

## **CHAPTER FOUR**

### **The Watershed: Ecological Response**

#### **I. Introduction**

This chapter summarizes the known changes to watershed ecology that have resulted from over 150 years of human intervention. It is essentially a snapshot of watershed ecology today, presented in terms of the same general conceptual framework of system structure and organization used in Chapter Two to describe the natural structure and function of the system. The same general categories of “essential ecological attributes” are also used in this chapter but in a reversed order. First, changes in the underlying geophysical processes that create and support these aquatic ecosystems and ecological opportunities - hydrology and sedimentology - are discussed and followed from the top of the watershed to the nearshore ocean. This is followed by discussions (by ecosystem type) of changes to habitats and biological assemblages that have resulted from the combined effects of hydrogeomorphic and other alterations of the environment.

The condition of the watershed today is the net outcome of numerous types of human activities, and in most cases represents the combined effects of structural and functional changes in habitat, along with more direct forms of human intervention (e.g., hunting). General trends, such as habitat degradation resulting from alterations of natural topography and/or hydrology, may be realistically linked to associated broad changes in community structure and composition. However, only in relatively few cases are the precise causes of sustained species or population declines reasonably well understood or documented.

#### **II. Changes in Hydrogeomorphic Processes**

The hydrology and geomorphology of the watershed have been altered dramatically in many ways throughout much of the system, through the combined effects of storage and diversion, land-use changes, and other factors described in the previous chapter.

##### **II.A. Hydrology**

###### **II.A.1. Stream Flows**

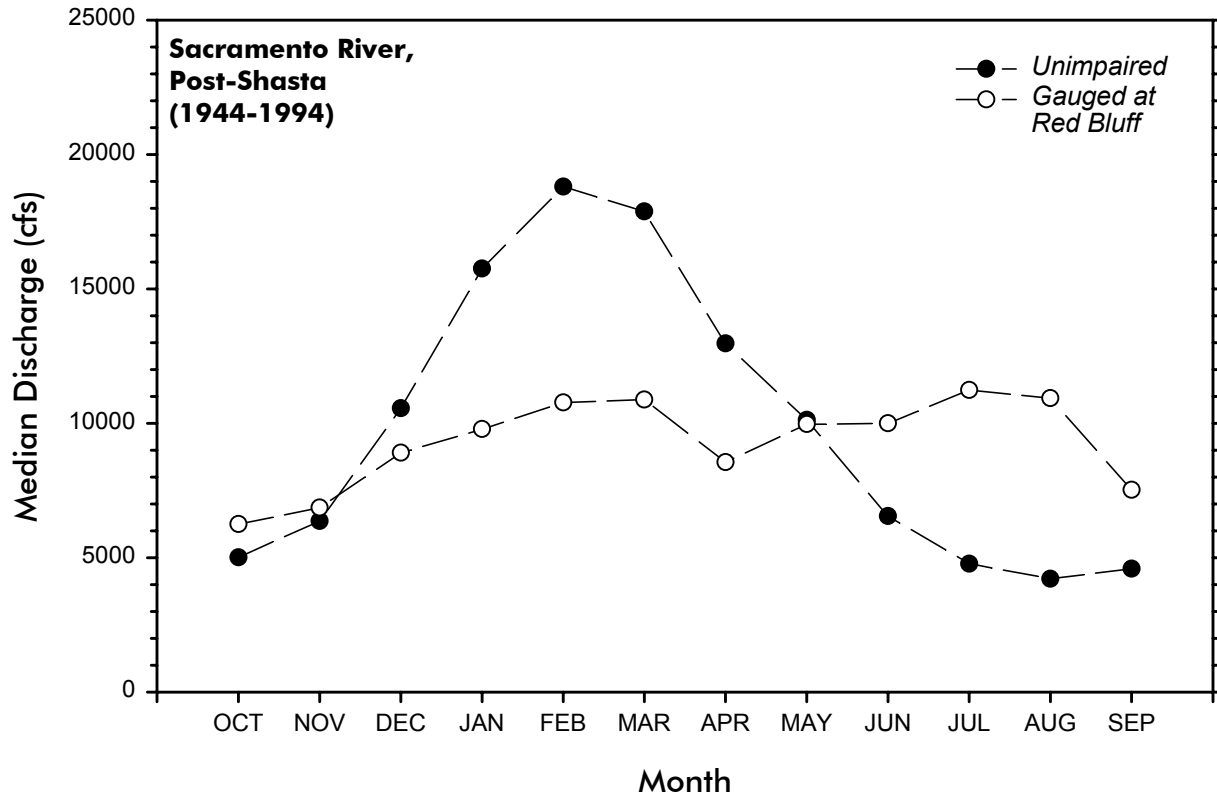
There are systematic differences in the nature and extent of changes in hydrogeomorphic processes upstream and downstream of dams. This is true on both larger waterways that have been dammed to create large terminal storage reservoirs, as well as on waterways of all sizes that have been interrupted by smaller hydroelectric dams.

In the upland part of the watershed, a large number of relatively small hydroelectric dams lie between headwaters and the large terminal storage reservoirs usually located near the “border” between the upland and lowland systems (about 300 ft. elevation). Upstream of these smaller dams, natural flow and sedimentation patterns remain relatively intact, unless locally altered by other interventions (e.g., stripping of vegetation) that have caused an increase in runoff and erosion in many parts of the upper watershed (Kattelman 1996). Below some of these smaller dams, however, some reaches have been dewatered and/or subjected to abrupt daily flow fluctuations. The effects of the smaller hydroelectric reservoirs vary from river to river, but the general effect is to alter seasonal flow variability in much the same manner (but to a lesser degree) as the larger terminal storage reservoirs. Natural flow variability is decreased, peak flows are subdued, and, where releases are conveyed into the natural channel rather than directly diverted into aqueducts or penstocks, base flows are increased as compared with “natural” conditions.

The main changes evident below the terminal storage dams are a pronounced reduction and temporal shift in flows, and reduced monthly and inter-annual variability. In some cases (most commonly in the Sacramento River Basin), average winter/spring flows are now lower, and summer/fall flows higher than they were under natural conditions. For example, on the Sacramento River (at Red Bluff), there has been a reduction in the median monthly discharge from December through April, and an increased discharge (some of which originates as diversion from the Trinity River) from June through October (Figure IV-A). (Median flows are used wherever possible because it is more representative of the commonly-occurring flow and eliminates the bias that a few very wet years can introduce when using the mean or average.) Additionally, the magnitude of the mean difference between high and low monthly discharges within the year has been reduced by about half. In other cases, particularly in the San Joaquin River Basin, changes in river hydrographs are even more pronounced. For example, on the Tuolumne River, median monthly flows in all months have been reduced by about two-thirds, and a once dynamic annual hydrograph has been converted to a nearly uniform discharge pattern (Figure IV-B). Monthly flow variability has also been reduced to about one-fifth of its prior value. Similar changes are evident on the San Joaquin River below Friant Dam (Figure IV-B).

The seasonal pattern of outflow of the Sacramento River drainage differs considerably from its pre-disturbance state (Figure IV-C). The Hall (1887) estimates give a rough approximation of the pattern of monthly flows for the Sacramento River at Collinsville before most of the Delta and upstream wetlands were reclaimed and the upstream flood basins were cut off from the river. The changes effected may be appreciated by comparing the 1879-85 pattern with the recent period (Figure IV-C), which shows that the combined effect of reclaiming the flood basins and storing and diverting spring

Figure IV-A  
Alteration of Median Monthly Inflow  
into the Lowland Sacramento River at Red Bluff

