5 CALIFORNIA CENTRAL VALLEY STEELHEAD *(ONCORHYNCHUS MYKISS)*

California Central Valley Steelhead pose a difficult management challenge in the Sacramento River. There has been only limited research and monitoring in comparison with Chinook salmon, so there is little specific information about the status and trend of the species and how adults and juveniles use habitats in the mainstem river and the Bay-Delta estuary. Though the upper reaches of the Sacramento River support a spawning population of resident rainbow trout, the mainstem river habitat used by the species is atypical for steelhead, which usually spawn in higher elevation, steeper, and narrower channels. Management of the species is also complicated by its polymorphism, with individuals being capable of exhibiting either a resident (e.g., rainbow trout) or an anadromous (e.g., steelhead) life history.

NOAA Fisheries listed the California Central Valley Steelhead Distinct Population Segment (DPS) as threatened under the Federal Endangered Species Act in 1998 (NMFS 1998).

5.1 Distribution

5.1.1 Historical distribution in the Central Valley

O. mykiss once occurred throughout the Central Valley, spawning in the upper reaches of tributaries to the Sacramento and San Joaquin rivers. Lindley et al. (2006) recently conducted GIS-based habitat modeling to estimate the amount of suitable habitat to support *O. mykiss* populations in the Central Valley, and their results suggest that steelhead were widely distributed throughout the Sacramento River basin, but relatively less abundant in the San Joaquin River basin due to natural barriers to migration. Yoshiyama et al. (1996) conducted a thorough review of historical sources to document the historical distribution of Chinook salmon in the Central Valley, which can be used to infer historical distribution of steelhead. The assumption that steelhead distribution in the Sacramento River basin overlapped with, and was likely more extensive than, spring-run Chinook distribution under historical conditions has been supported by studies conducted in the Klamath-Trinity river basin (CH2M Hill 1985, Voight and Gale 1998). Yoshiyama et al. (1996) concluded that, because steelhead upstream migration occurs during high flows, their leaping abilities are superior to those of Chinook salmon, and they have less restrictive spawning gravel criteria, steelhead in the Sacramento River basin "could have used at least hundreds of miles of smaller tributaries not accessible to the earlier-spawning salmon." The model created by Lindley et al. (2006) estimates that 80% of historically accessible habitat for Central Valley steelhead is now behind impassable dams; this figure is supported by other research into steelhead and Chinook salmon habitat loss in the Central Valley (Clark 1929, Yoshiyama et al. 1996, 2001).

5.1.2 Current distribution in the Sacramento River basin

In the Sacramento River basin, populations of *O. mykiss* are known to spawn in the upper Sacramento, Yuba, Feather, and American rivers, and in Deer, Mill, and Butte creeks. Saeltzer Dam was removed from Clear Creek in 2000, granting easier access to upstream habitats in the canyon reaches of the creek. Though improved access may have opened up suitable spawning and rearing habitat for steelhead, it is not clear if steelhead have colonized Clear Creek since removal of the dam. A summary of recent distribution information for steelhead in Sacramento River tributaries is shown in Table 62 of Good et al. (2005), which shows that steelhead are widespread in accessible streams, if not abundant.

5.2 Population Trends

In general, steelhead stocks throughout California have declined substantially. McEwan and Jackson (1996) reported that the adult population of steelhead in California was roughly 250,000, less than half the population that existed in the 1960s (McEwan and Jackson 1996). In the Central Valley, roughly 1–2 million adult steelhead may have returned annually prior to 1850, as based on historical Chinook salmon abundance (McEwan 2001, NMFS 2006). In the Sacramento River basin, the average run size of steelhead in the 1950s was estimated to be approximately 20,540 adults (McEwan and Jackson 1996). In contrast, escapement estimates in 1991 and 1992 were less than 10,000 adults, or less than half of the run size in the 1950s (McEwan and Jackson 1996). Similarly, counts of wild steelhead at Red Bluff Diversion Dam (RBDD) declined from an average annual run size of 12,900 in the late 1960s to 1,100 adults in the 1993–1994 season (McEwan and Jackson 1996). The most recent 5-year average for steelhead spawning upstream of Red Bluff Diversion Dam is less than 2,000 adults (Good et al. 2005). NMFS (2006) notes that there have not been any escapement estimates made for the area upstream of RBDD since the mid-1990s, and that estimates of abundance are currently derived from extrapolation of incidental catch of outmigrating juvenile steelhead captured as part of the midwater-trawl sampling for juvenile Chinook salmon at Chipps Island, downstream of the confluence of the Sacramento and San Joaquin rivers.

5.3 Life History

There are generally two types of steelhead: winter steelhead and summer steelhead. Winter steelhead become sexually mature during their ocean phase and spawn soon after arriving at their spawning grounds. Adult summer steelhead enter their natal streams and spend several months holding and maturing in fresh water before spawning. California Central Valley steelhead are predominantly winter steelhead; consequently, this section describes the life history and habitat requirements of winter steelhead.

