CALFED

TECHNICAL REPORT
AFFECTED ENVIRONMENT

FISHERIES & AQUATIC RESOURCES

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CALFED
BAY-DELTA
PROGRAM

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LIST OF ACRONYMS

CALFED	CALFED Bay-Delta Program
CCWD	Contra Costa Water District
CESA	California Endangered Species Act
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVP	Central Valley Project
CWA	Clean Water Act
DCC	Delta Cross Channel
DFG	California Department of Fish and Game
DDT	dichlorodi-phenlytrichloroethane
DWR	Department of Water Resources
USFWS	U.S. Fish and Wildlife Service
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
MAF	million acre-feet
μg/l	micrograms per liter
mm	millimeters
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
PG&E	Pacific Gas & Electric Company
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
RWQCB	Regional Water Quality Control Boards
PCBs	polychlorinated biphenyls
PG&E	Pacific Gas & Electric Company
ppt	parts per thousand
SRA	shaded riverine aquatic
SWP	State Water Project
SWRCB	State Water Resources Control Board

FISHERIES & AQUATIC RESOURCES

INTRODUCTION

This technical report describes the fisheries and aquatic resources that could be affected by implementation of the CALFED Bay-Delta Program (CALFED). The report describes conditions at an ecosystem level and subsequently provides information specific to selected species.

SOURCES OF INFORMATION

The principal sources of information and data used to prepare the affected environment technical report include the journal and agency reports listed in the bibliography. Information on species was obtained primarily from studies prepared by the California Department of Fish and Game (DFG), U.S. Fish and Wildlife Service (USFWS), and U.S. Environmental Protection Agency (EPA). In addition, information for species listed or considered for listing under the federal Endangered Species Act (ESA) was summarized from reports in the Federal Register. The *Status and Trends Report on Aquatic Resources in the San Francisco Estuary*, published by the San Francisco Estuary Project (1993), provided additional information on nutrients and the foodweb of the Bay-Delta.

The California Water Plan Update (Bulletin 160-93), provided watershed, hydrographic, and hydrologic data (DWR 1994). Additional hydrologic information was taken from the Department of Water Resources (DWR) DAYFLOW model and database, including historical river and Delta hydrologic characteristics and routine water quality monitoring data for the Bay-Delta. Information on suspended solids, nutrients, and phytoplankton abundance was obtained from the Interagency Ecological Program Homepage (http://www.iep.water.ca.gov).

A number of papers on San Francisco Bay, including *San Francisco Bay: The Urbanized Estuary* (Conomos 1979), provided information on Bay hydrographics, phytoplankton, and zooplankton abundance and distribution,and on historical conditions in the Bay-Delta.

Additional information on specific subjects is provided in other technical reports supporting the CALFED Programmatic Environmental Impact Statement/Environmental Impact Report (EIS/EIR). For contaminants and salinity, the Water Quality Technical Report provides additional information. River flow, net Delta channel flow, salinity distribution, tidal flow, reservoir operations, diversions and exports, and other flow-related data are provided in the Surface Water Resources Technical Report. Delta structure related to levees and channel dimensions is discussed in the Flood Control Technical Report.

ENVIRONMENTAL SETTING

Regulatory Context

Numerous federal, state, and local laws contain provisions aimed at protecting aquatic habitat. The federal Clean Water Act (CWA) is administered by the State Water Resources Control Board (SWRCB) and the Central Valley and San Francisco Bay Regional Water Quality Control Boards (RWQCB) under an agreement with the EPA. Under Section 303 of the CWA, water quality standards and implementation plans must be developed periodically, including effluent limitations, receiving-water ambient standards, and total maximum daily load standards for trace metals, sediment, or other pollutants. Section 303 also allows for revisions and intergovernmental cooperation; for adequate implementation, including schedules of compliance; and for revised or new water quality standards.

Section 402 of the CWA includes the National Pollutant Discharge Elimination System (NPDES), which implements standards established under other sections of the CWA, including Section 303. The EPA may issue permits for discharge of waste into navigable waters of the United States. Section 404 requires that permits be obtained from the U.S. Army Corps of Engineers (Corps) prior to dredging and filling. The Corps may issue a permit for the discharge of dredged or fill material into navigable waters at specified dredging and disposal sites.

The 1995 Water Quality Control Plan, implemented by SWRCB, establishes water quality objectives for the protection of fish and wildlife and for other beneficial uses of water (for example, consumptive and nonconsumptive use) in the San Francisco and Suisun Bays and in the Delta.

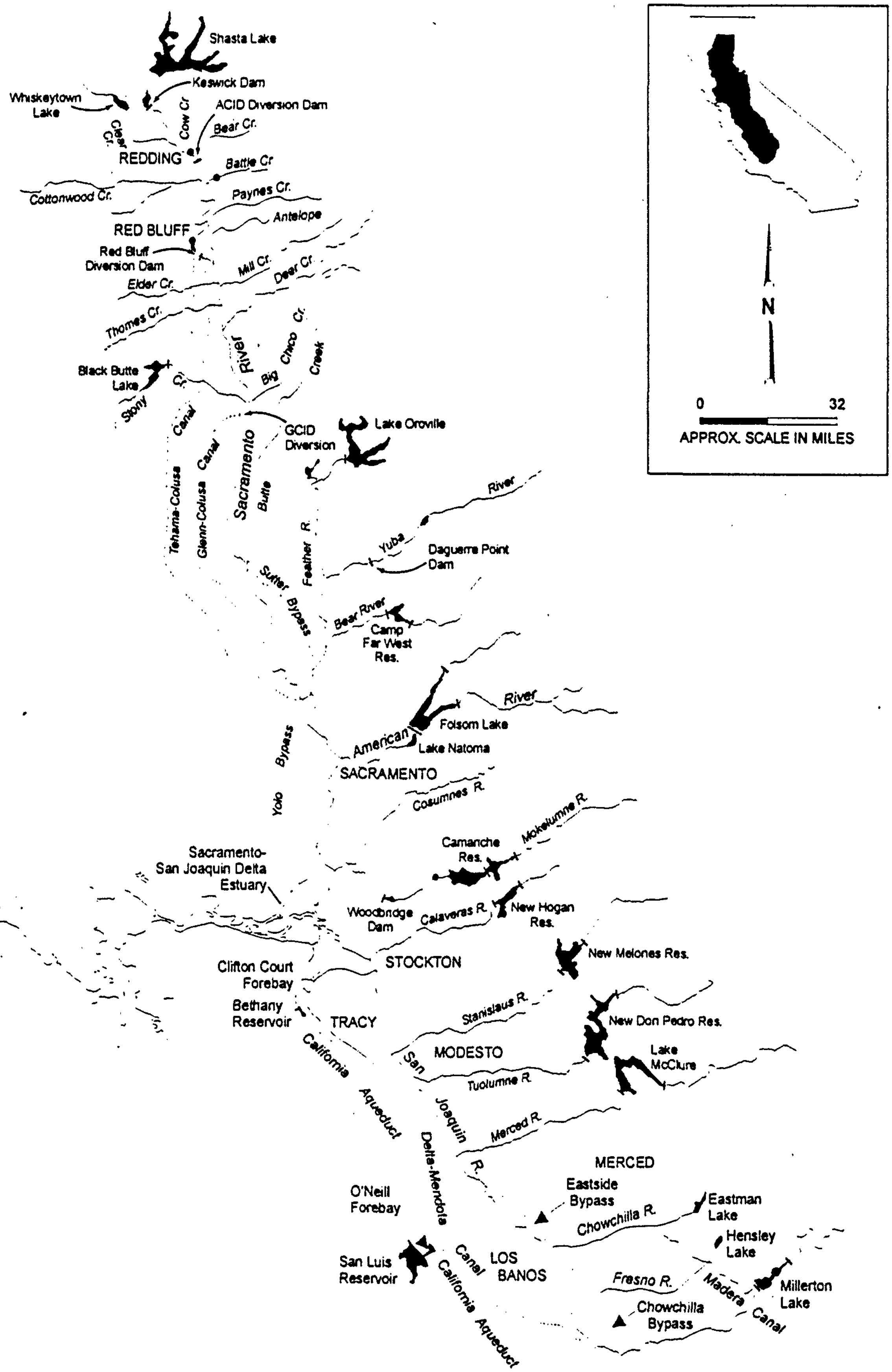
The Suisun Marsh Preservation Act requires maintenance of specific salinity levels in the marsh. The Suisun Marsh Salinity Control Structure was constructed as a barrier to prevent high-salinity waters from encroaching into the marsh. The structure is primarily for maintenance of freshwater marsh and wetland habitat to benefit waterfowl. The structure maintains fresh water suitable for waterfowl-management needs.

The federal ESA and the California ESA (CESA) protect estuarine aquatic inhabitants directly by regulating "take," and indirectly by protecting habitat. For example, critical habitat, which includes portions of the Sacramento River and the Delta, has been designated for winter-run chinook salmon and delta smelt. ESA compliance is enforced by USFWS and the National Marine Fisheries Service (NMFS); CESA compliance is enforced by the DFG. The DFG also enforces regulations under the Fish and Wildlife Protection and Conservation Act (California Fish and Game Code, Sections 1600 to 1608, also known as the Streambed Alteration Agreement).

Aquatic Ecosystem Conditions

The San Francisco Bay-Delta river system drains a catchment of approximately 40 million acres and extends from the crest of the Sierra Nevada, Cascade, and Coast Ranges to the Golden Gate Bridge (Figure 1). The inland portion of the system (approximately 413,400 acres) includes the reservoirs, streams, and mainstem channels of the Sacramento River, San Joaquin River, and other Central Valley rivers. This freshwater, nontidal system totals nearly 20 million acre-feet (MAF) and conveys an average of about 23 MAF of fresh water per year to the Delta. The Delta marks the beginning of the tidal portion of the system. Under existing conditions, the Delta is the confluence through which water, nutrients, and aquatic food resources are moved, mixed by tidal action in the channel and shoal areas, and diverted by pumps and siphons into Delta irrigation ditches or Central Valley Project/State Water Project (CVP/SWP) system canals. From Suisun Bay, these resources are transported by tidal flows to San Pablo Bay and the other sub-basins of the San Francisco Bay. Through the SWP and CVP canals and San Luis Reservoir, SWP and CVP transport water and nutrients to canals and reservoirs outside the Bay-Delta river catchment.

The following description focuses on the disposition of acreage, flow, sediment, nutrients, and food resources within and adjacent to the system, properties potentially modified by proposed CALFED actions. This description provides a baseline for evaluating the ecosystem-scale effects of proposed CALFED actions and serves as a backdrop for the species-



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level descriptions that follow. The description begins with the Delta, the focus of most CALFED actions.

DELTA REGION

HISTORICAL PERSPECTIVE

The ratio of water to land acreage was higher prior to levee construction and channelization, when wetlands dominated land cover throughout the Delta. Historically, a much higher percentage of the open water of the Delta consisted of back-water areas and tidal sloughs and channel networks that supplied and drained highly productive tidal-marsh complexes. The marsh vegetation, in turn, supplied the Delta aquatic system with an abundant source of coarse organic matter, such as dead tule stems, for microbial processing and a variety of microhabitats for algae, protists, invertebrates, and fish. The vegetation also slowed the movement of water through the Delta during floods, increasing hydraulic residence times and the opportunity for sediment and nutrients to settle to the bed. Trees and shrubs grew adjacent to many of these channels, providing shade, cover, and attachment sites, as well as organic matter. Under existing conditions, however, most of the open water is deep-channel habitat that has been dredged, leveed, and riprapped to provide passage for ocean-going vessels and efficient conveyance of fresh water from the Sacramento River through the Delta. The levees are kept bare of vegetation to reduce the probability of levee failure. The amount of shallow-water and shaded riverine habitat throughout the Delta is therefore much lower now than under historical conditions.

CURRENT RESOURCE CONDITIONS

The total surface area of the legal Delta is approximately 678,200 acres, of which 54,000 acres (8%) are occupied by channels, sloughs, and other open water. Riparian vegetation, wetlands, and other forms of "idle land" cover approximately 113,000 acres, and irrigated cropland accounts for 484,900 acres.

Total freshwater inflow to the Delta averages 23 MAF per year (31,624 cubic feet per second [cfs]). The bulk of this water (over 70%) flows from the Sacramento River. Most of the annual inflow occurs during the spring thaw and winter rainy seasons, but upstream reservoirs have reduced the intensity and frequency of peak flows and increased the amount of inflow during the dry season compared to conditions prior to reservoir construction. Under existing conditions, about 68% of total inflow occurs during the wet season (November to April) and 32% during the dry season (May to October). Combined with the structural changes imposed by levees, dikes, dredging, and channelization, the average residence time of Delta water, nutrients, algae, and other forms of fine particulate organic matter has been greatly reduced compared to historical conditions. This reduction has been greatest for the dry season (May to October), when most primary and secondary production normally takes place throughout the system. (Figure S-1 in the Supplement illustrates this information.)

SWP and CVP pumps in the southern Delta export an average of approximately 5 MAF per year, or 21% of mean annual inflow. During dry years or dry periods of average flow years, SWP and CVP facilities export more than 60% of freshwater inflow. A much greater proportion of the inflow is diverted when agricultural diversions are included. Under these circumstances, the amount of water, sediment, and nutrients flowing out of the Delta to Suisun Bay is greatly reduced and the direction of net flows in some central- and south-Delta channels is reversed, resulting in net flows moving upstream toward the pumps instead of bayward. On average, the pumps remove approximately 60% of the algae that flows into the Delta from the Sacramento and San Joaquin Rivers from May through October. Trash racks at the pumping facilities also trap hundreds of tons of water hyacinth and other forms of aquatic plant biomass swept in from upstream and Delta

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locations, especially during the first high flows of early winter. Reverse flows and loss of algae and other food resources to SWP and CVP exports have contributed to the loss of Bay-Delta productivity and some Bay-Delta invertebrate and fish populations (see "Selected Species" below). (Figures S-2 and S-3 in the Supplement illustrate this information.)

As a result of production of algae within the Delta, from May through October algal biomass flowing out of the Delta exceeds the amount transported in from the rivers by an average of 40%. The biomass transported to or produced within the Delta flows to Suisun Bay or is exported by the SWP and CVP pumps and diverted into agricultural fields. Of the total algal biomass exiting the Delta, two-thirds goes to Suisun Bay and one-third is exported and diverted.

The rivers flowing into the Delta, together with agricultural return flows and urban wastewater flows within the Delta, transport contaminants in addition to water, sediment, and nutrients. Some contaminants arrive in dissolved forms, but most, such as trace metals, a number of herbicides, and other synthetic organic toxicants, are transported in association with fine particulate sediment and organic matter. Laboratory tests indicate that contaminant concentrations in the lower Sacramento and San Joaquin rivers during high flow events can be high enough to kill fathead minnow larvae or other test organisms, but it is not clear what effect the usually relatively low concentrations that prevail under normal flow conditions might have at the population, community, or ecosystem level. It is known, however, that some contaminants, such as mercury, polychlorinated biphenyls (PCBs), and other potentially harmful chemicals, bioaccumulate within the foodweb. The concentration in fish or other high-trophic-level organisms can be orders of magnitude greater than concentrations in the water or in algae, invertebrates, and other lower trophic-level organisms. Bioaccumulation of mercury in resident fish has prompted the State to issue a fish-consumption advisory for the Delta.

BAY REGION

HISTORICAL PERSPECTIVE

Wetlands and related habitat are some of the most valuable natural resources in the Bay. During the past 140 years, most of the mudflats, tidal and seasonal marshes, and riparian woodland have been drastically reduced. Since 1850, more than 484,000 acres of the historical wetlands have been modified. Tidal wetlands that once covered 545,000 acres in 1850 diminished to 45,000 acres by 1985, primarily as a result of urban and agricultural development. Large areas that were once tidal marsh habitat have been transformed into saltponds. In addition, the Bay's open-water area has diminished by one-third. In the Bay, waterway channelization, shoreline riprapping, urban development, and flood control projects have eliminated or degraded wetland and riparian wildlife habitats, increased seasonal stormflows, and changed sediment transport in the estuarine ecosystem. Past hydraulic-mining debris and diking and filling of tidal marshes have decreased the surface area of San Francisco Bay by 37% and removed valuable habitat for aquatic and terrestrial organisms.

There are many tributary streams in the Bay Region, many of which flow directly into the Bay. Most streams have lost habitat through channelization, riparian vegetation removal, reduced water quality, and the construction of fish barriers. The fish of the tributary streams of the Bay are sensitive to changes in habitat, and fish abundance in these streams generally reflects the intensity of urbanization of the surrounding lands.

CURRENT RESOURCE CONDITIONS

The Bay Region aquatic system covers 302,460 acres, not including Suisun Marsh, and occupies an average volume of 4,893,000 acre-feet. Mean depth (volume divided by area) is approximately 16 feet, but most areas are less than 6 feet deep. Shoals and mudflats cover most of the surface area, whereas most of the Bay Region's volume is contained within deep, fairly narrow channels that are dredged periodically to maintain shipping lanes for ocean-going cargo vessels.

From an ecosystem standpoint, the Bay Region functions as temporary storage, mixing and processing freshwater, sediment, nutrients, and food resources flowing out of the Delta. The first embayment to receive these resources is Suisun Bay. This embayment is one of the critical food production and food consumption areas of the Bay Region aquatic ecosystem, and serves as a critical rearing area for resident and anadromous fish.

The Bay-Delta foodweb has undergone a number of changes in recent years; most notably, algae abundance has declined in Suisun Bay. Lowered algae abundance in Suisun Bay coincides with very low Delta outflow during drier years, particularly in drought years, such as 1977 and from 1987 through 1992, and with very wet years, such as 1983 and 1995. Chlorophyll levels greater than 20 micrograms per liter (μg/l) represent productive water. Such levels have not been reached in Suisun Bay since 1986.

A pattern of very low chlorophyll levels in Suisun Bay began in 1987. _These low levels may be the result of high densities of Asian clams that colonized the Bay after being introduced accidentally from the ballast waters of ships. Large numbers of the clams colonized this area of the estuary during the drought from 1987 to 1992.

In wet years, some of the algae biomass in Suisun Bay is washed downstream into the wider expanses of San Pablo Bay and other portions of San Francisco Bay. Spring and summer chlorophyll levels in San Pablo Bay are generally low compared with those in Suisun Bay and the Delta. Peak concentrations in the past 3 decades occurred in wet years (1982, 1983, 1984, and 1986).

Aquatic invertebrate population trends followed those of algae over the past 3 decades. Species that once dominated the aquatic invertebrate community have become relatively scarce, while other species have increased in relative abundance. Many native species have become less abundant or more narrowly distributed, while dozens of new non-native species have become well established and widely dispersed. In general, the abundance of plankton has declined, while populations of many bottom-dwelling invertebrates, most notably Asian clams, have increased. This transition has been most evident in Suisun Bay and other traditionally important fish-rearing areas.

