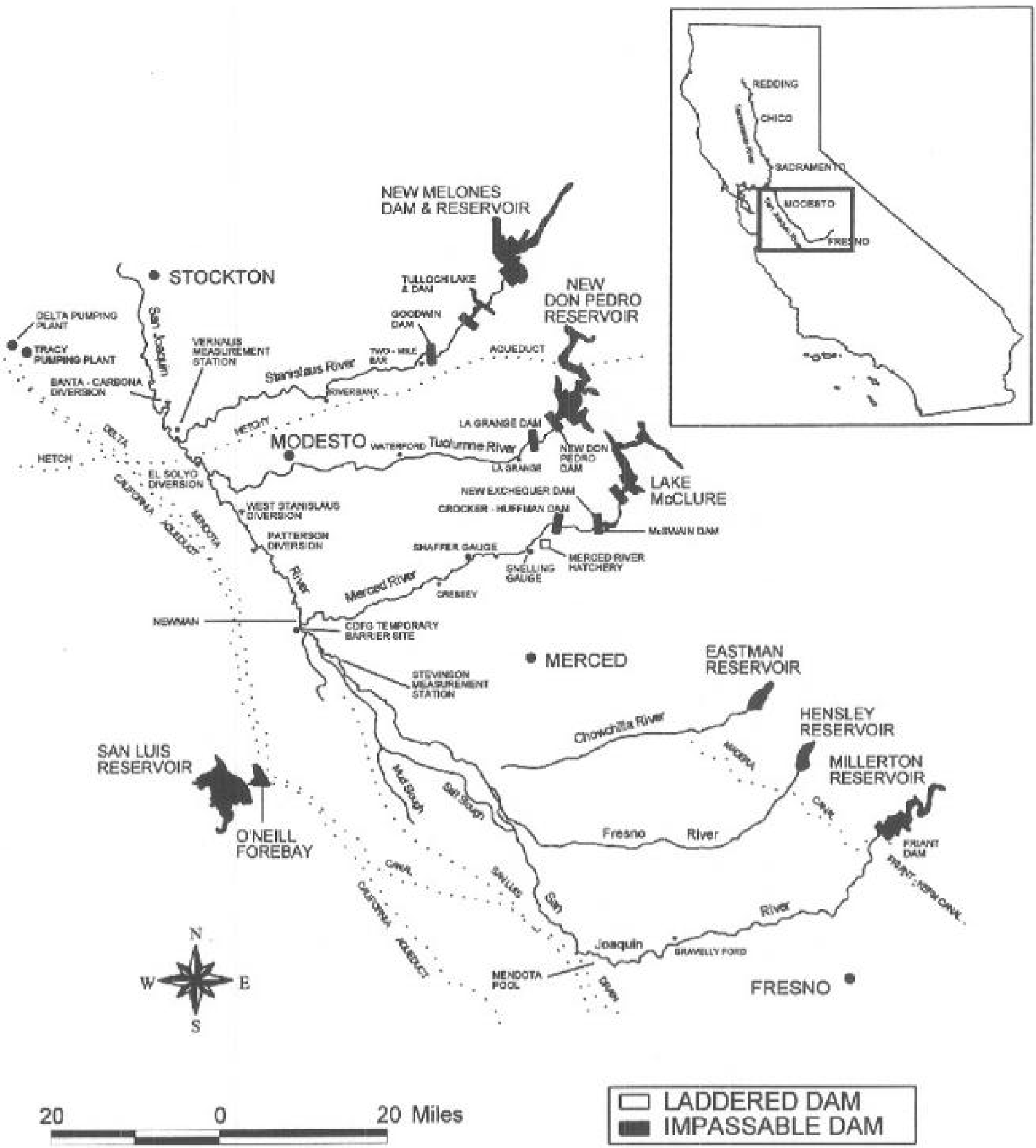
MAP OF THE LOWER SACRAMENTO AND SAN JOAQUIN RIVERS DEPICTING THE EASTSIDE TRIBUTARY STREAMS

FIGURE 2-V-13



CALAVERAS RIVER MEAN MONTHLY FLOW BELOW NEW HOGAN RESERVOIR: ACTUAL (1967-1991) AND UNIMPAIRED (1922-1991)

FIGURE 2-V-14



MAP OF THE SAN JOAQUIN BASIN DEPICTING LOCATIONS OF THE STANISLAUS, TUOLUMNE, MERCED, AND SAN JOAQUIN RIVERS

FIGURE 2-V-15

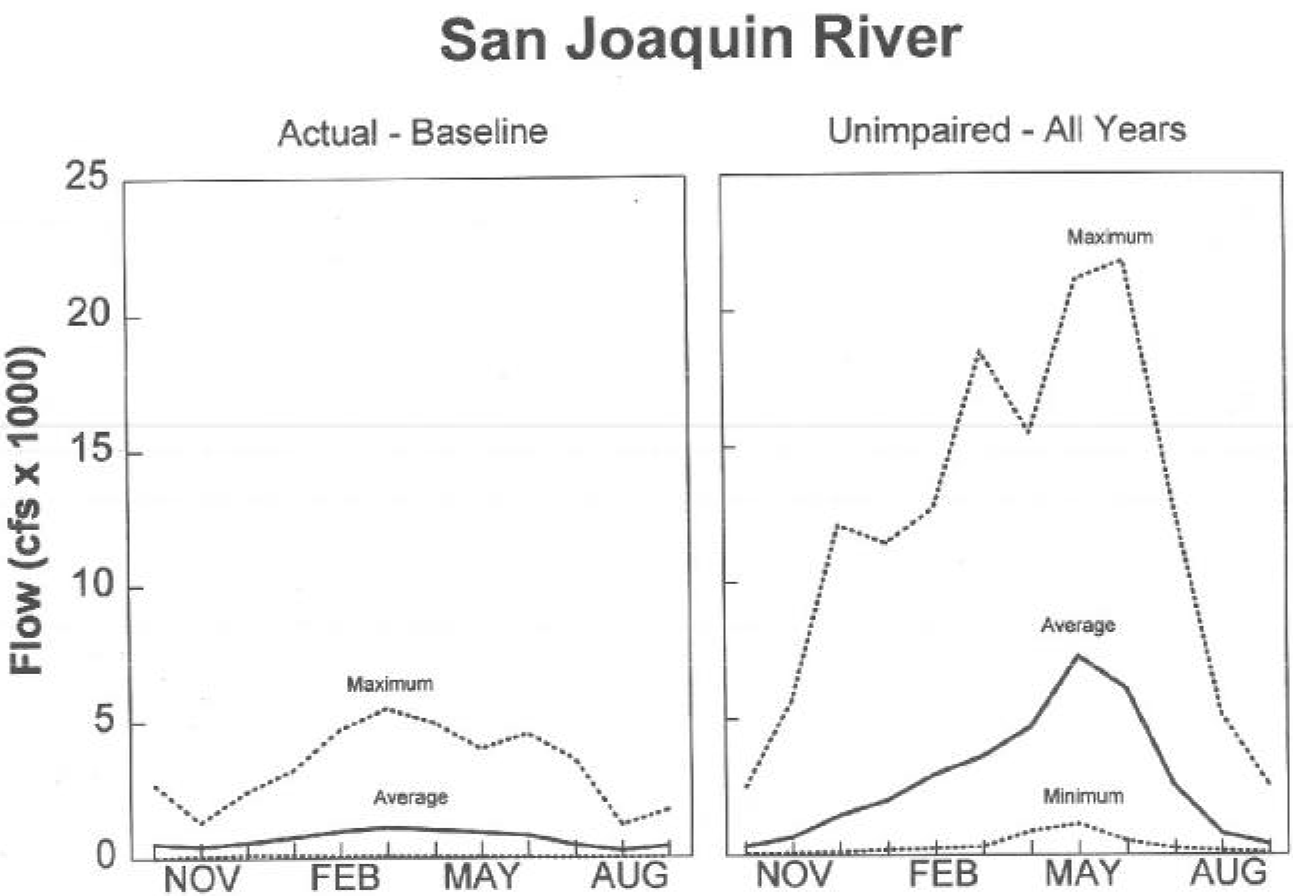
through April. The portion of the river in the valley commonly is subject to periods of low or even no flow for many days or weeks in late summer and early fall. However, deep pools do exist in the approximately 6-mile-long reach from New Hogan Dam to Jenny Lind, providing suitable holding areas for salmon and resident trout in all but the driest of years.

SAN JOAQUIN RIVER BASIN

Lower Mainstem San Joaquin River

The 250-mile-long San Joaquin Valley makes up the southern half of the Central Valley. The Tulare Lake basin to the south is normally considered a separate drainage basin, but during wet years it has historically contributed occasional flood overflows and subsurface flows to the San Joaquin River. The San Joaquin River basin is bounded on the west by the Coast Range and on the east by the Sierra Nevada. The San Joaquin River drains west from the Sierra Nevada, turns sharply north at the center of the valley floor, and flows north through the valley into the Sacramento-San Joaquin Delta (Figure 2-V-15). On the arid westside of the basin, relatively small intermittent streams drain the eastern flanks of the Coast Range but rarely reach the San Joaquin River. Natural runoff from westside sloughs is augmented by agricultural drainage and spill flows. On the eastside, numerous streams and three major rivers drain from the west slope of the Sierra Nevada and contribute flow to the San Joaquin River. The major eastside tributaries south of the Delta, all of which support salmon spawning and rearing, are the Stanislaus, Tuolumne, and Merced rivers.

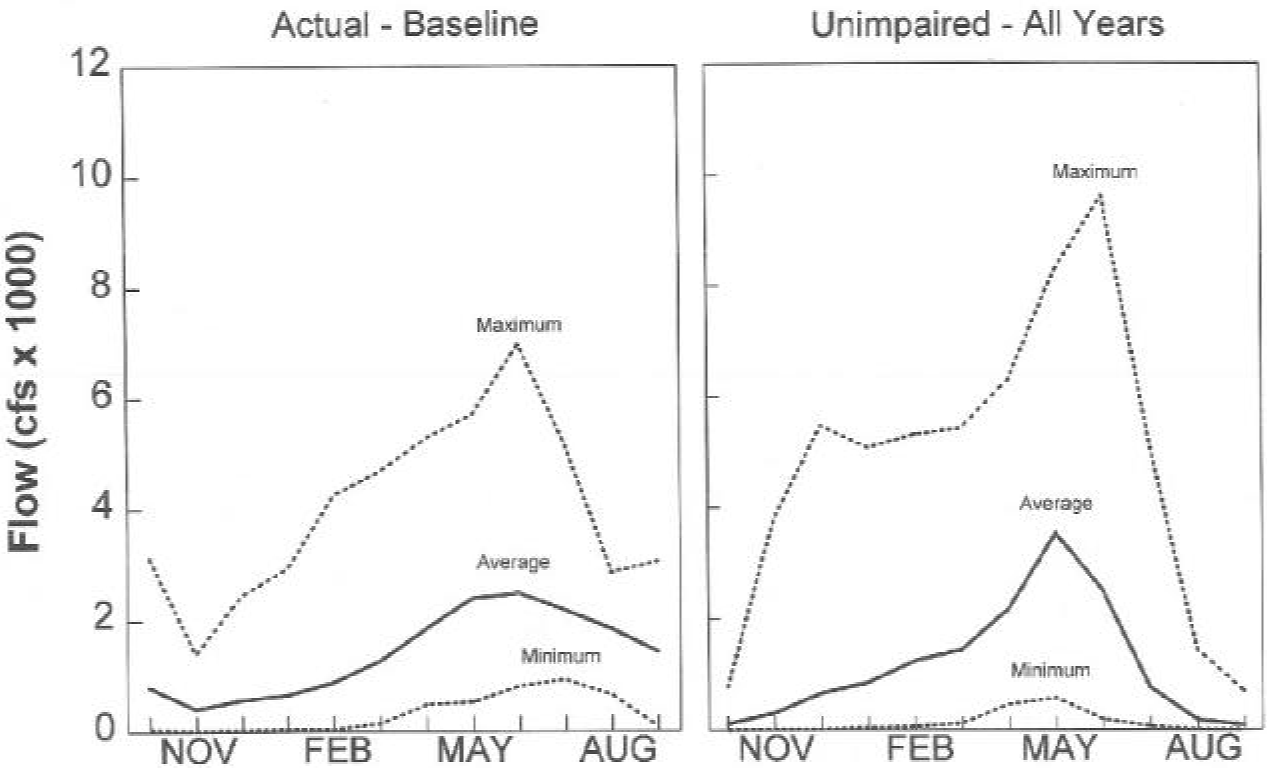
Precipitation in the San Joaquin River basin averages about 27.3 inches per year. Runoff from snowmelt is the major source of water to the upper San Joaquin River and the larger eastside tributaries. The median historical unimpaired runoff is 1.4 maf, with a range of 0.4-4.6 maf (Figure 2-V-16). Historically, peak flows occurred in May and June and flooding occurred in most years along all the major rivers. When flood flows reached the valley floor, they spread out over the lowlands, creating several hundred thousand acres of permanent tule marshes and more than 1.5 million acres of seasonally flooded wetlands. The rich alluvial soils of natural levees once supported large, diverse riparian forests. It has been estimated that as much as 2 million acres of riparian vegetation grew on levees, floodplains, and along small stream courses. Above the floodplain, the riparian zone graded into valley oak savanna and native grasslands interspersed with vernal pools.



SAN JOAQUIN RIVER MEAN MONTHLY FLOW: ACTUAL (AT STEVINSON, 1967-1991) AND UNIMPAIRED (AT MILLERTON RESERVOIR, 1922-1991)

FIGURE 2-V-16

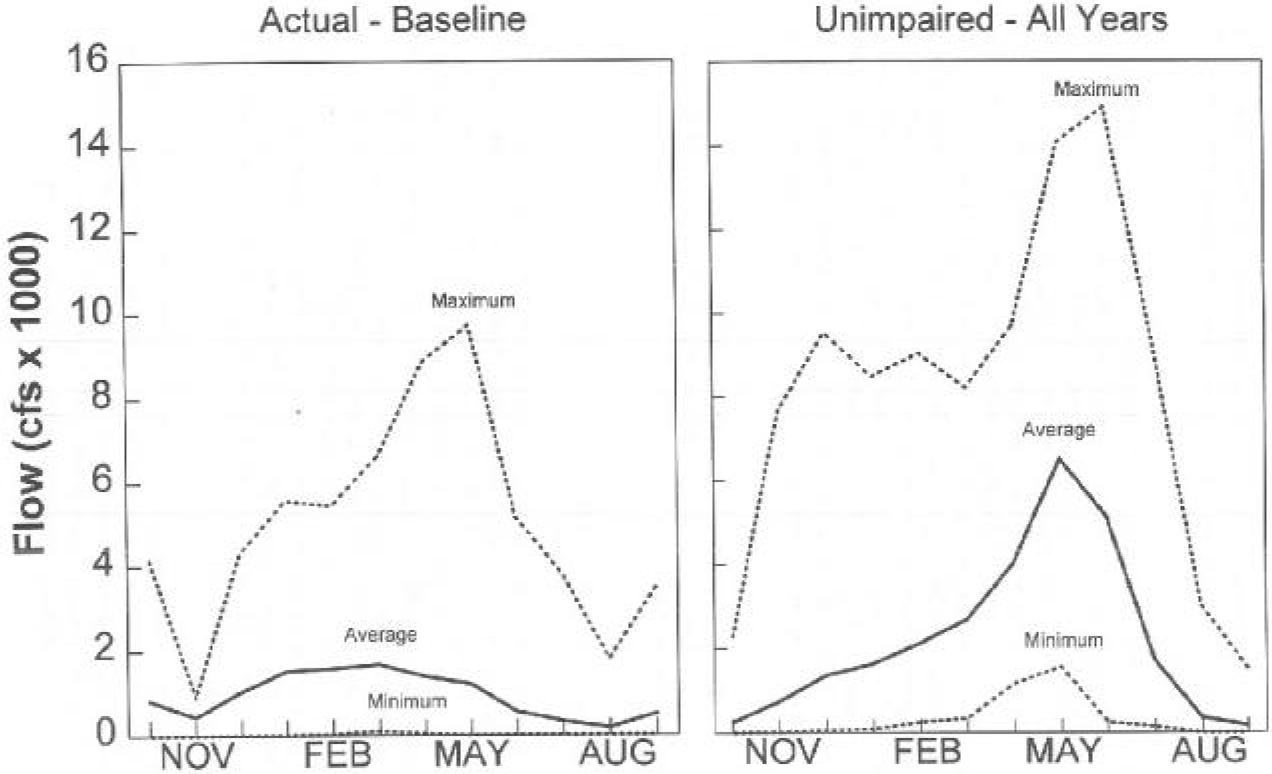
Merced River



MERCED RIVER MEAN MONTHLY FLOW: ACTUAL (BELOW MERCED FALLS DAM, 1967-1991) AND UNIMPAIRED (BELOW NEW EXCHEQUER DAM, 1922-1991)

FIGURE 2-V-17

Tuolumne River



TUOLUMNE RIVER MEAN MONTHLY FLOW: ACTUAL (BELOW LA GRANGE DAM, 1967-1991) AND UNIMPAIRED (AT NEW DON PEDRO RESERVOIR, 1922-1991)

FIGURE 2-V-18

Lower San Joaquin River Tributaries

Merced River - The Merced River is presently the southernmost stream used by chinook salmon in the San Joaquin River basin and in California. The river flows westward into the valley, draining approximately 1,040 square miles (Figure 2-V-15). The average unimpaired runoff in the basin is approximately 1.0 maf, similar to the Stanislaus River drainage. The median historical unimpaired runoff is 0.8 maf, with a range of 0.2-2.8 maf (Figure 2-V-17).

Agricultural development began in the 1850s, and significant changes have been made to the hydrologic system since that time. The enlarged New Exchequer Dam, forming Lake McClure with a gross storage capacity of 1.0 maf, was constructed in the late 1960s and now regulates releases to the lower Merced River. The dam is operated by Merced Irrigation District for power production, irrigation, and flood control. The river is also regulated by McSwain Dam (an afterbay for New Exchequer Dam) and Merced Falls and Crocker-Huffman dams located downstream. Crocker-Huffman Dam near the town of Snelling is the upstream barrier for salmon migration.

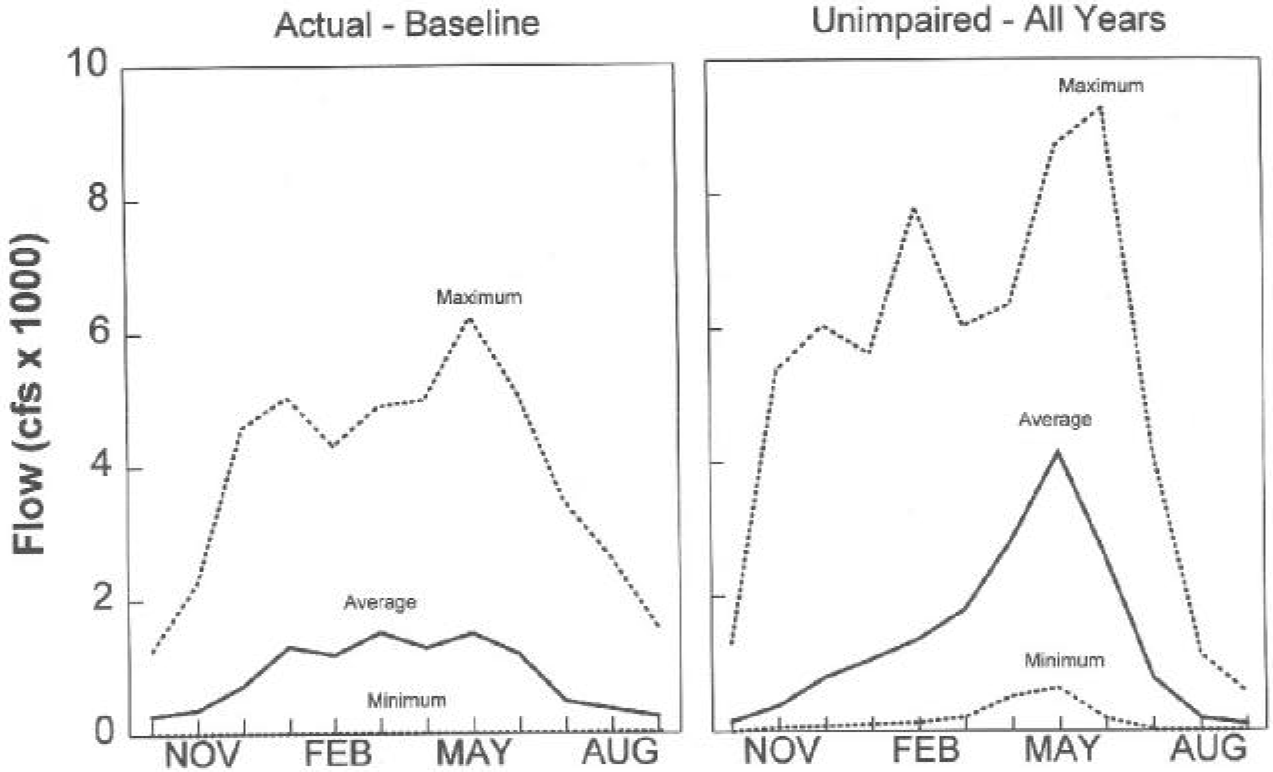
Salmon spawn in the 24-mile reach between Crocker-Huffman Dam and the town of Cressy. Rearing habitat extends downstream of the designated spawning reach, requiring the protection of the entire tributary from Crocker-Huffman Dam to its mouth.

Tuolumne River - The Tuolumne River is the largest tributary in the San Joaquin River basin, with an average annual runoff of 1.95 maf, and a drainage area of approximately 1,540 square miles (Figure 2-V-15). The median historical unimpaired runoff is 1.8 maf, with a range of 0.4-4.6 maf (Figure 2-V-18). The Modesto and Turlock Irrigation Districts jointly regulate the flow to the lower river from New Don Pedro Reservoir, which has a gross storage capacity of 2.0 maf. The reservoir, completed in 1970, provides power, irrigation, and flood control protection. The river above New Don Pedro is regulated by three reservoirs (Cherry Lake, Lake Eleanor, and Hetch Hetchy Reservoir) owned and operated by the City and County of San Francisco. These reservoirs have a combined storage capacity of 800 taf or more. During each of the past 10 years, approximately 220 taf of Tuolumne River water has been annually exported to San Francisco. Other small impoundments in the watershed include Modesto Reservoir (29 taf) and Turlock Lake (45.6 taf). LaGrange Dam, located downstream from New Don Pedro Dam, diverts approximately 900 af per year for power, irrigation, and domestic purposes. LaGrange Dam is the upstream barrier to salmon migration.

Salmon spawn in the 25-mile reach between LaGrange Dam and the town of Waterford and rear in the entire lower river. The river now supports fall-run chinook salmon and a small population of late fall-run chinook salmon.

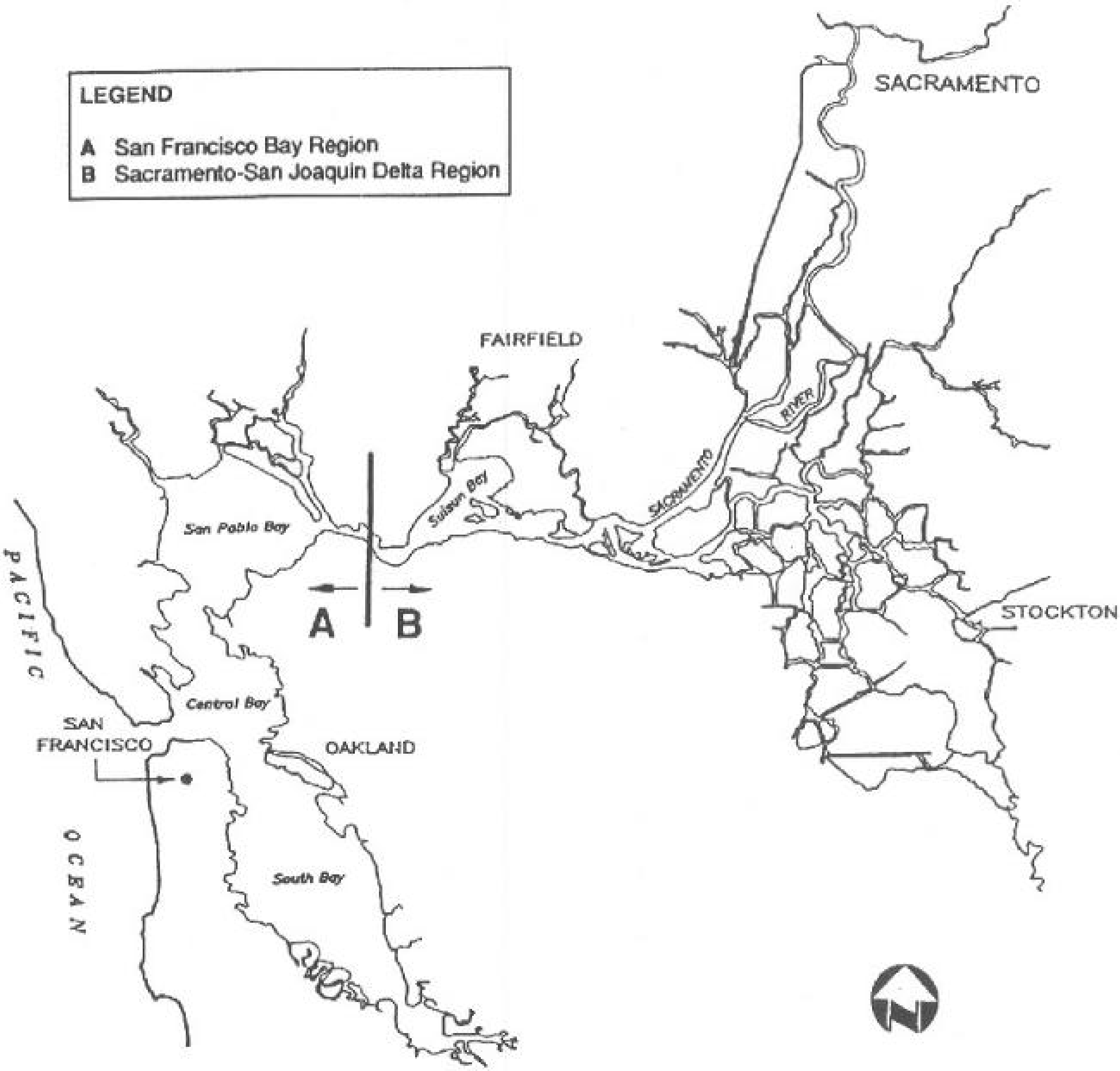
Stanislaus River - The Stanislaus River is the northernmost tributary in the San Joaquin River basin used by chinook salmon. The river flows westward into the valley, draining approximately 900 square miles (Figure 2-V-15). The average unimpaired runoff in the basin is about 1.2 maf. The median historical unimpaired

Stanislaus River



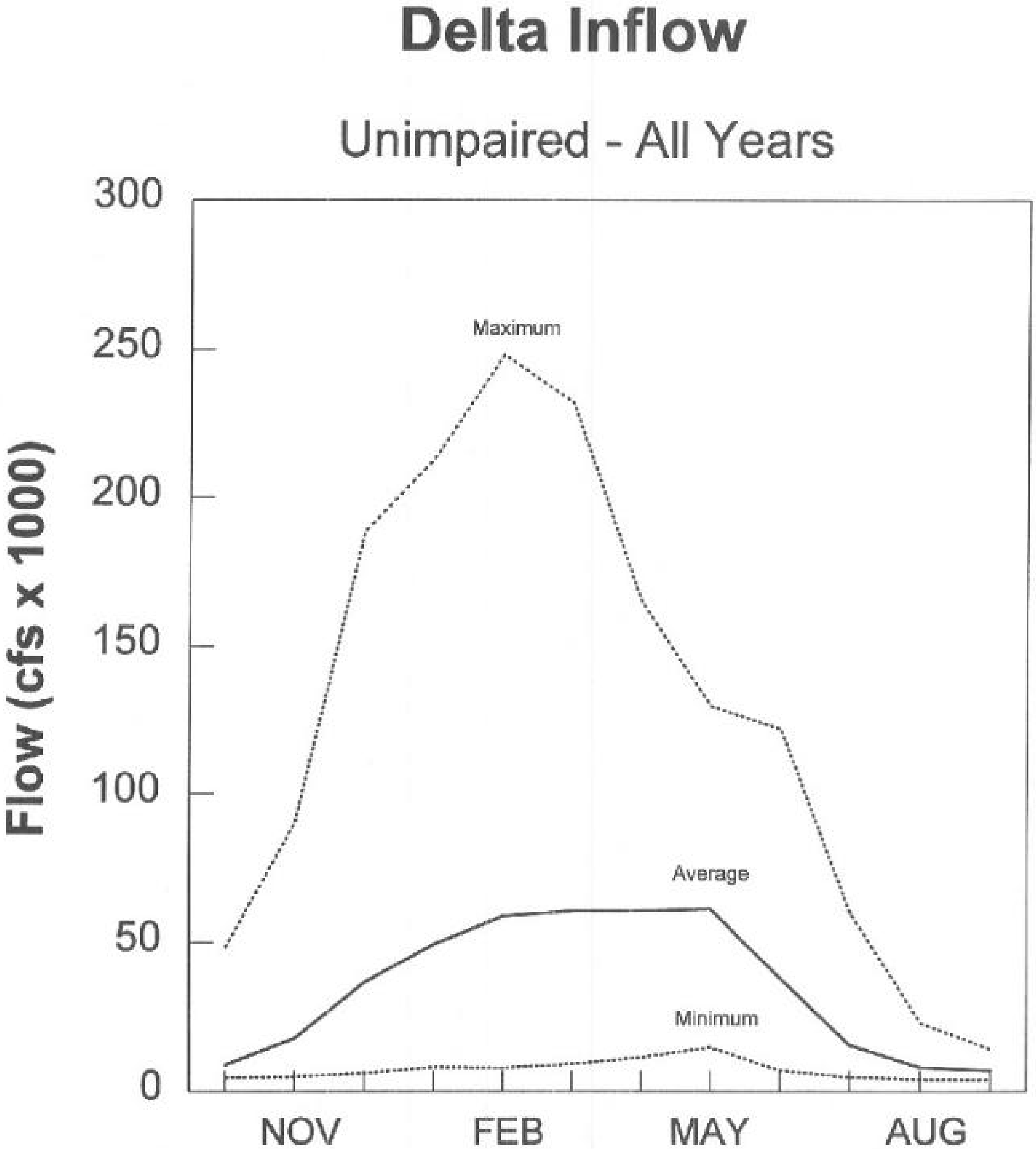
STANISLAUS RIVER MEAN MONTHLY FLOW: ACTUAL (BELOW GOODWIN DAM, 1967-1991) AND UNIMPAIRED (AT NEW MELONES RESERVOIR, 1922-1991)

FIGURE 2-V-19



SACRAMENTO-SAN JOAQUIN DELTA AND SAN FRANCISCO BAY REGIONS

FIGURE 2-V-20



MEAN MONTHLY DELTA INFLOW: UNIMPAIRED (1922-1991)

FIGURE 2-V-21

runoff is 1.1 maf, with a range of 0.2-3.0 maf (Figure 2-V-19). Significant changes have been made in the basin hydrology since agricultural development began in the 1850s. New Melones Dam, completed by the Corps in 1978 and approved for filling in 1981, is now the largest storage reservoir in the Stanislaus basin, with a gross storage capacity of 2.4 maf. The project is operated by USBR as part of the CVP. Downstream from New Melones Dam, Tulloch Reservoir, with a gross storage capacity of 68 taf, regulates water releases from New Melones Dam. Goodwin Dam, also downstream, regulates releases from Tulloch Reservoir and diverts water for power and irrigation to South San Joaquin Irrigation District and Oakdale Irrigation District. Goodwin Dam is the upstream barrier for salmon migration. Other impoundments in the watershed include Beardsley Reservoir and Donnell Reservoirs, with a combined storage capacity of more than 130 taf.

Salmon spawn in the 23-mile reach between Goodwin Dam and the town of Riverbank and rear in the entire lower river. The river now supports fall-run chinook salmon and small populations of late fall-run chinook salmon and steelhead.

SACRAMENTO-SAN JOAQUIN DELTA

The Delta is located at the confluence of the Sacramento and San Joaquin rivers and represents the most important, complex, and controversial geographic area both for anadromous fisheries production and distribution of California water resources for numerous beneficial uses (Figure 2-V-20). Approximately 42% of the state's annual runoff flows through the Delta's maze of channels and sloughs surrounding 57 major reclaimed islands and nearly 800 unleveed islands (Water Education Foundation 1992b). The median historical unimpaired runoff is 25.5 maf, with a range of 6.8-72.8 maf (Figure 2-V-21). The Delta includes almost 700 miles of waterways and more than 1,000 miles of levees in it's 1,150 square miles (DWR 1993). The Delta's channels are used to transport water from upstream reservoirs to the south Delta, where federal and state facilities (Tracy Pumping Plant and Harvey O. Banks Delta Pumping Plant, respectively) pump water into the CVP and SWP canals. Other Delta diversions include the Contra Costa Canal, North Bay Aqueduct, and more than 1,800 agricultural users.

An estimated 25% of all warmwater and anadromous sport fishing and 80% of the state's commercial fishery depend on species that live in or migrate through the Delta. The Delta serves as a migration path for all anadromous species returning to their natal rivers to spawn. Adult chinook salmon move through the Delta every month. Salmon and steelhead juveniles depend on the Delta as transient rearing habitat during migration through the system to the ocean and may rear for several months, feeding in marshes, tidal flats, and sloughs. All life stages of striped bass and American shad are found in the Delta; approximately 45% of striped bass spawn in the Delta, as do some American shad. Numerous resident native and introduced species live in the Delta year-round, including native Delta smelt (a species federally listed as threatened) and Sacramento splittail (a species proposed for federal listing as threatened).

Most of the flows into the Sacramento-San Joaquin Delta are provided by the Sacramento, San Joaquin, Mokelumne, and Calaveras rivers. The Sacramento River supports chinook salmon populations that provide most of the state's sport and commercial catch, as well as steelhead, striped bass, American shad, and white and green sturgeon. The San Joaquin River's eastside tributaries support severely depressed yet potentially significant chinook salmon populations, while chinook salmon in the upper San Joaquin River are essentially gone. The San Joaquin River also supports unknown sizes of populations of striped bass and sturgeon. The Calaveras, Mokelumne, and Cosumnes (a tributary to the Mokelumne) rivers are minor tributaries to the Delta, supporting small chinook salmon and steelhead populations. No chinook salmon have been observed in the Calaveras River since 1984.

SECTION VI. CENTRAL VALLEY ANADROMOUS FISHES - HISTORIC AND EXISTING CONDITIONS

LIFE HISTORIES

Chinook Salmon

General chinook salmon life history traits are described below, along with a review of traits that distinguish each of the four races of salmon. Figure 2-VI-1 illustrates the general chinook salmon life cycle. Figure 2-VI-2 shows the location of major spawning and rearing areas for each chinook salmon race. Figures 2-VI-3 through 2-VI-5 summarize the timing and abundance of chinook salmon races by life stage in the Sacramento River basin, the timing of adult upstream migration through the Delta, and the general timing and abundance of juvenile chinook salmon in the Delta.

Based on variations in their life histories, chinook salmon can be grouped into either stream- or ocean-"types". These variations in behavior patterns appear to have evolved to spread the risk of mortality across years and habitats (Healey 1991).

Stream-type chinook salmon are most common in populations north of 56^0N along the North American coast (Healey 1991). This group of races is characterized by long freshwater residence as juveniles (1+ years). Adults generally migrate upstream in spring and summer and hold in cool-water pools prior to spawning approximately 2-3 months later. The fecundity of adult females is relatively high.

Ocean-type chinook salmon are more common in populations found along the North American coast south of 56^0N (Healey 1991). This race is characterized by short freshwater residence as juveniles (2-3 months). Adults migrate upstream in summer and fall and spawn shortly after. The fecundity of adult females is relatively low.

Chinook salmon of the Sacramento-San Joaquin system are 10-18% stream type (spring and late fall runs) and 82-90% ocean type (fall run). The winter-run fish appear to have characteristics of both steam- and ocean-type life histories, with delayed spawning after river entry (stream type) and short stays in the river system before migration to sea (ocean type) (Healey 1991).

Run timing, spawning periods, and early life history phases of the four races (fall, late fall, winter, and spring) that occur in the Sacramento River all overlap; thus spawning may occur virtually year-round, and each of the freshwater life stages of chinook salmon may be found every month of the year.

Upstream migration and spawning - Salmon in general return to their natal stream to spawn with considerable fidelity. While the straying of chinook salmon from their natal stream is documented for hatchery-raised fish, it is not known to what extent this occurs with naturally produced fish.
Adult fall-run chinook salmon migrate through the Sacramento-San Joaquin Delta and into Central Valley rivers from July through December and spawn from October through December. Peak spawning activity usually occurs in October and November.

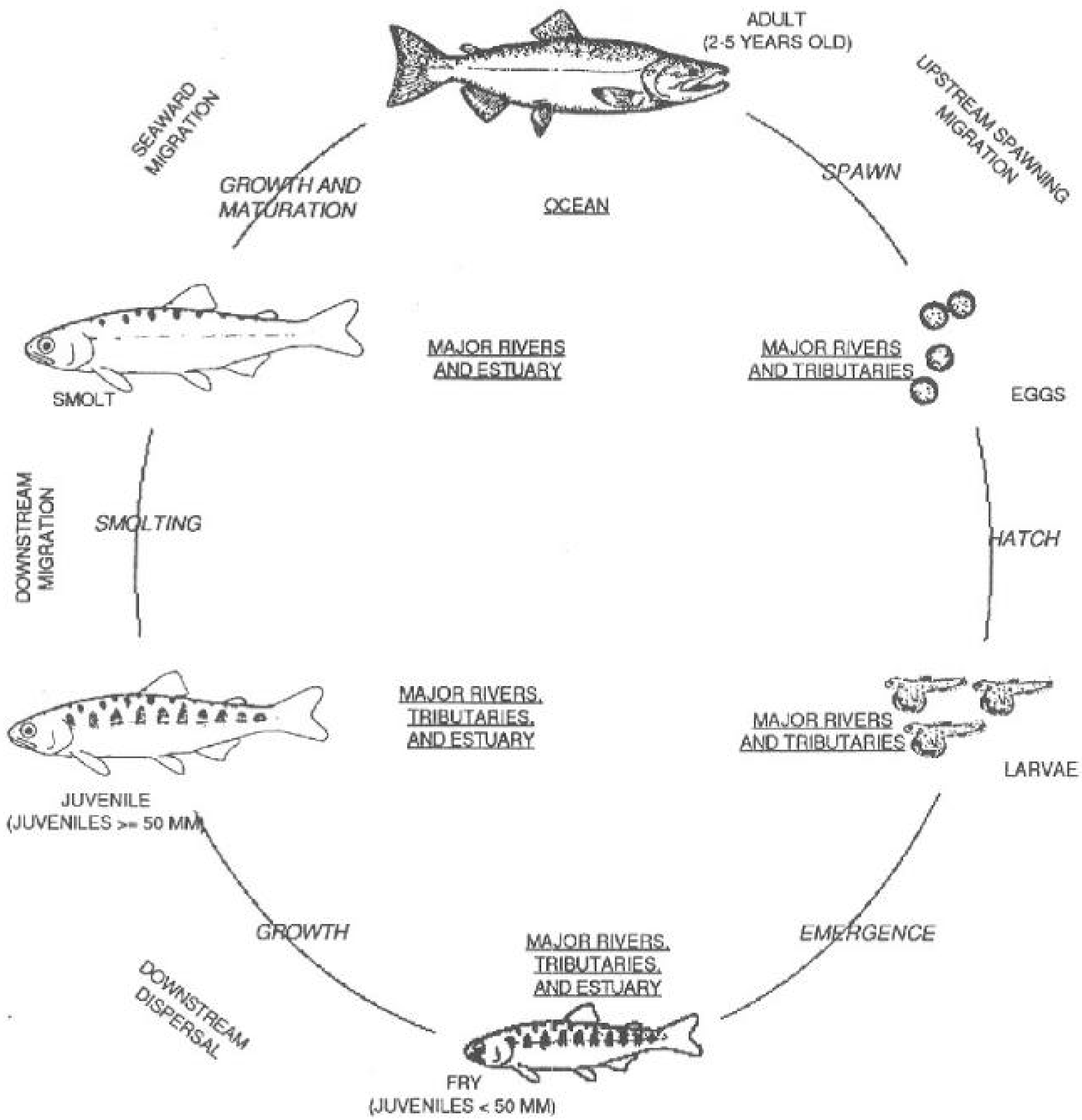
Adult late fall-run chinook salmon migrate through the Delta and into the Sacramento River from October through April and may wait 1-3 months before spawning from January through April. Peak spawning activity occurs in February and March.

Adult winter-run chinook salmon migrate through the Delta and into the Sacramento River from December through July. Winter-run chinook salmon do not spawn immediately but remain in the river up to several months before spawning. Spawning occurs from April through July, with peak spawning activity in May and June.

Adult spring-run chinook salmon migrate through the Delta and into the Sacramento River from March through September and remain in the river up to several months before spawning. Spawning occurs from August through October, with peak spawning activity in September.

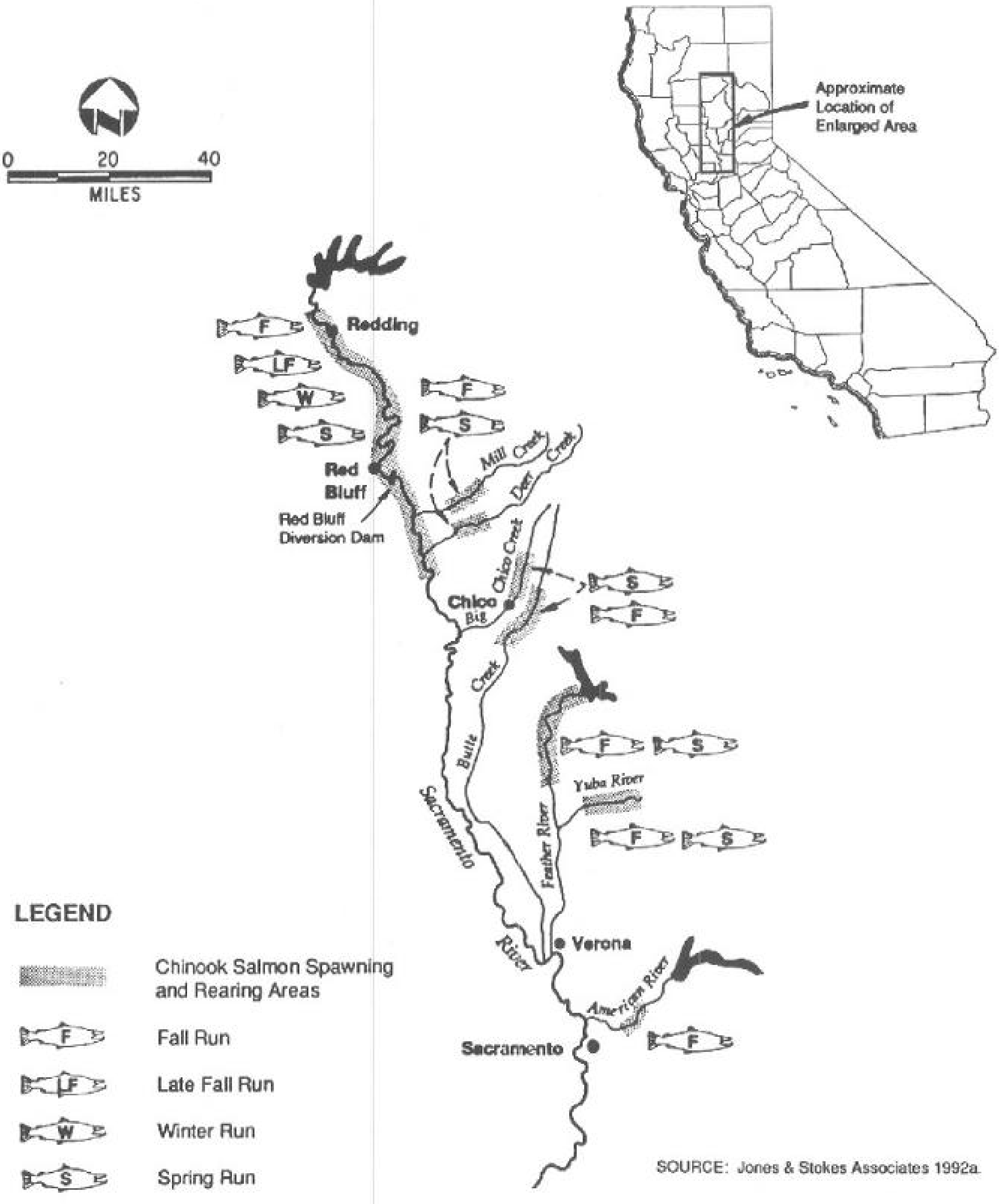
In preparation for spawning, a female chinook salmon digs a shallow depression in the gravel of the stream bottom in an area of relatively swift water by performing vigorous swimming movements on her side near the bottom. Gravel and sand thrown out of the depression accumulate in a mound, or "tailspill", at the downstream margin of the depression. During the act of spawning, the female deposits a group or "pocket" of eggs in the depression and then covers it with gravel. Over the course of one to several days, the female deposits four or five such egg pockets in a line running upstream, enlarging the spawning excavation in an upstream direction as she does so. The total area of excavation, including the tailspill, is termed a "redd". The eggs are fertilized by one or more males, after which the female buries the eggs by displacing gravels upstream of the redd. The size of a chinook salmon redd is highly variable and can range from 2.4 to 54 square yards (Chapman et al. 1986). Fecundity varies among different populations, between individuals within a population, and between years (Healey 1991). The Sacramento River population has an unusually high fecundity for one so far south. Body size appears to contribute to variations in fecundity to a lesser degree for chinook salmon than for other fishes. Healey and Heard (1984) found the fecundity of chinook females in 18 populations surveyed ranged from fewer than 2,000 to more than 17,000 eggs. All adult chinook salmon die after spawning.

Incubation - Egg incubation for Central Valley fall-run chinook salmon begins with spawning in October and can extend into March. Egg incubation for late fall-run salmon occurs from January through June. Winter-run chinook egg incubation occurs from April through October, although most fry have emerged by the end of September. Incubation of spring-run eggs occurs from August through December, except for Mill and Deer creeks, where eggs incubate from September through March (Fisher pers. comm.).



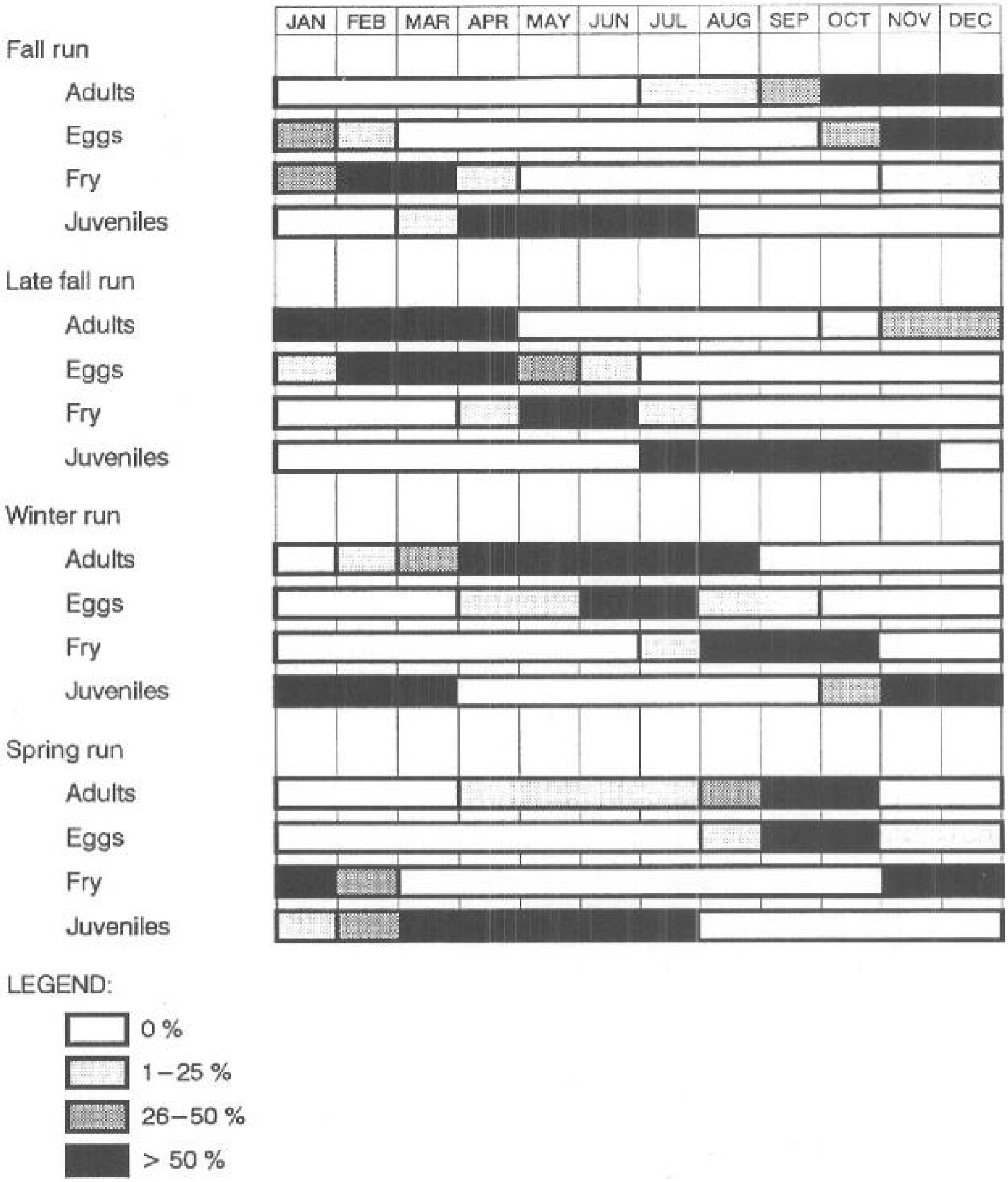
LIFE HISTORY OF CHINOOK SALMON

FIGURE 2-VI-1



MAJOR CHINOOK SALMON SPAWNING AND REARING AREAS IN THE SACRAMENTO RIVER BASIN

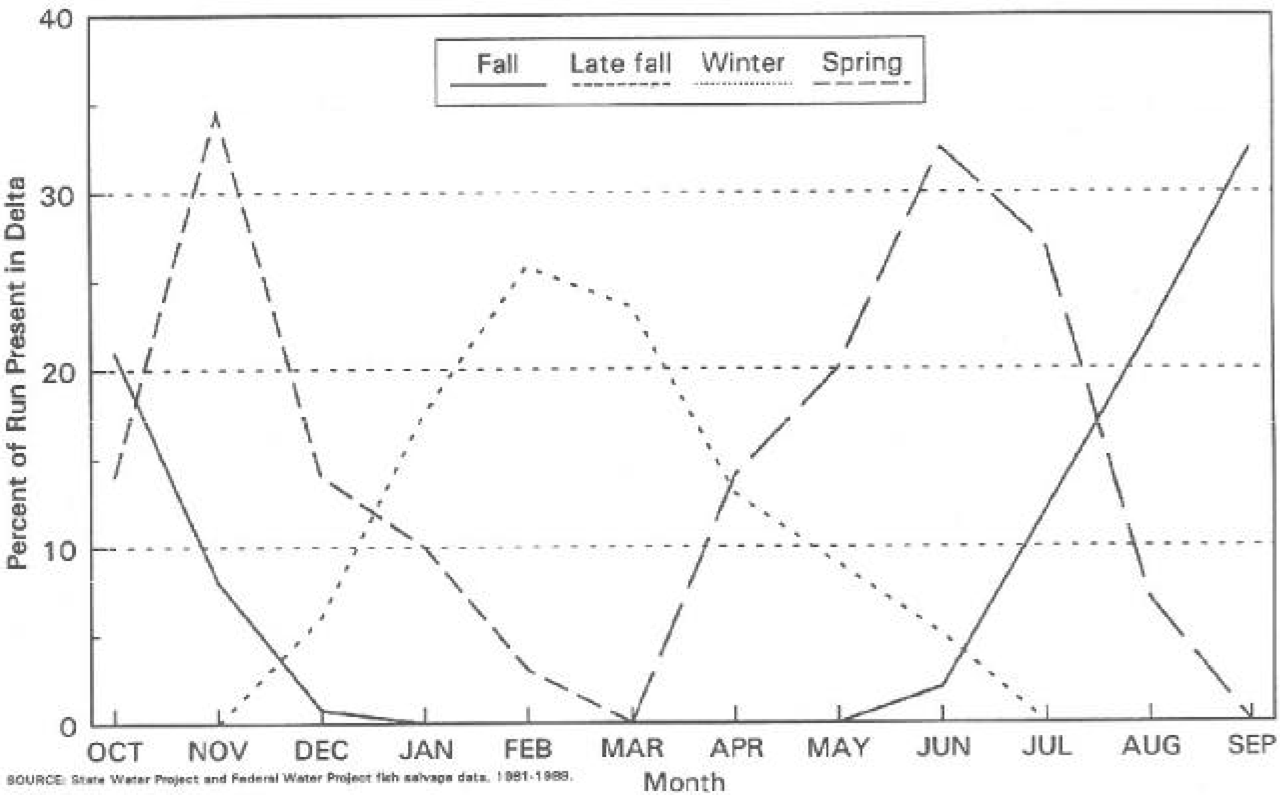
FIGURE 2-VI-2



NOTES: Adults are in cumulative percent.
Other life stages are the percent of year's brood.

OCCURRENCE OF CHINOOK SALMON BY LIFE STAGE IN THE SACRAMENTO RIVER BASIN

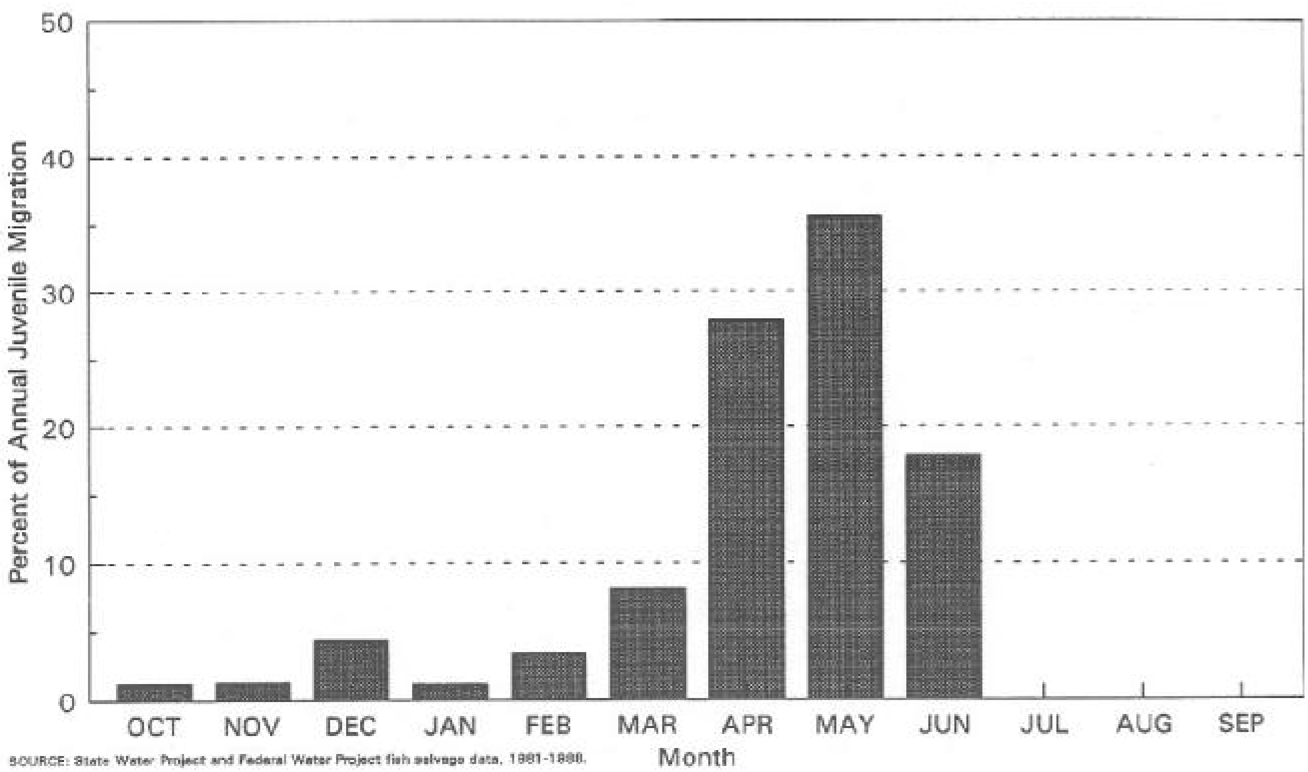
FIGURE 2-VI-3



SOURCE: State Water Project and Federal Water Project fish salvage data, 1981-1988.

TIMING OF ADULT CHINOOK SALMON MIGRATION THROUGH THE SACRAMENTO-SAN JOAQUIN DELTA

FIGURE 2-VI-4



TIMING OF JUVENILE CHINOOK SALMON MIGRATION THROUGH THE SACRAMENTO-SAN JOAQUIN DELTA

FIGURE 2-VI-5

Incubation time is inversely related to water temperature. Eggs generally hatch in approximately 6-9 weeks, and newly emerged fry remain in the gravel for another 2-4 weeks until the yolk is absorbed. The survival of eggs in undisturbed natural redds appears to be quite good (Briggs 1953, Vronskiy 1972).

Rearing - The timing and dynamics of the rearing and downstream migration periods of each run of Sacramento River chinook salmon, though not as well understood as the timing of spawning activities, are described below.

Fall-run chinook salmon fry (i.e., juveniles less than 2 inches long) generally emerge from December through March, with peak emergence occurring by the end of January. Most fall-run fry can be found rearing in freshwater from December through June, with emigration as smolts occurring from April through June. A very small number (generally considered <5%) of fall-run juveniles spend over a year in fresh water and emigrate as yearling smolts the following November through April.

Late fall-run chinook salmon fry generally emerge from April through June. Late fall-run fry can be found rearing in freshwater from April through the following April and emigrating as smolts from November through April.

Winter-run chinook salmon fry emerge from July through October. Winter-run fry can be found rearing in freshwater from July through May and emigrating as smolts from January through May.

Most spring-run fry emerge from November through January. True stream-type spring-run fry, thought to be found only in Deer and Mill creeks in the Central Valley system (Fisher pers. comm.), rear in fresh water for more than a year and emigrate as yearling smolts the following November through April. Mainstem spring-run fry, exhibiting a strategy similar to fall-run chinook fry, can be found rearing in fresh water from November through June and emigrating as smolts from March through June.

Although not well documented, emergence appears to be a difficult time for fry (Healey 1991). In systems studied, under natural conditions, 30% or less of the potential eggs deposited resulted in emergent fry or fry and fingerling migrants. After emerging, chinook salmon fry swim, or are displaced, downstream and begin to feed and grow in the stream environment. Ocean-type juveniles typically rear in fresh water for 2-3 months, while stream-type juveniles remain in freshwater 1+ years prior to outmigrating during the following winter or spring (Healey 1991).

Downstream migration - Most chinook salmon stocks of the Central Valley are characterized by an ocean-type life history pattern, in which juveniles migrate seaward as smolts in their first year of life. During the smolting process, juvenile chinook salmon undergo physiological, morphological, and behavioral changes that stimulate emigration and prepare them for ocean life.

Generally, fry emigrate from December through March and smolt from April through June. A small proportion of the population emigrates as yearlings from October through December.

Two principal movements of juvenile fall-run chinook salmon into the Sacramento-San Joaquin estuary have been identified. Fry begin entering the estuary in January, with peak abundance occurring in February and March. In general, fry abundance in the Delta increases following high winter flows. A later emigration of smolts occurs from April through June. Fry continue to rear in the upper estuary and emigrate as smolts during the normal smolt emigration period. Smolts arriving in the estuary from upstream rearing areas migrate quickly through the Delta and Suisun and San Pablo bays.

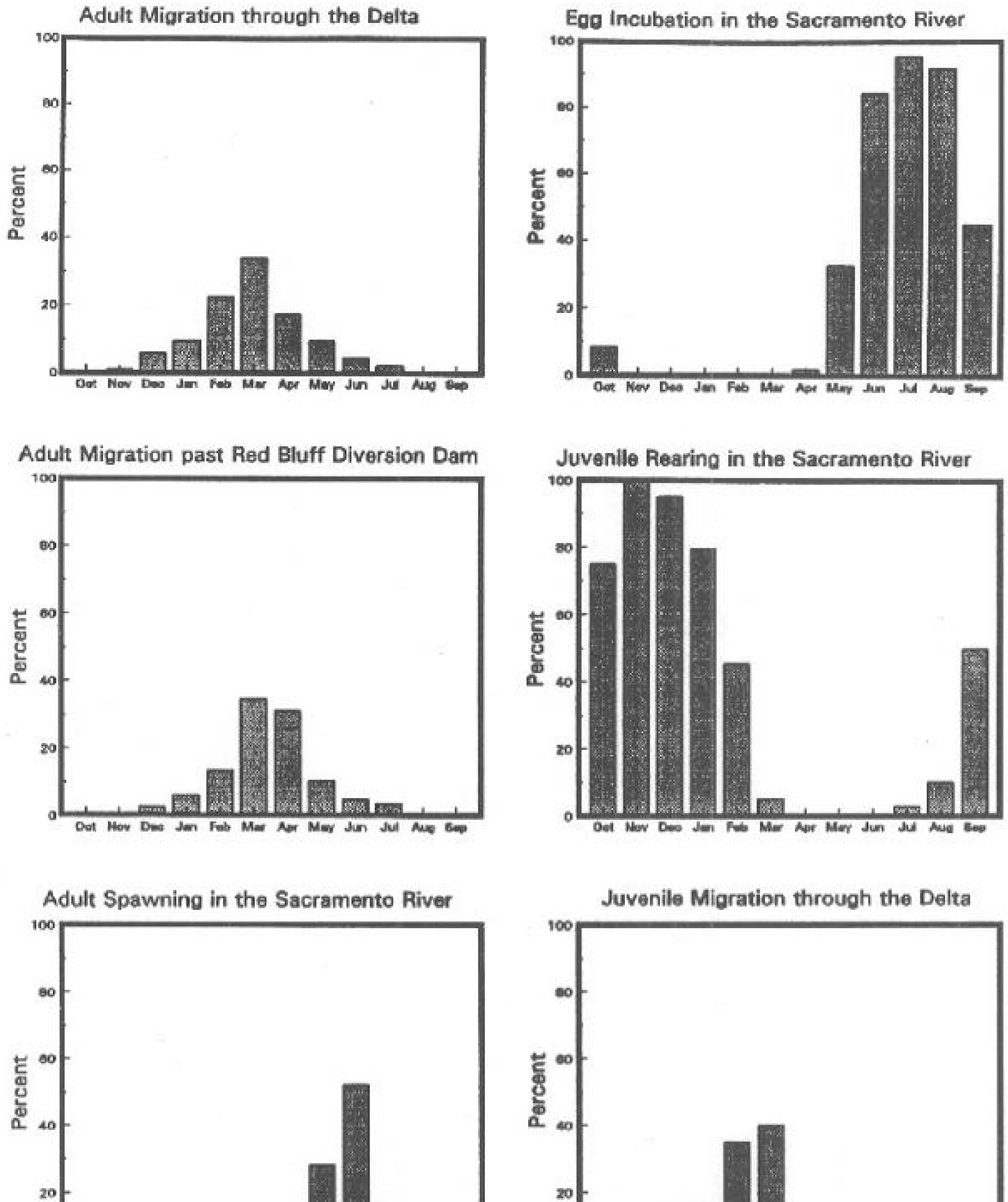
Rearing and emigration of late fall-run fry and smolts occur from April through December. Winter-run chinook salmon can appear in the Delta beginning in December, but smolts migrate through the Delta primarily from January through March. Figure 2-VI-6 summarizes the distribution and relative monthly abundance of winter-run chinook salmon by life stage and location.

Ocean life - The stream-type chinook salmon move offshore early in their ocean life, whereas ocean-type chinook remain in sheltered coastal waters. Stream-type fish maintain a more offshore distribution throughout their ocean life than do ocean-type fish. Available data suggest a northward dispersal of juveniles along the coast, followed by a southward homing migration of maturing adults (Healey 1991). The diet of chinook salmon in the ocean can vary regionally, annually, and seasonally, with small fish (e.g., herring, anchovy, and rockfish), squid, and euphausiids as typical prey items. Chinook salmon typically spend 2-4 years maturing in the ocean before returning to their natal streams to spawn. Historically, most Sacramento River chinook salmon returning to spawn have been 4 years of age (Clark 1929). It has been documented for the Sacramento River that a few male chinook may mature without migrating to sea (Rich 1920), and it may be that this type of maturation is characteristic of stream-type chinook (Healey 1991).

Steelhead

Steelhead are generally classified into two noninterbreeding races--winter steelhead and summer steelhead--depending on the time of year they enter fresh water on their upstream migration. Only winter steelhead occur in the Sacramento River system. Summer steelhead have been introduced into the basin, however, as have strains of winter steelhead from the Eel and Mad rivers and even Oregon (Rogue River) and Washington (Washougal River) river basins. Consequently, the genetic composition of the native steelhead has been significantly modified. Because of the modified genetic composition and the influence of modified and unnatural flow and temperature regimes throughout the basin, the current Central Valley steelhead strains can be found as adults in fresh water in every month of the year. The general life history pattern followed by a "typical" steelhead is described below and presented in Figure 2-VI-7.

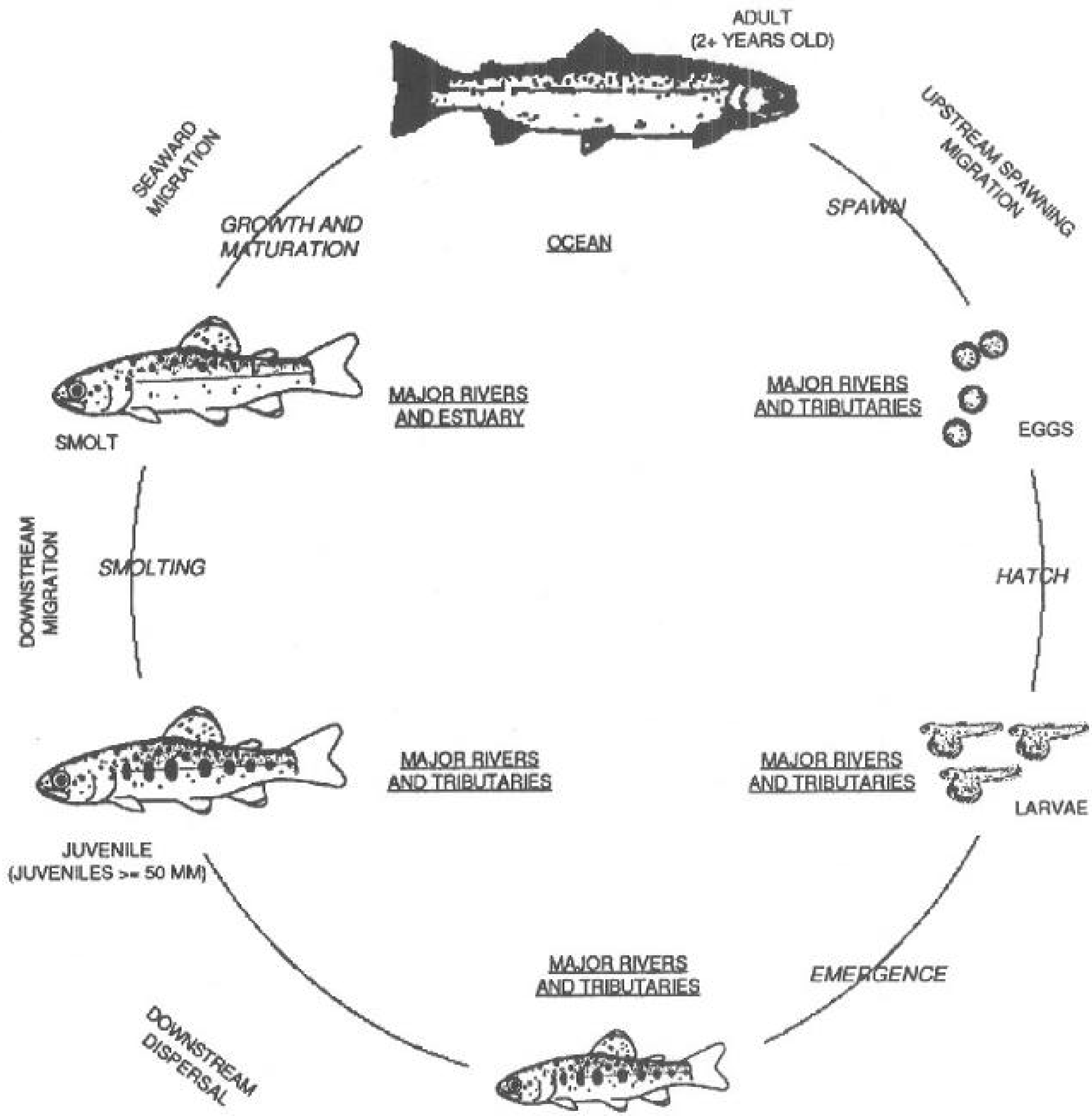
Upstream migration - Steelhead, like salmon, are anadromous species, migrating to sea as juveniles and typically returning to inland waterways as 2- to 4-year-old adults to spawn. Upstream migration occurs in August through March as a result of interbreeding with numerous hatchery strains and altered flow and



SOURCE: Jones and Stokes Associates 1992b.

DISTRIBUTION AND RELATIVE MONTHLY ABUNDANCE OF WINTER-RUN CHINOOK SALMON BY LIFE STAGE AND LOCATION

FIGURE 2-VI-6



LIFE HISTORY OF STEELHEAD TROUT
FIGURE 2-VI-7

temperature conditions below major dams. Reservoir releases of cold and high water occasionally occur in major Sacramento River tributaries and can attract steelhead into the tributaries as early as August. In addition to sexually mature adults, a small portion of the upstream-migrating run is composed of immature grilse, which have spent only a few months at sea.

It is unknown whether separate fall and winter runs of steelhead exist in the Sacramento River system. The smaller and younger steelhead that enter the river starting in July, peak in November, spawn primarily in late December and January, and complete spawning by mid-February are sometimes called fall-run steelhead. The larger winter-run steelhead migrate upstream during mid-December through February and spawn in late January through early March, and the run is over by April 1.

Because of the mixed genetic stock, Sacramento River steelhead have higher straying rates than native fish. Consequently, steelhead stocks in the Sacramento River are subject to a greater degree to environmental conditions than are pure native stocks.

Life history aspects of the few steelhead in the San Joaquin River system are assumed to be similar to those described for the Sacramento River system. Upstream spawning migration runs in the Mokelumne River extend from September through January (California Department of Fish and Game [DFG] 1991).

Adult steelhead rarely eat, and they grow very little while they are in fresh water (Pauley et al. 1986).

Spawning - Natural spawning of steelhead in the Sacramento River system has been greatly reduced by dams and other artificial barriers to historical spawning grounds and by reduced spawning flows and other forms of habitat degradation in the stream reaches to which they have access. As a result, steelhead depend highly on hatchery operations to maintain their populations. Spawning in the Sacramento River basin occurs in December through April, with most spawning occurring from January through March.

Unlike chinook and other Pacific salmon, most steelhead do not die after spawning, and a small portion of these survive to become repeat spawners. During spawning, the female digs a redd and deposits her eggs, which are then fertilized by the male. The number of eggs is largely a function of the size of the female. Female steelhead in the American River each carry an average of 3,500 eggs, or a range of 1,500 to 4,500 eggs (Mills and Fisher 1993). Female steelhead in the Sacramento River are smaller, and each carrying an average of approximately 1,500 eggs (Bell 1990). Females may deposit from a few hundred to more than 1,000 eggs per redd and require up to six or seven redds to complete spawning (Skinner 1962). Females have a higher survival rate than males during and after spawning, and a few females may spawn up to four times. Spawning males usually spawn with more than one female, remain in the stream up to 2 weeks longer than females after spawning, and experience more physical exertion (Barnhart 1986). Individual adult steelhead that survive spawning return to the sea between April and June (Mills and Fisher 1993).

Incubation - Steelhead embryology is similar to that of salmon and of other trout.

Rearing - Juvenile steelhead generally rear in fresh water for nearly 1 year or longer before emigrating, generally in spring. Rearing juveniles feed on a variety of aquatic and terrestrial insects and other small invertebrates, and newly emerged fry sometimes become prey of older steelhead.

Downstream migration - Juvenile steelhead generally emigrate downstream to the ocean in November through May (Schaffter 1980), although most Sacramento River steelhead migrate in spring and early summer (Reynolds et al. 1993). Sacramento River steelhead generally migrate as 1-year-old fish at a length of 6-8 inches (Barnhart 1986, Reynolds et al. 1993).

Ocean life - Much of the life of steelhead in the ocean remains a mystery. Steelhead can live 1-4 years in the ocean, but usually they survive only 1-2 years. They grow rapidly, reaching an average length of 23 inches after 2 years in the ocean. Immature grilse grow about 1.2 inches each month they are in the ocean.

Steelhead migration patterns at sea are not well known. They appear to tend to migrate north and south along the Continental Shelf, and at least some spend part of their ocean life in the Alaskan gyre (Barnhart 1986, Pauley et al. 1986).

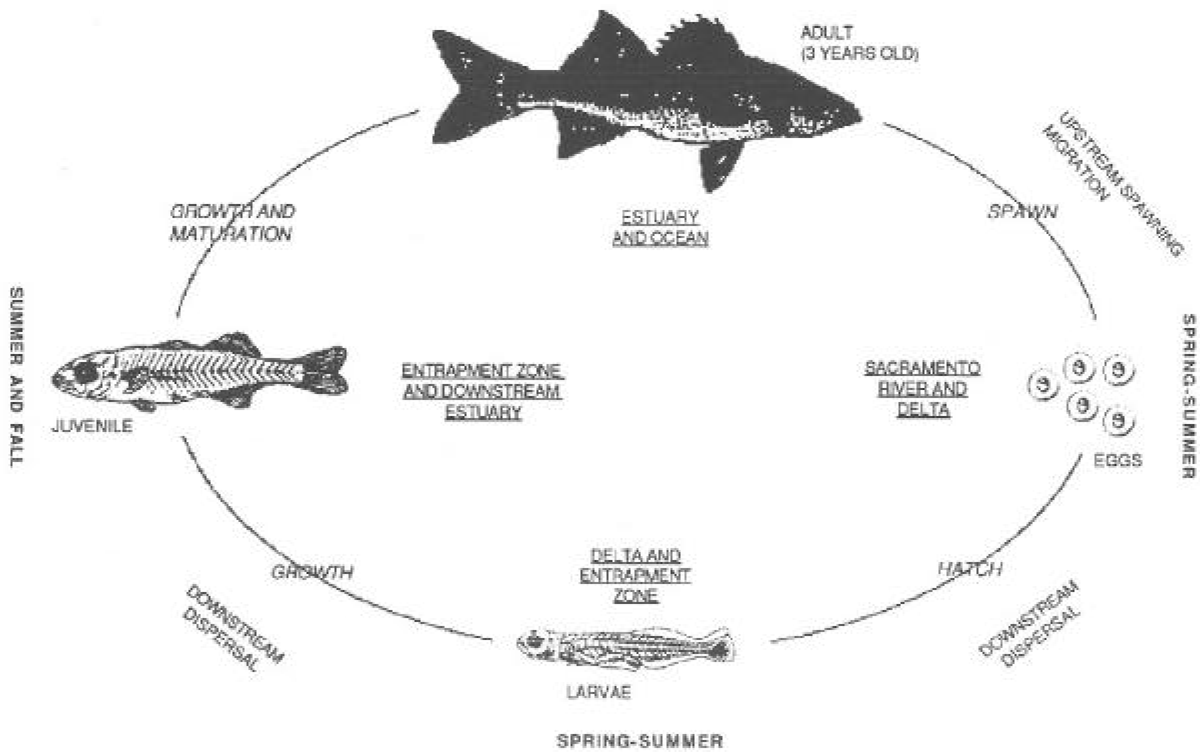
Striped Bass

Striped bass inhabit fresh and ocean waters (Figure 2-VI-8). They require riverine habitat for spawning with currents sufficient to keep the eggs suspended off the bottom (Moyle 1976). Estuarine habitat with high invertebrate densities is needed to support larval and early juvenile bass. Adult bass survive and grow best in water bodies supporting a large prey base (i.e., large populations of forage fishes). The Sacramento and San Joaquin rivers, the Delta, Suisun Bay, San Francisco Bay, and the Pacific Ocean provide conditions that have sustained the striped bass population for more than 100 years since the species' introduction to California in the late 1800s.

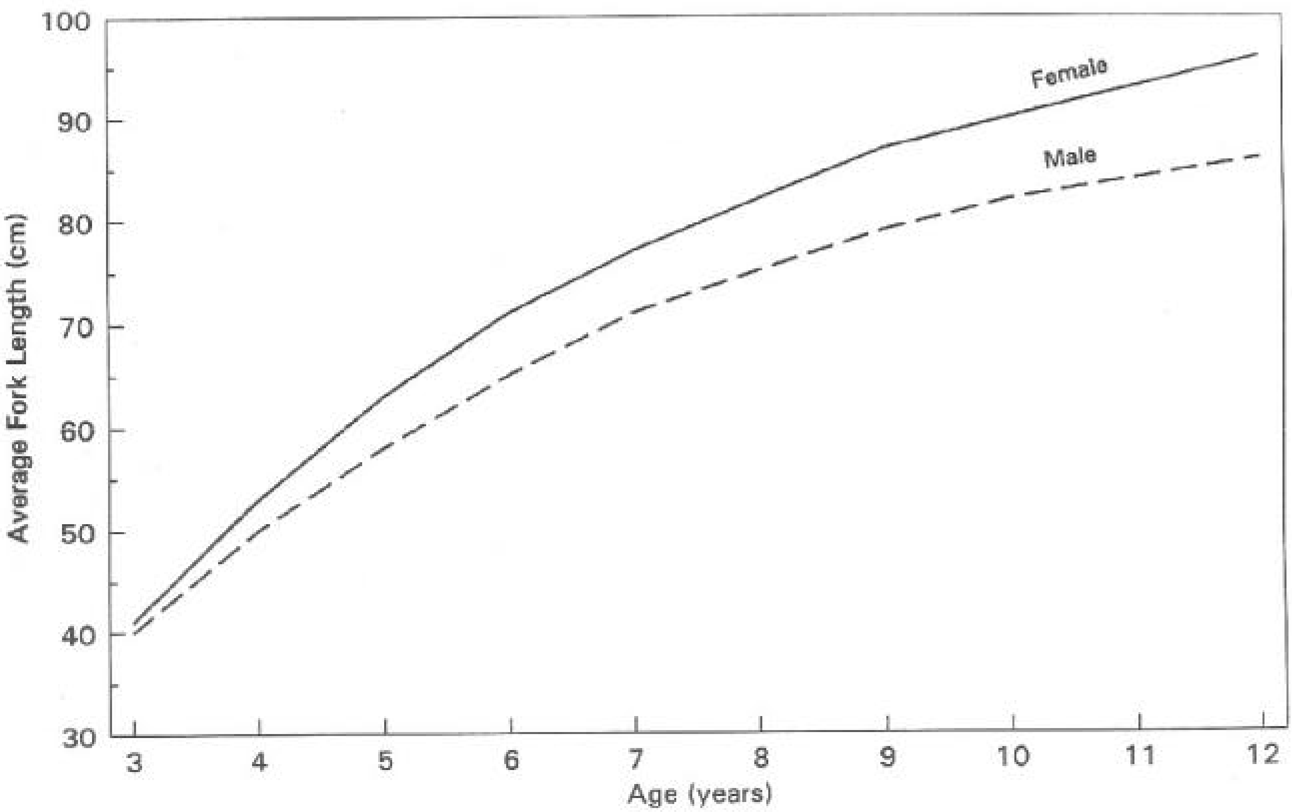
Striped bass are considered adults at 3 years old (when they are approximately 15.2 inches long) and may live for more than 30 years (Moyle 1976). Most adult striped bass in the Sacramento-San Joaquin estuary are between 3 and 8 years old. Female striped bass grow faster than males, and most 6-year-old females are the same size as 7-year-old males (Figure 2-VI-9) (Collins 1981). Most growth occurs during May to November. In California, striped bass can grow to approximately 54 inches long and weigh more than 60 pounds.

