DRAFT v.1-10/9/98: This has not been reviewed by the Steelhead PWT and is subject to change.

Monitoring, Assessment, and Research on Central Valley Steelhead: Status of Knowledge, Review of Existing Programs, and Assessment of Needs.

Steelhead Satellite Project Work Team

INTRODUCTION

Overview of Life History, Taxonomy, and Population Structure

Steelhead *(Oncorhynchus mykiss*) are the anadromous form of rainbow trout, a salmonid species native to western North America and the Pacific coast of Asia. In North America, steelhead are found in Pacific Ocean drainages from southern California to Alaska. In Asia, they are found in coastal streams of the Kamchatka Peninsula, with scattered populations on the mainland (Burgner et al. 1992). In California, known spawning populations are found in coastal streams from Malibu Creek in Los Angeles County to the Smith River near the Oregon border, and in the Sacramento River system. The present distribution of steelhead in California has been greatly reduced from historical levels.

Steelhead are similar to some Pacific salmon in their ecological requirements. They are born in fresh water, then emigrate to the ocean where most of their growth occurs, and then return to fresh water to spawn. Unlike Pacific salmon, steelhead do not necessarily die after spawning. Post-spawning survival rates are generally quite low, however, and vary considerably between populations.

In California, peak spawning occurs from December through April in small streams and tributaries where cool, well oxygenated water is available year-round. The length of time it takes for eggs to hatch depends mostly on water temperature. Hatching of steelhead eggs in hatcheries takes about 30 days at 51^{o} F (Leitritz and Lewis 1980). Fry emerge from the gravel usually about four to six weeks after hatching, but factors such as redd depth, gravel size, siltation, and temperature can speed or retard this time (Shapovalov and Taft 1954). The newly emerged fry move to the shallow, protected areas associated with the stream margin (Royal 1972; Barnhart 1986). They soon move to other areas of the stream and establish feeding locations, which they defend (Shapovalov and Taft 1954). Most juveniles inhabit riffles but some of the larger ones will inhabit pools or deeper runs (Barnhart 1986).

The life history of steelhead differs from that of Pacific salmon principally in two aspects: juveniles have a longer fresh water rearing requirement (usually from one to three years) and both adults and juveniles are much more variable in the amount of time they spend in fresh and salt water. Throughout their range, steelhead typically remain at sea for one to four growing seasons before returning to fresh water to spawn (Burgner et al. 1992). Boydstun (1977) found that most Gualala River steelhead migrated to sea as two-year old fish and returned after spending two years in the ocean. In Scott and Waddell creeks, the majority of adults returning to the stream to spawn had spent two years in fresh water and one or two years in the ocean. However, steelhead from these streams occasionally exhibited other life history patterns: scale analysis of adults indicated that they spent from one to four years in fresh water and from one to three years in the ocean (Shapovalov and Taft 1954). Steelhead do not necessarily migrate at any set age. Some individuals will remain in a stream, mature, and even spawn without ever going to sea, others will migrate to sea at less than a year old, and some will return to fresh water after spending less than a year in the ocean.

Steelhead have traditionally been grouped into seasonal runs according to their peak migration period: in California there are well-defined winter, spring, and fall runs. This classification is useful in describing actual run timing, but is confusing when it is used to further categorize steelhead populations. Seasonal classification does not reflect stock characteristics, spawning strategies, and run overlap between summer and winter steelhead.   Run timing is a characteristic of a particular stock, but, by itself, does not constitute race or ecotype.

There are two basic steelhead ecotypes: *stream-maturing* steelhead, which enter fresh water with immature gonads and consequently must spend several months in the stream before they are ready to spawn; and *ocean-maturing* steelhead, which mature in the ocean and spawn relatively soon after entry into fresh water. This corresponds to the accepted classification that groups steelhead into two seasonal "races": summer and winter steelhead (Withler 1966; Royal 1972; Roelofs 1983; Barnhart 1986; Burgner et al. 1992). Stream-maturing steelhead (summer steelhead) typically enter fresh water in spring, early summer, and fall. They ascend to headwater tributaries, hold over in deep pools until mature, and spawn in winter. Ocean-maturing steelhead (winter steelhead) typically begin their spawning migration in fall, winter, and spring and spawn within a few weeks to a few months from the time they enter fresh water. Ocean-maturing steelhead generally spawn January through March, but spawning can extend into spring and possibly early summer months. Prior to the intensive water development of this century, stream-maturing steelhead were probably more common in California than they are today. At present, stream-maturing steelhead are found only in north coast drainages, mostly in tributaries of the Eel, Klamath, and Trinity river systems. Ocean-maturing steelhead are also present in north coast drainages, and are also found in the Sacramento River system and central and south coast drainages.

This classification is mostly based on behavioral and physiological differences and may not reflect genetic or taxonomic relationships (Allendorf 1975; Allendorf and Utter 1979; Behnke 1992). Genetic similarity appears to be mostly a reflection of geographical relationships; that is, summer steelhead occupying a particular river system are more genetically similar to winter steelhead of that system than they are to summer steelhead in other systems. Allendorf (1975) found that summer steelhead from several coastal streams in Washington were genetically indistinguishable from coastal winter steelhead of the same streams, but showed no genetic affinities with inland (upper Columbia River) summer steelhead.

Rainbow trout[1] have also been classified on the basis of anadromy. In the past, steelhead and non-anadromous rainbow trout have been classified as two different subspecies and even different species by early researchers (Allendorf 1975; Behnke 1992). However, little or no morphological or genetic differentiation has been found between anadromous and non-anadromous forms inhabiting the same stream system (Behnke 1972; Allendorf 1975; Allendorf and Utter 1979; Busby et. al 1993; Nielsen 1994). The conversion of anadromous forms that have become isolated upstream of dams to non-anadromous populations (e.g. Whale Rock Reservoir and Redwood Creek populations) is a further indication of the close genetic and taxonomic relationships of the different life history forms. Anadromous and non-anadromous rainbow trout apparently did not arise from two distinct evolutionary lines, but rather the two forms have given rise to each other independently (Behnke 1992).