It is worth noting that summer steelhead occur in coastal tributaries of northern California, and some investigators hypothesize that summer steelhead may have been more prevalent in California before larger dams eliminated access to historical holding habitat (McEwan 2001). Like summer steelhead, spring-run Chinook salmon are also stream-maturing; their historical distribution throughout Central Valley tributaries suggests that there was habitat available to support the life history strategy of summer steelhead as well (e.g., deep, coldwater holding pools located in high elevation reaches). Although the availability of suitability habitat is not proof that summer steelhead were present, there appear to be at least a few records of summer steelhead from fish counts conducted in the Sacramento River system from before the large dams were constructed (Needham et al. 1941, USFWS and CDFG 1953; both as cited in McEwan 2001). NMFS (1998) notes that three distinct runs of steelhead may have been present in the Sacramento River basin as recently as 1947, including a summer run in the American River (Cramer et al. 1995, McEwan and Jackson 1996).

The management of steelhead populations in Central Valley tributaries is usually subsumed within the management of Chinook salmon populations because of their similar life history strategies and habitat requirements. Nevertheless, steelhead generally exhibit a more flexible life history strategy than Chinook salmon, and the habitat requirements of juvenile steelhead differ from those of juvenile Chinook.

Steelhead migrate up the Sacramento River nearly every month of the year, with the bulk of migration occurring from August through November, and the peak in late September (Bailey 1954; Hallock et al. 1961, both as cited in McEwan and Jackson 1996; McEwan 2001). Spawning in the upper Sacramento River generally occurs between November and late April, with a peak between early January and late March (USBR 2004). Fry emergence is influenced by water temperature, but hatching generally requires four weeks, with another four to six weeks in the gravels before emergence. Juvenile steelhead typically rear in freshwater from 1 to 3 years before emigrating (McEwan and Jackson 1996). The majority of returning adult steelhead in the Central Valley have spent two years in fresh water before emigrating to the ocean (McEwan 2001). A scale analysis conducted by Hallock et al. (1961, as cited in McEwan 2001) indicated that 70% emigrated after two years, 29% after one year, and 1% after three years in fresh water. Juvenile emigration from the upper Sacramento River occurs between November and late June, with a peak between early January and late March (USBR 2004).

Unlike Chinook salmon, steelhead can be iteroparous, which means that they can survive spawning, return to the ocean, and then migrate into fresh water to spawn again. Post-spawning adults are known as kelts; although some kelts have been documented in the Sacramento River, there are probably few repeat spawners in the Sacramento River population (USBR 2004).

In coastal populations of winter steelhead, it is a common life history strategy for juvenile steelhead to migrate downstream at age 1+ and rear in the estuary for an additional year before smolting. Some of the age 1+ steelhead captured in rotary screw traps t RBDD, GCID, and Knights Landing may continue rearing for another year before entering the ocean, but little information is available regarding steelhead use of the Sacramento-San Joaquin Delta estuary as rearing habitat. In addition, the potential effects of Delta water operations on steelhead have not been evaluated (McEwan 2001). There may be some areas of the Bay-Delta estuary where summer water temperatures are moderated by tidal action so that steelhead 1+ migrants are able to rear throughout the summer; however, this is currently an uncertainty that requires additional research.

5.4 Habitat Requirements

5.4.1 Spawning habitat

O. mykiss currently spawn in the mainstem Sacramento River below Keswick Dam (RM 302), with peak spawning occurring from January through March when water temperatures throughout much of the Sacramento River are suitable to support egg incubation and emergence. However, the downstream extent of spawning is likely determined by the location of suitable water temperatures to support summer rearing of 0+ juveniles, which lack the swimming ability to move significant distances upstream to follow the upstream retreat of cold water in the summer. The progeny of any adults that construct redds downstream of locations with suitable water temperatures in the summer likely suffer high rates of mortality and contribute little to the population.

Unlike the annual redd surveys conducted by CDFG to document the spawning locations of Chinook salmon, no regular surveys are conducted to document locations of *O. mykiss* spawning in the Sacramento River. Steelhead migrate and spawn during high flows when observations and sampling are difficult (McEwan 2001). It may be possible to use late-fall-run Chinook salmon spawning distribution as a proxy for steelhead spawning distribution, because the two species have similar juvenile life history strategies (juveniles rear in the river for at least one summer before emigrating), and redds must be located where summer water temperatures are suitable to support summer rearing. As discussed in Chapter 4.5, we hypothesize that the downstream extent of late-fall run Chinook spawning is generally located near Ball's Ferry Bridge (RM 276) in most years because this area defines the location of suitable summer water temperatures to support summer rearing. Steelhead generally have higher thermal tolerances than Chinook salmon (Moyle 2002), so the downstream extent of steelhead spawning may be slightly further downstream than for Chinook salmon.

As with Chinook salmon, steelhead spawn in areas with suitable gravel and hydraulics. Bovee (1978) reports that steelhead prefer water depths of 14 in (36 cm) for spawning, with a range between 6 and 24 in (15 and 61 cm), and water velocities of 2 ft/sec (61 cm/s), with a range of 1 to 3.6 ft/sec (30 to 110 cm/s), which is similar to the hydraulic conditions preferred by Chinook salmon in the Central Valley. As with Chinook salmon, steelhead generally prefer to spawn in gravels, with optimal grain sizes reported to range between 0.6 cm and 10 cm (6 mm and 102 mm) (Bjornn and Reiser 1991). Grain sizes used by spawning Chinook have been found to range from a D_{50} of 0.43 in (10.8 mm) (Platts et al. 1979, as cited in Kondolf and Wolman 1993) to a D_{50} of 3.1 in (78.0 mm) (Chambers et al. 1954, 1955, as cited in Kondolf and Wolman 1993).