The deterioration of the zooplankton community and its algal food supply in critical habitat areas of the Bay Region is viewed by many as a serious problem because striped bass, delta smelt, chinook salmon, and other species that use Suisun Bay and the Delta as a nursery area feed almost exclusively on zooplankton during early stages of their life cycles. Research indicates that survival and growth of fish larvae generally increase with increased concentration of zooplankton.

Areas of the Bay Region where hydraulic conditions allow food resources to accumulate in the water column rather than settling or washing out (the entrapment zone) are important habitats for plankton. The accumulation of plankton results from passive processes and from active algal, microbial, and zooplankton reproduction. The entrapment zone permits the development of high zooplankton populations on which many estuarine resident and anadromous fish depend, especially during their early life stages. Horizontal salinity stratification enhances this process, especially when the entrapment zone is in Suisun Bay.

Much of the plant biomass and other forms of fine particulate organic matter consumed by zooplankton in the Bay Region is not produced in the Bay, but is transported in from the Sacramento and San Joaquin Rivers and accumulates in Suisun Bay and the western Delta. Organic matter originates from the lower mainstem rivers and from side channels, side sloughs, and floodplain areas. Large amounts of organic matter and associated bacterial biomass enter the rivers, Bay, and Delta as crop residue, leaf litter, dead tule stems, and other organic debris from riparian corridors, floodplains, or other areas subject to periodic inundation by tides and floodflows. Historically, considerable organic material entered the rivers and Bay-Delta from sewage- and food-processing plants. These point-source loadings have since been reduced as part of an overall effort to improve water quality.

The proportion of the organic material imported to or produced within the Delta that reaches Suisun Bay varies considerably from year to year and depends, in part, on prevailing flow conditions. At higher flows, much of the organic material brought in by the rivers will travel to Suisun Bay or to San Pablo and central San Francisco Bays. At low flows, more biological production remains in the Delta.

The decline of plankton populations and chlorophyll concentration in the Bay Region may be a result, at least in part, of the effects of heavy metals, herbicides, pesticides, and other toxic substances. Some of these toxicants are extremely persistent. For example, despite a total ban on the use of dichlorodi-phenlytrichloroethane (DDT) in 1972, DDT and its degradates are still detected in Bay Region sediments. A number of other organochlorine compounds that, like DDT, bioaccumulate in the foodweb, are also widespread in Bay Region sediments. These include compounds derived from industrial and agricultural sources. Very low concentrations of these substances in the water column may act individually or in combination to reduce productivity of plant and animal plankton.

Delta outflow transports organisms and organic material into Suisun Bay and is affected by upstream river inflow and Delta diversions. High Delta outflow can transport organisms out of the Delta into Suisun Bay, where conditions for survival are improved over conditions within the Delta. Low Delta outflow could retain organisms within the Delta. Riverine loading is a dominant organic carbon source for the Bay, and it is reduced when Delta outflow is reduced. Delta outflow also affects the location of X2 (the in-channel distance upstream of the Golden Gate Bridge in kilometers where the near-bottom salinity is 2 parts per thousand [ppt]), which determines the amount of estuarine habitat available within the Bay. High outflow shifts X2 downstream, and low outflow shifts X2 upstream. When outflow causes the location of X2 to occur within the extensive shallow regions of the Bay, the residence time of phytoplankton increases, which is important for survival of planktonic fish larvae. The operation of dams on the tributary streams and diversions in and upstream of the Delta has reduced Delta outflow; the greatest effects occur during spring and summer, especially during drier periods. (A graph illustrating this information is provided in the Supplement - Figure S-4.)

SACRAMENTO RIVER REGION

<u>HISTORICAL PERSPECTIVE</u>

Historically, wetlands probably covered over 1,400,000 acres of the Sacramento Valley. These wetlands comprised mostly riparian forests and semipermanently flooded tule marshes. Currently, approximately 170,000 acres of wetlands remain and are dominated by tule marsh. In addition, approximately 400,000 acres of agricultural lands are subject to flooding from mainstem overflows and local runoff during wet years. Some 500,000 acres of riparian forest historically fringed the entire length of the mainstem Sacramento River channel, as well as the sloughs, oxbows, side channels, and meander scars. Today, less than

5% of the mainstem riparian forest remains. As in the Delta, wetland plants and riparian forests provided food and shelter for aquatic biota and greatly increased hydraulic residence time of the system. Under existing conditions, most of the acreage adjacent to the river is protected by levees, and long sections of the river have been straightened to maximize agricultural land and improve channel conveyance capacity. As in the Delta, levees are reinforced with riprap and kept relatively free of vegetation, measures that have greatly reduced the supply of organic material and the quality of invertebrate and fish habitat in the river ecosystem.

CURRENT RESOURCE CONDITIONS

The Sacramento River catchment encompasses 17,250,000 acres. Most of the catchment (more than 65%) is covered by forest and pastureland, whereas about 12% consists of rice, orchard, and other irrigated croplands of the valley floor and surrounding mountain valleys. The Sacramento River system itself consists of the mainstem channel; Lake Shasta Reservoir, Oroville Reservoir, and about 40 other major reservoirs; a dozen or so major tributaries, including the Feather and American Rivers; and hundreds of minor tributaries. The system also receives water (about 880,000 acre-feet per year) diverted from Clair Engle Reservoir in the Trinity River catchment directly to the northwest. The entire aquatic system covers about 260,000 acres, or 1.6% of the catchment.

The Sacramento River system has an average volume of 11.6 MAF. Ninety-one percent of that volume is stored in reservoirs; therefore, Sacramento River and tributary flows are highly regulated and under the direct control of the U.S. Bureau of Reclamation (Reclamation), DWR, and others. The main purposes of the reservoirs are flood-control storage of winter rain and spring snowmelt for subsequent release to downstream diverters and generation of electricity. Ancillary functions include lake recreational opportunities. Relative to the natural flow regime, the present river flows are lower in spring and winter but higher in summer and fall. (Figure S-5 in the Supplement shows Feather River flow under unimpaired and existing conditions as an example of flow change on rivers that is attributable to reservoirs.)

Total runoff from the catchment averages about 22.4 MAF per year, about one-third of California's total natural runoff. About 7.8 MAF are diverted annually to irrigate rice fields, orchards, and other crops in the Sacramento Valley. Some of this diverted water comes back to the river as agricultural return flow, but most (greater than 70%) is transpired by plants or otherwise lost from the system to the atmosphere or groundwater. Wetlands consume about 35% of the average 484,000 acre-feet applied to them each year. Overall, about 6 MAF of Sacramento River runoff are evaporated, transpired, or otherwise consumed within the catchment, and another 6 MAF are exported to regions to the south and west through federal, state, and local conveyance facilities.

The reservoirs also function as settling basins for all of the coarse sediment and organic material and a large fraction of the fine sediment brought in each year by inlet streams. Some reaches downstream of reservoirs have become "armored" because reservoir releases carry away fine sediment, leaving behind coarse material. A few of the smallest reservoirs have filled with sediment, but the major reservoirs are expected to continue to function because it will take hundreds of years before they fill.

The major reservoirs have low nutrient levels and support modest phytoplankton production. The shoreline of reservoirs is mostly barren because water levels fluctuate and littoral macrophyte and wetland plant communities are not supported. The Feather River, American River, and other major tributaries of the Sacramento River are low in nutrients. Unlike the reservoirs and the lower mainstem of the Sacramento River, primary production in the tributaries and upper reaches of the mainstem is

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dominated by algae that grow on the streambed rather than suspended in the water.

Algal biomass and fine particulate organic matter derived from terrestrial vegetation form the basis of the foodweb in these stream ecosystems.

Nutrient levels increase abruptly in the lower mainstem channel downstream of the confluence with the Colusa Basin drain. This drain conveys agricultural return flows from the west side of the valley that are relatively high in phosphorus and nitrogen. The lower mainstem also is enriched by treated effluent from the Sacramento Regional Wastewater Treatment Facility. Planktonic algae abundance is generally low because residence time is short and relatively high amounts of suspended sediment prevent light penetration. The only recorded phytoplankton bloom in the lower Sacramento River occurred during the extremely dry summer of 1977, when flow was extremely low and residence time was comparatively long.

Inactive and abandoned mines discharge acid mine drainage into the upper Sacramento River and tributaries. This drainage contains trace metals, especially copper and zinc, that are toxic to aquatic organisms. The main source of this metal contamination on the Sacramento River is the Iron Mountain mine complex, an EPA Superfund site. Abandoned mines and natural erosion in other parts of the catchment input mercury and increase levels in fish and invertebrates that sometimes exceed the U.S. Food and Drug Administration or National Academy of Sciences criteria. Tributaries transporting mercury include the American River, Beach Lake, Lake Berryessa, Clear Lake, and the Feather River. Urban runoff and municipal and industrial discharges are sources of metals and organochlorine compounds that can, like mercury, bioaccumulate in fish and other high-trophic-level aquatic organisms. Agricultural return flows, including flow in the Colusa Basin drain, discharge potentially harmful herbicides and pesticides into the system.

San Joaquin River Region

Historical Perspective

Precipitation in the San Joaquin River Basin averages about 13 inches per year; 23 inches less than the average for the Sacramento River Region. Snowmelt runoff is the major source of water to the upper San Joaquin River and the larger eastside tributaries. Historically, peak flows occurred in May and June and natural overbank flooding occurred in most years along all the major rivers. When floodflows reached the valley floor, they spread out over the lowland, creating several hundred thousand acres of permanent tule marshes and over 1.5 million acres of seasonally flooded wetlands and native grasslands. The rich alluvial soils of natural levees once supported large, diverse riparian forests. It has been estimated that as many as 2 million acres of riparian vegetation grew on natural levees, on floodplains, and along small streamcourses. Above the lower floodplain, the riparian zone graded into higher floodplains, supporting valley oak savanna and native grasslands interspersed with vernal pools. Currently, about 126,000 acres of wetlands remain in the San Joaquin Valley. Riparian forest acreage is less than 5% of its former extent and exists in small isolated patches. Human-made levees isolate the river from most of its former floodplain.

Current Resource Conditions

The San Joaquin River Region includes the San Joaquin, Cosumnes, and Mokelumne rivers. The region encompasses approximately 10,200,000 acres, of which approximately 3,500,000 acres compose the San Joaquin Valley. The eastern foothills and mountains total 5,800,000 acres, and the western coastal mountains comprise 900,000 acres. Some 1,955,000 acres support irrigated agriculture, whereas approximately 295,000 acres are in urban areas. The aquatic system occupies 1.2% (130,000 acres) of the catchment and, as in the

Sacramento River, consists of a mainstem channel and its major tributaries; the Stanislaus, Tuolumne, and Merced rivers; several hundred small tributary streams; and about 16 major reservoirs.

The rivers and reservoirs of the San Joaquin Region occupy an average volume of nearly 7 MAF. Ninety-eight percent of the total volume is stored in reservoirs; therefore, outflow from this region is highly regulated. Relative to natural flow conditions, the present flow of the San Joaquin River and tributaries is lower in spring and winter, and higher in summer and fall. The reservoirs function as settling basins for all of the coarse sediment and organic material, and a large fraction of the fine sediment brought in each year by inlet streams.

The San Joaquin River receives substantial agricultural wastewater inflow during the main summer growing season. Most of the flow in the mainstem of the San Joaquin River consists of agricultural return flow rich in nutrients and suspended solids. In winter, soils are flushed to reduce salt buildup, and the resulting wastewater is conveyed to the streams and San Joaquin River by an extensive system of tile lines and drainage ditches. High nutrient concentrations and long residence times combine to make the San Joaquin River mainstem an extremely productive system. Chlorophyll concentration in the San Joaquin River at Vernalis reaches average summer levels that are among the highest in the world.

Annual mean discharge in the San Joaquin River at Vernalis is about 3 MAF per year. This represents about 17% of the total inflow to the Delta; however, because of its high fertility and productivity, the San Joaquin River contributes a disproportionately high percentage of inflowing nutrients and food resources to the Delta. From May through October, the San Joaquin River accounts for about 40% of the sediment loading, 25% of the phosphorus loading, 37% of the nitrogen loading, 35% of fine-particulate organic matter loading, and 58% of the phytoplankton loading to the Delta. These nutrients and food resources benefit the ecosystem by contributing to the Bay-Delta productivity but can, in combination with sewage and urban discharge, lead to reduced summer and fall dissolved-oxygen levels in localized reaches of deep, poorly flushed channels, such as the Stockton Ship Channel.

On the west side of the region, over 100,000 acres of land are underlain by shallow, semi-impermeable clay layers that prevent water from percolating downward. Soils in this region are naturally high in selenium. Inadequate natural drainage, salt accumulation, and high selenium concentrations in agricultural return flow have been long-standing problems in this area and have intensified with the importation of irrigation water from the Delta. Subsurface tile line systems have been constructed throughout much of this area to increase drainage, but salt accumulation and selenium contamination remain pressing problems.

In addition to sediment, nutrients, and food resources, the San Joaquin River is an important source of herbicide and pesticide loading to the Delta. Loadings occur primarily during high flows, especially those immediately after pesticide application.

SWP AND CVP SERVICE AREAS OUTSIDE THE CENTRAL VALLEY

HISTORICAL PERSPECTIVE

The Pajaro-Salinas river system and the south coastal drainages constitute the aquatic areas in the SWP and CVP Service Areas Outside the Central Valley (including Santa Cruz, San Benito, Santa Clara, San Louis Obispo, and Santa Barbara counties, as well as the urbanized areas of southern California). The coastal streams range from warm, intermittent streams at low elevations to permanent, coolwater streams at higher elevations. Most streams are characterized by torrential winter and spring flooding, and low to intermittent flow in fall and winter. The Pajaro-Salinas river system supported native freshwater fish fauna similar to Central Valley streams (Moyle 1976). South coastal drainages support only four native freshwater fish, including arroyo chub (*Gila oreutti*), speckled dace (*Rhinichthys osculus*), Santa Ana sucker (*Catostomus santaanae*), and unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*). Both drainages support anadromous species, including pacific lamprey and steelhead. Introduced species include many of the species found in Central Valley systems.

CURRENT RESOURCE CONDITIONS

Water, sediment, nutrients, and biota pumped from the Delta by the SWP and CVP maintain or affect aquatic ecosystems outside the Bay-Delta catchment. The California Aqueduct supplies water to Pyramid Lake, Castaic Lake, and other reservoirs in southern California. The main purpose of these reservoirs is to supply drinking water. The reservoirs are maintained by water pumped from the Delta and are highly productive, as evidenced by relatively abundant phytoplankton populations, the dominance of scum-forming blue-green algae in late summer and early fall, and relatively high levels of dissolved and particulate organic carbon.

The Pajaro-Salinas river system and the south coastal drainages have been highly modified. Groundwater and surface water diversions, reservoir operations, changes in land use (grazing, urbanization, and road construction), and other human-induced factors have reduced streamflow. Reduced streamflow, blockage of stream channels by dams and other barriers, channelization, discharge of contaminants (sewage, storm water runoff, industrial waste, and agricultural runoff), removal of riparian vegetation, introduced species, and other factors have substantially reduced the abundance and distribution of native species. The input of water from the Delta into the Pajaro-Salinas river system and the south coastal drainages has induced additional urban and agricultural development, and introduced new aquatic species. The degraded condition of stream and other aquatic communities is reflected by the number of native fish species listed under the federal and CESAs, including tidewater goby (*Eucyclogobius newberryi*), unarmored threespine stickleback, Santa Ana sucker, and steelhead.

Selected Species

STEELHEAD

Historically, steelhead (*Oncorhynchus mykiss*) spawned and reared in the most upstream portions of the upper Sacramento and San Joaquin rivers and most, if not all, of their 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 lower.

LIFE HISTORY

As an anadromous species, steelhead migrate to sea as juveniles and typically return to natal streams to spawn as 2- to 4-year-old adults (Figure 2). Upstream migration is typically from July through February, depending on prevailing flow and temperature conditions. Relatively early attraction of steelhead into the tributaries can be triggered by reservoir releases of cold water and natural high-water conditions in major Sacramento River tributaries. While adult steelhead are in freshwater, they rarely eat and consequently grow very little (Pauley et al. 1986). The majority of spawning takes place between late December and March. Although most steelhead die after spawning, a small proportion return to the sea between April and June (Mills and Fisher 1993).

Egg incubation time in the gravel is determined by water temperature and varies from approximately 19 days at an average water temperature of 60°F to approximately 80 days at

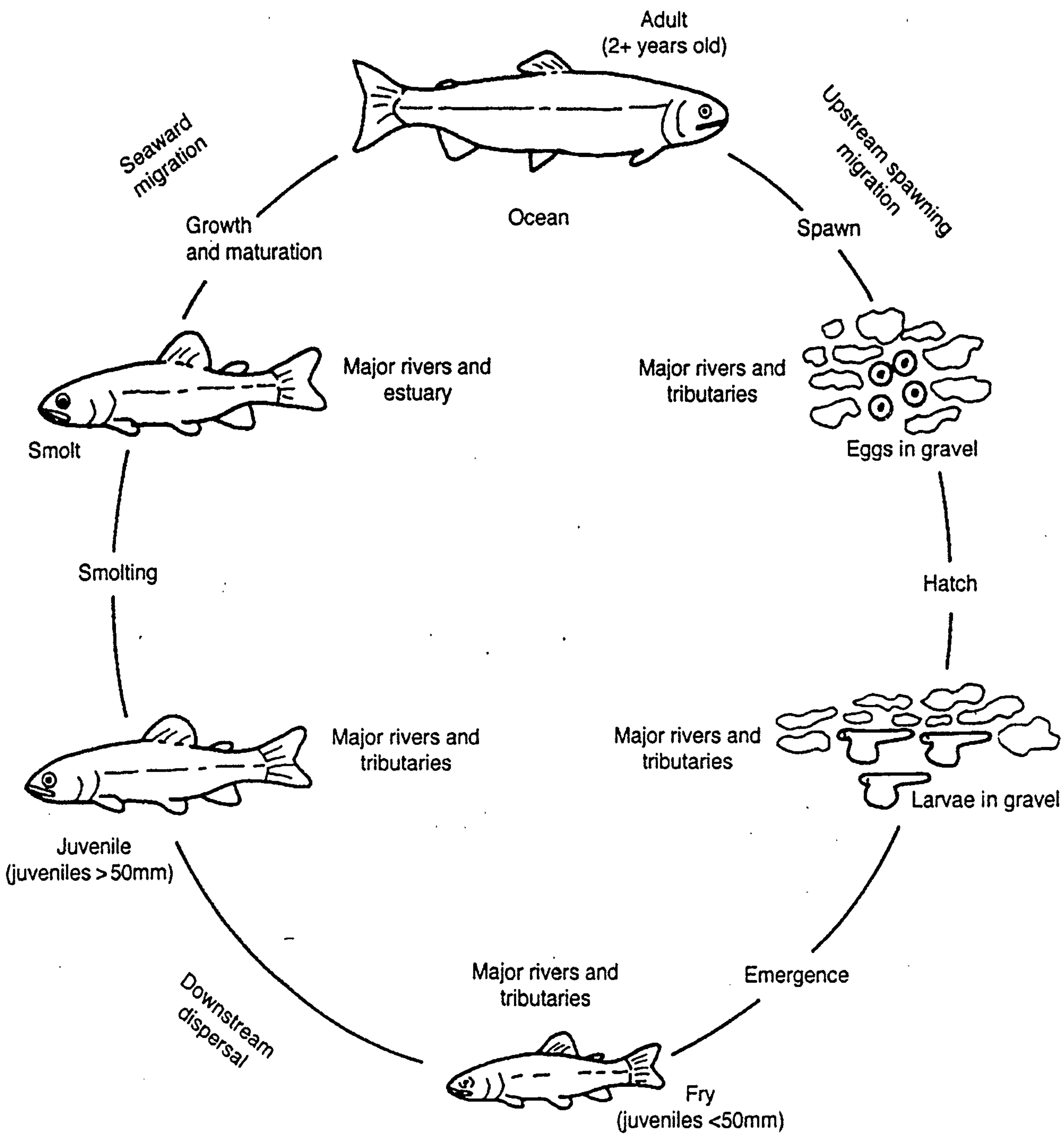

Figure 2. Life History of Steelhead Trout

C-007996

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an average temperature of 40°F. After hatching, steelhead larvae remain in the gravel for 2 to 8 weeks. (Barnhart 1986, Reynolds et al. 1993).