Behnke (1972), Allendorf (1975), Allendorf and Utter (1979), and Wilson et al. (1985) conclude that rainbow trout cannot be separated taxonomically by timing of return to fresh water (summer vs. winter steelhead) or their tendency for anadromy (steelhead vs. non-anadromous forms). Rather, rainbow trout are taxonomically structured on a geographic basis (coastal vs. inland forms). Similarly, Behnke (1992) identifies three subspecies of rainbow trout that exhibit anadromy: coastal rainbow trout (*O. m. irideus*), Columbia River redband trout (*O. m. gairdneri*), and *mikizha* or Kamchatka rainbow trout *(O. m. mykiss*). All steelhead populations of *O. m. gairdneri* are summer steelhead (Behnke 1992; Burgner et. al 1992) and occupy upper

[1] The term >resident rainbow trout= or simply >rainbow trout= is often used in reference to non-anadromous forms of *O. mykiss*. We find this convention confusing and technically inaccurate because rainbow trout is the common name of the biological species *O. mykiss*, and the term >resident= used in this sense ignores other, non-anadromous migratory behaviors. In this document, the term >rainbow trout= refers to the biological species *O. mykiss* regardless of life history, and the different life history forms are referred to as anadromous (or steelhead), coastal, estuarine, potomadromous, or resident, depending on their migratory behavior (or lack thereof in the case of residents). The term >non-anadromous= is used to refer collectively to all life history types other than anadromous.

Columbia River tributaries east of the Cascades. *O. m. mykiss* is found in streams along the west coast of the Kamchatka peninsula of Russia. *O. m. irideus* is distributed along coastal rivers and streams from California to Alaska and consists of both summer and winter steelhead populations. All steelhead in California are *O. m. irideus* (Behnke 1992).

The present taxonomic classification recognizes the extreme polymorphism that occurs among rainbow trout populations (Behnke 1992). Rather than the different life history forms being distinct populations, it appears that rainbow trout populations are structured around a continuum of migratory behaviors, the two extremes being anadromous (strongly migratory) and resident (non-migratory). Within these extremes are potamodromous forms, and possibly estuarine and coastal (weakly anadromous) forms that are typical of coastal cutthroat trout *(O. clarki*) populations (Northcote 1997). This type of population structure has been identified among Kamchatka rainbow trout populations in several rivers in western Kamchatka, Russia, where steelhead (strongly-anadromous), coastal (weakly-anadromous), and riverine (potomodromous and resident) life-history polymorphisms have been identified, and appear to form a single interbreeding population within each river (Savvaitova et al. 1973; 1997).

Lack of genetic differences indicates that there may be substantial gene flow between anadromous and non-anadromous life history forms within a stream system. It is not uncommon in trout populations that have anadromous life history forms, including rainbow trout, for males to mature as parr, then assume a stream-dwelling life history (see Thorpe 1987 for review; Titus et al. in press), and for progeny of one life history form to adopt a life history strategy different from their parents. Mature male parr rainbow trout have been observed spawning with female steelhead in Waddell Creek (Shapovalov and Taft 1954) and they have been observed in other coastal streams as well (Robert Titus, DFG Environmental Specialist, pers comm.).

This polymorphism in life history forms and resultant differing and flexible reproductive strategies may be a response to unstable and variable climatic, hydrographic, and limnological conditions that frequently exist at the margins of a species= range, which for steelhead is probably those stream systems in the Central Valley and those south of San Francisco Bay in California, and Kamchatka on the other end of the range. Stream systems in California are subject to extreme variations in rainfall which can result in high volume, flash flood runoff, or droughts lasting several years. Natural stream flow in these streams can vary greatly, both seasonally and annually. It was not uncommon, under natural conditions, for the lower reaches of many of these streams in this area to become intermittent during the dry season (and longer), isolating, possibly for many years or even decades, stream dwelling forms in the perennial headwaters. Thus, a polymorphic population structure may be a response to an environment that is frequently suboptimal and not conducive to a consistent, annual recruitment of migrants to the ocean, and may be necessary for the long-term persistence of a population in these types of environments. Having several different life-history strategies among a single population is one means to Abet-hedge@ against extinction, and has been theorized as a reason for the occurrence of similar polymorphic population structure in coastal populations of cutthroat trout (Northcote 1997) and brown trout (*Salmo trutta*) (Jonson 1985, as cited in Northcote 1997; **Titus and Mosegaard 199?**) occupying unstable environments.

The likelihood that anadromous and non-anadromous rainbow trout can form a single interbreeding population in a particular stream has important management implications. Management of steelhead populations must include measures to protect and restore non-anadromous rainbow trout forms and especially the ecological linkages between the different forms. The large-scale disruption of this linkage that has occurred in the Central Valley through the placement of impassable dams on many streams may go a long way in explaining the near collapse of Central Valley steelhead stocks.

Life History and Status of Central Valley Steelhead

There is little documentation of historical distribution of steelhead in the Central Valley. However, the documentation that does exist indicates that steelhead were well-distributed throughout the Sacramento and San Joaquin river systems (Yoshiyama et al. 1996): from the upper Sacramento/Pit river systems south to the Kings and possibly Kern river systems in wet years. This is corroborated by the more extensive documentation of chinook salmon distribution showing that chinook salmon were present throughout the basin: in nearly all streams outside of the Central Valley that contain chinook salmon, steelhead are present as well.

Presently, the Central Valley contains only winter steelhead. However, there are indications in early, pre-dam fish counts that summer steelhead were present in the Sacramento system as well (Needham et al. 1941; anonymous 1953). The presence of suitable oversummering habitat, a stable hydrology strongly influenced by snowmelt, and the wide-spread occurrence of spring-run chinook salmon in the system (which have a similar life history to summer steelhead) are further indications that summer steelhead were probably present. There are no summer steelhead in the Sacramento River system today. Because of the need of adults to over-summer in deep pools in mid to high elevation tributaries, they were probably eliminated with the commencement of the large-scale dam construction period of the 1940's, 50's, and 60's.