Under historical conditions, steelhead likely spawned in much higher-gradient reaches in the Sacramento River and its tributaries, as do steelhead in other portions of their range. Steelhead are common in reaches with gradients of less than 6% (Burnett 2001, Harvey et al. 2002, Hicks and Hall 2003; all as cited in Lindley et al. 2006), and occur in some systems in reaches of up to 12% and more (Engle 2002, as cited in Lindley et al. 2006).

There is no Sacramento-specific information about water temperature requirements for successful spawning and incubation, but values derived from other steelhead stocks in more northerly locations suggest optimal spawning temperatures are between 39°F (4°C) and 52°F (11°C), with egg mortality occurring at water temperatures above 56°F (13°C) (Hooper 1973, Bovee 1978; Reiser and Bjornn 1979; Bell 1986; all as cited in McEwan and Jackson 1996). More research is needed to understand the specific temperature tolerances of steelhead in the Central Valley and southern portions of their range. There is some evidence that different strains of *O. mykiss* may have different thermal tolerances at the egg and embryo stage (Myrick and Cech 2001).

5.4.2 Summer rearing habitat

After emerging, steelhead fry typically disperse to shallow (< 14 in [36 cm], low-velocity near-shore areas such as stream margins and low-gradient riffles and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). Everest and Chapman (1972) found that juvenile steelhead of all sizes most often chose territories over large-sized substrates. As they increase in size in the late summer and fall, they increasingly use areas with cover and show a preference for higher-velocity, deeper mid-channel areas near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). Bovee (1978) reports that fry prefer water depths of 10 in (25 cm), with a range between 10 in (25 cm) and 20 in (51 cm) and water temperatures ranging between 45°F (7°C) and 60°F (16°C). Age 0+ steelhead have been found to be relatively abundant in backwater pools and often live in the downstream ends of pools in late summer (Bisson et al. 1988, Fontaine 1988).

Steelhead fry may establish and defend territories soon after emerging (Shapalov and Taft 1954). Fry and juvenile steelhead that are unsuccessful in establishing a territory may suffer density-dependent mortality or be displaced downstream where they may suffer higher rates of mortality from predation, entrainment, or elevated water temperatures (Dambacher 1991, Peven et al. 1994, Reedy 1995). Keeley (2001) found that increased competition between juvenile steelhead, caused by higher fish densities or lower food densities, caused increased mortality, lower or more variable growth rates, and emigration of smaller fish. Downstream dispersal due to density dependence or high flows in rearing habitat does not necessarily result in increased mortality where there is suitable habitat downstream (Kahler et al. (2001). Downstream dispersal to larger stream reaches for further rearing prior to smolting appears common in many systems (Bjornn 1978, Loch et al. 1985, Leider et al. 1986, Dambacher 1991).

Summer habitat can generally be assumed to be more limiting for age 1+ and 2+ juvenile steelhead than for age 0+ in many streams. Older age classes of juvenile steelhead (ages 1+ and 2+) prefer deeper water in the summer than fry, and show a stronger preference for pool habitats, especially deep pools near the thalweg with ample cover, as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, 1988; Dambacher 1991). Dambacher (1991) observed that most 1+ steelhead in the Steamboat Creek watershed of the North Umpqua River, Oregon were concentrated in mainstem reaches with relatively deep riffles and large substrates. Age 1+ fish typically feed in pools, especially scour and plunge pools (Fontaine 1988, Bisson et al. 1988). Age 1+ steelhead appear to avoid secondary channel and dammed pools, glides, and low-gradient riffles with mean depths less than 7.8 in (20 cm) (Fontaine 1988, Bisson et al. 1988, Dambacher 1991). Beecher et al. (1993) reported that juvenile steelhead > 3 in (75 mm) in length avoided areas with depths of less than 6 in (15 cm). Reedy (1995) indicates that age 1+ steelhead especially prefer high-velocity pool heads, where food resources are abundant, and pool tails, which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads. Fast, deep water, in addition to optimizing feeding versus energy expenditure, provides greater protection from avian and terrestrial predators (Everest and Chapman 1972).

5.4.3 Winter rearing habitat

For juvenile steelhead to survive the winter, they must avoid predation and high flows. The higher-gradient reaches typically used for spawning by steelhead (generally > 3%) are often confined and characterized by coarse substrate that is immobile at all but the highest flows. Juvenile steelhead often use the interstitial spaces between cobbles and boulders as cover from high water velocity, and presumably, to avoid predation (Bjornn 1971, Hartman 1965, Bustard and Narver 1975, Swales et al. 1986, Everest et al. 1986, Grunbaum 1996). Access deep into the streambed may be required to avoid turbulent conditions near the surface or even beneath the first layer of the subsurface (Stillwater Sciences, unpubl. data). Age 0+ steelhead can use shallower habitats and can find interstitial cover in gravel-size substrates, while age 1+ or 2+ steelhead, because of their larger size, need coarser cobble/boulder substrate for cover (Bustard and Narver 1975; Bisson et al. 1982, 1988; Fontaine 1988; Dambacher 1991). Bustard and Narver (1975) reported that 1+ steelhead prefer water deeper than 17.5 in (45 cm) in winter, while age 0+ steelhead often occupy water less than 5.8 in (15 cm) deep and are rarely found at depths over about 23.4 in (60 cm). In winter, age 1+ steelhead typically stay within the area of streambed that remains inundated at summer low flows, while age 0+ fish frequently overwinter beyond the summer low flow perimeter along the stream margins (Everest et al. 1986). Consequently, winter rearing habitat for age 1+ and 2+ juvenile steelhead is assumed to be more limiting than for age 0+ juveniles.