Following emergence from the gravel, steelhead fry live in small schools in shallow water along streambanks. As the steelhead grow, they establish individual feeding territories. Although most live in riffles during their first year of life, some of the larger steelhead live in deeper, faster runs or pools. Juvenile steelhead feed on a variety of aquatic and terrestrial insects and other small invertebrates, and newly emerged fry are sometimes preyed on by older steelhead.

Juvenile steelhead typically rear in streams for 1 to 2 years prior to emigration. Juveniles from most steelhead stocks emigrate downstream to the ocean from November through May (Schaffter 1980). Sacramento River steelhead, however, migrate in spring and early summer (Reynolds et al. 1993), with peak migration through the Delta occurring in March and April. Steelhead may remain in the ocean from 1 to 4 years, growing rapidly as they migrate north and south along the Continental Shelf (Barnhart 1986, Pauley et al. 1986).

POPULATION TRENDS

Few specific data are available regarding historical steelhead abundance, but populations have clearly declined in size and distribution. Historically, steelhead runs were sustained in all tributaries with adequate flow and habitat quality, although no firm estimates of steelhead abundance exist prior to stream alterations. A commercial fishery for steelhead has never existed, and quantitative estimates of population abundance were not developed until the 1950s. Steelhead within the Sacramento-San Joaquin Central Valley are proposed for federal listing as endangered (61 FR 41541 August 9, 1996). (Current geographic distribution is shown in Table S-3 in the Supplement.)

A distinct population decline has occurred in both hatchery and natural stocks of steelhead in the Sacramento River system. The estimated total steelhead run size for the upper Sacramento River system, as counted at Red Bluff Diversion Dam (RBDD), has decreased from an annual average of 15,055 fish from 1967 to 1971, to 850 fish from 1989 to 1993. This estimate includes adults that are naturally produced and those that are produced at the Coleman National Fish Hatchery that return to the upper Sacramento River system. The average steelhead return to Coleman National Fish Hatchery has decreased from an annual average of 3,498 fish from 1967 to 1971, to 979 fish from 1988 to 1992. Coleman National Fish Hatchery produces approximately 65 to 70% of the steelhead run to the upper Sacramento River (Reclamation 1985, Reynolds et al. 1990).

The Fish and Wildlife Plan (DFG 1965) estimated that spawning escapements of steelhead in the Feather and Yuba rivers were 2,500, and 500 fish, respectively. It is likely that both river systems supported large steelhead runs in the 1800s; however, hydraulic mining and diversion and storage dams on both rivers significantly reduced steelhead populations. For example, from 1910 to 1949, Daguerre Point Dam blocked upstream migration (Dunn et al. 1992). Limited information indicates that steelhead populations have increased on the Yuba River since the 1970 completion of New Bullards Bar Dam and Reservoir, which provided cool water during summer rearing. DFG introduced hatchery-raised steelhead juveniles to the Yuba River in most years from 1971 through 1983. Natural production of steelhead in the Feather River currently is limited to the production of yearlings in the low-flow section (Meyer 1992). Hatchery returns have increased from an annual average of 790 fish from 1967 to 1971, to 1,386 fish from 1988 to 1992.

The steelhead run in the American River is estimated to have exceeded 100,000 fish annually before completion of Folsom and Nimbus dams in 1955. By 1970, however, steelhead runs were estimated to average about 5,000 fish (Reynolds et al. 1993). The Fish and

Wildlife Plan (DFG 1965) estimated that the spawning escapement of steelhead on the American River was 2,500 fish. Recently, the number of adults returning to the Nimbus Fish Hatchery also has declined. Nearly all steelhead in the American River are hatchery produced, and many of the steelhead produced at Coleman National Fish Hatchery and Feather River Fish Hatchery stray and return to the American River and Nimbus Fish Hatchery.

Historical documentation shows that steelhead were widespread throughout the San Joaquin River system. Historical chinook salmon distribution in the San Joaquin system provides further indication of the extent of steelhead distribution. In many west coast drainages, streams supporting chinook salmon spawning and rearing also support steelhead populations and, in many cases, steelhead migrate higher in the watershed. If chinook salmon were able to access and utilize habitat in the mainstem San Joaquin River and its tributaries, it is likely that steelhead could as well.

Evidence indicates that remnant steelhead populations persist in tributaries of the San Joaquin River system. Recent documentation of juvenile rainbow trout exhibiting smolting characteristics from several biological surveys, angler information, and observations at Merced

River Hatchery provide substantial evidence of a small steelhead population in the San Joaquin River system.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Survival of steelhead in the Sacramento River system is affected by several factors, including water temperature, flows, barriers, spawning gravel quality, and fishing.

Habitat

Major dams have blocked access to most steelhead habitat in Central Valley rivers and streams; smaller dams also cause migration delays. Barriers at low elevations on all of the major tributaries have blocked access to an estimated 95% of historical spawning habitat in the Central Valley (Reynolds et al. 1993, Yoshiyama et al. 1996); therefore, steelhead are limited to spawning and rearing in habitats that are marginal, formerly utilized only as migration corridors. Loss of habitat attributable to blockage by dams is a primary cause of low abundance relative to historical levels.

Steelhead spawning, egg incubation, and fry emergence also are affected by flow conditions. Successful steelhead spawning requires an average water depth of approximately 14 inches and current velocities of approximately 2.0 feet per second (fps) (Barnhart 1986). In addition, flow conditions can significantly affect egg incubation and fry emergence. Eggs are most susceptible to mortality during the early stages of development. Flow conditions affect water temperature, oxygen level, and percolation rate around steelhead eggs incubating within their gravel redds. Sudden changes in conditions can increase mortality.

In conjunction with water temperature, flow is generally characterized as a major factor limiting steelhead abundance in the Sacramento River system during summer. Flows must be adequate to provide the physical habitat needed by steelhead fry and juveniles, as well as to support the aquatic insects and other invertebrates on which they feed. Bovee (1978) determined that depths of approximately 8 inches and velocities of approximately 0.6 fps are optimal. The existence of deep pools can be especially important in streams that are naturally or artificially subjected to low-flow conditions in summer and fall. Although in most streams critical limiting factors occur during summer, steelhead rear year round; therefore, suitable flows must be provided continuously.

Steelhead generally spawn in gravel that is 0.25 to 3.0 inches in diameter (Reynolds et al. 1993). Currently, natural production of steelhead in the mainstem Sacramento River is limited by the shortage of suitable gravel resulting from blockage and capture in upstream reservoirs (Reynolds et al. 1990).

Water Quality

The optimum water temperature for spawning is 46 to 52°F (Leidy and Li 1987); however, because spawning occurs from December through April, water temperature is not considered a limiting factor for steelhead spawning in most of the Sacramento River Basin. Low water temperature also is needed for egg incubation and fry and juvenile rearing in streams. The optimum water temperature for fry and juvenile rearing is 55 to 60°F (Leidy and Li 1987). Eggs are most susceptible to mortality during early development and sudden changes in water temperature can increase egg mortality. The actual effects of temperatures on abundance, however, are influenced by a number of factors, such as duration of exposure, acclimation, food availability, water quality, and coolwater refuges. Water temperature is considered the main factor currently limiting natural steelhead rearing in many Sacramento River Basin streams (Reynolds et al. 1993, California Resources Agency 1989).

Entrainment

Unscreened agricultural, municipal, and industrial diversions in the Delta and rivers cause entrainment losses of emigrating juvenile steelhead. The SWP Banks Pumping Plant and the CVP Tracy Pumping Plant have louver-type fish screens that may be 90% effective for preventing entrainment of downstream-migrating steelhead. Prescreening losses of 75% have been estimated at SWP pumping facilities, resulting from predation in Clifton Court Forebay, while losses at CVP facilities are approximately 15%. "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.

Movement

In general, steelhead are attracted to high, cold flows, which provide optimal migration opportunities. These flow conditions, along with unimpeded access during primary migration months, are necessary to ensure that steelhead reach optimal upstream spawning habitats. Throughout the Central Valley, a 95% reduction in availability of river habitat (Reynolds et al. 1993) has affected steelhead the most because steelhead used habitat in tributary streams above existing dams that block migration. The timing of downstream migration by juveniles is also affected by streamflow, temperature, barriers, and other factors. In addition, reverse flows in Delta channels caused by pumping operations may have adverse effects on steelhead similar to effects seen for chinook salmon (USFWS 1993).

Artificial Production

Over 90% of the adult steelhead (over 15 inches long) in the Central Valley are produced in hatcheries (Reynolds et al. 1990); therefore, the number and rate of survival to adulthood of hatchery-released steelhead has far more bearing on existing steelhead population abundance than does natural production. The survival rate of eggs, fry, and juveniles before release is much higher for hatchery-produced fish than for natural fish. To optimize survival rates, hatchery-produced steelhead are released during periods and at sites most conducive to survival. Release at sites distant from natal streams increases straying to other rivers.

Harvest

Adult and juvenile steelhead are heavily fished by sport anglers within the Central Valley watershed. Illegal fishing contributes to mortality from angling. There is no commercial or sport fishery for steelhead in the ocean and, for unknown reasons, steelhead are rarely taken by commercial or sport salmon trollers (Skinner 1962).

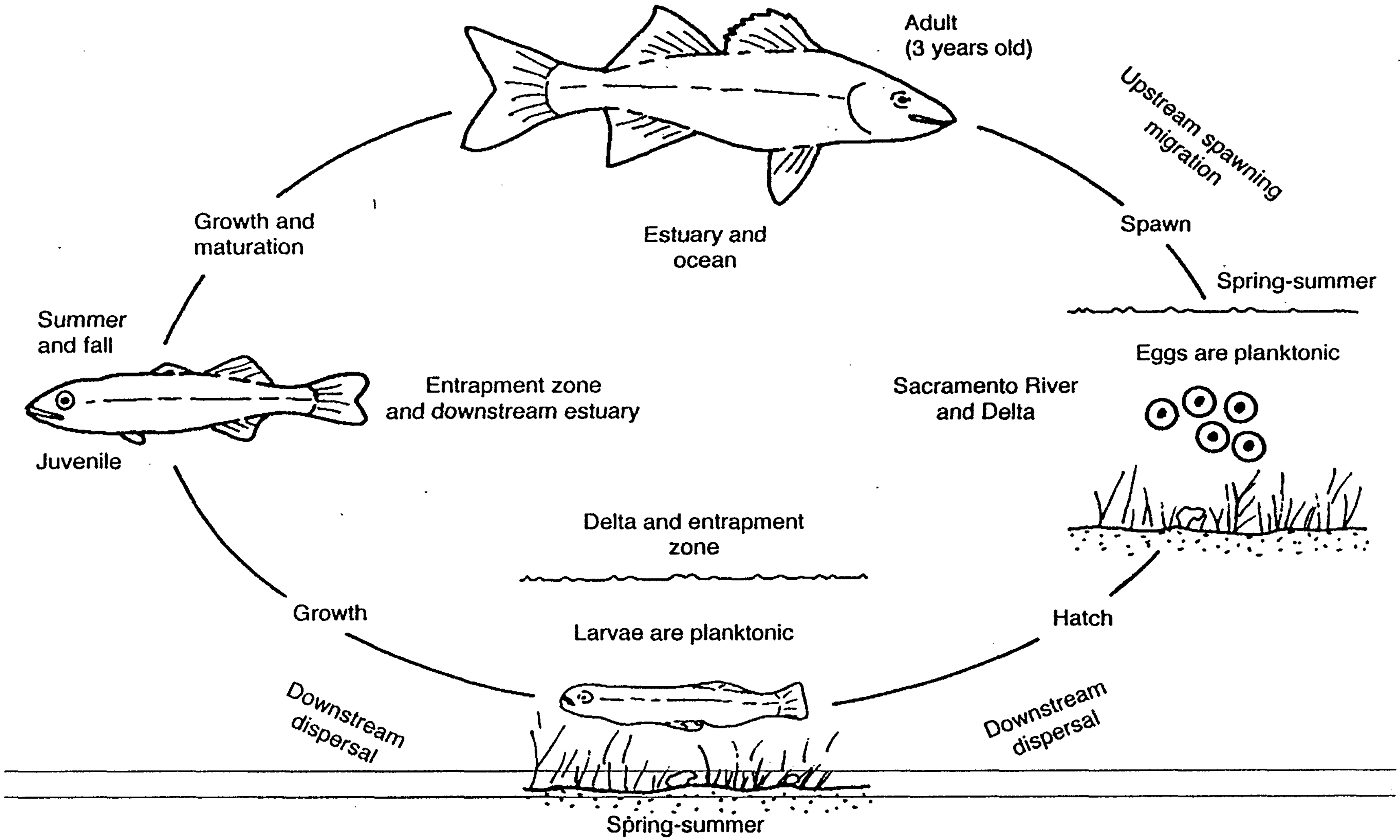

Figure 3. Life History of Striped Bass

STRIPED BASS

Striped bass (*Morone saxatilis*) are native to the Atlantic Coast and were introduced to the Delta around 1880. Striped bass are anadromous, spending part of their life in the Bay and ocean but spawning in freshwater.

LIFE HISTORY

In fall, adult striped bass migrate upstream to Suisun Bay and the Delta, where they overwinter (Chadwick 1967, Mitchell 1987). During spring, striped bass disperse throughout the Delta and into the tributary rivers to spawn (Figure 3 and Table S-4 in the Supplement). They migrate back to the Delta, Suisun Bay, and San Francisco Bay during summer. Since the mid-1960s, most striped bass have inhabited Suisun Bay and the Delta during summer and fall, and migrations to San Francisco Bay and the Pacific Ocean have declined.

Typically, male striped bass reach sexual maturity at 2 to 4 years and females at age 5 or over (Moyle 1976). Striped bass can live for more than 20 years (Moyle 1976). The majority of adult striped bass in the Delta are between 3 and 8 years old. Striped bass spawn in the Sacramento River between Sacramento and Colusa, and in the Delta in the San Joaquin River between Antioch and Venice Island. In wetter years, spawning also has been documented in the lower San Joaquin River above the Delta and farther upstream in the Sacramento River (Turner 1976).

The timing of striped bass spawning is related to water temperature and sometimes occurs later in the rivers (May to June) because of lower river-water temperature than that in the Delta (April and May). Egg production in females is high, with the number of eggs produced being a function of body size. (Turner 1976). Striped bass spawn in the water column and their eggs are planktonic, or free floating. Eggs are slightly denser than fresh water and are maintained in the water column by turbulence and current. As the eggs are transported downstream from the spawning areas, they slowly sink and are generally concentrated within a few meters of the bottom (Turner 1976, Wang 1986). The eggs hatch after approximately 2 days.

Approximately 40% of the striped bass population spawns in the Delta, generally in the lower San Joaquin River from Venice Island downstream to Antioch. 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 1987a). Striped bass generally return to the same spawning area each year, but regular occurrence of high salinity may gradually reduce the use of the lower San Joaquin River in the Delta as a spawning area because of the need for fresh water for spawning.

Initially, egg and larval striped bass are passive, relying on the currents to transport and disperse them to the lower, more productive areas of the Delta. Both larvae and juveniles accumulate in or upstream of the entrapment zone, the location where the fresh and saline waters mix and productivity is high (Fujimura 1991, Kimmerer 1992). In high-flow years, the entrapment zone is typically located in Suisun Bay, but in low-flow years, it is located in the Delta.

POPULATION TRENDS

Data from the sport fishery and mark-recapture studies indicate that the adult population declined from approximately 3 million striped bass in the early 1960s to 1.7 million in the early 1970s, to 1.1 million by 1980, and to 600,000 to 800,000 during the 1990s. A record low adult striped bass population of 604,000 fish was estimated in 1993. Surveys indicate that larval striped bass are also in decline (DFG 1987a). The estimated hatchery contribution to the total adult striped bass population increased from less than 1% in 1984 to 26% in 1993. The greater percentage contribution to the natural population is attributable to increased annual stocking of yearling hatchery fish and to the declining population of natural fish. Stocking levels were reduced in 1991 and in 1994; only an estimated 9% of the adult population consisted of hatchery fish.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Delta outflow and diversions are considered by DFG (1992a) to be the primary factors contributing to the continuing 30-year decline of striped bass in the Sacramento-San Joaquin estuary. The decline in juvenile striped bass abundance correlates significantly with numerous flow and diversion-related variables (Stevens et al. 1985, DFG 1992a). The mechanisms causing the population decline are unclear because the variables are highly interdependent, but it is clear that the decline of the striped bass population is closely associated with increased water development, particularly increased exports of water and entrainment of young fish from the Delta.

Habitat

In the Delta, less than 3% of the habitat remains in a state similar to that of 150 years ago (Herbold et al. 1992). Diking and filling have restricted striped bass habitat and reduced tidal mixing and overall estuary productivity. Most diking and filling in the estuary preceded the recent precipitous 30-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 continued population decline, restoration of diked and filled wetlands, with subsequent reconnection to the estuary, could provide additional habitat for striped bass and may increase overall productivity of the estuary.

Delta outflow partially determines suitable habitat area available for striped bass. Striped bass survival from egg or larvae to 38 millimeters (mm) long is higher at higher outflows as a result of increased nursery area, shallow habitat area, and food abundance (Herbold et al. 1992, DFG 1992a, and San Francisco Estuary Project 1993).