Upstream migration and spawning - Male striped bass may be sexually mature at the end of their first year, but most reach sexual maturity after 2-3 years (Moyle 1976). Sexual maturity occurs at a later age in females, usually after 4-6 years.

Striped bass always spawn in fresh water (DFG 1987). Striped bass spawn in the Sacramento River between Sacramento and Colusa (including the Feather River below Marysville [Wang 1986]) and in the



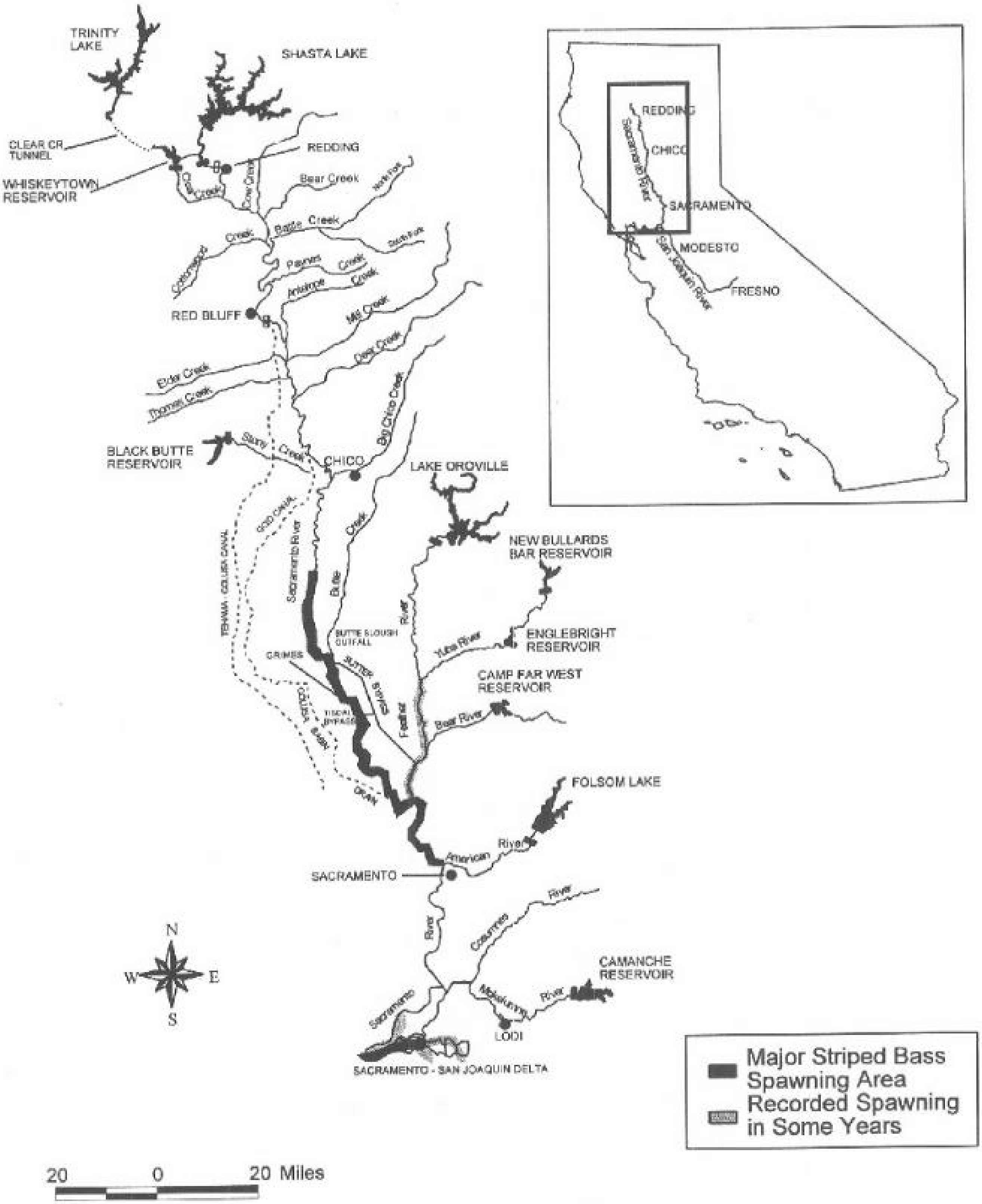
LIFE HISTORY OF STRIPED BASS
FIGURE 2-VI-8



Source: Collins (1981).

GROWTH OF ADULT STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

FIGURE 2-VI-9



STRIPED BASS SPAWNING AREAS IN THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

FIGURE 2-VI-10

San Joaquin River part of the Delta between Antioch and Venice Island (Figure 2-VI-10). Spawning has also been recorded in the lower San Joaquin River above the Delta (Turner 1976). Usually, approximately 60% of the spawning population uses the Sacramento River, and 40% spawn in the Delta. The proportion spawning in each area varies annually, but 50-66% of the annual egg production is from the Sacramento River spawn. Spawning in the Sacramento River occurs farther upstream during years of high flow (Turner 1976).

Spawning begins first in the Delta, usually in mid- to late April, and continues sporadically over 3-5 weeks (Mitchell 1987, DFG 1987). Spawning in the Sacramento River takes place an average of 15 days later than spawning in the Delta and usually begins in early or late May and ends in early June (Turner 1976). Cooler water temperatures delay spawning in the Sacramento River relative to the Delta. High flow tends to dampen increases in temperature, and the delay period is greater during high-flow years.

Striped bass are mass spawners, broadcasting eggs and sperm into the water column (Moyle 1976, Wang 1986). Groups consisting of 5-30 striped bass, predominantly males, move into the main current of the river to spawn near the surface. Spawning can occur any time of day but generally takes place in the late afternoon and evening. Females are prolific, producing from 11,000 to more than 2,000,000 eggs each. The number of eggs produced is a function of size. A 4-year-old female produces more than 200,000 eggs, an 8-year-old female produces more than 1,000,000 eggs, and a 12-year-old female produces more than 1,800,000 eggs (DFG 1987).

Incubation - Eggs are slightly denser than fresh water, and in the absence of current, sink slowly to the bottom (Moyle 1976). In the Sacramento River near Verona, where flows are turbulent in the relatively narrow and shallow river, egg densities were variable but tended to be greatest at the surface (Fujimura 1991). Apparently, eggs suspended by turbulent flow remain near the surface where they were spawned by the female bass. Farther downstream near Walnut Grove, eggs are generally concentrated at mid-depth and near the bottom. The river near Walnut Grove is wider, deeper, and has more uniform laminar flow, and currents slow when flood tides back up against the downstream river flow. Eggs transported downstream from the spawning areas sink slowly and are generally concentrated within a few meters of the bottom (Turner 1976, Wang 1986).

Eggs hatch in approximately 2 days at 18-19^{o}C (Moyle 1976, Wang 1986). Larvae measuring approximately .12-.16 inch long at hatching are sustained by their yolk sac for 7-9 days, after which they exceed .24-.28 inch in length and begin feeding on small zooplankton. As larvae increase in size, their swimming ability and control over position in the water column increases (Fujimura 1991). Until the transition to external feeding, however, larvae are weak swimmers and are passively dispersed by currents.

Rearing - Larval stages last 4-5 weeks, and, when they reach about .72 inch long, the young bass have developed all the features characteristic of juveniles (Wang 1986, DFG 1987). Within another 4-5 weeks (usually in July), depending on water temperature and food availability, juvenile bass will have grown to lengths of 1.52 inches. By September, the length of the juveniles in the current year-class ranges from 20 to 48 inches (Sasaki 1966). By August of the following year, the length of juveniles ranges from 4.8 to 9.2 inches. By the end of their third year, the average length is 15.2 inches and the young bass are considered adults.

Striped bass larvae eat several species of copepods (including *Eurytemora* sp., *Sinocalanus* sp., and *Cyclopidae*), several species of Cladocerans (including *Bosmina longirostrus* and *Daphnia* spp.), and the mysid *Neomysis* sp. The copepod *Eurytemora* sp. is the preferred food of larval striped bass in the Sacramento-San Joaquin estuary. In the San Joaquin River portion of the Delta, the Cladoceran *Bosmina longirostrus* is sometimes heavily selected as prey by striped bass larvae.

Larval striped bass generally select prey larger than .04 inch within each species and each species group. *Neomysis* is generally too large for larvae to consume but becomes progressively more important in the diet as larvae increase in size.

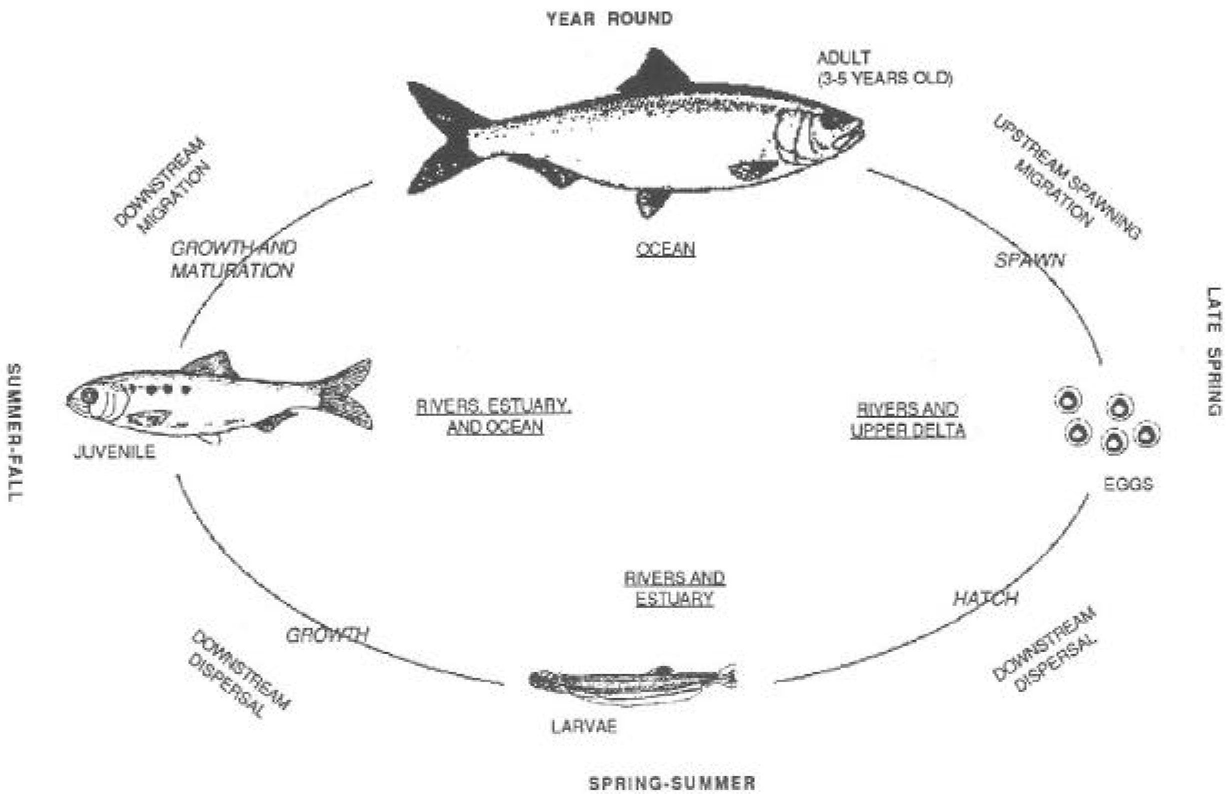
Similar to larvae, juvenile striped bass select progressively larger prey as they grow (Thomas 1967). The primary prey of juvenile bass during their first year is *Neomysis* sp. and amphipods in the genus *Corophium* (Stevens 1966). As the bass grow, the diet of juvenile bass shifts more to fish and becomes similar to the diet of adult striped bass.

For adults in the Central Valley, food preference is primarily a function of prey availability, which depends on habitat and season. In general, adult striped bass feed on fish, including smaller striped bass. In the Delta, adult bass prey primarily on threadfin shad, American shad, and young striped bass (Stevens 1966). Anchovies, chinook salmon, Delta smelt, and mysids are seasonally eaten in the lower Delta and Suisun Bay (Thomas 1967). In San Pablo and San Francisco Bay, anchovies, bay shrimp (*Crangon* sp.), and shiner perch are the primary prey items. When striped bass inhabit rivers, juvenile chinook salmon and carp are key prey species.

Estuarine and ocean migration - Adult bass are found throughout the year in rivers (the Sacramento, San Joaquin, and Mokelumne rivers, and their major tributaries), the Delta, San Francisco Bay, and the Pacific Ocean, but they show definitive migration patterns. In fall, adult striped bass migrate upstream to Suisun Bay and the Delta, where they overwinter (Chadwick 1967, Mitchell 1987). During spring, bass disperse throughout the Delta and into the tributary rivers to spawn. Migration back to the Delta, Suisun Bay, and San Francisco Bay occurs during summer. After the mid-1960s, however, most striped bass have inhabited Suisun Bay and the Delta during summer and fall; migration to San Francisco Bay and the Pacific Ocean has declined.

American Shad

With only a few exceptions, American shad are anadromous, spending most of their life in the ocean and returning as adults to spawn in freshwater rivers. Adult spawning migrations occur primarily in April-June, with most spawning taking place in the American, Feather, Yuba, and upper Sacramento rivers. Some



LIFE HISTORY OF AMERICAN SHAD

FIGURE 2-VI-11

spawning also takes place in the lower San Joaquin, Mokelumne, and Stanislaus rivers. Spawning occurs in moderate currents sufficient to keep eggs suspended off the bottom. The young can rear for several months in the Feather and Sacramento rivers or migrate downstream soon after hatching, lingering in the Delta for several weeks to several months. Information presented on American shad life history is based primarily on Moyle (1976), Painter et al. (1980), Stier and Crance (1985), Wang (1986), and Jones & Stokes Associates (1990). American shad life history is summarized in Figure 2-VI-11.

Upstream migration and spawning - American shad become sexually mature while in the ocean at an average age of 3-5 years; the oldest fish on record lived to be 11 years old (Painter 1980). Most males reach maturity at 3-4 years, and most females become sexually mature at 4-5 years (Painter et al. 1980). Some shad have been found to spawn as young as 2 years of age. At maturity, male shad typically average 3 pounds, and female shad average almost 4 pounds; shad as large as 6-8 pounds are rare (Skinner 1962). Although shad are strongly anadromous, they are capable of surviving and reproducing while landlocked in freshwater reservoirs (Moyle 1976). In California, all American shad except the Millerton Lake shad populations have an anadromous life cycle.

Unripe, male shad make up most of the early run and smaller, unripe females are known to precede the larger, later-migrating ripe females (Moyle 1976, Painter et al. 1980). The ratio of males to females was found on the Yuba River to be 1:1 during the first half of the season and over 3:1 during the last half of the season (Jones & Stokes Associates 1990). Most migrating shad are 3-year-old males and 4-year-old females ranging in size from 12 to 30 inches (Wixom 1981). Approximately 70% of the shad run in central California are fish that are spawning for the first time (i.e., virgin spawners) (Painter et al. 1980).

Adult American shad initiate their spawning migration as early as February; however, most adults do not migrate into the Delta until March or early April (Skinner 1962). Studies suggest that adults require 2-3 days to adapt to fresh water (Stier and Crance 1985). Typically, most migrating adults need 3 months (March-May) to pass through the Sacramento-San Joaquin estuary (Painter et al. 1980). The exact timing of shad migration appears to be regulated by water temperatures in the ocean and natal rivers. Typically, adult shad do not enter fresh water until water temperatures approach 52^{o}F.

Peak spawning migration into spawning habitats takes place when water temperatures are much higher (59-68^{o}F), usually in late May or early June (Moyle 1976). During studies in the western Delta (1976-1977), DFG tagged the most migrating shad when water temperatures were between 57 and 66^{o}F (Painter et al. 1980). Despite the importance of temperature, studies on both the Feather River (Painter et al. 1977, 1980) and the Yuba River (Jones & Stokes Associates 1990) suggest that increased flows, not water temperatures, were the primary factors responsible for attracting shad into these streams. Migration appears to decline after water temperatures exceed 68^{o}F, usually in early July (Moyle 1976). Peak migration in the Sacramento River upstream of the Feather River occurs in May, and angling surveys indicate that peak migration in the Feather and Yuba rivers occurs during June (Stevens 1972, Jones & Stokes Associates 1990).

American shad spawn exclusively in freshwater, although spawning may be possible in brackish water (Wang 1986). There does not appear to be a specific distance upstream of brackish water required for spawning to occur (Painter et al. 1980). American shad spawn in the main channels of the Sacramento River from Red Bluff downstream to Hood; the American, Feather and Yuba rivers; the lower reaches of the San Joaquin River; and the Mokelumne and Stanislaus rivers (Wang 1986). It unknown if shad return to their natal rivers to spawn.

Spawning can occur at any time of day but usually takes place at night as a mass affair, often among small schools. Spawning is initiated when a male swims alongside a female and the two adults swim rapidly side by side. The males fertilize the eggs as the female releases them into the water column. Each fish spawns repeatedly and some survive the spawn and return the following year after emigrating to the ocean. Postspawning adults emigrate through the Delta and Suisun Bay as late as August and September. Spawning mortality appears to be greater at higher water temperatures, especially above 68^{o}F (Moyle 1976).

Unlike shad on the Atlantic Coast, adult shad in the Delta feed while in fresh water, probably because of the abundance of large zooplankters. However, not all adult shad feed while in the Delta, and most feeding ceases once they enter the main rivers (Moyle 1976). While in the Delta, adult shad feed primarily on opossum shrimp (*Neomysis mercedis*), followed by copepods, cladocerans, and amphipods (*Corophium* sp.) (Moyle 1976). The presence of these zooplankters in shad stomachs appears to be directly related to zooplankton concentrations in the Delta (Stevens 1966). On occasion, adult shad have been known to prey on clams and fish larvae.

Incubation - American shad eggs are slightly heavier than water and are suspended in the water column by the slightest current. Although shad eggs can be found throughout the water column, the greatest concentration appears to be near the river bottom. The eggs drift with the current and hatch in 3-6 days at water temperatures of 52 to 79^{o}F (Stevens 1972). Although hatching occurs sooner at higher water temperatures, egg survival is reduced.

Rearing - Larval shad range from .23 to .40 inch long at hatching and grow rapidly, tripling their length in the first month. Larval stages last approximately 30-40 days, and the young shad have developed adult features and are classified as juveniles when they grow to .96-1.12 inches long (Painter et al. 1980). The newly hatched larvae are pelagic (i.e., they inhabit open water), are most abundant at the water surface, and feed on zooplankton within 4-5 days of hatching (Painter et al. 1980, Wang 1986). Larval shad initially prey predominantly on cladocerans but increasingly feed on ostracods, insects, insect larvae, and copepods as they grow. Shad larvae usually consume food items that are most readily available (Painter et al. 1980). Newly hatched larvae are found downstream of spawning areas and can be rapidly transported downstream by river currents because of their small size.

Season-long rearing of juvenile shad occurs in the Mokelumne River near the Delta Cross Channel to the San Joaquin River, the lower Sacramento River below Knights Landing, the Feather River below Yuba City, and the Delta. No rearing occurs in the American and Yuba rivers. (Painter et al. 1980.)

Some juvenile shad appear to rear in the Delta for up to a year or more before emigrating to the ocean. While in the Delta, juvenile shad are opportunistic feeders and prey on *Neomysis* sp., copepods, amphipods, chironomid midge larvae, and surface insects (Moyle 1976). Depending on water temperature and food availability, young-of-year (YOY) shad in the Delta are an average length of 1.2 inches in July, 3.24 inches in September, and 4.56 inches in November (Stevens 1972). By the time they enter saltwater, shad range in size from 3.2 to 7.2 inches long.

Downstream migration - Presumably, all juvenile shad eventually emigrate to the ocean because immature shad greater than 8 inches long are rarely caught in the Delta (Moyle 1976). Most shad enter saltwater when they are between 80 and 7.2 inches long. Seaward migration of juvenile shad in the Delta begins in late June and continues through November, with peak migration occurring between September and November (Stevens 1972, Painter et al. 1980).

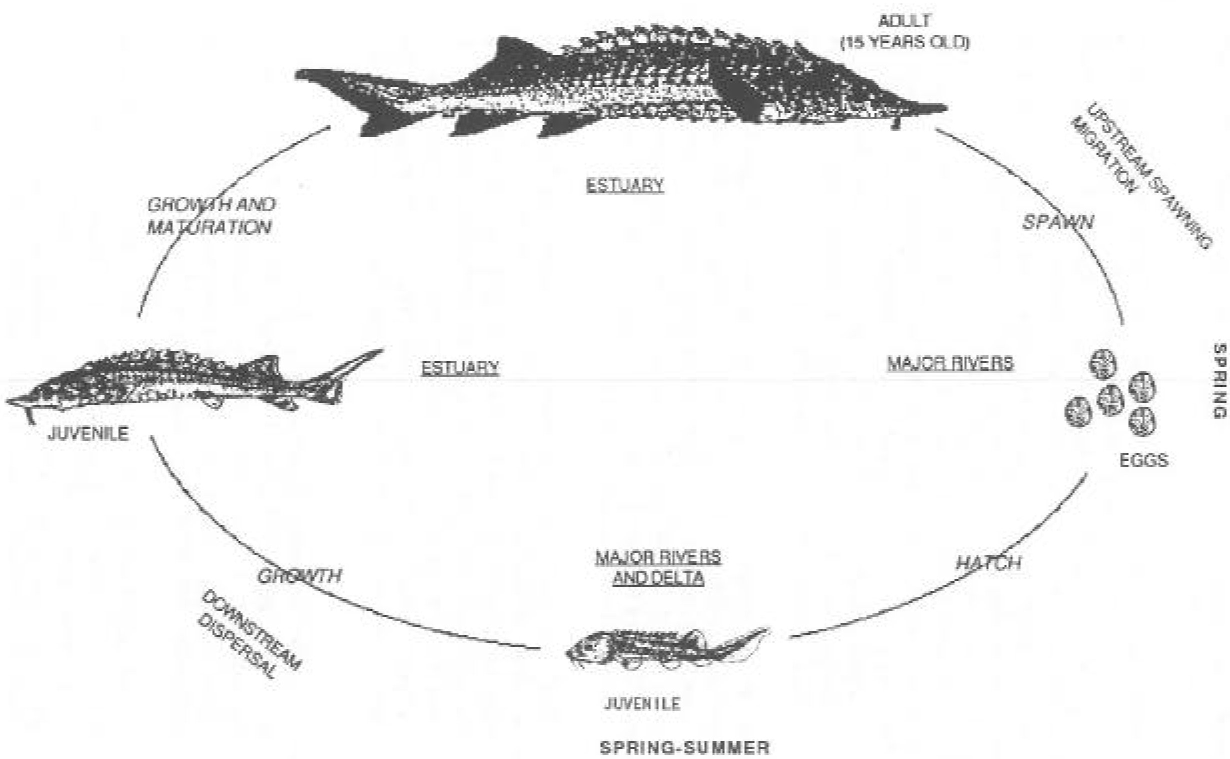
Ocean life - Little is known about the oceanic ecology and behavior of juvenile and adult American shad. As stated earlier, shad are found in the Pacific Ocean from Baja California to Alaska; however, they are seldom found south of Monterey, California (Fry 1973). Their wide distribution along the Pacific Coast suggests that shad in the Pacific Ocean may exhibit migrational patterns similar to those of Atlantic Ocean shad (Moyle 1976, Painter et al. 1980).

White Sturgeon

White sturgeon are the largest freshwater or anadromous fish species in North America, reaching weights in excess of 1,300 pounds. Historically, white sturgeon populations ranged from Alaska to central California (Scott and Crossman 1973). However, major spawning populations are now limited to the Fraser (British Columbia, Canada) and Columbia (Oregon) rivers and the Sacramento-San Joaquin River system.

Compared to salmon and steelhead, less is known about sturgeon life history. This is due in part to limited scientific investigations and to variances in life history between and within populations. To overcome these deficiencies in Central Valley sturgeon, life history is augmented with information from other northeast Pacific population. White sturgeon life history is summarized in Figure 2-VI-12.

Upstream migration - Each year, a portion of the adult population moves upriver from the San Francisco and San Pablo bays, the estuary, and the Delta to spawn. Data from the Sacramento River indicate that sturgeon start migrating into the river in October and spawn as early as February (Schaffter pers. comm.). Most spawning in the Central Valley occurs during March through May, and approximately 20-30% of the sturgeon spawn in February and June (Doroshov pers. comm.). Studies conducted by DFG indicate most spawning occurs between Knights Landing (river mile [RM] 85) and Princeton (RM 164), with primary



LIFE HISTORY OF WHITE STURGEON
FIGURE 2-VI-12

spawning areas near Colusa (RM 144). Juvenile sturgeon have been found as far upriver as the Glenn-Colusa Canal near Hamilton City, indicating that some sturgeon may migrate farther upriver (Kohlhorst 1976). Some spawning may also occur as far upstream as the Red Bluff Diversion Dam (RBDD) (RM 243), as indicated by larval and juvenile entrainment noted there (Brown pers. comm.).

Tag recoveries and catches in the sport fishery indicate that some adult sturgeon also migrate into the San Joaquin River. Adult sturgeon are caught in the sport fishery between Mossdale and the mouth of the Merced River in late winter and early spring, which suggests this is a spawning run (Kohlhorst 1976). Based on the ratio of tags recovered, Kohlhorst et al. (1991) estimated that approximately 10% of the Sacramento-San Joaquin River system spawning population migrates up the San Joaquin River. However, no studies have been conducted to definitively determine whether and where sturgeon spawn in the San Joaquin River.

Evidence also suggests that sturgeon reproduction occurs in both the Feather and Bear rivers. Adult sturgeon migrated into the Feather River historically and in more recent times. Several articles recount large sturgeon caught in the Feather River in the early 1900s (Talbitzer 1959, Anonymous 1918). More recent accounts include recovery of one tagged adult sturgeon in April 1968 (Miller 1972a). Green sturgeon were caught every year during the mid-1970s to early 1980s (Anonymous pers. comm.). Most catches occurred between March and May, with occasional catches in July and August. During spring 1991, two radio-tagged adult sturgeon were tracked 6.4 miles up the Feather River. Subsequent efforts to relocate these fish were unsuccessful (Schaffter 1991). Finally, during spring 1993, several adult green sturgeon (of lengths from 60.8 to 73.2 inches) were caught at Thermalito Afterbay outlet (Foley pers. comm.). Green and white sturgeon are also known to enter the Bear River typically during the spring of most wet and some normal water years (Lenihan and Myers pers. comms.). Adult sturgeon were observed in shallow pools between the Highways 70 and 65 bridges during spring 1989, 1990, and 1992 (Lenihan pers. comm.).

During July 1989, approximately 100 sturgeon were trapped in pools between the Highways 70 and 65 bridges as a result of reduced flows (Myers pers. comm.). At least 30-40 sturgeon (weighing from 60 to 100 pounds and at least 5 feet long) were poached from this area during a 2-week period in July. Of the seven sturgeon confiscated by DFG game wardens, all were white sturgeon. Though no spawning or presence of larvae or juveniles has been documented, reproduction is believed to occur in the Feather and Bear rivers because of the presence of adults.

Upstream migration is probably triggered by both endogenous (i.e., sexual maturation) and abiotic (i.e., temperature, flow, and photoperiod) factors, although these factors are not well understood. Mature fish may be stimulated to migrate upstream by cues triggering the final stages of gonadal development, which may include flow velocity, photoperiod (i.e., the number of daylight hours best suited to the growth and maturation of an organism), or temperature (Pacific States Marine Fisheries Commission 1992). The speed of instream movement of radio-tagged white sturgeon in the Sacramento River was as high as 15 mile per day and was often stimulated by small increases in river flow (Schaffter 1991).

Spawning - Sturgeon spawn in the Sacramento River between mid-February and late May, with a peak in spawning (93%) occurring between March and April (Kohlhorst 1976). Not all adults migrate upstream to spawn each year. Sexual cycles in sturgeon are complex because these fish mature at a late age and adults do not spawn every year. It is likely that mature sturgeon migrate upriver to spawn and most immature fish or fish in resting stages remain in the estuary.

Chapman (1989) studied sexual maturation in 836 white sturgeon collected over several years from the Delta. The sex ratio in the overall population was approximately 1:1. The ratio of mature males to mature females was 2:1. The size range of adult sturgeon was bimodal, with the average length of males (52 inches) smaller than that of females (57 inches). Fish less than 35 inches showed no gonadal development. There were no fish less than 39 inches with mature gonads. Of the fish studied, 44% were immature or in a resting phase of gonadal development, 31% showed active egg and sperm development, and 28% contained mature gonads. The youngest mature fish were a 12-year-old male and a 14-year-old female. A higher percentage of the males (37%) were ripe than were females (15%).

Fecundity and periodicity of spawning of female sturgeon appear to depend on female age or size (Pacific States Marine Fisheries Commission 1992). Depending on age and size, mature female sturgeon may carry 0.1 million to 7 million eggs, representing 7-30% of a female's weight. Recent analyses of sturgeon in the Sacramento-San Joaquin River suggest that females spawn every 4 years and males spawn in alternate years (Kohlhorst pers. comm.). Females also appear to have the ability to reabsorb eggs and forego spawning under unfavorable environmental conditions. Sturgeon stocks outside of the Central Valley are known to spawn in streams with gravel or rock bottoms, moderate to fast currents (Dees 1961, Nikolskii 1961), and depths exceeding 9 feet (Galbreath 1979, Doroshov 1985). Spawning habitat requirements for white sturgeon in the Sacramento-San Joaquin River system have not been definitively identified.

Few observations of wild sturgeon spawning have been reported. Apparently sturgeon broadcast spawn in swift water. It is unknown if eggs are fertilized while they are in the water column or after they contact the bottom. The current initially disperses the adhesive eggs, which sink and adhere to gravel and rock. Adhesive eggs allow spawning and retention of eggs within swift current environments.

Incubation - Incubation and emergence of white sturgeon have been studied under laboratory conditions to determine protocols for hatchery rearing. Egg incubation can last 4-14 days after fertilization; yolk depletion can occur 15-30 days after fertilization (Wang et al. 1985, Conte et al. 1988). Hatching time depends on water temperature. Temperatures between 10 and 17°C (52-63°F) are considered optimum for spawning, incubation, and development (Pacific States Marine Fisheries Commission 1992). The most sensitive stage in development is the first 24 hours after fertilization.

Rearing - Nursery areas for juvenile white sturgeon extend downriver from spawning areas to the Delta. Distribution of juvenile white sturgeon within the Sacramento River system is determined by river flow. Larvae are distributed farther downriver during wet years and remain further upstream during drier years

(Stevens and Miller 1970, Kohlhorst 1976). Eggs and larvae have been collected primarily near Colusa, Knights Landing, and the mouth of the Feather River; however, YOY white sturgeon have been found as far upstream as Hamilton City (Stevens and Miller 1970, Kohlhorst 1976). Larvae and YOY fish have been found in the Delta between Collinsville and Rio Vista and as far downriver as Suisun Bay (Radtke 1966, Stevens and Miller 1970).

Laboratory studies indicate that larval white sturgeon demonstrate three behavioral phases after emergence: swim-up and dispersal, hiding, and feeding (Brannon et al. 1986, Brewer 1987, Duke et al. 1990, Miller et al. 1991). After hatching, yolk sac larvae swim up into the water column where currents disperse them downstream of spawning areas. Larvae swim toward or to the surface, then passively sink to the bottom (Brewer 1987). Immediately or shortly after touching bottom, the larvae repeat the swimming activity. The duration of this phase varies, lasting from 1 to 5 days (Brewer 1987). However, Brewer (1987) indicated larvae initiated the hiding phase more rapidly at higher flow velocities (0.3 feet per second [fps]).

When larvae enter the hiding phase, they are still nourished from the yolk sac. To hide, larvae place their heads within substrates (either rock or vegetation) and maintain a constant tail beat to maintain their position. During this phase, larvae exhibit negative phototaxis (movement away from light), seeking dark substrates. This hiding behavior is thought to provide protection from predation as the larvae develop (Brewer 1987). Despite this behavior, larvae between .32 and .88 inch still drift downstream with the current if they are caught in stationary nets (Kohlhorst pers. comm.).

Larvae develop mouth and olfactory organs needed for feeding before the yolk sac is completely absorbed. Although feeding can occur during the hiding phase if food is present at the hiding site (Brewer 1987), exogenous feeding does not occur until 12 days after hatching at temperatures of 63°F (17°C) (Buddington and Doroshov 1984). During the feeding phase, larvae move from hiding to active food forage. Young sturgeon appear to be opportunistic feeders, using both olfactory and chemoreception to locate food items. No field studies have been conducted to determine wild sturgeon larvae diet. However, periphyton and/or benthos probably dominate larval sturgeon diet (Brannon et al. 1984).

Sturgeon diet becomes more diverse as the fish become larger. YOY sturgeon (<8 inches long) feed on small crustaceans, insect larvae, and potentially small fish. The most common prey of juvenile sturgeon in the Sacramento-San Joaquin River system were amphipods (Schreiber 1962).

Sturgeon continue to be opportunistic feeders as adults. Adult sturgeon caught in San Pablo and Suisun bays fed primarily on benthic invertebrates (i.e. clams, barnacles, crab, and shrimp) (McKechnie and Fenner 1971). Seasonally, herring eggs and small fish (i.e., striped bass, flounder, goby, and herring) are important prey items. Although numerous in the estuary, worms, such as polycheates and nematodes, were seldom consumed.

Downstream, estuarine, and ocean migration - There is no defined age or size at which juvenile sturgeon from anadromous populations enter the estuarine environment (Binkowski and Doroshov 1985). In the

Central Valley, the older and larger a sturgeon is the greater its chance of inhabiting estuarine or marine environments (Kohlhorst pers. comm.).

Both adult and subadult sturgeon inhabit Suisun, San Pablo, and San Francisco bays and the Delta year-round (Miller 1972b, Shirley 1987, Kohlhorst et al. 1991). Delta distribution is thought to depend primarily on river flow and consequent salinity.

Shirley (1987) studied the age structure of adult sturgeon in the estuary and found differences in age structure of fish from different regions of the estuary. Relatively young fish were captured from Suisun and Grizzly bays and near Candlestick Park in San Francisco Bay, while older fish were caught in Carquinez Strait, San Pablo Bay, and near Tiburon. Sturgeon captured near Tiburon (close to the mouth of San Francisco Bay) had a significantly older age structure. Very few sturgeon (four) older than 20 years were caught at locations other than Tiburon. At Tiburon, 34 fish were older than 20 years, with the oldest fish estimated to be 27 years old. Age structures of all groups had peaks in the age distribution between 11 and 15 years old.

Some coastal migrations have been noted for adult sturgeon. Tagged white sturgeon, landed by commercial fishing near Bristol Bay in southwest Alaska, originated in the Columbia River in 1983 2,000 miles away. However, these represent less than 1% of total recoveries of tagged white sturgeon. White sturgeon tagged in the Sacramento-San Joaquin River system were captured in Oregon estuaries (Yaquina and Umpqua rivers and Tillamook Bay) and in Washington (the Columbia, Chehalis, and Willapa rivers) (Chadwick 1959, Kohlhorst et al. 1991). Tag recoveries of Sacramento-San Joaquin River sturgeon in distant coastal systems from recent tagging studies may be related to drought conditions, which have persisted between 1987 and 1992 (Kohlhorst pers. comm. cited in Pacific States Marine Fisheries Commission 1992).

Green Sturgeon

Little is known about green sturgeon life history. Brief summaries are found in Moyle (1976) and Kohlhorst et al. (1991).

Green sturgeon are smaller than white sturgeon, reaching average weights of 350 pounds and lengths of 7 feet. Green sturgeon are relatively short lived, reaching a maximum of 40 years.

In California, green sturgeon are found in the lower reaches of the Sacramento-San Joaquin River basin and the Eel, Mad, Klamath, and Smith rivers. Currently, green sturgeon seem to be the most common sturgeon in the Klamath and Trinity rivers (Moyle 1976), but it is only a minor component of the Central Valley populations. Green to white sturgeon ratios in the Delta have ranged from 1:39 to 1:164 (Mills and Fisher 1993) (Table 2-VI-1).

Table 2-VI-1. Annual estimates of adult white and green sturgeon in the Central Valley (1967-1991)

Year	Sturgeon abundance	Years abundance estimated	Ratio of white to green sturgeon	Green sturgeon abundance
1967	14,700	X	62.0:1	1,850
1968	40,000	X	38.6:1	1,040
1969	36,783			900
1970	33,567			760
1971	30,350			620
1972	27,133			480
1973	23,917			340
1974	20,700	X	101.9:1	200
1975	31,460			444
1976	42,220			688
1977	52,980			932
1978	63,740			1,176
1979	74,500	X	52.6:1	1,420
1980	83,120			1,378
1981	91,740			1,336
1982	100,360			1,294
1983	108,980			1,252
1984	117,600	X	106.3:1	1,210
1985	107,700	X	127.3:1	760
1986	96,850			635
1987	86,000	X	163.7:1	510
1988	66,267			520
1989	46,553			530
1990	26,800	X	49.7:1	540
1991	--			--
Average	63,501			867

Source: Mills and Fisher 1993.

Upstream migration - Virtually no information is available for upstream migration of green sturgeon in the Sacramento-San Joaquin system. On March 7, 1991, a male green sturgeon, 73.6 inches long, was caught, radiotagged, and released into the Sacramento River between Courtland (RM 34.8) and Freeport (RM 46). It was last located on March 13, 1991, near the mouth of the Feather River (RM 67.1) (Kohlhorst pers. comm.). Seven adult green sturgeon were caught by fishers during spring 1993 at the Thermalito Afterbay Outlet in the Feather River. Sizes ranged from 60.9 to more than 73.2 inches.

During April and May 199l, several adult green sturgeon were observed in the Sacramento River within a 10-mile stretch below the RBDD (Brown pers. comm.). A dead adult green sturgeon was recovered on April 18, 1991. A combined total of 18 sightings were made at Patterson riffle (RM 144.5), Ohm Riffle (RM 145.4), lower Todd Riffle (RM 236), and upper Todd Riffle (RM 147.9). Additional sightings were made in 1992 (Brown pers. comm.).

The extent of inland migrations in the Sacramento system is unclear, but landlocked populations of the sturgeon are currently unknown. There are no records of green sturgeon from Lake Shasta or Lake Oroville. However, anecdotal information suggests that sturgeon have been seen jumping and breaching in Lake Oroville (Hodges pers. comm.). The theoretical limit to upstream migration in the mainstem Sacramento River is Keswick Dam. Passage above the RBDD is possible, but only when the gates are raised. The theoretical limit to upstream migration in the Feather River is the Fish Barrier Dam. Shanghai and Sunshine Pumps may be migrational impediments under certain conditions.

Data on the upstream migration of green sturgeon in the Klamath Basin have been collected by the U.S. Fish and Wildlife Service (USFWS) from 1981 to 1994. At this latitude (41^{o} 34'N), it appears that mature green sturgeon begin entering the Klamath River as early as March. However, native fishing effort is usually decreased during winter and early migrants may have been missed. Most spawners move upstream from April through June, with some ripe fish having been seen into July. A few fish may enter the river during fall, overwinter in the system, and spawn the following spring, but this remains to be proven.

The effects of environmental cues on sturgeon migrations are not understood. In general, a positive correlation exists between increasing flow, increasing photoperiod, increasing temperatures, and upstream migration. Increasing water temperature is generally associated with upstream migration. Surface temperatures for the Klamath River at Cappell Creek (RM 33.2) were taken intermittently during the 1990 spawning run. A surface temperature of 6.9^{o}C was recorded on March 13, and sturgeon were absent from the local native fishery. By March 24, surface temperatures had increased to 10^{o}C-11^{o}C and natives began taking spawning migrants. Sturgeon continued to be caught into April, but, by the end of the month, the number taken throughout the lower 43.5 miles had decreased. Surface temperatures were near 16^{o}C.

In 1987, Artyukhin and Andronov (1990) collected six spawning migrants from the estuary of the Tumnin River, Russia. Six additional migrants were captured in 1991 (Artyukhin and Andronov 1994). Collections were made from late May through early July as water temperatures varied from 7.2 ^{o}C to 11.5 ^{o}C.

Parasitological evidence indicates that some green sturgeon rapidly travel upstream after leaving the marine environment. The external marine trematodes *Paradiclybothrium pacificum* and *Nitzschta quadritestes* were collected from a green sturgeon at RM 43.5 in the Klamath River. These parasites would be expected to drop off their host shortly after entering fresh water, but the exact timing is unknown.

Spawning - Distinct sexual characteristics are generally absent, but male and female sturgeon can be distinguished in the final stages before spawning (Dadswell et al. 1984). The time to reach sexual maturation is variable and can range from 10 to 30 years in wild populations (Doroshov 1994). In culture, the onset of puberty occurs at a younger age, and evidence suggests that gonadal development depends more on size than on age (Conte et al. 1988). Chapman (1989) hypothesized that poor nutrition may delay the onset of puberty. Males generally reach sexual maturation at a smaller size and younger age than females. Gonads in both sexes are bilateral. Mature ovaries are proportionately larger than mature testes. Female sturgeon are gymnoovarian; in some species, fecundity may reach over 1,000,000 eggs.

Almost all Acipenserids spawn in spring and summer (Detlaff et al. 1993). Only l-20% of an indigenous adult population will participate in a typical spawning run (Conte et al. 1988). Spawning individuals vary in size and represent several different age classes. Detlaff et al. (1993) characterized Acipenserid spawning areas as having swift currents and dense substrates. Males typically outnumber females on the spawning grounds. Fertilization is external and parental care is lacking. Sturgeon may live to an advanced age (Moyle and Cech 1982).

Although most green sturgeon spawn in spring, it has been suggested that some individuals may spawn in winter. However, there are no confirmed observations of green sturgeon spawning activity. Moyle (1976) suggested that leaping and other frantic behavior may be indicative of spawning or courtship. Newly spawned adhesive eggs from white sturgeon were collected in conjunction with observations of breaching fish (Underwood and Beckman 1989). Spawning habits are currently unknown.

Evidence suggests that green and white sturgeon are reproductively isolated, even in basins in which both species are known to spawn. Wild hybrids are not currently recognized, but hybridization is theoretically possible. A California aquaculturist in the 1980s allegedly produced hybrid green sturgeon x white sturgeon by using milt from a green sturgeon and eggs from a white sturgeon. All progeny were subsequently destroyed by DFG.

Green sturgeon eggs are relatively large. Tracy (1990) indicated eggs are about 0.15 inch in diameter. In 1990, 30 eggs from a migrating Klamath River female collected at RM 41.3 were examined. Sizes ranged from 0.15 to 0.16 inch. Shape was ovoid and slightly pointed. The basic color was olive-gray with some mottling. The animal pole was lighter compared to the vegetal pole. Germinal vesicles were located near the animal pole, estimated to be in position 4 or 5 described by Lutes et al. (1987).

Specific information on spawning of green sturgeon in the Sacramento-San Joaquin system is limited. Kohlhorst (1976) found sturgeon eggs and larvae in the Sacramento River from mid-February through late May, but specific identifications were not made.

Klamath Basin green sturgeon were initially thought to enter the spawning population at age 16 or older (USFWS 1982, 1983). More recent investigations, however, have suggested that this may be an overestimate and males may enter the spawning population as early as 8 years of age (Kisanuki pers. comm.). Females appear to be slightly older before they enter the spawning population, and their sexual maturation may not occur until age 13 (Kisanuki pers. comm.).

Incubation - No information is available on green sturgeon egg incubation.

Rearing - No information is available on green sturgeon rearing.

Downstream, estuarine, and ocean migration - Juveniles inhabit the estuary until they are about 4-6 years old, when they migrate to the ocean (Kohlhorst et al. 1991). Green sturgeon can make extensive ocean migrations. Green sturgeon tagged in San Pablo Bay have been recovered in rivers and estuaries in Oregon and Washington. Juvenile fish have been collected in the Sacramento River, near Hamilton City, and in the Delta and San Francisco Bay. Adults have been observed near RBDD in late winter and early spring.

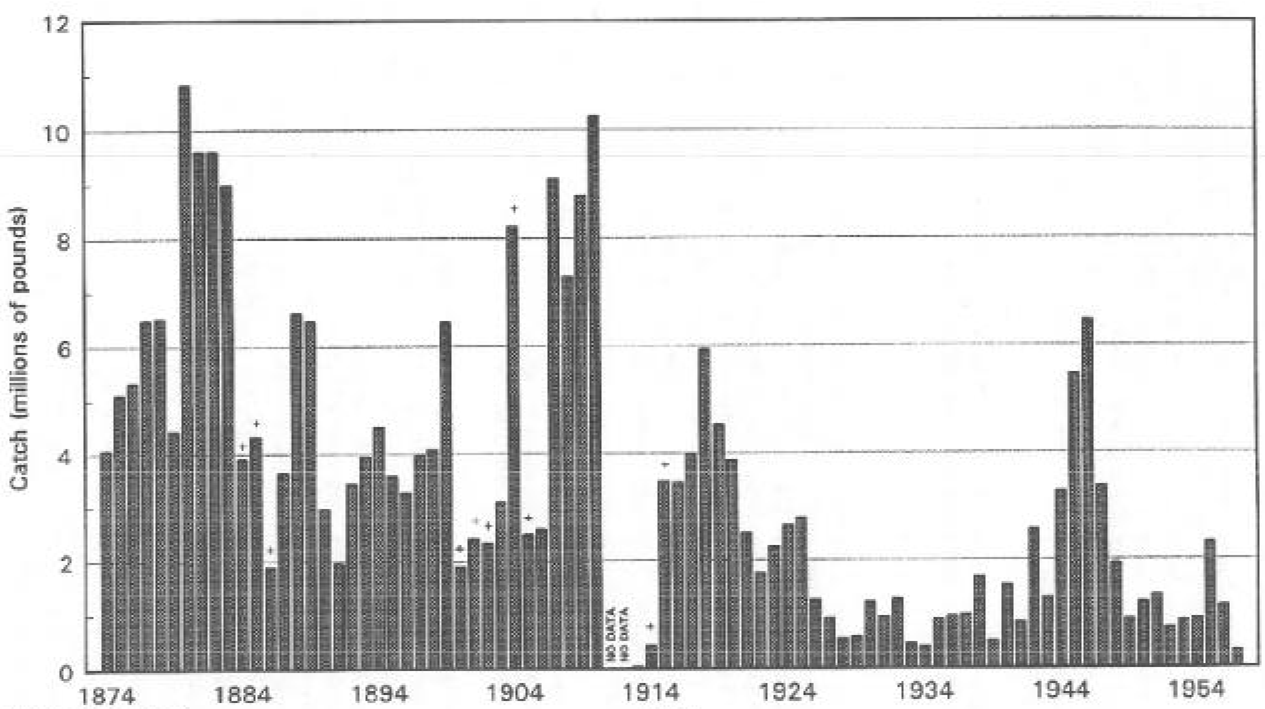
The diet of adult green sturgeon appears to be similar to that of white sturgeon: bottom invertebrates and small fish (Ganssle 1966). Juveniles in the Delta feed on opossum shrimp and amphipods, such as *Corophium* (Radtke 1966). Little information is available about green sturgeon age and growth; in the Delta they seldom exceed 4 feet in length (Skinner 1962, Moyle 1976).

ABUNDANCE AND DISTRIBUTION (PRE-1967)

Chinook Salmon

Early trends in Central Valley chinook salmon populations were indirectly monitored by commercial catch records dating back to 1874 when complete records of commercial gill net landings were first available. These records are of limited use in determining population trends for specific streams or runs but provide an indicator of major trends in the abundance of Central Valley chinook salmon.

Early accounts indicate that the commercial salmon fishery in California began around 1850. The Gold Rush and the ensuing human population growth in California led to rapid expansion of the fishery. Hydraulic



SOURCE: Skinner (1962).

NOTE: Gillnet fishery discontinued by legislative action in 1957.

+ Indicates that total pounds in that year are based on recorded pack of canned salmon only.

SACRAMENTO-SAN JOAQUIN RIVER COMMERCIAL GILLNET SALMON LANDINGS (1874-1957)

FIGURE 2-VI-13

gold mining, logging, agricultural, and grazing activities also increased rapidly, leading to the first major human impacts on stream habitat and fish populations in the Sacramento River basin (Buer et al. 1984). Later, construction of agricultural, power generation, and debris dams accelerated declines in chinook salmon populations by preventing access to historical spawning and rearing habitat or substantially reducing the amount of available habitat (Clark 1929).

Between 1874 and 1910, total gill net landings fluctuated between 2 million and 11 million pounds and averaged about 6 million pounds. A distinct downward trend in gill net landings after 1910 led to a period of extremely poor catches between 1926 and 1943, in which annual yields ranged from 0.4 to 2.5 million pounds per year and averaged approximately 1 million pounds per year (Skinner 1962) (Figure 2-VI-13). This decline coincided with a decline in the number of adult salmon returning to hatchery facilities in the Sacramento River between 1915 and 1924 (Clark 1929). The California ocean troll fishery, the dominant commercial salmon fishery by 1916, also had catches reduced from about 6 million pounds per year before 1920 to an average of about 4 million pounds per year during the 1920s and 1930s, despite increasing effort. Clark concluded that the Sacramento-San Joaquin salmon fishery was in a "state of serious depletion" by 1929, citing overfishing, loss of spawning areas from dam construction, loss of young salmon in overflow basins, and losses to predatory fishes as principal causes. Following a brief increase to approximately 6.5 million pounds in 1946, annual gill net landings returned to an average of approximately 1 million pounds per year through the 1950s (Skinner 1962).

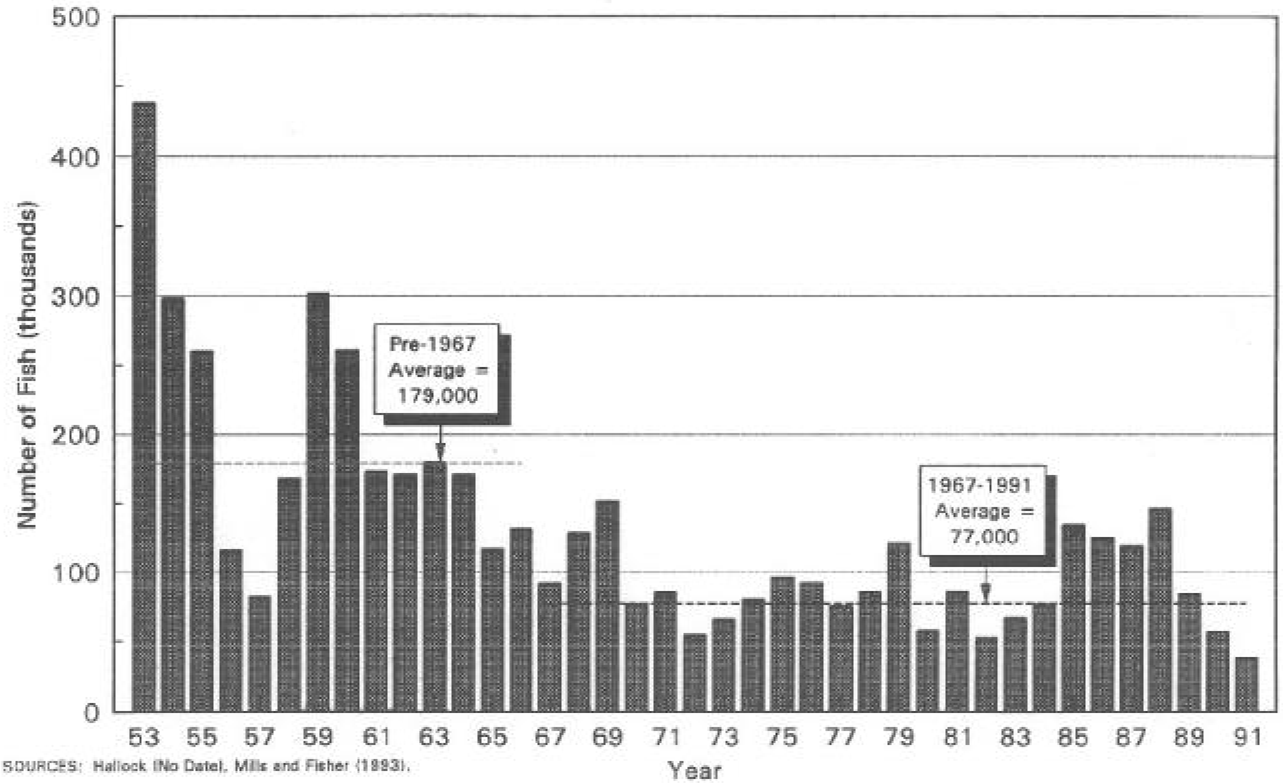
Four races of chinook salmon, recognized by the season of their upstream migration, are found in the Sacramento basin: fall-, late fall-, winter-, and spring-run chinook salmon.

Sacramento River -

Fall-run chinook salmon - Historically, fall-run chinook salmon were one of the more abundant salmon races in the Central Valley. Counts of adult salmon as they passed over the Anderson-Cottonwood Irrigation District Dam were obtained as early as 1937, but complete estimates of fall-run chinook salmon abundance in the Sacramento River and its major tributaries were not made until 1953 (Hallock n.d.). Annual estimates of spawning escapement (i.e., the total number of adult salmon [age 2 and older] that "escape" the fishery and return to spawn) in the mainstem Sacramento River reveal a gradual but steady decline during the 1950s and 1960s; annual run size declined from an average of 179,000 adults during 1953-1966 to an average of 77,000 adults during 1967-1991 (Figure 2-VI-14).

Late fall-run chinook salmon - Because of high flows and turbid conditions that generally prevail during the late fall-run chinook salmon spawning period, annual abundance estimates were possible only after construction of the RBDD and its associated fish counting facilities in 1967.

Winter-run chinook salmon - Before construction of Shasta and Keswick Dams in 1945 and 1950, respectively, winter-run chinook salmon were reported to spawn in the upper reaches of the Little Sacramento, McCloud, and lower Pit rivers (Moyle et al. 1989). Specific data relative to historical run



SOURCES: Hallock (No Date), Mills and Fisher (1993).

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE MAINSTEM SACRAMENTO RIVER (1953-1991)

FIGURE 2-VI-14

sizes prior to 1967 are sparse and mostly anecdotal. Slater (1963) is frequently cited to indicate that winter-run populations were small and limited to the McCloud River before construction of Shasta Dam. Recent DFG research in the California State Archives indicates that the winter-run chinook salmon population may have numbered over 200,000 (Rectenwald and Fox pers. comms.). Cold hypolimnetic releases from Shasta Reservoir enabled the run to spawn successfully in the Sacramento River below Keswick Dam. Under these favorable habitat conditions, the run was maintained at more than 80,000 adults by the mid 1960s (U.S. Bureau of Reclamation [USBR] 1986).

Spring-run chinook salmon - Historically, spring-run chinook salmon were one of the more abundant salmon races in the Central Valley. The principal holding and spawning areas were in the middle reaches of the San Joaquin, Feather, upper Sacramento, McCloud, and Pit rivers upstream of the present location of major dams. Smaller runs occurred in tributaries large and cold enough to support adults during the summer holding period.

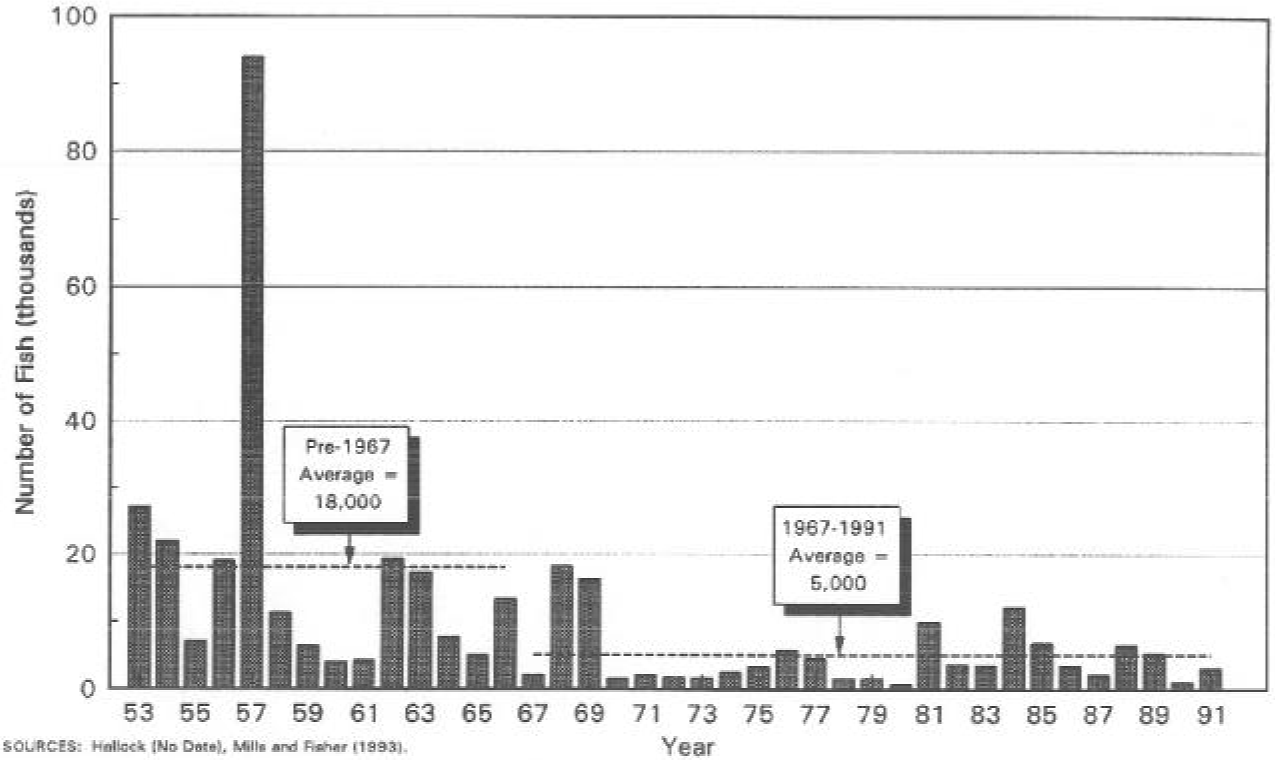
Gold mining, agricultural diversions, logging, and overharvest caused the first major declines in spring-run chinook populations. By 1930, agricultural and sediment control dams on tributary streams had caused severe declines and extirpation of tributary stocks by preventing spring-run adults from reaching critical summer holding and spawning habitat. Further extirpations occurred following the construction of major storage reservoirs on the Sacramento River and major tributaries in the 1940s and 1950s. By 1966, only remnant populations of spring-run chinook salmon were present below these dams.

Considerable overlap in spawning period with fall-run on the mainstem Sacramento River and major tributaries has probably resulted in significant introgression (i.e., loss of genetic purity) of spring-run stocks (Slater 1963).

Sacramento river tributaries - Fall-run chinook salmon runs in minor Sacramento River tributaries, including Clear Creek, Cow Creek, Cottonwood Creek, Antelope Creek, Mill Creek, and Deer Creek, were not regularly monitored, although declines in abundance are evident since 1953 (Figure 2-VI-15). Annual spawning escapement in Battle Creek during 1953-1966 exhibited a general decline similar to the pattern observed in the mainstem Sacramento River. Total run size averaged 17,000 adults, with an average 9,000 adults spawning in Battle Creek and 8,000 spawning in Coleman National Fish Hatchery (CNFH) (Figure 2-VI-16).

Genetically pure spring-run chinook stocks may occur only in two minor Sacramento River tributaries: Mill and Deer creeks.

Average annual run size in the American River averaged approximately 26,000 adults before construction of Folsom Dam and Nimbus Salmon and Steelhead Hatchery in 1955 (Fry 1961). By 1966, average run size, including river and hatchery spawners, had increased to approximately 39,000 adults. Average annual spawning escapement in the American River during 1953-1966 was approximately 30,000 adults; on average, 19,000 adults spawned in the river, while 11,000 were spawned in the hatchery (Figure 2-VI-17).

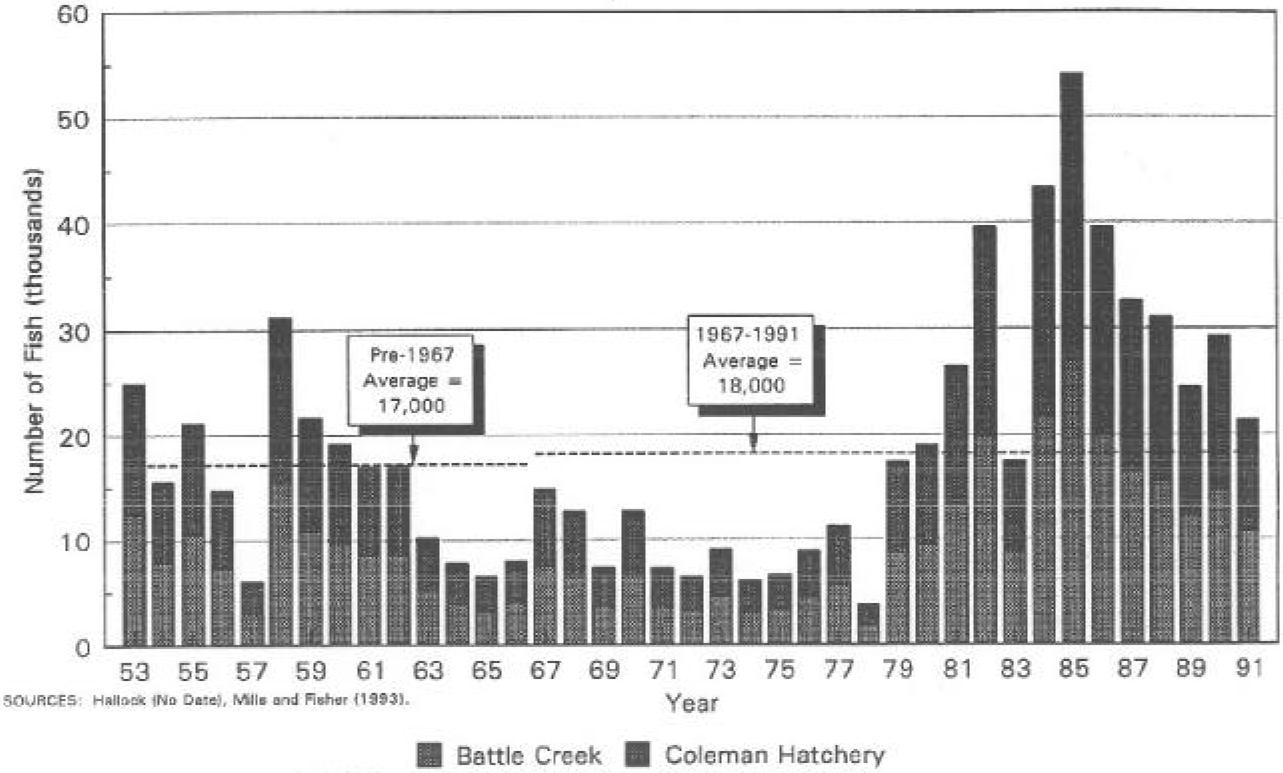


SOURCES: Hallock (No Date), Mills and Fisher (1993).

NOTE: Annual estimates are not strictly comparable because of inconsistent monitoring of tributary salmon runs.

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN MINOR SACRAMENTO RIVER TRIBUTARIES (1953-1991)

FIGURE 2-VI-15

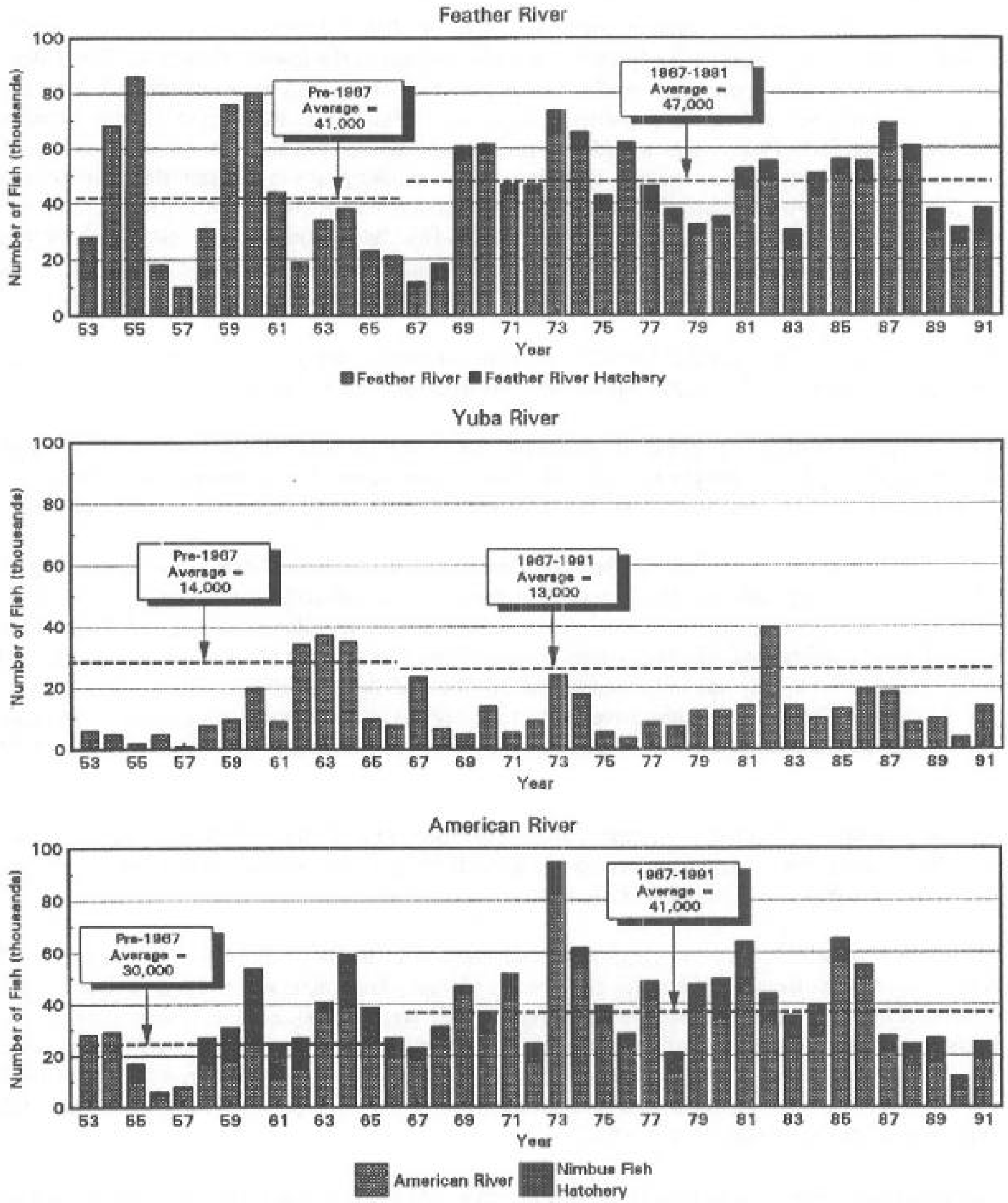


SOURCES: Hallock (No Date), Mills and Fisher (1993).

NOTE: Coleman Hatchery began operating in 1943.

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN BATTLE CREEK AND COLEMAN NATIONAL FISH HATCHERY (1953-1991)

FIGURE 2-VI-16



SOURCES: Hallock (No Date), Mills and Fisher (1993).

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE FEATHER, YUBA, AND AMERICAN RIVERS (1953-1991)

FIGURE 2-VI-17

Feather River basin - Fall-run chinook salmon in the major Sacramento River tributaries exhibited variable abundance patterns during the 1950s and 1960s. Between 1953 and 1966, annual spawning escapement in the Feather River fluctuated widely and averaged about 41,000 adults (Figure 2-VI-17). During this period, the Yuba River, a major tributary of the Feather River, underwent a marked increase in annual run size from an average level of 5,000 adults in the 1950s to a peak of 37,000 adults in 1963. Average annual spawning escapement in the Yuba River during 1953-1966 was approximately 14,000 adults (Figure 2-VI-17).

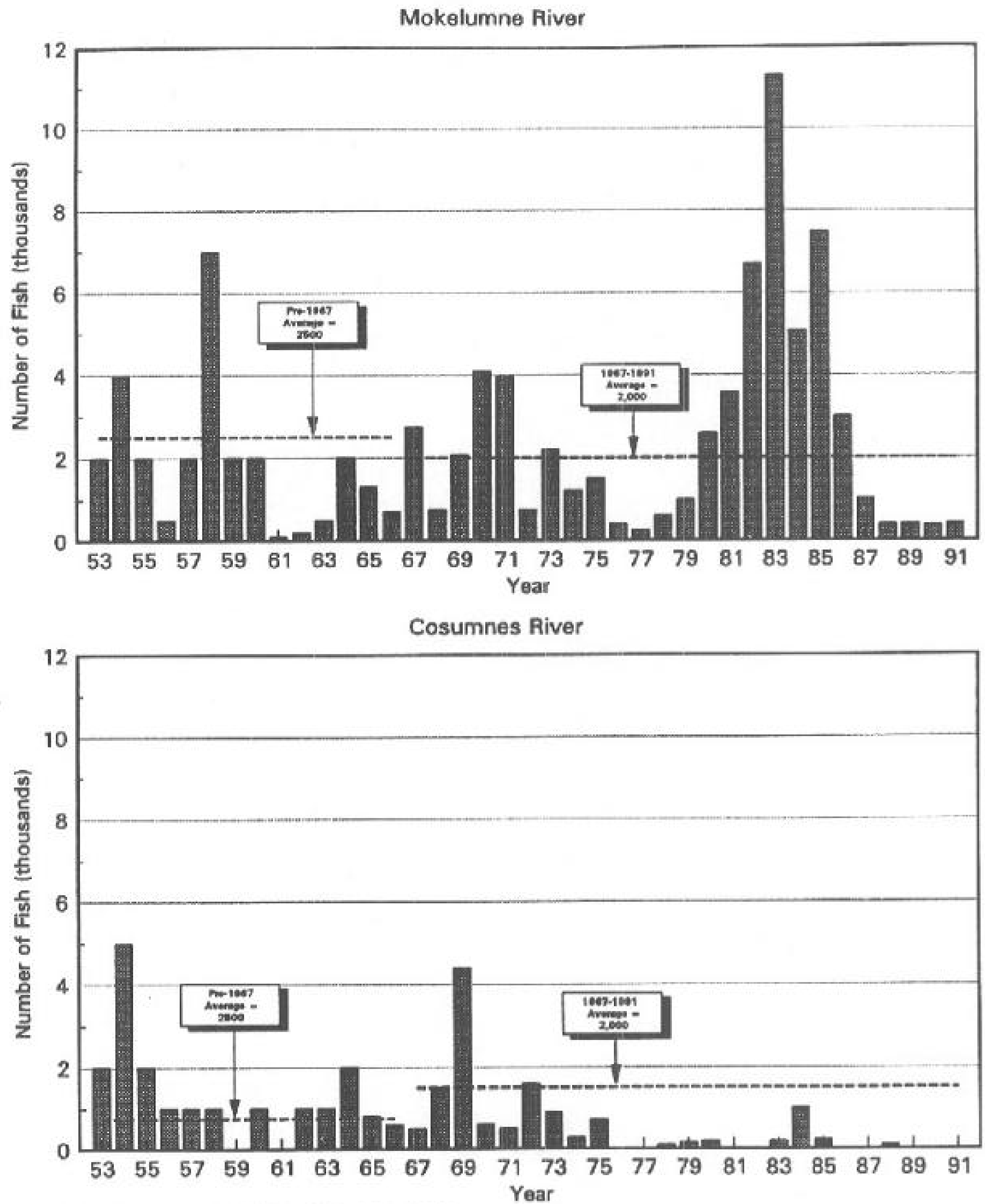
Eastside tributaries - The earliest records indicate that fall-run chinook salmon occurred in the Mokelumne, Cosumnes, and Calaveras rivers (Clark 1929). Spring-run chinook salmon were probably present in the Mokelumne River before the construction of Pardee Dam in 1929. Dams, poaching, and sedimentation caused by gold mining eliminated the spring-run chinook salmon in the Mokelumne River (Reynolds et al. 1990).

Declines in fall-run chinook salmon stocks probably paralleled declines occurring in major San Joaquin tributaries. Since the early 1900s, chinook salmon in the lower Mokelumne River were adversely affected by poor water quality associated with winery and mine wastes, fish losses at unscreened diversions, and migration barriers due to dams (DFG 1991). Runs up to 12,000 fish were recorded in the early 1940s. Since 1953, fall-run chinook salmon run size has varied considerably, with peak salmon abundance generally corresponding to similar peaks in the Stanislaus, Tuolumne, and Merced rivers. Annual spawning escapement fluctuated between 100 fish in 1961 and 7,000 fish in 1958 and averaged about 1,900 fish (Figure 2-VI-18). Mokelumne River Fish Hatchery was constructed in 1964 as mitigation for loss of spawning habitat between Camanche and Pardee Dam. The hatchery has received an average of about 500 chinook salmon adults between 1967 and 1991.

Between 1953 and 1966, annual fall-run chinook salmon spawning escapement in the Cosumnes River ranged from zero in 1961 to 5,000 fish in 1954 and averaged 2,500 fish (Figure 2-VI-18).

A small population of fall-run chinook salmon may have been present in the Calaveras River before the construction of New Hogan Dam in 1963 (White pers. comm.). Historically, chinook salmon production in the Calaveras River was limited by low, intermittent flows during summer and fall.

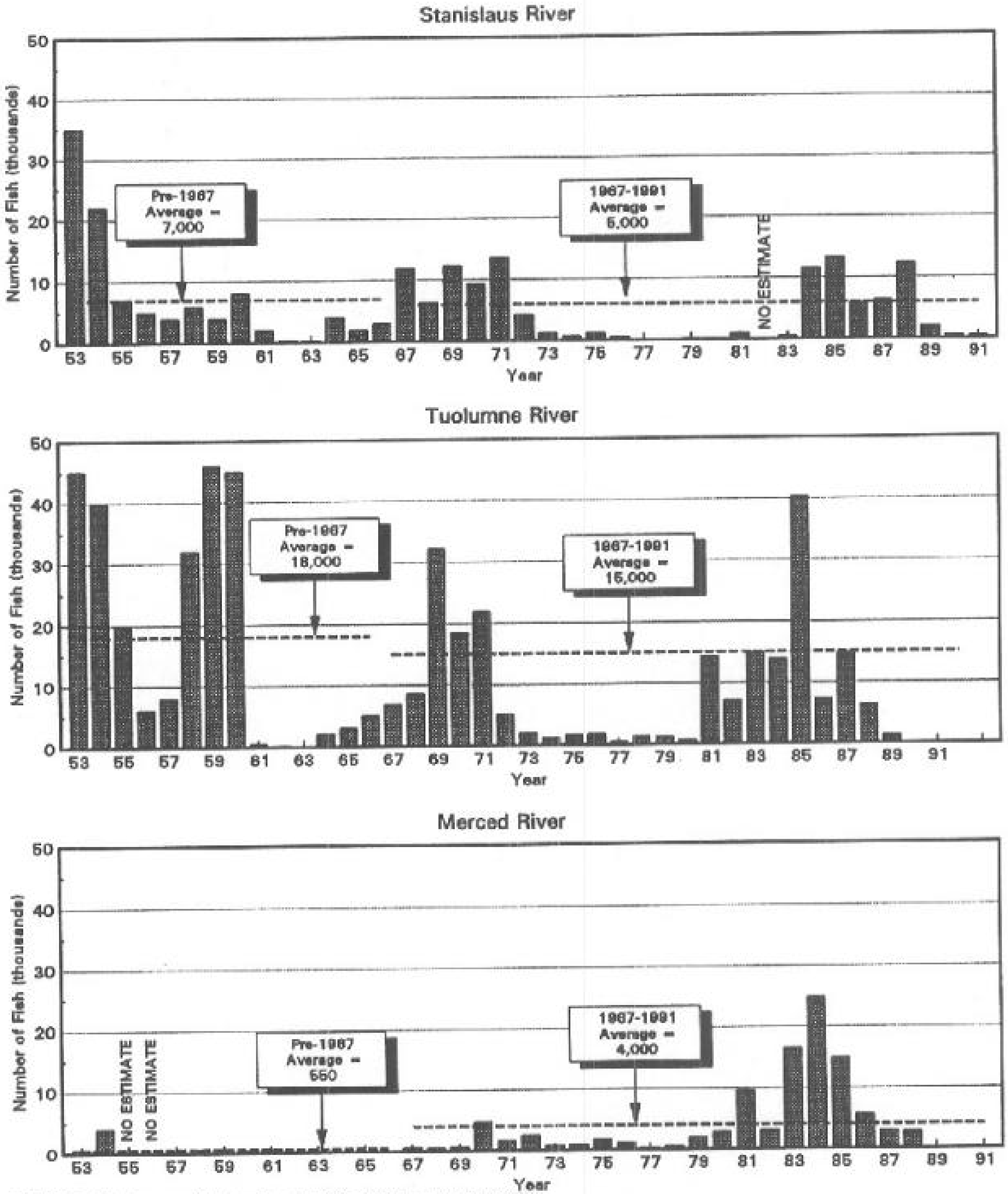
San Joaquin River - Early impacts on chinook salmon in the San Joaquin basin were caused by gold mining activities, agricultural and power diversions, and overfishing (Clark 1929). The most abundant salmon race, spring-run chinook salmon, was completely eliminated after 1947 above the Merced River confluence following construction of Friant Dam, which blocked access to historical holding and spawning habitat and severely reduced flows in the San Joaquin River below the dam (DFG 1987b). Fall-run chinook also have been extirpated in the San Joaquin River from Friant Dam downstream to the confluence with the Merced River due to insufficient flow releases from Friant Dam.



SOURCES: U.S. Bureau of Reclamation (1986b) and Mills and Fisher (1993).

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE MOKELUMNE AND COSUMNES RIVERS (1953-1991)

FIGURE 2-VI-18



SOURCES: U.S. Bureau of Reclamation (1986b) and Mills and Fisher (1993).

ANNUAL ESTIMATES OF FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE STANISLAUS, TUOLUMNE, AND MERCED RIVERS

FIGURE 2-VI-19

San Joaquin River tributaries - Annual spawning escapement estimates of fall-run chinook salmon in the San Joaquin River basin have been made since 1940, but early estimates are often incomplete and based on subjective methods (USBR 1986b).

Fall-run chinook salmon have undergone major reductions since the 1940s but have persisted as small but fluctuating populations below major dams on the Merced, Tuolumne, and Stanislaus rivers. Low returns of fall-run salmon to all three tributaries in 1961 were attributed to a fall migration barrier caused by low San Joaquin River flows, flow reversals, and low dissolved oxygen levels in the lower San Joaquin River and south Delta channels (Figure 2-VI-19). Nearly complete run failures in 1962 and 1963 appeared to be related to low spring flows in 1959, 1960, and 1961 rather than fall migration conditions (Hallock et al. 1970).

Spring-run chinook salmon on the Stanislaus, Tuolumne, and Merced rivers were probably eliminated by 1930 as a result of dam construction.

Steelhead

Unlike chinook salmon, there are few specific data regarding historical steelhead abundance. There has never been a commercial fishery for steelhead, and quantitative estimates of population abundance were not developed until the 1950s (and later than that in most streams).