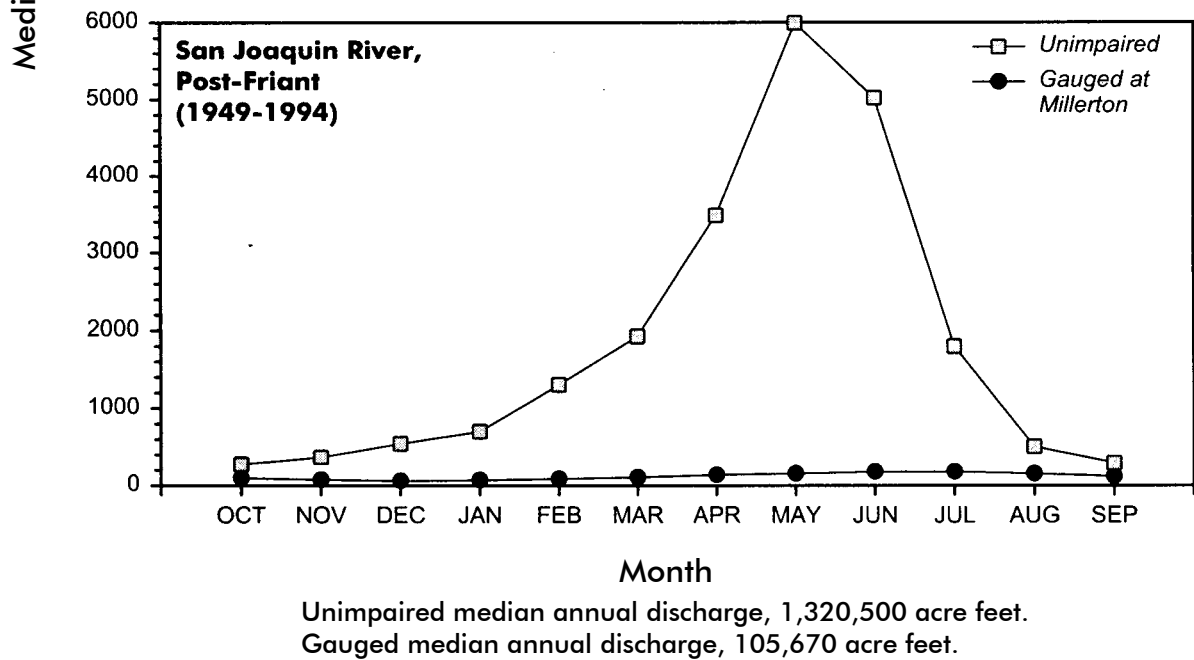
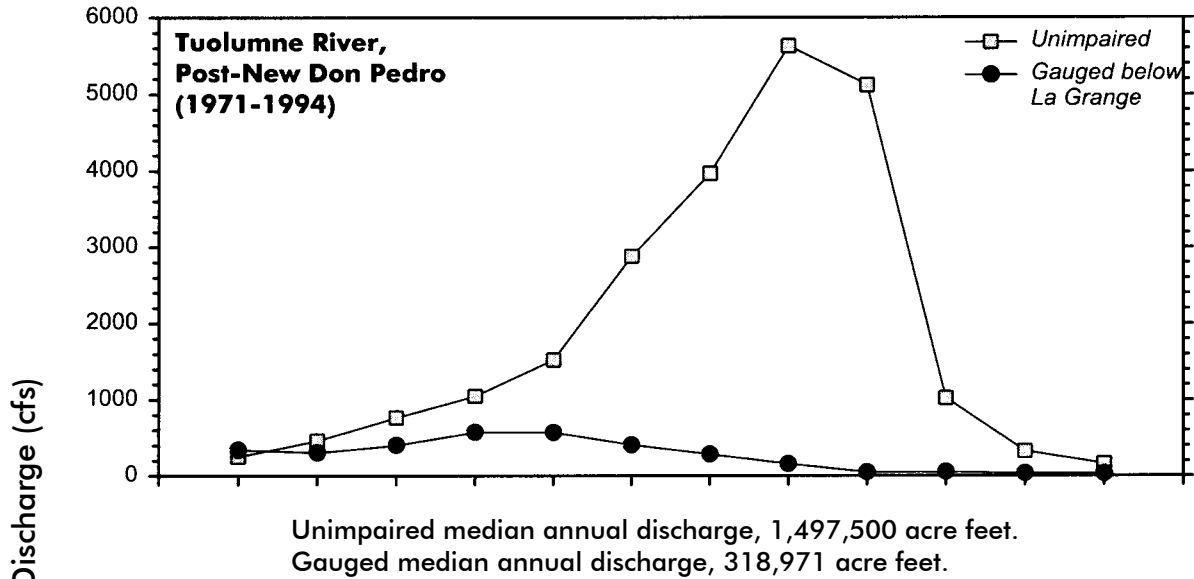


Unimpaired Data: median annual discharge, 7,278,000 acre feet.  
 Gauged Data: median annual discharge, 7,541,236 acre feet.  
 Median monthly values calculated for each month from period of record.  
 Median annual values calculated from annual runoff record.

Shasta Dam and associated water project operations have redistributed and dampened median monthly flows on the Sacramento River downstream of Red Bluff. The slightly greater annual median gauged value is due to the diversion of Trinity River flows into the Sacramento River.

**Data from California Department of Water Resources and U.S. Geological Survey.**

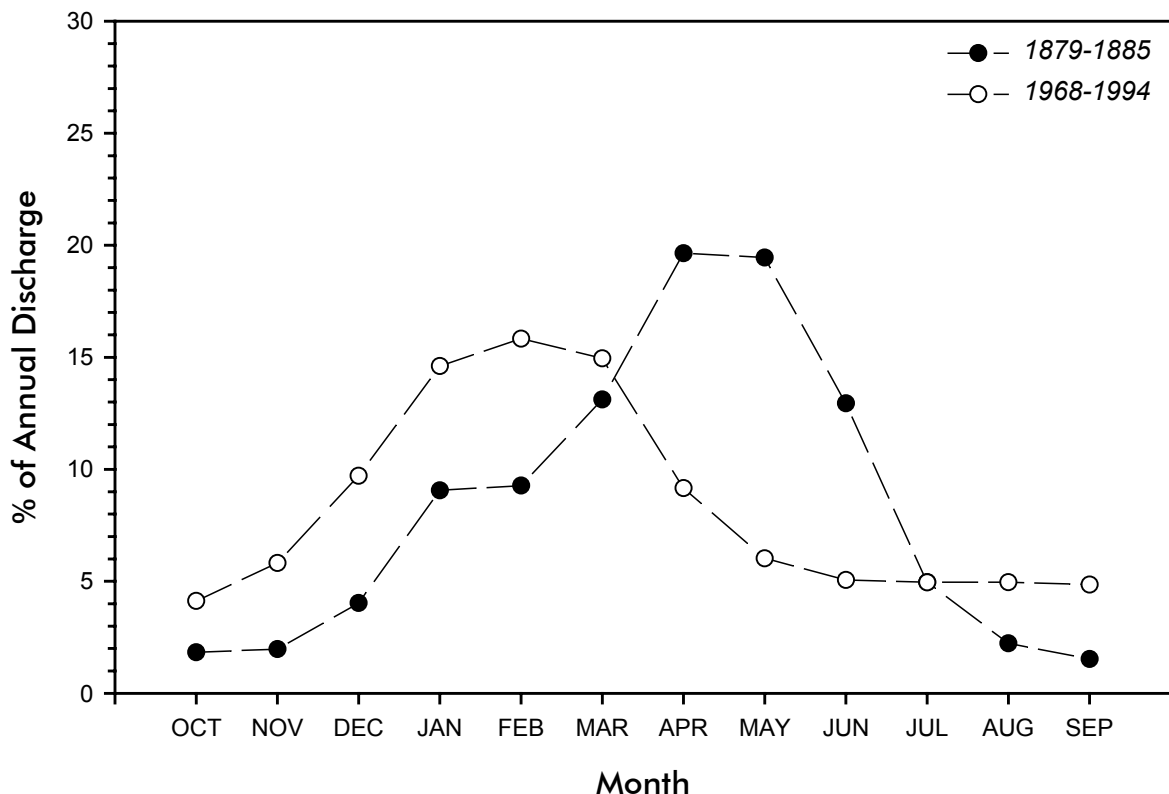
**Figure IV-B**  
**Alteration of Median Monthly Inflow into**  
**the Lowland Tuolumne and San Joaquin Rivers**



Reservoir operations, combined with canal diversions, have dramatically reduced flows and suppressed seasonal variability. Median monthly values calculated for each month from period of record. Median annual value calculated from annual runoff record.

**Data from California Department of Water Resources and U.S. Geological Survey.**

**Figure IV-C**  
**Estimated Alteration of Sacramento River**  
**Monthly Outflow Pattern**



Water project operations and modern land use practices have resulted in substantially lower spring flows and slightly greater late summer and fall flows into the Delta from the Sacramento Valley. The higher proportion of estimated historic spring flows may be partially due to a greater proportion of the annual flow derived from snowmelt during the 19th century compared to the latter half of the 20th century, which has had a higher proportion of the annual flow derived from winter rainfall runoff.

**Data from Hall 1887 and California Department of Water Resources.**

runoff has had the most dramatic effect on the April-June period. Mean outflow has been reduced in that period from nearly 50% to only about 20% of the total mean annual outflow. Today the highest mean flow months are January, February, and March. In terms of timing, variability and magnitude, San Joaquin River outflow has been altered even more drastically than that of the Sacramento River. In most years, the May-June snowmelt flood peak has been eliminated, total discharge reduced, and

seasonal variability nearly eliminated. Only in “wet” years is there a marked late spring outflow peak.

### **II.A.2. Delta Outflow**

Changes in the pattern of Delta outflow are similar to what Figure IV-C shows for the Sacramento River. It is impossible to precisely quantify the magnitude of the changes in total Delta outflow from the natural condition 150 years ago because of the lack of data (see Chapter 2, Sections IV.C.1.c and V.B.1.a). By the 1920s, when the first reliable estimate of Delta outflow was made (an estimate referred to as the computed Delta outflow which is based on the measured Delta inflow and the estimated net use within the Delta), the Delta outflow hydrograph had already been somewhat modified by the combined effects of natural vegetation removal, reservoir storage, irrigation withdrawals, channel changes, and elimination of the natural flood basin storage and release. Reductions in spring and summer outflow were the biggest impact of these early interventions. Continued urban and agricultural water development over the last 70 years has had further, and in many years much more significant, impacts on the pattern and magnitude of Delta outflow. The large dams and water transfer projects further reduce spring flows and often reduce winter flows while in some year types the summer flows are higher than what they were in the early part of the 20th century. Insight into the effects of the large water transfer and dam projects can be gained by comparing computed Delta outflow in 1921-43 (pre-project) period with that of the 1968-94 (post-project) period. Estimated mean annual Delta outflow during the pre-project period was only about 14% more than the post-project period, but that number must be considered in the context of precipitation differences between the two compared periods. The net effects of water resource development were somewhat greater than a measured 14% outflow decrease would indicate, because the post-project period of comparison was about 10% wetter. Because of a general trend of increasing precipitation over the 1921-1990 period, Fox et al. (1990) concluded that there was no statistically discernible trend in Delta outflow over the entire period. Nonetheless, when all but the “wet” year types are examined, annual Delta outflow is 30% to 60% less than comparable years of the pre-project period, with even greater percent reductions in spring outflows in some year types.