Water Quality

Survival of adult striped bass may be affected by toxic materials entering the Bay-Delta estuary from agricultural runoff, discharge of industrial and municipal waste, and runoff from non-point sources (stormwater runoff). Increased outflows can increase dilution of toxic materials (Herbold et al. 1992, DFG 1992a, and San Francisco Estuary Project 1993). Tissues from adult striped bass contain concentrations of toxic materials exceeding levels recommended for human consumption (Herbold et al. 1992). Although the dieoff has been less in recent years, 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). Livers from dead striped bass were found to be contaminated with higher concentrations of toxic materials than the livers of healthy fish taken from the Delta. The relatively high concentration of toxic materials may have contributed to factors that resulted in mortality. In addition, the number of viable eggs may be affected by contaminant levels in prespawning females, causing resorption of eggs or production of abnormal embryos (Brown 1987, DFG 1987a); however, recent analyses have not found strong associations between contaminant levels in prespawning females and egg resorption or abnormalities.

Survival of larval striped bass may be 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, thereby limiting chances for survival (Brown 1987). Contamination of the Sacramento River increased substantially in the mid-1970s when application of rice pesticides increased (Herbold et al. 1992). Discharge of contaminated rice-field water coincides with striped bass spawning and may affect survival of eggs and larvae. In recent years, loading of rice herbicides in the Sacramento River has been significantly reduced.

Entrainment

In addition to flow effects on survival, diversions from the Sacramento River and the Delta may entrain eggs and larvae and reduce riverflow. Diversions from the Sacramento River in the spawning reach between Sacramento and Colusa are relatively small; therefore, the entrainment effects of Sacramento River diversions on striped bass would also be expected to be relatively small, although they contribute to the cumulative effect of total diversions.

Losses to diversions depend on the timing, size, design, and location (geographically and position in the channel) of individual diversions relative to the seasonal abundance and distribution of striped bass. In the south Delta, SWP and CVP pumps export an average of approximately 5 MAF per year, or 21% of mean annual inflow. During dry years or dry periods of average flow years, SWP and CVP facilities export more than 60% of freshwater inflow. Losses of egg and larval striped bass could be most effectively minimized by curtailing Delta exports in May and June. Most agricultural diversion takes place in the interior Delta where there are generally fewer bass; therefore, the effect may be less than that of other diversions (Cannon 1982).

High adult abundance results from year-classes that are initially abundant and experience minimal losses during late-summer-through-winter 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). Millions of eggs, larvae, and juvenile striped bass (longer than 20 mm) are entrained in diversions at the SWP and CVP Delta pumping facilities each year. Most entrained bass are lost, although 5 to 30% of all juvenile bass entrained at SWP are salvaged and returned to the Delta alive (DFG 1992b). The proportion salvaged depends on screen efficiency (a function of screen design and pumping volume), fish size, predation rates, and handling and trucking mortality. The bulk of entrainment loss comprises early juvenile life stages (less than 38 mm long) and occurs from May through August. Substantial losses of young-of-year bass also have occurred between November and January and are a function of young bass distribution relative to the location of X2 and water export rates.

In the Delta, Delta outflow affects the position of X2 (a location of about 2 ppt estuarine salinity). The farther upstream X2 is located, the farther upstream spawning generally occurs. Eggs spawned in the Delta (in the lower San Joaquin River) are more vulnerable to entrainment in water exports from the south-Delta (DFG 1992a). Striped bass survival from egg or larvae to 38 mm long is higher at higher outflows as a result of reduced exposure to Delta diversions (Herbold et al. 1992, DFG 1992a, and San Francisco Estuary Project 1993).

Movement

Delta outflow affects the distribution of striped bass larvae. When outflow is high, larvae density is greatest in Suisun Bay; when outflow is low, larvae density is greatest in the Delta.

Striped bass survival is adversely affected by reduced Sacramento River flow (DFG 1992a). Reduced flow causes eggs and larvae to settle on the bottom and die; delayed movement to downstream nursery areas; increased exposure to toxic substances carried by the river; and an increased proportion of larvae drawn through the Delta Cross Channel (DCC) and Georgiana Slough into the central Delta, where they are exposed to diversions.

Species Interactions

The composition and abundance of larval striped bass prey have changed dramatically. The abundance of the copepod *Eurytemora*, the "preferred" prey of larval striped bass, has declined and been replaced by *Pseudodiaptomus* and *Sinocalanus*, both introduced species (Herbold et al. 1992). Although striped bass do not effectively feed on *Sinocalanus*, they do feed on *Pseudodiaptomus forbesi*, which is found in fresh water at concentrations greater than those of *Eurytemora* (Interagency Ecological Studies Program 1994). Striped bass mortality is negatively correlated with prey density (Herbold et al. 1992); therefore, relatively low prey densities in the Bay-Delta estuary may result in slower striped bass larval growth rates and, consequently, increased mortality from predation. However, prey densities have historically been lower in the Delta than appears necessary for optimum striped bass growth; therefore, changes in prey species probably have not contributed significantly to the recent precipitous decline in striped bass abundance.

In addition, Delta outflow affects predation and intraspecific competition. Striped bass survival from egg or larvae to 1.5 inches long is higher at higher outflows, possibly as a result of reduced predation and intraspecific competition (Herbold et al. 1992, DFG 1992a, and San Francisco Estuary Project 1993). High outflows increase turbidity, which makes predation on striped bass eggs and larvae more difficult. High outflows also increase dispersion of eggs and larvae, which reduces intraspecific competition.

Introduction of non-native organisms has substantially altered the biological structure of the estuary. Non-native organisms may affect striped bass through competition, predation, and change in trophic dynamics or the availability of prey. Although many introduced fish and invertebrate species have become abundant (Brown 1992), the effect on striped bass survival is unknown.

Artificial Production

More than 3 million juvenile striped bass were released into the Bay-Delta estuary in 1990. Release of hatchery juveniles could have a detrimental effect on the natural juvenile population when habitat and food resources are limited. To minimize potential impacts, the recent practice has been to stock yearlings in San Pablo Bay downstream of the primary nursery area of naturally produced fish. The release of hatchery-reared juvenile striped bass was discontinued by the DFG after 1991 as part of an effort to avoid the risk of adverse effects on winter-run chinook salmon (Ford pers. comm.). In 1992, low numbers (32,000) of juvenile striped bass were released to the Bay-Delta estuary as part of an experimental net pen-rearing project. Since that time, the DFG has expanded the stocking of artificially reared bass. In 1997, 113,000 juvenile striped bass are being released.

Harvest

The recent (1988 to 1992) annual catch of striped bass is approximately 85,000 fish (approximately 9 to 14% of the adult population) (DFG 1992a). In addition, illegal harvesting may kill thousands of juvenile striped bass each year (Brown 1987). 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). More stringent sport fishing regulations and stricter enforcement could reduce adult mortality and increase egg production.

CHINOOK SALMON

Four runs of chinook salmon (fall, late-fall, winter, and spring) occur in the Sacramento and San Joaquin River systems. Because of the overlap in run timing, spawning periods, and early life-history phases, the upper Sacramento River supports all freshwater life stages of this species during all months. The San Joaquin River and its tributaries support fall-run chinook salmon. (Detailed information is provided in Tables S-5 to S-8 in the Supplement.)

LIFE HISTORY

Chinook salmon require cold, freshwater streams with suitable gravel for reproduction. Females deposit their eggs in nests, which they excavate in the gravel bottom in areas of relatively swift water (Figure 4). The eggs are fertilized by one or more males. Eggs generally hatch in approximately 6 to 9 weeks, and newly emerged larvae remain in the gravel for another 2 to 4 weeks until the yolk is absorbed. Maximum survival of incubating eggs and larvae occurs at water temperatures between 41 and 56°F. After emerging, chinook salmon fry tend to seek shallow, nearshore habitat with slow 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. Juveniles typically rear in freshwater for 2 to 3 months before migrating to sea. They spend 2 to 4 years maturing in the ocean before returning to their natal streams to spawn. Most chinook salmon in the Sacramento and San Joaquin River system mature at 2 and 3 years. All die after spawning.

POPULATION TRENDS

Fall-Run Chinook Salmon

In the mainstem Sacramento River, fall-run chinook salmon have gradually declined in abundance since the 1950s and 1960s when annual escapement (the number of adults returning from the ocean to spawn in river habitat) averaged 179,000 adults. A decline during the recent drought led to a record low spawning escapement of approximately 29,000 adults in the mainstem river in 1991. Spawning escapement in tributaries to the Sacramento River has generally been stable or even increased as a result of stocking of hatchery fish.

In the San Joaquin River system, abundance of fall-run chinook salmon has been seriously reduced with sequential water development in the tributaries and the Delta since the 1940s. The closure of Friant Dam on the mainstem San Joaquin River in 1949 eliminated spring- and fall-run chinook salmon from the upper river. The fall run has persisted in small but widely fluctuating populations below major dams on the eastside tributary streams and the Merced, Tuolumne, and Stanislaus rivers. Populations generally increase to near optimum production levels in response to infrequent high-runoff conditions when reservoir storage capacities are exceeded and natural unimpaired conditions are approximated in the tributaries, mainstem river, and through the Delta. Very low spawning escapements since 1990 are related to recent drought conditions (1987 to 1992). The hatchery contribution to San Joaquin River chinook salmon stocks (Merced River Hatchery) is less than 5% (DFG 1987b).

Winter-Run Chinook Salmon

Recent DFG research in the California State Archives indicates that the winter-run chinook salmon populations historically may have numbered more than 200,000 fish (Fox and Rectenwald pers. comms.). Coldwater releases from Shasta Reservoir enabled the run to spawn successfully in the Sacramento River after construction of Keswick and Shasta dams blocked access to historical spawning habitat. Under these favorable habitat conditions, the run was maintained at more than 80,000 adults through the 1960s (Reclamation 1986a); however, winter-run chinook salmon suffered a precipitous decline to an estimated run size of 191 in 1991. Since then, run sizes have not been greater than 2,000 fish. Factors contributing to the decline include water temperature impacts associated with reservoir operation, adult and juvenile passage problems at the RBDD, modification and loss of spawning and rearing habitats, predation, pollution, and entrainment in water diversions on the Sacramento River and in the Delta. The recent drought in California

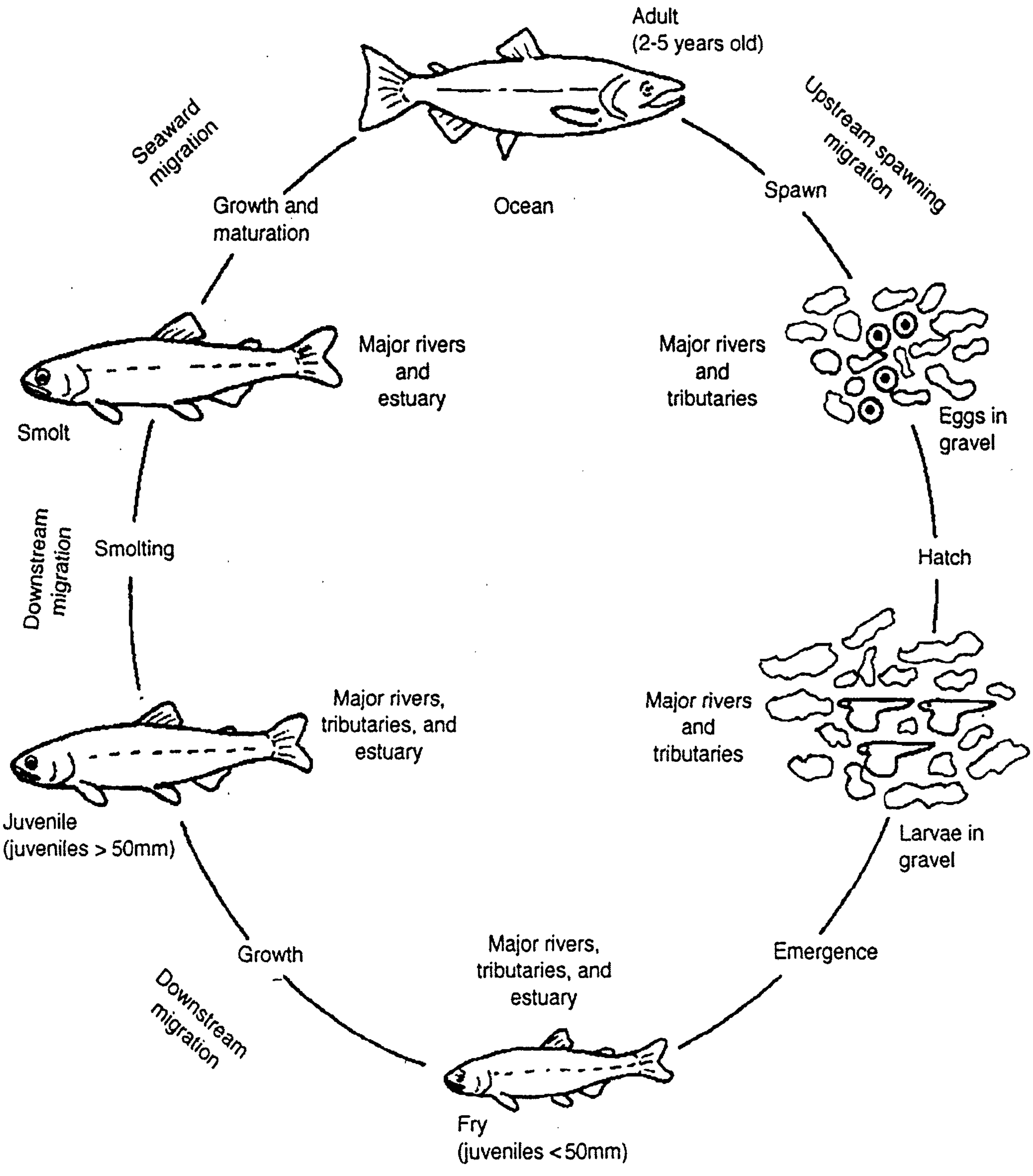

Figure 4. Life History of Chinook Salmon

(1987 to 1992) exacerbated these impacts (NMFS 1992).

The return of only 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. The 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 ESA (NMFS 1992).

Spring-Run Chinook Salmon

Historically, spring-run chinook salmon was the most abundant salmon race in the Central Valley. Gold mining, agricultural diversions, logging, and overharvesting caused the first major declines in spring-run chinook populations. By 1930, agricultural and sediment-control dams on tributary streams resulted in severe declines and extirpation of tributary stocks by preventing spring-run adults from reaching critical summer holding and spawning habitat. Further extirpations followed construction of major storage reservoirs on the Sacramento and San Joaquin rivers and major tributaries in the 1940s and 1950s. By 1966, only remnant populations of spring-run chinook salmon were present below these dams. The number of adults passing RBDD has fluctuated between highs of more than 25,000 fish to a record low of 773 fish in 1991. An average of approximately 11,000 fish migrated past the dam between 1967 and 1994.

Considerable overlap in the spawning period with fall-run on the mainstem Sacramento River and major tributaries has probably resulted in significant introgression (the loss of genetic purity) of spring-run stocks (Slater 1963). Genetically pure stocks occur in two minor Sacramento River tributaries, Mill and Deer creeks, and possibly in Big Chico and Butte creeks.

Late-Fall-Run Chinook Salmon

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

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Habitat

Major dams have blocked upstream access to most chinook salmon habitat in Central Valley rivers and streams, and smaller dams contribute to migration delay; therefore, chinook salmon may be limited to rearing in habitats that are marginal. Loss of habitat attributable to blockage by dams is a primary cause of low abundance relative to historical levels.

Riparian vegetation performs a variety of 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 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 (from fallen trees) to the stream, which provides important instream cover and contributes to channel and habitat diversity. Riparian vegetation has been significantly reduced along much of the

Sacramento and San Joaquin rivers and major tributaries as a result of agricultural conversion, urbanization, timber and fuel harvesting, channelization, levee construction, streambank protection, and streamflow regulation.

Shaded riverine aquatic (SRA) habitat is of greatest concern because of the unique fishery values associated with this habitat type and substantial losses of SRA habitat already have occurred. Replacement of naturally eroding banks with rock revetment has been shown to reduce densities of juvenile chinook salmon locally; chinook salmon densities in undisturbed areas are typically 4 to 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. These structures also reduce gravel recruitment into affected reaches and degrade spawning and rearing habitat.

In addition, streamflow influences the quantity, quality, and distribution of chinook salmon spawning habitat. Streamflow directly affects the amount of available spawning habitat by determining the stream area with appropriate combinations of water depths; velocities; and streambed characteristics such as substrate composition. Indirect effects of flow on spawning habitat include effects on water quality, such as water temperature, which can influence the longitudinal extent and seasonal availability of suitable spawning habitat; flow reductions during the incubation period that cause inadequate intragravel flow and dewatering; and flushing flows that remove harmful quantities of sediment and plant growths from the spawning gravels.

During chinook salmon rearing, streamflow directly determines the amount of physical habitat with appropriate combinations of depth, velocity, substrate, and cover. Streamflow also influences water quality and habitat necessary for production of aquatic invertebrates, a major food source for juvenile salmonids in fresh water. 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.

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 nonquantified, water quality impacts on chinook salmon populations in the Sacramento and San Joaquin rivers and tributaries include effects related to elevated stream temperatures; heavy metal pollution; high suspended-sediment levels; and elevated nutrient, herbicide, and pesticide levels from agricultural drainage.

Mature female chinook salmon exposed to water temperatures above 60°F or below 38°F for prolonged periods experience poor survival and produce less viable eggs than females subjected to lower water temperature (Hinze 1959). Water temperatures also limit the geographic range where chinook salmon can successfully spawn.

Appropriate water temperature for egg incubation and emergence is a critical concern for Sacramento and San Joaquin River chinook salmon. Maximum survival of incubating eggs and yolk-sac larvae occurs at water temperatures between 41 and 56°F. Juvenile chinook salmon might tolerate water temperatures from 32 to 75°F, but the optimal range for survival and growth (provided an adequate food supply exists) ranges from 53 to 64°F (Raleigh et al. 1986). 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.

Entrainment

Water diversions reduce survival of emigrating juvenile salmonids through direct losses at unscreened or inadequately screened diversions and indirect losses associated with reduced streamflows. Diversion impacts on chinook salmon populations depend on diversion timing and magnitude, river discharge, species (race), life stage, and other factors. Fall-run chinook salmon juveniles are particularly vulnerable to diversion-related mortality because the fall-run smolt emigration period (April to June) generally coincides with the onset of the irrigation season (April to October). Chinook salmon losses are decreased 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 beginning of the irrigation season (April and May) and the latter part of the irrigation season (September and October), after which diversions are negligible.

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.

The SWP (Banks) and CVP (Tracy) export facilities in the south Delta entrain thousands of juvenile chinook salmon annually (DFG 1987c). Unscreened Delta agricultural diversions also contribute to fish losses.