5.5 Conceptual Model of Historical Habitat Conditions

Steelhead likely migrated the farthest upstream of all anadromous salmonid species in the Central Valley. Their superior jumping ability and migration during high flows probably enabled them to navigate past obstacles that may have impeded winter-run and spring-run Chinook salmon, which also ascended the high-elevation reaches of Sacramento River tributaries (Yoshiyama et al. 1996). Greater access to upstream reaches probably enabled steelhead to spawn and rear where there was less competition from spring- and winter-run Chinook salmon than in downstream reaches.

Because spawning gravels in higher-gradient reaches are often more patchily distributed than in lower-gradient reaches, steelhead likely spawned in small riffles located between steep reaches of channel and in pockets of gravel located behind boulders and LWD. Late snowmelt and volcanic springs supplied cold water to these upstream reaches throughout the summer, thus providing suitable rearing conditions throughout the summer months. Once fry emerged from the gravels, they probably migrated to nearby gravel riffles to establish and defend territories, which caused some fry to move farther downstream once rearing habitat was saturated upstream. As they dispersed downstream, steelhead fry may have encountered greater predation pressure and competition for rearing habitat from larger spring-run Chinook salmon juveniles that had established territories after emerging months earlier, and from 1+ and 2+ juvenile steelhead that had established territories in previous years. Thus, the availability of summer rearing habitat likely exerted a control on historical steelhead population abundance by limiting fry production.

Winter rearing habitat may have limited steelhead populations as well, because juveniles probably competed for limited velocity refugia during high flow events in the winter and spring. In the steep channels of higher elevation streams, juvenile steelhead find velocity cover in eddy zones associated with LWD or in the interstices between coarse sediment particles to avoid downstream displacement. Because smaller juvenile steelhead can presumably find cover in a wider range of particle sizes than larger 1+ and 2+ juveniles, and can use much shallower habitats than larger juveniles, winter habitat may be more likely to be limiting for these older age classes.

Hydrologic and geologic variability in the tributaries of the Sacramento River likely contributed to the life history flexibility displayed by steelhead. As described above, high flow events may cause age 0+ and 1+ juveniles to move downstream to lower reaches, while other juveniles took advantage of available velocity refugia to spend an additional year rearing in their natal stream before emigrating as 2+ (or occasionally 3+) juveniles.

We assume that rearing habitat for age 1+ and 2+ steelhead is likely limiting populations of steelhead in the Sacramento River system. In contrast to juvenile Chinook, which are frequently found in schools, juvenile steelhead are strongly territorial (Everest and Chapman 1972, Hillman et al. 1987). Several studies support the hypothesis that density dependence acts on the parr-to-smolt life stage rather than the egg-to-fry life stage, and that it is rearing habitat capacity that limits population size of steelhead (Bjornn 1978, Cramer et al. 1985, Ward and Slaney 1993, Cramer 2001). This is evidenced by studies showing the number of age 0+ juvenile steelhead to vary substantially over the years, while the yearly abundance of age 1+ or 2+ juveniles remains relatively stable (Bjornn 1978, Everest et al. 1987, Ward and Slaney 1993, Reeves et al. 1997). Both hatchery as well as field studies have shown that smolt-to-adult survival increases with smolt size (Shapovalov and Taft 1954, Ward et al. 1989), which emphasizes the importance of providing habitat for older age classes of juvenile steelhead.

5.6 Effects of Anthropogenic Changes on *O. mykiss* Habitat

Native Americans harvested Chinook salmon and steelhead as a food staple, and tribes located in the upper Sacramento River were particularly dependent on anadromous salmonid runs to provide sufficient food resources. However, the larger scale anthropogenic changes that have occurred in the past 150 years in the Sacramento River basin produced more significant effects on anadromous fish populations. This section describes some of the more significant anthropogenic changes to the landscape that likely had negative effects on steelhead populations in the basin.

5.6.1 Gold mining

Because steelhead ascended to the upper reaches of Sacramento River tributaries, both resident and anadromous forms of the species were often located near mining camps that were established throughout the Sierra Nevada range, thus supplying the camps with a food staple. However, alteration of aquatic habitats likely had a greater effect on *O. mykiss* populations than angling. Miners often re-routed flows from natural channels and increased sediment delivery to channels, thus degrading spawning and rearing habitat. Flow diversion may have created new flow-related passage barriers to adult upstream migration, and it probably exacerbated summer rearing habitat limitations by reducing the extent of inundated habitat, and increasing competition for limited space. In addition to reducing juvenile survival, flow diversion may have simulated the effects of drought conditions and forced *O. mykiss* juveniles to become residents to survive low flow and elevated water temperature conditions.