### **II.A.3. Floods**

The frequency and magnitude of flood events has been substantially altered throughout the system. Although the system had been modified in many ways by the early part of the 20th century, recorded data from that period (prior to the development of massive water management infrastructure) may be used to indicate the general nature of the differences between modern and historical conditions. First, flood frequency has been

reduced. In the Sacramento Valley, the historical 2-year flood (occurring once in every 2 years on average) now occurs once every 7 to 13 years on average, and the “natural” 10-year flood every 100 years. Also, natural inter-annual variability in total flow has been suppressed. The frequency of small to moderate floods has been greatly curtailed, and heavy precipitation leads instead to uniform prolonged winter and spring flood releases with little variability. During large floods, releases are increased, but not to historical levels. On a valley-wide basis, the volumes of large floods remain largely unchanged, although only in very heavy snowpack years do flood flows approach historical levels in the San Joaquin Valley. Rather than regularly spilling out onto floodplains, flood flows today are instead confined to the river channels (or bypass channels) and quickly conveyed out of the river systems and into the lower estuary and the Pacific Ocean.

#### **II.A.4. Estuarine Circulation**

The changes in the volume and pattern of Delta outflow documented above have substantially modified estuarine hydrodynamics and ecosystems within the Bay and nearshore ocean that are dependent upon the temporal dynamics of the estuary (Cloern and Nichols 1985). Nothing is known about circulation and mixing in the natural system. However, it is evident, based on the above discussion, that significant modifications have occurred.

Changes in the volume and pattern of Delta outflow would have fundamentally altered estuarine circulation patterns, modifying biological and chemical (i.e., nutrient) exchanges between the Bay and nearshore ocean. Circulation and mixing can influence the retention or advection of young fishes and their food organisms. Fresh water inflows induce gravitational circulation in Bay waters caused by significant differences in salinities in the landward-seaward direction. Heavier saltier bottom waters move landward or toward the east and lighter surface waters move seaward at the water surface. It is generally believed that larval organisms, shrimp, and fish near the bottom in the Central Bay and nearshore ocean are transported into the northern reach of the Bay during high Delta discharges (Smith 1987), contributing to the diversity of the rich estuarine environment. In the so-called entrapment zone, bottom and surface velocities are equal, and the interaction of tidal currents with gravitational circulation retains fish in the upper estuary, allowing them to co-occur with patches of food. Estuarine circulation is dominated by tidal mixing, rather than gravitational circulation, during low flows, resulting in the loss of organisms from their optimal habitat by diffusive or advective processes (Bennett and Moyle 1996, Arthur et al. 1996).

Probably the greatest hydrodynamic modification of the Bay has been the almost total elimination of gravitational circulation in the South Bay, which today is more like a

salty lagoon than an arm of a resilient estuary. Isotopic analyses of 167 fossil mussel shells suggest that South Bay salinity over the past 2,400 years was 2.1 ppt lower than at present (Ingram et al. 1996). Today, the South Bay receives negligible fresh water inflow, and circulation is controlled by the tides and winds. Gravitational circulation is only induced by very high Delta outflows (Smith 1987, McCulloch et al. 1970). These events reduce bioaccumulation of metals by benthic organisms and reduce salinity and residence times (Luoma et al. 1985), flushing out the accumulated waste products of the huge populations and numerous industries ringing the South Bay. Likewise, in the northern part of the estuary, gravitational circulation has been fundamentally altered, which has probably reduced the suitable habitat for young fish and reduced the diversity and abundance of organisms transported into the Bay from the nearshore ocean.

Systematic reductions in flood frequency and magnitude have altered the spatial and temporal distribution of the surface freshwater plume (created by riverine discharge overrunning denser seawater) that extends across the surface of the Bay and westward into the nearshore ocean. It is probably less extensive and frequent than it was historically. This feature was historically most pronounced during high winter and spring outflows and flood events, which have been curtailed by water management. Nonetheless, surface salinities at Fort Point (just beyond the Golden Gate) still average about 31 ppt or about 2 ppt less than oceanic, confirming the continued persistence of the plume. However, salinity at the ocean boundary has increased by about 12 ppm per year since 1920, or by about 3% total (Fox et al. 1991), suggesting the plume has been somewhat diminished.

Finally, oceanic conditions can also affect estuarine fish, especially anadromous forms. El Niño events, such as those which occurred in 1976-77 and 1983, can significantly reduce ocean productivity, which can reduce growth and survival of fish such as chinook salmon and pacific herring (Bennett and Moyle 1996). Frequent and prolonged periods of rising ocean temperature, associated with frequent El Niño Southern Oscillations after 1976, have been implicated as a factor contributing to the decline of older striped bass in the Bay-Delta estuary (Bennett and Howard, 1998).

## **II.B. Sedimentology**

Today, sediment loads are generally greater than pre-mining values, which were limited by bedrock-dominated channels. Prior to mining, mountain channels had only thin patches of alluvium and were dominated by bedrock and coarse boulder material. Today, substantial amounts of mining debris remain in channels that drained gold mining regions (i.e., Feather, Yuba, Bear Rivers). These stored materials are readily reworked and entrained, resulting in sustained high transport rates that cause erosion

and deposition at channel cross-sections, terrace-scarp erosion, sedimentation in deltas, erosion downstream of modern reservoirs, and lateral channel migration. In the lower Bear Basin, for example, subsurface coring indicates that about 138 million cubic yards of mining sediment remain in storage (James 1989). Reservoir sedimentation data indicate that delivery rates for the upland rivers of the heavily mined basins remain two to eight times greater the natural rates (Kattelman 1996).

Dams, in addition to storing flows, intercept and trap the sediment eroded from the upper watershed, preventing its natural downstream transport. This affects waterway topography and morphology throughout the downstream portion of the system, frequently causing channel scouring and bank erosion (Mount 1995). Major foothill storage reservoirs typically capture most incoming sediment, including all of the bed load before discharge to the valley floor. Today, rivers below the dams have no source from which to replace sediments removed from their channels (and floodplains), save for below-dam erosion of upslope soils and channel beds and banks. Thus, sediment transport through the river system has been greatly altered. There has been a net loss of sediment delivery from the upland system to the Sacramento River, and the main local source (bank erosion) is now prevented or inhibited in many locations by levee armoring. Without the natural protection afforded by heavier sediments, rivers erode channel beds and banks to a greater degree, changing channel morphology. Sediment transport on upper river reaches has been altered even more on the San Joaquin side of the valley. In the lower part of the river, where finer sediments dominate, sediment supply and distribution does not appear to have been as dramatically altered, and net long-term sediment discharge to the estuary appears to still be above natural levels.

Almost all the sediment delivered to the Delta is transported by alluvial rivers, with about 90% of it now supplied by the Sacramento River. Today, watershed delivery rates to the estuary are higher than those believed to have occurred naturally (i.e., prior to human intervention), but it is likely that almost all sediment conveyed by the Sacramento River passes through the Delta in suspension, and is discharged instead in Suisun Bay. In San Francisco Bay, mudflats are starting to erode, while net sediment gains continue in deeper areas. Subtidal areas of the Central Bay are also showing net accretion.

### **III. Changes in Habitats and Biological Communities**

#### **III.A. Upland River-Riparian Ecosystems**

##### **III.A.1. Habitat Changes**

While much of the mountainous region surrounding the Central Valley remains comparatively remote, over 150 years of human intervention have nonetheless taken a toll. A recent comprehensive study concluded that, “*aquatic/riparian systems are the most altered and impaired habitats of the Sierra Nevada*” (SNEP 1996). Moyle and Randall (SNEP 1996) recently evaluated 100 Sierra watersheds, and concluded that only 7 (all undammed) were in “excellent” condition, and assigned the highest scores to Deer Creek, Mill Creek, and Clavey River. Perhaps the most notable and pervasive overall changes in the structure of upland river-riparian systems have been the loss and degradation of riparian zones, and the fragmentation of once-continuous river reaches. At least 620 mi (1,000 km) of historical length of riparian zone is now covered by standing water, and of 130 watersheds studied, almost all (121) now show substantial gaps in the riparian zone (Kondolf et al. 1996). Recently, it was estimated that about 95% of 3,000 acres (1,200 ha) mapped as riparian hardwood forest had no old growth characteristics intact, with the only remaining old growth in deep, inaccessible river canyons (Franklin and Fites-Kaufmann 1996).

The removal of the riparian zone by logging has locally increased stream temperatures in upland areas, resulting in shifts in biological assemblages. Salmon (*Onchorynchus spp.*), brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*), species that were either native (salmon) or introduced (trout), prosper in streams that are between 50°F and 64°F and may die if water temperatures exceed 75°F, depending upon acclimation temperatures, pH, and dissolved oxygen (Patton 1973). Timber harvest has locally resulted in the replacement of these high-value, cold-water fish species with warm-water fish (McGurk 1989).

The once-continuous network of channels stretching from high elevations to the valley floor and beyond is now dissected by dams, dip crossings in roads, and water diversion structures, and other barriers into a series of disconnected reaches (Figure G3). It has been estimated that because of such barriers, about 82% (Yoshiyama et al. 1996) to 95% (CDFG, 1993) of historical salmon spawning and holding habitat in the Sacramento-San Joaquin system is no longer accessible to these fishes (Figures G2, G3). Construction of Shasta and Keswick dams alone blocked about 50% of the spawning and nursery habitat previously available to chinook salmon in the Sacramento River (Moffett 1949). The amount of large woody debris in streams, which normally originates in nearby forests, has declined markedly throughout much of the Sierra, simplifying in-stream

habitat. Downstream of dams, altered channel morphology, turbidity, flows, and benthic sediment characteristics are widespread.