The dominant run-type before the occurrence of large-scale changes to the hydrology of the system appears to have been fall-run, with a smaller winter-running component (Hallock et al. 1961; Hallock 1989). The peak migration into the upper Sacramento River above the mouth of the Feather River from 1953 to 1959 appears to have been in late September (Hallock et al. 1961). Adult counts at Red Bluff Diversion Dam from 1969 to 1982 also show this same pattern (Hallock 1989), and adult counts at Clough Dam on Mill Creek for a 10-year period beginning in 1953 indicate that the peak of adult migration into that stream occurs in late October, with a smaller peak about mid-February (Hallock 1989).

Hallock et al. (1961) found that juvenile steelhead migrated downstream during most months of the year, but the peak period of emigration occurred in spring, with a much smaller peak in fall. Most naturally-produced Central Valley steelhead rear in freshwater for two years before emigrating to the ocean. Scales analysis indicated that 70% had spent two years in freshwater before emigrating to the ocean, 29% had spent one year, and 1% had spent three years (Hallock et al. 1961).

Yoshiyama et al. (1996) estimate that 82% of chinook salmon spawning and rearing habitat in the Central Valley had been lost and they state that the percentage of lost habitat for steelhead was undoubtedly higher because steelhead go higher into the drainages than do chinook salmon. The California Fish and Wildlife Plan estimated that there were 40,000 adult steelhead in the Central Valley drainages in the late 1950's. Hallock et al. (1961) estimated the average annual steelhead run size in the Sacramento River system above the mouth of the Feather River in the 1950's was 20,540 adults.

Although an accurate estimate of steelhead abundance in the Central Valley is not available, the annual run size for the entire system in the early 1990's, based on Red Bluff Diversion Dam (RBDD) counts, hatchery counts, and past natural spawning escapement estimates for tributaries, is probably less than 10,000 adult fish. A more reliable indicator of the magnitude of the decline of Central Valley hatchery and wild stocks is the trend reflected in the RBDD counts. Steelhead counts at the RBDD have declined from an average annual count of 11,187 adults for the ten-year period beginning in 1967, to 2,202 adults annually in the 1990's (McEwan and Jackson 1996). Natural spawning escapement estimates above RBDD for the period 1967 to 1991, averaged 3,465 and ranged from 0 (1989 and 1991) to 13,248 (1968) (McEwan and Jackson 1996). These estimates should be considered maximum estimates, however, because mortality from natural causes is not considered.

Presently, approximately 10% to 30% of the adults returning to spawn in the Sacramento system are of natural origin (Frank Fisher, DFG Associate Fishery Biologist, pers. comm.). Hallock et al. (1961) reported that the composition of naturally produced steelhead in the population estimates for the 1953-54 through 1958-59 seasons ranged from 82% to 97% and averaged 88%. Clearly, the decline of natural reproducing populations has been more precipitous than that of the hatchery stocks. There are four hatcheries in the Central Valley that collectively produce approximately 1.5 million steelhead yearlings annually.

At present, naturally spawning populations of steelhead have been found in the upper Sacramento River and tributaries, Mill, Deer, and Butte creeks, and the Feather, Yuba, American, and Stanislaus rivers. The presence of naturally spawning populations appears to coincide with the presence of anadromous fish monitoring programs, and implementation of recent monitoring programs has found steelhead in streams previously thought to not contain a population, such as Auburn Ravine, Dry Creek, and the Stanislaus River. It is likely that naturally spawning populations exist in many other streams but are undetected due to lack of monitoring or research programs.

The issue of whether a steelhead population exists in the Stanislaus River is controversial. However, it is our opinion that substantial evidence exists to show that there is an extant self-sustaining steelhead run in the Stanislaus River. We note that this is the opinion of the Department of Fish and Game as well (CDFG 1997). We base our opinion on:

< The capture of a small number of steelhead smolts in rotary screw traps in two locations every year for the past four years. These fish do not appear to be the result of straying of juvenile hatchery steelhead planted in the Mokelumne River because none of the smolts captured this year in the screw traps were adipose fin clipped (Doug Demko, S.P. Cramer and Associates, pers. comm.) (1997 was the first year of 100% of hatchery steelhead at Mokelumne River Hatchery). Further, although juvenile steelhead have been shown to stray into non-natal streams, they don=t normally stray between basins.

There is some evidence that these fish are not the progeny of straying adult Mokelumne River Hatchery steelhead because recent genetic analysis of rainbow trout captured in the anadromous reach below Goodwin Dam show that this population has close genetic affinities to upper Sacramento River steelhead (NMFS 1997). Further, this group appears to be genetically distinct from all other samples of steelhead analyzed. In the same analysis, Nimbus Hatchery steelhead, from which eggs to maintain the Mokelumne River Hatchery steelhead run are procured, appeared to be similar to coastal steelhead, which accurately reflects the founding history of Nimbus Hatchery steelhead (broodstock was founded with Eel River steelhead eggs). Mokelumne River Hatchery is the only steelhead hatchery in the San Joaquin River system and juveniles steelhead are not stocked anywhere in the San Joaquin system except the Mokelumne River.

< CDFG fishery biologists have documented successful reproduction (juvenile out-migrants) in the lower San Joaquin River since 1987 (CDFG 1997).

< Anglers in the Oakdale area report occasional steelhead from 2 to 10 pounds and creel census information obtained by CDFG documents the catch of rainbow trout greater than 20 inches (DFG data). Examination of scale samples from these larger trout by CDFG biologists show an accelerated growth period typical of estuary or ocean residence (Bill Loudermilk, CDFG Senior Biologist, pers. comm.).