5.6.2 Early commercial fishing

In the middle- to late-nineteenth century, several fish canneries began operating in the lower Sacramento River and Delta to harvest the abundant salmon resources of the Central Valley. These early commercial fishing operations often used barriers and gill nets that spanned the width of channels in the Delta and the Sacramento River, effectively creating a seasonal barrier that prevented the upstream migration of anadromous species (Clark 1929). The upstream migration of steelhead generally overlaps with that of fall-run Chinook salmon, so steelhead were likely effected by the fishing operations, and they may have been a targeted species. The barriers likely caused only a partial blockage of upstream migration, because the fish racks and nets often had holes and seams that allowed individuals to pass (Hallock et al. 1961); nevertheless, early commercial fishing likely reduced steelhead escapements in the Central Valley. As Chinook salmon populations began to plummet in the late nineteenth century, the California Fish Commission began implementing angling restrictions (e.g., seasonal closures, gear restrictions) that likely reduced harvest mortality.

5.6.3 ACID Dam

The construction of the ACID Dam (RM 298.4) near Redding in 1916 likely caused delays in the upstream migration of adult steelhead, which may have caused the peak of spawning activity to shift. ACID Dam was operated seasonally, typically between April and October, so the flashboards were often in place during the beginning and the peak of steelhead upstream migration in late September. Though the delays may not have caused direct mortality, they may have contributed indirectly to adult mortality by exposing spawners to increased angling pressure as they congregated downstream of the dam. Following construction of the dam, observers noted lower escapements of Chinook salmon in the upper reaches of the Sacramento River and its tributaries (Yoshiyama et al. 1996), so the dam may have also reduced the steelhead population. The ACID Dam diversion was unscreened for many years, so juvenile steelhead migrating downstream may have been entrained in the ACID canal; however, juvenile steelhead likely suffered less entrainment mortality than juvenile winter-run Chinook salmon, because they emigrate as larger juveniles with better ability to avoid entrainment.

5.6.4 Keswick and Shasta dams

The construction of large water supply dams in the Central Valley has probably had the greatest impact on *O. mykiss* populations because it eliminated access to nearly 80% of historical spawning and rearing habitat (Lindley et al. 2006). The construction of Shasta and Keswick dams eliminated access to many of the upstream tributaries (e.g., McCloud River, Pit River, little Sacramento River) that provided the cold water temperatures required for year-round rearing by steelhead. Dam construction also landlocked potentially anadromous *O. mykiss* populations in the upper watershed, forcing them to adopt a resident life history strategy (McEwan 2001).

Though steelhead generally prefer to spawn in the higher-gradient, more confined channels associated with smaller tributaries, they will spawn in mainstem river channels; however, it is unlikely that steelhead used to spawn in the reach of the mainstem Sacramento River below Keswick Dam where they currently spawn because summer water temperatures in this reach were likely too high to support oversummering by juveniles.

Shasta Dam altered the water temperature regime of the Sacramento River, which made it possible for steelhead to spawn and rear below Keswick Dam, but it is unclear how the substitution of spawning and rearing habitats in the mainstem channel for those in the upstream tributaries affected steelhead populations. Section 4.2 described how Shasta Dam may have initially increased the amount of spawning habitat available for winter-run Chinook salmon by reducing temperatures, until bed coarsening eventually reduced spawning gravel suitability. Steelhead may have experienced similar initial increases in spawning habitat downstream of Shasta Dam, which may have compensated for some of the upstream habitat lost when the dam was completed, but this increase in spawning habitat may not have resulted in increased escapements. Steelhead employ a different life history strategy than winter-run Chinook salmon, with juveniles typically rearing in fresh water for two years before emigrating to the ocean. As juvenile steelhead establish and defend territories, rearing habitat becomes saturated, which displaces other juveniles downstream where the risk of mortality from predation, entrainment, and elevated water temperatures increases. As a result, rearing habitat, rather than spawning habitat, is more likely to be a limiting factor for steelhead, and Shasta Dam eliminated access to more summer and winter rearing habitat than was created downstream of the dam by changes in temperature regimes. Habitat modeling conducted by Lindley et al. (2006) reinforce the idea that more rearing habitat was lost than gained by indicating that Shasta Dam eliminated access to a substantial amount of rearing habitat in the McCloud, Pit, and Little Sacramento River drainages. The dam likely reduced winter rearing habitat as well by eliminating access to the cobble-bedded reaches of the upstream tributaries that provided more velocity refugia for larger juveniles during high flow events.

5.6.5 Hatchery production

Hatchery production of steelhead is very large compared to natural production, based on the Chipps Island trawl data (Good et al. 2005). The bulk of hatchery releases in the Central Valley occur in the Sacramento River basin. An analysis of steelhead captures from trawl data by Nobriga and Cadrett (2001, as cited in Good et al. 2005) indicated that hatchery steelhead comprised 63–77% of the steelhead catch. Steelhead stocks at the Mokelumne River Hatchery and Nimbus Hatchery on the American River are not part of the California Central Valley steelhead DPS due to the source of broodstock used and genetic similarities to Eel River stocks (Good et al. 2005). There are many uncertainties regarding how the hatchery programs affect the Central Valley steelhead DPS (NMFS 2006)

5.7 Management Implications, Key Hypotheses, and Uncertainties

We hypothesize that rearing habitat is the primary limiting factor for steelhead populations in the mainstem Sacramento River, especially for older age classes of juveniles (age 1+ and 2+).