Sediment-depleted waters scour out spawning gravels below some dams, decreasing suitable salmon spawning habitat. The timing of reservoir releases are also frequently incompatible with migratory, spawning, and rearing habits of anadromous fishes. Large releases during the egg incubation period, or immediately after hatch, can scour spawning gravels, removing the eggs. Low flows during the early migration of young can interfere with their ability to reach the ocean (Mount 1995).

The water temperature distributions throughout the system have also been modified by various water storage and transfer facilities. Since the beginning of the impoundment of Sacramento River water in December 1943, maximum daily water temperature for some distance downstream from Shasta Dam became cooler than previously existed in the summer, creating new habitat where none formerly existed. However, it also resulted in temperatures somewhat warmer than those previously existing in late fall or early winter. These warmer temperatures have had detrimental effects on egg development, feeding ability, growth rate, benthic productivity, and other factors related to the survival of chinook salmon (CDWR 1988). Generally, shifts in temperature distribution adversely impact native fish assemblages, which need relatively cold water to survive and thrive. In the recent past, temperatures in the upper Sacramento River and its tributaries have often exceeded 56°F (13°C), temperatures that may have killed about 15% of the winter-run chinook produced in 1992.

Water quality problems continue to plague much of the upper watershed. Acidic, sediment-laden mine drainage, high in heavy metal concentration, continues to adversely affect nearby streams. Particularly toxic substances, including arsenic and mercury, remain in the proximity of inactive gold mines or in downstream sediments of the Feather, Bear, and Yuba River watersheds. Toxic discharges from numerous abandoned mines continue to cause violations of state standards on four metals - cadmium, copper, mercury, and zinc. Elevated concentrations of copper, cadmium, and zinc have been found in waterweed (*Elodea canadensis*), aquatic insects (midge larvae, mayfly nymphs), and fish (chinook salmon, Sacramento squawfish, Sacramento sucker, threespine stickleback) in streams receiving acid-mine drainage compared to reference streams (Saiki et al. 1995). In addition, water quality is adversely affected by increased sedimentation and erosional processes that result from overgrazing and bad forestry practices. Elevated sediment input may smother fish eggs and cause greater water column turbidity, which increases individual susceptibility to predators.

### **III.A.2. Changes in Biological Community Structure and Function**

Invertebrate assemblages of upland streams are known to be sensitive to changes in flow regime, temperature, predation pressure, sediment transport and deposition, herbicides and pesticides, and the availability of substrate such as woody debris (Erman 1996). Although largely undocumented, the abundance, diversity, and species composition of aquatic invertebrate assemblages have probably changed in many parts of the upland riverine system as a result of changes in such factors, as well as other alterations of habitat quality and extent (see above). The most comprehensive recent report on Sierra ecosystems (SNEP 1996) concluded that “*local degradation of habitats has led to significant impacts on aquatic invertebrates, which make up the vast majority of aquatic species in the Sierra Nevada.*”

Non-native fishes are now widespread and abundant throughout much of the upland system. Introduced trout, in particular, continue to affect the distribution of a wide range of native benthic macroinvertebrates, as well as of native fishes, amphibians, and zooplankton. Historically, trout were absent above approximately 6,000 feet in the Sierra Nevada. Many aquatic organisms in these reaches lack the defense mechanisms needed to cope with such predators. The decline of at least one amphibian species, the mountain yellow-legged frog (*Rana muscosa*), has been attributed to predation by introduced trout (Knapp 1996). Reservoirs, particularly low elevation reservoirs, harbor introduced species which continually invade upstream reaches disrupting native aquatic assemblages.

Changes in riparian vegetation assemblages of the Sierra Nevada have recently been documented (SNEP 1996), and it is likely that most of the changes noted in that study may be extrapolated to most of the remainder of the upland system as well. Graber (1996) estimated that as many as 25% of the species dependent upon riparian habitat of the region are now at risk of extinction. At all elevations, “*amphibian species have severely declined throughout the Sierra Nevada,*” with over half of the 29 native species now at risk of extinction (Jennings 1996). Such effects are known to be commonly associated with riparian habitat fragmentation and degradation (Jennings 1996). In general, bird populations associated with riparian habitat have also declined (Ohmart 1994; Manley and Davidson 1995), and the ranges of some have become more restricted (Harris et al. 1987). The least Bell’s vireo, once common in many areas, has now been extirpated from the Sierra Nevada. For a comprehensive list of threatened or endangered species of the Sierra Nevada, readers are referred to the final report of the Sierra Nevada Ecosystem Project (SNEP 1996).

Nutrient composition, concentration and distribution have been substantially altered throughout much of the upland waterways. Although definitive historical data that

would allow quantitative comparison is lacking, the noted loss of riparian habitat along with a huge reduction in spawning salmon - two major sources of nutrients in upland streams - has unquestionably led to a general and seasonal decrease in nutrient availability in many cases. Another notable change has been a general reduction in both flood frequency and seasonal shifts of upland stream levels, alterations that inherently inhibit the transfer of nutrients between remaining riparian zones and their streams, thereby altering food webs and nutrient dynamics. For example, Wooten et al. (1996) concluded, from a study of Central Valley rivers, that a reduction in flood disturbance in this system routed energy away from predatory fish and into an alternate pathway of predator-resistant caddisflies. For the most part however, documentation of such effects is lacking.

### **III.B. Lowland River Floodplain Systems (Sacramento and San Joaquin)**

#### **III.B.1. Habitat Changes**

The extent and morphology of aquatic habitat in the lowland system is considerably different than it was at the beginning of the last century. Tulare Lake is now converted to agriculture, and its tributaries are hydrologically disconnected from the San Joaquin River except in wet years. Today, many of the rivers crossing the Central Valley alluvial floodplain are generally constrained in straightened leveed sections. Over 150 miles of the Sacramento River banks are now lined with riprap, an armor layer of rocks placed on river banks or levees to control erosion. This has resulted in less complex, deeper channels contained between levees which now rise up to 15 to 20 feet above the surrounding countryside. Riprap inhibits natural erosional processes, as well as groundwater exchange by interfering with absorption. Confinement of the main channel between riprapped levees and loss of bordering riparian vegetation also greatly simplified natural habitat complexity by eliminating most meander cutoffs and oxbows, pool/riffle sequences, sunken woody debris and other irregularities. Structural characteristics of benthic (river bottom) habitat throughout the Central Valley have been substantially altered by changes in natural sediment supply from the upland system, and local transport and deposition patterns.

An extensive series of screened and unscreened agricultural diversions of varying size unnaturally connect rivers and agricultural lands. These structures siphon off unknown (in their totality) quantities of water, and on occasion eggs, larvae, and small aquatic organisms, including juvenile fish, which are sometimes discharged into farm fields.

The loss of lowland riparian forest has substantially degraded riverine habitats, altering temperature regimes, eliminating essential habitat, and increasing siltation from unprotected soil. Overhanging vegetation in near bank areas, abundantly documented

in the natural system from eyewitness accounts, historically provided a rich source of food for juvenile fish in the form of terrestrial insects and important thermal refugia for fish. Shade and cool air temperatures from the deep riparian forests extended across some part of the river's surface, decreasing net heat flux at the air-water interface. Large woody debris introduced into the river from surrounding riparian forests through natural erosion and deposition provided physical cover for small fish, creating low velocity holding areas. Finally, the erosion/deposition cycle associated with riparian zones supplied gravel for successful spawning and egg incubation (Orlob and King 1997). These important habitat attributes are no longer present throughout most of the former riparian zone of the Central Valley.

The early harvesting of riparian forests undoubtedly increased river temperatures. Recent studies at two sites along the Sacramento River demonstrate that riparian zones decrease stream temperatures in nearshore areas by up to about 2°F between the hours of 0600 and 1800, compared to the main channel and unshaded nearshore areas (Orlob and King 1997). Another study conducted in the upland area reported a 10°F rise in temperature through a 1,250 foot section after clearcutting the bordering fir forest along McGill Creek in the Upper Sacramento Basin, 38 miles northeast of Redding (McGurk 1989).

Numerous studies suggest that temperatures in the lowland rivers today frequently exceed levels considered to be detrimental to juvenile native chinook salmon. Adequate temperature regimes are critical to the survival of salmon. Spawning adults are susceptible to lethal disease when temperatures reach 61°F. Juvenile salmon become more susceptible to diseases, parasites and predation when temperatures exceed 60°F. A temperature of 64°F results in a 20% reduction in growth rate for ration levels of 60% of maximum. About 50% of juvenile salmon die when temperatures reach 73°F (Baker et al. 1995; Orlob and King 1997; Mitchell 1987; CDWR 1988; Brett 1952; Seymour 1956).

Between 1978 and 1986, the temperature at four locations along the Sacramento River between Butte City and Rio Vista exceeded 64°F 14 to 16 days in May and 27 to 28 days in June (Mitchell 1987). In comparison, between September 15, 1885 and September 15, 1886, the only historical period for which temperature data are available (and after a considerable portion of the riparian forest had been harvested), the water temperature at Sacramento exceeded 64°F only 2 days in May and for the entire month of June (Buckingham et al. 1886). Since 1977, the average spring temperature of the Sacramento River has increased 2°F to 4°F (Reuter and Mitchell 1987).