Sacramento River - Historically, steelhead spawned and reared in the most upstream portions of the upper Sacramento River and most, if not all, of its perennial tributaries. Because they have greater swimming and leaping abilities than chinook salmon, steelhead could migrate farther into headwater streams where water temperatures were generally cooler. Hanson et al. (1940) estimates that 187 miles of accessible rivers and streams were blocked to chinook salmon by Keswick and Shasta Dams alone; even more miles would have been blocked for steelhead. Dams and diversions for water supply, flood control, and sediment control were located on each of the major tributaries and blocked steelhead migrations to preferred spawning and rearing habitats.

Annual estimates of total (natural spawning and hatchery returns) Sacramento River steelhead runs upstream of both the American and Feather rivers at the Fremont Weir ranged from 14,340 to 28,400 from 1953-1959, and averaged 20,500 (Skinner 1962). The average estimated natural spawning portion of these runs was 88.6%.

Sacramento River tributaries - Historically, steelhead runs were sustained in all tributaries with adequate flow and habitat qualities, although no firm estimates of steelhead abundance exist. Counts conducted before 1967 enumerated populations in excess of 1,000 steelhead in both Mill and Deer creeks (Mills and Fisher 1993). Average estimates for the 1950s and 1960s were approximately 300 steelhead in Antelope Creek and 150 steelhead in Big Chico Creek. These general estimates, however, were developed after water diversions, barriers, and habitat degradation had occurred on most sections of these streams; steelhead runs were likely much larger in these streams before the 1900s.

No definitive population estimates exist for steelhead in the American River historically. The steelhead run is estimated to have exceeded 100,000 fish annually before the completion of Folsom and Nimbus Dams in 1955, but before 1970, steelhead runs were estimated to average about 5,000 fish (Reynolds et al. 1993).

Feather and Yuba Rivers - No definitive population estimates exist for steelhead in the Feather or Yuba rivers. It is likely that both river systems supported large steelhead runs in the 1800s. Hydraulic mining and diversion and storage dams on both rivers significantly reduced steelhead populations. For example, from 1910 to 1949 there was complete or nearly complete blockage of upstream migration at Daguerre Point Dam, located on the Yuba River only 12 miles from its mouth (Dunn et al. 1992).

Steelhead populations of the Feather River before construction of Oroville Dam were estimated to average about 1,000 fish above the dam site (Reynolds et al. 1990). Wooster and Wickwire (1970) estimated that about 200 steelhead spawned annually in the Yuba River before 1970.

Eastside tributaries - Steelhead historically had sustained annual runs up the Mokelumne River. No information exists on the size of these runs.

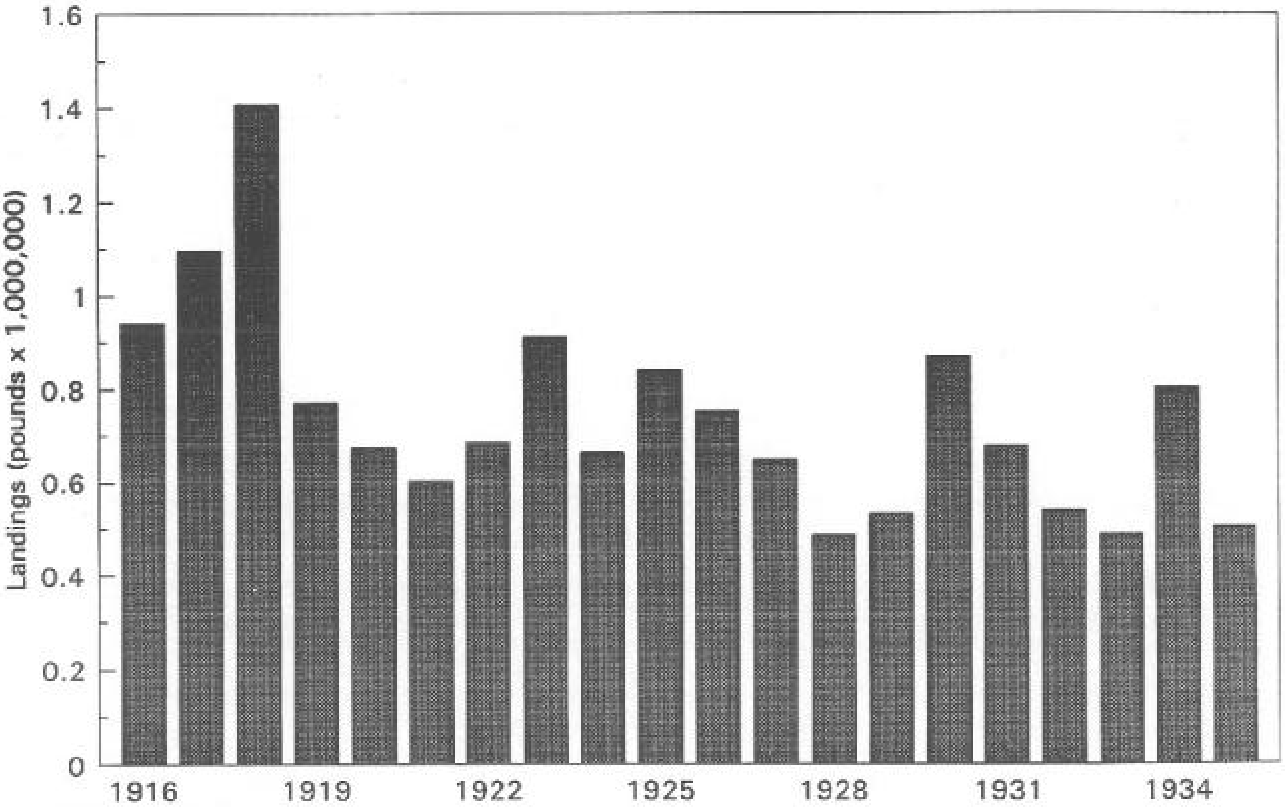
San Joaquin River - Presumably, steelhead had access upstream of the present location of Friant Dam on the mainstem San Joaquin River. No information exists on the size of these runs.

San Joaquin River tributaries - Steelhead historically had sustained annual runs up the San Joaquin, Mokelumne, Stanislaus, Tuolumne, and Merced rivers. Steelhead runs would also have occurred in any other smaller tributaries having accessible headwaters, cool water temperatures, and appropriately sized gravels. Water development facilities and operations and other forms of habitat loss and degradation substantially reduced steelhead resources to remnant levels.

Striped Bass

Striped bass are native to the east coast of the United States. Juvenile striped bass were taken from rivers in New Jersey and introduced to California waters; approximately 130 juvenile fish were released in Carquinez Strait in 1879, and another 300 fish were released in Suisun Bay in 1882 (California Bureau of Marine Fisheries 1949, Skinner 1962). Successful reproduction was observed before 1882, and the population quickly multiplied to several million adult bass.

A few of the fish planted in 1879 were reportedly caught in 1880, and striped bass weighing more than 16 pounds were caught in 1883 and 1884 (California Bureau of Marine Fisheries 1949, Skinner 1962). By 1888, striped bass supported a significant fishery in San Francisco Bay and several thousand fish were



Source: U. S. Bureau of Marine Fisheries (1949).

COMMERCIAL LANDINGS OF STRIPED BASS (1916-1935)

FIGURE 2-VI-20

available in local fish markets. A minimum size limit of 8 pounds, the first fishing regulation for striped bass in California, was enacted in 1890. State regulations set a minimum size limit of 3 pounds in 1897.

The 1899 commercial catch was reported as 1,234,000 pounds (Skinner 1962), and commercial landings in 1916-1935 ranged from 0.5 million to 1.5 million pounds (Figure 2-VI-20). Sport fishing for striped bass became increasingly popular after 1895, leading to more restrictive commercial fishing regulations. Commercial fishing for striped bass with nets was prohibited in 1931, and all commercial striped bass fishing was prohibited after 1935.

From 1936 on, the striped bass fishery was reserved exclusively for sport anglers. Annual striped bass landings by the sport fishery were reported to be much larger than commercial striped bass landings ever were (California Bureau of Marine Fisheries 1949). By 1955, more than 200,000 anglers participated in the fishery, catching more than 1 million striped bass annually with an aggregate weight of approximately 4 million pounds (Skinner 1962).

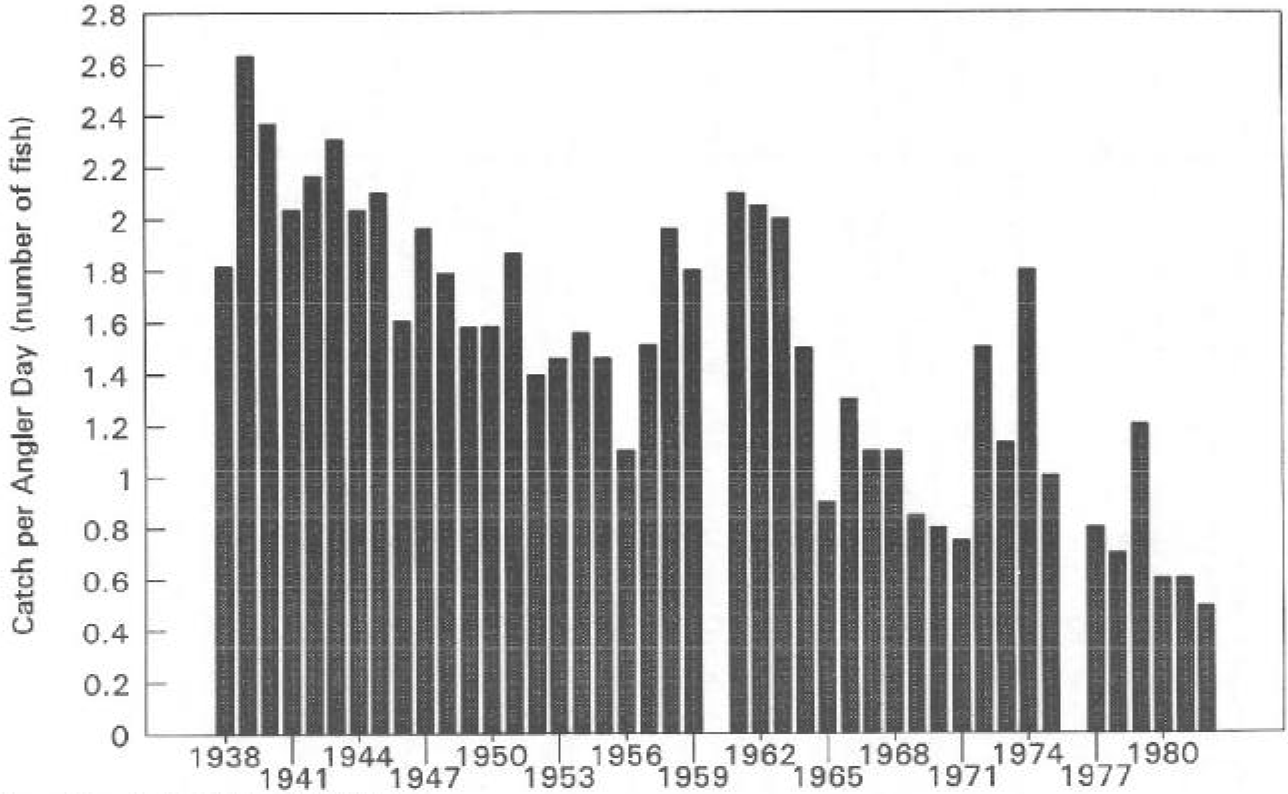
Analysis of sport catch records and other data showed a decline in the fishery after 1944 and a severely depleted adult striped bass population by 1970 (Skinner 1962, DFG 1989). Data from the sport fishery and mark-recapture studies indicate that the population declined from approximately 3 million bass in the early 1960s to a population level of approximately 1.7 million by the late 1960s.

Charter boat records provide the best information on the striped bass fishery from 1938 to 1982. The catch per angler-day was greatest during the early years of the charter boat fishery and decreased over time (Figure 2-VI-21). The reduction in the catch per angler-day may indicate decreasing striped bass population abundance; however, changes in fishing regulations and sport-fishing efforts affect statistics on catch per angler-day.

Factors contributing to increased mortality before 1967 include fishing, entrainment in diversions, exposure to toxic materials, and habitat loss. Sport fishing annually removed 20-30% of the striped bass population longer than 16 inches.

Incidental catch in net fisheries targeting other species may have caused annual mortality approaching 50,000 adult striped bass before the net fisheries were prohibited in 1957. Entrainment in the Contra Costa Steam Plant (Pacific Gas and Electric Company [PG&E]) and the Tracy Pumping Plant diversions may have reduced the juvenile striped bass population by more than 20% each year. Salvage operations at both facilities greatly reduced the number of fish destroyed, but losses continued to occur after 1957.

In the Napa River and San Francisco Bay, anecdotal information indicates pollution by tannery, chemical company, and garage discharges may have resulted in substantial mortality of striped bass as early as 1924.



Sources: Skinner (1982), State Water Contractors (1987).

CATCH OF STRIPED BASS PER ANGLER DAY FOR CHARTER BOATS (1938-1982)

FIGURE 2-VI-21

Between 1860 and 1959, nearly half of the estimated 570 square miles of marsh and tidal habitat were filled and leveed off (DFG 1989). Sloughs that formerly afforded good fishing and habitat were no longer accessible to striped bass. Diking and filling not only restricted striped bass habitat, but also reduced tidal mixing (i.e., potential for reduced dilution of toxic materials) and overall estuary productivity.

American Shad

American shad are native to the east coast of the United States. Juvenile shad were transported from New York and introduced into California in 1871, when approximately 10,000 juveniles were released in the Sacramento River near Tehama (Painter et al. 1980). An additional 824,000 juvenile shad were introduced into California from 1873 to 1881 (Skinner 1962). The shad quickly multiplied and by 1880 were found as far north as the Columbia River in Washington (Fry 1973). A commercial fishery for shad developed by 1879, and by 1886, the State Board of Fish Commissioners estimated that 1 million mature fish were taken (Skinner 1962).

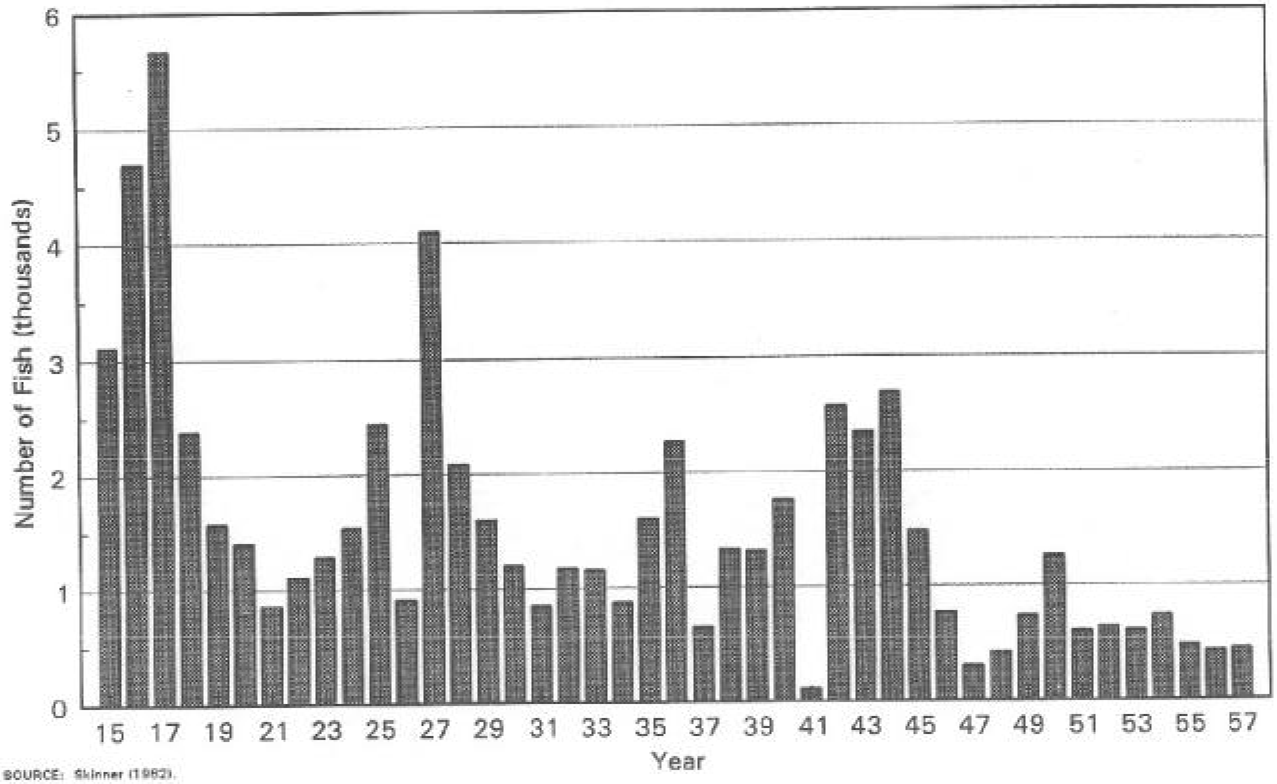
Before 1899, the commercial catch never exceeded 1 million pounds. From 1899 to 1914, commercial catch data are limited but indicate that commercial landings ranged from 620,891 to 1,169,000 pounds (Skinner 1962). Commercial landings from 1915 to 1945 ranged from approximately 0.1 to 5.5 million pounds; however, commercial landings below 1 million pounds were rare. After 1945, commercial shad landings exceeded 1 million pounds only once (Figure 2-VI-22). The commercial gill net fishery in the Sacramento-San Joaquin River estuary was eliminated through legislation in 1957 (Skinner 1962).

It is unknown when sport fishing for shad first occurred, although some angling was reported in the 1930s and 1940s (Painter et al. 1980). After 1950, sport fishing for shad became extremely popular. One popular method of taking shad, called "bumping", was conducted from boats using hand-held nets. Anecdotal information indicates that 2,500 anglers operating out of a single recreational fishing business caught 30,000 shad in 1954 using this method (Skinner 1962). No reliable sport catch records are available to determine the relative proportion of the fishery caught by sport anglers; however, by the mid-1960s, an estimated 100,000 angler days per year were spent sport fishing for shad (Painter et al. 1980).

Analyzing commercial and sport catch data to determine shad abundance is difficult because commercial landings were more influenced by market, economic, and angling factors than by shad abundance (California Bureau of Marine Fisheries 1949). Therefore, commercial catch data do not provide an accurate measure of shad abundance during this period.

White Sturgeon

Little information is available concerning white sturgeon abundance in the Sacramento-San Joaquin system prior to 1967. Skinner (1962) summarized U.S. Commissioner of Fisheries annual reports to provide commercial catch statistics (by weight) for many years prior to 1918. With substantial assumptions, these



SOURCE: Skinner (1982).

COMMERCIAL LANDINGS OF AMERICAN SHAD (1915-1957)

FIGURE 2-VI-22

can be used to construct likely population parameters during the late 1800s for comparison with present population characteristics. These assumptions include:

1) The initial (1875) mean weight of harvested fish was 120 lbs, based on the Report of the Commissioners of Fisheries of the State of California for the Years 1878 and 1879 that indicated a mean weight of harvested sturgeon of 75 and 86 lbs, respectively, in these 2 years. It was further assumed that mean weight decreased to 50 lbs in 1891 and to 25 lbs by 1899 as large, old fish were removed by the fishery.

2) Initial abundance was 220,000 fish $\geq$ 40 inches total length, which corresponds to potential abundance with no fishing mortality projected by an age-structured model of the population developed to evaluate alternative angling regulations (Kohlhorst 1993). Postulating alternative initial abundances when formulating this assumption indicated that values less than 216,000 led to extinction.

3) The white sturgeon population exhibited no compensation in terms of increased growth rate, increased fecundity, or increased natural survival in response to elevated exploitation rate.

With these assumptions, it can be postulated that white sturgeon abundance decreased from 220,000 fish $\geq$40 inches in 1875 to only 5,200 fish in 1901 (Table 2-VI-2), when the commercial fishery was closed by the Legislature. During this time, exploitation rate increased irregularly from <1% to about 47% in 1899. Harvest in numbers of fish reached a peak of 23,700 in 1887.

The commercial sturgeon fishery was reopened in 1916, but only about 500 fish were caught that year and about 300 were caught in 1917. Because the population had not rebounded, both commercial and sport fishing were prohibited starting in 1917.

When a sportfishing-only season was initiated in 1954, the first tagging program to estimate abundance, harvest rate, age composition, and growth was undertaken. This research provided not only the first direct abundance estimate (11,200 fish $\geq$ 40 inches TL), but evidence from the age composition of the tagging catch that any recovery of the population up to that time was largely due to the extremely strong 1938 year class (Pycha 1956).

White sturgeon occur in rivers and estuaries along the west coast of North America, primarily the Fraser, Columbia, Sacramento, and San Joaquin rivers, but their distribution in the Sacramento-San Joaquin system before 1967 is even less well described than abundance. The earliest mention of sturgeon occurrence in the Sacramento River dates from October 1837, when large sturgeon-like fish were observed jumping in the vicinity of the mouth of the Feather River (Belcher 1843); it is unknown whether these were white or green sturgeon. In the early 1900s, large white sturgeon were occasionally caught during late summer in the Feather River from Biggs to Oroville (Anonymous 1918; Anonymous 1959).

DFG Region 1 files provide some information about white sturgeon distribution in the upper Sacramento River drainage before and after construction of Shasta Dam (T. P. Healey, California Department of Fish and Game, personal communication). Sturgeon probably inhabited the entire Pit River up to Pit River Falls prior to construction of Britton Dam by PG&E in 1925. A substantial number of white sturgeon were trapped in and above Lake Shasta when Shasta Dam was closed in 1944. These fish and their progeny primarily used the Pit River arm of the lake. Successful reproduction apparently continued until the early 1960s, when construction of additional hydropower dams on the Pit River just above Lake Shasta eliminated the last of the sturgeon spawning habitat.

Other information about historical sturgeon distribution is provided by Skinner (1962), who states that "white sturgeon appear to make a general migration out of the Bay into upstream waters in the spring but data are lacking to support this point". He also reports sturgeon in the San Joaquin River at the face of Mendota Dam in 1947. He indicates that 5- to 6-inch sturgeon were found at water diversion sites in the Delta and that 18- to 30-inch fish were common in the Delta and Bay Area.

Table 2-VI-2. Estimates of potential historical white sturgeon population parameters from catch statistics in Skinner (1962) and mean weights interpolated from weights for 1878 and 1879 in the Report of the Commissioners of Fisheries of the State of California for the Years 1878 and 1879.

Year	Catch (lbs)	Mean weight (lbs)	Catch (number)	Harvest rate	Abundance	Recruits
1875	118,350	120	986	0.004	220,000	22,000
1876	274,375	110	2,494	0.011	219,014	21,901
1877	295,650	90	3,285	0.015	216,519	21,652
1878	334,500	75	4,460	0.021	213,234	21,323
1879	607,800	86	7,067	0.034	208,774	20,877
1880			5,353	0.027	201,707	20,171
1881	291,050	80	3,638	0.019	196,354	19,635
1882	251,700	75	3,356	0.017	192,716	19,272
1883	125,850	75	1,678	0.009	189,360	18,936
1884			7,180	0.038	187,682	18,768
1885			12,682	0.070	180,502	18,050
1886			18,184	0.108	167,820	16,782
1887	1,658,000	70	23,686	0.158	149,637	14,964
1888	460,000	60	7,667	0.061	125,951	12,595

Year	Catch (lbs)	Mean weight (lbs)	Catch (number)	Harvest rate	Abundance	Recruits
1889	495,000	55	9,000	0.076	118,284	11,828
1890	587,625	55	10,684	0.098	109,284	10,928
1891	715,795	50	14,316	0.145	98,600	9,860
1892	765,297	45	17,007	0.202	84,284	8,428
1893			13,835	0.206	67,278	6,728
1894			10,664	0.200	53,442	5,344
1895	299,729	40	7,493	0.175	42,778	4,278
1896	175,675	35	5,019	0.142	35,284	3,528
1897	190,445	30	6,348	0.210	30,265	3,027
1898			6,500	0.272	23,917	2,392
1899	205,659	25	8,226	0.472	17,417	1,742
1900			4,000	0.435	9,191	919
1901					5,191	519
1902					5,191	519
1903					5,191	519
1904					5,191	519
1905					5,191	519
1906					5,191	519
1907					5,191	519
1908					5,191	519
1909					5,191	519
1910					5,191	519
1911					5,191	519
1912					5,191	519
1913					5,191	519
1914					5,191	519
1915					5,191	519
1916	15,178	30	506	0.097	5,191	519
1917	9,822	30	327	0.070	4,685	468

Note: It is assumed that a natural mortality rate of 0.10 was exactly balanced by recruitment and that the population showed no compensatory response to higher mortality and reduced abundance.

Green Sturgeon

Information on the distribution and abundance on green sturgeon before 1967 is extremely limited.

ABUNDANCE AND DISTRIBUTION (1967-1991)

Chinook Salmon

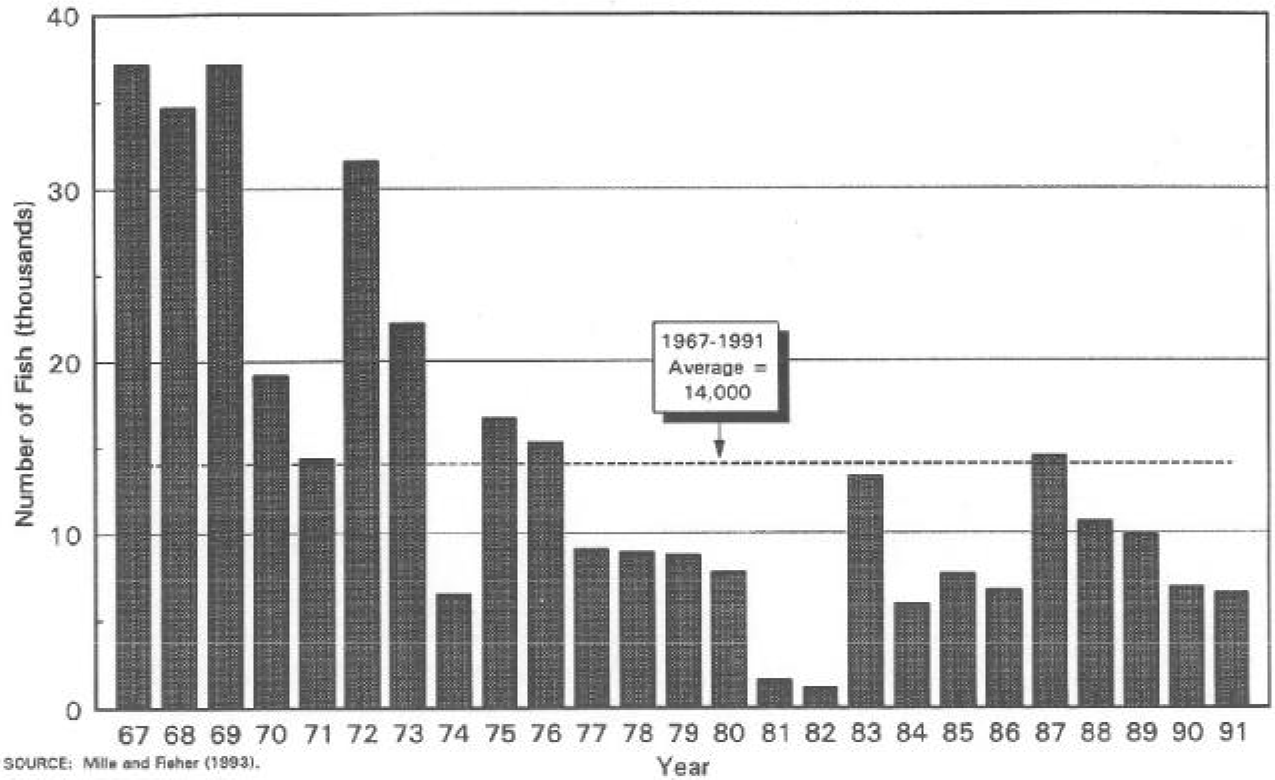
Sacramento River -

Fall-run chinook salmon - The overall decline in mainstem Sacramento River fall-run chinook salmon abundance during the 1950s and 1960s was followed by low but relatively stable population levels during the 1970s and 1980s. A decline during the recent drought, however, led to a record low spawning escapement of about 29,000 adults in 1991. Average annual spawning escapement of fall-run chinook salmon in the Sacramento River during 1967-1991 was approximately 77,000 fish (Figure 2-VI-14).

Late fall-run chinook salmon - Counts of chinook salmon passing the RBDD since 1967 provide the most reasonable indication of overall trends in late fall-, winter, and spring-run chinook salmon abundance in the upper Sacramento River. The number of late fall-run chinook salmon passing the RBDD declined from an average 35,000 adults in the late 1960s to an average of 7,000 adults in recent years (Figure 2-VI-23). Hatchery returns to CNFH during this period have fluctuated between 200 and 3,000 fish, with record low returns in 1990 and 1991 (Figure 2-VI-24).

Winter-run chinook salmon - Winter-run chinook salmon suffered a precipitous decline from an average of approximately 80,000 adults in the late 1960s to estimated run sizes of 547, 441, and 191 in 1989, 1990, and 1991, respectively (Figure 2-VI-25). Estimated run sizes in 1992 and 1993 were 1,180 and 341, respectively. Factors contributing to this decline include water temperature impacts associated with operation of Shasta and Keswick Reservoirs, adult and juvenile passage problems at the RBDD, modification and loss of spawning and rearing habitat, predation, pollution, and entrainment in water diversions on the Sacramento River and in the Delta. The recent drought in California (1987-1992) exacerbated these impacts. (National Marine Fisheries Service [NMFS] 1992.)

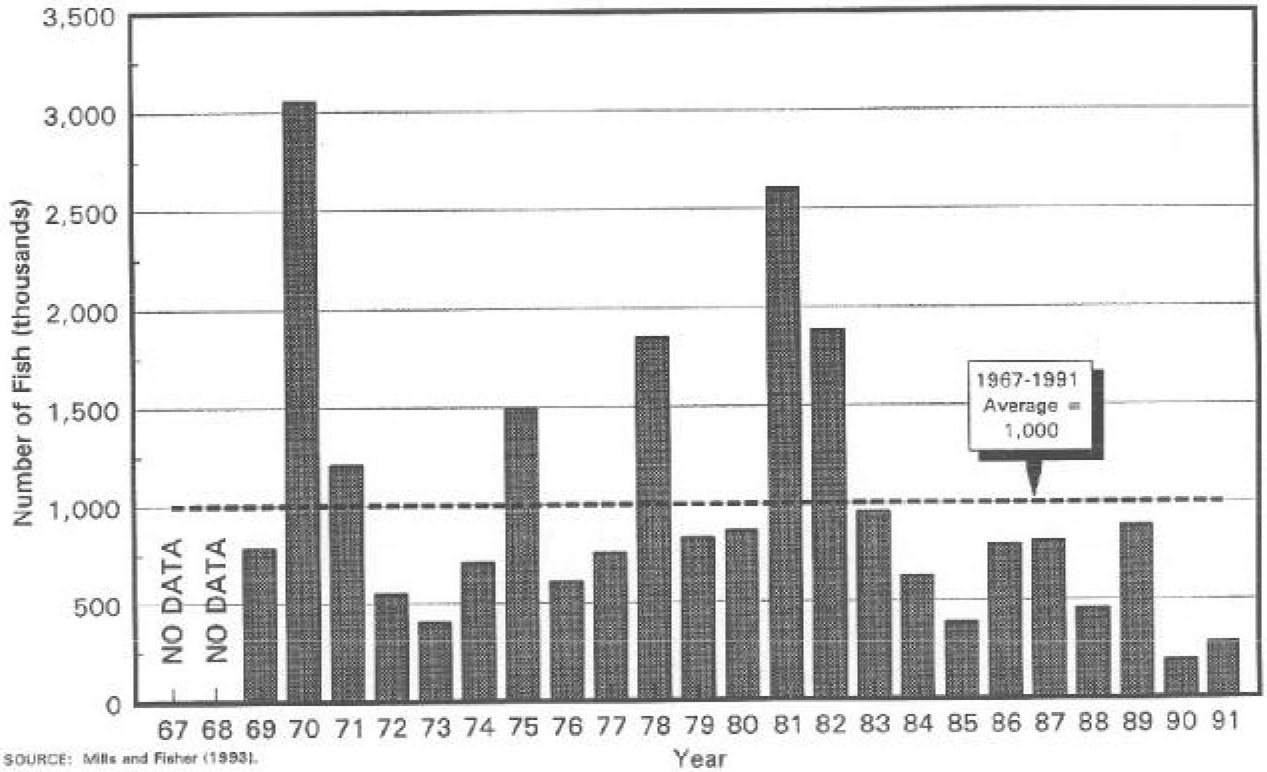
The return of an estimated 550 adults in 1989 prompted listing of the winter-run chinook salmon as an endangered species by the State of California and as a threatened species by the federal government. Another record low spawning escapement of 191 fish in 1991 prompted review and subsequent reclassification of the winter-run chinook salmon to endangered status under the federal Endangered Species Act (NMFS 1992).



SOURCE: Mills and Fisher (1993).

ANNUAL ESTIMATES OF LATE FALL-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE MAINSTEM SACRAMENTO RIVER (1967-1991)

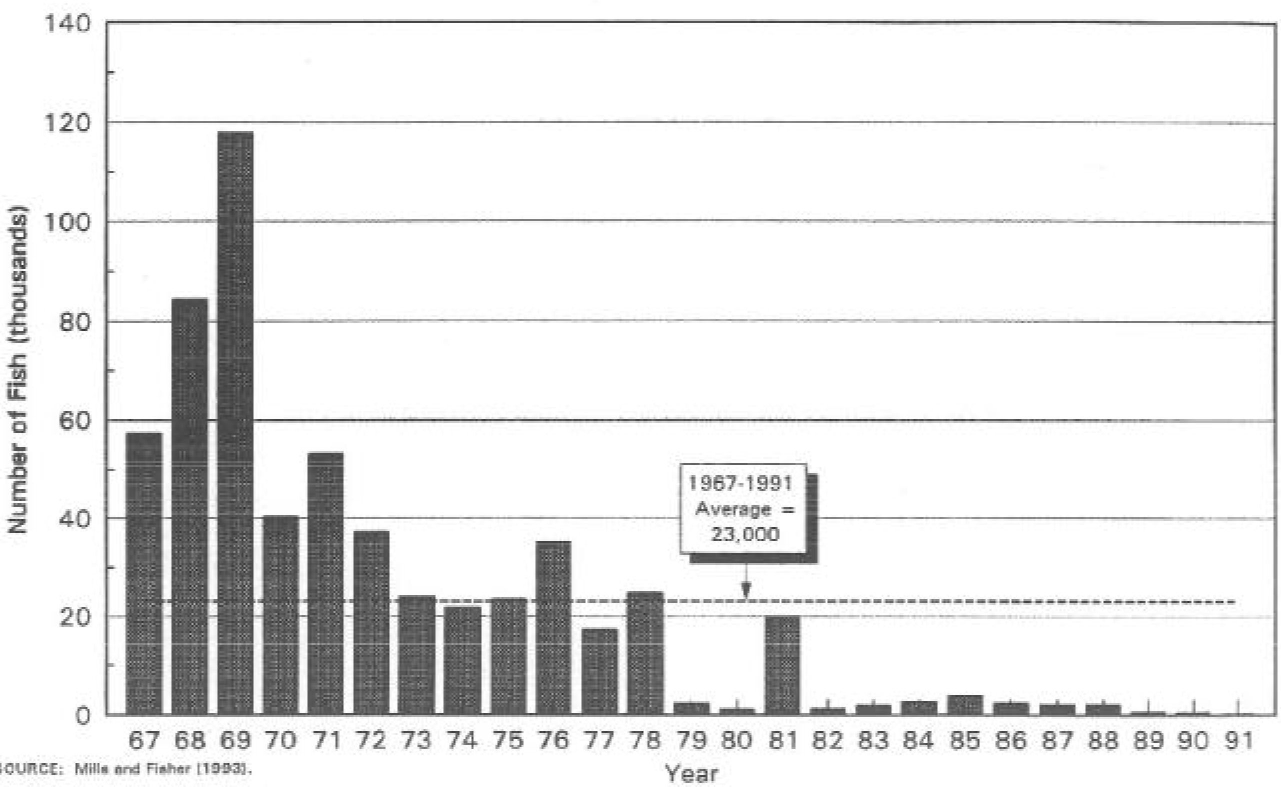
FIGURE 2-VI-23



SOURCE: Mills and Fisher (1993).

ANNUAL RETURNS OF LATE FALL-RUN CHINOOK SALMON TO COLEMAN NATIONAL FISH HATCHERY (1967-1991)

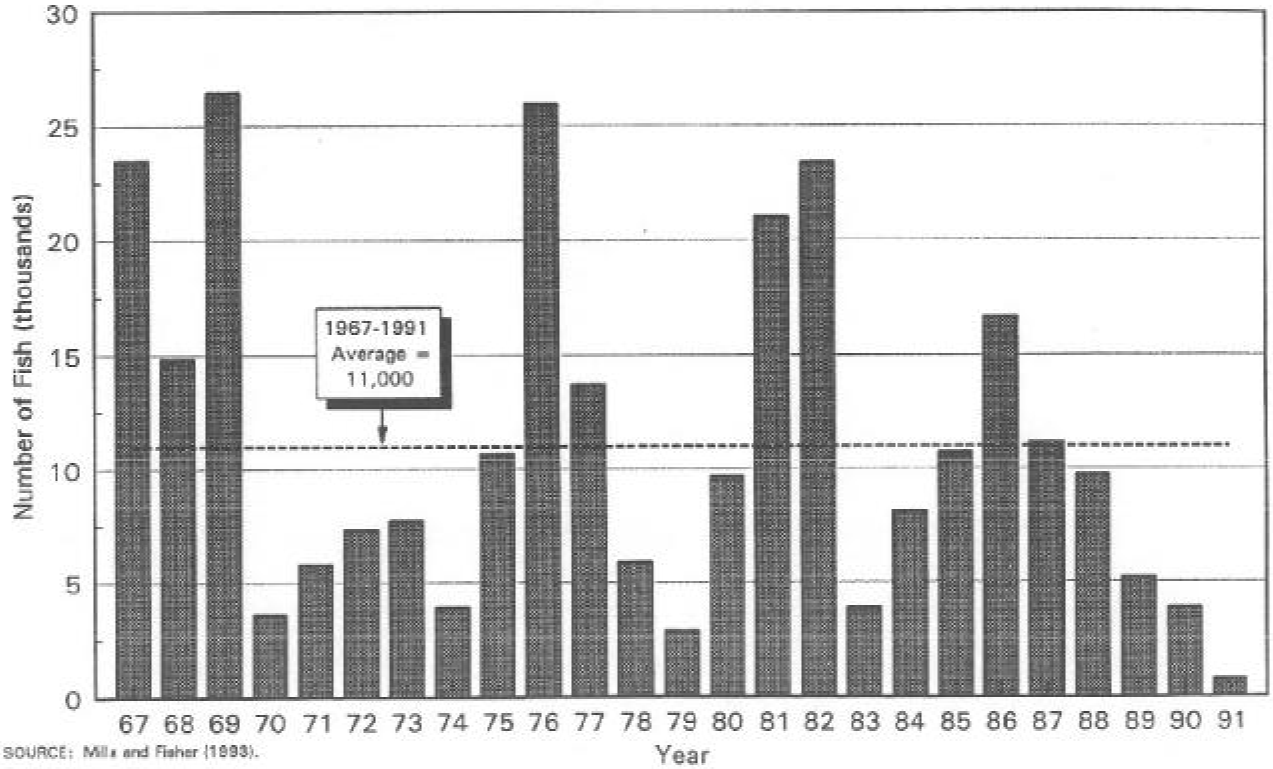
FIGURE 2-VI-24



SOURCE: Mills and Fisher (1993).

ANNUAL ESTIMATES OF WINTER-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE MAINSTEM SACRAMENTO RIVER (1967-1991)

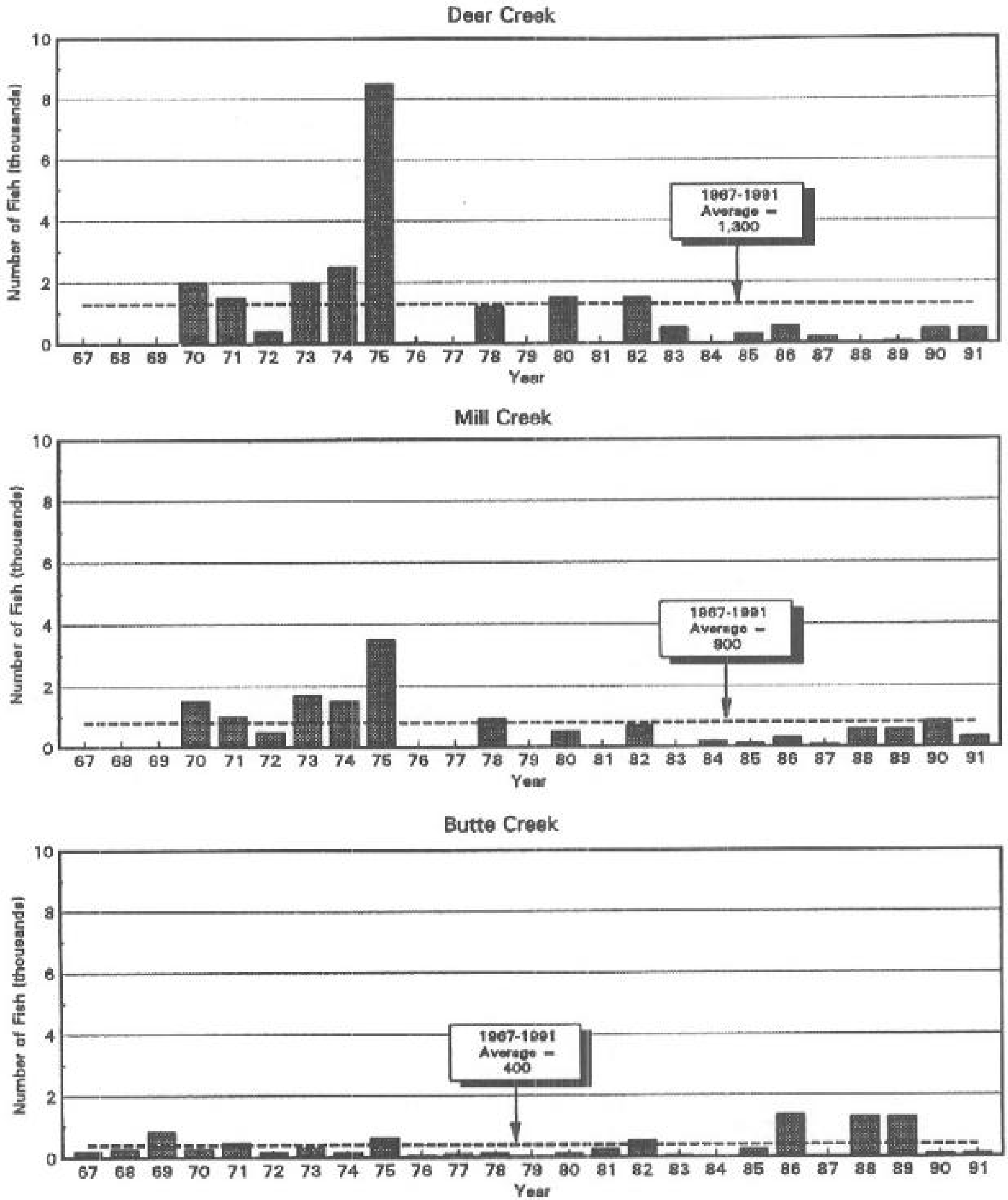
FIGURE 2-VI-25



SOURCE: Mills and Fisher (1993).

ANNUAL ESTIMATES OF SPRING-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN THE MAINSTEM SACRAMENTO RIVER (1967-1991)

FIGURE 2-VI-26



SOURCE: Mills and Fisher (1993).

ANNUAL ESTIMATES OF SPRING-RUN CHINOOK SALMON SPAWNING ESCAPEMENT IN DEER, MILL, AND BUTTE CREEKS (1967-1991)

FIGURE 2-VI-27

Spring-run chinook salmon - The number of adults passing the RBDD has fluctuated between highs of more than 25,000 fish to a record low of 773 fish in 1991 (Figure 2-VI-26). An average of approximately 11,000 fish migrated past the dam between 1967 and 1991.

Sacramento River tributaries - Estimates of fall-run chinook salmon spawning escapement in minor Sacramento River tributaries (excluding Battle Creek) are incomplete for the 1967-1991 period. No trends in run size are apparent for Clear Creek, Cow Creek, Cottonwood Creek, Paynes Creek, Antelope Creek, Mill Creek, Deer Creek, and Butte Creek, although record low escapements occurred in most of these creeks in recent years (Figure 2-VI-15). Annual spawning escapement in Battle Creek during 1967-1991 averaged approximately 18,000 adults; on the average, approximately 8,000 adults spawned in Battle Creek while 10,000 were spawned in CNFH (Figure 2-VI-16). Increases in production capacity and improved water quality, temperature, and disease control techniques at CNFH resulted in record run sizes in recent years (USBR 1985).

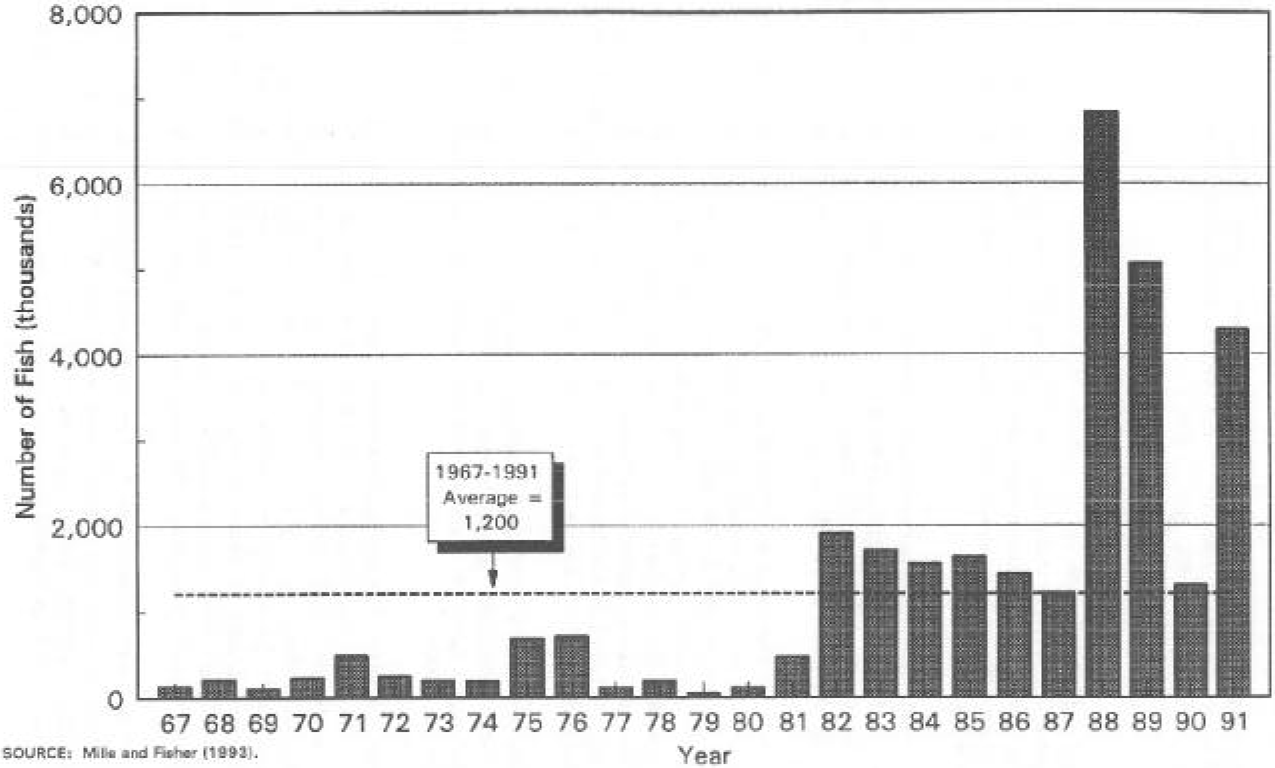
The 1967-1991 average spawning escapement of spring-run chinook salmon in Deer and Mill creeks was 1,300 and 800 adults, respectively (Figure 2-VI-27). Run sizes have declined by 85% in Mill Creek and 80% in Deer Creek since 1967. A small run averaging approximately 400 fish spawns in Butte Creek (Figure 2-VI-27). This run has been supported by natural reproduction and plants of chinook salmon smolts from Feather River Hatchery.

Fall-run chinook salmon spawning escapement in the American River during 1967-1991 averaged 41,000 adults; on the average, 32,000 adults spawned in the river, while 9,000 were spawned in Nimbus Fish Hatchery (Figure 2-VI-17).

Feather River - Annual fall-run chinook salmon spawning escapement in the Feather River increased and became less variable following completion of Oroville Dam and Feather River Salmon and Steelhead Hatchery in 1968; average run size increased sharply in 1969 and remained relatively high through 1991. Annual spawning escapement of fall-run chinook salmon in the Feather River during 1967-1991 averaged approximately 47,000 adults; on the average, 41,000 adults spawned in the river, while 6,000 were spawned in the hatchery (Figure 2-VI-17). Annual spawning escapement in the Yuba River during 1967-1991 averaged approximately 13,000 adults with no apparent trend (Figure 2-VI-17).

Numbers of spring-run chinook salmon entering Feather River Hatchery increased from an average of approximately 300 adults from 1967-1981 to an average of approximately 2,000 adults from 1982-1991 (Figure 2-VI-28). Increased returns are associated with the recent practice of trucking and releasing large numbers of hatchery smolts in the lower Sacramento River and Delta. Annual hatchery returns are based on the assumption that all salmon entering the hatchery before October 1 are spring-run fish. Fish entering after that date are considered to be fall-run fish. Small numbers of spring-run chinook salmon migrate into the Yuba River, but these fish appear to be primarily strays originating from the Feather River Fish Hatchery.

Eastside tributaries - Since 1967, annual fall-run chinook salmon spawning escapement in the Mokelumne River has fluctuated between 250 and 11,000 fish and averaged about 2,600 fish (Figure 2-VI-18).



SOURCE: Mills and Fisher (1993).

ANNUAL RETURNS OF SPRING-RUN CHINOOK SALMON TO FEATHER RIVER SALMON AND STEELHEAD HATCHERY (1967-1991)

FIGURE 2-VI-28

Increased abundance during the 1980s has been attributed to increased smolt survival resulting from several high spring runoff years and increased production of juvenile salmon at Merced River Fish Facility. Annual run size declined steadily following a peak in 1982 and has remained low during the recent drought period (1987-1992).

Annual fall-run chinook salmon spawning escapement in the Cosumnes River since 1967 ranged from zero to 4,400 fish and averaged about 750 fish (Figure 2-VI-18). Since 1987, 3 years of no streamflow during the spawning season have precluded perpetuation of a natural run (Reynolds et al. 1990).

Operation of New Hogan Reservoir since 1963 resulted in sustained flows in the lower Calaveras River during summer and fall. Several hundred winter-run chinook salmon and smaller runs of fall-run chinook salmon and steelhead were thought to have entered the Calaveras River before the recent drought period. Since 1987, low flows and high water temperatures appear to have eliminated these runs (White pers. comm.).

San Joaquin River and tributaries - All successful chinook salmon spawning in the San Joaquin River basin takes place in three major tributaries. Recent spawning escapement levels of fall-run chinook salmon in the Merced, Tuolumne, and Stanislaus rivers show considerable annual variability, with peak abundance generally following high spring runoff years (Figure 2-VI-19). Conversely, small spawning escapements generally occur following below-normal or dry runoff years. Very low spawning escapements since 1990 are related to recent drought conditions (1987-1992).

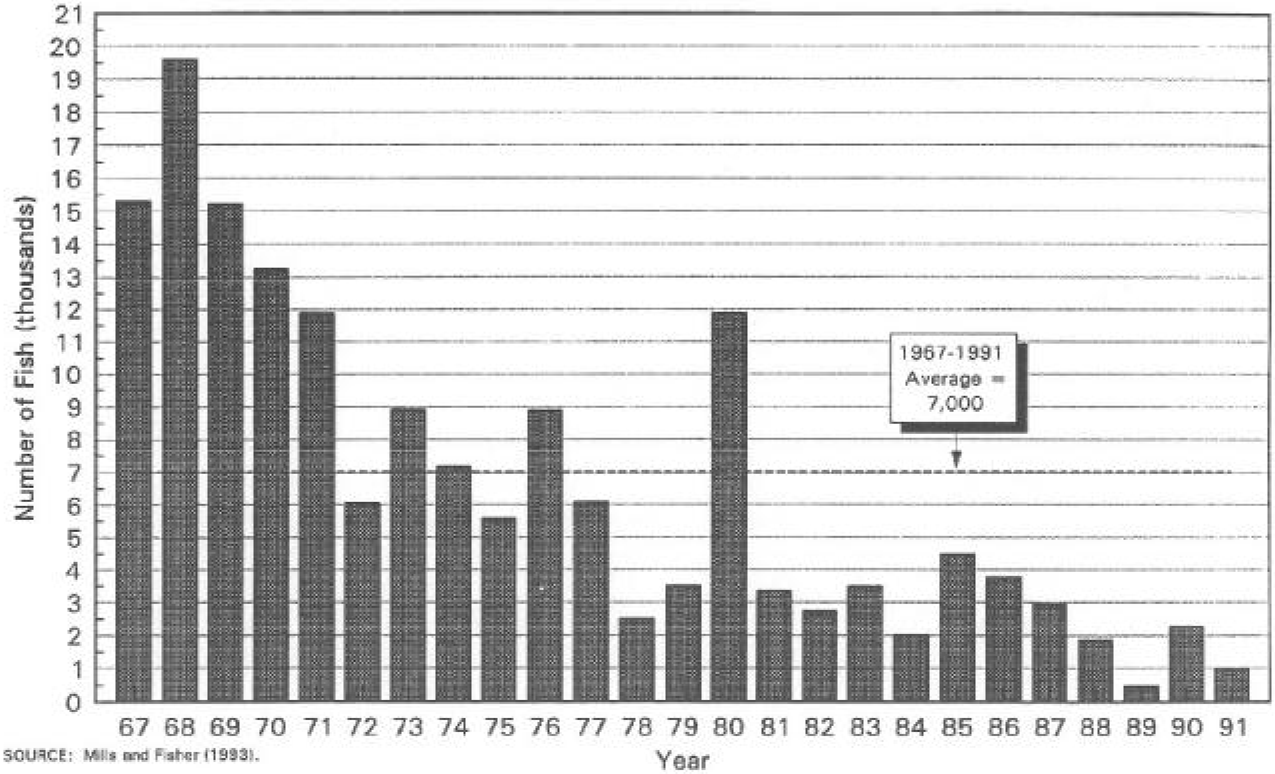
The Merced River run has been partially sustained by production of yearling fall-run chinook salmon at the Merced River Fish Facility since 1972. The hatchery contribution to San Joaquin River chinook salmon stocks is less than 5%. (DFG 1987b.)

Steelhead

Throughout the Central Valley, a 95% reduction (6,000-300 miles) of river available to anadromous fish (Reynolds et al. 1993) affects steelhead the most because of its migratory prowess. Although in some cases dams created favorable temperature conditions downstream, the physical habitat in the lower portions of these streams is not as conducive to steelhead spawning and rearing as are stream reaches higher in the watersheds.

The average annual total steelhead run in the Sacramento River system was estimated by DFG in 1990 to be about 35,000 fish, primarily hatchery-produced fish from CNFH, Feather River Fish Hatchery, and Nimbus Fish Hatchery. More than 90% of the annual steelhead run in the Central Valley is the result of hatchery-raised fish stocked as smolts or fingerlings (Reynolds et al. 1990).

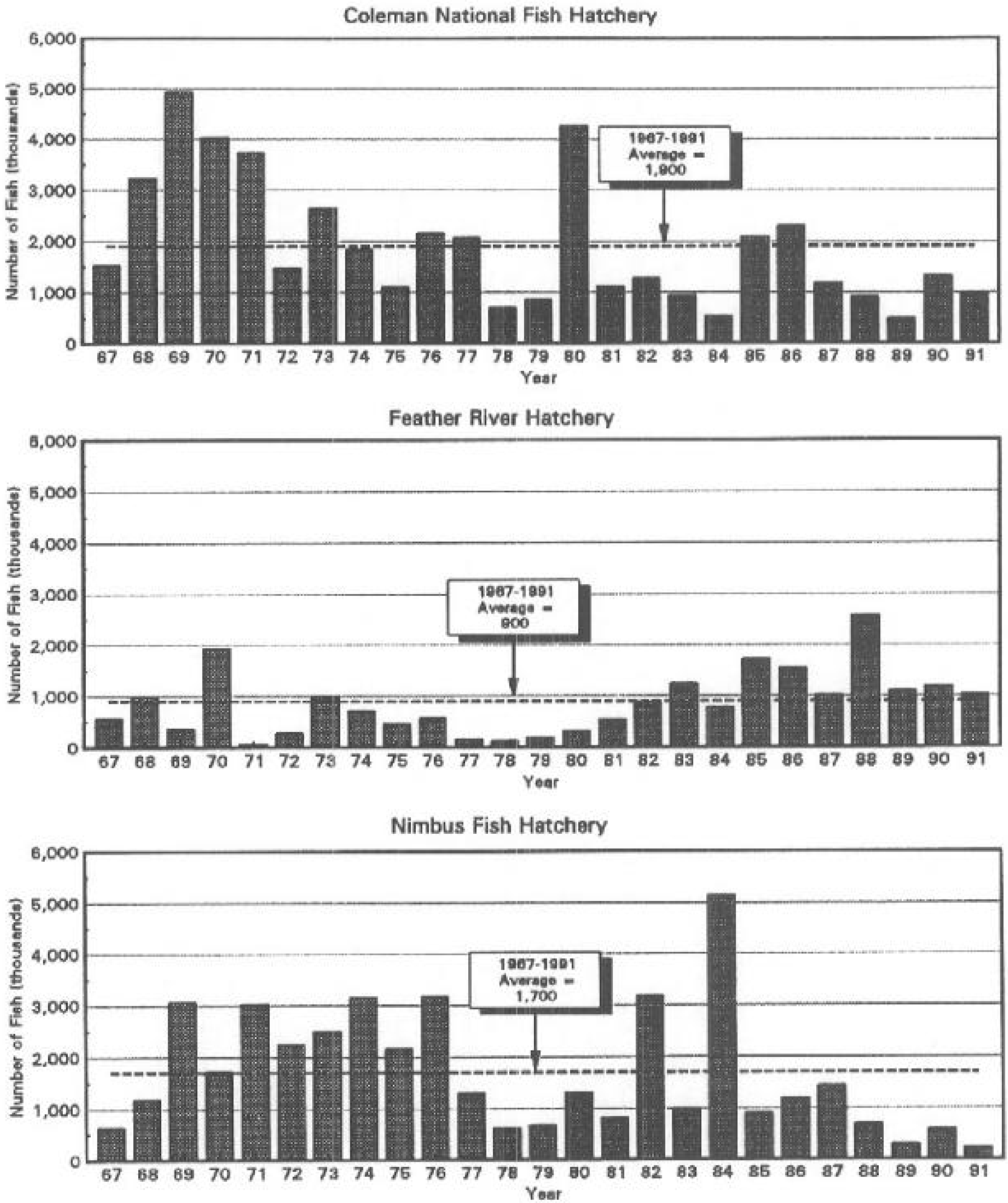
Sacramento River - Following completion of RBDD in 1967, steelhead runs could be counted at that location, although the counts underestimate the total natural spawning run in the drainage because an



SOURCE: Mills and Fisher (1993).

ANNUAL ESTIMATES OF ADULT STEELHEAD TROUT ABUNDANCE IN THE UPPER SACRAMENTO RIVER (1967-1991)

FIGURE 2-VI-29



SOURCE: Mills and Fisher (1993)

ANNUAL RETURNS OF ADULT STEELHEAD TROUT TO SACRAMENTO RIVER HATCHERIES (1967-1991)

FIGURE 2-VI-30

unknown number remain below RBDD and spawn in the lower river and tributaries. With that limitation, less the number of steelhead returning to the CNFH, an estimated average of 6,574 steelhead spawned naturally in the Sacramento River system above RBDD in the 1967-1991 period (Figure 2-VI-29). Maximum and minimum estimated runs were 19,615 fish in 1968 and 470 fish in 1989, respectively. A distinct decline has occurred, with the estimated average run size decreasing from 15,055 fish in the first 5 years of the 25-year period to only 1,714 fish in the last 5 years.

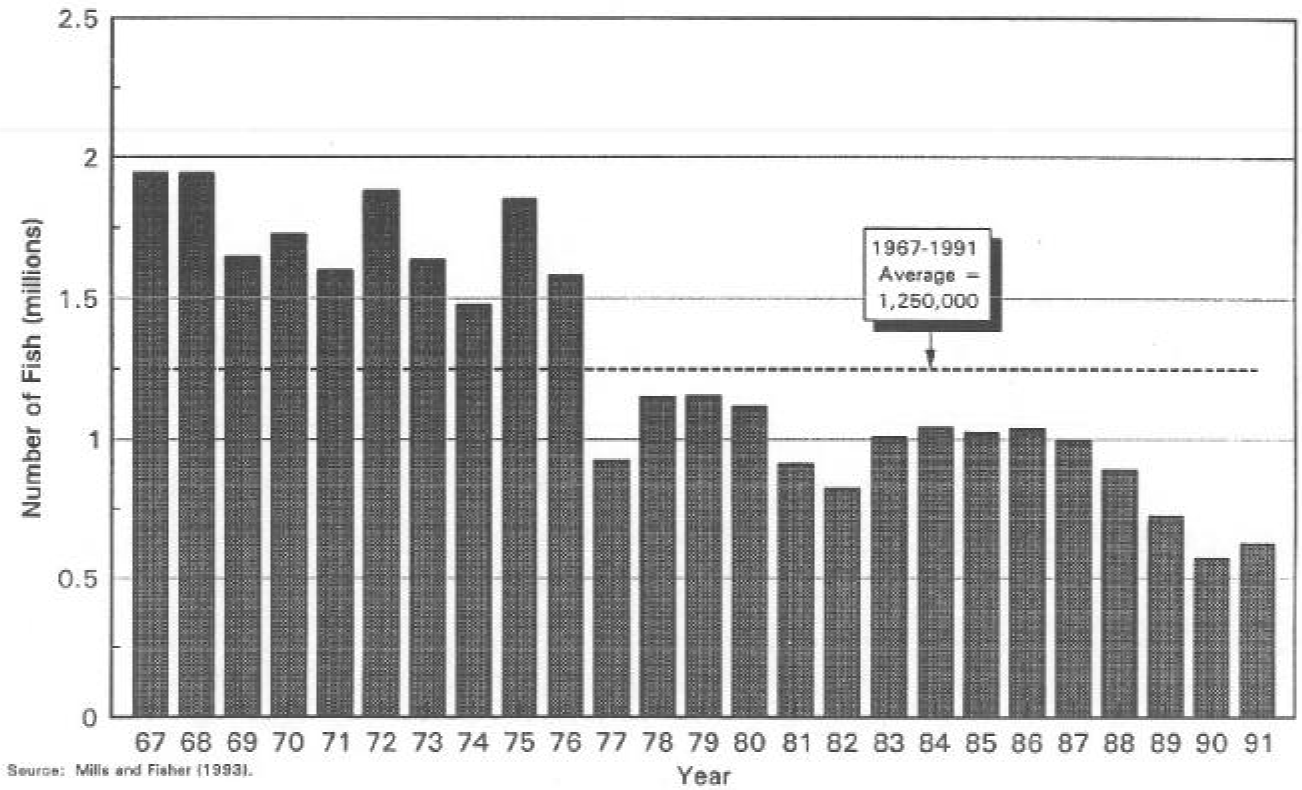
Average steelhead returns to the CNFH over the same 25 years averaged 1,910 fish, averaging 3,498 fish in the first 5 years and 979 fish in the last 5 years, a decline of nearly 75% (Figure 2-VI-30). The hatchery produces approximately 65-70% of the steelhead run to the upper Sacramento River (USBR 1985, Reynolds et al. 1990).

Sacramento River tributaries - Because counts of steelhead generally come only from hatcheries or are incidental to counts of chinook salmon, no firm estimates of steelhead run sizes exist for minor Sacramento River tributaries. Steelhead runs are believed to have declined since the 1950s and 1960s in most of these streams. Runs in the larger tributaries, Big Chico, Mill, Deer, and Antelope creeks, are probably about 50-200 fish annually. Even smaller (but unknown) numbers of steelhead also use Clear, Cow, Cottonwood, Battle (in addition to those going to CNFH), Paynes, and Butte creeks and Bear River (Reynolds et al. 1993). An estimated 25% of all steelhead migrating into the upper Sacramento River system spawn in Deer, Mill, and Antelope creeks (Hayes and Lindquist 1967).

Steelhead migrate up the American River to Nimbus Dam and the Nimbus Fish Hatchery, 23 miles up from its mouth. Adults returning to Nimbus Fish Hatchery averaged 1,694 fish in the 1967-1991 period, with no particular trend until the decline during the last 4 years (Figure 2-VI-30). Nearly all steelhead in the American River are believed to be hatchery produced, and many of the steelhead produced at the Coleman National Fish Feather River Fish Hatcheries stray and return to the American River.

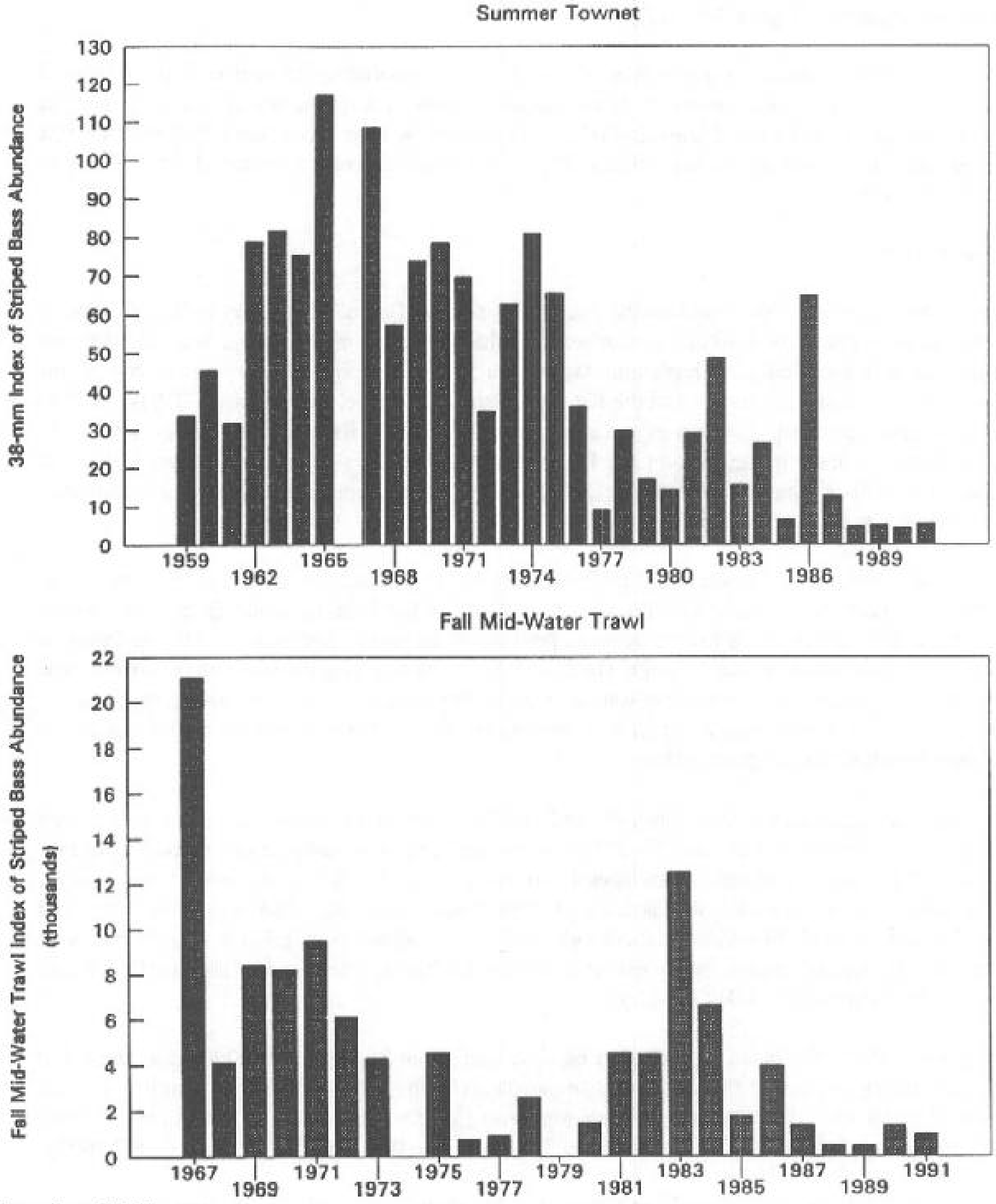
Feather River - Steelhead currently spawn in the Feather River up to the fish barrier dam below Lake Oroville and in the Yuba River up to Englebright Dam. Steelhead in the Feather River primarily originate from the Feather River Fish Hatchery; there is only limited natural production in the Feather River. Steelhead runs immediately before 1967 were maintained during the 1967-1975 period after Oroville Dam and the Feather River Fish Hatchery were in operation in 1967 (Painter et al. 1977). Overall, hatchery returns averaged 858 fish in the 1967-1991 period, with an increasing trend from an average of 790 in the first 5 years of the period to 1,386 fish in the last 5 years (Figure 2-VI-30). Annual angler catches of steelhead in the Feather River have been estimated as high as 7,875 fish in the past 10 years (Reynolds et al. 1993).

Yuba River - Limited information indicates that steelhead populations have increased on the Yuba River since New Bullards Bar Dam and Reservoir, which provided cooler summer rearing temperatures, were



ANNUAL ESTIMATES OF ADULT STRIPED BASS ABUNDANCE IN THE CENTRAL VALLEY (1967-1991)

FIGURE 2-VI-31



Source: Herrgesell (1993)

YOUNG-OF-YEAR STRIPED BASS ABUNDANCE IN THE SACRAMENTO-SAN JOAQUIN ESTUARY (1959-1991)

FIGURE 2-VI-32

constructed in 1970. DFG planted hatchery-raised steelhead smolts and fingerlings in most years from 1971 through 1983, and DFG estimated the 1975 run at 2,000 fish (Rogers pers. comm.).

Eastside tributaries - Steelhead populations in east side tributaries are generally small.

San Joaquin River and tributaries - Few, if any, naturally produced steelhead populations exist in the San Joaquin River system.

Striped Bass

Although the striped bass population had declined from historical levels by 1967, the period over which the decline occurred is unclear (Turner 1987). A more precipitous decline was documented after 1967 and continues to the present (Figure 2-VI-31). The average adult population size in the late 1960s and early 1970s of approximately 1.7 million striped bass declined to an average adult population size of less than 1 million in the 1980s (DFG 1989). The average adult striped bass population size for the 1967-1991 period was approximately 1.25 million fish. A record low population of 680,000 adult striped bass was estimated in 1990, including approximately 90,000 bass that were raised in hatcheries and stocked in the Delta and Bay (DFG 1992a).

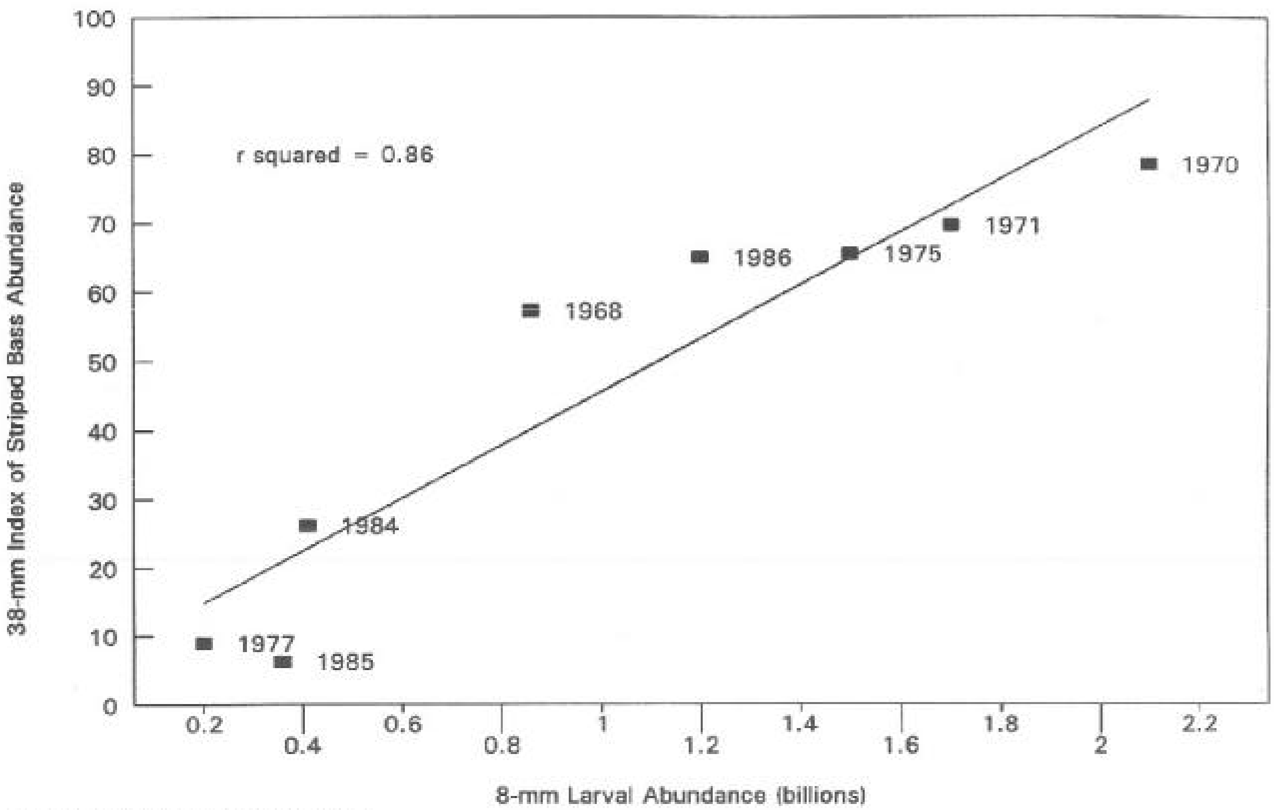
The adult population decline primarily reflects a decline in the number of new fish reaching legal size. The youngest and most numerous component of the adult striped bass population (i.e., 3-year-old fish) had declined to record lows by 1990 (DFG 1992a).

A summer tow-net survey was initiated in 1959 by DFG to provide an index of YOY abundance (i.e., the 1.52-inch index). The 1.52-inch index declined coincidentally with the decline in adult abundance since the mid 1960s (Figure 2-VI-32). The peak 1.52-inch index was 117 in 1965, and the lowest index was 4.3 in 1991 (DFG 1992a). The index averaged 1.52 for the 1967-1991 period. The fall midwater trawl surveys initiated in 1967 also provided an index of YOY abundance during September-December (Figure 2-VI-32).

Reduced populations of larvae larger than .32 inch have contributed to the decline in the 1.52-inch index (DFG 1987). Low abundance of 1.52-inch index juveniles was preceded by low abundance of .32-inch-long or larger larvae (Figure 2-VI-33). Although low larval abundance may indicate that year-class abundance will remain low, high 1.52-inch indices likely reflect increased survival during and after the larval period.

American Shad

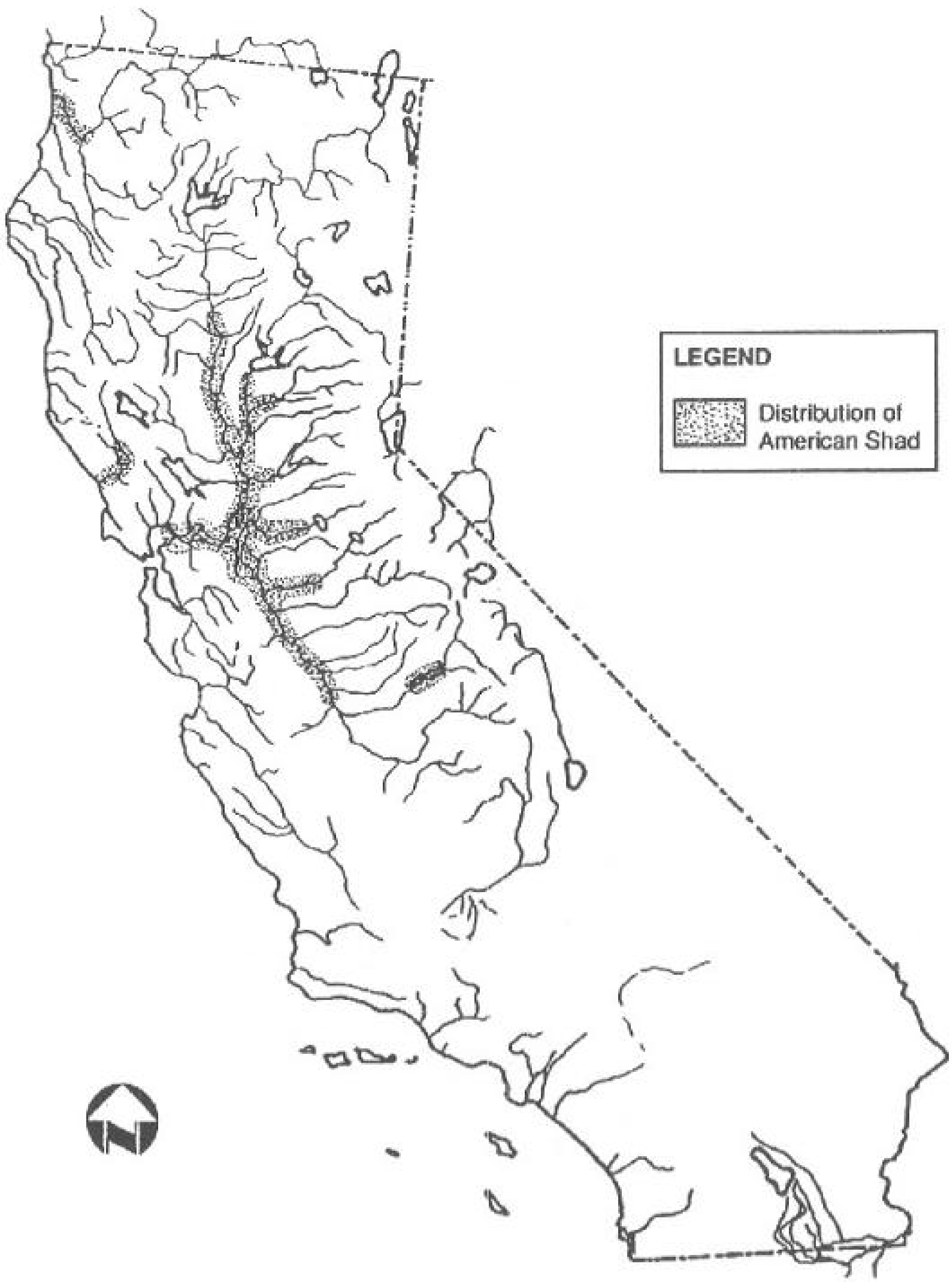
Presently, American shad are found on the Pacific Coast from Todos Santos Bay in Baja California northward to Alaska. In California, anadromous shad populations are found seasonally in the Sacramento and San Joaquin rivers and Delta; the Feather, Yuba, and American rivers; the Mokelumne and Stanislaus



Source: Interagency Ecological Study Program (1987).