Because steelhead fry require low-velocity shallow habitat upon emergence (Hartman 1965, Everest et al. 1986, Fontaine 1988), and because an average female might lay 5,500 eggs, the number of age 0+ steelhead that a reach of stream can support is small relative to the number of eggs that may be deposited, even under conditions of low escapement or high egg mortality. However, it is generally accepted that it is rearing habitat for the older age classes (age 1+ and 2+) that is usually limiting steelhead populations, as they have narrower habitat requirements. Although habitat for age 2+ juvenile steelhead is likely suitable for age 1+ juveniles, the reverse may not be true, as the older and larger juveniles may require deeper habitats in the summer and larger interstitial habitats for overwinter survival. Therefore, we hypothesize that it is the amount of summer and winter rearing habitat available to age 2+ juveniles that most likely ultimately limits the production of adult steelhead.

Trap-and-haul operations have often been criticized as an artificial and flawed method for managing fishery stocks, but it is an improvement over hatchery supplementation practices because it allows fish to spawn and rear under natural conditions and presumably reduces domestication selection.

5.7.1 Provide rearing habitat with cobble-boulder structures

As discussed above, we hypothesize that rearing habitat to support age 2+ (and possibly older) juvenile steelhead is likely the limiting factor for populations of steelhead in the Sacramento River. To expand summer and winter rearing habitat for these older juvenile steelhead, we recommend placing cobble-boulder structures in the upper Sacramento River at locations between Keswick Dam (RM 302) and Clear Creek (RM 290). The cobble-boulder structures can be placed near highways (e.g., bridge piers) and water supply structures (e.g., diversion points) in the upper Sacramento River to provide the added benefit of protecting infrastructure from channel incision and erosion. However, it is important to place cobble-boulder structures in locations where the river is not expected to meander (i.e., where the channel is confined) in order to prevent future conflicts with restoring ecological processes.

Chapter 4 described how the channel bed of the upper Sacramento River has been coarsening as a function of continued high flow releases from Shasta Dam combined with reduced sediment supply from the upper watershed. However, a channel bed that is coarsening does not necessarily mean that rearing habitat for age 2+ steelhead has been increasing as the percentage of cobble covering the bed surface has increased. The coarsened bed of the upper Sacramento River is also embedded, with gravels filling the interstitial spaces between cobbles that are used as cover by juvenile steelhead. This filling of interstitial spaces can affect habitat for all age classes of juvenile steelhead, but because of the larger size of age 1+ and older juveniles, their habitat will be reduced at lower levels of embeddedness than for age 0+ steelhead that can make use of smaller crevices. The extent to which steelhead may use riprap as cover in the Sacramento River is unknown, but its use in the Sacramento River has been documented (Schaffter et al. 1983). Lister et al. (1995) found steelhead to prefer banks protected by large, coarse riprap to those stabilized with smaller materials.

Other potential restoration measures include more significant gravel augmentation in the upper Sacramento River, coupled with flow releases that mobilize the bed periodically, which may help to create the interstices between individual sediment grains that juvenile steelhead require for cover. Another potential measure includes ripping the coarse surface layer, coupled with high flow releases, to expose coarse sediment stored in the channel subsurface to transport, which may help establish larger areas of clean gravel and gravel-cobble in downstream reaches.

5.7.2 Water temperature compliance point

As discussed in Section 5.4, moving the water temperature compliance point designed to protect winter-run Chinook salmon redds upstream from Bend Bridge (RM 258) to Balls Ferry (RM 276) could reduce the amount of spawning and rearing habitat available for late-fall-run Chinook salmon in the mainstem Sacramento River. Steelhead would likely experience loss of habitat because juveniles also rear in the mainstem river throughout the summer. However, as discussed above, we hypothesize that summer and rearing habitat to support age 2+ juveniles is likely the primary limiting factor for steelhead in the Sacramento River, but we do not know how they respond during the summer when cold water temperatures are retreating upstream. Nevertheless, the improved swimming ability and thermal tolerance of age 2+ steelhead, relative to 0+ late-fall-run Chinook oversummering in the river, suggests that the steelhead population would likely be less affected than the late-fall-run population. Consequently, future analyses of moving the water temperature compliance point to protect winter-run Chinook salmon redds should focus on the effects on the late-fall-run Chinook salmon population.

5.8 References

Bailey, E. D. 1954. Time pattern of 1953-54 migration of salmon and steelhead into the upper Sacramento River. Unpublished report. California Department of Fish and Game.

Beecher, H. A., T. H. Johnson, and J. P. Carleton. 1993. Predicting microdistributions of steelhead (*Oncorhynchus mykiss*) parr from depth and velocity preference criteria: test of an assumption of the Instream Flow Incremental Methodology. Canadian Journal of Fisheries and Aquatic Sciences 50: 2380-2387.

Bell, M. C., editor. 1986. Fisheries handbook of engineering requirements and biological criteria. Report No. NTIS AD/A167-877. Fish Passage Development and Evaluation Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Bisson, P. A., K. Sullivan, and J. L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead trout, and cutthroat trout in streams. Transactions of the American Fisheries Society 117: 262-273.