< An 28-inch steelhead illegally harvested from the Stanislaus River was confiscated by Fish and Game Wardens in 1995.

Habitat Criteria

Depth. The preferred depth for steelhead spawning is approximately 14 inches and ranges from 6 to 24 inches (Bovee 1978). Fry prefer water approximately 8 inches in depth and utilize water 2 to 14 inches deep, while parr prefer a water depth of 10 inches but utilize water 10 to 20 inches deep (Bovee 1978).

In natural channels, water depth usually does not hinder adult migration because adult steelhead normally migrate during high flows. Depth can become a significant barrier or impedance in streams that have been altered for flood control purposes, especially those that do not have a low flow channel. It has been reported that seven inches is the minimum depth required for successful migration of adult steelhead (Thompson 1972, as cited in Barnhart 1986) although the distance fish must travel through shallow water areas is also a critical factor. Excessive water velocity and obstacles which impede the swimming and jumping ability are more significant in hindering or blocking migration (Barnhart 1986).

Velocity. Water velocities of 10 to 13 ft/s begin to hinder the swimming ability of adult steelhead and may retard migration (Reiser and Bjornn 1979). Steelhead spawn in areas with water velocities ranging from 1 to 3.6 ft/s but prefer velocities of about 2 ft/s (Bovee 1978). The ability to spawn in higher velocities is a function of size: larger steelhead can establish redds and spawn in faster currents than smaller steelhead (Barnhart 1986).

Substrate. Adult steelhead have been reported to spawn in substrates from 0.2 to 4.0 inches in diameter (Reiser and Bjornn 1979). Based on the Bovee (1978) classification, steelhead utilize mostly gravel-sized material for spawning but will also use mixtures of sand-gravel and gravel-cobble[2]. Fry and juvenile steelhead prefer approximately the same size of substrate material (cobble/rubble) which is slightly larger than that preferred by adult steelhead for spawning (gravel) (Bovee 1978). The gravel must be highly permeable to keep the incubating eggs well oxygenated and should contain less than 5% sand and silt.

Temperature. The preferred water temperature for various life stages of steelhead is well documented (Bovee 1978; Reiser and Bjornn 1979; Bell 1986) (Table 1). Optimum temperature requirements of steelhead may vary depending on season, life stage, and stock

[2] According to the Unified Soil Classification System, sand is defined as particles with diameters from 0.003 to 0.19 inches, gravel is from 0.19 to 3.0 inches, and cobble is from 3.0 to 11.8 inches.

characteristics. Egg mortality begins to occur at 56° F. Steelhead have difficulty extracting oxygen from water at temperatures greater than 70° F (Hooper 1973, as cited in Barnhart 1986). In California, low temperatures are not as much of a concern as high temperatures, especially high temperatures that occur during adult migration, egg incubation, and juvenile rearing.

Table 1. Preferred water temperatures for various steelhead life history stages.

Life History Stage	**Temperature Range (°F)**
Adult migration	46 to 52
Spawning	39 to 52
Incubation and emergence	48 to 52
Fry and juvenile rearing	45 to 60
Smoltification	< 57

The temperatures noted in Table 1 are optimal conditions. Rainbow trout are known to exist in relatively high temperature regimes, some of which exceed the preferred temperatures for considerable lengths of time (e.g. steelhead in south coastal streams).

STRESSORS

The single greatest stressor for Central Valley steelhead is the large-scale loss of spawning and rearing habitat. Because juvenile steelhead must rear in fresh water for one year or longer, water temperatures must remain suitable year-round. For the most part, this occurred naturally only in the mid- to high- elevation reaches and tributaries, which necessitated that adult steelhead migrate higher into the drainage to spawn. Approximately 82% of their historical spawning and rearing habitat is now inaccessible because of impassable dams (Yoshiyama et al. 1996). Consequently, juvenile steelhead rearing is mostly confined to lower elevation reaches where high water temperatures during late-summer and fall is a major stressor.

Stressors affecting fish abundance, persistence, and recovery have been identified for anadromous fishes in the upper Sacramento River basin (see conceptual model done by Upper Sacramento River Satellite Project Workteam) and this adequately describes stressors affecting steelhead populations throughout the Central Valley. However, most of the stressors were identified as factors that constrain chinook salmon populations, and have been applied to steelhead secondarily because they are an anadromous fish with a somewhat similar life history. While this may be appropriate given that many of the factors that have impacted chinook salmon are affecting steelhead, the major disadvantage to this approach is that it is assumed that steelhead have been affected by the stressors to the same degree as chinook salmon, hence it is mistakenly believed that alleviation of the stressor to the level that it no longer impacts a chinook salmon population should result in steelhead population increases. In reality, some stressors cause greater impacts on steelhead populations than they do chinook salmon. For example, high water temperatures affect juvenile steelhead to a much greater degree than juvenile chinook salmon because most chinook salmon have emigrated to the ocean by early summer before high water temperatures occur, and steelhead must rear through summer and fall when water temperatures are more likely to become critical.

The creation of large impoundments with well-stratified waters has allowed for better management of water temperatures in the reaches below large dams. However, hypolimnetic releases to create suitable water temperatures has been made almost exclusively to benefit immigrating adult fall-run chinook salmon, and little effort has been made to utilize this water to maintain suitable water temperatures for rearing steelhead during the critical late summer and fall period. Some dams in the Central Valley were constructed with inadequate release structures so that it is difficult to maximize releases from the hypolimnion. Others may not have adequate minimum pool storage requirements. Consequently, many reservoirs currently are not able to provide releases necessary to maintain suitable temperatures for steelhead rearing through the critical summer and fall periods, especially during dry and critically-dry years.