RELATIONSHIP BETWEEN 8-MM LARVAL STRIPED BASS ABUNDANCE AND 38-MM JUVENILE STRIPED BASS ABUNDANCE

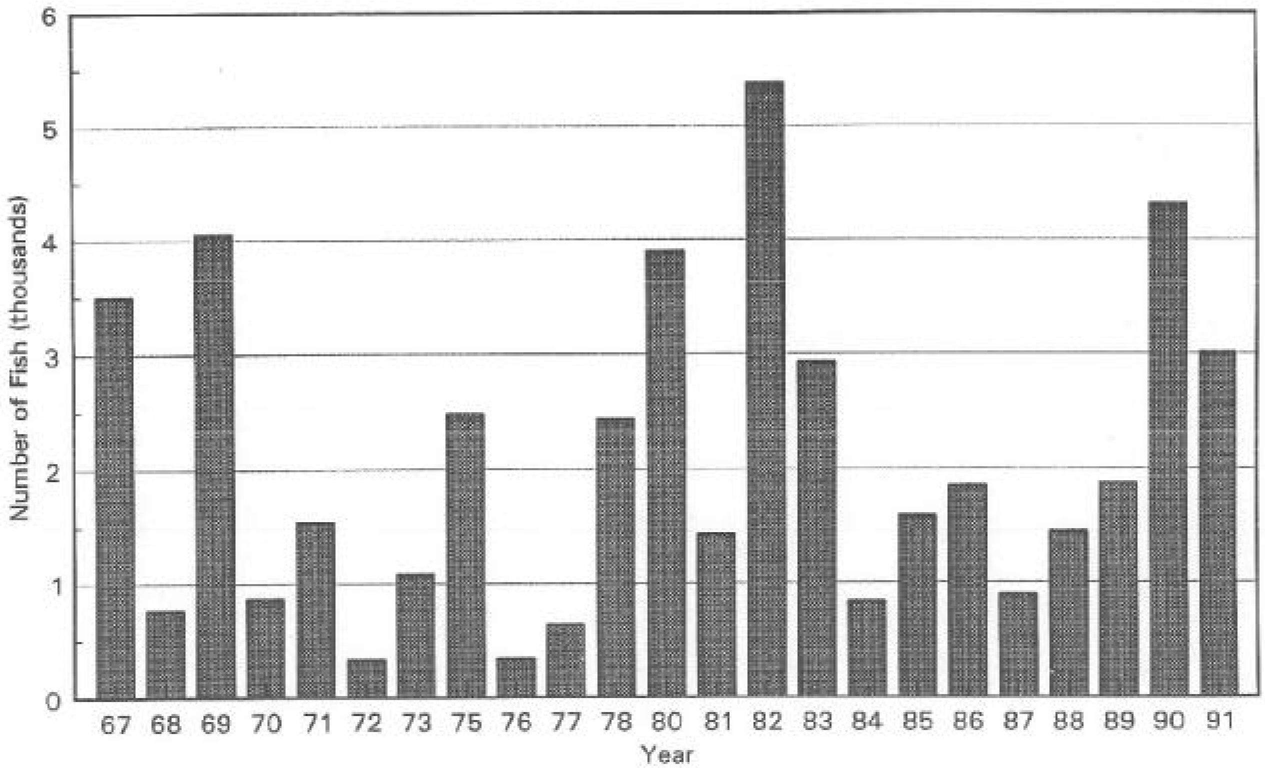
FIGURE 2-VI-33



SOURCE: Moyle 1993.

DISTRIBUTION OF AMERICAN SHAD IN CALIFORNIA

FIGURE 2-VI-34



YOUNG-OF-YEAR AMERICAN SHAD ABUNDANCE IN THE SACRAMENTO-SAN JOAQUIN ESTUARY (1967-1991)

FIGURE 2-VI-35

rivers; and the Klamath, Russian, and Eel rivers (Figure 2-VI-34). The greatest proportion of the population is found in the Sacramento River drainage (Skinner 1962). Smaller shad runs occur in the Mokelumne River, Stanislaus River, sloughs of the south Delta, and the San Joaquin River (Stevens 1972, Moyle 1976). A landlocked population also exists in Millerton Lake (Fresno and Madera counties).

The upstream limit of shad migration is presently dictated by impassable barriers such as dams and water diversion structures. Adult shad do not appear to utilize fish ladders to any appreciable extent, although passage over these barriers is believed possible given proper hydraulic conditions (Skinner 1962). In the Sacramento River drainage, shad migrate up the Sacramento River as far upstream as the RBDD, the Feather River as far upstream as Oroville, the Yuba River as far upstream as Daguerre Point Dam, and the American River as far upstream as Nimbus Dam. Shad are occasionally seen upstream of RBDD and Daguerre Dam.

DFG conducted population estimates in 1976 and 1977 using mark-recapture techniques to estimate the size of the spawning run of adult shad. Fish were captured using gill nets and marked with tags that ensured a reward to anglers as an incentive to return the tags. These studies provide the only specific attempt to estimate adult shad abundance. DFG estimated that the shad population numbered 3.04 million adults and 2.79 million adults in 1976 and 1977, respectively. DFG estimates that these population estimates are approximately one-third to one-half the number present during 1917, based on commercial catch data. (DFG 1987.)

During 1976-1978, the mean annual sport catch ranged from 86,200 to 152,000 adult shad, and angling effort ranged from 35,000 to 55,000 angler-days (Meinz 1981). During this period, 60% of the annual catch was taken from the Sacramento River (Meinz 1981). Angler surveys in 1977 and 1978 determined that sport anglers harvested 79,000 and 140,000 shad, respectively (DFG 1987).

Fall midwater trawl surveys provide an index of YOY abundance in the Delta during September-December (Figure 2-VI-35). These annual surveys have been conducted since 1967 and provide the longest, most accurate index of shad abundance. The peak abundance index was 5,386 in 1982 and the lowest index was 334 in 1972. The index averaged 2,070 during the 1967-1991 period and the median index was 1,596 (occurring in 1985).

White Sturgeon

Mark-recapture population estimates for white sturgeon ≥ 40 inches TL are available from intermittent tagging between 1967 and 1994 (Kohlhorst et al. 1991; California Department of Fish and Game, unpublished data). Estimated abundance was high in 1967 (115,000 fish), decreased to about 21,000 in 1974, then increased to another peak of 120,000 in 1984. Since 1984, the estimated population has decreased again to 37,000 in 1990. Mean estimated white sturgeon abundance from 1967 to 1991 was 77,500.

Catch and catch per net-hour during tagging are generally consistent with the changes in abundance portrayed by the mark-recapture estimates. This does not verify the absolute magnitude of the abundance estimates, but does suggest that they accurately depict general population trends.

Using a maturation schedule and spawning frequency derived from data presented by Doroshov et al. (1988), size composition of the tagging catch, and the mark-recapture population estimates, the number of white sturgeon spawning each year can be estimated (Table 2-VI-3). Since 1967, the spawning population has varied from highs of 25,000-27,000 fish in 1967, 1984, and 1985 to a low of 4,700 fish in 1993. Due to earlier maturation and more frequent spawning, the spawning population consists of about four times as many males as females. In 1990, the most recent year between 1967 and 1991 for which an abundance estimate is available, about 2,200 females spawned (Table 2-VI-3).

Annual recruitment of adults was estimated from abundance estimates and age-composition data. Age composition was estimated by interpreting age from cross sections of the first pectoral fin rays from a sample of fish (1967-1976) or by applying an age-length key derived from these data to lengths of a sample of fish (1979-1993). Age 15 was assumed to be the age of recruitment to adulthood as that is approximately the mean age of first spawning for female white sturgeon in the Sacramento-San Joaquin system. From 1967 to 1991, the number of age 15 recruits varied from about 1,400 in 1974 to 11,500 in 1967. Mean recruitment for this period was 5,600.

Tag returns from anglers catching tagged fish provide an accurate picture of seasonal and annual changes in distribution of white sturgeon if angling effort is distributed similarly to the fish. From 1974 to 1994, 66% of tag returns were received from the Suisun and San Pablo Bay area (Table 2-VI-4). Many sturgeon are found in these two bays throughout the year, but peak fishing in Suisun Bay occurs from November through February; it occurs from December through March in San Pablo Bay (Table 2-VI-4). In San Francisco Bay, over half the annual catch is taken from January through March and almost no fish are caught from August through October.

Some sturgeon move into the Delta in fall and their numbers increase in winter (Table 2-VI-4). A portion of these fish, presumably those that are mature and ready to spawn, move up the Sacramento River and are at highest abundance there from March through May.

Movement of white sturgeon into the San Joaquin River in the spring (Table 2-VI-4) suggests spawning occurs there also. If the number of tag returns from each river is a valid indicator of the relative number of spawning fish, ten times (spring tag return ratio of 60:6; Table 2-VI-4) as many white sturgeon spawn in the Sacramento River as in the San Joaquin River.

In recent years, some white sturgeon have moved out of the estuary and migrated up the coast to Oregon and Washington. Chadwick (1959) reported one white sturgeon tagged in 1954 was returned from the Columbia River, but no additional evidence of coastwise migration was seen until 1985 when a white sturgeon tagged in 1979 was captured in the Chehalis River, Washington. Since then, 15 more tagged white sturgeon have been caught in six river systems north of California. In spite of a large-scale white sturgeon tagging program in the Columbia River in recent years, no Columbia River fish have been recaptured in the Sacramento-San Joaquin system.

The distribution of the white sturgeon catch within the Sacramento-San Joaquin Estuary has changed over the years. Recently, the percentage of tag returns from the delta has increased substantially while returns from San Francisco Bay have declined (Table 2-VI-5). Whether this reflects a change in sturgeon behavior or only a shift in angler effort is unknown.

Another prominent change in the distribution of tag returns occurred in the early 1980s when catches in Suisun Bay decreased and catches in San Pablo Bay increased (Table 2-VI-5). This probably reflects a response to the two extremely wet years (1982 and 1983) in this period because white sturgeon appear to move within the estuary in response to flow, which affects salinity. They are farther upstream when saline water encroaches eastward in dry years and farther downstream when brackish water is pushed westward in wet years. In dry years, 31% of tag returns came from Suisun Bay and 22% from San Pablo Bay. In wet years, 17% of tag returns came from Suisun Bay and 47% from San Pablo Bay.

Table 2-VI-3. Estimate of the number of white sturgeon spawning each year in the Sacramento and San Joaquin rivers.

Year	1954	1967	1968	1974	1979	1984	1985	1987	1990	1993
Abundance	11200	114700	40000	20700	74500	119800	107700	106100	36700	23100
Size composition										
100-120 cm	0.1666	0.4341	0.4341	0.386	0.5985	0.5413	0.4126	0.442	0.3977	0.6993
121-140 cm	0.2102	0.3492	0.3492	0.2641	0.2744	0.3486	0.4376	0.3821	0.3324	0.1812
141-160 cm	0.4723	0.1614	0.1614	0.2596	0.089	0.087	0.1207	0.1366	0.2031	0.082
161-180 cm	0.1295	0.041	0.041	0.077	0.034	0.02	0.025	0.031	0.048	0.031
>180 cm	0.021	0.014	0.014	0.014	0	0	0	0.01	0.019	0.01
Fraction mature		Males	Females							

100-120 cm		0.28	0.05							
121-140 cm		0.41	0.12							
141-160 cm		0.47	0.20							
161-180 cm		0.54	0.27							
>180 cm		0.33	0.26							
Spawners (by size group)										
Year	1954	1967	1968	1974	1979	1984	1985	1987	1990	1993
Males										
100-120 cm	261	6971	2431	1119	6242	9079	6221	6565	2043	2262
121-140 cm	483	8211	2863	1121	4191	8561	9662	8311	2501	858
141-160 cm	1243	4350	1517	1263	1560	2444	3055	3406	1752	442
161-180 cm	392	1273	444	429	676	634	715	874	479	192
>180 cm	40	269	94	46	54	75	78	154	112	27
Total males	2418	21074	7349	3978	12723	20793	19731	19310	6886	3782
Females										
100-120 cm	47	1245	434	200	1115	1621	1111	1172	365	404
121-140 cm	141	2403	838	328	1227	2506	2828	2432	732	251
141-160 cm	529	1851	646	537	664	1040	1300	1449	745	188
161-180 cm	196	636	222	215	338	317	358	437	239	96
>180 cm	31	212	74	36	43	59	62	121	88	22
Total females	944	6347	2214	1316	3386	5543	5658	5612	2170	961
Total spawners	3362	27421	9563	5294	16109	26336	25389	24922	9056	4742

Note: Abundance estimates in 1991 and 1993 are based on the ratio of tagging catch per net-hour in those years to catch per net-hour in 1990.

Table 2-VI-4. Tag returns by area and month for white sturgeon tagged in the Sacramento-San Joaquin Estuary and recovered by anglers from 1974 to 1994.

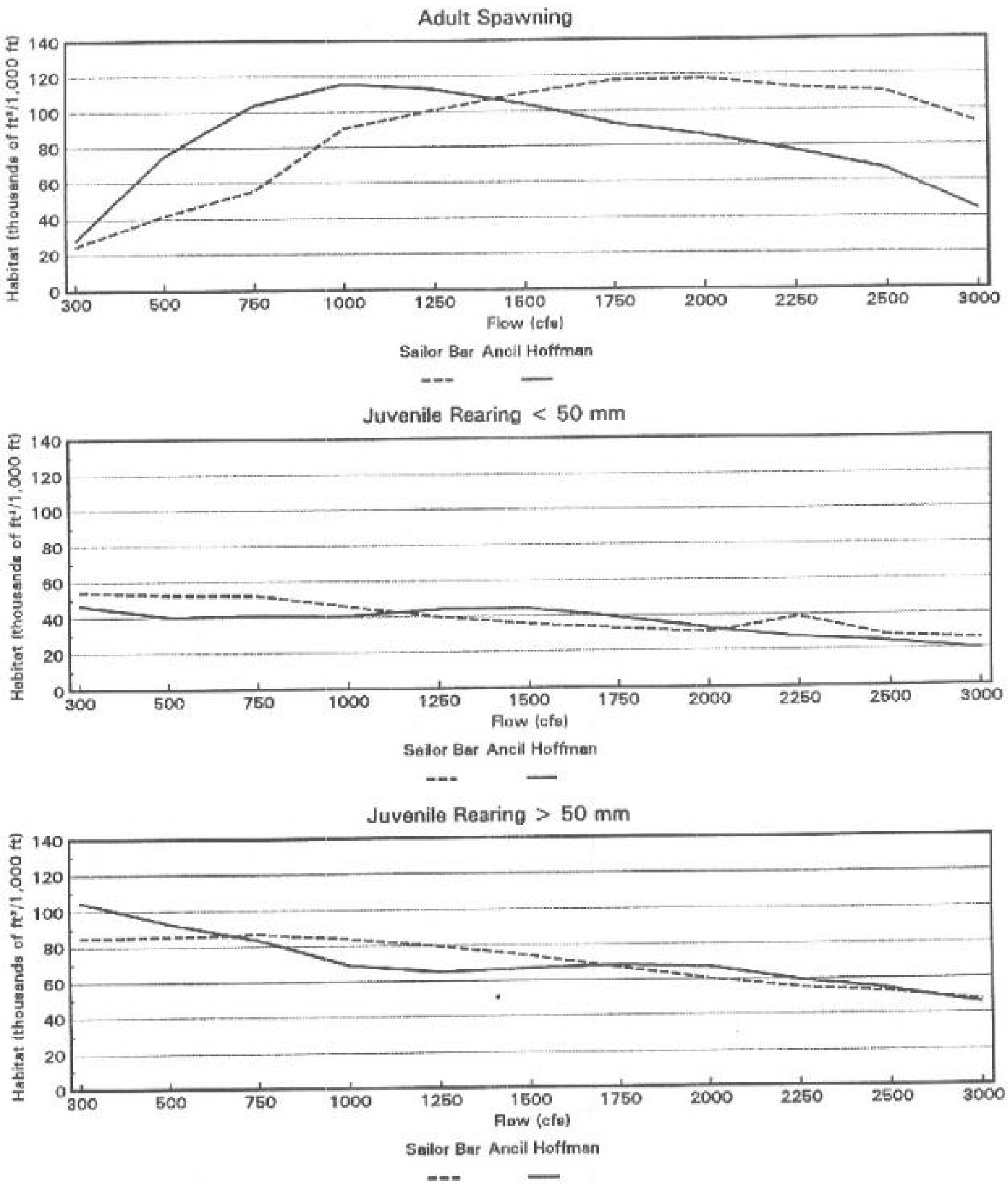
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Sacramento River	3	2	20	30	10	3	1	0	0	0	1	2	72
Feather River	0	0	0	0	0	0	1	0	0	0	0	0	1
San Joaquin River	0	0	4	1	1	0	0	0	0	0	0	0	6
Delta	30	34	31	20	10	4	0	0	7	6	17	16	175
Suisun Bay	69	50	35	32	33	32	28	24	26	34	55	71	489
San Pablo Bay	82	91	141	61	48	43	22	16	16	36	43	82	681
San Francisco Bay	58	51	84	46	19	5	2	1	1	1	14	49	331
Pacific Ocean	0	0	1	1	0	1	0	0	0	0	0	0	3
Oregon-Washington	0	4	2	2	0	1	4	2	1	0	0	0	16
Total	242	232	318	193	121	89	58	43	51	77	130	220	1774
Percent of total	14	13	18	11	7	5	3	2	3	4	7	12	

Table 2-VI-5. Tag returns by area and 5-year period for white sturgeon tagged in the Sacramento-San Joaquin Estuary and recovered by anglers from 1975 to 1994.

Location	1975-1979	1980-1984	1985-1989	1990-1994
Sacramento River	5	5	3	6

Location	1975-1979	1980-1984	1985-1989	1990-1994
Feather River	0	0	<1	0
San Joaquin River	1	1	<1	<1
Delta	9	9	8	21
Suisun Bay	28	14	30	32
San Pablo Bay	43	53	36	31
San Francisco Bay	14	18	22	7
Pacific Ocean	0	<1	<1	<1
Oregon-Washington	0	0	1	2

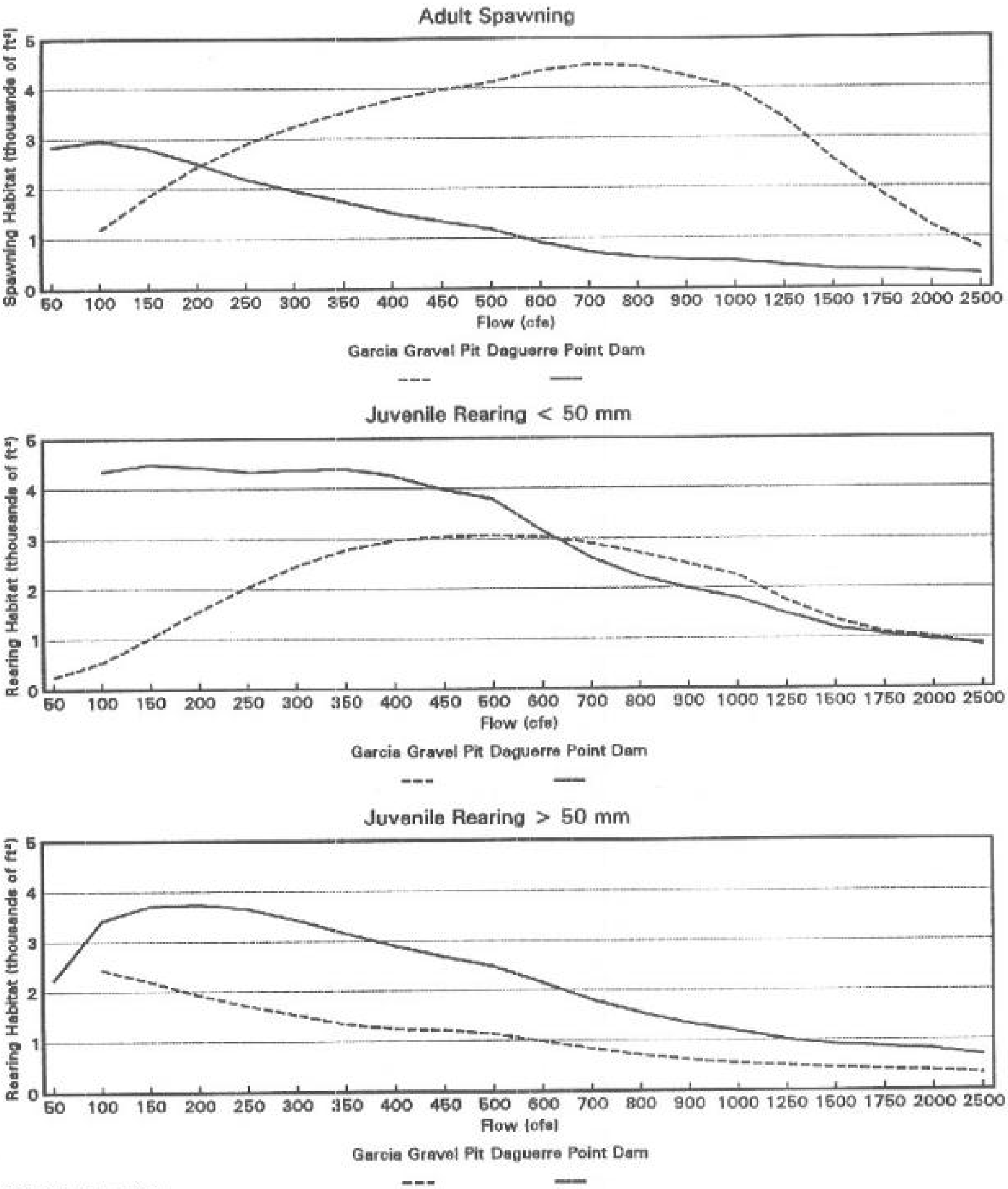
Note: Values in the table are percentages of the total 5-year period tag returns.



SOURCE: U. S. Fish and Wildlife Service (1985).

FLOW VERSUS HABITAT AVAILABILITY FOR CHINOOK SALMON SPAWNING AND JUVENILE REARING IN SELECTED REACHES OF THE LOWER AMERICAN RIVER

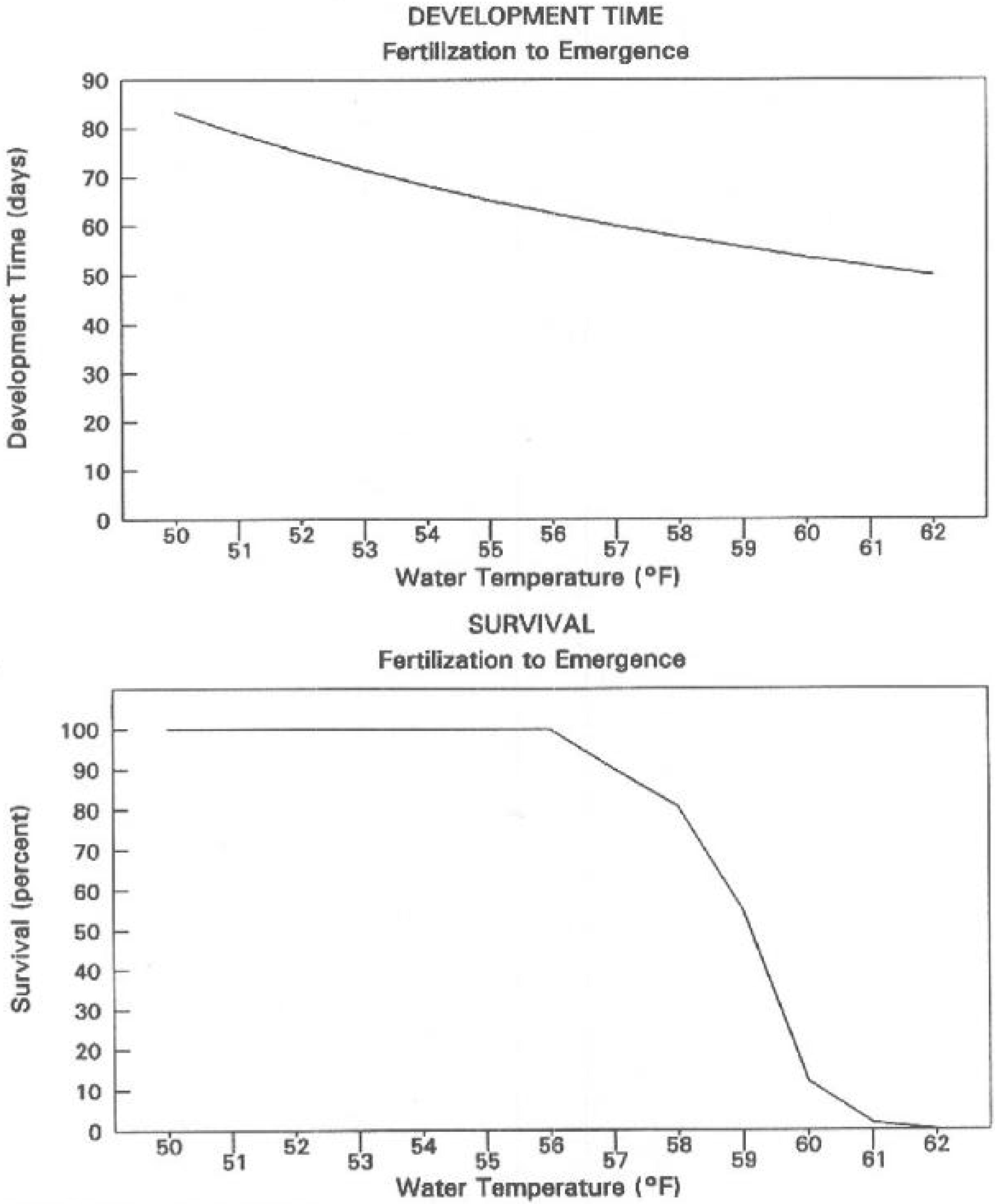
FIGURE 2-VI-36



SOURCE: Beak (1989).

FLOW VERSUS HABITAT AVAILABILITY FOR CHINOOK SALMON SPAWNING AND JUVENILE REARING IN SELECTED REACHES OF THE YUBA RIVER

FIGURE 2-VI-37



SOURCE: U. S. Bureau of Reclamation 1992a.

CHINOOK SALMON EGG AND LARVAL DEVELOPMENT TIME AND SURVIVAL VERSUS WATER TEMPERATURE

FIGURE 2-VI-38

Green Sturgeon

During the baseline period, 143 green sturgeon were tagged, and an additional 26 fish were tagged between 1954 and 1965. None have been recaptured during subsequent sampling, so no independent estimates of abundance is possible. As an alternative, green sturgeon abundance in the estuary in the fall was estimated by dividing white sturgeon abundance estimates by the ratio of white to green sturgeon observed during tagging. Because the number of green sturgeon captured each year was so low, no length-age analysis was available to provide information regarding production.

During the baseline period, green sturgeon populations varied from a high of 1,850 fish in 1967 to a low of 203 fish in 1974. The estimate of average baseline population was 983 fish.

ENVIRONMENTAL REQUIREMENTS

Chinook Salmon

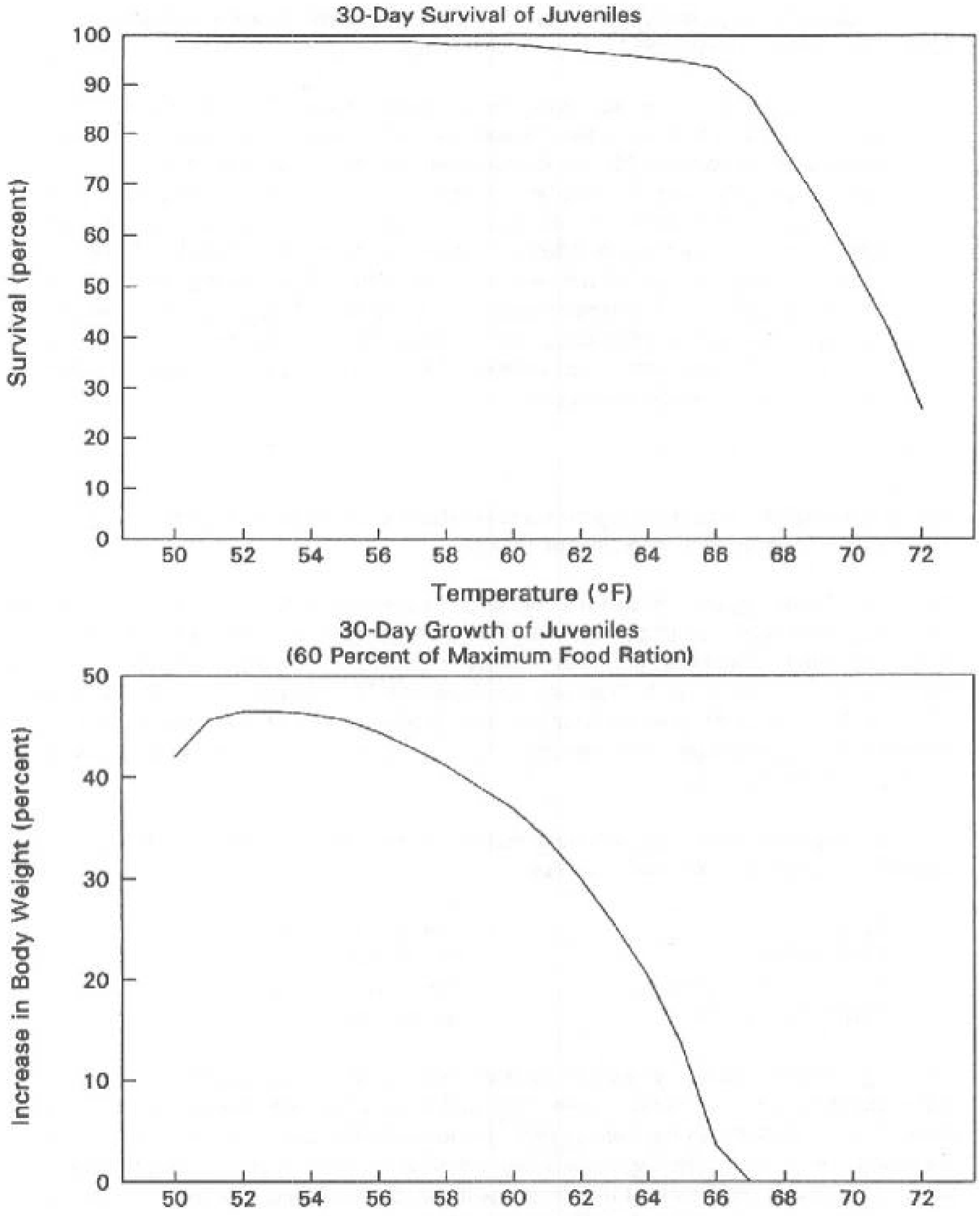
Upstream migration - Seasonal increases in streamflow provide an important migration cue for adult chinook salmon. Higher flows and associated lower water temperatures in the fall stimulate upstream migration of fall-run chinook salmon.

Upstream migrations of fall-run chinook salmon generally coincide with decreasing water temperatures in fall. Water temperatures during upstream migration usually range from 51°F to 67°F (Bell 1973). Hallock (1970) found that chinook salmon initiated migration into the lower San Joaquin River as water temperatures declined from 72°F to 66°F.

Minimum depths are necessary for successful upstream migration of adult salmon. For chinook salmon, Thompson (1972) recommended that a minimum depth of 0.8 foot extend over at least a 10% continuous portion of the stream's cross-sectional profile. In addition, the minimum depth should extend over at least 25% of the stream's cross-sectional profile overall.

Spawning - Spawning typically occurs at the lower end of a pool or head of a riffle. Females generally prefer gravel ranging from 1 to 6 inches in diameter, depths exceeding 0.5 foot deep, and water velocities ranging from 1.5 to 2.5 fps (Vogel and Marine 1991), although the range in depths, water velocities, and substrate composition that chinook salmon find acceptable is very broad (Healey 1991). Provided the condition of good subgravel flow is met, chinook salmon apparently will spawn in water that is shallow or deep, slow, or fast and where the gravel is coarse or fine.

Streamflow influences the quantity, quality, and distribution of chinook salmon spawning habitat. Streamflow directly affects the amount of available spawning habitat by defining the stream area with



SOURCE: Jones and Stokes Associates 1992b.

JUVENILE CHINOOK SALMON GROWTH AND SURVIVAL VERSUS WATER TEMPERATURE

FIGURE 2-VI-39

appropriate combinations of water depths, velocities, and streambed characteristics (e.g., substrate composition). Indirect effects of flow on spawning habitat include effects on water temperature and water quality, which influence the longitudinal extent and seasonal availability of suitable spawning habitat.

Relationships between streamflow and chinook salmon spawning habitat availability have been developed for several streams in the Sacramento basin through application of the Instream Flow Incremental Methodology (IFIM) (Bovee 1982) and related techniques. The results have formed the basis for assessing instream flow requirements or evaluating alternative operations and reservoir release schedules. Habitat-discharge relationships are currently available for the American River (USFWS 1985) and Yuba River (Beak 1989) (Figures 2-VI-36 and 2-VI-37) and are being developed for the Feather and upper Sacramento rivers.

Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females subjected to lower water temperatures. Extremely cold water (less than 38°F) also results in poor adult survival and egg viability (Hinze 1959).

Incubation - Incubation time declines with increasing water temperatures. Maximum survival of incubating eggs and yolk-sac larvae occurs at water temperatures between 41°F and 56°F. At constant water temperatures, survival through emergence decreases at water temperatures exceeding 56°F, with no survival occurring at 62°F or higher (Figure 2-VI-38). The effects of hourly or daily fluctuations in water temperature above 56°F on eggs and yolk-sac larvae are largely unknown.

Hatching success is also adversely affected by reductions in dissolved oxygen and increases in metabolic waste products resulting from inadequate water flow through the redd. Inadequate intragravel flow may be caused by streamflow reductions following spawning or increases in the quantity of fine sediments in the gravel. Incubating eggs and larvae require dissolved oxygen at saturation levels. Optimum levels equal or exceed 8 milligrams per liter at temperatures between 44°F and 50°F and equal or exceed 12 milligrams per liter at temperatures above 50°F (Raleigh et al. 1986).

Rearing - Chinook salmon fry tend to seek shallow, nearshore habitat with low water velocities and move to progressively deeper, faster water as they grow. In streams, chinook salmon fry feed mainly on drifting terrestrial and aquatic insects, but zooplankton become more important in the lower river reaches and estuaries.

Streamflow is a dominant variable affecting chinook salmon rearing habitat. Streamflow directly determines the amount of physical habitat with appropriate combinations of depth, velocity, substrate, and cover for chinook salmon rearing. Streamflow also influences the extent of suitable water temperatures, water quality conditions, and habitat for production of aquatic invertebrates, a major food source for juvenile salmonids in fresh water. Relationships between streamflow and juvenile rearing habitat have been developed for the American and Yuba rivers through application of IFIM (Bovee 1982) (Figures 2-VI-36 and 2-VI-37).

The habitat preferences of juvenile chinook salmon change with increasing body size; newly emerged chinook salmon fry typically occur along marginal areas of streams but seek faster, deeper water as they grow (Lister and Genoe 1970, Everest and Chapman 1972). Generally, chinook salmon fry prefer depths of 0.5-3 feet and water velocities of 0.1-1 fps (Raleigh et al. 1986).

In general, juvenile chinook salmon tolerate water temperatures from 32°F to 75°F, but the optimal range for survival and growth is from 53°F to 64°F (Raleigh et al. 1986). In the natural environment, water temperature affects juvenile chinook salmon growth and survival through complex physiological responses that can be modified by acclimation and behavior. In general, responses to water temperature vary depending on fish size; the duration and frequency of exposure to a given water temperature; physical habitat conditions; food availability; and the presence of competitors, predators, or disease.

Figure 2-VI-40 presents survival and growth rates of juvenile chinook salmon fed maximum rations and exposed to different water temperatures under laboratory conditions. Because maximum feeding levels are probably seldom realized in the natural environment, the growth curve was modified based on a 60% ration level.

Downstream migration - Flow influences distribution, abundance, and survival of emigrating juvenile salmonids. Generally, higher flows improve survival and migration success of juvenile salmonids by increasing migration rates, reducing exposure to diversions (i.e., reducing the proportion of flow diverted), and maintaining favorable water quality conditions (e.g., water temperature). Other factors that may influence the success and timing of juvenile chinook downstream migrations include growth rate, interspecific competition, and genetic makeup (i.e., ocean-versus stream-type life history strategies).

Ocean life - Overall salmon production depends on both freshwater conditions (factors affecting adult migration, spawning, incubation, rearing, and emigration) and ocean conditions (factors affecting ocean salmon growth, survival, and migration back to fresh water). Much more is known about the freshwater life history, biology, and environmental requirements of salmon. The ocean ecology of salmon has been generally neglected, and studies of the factors affecting chinook salmon populations in the ocean have only recently been initiated (Pearcy 1992).

Ocean survival of salmon depends on a complex interaction of oceanographic, meteorologic, and biologic factors. Increased marine survival of Pacific salmon is commonly associated with upwelling events that bring cold nutrient-rich water from deep ocean layers to the surface along the eastern Pacific Coast during spring and summer (Lichatowich 1993). El Niño events, which transport warm, low-salinity water from subtropical regions, can suppress or reduce the intensity of upwelling, leading to poor marine survival and reduced abundance of adult salmon. The periodic, southward transport of subarctic waters also enhances productivity off California. In addition, increased marine exploitation of important forage species (e.g., California sardine, hake, and anchovy) has likely affected ocean salmon production. Overall, forage fish biomass in the California current declined from approximately 25 million tons in 1905 to 4.5 million tons by

1950 and has remained well below historical levels. Before the collapse of the California sardine market, the sardine may have been an exceptionally rich energy source for salmon and a buffer against predation during the species' first summer at sea (Lichatowich 1993). Lichatowich stated:

> If the California current has undergone a "change in state" that influences salmon production then it follows that the state of the freshwater links in the chain may become more important. Healthy freshwater habitats may become more critical when oceanic productivities are lower and marine mortality higher. Our degradation of freshwater habitat combined with cyclic changes in ocean productivity and high harvest rates may have had the effect of "burning the candle at both ends." Cycles of ocean productivity can at the very least mask the effects of improvements in freshwater habitat or hatchery production or cause us to falsely attribute increased marine survival to restoration effects in freshwater. However, there may be important additive or multiplicative consequences of freshwater habitat degradation in the troughs of ocean productivity cycles.

Steelhead

Upstream migration - Upstream migrations of steelhead generally coincide with flow increases and temperature decreases, similar to chinook salmon.

Spawning - Spawning flow needs for steelhead are a function of the flow necessary over suitable spawning gravels to provide appropriate water depths and current velocities for successful spawning. The water also must be of sufficient temperature and quality. Barnhart (1986) reported steelhead spawning in water depths of 5-28 inches, and Bovee (1978) reported an average water depth of 14 inches. Barnhart (1986) also reported steelhead spawning in water velocities of 0.5-3.6 fps, and Bovee (1978) reported a preferred velocity of 2.0 fps. Reynolds et al. (1993) reported a spawning velocity preference of 1.5 fps.

From various experiments and literature sources, Leidy and Li (1987) reported the following temperature ranges for steelhead spawning:

Optimum	46.0-52.0°F
Chronic low stress	52.1-57.5°F
Chronic medium stress	57.6-61.0°F
Chronic high stress	Greater than 61.0°F

Spawning redd sites selected by steelhead generally have gravel particle sizes that are 0.25-3.0 inches in diameter (Reynolds et al. 1993). The average redd size for Sacramento River basin steelhead also appears to be smaller than the average redd size in California streams reported as 56 square feet (Reynolds et al. 1993). Spawning success (egg hatching and fry emergence) is highly dependent on flow, temperature, and dissolved oxygen surrounding the developing embryos. Gravels with high permeability and few fines (less than 5% sand and silt by weight) were reported by Barnhart (1986) as existing in highly productive steelhead spawning streams.

Incubation - Egg incubation time in the gravel is determined by water temperature, varying from about 19 days at an average water temperature of 60°F to about 80 days at an average temperature of 40°F. Up to 80-90% of the eggs hatch under favorable conditions (Skinner 1962). Steelhead seem to tolerate fewer fines than chinook salmon, probably because oxygen requirements for developing embryos are higher (Reynolds et al. 1990). Positive correlations have been demonstrated between steelhead egg and embryo survival and both the percolation rate of water through gravels and the oxygen content of the water (Reynolds et al. 1990). Steelhead fry usually emerge from the gravel 2-8 weeks after hatching (Barnhart 1986, Reynolds et al. 1993), which usually occurs in April and May on the American River (McEwan and Nelson 1991).

In order for the fry to emerge, physical and chemical conditions must remain fairly constant within the indicated ranges throughout the approximate 2-month period that the eggs and pre-emergent fry are in the gravel.

Rearing - Steelhead fry usually live in small schools in shallow water along stream banks following emergence from the gravel. Mortality is high in the first few months after emergence. As the steelhead grow, the schools break up and the fish establish individual feeding territories. Though most live in riffles in their first year of life, some of the larger steelhead live in deeper, faster runs or pools. Their appearance and life are similar to that of nonanadromous resident rainbow trout.

Habitat and other related factors affecting juvenile steelhead in the Sacramento River system are similar to those described for juvenile chinook salmon. Chinook salmon generally emigrate within a few months after emergence, however, and steelhead rear to a larger size than salmon. Consequently, juvenile steelhead are more dependent on larger and more abundant food resources than are salmon and also utilize deeper and faster runs and pools as they grow to larger sizes before emigration.

Another major difference between salmon and steelhead juvenile rearing is that steelhead juveniles must have suitable summer habitats (e.g., flows and water temperatures); juvenile chinook salmon generally are not present in tributary streams during summer. Juvenile steelhead summer rearing habitat in the form of suitable flows and water temperatures is generally characterized as the major factor limiting steelhead abundance. The presence of upstream barriers, typically large dams, also limits steelhead rearing to physical habitats (typically large, mainstem tributary rivers) that are not optimal or suitable for steelhead rearing.

Rearing flows need to be adequate to provide the physical habitat needed by steelhead fry and juveniles, as well as that needed to produce the aquatic insects and other invertebrates on which they feed. Bovee (1978) shows steelhead fry using water approximately 2-15 inches deep but preferring water about 8 inches deep. Suitable water velocities are generally 0.3 to 1.0 fps, with optimal velocities about 0.6 fps. Bovee (1978) shows steelhead juveniles using deeper and faster water with water depths approximately 7-24 inches deep, with optimal depths about 14 inches, and velocities about 0.3-1.5 fps, with optimal velocities about 0.9 fps. The existence of pools can be especially important in streams that are naturally or artificially subjected to low-flow conditions in summer and fall.

From various experiments and literature sources, Leidy and Li (1987) generated the following temperature ranges for steelhead fry and juvenile rearing in the American River:

Optimum	55.0-60.0°F
Chronic low stress	60.1-68.0°F
Chronic medium stress	68.1-72.5°F
Chronic high stress	Greater than 72.5°F

The actual effects of chronic low, medium, or high stress temperatures on abundance, however, depend on several factors, including exposure duration, acclimation abilities, food availability, water quality, and groundwater dynamics. Numerous other water temperature criteria available for steelhead fry and juvenile that are not presented here are the basis of the criteria developed by Leidy and Li (1987).

Juvenile downstream migration - Juvenile steelhead emigration rates are influenced by water temperatures and current velocities. Although some steelhead have been collected in most months at the state and federal pumping plants in the Delta, the peak numbers salvaged at these facilities have been primarily in March and April in most years.

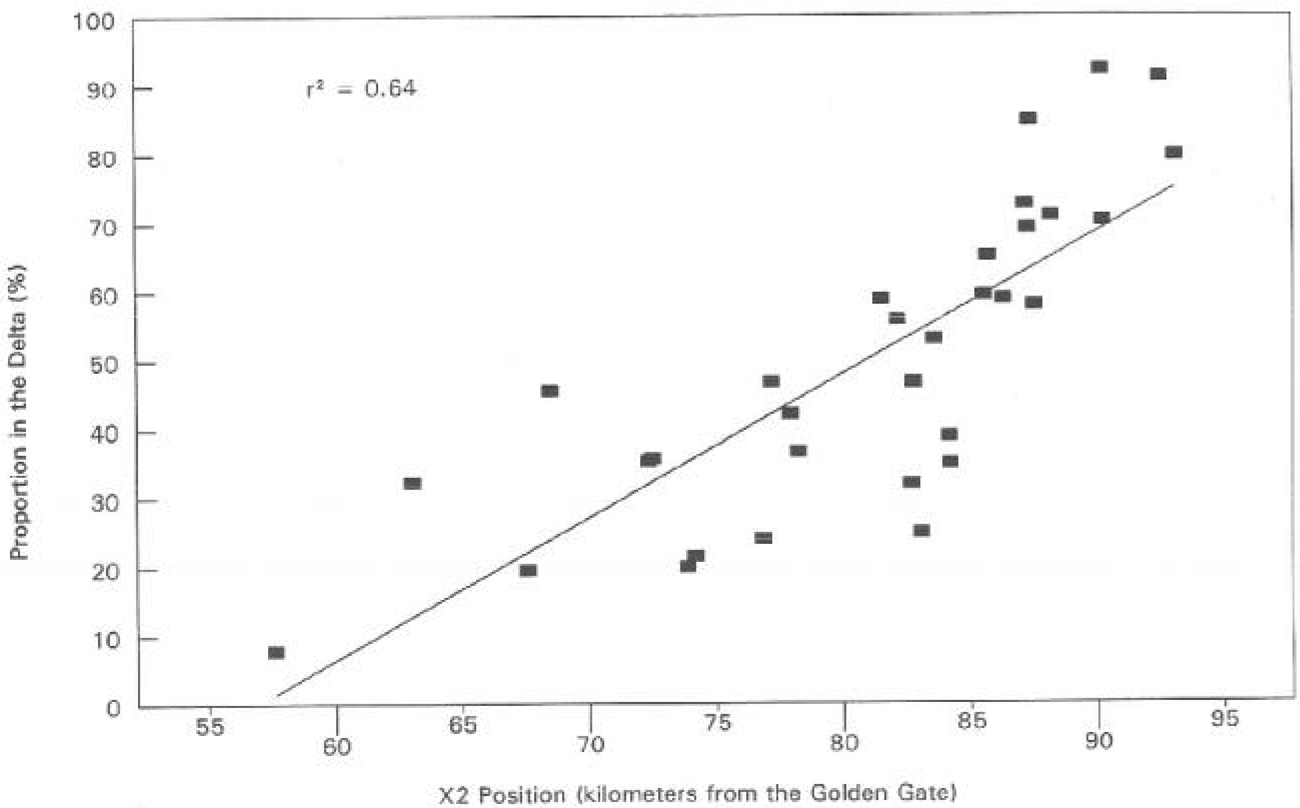
From various experiments and literature sources, Leidy and Li (1987) reported the following temperature ranges for steelhead emigration and smoltification:

Optimum	44.4-52.3°F
Chronic low stress	52.4-59.3°F
Chronic medium stress	59.4-63.2°F
Chronic high stress	Greater than 63.2°F

Again, these are general ranges and the actual effects of these temperature ranges on steelhead emigration survival depend on numerous other factors. Additional sources of information that cite temperature criteria or preferences for steelhead are available.

In their review, Raleigh et al. (1984) reported that photoperiod appeared to be the dominant triggering mechanism for smolt transformation, with temperature affecting the rate of transformation. Juvenile steelhead kept in water warmer than 55.4°F from March through June were reported to sustain reduced levels of smoltification. However, reduced flows and coincident warming spring water temperatures, a natural phenomena prior to dams, and high flows or freshets may also trigger juvenile emigration.

Ocean life - Little is known about steelhead and their environmental requirements during the 1 or 2 years that most spend in the ocean. Mortalities during this period are almost exclusively from natural conditions in



Source: Herrgesell (1993).

PROPORTION OF THE YOUNG-OF-YEAR STRIPED BASS POPULATION (38-MM INDEX) IN THE DELTA RELATIVE TO THE LOCATION OF X2 (2 PPT SALINITY OR ABOUT 3,000 μS EC) IN JULY (1959-1991)

FIGURE 2-VI-40

the ocean environment. There is no commercial or sport fishery for steelhead in the ocean, and for unknown reasons, they are rarely taken by commercial or sport salmon trollers (Skinner 1962).

Striped Bass

Upstream migration - Upstream migration of striped bass is likely controlled by flow, water temperature, and seasonal factors in the Sacramento-San Joaquin River system.

Spawning - Spawning may begin after the water temperature exceeds approximately 58^{o}F and during, or immediately following, an average temperature rise of 34-36^{o}F (Turner 1976). Spawning generally occurs when temperatures are increasing and is most intense at water temperatures from 63-68^{o}F to (Turner 1976, Mitchell 1987). Most eggs are spawned during peaks that may last one or several days (Interagency Ecological Studies Program 1991, 1993). During the spawning season, two to four peaks encompass most of the annual egg production.

Spawning peaks in the Sacramento River and the Delta have occurred over a temperature range of 58-71^{o}F. The average water temperature during a peak spawning event was 64^{o} F.

Although spawning in the Delta has occurred when salinity exceeded 1,500 microsiemens (uS) electrical conductivity (EC), the effect on egg and larva survival is unknown (DFG 1987). Laboratory studies indicate that salinities less than 1,500 uS EC do not adversely affect egg survival.

The downstream extent of spawning is usually near Antioch, but in years when salinity intruded into the Delta, spawning occurred several miles farther upstream (DFG 1987). The shift in spawning has not always avoided higher than normal salinity, and spawning has been recorded in salinities exceeding 1,500 uS EC. Striped bass generally return to the same spawning area each year, but regular occurrence of high salinities may gradually reduce the use of the lower San Joaquin River in the Delta as a spawning area because of the preference of fresh water for spawning.

Incubation - In the Sacramento River, eggs and larvae are transported downstream of Rio Vista within a few days and arrive in the Delta before larvae begin feeding (Low and Miller 1986). The destination of egg and larval striped bass appears to be a function of flow conditions (Turner 1987). Under high Sacramento River flow and high Delta outflow, eggs and larvae from both the Sacramento River and Delta spawnings are concentrated downstream in Suisun Bay. Under low-flow conditions, eggs and larvae are generally concentrated in the Delta.

The movement of eggs and larvae downstream in the Sacramento River is clearly a function of flow, with higher flows moving eggs and larvae more rapidly downstream. Once eggs and larvae are in the Delta, movement downstream may become more dependent on larval and juvenile behavior and the location of the entrapment zone (i.e., the zone where salinity is between 2,000 and 10,000 uS EC).

Larval striped bass accumulate in or upstream of the entrapment zone (i.e., near or upstream of salinity greater than 2,000 uS EC) (Fujimura 1991, Kimmerer 1992). Larvae are concentrated in the entrapment zone and slightly upstream, consistent with larval behavior to avoid the surface and to concentrate at mid-depth and near the bottom (Fujimura 1991). Striped bass do not appear to undergo diel (i.e., night and day) vertical movements to maintain position with their prey. Position in the water column may be a function of factors other than feeding.

Rearing - Similar to larvae, early juveniles at least 1.52 inches long accumulate in or upstream of the entrapment zone (i.e., near or upstream of salinity greater than 2,000 uS EC) (Fujimura 1991, Kimmerer 1992) (Figure 2-VI-40). During high-flow years, the entrapment zone and most YOY striped bass are located in Suisun Bay into fall (Turner and Chadwick 1972). During low-flow years, the entrapment zone and most YOY striped bass are located in the Delta. YOY bass tend to move out of the Delta and into Suisun and San Pablo bays during late fall and winter (Sasaki 1966a, 1966b; Turner and Chadwick 1972). Movement downstream is more apparent in low-flow years and obscured during high flow years. After the winter of the first year, movements of juvenile striped bass appear to be similar to adult bass.

American Shad

Upstream migration and spawning - Instream flows and water temperatures are the most critical environmental requirements for successful shad migration and spawning. Flow relationships are important for determining the spawning river chosen by virgin shad, and temperature is an important factor triggering migration and spawning behavior.

The timing of spawning migrations is highly correlated with water temperature. Upstream migration of adult shad generally occurs as water temperatures increase during spring. However, adult shad may discontinue their upstream migration if water temperatures exceed 68°F (Stier and Crance 1985). Furthermore, water temperatures exceeding 68°F are known to increase mortality among postspawning adults (Moyle 1976). The initiation of spawning is also correlated with water temperatures; spawning is generally delayed until water temperatures exceed 60°F.

Water temperature appears to be the most important factor that determines the timing of shad spawning. Spawning may occur at water temperatures as low as 50°F, but the general range appears to be 60-75°F. The optimum range is likely 62-68 °F (Skinner 1962). In the Feather River, shad spawning does not occur until water temperatures reach 60°F and peaks at 70°F (Painter et al. 1977). In the Yuba River, shad spawning did not occur until mean daily temperature reached 61°F (Jones & Stokes Associates 1990). Most shad spawning occurs in May and June.

Spawning typically occurs over sand to gravel substrates in depths of 3-30 feet (Painter et al. 1980). Jones & Stokes Associates (1990) concurred with the depth findings but found spawners concentrated within a specific range of mean water velocities of 1.5-2.4 fps on the Yuba River. Because shad spawning is pelagic and not limited to a fixed site, as is salmon and steelhead spawning, it can occur repeatedly at the same locations without any apparent adverse effect on egg survival.

Dissolved oxygen concentrations of 5.0 milligrams per liter or more are required throughout spawning areas (Walburg and Nichols 1967).

Incubation - Egg survival is closely related to water temperatures. Temperatures for maximum hatching and survival of eggs and larvae are 60°F to 79°F. Leach (1925) reported that 52°F is very near minimum temperature for successful egg incubation. Water temperatures exceeding 80°F are unsuitable for egg hatching and eventual larval development (Carlson 1968). Young shad appear to be extremely tolerant of salinity and salinity changes, beginning at the earliest stages of life. (Steir and Crantz 1985.)

Rearing - Water temperature is an important factor affecting growth and survival of juvenile American shad. The lower thermal tolerance limit is about 36°F, but sublethal effects suggest that prolonged exposure to 40-43°F cannot be tolerated. Juveniles have been generally found in water temperatures ranging from 50°F to 85°F. (Steir and Crance 1985.)

Dissolved oxygen concentration requirements for juvenile rearing are similar to those for adults during upstream migration and spawning.

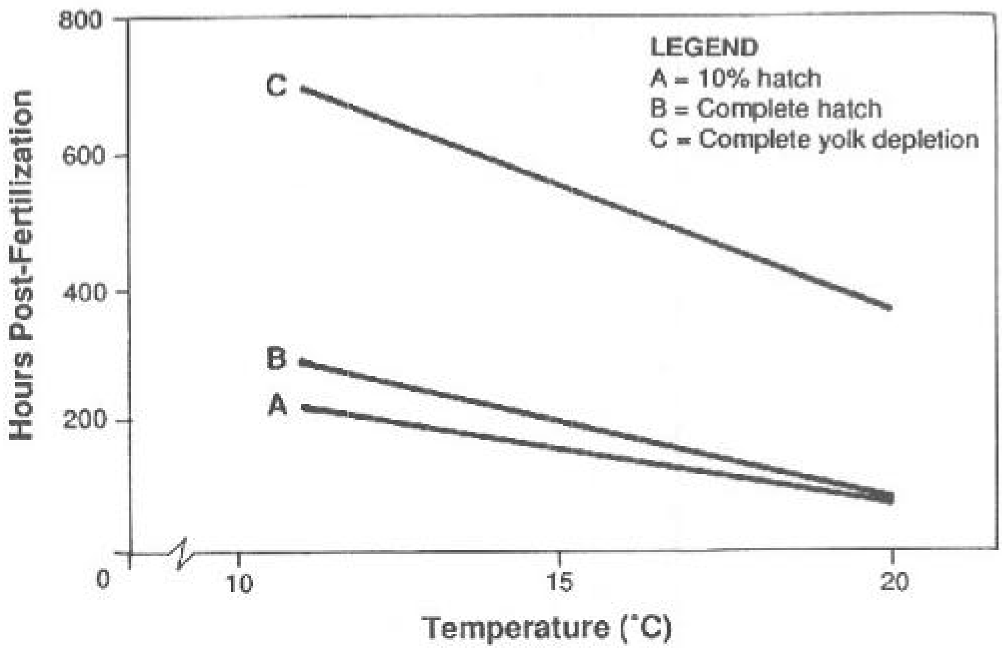
It appears that shad larvae are much less tolerant of suspended sediments than are eggs. Auld and Schubel (1978) reported that concentrations of suspended sediments greater than 100 parts per million significantly reduced survival of shad larvae continuously exposed for 96 hours. (Stier and Crance 1985.)

Food availability could be an important factor for some shad populations. The most critical time in the life cycle apparently occurs when the larvae have first absorbed the yolk and must find their own food (Hildebrand 1963). May (1974), however, does not believe that available data support Hildebrand's hypothesis.

Downstream migration - Little specific information exists on downstream migrations of American shad in California. Juveniles begin emigrating from rivers when water temperatures drop below 60°F (Leggett and Whitney 1972). Environmental requirements are likely similar to those for rearing.

White Sturgeon

Upstream migration - Little information is available concerning the abilities of white sturgeon to negotiate upstream passage barriers. A recent literature search failed to locate information on cruising, sustaining, and darting speeds for white sturgeon (Jones & Stokes Associates 1992). However, sturgeon do spawn in relatively swift water with velocities as high as 10 fps measured in areas where sampling has determined the presence of sturgeon eggs (Parsley et al. 1989).



Source: Wang 1984.

DEVELOPMENTAL TIME OF WHITE STURGEON

FIGURE 2-VI-41

Sturgeon are bottom-oriented fish with limited jumping abilities and have little success migrating past barriers. Warren and Beckman (1991) report that modified fish ladders in the Columbia River that provided orifices through the weirs at the ladder floor increased passage of white sturgeon over several Columbia River dams.

Though limited data exist on environmental conditions required to cue spawning, evidence from the Central Valley indicates that increases in flow may trigger adult movement and spawning. For example, no spawning was detected near Colusa with flows less than 6,356 cubic feet per second (cfs), but spawning did occur after 1 to 3 days of increased flow over that level (Schaffter 1991).

Little is known of the effects of water temperature on upstream migration of white sturgeon in the Sacramento-San Joaquin River system. Water temperature and photoperiod could promote the final stages of egg maturation and initiate upstream migration. Chapman (1989) found that temperature did affect sperm production and hypothesized that it likely affected egg production. Although it has not been shown in the literature for the Sacramento-San Joaquin River system, a threshold temperature may initiate upstream migration and spawning in some populations. Haynes et al. (1978) found that sturgeon migrations in the Columbia River occurred only at temperatures above 55^{o}F. However, sturgeon in the Sacramento River have migrated at temperatures as low as 46^{o}F (Kohlhorst 1976).

Spawning - Little information relating environmental conditions to the initiation or success of spawning in sturgeon is available. In particular, few data exist relating flow with sturgeon spawning habitat or success. White sturgeon in the lower Columbia River spawned in the swiftest water available (2.6 to >9.2 fps mean column velocity) (Parsley et al. 1992). Some preliminary data suggest that flow velocity may trigger spawning in female sturgeon (Schaffter 1990). River flow acts to disperse eggs and prevent clumping of the adhesive eggs.

Sturgeon in the Sacramento-San Joaquin River system spawn within temperature ranges of 46-64^{o}F, with most spawning occurring when water temperatures are 58^{o}F (Kohlhorst 1976); however, Kohlhorst did not note a temperature effect on the intensity of spawning or a temperature threshold for spawning.

Substrate requirements for spawning have not been determined. However, Schaffter (1991) collected fertilized eggs where substrates were primarily gravel and rubble. Because of the adhesive nature of sturgeon eggs, areas of silt-free gravel appear to be required for successful sturgeon spawning. The nature of spawning site selection and the availability of clean gravel spawning areas with sufficient flow are unknown.

Incubation - There are no published data relating environmental conditions to egg incubation and hatching in the wild. Data presented below are from laboratory studies.

Optimum temperatures for incubation and hatching range from 52^{o}F to 63^{o}F; higher temperatures result in greater mortality and premature hatching (Wang et al. 1985, 1987). Under culture conditions, white sturgeon eggs hatch synchronously (Brewer 1987, Conte et al. 1988). Mass hatching of sturgeon eggs generally occurs during darkness (Brewer 1987). Both synchronous hatching and hatching during darkness may be adaptive mechanisms to minimize predation on larvae.

River flow is important to maintain oxygen levels and remove waste products at the egg surface. After sturgeon larvae hatch, the currents act to disperse the larvae downstream from the spawning grounds. Several authors have reported the effects of temperature on incubation and early development of sturgeon (Wang 1984, Wang et al. 1985, Doroshov 1985, Conte et al. 1988). Wang (1984) found a strong inverse correlation between temperature (52-68^{o}F) and incubation period (-0.9567), and temperatures and yolk depletion (-0.9943) in the temperature range of normal development (Figure 2-VI-41). Egg incubation can last 4-14 days after fertilization, while yolk depletion can occur 15-30 days after fertilization. Optimum temperatures for white sturgeon incubation and larval development are between 52^{o}F and 63 ^{o}F (Wang et al. 1987). Higher mortality and premature hatching occurs at 64-68^{o}F. Temperatures of 73-79^{o}F are lethal to sturgeon embryos (Wang 1984). A lower temperature limit has not been defined; however, Wang et al. (1987) suggest that it might be between 43^{o}F and 46^{o}F. Based on Wang's (1984) correlations, incubation and yolk depletion at temperatures reached during the peak spawning season (58^{o}F) (Kohlhorst 1976) would be approximately 9 days and 24 days after fertilization, respectively.

Effects of most water quality parameters on incubation and emergence of white sturgeon are not well documented.

Rearing - Water temperature can affect juvenile sturgeon growth and health. Under laboratory conditions, maximum growth occurs at rearing temperatures of 68^{o}F, but rearing at lower temperatures (61-65^{o}F) reduces the incidence of disease (Cech et al. 1984, Conte et al. 1988).

Daily food ration needs for wild fish are unknown. Under culture conditions promoting maximum growth, young sturgeon are fed 20-30% of their body weight per day until they reach 3 grams and 15% of their body weight until they reach 15 grams (Doroshov et al. 1983). Sturgeon that weigh over 28 grams are fed 1-1.5% of their body weight per day. Because sturgeon primarily feed on benthic organisms, reduced populations of these organisms would likely have the most detrimental effect on sturgeon growth and survival.

Juvenile sturgeon are known to be sensitive to salinity (McEnroe and Cech 1985, Brannon et al. 1985, Brewer 1987), but the effects of other water quality parameters are relatively unknown. Young Sacramento River white sturgeon had low survival in 10 parts per thousand (ppt) salinity (McEnroe and Cech 1985). Salinity tolerance did not appear to change with age or size in larval and juvenile Columbia River white sturgeon (1-83 days before hatching) (Brannon et al. 1985). Larvae and juveniles could not tolerate direct salinity increases to 11 ppt, and no fish survived transfer to aquaria with 16 ppt. Those fish that survived 11 ppt salinity were sluggish in response. Acclimation of larger fish improved tolerance to 15 ppt. Brannon et al. (1985) also demonstrated that sturgeon larvae and fry can respond to salinity gradients by avoiding higher salinity areas in aquaria.

Downstream migration - Adult and subadult Sacramento River white sturgeon currently use San Francisco, San Pablo, and Suisun bays and the Delta year-round (Miller 1972b). Sturgeon distribution in the Delta is significantly correlated to river flow, which also influences salinity regimes (Kohlhorst et al. 1991). As river flow is decreased, the marine waters penetrate farther up into the Delta. During dry years, more tagged fish have been recaptured in Suisun Bay than areas farther downriver. During wet years with higher river flows, more tagged fish were recaptured in San Pablo Bay and areas farther downstream.

Green Sturgeon

Environmental requirements for green sturgeon are largely unknown, but are assumed to be similar to those of white sturgeon.

SECTION VII. PROBLEMS FOR CENTRAL VALLEY ANADROMOUS FISHES

CHINOOK SALMON

General Problems

Upstream migration - Reservoir operations have altered the natural flow regime of Central Valley streams by changing the frequency, magnitude, and timing of flow. These changes potentially affect all chinook salmon lifestages. Extremely low or high flows can block or delay migration to spawning areas by preventing passage over shallow riffles or creating excessive water velocities.

Water temperature affects the timing of chinook salmon spawning migrations, although the migratory response to water temperature may differ among chinook salmon races. Low flows and higher water temperatures can inhibit or delay migration to spawning areas.

Spawning - Water temperatures limit the geographic range in which chinook salmon can successfully spawn and adversely affect survival at temperatures above 56^{o}F.

Declining flows and consequent water surface elevations during the chinook salmon incubation period can cause mortality of eggs and alevins by dewatering redds, reducing flow rates through the redd, or increasing water temperatures. For example, fall-run chinook salmon redds are subject to potential dewatering as a result of streamflow reductions during the reservoir storage phase, which may begin during the winter incubation period. Redd dewatering impacts have generally been assessed using stage-discharge relationships for known spawning areas and chinook salmon spawning depth criteria (Jones & Stokes Associates 1991, 1992c).

Rearing - Rapid flow fluctuations can cause stranding of juvenile chinook salmon and subsequent mortality of juveniles unable to return to the river. Causes of mortality include elevated water temperatures, low dissolved oxygen levels, and predation.

Elevated water temperatures affect juvenile survival directly through acute (i.e., lethal) effects and indirectly through chronic (i.e., sublethal) effects. Water temperature becomes lethal at 75^{o}F. Chronic temperature effects occur at lower temperatures and include physiological stress, reduced growth rates, and increased vulnerability to disease and predation. Under laboratory conditions, American River juvenile chinook salmon experienced increasing levels of chronic thermal stress as water temperatures increased from 60^{o}F to 75^{o}F (Rich 1987).

Water diversions reduce survival of emigrating juvenile salmonids through direct losses at unscreened or inadequately screened diversions and indirect losses associated with reduced streamflows. Fish screening and salvage efforts at major agricultural diversions have met with variable success, and many smaller unscreened or inadequately screened diversions continue to operate. Fish losses at diversions can occur through physical injury, impingement, or entrainment. Delayed passage, increased stress, and increased vulnerability to predation are also factors contributing to mortality at diversions. Diversion impacts on anadromous fish populations depend on diversion timing and magnitude, river discharge, species (i.e., race), life stage, and other factors.

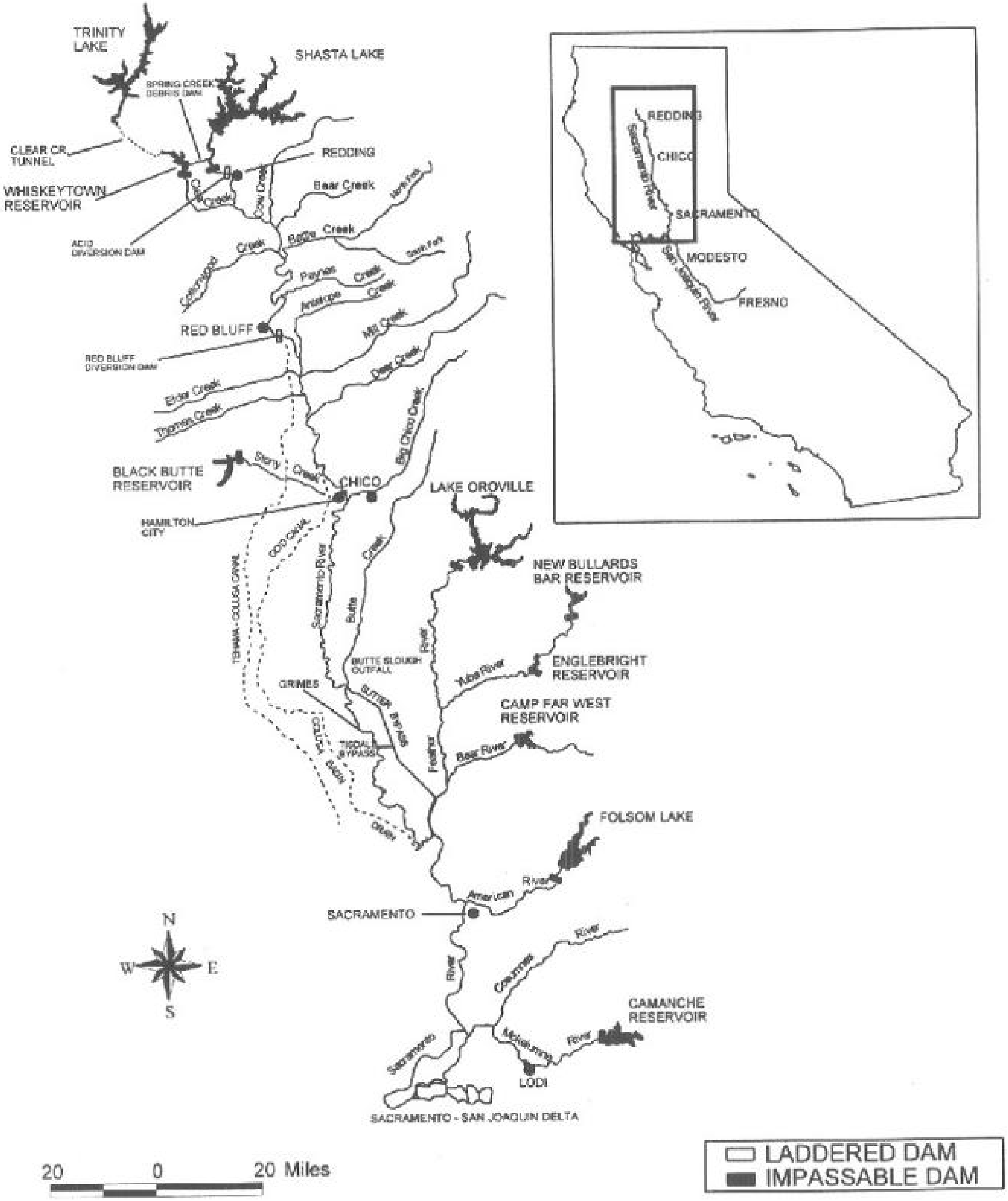
Predation on emigrating salmonids is probably of minor significance in unobstructed portions of the Sacramento River system, but predator efficiency increases at artificial structures and impoundments where fish are concentrated, stressed, or delayed in their downstream migration (U.S. Bureau of Reclamation [USBR] 1983b).

Substantial losses in streamside riparian vegetation adversely affect chinook salmon throughout their Central Valley distribution. Riparian vegetation performs critical functions in stream ecosystems by maintaining bank stability, providing overhead and instream cover for aquatic organisms, moderating water temperatures, contributing nutrients and energy, and providing habitat diversity. The presence of riparian vegetation along natural streambanks greatly enhances the quality of nearshore aquatic habitat for juvenile chinook salmon. Overhanging and submerged branches and root systems provide favorable hydraulic characteristics for resting and feeding; food inputs (primarily terrestrial insects); and shelter from strong, light, swift currents, and predators. In addition, naturally eroding streambanks are a valuable source of large woody material (e.g., fallen trees) in the stream, providing important instream cover and contributing to channel and habitat diversity.

Sacramento River

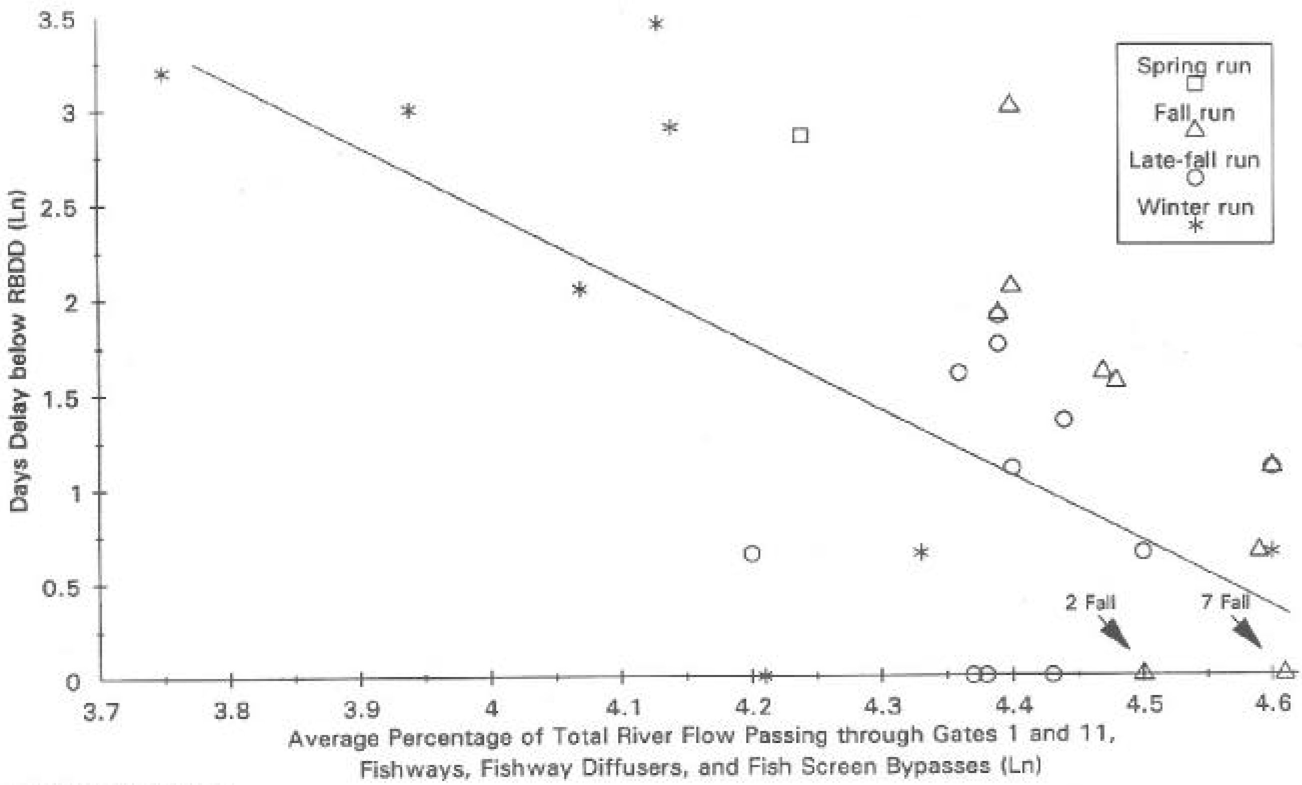
Upstream migration and spawning -

Passage barriers - On the upper Sacramento River, the Red Bluff Diversion Dam (RBDD) is a major impediment to upstream migration of adult salmon (Hallock et al. 1982, Vogel et al. 1988) (Figure 2-VII-1). After completion of the RBDD in 1966, the proportion of fall-run chinook salmon spawning above the dam declined from an estimated average of 94% during 1964-1968 to an average of 63% during 1977-1981 (USBR 1985). The extent of delay and blockage was found to increase with increasing river discharge as a result of decreases in the proportion of total discharge passing through or adjacent to the fish ladders (Figure 2-VII-2). Blockage of fall-, late fall-, winter-, and spring-run chinook salmon ranged from 8% to 44% and can be related to the extent of delay (Figure 2-VII-3). Vogel et al. (1988) concluded that adult salmon passage problems at the RBDD were caused primarily by insufficient attraction flows in the fish ladders, operation and maintenance problems, and improper configuration of the fish ladder entrances.



MAP OF THE SACRAMENTO RIVER BASIN

FIGURE 2-VII-1

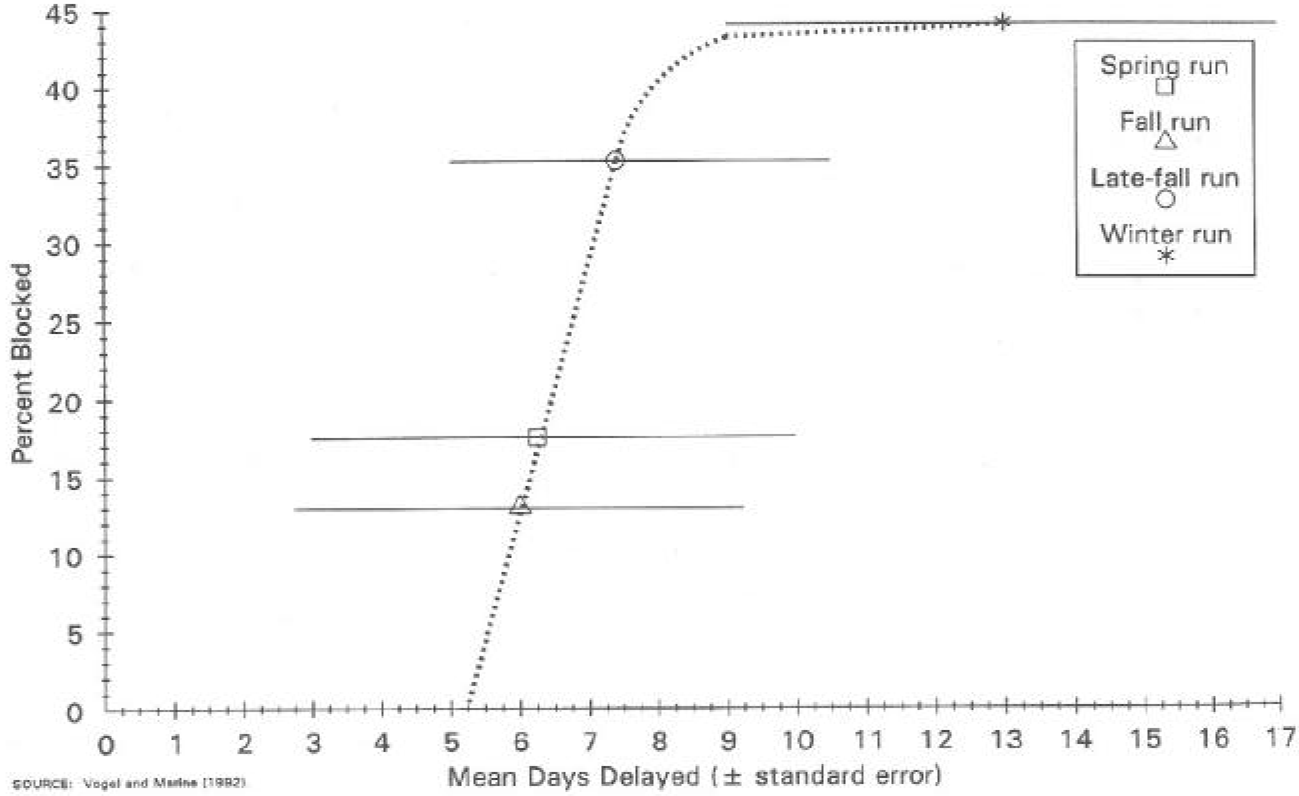


SOURCE: Hallock et al. (1982).

NOTE: All data transformed to natural logarithms.

DELAY OF RADIO-TAGGED SALMON THAT PASSED RED BLUFF DIVERSION DAM VERSUS MEAN PROPORTION OF TOTAL RIVER FLOW PASSING THROUGH OR NEAR THE FISHWAYS

FIGURE 2-VII-2



SOURCE: Vogel and Marine (1992)

DELAY VERSUS BLOCKAGE OF CHINOOK SALMON AT RED BLUFF DIVERSION DAM

FIGURE 2-VII-3

Potential effects of blocked or delayed migration of adult chinook salmon include pre-spawning mortality, reduced egg viability, and shifts in spawning distribution. Obstructions can cause excessive delay and energy expenditure, which can result in pre-spawning mortality of adults and reduced fecundity. Fall-run and late fall-run chinook salmon are probably most susceptible to this source of mortality because they spawn immediately after migration. Winter-run chinook salmon that do not reach spawning areas above the dam generally have poor spawning success because water temperatures in the Sacramento River below the RBDD frequently exceed tolerance levels for eggs and fry during the summer incubation period (Hallock and Fisher 1985).

Raising the RBDD gates during the nonirrigation season (November 1-April 30) is currently being implemented to facilitate upstream passage of adult winter-run chinook salmon. USBR is currently investigating alternatives that would permit the RBDD gates to be raised permanently or for longer periods to provide unimpeded passage of adult and juvenile chinook salmon.