Bisson, P., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflows. Pages 62-73 in N. B. Armantrout, editor. Proceedings of the symposium on acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Transactions of the American Fisheries Society 100: 423-438.

Bjornn, T. C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Bulletin No. 27. Prepared by Idaho Cooperative Fishery Research Unit, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow for Idaho Department of Fish and Game.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19:83-138.

Bovee, K.D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper 4, U.S. Fish and Wildlife Service, FWS/OBS-78/07. 79pp.

Burnett, K. M. 2001. Relationships among juvenile anadromous salmonids, their freshwater habitat, and landscape characteristics over multiple years and spatial scales in the Elk River, Oregon. Doctoral dissertation. Oregon State University, Corvallis, Oregon.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 32: 667-680.

CH2M Hill. 1985. Klamath River basin fisheries resource plan. Prepared for U.S. Department of the Interior.

Chambers, J. S., R. T. Pressey, J. R. Donaldson, and W. R. McKinley. 1954. Research relating to study of spawning grounds in natural areas. Annual Report, Contract No. DA 35026-Eng-20572. Prepared by Washington State Department of Fisheries, Olympia for U.S. Army Corps of Engineers, Fisheries-Engineering Research Program, North Pacific Division, Portland, Oregon.

Chambers, J. S., G. H. Allen, and R. T. Pressey. 1955. Research relating to study of spawning grounds in natural areas. Annual Report, Contract No. DA 35026-Eng-20572. Prepared by Washington State Department of Fisheries, Olympia for U.S. Army Corps of Engineers, Fisheries-Engineering Research Program, North Pacific Division, Portland, Oregon.

Clark, G. H. 1929. Sacramento-San Joaquin salmon (*Oncorhynchus tshawytscha*) fishery of California. California Department of Fish and Game Fish Bulletin 17: 1-73

Cramer, S. P. 2001. The relationship of stream habitat features to potential for production of four salmonid species. Prepared by S. P. Cramer and Associates, Gresham, Oregon for Oregon Building Industry Association.

Cramer, S. P., D. W. Alley, J. E. Baldrige, K. Barnard, D. B. Demko, D. H. Dettman, B. Farrell, J. Hagar, T. P. Keegan, A. Laird, W. T. Mitchell, R. C. Nuzum, R. Orton, J. J. Smith, T. L. Taylor, P. A. Unger, and E. S. Van Dyke. 1995. The status of steelhead populations in California in regards to the Endangered Species Act. Special report submitted to National Marine Fisheries Service on behalf of Association of California Water Agencies. S. P. Cramer & Associates, Gresham, Oregon.

Cramer, S. P., T. D. Satterthwaite, R. B. Boyce, and B. P. McPherson. 1985. Impacts of the Lost Creek Dam on the biology of anadromous salmon in the Rogue River. Report No. DACW57-77-C-0027. Prepared by Oregon Department of Fish and Game, Research and Development Section for U.S. Army Corps of Engineers.

Dambacher, J. M. 1991. Distribution, abundance, and emigration of juvenile steelhead (*Oncorhynchus mykiss*), and analysis of stream habitat in the Steamboat Creek basin, Oregon. Master's thesis. Oregon State University, Corvallis.

Engle, R. O. 2002. Distribution and summer survival of juvenile steelhead trout (*Oncorhynchus mykiss*) in two streams within the King Range National Conservation Area, California. Master's thesis. Humboldt State University, Arcata, California.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29: 91-100.

Everest, F. H., G. H. Reeves, J. R. Sedell, J. Wolfe, D. Hohler, and D. A. Heller. 1986. Abundance, behavior, and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon, as influenced by habitat enhancement. Annual Report 1985 Project No. 84-11. Prepared by U.S. Forest Service for Bonneville Power Administration, Portland, Oregon.

Everest, F. H., G. H. Reeves, J. R. Sedell, and D. B. Hohler. 1987. The effects of habitat enhancement on steelhead trout and coho salmon smolt production, habitat utilization, and habitat availability in Fish Creek, Oregon, 1983-86. Annual Report 1986, Contract DE-A179-BP16726, Project 84-11. Prepared for Bonneville Power Administration, Portland, Oregon.

Fontaine, B. L. 1988. An evaluation of the effectiveness of instream structures for steelhead trout rearing habitat in the Steamboat Creek basin. Master's thesis. Oregon State University, Corvallis.

Good, T. P., R. S. Waples, and P. Adams. 2005. Updated status of federally listed ESUs of west coast salmon and steelhead. NOAA Technical Memorandum NMFS-NWFSC-66. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington and NMFS, Southwest Fisheries Science Center, Santa Cruz, California.

Grunbaum, J. B. 1996. Geographical and seasonal variation in diel habitat use by juvenile (age 1+) steelhead trout (*Oncorhynchus mykiss*) in Oregon coastal and inland streams. Master's thesis. Oregon State University, Corvallis.

Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. Fish Bulletin 114. California Department of Fish and Game.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 22: 1035-1081.

Harvey, B. C., J. L. White, and R. J. Nakamoto. 2002. Habitat relationships and larval drift of native and nonindigenous fishes in neighboring tributaries of a coastal California river. Transactions of the American Fisheries Society 131: 159-170.