Although not a >stressor= in the strict sense of the word, changing population demographics brought about by anthrogenic effects may be contributing to the decline of Central Valley steelhead. Emigration of salmonids to the ocean appears to be partially controlled by density-dependent factors: when food resources are abundantly available in a stream, as they would be in a low density population, relatively rapid growth rates lead to a greater propensity for parr maturation among the population (Thorpe 1987). Conversely, it has been shown that high juvenile densities cause greater resource competition and those that can=t establish and defend suitable stream positions are forced to migrate (Titus and Mosegaard, **199?**). If populations of rainbow trout are consistently reduced to low densities through anthrogenic effects, then food resources are more abundant and the population may become skewed towards the non-anadromous life history types. This may explain, in part, the low numbers of steelhead observed in the past several years in relatively pristine habitats such as Mill and Deer creeks.

Another potential population stressor is the disruption of interrelationships among subpopulations. Due to the relatively harsh natural conditions that are part of the evolutionary legacy of Central Valley steelhead, metapopulation interrelationships may be essential to the persistence of rainbow trout populations. Historically, under natural conditions, larger *source* populations occupying the more stable habitats (e.g. Feather, Yuba, and American rivers) provided a source for recolonization and gene flow to the smaller, less-persistent *sink* subpopulations occupying the more hydrologically unstable smaller stream systems. Conversely, the long-term persistence of the source population is contingent upon the maintenance of a diversity and combined robustness of the smaller subpopulations. The precipitous decline of Central Valley steelhead has been alarming not only from the standpoint of reduction in absolute numbers, but also in the elimination of the subpopulations that occupied the many tributaries. This loss of inter-population dynamic relationships may also explain the precipitous decline of steelhead in the smaller stream systems, in spite of the large amount of quality habitat that still exists in these systems. Thus, restoration that focuses only on increasing absolute numbers and ignores the need to increase population diversity may be inadequate.

MONITORING AND RESEARCH

Constraints to Monitoring and Research

Constraints to steelhead monitoring and research has led to the paucity of baseline information regarding Central Valley steelhead. These constraints fall mainly into two categories: institutional and natural. Institutionally, the lack of adequate funds for monitoring often necessitates that monitoring programs adopt a narrow focus. Because chinook salmon are commercially exploited, highly visible, prized among sport anglers and non-anglers, and politically sensitive, they have received the majority of monitoring funds and effort. This narrow focus was reinforced by the aforementioned belief among resource agencies that steelhead suffer from the same level of impacts as do chinook salmon, and assessment of impacts would be similar for steelhead.

Natural constraints result from life history traits that are common to all Central Valley steelhead that make them difficult to monitor and assess. Adults tend to migrate on high flows which make it difficult to observe them and difficult to maintain counting weirs and other structures. Carcass surveys, a reliable method to estimate chinook salmon spawning escapement, is not applicable to steelhead because many survive spawning and most others do not die on the spawning grounds. Although steelhead redds can be discerned from salmon redds, they are difficult to observe because steelhead spawn at higher, more turbid flows that do chinook salmon. Trap efficiencies are lower for juvenile steelhead because emigrating juveniles can more readily escape trapping because of their larger size, relative to chinook salmon.

Recent Management and Research

The only large-scale study of Central Valley steelhead was done by Hallock, Van Woert, and Shapovalov for a six year period beginning in 1953 (Hallock et al. 1961). Despite obtaining valuable information regarding natural and hatchery steelhead stocks, this program was canceled due to Alack of interest in steelhead....by administrators@ (Hallock 1989). The cancellation of this program, and other steelhead research programs in other areas of California, coincided with the need to initiate monitoring programs to gather information to promulgate ocean harvest regulations for salmon. In more recent years, efforts to restore Central Valley steelhead populations have been hampered by an acute lack of baseline information.

In 1993, fish counters were installed at Clough and Vina dams (Harvey 1995). The counters, although not operated continuously due to malfunction and high flows, were in place from mid-October, 1993 to mid-January, 1994. Historically, approximately 60% of the run passed the fishways on these dams during this time period (Hallock 1989). Fourteen steelhead were visually counted on Mill Creek, which yields a total estimate of 28 adult steelhead passing Clough Dam. On Deer Creek, zero steelhead were observed during this same time period. Because the counters were not operated continuously, these estimates should be considered minimum estimates. It is clear, however, that there has been a tremendous decline of steelhead in these two streams.

NMFS has done an a genetic (allozyme) analysis of rainbow trout samples collected from Coleman, Nimbus, and Feather River hatcheries, Mill and Deer creeks, and the Stanislaus and American rivers. They found that the Stanislaus River, Coleman and Feather River hatchery, and Deer and Mill creek populations form a genetic group distinct from all coastal samples of steelhead (Busby 1996; NMFS 1997). In contrast, the American River samples (wild fish and those from Nimbus Hatchery) are genetically most similar to a sample from the Eel River (NMFS 1997) which may reflect the founding history for Nimbus Hatchery.

Existing Monitoring and Research Efforts

Presently, there are 34 monitoring and research projects that obtain steelhead information. We have categorized these projects into three categories: salmon focused, anadromous salmonid focused, and steelhead focused. Not included are projects judged by us to be exclusively chinook salmon focused and which do not provide meaningful information regarding steelhead.

Salmon focused monitoring and research projects **(SAL/st)** have objectives that are aimed at obtaining information on chinook salmon and use methods and periods of operation to accomplish the objectives, but some useful steelhead information is collected incidently. Of the 34 total projects, 9 are of this type.

Anadromous salmonid focused projects **(ANAD**) have objectives that pertain to collecting both salmon and steelhead information and use methods and periods of operations designed to collect steelhead, as well as salmon, information. Of the 34 total projects, 18 are of this type.

Steelhead focused projects (**ST**) have objectives that pertain to collecting steelhead information and use methods and periods of operations designed to collect steelhead information exclusively. Of the 34 total projects, 7 are of this type (in contrast, there are 42 projects that are designed to collect chinook salmon information exclusively and which provide no meaningful steelhead information).