Water quality remains severely degraded throughout most of the Central Valley waterways. Inactive mine discharge, and urban and agricultural runoff are still problematic, and contribute hydrocarbons, pesticides, metals, and other harmful

chemicals to lowland waters, causing chronic and acute toxicity to sensitive birds, fish, invertebrates, and algae in some places. Discharges from abandoned mines in the upland system, although highly diluted by the time they reach most of the lowland system, nonetheless continue to contribute to water quality problems there (see Chapter 3, Section II.E, Mining). Urban runoff alone is estimated to annually contribute up to 3,600 tons/yr. of hydrocarbons, PCBs, metals, and chlorinated hydrocarbon pesticides to Central Valley waterways (SFEI 1987, Montoya 1987).

Floodplain habitat has also been dramatically altered. The historical 2-year floodplain along the Sacramento River channel is now a narrow terrace, while the frequently inundated portion of the floodplain is limited to the area between the levees and the flood bypass channels (Figure G5). Many miles of meandering natural backwater sloughs have been eliminated, replaced by straightened, lightly-vegetated drainage ditches whose flow levels are carefully controlled and discharged back to the river. Most of the natural flood basins are now only connected with the river system during floods, usually via the controlled flows in the bypasses. As a result, the once extensive riparian zones and wetlands that historically bordered lowland rivers and occupied much of the flood basins have been almost entirely lost, mostly converted to agricultural production.

Less than 5% of historically mapped wetlands remain (Figures G5, G7, G9), and many backwater areas previously connected to the river channel are now effectively isolated. Much of the current wetland acreage shown on Figures G5, G7, and G9 does not occur on what the 19th century surveyors mapped as permanent wetlands, but rather occurs on what is shown in Figures G4 and G6 as other floodplain habitat, which included seasonal wetlands. The current wetlands largely occur in state and federal wildlife refuges and private duck clubs and nature preserves. They are intensively-managed areas generally not naturally connected to the rivers. Instead they have artificial hydrologic regimes, the primary goal of which is the manipulation of water levels to optimize wintering waterfowl habitat, or more specifically to provide better duck hunting opportunities. Typically, these wetlands are flooded in October and drained in the early spring.

The riparian acreage that exists today in the Sacramento and San Joaquin Valleys is estimated by Katibah (1984) to be about 102,000 acres, or about 11% of the historical riparian habitat he conservatively estimated. Katibah (1984) estimated that nearly half of the remaining acreage is disturbed or degraded and most of the balance “*is heavily impacted by human activities.*” The current riparian acreage shown on Figures G5 and G7, which is derived from the California Department of Fish and Game’s Wetlands and Riparian Geographical Information System Database, equals about 56,000 acres or about 6% of the historical riparian zone acreage in the Sacramento and San Joaquin Valley (as

discussed in Chapter 2, Section IV.A.2.a, the actual historical vegetated acreage is somewhat less than the riparian zone acreage). Most existing riparian vegetation occurs as narrow, fragmented patches less than 100 yards wide and confined to bank slopes of streams and sloughs, abandoned meanders, or on the river side of artificial levees (Thompson 1980). Remaining fragments of the riparian zone are also, in most cases, structurally simplified. The complex terraced topography and natural riparian successional processes that naturally support and maintain a diverse mixture of successional stages and plant associations have been largely eliminated by the suppression of flood flows. Channelization has effectively limited the width of the riparian zone, and continues to prevent the natural re-establishment of high terrace, mature riparian forest assemblages (see Chapter 2, Section IV.A.2.b).

### **III.B.2. Changes in Biological Community Structure and Function**

Major changes evident in native plant associations bordering the lowland rivers were discussed above in the context of habitat changes. As with the upland river system, a general lack of historical information on the nature of most animal assemblages here makes it difficult to quantify, or in some cases even qualitatively describe many of the most notable changes that have undoubtedly occurred. This is particularly true of smaller, less conspicuous organisms such as benthic invertebrates and riparian insects.

The herds of large mammalian herbivores - deer, antelope and elk - and their mammalian predators that once depended upon the forests and marshes have been reduced to a few scattered remnant populations, a fate also endured by many of the small mammals that typically occupied these habitats. This has undoubtedly had substantial effects upon riparian and wetland habitat complexity and diversity, as well as on community structure and processes (Naiman and Rogers 1997). Some mammals, like the once-plentiful grizzly bear, are nowhere to be found in today's Central Valley. Bird populations and species diversity in these ecosystems have been particularly hard-hit, with many once-common species including the double-crested cormorant (Belding 1878), great blue heron and great egret (Cogswell 1956), Cooper's hawk (Dawson 1923), bald eagle and yellow-billed cuckoo (Grinnell 1915), now decimated or gone completely. Waterfowl that once blackened the skies above Central Valley marshes are present today in far fewer numbers.

In many cases, native fish assemblages of the lowland rivers no longer exist as such, and today "*the fish fauna of the valley floor is dominated by introduced species*" (Brown 1996; p. 13). At a number of sites examined by Saiki (1984), over 70% of the species present were non-native. The thickettail chub is now extinct, and the Sacramento perch has been displaced from the major portion of its range on the valley floor. The best remaining examples of native fish assemblages of lowland rivers now are found in the foothills,

but even these are declining (Brown and Moyle 1987, 1992). Probably the best remaining example of native Central Valley fishes in the entire watershed is found in Deer Creek (Moyle and Baltz 1985).

The loss of large areas of riparian forest and marshes, along with the noted geomorphic and hydrologic alterations, has severely altered the nutrient dynamics of lowland river-floodplain ecosystems. In the minimal amounts of natural floodplain habitat remaining, it is only during extreme floods that river waters exchange materials and organisms with their riparian zones today. Rather, most nutrients that reach the rivers today are in the form of agricultural return water, livestock and industrial wastes, and municipal effluents. The natural composition, amounts, and seasonal timing of nutrient influx from the upland system, much of which was historically transported by now-extirpated large mammals, has also been disrupted. These factors, in combination, have undoubtedly led to highly modified food webs and energy/nutrient pathways (Wooten et al. 1996, Naiman and Rogers 1997).

### **III.C. The Delta**

#### **III.C.1. Habitat Changes**

The Delta of today bears little resemblance to its historical condition (Figure G11). Today, over 95% of the original 350,000 acres (550 mi<sup>2</sup>) of tidal wetlands and many miles of historical tidal sloughs are gone, as is most of the riparian vegetation that once bordered the larger waterways. In its place, are a patchwork of agricultural “islands,” straightened and deepened channels, riprapped levees, and the flooded remnants of former wetlands now too far underwater to allow the re-establishment of emergent vegetation. Only a few isolated pockets of somewhat “pristine” tidal and non-tidal wetland habitat still exist on the interior of some Delta islands (Atwater 1979).

State and Federal pumping plants near Tracy and Banks now link the natural Delta waterways with Federal and State aqueducts. Approximately 1,800 unscreened agricultural diversions provide links to nearby farms. Pollution remains a serious and continuing concern. The combined effects of municipal and industrial dischargers along with agricultural runoff and residual contaminants continue to pose a serious threat to Delta water quality, particularly in dead-end sloughs that have poor circulation and exchange. Boating in Delta waterways has grown rapidly, and presents a relatively new major source of pollutants, as well as resulting in continual re-suspension of sediments and loss of subtidal vegetation, particularly in shallow areas.

Today, as in the past, Delta waterways generally contain fresh water. Intrusions of brackish water into the western edge of the Delta commonly occur in the late

summer/early fall as they did under natural conditions. Occasional intrusions into the western Delta can also occur today during the springs and early summers of dry years when river outflow is disproportionately reduced. This differs from the 19th century pattern in which spring outflow was probably high enough in nearly every year to keep brackish water out of the Delta until the summer. Under natural conditions, however, brackish water probably spread further east into the Delta during dry periods compared to current conditions in which reservoirs are managed to maintain freshwater consumptive uses in the central and eastern Delta.

Currently, salinity in the Delta and Suisun Bay is controlled during much of the year by reservoir releases designed to protect agriculture, urban water supplies, and aquatic organisms (SWRCB 1995). Statistically significant relationships have been demonstrated between the position of the 2 ppt isohaline (X2) and the abundance of estuarine species, including striped bass, *Neomysis*, *Crangon*, starry flounder, and the base of the food chain, phytoplankton-derived particulate organic carbon (Jassby et al. 1995). Some of these relationships appear to have weakened somewhat and shifted downward since the introduction of *Potamocorbula* in 1986 (Kimmerer 1998). Aquatic organisms are now protected during February through June by requiring minimum flows at Collinsville (confluence of the Sacramento and San Joaquin Rivers), and by controlling the number of days that X2 is present at Chipps Island and Port Chicago.

One hundred and fifty years ago, detrital food webs were supported by vast amounts of organic carbon from the rich intertidal wetlands. These detrital food webs probably dominated community energetics within the upper estuary, providing widely-distributed high-quality habitat for aquatic estuarine species both upstream and downstream of Suisun Bay. With suitable habitat and food plentiful throughout the area, fishes could move about freely to rear, spawn, or adjust to salinity variations (see Chapter 3, Sections II.B.1 and 2). The modern focus on the position of the mixing zone in Suisun Bay in part reflects the loss of this formerly more widely distributed habitat.