Movement

Reservoir operations have altered the natural flow regime of Central Valley streams by changing the frequency, magnitude, and timing of flow. Seasonal increases in streamflow provide an important migration cue for adult chinook salmon. Higher flows and associated lower water temperatures in fall stimulate upstream migration of fall-run chinook salmon. Conversely, low flows and higher water temperatures can inhibit or delay migration to spawning areas. Water temperatures during upstream migration usually range from 51 to 67°F (Bell 1973). Extremely low or high flows can block or delay migration to spawning areas by preventing passage over shallow riffles or creating excessive water velocities.

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 by reducing the proportion of flow diverted, and maintaining favorable water quality conditions. High flows during the early rearing period result in downstream displacement or active migration of large numbers of fry. Under low-flow conditions, most of the fry remain in upstream rearing areas and emigrate during the normal smolt emigration period.

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 found in the bypasses during major winter floods, survival rates associated with these migration routes are unknown. Juvenile salmon suffer mortality attributable to predation and stranding. Adult salmon entering the bypasses during their upstream migration may be delayed or blocked by control structures in the bypass channels. Efforts have been made by the DFG to alleviate passage problems by installing or upgrading fish ladders at known obstructions to allow the fish to escape before dewatering.

Fall-run salmon smolts diverted from the Sacramento River into the central Delta through the DCC or Georgiana Slough have much higher mortality rates (50%) than smolts that remain in the Sacramento River. 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. Other factors, such as inflow, tides, and exports, also may influence survival.

Extensive export pumping and diversion cause movement of Sacramento River water into the central and south Delta and may increase the number of adult salmon reaching the Sacramento River through the Mokelumne River and the DCC or Georgiana Slough. 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.

Diversion dams are a major impediment to upstream migration of adult salmon. Vogel et al. (1988) concluded that adult salmon passage problems at RBDD were caused primarily by insufficient attraction flows in the fish ladders, operation and maintenance problems, and improper configuration of the fish-ladder entrances. Fall-run and late-fall-run chinook salmon are probably most susceptible 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 RBDD frequently exceed tolerance levels for eggs and fry during the summer incubation period (Hallock and Fisher 1985).

Species Interactions

Predation on emigrating salmonids is probably of minor significance in unobstructed portions of the Sacramento River system; however, predator efficiency increases at human-made structures, such as RBDD and Clifton Court Forebay, and impoundments where fish are concentrated, stressed, or delayed in their downstream migration (Reclamation 1983b). Abandoned gravel-mining pits also create habitat for predators.

Artificial Production

Hatchery production and planting practices significantly affect the abundance and distribution of salmon in the Sacramento River system. Hatchery production makes up 70 to 80% of the total ocean catch and returns to some of the major rivers in the Sacramento Basin. The release of smolts in the estuary and even in San Francisco Bay has greatly improved survival; however, fish released away from the hatchery have a higher tendency to stray on return than fish released directly from the hatchery (Cramer et al. 1990). Releasing smolts at a larger size also has tended to increase survival.

The release of large numbers of hatchery fish can threaten natural fish populations. Potential adverse impacts include direct competition for food and other resources between natural and hatchery fish, predation of hatchery fish on natural fish, genetic dilution of natural fish stocks by hatchery fish that return to spawn naturally, and increasing fishing pressure on natural stocks resulting from hatchery production. Because of the increased survival from eggs to smolts under hatchery conditions, fewer adults are needed to maintain a hatchery run. In a mixed-stock fishery of hatchery and natural fish, a harvest rate based on the relatively stable production of hatchery fish will tend to over-harvest natural fish, especially during years when natural production is low (Hilborn 1992). Management options are available to protect natural stocks, such as tagging and fin clipping all hatchery fish and restricting harvest to these marked fish.

Harvest

Total annual commercial and sport landings from 1967 to 1995 ranged from 237,000 pounds in 1992 to 1,488,000 pounds in 1988 and averaged 683,000 pounds (Pacific Fishery Management Council 1996). Since 1988, total landings have generally decreased; however, in 1995, there were near-record landings of 1,026,000 pounds. Ocean commercial and sport fishing, inriver sport fishing, and illegal harvest probably are significant factors affecting the abundance and distribution of chinook salmon. 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).

WHITE AND GREEN STURGEON

White sturgeon are long lived and mature some time after 10 years. Their longevity allows them to reach large sizes, reportedly weighing as many as 1,300 pounds at more than 100 years of age. The California sport fishing record is a 468-pound fish that was probably 40-50 years old when caught in the mid-1980s. Most females spawn for the first time at approximately age 15 and may spawn as infrequently as every 5 years thereafter (Kohlhorst et al. 1991).

Green sturgeon are found in large rivers in the Sacramento-San Joaquin River Basin, and the Eel, Mad, Klamath, and Smith Rivers (Moyle 1976). Green sturgeon are a minor component of the sturgeon populations in the Central Valley; ratios of adult green sturgeon to white sturgeon during tagging studies in the Delta have ranged from 1:39 to 1:164 (Mills and Fisher 1993).

LIFE HISTORY

Upstream spawning migration of white sturgeon in the Sacramento-San Joaquin River system occurs between November and May, and spawning occurs from February to May (Miller 1972a, Kohlhorst 1976, and Kohlhorst et al. 1991) (Figure 5 and Table S-9 in the Supplement). Only a portion of the total adult sturgeon population migrates upstream from the Delta each year. Sturgeon that do move upstream are believed to be mature and ready to spawn. Few observations of sturgeon spawning in the wild have been reported but, apparently, sturgeon spawn in swift water. The current initially disperses the adhesive eggs, which sink and adhere to gravel and rock on the bottom of the river. Because of the adhesive nature of sturgeon eggs, areas of silt-free gravel appear to be needed for successful spawning. Egg incubation lasts 4 to 14 days; yolk depletion occurs 15 to 30 days after fertilization (Wang et al. 1985, Conte et al. 1988). Optimum temperatures for incubation and hatching range from 52 to 63°F; higher temperatures result in greater mortality and premature hatching (Wang et al. 1985, 1987).

After hatching, yolk-sac larvae swim up into the water column. The currents act as a dispersal mechanism, transporting larvae downstream of the spawning area. Juvenile sturgeon rear in fresh or slightly brackish waters for some period of time, dispersing downstream with the river currents. When Sacramento River flows are high, larvae are found in the Delta and Suisun Bay. Subadults commonly rear in river sloughs, estuaries, or bays during summer and can move into deeper freshwater areas upstream, into the marine environment, or remain in the estuary in fall and winter. The proportion of sturgeon that use the marine environments is unknown, but tagging studies have demonstrated that some adults migrate north along the coast (Kohlhorst et al. 1991).

Young Sacramento River white sturgeon had low survival in 10 to 16 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 to 83 days after hatching) (Brannon et al. 1985). Acclimation of larger fish improved tolerance to 15 ppt.

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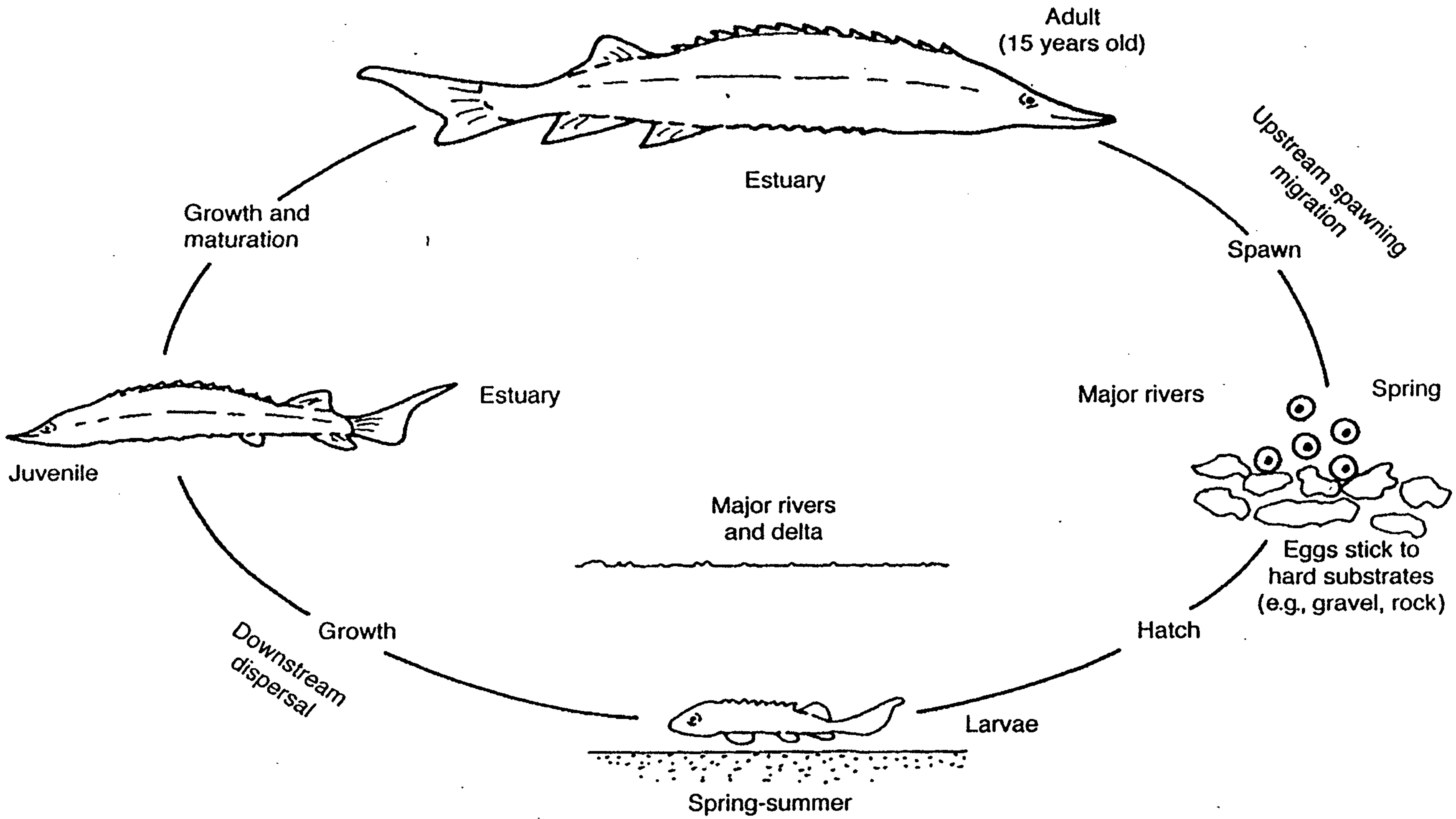

Figure 5. Life History of White Sturgeon

The diet of 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 *(Neomysis mercedis)* and amphipods, such as *Corophium* spp. (Radtke 1966). The introduced Asian clam commonly is found in sturgeon stomachs and may be an important component of white sturgeon diet. Little information is available about green sturgeon age and growth; those from the Delta seldom grow over 4 feet long (Skinner 1962, Moyle 1976).

Green sturgeon spend less time in estuaries and freshwater than do white sturgeon and also make extensive ocean migrations; consequently, most recoveries of tagged individuals originating from San Pablo Bay have come from the ocean and from rivers and estuaries in Oregon and Washington. Juveniles inhabit the estuary until they are approximately 4 to 6 years old, when they migrate to the ocean. (Kohlhorst et al. 1991.)

POPULATION TRENDS

Population estimates and trends in abundance of white sturgeon in the Sacramento-San Joaquin River system have been conducted intermittently since 1954 (Pycha 1956; Miller 1972a; Kohlhorst 1979, 1980; and Kohlhorst et al. 1991). The estimates relied on the recovery of tagged adult sturgeon and catch statistics from the sport fishery (fish longer than 40 inches). The first population estimate available for white sturgeon in the Sacramento-San Joaquin River system was reported for 1954 as 11,540 adults in San Pablo Bay. Population estimates made by Miller (1972a) for 1967 were much higher (114,667) than the 1954 estimates. Population estimates reached a high of 117,600 in 1984 but declined to 26,800 by 1990. In 1994, the population of fish over 40 inches long was estimated at 26,000.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Water Quality

The influence of water pollution and temperature on sturgeon is not well documented. Sturgeon tissue has been found to contain PCBs, organochlorides, mercury, selenium, and dioxins (Pacific States Marine Fisheries Commission 1992). Egg tissues also can contain toxins, which could reduce reproductive potential (Doroshov 1990). Turbidity can affect the adhesiveness of eggs and could displace eggs to less-than-optimum habitats during incubation. Chapman (1989) found that temperature did affect sperm production and hypothesized that it also most likely affected egg production. Although it has not been shown in the literature for the Sacramento-San Joaquin River system, water temperature conditions may initiate upstream migration and spawning in some populations. Sturgeon in the Sacramento River migrate at temperatures as low as 46°F (Kohlhorst 1976).

Sturgeon in the Sacramento-San Joaquin River system spawn within temperature ranges of 46 to 64°F, with most fish spawning when water temperatures are 58°F (Kohlhorst 1976). Optimum temperatures for white sturgeon incubation and larval development range between 52 and 63°F (Wang et al. 1987). Temperatures above 63°F may be detrimental to sturgeon egg survival (Doroshov 1990). Under laboratory conditions, maximum growth occurs at rearing temperatures of 68°F, but rearing at lower temperatures (61 to 65°F) reduces the incidence of disease (Cech et al. 1984, Conte et al. 1988).

Entrainment Relationships

Larval and juvenile sturgeon are weak swimmers; they are transported downstream primarily by the currents. They may be susceptible to entrainment and impingement on fish screens associated with water diversion projects in the Sacramento River and Delta; however, sturgeon are bottom oriented, reducing exposure to diversions.

The magnitude of entrainment losses and the effects on population abundance are unknown. Fish screen designs are important, however, to successfully pass juvenile sturgeon at diversions and prevent their impingement on the screens.

Movement Relationships

White sturgeon eggs have been found in water column velocities as high as 10 fps (Parsley pers. comm.), and data suggest that flow velocity may be a factor that triggers spawning in female sturgeon (Schaffter 1990). Riverflow acts to disperse and prevent clumping of the adhesive eggs. High riverflow also may attract adult sturgeon to upstream spawning areas. Kohlhorst et al. (1991) found a significant positive correlation between a year-class strength index and Sacramento River outflow in spring and early summer (April to July). Sturgeon are bottom-oriented fish with limited jumping abilities and have little success passing barriers along the channel bottom. Little information is available concerning the abilities of white sturgeon to negotiate upstream passage barriers. Warren and Beckman (1991) reported that modified fish ladders in the Columbia River with orifices through the weirs at the ladder floor increased passage of white sturgeon over several Columbia River dams.

Harvest

Annual sport harvest rates of white sturgeon in the Sacramento-San Joaquin River system increased substantially in the 1980s as a result of increased popularity of the fishery, the discovery of appropriate bait, and the use of more sophisticated means of locating and landing sturgeon. In the 1980s, the exploitation rate increased by 40% (Kohlhorst et al. 1991) and patterns in the size of landed sturgeon indicated that recruitment of fish to harvestable size declined during this period (Pacific States Marine Fisheries Commission 1992). In response, new size limits were imposed in 1990, resulting in a dramatically reduced harvest rate.

AMERICAN SHAD

American shad (*Alosa sapidissima*) become sexually mature while in the ocean at an average age of 3 to 5 years and a weight of 3 to 4 pounds (Painter et al. 1980). 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 population, have an anadromous life cycle.

LIFE HISTORY

Adult American shad begin their spawning migration as early as February; however, most adults do not initiate migration into the Delta until March or early April (Skinner 1962) (Figure 6 and Table S-10 in the Supplement). Typically, migration occurs from March through May through the Sacramento-San Joaquin estuary (Painter et al. 1980). The 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°F. Peak migration into spawning habitats occurs when water temperatures are 59 to 68°F, usually in late May or early June (Moyle 1976).

Shad typically spawn over sand and gravel substrates in depths of 3 to 30 feet (Painter et al. 1980). Their 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 to 6 days at water temperatures of 74 and 57°F, respectively (Stevens 1972). Although hatching occurs sooner at higher water temperatures, egg survival is reduced (MacKenzie et al. 1985).

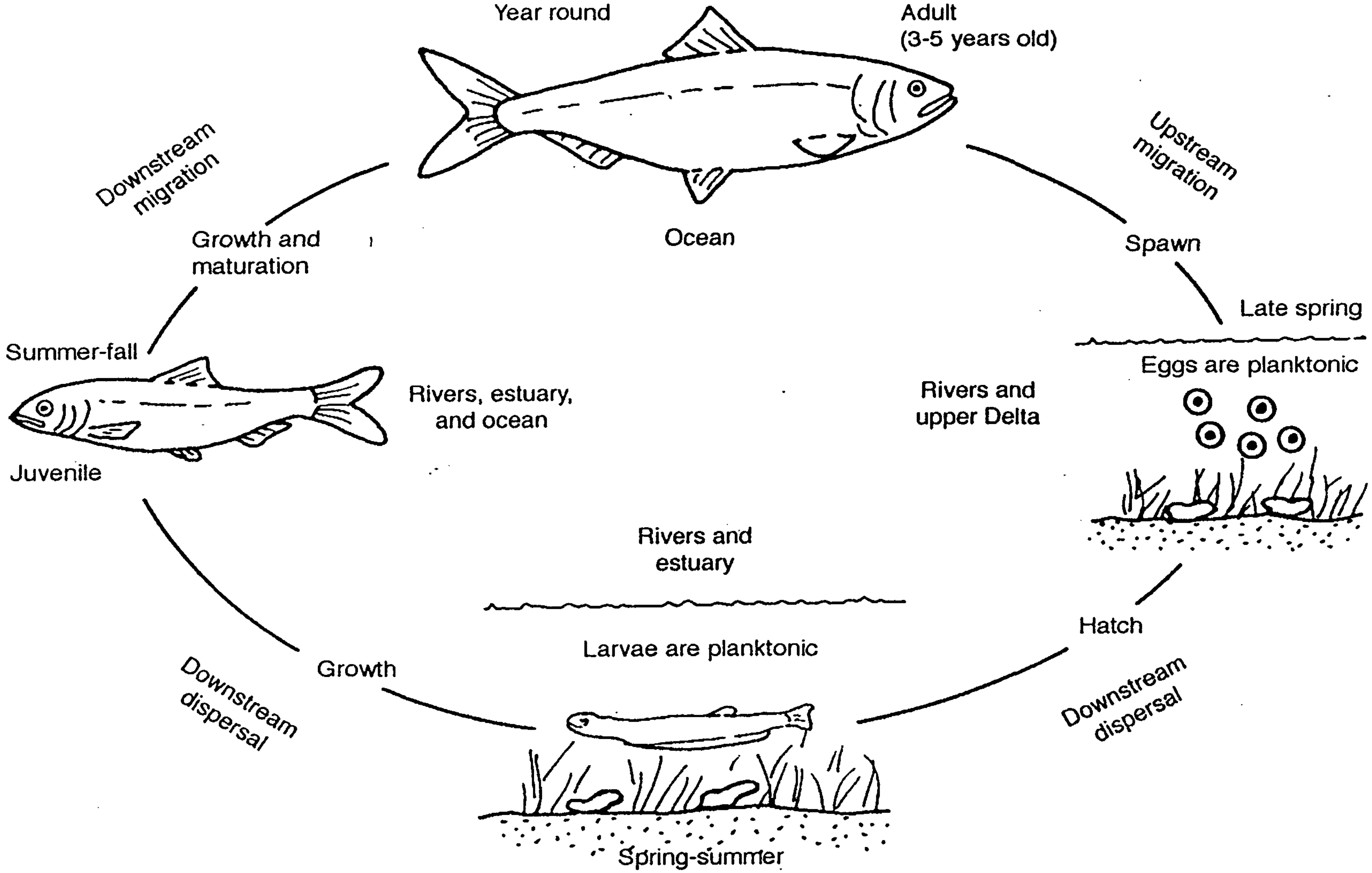

Figure 6. Life History of American Shad

The newly hatched pelagic larvae are most abundant at the water surface and feed on zooplankton within 4 to 5 days of hatching(Painter et al. 1980, Wang 1986). Although larval shad initially prey predominantly on zooplankton, including cladocerans and ostracods, they increasingly feed on insects, insect larvae, and copepods as they grow. Shad larvae usually consume whatever food items are most readily available (Painter et al. 1980). Growth is rapid, and the larval stages last approximately 4 to 6 weeks. By the time they enter saltwater, shad juveniles range from 3 to 7 inches long.