The Anderson-Cottonwood Irrigation District's (ACID's) diversion dam, a seasonal flashboard dam on the Sacramento River near Redding, California (Figure 2-VII-1), has caused fish passage problems since its construction in 1917. A fish ladder, completed in 1927 and still in place today, does not effectively attract and convey upstream migrating chinook salmon past the dam (USBR 1983a). A new fishway was recently installed on the opposite side of the dam, but its passage effectiveness has not yet been evaluated. The ACID's dam is usually installed in early April and removed in late October or early November, resulting in potential delay and blockage of winter-, spring-, and fall-run chinook salmon to upstream spawning areas.

Water temperature and spawning gravels - In the upper Sacramento River, high water temperatures observed during summer and fall limit the range of successful spawning for winter-, spring-, and fall-run salmon during July-October (Vogel and Rectenwald 1987). The downstream limit of suitable water temperatures for fall-run chinook salmon in most years is near Hamilton City, whereas suitable temperatures for winter- and spring-run salmon are typically limited to the reach above the RBDD (Figure 2-VII-1).

Construction of Shasta and Keswick dams blocked the recruitment of spawning gravels from upstream sources to the upper Sacramento River. Lack of gravel recruitment and increases in the average size of streambed materials have degraded spawning habitat below Keswick Dam to at least Clear Creek. Below Clear Creek, tributary streams increase in importance as a source of spawning gravels to the Sacramento River. Intensive gravel mining in most of these tributaries has reduced gravel recruitment to the mainstem Sacramento River by more than 50%. Below Red Bluff, gravel recruitment principally occurs from the natural erosion of historical deposits along the banks of the Sacramento River. Bank protection and levee projects in the middle and lower Sacramento River have substantially reduced gravel recruitment into these reaches. (Buer et al. 1984.)

Existing gravel supplies are adequate to support current population levels of chinook salmon in the upper Sacramento River. With future population increases, however, spawning gravel may become limited and gravel restoration would be necessary. Recent restoration efforts by the California Department of Fish and Game (DFG) and the California Department of Water Resources (DWR) have included placement of spawning gravel to restore degraded spawning riffles in the upper Sacramento River above Clear Creek. (DWR 1992.)

Incubation -

Water temperature - Appropriate water temperatures for egg incubation and emergence are a critical concern for Sacramento River chinook salmon. Historically, fall water temperatures were warm in the lower reaches of the upper Sacramento, Feather, Yuba, and American rivers, particularly during dry water years. Spring-run chinook salmon was a dominant race and spawned at higher elevations, where temperatures were not a major limiting factor. Fall-run chinook salmon spawned at lower elevations, but in fall to avoid lethal water temperatures. In general, immediately after dam construction, reservoirs were kept relatively high and provided colder water in the lower reaches of these rivers. Fall-run chinook salmon populations responded to the colder flows earlier in the year, mixed genetically with hatchery salmon, and began to spawn much earlier than historical salmon runs. Coincidentally with these earlier runs, Sacramento River basin reservoirs have, over time, reached lower elevations because of greater demands for spring and summer releases for agricultural and municipal demands. These lower elevations, particularly during dry water years, now frequently result in warm water being released from the reservoirs, which causes high mortalities to incubating fall-run chinook salmon eggs.

Increasing water demands and prevailing drought conditions in recent years have limited the ability to maintain suitable water temperatures in the principal winter-run chinook salmon spawning area in the upper Sacramento River. During the recent drought period, USBR initiated alternative reservoir operations, including increases in the relative amount of cold water from the Trinity River system and low-level bypass releases at Shasta Dam, in an effort to reduce the severity and extent of deleterious water temperatures. A proposed outflow temperature control structure would improve USBR's ability to control water temperatures and significantly benefit winter-run chinook salmon without foregoing power generation. The planning report and final environmental impact statement for the Shasta outflow temperature control device have been completed (USBR 1992b).

Water quality - Water quality impacts on aquatic resources vary by location and season in response to variable streamflows and pollutant levels in point-source and non-point-source agricultural, municipal, and industrial discharges. Although largely unquantified, water quality impacts on fish populations in the Sacramento River and its tributaries include effects related to heavy metal pollution; high levels of suspended sediments; and elevated levels of nutrients, herbicides, and pesticides from agricultural drainage.

Simpson Paper Company, which operates a pulp and paper mill near Anderson, has achieved an approximate 98% reduction in the discharge rate of dioxins and related compounds in recent years. As a result, dioxin concentrations in fish tissues from the Sacramento River have been reduced 80-90%, and the current health advisory on consumption of fish taken from the Sacramento River between Redding and Red Bluff may be lifted in the near future (Sacramento River Information Center 1993).

Heavy metal pollution caused by acid mine runoff principally from the Spring Creek basin continues to be a major source of water quality degradation and fish mortality in the upper Sacramento River. The Spring Creek Debris Dam (Figure 2-VII-1) was constructed by USBR in 1963 to control toxic discharges by coordinating releases with dilution flows from Shasta Reservoir and the Spring Creek Power Plant. Because of limited storage in Spring Creek Reservoir and availability of dilution flows, copper and zinc levels in downstream waters periodically exceed levels considered toxic to aquatic life (The Resources Agency 1989).

In 1984, the Central Valley Regional Water Quality Control Board (CVRWQCB) adopted water quality objectives for copper, zinc, and cadmium in the Sacramento River based on criteria developed by DFG (Table 2-VII-1).

The U.S. Environmental Protection Agency (EPA) listed the Spring Creek basin as an EPA Superfund cleanup site. EPA actions have reduced acid mine drainage and ongoing efforts are aimed at further remediation of toxic discharges. EPA selected a neutralization treatment plant as an interim strategy that will virtually eliminate existing threats to the Sacramento River fishery and the Redding municipal water supply (Sacramento River Information Center 1993).

Rearing -

Flow fluctuations and diversions - Fish losses due to stranding have not been well monitored or documented in Central Valley streams. Stranding of juvenile winter-run chinook salmon has occurred in the upper Sacramento River following rapid flow reductions associated with operation of the ACID's dam. Since 1970, limitations on flow reduction rates at Keswick Dam have minimized stranding losses (USBR 1983a).

Table 2-VII-1. Lethal concentrations of dissolved metals

Metal	96-hour LC10 (mg/l)	96-hour LC50 (mg/l)
Copper	19	32
Zinc	40	84
Cadmium	0.8	1.1

Note: mg/l = milligrams per liter.

Source: Vogel and Rectenwald (1987).

Flood control structures on the Sacramento River (Moulton, Colusa, Tisdale, and Fremont Weirs) divert Sacramento River water from the main river into the Butte Creek basin and the Sutter and Yolo Bypasses during major flood events. As a result, juvenile chinook salmon and other anadromous species migrating down the Sacramento River can be diverted into the bypasses, where they are subject to potential migration delays or entrapment as floodflows recede. Although juvenile fall-, spring-, and winter-run chinook salmon are likely to be present in the bypasses during major winter floods, survival rates associated with these migration routes are unknown. Adult salmon entering the bypasses during their upstream migration may be delayed or blocked by control structures in the bypass channels, but efforts have been made to alleviate passage problems by installing or upgrading fish ladders at known obstructions.

Riparian habitat - Riparian vegetation has been significantly reduced along much of the Sacramento River and its major tributaries as a result of agricultural conversion, urbanization, timber and fuel harvesting, channelization, levee construction, streambank protection, streamflow regulation, bank erosion, and other land use activities. Existing riparian woodland along the Sacramento River is less than 5% of its historical acreage and river edge vegetation is less than 50% of its historical extent (The Resources Agency 1989). Approximately 5-15% of the historical acreage remains on tributary streams (Mills and Fisher 1993).

Riparian loss has been greatest in the middle and lower reaches of the Sacramento River and Delta as a result of levee construction and bank protection projects. The most significant fisheries impacts are attributable to bank protection projects, which typically require removal of nearshore riparian vegetation, grading of the bank slope, and placement of rock revetment over the graded slope. Shaded riverine aquatic habitat is of greatest concern because of the unique fishery values associated with this habitat type and substantial losses that have already occurred. Replacement of naturally eroding banks with rock revetment has been shown to locally reduce densities of juvenile chinook salmon; chinook salmon densities in undisturbed areas are typically 4-12 times higher than in riprapped sites (Michny and Hampton 1984, Michny and Deibel 1986).

Levees and other flood control structures have drastically reduced the occurrence and extent of temporarily flooded terrestrial habitat that seasonally provided thousands of acres of potential rearing habitat for juvenile chinook salmon.

Since 1971, the U.S. Army Corps of Engineers (Corps) incorporated several features into the Chico Landing to Red Bluff Bank Protection Project to mitigate project impacts on fish and wildlife resources. The primary mitigation measures were using rock fill to save riparian vegetation that would otherwise be removed, replanting affected areas with riparian vegetation, and constructing artificial rearing benches or fish slopes.

Little information is available to assess food availability for juvenile chinook salmon in relation to environmental variation. Comparative studies of invertebrate production in revetted versus natural bank areas have not been conducted. Drift densities of invertebrate prey species were not substantially different between revetted and natural banks (Schaffter et al. 1983).

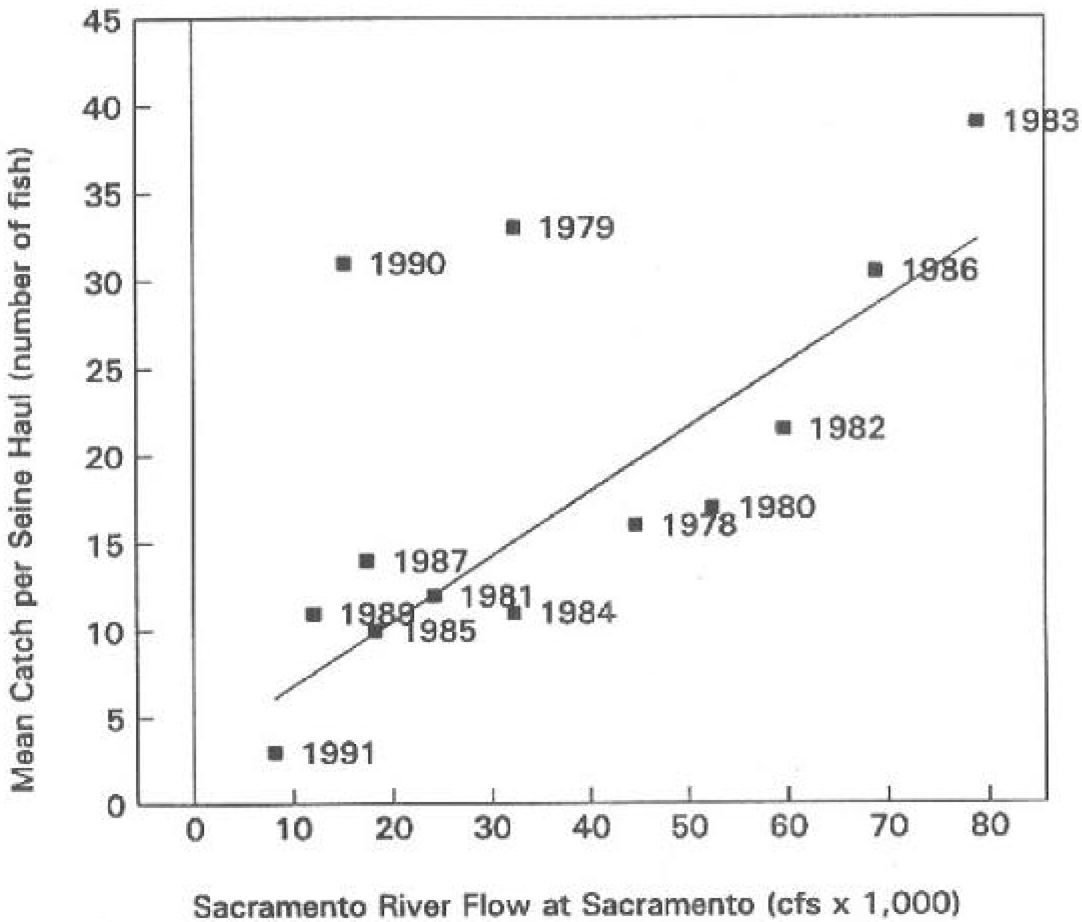
Downstream migration -

Flow and water temperature - In recent years, increased flow releases from Keswick Reservoir (up to 14,000 cubic feet per second [cfs]) and reduced diversions in May have been designed to assist the downstream migration of hatchery juveniles released in the upper Sacramento River (USBR 1986a). Correlations between Sacramento River flows during the chinook salmon smolt emigration period and the number of adults returning to Sacramento River tributaries (Dettman et al. 1987) indicate that flow, or factors related to flow, significantly affect chinook salmon survival and abundance.

The timing and distribution of chinook salmon emigration in the Sacramento system are affected by runoff conditions. In general, high flows during the early rearing period result in downstream displacement or active migration of large numbers of fry. Under low-flow conditions, most fry remain in upstream rearing areas and emigrate during the normal smolt emigration period. Fall-run chinook salmon fry abundance in the lower Sacramento River and northern Delta during the winter months generally increases as Delta inflow increases (Figure 2-VII-4). Peak numbers of fry in the lower Sacramento and Delta are associated with high winter flows or flow pulses in the Sacramento River (U.S. Fish and Wildlife Service [USFWS] 1993).

Figure 2-VII-5 shows a general relationship between average monthly Sacramento River flow to the Delta and the proportion of juveniles moving downstream. Factors influencing smolt emigration timing appear to be more closely related to growth rate, fish size, and water temperature, although increased flow may act to stimulate downstream migration (Wedemeyer et al. 1980). Downstream movement of juvenile chinook salmon may also be triggered by declining flow and rising water temperatures during the late spring months. Peak emigration rates generally occur at night or during periods of high turbidity (Vogel et al. 1988).

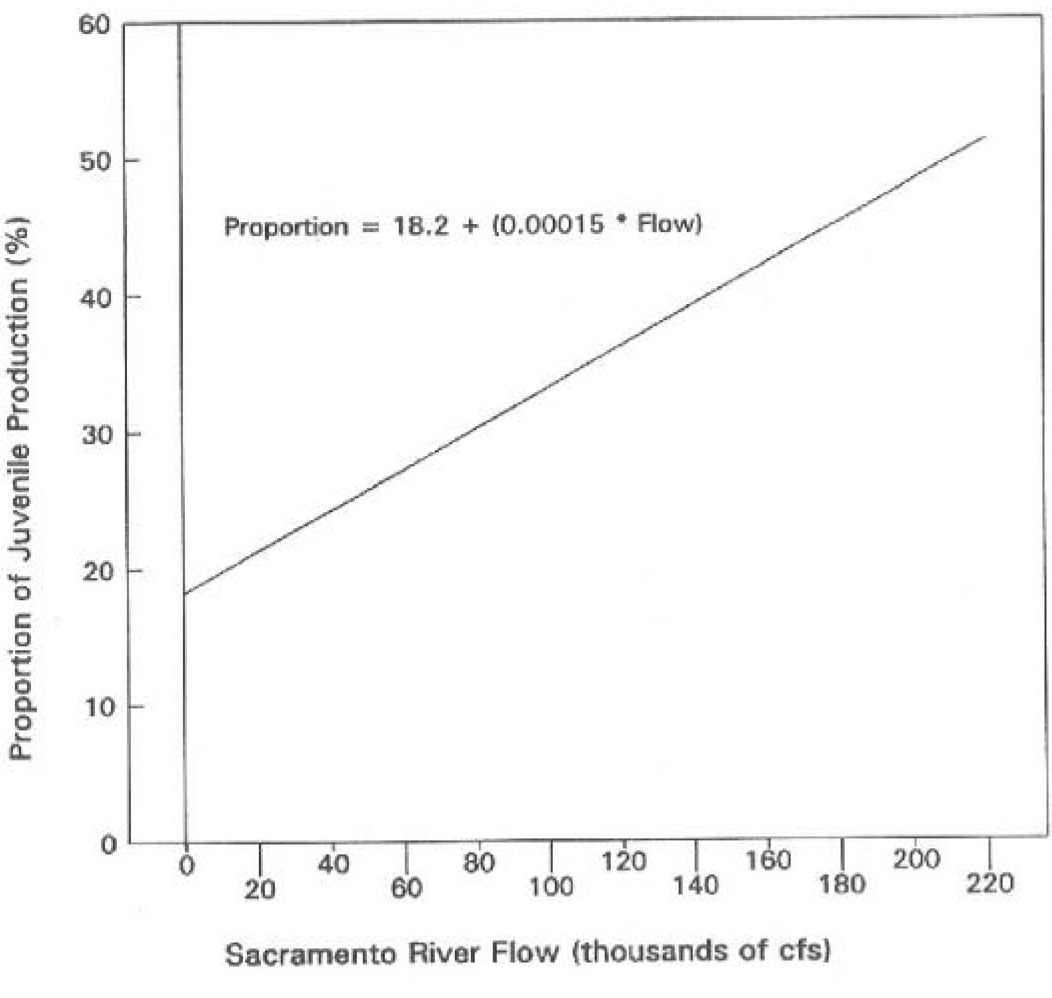
Mark-recapture studies of fall-run chinook salmon smolts demonstrated that smolt survival through the Delta was positively correlated with Sacramento River flows and negatively correlated with water temperatures and the fraction of Sacramento River flow diverted into the Delta Cross Channel (DCC) and Georgiana Slough during the April-June emigration period (USFWS 1987). Further studies designed to estimate the independent effects of these variables indicated that water temperature and diversions were key causal factors affecting smolt survival (Kjelson and Brandes 1988). A regression model was developed to estimate Delta smolt mortality as a function of Sacramento River water temperatures at Freeport, the fraction of Sacramento River flow diverted at Walnut Grove, and total State Water Project (SWP) and Central Valley Project (CVP) exports in the south Delta (Kjelson et al. 1989). Figure 2-VII-6 illustrates



SOURCE: U.S. Fish and Wildlife Service (1992).

RELATIVE ABUNDANCE OF CHINOOK SALMON FRY IN THE SACRAMENTO-SAN JOAQUIN DELTA VERSUS SACRAMENTO RIVER FLOW IN FEBRUARY (1978-1991)

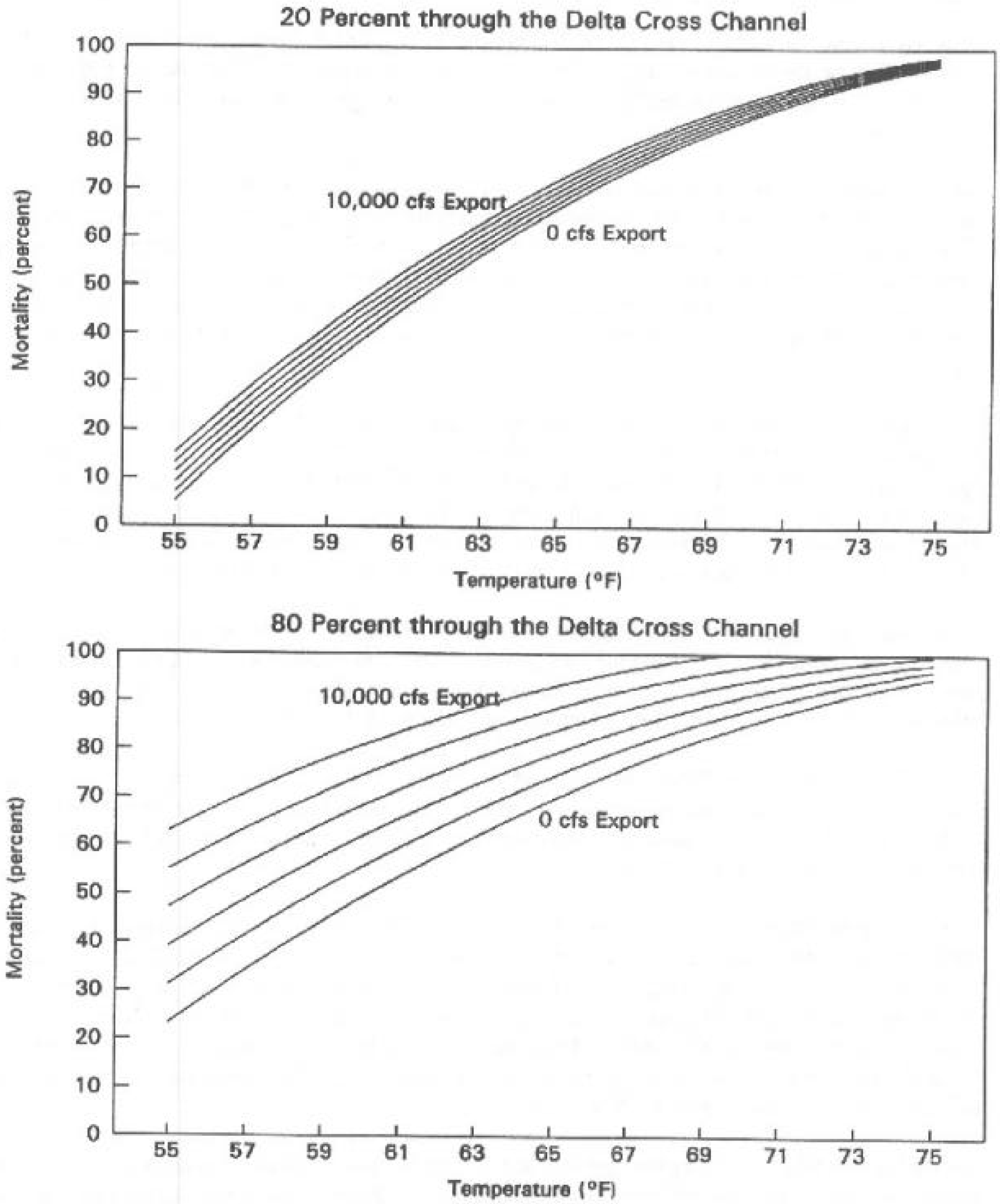
FIGURE 2-VII-4



SOURCES: Hillaire (1992) and U.S. Geological Survey (1992).

AVERAGE MONTHLY SACRAMENTO FLOW TO THE DELTA VERSUS PROPORTION OF JUVENILE PRODUCTION MOVING DOWNSTREAM

FIGURE 2-VII-5



SOURCE: Kjelson et al. (1989).

PREDICTED SACRAMENTO RIVER CHINOOK SALMON SMOLT MORTALITY THROUGH THE DELTA VERSUS SACRAMENTO RIVER WATER TEMPERATURE AND DELTA EXPORT PUMPING RATES

FIGURE 2-VII-6

model predictions for various combinations of water temperature, export pumping rates, and diversion fractions.

A general increase in the frequency of suboptimum water temperatures for juvenile chinook salmon in the lower Sacramento River appears to have occurred since the mid-1970s (Reuter and Mitchell 1987).

Diversions -

General - Fall-run and late fall-run chinook salmon juveniles are particularly vulnerable to diversion-related mortality because the smolt emigration period (April-June) generally coincides with the onset of the irrigation season (April-October). Chinook salmon losses are minimal during the summer irrigation season because juvenile salmon do not actively migrate during summer.

Winter-run chinook salmon are subject to diversion losses during the latter part of the irrigation season (September-October), after which diversions are negligible. Because of their earlier emergence time, spring-run chinook are likely somewhat less vulnerable to irrigation diversions than other races.

Annual variation in runoff conditions also affects the magnitude of diversion losses. High river flows during winter or early spring may displace large numbers of fall-run juveniles downstream of most of the unscreened diversions on the Sacramento River before diversion activity begins. Continued high spring flows delay the onset of diversions and maintain favorable survival conditions, including a high ratio of river discharge to volume diverted. Fish losses are generally increased under low-flow conditions because of little downstream displacement, earlier diversion activity, and less favorable survival conditions.

Total Sacramento River diversions, including riparian rights and CVP contract diverters, are 2.7 million acre-feet (maf) per year, plus an estimated 500,000 acre-feet of uncontracted diversions by riparian rights holders. Ten diverters account for most of the water diverted from the Sacramento River, and only three of these have fish screens or bypass systems. More than 300 unscreened diversions account for 1.2 Maf of water diverted annually in the Sacramento River. Annual losses of juvenile salmon in these diversions may reach 10 million fish (The Resources Agency 1989).

USBR initiated a Pilot Fish Screen Demonstration Program in 1993 to assist diverters in screening existing unscreened diversions along the Sacramento River. The main objective of the program is to participate with diverters in demonstrating approved fish screen technologies and experimenting with other technologies to evaluate their effectiveness in guiding fish safely past water diversions.

Specific - The ACID's diversion canal is screened but requires frequent maintenance and inspection. In general, potential impacts on downstream migrating salmon are considered minor because of the small proportion of juvenile salmon produced in the Sacramento River above the district's diversion canal (USBR 1986).

Losses of downstream migrating chinook salmon past the Tehama-Colusa Canal (TCC) and the RBDD during the winter and spring chinook salmon emigration period occur as a result of entrainment through the TCC headworks, physical injury as juveniles pass through the headworks fish bypass system, and predation as juvenile salmon pass under the RBDD gates or through the fish bypass system (Vogel et al. 1988). Maximum estimated losses attributable to entrainment and physical injury were 0.6% and 4.1%, respectively. Predation presumably accounted for the remainder of estimated losses, ranging from 16% to 55%.

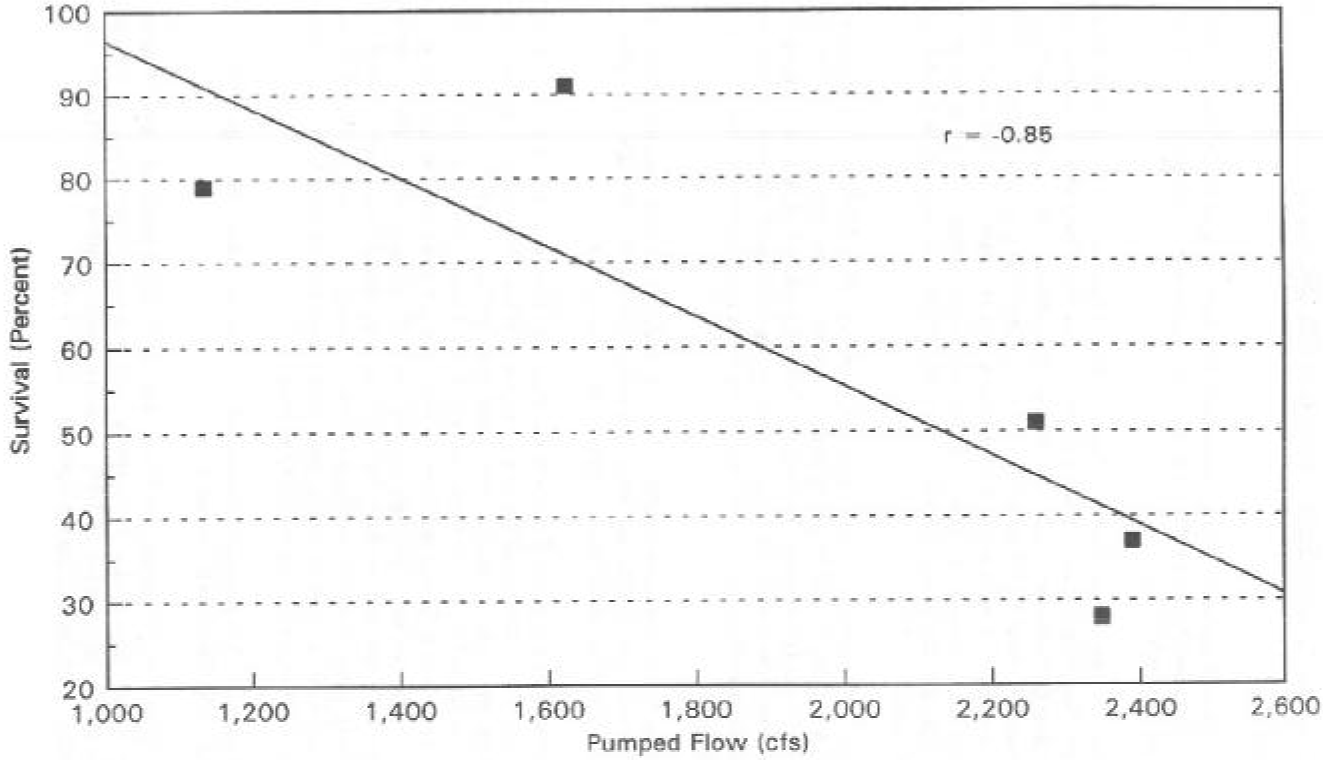
Raising the RBDD gates during the nonirrigation season is currently being implemented to facilitate upstream passage of adult winter-run chinook salmon. Downstream migrating juvenile salmon (primarily late fall- and winter-run salmon) also benefit from this measure because of unimpeded flow conditions past the dam, although predation rates during this period are thought to be low. The TCC headworks louver fish screens and bypass system were replaced with "state-of-the-art" rotary drum screens and an improved fish bypass system in 1990.

Past evaluations of screen efficiency and fish mortality at the Glenn-Colusa Irrigation District's (GCID's) diversion near Hamilton City have identified major problems in design and operation of the facility that have caused significant losses of downstream migrating salmonids. These problems included an inadequate bypass system, excessive approach velocities, and inadequate bypass flows. After construction of the present fish screens in 1972, natural degradation of the Sacramento River channel lowered the water elevation at the fish screen by 4 feet, causing excessive water velocities (up to 0.78 feet per second [fps]) at the screen face (relative to DFG's current criterion of 0.33 fps) at pumped flows over 1,500 cfs. (GCID et al. 1989.)

Recent mark-recapture studies using fall-run chinook salmon juveniles showed that the survival rates (i.e., fish bypass efficiencies) were negatively correlated to pumping flows (Figure 2-VII-7), indicating that fish losses were being caused by impingement, entrainment, or predation at the screen. The data also indicated that chinook salmon fry (less than 2 inches long) were more vulnerable to loss than larger juveniles or smolts; in general, fish bypass efficiency increased as fish size increased (Cramer et al. 1990).

An injunction obtained by the National Marine Fisheries Service (NMFS) against the GCID for the illegal take of winter-run chinook salmon requires the district to operate the diversion within specific criteria designed to avoid or minimize losses of winter-run chinook salmon. An environmental impact report/EIS is currently being prepared to identify a permanent solution to diversion impacts on all anadromous fish species (Beak Environmental Consultants in press). Potential solutions being evaluated include improving the existing screens and bypass system, constructing new screens, relocating the intake, restoring the gradient of the Sacramento River at the head of the GCID's diversion channel, or some combination thereof (58 FR 194, October 8, 1993).

Predation - Vogel et al. (1988) concluded that predation is the primary cause of downstream migrant salmon mortality at RBDD, accounting for losses ranging from 16% to 55%. Disorientation of downstream



SOURCE: Cramer et al. (1990).

ESTIMATED CHINOOK SALMON SURVIVAL RATE THROUGH GLENN-COLUSA IRRIGATION DISTRICT DIVERSION CHANNEL VERSUS FLOW PUMPED

FIGURE 2-VII-7

migrants as they pass under the dam gates or through the Tehama-Colusa headworks fish bypass system increases their vulnerability to predators. Predation by squawfish is particularly evident in spring when adult squawfish congregate at the RBDD during the emigration period for fall-run chinook salmon.

Yuba River

Downstream migration - Water temperature influences chinook salmon emigration timing. In the Yuba River, an extended period of cold water lasting into summer delays smolt emigration. Later emigrating smolts may experience higher water temperatures and increased mortality on reaching the lower Sacramento River and Delta (Jones & Stokes Associates 1992c).

Eastside Tributaries

Nearly all information on factors affecting abundance in Delta tributaries pertains to the Mokelumne River. *Upstream migration* -

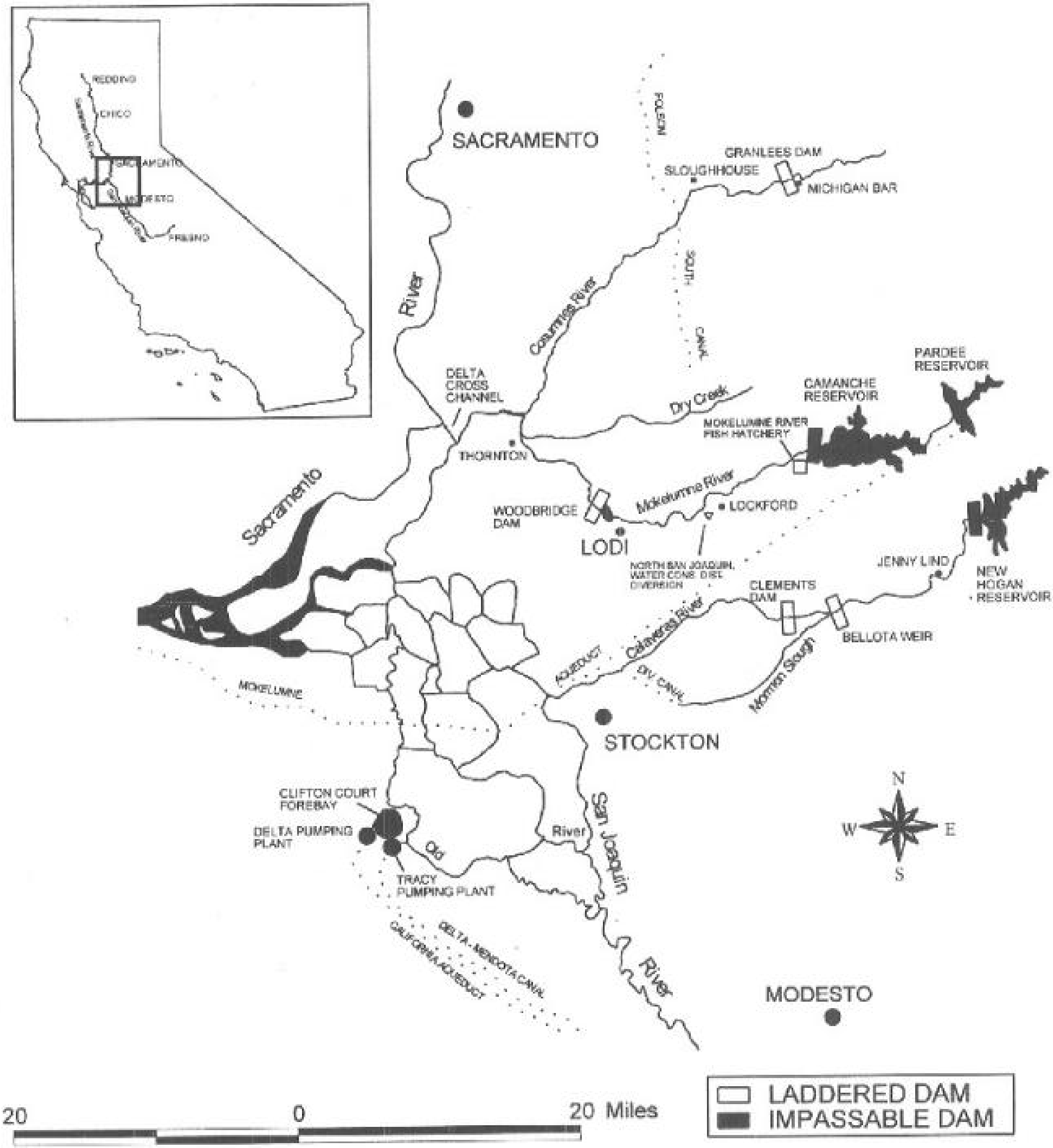
Passage barriers and flow - Using Thompson's (1972) criteria, DFG identified a shallow portion of the Mokelumne River near Thornton as a migration barrier to adult chinook salmon at flows less than 60 cfs (DFG 1991).

The major barrier to upstream migrating chinook salmon adults on the Mokelumne River is Woodbridge Dam. Woodbridge Dam, a flashboard dam constructed on the lower Mokelumne River in 1910, contained no fish ladder until 1925. Fish passage depended on river flows and the length of the irrigation season. Upstream migration of adult chinook salmon was generally possible only after the flashboards were removed at the end of the irrigation season (October). The fish ladder proved to be ineffective and was reconstructed in 1955. Recent analyses of passage conditions indicate that migration of adult chinook salmon past the dam is potentially impaired by spills that attract fish away from the fish ladder (DFG 1991).

Inadequate attraction and migration flows (generally less than 50 cfs) below Woodbridge Dam (Figure 2-VII-8) during October and November have resulted in poor adult returns to the Mokelumne River and Merced River Fish Facility. The failure of returning adults to detect Mokelumne River outflow may be exacerbated by diversion of proportionately large volumes of Sacramento River water into the lower Mokelumne River via the DCC and reverse flows in the lower San Joaquin River and south Delta channels.

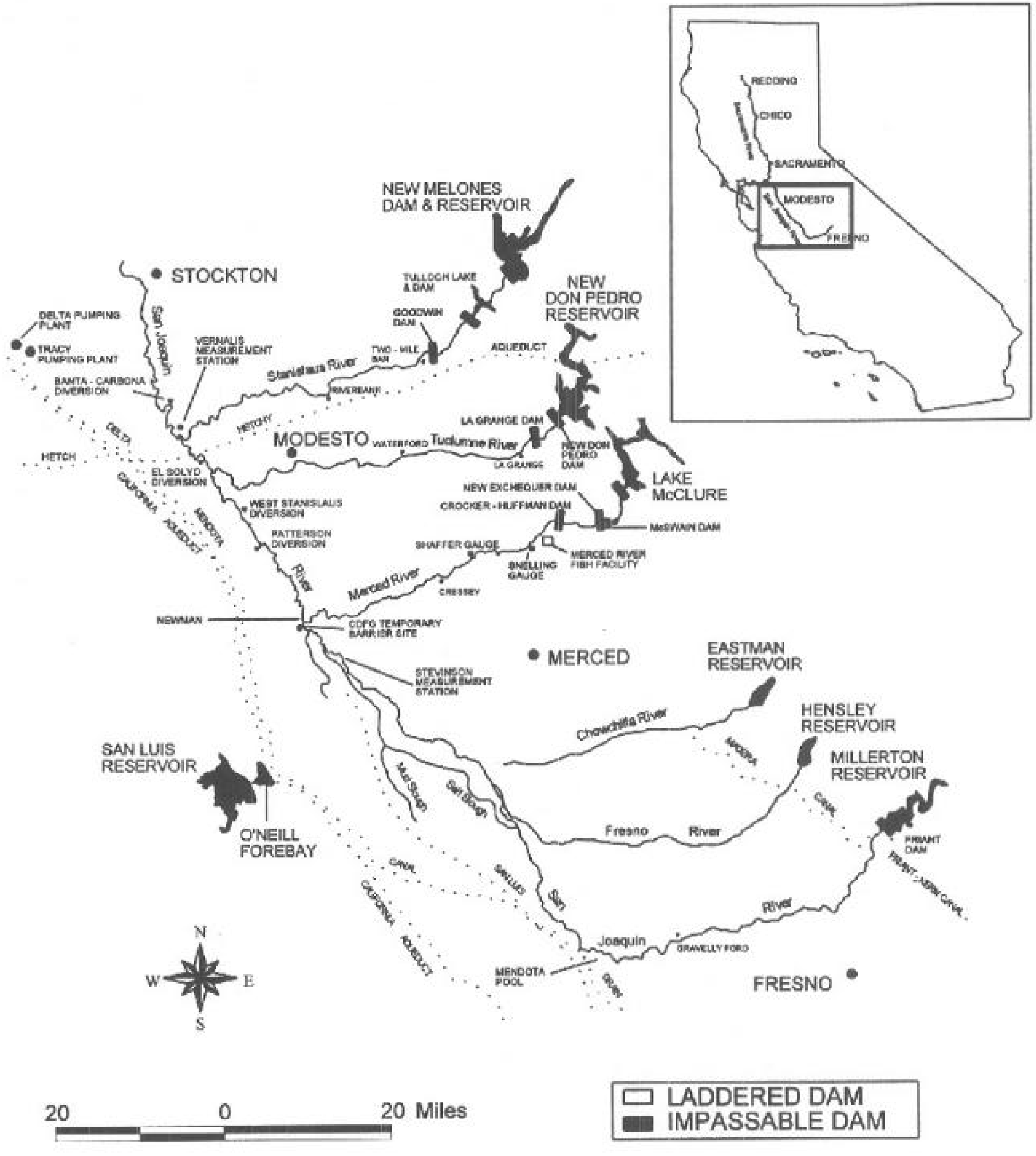
Water temperature and water quality - Upstream migration of adult chinook salmon in the Mokelumne River can be delayed by high water temperatures below Woodbridge Dam, which can persist until early November, even during a normal water year (DFG 1991).

Poor water quality conditions below Camanche Reservoir may adversely affect chinook salmon by inhibiting upstream migration of adult chinook to spawning areas. Water quality problems in the Mokelumne River have been associated with heavy metal pollution from Penn Mine, drought conditions, and Pardee and



MAP OF THE LOWER SACRAMENTO AND SAN JOAQUIN RIVERS DEPICTING THE EASTSIDE TRIBUTARY STREAMS

FIGURE 2-VII-8



MAP OF THE SAN JOAQUIN BASIN DEPICTING LOCATIONS OF THE STANISLAUS, TUOLUMNE, MERCED, AND SAN JOAQUIN RIVERS

FIGURE 2-VII-9

Comanche Reservoir operations. Recent fish kills at the Merced River Fish Facility were attributed to Camanche Reservoir discharges containing toxic levels of copper and zinc, low dissolved oxygen levels, and high concentrations of hydrogen sulfide. These conditions were associated with low inflows from Pardee Reservoir; record low reservoir levels; and hypolimnetic mixing, which may have mobilized sediments during the late summer and fall turnover of the reservoir (DFG 1991). DFG (1991) recommended water quality standards to protect aquatic resources in the receiving waters below Camanche Dam.

Spawning - Figure 2-VII-9 presents relationships between chinook salmon spawning habitat availability and flow for the Mokelumne River.

Suitable water temperatures for chinook salmon spawning in the Mokelumne River below Camanche Dam generally do not occur until early November during a normal water year. Water quality standards have been recommended by DFG, including water temperatures to protect aquatic resources, including adult chinook salmon spawners. (DFG 1991).

Camanche Dam also prevents the natural recruitment of gravel from upstream sources to spawning areas below the dam. Net losses of spawning gravels and a general increase in the size of streambed materials have reduced the amount of suitable spawning area. In addition, armoring or compaction of spawning substrate has reduced spawning gravel quality.

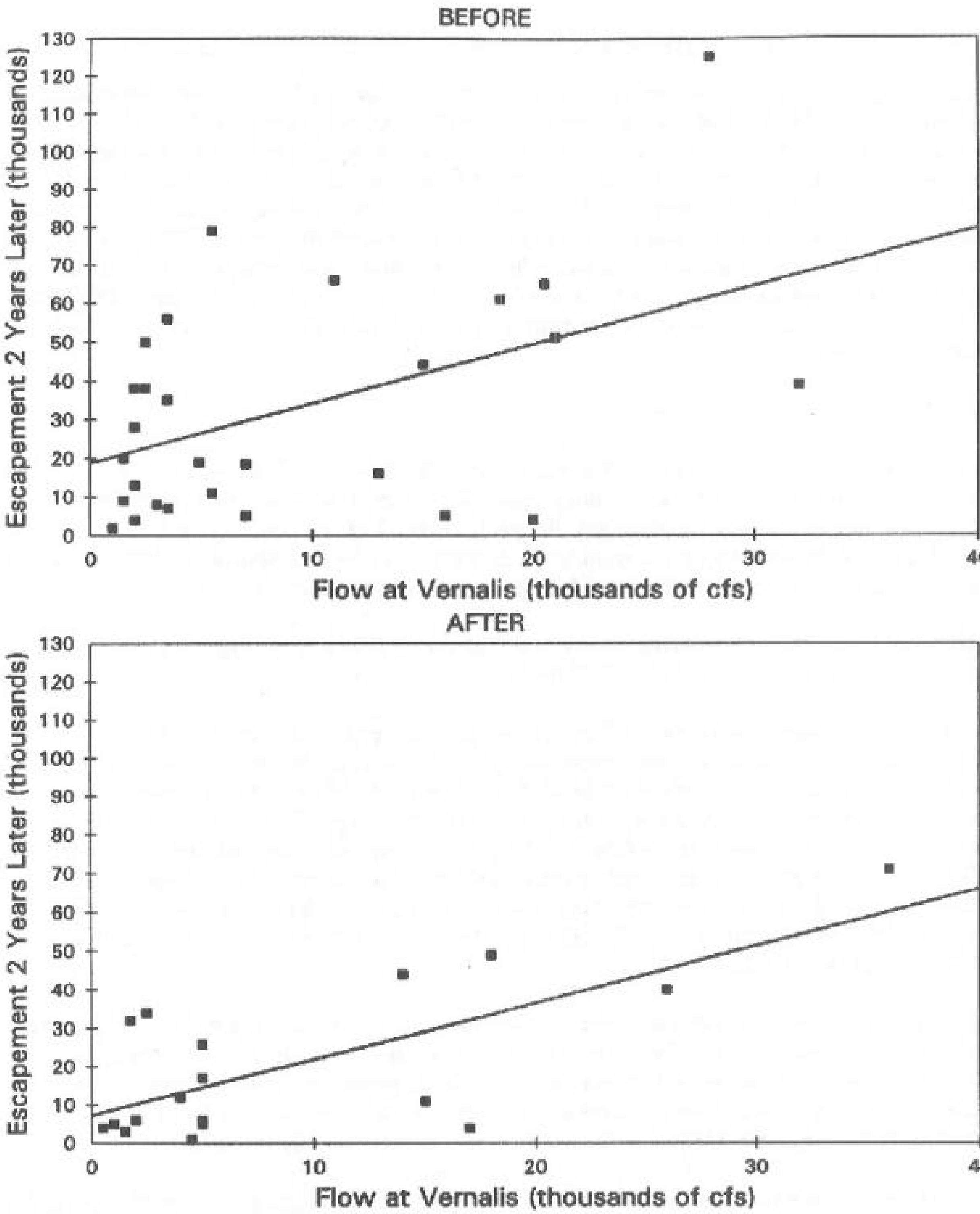
Incubation - Suitable water temperatures for chinook salmon incubation and emergence in the Mokelumne River below Camanche Dam generally do not occur until early November during a normal water year. Water quality and temperature standards recommended by DFG are designed to protect aquatic resources, including incubating eggs and fry. (DFG 1991).

Rearing - Figure 2-VII-10 presents relationships between chinook salmon rearing habitat availability and flow for the Mokelumne River.

Potential stranding of juvenile salmonids as a result of flow fluctuations was evaluated in several reaches downstream of Camanche Dam based on predicted changes in wet surface area over a range of flows. The stranding potential increased at flows below 400 cfs. Rapid flow reductions also increased the stranding potential. (DFG 1991.)

Water temperatures in the Mokelumne River below Camanche Dam remained within suitable levels for juvenile rearing and emigration through June during a normal water year. Water temperatures exceed suitable levels from March to early June at Woodbridge Dam during all water year types examined. Under existing project operations, water temperatures at Woodbridge Dam are strongly influenced by air temperatures. (DFG 1991.)

Water temperatures exceed suitable levels by April to early May at the Cosumnes River confluence.



SOURCE: California Department of Fish and Game (1987b).

TOTAL ESCAPEMENT IN THE SAN JOAQUIN DRAINAGE AND VERNALIS FLOWS BEFORE AND AFTER THE EXISTING STATE WATER PROJECT IN THE SOUTH DELTA VERSUS MAJOR STORAGE INCREASES IN THE SAN JOAQUIN DRAINAGE

FIGURE 2-VII-10

Downstream migration - Dry year flows in the lower Mokelumne River below Woodbridge Dam during the spring chinook salmon emigration period are inadequate to effectively convey juvenile chinook salmon migrants downstream and through the Delta. Juvenile chinook salmon in the Mokelumne River are allowed to migrate naturally to the ocean in wet year types but are trapped at Woodbridge Dam and trucked to Rio Vista in drier years. In general, peak adult returns to the Mokelumne River indicate favorable rearing and emigration conditions during preceding wet years. Nearly all chinook salmon produced at the Merced River Fish Facility are trucked as yearlings to release locations in the western Delta.

Major diversions affecting juvenile chinook salmon emigrants from the Mokelumne River are the Woodbridge Canal diversion and the south Delta SWP and CVP export facilities. The Woodbridge Canal diversion was screened in 1968 and currently operates from April to October, depending on irrigation demands. The Woodbridge Canal fish screen currently does not meet current DFG fish screen velocity and design criteria but has not been shown to result in significant losses of downstream migrants. Delta export facilities effects on juvenile salmon are discussed under the "Sacramento River" section.

Smolts migrating naturally out of the Mokelumne River are exposed to Delta flow patterns in the central and south Delta. Mark-recapture studies indicate that juvenile chinook salmon released in the lower Mokelumne River experience higher mortality than those released in the Sacramento River below the DCC under dry year conditions (USFWS 1987). Reverse flows caused by CVP and SWP export pumping in the south Delta contribute to poor survival of juvenile chinook salmon that enter the central Delta from the Mokelumne River or from the Sacramento River via the DCC or Georgiana Slough. Other mortality factors associated with this migration route are high water temperatures, predation, unscreened agricultural diversions, and direct entrainment losses at the south Delta pumps. These factors would also affect down-stream migrant chinook salmon from the Cosumnes and Calaveras rivers.

San Joaquin River

Upstream migration and spawning - For many years, attraction flows from the Merced River have been inadequate during October, resulting in straying of adult salmon into agricultural drainage ditches, primarily Mud and Salt Sloughs (Figure 2-VII-8). Barriers (electrical and physical) were installed across the San Joaquin River upstream of the Merced River confluence in 1992 to prevent salmon migration into these sloughs and help guide them into the Merced River.

Hallock et al. (1970) found that chinook salmon initiated migration into the lower San Joaquin River as water temperatures declined from 72^{o}F to 66^{o}F.

Low dissolved oxygen levels (less than 5 parts per million) and high water temperatures (greater than 66^{o}F) in the San Joaquin River near Stockton delayed or blocked the migration of adult chinook salmon during the 1960s (Hallock et al. 1970). Since 1964, fall migration problems have been reduced by improved wastewater treatment and installation of a physical barrier at the head of Old River in dry years to direct most of the San Joaquin flows down the main channel past Stockton. Despite these efforts, low dissolved oxygen levels recurred during recent drought conditions. Remedial measures that are currently proposed include increasing tributary outflow, evaluating and monitoring dredging activity in the Delta, and further evaluating the fall barrier at Old River (The Resources Agency 1992).

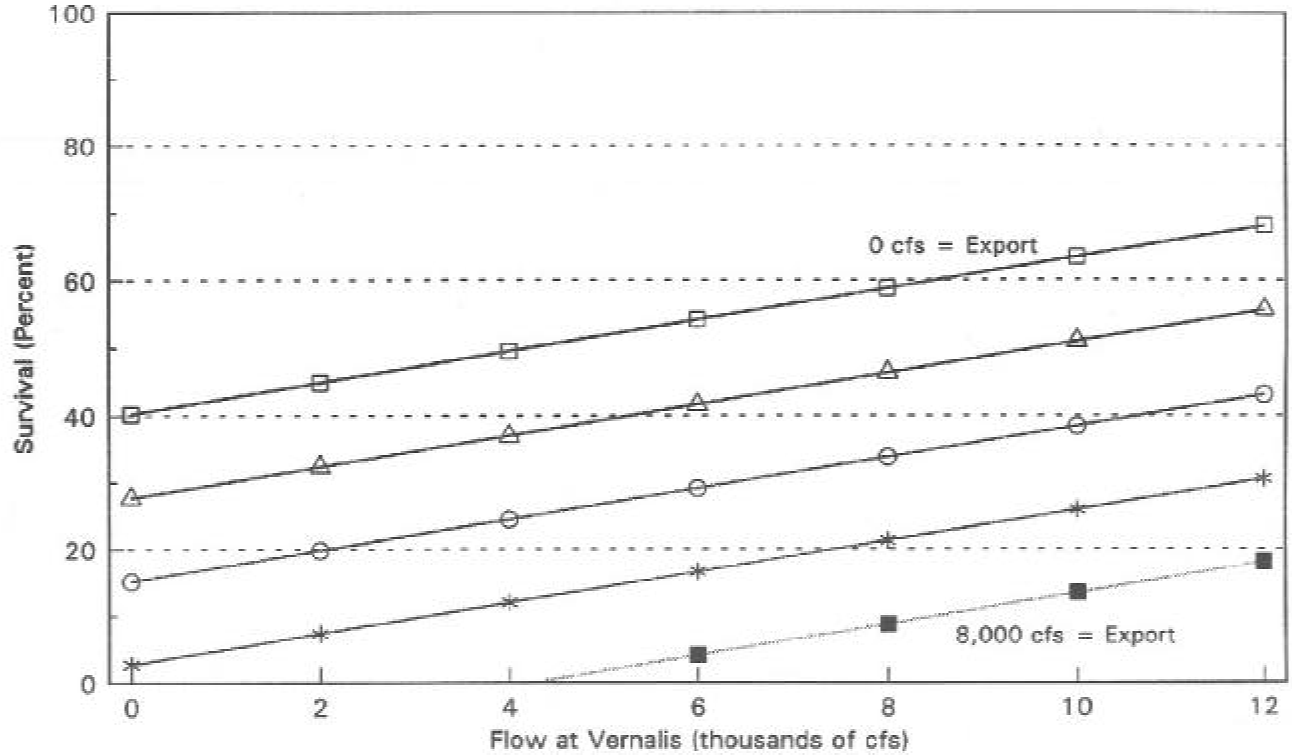
Rearing - Selenium in agricultural drainage water poses a potential risk to juvenile chinook salmon in the main San Joaquin River. Selenium is directly toxic to fish at elevated levels in the water column and through bioaccumulation in body tissues. Growth and survival of juvenile chinook salmon are adversely affected by exposure to dissolved and dietary selenium, but harmful levels have not been detected in the major San Joaquin River and tributary rearing areas (DFG 1987b).

Downstream migration - Spring flows in the San Joaquin River and major tributaries during the chinook salmon emigration period appear to have a major influence on the number of adults returning to San Joaquin River basin. Significant positive correlations exist between spring flows in the San Joaquin River and total chinook salmon spawning escapement 2.5 years later (Figure 2-VII-10). Similar relationships for San Joaquin River tributary stocks indicate that the flow required to maintain a given spawning escapement level increased following operation of the CVP and SWP. Over time, increases in the significance of other mortality factors, such as increased Delta exports, have diminished the positive effects of incremental increases in spring flows. (DFG 1987b.)

Declining streamflow during the spring emigration period of fall-run chinook salmon coincides with rising air temperatures and increased agricultural return flows to the San Joaquin River, often resulting in deleterious water temperatures along much of the emigration route in the lower San Joaquin River. In May, water temperatures in the San Joaquin River near Vernalis often reach high chronic stress levels (greater than 67.6^{o}F) at flows of 5,000 cfs or less. Under these conditions, up to half the production of San Joaquin River chinook salmon can be subjected to harmful water temperatures. (DFG 1987b.)

Smolts migrating down the San Joaquin River and through the southern Delta frequently encounter low flows, high temperatures, and high diversion rates. Currently proposed spring outflow recommendations for the Merced, Tuolumne, and Stanislaus rivers are designed to improve survival of juvenile salmon migrating down the tributaries, mainstem San Joaquin River, and through the Delta. Recent evaluations have focused on the effectiveness of releasing short-duration, high-amplitude flows (i.e., pulsed flows) from tributary streams in conjunction with reduced Delta exports.

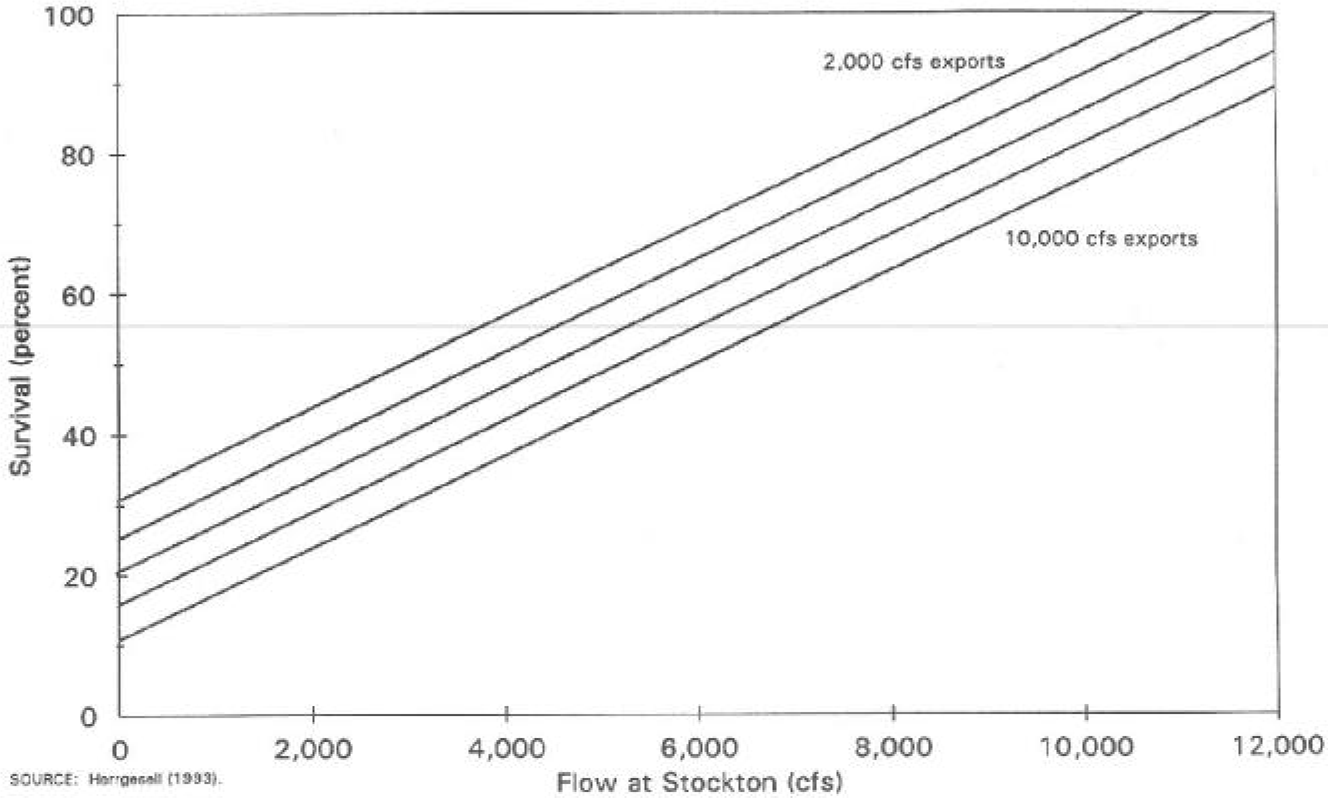
Existing data indicate that pumping by the CVP and SWP export facilities in the south Delta has a major impact on survival of emigrating juvenile chinook salmon. High juvenile mortality in the lower San Joaquin River and Delta is associated with low spring outflows and corresponding increases in the proportion of San Joaquin River flow diverted by CVP and SWP export facilities. At low San Joaquin River flow, high diversion rates increase the proportion of San Joaquin River flow drawn toward the pumps via Old River. Juvenile salmon, diverted with the flow, experience reduced survival associated with increased migration time, high water temperatures, predation, entrainment in unscreened agricultural diversions, and Delta export



SOURCE: Hengesell (1993).

PREDICTED SAN JOAQUIN RIVER CHINOOK SALMON SMOLT SURVIVAL VERSUS FLOW AT VERNALIS AND COMBINED CENTRAL VALLEY PROJECT/STATE WATER PROJECT EXPORTS

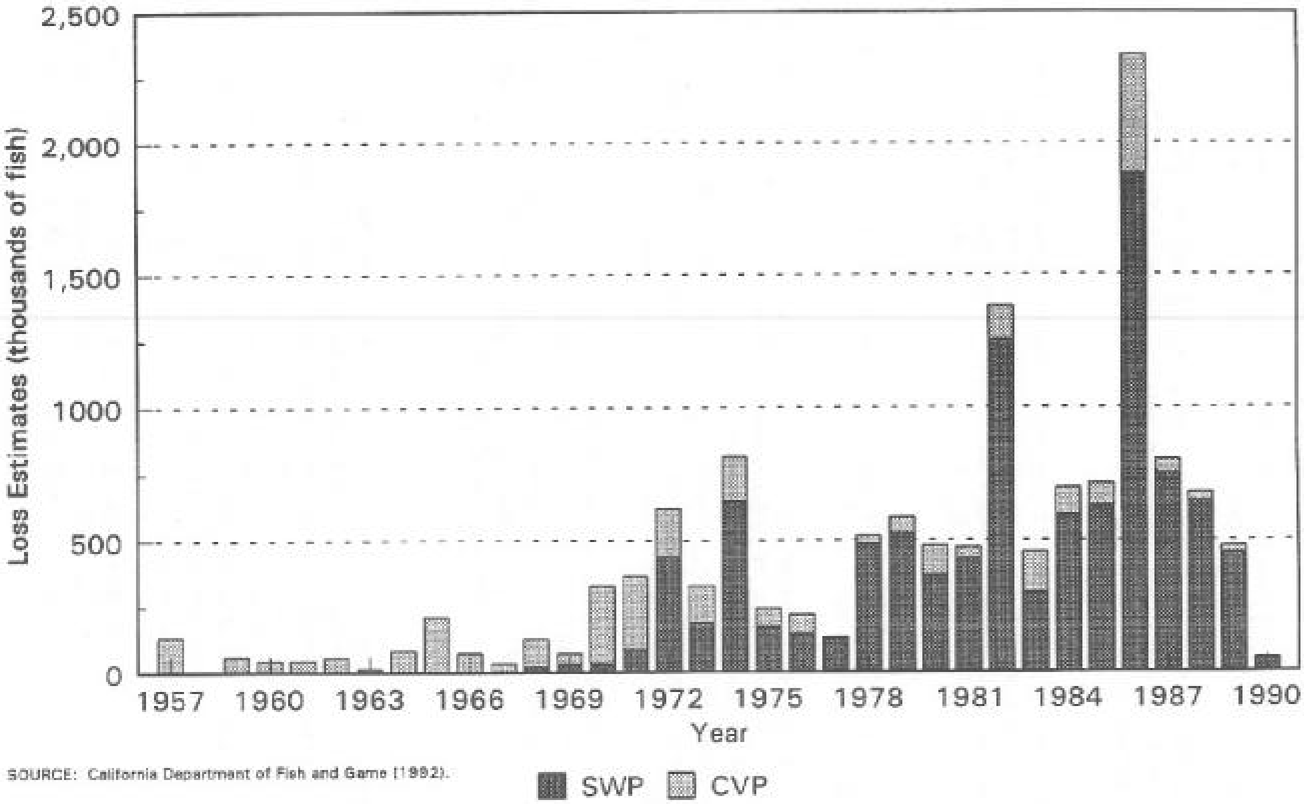
FIGURE 2-VII-11



SOURCE: Herrgesell (1993).

PREDICTED SAN JOAQUIN RIVER CHINOOK SALMON SMOLT SURVIVAL THROUGH THE DELTA VERSUS FLOW AT STOCKTON AND COMBINED CENTRAL VALLEY PROJECT/ STATE WATER PROJECT EXPORTS WITH A BARRIER AT THE HEAD OF OLD RIVER

FIGURE 2-VII-12



SOURCE: California Department of Fish and Game (1992).

CHINOOK SALMON LOSS ESTIMATES FOR THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT FACILITIES (1957-1990)

FIGURE 2-VII-13

pumping. Mark-recapture studies since 1985 demonstrated that chinook salmon smolts released in the San Joaquin River downstream of the head of Old River survived better than those released into upper Old River (USFWS 1987, 1990) (Figure 2-VII-11). Maximum survival benefits are expected by installing a barrier at the head of Old River during the spring emigration period in combination with reduced exports and increased San Joaquin flows (USFWS 1993) (Figure 2-VII-12).

Most chinook salmon reaching the CVP and SWP export facilities in the south Delta are from the San Joaquin basin (USBR 1986b). Monthly salvage estimates at the CVP and SWP export facilities indicate the primary periods when juvenile chinook salmon are vulnerable to direct entrainment losses and mortality associated with salvage operations (Figure 2-VII-13).

San Joaquin River Tributaries

Upstream migration and spawning - Figure 2-VII-18 presents relationships between chinook salmon spawning habitat availability and flow for the Merced, Tuolumne, and Stanislaus rivers.

Water temperatures below major reservoirs in the San Joaquin River tributaries frequently do not permit successful spawning of fall-run chinook salmon until November.

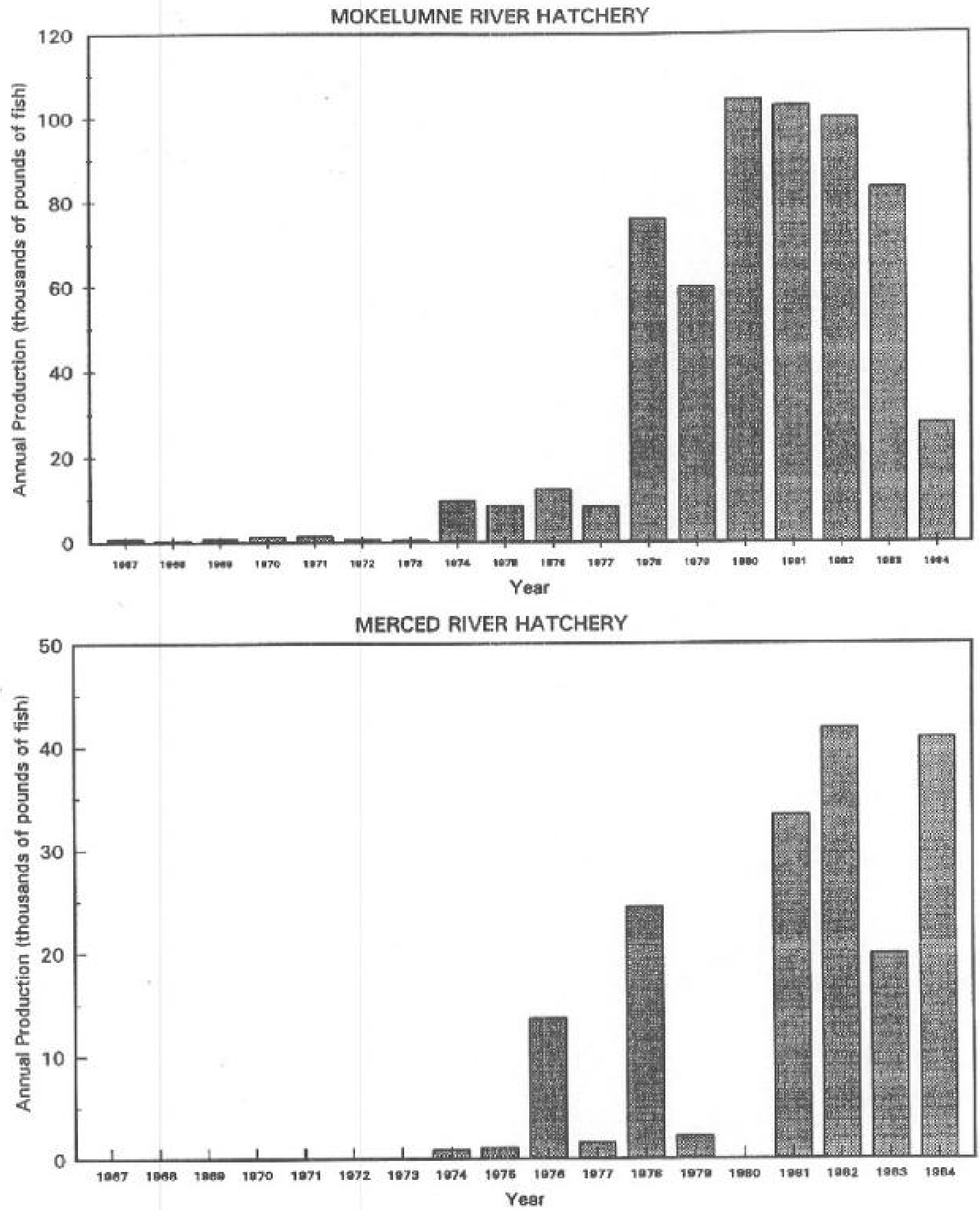
Although spawning habitat does not appear to be limiting recovery of fall-run chinook salmon stocks in the San Joaquin River basin, spawning gravel restoration may be needed in the future to offset gravel depletions below dams and provide sufficient spawning habitat to accommodate future adult populations.

The fishery management agencies have proposed an interim temperature objective of 42-56^{o}F throughout the designated chinook salmon spawning reaches in the Tuolumne, Merced, and Stanislaus rivers during the fall-run spawning and incubation periods. Special water operations using this objective were implemented on the Stanislaus River in 1991 and 1992 (The Resources Agency 1992).

Rearing - Figure 2-VII-14 presents relationships between chinook salmon rearing habitat availability and flow for the Merced, Tuolumne, and Stanislaus rivers.

Streamflow has been identified as the primary factor affecting abundance of chinook salmon stocks in the San Joaquin River basin. Streamflow reductions after April and May in the Merced and Tuolumne rivers result in poor survival conditions for chinook salmon juveniles that remain in these tributaries beyond these months. High mortality is generally the result of reduced living space, high water temperatures, and increased predation. Current interim instream flow requirements in the Stanislaus River provide adequate flow conditions through the chinook salmon rearing period.

Generally, water temperatures below major dams on the San Joaquin River tributaries become unsuitable for chinook salmon rearing in May or June, causing high mortality of juvenile chinook salmon that have not emigrated. In the Stanislaus River, however, releases of cold hypolimnetic water from New Melones



SOURCES: California Trout, Salmon, and Warmwater Fish Production and Costs (1967-85).

ANNUAL PRODUCTION OF CHINOOK SALMON AT MOKELUMNE AND MERCED RIVER HATCHERIES (1967-1991)

FIGURE 2-VII-14

Reservoir have improved water temperatures during the late spring rearing period relative to preimpoundment conditions (USBR 1986b).

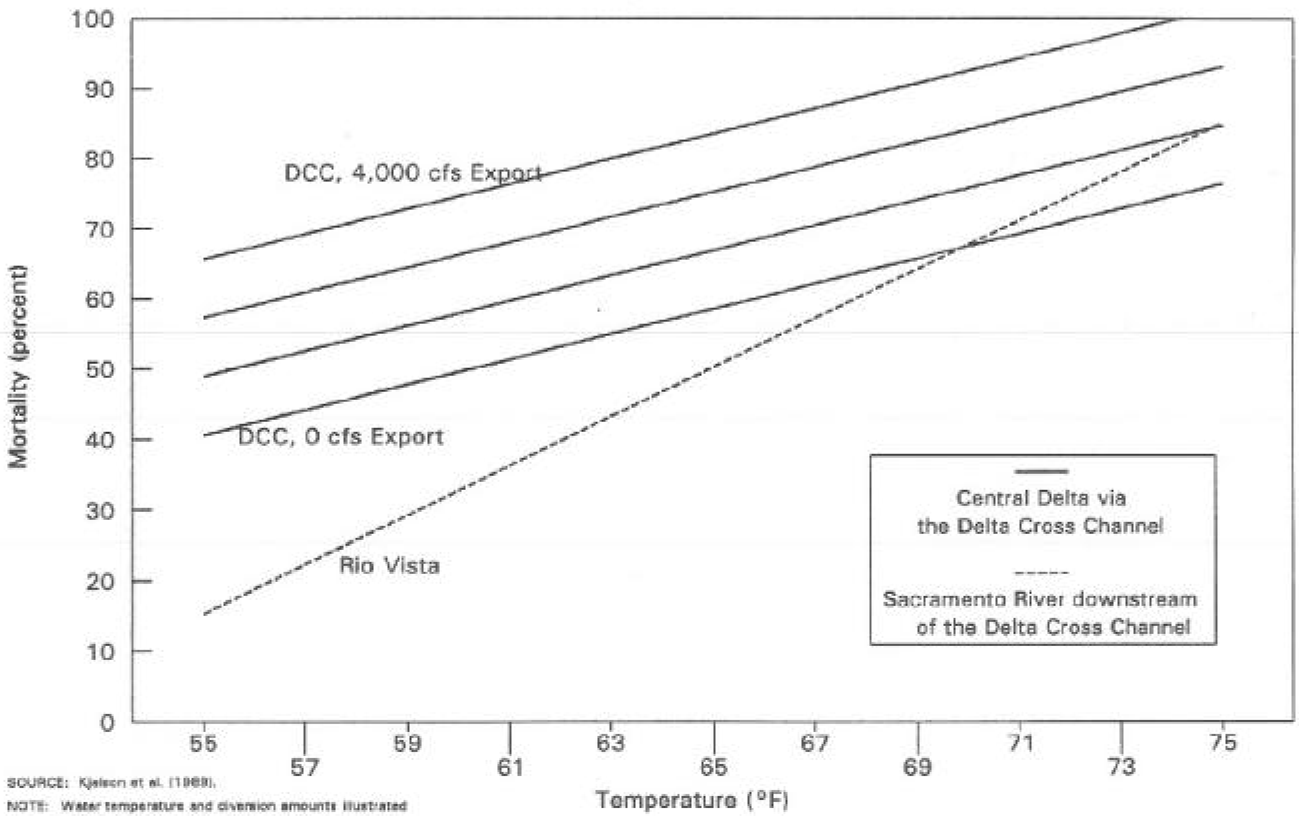
Delta/Bay

Upstream migration - High export pumping and diversion of Sacramento River water into the central and south Delta may increase the number of adult salmon gaining access to the Sacramento River via the Mokelumne River and DCC or Georgiana Slough. During upstream migration, adult salmon primarily use their sense of smell to find their home stream. Thus, salmon destined for the Sacramento River that are drawn into the central Delta may be delayed by the longer migration distance and greater number of channels that must be negotiated in this portion of the Delta. Large volumes of Sacramento River water and reverse flows in the lower San Joaquin River can also inhibit or delay migration of San Joaquin River spawners (Hallock et al. 1970).

Downstream migration - The SWP (Banks) and CVP (Tracy) export facilities in the south Delta adversely affect anadromous fish survival in the Delta through direct entrainment losses and indirect effects related to changes in the magnitude and direction of flow in the Delta channels. Increases in upstream storage and diversions over the last 20 years have significantly reduced inflow to the Delta. Reduced inflow, in combination with increased diversions from the Delta, has caused increasing adverse impacts on anadromous and resident species by reducing net flow through the Delta and Delta outflow; causing reverse flow conditions in central and south Delta channels; and increasing entrainment of fish eggs, larvae, and juveniles. Unscreened Delta diversions have contributed to fish losses.

Fall-run salmon smolts diverted from the Sacramento River into the central Delta via the DCC or Georgiana Slough experience higher mortality rates than smolts that remain in the Sacramento River (Figure 2-VII-15). At a given water temperature, the survival of hatchery fall-run chinook salmon smolts that enter the DCC averages about 50% less than for smolts released in the Sacramento River below the DCC diversion when Delta exports total about 3,000 cfs. Poor survival of smolts diverted into the central Delta is attributed to increased migration time, high water temperatures, predation, entrainment in unscreened agricultural diversions, and exposure to reverse flows in the central and south Delta channels. The proportion of Sacramento River flow diverted and total Delta exports are important regression variables in the U.S. Fish and Wildlife Service's Delta mortality model for chinook salmon smolt (Kjelson et al. 1989). Recent mark-recapture experiments provide evidence that a positive net flow at Jersey Point increases the survival of salmon migrating down both the Sacramento and San Joaquin rivers, including those migrants that are diverted from the Sacramento River into the central Delta and move to the San Joaquin via the Mokelumne River (USFWS 1993) (Figure 2-VII-16).

Delta flow and operational criteria established by the NMFS for protection of winter-run chinook salmon for February 15, 1993, through February 15, 1994, included closing the DCC gates during the main emigration period through the Delta and operating the CVP and SWP Delta export facilities to maintain

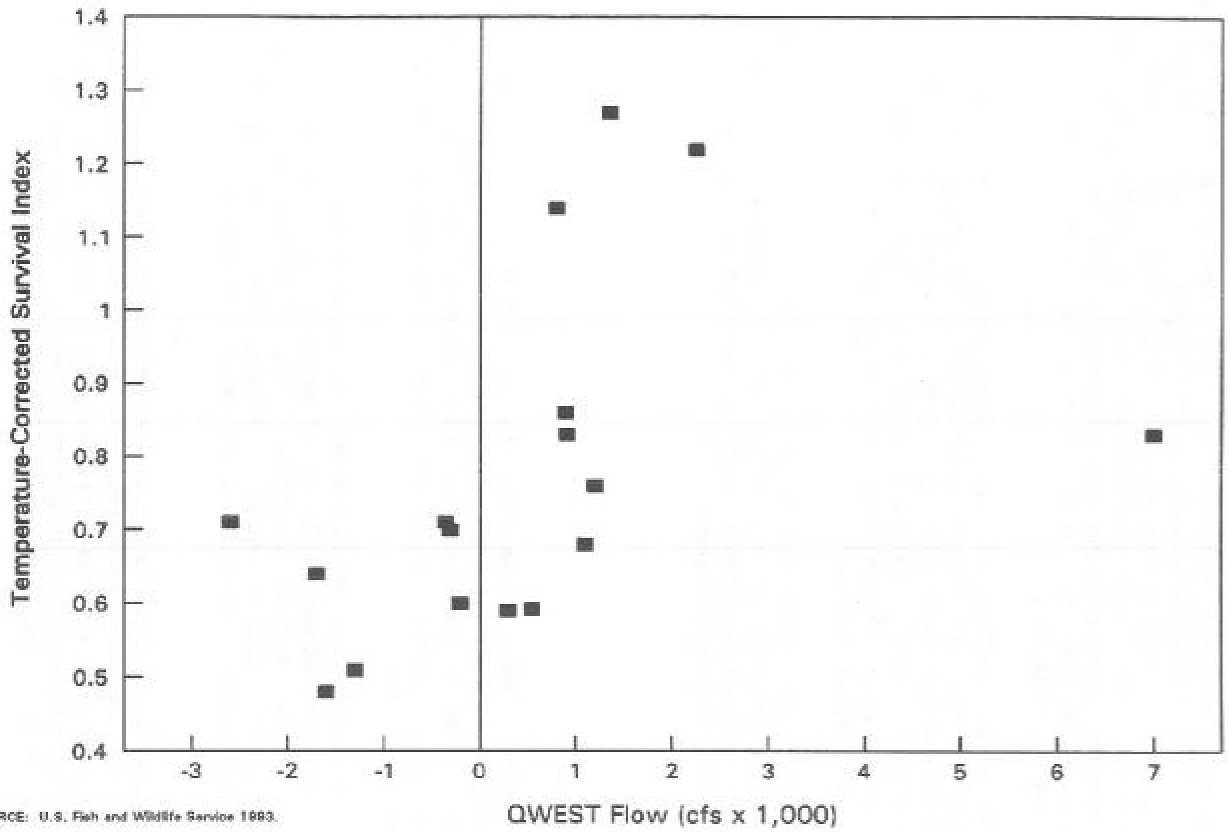


SOURCE: Kjelson et al. (1989).

NOTE: Water temperature and diversion amounts illustrated for the Delta Cross Channel route only.

PREDICTED SACRAMENTO RIVER CHINOOK SALMON SMOLT MORTALITY FOR TWO DELTA MIGRATION PATHWAYS VERSUS SACRAMENTO RIVER WATER TEMPERATURE

FIGURE 2-VII-15



SOURCE: U.S. Fish and Wildlife Service 1993.

TEMPERATURE-CORRECTED SURVIVAL FOR FISH RELEASED AT RYDE VERSUS QWEST FLOW (1984-1992)

FIGURE 2-VII-16

specific minimum running average QWEST (i.e., computed net flow at Jersey Point) values during the Delta rearing and emigration periods (NMFS 1993).

Entrainment - Annual losses of chinook salmon at the SWP and CVP Delta export facilities have usually ranged from 400,000 to 800,000 in recent years, assuming 75% mortality in Clifton Court Forebay (CCF) (Figure 2-VII-13). Salvage records from the SWP pumping plant indicate salmon fry and smolts are entrained year-round, but peak levels generally occur in late winter and spring when fall-run chinook salmon pass through the Delta (Figure 2-VII-5). Juvenile chinook salmon salvaged at the SWP export facility during December 1992-April 1993 were classified according to race based on size criteria developed by DFG. Although fall-run chinook salmon produced in the Sacramento River presently constitute about 80% of the total number of chinook salmon passing through the estuary, only a small percentage of chinook salmon juveniles released in the Sacramento River typically reach the CVP and SWP export pumps (USFWS 1987). Most salmon juveniles salvaged at the Delta pumps during the spring are from the San Joaquin River.