### **III.C.2. Changes in Biological Community Structure and Function**

The combination of habitat loss and successful invasion by a virtual army of non-native species has almost completely obliterated the natural biological community of the Delta. Benthic assemblages are dominated by non-natives, particularly five species of filter feeders. Two of the three historically dominant fish species are no longer found in the Delta: Sacramento perch (extirpated in the Delta) and thicketail chub (extinct). The historical resident fish fauna of 29 species has been replaced by a modern assemblage of 58 species, with non-natives such as threadfin shad, carp, white catfish, inland silversides, and striped bass now the most abundant species (Herbold and Moyle 1989). Waterfowl, once extremely abundant in the Delta's tidal marshes, are now drastically

reduced in numbers. Even so, at least 26 species of waterfowl (two swan, four goose, and 20 duck species), still take refuge here in high numbers during the winter months. Large members of the once diverse and abundant native mammalian fauna such as tule elk and grizzly bears, showed rapid declines following the reclamation of Delta islands. Smaller species, such as river otters, beaver and muskrat, were greatly reduced due to unrestricted fur hunting until early wildlife conservation laws were enacted. These species now occur in varying numbers at scattered locations in the Delta. Other species, such as raccoon and opossum, have altered their habits to exploit new Delta habitats.

The sources, composition, amounts, and disposition of organic carbon and nutrients within Delta food webs have been greatly modified. Today, most of the original marshes are gone, and the food web of the Delta is instead highly dependent upon primary production by Delta phytoplankton (mainly diatoms), or organic contributions from upstream rivers. Changes in the contribution of nutrients entering the Delta from upstream are difficult to document, because the comparative rates at which riverine nutrients were consumed then and now is largely unknown, as are the comparative overall residence times (i.e., the time available for consumption) in the Delta. Discharges from waste-treatment plants, urban runoff, and the transport of fertilizers from agricultural runoff also contribute to modern organic carbon sources in the Delta. Food webs have been drastically altered. Introduced copepods replaced the historically abundant *Eurytemora affinis* as a dominant element of the system's zooplankton communities. An even more ominous problem for phytoplankton communities appears to be related to the recent introduction of an Asiatic clam, *Potamocorbula amurensis*, to the western Delta and San Francisco Bay. The population has exploded, and has the capacity to consume incredible quantities of phytoplankton. The filter-feeding freshwater Asiatic clam (*Corbicula fluminea*) may also attain very high densities at times (Cohen 1991). Recent extensive discussions of modern Delta food webs and trophic dynamics are provided by IEP (1995) and Herbold et al. (1992).

### **III.D. San Francisco Bay**

#### **III.D.1. Habitat Changes**

San Francisco Bay has undergone major habitat alterations over the course of the last 150 years (Figure G13), primarily from farming, salt production, and urbanization (Monroe and Kelly 1992). The topography of the Bay floor continues to be periodically disturbed by dredging and maintenance of shipping channels. Millions of cubic yards of sediment are dredged annually for such purposes (Cohen 1991). Changes in upstream hydrology and erosion, sediment transport and deposition rates have affected sediment types and distribution, and therefore benthic invertebrate assemblages throughout the Bay (Nichols 1979).

Bay filling and diking have decreased the open-water areas and wetlands of the Bay by raising what were naturally subtidal areas to intertidal or supratidal elevations. Pelagic (open water) habitat is perhaps the least altered, although some changes are clearly evident. Open water areas (bay and major tidal channels) have decreased by about 7%, from about 274,000 acres to 254,000 acres. Deep bay and channel (>18 ft) have decreased more (from about 100,000 acres to 83,000 acres) than shallow bay and channel (from about 174,000 acres to 172,000 acres) (SFEI 1998, Figure G13).

Intertidal habitat has been severely modified throughout the Bay's margins. Of some 51,000 acres of channel and Bay tidal mudflats that existed under natural conditions, 58% or about 29,000 acres remain today. Natural wetlands, land that was once subject to natural tidal action, historically occupied about 192,000 acres of the Bay's margin. Today, only 21% or some 40,000 acres remain and some of that is degraded. The balance has been converted to other uses, including 9,000 acres to diked wetlands and another 54,000 acres to managed wetlands, mostly in Suisun Bay; 32,000 acres to farmed and grazed baylands, mostly in the North Bay; 37,000 acres to salt ponds in the San Pablo and South Bays; and the balance (about 20,000 acres) to urban uses in the Central and South Bay (SFEI 1998).

A general lack of accurate historical information prohibits quantitative description of possible changes in the extent of rocky intertidal habitat in the Bay. However, it has been documented that the introduced boring isopod *Sphaeroma quoyanum* has altered rocky intertidal habitat topography on many Bay shores, weakening the rock and thereby facilitating its removal by wave action. At some sites the land/water margin may have retreated by a distance of at least several meters due to this isopod's boring activities (Cohen and Carlton 1995).

Habitat characteristics of the water column include vertical stratification, tides, salinity distribution and water quality, all of which have been somewhat modified by human intervention. Early observers noted changes in tides. A riverboat captain who spent his life plying the Bay and upland rivers from the 1860s to 1914, noted in his memoirs that *"the tides at the ferry landing at San Francisco (and in fact on the city front generally) are not so strong as in former years. The reason is that the by-passes on the Sacramento River -- such as the cut from Rio Vista to the lower end of Horseshoe Bend -- do not allow the winter water to accumulate in the Delta regions. All the water from the river-floods goes through Raccoon Straits or around Angel Island point out the Golden Gate to the Sea. As the young flood tide 'makes,' the river water presses it out to the city shore, and as the flood strengthens, it forces the river water toward the city, then in time -- for a short while -- the flood joins forces with the river water and this is called the bore"* (Leale 1939).

The current average annual salinity of the Bay appears to be within the range of that experienced over the last several millennia (Ingram et al. 1996, Peterson et al. 1989, Conomos et al. 1979, Fox et al. 1991). However, human interventions have unquestionably altered the temporal and spatial salinity distribution patterns within the estuary, particularly during dry years, through alteration of Delta outflow. Salinity has generally increased since 1920 from February through June and decreased at other times (Fox et al. 1991).

Water quality has been severely degraded. Some 41 municipal wastewater treatment plants, six refineries, and a number of other major and small industrial facilities discharge over 750 million gallons per day of treated wastes into the Bay, but as a result of substantial recent improvements in treatment, these discharges are far less problematic today than in the recent past. Instead, urban runoff is now the principal source of pollutants, contributing up to 13,000 tons/yr to the Bay, of which 90 percent is hydrocarbons (SFEI 1987, Montoya 1987).

### **III.D.2. Changes in Biological Community Structure and Function**

Descriptions of the historical Bay tell of a body of water that “*stretched farther than the eye could see, abounding with game, fish and fowl of all kinds*” (Thompson 1957). Habitat alteration, overhunting and fishing, pollution, and the successful invasion of many exotic species have all contributed to sweeping changes in this picturesque description of the natural richness and diversity of the native Bay biological community.

The successful establishment of non-native species constitutes the most pronounced change of the past 140 years, an alteration frequently associated with changes in nutrient dynamics and alterations of habitat structure (Zedler, personal communication), both of which have characterized the last 150 years of the Bay’s history. Benthic invertebrate assemblages are perhaps the most altered (Nichols 1979). Of all the presently common species, only the polychaete *Glycinde spp.* and the bivalve mollusks *Macoma balthica* and *Mytilus edulis* are considered natives (Nichols and Pamatmat 1988). The Asiatic clam (*Potamocorbula amurensis*) is probably the most significant introduction to the estuary. It is capable of achieving densities that allow local populations to filter the entire water column over the channels more than once per day. Dungeness crab (*Cancer magister*), which was historically abundant in the Bay (Skinner 1962), persists at low levels today (Herrgesell et al. 1983).

Plankton assemblages appear to have been substantially altered. The introduced *Acanthomysis spp.* was reportedly more abundant than the native opossum shrimp *Neomysis mercedis* by 1994 (Cohen and Carlton 1995). Phytoplankton growth rate in San Francisco Bay is currently controlled mainly by light, with nutrient concentrations

having little or no effect except when they are depleted during blooms (Nichols and Pamatmat 1988). Since the appearance of *Potamocorbula*, the summer phytoplankton bloom in the North Bay has disappeared. The primary mechanism now controlling phytoplankton biomass in the South Bay during summer and fall is believed to be filter feeding by the introduced Japanese clams *Venerupis* and *Musculista* and the Atlantic clam *Gemma* (Cohen and Carlton 1995).

There is evidence suggesting that fish assemblages of the Bay west of Carquinez Strait have been substantially modified over the last 150 years. Drastic reductions in commercially harvested populations were noted by the end of the 19th century (Jordan 1887), and persist today. As in the past, Central and South Bays still harbor an assortment of marine fishes. San Pablo Bay harbors a resident assemblage of typically estuarine species which, at times of increased salinity, is augmented by upstream movement of marine species from Central Bay (Herbold et al. 1992). A major species shift occurs east of the Carquinez Strait in Suisun Bay, which today is typically occupied by a characteristic six-species assemblage (which includes the introduced striped bass (*Morone saxatilis*), although this group is subject to some temporal instability in terms of species composition (Herbold et al. 1992).