While in the Delta, juvenile shad are opportunistic feeders and prey on *Neomysis* spp., copepods, amphipods, chironomid midge larvae, and surface insects (Moyle 1976). Some juvenile shad apparently remain in the Delta for 1 year or more before emigrating to the ocean. Seaward migration of juvenile shad through the Delta begins in late June and continues through November, peaking between September and November (Stevens 1972, Painter et al. 1980).

POPULATION TRENDS

American shad are native to the east coast of the United States. Juvenile shad were transported from New York to 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). A commercial fishery for shad developed by 1879; by 1886, the State Board of Fish Commissioners estimated that 1 million mature fish were taken (Skinner 1962). The commercial gill net fishery in the Sacramento-San Joaquin estuary was eliminated through legislation in 1957 (Skinner 1962).

In 1976 and 1977, DFG estimated the shad population at 3.04 million adults and 2.79 million adults, respectively. DFG further estimated that these population numbers are approximately 33 to 50% of the number present during 1917, based on commercial catch data. (DFG 1987d.)

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Habitat

Dams have restricted access of adult shad 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 aquatic habitat in the Delta. 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.

Water Quality

The timing of spawning migrations correlates 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). Additionally, water temperatures exceeding 68°F are known to increase mortality among post-spawning adults (Moyle 1976). The initiation of spawning also correlates with water temperatures; spawning is generally delayed until water temperatures exceed 60°F.

The survival of shad eggs and larvae also is closely related to water temperature. Exceedingly low water temperature (less than 52°F) can reduce hatching success (Stier and Crance 1985). Similarly, exceedingly high water temperatures (greater than 80°F) can be unsuitable not only for hatching but also for the eventual development of larvae (Stier and Crance 1985). Less-than-optimal water temperature may cause poor development, reduced growth rates, and increased mortality of developing larvae.

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 such as urban stormwater runoff. In the Delta, pollutants of particular concern are trace elements, such as 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 toxicants on adult shad may be similar to effects on other Delta fish species, such as effects described for striped bass. Because American shad spend most of their lives in the ocean, they are undoubtedly less exposed to toxic materials than species spending much of their life in the estuary.

Entrainment

Entrainment losses depend on the timing, size, and location of individual diversions relative to the seasonal abundance and distribution of American shad. Entrainment of juvenile shad occurs primarily during outmigration in fall months. Losses of larval shad in the Delta could be most effectively minimized by reducing diversions and exports from July through November.

Thousands of American shad are salvaged annually by SWP and CVP fish protection facilities, and thousands more are lost to these and other diversions. Entrainment losses, including predation, handling, and trucking mortality, have not been quantified. Salvaged American shad suffer mortality rates in excess of 50% during summer, with slightly lower mortality rates during the cooler fall (DFG 1987d).

Movement

Although shad on the east coast exhibit a tendency to spawn in their natal streams, river flow appears to be largely responsible for the distribution of first-time spawners in the Sacramento River system (Painter et al. 1980). Adult passage into tributary streams is also important 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 riffle habitats and cause shad to spawn where habitat or environmental conditions are less favorable, reducing reproductive success. It is unclear whether survival of shad spawned in the major tributaries is greater than that of shad spawned in the Sacramento River.

It is unknown whether young-of-the-year abundance is a function of the distribution of flows (and therefore spawners) or increased flows in general. Young-of-the-year shad abundance appears to be positively correlated with flow during the primary spawning months (April to June) (Painter 1979). Low flows could reduce shad abundance because eggs and larvae are more likely to settle to the river bottom and die; survival of eggs and larvae is reduced from higher water temperatures; eggs and larvae are more susceptible to exposure to toxic substances in the rivers and Delta; a lower proportion of larvae are carried to the Delta; and a higher proportion of larvae are drawn into the central and south Delta, where vulnerability to entrainment in diversions is greater.

American shad have a wide range of salinity tolerances; however, studies suggest that adults require 2 to 3 days to adapt to fresh water (Stier and Crance 1985). Upstream water storage projects, diversions, and Delta export pumping have reduced and modified Delta outflows and altered salinity distribution in Suisun Marsh, Suisun Bay, and the lower Delta; consequently, changing salinity in the estuary may influence migrating adult shad and Delta spawning and rearing.

Harvest

Currently, shad are harvested only by sport anglers. Angler surveys in 1977 and 1978 determined that sport anglers harvested 79,000 and 140,000 shad, respectively (DFG 1987d). The present sport harvest limit is 25 shad per angler (DFG 1997). Although typical shad anglers practice catch and release, many anglers keep their limits on consecutive days during the peak of the spawning runs. There is some concern that sport fishing take may directly or indirectly affect population levels in subsequent years.

DELTA SMELT

Delta smelt (*Hypomesus transpacificus*) are found mainly in the waters of the Delta and Suisun Bay. Delta smelt are small (usually less than 3.5 inches long) plankton-feeding fish that live for only 1 year. They have no direct commercial value but may have been one of the most historically abundant fish species in the Delta and are potentially important prey for valuable predator species, such as striped bass. (Table S-11 in the Supplement provides detailed geographic and occurrence information.)

LIFE HISTORY

Delta smelt begin to mature in fall, 7 to 9 months after hatching. Prespawning adults are found near the entrapment zone in Suisun Bay or in the Delta as early as September. During the months preceding spawning, the smelt grow little in length because they allocate most growth energy to gonadal development. Smelt that survive to spawn a second year may grow to be as large as 5 inches long, but most die during or shortly after their first spawning season.

Delta smelt adults and older juveniles live principally in shallow water or near the surface in deeper water, where they feed on zooplankton, particularly copepods (*Eurytemora affinis*, *Pseudodiaptomus forbesi*, and others) (Moyle et al. 1992). Mysids (*Neomysis mercedis*), cladocerans, and amphipods may be important food items, depending on prey availability and the size of the smelt.

Delta smelt disperse in the Delta during spawning migrations. The spawning distribution is probably related to the salinity gradient. In most years, smelt spawn primarily in the upper end of Suisun Bay, in Montezuma Slough, and in the lower and central Delta. In the Delta, they spawn mostly in the Sacramento River channel and adjacent sloughs (59 FR 852, January 6, 1994). Delta smelt generally spawn in fresh water (Wang 1991). Spawning is believed to take place primarily in shallow edgewaters and river areas under tidal influence with moderate-to-fast velocities (Wang 1991, DWR and Reclamation 1993). The eggs are adhesive and are probably deposited on rocks or aquatic plants (Figure 7). Delta smelt typically spawn from February through May. A female deposits approximately 1,200 to 2,600 eggs at one time (Moyle et al. 1992); fecundity is low compared to that of most fish species.

Delta smelt eggs sink toward the bottom and adhere to any available hard substrate (Figure 7). The eggs hatch in 9 to 14 days at 63°F and the larvae begin feeding 4 to 5 days after hatching (DWR and Reclamation 1993). Larvae abundance generally peaks during March, April, or May (DFG 1992a), although earlier peaks may occur in years with early freshwater outflow events (Baxter pers. comm.). In the Delta, the larvae are presumably transported downstream during a brief period of buoyancy. Unfortunately, little is known about how the larvae are distributed in the water column at different stages of development.

The entrapment zone, or the area just upstream of it, is the principal habitat of delta smelt larvae and young juveniles, where mixing saltwater and freshwater currents apparently keep the larvae circulating with the abundant zooplankton that also occur in this zone (Herbold et al. 1992, and Kimmerer 1992, and Jassby 1993). Little information exists on food habits of delta smelt

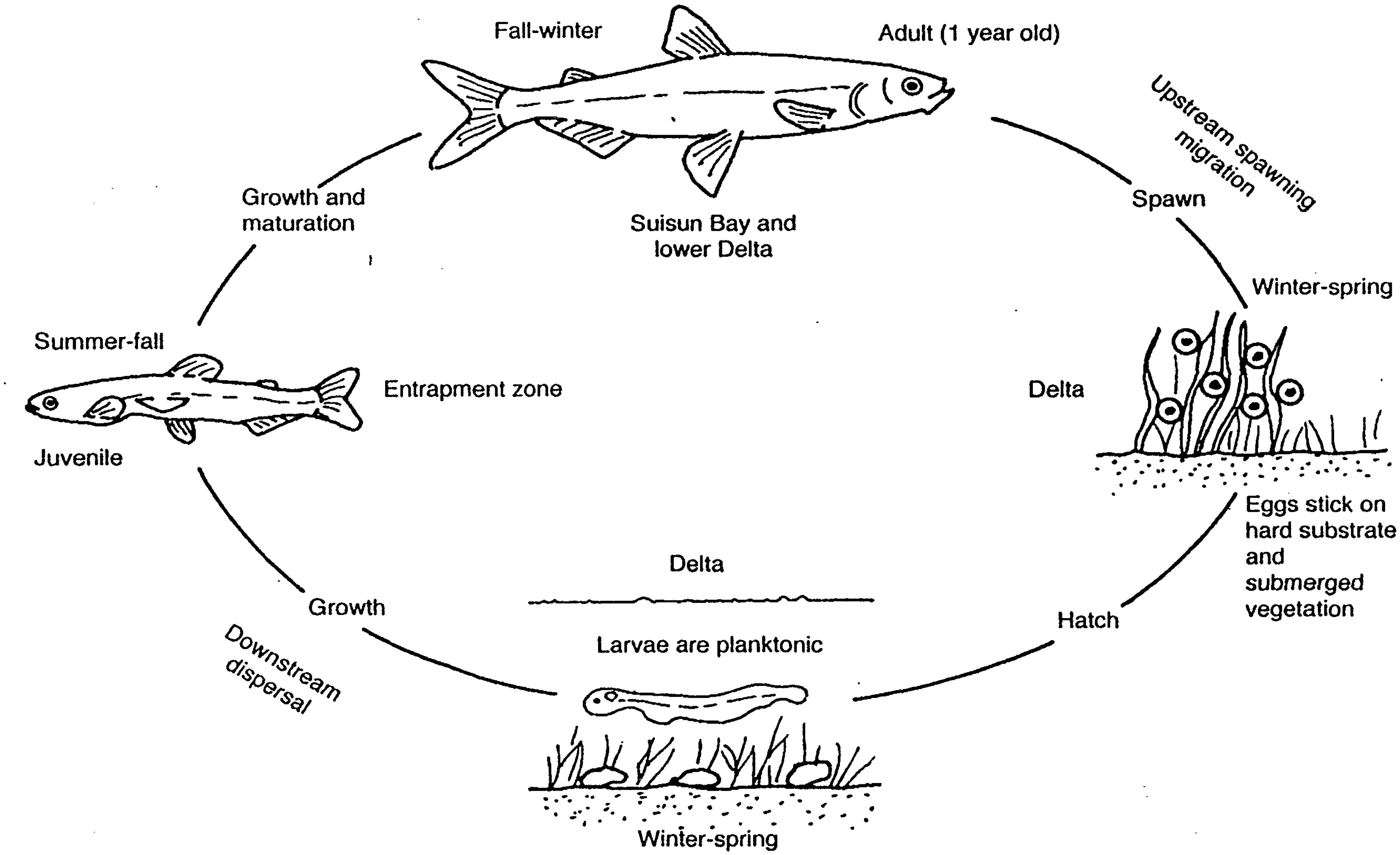

Figure 7. Life History of Delta Smelt

larvae; however, fish larvae of most species feed on phytoplankton and small zooplankton, such as rotifers and copepod nauplii (Hunter 1981). Metamorphosis of delta smelt from larval to juvenile form occurs when the smelt reach a length of approximately 0.7 inch (Wang 1991). The juveniles grow rapidly and reach adult length (approximately 2 inches) within 6 to 9 months.

POPULATION TRENDS

Delta smelt are characterized as historically abundant in the estuary (Moyle 1976), but specific data on abundance are unavailable for years prior to 1959. Surveys conducted after 1959 provide strong evidence of a substantial decline in delta smelt abundance since 1982. On March 5, 1993, the USFWS designated the delta smelt as a threatened species under the federal ESA of 1973 (58 FR 12854). The USFWS' earlier proposal to list the delta smelt (56 FR 50075, October 3, 1991) indicated that federal listing was justified by (1) the apparent decline in delta smelt abundance and continued threats to its existence from the upstream shift of the delta smelt's aquatic estuarine habitat, reduced habitat availability, poor water quality, and changes in food availability; and (2) the inadequacy of existing regulatory mechanisms to ensure the long-term existence of delta smelt or its habitat. Critical habitat for delta smelt includes the Delta and Suisun Bay (59 FR 65256, December 19, 1994). Because the delta smelt has low fecundity compared to many fish species, the abundance of delta smelt in one year is potentially limited by the number of spawning adults present in the previous year, and the risk of extinction during a year is related to the population abundance in that year.

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Habitat

Prespawning adults and juvenile delta smelt are generally most abundant above the upstream end of the entrapment zone, at salinity of approximately 0.45 to 4.40 ppt (DWR and Reclamation 1993). The delta smelt population is concentrated in the estuary west of the confluence of the Sacramento and San Joaquin rivers in high-outflow years and in the Delta in low-outflow years (Stevens et al. 1990, Moyle et al. 1992). The distribution of prespawning adults and juveniles is related to Delta outflow.

Delta outflow probably also affects where delta smelt adults spawn in the estuary. Delta smelt spawn primarily in fresh water, and the downstream distribution of fresh water is determined by the amount of flow in the Sacramento and San Joaquin rivers. Fresh water in high-outflow years in the upper Suisun Bay may encourage spawning in Suisun Bay. In low-outflow years, the adult smelt must migrate into the Delta to reach fresh water (Wang and Brown 1993).

Delta smelt are found at salinity of 0 to 14 ppt (Moyle et al. 1992), but they are most abundant at salinity between approximately 0.45 and 4.40 ppt (DWR and Reclamation 1993). The latter salinity range typically encompasses the upper part of the entrapment zone; therefore, it is not clear whether delta smelt actually "prefer" this salinity range or whether this association results from the smelt gathering in the entrapment zone for other reasons, for example, for food abundance. Delta smelt abundance between 1984 and 1991 was inversely correlated with salinity in Suisun Bay (DWR and Reclamation 1993). Whether this correlation is a direct or indirect effect on abundance is unclear because salinity is related to Delta outflow that influences entrainment, food availability, and other factors. There is no evidence that salinity has any direct effect on adult delta smelt but, as noted above, freshwater flow patterns may influence spawning migration.

Water Quality

Agricultural chemicals (including pesticides and herbicides), heavy metals, petroleum-based products, and other waste materials toxic to aquatic organisms enter the estuary through non-point source runoff, agricultural drainage, and municipal and industrial discharges. Pesticides have been found in the Sacramento River in recent years at concentrations potentially harmful to fish larvae (Herbold et al. 1992). Recent bioassays by the Central Valley RWQCB indicate that water in the Sacramento River is periodically toxic to larvae of the fathead minnow, a standard EPA test organism (Stevens et al. 1990). The short life span of delta smelt and their relatively low position in the food chain probably reduce the accumulation of toxic materials in their tissues and make them less susceptible to chronic toxic effects than species that live longer.

Delta smelt are found in waters ranging from 43 to 73°F (Moyle et al. 1992). Water temperature during delta smelt spawning is reported to be 45 to 59°F (Wang 1986), although water temperature during the period of peak larval abundance is typically 59 to 73°F (DFG 1992c). Regression analysis found no relationship between delta smelt abundance and water temperature (Stevens et al. 1990). Delta smelt may be sensitive to heated discharges to the Delta channels.

Entrainment

Thousands of diversions occur from the Delta, but adult delta smelt are probably entrained primarily at four major diversions: the SWP and CVP pumping facilities in the south Delta and Pacific Gas & Electric Company's (PG&E's) Contra Costa and Pittsburg generating facilities (DWR and Reclamation 1993, PG&E 1985).

Entrainment of delta smelt by SWP and CVP pumps primarily affects spawning adults, larvae, and young juveniles. Prespawning adults and older juveniles inhabit the western Delta and Suisun Bay, which, depending on salinity conditions, are probably beyond the influence of SWP and CVP pumps. Although delta smelt entrained at SWP and CVP facilities are salvaged and returned by truck to downstream areas in the Delta, survival of the salvaged smelt is believed to be low (DWR and Reclamation 1993). A significant inverse correlation exists between Delta outflow and salvage of delta smelt (DWR and Reclamation 1993). Low outflow may increase entrainment because the distribution of smelt, in response to salinity, is farther upstream in the Delta.

PG&E operates power plants located near Antioch and Pittsburg that divert cooling water. Antioch and Pittsburg are located near the confluence of the Sacramento and San Joaquin Rivers, an important rearing and spawning area for delta smelt. The diverted cooling water is returned to the estuary, but nothing is known about survival of the smelt entrained in the water. Although the power plant intakes are screened to protect most adult and older juvenile delta smelt from entrainment, these smelt may be impinged on the screens. From 1978 to 1979, estimates of delta smelt impingement were 10,000 smelt at the Pittsburg plant and 6,400 smelt at the Contra Costa (Antioch) plant (Stevens et al. 1990).

Adult delta smelt are vulnerable to entrainment at diversions other than the SWP and CVP pumps, but entrainment at other diversions has not been studied in detail. During dry years, adults appear to spawn in and near Barker and Lindsey sloughs, which are near the intake for the North Bay Aqueduct (BioSystems Analysis 1993, DWR and Reclamation 1993). Adults have rarely been found in Contra Costa Water District's (CCWD's) Rock Slough diversion, but existing information is inadequate to rule out spawning activity in the area.