These projects are described below (descriptions are taken from the Upper Sacramento PWT, San Joaquin PWT, and Delta PWT documents, and information from Steelhead PWT members). Project category (**SAL/st, ANAD, ST**) corresponds to the category descriptions above.

System-Wide

System-Wide Hatchery Marking (USFWS, CDFG) - **ST**. All steelhead produced at Coleman, Feather River, Nimbus, and Mokelumne hatcheries are marked with an adipose fin clip. This program began in 1997 and will continue indefinitely. (In 1997, Coleman hatchery released 50,000 steelhead that were not marked.)

Salmon and Steelhead Scale and Otolith Collections and Analysis (CDFG - ESD) - ANAD. CDFG=s Stream Evaluation Program is using scale and otolith microstructure analysis to address several areas of question regarding stock identification, habitat use, life history, and age and growth of Central Valley salmon and steelhead. The program has also begun conducting pilot work on distinguishing natal rearing areas of salmon and steelhead by measuring the concentration of strontium in various Central Valley spawning streams, including the upper Sacramento River and tributaries. Collection of adult salmon scales and otoliths in the upper Sacramento River, tributaries, and at Coleman National Fish Hatchery began in fall 1995 and has continued since then with all races as available, in conjunction with adult salmon escapement surveys and hatchery operations. Collection of juvenile salmon (excluding winter run) and steelhead in the upper Sacramento River, tributaries, and at Coleman for scales, otoliths, and other information began in 1996, and more comprehensively during 1997-1998.

Basin-Wide Angler Survey (CDFG - IFD) - ANAD. An angler survey will be conducted to evaluate salmon, steelhead trout, and sturgeon fisheries in Sacramento and San Joaquin rivers and tributaries downstream to Carquinez. The survey samples each section 8 or 9 times per month (4 weekdays and 4 weekend days). CWT tags, cut heads and scale samples will be requested from fishermen.

<u>Main Stem Sacramento River</u>

Upper Sacramento River juvenile salmonid monitoring (CDFG-ESD) - ANAD. Rotary Screw Traps (RSTR) are operated upstream of Balls Ferry Bridge (river mile 278) and Deschutes Road Bridge (river mile 281). The purpose of this work is to determine timing of emigration and relative abundance for the four runs of salmon and potentially steelhead relative to precedent conditions of spawning and rearing in the upper Sacramento River. These data are also used in combination with RBDD and Knights Landing data to evaluate cohort survival to the Delta. Data collected includes number of hours the traps are fished and race of each salmon trapped (based on the Fisher length-at-age criteria). Most salmon identified as WCS, SCS, or LCS and all juvenile rainbow trout are measured and weighed. Up to 300 fall-run-sized salmon per trap are also measured and weighed up to twice daily. Trap efficiency of the Balls Ferry traps are evaluated using a mark-and-recapture approach. A portion of the catch at Balls Ferry are marked then transported about 2,500 feet upstream and released. Those marked at Deschutes Road Bridge are released at that site. Winter run are not used to evaluate trap efficiency.

GCID Rotary-screw trap (CDFG - R2) - SAL/ st. Sampling site is located approximately 45 miles below RBDD. This project is funded through a court order which requires monitoring of juvenile WCS until a permanent solution to GCID screening is found. GCID uses one rotary-screw trap to sample year round. Currently no trap efficiency studies have occurred but are planned for the future.

River-Wide Beach Seining, River Mile 300 to 163 (USFWS) - ANAD. Information regarding the rearing and outmigration timing of juvenile salmonids is critical. Resource managers utilize these data to minimize or eliminate impacts from water projects, reservoir discharges (e.g. water temperature and flows), and releases of toxic effluents from abandoned mines. The goal of this project is to determine the spatial and temporal distribution of four runs of juvenile chinook salmon and steelhead trout in the upper Sacramento River. Sampling with beach seines is conducted biweekly or monthly, year-round at 13 fixed-site locations on the main-stem Sacramento River from river mile 300 (Caldwell Park) to RM 163 (Princeton). Sampling is usually conducted bi-weekly and reports are distributed to interested parties.

Beach Seining, River Mile 144 to 71 (USFWS) - SAL/st. The Stockton FWS beach-seines weekly on the main-stem Sacramento River between river mile 144 (Colusa) and river mile 71 (Elkhorn) to document spatial and temporal trends of juvenile salmonids. One haul (15 meter .25" delta mesh seine with bag) is accomplished at each of seven established sites per week. Additional seining occurs on the main-stem October 15 to January 31 during winter run out migration season between river mile 80 (Verona) and river mile 43 (Clarksburg) three days per week. This additional seining is done to detect winter run before they reach the Delta. Weekly electronic reports are sent via e-mail to interested parties during this time.

Rearing Habitat Evaluation (CDFG - ESD) ANAD. The purposes of these surveys are to determine relative significance of the different habitats to various life stages of anadromous salmonids. Seine and snorkel surveys are used to evaluate rearing habitat. Survey sites are randomly selected from the 143 habitat units that have been previously mapped by the Department. The habitat mapping was based on channel morphology using a stratified classification system: Habitat types (pool, riffle, run and glide) were stratified by habitat zone (flat water, bar complex, side channel, and off channel). Data collected during snorkel survey include number of fish observed in five different 25-mm size classification. Data collected during the seine survey includes number of fish observed, and weights and length. General habitat information is collected at all survey sites. Beach- seine and snorkel surveys are conducted from Battle Creek to Caldwell Park.

Spawning Gravel Investigations (CDFG - ESD) - ANAD?. A study is scheduled for later this year to identify the physical attributes that differentiate habitat used for spawning from apparently suitable habitat that remains unused. The attributes to be studied include substrate gravel size, armoring, water velocity and depth, and substrate permeability. Initial investigations will be limited to the reach of river between Clear Creek and Keswick Dam. Two methods will be used: bulk substrate sampling (frequency be sampling, intragravel permeability and substrate water temperatures and dissolved oxygen levels will also be measured.