Tidal wetland plant assemblages have remained relatively intact where this habitat still exists, with few successful introductions (Josselyn 1983; Atwater 1979), although a non-native marsh grass (*Spartina alterniflora*) has become established in San Francisco Bay and is now believed to be competing with native plants. However, native animal assemblages of the remaining Bay wetlands have not fared so well; “*The distribution and abundance of invertebrates in tidal marshes [of San Francisco Bay] have been altered greatly through intended or inadvertent introductions and vector control activities...The result is a mix of species unlike any other along the west coast of North America, even in comparison to nearby embayments like Bodega and Tomales Bays*” (Josselyn 1983; pg. 57). The introduced Atlantic mudsnail *Ilyanassa* is likely playing a role in altering the diversity, abundance, size distribution, and recruitment of many species on intertidal mudflats (Cohen & Carlton 1995). Changes in the natural hydrology of the watershed have also contributed to these alterations (Hedgepeth 1979).

Bird populations have clearly declined in abundance and diversity over the last 150 years. Even with the massive reductions in population numbers of avian fauna, San Francisco Bay supports more than 57% of the total diving ducks in California (USFWS 1990 in SFEP 1991). The California clapper rail (*Rallus longirostris*) at one time was “*exceedingly abundant, a highly prized game bird and was one of the more common species in the San Francisco markets*” (Skinner 1962). Its populations have now been drastically reduced, warranting its inclusion on the federal and state lists of endangered species. Other species no longer common in the estuary which were known to be common

historically include the American white pelican (*Pelecanus erythrorhynchos*), American bittern (*Botaurus lentiginosus*), white-faced ibis (*Plegadis chihi*), tundra swan (*Cygnus columbianus*), trumpeter swan (*C. buccinator*), Canada goose (*Branta canadensis*), wood duck (*Aix sponsa*), California condor (*Gymnogyps californianus*), bald eagle (*Haliaeetus leucocephalus*), mountain plover (*Charadrius montanus*), snowy plover (*C. alexandrinus*), long-billed curlew (*Numenius americanus*), sandhill crane (*Grus canadensis*), long-eared owl (*Asio otus*) and short-eared owl (*A. flammues*) (USFWS 1990 in SFEP 1991). Populations of native mammals have also suffered irreversible declines (Josselyn 1983).

Trophic dynamics and food webs of the Bay have been highly modified. Nutrient production within the Bay has been curtailed by the loss of several hundred thousand acres of highly productive tidal marsh. Because of the exceptionally high production rates of tidal marshes, and their former extent of well over half a million acres in the estuary, this source historically constituted a major form of organic input to Bay waters. Today, this contribution is estimated to be only a few percent of total annual organic production, the balance of which is now primarily attributed to phytoplankton and benthic microalgae (Herbold et al. 1992). Additionally, the large amount of detritus previously reaching the Bay in the form of Delta export is gone.

### **III.E. The Nearshore Ocean**

#### **III.E.1. Habitat Changes**

Substantive information about the subtidal ecology of this system has become available only in the last 50 years. Thus, there is relatively little documentable evidence of habitat or community change for most of this system over the “historical” period that forms the basis of this report. Shoreline habitats throughout the region have been severely modified in many cases through extensive urbanization and development of beach areas for recreation. The natural dunes that once formed the landward margin of the area’s beaches have been largely destroyed, along with their natural vegetation and animal assemblages. Many rocky intertidal communities throughout the region have been ravaged by intensive trampling of curious but careless tidepool and shore explorers, and food gathering by local residents.

Sediment characteristics are known to be a primary determinant of benthic communities in the nearshore ocean (USEPA 1993). Sediment structure, particularly near the Golden Gate, may have been altered due to changes in large-scale sediment transport processes in the watershed over the last 150 years, which have changed the natural pattern of seasonal and annual deposition of fine-grained sediments associated with outflow from San Francisco Bay (SAIC 1992). Intensive fishing of these waters began in response to the rapid depletion of Bay fisheries in the late 19th and early 20th

centuries (Skinner 1962), but the nature and/or extent of benthic habitats that may well have been altered by many years of intensive bottom trawling has not been documented. Certain types of commercial fishing gear, particularly roller trawls, are capable of digging up large areas of benthic sediments and crushing outcroppings of reef-type habitat. A well-documented alteration of benthic habitat here was provided by the addition of structure to otherwise featureless sand plains in the form of hundreds of drums of radioactive waste dumped by the U. S. Navy. (Figure G14). This converted natural sand plains into reef-like habitat, two types of subhabitat that in this region (as with most inshore marine areas) are characteristically occupied by far different assemblages of benthic and demersal fishes and other forms of marine life (EPA 1993).

Documented changes in pelagic habitat of the nearshore ocean ecosystem are of two main types: gradual warming (which many now believe to be human-induced) and increased pollution. At nearby Monterey, annual mean inshore temperatures and mean summer maximum temperatures have increased during the last 60 years (Barry et al. 1995), with measurable effects on intertidal associations and vital ecological processes, such as upwelling and associated primary productivity. Such effects may also have occurred offshore of San Francisco Bay, but are undocumented. Pollution is generally not high offshore relative to inshore coastal sites of Central California (Nybakken et al. 1984; deLappe et al. 1980). Nonetheless, pelagic and intertidal habitats are occasionally affected by pollution, most of which appears to be derived from exchange with the Bay. For example, unexplained high readings of lead have been found in intertidal mussels (Nybakken et al. 1984), and elevated concentrations of dioxin have recently been reported in seabirds (and their eggs) within this region (Jarman et al. 1997).

### **III.E.2. Changes in Biological Community Structure and Function**

Not enough is known to make all but the most cursory comments on changes due to human intervention that may have occurred over the last 150 years in the biological community of the nearshore ocean. Continued harvesting of once-plentiful abalone and other shellfish that has occurred for the last 100+ years (Skinner 1962) has undoubtedly affected rocky intertidal communities, but the precise nature of these effects is unknown. Marine mammals are now under federal protection, and many populations along the coast, particularly those of the Farallon Islands, have made substantial recoveries in recent years, as have many seabird populations ravaged during the late 19th century by egg gathering (Skinner 1962). Salmon harvest is highly regulated, but wild stocks remain at alarmingly low levels. Most commercial salmon fishing today exploits hatchery produced fish, but recent estimates suggest that as many as 50% of endangered winter-run chinook returning spawners may be unintentionally landed now by sport and commercial boats (NMFS Biological Opinion 1996).

The nearshore ocean is subject to considerable short and long-term variability in terms of annual productivity, depending upon upwelling events and large-scale weather patterns and oceanic circulation patterns - processes that have been modified over the last century due to global warming. Analysis of possible effects of altered nutrient outflow from the Bay that has likely occurred over the last century on nearshore ocean productivity or community energetics are confounded by such considerations, and are therefore difficult to assess.

#### **IV. A Watershed-Scale Perspective**

The sections of this chapter have documented the many severe and more obvious alterations in hydrogeomorphic processes as well as the habitats and biological communities of this watershed. A summary of the alterations by ecosystem type over the last 150 years is shown in Table IV-A. In its totality, the scale of habitat loss and degradation and process alteration in this watershed is truly staggering. Large and complex river systems have been functionally (and to some degree structurally) converted into a series of managed storage facilities, pumps, and concrete-lined channels. The large areas of wetlands and riparian habitat have been reconfigured into the urban and agricultural landscape of the San Francisco Bay Area and Central Valley (Figure G3).

At the landscape scale, alterations of two main types of attributes emerge that transcend the ecosystem-scale alterations discussed above - extent/distribution relationships among component ecosystems (mosaic), and connectivity among component ecosystems. Unquestionably, the single most influential factor that naturally connected and integrated these aquatic ecosystems into a larger ecological unit (i.e., watershed) was the natural downstream movement of water and sediments. The migrations and movements of a comparatively few wide-ranging species played a lesser, but not trivial, role. Thus, in terms of system integration at the watershed scale, it is the fundamental changes wrought in system hydrology (see above) by human intervention over the last 150 years - changes *not* reasonably attributable to unusual climatic trends or events during this period - that appear to have had the greatest and most pervasive effects.

Figure G3 provides a watershed-scale appreciation of the natural habitat and stream connectivity lost during the last 150 years. Natural connectivity among ecosystems has also been highly modified through the construction of permanent basins (dams), the disruption of wetland and riparian corridors, and the loss of many of the watersheds' native larger wide-ranging fishes and wildlife that formed the natural biological links among watershed ecosystems. Two of the watershed's four wild salmon runs that existed at the time of the Gold Rush (spring and winter), each once numbering in the hundreds of thousands, have been drastically reduced in number and are now federally

listed. Gone also are the countless elk, antelope, and deer, and other large and small mammals and birds that regularly commuted between Central Valley waterways and the drier habitats of the woodlands and prairies, exchanging untold quantities of carbon and nutrients among ecosystems.

It is unlikely that we will ever be able to truly assess the full nature and extent of ecological change that has occurred in this vast watershed over the last 150 to 200 years. The alterations actually documented or reasonably inferred (as described above) are probably only the “tip of the iceberg” in terms of ecological change of the last 150 years. Most ecological information is collected on large-scale habitats (such as those defined here) or larger, more conspicuous plants and animals. Nonetheless, at the bases of food chains and cycling processes are a much larger biomass in the form of tiny or microscopic forms with particular micro-habitat requirements. These too have unquestionably been severely altered by the massive environmental changes of the last 150 years, yet empirical data documenting such changes is largely lacking.