Few studies have been conducted on the entrainment of delta smelt larvae at the North Bay Aqueduct and CCWD diversions. An estimated 432 to 4,320 delta smelt larvae per day could be entrained in the North Bay Aqueduct (DWR and Reclamation 1993). Relatively few delta smelt larvae were collected at the Rock Slough station near CCWD's intake during the egg and larval survey in 1992 and 1993 (DWR and Reclamation 1993); therefore, entrainment of larvae by this diversion may be low.

Delta smelt larvae may be vulnerable to entrainment in agricultural diversions from April through June, when the irrigation season begins and larvae are relatively abundant in the Delta; however, few delta smelt larvae were recovered in agricultural diversions during 1992 and 1993 in DWR's agricultural diversions study (DWR and Reclamation 1993). The low recovery rate could result from low abundance of delta smelt larvae or from larval behavior that makes them less vulnerable to entrainment. Delta smelt larvae may remain close to the bottom after they lose their buoyancy (Mager pers. comm.), making them less vulnerable to entrainment.

Movement

When outflow is low and exports at the SWP and CVP pumps are high, the net flow in the lower San Joaquin River may be toward the pumps rather than downstream. These reverse flows, which contain relatively fresh water drawn from the Sacramento River, may encourage upstream migration of delta smelt adults in the south Delta—where they and their larvae are vulnerable to entrainment and other sources of mortality. Positive outflow from the central Delta may aid movement of larvae to downstream habitat.

Species Interactions

Food availability may be an important factor affecting survival of delta smelt larvae. Abundance of rotifers and phytoplankton has declined in recent years (Obrebski et al. 1992). These prey species are small and may be important to the diet of delta smelt (DWR and Reclamation 1993) and other fish larvae (Hunter 1981). Year-class strength of many fish populations, particularly species with planktonic larvae, is believed to be strongly influenced by concentrations of small-size prey during the larval life stage (Lasker 1981).

Adult delta smelt prey chiefly on copepods, but they seasonally prey on cladocerans and mysids as well. *Eurytemora affinis*, one of the principal prey species of delta smelt, has substantially declined in recent years (Obrebski et al. 1992) and this decline may have contributed to the recent decline in delta smelt abundance (Stevens et al. 1990). An introduced copepod, *Pseudodiaptomus forbesi*, became abundant in the estuary in 1988, however, and diet studies indicate that it is now the main food item of delta smelt. Consequently, overall food availability for delta smelt may not have declined (Herbold et al. 1992). Many non-native species have invaded the estuary in recent years and may compete with or prey on delta smelt. The recently introduced Asian clam is currently abundant in Suisun and San Pablo bays, where it feeds on zooplankton and phytoplankton and thus may compete with delta smelt for prey organisms. Several introduced fish species, including the inland silverside, the yellowfin goby, and the chameleon goby, also may compete with or prey on delta smelt.

LONGFIN SMELT

Longfin smelt (*Spirinchus thaleichthys*) is a 3- to 6-inch-long silvery fish (Moyle 1976). Longfin smelt were the most abundant smelt species in the Bay-Delta estuary prior to 1984 and have been commercially harvested (Wang 1986). Except when spawning, longfin smelt are most abundant in Suisun and San Pablo bays, where salinity generally ranges between 2 and 20 ppt (Natural Heritage Institute 1992). Adults are found seasonally as far downstream as the South Bay and are occasionally collected in the open ocean. Longfin smelt are regularly found in the Gulf of the Farallones during fall and following high outflows (Baxter pers. comm.). They are anadromous and spawn in fresh water, primarily in the upper end of Suisun Bay and in the lower and middle Delta (Wang 1991). (Table S-12 in the Supplement provides detailed geographic and occurrence information.)

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Life History

Most longfin smelt spawn and die at 2 years of age (DFG 1992c, Natural Heritage Institute 1992). Its life cycle is similar to that shown for delta smelt (Figure 7). Spawning occurs primarily from January through April. The eggs are adhesive and are deposited on rocks or aquatic plants. They hatch in 37 to 47 days at 45°F. Larval abundance in the Bay-Delta estuary peaks from February to April (DFG 1992c). Early development of gas bladders by longfin smelt relative to that of delta smelt may enhance buoyancy and explain why longfin smelt larvae are dispersed much farther downstream in the estuary than are delta smelt larvae (Baxter pers. comm., DFG 1992c).

The main prey of adult longfin smelt is the opossum shrimp (Natural Heritage Institute 1992). There is little information on food habits of longfin smelt larvae; but fish larvae of most species are known to feed on phytoplankton and small zooplankton, such as rotifers and copepod nauplii (Hunter 1981, DWR and Reclamation 1993). Juvenile longfin smelt feed on copepods, cladocerans, and mysids.

Population Trends

Longfin smelt have declined in abundance since 1982. In 1993, USFWS was petitioned to list the longfin smelt under the federal ESA; however, in January 1994, USFWS determined that the longfin smelt did not warrant listing because (1) other longfin smelt populations exist along the Pacific Coast, (2) the Bay-Delta estuary population does not appear to be biologically significant to the species as a whole, and (3) the Bay-Delta estuary population may not be sufficiently reproductively isolated (59 FR 869, January 6, 1994).

Factors Affecting Abundance and Distribution

Habitat

The position of the entrapment zone and volume of critical nursery habitat are determined by Delta outflow and are factors related to longfin smelt abundance (Jassby 1993). High Delta outflow may increase the amount of suitable brackish-water rearing habitat, reduce salinity in the estuary, and increase phytoplankton and zooplankton production. Food limitation may be important because year-class strength of many fish populations, particularly species with planktonic larvae, may be strongly influenced by feeding conditions during the larval life stage (Lasker 1981).

Outflow may influence the timing and location of longfin smelt spawning, which may begin as early as November (Natural Heritage Institute 1992). In years of high outflow, upper Suisun Bay has relatively fresh water that may support spawning. In years of low outflow, the smelt migrate into the Delta to reach fresh water.

Water Quality

Toxic materials are likely to have an adverse effect on longfin smelt, but there is no evidence to suggest that contaminants are the cause of variability in longfin abundance.

Entrainment

Entrainment of longfin smelt by Delta diversions affects spawning adults, larvae, and early juveniles. Older juveniles and prespawning adults generally, in addition to benefitting from fish screens, inhabit areas downstream of the Delta and most major diversions.

Movement

The distribution of longfin smelt larvae is strongly related to Delta outflow. Higher outflows lead to greater downstream dispersion and transport of larvae out of the Delta and away from diversions (DFG 1992c, Stevens and Miller 1983, and Baxter pers. comm.). In years of low outflow (1981, 1985, 1987, and 1988), longfin smelt larvae were found primarily in the western Delta and Suisun Bay; in years of high outflow (1980, 1982 to 1984, and 1986), larvae were equally or more abundant in San Pablo and San Francisco bays. Juveniles older than 1 year may be dispersed farther downstream by winter and spring outflow. Higher outflows result in higher longfin smelt survival, especially of larvae and early juveniles. Year-class strength may be largely determined by survival of longfin smelt during early life stages.

Species Interactions

High Delta outflow may reduce competition and predation by marine organisms. In particular, at high delta outflows, young smelt would be more dispersed and turbidity would be increased, making them less prone to predation. In addition, introduced species may affect longfin smelt survival through competition for food and habitat.

SPLITTAIL

Sacramento splittail (*Pogonichthys macrolepidotus*) are large cyprinids (minnow family) endemic to the lakes and rivers of the Central Valley of California (Moyle et al. 1989). Existing information on the life history of Sacramento splittail is based largely on Moyle (1976); Daniels and Moyle (1983); Wang (1986); Moyle et al. (1989); and 59 FR 862, January 6, 1994.

Splittail are freshwater fish capable of tolerating moderate levels of salinity from 10 to 18 ppt. They grow up to 16 inches long and live approximately 5 years. Adults are primarily bottom foragers with a diet that includes detritus, earthworms, clams, insect larvae, and other invertebrates. Opossum shrimp appear to be the dominant prey item, although detritus constitutes a large proportion of their stomach contents. Juvenile splittail feed primarily on algae and invertebrates, and are often preyed on by Sacramento squawfish and striped bass.

LIFE HISTORY

Splittail typically spawn in dead-end sloughs and slow reaches of large rivers over submerged vegetation. Male and female splittail become sexually mature by their second winter. Female splittail are capable of producing more than 100,000 eggs per year. Incidental information indicates that adult spawning migration occurs during winter and spring (Figure 8). The onset of spawning appears to be associated with increasing water temperatures and increasing day length. Spawning occurs in late April and May in the Suisun Marsh and between early March and May in the upper Delta. Spawning in the tidal freshwater habitats of the Sacramento-San Joaquin River estuary has been observed as early as January and through July. Spawning occurs primarily in the lower reaches and flood bypasses of the Sacramento and San Joaquin rivers. Shallow, weedy areas resulting from seasonal flooding provide ideal habitat for adult spawning and foraging and subsequent egg development and larval and early juvenile rearing. (Table S-13 in the Supplement provides detailed geographic and occurrence information.)

As ephemeral flooded habitat disappears, splittail larvae are forced out into permanently inundated areas by summer. Although splittail use deeper, open water as they grow, much of the population continues to use shallow (< 10 feet) edge habitat as adults (Meng and Moyle 1995, Baxter pers. comm.). Larvae are occasionally found in San Pablo Bay and have even been collected near the Berkeley Marina in San Francisco Bay. Juvenile splittail are commonly found in Delta sloughs in late winter and spring, and are particularly abundant in the vicinity of Montezuma Slough. As summer progresses, juvenile splittail occupy the deeper, open-water habitats of Suisun and San Pablo bays. In upstream areas, juveniles are found in

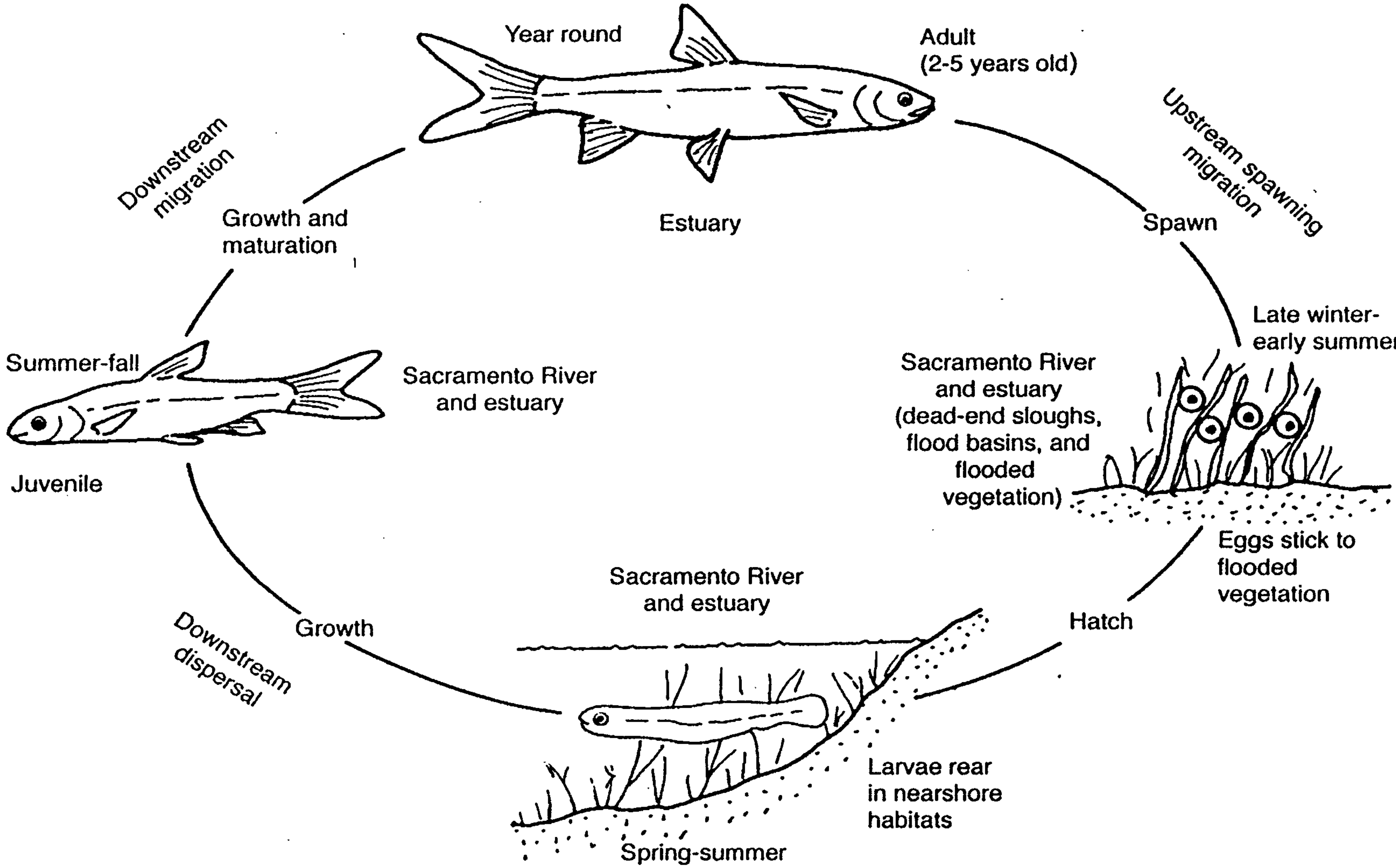

Figure 8. Life History of Sacramento Splittail

shallow, flooded areas where higher water temperatures and low water velocities persist. Juvenile splittail have been collected from the lower reaches of the Sutter Bypass during spring, and from the Sacramento River near Colusa and Princeton in Colusa County.

POPULATION TRENDS

DFG estimates recent young-of-year splittail abundance in the Delta to be only 35 to 60% of 1940 levels (DFG 1992d). The decline in abundance has prompted DFG to designate splittail as a species of special concern and the USFWS to propose the species for federal listing as threatened. Splittail abundance rebounded in 1995, indicating the resilience of the species in response to high flow conditions.

Splittail are seasonally confined mostly to the Delta, Suisun Bay, Suisun Marsh, Petaluma River, and Napa Marsh but spawn and rear in the Sutter, Sacramento, and Yolo Bypasses when flooded (Moyle et al. 1989, Natural Heritage Institute 1992, and Jones & Stokes Associates 1993). Adults are most abundant in Suisun and Grizzly bays (59 FR 862, January 6, 1994). In the Delta, splittail are most abundant in the western and northern portions (Moyle et al. 1989). During the 1987 to 1992 drought, however, their distribution appears to have shifted to the lower Sacramento River and south Delta, possibly as a result of reductions in Delta outflow (59 FR 862, January 6, 1994).

Splittail frequently are caught in the lower Sacramento, Feather, and American rivers. Recently, seining surveys of the lower reaches of the Sutter Bypass near Karnak (Sutter County) recorded the occurrence of both juvenile and adult splittail (Jones & Stokes Associates 1993). In the San Joaquin River drainage, splittail appear to be less common than in the Sacramento River drainage, although large year-classes occur in some years, such as 1995. Limited numbers of splittail were collected in the late 1980s from the San Joaquin River near the confluences of the Tuolumne and Merced rivers and in Mendota Pool, which receives water pumped from the Delta through the Delta-Mendota Canal (Jones & Stokes Associates 1987, Natural Heritage Institute 1992). Occasionally, splittail are caught in San Luis Reservoir (Merced County), which receives Delta water through the Delta-Mendota Canal and the California Aqueduct (Natural Heritage Institute 1992).

FACTORS AFFECTING ABUNDANCE AND DISTRIBUTION

Habitat

Habitat modification through diking and filling of wetlands preceded the recent decline in splittail abundance; however, habitat modification is probably the largest single factor contributing to the long-term decline of splittail (DFG 1992d). Land reclamation, flood control facilities, and agricultural development have eliminated and drastically altered much of the splittail habitat in the lowland areas. Dams have restricted access to upstream spawning and rearing habitats.

Levee construction, bank stabilization practices such as riprapping, river channelization, dredging, and the diking and filling of historical floodbasins have drastically reduced shallow-water habitats available to spawning adults. An estimated 96% of historical wetland habitats either are unavailable to splittail or have been eliminated (50 Code of Federal Regulations, Part 17).

Aside from habitat modifications, including levees, upstream water storage facilities and water diversions have affected migrating splittail by reducing the incidence and duration of floodflows that inundate lowland areas. Consequently, passage into inundated habitats is compromised, resulting in reduced spawning success because splittail are unable to exploit former spawning areas. Furthermore, reduced flood duration increases the risk that splittail become stranded in temporarily inundated habitats, such as those in the Sutter and Yolo bypasses.

Splittail abundance has been shown to be strongly associated with high Delta outflows during primary spawning months (March through May) (DFG 1992d). High Delta outflows during late winter and spring correlate with increased total surface area of shallow-water habitats containing submerged vegetation, both within and upstream of the Delta. Adult splittail spawn in areas of submerged vegetation where they lay their adhesive eggs. During years of severely reduced Delta outflow, such as the 1986-1992 drought, spawning success may have been greatly reduced, contributing to reduced abundance.

Delta diversions, including SWP and CVP pumping facilities, coupled with upstream storage reservoirs, may have adversely affected spawning adults by reducing freshwater outflow and habitat abundance in Suisun Marsh. Consequently, spawning adults are forced to use habitat outside the marsh, reducing the likelihood of juveniles returning to rear in the marsh. Upstream water storage projects, diversions, and Delta export pumping have reduced Delta outflow. Reduced outflow increases salinity in Suisun Marsh, Suisun Bay, and the lower Delta. Although adult splittail may spawn successfully in habitats containing low (0.3 to 5.0 ppt) salinity (Wang 1986), excessive salinity most likely inhibits use of spawning habitats downstream of the Delta. Larval splittail appear to be somewhat tolerant of low salinity (Wang 1986); however, the effects of salinity on developing eggs are unknown.

Water Quality

Toxic materials are likely to have an adverse effect on all splittail life stages, but there is no evidence to suggest that contaminants are the cause of variability in splittail abundance.

Entrainment

SWP and CVP exports entrain substantial numbers of splittail in some years. Adult and juvenile splittail entrained in the SWP and CVP diversions are salvaged and returned to the Delta alive. Mean annual salvage (1979 to 1989) of splittail at the SWP and CVP facilities is approximately 213,000 and 190,500, respectively. Adult splittail are entrained year round but most are entrained from January to April, which coincides with the spring spawning migration. Juvenile splittail are entrained year round, although most are entrained from April through August (Barrow pers. comm.). Thousands of larval splittail are entrained in SWP and CVP exports annually, although larval splittail generally occur in habitat where entrainment vulnerability is low. Most larvae are entrained from April through July (Barrow pers. comm.). Additional losses to entrainment, including predation, handling, and trucking mortality, have not been quantified.