Lower Sacramento River Juvenile Salmonid Emigration (CDFG - ESD) - ANAD. Emigration of juvenile and post-spawner adult steelhead from the upper Sacramento River and tributaries: two rotary screw traps near Knights Landing (river mile 89); two more on the lower Sacramento River beginning in 1998-1999 to bracket Tisdale Weir and evaluate the effect of Sutter Bypass on downstream migration of juvenile salmonids, including steelhead.

Sacramento River Tributaries

Lower American River Juvenile Salmonid Emigration (CDFG - ESD) - ANAD. Downstream movement of juvenile steelhead: two rotary screw traps at Watt Avenue crossing (river mile 9). Appears to work well in detecting downstream dispersal of steelhead fry in high production years, but less effective for sampling emigrating yearlings (pre-smolts and smolts).

Lower American River Juvenile steelhead rearing habitat evaluation (CDFG - ESD) - ST. Seine, snorkel, and electrofishing surveys from Paradise Beach (river mile 5) to Nimbus Dam (river mile 23). Seining effective for monitoring emergence timing of steelhead fry.

Dry Creek Drainage (Sacramento and Placer counties) Steelhead Emigration (CDFG-ESD) - ST. Downstream movement (including emigration) of juvenile and post-spawner adult steelhead: one rotary screw trap downstream from the confluence of Secret and Miners ravines, the primary salmonid production areas in the system).

Dry Creek Drainage juvenile steelhead rearing habitat evaluation (CDFG-ESD) - ST. Juvenile steelhead rearing habitat evaluation: habitat type Secret and Miners ravines, select subsample of habitat units, determine distribution and abundance of juvenile steelhead, PIT tag juvenile steelhead (scheduled for early fall 1998). **[Has this begun??]**

Feather River Juvenile Salmonid Rearing and Emigration (DWR) - ANAD. Screw trapping done is in two locations from early December through the end of June to monitor emigration. Beach seining is done twice monthly at six locations (boat ramps) to obtain baseline information, and once monthly at additional locations. Low numbers of steelhead are caught in the screw traps and by seining. Snorkel surveys are done monthly to determine where juvenile steelhead are rearing. Most juvenile steelhead hold at the upper end of the low flow channel until mid-September.

Feather River Hatchery steelhead evaluation (DWR) - ST. Beginning last year (BY 1997), all hatchery steelhead were injected with CWT=s to evaluate return rate, straying rate, and survival. Methods to recover tags has not yet been determined, however.

Feather River Temperature Modeling (DWR) - ANAD. Water temperature is being monitored with continuous loggers at 12 stations on the river and in the Thermolito Complex. This is being done to develop a temperature model for the river.

Feather River Flood Effects Evaluation (DWR) - ANAD. Channel changes and riparian vegetation mapping is being done to compare before and after flood events. Isolated ponds are seined to assess stranding of juvenile salmonids.

<u>Delta</u>

Kodiak/ Midwater Trawling (USFWS) - SAL/st. This is done to assess juvenile salmon outmigration. Some steelhead information is obtained.

Kodiak Trawling at Mossdale (USFWS) - SAL/st. This is done to assess juvenile salmon outmigration. Some steelhead information is obtained

Beach Seining (USFWS) - SAL/st. This is done to assess juvenile salmon outmigration. Some steelhead information is obtained.

Trawling at Chipps Island (USFWS) - SAL/st. This is done to assess juvenile salmon outmigration. Some steelhead information is obtained.

Sampling at Fish Screening Facilities (USBR and CDFG) - SAL/st. Fish salvaged at CVP (USBR) and SWP (DWR) fish screening facilities are sampled every two hours to estimate number salvaged and lost through the screens, by species.

<u>San Joaquin River System</u>

Mokelumne River Habitat Typing (EBMUD) - ANAD. A modified habitat typing has been performed for each of six distinct reaches on the lower Mokelumne River between the mouth of the Cosumnes River and Camanche Dam. This allows random surveys to monitor fish assemblages and usage of these habitats and reaches during seasonal, flow, and temporal changes. These habitats have been incorporated into a GIS program for the lower Mokelumne River watershed.

Mokelumne River Fish Community Surveys (EBMUD) - ANAD. Monthly seining provides monitoring of juvenile fish species, and to a lessor extent, some adults throughout the entire lower Mokelumne River. Seasonal electrofishing provides monitoring of fish not generally susceptible to beach seining, such as larger steelhead/rainbow trout, Sacramento squawfish etc. These data have shown that the Mokelumne River has both resident rainbow and anadromous steelhead year round.

Mokelumne River Redd Surveys (EBMUD) - SAL/st . Salmonid redd surveys are done twice monthly form October 1 - January 1 and once monthly from January through

April 1. High flows and unnatural channelization of the lower Mokelumne River make redd surveys for steelhead and rainbow trout during the late winter and spring difficult and redd numbers for these fish are generally underestimated.

Mokelumne River Dietary Analysis (EBMUD) - ST. Gastric levage is performed on all steelhead/rainbow trout captured during electrofishing surveys (FL > 140 mm). Very little is known about the diets of steelhead in the lower Mokelumne River and it is the intent of this project to provide baseline information that may further develop studies to better understand habitat needs and limiting factors affecting these fish. Dietary analysis has also been done on juvenile Mokelumne River chinook salmon in 1997 and 1998.

Mokelumne River Mark and recapture studies (EBMUD) - ANAD. Since 1997, a select number of steelhead/rainbow trout and juvenile chinook salmon have been marked with non-toxic latex paint tattoos. This form of marking appears promising. Preliminary data suggests a 6 - 7% recapture rate of juvenile chinook salmon and that some marked steelhead and chinook have been re-captured in Delta pump salvage operations.