Finally, it is worth noting that much of the large-scale water transfer and ecosystem protection infrastructure of the Bay-Delta system were developed in a period of relative wetness (mid-1930s to mid-1970s) without persistent periods of drought or floods. Planning and management is based upon an assumption of climatic stability because change is unpredictable. Climate change, however, is inevitable and the relative extremes of wet and dry that we have experienced in the last two decades may become the norm rather than the exception. The habitats and biota of the Bay-Delta watershed evolved with the highly variable Mediterranean climate and adapted to the seasonal and long-term swings of climate. By dramatically reducing the extent, diversity, and complexity of the natural aquatic habitats of the system, as well as inhibiting the physical processes that create and sustain those habitats, we have severely compromised the biotic system’s ability to adapt to natural and human-induced climate change.

**Table IV-A. Summary (by ecosystem-type) of Major Ecosystem Alterations Over the Last 150 Years (see text for discussion)**

Structural Alterations	Process Alterations
<p><b>UPLAND RIVERS</b> <i>Above Large Upland System Dams</i></p> <ul style="list-style-type: none"> <li>• Loss of riparian habitat; remainder highly fragmented</li> <li>• Fragmentation of riverine habitat due to hydroelectric dams, road crossings, and other barriers</li> <li>• Degradation of water quality</li> <li>• Loss of channel continuity to remainder of watershed; complete loss of chinook salmon spawning habitat</li> <li>• Biological communities altered, including: <ul style="list-style-type: none"> <li>* <i>loss of native species</i></li> <li>* <i>population losses in many taxonomic groups</i></li> <li>* <i>successful establishment of exotic species</i></li> </ul> </li> <li>• Large sediment accumulations behind dams</li> <li>• Loss of instream complexity/large woody debris</li> </ul>	<ul style="list-style-type: none"> <li>• Increased sedimentation from surrounding systems</li> <li>• Alteration of trophic dynamics/nutrient exchange with lower watershed</li> <li>• Nutrient dynamics altered, including: <ul style="list-style-type: none"> <li>* <i>supply/exchange of nutrients between riparian zone and streams altered</i></li> <li>* <i>loss of nutrient contribution of spawned salmon carcasses in historic salmon streams</i></li> <li>* <i>alteration of food webs</i></li> </ul> </li> <li>• Natural hydrologic patterns altered below smaller dams due to diversions and storage and later release of seasonal high flows</li> </ul>
<p><i>Below Large Upland System Dams</i></p> <p><i>As above, but also:</i></p> <ul style="list-style-type: none"> <li>• Channel morphology altered and degraded, including pool/riffle ratios, substrate composition</li> <li>• Water temperatures altered</li> </ul>	<p><i>As above, but also:</i></p> <ul style="list-style-type: none"> <li>• Natural hydrologic patterns altered, including: <ul style="list-style-type: none"> <li>* <i>loss of natural seasonal and interannual flow variability</i></li> <li>* <i>amount and timing of minimal/maximal flows altered; flood peaks reduced</i></li> <li>* <i>spring flows lowered</i></li> <li>* <i>average summer flows increased in some reaches</i></li> <li>* <i>total or near-total elimination of flows in some reaches</i></li> <li>* <i>groundwater/surface water exchange processes disrupted</i></li> <li>* <i>increase in daily flow and temperature variability</i></li> </ul> </li> <li>• Sediment supply and deposition processes disrupted</li> <li>• Seasonal flushing of riparian nutrients/litter into streams curtailed</li> <li>• Upstream movement of aquatic organisms blocked</li> </ul>

**Table IV-A. Summary (by ecosystem-type) of Major Ecosystem Alterations Over the Last 150 Years (see text for discussion)**

Structural Alterations	Process Alterations
<p><b>LOWLAND RIVERS</b></p> <ul style="list-style-type: none"> <li>• 94% of riparian zone lost; remainder highly fragmented</li> <li>• 95% loss of historically mapped wetlands</li> <li>• 85% of inundated area lost</li> <li>• Channel morphology greatly altered, including channelization, raised levees, and altered substrate composition</li> <li>• Loss of “backwater” areas</li> <li>• Tulare Lake converted to agriculture</li> <li>• Water quality degraded</li> <li>• Biological communities altered, including:               <ul style="list-style-type: none"> <li>* <i>loss of native species</i></li> <li>* <i>population losses in many taxonomic groups</i></li> <li>* <i>successful establishment of exotic species</i></li> <li>* <i>abundance relationships shifted</i></li> </ul> </li> <li>• Numerous screened and unscreened diversions connect river channels with agricultural fields</li> </ul>	<ul style="list-style-type: none"> <li>• Natural hydrologic patterns altered, including:               <ul style="list-style-type: none"> <li>* <i>loss of seasonal and interannual flow variability</i></li> <li>* <i>flood magnitude, frequency, duration, and area of inundation altered; small to moderate floods largely eliminated or reduced; large floods increased</i></li> <li>* <i>spring flows reduced and snowmelt peak largely eliminated</i></li> <li>* <i>summer flows augmented in some reaches</i></li> <li>* <i>total discharge reduced</i></li> </ul> </li> <li>• Sediment delivery and deposition reduced</li> <li>• Nutrient dynamics altered, including:               <ul style="list-style-type: none"> <li>* <i>riparian/marsh contribution nearly eliminated</i></li> <li>* <i>exchange and cycling of nutrients between rivers and floodplains disrupted</i></li> <li>* <i>alteration of food webs</i></li> </ul> </li> <li>• Animal movement patterns disrupted</li> <li>• Community successional processes disrupted</li> </ul>
<p><b>DELTA</b></p> <ul style="list-style-type: none"> <li>• Conversion of over 95 % of tidal wetlands to agriculture or deep subtidal area; remainder fragmented in small isolated patches</li> <li>• Loss of most riparian vegetation</li> <li>• Gross reconfiguration of subtidal channel morphology/distribution</li> <li>• Water quality degraded</li> <li>• Levees armored (rip-rapped)</li> <li>• Biological communities altered, including:               <ul style="list-style-type: none"> <li>* <i>loss of native species</i></li> <li>* <i>successful establishment of exotic species</i></li> <li>* <i>population losses in many taxonomic groups</i></li> <li>* <i>abundance relationships shifted</i></li> </ul> </li> <li>• Numerous unscreened diversions connect aquatic habitat to agricultural fields</li> <li>• Large pumping plants connect aquatic habitat to agricultural aqueducts</li> <li>• Natural pattern of seasonal salinity intrusion altered in some locations</li> </ul>	<ul style="list-style-type: none"> <li>• Natural hydrologic patterns altered as above, including:               <ul style="list-style-type: none"> <li>* <i>winter, spring, and early summer flows further reduced by export pumping</i></li> <li>* <i>water movement patterns altered at local and broad scales</i></li> </ul> </li> <li>• Natural soil accretion rates disrupted; soil subsidence occurring at problematic rate</li> <li>• Nutrient dynamics altered, including:               <ul style="list-style-type: none"> <li>* <i>detrital inputs from marshes and riparian nearly eliminated</i></li> <li>* <i>alteration of food webs and trophic structure of community</i></li> </ul> </li> </ul>

**Table IV-A. Summary (by ecosystem-type) of Major Ecosystem Alterations Over the Last 150 Years (see text for discussion)**

Structural Alterations	Process Alterations
<p><b>SAN FRANCISCO BAY</b></p> <ul style="list-style-type: none"> <li>• 79% of tidal marshes lost; remainder highly fragmented and in some cases degraded</li> <li>• 42% of tidal mudflats lost</li> <li>• Ship channels dredged and deepened</li> <li>• Intertidal mudflat habitat lost</li> <li>• Rocky intertidal habitat lost</li> <li>• Water quality degraded</li> <li>• Subtidal sediment composition and distribution altered</li> <li>• Biological community highly altered, including:               <ul style="list-style-type: none"> <li>* <i>loss of native species</i></li> <li>* <i>successful establishment by exotic species</i></li> <li>* <i>population losses in many taxonomic groups</i></li> <li>* <i>changes in dominant species at many trophic levels</i></li> </ul> </li> <li>• Natural seasonal pattern of salinity variability and distribution altered</li> </ul>	<ul style="list-style-type: none"> <li>• Natural hydrologic patterns altered, including:               <ul style="list-style-type: none"> <li>* <i>seasonal patterns of fresh water inflow altered and reduced</i></li> <li>* <i>tidal prism reduced</i></li> </ul> </li> <li>• Sediment delivery and deposition processes altered</li> <li>• Nutrient dynamics altered, including:               <ul style="list-style-type: none"> <li>* <i>detrital inputs from Delta and Bay marshes nearly eliminated</i></li> <li>* <i>long-term changes in oceanic productivity</i></li> <li>* <i>alteration of food webs and trophic structure</i></li> <li>* <i>pelagic food webs altered by high filtration rates of exotic filter feeding invertebrates</i></li> </ul> </li> </ul>
<p><b>NEARSHORE OCEAN</b></p> <ul style="list-style-type: none"> <li>• Natural seasonal extent of freshwater plume altered</li> <li>• Benthic sediment composition altered, particularly near Golden Gate</li> <li>• Alteration of benthic habitat by dumping and destructive fishery harvest methods</li> <li>• Alteration and loss of shoreline habitat (beaches, rocky intertidal) through multiple human-use effects</li> <li>• Biological communities altered, including:               <ul style="list-style-type: none"> <li>* <i>population losses in many taxonomic groups</i></li> </ul> </li> <li>• Increase in mean annual and summer maximum temperatures</li> </ul>	<ul style="list-style-type: none"> <li>• Natural hydrologic patterns altered               <ul style="list-style-type: none"> <li>* <i>seasonal pattern of freshwater discharge altered</i></li> </ul> </li> <li>• Long-term changes in oceanic productivity</li> </ul>