Hicks, B. J., and J. D. Hall. 2003. Rock type and channel gradient structure salmonid populations in the Oregon Coast Range. Transactions of the American Fisheries Society 132: 468-482.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116: 185-195.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Pacific Gas and Electric Company, Department of Engineering Research, Emeryville, California.

Kahler, T. H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58: 1947-1956.

Keeley, E. R. 2001. Demographic responses to food and space competition by juvenile steelhead trout. Ecology 82: 1247-1259.

Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Leider, S. A., M. W. Chilcote, and J. J. Loch. 1986. Movement and survival of presmolt steelhead in a tributary and the main stem of a Washington river. North American Journal of Fisheries Management 6: 526-531.

Lindley, S.T., R.S. Schick, A. Agrawal, M. Goslin, T.E. Pearson, E. More, J.J. Anderson, B. May, S. Greene, C. Hanson, A. Low, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2006. Historical Population Structure of Central Valley Steelhead and its Alteration by Dams, San Francisco Estuary and Watershed Science, Vol. 4, Issue 1: 1-19.

Lister, D. B., R. J. Beniston, R. Kellerhals, and M. Miles. 1995. Rock size affects juvenile salmonid use of stream bank riprap. Pages 621-632 in C. R. Thorne, S. R. Abt, F. J. B. Barends, S. T. Maynord and K. W. Pilarczyk, editors. River, coastal and shoreline protection: erosion control using riprap and armourstone. John Wiley and Sons, New York.

Loch, J. J., M. W. Chilcote, and S. A. Leider. 1985. Kalama River studies final report. Part II: Juvenile downstream migrant studies. Fish Management Division Report No. 85-12. Washington Department of Fish and Game, Olympia.

McEwan, D. and T.A. Jackson. 1996. Steelhead Restoration and Management Plan for California. California Department of Fish and Game.

McEwan, D. 2001. Central Valley Steelhead. In Contributions to the Biology of Central Valley Salmonids, Fish Bulletin 179. California Dept. of Fish and Game.

Moyle, P. B. 2002. *Inland Fishes of California*. Revised and Expanded. Berkeley: University of California Press 502 pp.

Myrick, C. A., and Jr. J. J. Cech. 2001. Temperature effects on chinook salmon and steelhead: a review focusing on California's Central Valley populations. Prepared by Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins and Department of Wildlife, Fish, and Conservation Biology, University of California, Davis for the Bay-Delta Modeling Forum. http://www.sfei.org/modelingforum/.

Needham, P. R., O. R. Smith, and H. A. Hanson. 1941. Salmon salvage problems in relation to Shasta Dam, California, and notes on the biology of the Sacramento River salmon. Transactions of the American Fisheries Society 70: 55-69.

NMFS (National Marine Fisheries Service). 1998. Endangered and threatened species; threatened status for two ESUs of steelhead in Washington, Oregon, and California. Federal Register 63: 13347-13371.

NMFS. 2006. Endangered and threatened species: final listing determinations for 10 Distinct Population Segments of west coast steelhead. Federal Register 71: 834-862.

Nobriga, M., and P. Cadrett. 2001. Differences among hatchery and wild steelhead: evidence from delta fish monitoring programs. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 14: 30-38.

Peven, C. M., R. R. Whitney, and K. R. Williams. 1994. Age and length of steelhead smolts from the mid-Columbia River basin, Washington. North American Journal of Fisheries Management 14: 77-86.

Platts, W. S., M. A. Shirazi, and D. H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. Ecological Research Series EPA-600/3-79-043. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oregon.

Reedy, G. D. 1995. Summer abundance and distribution of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) in the Middle Fork Smith River, California. Master's thesis. Humboldt State University, Arcata, California.

Reiser, D. W., and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Pages 1-54 *in* W. R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. General Technical Report PNW-96. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Schaffter, R. G., P. A. Jones, and J. G. Karlton. 1983. Sacramento River and tributaries bank protection and erosion control investigation, evaluation of impacts on fisheries. Final Report. California Department of Fish and Game.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead Rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. DFG Bulletin No. 98.

Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64: 1506-1514.

USBR (U.S. Bureau of Reclamation). 2004. Long-term Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. USDI Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

USFWS and CDFG (U.S. Fish and Wildlife Service and California Department of Fish and Game). 1953. A plan for the protection and maintenance of salmon and steelhead in the American River, California, together with recommendations for action. Unpublished report.

Voight, H. N., and D. B. Gale. 1998. Distribution of fish species in tributaries of the lower Klamath River: an interim report, FY 1996. Technical Report No. 3. Yurok Tribal Fisheries Program, Habitat Assessment and Biological Monitoring Division.

Ward, B. R., and P. A. Slaney. 1993. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead. Pages 209-217 *in* R. J. Gibson and R. E. Cutting, editors. Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46: 1853-1858.

Yoshiyama RM, Gerstung ER, Fisher FW, Moyle PB. 1996. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. In: Sierra Nevada ecosystem project: final report to Congress. Volume III: assessments, commissioned reports, and background information. Davis (CA): University of California, Centers for Water and Wildlife Resources. p 309–61.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2001. Historical and present distribution of chinook salmon in the Central Valley drainage of California. Pages 71-176 in R. L. Brown, editor. Contributions to the biology of Central Valley salmonids. Fish Bulletin 179: Volume 1. California Department of Fish and Game, Sacramento.