Mokelumne River Angler Survey (EBMUD) - ANAD. We have been performing roving angler surveys on the Mokelumne River from Camanche Dam to Lake Lodi since 1995. This data provides excellent information on the harvest of steelhead/rainbow trout, chinook salmon in the upper river and other fish species and anecdotal information on salmonid run size. We are performing preliminary angler surveys on the Mokelumne River below Camanche Dam to evaluate the feasibility of estimating in-river harvest, which appears to be quite high in some years.

Video Monitoring at Woodbridge Dam on the Mokelumne River (EBMUD) - ANAD. This monitoring has been performed since 1992 in the upper-stage fish ladder at Woodbridge Dam. Video monitoring has typically been started in mid-September. However, this has been extended into the second week of August. Overhead and side view monitoring provides species identification, size and sex (in some cases) of fish ascending and descending the ladder. After drawdown of Lake Lodi (usually Nov. 1) trapping is performed in the lower-stage ladder until December 31 or until high flows make this too difficult. Video monitoring has been extended through March 1. Because of the archaic construction of the dam and the presence of remnant fish ladders, it is quite possible that fish numbers are underestimated, especially during flows greater than 1,200 cfs.

Screwtrap Operations at Woodbridge Dam (EBMUD) - ANAD. Screwtrap monitoring of juvenile, outmigrating, anadromous fish has been performed on the lower Mokelumne River since 1992. Trapping provides an index of natural river production and has recently been incorporated into CAMP. This past season the project began preliminary steelhead calibrations for the traps with hatchery juvenile steelhead. Steelhead calibrations appeared successful.

Mokelumne River Preliminary Genetic Research (EBMUD) - ST. Thirty (30) fin-clip samples from steelhead/rainbow trout collected on the Mokelumne River at the hatchery and during electrofishing surveys from December 1996 through April 1997 were tested for allelic variation using mtDNA control region sequence and ten microsatellite markers. The data suggests some hatchery mixing but expansion of testing throughout all California drainages may provide a more clear picture.

Mokelumne River Gravel Restoration Projects (EBMUD) - ANAD. Salmonid spawning habitat restoration projects on the lower Mokelumne River have been done since 1990. Since 1996, monitoring has been expanded to evaluate improvement of parameters such as: gravel permeability, dissolved oxygen and temperature, macroinvertebrate recolonization and use of restoration sites by adult and juvenile salmonids.

Stanislaus River Chinook Salmon Emigration (S.P. Cramer) - SAL/st. Screw traps are operated at two sites (Caswell State Park and Oakdale) to monitor and assess chinook salmon outmigration. Steelhead smolts have been observed every year that the sampling has been done.

<u>Monitoring and Assessment Needs</u> **[Not Complete]**

Determination of origin. Beginning in 1997, all steelhead produced in Central Valley hatcheries (Coleman, Feather River, Nimbus, and Mokelumne hatcheries) were marked with an adipose fin clip. This program will continue as a permanent hatchery practice at these hatcheries.   Marked juvenile fish were captured in smolt emigration studies in 1998 and marked adult steelhead will begin returning in winter 1999. All existing monitoring projects should begin recording the presence or absence of adipose fins on all rainbow trout observed.

Current distribution of naturally spawned steelhead. The Steelhead Satellite Project Work Team has proposed the implementation of a rainbow trout life stage protocol to be used by all monitoring projects. Under the protocol, all rainbow trout observed will be assigned one of five life stage rankings: yolk-sac fry, fry, parr, silvery parr, or smolt. Observing and enumerating smolts will allow us to document the occurrence of steelhead within stream systems. This will be an important tool in determining current distribution of steelhead throughout the Central Valley. The protocol will also enhance our understanding of life stage development and spatial and temporal aspects of smoltification.

For those streams where there is currently no monitoring projects (e.g. Stony, Thomes, Antelope, Putah creeks, etc.), index reaches should be established and monitored by electrofishing, beach seining, hook and line, or some other method to document and assess smolt production.

Upper Sacramento River spawning escapement. Prior to 1993, run size estimates were made for steelhead at the fishway on the Red Bluff Diversion Dam (RBDD). From these, estimates of natural spawning escapement for the upper Sacramento River above RBDD could be made. Because of impacts to winter run chinook salmon, the operation of RBDD was changed so that the dam gates were raised earlier in the season, and this eliminated our ability to generate run size estimates. Another method of generating run size estimates, or perhaps an index, needs to be developed.

San Joaquin River system monitoring. There is an acute lack of monitoring and assessment of steelhead populations in the San Joaquin River system, excluding the Mokelumne River. The chinook salmon emigration study on the Stanislaus River provides evidence that steelhead persist in this system, but lack of efforts focused on steelhead hampers our ability to determine how robust and extensive these populations are, hence hampers our ability to recover them. The current salmon emigration monitoring projects on the Stanislaus, Tuolumne, and Merced rivers need to be augmented so that information regarding steelhead distribution, emigration timing, and other attributes can be obtained.

Temperature Modeling (river and reservoir).

Habitat Availability below dams

Micro habitat usage below dams

Hatchery evaluations

- degree of straying between basins - mass-mark otoliths
- degree of straying within basins - introgression with natural stocks

Yuba River Monitoring

Clear Creek salmonid out-migration monitoring (USFWS - CAMP) - ANAD. USFWS plans juvenile salmonid out-migration monitoring under the Comprehensive Assessment and Monitoring Program (CAMP)Cstarting 1999. A trap site (has been identified approximately 1.5 miles from mouth. Monitoring will occur during January through July. Electrofishing for stranding surveys will occur with ramping down of river flows.

Research Needs **[Under development]**

Basic life history
- run timing
- spawn timing-dominant paradigm (Jan-March) is probably based on hatchery timing - need to find out about late-spawning fish
- ocean-maturing vs. stream maturing

genetic Evaluation

role of Central Valley floor tribs

microhabitat usage - otoliths

habitat availability above dams, then engineering feasibility studies

population dynamics: source/sink; dynamics/relationships of different life history strategies

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