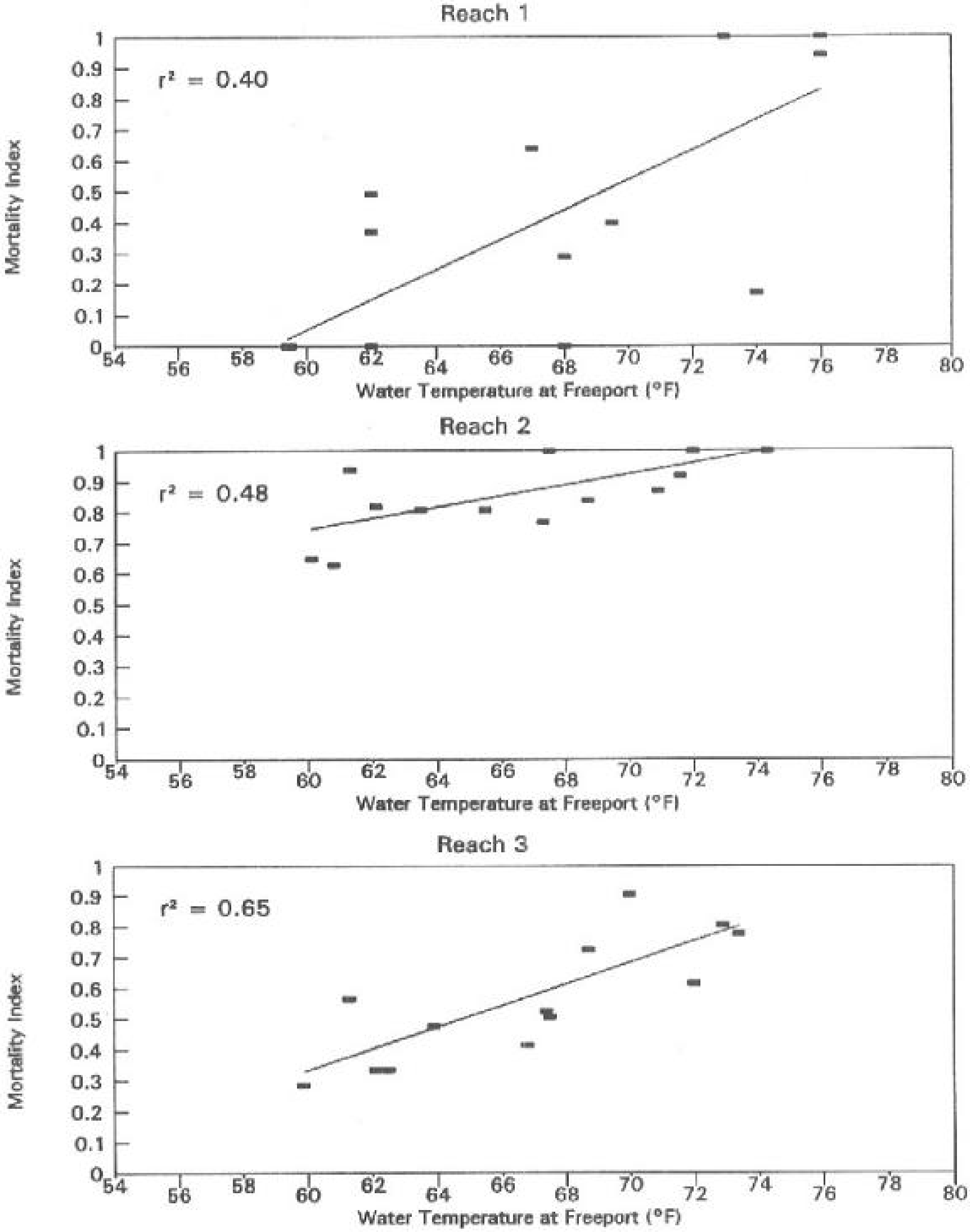
Unknown numbers of salmon are also entrained in other Delta diversions, including over 1,800 unscreened agricultural diversions; the Contra Costa Canal; the City of Vallejo diversion; and western Delta industry diversions (DWR 1993).

Water temperature - The Delta chinook salmon smolt mortality model includes three predictive relationships describing changes in smolt mortality as a linear function of water temperature for three major Delta reaches (Figure 2-VII-17). Based on multiple regression analysis, water temperature was found to be the best predictor of smolt mortality among the major environmental variables thought to influence smolt survival in each of the three reaches (Kjelson et al. 1989). Smolt survival appears to decline at temperatures above 60°F, indicating that sublethal effects may be occurring at relatively low water temperatures in the Delta.

Predation - Predation by striped bass is considered the primary cause of high pre-screening mortality of juvenile chinook salmon at the SWP export facility in the south Delta. Although data are limited, estimated losses of juvenile chinook salmon entrained into CCF range from 63% to 86% (DFG 1987a). Predation losses at the CVP export facility are assumed to be lower because of the absence of extensive predator habitat. The significance of predation at other diversion facilities and in the Delta has not been adequately evaluated.

Suisun Marsh Salinity Control Structure - The Suisun Marsh Salinity Control Structure, designed to improve water quality in Montezuma Slough and Suisun Marsh during periods of low to moderate Delta outflow, may delay upstream migration of adult chinook salmon and other anadromous species when it is operating (Herrgesell 1993) (Figure 2-VII-18).

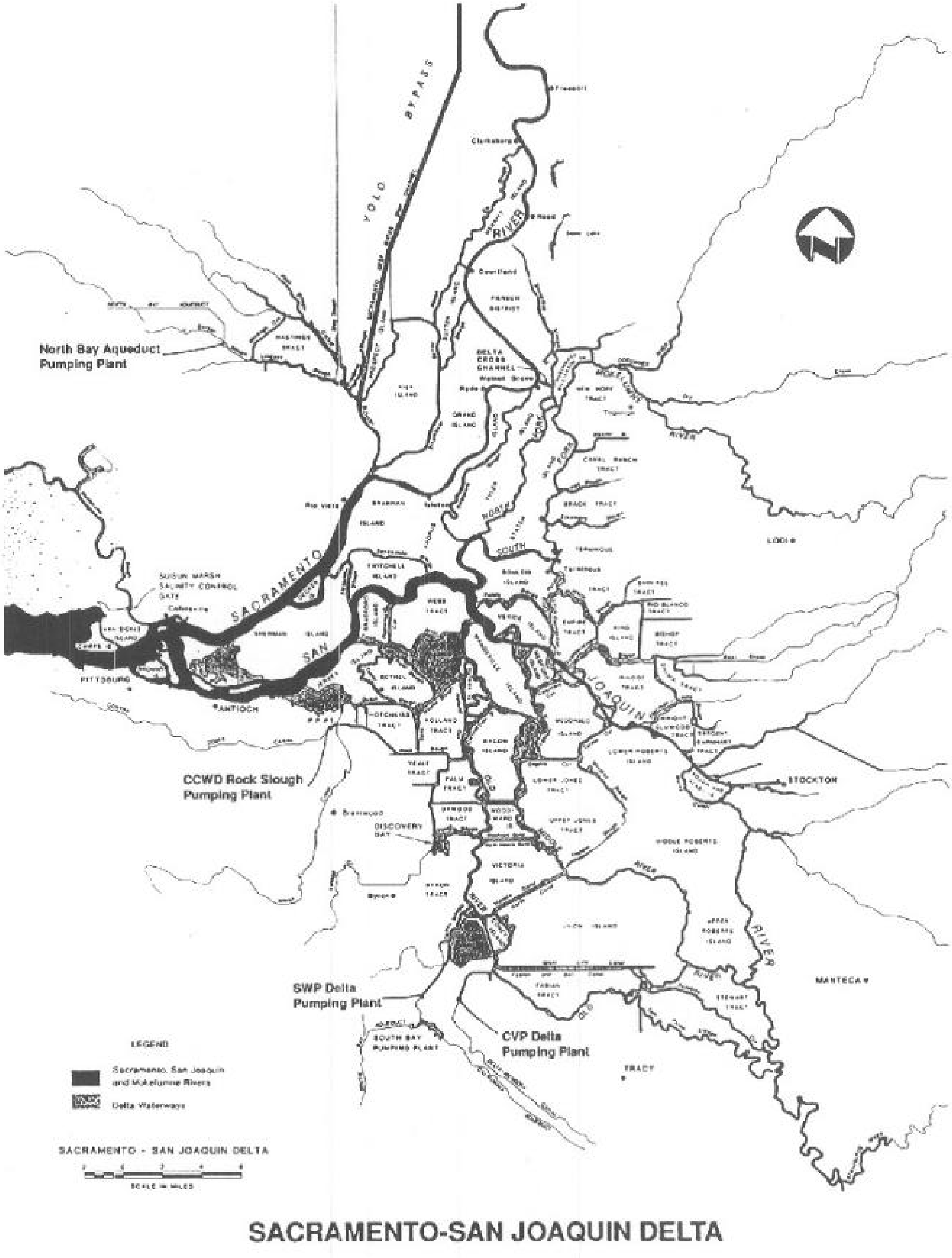
STEELHEAD



SOURCE: Kjelson et al. (1989).

ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACHES 1-3

FIGURE 2-VII-17



SACRAMENTO-SAN JOAQUIN DELTA

FIGURE 2-VII-18

General Problems

Upstream migration, spawning, and incubation - Passage at natural riffles is not as much of a concern for steelhead as it is with chinook salmon because steelhead are smaller and better swimmers and can better negotiate natural riffles and partial barriers. Nonetheless, minimum migration flows during major migration months are necessary to ensure that steelhead reach upstream spawning habitats, which are preferred.

Flow fluctuation, water temperature, and water quality-related factors affecting successful steelhead spawning, egg incubation, and emergence for steelhead are basically the same for chinook salmon. Flow fluctuation factors, in particular, can significantly reduce egg incubation and fry emergence success. Eggs are most susceptible to mortality during the early stages of development, and sudden changes in water temperature, oxygen availability, or percolation rates around the eggs can increase mortalities.

Rearing and downstream migration - Factors affecting juvenile steelhead rearing and emigration in the Sacramento River system are similar to those affecting fall-run chinook salmon because of similarities in the timing and environmental needs of these two species during downstream migration. The principal difference between the two species is that steelhead juveniles rear longer and are larger than most salmon emigrants. Other than their greater swimming ability, which can help them avoid or escape some sources of mortality better than salmon, steelhead are subject to the same sources of mortality and mechanisms as salmon. For the most part, steelhead emigrate during spring.

Because steelhead rear year round, suitable flows must be provided year-round, although in most streams, the critical limiting factors occurs during summer. Steelhead are also susceptible to flow fluctuations and other flow characteristics year round, unlike juvenile salmon, and are therefore exposed to in-river mortality factors for a longer time.

Water temperature is obviously related to flow and is the factor that is most likely currently limiting natural steelhead production on many streams. While coldwater releases occur below some dams, the amount (and quality) of habitat available for steelhead rearing below these dams is a fraction of what it was before human disturbances. In addition, coldwater releases are not available below many migration barriers or are only possible when reservoirs are full. Appropriate water temperature regimes below many dams are not consistently maintained as they were naturally in the well-shaded upper watersheds before human disturbances.

Sacramento River

Upstream migration and spawning - The timing of upstream steelhead migration coincides with the timing of upstream migration of fall-, late fall-, and winter-run chinook salmon. Consequently, flow, water temperature, and passage-related factors affecting upstream migration of adult steelhead in the Sacramento River system are similar to those affecting chinook salmon.

Hallock (1989) estimated that passage problems at RBDD alone had reduced annual adult steelhead runs in the upper Sacramento River system by about 6,000 fish. That number would undoubtedly be larger now due to the subsequent recorded declines in steelhead counts at RBDD. In general, steelhead are attracted to high, cold flows, and such conditions provide optimal migration opportunities. Without removal of entire dams, however, steelhead production is probably not currently limited by barriers below the major dams.

Several instream flow studies have been conducted in the Sacramento River basin and have developed spawning habitat-discharge relationships for steelhead. Information involving these spawning habitat-discharge relationships have been developed incidental to studies for chinook salmon. Implementation of flows providing optimal spawning habitat may or may not increase steelhead abundance, depending on the limiting factors in each drainage. Arguably, spawning habitat may not be a limiting factor for steelhead production in most of the Sacramento River basin.

Because steelhead spawning in the Sacramento River and its tributaries occurs from December through April (primarily January through March), water temperature is not considered a limiting factor for steelhead spawning in most of the Sacramento River basin.

Most of the natural production of steelhead occurs in tributaries to the upper Sacramento River because mainstem spawning is limited by the shortage of smaller sized gravel, which occurs principally in the wide, braided areas of the river (Reynolds et al. 1990). Although steelhead generally select somewhat smaller sized spawning gravels than do chinook salmon, the factors affecting spawning gravels for steelhead production in the Sacramento River system are similar to those affecting spawning gravels for fall-run chinook salmon production, particularly in the larger stream systems and downstream of the larger dams. In some of the minor tributaries where passage is available during the spawning season, some steelhead ascend higher in the watershed than salmon, where they find suitable pockets of gravel to spawn.

Downstream migration - Extended coldwater releases below dams may actually retard emigration until late spring, when increasing water temperatures and diversions in the mainstem Sacramento River and Delta result in a larger mortality factor for steelhead smolts.

Sacramento River Tributaries

Low summer flows and high temperatures have been identified as creating unfavorable conditions in Clear, Cottonwood, Mill, Deer, and Butte creeks for steelhead rearing (The Resources Agency 1989).

In the lower American River, water temperatures are commonly 60-77^{o}F from July through October and are not conducive to juvenile steelhead survival. Steelhead generally do not survive the extended warm waters in many years and move prematurely out of the American River to seek cooler water (McEwan and Nelson 1991). These temperatures have been a major contributing factor to natural production contributing less than 5% of the adult steelhead population in the American River.

San Joaquin River and Tributaries

Factors affecting steelhead abundance in the San Joaquin River basin are assumed to be similar to those described in detail for San Joaquin River fall-run chinook salmon. The primary factors limiting abundance and distribution are dams, water diversions, poor water quality, and riparian impacts. Low summer flows and concurrent high water temperatures preclude the necessary year-round rearing habitat for steelhead below the lowermost impassable dams (Friant, Crocker Huffman, LaGrange, Goodwin, and Camanche dams) that exist on the mainstem San Joaquin River and its major tributaries.

Delta/Bay

Delta flows and exports may affect the abundance of downstream migrating steelhead much the same way as they affect fall-run chinook salmon.

The average annual number of steelhead salvaged at the SWP intake for 1968-1980 was 2,453 (DFG 1981). Table 2-VII-2 lists the number of steelhead salvaged at these two pumping plants during the primary emigration months of February-May.

Table 2-VII-2. Number of steelhead trout salvaged at SWP and CVP Delta Pumping Plants in February-May (1979-1991).

Year	February		March		April		May	
	SWP Intake	CVP Intake	SWP Intake	CVP Intake	SWP Intake	CVP Intake	SWP Intake	CVP Intake
1979	25	372	454	444	1,407	1,080	969	0
1980	835	0	74	90	118	243	210	126
1981	1,509	1,258	3,088	1,008	4,902	168	0	267
1982	1,432	0	1,110	0	10,965	0	2,441	297
1983	89	0	0	0	0	0	256	0
1984	0	0	41	146	357	187	18	70
1985	325	83	1,221	134	1,165	127	647	101
1986	139	524	54	127	1,328	505	446	238
1987	69	112	3,387	718	976	776	446	275

	February		March		April		May	
1988	2,403	0	823	491	2,116	1,039	426	1,646
1989	499	252	4,767	5,051	2,105	3,139	404	1,212
1990	1,317	1,085	3,115	2,139	1,039	786	19	0
1991	23	109	5,799	4,412	2,692	1,263	91	98

Source: California Department of Fish and Game salvage database.

Table 2-VII-3 provides losses of yearling equivalent steelhead at the SWP intake estimated by a formula negotiated between DFG and DWR. Salvaged steelhead are trucked to either the north or south side of Sherman Island or near Antioch. Some of these fish are lost to predation and stress associated with handling and trucking. Reverse flows in Delta channels caused by pumping operations can also cause disorientation, delay, and additional predation in Delta channels for steelhead not affected directly by the pumping facilities. Although both pumping plants have louver fish screens that may be 90% effective for downstream migrating steelhead, prescreening losses are probably 75% at SWP pumping facilities, mostly due to predation in CCF, and are probably 15% at Tracy.

Table 2-VII-3. Estimated annual losses of steelhead trout
at the SWP Delta intake (1982-1991).

Year	Calculated steelhead lost	
	Young-of-year	Yearling
1982	0	73,748
1983	0	2,945
1984	0	1,713
1985	0	15,621
1986	0	15,663
1987	747	21,266
1988	0	25,080
1989	253	32,571

1990	0	19,187
1991	0	38,430

Note: Estimates use the formula established under the 1986 pumping plant agreement between DWR and DFG.

Source: California Department of Water Resources 1993.

Unscreened diversions at the Contra Costa Water District's (CCWD's) intake at Rock Slough and at more than 1,500 agricultural water diversions in the Delta also cause unknown losses of emigrating steelhead. No steelhead have been caught in routine entrainment and impingement sampling at the screened intakes of Pacific Gas and Electric Company's (PG&E's) power plants at Antioch and Pittsburg in the western Delta (Running 1993).

A portion of the water flowing down the Sacramento River is diverted into Georgiana Slough, the DCC, and Threemile Slough into the lower San Joaquin River. A portion of the juvenile steelhead migrating down the Sacramento River enter these channels, and many are subsequently drawn toward the SWP Banks Pumping Plant and the CVP Tracy Pumping Plant.

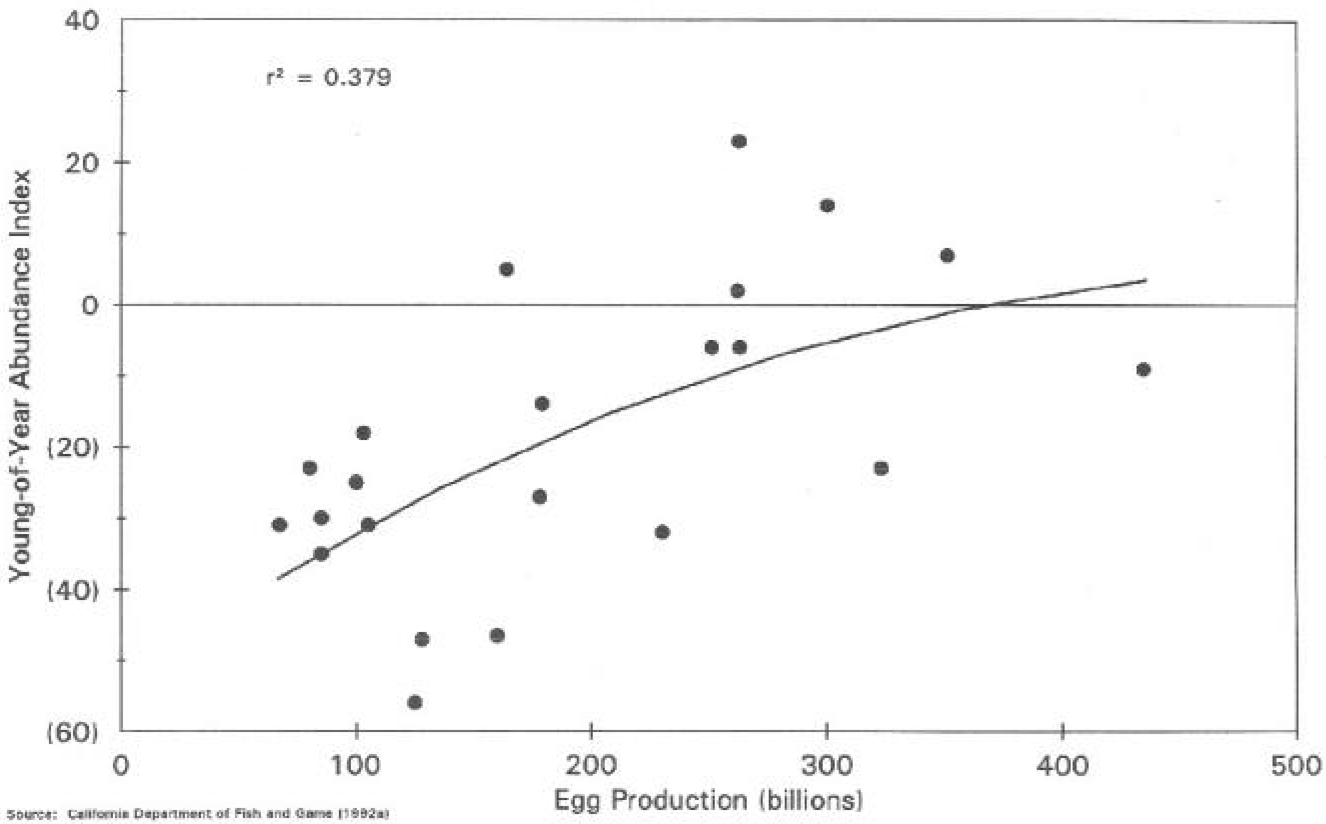
STRIPED BASS

General Problems

The decline of the striped bass population in the Sacramento-San Joaquin estuary has generated substantial evaluation of causal factors. The decline in population abundance is a result of increased mortality and reduced reproduction. This section provides information on stock-recruitment and other life stage relationships, as well as on the specific problems that may be increasing mortality and reducing fecundity and fertility. The focus of this section is on anthropogenic (i.e., human-caused) factors that may continue to affect abundance, especially factors that are affected by CVP facilities and operations. In addition, information is provided on environmental conditions that may exacerbate the effects of CVP operations and facilities on conditions that may suppress the benefits of actions implemented under the CVPIA.

Factors that may have contributed to increased mortality after 1967 include the same factors that affected mortality before 1967 (i.e., fishing, entrainment in diversions, exposure to toxic materials, and habitat loss). Additional factors that affect mortality include reduced Delta inflow and outflow, altered Delta flow patterns, dredging and spoil disposal, diseases and parasites, and introduction of exotic species.

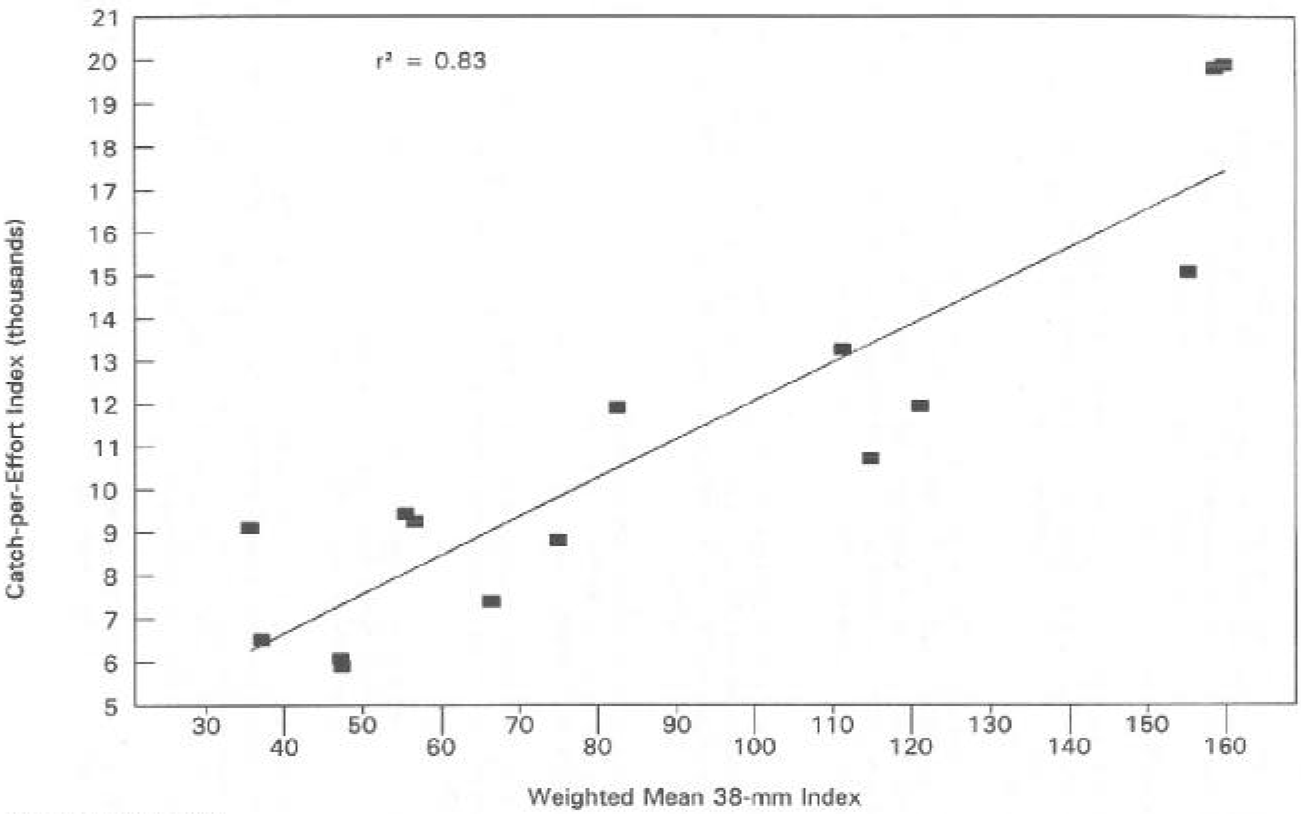
Stock-recruitment and other life stage relationships - DFG (Kohlhorst et al. 1992) has suggested that a significant stock-recruit relationship exists for striped bass (i.e., the number of bass produced in any given



Source: California Department of Fish and Game (1992a)

RELATIONSHIP BETWEEN YOUNG-OF-YEAR ABUNDANCE INDEX AND EGG PRODUCTION IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

FIGURE 2-VII-19



Source: Kohlhorst et al. (1992).

RELATIONSHIP BETWEEN ADULT POPULATION ABUNDANCE (STRIPED BASS TAGGING STUDY CATCH-PER-EFFORT INDEX) AND WEIGHTED MEAN YOUNG-OF-YEAR INDEX 3-7 YEARS EARLIER

FIGURE 2-VII-20

year depends to some extent on egg production) (Figure 2-VII-19). If the stock-recruit relationship is valid, the existing adult striped bass population may be unable to produce sufficient numbers of eggs to sustain existing mortality rates on all life stages. Increased mortality of the adult striped bass population and reduced recruitment to the adult population would result in continued decline. However, reduced adult mortality, in combination with improved habitat conditions, could enhance the ability of the population to recover to historical levels.

Adult population abundance is correlated with the 1,52-inch index (Figure 2-VII-20), indicating that reduced recruitment to the adult population has been the major cause of declining adult abundance (Kohlhorst et al. 1992). Lower recruitment is estimated to account for 75% of the adult decline, while lower adult survival rates account for the remaining 25%.

Annual adult striped bass mortality rates increased from approximately 40% in the early 1970s to 53% in recent years (DFG 1987). The cause of increased adult mortality rates may be attributed to habitat loss, increased levels of toxic materials, sport and illegal fishing, and other factors.

As discussed above, lower recruitment is estimated to account for 75% of the adult decline that has occurred since the late 1960s. Recruitment to the adult population depends on survival of eggs, larvae, and juvenile bass. Studies have shown a significant relationship between the annual abundance of larval striped bass (0.32 inch long) and juvenile striped bass (1.52-inch index), and between juvenile striped bass and recruitment to the population 4 years later, indicating that year-class strength of the population is set early in the life cycle (Turner 1987) (Figures 2-VII-19 and 2-VII-20). The number of 0.32-inch-long larvae is a function of the number of viable eggs spawned, spawning timing and location, flow conditions, direct diversion effects, and development rates (a function of water temperature). Many of the factors affecting abundance of eggs and larvae equally apply to the early juvenile stages (greater than 1.52 inch long).

Although year-class strength of the population is set early in the life cycle of striped bass, perhaps before the juvenile life stage, survival of juveniles ultimately determines the number of bass recruited to the adult population. Losses of juvenile striped bass are important in determining adult abundance (Kohlhorst et al. 1992).

Decreased fecundity and fertility - Reduced reproduction results from fewer fertile eggs being produced by the population each year. Factors that may have affected the number of fertile eggs produced include factors affecting the abundance, size, and health of female striped bass. Mortality rates determine the abundance of female bass. Factors affecting size and health of female striped bass include accumulation of toxic materials by the female bass, diseases and parasites, and reduced food availability.

Egg production depends on the abundance and fecundity of adult female striped bass. From the early 1970s to the present, the number of eggs produced by the population declined, the result of reduced adult striped bass abundance (DFG 1987). Average egg production during 1981-1986 was 17% of the 1969-1973 average egg production.

Flow and water temperature - Other than the relationship of Delta inflow to exports and Delta outflow to location of X2 (area in which salinity is 2 parts per thousand or approximately 3,000 uS EC), flow likely has minimal direct effects on juvenile striped bass.

High water temperature has not caused substantial direct mortality of eggs and larvae and has not played a major role in the recent decline of young striped bass in the Sacramento-San Joaquin River system (Mitchell 1987).

Habitat - The effects of habitat loss on eggs and juvenile striped bass are currently unknown. Effects on overall estuary productivity, however, may have had substantial adverse effects on larval survival, but this does not account for the population decline after 1970.

Toxic substances - Larval striped bass survival may have been reduced by the toxic effects of insecticides, herbicides, trace elements, and other toxic materials that have entered the estuary from agricultural runoff and municipal and industrial discharge. Toxic materials can affect larval bass directly and indirectly, causing mortality within a short period (days) or adversely affecting growth and development, which limit the chances for survival (Brown 1987).

Although the decline in striped bass abundance that has occurred over the last 20 years is not attributable to toxic materials alone, toxics may have substantially reduced survival of striped bass compared to other estuaries. The issue of toxic materials needs to be addressed in much greater detail to determine the effect on striped bass abundance.

Competition and predation - The effects of competition and predation are difficult to evaluate in wild populations. Parallel trends (i.e., abundance declines of one species during the same period that abundance of a competing or predator species increases) would suggest competition or predation effects. A consistent increase in the abundance of species that compete with or prey on striped bass is not apparent from analysis of available data (DFG 1987).

Introduction of exotic organisms has substantially altered the biological structure of the estuary. Exotic organisms affect striped bass through competition, predation, and change in trophic dynamics (i.e., the availability of prey). Although numerous introduced fish and invertebrate species have become abundant (Brown 1992), the effect on striped bass survival is unknown.

Prey availability - Decline in the copepod *Eurytemora*, the preferred prey of larval striped bass, occurred during the period that striped bass declined in abundance (DFG 1992a, Obrebski et al. 1992). The composition and abundance of larval striped bass prey have changed dramatically since 1979; some species increased in abundance while others declined. Although the introduced *Sinocalanus* has replaced declining populations of *Eurytemora* (Herbold et al. 1992), striped bass larvae do not effectively feed on the recently abundant *Sinocalanus*.

Laboratory experiments show that striped bass mortality is negatively correlated with prey density (Herbold et al. 1992). Field studies indicated that prey density in the estuary was low relative to densities needed to support high survival in the laboratory. Larvae collected from the estuary do not show signs of starvation, but low densities may result in slower larval growth rates and increased mortality from predation. Larval mortality in the estuary was estimated to be higher than larval mortality for similar prey densities in the laboratory.

Reduced abundance of striped bass attributable to reduced prey abundance should be reflected in reduced larval survival rates for any given level of outflow and diversion (DFG 1992a). Larval survival over the historical period (1969-1990), however, appeared to be unchanged, except for the effects of diversion and outflow. Additional studies are needed to resolve questions on prey availability and the effect on striped bass survival.

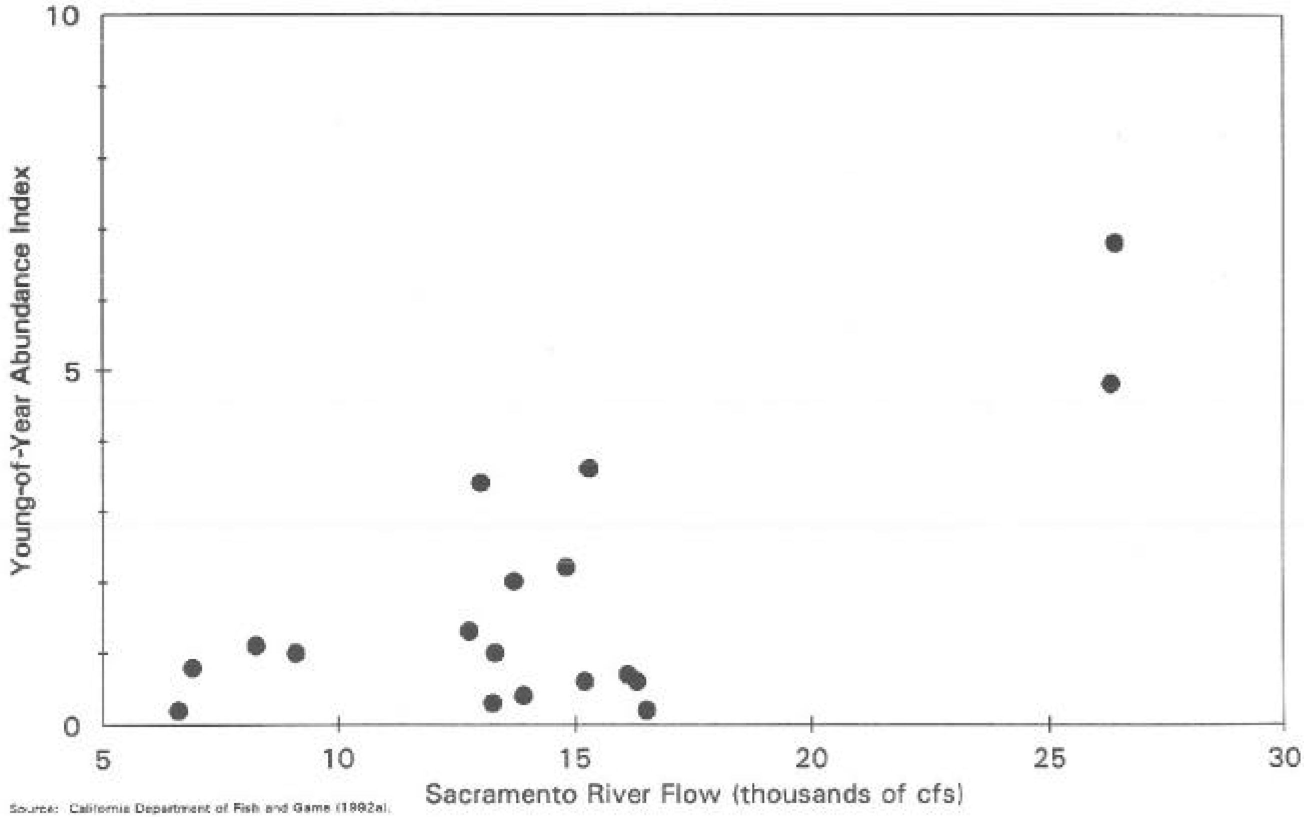
As discussed for larvae, additional studies are needed to resolve questions on prey availability and the effect on striped bass survival. As discussed under "Life History," juvenile striped bass (especially during their first year of life) feed primarily on the mysid *Neomysis*. *Neomysis* declined in abundance during the 1970s, but declines were significant only during fall (Obrebski et al. 1992). Reduced abundance of prey could slow the growth of striped bass and increase mortality from predation.

Sacramento River

Flow - The survival (survival index) between the egg and the 0.24-inch-long larvae stage in the Sacramento River is low when Sacramento River flow is low (Figure 2-VII-21) (DFG 1992a). Survival is always low when flow is less than 13,000 cfs. The following mechanisms may explain reduced survival at lower Sacramento River flows:

- Eggs and larvae settle to the river bottom and die when they encounter near zero velocity in tidally affected reaches.
- Larval survival is reduced because arrival in higher quality downstream nursery areas is delayed.
- Larvae are subjected to increased exposure to toxic substances carried by the river.
- A higher proportion of larvae are drawn through the DCC, Georgiana Slough, and Threemile Slough into the central Delta where vulnerability to entrainment in diversions is greater.

Feeding efficiency, and thus growth and survival, may be greater in downstream reaches because the density of striped bass prey in the Sacramento River is higher in the reaches below Rio Vista (DFG 1992a).



Source: California Department of Fish and Game (1992a).

RELATIONSHIP BETWEEN SURVIVAL OF STRIPED BASS (EGGS TO 6MM) AND SACRAMENTO RIVER FLOW

FIGURE 2-VII-21

Assuming that the proportion of eggs and larvae drawn into the DCC, Georgiana Slough, and Threemile Slough depends on the proportion of Sacramento River flow diverted, more eggs and larvae would be drawn into the central Delta at lower flows than at higher flows.

In addition to flow effects on survival, diversions from the Sacramento River may entrain eggs and larvae and reduce river flow. In proportion to Sacramento River flow, diversions from the Sacramento River in the spawning reach (between Sacramento and Colusa) are small. The effect of Sacramento River diversions on striped bass, although they contribute to the cumulative effect of total diversions and upstream storage, would also be expected to be relatively small.

Toxic substances - Recent studies indicate that larvae from the Sacramento River show a higher incidence of liver malformation than larvae from other areas of the estuary. Contamination of the Sacramento River increased substantially in the mid-1970s when application of rice pesticides increased (Herbold et al. 1992). Measured toxic concentrations were sufficient to kill fish in sloughs draining rice fields, and estimated toxic concentrations for the Sacramento River during 1970-1988 may have deleteriously affected striped bass larvae (Bailey 1992). Discharge of contaminated rice field water coincides with striped bass spawning and may account for part of the decline in striped bass abundance. Pesticide application has correlated with young striped bass abundance, but direct relationships are inconclusive.

San Joaquin River

The farther upstream X2 is located, the farther upstream spawning generally occurs (Figure 2-VII-22). Eggs spawned upstream in the Delta (in the lower San Joaquin River) are more vulnerable to entrainment in water exports from the south Delta (DFG 1992a). Existing Delta water quality requirements (California State Water Resources Control Board 1978) do not require sufficient outflow to encourage striped bass spawning in the lowermost 10-kilometer reach of the San Joaquin River.

Wendt (1987) showed that flow in the lower San Joaquin River (along with export volume and striped bass abundance and size) was significantly correlated with entrainment losses at the CVP and SWP Delta pumping facilities. Lower San Joaquin River flow, however, is determined by Delta inflow and export, as is the location of X2 in the estuary (San Francisco Estuary Project 1993). For juvenile striped bass, their location in the estuary may be more important than flow in determining the effect of other factors (i.e., entrainment).

Delta/Bay

Flow - Delta outflow is highly variable across years, seasonally, and, at times, weekly. In general, month-to-month outflows in any given year are highly autocorrelated, whereas year-to-year outflows are not. This generally means that high outflows occur across several months in wet years (Herbold et al. 1992). In any given year, outflow has ranged from less than 10 maf to more than 50 maf.

Although dependent on the natural hydrology of the Sacramento-San Joaquin River system, the timing and volume of Delta outflow have been substantially modified by changes in system characteristics; channelization and flood control projects; and by operations of water project facilities, reservoirs, and diversions (Herbold et al. 1992). Channelization and flood control projects (not including reservoir storage) enable water to move more quickly to the Delta. Reservoir storage reduces peak flows and changes the timing of water movement down the rivers. Consumptive diversions remove water from the system.

In general, water projects have increased summer and fall outflow and reduced winter and spring outflow (Herbold et al. 1992). Total annual Delta outflow can be reduced by 50-60% of the outflow expected in the absence of storage and diversions, with less proportional change in wet years and greater in dry years.

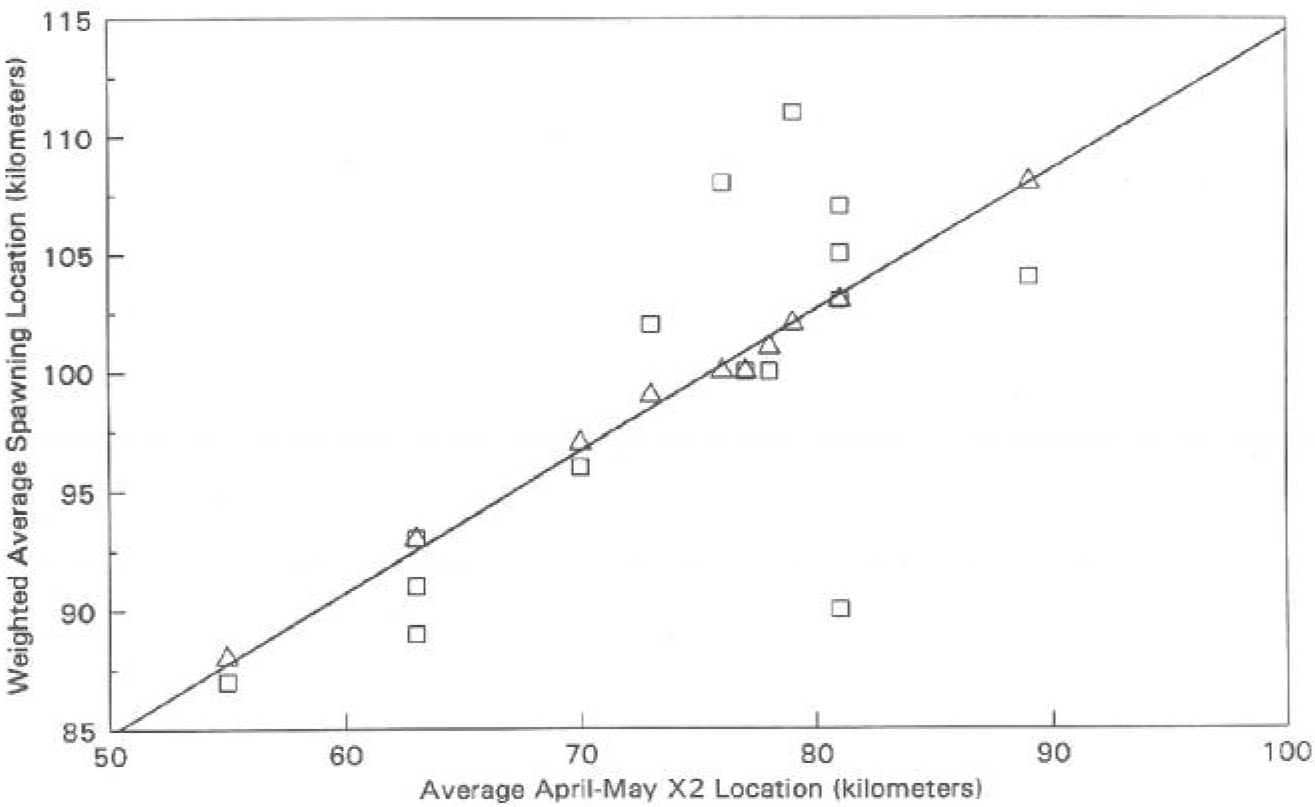
Delta outflow and diversions are considered by DFG to be the primary factors contributing to the continuing 20-year decline of striped bass in the Sacramento-San Joaquin estuary (DFG 1992a). The decline in striped bass abundance correlates significantly with numerous flow-related variables, including water temperature, Delta inflow, Delta outflow, salinity, and diversions (Turner and Chadwick 1972). Because the variables are highly interdependent, the mechanisms causing the decline are unclear.

Delta outflow affects the distribution of striped bass larvae. The location of X2 in the estuary is indicative of the level of Delta outflow; as outflow increases, X2 moves farther downstream (San Francisco Estuary Project 1993). When X2 is in Suisun Bay, larvae density is greatest in Suisun Bay; when X2 is in the Delta, larvae density is greatest in the Delta. Figure 2-VII-41 shows a similar relationship for 1.52-inch-long striped bass juveniles. The mechanism of distribution (i.e., whether outflow transports the larvae downstream or larvae actively maintain their position relative to the entrapment zone) is not known, but the location of larvae relative to X2 is consistent with larval avoidance of the surface.

Striped bass survival from egg size to 1.52 inches long and from 0.36 to 1.52 inches long is higher at higher outflows (i.e., when X2 is farther downstream) (DFG 1992a, San Francisco Estuary Project 1993) (Figure 2-VII-23). High outflow may benefit larval striped bass by:

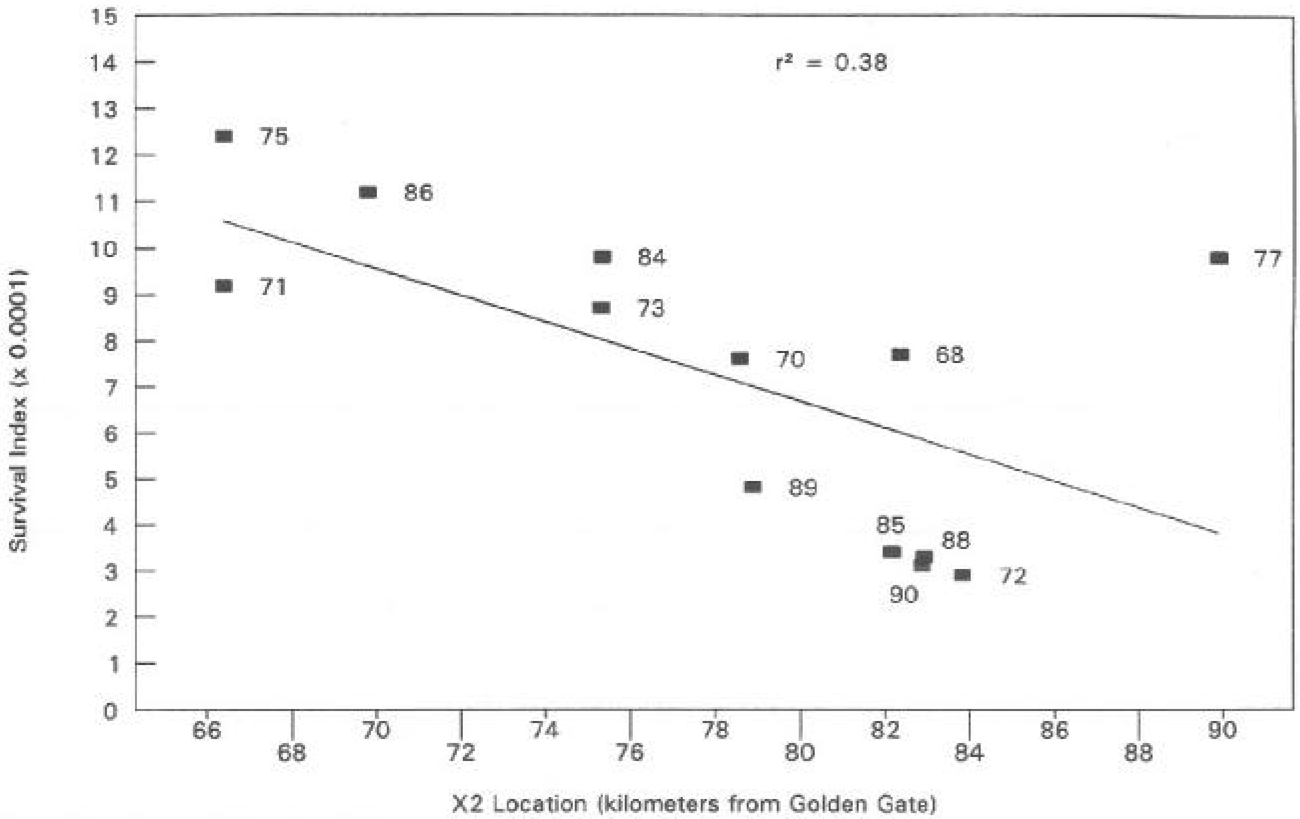
- increasing the nursery area and reducing intraspecific competition,
- increasing shallow habitat area and food abundance,
- diluting toxic materials,
- increasing turbidity and reducing predation, and
- reducing vulnerability to entrainment in Delta diversions (Herbold et al. 1992).

The Suisun Marsh Control Structure affects flows in Suisun Marsh and also may affect striped bass survival. After installation and operation of the Suisun Marsh Control Structure in 1989, the flow in Montezuma Slough greatly increased, averaging more than 2,000 cfs toward Suisun Marsh during operation of the structure. The timing of operations extends through the striped bass egg and larval period. The effect on striped bass is currently unknown, but operations could reduce survival through increased predation at the



RELATIONSHIP BETWEEN THE LOCATION OF STRIPED BASS SPAWNING IN THE LOWER SAN JOAQUIN RIVER PORTION OF THE DELTA AND THE LOCATION OF X2 (KILOMETERS FROM THE GOLDEN GATE BRIDGE) IN THE ESTUARY

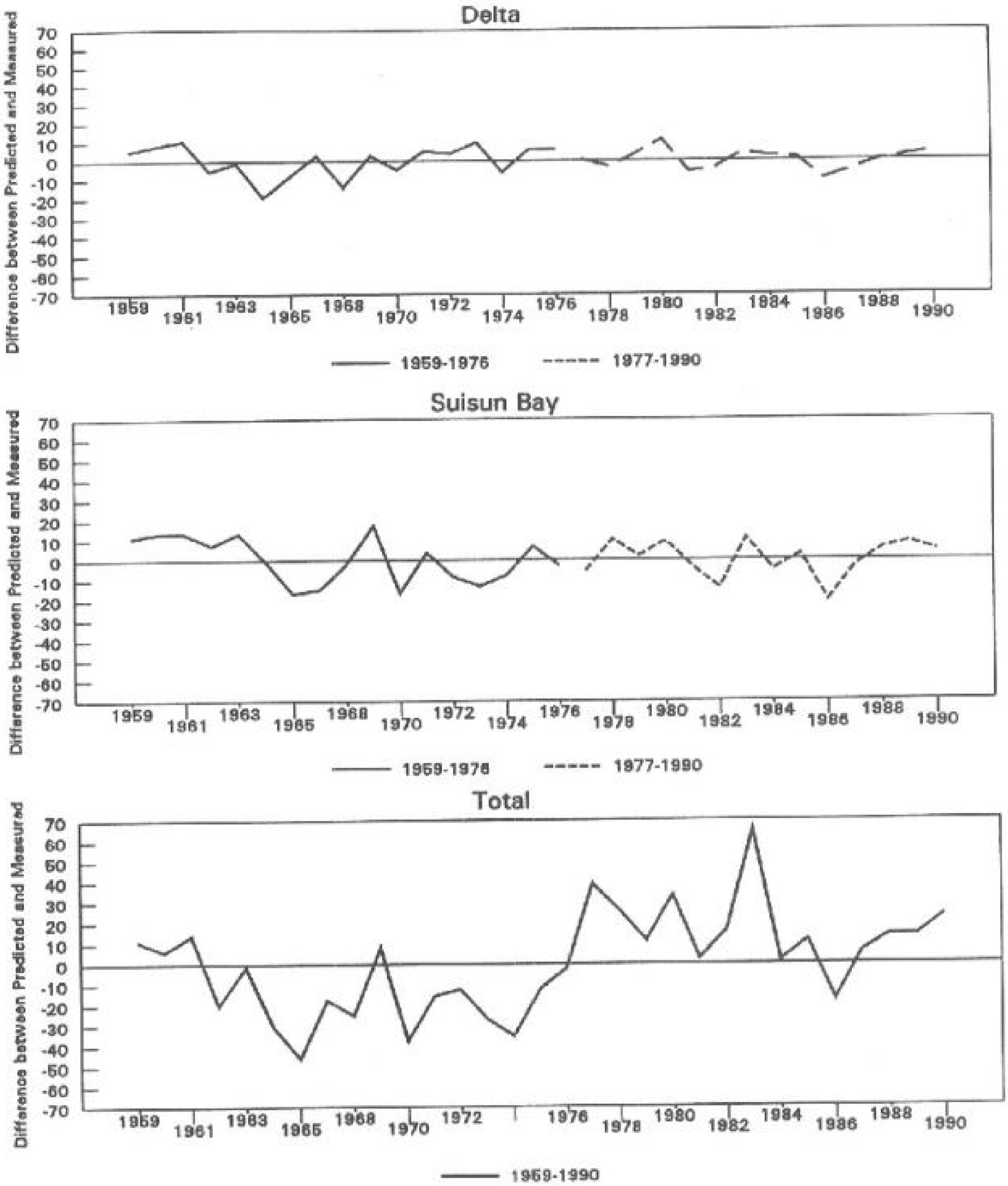
FIGURE 2-VII-22



Source: California Department of Fish and Game (1992a).

RELATIONSHIP BETWEEN THE SURVIVAL INDEX (FOR 9-MM TO 38-MM STRIPED BASS) AND THE LOCATION OF X2

FIGURE 2-VII-23

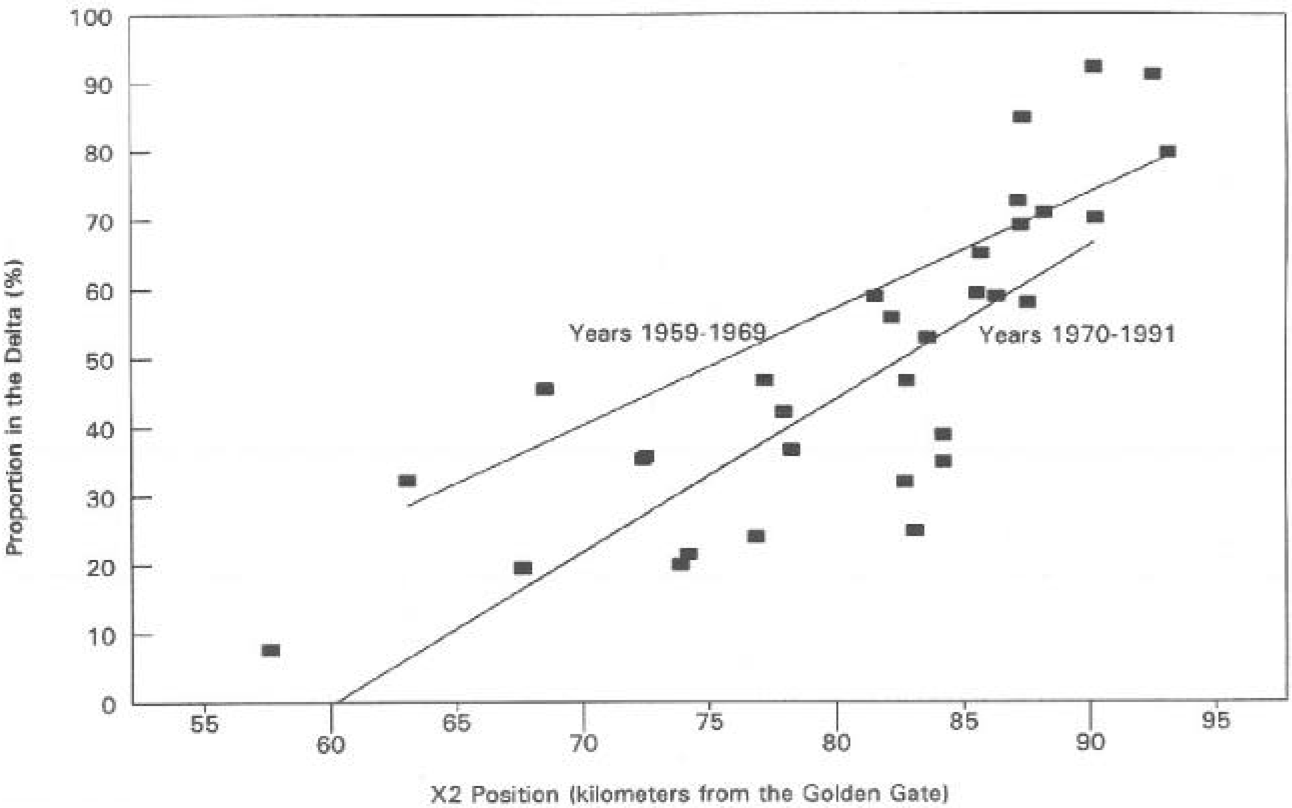


Sources: California Department of Fish and Game (1992a), Herrgesell (1993)

Note: Different equations were used for 1959-1976 and 1977-1990 to calculate the Delta and Suisun Bay indices.

DIFFERENCE BETWEEN THE PREDICTED AND MEASURED ABUNDANCE INDICES FOR STRIPED BASS IN THE DELTA, SUISUN BAY, AND IN BOTH THE DELTA AND SUISUN BAY (TOTAL)

FIGURE 2-VII-24



Source: Herrgesell (1993).

COMPARISON OF THE 1959-1969 AND 1970-1991 RELATIONSHIPS BETWEEN THE PROPORTION OF STRIPED BASS IN THE DELTA AND THE LOCATION OF X2

FIGURE 2-VII-25

Suisun Marsh Control Structure (Herrgesell 1993) and exposure to conditions within Montezuma Slough that may be less conducive to survival than conditions in Suisun Bay.

Also, the effect of the diversion by the Suisun Marsh Control Structure on the location of X2 is unknown. If diversion causes X2 to be located farther upstream relative to the location of X2 without operation of the Suisun Marsh Control Structure, survival of striped bass could be reduced (Figure 2-VII-23).

Salinity - Approximately 40% of the striped bass population spawns in the Delta, generally in the lower San Joaquin River, from Venice Island downstream to Antioch. Salinity in the western Delta affects the spawning distribution in the Delta (DFG 1987). The lowest salinity occurs immediately downstream of the confluence of the San Joaquin and Mokelumne rivers, where fresh water from the Mokelumne and Sacramento rivers enters the San Joaquin River. To the east, the San Joaquin River discharges water contaminated with salty agricultural drainage. To the west, seawater intrusion increases the salinity. Adult striped bass react to increasing salinity from agricultural salts in the San Joaquin River and do not migrate through salinity exceeding 550 uS EC (Radtke 1966, DFG 1987).

Diversions - Consumptive diversions from the Delta include the CVP and SWP Delta pumping facilities; more than 1,800 agricultural diversions; CCWD's Rock Slough diversion; the North Bay Aqueduct; and numerous other municipal and industrial diversions. Up to 4,600 cfs and 10,300 cfs can be diverted from the CVP and SWP Delta pumping facilities, respectively. CCWD has a maximum diversion capacity of approximately 300 cfs, and the North Bay Aqueduct has a maximum capacity of approximately 140 cfs. Maximum agricultural diversions during the peak summer irrigation season may exceed 4,000 cfs (DWR 1993a). Total diversions from the Delta can exceed 80% of the total Delta inflow (Turner and Chadwick 1972, DWR 1993b).

Diversions entrain striped bass (discussed below under "Entrainment") and affect Delta outflow and flows in the Delta channels. Considering the historical magnitude and location of diversions relative to striped bass distribution and life history patterns, Delta diversions could have been a major factor contributing to reduced striped bass survival. Delta diversions, primarily by the CVP and SWP, are considered by DFG to be responsible for the depleted state of the striped bass population (DFG 1992a).

Over the 1959-1990 period, the abundance of striped bass (1.52-inch index) was negatively correlated with the combined effects of Delta diversions and outflow (DFG 1987, 1992). If data for the entire 1959-1990 period are used to develop the regression equation, the total predicted abundance is generally less than the total measured abundance for 1959-1976 and greater than measured abundance for 1977-1990 (Figure 2-VII-24). When separate equations are used for 1959-1976 and 1977-1990 for Suisun Bay (using Delta outflow only) and for the Delta (diversion and outflow), the predictions are greatly improved (Figure 2-VII-24).

DFG has hypothesized that the difference between the 1959-1976 and 1977-1990 relationships is attributable to the decline of the adult population to a level that caused egg production to become limiting (i.e., the stock-recruit relationship is partially controlling abundance) (Figure 2-VII-20) (DFG 1992a). Changes in estuarine productivity, toxic materials entering the estuary, and other factors may also explain the change in the relationship between abundance and the combined effects of diversion and outflow during the 1970s.

After 1970, striped bass survival in Delta habitats appears to have declined (DFG 1992a). The difference in the relationships between the proportion of striped bass in the Delta and the location of X2 for the 1959-1969 and 1970-1991 periods (r squared = 0.85 and 0.62, respectively) indicates that use of the Delta as a nursery may have declined or that survival may have been lower for the 1970-1991 period (Figure 2-VII-25). The lower position of the line representing the 1970-1991 correlation between the proportion of striped bass in the Delta and the location of X2 indicates that fewer bass were in the Delta during similar outflow conditions (i.e., X2 locations).

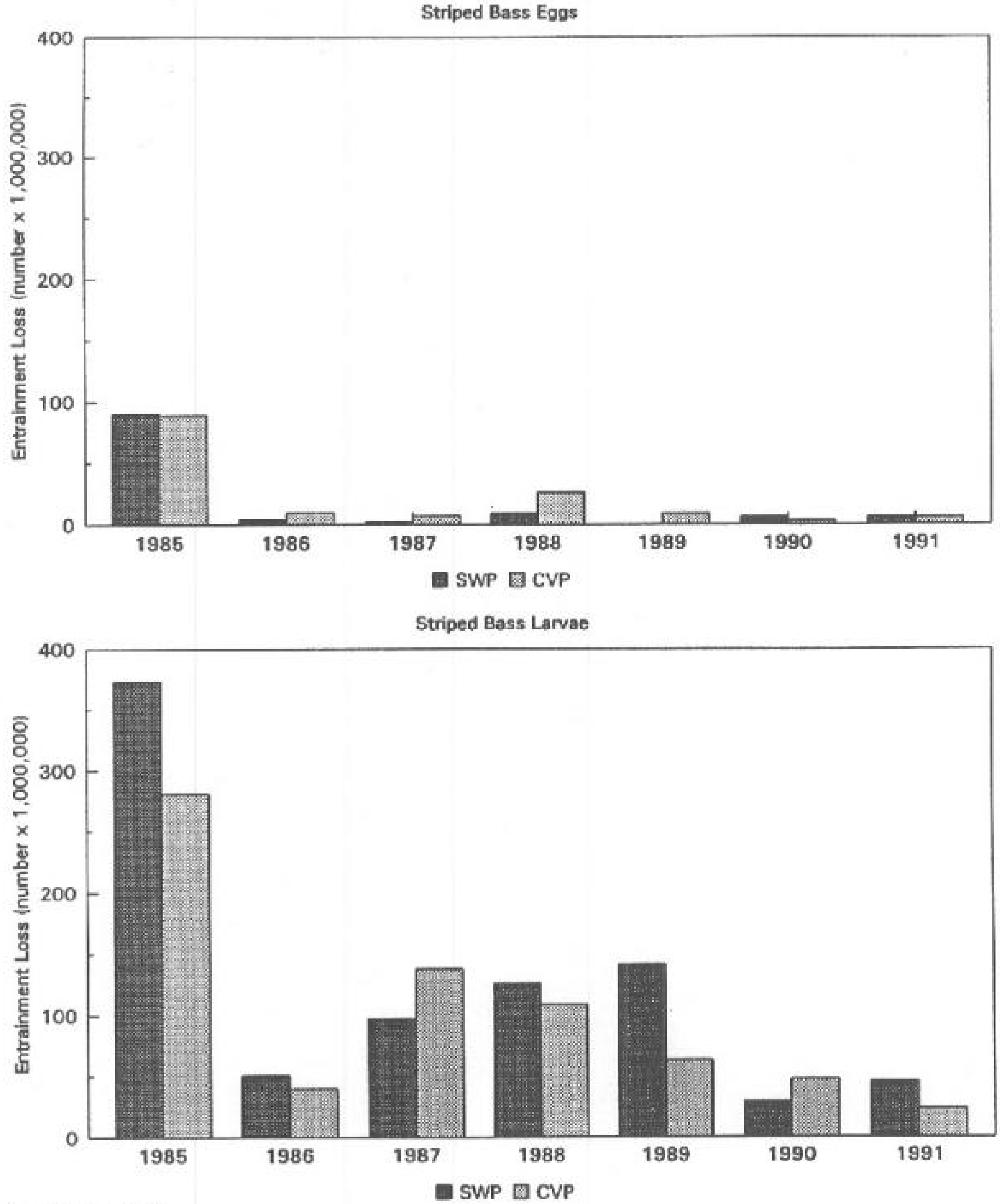
If survival rates in the Delta declined after 1970, reduced survival could be attributed to the SWP Delta pumping facilities. The SWP began exporting water after 1968 and began significant pumping by 1970. Other factors may have contributed to the decline (e.g., toxic materials entering the estuary), but insufficient data may exist for evaluation.

Entrainment - Entrainment losses were at least partly responsible for the decline in striped bass after 1970. Entrainment losses appear to be greater in low-flow years, as evidenced by greater losses at the CVP Delta pumping facilities and by the close relationship between striped bass abundance and the percentage of inflow diverted (DFG 1987).

High adult abundance results from year classes that experience minimal late summer through winter losses to export pumping (Kohlhorst et al. 1992). The magnitude of juvenile striped bass losses is potentially affected by the abundance and distribution of juvenile bass and the magnitude of exports (Wendt 1987, Kohlhorst et al. 1992).

CVP and SWP Delta pumping facilities - As discussed previously, the CVP and SWP Delta pumping facilities are the largest diversions from the Delta. Millions of striped bass eggs and larvae are lost to annual entrainment in export by the CVP and SWP Delta pumping facilities (Figure 2-VII-26). Based on estimated egg and larval survival rates (Figure 2-VII-27), the adult equivalent loss amounts to thousands of yearling striped bass each year (Figure 2-VII-28).

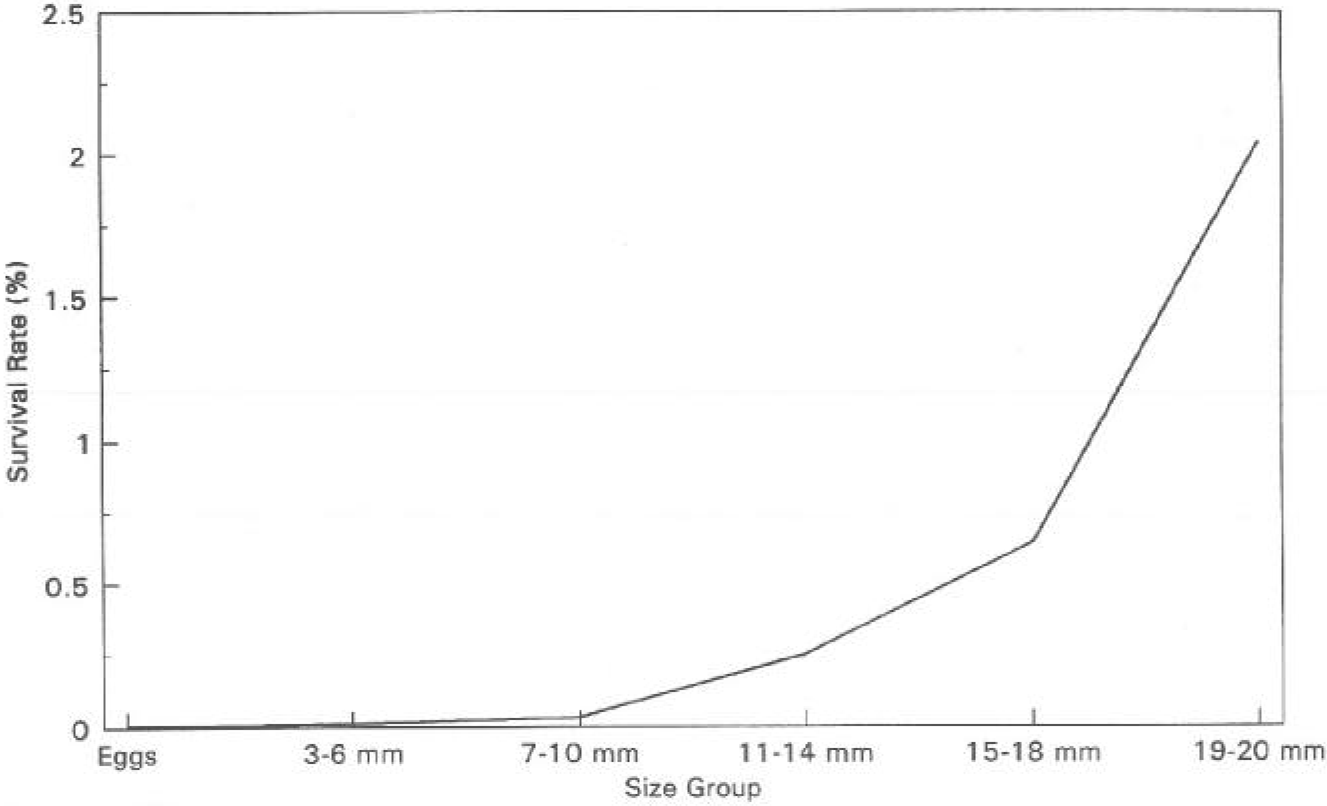
Millions of juvenile striped bass (greater than 0.8 inches long) are entrained in diversions at the CVP and SWP Delta pumping facilities each year. Most of the entrained striped bass are lost (Figure 2-VII-29), although 5-30% of all juvenile bass entrained were salvaged and returned to the Delta alive (DFG 1992b). The proportion salvaged depended on screen efficiency (a function of screen design and pumping volume),



Source: Herrgesell (1993).

ENTRAINMENT LOSS OF STRIPED BASS EGGS AND LARVAE IN DIVERSIONS BY THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT DELTA PUMPING FACILITIES (1985-1991)

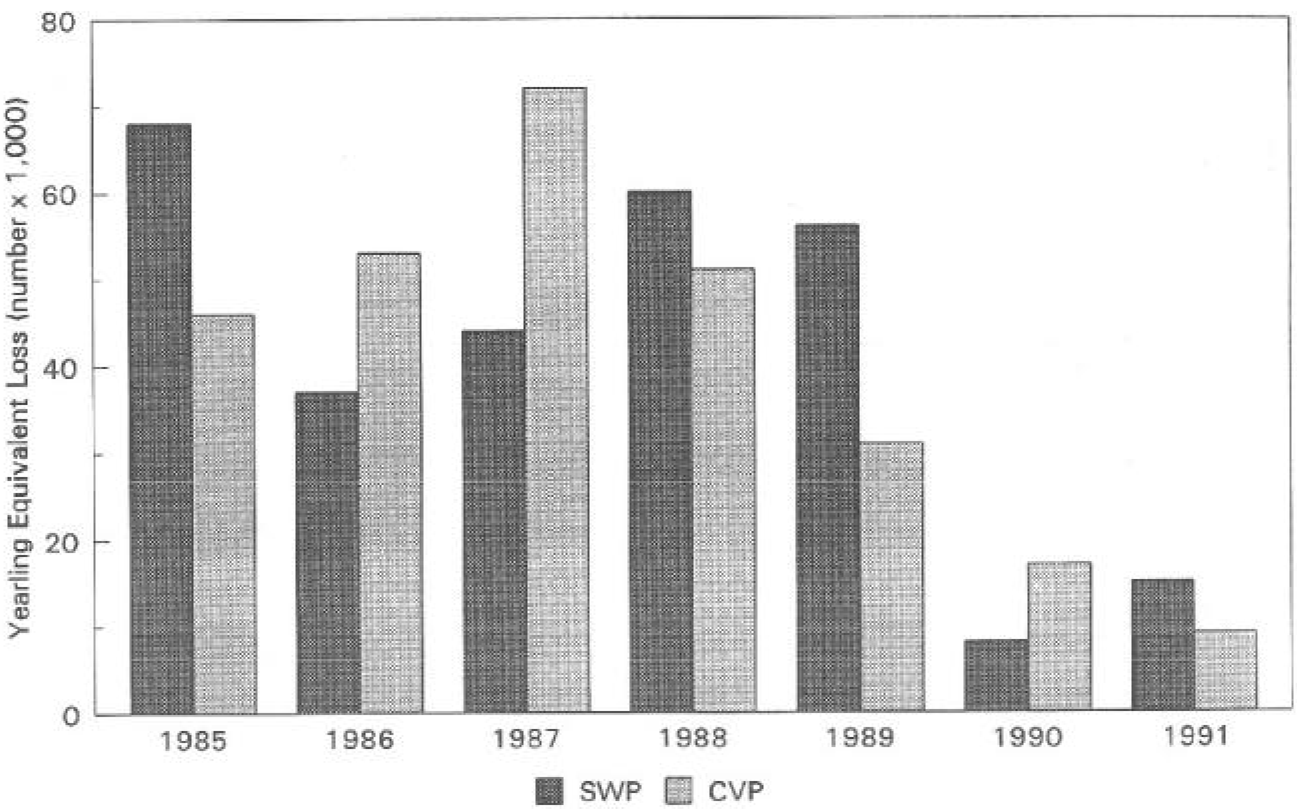
FIGURE 2-VII-26



Source: Hamgesell (1993).

SURVIVAL RATES USED TO CONVERT EGG AND LARVAL ENTRAINMENT LOSSES TO YEARLING EQUIVALENTS

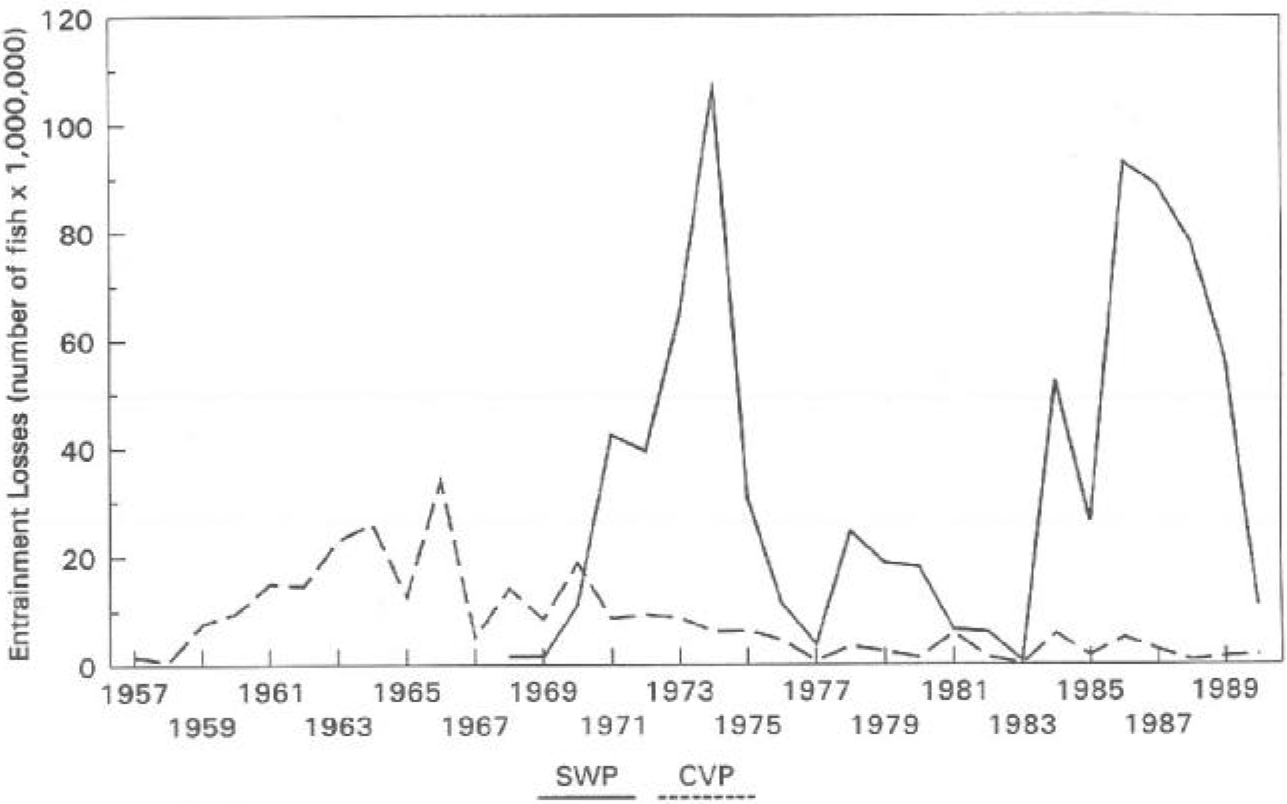
FIGURE 2-VII-27



Source: Herrgesell (1993).

YEARLING EQUIVALENTS FOR STRIPED BASS EGGS AND LARVAE LOST IN DIVERSIONS BY THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT DELTA PUMPING FACILITIES (1985-1991)

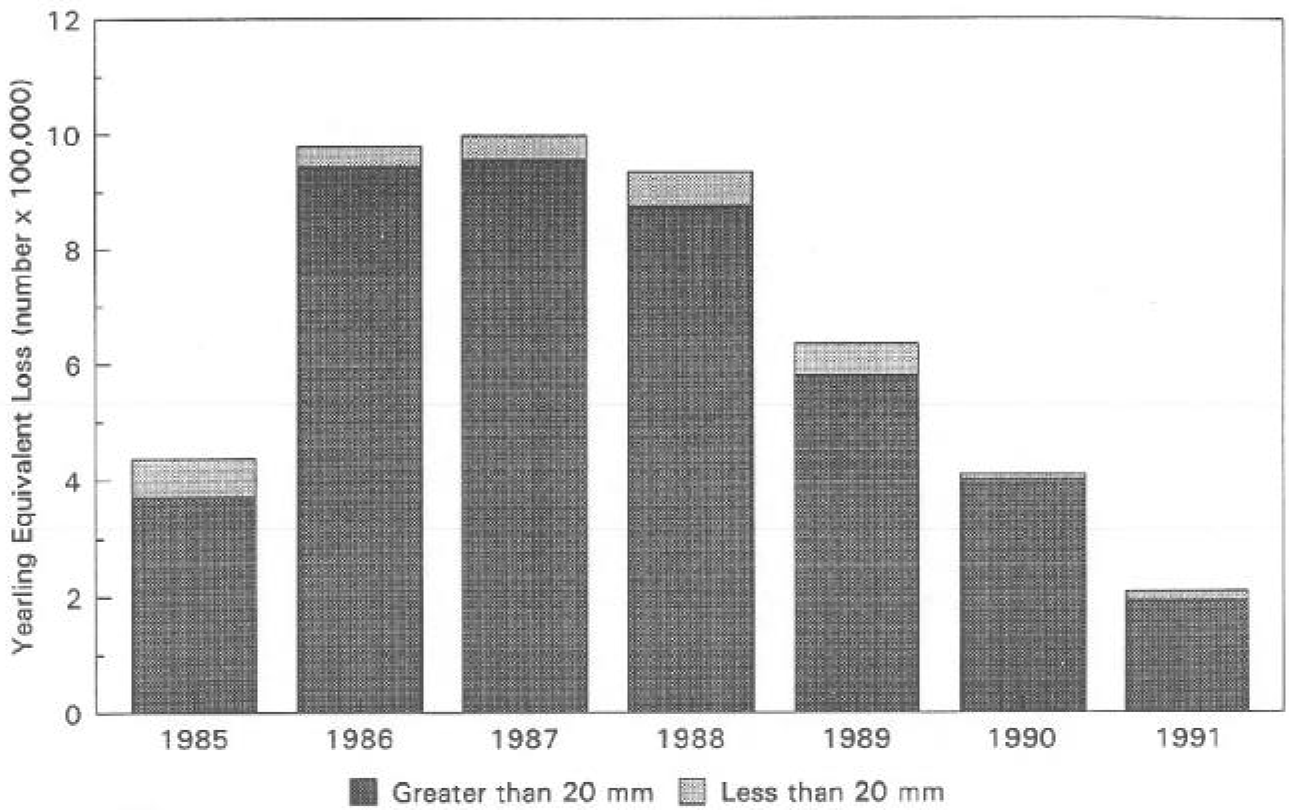
FIGURE 2-VII-28



Source: California Department of Fish and Game (1992b).