Losses of splittail to agricultural diversions may be considerable given that these diversions account for approximately one-third of the volume of water diverted from the Delta. No data are available on agricultural diversion losses. Juvenile and adult splittail may be entrained and die in the PG&E cooling water intakes at Pittsburg and Antioch; however, splittail entrainment losses at these facilities have not been quantified and existing fish screens may reduce losses of adults.

Species Interactions

The effects of increased competition and predation resulting from species introductions are difficult to evaluate in natural populations. There is no evidence to indicate that predation or competition from introduced non-native species is responsible for the decline in splittail. As with delta smelt, factors affecting food abundance may affect the abundance and distribution of splittail.

Harvest

Splittail have not been commercially harvested in the Delta since the 1950s. Currently, splittail are harvested only as food and bait by sport anglers. No evidence exists to suggest that the sport harvest has contributed to the decline in abundance (50 Code of Federal Regulations, Part 17).

OTHER SPECIES

SACRAMENTO SQUAWFISH

The Sacramento squawfish (*Ptychocheilus grandis*), a member of the minnow or cyprinid family of fishes, is a native to northern California streams and rivers. It is a top predator, growing up to 3 feet long. Young squawfish feed on earthworms, mayflies, and crayfish. As juveniles, Sacramento squawfish begin feeding on other fish. Adults feed extensively on juvenile salmon migrating downstream toward the ocean. Spawning takes place in spring when they form large spawning aggregations. Squawfish tend to migrate upstream from April through June and spawn in the lower end of pools or on riffles in smaller tributaries to the main rivers. A single squawfish may lay over 20,000 eggs in a season. The eggs are adhesive, sticking to rocks and gravel on the stream bottom, and hatch in about 14 days (McGinnis 1984, Moyle 1991, and Calhoun 1966).

Squawfish occupy the same general habitat as rainbow trout and juvenile salmon. They are rarely targeted as a sport fish, but some are taken incidentally by sport fishers fishing for steelhead and trout. Losses also occur from dams blocking the upstream migration of adults seeking suitable spawning sites. Newly hatched larvae and juveniles are subject to entrainment in agricultural diversions as they move downstream.

SACRAMENTO BLACKFISH

The Sacramento blackfish (*Orthodon microlepidontus*) belongs to the cyprinid family of fish and is related to the squawfish described above. Sacramento blackfish tend to inhabit warm backwater areas of the Delta and some reservoirs. They become sexually mature in about 3 years and spawn in spring. They can reach lengths of over 2 feet. The eggs are adhesive and spawning takes place in shallow water over aquatic plants. Sacramento blackfish have large brush-like gill rackers that enable them to be efficient filter feeders of suspended organic matter in the water column.

Blackfish can live under extremely adverse conditions compared to other fish inhabiting the Delta. They are tolerant of very low levels of dissolved oxygen and high water temperatures. There is a blackfish fishery in the lower Sacramento and Delta that supplies the Asian food trade in San Francisco and Oakland.

RAINBOW TROUT

Rainbow trout (*Oncorhynchus mykiss)* is a highly complex species that exhibits a diversity of life-history and reproductive strategies that can range from being freshwater resident (rainbow trout) to being anadromous (discussed previously as steelhead). *O. mykiss* that do not exhibit anadromy are termed rainbow trout.

Resident rainbow trout are the most abundant and widespread salmonids in Central Valley reservoirs. Rainbow trout in most reservoirs are hybrids of native and non-native strains resulting from hatchery introductions from other habitats and regions. The cold, deep waters of reservoirs provide suitable rearing habitat for this species. Suitable spawning habitat must be available in tributaries to the reservoirs for populations to be self-sustaining. Rainbow trout usually spawn in spring, with specific timing varying primarily with reservoir elevation and water temperature. Trout typically enter reservoirs from the upstream spawning streams as fry or juveniles. Although benthic invertebrates and zooplankton seem to be the main prey items, terrestrial insects will be consumed when other food is scarce. Rainbow trout in reservoirs, particularly those over 12 inches long, also consume other fish. The forage fish in most reservoirs are threadfin shad and smelt, although sculpins and suckers will also be eaten.

Rainbow trout growth has been outstanding in Shasta Lake and Pine Flat Reservoir, where threadfin shad have been introduced (Borgeson 1966). Most reservoir populations of rainbow trout are partially sustained by hatchery production. Catchable-size trout are typically stocked in lakes and the rivers tributary to the lakes and caught within a few days. The rainbow trout that survive until spring may have difficulty accessing suitable spawning habitat in the tributaries. Additionally, tributary streams seldom have high-quality habitat for juvenile rearing because of upstream development (including reservoirs), agricultural activities, and steep stream gradient. Water quality conditions vary from reservoir to reservoir. Adverse water quality conditions, including low dissolved oxygen levels and elevated water temperature, may affect rainbow trout survival. Optimum temperature for growth and completion of most life stages of this species ranges from 55 to 70°F.

Rainbow trout also occur in the Sacramento and San Joaquin rivers and tributary streams. They occupy that same habitat and have the same environmental requirements as steelhead.

LARGEMOUTH BASS

Largemouth bass (*Micropterus salmoides*) were first introduced into California in 1874 and have since spread to most suitable waters. They are abundant in reservoirs and the Delta and are normally found in warm, quiet waters with low turbidity and beds of aquatic plants. Largemouth mature during their second or third spring. Spawning activity typically begins in April and continues through June. The eggs are adhesive and are deposited in a nest that the male constructs in a sand, gravel, or debris-littered bottom. Incubation lasts from 2 to 5 days and larvae remain near the nest for another 5 to 8 days.

For the first month or two, juveniles feed mainly on rotifers and small crustaceans. By the time they are 2 to 3 inches long, juveniles feed primarily on aquatic insects and fish. After they reach a length of 4 inches, largemouth bass feed primarily on fish and large aquatic invertebrates. Optimal temperature for growth ranges from 68 to 86°F.

Populations of largemouth bass have declined in reservoirs as a result of three main factors: fishing, habitat loss, and competition from other plankton-feeding fishes (Von Geldern 1974). Largemouth bass are extremely vulnerable to fishing, and at least 50% of the population of legal-size fish are caught annually in many reservoirs. Cover is reduced as reservoirs age, thus reducing suitable habitat and limiting largemouth bass populations. Water-level fluctuation can affect habitat availability and can limit populations if the changes are large or frequent. Competition from other species and reservoir aging reduce prey availability for largemouth bass, which limits their growth and proliferation. Largemouth bass are abundant in the Delta and there is no evidence of a population decline.

SMALLMOUTH BASS

Smallmouth bass (*Micropterus dolomieui*) were first introduced into California in 1874 and have since spread to most suitable waters. They have become established in large, two-story reservoirs and Central Valley rivers and streams. They are normally found in cool waters, often near the upstream end of impoundments and downstream of reservoirs. Compared to largemouth bass, smallmouth bass are of minor importance as a sport fish. Smallmouth reach maturity in 3 to 4 years. Spawning activity usually begins in April. Males build nests in rocky bottoms at a depth of 3 feet in the reservoir or in the lower portions of tributary streams of the larger rivers. The male guards the nest until the eggs hatch in 3 to 10 days. The larvae usually spend 3 to 4 days in the nest. The male herds and guards the larvae and juveniles for an additional 1 to 3 weeks, after which they disperse into shallow water.

For 1 to 2 months, fry feed mainly on rotifers and small crustaceans. By the time they are 2 to 3 inches long, they feed primarily on aquatic insects and fish. Once smallmouth bass exceed 4 inches, they feed primarily on fish and large invertebrates. Optimum temperature for growth and survival ranges from 68 to 81°F. Currently, populations are abundant.

TULE PERCH

Tule perch (*Hysterocarpus traskii*) inhabit large, low-elevation streams and occupy a wide range of habitats from sluggish, turbid channels in the Delta and in Napa and Suisun marshes, to clear, swift-flowing sections of rivers. They are typically associated with beds of emergent aquatic plants or overhanging banks. Tule perch are tolerant of brackish water but seldom occur there. They are viviparous, with mating occurring from July through September and the young being born in May or June. Tule perch are gregarious, especially when feeding. They feed on small, hard-shelled benthic invertebrates or aquatic plants, although they will also feed in midwater on zooplankton (Moyle 1976).

Tule perch populations appear to be declining slowly and they are absent from some locations where they were historically collected. Tule perch are very sensitive to water quality conditions and tend to disappear from streams that are polluted and have reduced flow. Tule perch require flowing water with abundant cover such as abundant aquatic macrophytes and fallen trees. Introduced fish predators, such as smallmouth bass, may contribute to reduced populations (Moyle 1976).

WHITE CATFISH

White catfish (*Ictalurus catus*) were introduced into the San Joaquin River in 1874 and have spread to almost every major drainage system in California. They are most abundant in the Delta. Spawning takes place in June and July, when water temperature exceeds 70°F. The female constructs a shallow nest depression by fanning away fine materials and pushing out larger objects. When the eggs are laid, they stick to each other and form an egg mass at the bottom of the nest. One or both parents will guard and fan the nest. Eggs hatch in about 1 week and the young stay together for 2 to 3 weeks, still guarded by one or both parents. They mature at 3 to 4 years of age.

White catfish are carnivorous bottom feeders, but occasionally feed on plankton-feeding fishes. Smaller fish eat smaller organisms, such as amphipods, opossum shrimp, and chrinomid midge larvae. As the fish grow larger, their diet will include fish and large invertebrates; however, amphipods and opossum shrimp are still the main food items.

White catfish are an important sport fish in the Sacramento-San Joaquin system. Water temperatures greater than 68°F are required in summer and temperatures up to 84 to 88°F are survivable. White catfish can live at salinity up to 11 to 12 ppt. Although they occur in Suisun Bay, they are most common in the south-Delta channels with moderately fast currents.

INLAND SILVERSIDE

Inland silversides (*Menidia audens*), native to the southern United States, were introduced in California in 1967. They are present in several Central Valley streams and reservoirs; frequently form large schools; and feed on zooplankton, fish eggs, and larvae. They are abundant in some reservoirs and in the Delta (Moyle 1976). Silverside grow to 3 to 4 inches in 1 year; most spawn and die after 2 years. Spawning occurs in aquatic vegetation and individuals may spawn several times over summer months. Eggs hatch within 30 days, depending on water temperature.

Following their introduction, inland silversides quickly spread throughout the Sacramento-San Joaquin drainage. Optimum temperature for spawning is 68 to 77°F. Inland silversides can

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survive salinity approaching that of sea water (Moyle 1976). They are an important forage fish; however, they may compete with or feed on native species, including delta smelt.

STARRY FLOUNDER

Starry flounder (*Platichthys stellatus*) are common in estuarine areas from Morro Bay northward. Starry flounder generally spawn outside San Francisco Bay in the ocean but can be found during all its life stages, including adult, within the Bay (Herbold et al. 1992). Historically, adults have been common in Suisun Bay. Spawning generally takes place from November through February, depending on location (DFG 1992c). Starry flounder eggs and larvae are pelagic, and larvae move into the Bay on currents and disperse into the upper reaches of the Delta and Suisun and San Pablo bays from May through October (Herbold et al. 1992). The younger and smaller larvae tend to be distributed farther upstream than the slightly older and larger larvae. As they grow and mature, starry flounder juveniles move into the more saline waters of San Pablo Bay. Starry flounder also occur in the Delta, generally as early juveniles.

Larval starry flounder consume phytoplankton and zooplankton. Juveniles less than 4 inches long eat copepods and other small crustaceans. Larger juveniles and adults eat crustaceans, including *Crangon* spp.; Dungeness crabs; worms; clams; and occasionally fish, including northern anchovy (Emmett et al. 1991). Starry flounder are most abundant and diverse in size in San Pablo Bay, but Suisun Bay is a very important nursery area for young-of-the-year (Herbold et al. 1992).

The starry flounder population has declined steadily over the years as a result of changing environmental conditions and, possibly, toxic contamination. DFG (1992c) abundance and Delta outflow models have demonstrated a strong positive relationship between starry flounder abundance and Delta outflow from March through June. The effect of contaminants on starry flounder and other estuary fish is not known, but tissue samples taken from estuary fish exceeded PCB screening levels for human consumption in 1994. Many estuary fish also exceed values for mercury, chlordanes, dieldrin, DDT, and dioxin.

PACIFIC HERRING

San Francisco and Tomales bays attract the largest spawning aggregations of Pacific herring (*Clupea harengeus*) in California (Herbold et al. 1992). Adult Pacific herring move onshore in fall and spawn within San Francisco Bay from November through March (Herbold et al. 1992). Spawning occurs in restricted intertidal and shallow-water habitats near Tiburon Peninsula, Angel Island, Berkeley, and Richmond (Herbold et al. 1992). Pacific herring spawn on eelgrass, algae, tubeworms, oysters, rocks, and other substrates, with the eggs adhering to these substrates until hatching is complete (Emmett et al. 1991).

Pacific herring eggs can tolerate salinity of 3 to 33 ppt but the optimum range is 12 to 20 ppt. Larvae are tolerant of salinity of 2 to 28 ppt. Increased turbidity may increase survival. Larval Pacific herring are selective planktivores and consume diatoms, invertebrate and fish embryos, crustacean and mollusk larvae, and zooplankton. Juvenile herring are also selective planktivores, consuming zooplankton and fish and other larvae (Emmett et al. 1991). Juvenile Pacific herring are widely distributed in the shallower habitats of South, Central, and San Pablo bays. As the juveniles grow and mature, they migrate into deeper water habitats in the Central Bay and emigrate from the Bay between April and August (Herbold et al. 1992).

Salinity effects on egg fertilization and hatching may reduce herring abundance in low Delta outflow years. High salinity and reduced hatching and fertilization rates are associated with low Delta outflows (Charr 1997). Eggs deposited on creosote-coated pilings fail to develop and hatch normally, even if the creosote is more than 40 years old (Charr 1997). The creosote apparently also affects eggs deposited several inches away.

INVERTEBRATES

MYSID SHRIMP

Mysid shrimp (also called opossum shrimp) are small (less than 17 mm) planktonic crustaceans that bear live young. The females are generally larger and more abundant than the males. Reproduction occurs during the cold months, usually between October and May. Several species of mysid shrimp have been recorded in the Bay-Delta, but by far the most important is *Neomysis mercedis*. The principal food source of mysid shrimp is phytoplankton. Mysid shrimp are an important food for fish in Suisun Bay and the Delta, especially for young-of-the-year striped bass.

The distribution of mysid shrimp is largely a function of tidal currents and estuarine circulation patterns. Mysid shrimp are most abundant in Suisun Bay and the western Delta, primarily that associated with the entrapment zone. They are also found in backwaters and sloughs in Suisun Marsh and throughout the Delta and are present in the Sacramento Deep Water Ship Channel and Lake Washington at West Sacramento. Water diversions have introduced mysid shrimp to the California Aqueduct; the Delta Mendota Canal; San Luis Reservoir; and, presumably, other water project reservoirs.

Populations of mysid shrimp have undergone a substantial decline over the last three decades to less than one-tenth of their former abundance, particularly since 1986. Historic abundance indices are correlated with Delta outflow and the location of X2 (San Francisco Estuary Project 1993). The continued decline from 1993 to 1995, despite the return of higher flows, is of particular concern and may be related to concurrent decline in algae production. In Suisun Bay, an additional new loss of phytoplankton may be a result of grazing by the Asian clam. Other factors known to affect survival are temperature, dissolved oxygen concentration, and contaminants.

ROTIFERS

Rotifers are very small (less than 0.3-mm long) invertebrates found throughout the freshwater and brackish-water areas of the Bay-Delta river system. Most species are sessile (living attached to solid objects), but a number of planktonic forms are important components of the Bay-Delta zooplankton community. Rotifers eat mostly algae and fine particulate organic matter (much of which consists of partially decomposed algal biomass).

A recent study by the Interagency Ecological Studies Program indicates that of the six species of rotifers that are most common in the Bay-Delta, all but one have declined significantly in abundance since 1972. In general, the study found that declines occurred throughout the entire estuary rather than being confined to particular regions; however, they tended to be more pronounced in the Sacramento and San Joaquin rivers than in Suisun Bay.

The reproductive rate of rotifers is primarily a function of temperature and the quality and abundance of food. These factors are of primary importance in determining the balance between the production of rotifer biomass and losses resulting from settling, washout, predation, and decomposition. The decline of rotifer populations in the Bay-Delta is thought to be primarily a result of changes in the quality and quantity of their food supply and of increased losses to diversions. Phytoplankton abundance has undergone a general decline throughout the Delta over the past 30 years. The export of Delta water entrains rotifers and their food supply. Other factors potentially affecting rotifers from the Bay-Delta system include contaminants and competition from introduced species.

ASIAN CLAM

The Asian clam (*Potamocorbula amurensis*) was first collected in the Delta in 1986, and was most likely introduced with ballast water discharged by a ship from southeast Asia. It has since greatly increased in abundance and become widely distributed in the upper Sacramento-San Joaquin Delta; abundance often exceeds 1,000 clams per square meter (Hymanson et al. 1994). Apparently, the species has altered the benthic community and trophic dynamics of the upper estuary. Asian clams consume phytoplankton, bacterioplankton, zooplankton nauplii, and other suspended particles. They have become an important food source for birds; fish such as sturgeon; and crabs (Hymanson et al. 1994).

CRAYFISH

Crayfish (*Pacifastacus leniusculus*) inhabit streams, rivers, reservoirs, and canals throughout the Central Valley and are abundant in the Delta. Males mature during their second and third year and females mature during their fourth year. Mating occurs in late fall. Females bear eggs through winter and hatching takes place in April and May. Within the Delta and lower Sacramento and American rivers, crayfish support a commercial fishery. Many fish and wildlife species feed on this species (DFG 1971).

BAY SHRIMP

Bay shrimp (*Crangon franciscorum*) are most abundant in brackish water portions of the Bay, particularly Suisun and San Pablo bays, but their habitat can include the Delta during low outflow years. Adult females migrate to higher salinity waters to incubate their eggs and release their larvae. Newly hatched larvae are planktonic, and post-larvae and juveniles migrate to low-salinity nursery areas of the estuary where they grow and mature for 4 to 6 months (DFG 1992c). During maturation, juvenile bay shrimp move to progressively more saline water. Bay shrimp mature at one year of age. Bay shrimp are an important food source for many fishes, including striped bass, green and white sturgeon, starry flounder, and Pacific tomcod (Herbold et al. 1992). A bait fishery removes 68 to 91 tons of bay shrimp annually from the Bay-Delta (Herbold et al. 1992).

Bay shrimp are good indicators of salinity change within the estuary because their distribution, recruitment, growth, and survival respond to Delta outflow (Emmett et al. 1991). The abundance of bay shrimp is strongly correlated with Delta outflow ($r = 0.91$ for 1980 to 1988) (Herbold et al. 1992).

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