ENTRAINMENT LOSS OF JUVENILE STRIPED BASS IN DIVERSIONS BY THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT DELTA PUMPING FACILITIES (1957-1990)

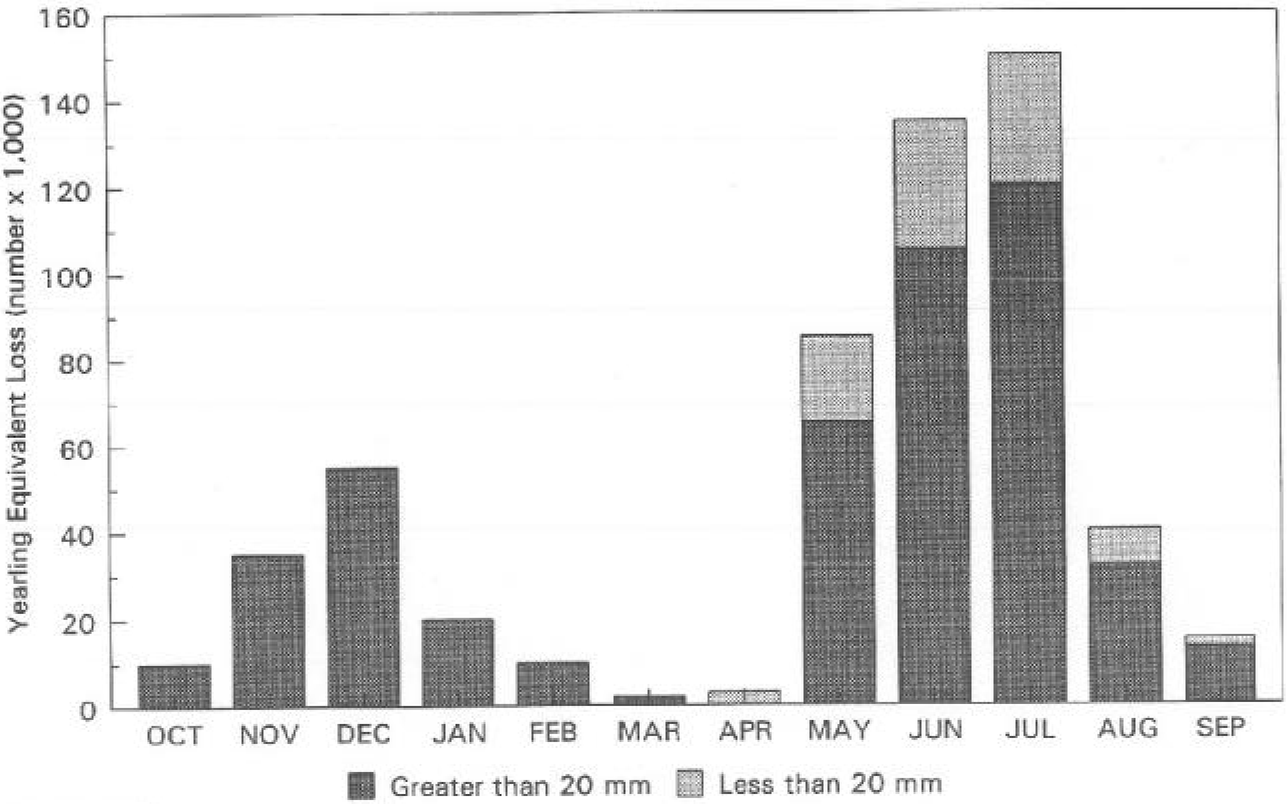
FIGURE 2-VII-29



Source: Brown (1992).

YEARLING EQUIVALENT ENTRAINMENT LOSS OF STRIPED BASS AT THE STATE WATER PROJECT FACILITY (1985-1991)

FIGURE 2-VII-30



Source: Brown (1992).

ANNUAL ENTRAINMENT PATTERN FOR STRIPED BASS AT THE STATE WATER PROJECT FACILITY (1986-1991)

FIGURE 2-VII-31

fish size, predation rates, and handling and trucking mortality. These factors are different for the CVP and SWP pumping facilities.

Entrainment loss of larger bass has a more adverse effect on the population than the loss of the same number of smaller bass. Conversion to yearling equivalents shows the relative annual loss for all sizes combined, including eggs and larvae (Figure 2-VII-30). The bulk of entrainment loss is composed of early juvenile life stages (prior to 1.52 inches) and occurs during May-August (Figure 2-VII-31). Substantial losses of young-of-the-year bass have also occurred during November-January and may be a function of young bass distribution (i.e., relative to the location of X2).

Agricultural diversions - Losses of striped bass to agricultural diversions are believed to be considerable (Odenweller 1981) and have been estimated to be in the millions, possibly equivalent to entrainment loss to SWP and CVP diversions (Stevens et al. 1985, Brown 1992). Actual loss estimates are currently unavailable (Brown n.d.). Losses to agricultural diversions depend on the timing, size, and location (geographically and position in the channel) of individual diversions relative to the seasonal distribution and abundance of striped bass. Losses of egg and larval striped bass could be most effectively minimized by curtailing diversions in May and June.

Juvenile striped bass may have the swimming ability to avoid entrainment in small intakes, but losses have been documented. The magnitude of entrainment losses of juvenile bass to agricultural diversions is currently unknown. Entrainment of juvenile bass in agricultural diversions is a function of diversion location (including location in the channel relative to distance from shore and depth); diversion volume and design; and distribution, size, and behavior of young striped bass. Most agricultural diversion occurs in the interior Delta, where there are generally fewer bass; therefore, the effect may be less than for other diversions (Cannon 1982).

Power generation facility diversions - Two of the largest nonconsumptive diversions in the Delta are PG&E's Contra Costa and Pittsburg Power Plants. Considering the location of the facilities' intakes in the striped bass rearing area (near Antioch and Pittsburg) and the size of the diversions (nearly 1,500 cfs at each power plant, depending on power generation needs), substantial numbers of egg and larval striped bass could be entrained and lost in the diversions (PG&E 1985). From 1984 to 1989, 10,000-61,000 striped bass yearling equivalents were killed at the two power plants (PG&E 1990).

Losses of striped bass, however, have been reduced from previous operations. Annual variability in water temperature (a factor controlling bass mortality) and variability in the availability of alternative power supplies have prevented the power plants from additional reductions in striped bass losses. PG&E has participated in the juvenile striped bass stocking program to mitigate losses.

PG&E's Contra Costa and Pittsburg power plants have fish salvage facilities, but the efficiency of the salvage facilities and the loss of juvenile bass could not be determined with available data. As discussed previously for eggs and larvae, losses to the power plant diversions are likely substantial because of the location of the intakes in proximity to striped bass rearing areas (Cannon 1982).

Other diversions - Other diversions also entrain and kill striped bass eggs and juveniles. The largest diversions not previously discussed are the North Bay Aqueduct diversion and CCWD's Rock Slough diversion. Losses of eggs and juveniles to diversions other than those described in previous sections are currently unquantified.

Egg and larval sampling in the sloughs leading to the North Bay Aqueduct indicate that striped bass abundance has increased (Herrgesell 1993). Diversion during the striped bass spawning and early rearing period may draw water and the associated eggs and larvae off the Sacramento River. Other diversions would likely have similar effects.

The fish screen at the North Bay Aqueduct diversion prevents entrainment of juvenile striped bass into the diversion. Indirect losses (i.e., predation and other factors associated with the screen) have not been determined. Relative to other diversions, the effect on juvenile bass is probably minimal because of the location relative to the main striped bass rearing areas.

Annual entrainment losses of eggs and larvae to CCWD's Rock Slough diversion are unknown. The diversion is not located near the main striped bass spawning area; however, high entrainment losses of striped bass eggs and larvae occur at the SWP and CVP Delta pumping facilities. Old River transports water and striped bass eggs and larvae to the SWP and CVP Delta pumping facilities. Diversion during the striped bass egg and larval period draws water and the associated eggs and larvae off of Old River and to the Rock Slough diversion.

Annual entrainment losses to CCWD's Rock Slough diversion may have historically exceeded 1 million juvenile striped bass (Odenweller 1992). Sampling of striped bass entrainment, however, has not been consistent, and actual entrainment losses are unknown. The diversion is not located near the main striped bass rearing areas, but striped bass juveniles are abundant in some years in Old and Middle rivers, which transport water to the SWP and CVP Delta pumping facilities (as supported by high entrainment losses of juveniles at those facilities). The Rock Slough diversion draws water off the Old River channel.

Toxic substances - Survival of adult striped bass may be affected by toxic materials entering the Sacramento-San Joaquin estuary from agricultural runoff, discharge of industrial and municipal waste, and runoff from non-point sources (i.e., stormwater runoff). Adult striped bass tissues contain concentrations of toxics exceeding levels recommended for human consumption; however, data prior to the striped bass decline after 1970 are unavailable for comparison (Herbold et al. 1992). Relative to striped bass on the Atlantic Coast and in other estuaries, striped bass from the Sacramento-San Joaquin estuary appear to be in poor health and often have open lesions (reactions to parasite infection) (Brown 1987).

Every year, during May and June, hundreds to thousands of adult striped bass die and wash up along the shoreline of the estuary (Brown 1992). The highest density of dead adults is found in Carquinez Strait. Livers from dead striped bass were contaminated with higher concentrations of toxic materials than the livers of healthy fish taken from the Delta. A causative factor for the die-off has not been identified, but the relatively high concentration of toxic materials may contribute to factors resulting in the mortality.

The number of viable eggs is directly affected by contaminant levels in prespawning females, causing resorption of eggs or production of abnormal embryos (Brown 1987, DFG 1987). Analysis has not shown strong relationships between reproductive condition, parasite burdens, and pollutant concentrations. Female striped bass in the Sacramento-San Joaquin estuary, however, are less fecund than female bass from other estuaries. Reduced fecundity appears to be related to the effects of toxic materials, but the extent of reduced fecundity is unknown.

Habitat - As noted previously, nearly half of the available marsh and tidal habitat was filled and leveed off (DFG 1989). In the Delta, less than 3% of the habitat remains in a state similar to Delta habitat 150 years ago (Herbold et al. 1992). Diking and filling restricted striped bass habitat and reduced tidal mixing and overall estuary productivity. However, most diking and filling in the estuary preceded the recent precipitous 20-year decline in the population. Since 1970, only relatively small habitat areas have been lost to levee riprapping and additional filling. Although habitat loss does not account for the population decline, restoration of diked and filled wetlands, with subsequent reconnection to the estuary, could provide additional habitat for adult striped bass and increase overall productivity of the estuary.

AMERICAN SHAD

General Problems

Since the early 1900s, the shad population is believed to have experienced a gradual decline in abundance. Evidence suggests that this decline has occurred primarily from anthropogenic factors, such as water development, that likely continue to affect abundance. The rapid increase in American shad abundance and distribution shortly after their introduction indicates that habitat and environmental conditions historically were ideal for shad. Although the rivers and Delta were largely leveed and many of the wetlands were diked and filled soon after the introduction of shad, the Delta environment and river flow patterns were relatively unmodified compared to current conditions.

Undoubtedly, many factors have combined to decrease California's American shad populations, and historical conditions for successful shad spawning, growth and development, and emigration have been impaired. Although knowledge of American shad ecology and specific factors limiting shad abundance in California has been primarily limited to DFG's American shad studies in the mid 1970s, additional information being developed in the context of other studies could assist in understanding factors affecting shad abundance in the future.

Many of the factors affecting the abundance of eggs and larvae equally apply to the juvenile stage. Although year class strength of the shad population may be set early in the life cycle of American shad, probably occurring before the juvenile stage, survival of juvenile shad ultimately determines the number of shad recruited to the adult population. Therefore, factors affecting juvenile shad may be important in determining adult shad abundance.

In general, overall shad production depends on both freshwater conditions (factors affecting adult migration, spawning, egg incubation, rearing, and emigration) and oceanic conditions (factors affecting ocean shad growth, survival, and migration back to fresh water). More is known about the freshwater life history, biology, and environmental requirements of shad. The oceanic ecology of shad in the Pacific Ocean has been generally neglected. Oceanic conditions should not be entirely dismissed as a factor affecting abundance, however, because DFG viewed the 1982-1983 El Niño conditions in the ocean as having detrimental impacts on shad populations (Messersmith pers. comm.), and oceanic conditions are being found to have greater effects on salmon populations than once thought.

Flow and water temperature - River flows are important in determining the spawning locations of virgin American shad, while water temperature appears to be the most important mechanism triggering the onset of spawning. Water temperatures outside the optimum range for migrating and spawning adult shad may affect shad abundance by reducing reproductive success or by increasing mortality in post-spawning adults.

Operation of large upstream reservoirs has altered historical water temperature regimes in tributary rivers. The survival of shad eggs and larvae are closely related to water temperatures. Exceedingly low water temperatures (less than 52^{o}F) can reduce hatching success of shad eggs (Stier and Crance 1985). Similarly, exceedingly high water temperatures (greater than 80^{o}F) can be unsuitable for hatching of eggs and eventual development of larvae (Stier and Crance 1985). Less than optimal water temperatures may cause developing larvae to sustain poor development, reduced growth rates, and increased mortality.

Diversions - American shad eggs, larvae, and juveniles are susceptible to unscreened and sometimes screened diversions that occur throughout the distributional range of shad in the Sacramento-San Joaquin River system. Direct losses to these diversions are, for the most part, largely unknown.

Habitat - Habitat modifications have had the greatest effect on shallow-water habitats particularly important to developing larvae. Important shallow-water habitats provide optimal water temperatures necessary for growth and proper development and excellent conditions for food production. As noted previously, levee construction, river channelization, dredging, and the diking and filling of historical flood basins have drastically reduced the amount of shallow-water habitats available to young shad both in the major river systems and the Delta.

Toxic materials - All life stages of American shad may be affected by toxic materials entering the Sacramento-San Joaquin River system from agricultural runoff, discharge of industrial and municipal waste, and runoff from non-point sources (e.g., urban stormwater runoff). In the Delta, pollutants of particular concern are trace elements (e.g., selenium, copper, cadmium, and chromium) and agricultural chemicals and their derivatives, which are used extensively in the Central Valley.

Although no specific information is available on how toxic materials are affecting shad populations in the rivers or Delta, the effects of toxics on adult shad may be similar to known effects on other Delta fish species. For instance, toxics exceeding levels considered safe for human consumption have been found in tissue samples of adult striped bass and appear to reduce fecundity in female striped bass. Although toxic materials likely have an adverse affect on adult shad, no evidence exists to suggest that these materials are causing a decline in shad abundance. Toxic materials may affect adults either directly or indirectly, thereby reducing reproductive success and survival.

One of the complicating factors in understanding the effects of toxics on ecological processes in the estuary is the complex distribution of "hot spots" (i.e., areas with high concentrations of toxics), both spatially and temporally (Herbold et al. 1992). These hot spots may cause adults to avoid biologically important habitat or alter movements.

Although shad spawn when flows are typically high and pollutant concentrations are probably relatively low (because of the diluting effects of high freshwater flows), localized populations of young shad and eggs may be disproportionately affected by pollutants if developing eggs and larvae encounter discharges containing high pollutant concentrations. Developing eggs and larvae in the vicinity of these discharges may experience poor development, reduced growth rates, and increased mortality, but specific data are unavailable to ascertain the importance of toxic materials in determining shad abundance.

Competition and predation - The effects of increased competition and predation resulting from species introductions are difficult to evaluate in wild populations. Competition-predation effects would be distinguishable if there was a concomitant increase in the abundance of an introduced species with the decline in abundance of shad.

Striped bass are known to prey on young shad; however, it is unlikely that they are responsible for the decline in abundance because shad and striped bass have coexisted since shortly after shad were introduced. Furthermore, historical shad populations were abundant at the same time that healthy striped bass populations occurred. More recently, striped bass populations have been declining along with other Delta species, including shad.

Competition is a more likely source of mortality for larval shad. Numerous accidental species introductions have occurred since shad were introduced to the Sacramento-San Joaquin River system and, in combination with modified habitats, could have adversely affected shad survival in several ways. These mechanisms have been described in detail for striped bass.

Prey availability - Prey availability for larval shad appears to be adversely affected by human-induced factors. Removal of riparian and streamside vegetation in the Sacramento River system upstream of the Delta potentially reduces the recruitment of terrestrial insects. Young shad in these upstream areas rely on terrestrial insects as a food source, which has been decreasing as more river sections are leveed. (DFG 1987.)

Sacramento River

Although shad on the east coast are known to exhibit a tendency to spawn in their natal streams, river flow appears to be largely responsible for affecting the distribution of virgin spawners in the Sacramento River system (Painter et al. 1980). Within the Sacramento River system, the relative magnitude of tributary flow to the mainstem rivers appears to determine the relative percentage of virgin spawners using those tributary rivers (Painter et al. 1980).

Based on 1975-1978 data, flow relationships have been developed that indicate that virgin shad are attracted into the upper Sacramento, Yuba, and American rivers when flows in these rivers relative to the Feather, Feather, and Sacramento rivers, respectively, are relatively large during May and June (Table 2-VII-4) (Painter et al. 1980). A strong relationship does not exist in the Feather River, however, where it is believed that the longer rearing time allows juveniles to become imprinted for homing (DFG 1987). The lack of such a relationship has recently been verified using 1990-1993 shad data from the Sacramento, Feather, and Yuba rivers (Sommer pers. comm.). Equally strong relationships also exist in the 1975-1978 data between the percentage of virgin shad attracted into the upper Sacramento, Yuba, and American rivers and total May-June flows in these rivers, without consideration of the flow percentages between any two rivers (Jones & Stokes Associates file data).

Table 2-VII-4. Percentage flow and virgin shad in the upper Sacramento, Feather, Yuba, and American rivers (1975-1978)

Year/Coefficient	Upper Sacramento		Feather		Yuba		American	
	%Q[a]	%V	%Q[b]	%V	%Q[c]	%V	%Q[d]	%V
1975	65.8	72.7	34.2	62.7	33.8	70.45	19.0	96.8
1976	79.5	90.8	21.5	29.0	10.3	32.61	10.5	71.7
1977	76.8	85.4	23.2	82.2		N/A	5.4	58.8
1978	60.1	63.9	39.9	80.1	38.9	80.06	18.2	91.9
Coefficient of correlation	0.9971		0.5020		0.9997		0.9978	

[a] Percent upper Sacramento of upper Sacramento plus Feather River flow.
[b] Percent Feather River of Feather River plus upper Sacramento.
[c] Percent Yuba River plus Feather River at Yuba City.
[c] Percent American River of Sacramento River at Sacramento.

Notes:

1. Percent virgins each year from Wixom (1981), percent Q based on mean May-June flows, U.S. Geological Service data.

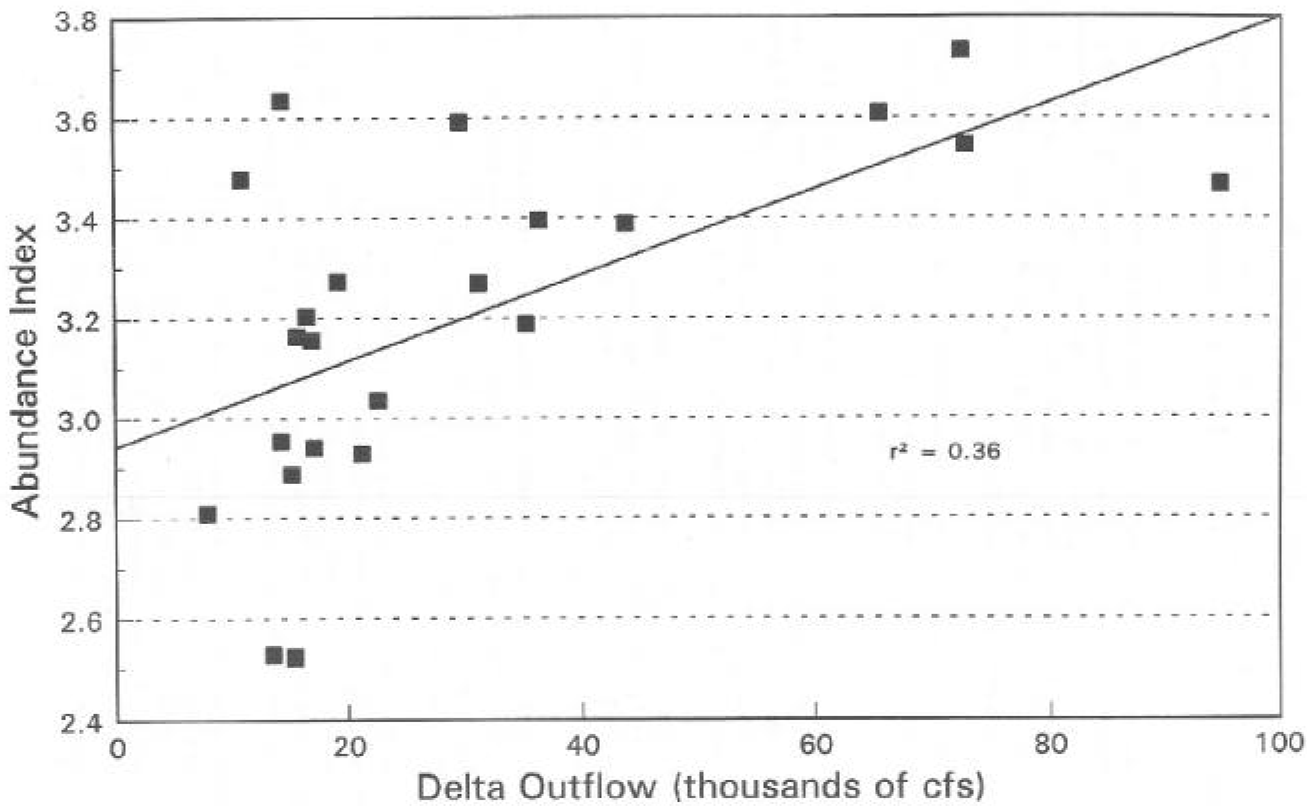
2. Predictive equations (y = percentage flow, x = percentage virgins) are as follows:

Upper Sacramento River	y	=	1.3284 x -15.5171
Feather River	y	=	1.3991 x +21.9482
Yuba River	y	=	1.6440 x +15.5572
American River	y	=	2.7208 x +43.6819

Source: Painter et al. 1980.

Despite these strong relationships, the effect of the relative distribution of virgin spawners on young-of-year (YOY) shad abundance and overall shad populations is unknown. Specifically, it is unclear whether there is increased survival from shad spawning in the major tributaries rather than spawning in the Sacramento River. It is unknown whether YOY abundance is a function of the distribution of flows (and therefore spawners) or increased flows in general. For instance, fall midwater trawl survey data suggest that YOY abundance is greater during years with high freshwater Delta inflow. However, during years of high Delta inflow, relatively more YOY shad may be washed downstream into the Delta compared to years with lower Delta inflows, causing the abundance index to be higher than it actually is.

Adult passage into tributary streams is also an important factor in determining the distribution of spawning adults. Relatively low flows during spring may reduce or restrict adult access to spawning areas in tributary rivers at critical riffle habitats. Critical riffle habitats occur when decreasing flows cause water depths to be too low to pass migrating adult shad. Reduced or restricted access to spawning areas may cause adult shad to spawn where habitat or environmental conditions are less favorable, thereby reducing reproductive success.



AMERICAN SHAD ABUNDANCE VERSUS AVERAGE APRIL-JUNE DELTA OUTFLOW

FIGURE 2-VII-32

San Joaquin River

All of the factors described above for the Sacramento River, and for American shad in general, have worked in concert to limit shad runs in the San Joaquin River basin. Of particular importance, however, is the lack of adequate spring instream flows and corresponding poor water quality.

Delta/Bay

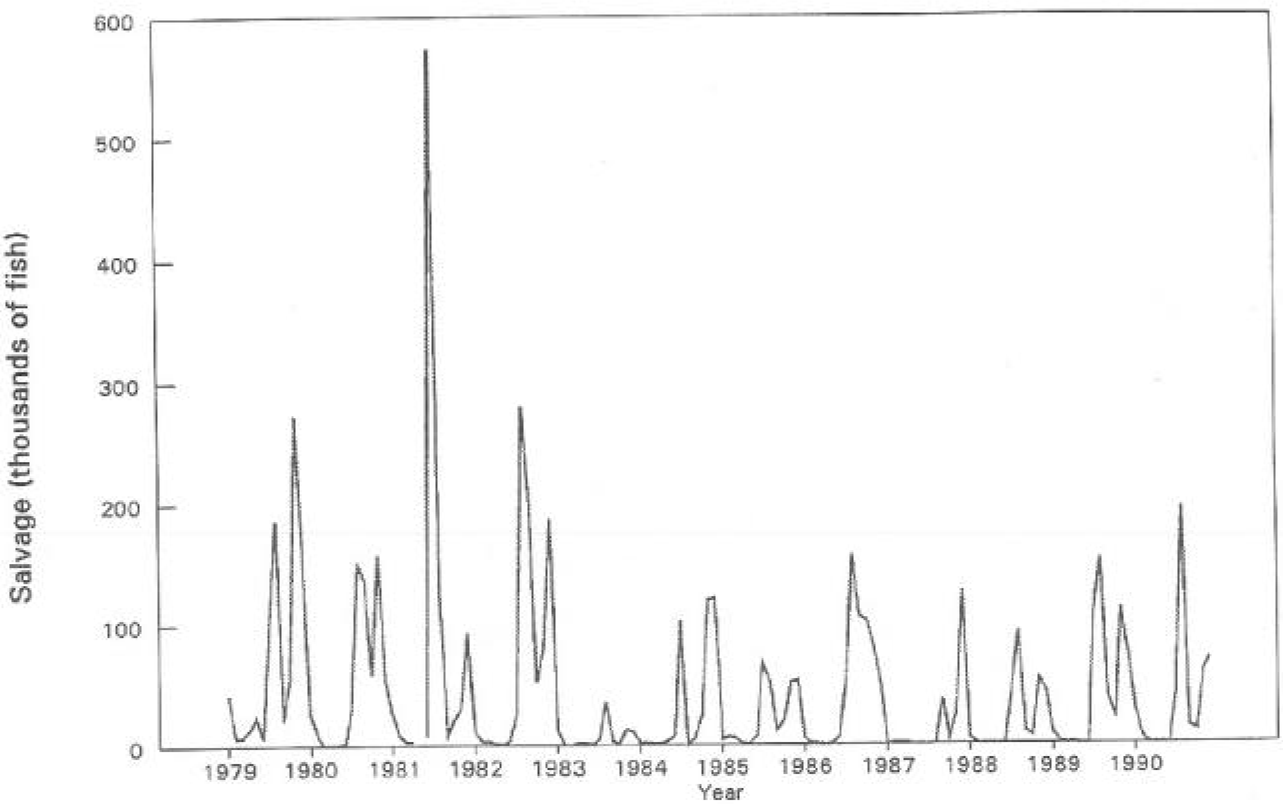
Flow - YOY shad abundance appears to be positively correlated with flow during the primary spawning months (April-June) (Painter 1979). Analysis of the 1967-1991 midwater trawl abundance indices indicates that YOY shad abundance is greater in years when April-June Delta outflows are greater (Figure 2-VII-32). Seining surveys conducted during the 1975-1978 period collected a greater number of juvenile shad in 1975 and 1978, compared to the 1976-1977 drought years (Painter et al. 1980).

The precise environmental mechanism responsible for increasing YOY shad abundance during years with increased April-June flows is unknown. However, the following mechanisms may explain reduced abundance at lower Delta outflows:

- Eggs and larvae are more likely to settle to the river bottom and die because water velocities, which are necessary to suspend eggs off the bottom, are reduced.
- Egg and larval survival is reduced because of warmer water temperatures associated with reduced river flows.
- Eggs and larvae are more susceptible to exposure of toxic substances in the rivers and Delta.
- A lower proportion of larvae are carried to the Delta where feeding efficiency and survival rates may be increased.
- A higher proportion of larvae are drawn into the central and south Delta where vulnerability to entrainment in diversions is greater.

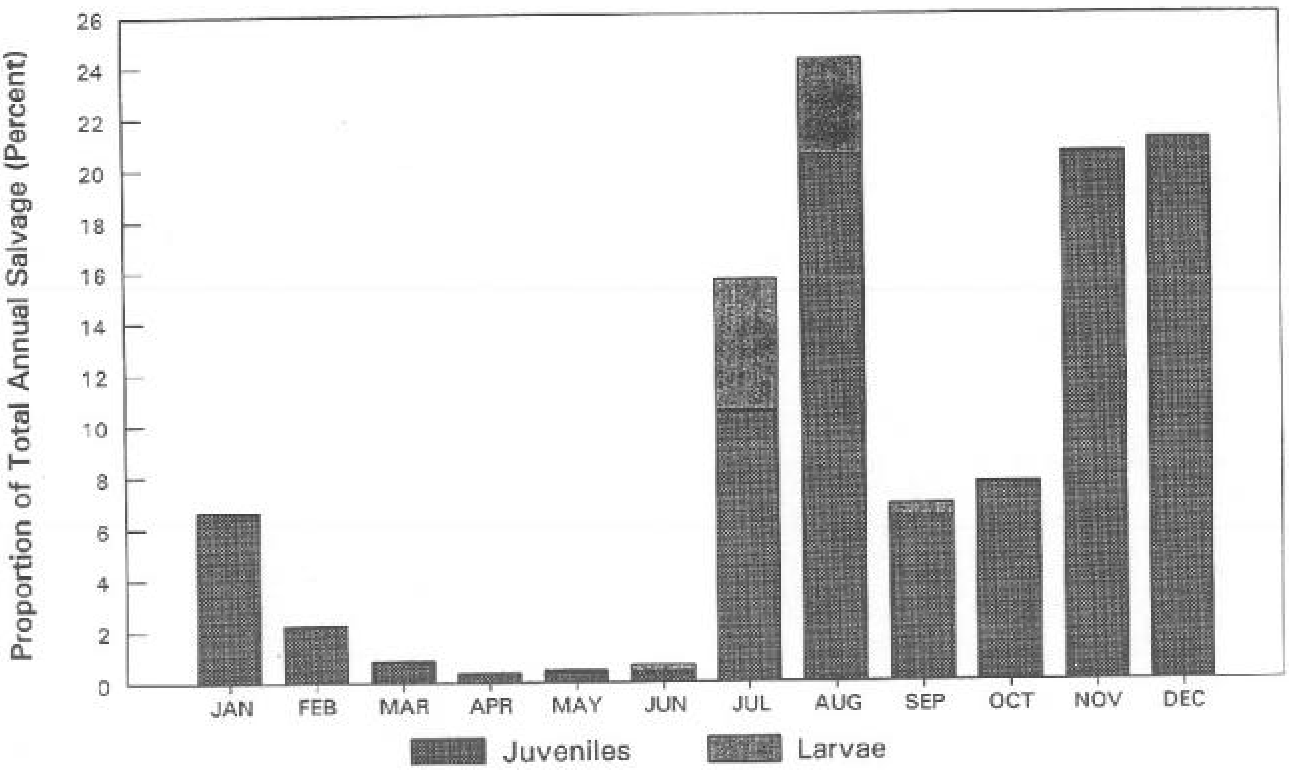
However, the precise environmental mechanism that determines shad abundance is unknown. Mechanisms that may contribute to reduced abundance of egg and larval stages likely apply to juvenile shad as well.

Salinity - As stated earlier, upstream water storage projects, diversions, and Delta export pumping have reduced Delta outflow and periodically increased salinity in Suisun Marsh, Suisun Bay, and the lower Delta. Because larval shad appear to be highly tolerant of salinity and salinity changes (Stier and Crance 1985), increased salinity in the estuary does not appear to directly affect young shad. However, increased salinity in the estuary may influence other environmental and biological factors such as prey availability, thereby indirectly affecting shad abundance.



TOTAL SALVAGE OF AMERICAN SHAD AT THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT FISH PROTECTION FACILITIES (1979-1990)

FIGURE 2-VII-33



AVERAGE MONTHLY PROPORTION OF ANNUAL AMERICAN SHAD SALVAGE AT THE STATE WATER PROJECT AND CENTRAL VALLEY PROJECT FISH PROTECTION FACILITIES (1979-1990)

FIGURE 2-VII-34

Entrainment - Entrainment losses depend on the timing, size, and location of individual diversions relative to the seasonal distribution and abundance of American shad. Losses of larval shad could be most effectively minimized by reducing diversions in July and August.

CVP and SWP Delta pumping facilities - CVP and SWP Delta Pumping Facilities are the largest diversions in the Delta, and young shad are vulnerable to diversion by these and other facilities. Thousands of American shad are salvaged annually by CVP and SWP fish protection facilities (Figure 2-VII-33), and thousands more are lost to the diversions. American shad are the third most common fish salvaged at the SWP screens (DFG 1987).

Thousands of juvenile shad (2.8-30 centimeters long) are entrained in diversions at the CVP and SWP Delta Pumping Facilities each year and account for most entrained shad. Although the bulk of juveniles are entrained from July through December, salvage records indicate that the juvenile shad are entrained year round (Figure 2-VII-34).

The relative proportion of entrained juveniles that are salvaged and returned to the Delta alive has not been quantified. Evaluations of screening efficiency comparable to studies for striped bass and salmon have not been conducted for American shad; however, it is believed that larger fish in fall are screened more efficiently than those in late spring and early summer (DFG 1987).

Entrainment losses occur from predation near the screening facilities and stress associated with handling and trucking. Salvaged American shad suffer mortality rates in excess of 50% during summer, with slightly lower mortality rates during the cooler fall (DFG 1987). Because of the high handling losses that occur at the CVP and SWP fish protection facilities, the only practical means of reducing these losses would be pumping restrictions during July through December.

Young shad spawned in the south Delta and Mokelumne River channels are drawn into the pumps as larvae and small juveniles; Sacramento River system juveniles tend to be drawn through the DCC and across the Delta during their downstream migration (DFG 1987). Salvage data from the CVP and SWP pumping facilities indicate that larval shad (less than 1.12 inches long) are entrained from May through September (Figure 2-VII-34). Most of the entrained larvae are lost in the diversions. Entrainment losses, including predation, handling, and trucking mortality, have not been quantified.

Agricultural diversions - Losses of larval shad to agricultural diversions are probably considerable because these diversions account for approximately one-third of the volume of water diverted from the Delta. Losses to agricultural diversions depend on the timing, size, and location (geographically and position within the channel) of individual diversions relative to the seasonal distribution and abundance of larvae. Entrainment losses to agricultural diversions have not been quantified.

Entrainment of juvenile shad to agricultural diversions is a function of fish size, location of the diversions (geographically and position within the channel), and the volume and design of the diversions. Although juvenile shad may be capable of avoiding smaller intakes, entrainment is likely. The magnitude of entrainment losses of juveniles to these diversions is currently unknown and depends on juvenile abundance and distribution in addition to the factors mentioned above.

Power generation facility diversions - PG&E's Contra Costa and Pittsburg Power Plants have fish salvage facilities, but entrainment rates, salvage efficiency, and associated losses of larval shad are not available. Shad larvae are known to occur in the Delta and Suisun Bay and are probably susceptible to entrainment as they pass near the intakes to these power plants.

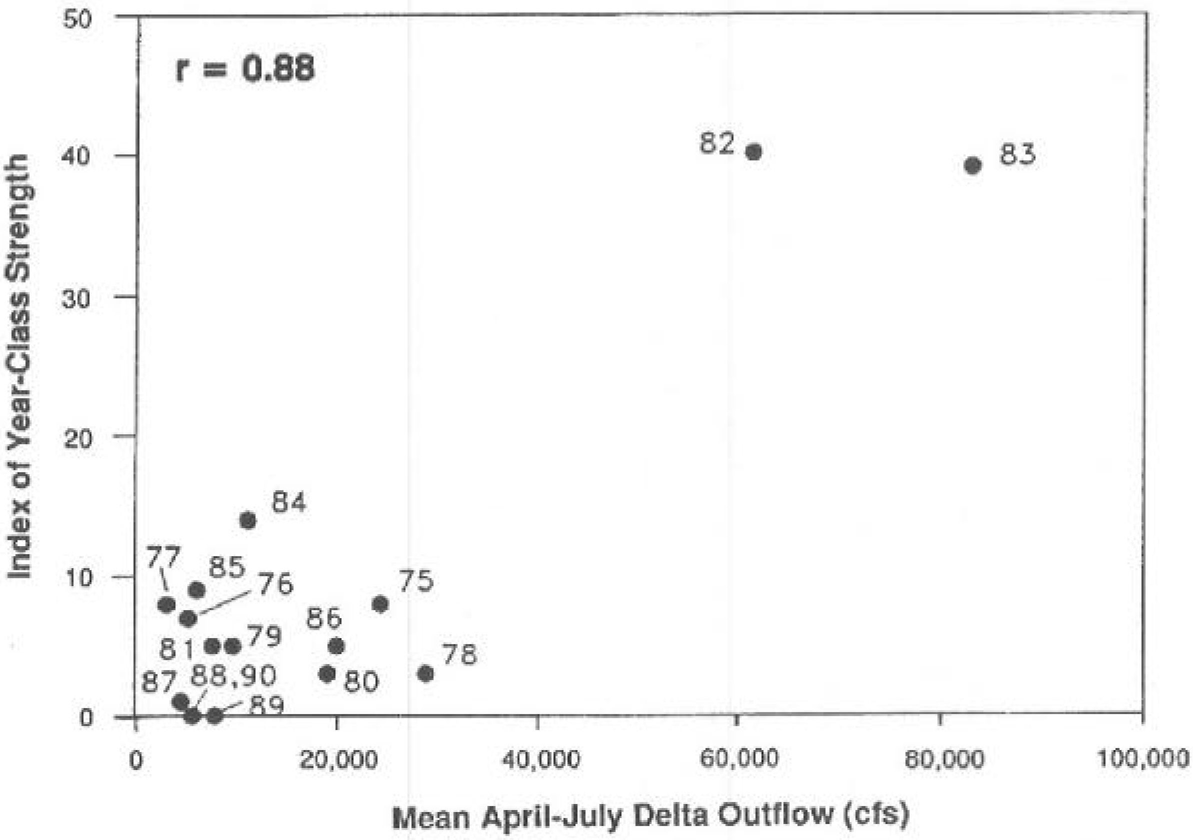
PG&E's Contra Costa and Pittsburg Power Plants have fish salvage facilities, but entrainment rates, salvage efficiency, and associated losses of juvenile shad are not available. Juvenile entrainment may be substantial because of the proximity of the intakes to juvenile rearing areas.

Other diversions - The magnitude of larval entrainment losses at the North Bay Aqueduct and CCWD's Rock Slough diversions is unknown. Losses at upstream diversions in rivers where shad spawn, rear, and emigrate undoubtedly occur but are not quantified. It would generally be expected that as the proportion of river flow diverted is increased, American shad egg, larvae, and juvenile survival would decrease if these life stages resided in the area of the river where the diversions were occurring.

The efficiency of the salvage facilities and the entrainment losses of juvenile shad at the North Bay Aqueduct and losses to CCWD's Rock Slough diversions are unknown. Diversions in known juvenile rearing areas in the rivers would have an adverse effect similar to that described for eggs and larvae but substantially diminished because of the swimming capabilities of the larger juvenile fish.

Habitat - Land reclamation, flood control facilities, and agricultural development have eliminated or drastically altered much of the aquatic habitat within the Central Valley. Dams may have restricted access to upstream spawning and rearing habitats and modified or reduced freshwater flows that provide the necessary conditions for optimal shad migration, spawning, egg incubation, and rearing. Diking and dredging have eliminated an estimated 96% of the wetland habitats in the lowland areas (50 CFR Part 17). Diking and filling of wetlands in the Delta have restricted shad habitat and, in combination with reductions in freshwater flows, have reduced tidal mixing and overall estuary productivity. Although many of these modifications occurred before the initial introduction of shad in California, more recent anthropogenic factors may exacerbate the effects of wetland filling and diking, thereby contributing to the decline in shad abundance.

Prey availability - Water development has affected zooplankton abundance in the Delta, primarily because the use of Delta channels to convey Sacramento River water to the south Delta has reduced water residence times in the Delta and increased the volume of zooplankton-deficient Sacramento River water that is transported to the central and south Delta (DFG 1987).

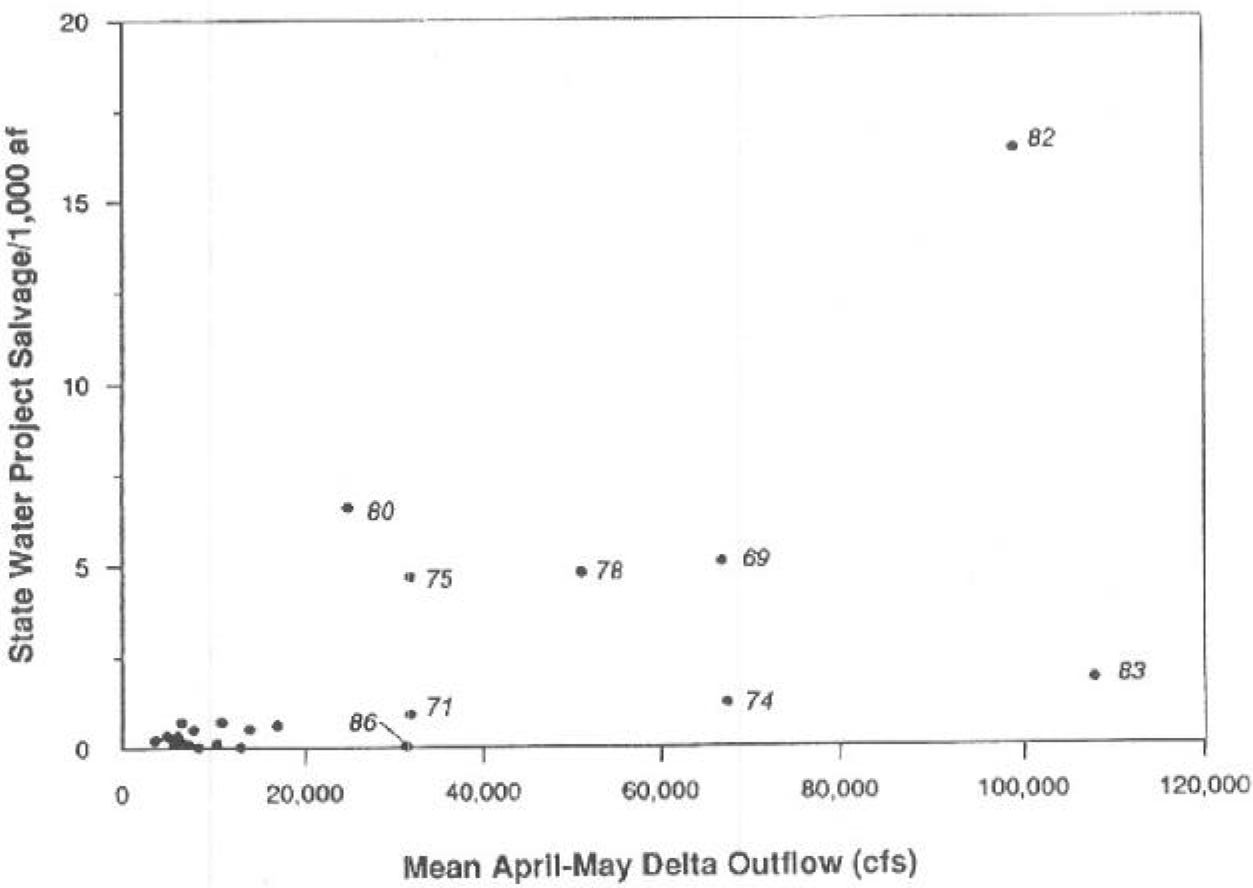


Source: Kohlhorst et al. 1991.

Note: Year-class index determined from trawl catches.

WHITE STURGEON YEAR-CLASS INDEX VERSUS MEAN DELTA OUTFLOW FOR APRIL THROUGH JULY (1975-1990)

FIGURE 2-VII-35



Source: California Department of Water Resources 1990.

Note: Year-class index determined from salvage at State Water Project Skinner Fish Facilities.

WHITE STURGEON YEAR-CLASS INDEX VERSUS MEAN DELTA OUTFLOW FOR APRIL THROUGH MAY (1968-1987)

FIGURE 2-VII-36

The introduced Asiatic clam (*Potamocorbula* sp.) may affect young shad abundance because the clam has become extremely abundant in Suisun Bay where it may compete with opossum shrimp, a prey item of American shad. Introduced species of copepods and cladocerans may have similar effects on young shad abundance.

WHITE STURGEON

Flows

Kohlhorst et al. (1991) found a significant positive correlation between a year-class strength index and Sacramento River outflow from April to July. During years with high April to July flows (1982 and 1983), white sturgeon year-class strength was greater than years between 1975 and 1985 with lower outflows (Figure 2-VII-35). SWP data from 1968 to 1987 also indicate that sturgeon production (as determined by the number of young sturgeon salvaged per acre-foot of water exported) was related to April-May Delta outflows (DWR 1990) (Figure 2-VII-36).

Mechanisms responsible for increased recruitment are not well defined. Likely contributing factors include increased spawning activity cued by high flows, larval dispersion by the currents to more productive or less utilized habitats, reduced entrainment, and increased nutrient loading to the nursery environment due to increased flows.

Diversions

Larval and juvenile sturgeon are weak swimmers that are transported downstream primarily by the currents. Consequently, larval and juvenile sturgeon are susceptible to entrainment and impingement on fish screens associated with water diversion projects in the Sacramento River and Delta. Magnitude of losses and effects on population abundance are unknown. Fish screen designs at diversions are important to successfully pass juvenile sturgeon at diversions and prevent impingement of sturgeon on the screens. Based on the work of Reading (1982), Ward (pers. comm.) suggested that required maximum approach velocities would need to be approximately 0.06 foot per second to protect juvenile sturgeon at diversions.

Water Quality

The influence of water pollution on sturgeon is not well documented. Sturgeon tissue has been found to contain polychlorinated biphenyls (PCBs), organochlorides, mercury, selenium, and dioxins (Pacific States Marine Fisheries Commission 1992). Egg tissues can also contain toxins, which could reduce reproductive potential (Doroshov 1990). Turbidity can affect the adhesiveness of eggs, which could displace eggs to less-than-optimum habitats during incubation.

Predation

There are no published data on the effects of predators on juvenile sturgeon in the Sacramento River. Mass nocturnal hatching, hiding behavior during yolk absorption, and avoidance of light are all adaptations to minimize predation. As sturgeon grow, they become less likely to be killed by predators. Adult sturgeon are not known to have any predators except humans. Benthic-feeding fish are most likely to consume sturgeon eggs and larvae. Dramatic increases in these predators could adversely affect sturgeon recruitment.

Migration Barriers

Though not well documented, low flows and physical obstructions can impede sturgeon migration. For example, blasting was required to remove an in-river obstacle on the Klamath River that was determined to impede sturgeon migration (USFWS 1982). Major physical barriers to adult sturgeon migration on the mainstem Sacramento River are RBDD and the ACID's diversion dam. Unimpeded migration past RBDD occurs during gates-raised operation roughly between mid-September through early May (as mandated by NMFS); while passage past the ACID's diversion dam occurs from November through March when dam flashboards are removed. Both RBDD and the ACID's diversion dam have fish ladders primarily designed to facilitate salmonid passage. Potential physical barriers to upstream migration in the Feather River are a rock dam at Sutter Extension Water District's sunrise pumps, Shanghai Bend, and several shallow riffles between the confluence of Honcut Creek upstream to Thermalito Afterbay outlet. Ted Sommer (pers. comm.) thought each of the above-listed physical barriers could impede adult upstream migration during low flows. Finally, on the San Joaquin River anglers describe sturgeon migrating through shallow water and believe that low water slows migration (Russell pers. comm.).

Low dissolved oxygen levels commonly occur near Stockton each fall due to dredging activities in the Stockton Ship Channel and turning basin, flow reversals due to high Delta exports, and effluent discharge from the Stockton Municipal Sewage Plant, and other sources. Low dissolved oxygen levels have been shown to inhibit adult salmon migration near Stockton. The quality and quantity of agricultural drainwater may also inhibit adult sturgeon migration. Whether or not low dissolved oxygen levels of other water quality conditions inhibit passage of adult sturgeon is unknown and needs to be investigated.

GREEN STURGEON

Problems affecting green sturgeon production are likely to be similar to those affecting white sturgeon.

SECTION VIII. MANAGEMENT FACTORS

AUTHORITIES AND AGENCY RESPONSIBILITIES

The management of Central Valley anadromous fish populations and their migration, holding, spawning, and rearing habitats is achieved through a broad diversity of state and federal laws and regulations. Significant responsibilities are vested through the Public Trust Doctrine, the state and federal Endangered Species Acts, the federal Clean Water Act, the State Porter-Cologne Water Quality Control Act, the U.S. Fish and Wildlife Coordination Act, the Magnuson Fishery Conservation and Management Act, the federal Water Pollution Control Act, the federal Rivers and Harbors Act, the federal Power Act, the National Environmental Policy Act, the California Environmental Quality Act, and numerous provisions of the California Fish and Game Code.

The following is a discussion of agencies, policies, and programs that affect management of Central Valley anadromous fisheries, riparian, and wetland resources.

Federal Role

The National Environmental Policy Act (NEPA) requires federal agencies to prepare detailed environmental impact statements when considering major federal actions that could significantly affect the quality of the human environment.

The Fish and Wildlife Coordination Act (FWCA) establishes a national policy of protection and enhancement of fish and wildlife that may be affected by federally constructed projects. The FWCA provides that "wildlife conservation shall receive equal consideration and be coordinated with other features of water development programs". Equal consideration is achieved primarily through the required consultation process. Federal agencies must consult with the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), and state fish and wildlife agencies on proposed projects and must adopt reasonable mitigation and enhancement measures.

The federal Endangered Species Act (ESA) limits the take of federally listed threatened or endangered species and their habitats. Federal agencies are required under ESA to consult with the appropriate federal fish and wildlife agency when proposing a project with the potential to affect a listed fish or wildlife species. Several federally listed species depend on Central Valley streams, wetlands, or riparian areas for their survival.

The U.S. Natural Resources Conservation Service (NRCS) (formerly the U.S. Soil Conservation Service [SCS]), U.S. Department of Agriculture, provides technical assistance in the conservation, development, and productive use of the nation's soil, water, and related resources. NRCS is staff to the Local Resource Conservation Districts in California. NRCS administers a Water Bank Program, with assistance from the Agricultural Stabilization and Conservation Service and other agencies. The objectives of the program are to preserve, restore, and improve habitat in important migratory waterfowl nesting and breeding areas and to benefit other wildlife. Landowners with eligible wetlands may enter into agreements to receive annual payments for conserving land as wetlands.

The mission of the NMFS, U.S. Department of Commerce, is to conserve, manage, and develop living marine resources and to promote the continued use of these resources for the nation's benefit. The NMFS administers the ESA for federally listed threatened or endangered anadromous fish species and marine species. In the Central Valley, NMFS has responsibility for the federally listed threatened Sacramento River winter-run chinook salmon.

The Federal Energy Regulatory Commission (FERC) is authorized by the federal Power Act to issue licenses for the development of hydropower projects. This authority is tempered by its obligations under environmental protection statutes. Conditions are placed on power licenses for the protection of fish, wildlife, and vegetation. For many streams in the Central Valley with hydroelectric power plants, the streamflows and fish passage facilities to maintain anadromous fisheries are required by conditions placed upon the FERC project licenses.

The mission of the U.S. Army Corps of Engineers (Corps), U.S. Department of Defense, is to develop, control, maintain, and conserve the nation's waterways and wetlands. The Corps plays a significant role in flood control. The Corps is the principal federal agency involved in the regulation of wetlands and shares a lead role with the U.S. Environmental Protection Agency (EPA) in preventing degradation and destruction of "waters of the U.S." (most freshwater, wetlands, estuaries, and coastal waters within the territorial limits). The Corps has authority under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act, which prohibit the discharge of dredged or fill material into waters of the United States, or the obstruction or alteration of navigable waters of the United States, without a permit.

The U.S. Bureau of Reclamation (USBR), U.S. Department of the Interior, constructs and maintains federal water development (reclamation) projects for irrigation water services, municipal and industrial water supply, hydroelectric power generation, water quality improvement, fish and wildlife enhancement, outdoor recreation, and river regulation and control. USBR operates the Central Valley Project (CVP), which consists of several large water storage reservoirs and export facilities in the Trinity River basin, the Sacramento Valley, the San Joaquin Valley, and the Sacramento-San Joaquin Delta.

The U.S. Geological Survey (USGS), U.S. Department of the Interior, provides geologic, topographic, and hydrologic information that contributes to the management of resources. USGS collects data on a routine basis to determine quantity, quality, and use of surface water and groundwater, conducts water resources appraisals describing the consequences of alternative plans for developing land and water resources, researches hydraulics and hydrology, and coordinates all federal water data acquisition.

The USFWS, U.S. Department of the Interior, is responsible for protecting and conserving fishes, wildlife (birds and most mammals), and their habitats for the benefit of the public. USFWS is the natural resource trustee for migratory birds, certain anadromous fish, endangered species, and certain federally managed water resources. Under the FWCA, USFWS reviews Corps Section 10 and 404 permit applications, FERC license applications, and federally permitted or constructed projects in or affecting waters of the United States with the goal of protecting and restoring the fish and wildlife values. The North American Waterfowl Management Plan seeks to restore and maintain the diversity, distribution, and abundance of waterfowl that occurred from 1970 to 1979 by solving habitat problems. The plan focuses on seven priority habitat areas; the Central Valley is one of these areas. The Central Valley Habitat Joint Venture is a group of private organizations and public agencies that have agreed to pool their resources to solve habitat problems in the Central Valley. The Migratory Bird Conservation Act of 1929 authorizes the USFWS to acquire lands for conservation of migratory waterfowl and the Fish and Wildlife Act of 1956 authorizes the acquisition of lands for wildlife refuges. The Emergency Wetland Resources Act of 1986 authorizes the Secretary of the Interior to acquire wetlands, and the North American Wetland Conservation Act of 1989 authorizes acquisition of wetlands to implement the North American Waterfowl Management Plan.

The EPA, Executive Branch, was established to protect, maintain, restore, and enhance environmental quality and human health through the regulation of activities that have potentially harmful effects on air, water, and land resources. EPA exercises authority through the National Pollution Discharge Elimination System (NPDES), National Pretreatment Program, Ocean Dumping/Dredging and Fill, and has delegated to the states the authority to certify that permitted actions are consistent with the state's water quality objectives under the Clean Water Act.

The Pacific Fishery Management Council (Council) and seven other regional councils were created by the Magnuson Fishery Conservation and Management Act in 1976 with the primary role of developing, monitoring, and revising management plans for fisheries conducted within 3 to 200 miles of the United States coast. The Council develops plans for ocean fisheries off California, Oregon, and Washington. The Council is not a federal agency but is a regional body funded through the U.S. Department of Commerce. The Council employs a professional staff headquartered in Portland, Oregon; a Scientific and Statistical Committee; several fishery management plan technical teams; and a citizen advisory panel.

The Council meets in various locations throughout its area of jurisdiction and discusses salmon management issues in March and April. The Council has 13 voting members, including the regional director of the NMFS; chief fishery officials of Oregon, Washington, California, and Idaho; and eight private citizens appointed by the Secretary of Commerce from lists submitted by each state governor.

The ocean salmon fisheries off Washington, Oregon, and California have been managed by the Council since 1977. Annual amendments to the Fishery Management Plan were used to provide required management flexibility each season until a framework concept was adopted. Beginning with the 1985 season, the ocean salmon fishery has been managed by a framework amendment that allows flexibility to adjust annual management regulations in response to varying stock abundance.

The harvest management objectives of the Council are to:

1. Establish ocean harvest rates for commercial and recreational fisheries that are consistent with requirements for optimum spawning escapements, treaty obligations, and continuance of established recreational and commercial fisheries within the constraints of meeting conservation and allocation objectives. Achievement of this objective requires that:

    a. Escapements of viable natural spawning stocks of salmon shall be sufficient to maintain or restore the production of such stocks at optimal levels.

    b. Escapement of hatchery stocks shall be sufficient to achieve production goals established by the management entity or entities with responsibility for establishing goals.

    c. In managing mixed stock salmon fishing, the level of exploitation that can be sustained by the weakest natural spawning stocks for which specific management objectives have been defined will be used by the Council to establish maximum fishing rates.

    d. Harvest allocation of salmon stocks between ocean and inside recreational and commercial fisheries shall be fair and equitable and fishing interests shall equitably share the obligations of fulfilling any treaty or other legal requirements for harvest opportunities.

2. Minimize fishery mortalities for those fish not landed from all ocean salmon fisheries as consistent with optimum yield.

3. Manage and regulate the fisheries so the optimum yield encompasses the quantity and value of food produced, the recreational value, and the social and economic values of the fisheries.

4. Develop fair and creative approaches to managing fishing effort and evaluate and apply effort management systems as appropriate to achieve these management objectives.

5. Achieve long-term coordination with the member states of the Council and other management entities which are responsible for salmon habitat or production in the development of a coastwide salmon management plan.

6. Manage consistent with any United States-Canadian salmon treaty.

7. Support the enhancement of salmon stock abundance in fishing effort management programs to facilitate a return to economically viable and socially acceptable commercial, recreational, and tribal seasons.

State Role

The California Environmental Quality Act (CEQA) requires the preparation of environmental impact reports for projects proposed or permitted by state or local agencies with the potential to significantly affect the environment. Its regulations include specific protection for species designated as threatened or endangered. The Sacramento-San Joaquin Delta is listed as having regional and statewide significance; wetlands and riparian lands are defined as significant. Impacts must be mitigated to a level of insignificance (or a finding of overriding consideration), and a mitigation monitoring plan must ensure the effectiveness of mitigation measures.

The California Endangered Species Act (CESA) controls take of state-listed threatened or endangered species. CESA requires state agencies to consult with the California Department of Fish and Game (DFG) on projects with the potential to affect state-listed species and to implement measures to minimize project effects on the listed species.

The California Department of Transportation (Caltrans) plans, designs, and builds the state highway system. Under the Assembly Bill 471 grant program, Caltrans provides $10 million per year for the enhancement of fish and wildlife in the state beyond the requirements of NEPA and CEQA.

The California State Water Resources Control Board (SWRCB) administers California's system of water rights and controls water quality. The SWRCB reviews applications for the diversion of water from the Delta or its tributaries to determine the effect of the proposal on the quantity and quality of water and the resultant effect on other uses of water in the Delta. The SWRCB is also chiefly responsible for implementing Section 208 of the Clean Water Act, the mandate to control "non-point" pollution. The SWRCB and regional water quality control boards review all proposed activities in the Delta that require federal grants, licenses, or permits to determine the effect of the proposed action on water quality. Several sections in the State Water Code refer to the protection of fish and wildlife. The SWRCB is charged with establishing water quality standards for the CVP and the State Water Project (SWP).

The Regional Water Quality Control Boards (RWQCBs) act as agents of the SWRCB and the EPA by issuing waste discharge permits under provisions of the Clean Water Act and Porter-Cologne Act. The San Francisco RWQCB jurisdiction includes the watershed of San Francisco Bay downstream of Chipps Island in the Delta. The Central Valley RWQCB jurisdiction includes the Delta from Chipps Island east and the Central Valley. DFG has legislative authority to preserve, protect, and manage the state's fish, wildlife, and vegetation. DFG administers provisions of the CESA. DFG is responsible for wildlife management, collection and management of data for waterfowl and nongame wildlife, disease research, wetland enhancement, habitat development and management on 76 designated state-owned wildlife areas, ecological reserves, and other public lands. DFG derives its duties and responsibilities from the California State Constitution, the Legislature, and the Fish and Game Code. Essentially, it is the policy of the Legislature that California's fish and wildlife resources are property of the people of the state, are of utmost public interest and concern, and should be protected, conserved, and managed for the benefit of the public today and in the future.

Several provisions in the Fish and Game Code provide an important basis for the protection of fish and wildlife. Sections 1600-1607 require a Streambed Alteration Agreement with DFG for projects that affect the flow, bed, channel or bank of any river, stream, or lake. Protective measures for fish, wildlife, and water quality are included in these agreements. Section 2760 et seq. provides policy relative to protection and restoration of the state's fisheries and makes significant findings relative to the impacts caused by water development. The Keene-Nielsen Fisheries Restoration Act of 1985 states that "California intends to make reasonable efforts to prevent further declines in fish and wildlife, intends to restore fish and wildlife to historic levels where possible, and intends to enhance fish and wildlife resources where possible." Sections 5900 et seq. deal with dams, conduits, and screens as they relate to protection of fishery resources. Section 5937 requires that the owner of any dam allow sufficient water at all times to pass downstream to keep in good condition any fish that may be planted or exist below the dam. Section 5650 prohibits the placement into waters of the state any substance or material deleterious to fish, plant, or bird life. Section 1505 of the code gives DFG the authority to manage, control, and protect the portions of designated salmon spawning reaches which occupy state-owned lands to the extent necessary to protect fish life in these areas. All of the major salmon spawning reaches of Central Valley streams are designated for protection in this code section.

The Salmon, Steelhead Trout, and Anadromous Fisheries Program Act of 1988 has been incorporated into Fish and Game Code Sections 6900-6924. The California Legislature declared as follows:

> a) It is the policy of the State to significantly increase the natural production of salmon and steelhead trout by the end of this century. The DFG shall develop a plan and a program that strives to double the current natural production of salmon and steelhead trout resources. b) It is the policy of the State to recognize and encourage the participation of the public in privately and publicly funded mitigation, restoration, and enhancement programs in order to protect and increase naturally spawning salmon and steelhead trout resources. c) It is the policy of the State that existing natural salmon and steelhead trout habitat shall not be diminished further without offsetting the impacts of the lost habitat.

Several California Fish and Game Commission policies, adopted pursuant to Section 703 of the Fish and Game Code, have widespread importance for the protection of fish and wildlife species in the Central Valley. The Commission's Water Policy describes specific actions that DFG shall take to provide maximum protection and enhancement of fish and wildlife and their habitat. The Commission's policy on wetlands is to provide for the protection, preservation, restoration, enhancement, and expansion of wetland habitat in California. Further, it is the policy of the Commission to strongly discourage development in or conversion of wetlands. It opposes, consistent with its legal authority, any development or conversion that would result in a reduction of wetland acreage or wetland habitat values. The Commission opposes wetland development proposals unless, at a minimum, project mitigation assures there will be "no net loss" of either wetland habitat values or acreage.

The Wildlife Conservation Board (WCB) acquires land, develops recreational facilities and public access to natural sites, and investigates areas to determine suitability for wildlife production, preservation, and recreation.

The mission of the California Department of Water Resources (DWR) is to evaluate present and projected needs for water and development programs and ensure the best use of the resource; to protect the public through water quality improvement, flood control, and dam safety programs; and to assist local water agencies with funds, expertise, and technical support to improve their water delivery systems. DWR administers the Davis-Grunsky Act grant program, which provides grants to local water districts for the construction of dams and reservoirs and provides for measures to enhance fishery and recreational resources. On several Central Valley streams, Davis-Grunsky Act contracts have provided important streamflow augmentations and other measures that benefit salmon. DWR also issues permits for activities involving dams or reservoirs. DWR is responsible for the SWP with major storage reservoirs and pumping facilities in the Delta near Byron. DWR is involved in a levee improvement program for flood protection that overlaps the North Delta Water Management Plans for widening channels.

DWR administers the legislatively mandated San Joaquin River Management Program (SJRMP) in the San Joaquin River basin. The mission of this interagency program is to develop consensus solutions to fishery, water supply, water quality, flood control, wildlife, and recreation problems in the basin. All federal, state, and local agencies with jurisdiction over the basin's resources participate in this process.

The Reclamation Board (RB), administratively part of DWR, exercises responsibilities for flood management on the Sacramento and San Joaquin rivers and their tributaries and participates with the federal government in the completion of federal levee and channel flood control projects.

The State Lands Commission (SLC) administers policies established by the Legislature and the SLC for the management and protection of lands that the state received from the federal government upon its entry into the Union. Such lands include the beds of all naturally navigable waterways such as major rivers, streams and lakes, tidelands and submerged lands that extend from the mean high tide line seaward to the 3-mile limit, swamp and overflow lands, vacant school lands, and granted lands. The state holds its sovereign lands in trust and they can no longer be sold. The SLC manages the resources in a manner consistent with the public trust values for fisheries, navigation, public access, recreation and wildlife habitat, and open space. The SLC requires a Land Use Permit or Lease for activities on its lands.

The Office of the Secretary for Resources (OSR) directs the State Resources Agency, which functions as an "umbrella" agency, setting major resource policy for the state and overseeing programs of agency departments, including DWR and DFG. The agency evaluates CEQA documents for consideration of existing state policy, programs, and plans and coordinates all state agency comments regarding permit applications administered by Corps for compliance with the Federal Clean Water Act.

The California Department of Parks and Recreation (DPR) administers the California Wildlife Protection Act of 1990; one provision provides $2 million in annual funding for grants to acquire, restore, or enhance aquatic habitat for spawning and rearing of anadromous salmonids and trout.

Local Agency Role

Resource Conservation Districts are authorized to assist the state in conserving soil and water on farm, range, urban, and timber lands. The districts provide assistance to landowners and government agencies to prevent soil erosion, control runoff, stabilize soils, and protect water quality.

Local water districts serve the water supply needs of users within specific geographic areas. Many are responsible for making instream flow releases or maintaining habitat or fish- and wildlife-related facilities on Central Valley streams used by anadromous fish.

Reclamation Districts are responsible for levee maintenance. These special districts are formed and supported by the landowners of the area protected by the levees.

Local governments are required to have a general plan with mandated elements including open space/conservation, safety, land use, and circulation. The conservation element addresses the conservation, development, and utilization of natural resources, including water, forests, soils, rivers and other waters, harbors, fisheries, wildlife, minerals, and other natural resources.

Federal Agencies and Statutes

The major federal agencies that have legal mandates and responsibilities for maintaining and restoring either populations of anadromous fish within the Central Valley or the aquatic and associated habitats on which those populations depend are presented below.

Federal agency	Legal mandate

U.S. Fish and Wildlife Service	Central Valley Project Improvement Act
	Endangered Species Act
	    Listing
	    Critical Habitat Designation
	    Recovery Planning
	    Consultations
	    Biological Opinions
	Fish and Wildlife Coordination Act

U.S Environmental Protection Agency	Clean Water Act
	    Water Quality Standards
	National Pollution Discharge Elimination System permits
	    Effluent Standards
	    State Certification
	    Performance Standards
	    Toxic Pollutants
	    Non-point source Decisions
	Information and Investigatory Activities
	Wetland Decisions
	Technical Assistance
	Contaminant Standards

National Marine Fisheries Service	Endangered Species Act
	    Listing
	    Critical Habitat Designation
	    Recovery Planning
	    Consultations
	    Biological Opinions
	Magnuson Fishery Conservation Act
	Fish and Wildlife Coordination Act

U.S. Bureau of Reclamation	Central Valley Project Improvement Act Reclamation Act of 1902 Reclamation Reform Act on 1982 Clean Water Act Agreement Between the U.S. and California for the Coordinated Operation of the CVP and the SWP
U.S. Army Corps of Engineers	Clean Water Act

Federal agency	Legal mandate
	Section 404 Permits Federal Rivers and Harbors Act of 1899 Water Resources Development Act
U.S. Forest Service	Forest and Rangeland Renewable Resources Planning Act Forest Plans Resource Assessment Program Research Program Federal Land Policy and Management Act of 1976
Natural Resource Conservation Service	Soil and Water Resources Conservation Act of 1977 Soil and Water Conservation Program Data Collection and Technical Assistance Public Law 566
Bureau of Land Management	Federal Land Policy and Management Act of 1976 Public Land Inventory Land Use Plans Management of Public Lands
Federal Energy Regulatory Commission	Federal Power Act
All federal agencies	National Environmental Policy Act Endangered Species Act U.S. Fish and Wildlife Coordination Act U.S. Wild and Scenic Rivers Act

State Agencies and Statutes

The major state agencies that have legal mandates and responsibilities for maintaining and restoring either populations of anadromous fish within the Central Valley or the aquatic and associated habitats on which those populations depend are presented below.

State agency	Legal mandate
California Department of Water Resources	California Water Code State Water Project Fish and Wildlife

State agency	Legal mandate
	Water Appropriations Agreement Between the U.S. and California for the Coordinated Operation of the CVP and the SWP Reasonable Use Doctrine California Water Plan Water Conservation Projects Act of 1985 Water Transfer Act of 1986 San Joaquin Drainage Relief Act Flood Plain Management Act Agricultural Water Suppliers Efficient Water Management Act U.S. Fish and Wildlife Coordination Act
California State Water Resources Control Board and Regional Water Quality Control Boards	Reasonable Use Doctrine Public Trust Doctrine Water Appropriation Fish and Wildlife Public Trust Water Quality Water Conservation Water Rights Determinations Perter-Cologne Water Quality Control Act Water Quality Policy Water Quality Plans Waste Discharge Requirements/NPDES Permits Clean Water Act Water Quality Standards State Certification Toxic Pollutants Non-Point Source Decisions Research and Investigatory Decisions Water Reclamation Law California Water Code
California Department of Fish and Game	California Endangered Species Act Listing Consultations Take Natural Community Conservation Planning Act

State agency	Legal mandate
	California Native Plant Protection Act Salmon, Steelhead Trout and Anadromous fisheries Program Act Fisheries Restoration Act of 1985 Fish and Wildlife and Recreation in Connection with State Water Project Trout and Steelhead Conservation and Management Planning Act of 1978 Commercial Fisheries Investigation Law Enhancement and Management of Fish and Wildlife Riparian Habitat Conservation Act
The Resources Agency	California Wild and Scenic Rivers Act
California Fish and Game Commission	California Endangered Species Act California Native Plant Protection Act Angling Regulations
State Lands Commission	State Lands Act
State Board of Forestry	Z/berg-Nejedly Forest Practices Act of 1973
Delta Commission	Delta Protection Act of 1992
All state agencies	California Environmental Quality Act Porter-Cologne Water Quality Control Act Federal Endangered Species Act California Endangered Species Act

DFG is the primary state trustee agency empowered to manage, enhance, restore, and protect the wide diversity of fish, wildlife, and plant species within the Central Valley. DFG meets its mandated goals regarding fish and wildlife through coordination with other regulatory agencies.

PUBLIC TRUST DOCTRINE

DFG has a public trust responsibility and acts as a steward for the fish and wildlife resources of California. Successful stewardship requires protection of all of California's biological diversity through such programs as law enforcement, management of lands and wildlife, and compensation of loss of wildlife habitat.

The U.S. Declaration of Independence, the Constitution, the legislative process using statute law, and the courts using case law, in conjunction with the principles of the public trust doctrine, can provide the foundation for the people to conserve and protect their common heritage of rivers, streams, lakes, marshlands, and tidelands and their associated resources, uses, and values (Smith 1989).

The California Constitution (Article 1, Section 25) clarifies the public fishing right:

> The people shall have the right to fish upon and from the public lands of the State and in the water thereof and no land owned by the State shall ever be sold or transferred without reserving in the people the absolute right to fish there upon . . . .

One can reasonably conclude that the right to fish cannot be enjoyed unless fish are in sufficient abundance to be harvested, provide healthful food and products, or just simply enjoyed (Smith 1989).

The California Supreme Court in its monumental 1983 Mono Lake Decision emphasized the state's overall duties and responsibilities to protect the people's common heritage of streams, lakes, marshlands, and tidelands for their many uses and values covered by the public trust.

In its 1983 ruling, the California Supreme Court also stated:

- Parties acquiring rights in trust property hold those rights subject to the trust, and can assert no vested right to use those rights in a manner harmful to the trust.

- The public trust is more than an affirmation of the State power to use public property for public purposes, it is the duty to take public trust properties (i.e., salmon and steelhead) into account in the planning and allocation of water and to avoid or minimize any harm to these properties, interests, or associated uses whenever feasible.

- The State, under its public trust responsibilities, has the affirmative duty and continuing authority to vigorously protect the public trust uses and to avoid or minimize any harmful impacts to such uses.

- The Public Trust is more than affirmation of State's power to use public property for public purposes. It is an affirmation of the duty of the State to protect the people's common heritage of streams, lakes, marshlands, and tidelands surrendering that right of protection and, in rare cases when the abandonment of that right is consistent with the purposes of the trust.

- The Public Trust includes the protection of ecological and biological values of water and waterways.

The California Fish and Game Commission has established a variety of policies that provide directions for DFG in regard to anadromous fish management and restoration, aquatic and riparian habitat management, and other issues of aquatic habitat management and the species that depend on those habitats.

It is the policy of the California Fish and Game Commission:

I. To maintain an adequate breeding stock, suitable spawning areas, and provide for the natural rearing of the young to migratory size. Hatchery production shall be limited to areas where it is necessary to supplement natural production in coastal streams.

II. That resident fish will not be planted or developed in coastal steelhead and salmon streams, except after prior Commission approval (a) where the stream is no longer adaptable to anadromous runs, or (b) during the mid-summer period in those individual streams considered on a water-by-water basis where there is a high demand for angling recreation and such planting or development has been determined by the Department not to be detrimental to the anadromous species.

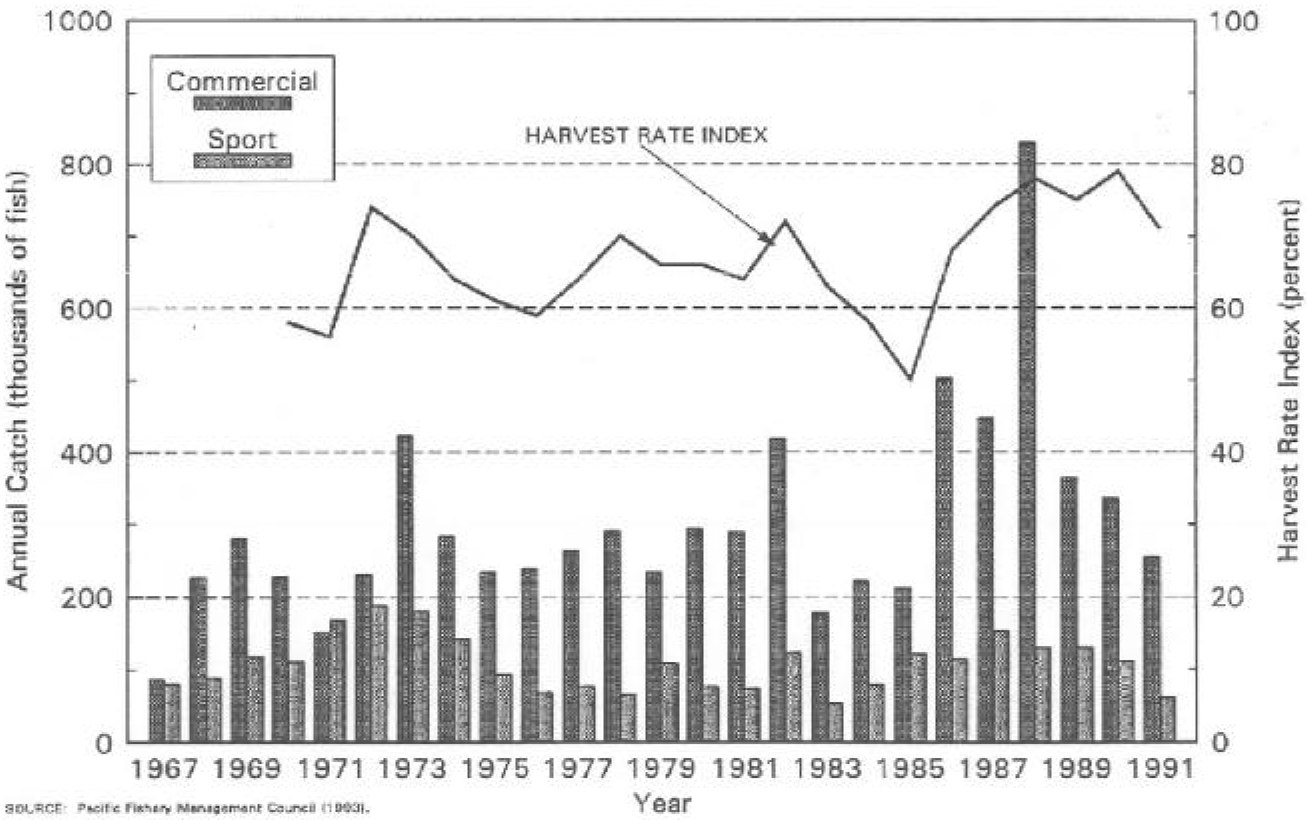
III. That salmon and steelhead may be rescued whenever the water supply is a stream is inadequate to maintain fish life.

CHINOOK SALMON

Harvest

Total commercial and sport annual landings from 1967 to 1991 ranged from 358,000 pounds in 1983 to 1,489,000 pounds in 1988 and averaged 707,000 pounds (Council 1993) (Figure 2-VIII-1). Since 1988, total landings have steadily decreased to levels near the historical minimum for the entire period of record. Catch-per-unit effort, roughly approximated by the number of fish landed per number of days fishing, was computed for commercial landings (1978-1990) and for sports landings (1962-1990) (Figure 2-VIII-2). Catch-per-unit effort for the sport fishery remained relatively constant during this period, while the commercial fishery exhibited a general upward trend over the last 13 years. From 1986 to 1989, catch-per-unit effort for commercial landings more than doubled, reflecting a large increase in ocean salmon abundance during these years.

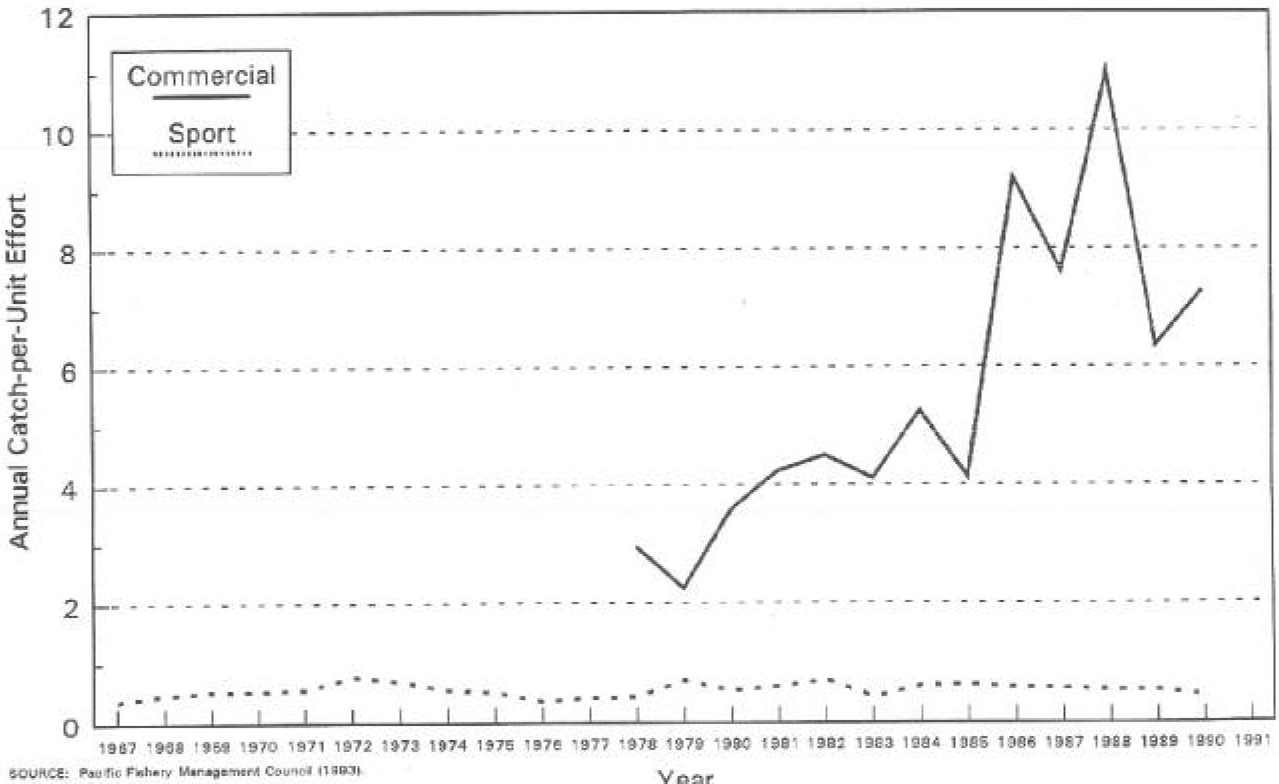
Intensive harvest of natural chinook salmon stocks for many years has resulted in a shift in age composition toward smaller, earlier maturing individuals. Historically, adult spawning populations in California appear to have been dominated by 4- and 5-year-old fish with smaller proportions of 2-, 3-, and 6-year-old fish. Today, spawning runs typically consist largely of 2- and 3-year-old fish with smaller numbers of 4-year-old



SOURCE: Pacific Fishery Management Council (1993).

ANNUAL HARVEST RATE INDEX AND LANDINGS FOR CALIFORNIA COMMERCIAL AND SPORT OCEAN FISHERIES (1967-1991)

FIGURE 2-VIII-1



SOURCE: Pacific Fishery Management Council (1993).

NOTE: No effort data are available for commercial fishery from 1967-1977.

ANNUAL CATCH-PER-UNIT EFFORT FOR CALIFORNIA COMMERCIAL AND SPORT OCEAN SALMON FISHERIES (1967-1991)

FIGURE 2-VIII-2

fish and very few 5-year-old fish (Dettman et al. 1987). Changes in age composition have been accompanied by a decrease in average size of fish landed in the California troll fishery since 1950 (Reisenbichler 1986). Major reasons for declining age and size of chinook salmon stocks include the selective harvest of larger or faster growing individuals; higher fishing mortality of later maturing fish that are exposed to ocean harvest for more years than earlier maturing fish; and the resulting long-term genetic selection for smaller, younger fish (Ricker 1980).

From 1977 to 1981, the average sport catch of fall-run chinook salmon in the Sacramento River was 1.8% of the total estimated run (Allen and Hassler 1986).

DFG initiated a 4-year program in 1990 to estimate annual angler effort and catch of salmon and steelhead in seven river reaches covering 420 miles of the Sacramento basin, including the reach from the Carquinez Bridge to Sacramento. Table 2-VIII-1 shows estimated annual catch of chinook salmon (excluding fish released) for each survey reach and period.

Table 2-VIII-1. Estimated chinook salmon sport landings for six Sacramento basin reaches from July 1, 1990 to June 30, 1993.

Period	Carquinez Bridge to Sacramento	Sacramento to Colusa	Colusa to Red Bluff	Red Bluff to Redding	Feather River	American River
July 1, 1990- June 30, 1991	34	276	724	2,174	1,547	12,155
July 1, 1991- June 30, 1992	1,834	2,122	2,436	5,909	9,207	13,035
July 1, 1992- June 30, 1993	2,730	1,644	2,463	3,503	5,187	6,526

Note: Numbers of fish landed exclude fish released.

Source: Wixom pers. comm.

Poaching, particularly during low flows, is another source of mortality for upstream migrating chinook salmon.

Fish Resource Agency Policy/Goals

It is the policy of DFG to maintain the genetic integrity of all identifiable stocks of salmon and steelhead in California. To protect the genetic integrity of California salmon and steelhead stocks, each salmon or steelhead stream shall be evaluated by the DFG and the stocks classified according to their probable genetic source and degree of integrity. Management and restoration efforts will be guided by this classification system, and policies relating to artificial production must also be compatible with this classification system (Reynolds et al. 1990).

Classification and management system - The classification system shall be employed to define the appropriate stocks and the role of artificial production for management of each salmon and steelhead stream in California. This classification may be applied to drainages, individual streams, or segments of streams as necessary to protect discrete stocks of salmon or steelhead. Only designated appropriate stocks may be placed or artificially produced in any stream within the guidelines specified under this classification system. Exceptions to these management constraints may be allowed only under emergency conditions that substantially threaten the long-term welfare of the fishery. Exceptions may be granted only on submission of a written request, which details the emergency conditions, by a region or an Inland Fisheries Division Assistant Chief to the Chief of Inland Fisheries Division. The Chief of Inland Fisheries Division will review the request and make recommendations for approval or denial to the Deputy Director of Fisheries who will then approve or deny the request.

Salmon and steelhead stream classification system terms - The salmon or steelhead stocks stream management goal shall manage streams for the following appropriate stock and only those stocks may be placed in the stream (each term is progressively inclusive of the preceding terms):

a. **Endemic** - Only historic naturally reproducing fish originating from the same stream or tributary.

b. **Naturally reproducing stocks within drainage** - Naturally reproducing stocks from streams basin of which the stream is part.

c. **Hatchery stocks within basin** - Stocks which may include hatchery produced fish from streams within the drainage.

d. **Naturally reproducing stocks from out of basin** - Naturally produced fish from streams outside the basin.

e. **Hatchery stocks out of basin** - Stocks which may include hatchery produced fish from streams outside the basin.

f. **Any stock** - Any stock which appears to exhibit characteristics suitable for the stream system.

Section 1505 of the California Fish and Game Code grants DFG the power to manage, control, and protect spawning areas on state-owned lands to the extent necessary. The identified areas are:

1) The Sacramento River between Keswick and Squaw Hill Bridge near Vina

2) The Yuba River between Englebright Dam and a point approximately 4 miles east of Marysville

3) The American River between Nimbus Dam and a point 1 mile downstream from Arden Way

4) The Mokelumne River between Pardee Dam and Lockeford

5) The Stanislaus River between Goodwin Dam and Riverbank

6) The Tuolumne River between La Grange Dam and the Geer Road (J14) Bridge

7) The Merced River between Crocker-Huffman Dam and Cressy
8) Battle Creek from its mouth to Coleman powerhouse

9) The Cosumnes River from Meiss Road Bridge to Latrobe Road Bridge

The Central Valley Salmon and Steelhead Restoration and Enhancement Plan (Reynolds et al. 1990) was the first step in developing a series of basin plans for all anadromous fish waters in California. It was prepared in response to California's Salmon, Steelhead Trout, and Anadromous Fisheries Program Act of 1988.

DFG has subsequently prepared a plan titled "Restoring Central Valley Streams: A Plan for Action" (Reynolds et al. 1993). This plan reviews anadromous fish resources of the Central Valley, discusses statutes and funding sources for restoration activities, and presents individual stream action plans for streams in the Central Valley basin, including the Sacramento River and all of its major, and most of its minor, tributaries.

DFG's Lower Mokelumne River Fisheries Management Plan (DFG 1991) identifies problems and recommends flows and other improvements for anadromous fish in that river. The draft Central Valley Anadromous Fisheries and Associated Riparian and Wetland Areas Protection and Restoration Action Plan (Reynolds et al. 1993) presents individual stream action plans for the San Joaquin River and its tributaries.

Hatchery/Production Facility Practices

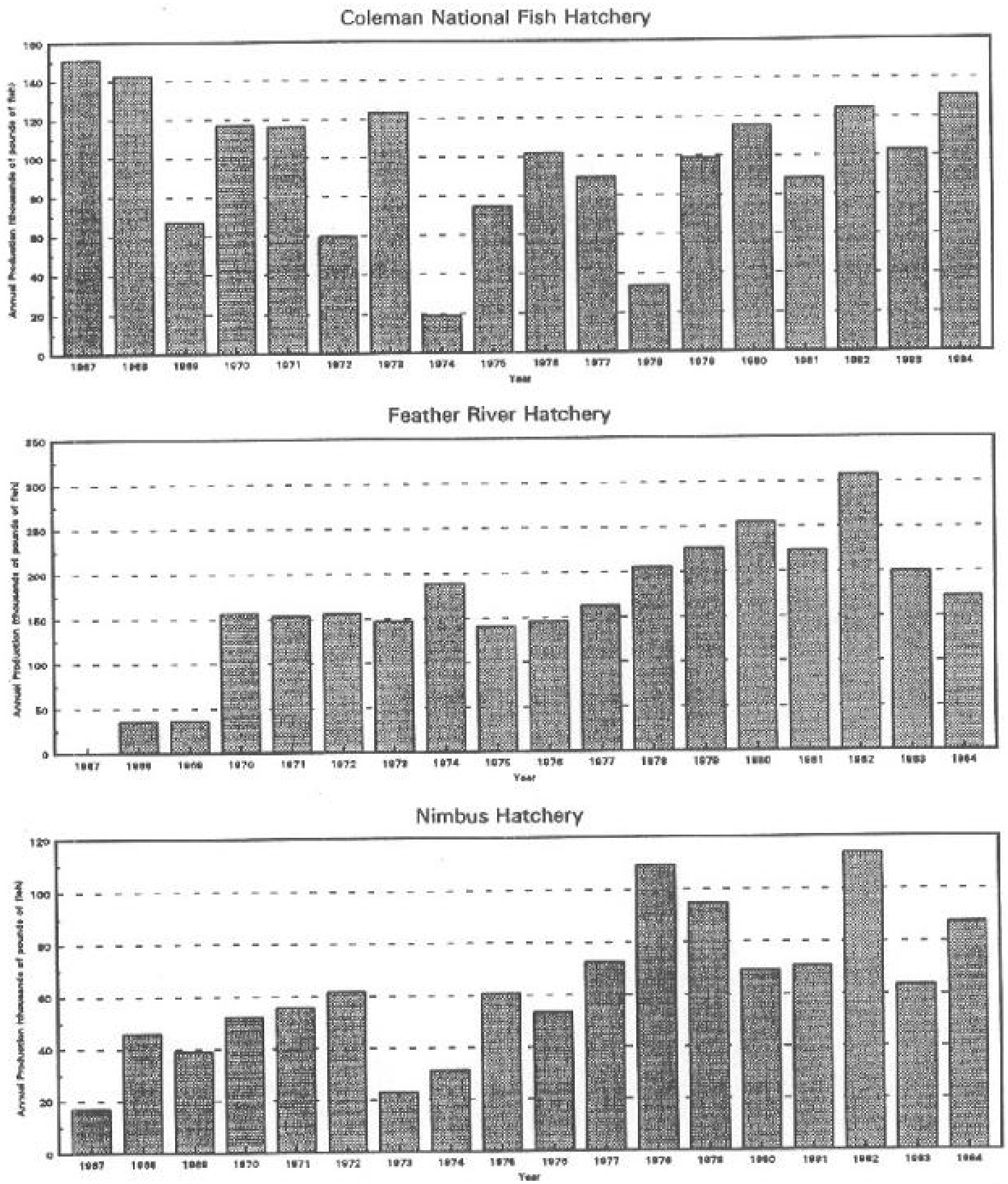
Hatchery production - Baird Hatchery was constructed on the McCloud River in 1872, marking the beginning of artificial propagation of chinook salmon in the Central Valley (Skinner 1962). Five hatcheries currently produce chinook salmon in the Central Valley (Table 2-VIII-2). The three largest hatcheries (Coleman, Feather River, and Nimbus) are located in the Sacramento River basin. Smaller hatcheries exist on the Mokelumne and Merced rivers in the San Joaquin River basin. DFG operates six other salmon hatcheries in northern California outside the Central Valley, including Trinity River Hatchery. Most of these salmon hatcheries were constructed between 1940 and 1970 as mitigation for specific dams or water projects. Only Nimbus and Coleman Hatcheries had significant production before 1967. The salmon hatcheries are funded by hatchery-specific mitigation agreements with state, federal, and public agencies and monies collected from commercial salmon fishers.

Table 2-VIII-2. Central Valley chinook salmon hatcheries.

Hatchery	Location	First Year of Operation	Operator	Primary Funding Source	1984-85 Salmon Production (lb/year)
Coleman National Fish Hatchery	Battle Creek near Cottonwood, CA	1942	USFWS	USFWS	130,958
Feather River Fish Hatchery	Feather River at Oroville, CA	1967	DFG	DWR	203,388
Merced River Fish Hatchery	Merced River near Snelling, CA	1974	DFG	DFG	49,188
Nimbus Fish Hatchery	American River below Nimbus Dam	1955	DFG	USBR	146,176

DFG hatchery production data were obtained from annual DFG reports (California Trout, Salmon, and Warmwater Fish Production and Costs [1959-1985]). Production data were last published in 1984-1985. The release numbers reported by Cramer (1990) for Coleman National Fish Hatchery were converted to weights using the average weight of each release type (e.g., fingerling). From 1967 to 1991, annual production of chinook salmon from Feather, Nimbus, Mokelumne, and Merced River Hatcheries exhibited a general increase, while Coleman showed no clear trend (Figures 2-VIII-3 and 2-VII-14). Total Central Valley salmon production nearly doubled during this period (Figure 2-VIII-4).

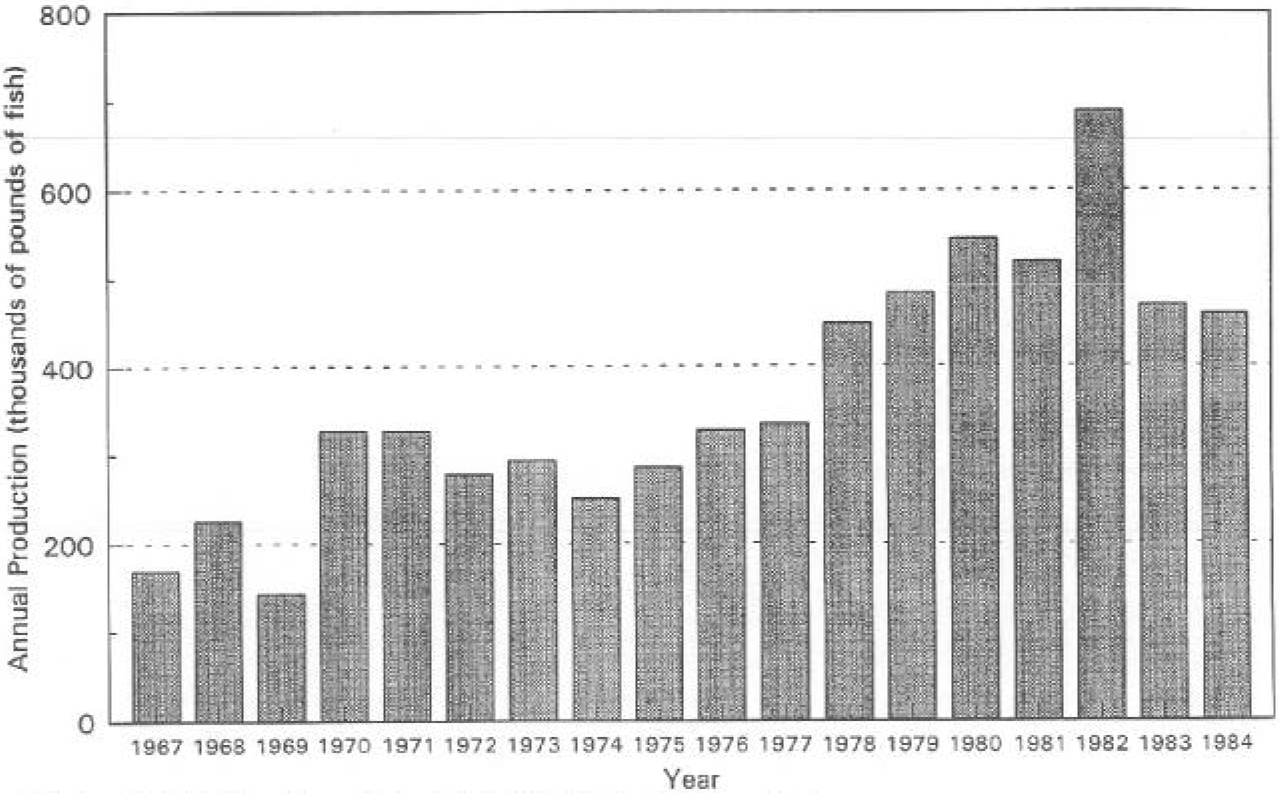
Release practices - Traditionally, Central Valley hatcheries have released fish directly into the river. To reduce downstream mortality, some of the hatcheries have trucked fish to locations nearer the ocean. At



SOURCES: Cramer (1990) and California Trout, Salmon, and Warmwater Fish Production and Costs (1967-85).

ANNUAL PRODUCTION OF CHINOOK SALMON AT COLEMAN NATIONAL FISH HATCHERY, FEATHER RIVER HATCHERY, AND NIMBUS HATCHERY (1967-1991)

FIGURE 2-VIII-3



SOURCES: Cramer (1990) and California Trout, Salmon, and Warmwater Fish Production and Costs (1967-85).

TOTAL ANNUAL HATCHERY PRODUCTION OF CHINOOK SALMON IN THE CENTRAL VALLEY (1967-1991)

FIGURE 2-VIII-4

Nimbus Hatchery, fish were predominantly released at the hatchery during the early 1970s, at Rio Vista during the late 1970s, and in the estuary during the 1980s. At Feather River Hatchery, most chinook salmon were released in the estuary after 1983. Survival was observed to be significantly greater for fish released farther downstream.

For paired releases from Feather River Hatchery in 1980, fish released at Port Chicago were four times more likely to survive than those released at the hatchery and two times more likely to survive than those released at Discovery Park (Cramer 1990). The increase in survival depended on the time of release, river temperature, oceanic conditions, and size of fish. Fish released off station have a higher tendency to stray on return than fish released on station.

Offsite releases, however, do have their drawbacks. Hatchery juveniles that have been transported and released at sites other than the hatchery or stream of origin may fail to imprint properly and may exhibit high straying rates on their return as adults. These adults tend to migrate where streamflows are greatest. Cramer (1990) estimated mean straying rates of 7% to 86% for Feather River and Coleman National Fish Hatchery adults, depending on release location.

Increased survival of hatchery fish has also been achieved by releasing juveniles at larger sizes. Survival significantly increases for fingerlings (1-5 grams) and smolts (5-10 grams) compared to fry (less than 1 gram) (Cramer 1990).

Increased production and survival of hatchery chinook salmon has resulted in increasing contributions of hatchery fish to adult spawning escapements since 1967. Annual contributions of hatchery fish to runs in the American and Feather rivers in recent years range from 33% to 80% (Dettman and Kelley 1987, Cramer 1990).

Hatchery contribution to ocean fishery - Accurate estimates of the Central Valley hatchery contribution to ocean chinook salmon landing have not been developed because of the lack of a consistent hatchery marking program in California. Kjelson and Brandes (1988) estimated that 21% of the smolts passing Chipps Island in 1988 were of hatchery origin. Cramer (1990) estimated that hatchery fish composed about one-third of the spawning escapement to the American and Feather rivers. This fraction is significantly lower than previous estimates developed by Dettman and Kelley (1987).

Because of increased survival from eggs to smolts under hatchery conditions, fewer adults are needed to maintain a hatchery run. Consequently, a harvest rate based on hatchery fish will tend to eliminate wild fish in a mixed fishery comprising wild and hatchery stocks (Hilborn 1992). Current harvest rates of Central Valley chinook salmon are high enough to adversely affect the natural production in some rivers.

Effects of hatchery production on natural production - There are growing concerns that the release of large numbers of hatchery fish can pose a threat to wild fish populations. Potential impacts include direct competition for food and other resources between wild and hatchery fish, predation of hatchery fish on wild fish, genetic dilution of wild fish stocks by hatchery fish allowed to spawn in rivers, and increased fishing pressure on wild stocks due to hatchery production. Because of increased survival from eggs to smolts under hatchery conditions, fewer adults are needed to maintain a hatchery run. In a mixed fishery of hatchery and wild fish, a harvest rate based on the hatchery fish will tend to eliminate the wild fish (Hilborn 1992).

STEELHEAD

Harvest

Sport fishing and illegal poaching affect migrating adult steelhead in the Sacramento River system in ways similar to how they affect chinook salmon. Poaching of steelhead is incidental compared to poaching of chinook salmon, however, because steelhead are smaller, more difficult to catch, and generally less accessible to poachers. Unlike salmon, steelhead do not generally die after spawning and are exposed to sport fishing on their return to the ocean.

Although the estimated annual sport catch of steelhead in the upper Sacramento River system above Big Chico Creek ranged as high as 11,000 fish in the 1950s and as high as 7,000 fish in the late 1960s, the present actual total population counts at Red Bluff Diversion Dam averaging 1,714 fish during 1987-1991 extrapolate to estimated catches of less than 1,100 fish (Reynolds et al. 1990). In the lower Sacramento River system from Big Chico Creek downstream, about 8,000 steelhead are harvested in the Feather River during about 30,000 angler days per year, and an additional 1,000-2,000 Feather River fish are harvested downstream in the Sacramento River system and in the American River. An estimated 20,000 angler days each year result in an estimated catch of 5,000 to 8,000 steelhead on the American River. Hundreds of American River fish, along with steelhead from other sources, are also estimated to be caught incidentally downstream in the Delta and Carquinez Strait sport fisheries for other species. No estimates of steelhead harvests in the Yuba River and other Sacramento River system tributaries are available for the present period (Reynolds et al. 1990).

Juvenile steelhead are indistinguishable from resident rainbow trout in appearance, feeding, and other activities, and many are caught by sport anglers fishing for resident trout. On a statewide basis in 1965, DFG estimated that the fishing pressure on juvenile steelhead exceeded that for adult steelhead (Barnhart 1986).

Fish Resource Agency Policy/Goals

Fish resource agency policies are discussed previously in the section on chinook salmon.

The 1990 Central Valley Salmon and Steelhead Restoration and Enhancement Plan inventories and identifies restoration needs for salmon and steelhead in the Sacramento-San Joaquin River system and states that, among other goals, the DFG has a goal of developing an annual steelhead run of 100,000 fish in the Sacramento River system; 50,000 in the upper Sacramento River and its tributaries; and 50,000 in the lower Sacramento River tributaries. In response to the 1988 act and other actions, DFG prepared a Steelhead Restoration Plan for the American River (McEwan and Nelson 1991).

The Central Valley Salmon and Steelhead Restoration and Enhancement Plan inventories and identifies restoration needs for steelhead in the Sacramento-San Joaquin River basin and identifies DFG's goal of attaining an annual steelhead run in the San Joaquin River system of 20,000 fish, equally divided between natural and hatchery production (Reynolds et al. 1990).

DFG is also developed a statewide steelhead management plan that identifies impacts on the state's steelhead resources and focuses mostly on habitat restoration and stock recovery, including stocks in the San Joaquin Drainage (McEwan and Jackson 1994).

Hatchery/Production Facility Practices

More than 90% of the adult steelhead (greater than 15 inches in length) in the Central Valley are produced from hatcheries (Reynolds et al. 1990). Therefore, the number and survival to adulthood of hatchery-released steelhead presently has far more bearing on steelhead run sizes than natural production. The sizes, timing, and points of release of hatchery-reared juvenile steelhead, as well as the same factors affecting naturally produced fish in the same physical environments, affect their survival rates. A major difference is that survival of eggs, fry, and juveniles prior to release is much higher for hatchery-produced fish. Because high survival rates of hatchery releases are desired, hatchery fish will be released during periods and at sites most conducive to survival, whereas natural fish cannot be controlled in such a manner. Consequently, the survival of juvenile hatchery fish may be higher than naturally produced juveniles, at least on entering the ocean.

In operation since 1943, Coleman National Fish Hatchery on Battle Creek has a capacity to raise about 1,000,000 yearling steelhead, which are raised to reach sizes of about seven fish per pound before being released to the upper Sacramento River near the mouth of Battle Creek, or in Battle Creek itself, in December and January (The Resources Agency 1989, Reynolds et al. 1990). Feather River Hatchery, in operation since 1967, and Nimbus Fish Hatchery on the American River, in operation since 1955, each have a capacity to raise about 400,000 yearling steelhead to a size of three to four fish per pound. The

Feather River Hatchery fish are planted in the Feather River below Yuba City, most by the end of March, and the Nimbus Fish Hatchery fish are trucked and released in the Carquinez Strait (Reynolds et al. 1990).

In the Delta and San Joaquin River tributaries, consistent hatchery-maintained steelhead runs now take place only in the Mokelumne River, with sporadic runs occurring up the Stanislaus and Merced rivers (Reynolds et al. 1993).

Steelhead migrate 64 miles up the Mokelumne River to the Mokelumne River Fish Hatchery (in operation since 1965) at Camanche Dam (completed in 1963). During 1967-1991, hatchery returns have been from 0 to 134 fish, with an average of only 40 fish. Efforts to create a naturally producing steelhead run have been unsuccessful to date (Reynolds et al. 1993), and there is no known recent natural spawning of steelhead in the Mokelumne River (Richardson 1993). Steelhead fry and juveniles have been known to rear only in the upper river reaches below Camanche Dam where temperatures are coolest (DFG 1991).

The present program for the Mokelumne River calls for about 30,000 yearlings or older steelhead to be planted on a weekly basis in the river during the recreation season (April-September). The program has provided a fishery for 12- to 20-inch trout that is popular with anglers; a few of these planted fish survive to return to the Mokelumne River as adults. (Reynolds et al. 1990.)

DFG has a goal of 2,000 adult steelhead spawners to return annually to the Mokelumne River Fish Hatchery. The hatchery, which has the capacity to raise 100,000 yearling steelhead, presently has a goal to annually raise 40,000 yearling steelhead for release into the Mokelumne River. Since the target number of adult spawners do not currently reach the hatchery, eggs are supplied primarily from surplus Feather River Hatchery and Nimbus Fish Hatchery eggs (Reynolds et al. 1993). Plants of steelhead raised at the Mokelumne River Fish Hatchery typically return as adults to the American River (Reynolds et al. 1990).

STRIPED BASS

Harvest

The annual sport catch in the late 1980s was less than 150,000 fish, compared to more than 300,000 fish landed by anglers in the early 1970s. After 1967, harvest rates have ranged from 10% to 24% of the adult striped bass population. (DFG 1992a.)

The existing annual catch of striped bass is 100,000-200,000 fish (i.e., approximately 15-30% of the adult population) (DFG 1992a). Incidental take of striped bass in legal commercial fisheries increases the annual harvest rate by an undetermined amount. Considering that fish populations can sustain high levels of fishing mortality and that striped bass populations on the Atlantic Coast have sustained harvest rates greater than 40%, the existing harvest rate, including illegal fishing, would likely have minimal effects on a healthy striped bass population. The precipitous decline in adult striped bass abundance over the past 20 years, however, indicates that the population is unhealthy (Figure 2-VI-31).

Illegal fishing may kill thousands of juvenile striped bass, possibly equivalent to the deaths of least 125,000 legal-sized bass each year (Brown 1987). This level of illegal fishing could equal or exceed the annual legal sport catch of 100,000-200,000 adult striped bass (DFG 1992a). As discussed previously, healthy fish populations can sustain high levels of fishing mortality, but the precipitous decline in adult striped bass abundance over the past 20 years indicates that the population is unhealthy (Figure 2-VI-31).

The declining status of the adult population has resulted in more stringent angling regulations, including an 18-inch minimum length and two-fish-daily bag limits (DFG 1992a). Before 1982, the minimum legal length was 16 inches and the daily bag limit was three fish. More stringent sport fishing regulations and stricter enforcement could reduce adult mortality and increase egg production.

Fish Resource Agency Policy/Goals

Because of the popularity of the sport fishery, DFG has focused considerable attention on monitoring striped bass and developing a management plan. Ongoing monitoring, enhancement, and habitat improvement actions for striped bass in the Sacramento-San Joaquin estuary are included in the Striped Bass Management Program (DFG 1991). The purpose of the Striped Bass Management Program guidelines is to describe ongoing and proposed actions designed to restore and improve the striped bass population. The guidelines require DFG to review the Striped Bass Management Program annually, receive public review and comment every 2 years, and revise the program every 2 years.

The specific striped bass resource goals are to stabilize, restore, and improve the striped bass fishery of the Sacramento-San Joaquin estuary. Specific objectives are to:

- restore a self-sustaining Bay-Delta striped bass population to levels of more than 3 million adult fish by 2000;

- provide Bay-Delta striped bass which, if consumed, will not endanger human health due to contamination from chemicals or trace-metals; and

- provide striped bass angling, aesthetic, and educational use opportunities.

Major aspects of the Striped Bass Management Program are listed below (Table 2-VIII-3).

Table 2-VIII-3. Summary table of the striped bass management program

Program element	Status	Agency
I. Develop public participation in plan preparation and implementation		
A. Submit draft of the plan to public, private, and government entities	U	S
B. Develop recommendations for tasks to be conducted by public, private, and government entities	U	S
C. Prepare information to increase public awareness	U	S
II. Resolve problems detrimental to striped bass		
A. Minimize entrainment losses of bass eggs, larvae, and young in Delta water diversions, including diversions by:		
1. SWP Delta pumping facilities: two-agency fish protective agreement	P, U	S
2. CVP Delta pumping facilities: agreement between U.S. Bureau of Reclamation and the DFG to reduce and offset direct fish losses	P, U	S, F
3. Contra Costa Water District	P, U	S, F
4. Pacific Gas and Electric Company (PG&E): operating permit for PG&E from the Central Valley Regional Water Quality Control Board (Contra Costa Power Plant) and the San Francisco Bay Regional Water Quality Control Board (Pittsburg Power Plant)	P, U	S, P
5. Agriculture	P, U	S, F, P
B. Eliminate reverse flows in the Delta east of Antioch when bass eggs and larvae are present (same participants as in "A" above)	P	S, F
C. Increase Delta outflow in spring and early summer (same participants as in "A" above)	P, U	S, F
D. Increase residence time in secondary Delta channels (i.e., not including the Sacramento and San Joaquin rivers) (same participants as in "A" above)	P	S
E. Reduce quantities of toxic materials contained in municipal, industrial, and agricultural discharges		
1. DFG Aquatic Toxicology Laboratory	P, U	S

Program element	Status	Agency
2. DFG Regions 2 and 3 are to continue monitoring and evaluating waste discharges	P, U	S
F. Reduce bass losses during fish screen salvage, handling, and fish release operations at SWP and CVP facilities		
1. DFG assumes operations of the fish protection facilities	P, U	S, F
2. Upgrade fish holding facilities	P, U	S, F
G. Install fish screens on larger Delta agricultural diversions		
1. Roaring River diversion in Suisun Marsh	P	S
2. Other	P	S, F, P
H. Improve existing fish screens	P	S, F
I. Consolidate and relocate Delta agricultural diversions to areas of lower bass abundance	P	S
J. Reduce predation at major water intake structures		
1. SWP Delta pumping and fish facilities and Clifton Court Forebay	U	S
2. CVP Delta pumping and fish facilities	U	S, F
K. Curtail channel dredging and prohibit dredge spoil disposal in Delta channels		
1. DFG review of U.S. Army Corps of Engineers (Corps) dredging permits	U	S, F
2. DFG review of Corps dredging spoils disposal permits	U	S, F
L. Eliminate future Bay-fill projects	U	S
M. Reduce illegal take and poaching		
1. Resolve illegal commercialization	P	S
2. Increase law enforcement activities	U	S
N. Reduce bass diseases and parasitic infestations	N	
O. Reduce the annual summer bass die-off near Carquinez Strait	P	S
P. Minimize kill of small bass by the commercial bay shrimp fishery	P	S
Q. Halt introductions of exotic aquatic organisms from maritime		

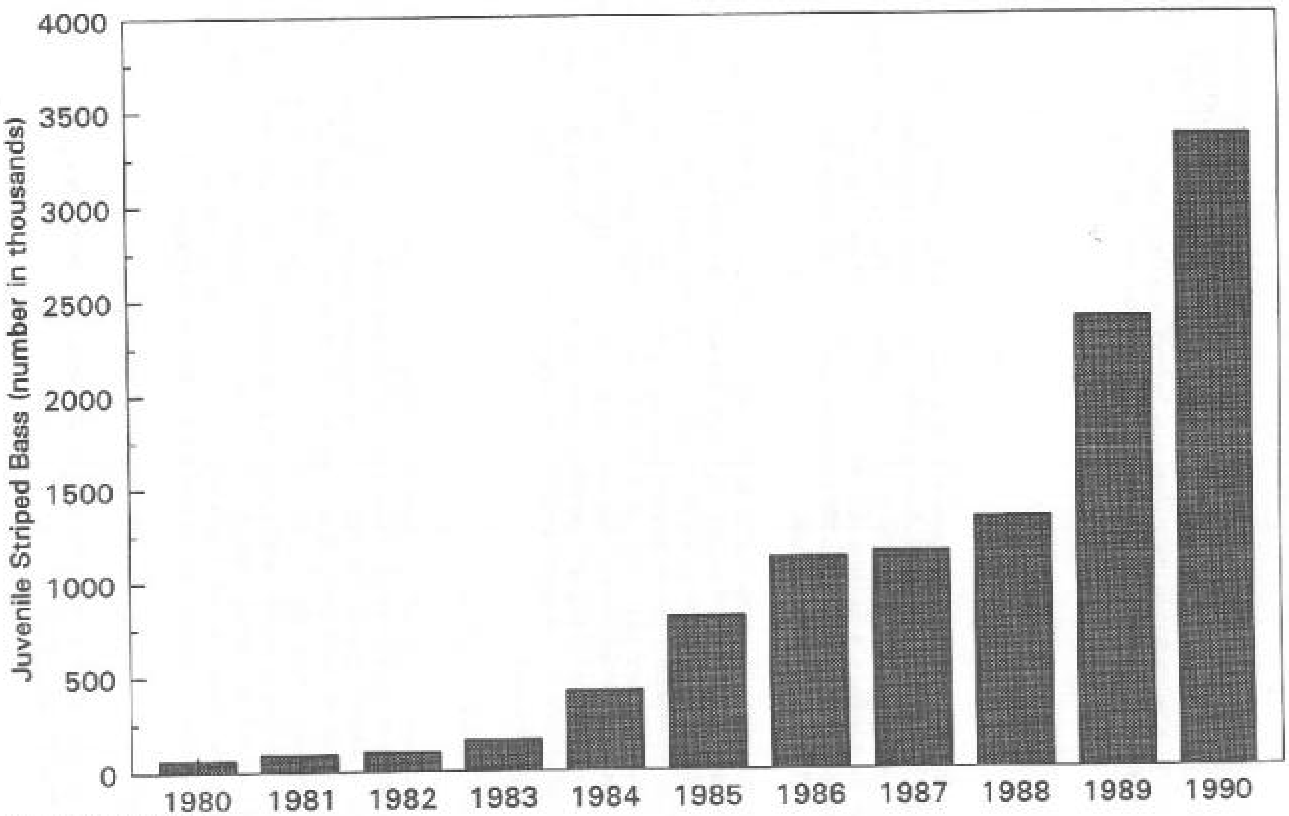
Program element	Status	Agency
shipping		
1. Federal regulations and legislation to restrict discharge of ship ballast	P	S, F
2. High seas exchange of ballast	P, U	S, F
III. Resolve problems of human use of striped bass		
A. Continue hatchery-reared striped bass stocking program	U	S, P
B. Improve pond production at state hatchery	N	
C. Maintain sport fishing and commercial regulations to protect the resource and allow angling opportunities	P, U	S
D. Reduce methyl mercury contamination of adult bass	U	F
E. Reduce diseases and parasitic infestations	N	
F. Reduce tainting of bass flesh	N	
IV. Conduct fishery and environmental studies		
A. Develop techniques to better detect large masses of bass eggs and larvae as they drift downstream		
1. U.S. Bureau of Reclamation	U	F
2. DFG egg and larval survey	U	S
B. Continue survey of annual production of bass eggs, larvae, juveniles, and adults	U	S, F, P
C. Improve annual larval bass growth and mortality estimates	U	S
D. Survey waste discharges to locate sources of toxic materials in the estuary		
1. Rice herbicides and insecticides	U	S
2. Colusa Basin Drain studies	U	S
3. Toxics and trace metals studies	U	S
E. Continue testing impacts of toxic materials on young bass and their food organisms	U	S
F. Develop a striped bass population model to evaluate factors	U, P	S, F, P

Program element	Status	Agency
affecting the bass population abundance		
G. Analyze bass food production in spring and determine if food is limited	U	S, F
H. Extend toxicology testing	U	S, F
I. Improve DFG ability to estimate striped bass egg and larval entrainment losses	U	S, F
J. Compare prey suitability of introduced and native copepods	N	S
K. Determine the effect of toxic materials on egg viability	N	P, S
L. Continue monitoring abundance of fish, invertebrates, and aquatic plants as indicators of adverse conditions for striped bass	U	S
M. Evaluate merits of adding Atlantic Coast bass stocks for improved growth and Sacramento-San Joaquin stock condition	N	
N. Develop improved model of striped bass mortality	N	S
O. Evaluate bass predation	U	S, F
P. Determine results of stocking hatchery-reared striped bass		
1. Stocking of tagged bass	U	S
2. Creel census	U	S
Q. Evaluate new stocking locations for tagged bass	N	
R. Evaluate potential of bass "grow-out" facilities	U	S

Notes:

Status
U = construction/operation underway
P = planning underway
N = no activity

Agency
S = state
F = federal
P = private
C = county



Source: Delisle pers. comm.

RELEASES OF HATCHERY-REARED JUVENILE STRIPED BASS TO THE SACRAMENTO-SAN JOAQUIN ESTUARY (1980-1990)

FIGURE 2-VIII-5

Source: California Department of Fish and Game 1991.

The EPA has proposed water quality standards for surface waters of the Sacramento River, San Joaquin River, San Francisco Bay, and Delta that would directly improve the habitat of striped bass (EPA 1994). The standards include:

- salinity criteria to protect the estuarine habitat and other designated fish and wildlife uses,
- salinity criteria to protect striped bass spawning habitat in the lower San Joaquin River, and
- salmon smolt survival index criteria to protect fish migration and cold fresh water habitat uses in the estuary (i.e., additional spring Delta inflow and reduced diversions).

Hatchery/Production Facility Practices

From 1981 to 1990, more than 10 million juvenile striped bass were raised in hatcheries and released in the Delta and Bay to supplement the wild population (Delisle pers. comm.). The hatchery contribution to the total adult striped bass population increased from less than 1% in 1984 to more than 12% in 1991. The greater percentage contribution to the wild population is attributable to increased annual stocking of hatchery fish and to the declining population of wild fish.

More than 3 million juvenile striped bass were released into the estuary in 1990 (Figure 2-VIII-5). If habitat and food availability are limiting juvenile survival, release of hatchery juveniles could have a detrimental effect on the wild juvenile population. Available data do not indicate any detrimental effects of hatchery releases on wild striped bass survival. The release of hatchery-produced juvenile striped bass was discontinued by DFG after 1991 as part of the effort to avoid the risk of adverse effects on winter-run chinook salmon (Ford pers. comm.). Low numbers (32,000) of juvenile striped bass were released to the Sacramento-San Joaquin estuary in 1992 as part of the pen-rearing project.

Prior to continuation of the striped bass stocking program, DFG has been asked by the NMFS to initiate Section 10 consultation under the federal ESA, specifically with regard to the potential effect on the endangered winter-run chinook salmon (Ford pers. comm.). DFG anticipates a similar request from the USFWS to initiate Section 10 consultation on the threatened Delta smelt. The results of the consultation will determine the immediate future of the striped bass stocking program.

AMERICAN SHAD

Harvest

Sport fishing for shad continues to be popular in the Sacramento, American, Feather, and Yuba rivers, with a smaller, less consistent fishery in the San Joaquin River and its tributaries (Painter et al. 1980). Evidence suggests that the shad catch and angler effort have both declined; however, it is unclear whether this is a reflection of a change in shad abundance or angler interest. During 1976-1978, the mean annual sport catch ranged from 86,200 to 152,000 adult shad, and angling effort ranged from 35,000 to 55,000 angler-days (Meinz 1981).

Commercial harvesting of American shad in the Delta has not occurred since 1957. Presently, shad are harvested only as food by sport anglers. Although the present sport harvest limit is 25 shad per day, most sport anglers typically release all or most of their catch (DFG 1987). Although it is unknown if caught-and-released fish have significantly higher prespawning mortality, shad are delicate fish and the slightest physical injury usually results in death (Skinner 1962). More recently, it appears that more shad caught in the Feather River are being kept, and many anglers catch and keep their limits on consecutive days during the peak of the spawning runs. If the number of spawned eggs significantly affects overall adult abundance, further increases in the number of fish caught and kept may affect population levels.

Fish Resource Agency Policy/Goals

Because of the popularity of the sport fishery, DFG originally had plans to focus on monitoring American shad and developing a detailed management plan for this species in the late 1970s, with the principal goal of maintaining and enhancing the adult shad population present at that time. Funding for further research on American shad and development of the detailed management plan was substantially reduced, ending the program and resulting in a management plan being developed (Painter et al. 1980) based on the available data. Little progress has been made since that time on basic shad research and management; however, many of the programs described for other anadromous species will provide benefits to American shad. For completeness, the original goals and recommendations for managing American shad are described below (Painter et al. 1980).

Specific objectives of the management plan included the following:

- identify factors affecting the survival of juvenile shad during their rearing and out-migration periods,
- determine the role and relative importance of the lower Delta and Bay in the growth of juvenile shad and the maintenance of adult shad populations,
- develop and implement methods to reduce entrainment losses at water diversions, and
- plan and implement studies to periodically monitor shad population abundance and sport harvest rates.

Recommendations proposed in the management plan focused on maintaining suitable habitat conditions (i.e., water temperature and instream flows). Specific recommendations included the following:

- maintain the highest practicable level of activities and studies to preserve and maintain shad habitat and implement program objectives;

- maintain a normal distribution of adult shad in tributary rivers by maintaining instream flows during May and June so that the Feather River flow is at least 34% of the Sacramento River flow, the Yuba River flow is at least 33% of the Feather River flow, and the American River flow is at least 10% of the Sacramento River flow at Sacramento; and

- maintain water temperatures between 60^{o}F and 70^{o}F in the upper Sacramento, Feather, Yuba, and American rivers during May and June.

Hatchery/Production Facility Practices

There are currently no hatchery or other production facilities for American shad in California.

In the late 1800s, shad hatcheries were built along the Atlantic Coast with the expectation of maintaining and increasing production. The hatching and stocking of young shad that was practiced from 1880 until 1950, however, did not significantly increase shad abundance. (Cheek 1968.)

WHITE STURGEON

Harvest

Annual exploitation rates (e.g., sport harvest rate) of white sturgeon in the Sacramento-San Joaquin River system have increased dramatically between the 1960s and 1970s and the mid-1980s due to increased popularity of the fishery, more effective bait, and more sophisticated means of locating and landing sturgeon. By the mid-1980s, exploitation rates increased by 40% (Kohlhorst et al. 1991). Increased exploitation rates decreased recruitment of fish to harvestable size (Pacific States Marine Fisheries Commission 1992).

As a means of decreasing mortality and increasing recruitment, stricter size limitations have recently been imposed on sport anglers. In 1990, the minimum size limit increased from 40 inches, and, for the first time, a 72-inch maximum size limit was imposed. The minimum size limit was increased in 2-inch increments from 42 inches in 1990 to 46 inches in 1992. As a result of these restrictions, harvest rate has been reduced approximately 70% from the high levels of the mid-1980s.

Fish Resource Agency Policy/Goals

New sport fishing regulations were designed to meet the following management goals for the white sturgeon in the Sacramento-San Joaquin River system. The regulations require:

- reduction in sturgeon harvest to 50% of that observed during the 1980s by March 1993,
- protection of large fecund females from sport harvest,
- maximization of sport angling opportunities consistent with the management plan, and
- maintenance of equal access to the resource for all sport anglers.

Ongoing monitoring of white sturgeon populations are being conducted by DFG (Pacific States Marine Fisheries Commission 1992). Current projects include:

- tag recapture programs to estimate abundance, mortality rates, and movement patterns;
- trapping of juvenile sturgeon to determine abundance and year-class strength on a monthly basis; and
- identification of spawning habitats, spawning migrations, and specific spawning sites in the Sacramento-San Joaquin River system.

Hatchery/Production Facility Practices

Stocking of hatchery fish in the Sacramento River and estuary has been prohibited because of iridovirus (Kohlhorst pers. comm.). However, regional DFG biologists are attempting to re-establish white sturgeon in Lake Shasta through stocking.

Several white sturgeon aquaculture programs are in progress at the University of California, Davis, to study:

- nutrition;
- reproductive endocrinology;
- domestic broodstock development and spawning;
- hatchery technology;
- population genetics;

pathology and virology;

molecular biology;

environmental physiology; and

age, size, and population structure (Pacific States Marine Fisheries Commission 1992).

At least two commercial aquaculture ventures are currently in operation.

GREEN STURGEON

Harvest

Relatively little is known about harvest of green sturgeon in the Central Valley. Trends in harvest are assumed to be similar to trends in harvest of white sturgeon.

Fish Resource Agency Policy/Goals

There is presently no active management of green sturgeon in the Central Valley, beyond what is deemed necessary to protect white sturgeon. Moyle et al. (1994) included green sturgeon as a Species of Special Concern in California and recommended it for threatened species status. USFWS (1994) listed recovery objectives and criteria for green sturgeon.

SECTION IX. KEY AFRP DOCUMENTS

PROCESS OF DEVELOPMENT FOR THE AFRP

A source document for guidelines used to develop the Working Paper was the May 1994 Anadromous Fish Restoration Program (AFRP) Plan of Action (POA), which is summarized below. The POA outlines the process that the Core Group originally envisioned would be followed in developing a Restoration Program by October 1995. Deviations from the POA have occurred as a result of delays in development of restoration actions and evolution of the public involvement concept. While the POA called for release of a Draft Restoration Program, the U.S. Fish and Wildlife Service (USFWS) and the Core Group have since endorsed the concept of first releasing a working paper that identifies restoration needs on the basis of the best available technical information. The working paper will remain open for revision to provide opportunities for input from groups with additional technical information; the final AFRP Plan will be developed based on the technical recommendations in the working paper as modified to reflect public and interest group concepts of reasonableness.

Introduction and Purpose of the Central Valley Anadromous Fish Restoration Program, Plan of Action, May 1994

The CVPIA requires the Secretary of the Interior (Secretary) to develop and implement a program, "which makes all reasonable efforts to ensure that, by the year 2002, natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991" (Section 3406[b][1]). The Secretary is also authorized and directed to provide flows of suitable quality, quantity, and timing to protect all life stages of anadromous fish on all CVP-controlled streams.

The plan of action to develop the AFRP involves the following tasks:

- identify the steps necessary to develop the AFRP,
- generally identify the responsibilities of the agencies involved in the development of the AFRP,
- provide all participating entities with guidance needed for its development,
- communicate to the public the overall intent of the effort and the activities to be undertaken, and
- describe a mechanism to solicit and incorporate public input into the process.

Participants

USFWS has the administrative lead for development of the AFRP, which includes the direct participation of the U.S. Bureau of Reclamation (USBR), National Marine Fisheries Service (NMFS), U.S. Environmental Protection Agency (EPA), California Department of Fish and Game (DFG), and California Department of Water Resources (DWR). AFRP development will be directed by a Core Group composed of representatives from these six agencies.

Other agencies with expertise and statutory or proprietary interest may include the U.S. Army Corps of Engineers (Corps), the U.S. Bureau of Land Management, the U.S. Natural Resources Conservation Service, the U.S. Forest Service (USFS), and the California State Water Resources Control Board (SWRCB). The public will also be invited to participate.

General Approach to Development of the AFRP

In general, the Core Group is responsible for directing the technical teams and developing a draft AFRP Plan; technical teams are responsible for providing specific recommendations to the Core Group; and USFWS is responsible for overseeing all aspects of the process, providing policy guidance and support to the Core Group and technical teams, and developing the final AFRP Plan.

The Core Group directing AFRP development depends on technical teams to provide written products and advice in developing the AFRP. Five of these teams are addressing chinook salmon and steelhead in mainstem Sacramento River, upper Sacramento tributaries, lower Sacramento and Delta tributaries, Sacramento-San Joaquin Delta, and San Joaquin River and tributaries. Three additional teams are addressing striped bass, American shad, and white and green sturgeon. The remaining team is addressing measurement of success. The Core Group and technical teams will also carefully consider all public input.

Each technical team will compile and review data presented in a draft document prepared by the DFG titled "Central Valley Anadromous Sport Fish Annual Run-Size, Harvest, and Population Estimates, 1967-1991" (Mills and Fisher 1994). The technical teams will use the data in the document to assist in:

- determining levels of natural production (or numeric restoration goals) for each species by geographic area,
- identifying factors potentially limiting natural production and developing an array of potential solutions to overcome those limiting factors,
- developing actions to ensure that natural production for the species will be sustainable, and
- identifying areas needing further study.

After each team has developed and analyzed a list of actions for each species, the Core Group will compare lists, identify conflicts between actions and species, and develop or ask the teams to develop alternative programs that meet the needs of all anadromous fish species.

With products from the technical teams, public input, and other information, the Core Group will develop a draft AFRP Plan. After developing the draft AFRP Plan, the Core Group will circulate it for interagency and public review and comment. Following receipt and analysis of comments, USFWS will finalize, adopt, and publicly release the AFRP Plan.

Restoration Goal and Program Evaluation

The CVPIA identifies an AFRP goal of natural production of anadromous fish at twice the average attained during 1967-1991 in Central Valley rivers and streams. In 1967-1991, data collection efforts varied and generally did not focus on estimating natural production; estimating levels of natural production for 1967-1991 will be challenging for most species and drainages because of incomplete data. The technical teams will work individually and together with the Core Group to develop estimates of natural production and to document estimation procedures, rationale for adoption of those procedures, and justification for final estimates.

The Core Group and technical teams will set numeric goals for each species and race by individual streams. If doubling the natural production of a species or race within a specific stream proves infeasible, the unmet production increment will be transferred to other individual streams.

A monitoring program to evaluate the effectiveness of the AFRP will focus on determining yearly levels of natural production and the effectiveness of restoration measures for each of the species and races of anadromous fish in each drainage identified in the AFRP. The AFRP will be considered successful when natural production of target species is doubled in the long term. Long term, in this context, must encompass at least several generations of fish (not less than five) over a variety of hydrologic conditions (to allow for natural variation in production) and will continue indefinitely. The Core Group and technical teams will document criteria and methods selected and the rationale used to determine these criteria and methods in the position paper or in the AFRP Plan itself.

Relationship to Other CVPIA Investigations, the Programmatic EIS, and Other Ongoing Activities

Because the AFRP Plan must be developed and implemented by October 30, 1995, this effort will be based largely on existing data. Efforts to develop additional data and information (required by the CVPIA or initiated to fill data gaps) will be undertaken concurrently with the development of the AFRP and will include the following investigations:

- a plan to address the fish, wildlife, and habitat concerns on the mainstem San Joaquin River;
- existing and future water supply, water quality, and fish and wildlife water needs of the Stanislaus River Basin;
- measures to maintain suitable temperatures for anadromous fish survival in Central Valley streams and the Delta;
- the need and opportunities for additional hatchery production while avoiding adverse effects on remaining wild stocks;
- ways to eliminate barriers to salmon and steelhead migration in Central Valley streams;
- the feasibility of temperature control devices at Trinity Reservoir to conserve cold water;
- the need to modify operations or construct new or improved facilities at the Delta Cross Channel (DCC) and Georgiana Slough to assist migration of anadromous fish;
- other measures to protect, restore, and enhance natural production of salmon and steelhead in tributary streams;
- ecologic and hydrologic models to support our understanding of the Central Valley ecosystem; and
- in consultation with the DFG, recommendations for instream flows for anadromous fish on all CVP-controlled streams.

Concurrent with the development of the AFRP and pursuant to Section 3409 of the CVPIA, USBR is preparing a programmatic environmental impact statement (PEIS) to generally cover the direct and indirect impacts and benefits of implementing Title 34, including the AFRP.

Numerous other activities in the Central Valley will either contribute to or be affected by the CVPIA implementation and the AFRP. Several projects being considered for implementation would, if implemented, also affect anadromous fishes. In the course of developing the AFRP, extensive coordination with the agencies involved and consideration of the potential impact of their actions will be required. Many ongoing federal, state, and private activities have the capability to contribute to anadromous fish restoration and could be incorporated into the AFRP.

Compliance with the National Environmental Policy Act and the Endangered Species Act

The options and alternatives that will be considered for the AFRP will be incorporated into and addressed in the PEIS that will cover the effects of implementing the CVPIA and will satisfy the requirements of the National Environmental Policy Act for development of the AFRP. The needs of threatened and endangered species will be taken into account and incorporated into the AFRP Plan. Consequently, formal and informal consultation under provisions of Section 7 of the Endangered Species Act will be initiated to ensure compliance with the law and protection of listed species.

Public Involvement

Throughout development of the AFRP, the public will be encouraged to provide input. All input received in writing or at public meetings and workshops will be fully considered and incorporated, if appropriate, into the AFRP. Core Group and technical team meetings will be open to observation by the public, and members of the public will be able to submit written comments to be considered by the group. Representatives of interested parties and members of the public with expertise in technical areas may be asked by the Core Group to serve on technical teams, although the Core Group will not include members of the public. Public meetings and workshops will be held periodically in various locations during the process of developing the AFRP. In addition to open meetings of the Core Group, a series of three workshops will be held at multiple locations.

GUIDING PRINCIPLES AND ASSUMPTIONS

One of the source documents for guidelines used to develop this working paper was described above for the "Central Valley Anadromous Fish Restoration Program, Plan of Action, May 1994". Presented in its entirety below is another source document titled "Position Paper for Development of the Central Valley Anadromous Fish Restoration Program".

POSITION PAPER FOR DEVELOPMENT OF THE CENTRAL VALLEY ANADROMOUS FISH RESTORATION PROGRAM

INTRODUCTION

The Plan of Action (POA) for the Central Valley Anadromous Fish Restoration Program (Program) identifies the steps necessary to develop the Program (USFWS 1994). One of the steps included the preparation of a Position Paper to be developed by the Core Group. This document is a draft of the Position Paper described in the POA.

This Position Paper is a reference document for use by the Core Group and the technical teams to guide Program development. Because it was impossible to anticipate all issues prior to drafting the Position Paper, this paper will be amended and supplements added as needed. To determine if your copy is current and to request copies of the Position Paper, contact the Public Information Officer, Central Valley Fish and Wildlife Restoration Program, 2800 Cottage Way, Sacramento, California 95825, (916) 978-4460.

The paper is divided into three sections: (1) Program goal and definitions, (2) Intent of Title 34, and (3) Implementation criteria. The first section states the Program goal and develops general definitions for each of the terms used in the Program goal. The second section presents and interprets the intent of Title 34 and reexamines some of the definitions presented in the first section. These first two sections lay the foundation for the last section.

In the last section, implementation criteria are discussed for the 1967-1991 (baseline) period and for the future. Discussions of implementation criteria are separated because the two periods require different criteria. As discussed later in this paper, limitations are imposed by the type or quantity of data collected during the baseline period. Future monitoring programs may be designed to avoid these limitations.

PURPOSE OF POSITION PAPER

The purposes of the Position Paper are two-fold: (1) to explain or clarify the Core Group's position on issues related to developing the Program and (2) to document reasons used to develop these positions.

PROGRAM GOAL AND RELATED DEFINITIONS

Title 34 requires that "...natural production of anadromous fish in Central Valley rivers and streams be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991..." (Section 3406[b][1]). Several terms need to be clearly defined before the program can be designed to meet this requirement: natural production, anadromous fish, Central Valley rivers and streams, sustainable, long-term basis, and average levels.

Natural Production

Title 34 defines natural production as: "... fish produced to adulthood without direct human intervention in the spawning, rearing, or migration processes" (Section 3403[h]). To apply this definition, we must develop an understanding of the meaning of each of the components of the definition. Important components that have been identified to date are the following: production, adulthood, and direct human intervention.

Production

Ricker (1958) defined production as "the total elaboration of new body substance in a stock in a unit of time, irrespective of whether or not it survives to the end of that time." Although Ricker's definition includes changes in mass as well as numbers of fish, Title 34 specifies "... fish produced to adulthood..." and therefore production will refer to numbers of fish produced.

Because a fish can only be "...produced to adulthood..." once in its lifetime, an individual fish should not be counted twice. In addition, production should be measured over a discrete time interval. Because all stocks under consideration are seasonal spawners, **a direct and simple approach will be to count the first-time spawners each spawning season**.

Ricker's definition also states that a fish is counted toward production for the time period over which production is being measured "...irrespective of whether or not it survives to the end of that time". Using Ricker's definition, juvenile fish that did not survive to adulthood would be counted. The definition of natural production in Title 34 specifies "... fish produced to adulthood..." and therefore does not count juvenile fish. On the other hand, Title 34 does not discriminate between adult fish that return to spawn and those taken in recreational and commercial fisheries. Because Ricker's definition includes fish that do not survive to the end of the time period, and because the definition of natural production in Title 34 specifies fish produced to adulthood, **all naturally produced, adult fish shall be counted, including those that are harvested prior to spawning**.

Including harvested fish is consistent with the definition of production in the California Salmon, Steelhead Trout and Anadromous Fisheries Program Act. The California Act defines production as "the survival of fish to adulthood as measured by abundance of the recreational and commercial catch together with the return of fish to the states spawning streams." Because both the Federal and State acts have similar purposes and goals, and because implementation of both acts should be coordinated, it is convenient that the definitions of production being implemented for both acts are similar.

Whether or not a fish attains adulthood is key to determining whether or not to count that fish toward the production goal. Adulthood is defined below.

Adulthood

Section 3403(h) includes the phrase "...fish produced to adulthood..." as part of the definition of natural production. Adulthood is not defined within Title 34. Adulthood is generally defined as the state, condition or quality of being fully developed and mature. Applying this definition to fish is complicated by the fact that most fish continue to grow throughout life (i.e., cessation of growth can't be used to indicate full development) and may become sexually mature several times during their lifetime (i.e., although developed gonads can be used to indicate maturity, lack of developed gonads cannot be used to indicate immaturity). Because the presence or absence of external characters can't always be used to identify adult fish, and because sexual maturity (i.e., developed gonads) is a transitory state, fishery managers often use size or age criteria to indicate maturity.

An adult fish will be defined as one that is capable of reproduction. Ability to reproduce should be based on some external characteristic, such as size. Because Title 34 requires that production be compared between baseline and goal periods, the same criteria for determination of adulthood will be applied to both periods.

Direct Human Intervention

The definition of natural production precludes "...direct human intervention..." in the spawning, rearing, or migration processes of an individual, naturally produced fish. A definition of direct human intervention is key to understanding the definition of natural production. Humans have pervasively intervened in the structure and function of the Sacramento-San Joaquin system. All anadromous fish that spawn in the system have been impacted by this intervention. Indeed, Title 34 has as one of its purposes "...to address impacts of the Central Valley Project on fish, wildlife, and associated habitats..." (Section 3402[b]). But not all human intervention is direct. The word direct is an important component of the phrase "...direct human intervention...".

Direct human intervention is any action taken in the absence of intervening elements. Any form of intervention that requires handling of fish is direct intervention due to a lack of intervening elements. Any action that includes one or more intervening elements would be considered indirect intervention.

Hatchery and artificial propagation, including supplementation and out-planting of eggs or any other life-stage, requires handling of fish by humans during the spawning and rearing processes and therefore are forms of direct intervention. Transporting fish, including truck and barge transport, and fish salvage require capture and handling of fish during the rearing or migration process and therefore are forms of direct intervention. Hatchery and artificial propagation, transport and salvage of fish, or any process that requires handling of any life-stage of fish will be considered direct human intervention.

Title 34 clearly states that fish produced with direct human intervention should not be included in counts of natural production. In developing the Program, we will avoid counting hatchery-produced fish or fish produced with any other form of direct human intervention in counts of natural production. The Core Group has determined that there will be one exception to this rule: the progeny of naturally spawning fish salvaged at the John E. Skinner Delta Fish Protective Facility and the Tracy Fish Protective Facility, if they reach adulthood, will be counted as naturally produced.

An example of a form of intervention that does not fit the definition of direct intervention is flow manipulation. When we manipulate flow to benefit fish, flow acts as the intervening element. Humans directly alter flows and flows alter fish spawning, rearing, or migration processes. Therefore, flow manipulation is not a direct but an indirect form of intervention. Construction of fish ladders, screens and barriers are forms of indirect intervention because each of these structures act as the intervening element. Reservoir or flow manipulations (including Delta flows and flows to maintain desired stream temperatures), ladders, screens, barriers, and other forms of habitat alteration and enhancement activities will not be considered direct human intervention because each of these is or has an intervening element and does not require handling of fish.

Because the definition of natural production in Title 34 includes the phrase "...produced to adulthood...", fish that are not subject to direct human intervention until after they reach adulthood would still be considered naturally produced. For example, a naturally produced fish that returned to a hatchery and was spawned in the hatchery would be considered naturally produced. Obviously, its progeny would not be considered naturally produced because they were produced in a hatchery. Similarly, naturally produced adult fish whose migration was subject to direct human intervention would still be considered naturally produced, although their progeny would not be considered naturally produced.

Anadromous Fish

Title 34 defines anadromous fish as "...those stocks of salmon (including steelhead), striped bass, sturgeon, and American shad that ascend the Sacramento and San Joaquin rivers and their tributaries and the Sacramento-San Joaquin Delta to reproduce after maturing in San Francisco Bay or the Pacific Ocean" (Section 3403[a]). This definition identifies five groups or species of fish: salmon, steelhead, striped bass, sturgeon, and American shad. The American Fisheries Society recognizes steelhead as the common name for the anadromous form of *Oncorhynchus mykiss* and striped bass and American shad as the common names for *Morone saxatilis* and *Alosa sapidissima* (AFS 1991). Clearly, Title 34 includes these species in the definition of anadromous fish. The names salmon and sturgeon both include multiple species of fish and the meaning of these terms in relation to Program development needs clarification. The term "stocks" in the definition of anadromous fish also needs clarification.

Salmon - Salmon is a common name for at least six species of fish. Five species of salmon have been observed in the Sacramento River: chinook (*O. tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon (Moyle 1976, Fry 1973). Chinook salmon are common in the Sacramento-San Joaquin system, the other four species are rare. Based on observations of adults during 1949 through 1958, Hallock and Fry (1967) concluded that sockeye, pink, and chum salmon entered the Sacramento River regularly enough to be regarded as very small runs, but that coho salmon were so scarce and irregular that they should be regarded as strays. Juvenile coho salmon were planted in Mill Creek in 1956, 1957, and 1958, but by 1963 coho salmon were almost as scarce as they had been before the introductions (Hallock and Fry 1967). During the baseline period, there is no evidence that coho, sockeye, pink, or chum salmon maintained self-sustaining spawning runs in the Central Valley (Fisher pers. comm.). Because the definition of anadromous fish specifies "...salmon... that ascend the Sacramento and San Joaquin rivers...to reproduce..." and because chinook salmon is the only salmon known to reproduce in the system on a regular basis during the baseline period, the use of the word salmon in the definition will be interpreted to mean chinook salmon.

Sturgeon - Two species of sturgeon are found in the Sacramento-San Joaquin system: white sturgeon (*Acipenser transmontanus*) and green sturgeon (*A. medirostris*) (Moyle 1976). Because both species of sturgeon reproduce in the Sacramento-San Joaquin system, the word sturgeon will be interpreted to include white and green sturgeon.

In summary, **the species of anadromous fish identified by Title 34 that reproduce in the Sacramento-San Joaquin system include chinook salmon, steelhead, striped bass, white sturgeon, green sturgeon, and American shad**. The Program will be designed to double the natural production of the anadromous forms of these six species.

Other anadromous fish - Title 34 does not identify several species of anadromous fish that spawn in Central Valley rivers and streams. These include threespine stickleback, brown trout, and two species of lamprey and smelt (Fry 1973). The Program will not establish restoration goals specific to these species.

Stocks

For purposes of the Program, **a stock is defined as a group of individuals which are more likely to mate with each other than with individuals not included in the group**. The term stock describes a fish population that spawns in a particular stream, or stream reach, at a particular season and that do not interbreed to a substantial degree with any group spawning in a different place, or in the same place at a different time. This definition does not rely upon absolute reproductive barriers. In fisheries management, stocks are recognized to maintain and improve the genetic basis for management.

Several stocks which meet this definition are already recognized. For example, chinook salmon are divided into several races based on the season during which they enter the rivers to begin their upstream spawning migrations as follows: fall, late-fall, winter, and spring runs. Others stocks which might be recognized in the future will likely become stocks of special concern.

Good evidence exists for salmon and steelhead that these species return to their natal streams to spawn. There is some evidence and little reason not to expect that the same relationship holds for some of the other anadromous species. As stated in the POA for the Program, the objective of the Program will be to double the natural production of all species and races within specific individual streams, and to preserve genetic stocks. If it proves unfeasible to double the natural production of a species or race within a specific stream, the unmet production increment will be transferred to other individual streams in the following order of priority: (1) another stream within the same drainage system, (2) another stream within the larger basin, such as the Sacramento River Basin, and (3) any stream within the Central Valley.

Central Valley Rivers and Streams

For the purposes of the Program, **Central Valley rivers and streams are defined as all rivers, streams, creeks, sloughs and other watercourses, regardless of volume and frequency of flow, that drain into the Sacramento River basin, the San Joaquin River basin downstream of Mendota Pool, or the Sacramento-San Joaquin Delta upstream of Chipps Island**.

Sustainable

Sustainable means capable of being maintained or kept in existence. In Title 34, sustainable refers to natural production, which is defined as "... fish produced to adulthood without direct human intervention...." Elimination of direct human intervention as a legitimate alternative requires reliance on restoration and maintenance of habitat conditions that allow anadromous fish populations to sustain themselves at levels consistent with numeric restoration goals. Therefore, in the context of Title 34, **sustainable is defined as capable of being maintained at target levels without direct human intervention in the spawning, rearing or migration processes**. Production levels specified by numeric goals will be considered sustainable when they are maintained under the entire range of conditions resulting from legal human activities, as superimposed on natural variability inherent in the system. Human activities shall include, but not be limited to, agricultural diversion and discharge, exports, flow manipulation, water pollution, dredge and fill, channel modification and damming.

There is an element of time implicit in sustainability. Therefore, if natural production is to be sustainable, modifications to system operations as well as improved physical habitat and water quality must be provided into the future. Title 34 requires that "...natural production...be sustainable, on a long-term basis" and provides for annual funding without a specified expiration date. The intent of Title 34 is that numeric restoration goals continue to be realized or exceeded in perpetuity.

Long-Term Basis

Long-term will encompass at least several generations of fish (not less than 5) over a variety of hydrologic conditions (to allow for natural variation in production) and will continue indefinitely.

Average Levels

As stated in Title 34, the goal is to sustain natural production "...at levels not less than twice the average levels attained during the period of 1967-1991..." To attach numeric values to this goal, we need to estimate average levels of production. One problem is that average is not a precise statistical term. In statistics, the term average can apply to several measures of central tendency (Langley 1971). The most commonly used measure of central tendency is the arithmetic mean (Lapin 1975). Consequently, the public generally understands average to mean arithmetic mean and it is reasonable to assume that this was the intent of the authors of Title 34. Therefore, **the definition of average will be the arithmetic mean**.

INTENT OF TITLE 34

Habitat Restoration

Of the six purposes of Title 34, three are particularly germane to discussion of the intent of Title 34 as it relates to the Program. These three purposes are listed below:

(1) to protect, restore, and enhance fish, wildlife, and associated habitats in the Central Valley and Trinity River basins of California (3402[a]);

(2) to address impacts of the Central Valley Project on fish, wildlife and associated habitats (3402[b]);

(3) to contribute to the State of California's interim and long-term efforts to protect the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (3402[e]);

In addition, Section 3406(b)(1)(A) states that the Program "...shall give first priority to measures which protect and restore natural channel and riparian habitat values through habitat restoration actions, modifications to Central Valley Project operations, and implementation of the supporting measures mandated by this subsection..." Because Title 34 directs that the Program shall emphasize habitat restoration, **emphasis will be placed on restoring habitat**.

Natural versus Hatchery Production

Title 34 requires that "...natural production of anadromous fish in Central Valley rivers and streams be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991..." (Section 3406[b][1]). The requirement that natural production be sustainable on a long-term basis suggests that the intent of Title 34 is for the definition of natural production to extend between generations of fish. Natural production should be self-sustaining. **The Program should not depend on hatchery-produced fish to sustain populations of naturally spawning fish**.

In addition, Title 34 requires investigations of "...opportunities for additional hatchery production to mitigate the impacts of water development and operations on, or enhance efforts to increase Central Valley fisheries; Provided, That additional hatchery production shall only be used to supplement or to re-establish natural production while avoiding adverse effects on remaining wild stocks" (Section 3406[e][2]). This section provides insight into the intent of Title 34 as it relates to the roles of natural and hatchery production and emphasizes avoiding adverse effects of hatchery production on wild (naturally produced) stocks. Under Title 34, **hatchery production should only be used as a last resort to supplement or to re-establish natural production, and then only after investigations on the desirability of developing and implementing additional hatchery production**.

Adverse effects of hatchery production on natural stocks can include reductions in population size caused by competition, predation, disease or other factors (Sholes and Hallock 1979, Waples 1991). A large potential for negative interaction exists when these stocks interbreed (Hindar et al. 1991, Taylor 1991, Waples 1991). The adverse effects of interbreeding increase as hatchery-produced fish become more prevalent in the naturally spawning population. Interbreeding reduces interpopulation diversity and may lead to a reduction in overall productivity and a greater vulnerability to environmental change (Waples 1991). Outbreeding depression may also result from interbreeding. In addition, large populations of hatchery-produced fish that are indistinguishable from naturally produced fish may intensify effects of harvest on naturally produced fish (Wright 1993). The simplest way to avoid adverse effects on naturally produced stocks is to minimize the opportunities for interaction between naturally and hatchery-produced fish. **The Program should be designed to avoid adverse effects of hatchery production on natural stocks**.

Harvest

Title 34 does not directly address harvest. Title 34 defines natural production as: "... fish produced to adulthood..." (Section 3403[h]) and requires that natural production be increased. Inclusion of the term production, and especially production to adulthood, suggests that **Title 34 does not intend for restriction of harvest to be used as a means of achieving Program goals**. As stated in the definition of production, harvested fish should be included in counts of production. Sound harvest management is designed to harvest only excess production, allowing for enough fish to escape harvest to maintain production at the highest level the habitat can support.

Title 34 requires that natural production be increased. There are two mechanisms by which natural production can be increased: (1) increasing the productivity of the existing habitat, and (2) increasing the amount of habitat. These mechanisms are consistent with the emphasis Title 34 places on habitat restoration. Doubling productivity of existing habitat would provide more offspring from the same number of spawners. If existing spawning habitat is being fully utilized, then increasing the number of spawners by reducing harvest would not increase production. If production of naturally produced fish is doubled and escapement is held to present levels, then harvest of naturally produced fish could more than double.

The second mechanism, doubling the amount of habitat, would accommodate twice the number of spawners. This would also provide twice the number of offspring. Under this scenario, harvest of naturally produced fish could double. Under either mechanism, barring other harvest restrictions, we would expect at least a doubling of harvest of naturally produced fish. To meet the Intent of Title 34, **harvest should be maintained at levels that allow sufficient numbers of naturally produced fish to spawn to meet goals for at least doubling natural production**.

IMPLEMENTATION CRITERIA

As stated earlier, criteria for determination of natural production will conform to the definition of natural production and intent of Title 34, including definitions and interpretations of intent discussed and refined in this Position Paper. Because determination of natural production in the past will require different criteria than in the future, criteria for these time periods will be discussed separately.

Criteria for the baseline period - In the past, data collection efforts have not focused on estimating natural production and existing data may not provide direct estimates of natural production. In order to establish numerical goals for the Program, average levels of natural production must be estimated for the baseline period. Estimates will require assessing existing data and developing criteria to determine which data are germane. Criteria may not strictly conform to the definitions in and intent of Title 34 but are a compromise necessitated by a lack of data on natural production.

As explained in the POA, the Core Group and technical teams are responsible for developing these criteria. Technical teams are asked to develop initial criteria and estimates of average levels of natural production for the baseline period.

Where data are lacking, technical teams will make assumptions to expand existing data, or put existing data in perspective. For example, run-size estimates for American shad exist for only two years. In addition, young American shad abundance has been sampled during the fall emigration each year since 1967, except for 1974 and 1979 (Mills and Fisher, in preparation). The American shad technical team could look at young American shad abundance data to determine if run-size estimates for adults are representative of the abundance of shad for the baseline period. This approach has assumptions (chief among these is that abundance of young American shad can tell us something about average adult run-sizes) which are probably violated to some degree and is only presented as an example of what might be considered. Technical teams will document options considered for estimating natural production in issue papers that will be appended to the Program Plan if not in the text. Data quantity and applicability toward estimating natural production varies between species and drainage. Each technical team will need to address these issues for each species and drainage separately. Criteria for determining natural production during the baseline period will be applicable to existing data.

Because there is a relative wealth of data for chinook salmon and because several Teams deal with chinook salmon, specific criteria are proposed for them. Most of the data necessary to estimate production of each stock of chinook salmon for the baseline period are compiled in Mills and Fisher (1994). The proposed procedure for estimating yearly production of each race of chinook salmon for each stream during the baseline period follows.

In the following explanations and formulas, P is for production, E is for escapement, H is for harvest, and *h* is for the portion of total production not produced naturally. Subscripted letters following the normal letters and prior to the first comma represent different races of chinook salmon as follows: F for fall, L for late-fall, W for winter, S for spring, and C for all races combined. Subscripted letters following the first comma represent the following: O for ocean, D for downstream, I for instream, N for natural, H for hatchery, and T for total. Subscripted letters following the second comma represent the following: CV for Central Valley, SF for San Francisco, M for Monterey, and other letter combinations correspond to specific streams (e.g., AM for American River). Subscripted letters following a third comma refer only to ocean harvest and are C for commercial and R for recreational. In all cases, a subscripted X acts as a "wildcard" place holder for an unspecified subscript.

1. A portion of production returns to spawn in each stream, both naturally and in the hatchery. Some of these fish are captured before spawning. These fish are counted toward production for the stream in which they spawned or were harvested according to the following:

   a. To determine the total spawning escapement ($E_{X,T,XX}$) for each race in each individual stream, sum the estimated number of each race of chinook salmon returning to spawn naturally ($E_{X,N,XX}$) and in hatcheries ($E_{X,H,XX}$) for each individual stream.

   $$E_{X,T,XX} = E_{X,N,XX} + E_{X,H,XX}$$

   b. To determine the portion of production for each race returning to each stream (in-river run-size, $P_{X,I,XX}$), add $E_{X,T,XX}$ to the estimated number of each race of chinook salmon harvested in each stream ($H_{X,I,XX}$). Estimates of $H_{X,I,XX}$ do not exist for all streams and all years. Where estimates are not available or are inadequate, best professional judgement must be used. Technical Teams should document options considered for estimation of $H_{X,I,XX}$ in the Program Plan or in issue papers that will be appended to the Program Plan.

$$P_{X,I,XX} = E_{X,T,XX} + H_{X,I,XX}$$

c. To determine the total number of each race of chinook salmon returning to the Central Valley ($P_{X,I,CV}$), sum $P_{X,I,XX}$ for all streams in the Central Valley ($\lessgtr P_{X,I,XX}$) .

$$P_{X,I,CV} = \lessgtr P_{X,I,XX}$$

d. To determine the total number of chinook salmon (all races combined) returning to the Central Valley ($P_{C,I,CV}$), sum $P_{X,I,CV}$ for all races of chinook salmon ($\lessgtr P_{X,I,CV}$) .

$$P_{C,I,CV} = \lessgtr P_{X,I,CV}$$

2. A portion of production is harvested in the ocean and downstream of areas in rivers where the stream responsible for this production is not easily identified. To assign these harvested salmon to individual streams, the total number of salmon falling into this category is summed and subdivided to race and stream, proportional to the portion of production attributed to each race and returning to each stream, according to the following:

   a. To determine the Central Valley component of ocean harvest ($H_{C,O,CV}$), sum commercial catch at San Francisco ($H_{C,O,SF,C}$) and Monterey ($H_{C,O,M,C}$), sum recreational catch at these same ports ($H_{C,O,SF,R} + H_{C,O,M,R}$), and add these together. This estimate of $H_{C,O,CV}$ is based on the Central Valley Index (CVI), where harvest of Central Valley stocks equals landings at major ports south of Point Arena (San Francisco and Monterey). Use of CVI to estimate the Central Valley component of ocean harvest assumes that the number of Central Valley chinook salmon harvested from ports north of San Francisco is balanced by the number of chinook salmon from drainages north of the Central Valley harvested from San Francisco and Monterey. To carry $H_{C,O,CV}$ forward in subsequent calculations, assume that each chinook salmon harvested in the ocean fishery is equivalent to an adult salmon returning to spawn.

$$H_{C,O,CV} = H_{C,O,SF,C} + H_{C,O,M,C} + H_{C,O,SF,R} + H_{C,O,M,R}$$

   b. To account for that portion of inland harvest that occurs downstream of streams for which production is being estimated, estimate portion of inland recreational harvest captured downstream of spawning streams ($H_{C,D,CV}$). Information necessary to estimate $H_{C,D,CV}$ may not be available. If an estimate exists, use it. If an estimate of inland harvest for the entire Central Valley exists ($H_{X,I,CV}$), then sum all assignable inland harvest ($\lessgtr H_{X,I,XX}$) and subtract it from $H_{X,I,CV}$ to determine $H_{C,D,CV}$. If other options exist, these should be explored. $H_{C,D,CV}$ could be assumed to be small and therefore left out of the calculations or could be included in $H_{X,I,XX}$, in which case it would already to assigned to an individual stream.

c. To determine ocean and downstream inland harvest for the Central Valley ($H_{C,O+D,CV}$), sum $H_{C,O,CV}$ and $H_{C,D,CV}$.

$$H_{C,O+D,CV} = H_{C,O,CV} + H_{C,D,CV}$$

d. To assign portions of $H_{C,O+D,CV}$ to specific races, subdivide $H_{C,O+D,CV}$ to each race, proportional to the portion of production for each race returning to the entire Central Valley ($P_{X,I,CV}$) to the portion of production for all races combined returning to the entire Central Valley ($P_{X,I,CV}$).

$$H_{X,O+D,CV} = H_{C,O+D,CV} \bullet (P_{X,I,CV}/P_{C,I,CV})$$

e. To assign portions of $H_{X,O+D,CV}$ to specific streams, subdivide $H_{X,O+D,CV}$ to each stream, proportional to the portion of production for that race returning to each stream ($P_{X,I,XX}$) to the portion of production for that race returning to the entire Central Valley ($P_{X,I,CV}$).

$$H_{X,O+D,XX} = H_{X,O+D,CV} \bullet (P_{X,I,XX}/P_{X,I,CV})$$

3. To determine total production for each race and stream ($P_{X,T,XX}$), sum $P_{X,I,XX}$ and $H_{X,O+D,XX}$.

$$P_{X,T,XX} = P_{X,I,XX} + H_{X,O+D,XX}$$

4. A portion of the total production was not produced naturally (h). For the baseline period, only hatchery-produced salmon will be considered to be produced by other than natural means. To determine the natural production for each individual stream ($P_{X,N,XX}$), multiply $P_{X,T,XX}$ by (1-h). Technical Teams should document options considered and chosen for estimation of h in issue papers that will be appended to the Program Plan or in the text for the Program Plan.

$$P_{X,N,XX} = P_{X,T,XX} \bullet (1-h)$$

Numeric restoration goals for chinook salmon in each stream will be calculated as at least double the average of $P_{X,N,XX}$ for each of the years during the baseline period.

Criteria for the future - In the future, opportunities exist to improve estimates of natural production. These range from augmenting historic data collection activities with efforts to estimate the proportion of fish that are naturally produced, to designing new data collection to better account for natural production. The Core Group and technical teams are responsible for designing future monitoring programs.

The Core Group and technical teams have and will identify deficiencies in the baseline data. Future monitoring activities will be designed to address and avoid deficiencies. For example, monitoring programs should focus on estimating production, including harvest, on a consistent and regular basis, preferably yearly, in all of the streams in the Central Valley.

Monitoring programs should also estimate natural production, requiring some means of separating naturally produced fish from fish produced by other than natural means. At the very least, natural production must be discernable from hatchery production. Several methods can be used to separate naturally produced fish from hatchery-produced fish, including use of scale (Scarnecchia and Wagner 1980) or otolith (Paragamian et al. 1992) characteristics and constant fractional (Hankin 1982) or complete marking of hatchery-produced fish (Wright 1993), including incorporation of genetic markers (Waples 1991), inducement of otolith banding patterns (Volk et al. 1990), and more standard methods such as clipping fins. In addition, recommendations for the future should include managing naturally and hatchery-produced fish separately.

In addition, better estimates of harvest of Central Valley salmon in the ocean and of all anadromous fish in the Bay, Delta, and in each individual river and stream in the Central Valley should be developed. Harvest should be monitored continually.

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